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

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Overview of Invited Talks and Sessions

(Lecture Rooms A 310, E 001, E 214, E 415, F 128, F 142, F 303, and F 342; Poster Empore Lichthof)

Invited talks of the joint symposium SYED

See SYED for the full program of the symposium.

SYED 1.1	Mon	11:00–11:30	E 415	**Signatures of vibronic and vibrational coherences in electronic 2D-spectra of monomers and aggregates** — Franz Milota, Tomas Mancal, Harald F. Kauffmann, •Jürgen Hauer
SYED 1.2	Mon	11:30–12:00	E 415	**Beatings in Electronic 2D Spectroscopy** — •Tönu Pullerits
SYED 1.3	Mon	12:00–12:30	E 415	**Resonant 2D Raman Spectroscopy** — •Tiago Buckup, Jan Philip Kraack, Marcus Motzkus
SYED 1.4	Mon	12:30–13:00	E 415	**Coherent Two-Dimensional Electronic Spectroscopy With Triggered Exchange** — •Patrick Nuernberger, Stefan Ruetzel, Martin Kullmann, Johannes Buback, Tobias Brixner
SYED 2.1	Mon	14:00–14:30	E 415	**Two-dimensional UV and visible spectroscopy of biological system** — •Majed Chergui, Gerald Auböck, Cristina Consani, Roberto Monni, André El Haddad, Frank van Mourik
SYED 2.2	Mon	14:30–15:00	E 415	**Ultrabroad 2D-UV spectroscopy: from coherent internal conversion in pyrene towards exciton dynamics in DNA** — •Igor Pugliesi, Nils Krebs, Eberhard Riedle
SYED 2.3	Mon	15:00–15:30	E 415	**Multidimensional XUV-NIR spectroscopy of electronic dynamics in small quantum systems** — •Christian Ott, Andreas Kaldun, Kristina Meyer, Philipp Raith, Martin Laux, Alexander Blättermann, Thomas Ding, Thomas Pfeifer
SYED 2.4	Mon	15:30–16:00	E 415	**Correlated Two-electron Wave-Packets in Helium** — •Javier Madronero

Invited talks of the joint symposium SYQG

See SYQG for the full program of the symposium.

SYQG 1.1	Tue	11:00–11:30	E 415	**Does time exist in quantum gravity?** — •Claus Kiefer
SYQG 1.2	Tue	11:30–12:00	E 415	**How Attractive is the Moon for Relativity?** — •Jürgen Müller, Liliane Biskupek, Enrico Mai, Franz Hofmann
SYQG 1.3	Tue	12:00–12:30	E 415	**Interferometry with Bose-Einstein condensates in microgravity** — •Ernst Rasel
SYQG 1.4	Tue	12:30–13:00	E 415	**Relativistic effects in atom and neutron interferometry** — •Wolfgang Schleich

Sessions

Q 1.1–1.5	Mon	11:00–12:15	F 142	**Micromechanical oscillators I**
Q 2.1–2.5	Mon	11:00–12:30	F 128	**Precision measurements and metrology I**
Q 3.1–3.5	Mon	11:00–12:30	E 001	**Quantum gases: Interaction effects I**

Q 4.1–4.6	Mon	11:00–12:30	F 342	**Quantum information: Quantum communication I**
Q 5.1–5.6	Mon	11:00–12:30	E 214	**Quantum information: Atoms and ions I**
Q 6.1–6.5	Mon	11:00–12:30	A 310	**Ultracold atoms and molecules**
Q 7.1–7.5	Mon	11:00–12:30	B 305	**Ultra-cold atoms, ions and BEC I (with A)**
Q 8.1–8.6	Mon	14:00–15:30	F 142	**Micromechanic oscillators II**
Q 9.1–9.8	Mon	14:00–16:00	A 310	**Photonics I**
Q 10.1–10.6	Mon	14:00–15:45	F 128	**Precision measurements and metrology II**
Q 11.1–11.7	Mon	14:00–16:00	F 342	**Quantum effects: QED**
Q 12.1–12.7	Mon	14:00–16:00	E 001	**Quantum gases: Bosons I**
Q 13.1–13.8	Mon	14:00–16:00	E 214	**Quantum information: Concepts and methods I**
Q 14.1–14.8	Mon	14:00–16:00	F 428	**Ultra-cold atoms, ions and BEC II (with A)**
Q 15.1–15.8	Mon	16:30–18:45	F 142	**Matter-wave optics**
Q 16.1–16.8	Mon	16:30–18:30	A 310	**Photonics II**
Q 17.1–17.7	Mon	16:30–18:30	F 342	**Quantum effects: Interference and correlations**
Q 18.1–18.7	Mon	16:30–18:15	E 001	**Quantum gases: Mixtures, spinor gases, disorder effects**
Q 19.1–19.7	Mon	16:30–18:30	E 214	**Quantum information: Quantum computers**
Q 20.1–20.8	Mon	16:30–18:45	E 415	**Ultracold plasmas and Rydberg atoms**
Q 21.1–21.1	Mon	18:30–19:15	F 303	**DFG funding programs**
Q 22.1–22.6	Tue	11:00–12:30	F 142	**Laser development: Solid state lasers I**
Q 23.1–23.5	Tue	11:00–12:30	E 001	**Quantum gases: Interaction effects II**
Q 24.1–24.5	Tue	11:00–12:30	A 310	**Quantum information: Atoms and ions II**
Q 25.1–25.5	Tue	11:00–12:15	E 214	**Quantum information: Quantum communication II**
Q 26.1–26.6	Tue	11:00–12:30	B 302	**Ultra-cold atoms, ions and BEC III (with A)**
Q 27.1–27.4	Tue	11:00–12:00	F 342	**Ultrashort laser pulses: Generation I**
Q 28	Tue	13:00–14:00	F 342	**Fachverbandssitzung Quantenoptik**
Q 29.1–29.7	Tue	14:00–15:45	F 342	**Photonics III**
Q 30.1–30.7	Tue	14:00–16:00	F 128	**Quantum effects**
Q 31.1–31.8	Tue	14:00–16:15	E 001	**Quantum gases: Optical lattices I**
Q 32.1–32.7	Tue	14:00–16:00	A 310	**Quantum information: Atoms and ions III**
Q 33.1–33.8	Tue	14:00–16:00	E 214	**Quantum information: Concepts and methods II**
Q 34.1–34.7	Tue	14:00–15:45	F 142	**Ultrashort laser pulses: Applications**
Q 35.1–35.99	Tue	16:00–18:30	Empore Lichthof	**Poster I**
Q 36.1–36.6	Wed	11:00–12:30	F 428	**Ultra-cold atoms, ions and BEC IV (with A)**
Q 37.1–37.5	Wed	14:00–15:15	F 142	**Laser applications: Spectroscopy**
Q 38.1–38.7	Wed	14:00–16:00	E 001	**Precision measurements and metrology III**
Q 39.1–39.8	Wed	14:00–16:00	F 342	**Quantum effects: Light scattering and propagation**
Q 40.1–40.7	Wed	14:00–15:45	A 310	**Quantum gases: Optical lattices II**
Q 41.1–41.7	Wed	14:00–16:00	E 214	**Quantum information: Concepts and methods III**
Q 42.1–42.7	Wed	14:00–16:00	B 302	**Ultra-cold atoms, ions and BEC V (with A)**
Q 43.1–43.88	Wed	16:00–18:30	Empore Lichthof	**Poster II**
Q 44.1–44.6	Thu	11:00–12:30	F 128	**Laser development: Solid state lasers II**
Q 45.1–45.6	Thu	11:00–12:30	F 342	**Quantum gases: Bosons II**
Q 46.1–46.7	Thu	11:00–12:45	E 001	**Quantum information: Concepts and methods IV**
Q 47.1–47.6	Thu	11:00–12:30	B 305	**Ultra-cold atoms, ions and BEC VI (with A)**
Q 48.1–48.6	Thu	11:00–12:30	A 310	**Ultracold atoms: Traps and cooling**
Q 49.1–49.5	Thu	11:00–12:30	F 142	**Ultrashort laser pulses: Generation II**
Q 50.1–50.7	Thu	14:00–16:00	F 142	**Laser applications**
Q 51.1–51.7	Thu	14:00–16:00	F 128	**Precision measurements and metrology IV**
Q 52.1–52.6	Thu	14:00–15:45	F 342	**Quantum gases: Fermions**
Q 53.1–53.7	Thu	14:00–16:00	A 310	**Quantum information: Atoms and ions IV**
Q 54.1–54.7	Thu	14:00–16:00	E 001	**Quantum information: Photons and nonclassical light I**
Q 55.1–55.8	Thu	14:00–16:00	B 305	**Ultra-cold atoms, ions and BEC VII (with A)**
Q 56.1–56.99	Thu	16:00–18:30	Empore Lichthof	**Poster III**
Q 57.1–57.6	Fri	11:00–12:30	F 128	**Laser development: Nonlinear effects**
Q 58.1–58.6	Fri	11:00–12:30	E 001	**Precision measurements and metrology V**
Q 59.1–59.6	Fri	11:00–12:30	F 342	**Quantum gases: Optical lattices III**
Q 60.1–60.5	Fri	11:00–12:30	A 310	**Quantum effects: Entanglement and decoherence I**
Q 61.1–61.6	Fri	11:00–12:30	E 214	**Quantum information: Atoms and ions V**
Q 62.1–62.6	Fri	11:00–12:30	F 142	**Ultracold atoms: Manipulation and detection**
Q 63.1–63.8	Fri	14:00–16:00	F 128	**Photonics IV**
Q 64.1–64.7	Fri	14:00–15:45	E 001	**Precision measurements and metrology VI**

Q 65.1–65.7	Fri	14:00–16:00	F 342	**Quantum gases: Bosons III**
Q 66.1–66.6	Fri	14:00–15:45	A 310	**Quantum effects: Entanglement and decoherence II**
Q 67.1–67.8	Fri	14:00–16:00	E 214	**Quantum information: Concepts and methods V**
Q 68.1–68.8	Fri	14:00–16:00	F 142	**Quantum information: Photons and nonclassical light II**

Annual General Meeting of the Quantum Optics and Photonics Division

Dienstag 13:00–14:00 F 342

Q 1: Micromechanical oscillators I

Time: Monday 11:00–12:15 Location: F 142

Q 1.1 Mon 11:00 F 142

Multi mode quantum dynamics in optomechanical crystals — •Michael Schmidt[1], David Turban[1], Max Ludwig[1], and Florian Marquardt[1,2] — [1]Friedrich-Alexander-Universität Erlangen-Nürnberg, Staudtstr. 7, D-91058 Erlangen, Germany — [2]Max Planck Institute for the Science of Light, Günther-Scharowsky-Straße 1/Bau 24, D-91058 Erlangen, Germany

Optomechanical crystals are a novel realization of an optomechanical system that can be used to integrate many localized vibrational and optical modes on a single chip. The vibrational modes can be prepared in their ground state via optical side-band cooling. The great design flexibility allows to engineer interactions between modes, providing a versatile interacting quantum system. It may be used to implement phononic networks for quantum information processing or serve as a quantum bus to connect different quantum systems. We present our theoretical analysis of multimode quantum dynamics in optomechanical crystals.

Q 1.2 Mon 11:15 F 142

Light scattering of an optomechanical cavity coupled to a single atom — Daniel Breyer and •Marc Bienert — Theoretische Physik, Universität des Saarlandes, Saarbrücken

We theoretically analyze the light scattering of an optomechanical cavity which strongly interacts with a single two-level system and couples simultaneously to a mechanical oscillator by radiation forces. The analysis is based on the assumptions that the system is driven at low intensity, and that the mechanical interaction is sufficiently weak, permitting a perturbative treatment. We find quantum interference in the scattering paths, which allows one to suppress the Stokes component of the scattered light. This effect can be exploited to reduce the motional energy of the mechanical oscillator.

Q 1.3 Mon 11:30 F 142

Cryogenic cooling of a Michelson-Sagnac Interferometer — •Ramon Moghadas Nia, Henning Kaufer, Andreas Sawadsky, and Roman Schnabel — Institut für Gravitationsphysik, Leibniz Universität Hannover and Max-Planck-Institut für Gravitationsphysik (Albert-Einstein-Institut), Callinstr. 38, 30167 Hannover, Germany

Opto-mechanical experiments recently reached regimes in which direct observation of the quantum behaviour of mechanical oscillators is possible. The Michelson-Sagnac topology has turned out to be an excellent tool for measuring the displacement of a high optical and mechanical quality silicon nitride (SiN) membrane. It has been shown that this setup can provide a high interference contrast and therefore is compatible with recycling techniques, such as signal recycling. Because of thermal noise, however, the observation of the quantum back-action noise is possible only when operating the system at cryogenic temperatures. Here we present a new, cryogenic cooled Michelson-Sagnac interferometer operated at 8 Kelvin. The SiN membrane showed a high mechanical Q-factor of about 10^7. Our setup is expected to enable the direct observation of anticipated effects like radiation pressure noise and ponderomotive squeezing.

Q 1.4 Mon 11:45 F 142

Single-photon strong coupling signatures in optomechanically induced transparency — •Andreas Kronwald[1], Max Ludwig[1], and Florian Marquardt[1,2] — [1]Friedrich-Alexander-Universität Erlangen-Nürnberg, Staudtstr. 7, D-91058 Erlangen, Germany — [2]Max Planck Institute for the Science of Light, Günther-Scharowsky-Straße 1/Bau 24, D-91058 Erlangen, Germany

An optomechanical system consists of a laser-driven photonic mode coupled to mechanical motion. Recently, the existence of an optomechanical analog to electromagnetically induced transparency (EIT) was shown. The strongly laser-driven optomechanical system becomes fully transparent when probed by a second, weak laser. In contrast to earlier works, we analyze this effect in a regime where light and mechanics interact strongly on the level of single quanta.

Q 1.5 Mon 12:00 F 142

Anomalous dynamic back-action in interferometers: beyond the scaling law — •Sergey Tarabrin[1,2], Farid Khalili[3], Klemens Hammerer[1,2], Henning Kaufer[1], and Roman Schnabel[1] — [1]Institut für Gravitationsphysik, Leibniz Universität Hannover and Max-Planck-Institut für Gravitationsphysik (Albert-Einstein-Institut), Callinstraße 38, 30167 Hannover, Germany — [2]Institut für Theoretische Physik, Leibniz Universität Hannover, Appelstraße 2, 30167 Hannover, Germany — [3]Department of Physics, Moscow State University, Moscow 119992, Russia

We analyze dynamic back-action in the signal-recycled Michelson-Sagnac interferometer with a translucent membrane positioned in its arm, operated off dark port, and reveal its 'anomalous' features as compared to the ones of 'canonical' back-action, obtained within the scope of scaling law. Given the finite reflectivity of the membrane, optical damping as a function of detuning acquires (i) non-zero value on resonance and (ii) several stability/instability regions. In the case of absolutely reflecting membrane, corresponding to a pure Michelson interferometer, off-dark-port regime results in several intersecting regions of positive/negative values of optical spring and damping. For a certain region of parameters, stable sets of both effects in a free-mass interferometer with a single laser drive are possible. Our results can find implementations in both cavity optomechanics, revealing new regimes of cooling of micromechanical oscillators, and in the gravitational-wave detectors, revealing the possibility of stable single-carrier optical spring which can be utilized for the reduction of quantum noise.

Q 2: Precision measurements and metrology I

Time: Monday 11:00–12:30 Location: F 128

Group Report Q 2.1 Mon 11:00 F 128

Quantum Metrology and Tomography with Bose–Einstein Condensates — •Roman Schmied, Caspar Ockeloen, Max Riedel, and Philipp Treutlein — Departement Physik, Universität Basel, Klingelbergstrasse 82, 4056 Basel, Schweiz

We present our recent results on the creation, manipulation, use, and analysis of entangled states of Bose–Einstein condensates of about 1000 Rubidium-87 atoms.

We have used a Bose–Einstein condensate as an interferometric scanning probe to map out a microwave field near a chip surface with a few micrometers resolution [1]. Using entanglement between the atoms we overcome the standard quantum limit of interferometry by 4 dB and maintain enhanced performance for interrogation times up to 20 ms. This demonstrates the usefulness of quantum metrology with entangled states when the particle number is limited due to the small probe size, and extends high-precision atomic magnetometry to the micrometer scale and microwave frequencies.

To analyze the many-body states of our Bose–Einstein condensates we extend our previously published quantum-state tomography [2] by enforcing that tomographically reconstructed many-body density matrices are positive semi-definite. We use this method to extract quantitative data such as the Fisher information.

[1] C.F. Ockeloen *et al.*, *submitted.*
[2] R. Schmied and P. Treutlein, New J. Phys. **13**, 065019 (2011).

Q 2.2 Mon 11:30 F 128

Noisy metrology beyond the standard quantum limit — •Rafael Chaves[1,2], Jonatan Bohr Brask[2], Marcin Markiewicz[3], Janek Kołodyński[4], and Antonio Acin[2,5] — [1]Institute for Physics, University of Freiburg, Germany — [2]ICFO-Institut de Ciències Fotòniques, Castelldefels (Barcelona), Spain — [3]Institute of Theoretical Physics and Astrophysics, University of Gdańsk, Poland — [4]Faculty of Physics, University of Warsaw, Poland — [5]ICREA-Institució Catalana de Recerca i Estudis Avançats, Barcelona, Spain

Parameter estimation is of fundamental importance in areas from atomic spectroscopy to gravitational wave-detection. Entangled probes provide a significant precision gain over classical strategies in the absence of noise. However, recent results seem to indicate that any small amount of realistic noise restricts the advantage of quantum strategies to an improvement by at most a multiplicative constant. We identify a relevant scenario in which one can overcome this restriction and attain super-classical precision scaling even in the presence of uncorrelated noise. We show that the quantum improvement can be significantly enlarged when the noise is concentrated along some spatial direction, while the Hamiltonian governing the evolution which depends on the parameter to be estimated can be engineered to point along a different direction. In particular, in the case of perpendicular orientation, we find a maximal asymptotic precision scaling of $1/N^{5/6}$, where N is the number of probe particles, and identify a state which achieves this.

Q 2.3 Mon 11:45 F 128

Accuracy Limits on the Estimation of the Magnetic Field Gradient — •Iagoba Apellaniz and Philipp Hyllus — University of the Basque Country, P. O. Box 644, E-48080 Bilbao, Spain.

Entanglement between particles is a useful resource for quantum information processing tasks as well as for quantum metrology. For instance, it allows us to have a metrological accuracy higher than the shot-noise limit. The accuracy in the estimation of the phase shift θ in a Mach-Zehnder Interferometer can be improved by a factor of $\sqrt{N}$ with respect to the shot-noise limit, $\Delta\theta \sim 1/\sqrt{N}$, where N is the number of particles on the system which are analyzed to estimate θ.

The usefulness of a multi-particle system for measuring the magnetic field gradient is investigated in Ref. [1]. They consider a multi-particle singlet state for this purpose and incorporate the information about the particle positions in the Hamiltonian.

In our presentation, we use a general Hamiltonian for this class of systems, and the information about the position of the particles involved is encoded in the state, not the Hamiltonian.

We investigate bounds on the sensitivity of measuring the magnetic field gradient, b_1, with a one dimensional N-particle system. We use the so-called Cramér-Rao bound and the Quantum Fisher Information (QFI) in order to get the bounds for the shot-noise limit and the Heisenberg limit.

[1] I. Urizar-Lanz, P. Hyllus, I. Egusquiza, M.W. Mitchell, G. Tóth, *Macroscopic singlet states for gradient magnetometry*, arxiv:1203.3797.

Q 2.4 Mon 12:00 F 128

Application of multipartite quantum states for gradient magnetometry — •Iñigo Urizar-Lanz[1], Philipp Hyllus[1], Iñigo Egusquiza[1], Morgan Mitchell[2], and Geza Toth[1,3,4] — [1]Theoretical Physics, University of the Basque Country UPV/EHU, E-48080 Bilbao, Spain — [2]Institute of Photonic Sciences, ICFO, Mediterranean Technology Park, Barcelona, Spain — [3]IKERBASQUE, Basque Foundation for Science, E-48011 Bilbao, Spain — [4]Wigner Research Centre for Physics, H-1525 Budapest, Hungary

Singlet states are states with vanishing angular momentum. We investigate the possibilities of these states for measuring the gradient of a magnetic field. This kind of magnetometry is invariant under a homogeneous magnetic field. We calculate the precision of the measurement for this type of states, as well as for other states that are not invariant under homogeneous fields. We also consider the case of spins larger than 1/2 and the effect of noise.

Q 2.5 Mon 12:15 F 128

Enhancement of a single electron spin based magnetometer by utilizing a small nuclear spin quantum register — •Sebastian Zaiser[1], Philipp Neumann[1], Gerald Waldherr[1], Fedor Jelezko[2], and Jörg Wrachtrup[2] — [1]3. Physikalisches Institut, Universität Stuttgart — [2]Institut für Quantenoptik, Universität Ulm

The negatively charged nitrogen-vacancy (NV) center in diamond and its associated nuclear spins form a versatile small quantum register. Apart from its potential applications in quantum information processing the susceptibility of its quantum coherence to external stimuli like magnetic and electric fields render the NV center a tiny quantum sensor. Its high spatial confinement allows to build very small sensing devices which lead to a sample-probe distance of only a few nanometers potentially enabling the detection of single electron or even nuclear spins.

Here we show how a small quantum register of proximal nuclear spins around the NV center can be used to drastically increase the performance of the NV electron spin as a magnetic field sensor.

Q 3: Quantum gases: Interaction effects I

Time: Monday 11:00–12:30 Location: E 001

Group Report Q 3.1 Mon 11:00 E 001

Rydberg gases at room temperature - coherent dynamics and interaction — •Bernhard Huber, Andreas Kölle, Thomas Baluktsian, Robert Löw, and Tilman Pfau — 5. Physikalisches Institut, Universität Stuttgart

Rydberg atoms are of great interest due to their prospects in quantum information. Coherent control of the strong Rydberg-Rydberg interaction allows for the realization of quantum operations and devices which have been demonstrated in ultracold experiments. We present our progress on the coherent control and investigation of Rydberg atoms at room temperature. We show that we are able to drive Rabi oscillations on the nanosecond timescale to a Rydberg state by using a pulsed laser excitation and are therefore faster than the coherence time limitation given by the Doppler width [1]. By systematically investigating the dephasing of these oscillations for different atomic densities and Rydberg states we find evidence for van-der Waals interaction in thermal vapor [2]. The strength of the interaction exceeds the energy scale of thermal motion (i.e. the Doppler broadening) and therefore enables strong quantum correlations.

Furthermore we present our latest results on the combination of the pulsed Rydberg excitation with a four-wave-mixing scheme and our progress towards the creation of non-classical light.

[1] Huber et al., PRL **107**, 243001 (2011)
[2] Baluktsian et al., arXiv:1212.0690

Q 3.2 Mon 11:30 E 001

Ground states of dipolar Bose-Einstein condensates in triple-well potentials — •Damir Zajec and Günter Wunner — 1. Institut für Theoretische Physik, Universität Stuttgart

Dipolar Bose-Einstein condensates in triple-well potentials are model systems for larger periodic systems with important contributions of non-local dipole-dipole interactions. We perform grid calculations to determine the ground states of such systems by means of the Gross-Pitaevskii equation. The split-operator method is used to apply a general time evolution operator to an initial state, where time evolution is mainly described by a series of Fourier transforms. Since this numerical scheme is very demanding, the parallel computing architecture CUDA was used to implement the code. We study repulsive and attractive configurations with linear and triangular arrangements and present phase diagrams to illustrate the occurrence of different phases.

Q 3.3 Mon 11:45 E 001

Interband transport in a many-body Wannier-Stark setup — •Carlos Alberto Parra-Murillo[1], Javier Madroñ ero[2], and Sandro Wimberger[1] — [1]Institut für Theoretische Physik and Center for Quantum Dynamics, Universität Heidelberg, 69120 Heidelberg, Germany — [2]Physik Department, Technische Universität München, 85747 Garching, Germany

The transport properties of flat optical lattices loaded with ultracold atoms have been amply studied in recent years in theory as well as in experiment, especially under single band approximation. The coupling to higher Bloch bands can be introduced by a Stark force, which can be considered as a control parameter. This allows the realization of resonant tunneling between energy levels in different potential wells. We study a Wannier-Stark system based on a two-band Bose-Hubbard model. The spectral characteristics of this system in the regime of strong interparticle interaction offer the possibility of a dynamical preparation of specific upper band states and also the study of quench dynamics across the spectrum [1]. Dynamical correlations between the bands imply interesting perspectives for the state-of-the-art experiments with ultracold bosons.

[1] Parra-Murillo C. A., Madronero J., Wimberger S., arXiv:1207.4699 [cond-mat.quant-gas] (2012)

Q 3.4 Mon 12:00 E 001

Variational investigation of dipolar BEC in multi-well potentials — •Rüdiger Eichler, Jörg Main und Günter Wunner — 1. Institut für Theoretische Physik, Universität Stuttgart

The dipolar interaction of the atoms in Bose-Einstein condensates leads to a variety of interesting effects such as self-organization and formation of patterns. Multi-well potentials are well suited settings for the examination of these effects and the mechanisms behind. The dynamics of dipolar Bose-Einstein condensates in multi-well potentials can be described in the mean-field limit by an extended time-dependent Gross-Pitaevskii equation (GPE). We solve this GPE by a time-dependent variational principle where we use coupled Gaussian wave packets. With this method we do not only obtain the ground state of the condensate but the excited states as well. These play a crucial role e.g. in the creation of different phases. We show that this is connected to crossings of the involved states. Furthermore, dynamics in multi-well potentials will be shown which now can be interpreted by means of the presence of different states.

Q 3.5 Mon 12:15 E 001

Bifurcations and exceptional points in dipolar Bose-Einstein condensates — •Robin Gutöhrlein, Jörg Main, and Günter Wunner — 1. Institut für Theoretische Physik, Universität Stuttgart, 70550 Stuttgart, Deutschland

Bose-Einstein condensates are described in a mean-field approach by the nonlinear Gross-Pitaevskii equation and exhibit phenomena of nonlinear dynamics. The eigenstates can undergo bifurcations in such a way that two or more eigenvalues and the corresponding wave functions coalesce at critical values of external parameters, e.g. the scattering length. At the critical point the coalescing states show the properties of an exceptional point. We present a method to uncover all states participating in a pitchfork bifurcation, and investigate in detail the signatures of exceptional points related to bifurcations in dipolar condensates. For the perturbation by two parameters, viz. the scattering length and a parameter breaking the symmetry of the trap, two cases leading to different characteristic eigenvalue and eigenvector patterns under cyclic variation of the parameters need to be distinguished. The observed structures resemble those obtained by G. Demange and E.-M. Graefe [J. Phys. A, 45:025303, 2012] using perturbation theory for non-Hermitian operators in a linear model. Furthermore, the splitting of the exceptional point under symmetry breaking in either two or three branching singularities is examined. Characteristic features are observed when multiple exceptional points are simultaneously encircled.

Q 4: Quantum information: Quantum communication I

Time: Monday 11:00–12:30 Location: F 342

Q 4.1 Mon 11:00 F 342

Quantum repeaters and secret key rates: the role of distillation and classical communication — •Sylvia Bratzik, Silvestre Abruzzo, Hermann Kampermann, and Dagmar Bruss — Institut für theor. Physik III, Heinrich-Heine-Universität, Universitätsstr.1, 40225 Düsseldorf

Using the original repeater protocol [1] we calculate secret key rates and compare them for different distillation protocols (the *Deutsch et al.* protocol [2] and entanglement pumping [3]) and different distillation strategies (varying the number of distillation rounds in the nesting levels). The secret key rate is composed of the secret fraction and the repeater rate. In our analysis we derive formulas for the repeater rate which account for the classical communication time due to entanglement swapping and entanglement distillation. Depending on the type and value of the experimental imperfections, we show which distillation configuration leads to the optimal secret key rate.

[1] H.J. Briegel, W. Dür, J.I. Cirac, and P. Zoller, Phys. Rev. Lett. **81**, 5932 (1998).
[2] D. Deutsch et al., Phys. Rev. Lett. **77**, 2818 (1996).
[3] W. Dür, H.J. Briegel, J.I. Cirac, and P. Zoller, Phys. Rev. A **59**, 169 (1999).

Q 4.2 Mon 11:15 F 342

Light storage in the presence of four-wave mixing — •Nikolai Lauk, Christopher O'Brien, and Michael Fleischhauer — Fachbereich Physik, TU Kaiserslautern

We investigate the effects of four-wave mixing (FWM) in a quantum memory which exploits electromagnetically induced transparency (EIT) to map a signal field, ideally a single photon, onto a long-lived collective atomic excitation by adiabatically switching off and on a strong control field. At high optical depths a four-wave mixing process can occur in this scheme, since the control field starts to act on both possible transitions producing a new idler field, which in turn affects the propagation of the signal field. FWM amplifies the signal field but also introduces noise to the signal channel. We use a full quantum mechanical approach to solve the coupled Maxwell-Bloch equations in order to determine when FWM is beneficial and when it is detrimental to light storage.

Q 4.3 Mon 11:30 F 342

A wavelength tunable quantum light-emitting diode — •Jiaxiang Zhang[1], Fei Ding[1], Eugenio Zallo[1], Santosh Kumar[1], Bianca Höfer[1], Armando Rastelli[2], Rinaldo Trotta[2], and Oliver G. Schmidt[1] — [1]Institute for Integrative Nanosciences, IFW-Dresden, Helmholtzstrasse 20, D-01069 Dresden, Germany — [2]Institute of Semiconductor and Solid State Physics, Johannes Kepler University Linz, Altenbergerstrasse 69, A-4040 Linz, Austria

In an optical quantum network it is desirable to have trigged quantum light sources that emit single photons with exactly the same wavelength. Previous work has realized two photon interference of the emission from two self-assembled quantum dots (QDs). The key is to use giant Stark shift to tune the emissions [Nat. Photon. 4, 632 (2010)]. However the design is cumbersome for the purpose of electrical injection. Here we demonstrate an electrically driven, wavelength tunable singlephoton source utilizing self-assembled InAs/GaAs QDs embedded in a p-i-n light-emitting diode (LED). Triggered single-photon emission is realized by applying ultra-short electrical pulses to the LED, while the wavelength of the emitted single photons is precisely controlled ($>$ 10meV) by external biaxial stresses applied to the LED. We also characterize the decay dynamics of the excitonic states and the pulsed single-photon emission [g2(t)] in this device. Our technique therefore presents strong promise for the realization of two photon interference from separated electrically injected single-photon sources.

Q 4.4 Mon 11:45 F 342

Strain Tuning of Quantum Dot Emissions: Towards Indistinguishable Photons from Separate Sources — •Bianca Höfer[1], Fei Ding[1], Eugenio Zallo[1], Jaixiang Zhang[1], Armando Rastelli[2], Rinaldo Trotta[2], and Oliver G. Schmidt[1] — [1]Institute for Integrative Nanosciences, IFW-Dresden, Helmholtzstrasse 20, D-01069 Dresden,Germany — [2]Institute of Semiconductor and Solid State Physics,Johannes Kepler University Linz, Altenbergerstrasse 69, A-4040 Linz, Austria

For optical quantum networks it is necessary to create entangling states from separated single photon sources. Epitaxially grown semiconductor quantum dots QDs are promising candidates for this purpose, mainly due to the possibility to be integrated into solid state devices. In order to create entangled single photon states, the emission characteristics (such as energies, exciton lifetimes) of two QDs have to be identical. However, as-grown quantum dots have spectral inhomogeneity, which make post-growth tuning techniques indispensable. Among the others, strain has very recently emerged as a powerful tool to tune the excitonic emissions in QDs [R.Trotta et al., Advanced Materials 23, 2706 (2011)]. Here we present independent control over the exciton lifetime and the emission energy in a single InAs/GaAs QD, by using the combination of external strain and electrical fields. Our approach promises a higher degree of indistinguishability of photons emitted by separated QDs.

Q 4.5 Mon 12:00 F 342

State selective resonant excitation of single silicon-vacancy centres in diamond — •Tina Müller[1], Christian Hepp[2], Benjamin Pingault[1], Elke Neu[2], Christoph Becher[2], and Mete Atatüre[1] — [1]University of Cambridge, Cavendish Laboratory, Cambridge, United Kingdom — [2]Universität des Saarlandes, Saarbrücken, Germany

Colour centres in diamond have attracted wide interest in recent years for applications in quantum enabled technologies. The negatively charged silicon-vacancy (SiV) centre is a particularly promising candidate due to its exceptional brightness and high concentration of the emission into the zero-phonon line, which shows four individual transitions at liquid helium temperature. Also, electron-spin resonance measurements and calculations based on density-functional theory indicate a paramagnetic ground state with S=1/2 for this centre. However, no optical signature of this electronic spin has been observed yet.

Using resonance fluorescence to resonantly drive the SiV centre at finite magnetic fields, we show that the emission intensity into the individual Zeeman-split zero phonon line transitions depends strongly on the resonantly driven transition. Two subsets of transitions can be observed, which indicates that population transfer in the optical excited state e. g. via phonon-mediated thermalisation processes can be strongly suppressed. We propose that the reason for this selectivity are two different electron spin projections for these excited states. This is in good agreement with a recently developed model based on a S=1/2 electron associated with this centre.

Q 4.6 Mon 12:15 F 342

Towards indistinguishability of photons from dissimilar sources — •Christoph Berkemeier, Andreas Ahlrichs, Andreas W. Schell, Otto Dietz, Tim Kroh, Benjamin Sprenger, and Oliver Benson — AG Nano Optics, Institut für Physik, HU Berlin

Long-distance quantum key distribution will require quantum repeater nodes, which are necessary for entanglement swapping between entangled photon pairs. A first step towards this goal is tailoring photons from dissimilar sources, in this case quantum dots and a photon pair source, to be indistinguishable in all degrees of freedom [1]. To increase the distance between nodes, single photon conversion into the telecommunications bands as shown in [2] could interconnect the different units with a low damped wavelength for long distance transmission in fiber.

The sources we use are single photons from quantum dots, and those from a parametric downconversion source in a cavity. We present a cascaded Fabry-Pérot filtering system, based on [3], which is simultaneously applied on photons from both sources. The quantum dot photons are filtered to 100 MHz width, and the system is optimized for long-term stability.

[1] Solomon et al., J. Opt. Soc. Am. B, 29, 319 (2012)
[2] Zaske et al., Opt. Express, 19, 12825 (2011)
[3] Palittapongarnpim et al., Rev. Sci. Instrum. 83, 066101 (2012)

Q 5: Quantum information: Atoms and ions I

Time: Monday 11:00–12:30 Location: E 214

Q 5.1 Mon 11:00 E 214

Operating 2D Arrays of Addressable Ion Traps — •Muir Kumph[1], Michael Niedermayr[1], Michael Brownnutt[1], and Rainer Blatt[1,2] — [1]Institut für Experimentalphysik, Universitäts Innsbruck Technickerstr 25, 6020 Innsbruck, Austria — [2]Institut für Quantenoptik und Quanteninformation, Österreichische Akademie der Wissenschaften, 6020 Innsbruck, Austria

Controlling interactions between ions in a segmented linear ion trap is becoming standard technology. Extending these methods to two dimensions, however, is not trivial. The trapping and control of 40Ca+ ions in a 4 by 4 array of addressable planar-electrode ion traps is shown. Demonstration of the micromotion minimization and estimates of the heating rates will be given.

Q 5.2 Mon 11:15 E 214

Quantum quenches of ion Coulomb crystals across structural instabilities — •Jens D. Baltrusch[1,2], Cecilia Cormick[3], and Giovanna Morigi[1] — [1]Theoretische Quantenphysik, Universität des Saarlandes — [2]Grup d'Optica, Universitat Autònoma de Barcelona — [3]Institut für Theoretische Physik, Universität Ulm

We theoretically analyze the efficiency of a protocol for creating mesoscopic superpositions of ion chains, described in [Phys. Rev. A **84**, 063821 (2011)], as a function of the temperature of the crystal. The protocol makes use of spin-dependent forces, so that a coherent superposition of the electronic states of one ion evolves into an entangled state between the chain's internal and external degrees of freedom. Ion Coulomb crystals are well isolated from the external environment, and should therefore experience a coherent, unitary evolution, which follows the quench and generates a structural Schrödinger cat-like state. The initial temperature of the chain, however, introduces a statistical uncertainty in the final state. We characterize the quantum state of the crystal by means of the visibility of Ramsey interferometry performed on one ion of the chain [Phys. Rev. A **86**, 032104 (2012)], and determine its decay as a function of the crystal's initial temperature. This analysis allows one to determine the conditions on the chain's initial state for performing the protocol.

Q 5.3 Mon 11:30 E 214

Generation of quantum discord between trapped atomic ions — Ben P. Lanyon[1,2], •Petar Jurcevic[1,2], Cornelius Hempel[1,2], Rainer Blatt[1,2], and Christian F. Roos[1,2] — [1]Institut für Quantenoptik und Quanteninformation, Österreichische Akademie der Wissenschaften, Technikerstr. 21A, 6020 Innsbruck, Austria — [2]Institut für Experimentalphysik, Universität Innsbruck, Technikerstr. 25, 6020 Innsbruck, Austria

Quantum systems can be unentangled and yet correlated in a way that is not possible for classical systems. These correlations, which exist for mixed quantum states, can be quantified by the quantum discord. Like entanglement, discord is known to be useful in a range of information processing tasks.

In this work we show, experimentally, that discord can be generated by simple classical noise processes. First, starting from a state of two trapped ions with only classical correlations, we generate discord using local operations i.e. by manipulating of only one ion. Then we show that even stronger discordant correlations can be generated by collective dephasing channels.

Since entanglement cannot be generated via any of the above processes, these experiments highlight a fundamental difference between the two types of non-classical correlations. Our work contributes to the continuing research on distinguishing the quantum/classical boundary and the generated states will find application in quantum information processing tasks.

Q 5.4 Mon 11:45 E 214

Driven single-sideband geometric phase gates with trapped ions — •Andreas Lemmer, Alejandro Bermúdez, and Martin B. Plenio — Institut für Theoretische Physik, Universität Ulm, 89069 Ulm, Germany

We will present our recent work on the implementation of a two qubit quantum logic gate for trapped ions which is robust against both thermal and dephasing noise. In particular, it is simpler than previous schemes because it relies on a single red-sideband excitation for quantum logic while the robustness against thermal and dephasing noise is achieved by a strong driving from a microwave source [1]. By choosing the laser and microwave frequencies appropriately the gate can be transformed into a geometric phase gate and thus be made faster and more reliable [2].

[1] A. Bermúdez et *al.*, Phys. Rev. A **85**, 040302(R) (2012)
[2] A. Lemmer, A. Bermúdez and M. B. Plenio *in preparation*

Q 5.5 Mon 12:00 E 214

Large controllable phase shift from a single trapped ion — •Andreas Jechow[1,2], Erik Streed[2], Benjamin Norton[2], and David Kielpinski[2] — [1]Universität Potsdam, Photonik, Karl Liebknecht Str 24-25, 14476 Potsdam — [2]Centre for Quantum Dy-

namics, Griffith University, Brisbane, Australia

Laser cooled trapped atomic ions are effectively isolated atoms held at rest and largely free from perturbations, representing a quantum system with control over all degrees of freedom. Recently, we have demonstrated wavelength scale imaging resolution of ytterbium ions trapped in a radio frequency Paul trap utilizing a phase Fresnel lens (PFL). This high spatial resolution and the high NA of the PFL allowed us to perform absorption imaging with a single isolated atom [1].

Here we show new results obtained with the absorption imaging technique. We have induced and measured a large optical phase shift in light scattered by a single trapped atomic ytterbium ion. The phase shift in the scattered component was unraveled by performing spatial interferometry between the scattered light and unscattered illumination light. The optical phase shift of 1.3 radians reaches the maximum value allowed by atomic theory over the accessible range of laser frequencies. Single-atom phase shifts of this magnitude open up new quantum information protocols, including long-range quantum phase-shift-keying cryptography and quantum nondemolition measurement.

[1] E.W. Streed, A. Jechow, B.G. Norton, and D. Kielpinski "Absorption imaging of a single atom, " Nature Communications 3, 933 (2012)

Q 5.6 Mon 12:15 E 214

Präzise Vermessung des Kibble-Zurek Mechanismus in Ionenkristallen — •Stefan Ulm, Johannes Rossnagel, Georg Jacob, Charlotte Degünther, Sam T. Dawkins, Ulrich G. Poschinger, Ferdinand Schmidt-Kaler und Kilian Singer — QUANTUM ,Institut für Physik, Universität Mainz, Staudingerweg 7, 55128 Mainz, Germany

Wird ein System schnell über einen Phasenübergang zweiter Ordnung in einen symmetrisch entarteten Grundzustand getrieben, dann können strukturelle Defekte entstehen, wenn in unterschiedlichen, räumlich und kausal getrennten, Regionen das System eine unabhängige und verschiedene Wahl des Zustandes trifft. Die Anzahl der strukturellen Defekte folgt dabei einem universellen Skalierungsgesetz, welches von Kibble und Zureck eingeführt wurde [1].

Kristalle aus einzelnen kalten Ionen stellen ein nahezu ideales Modellsystem dar, um die universelle Skalierung der Defektrate zu studieren. Schnelle Änderungen der Fallenkontrollspannungen und exakt einstellbare Parameter ermöglichen eine genaue Beobachtung der Defekte beim Übergang von linearen zu zickzack Kristallen [2]. Die Experimente werden mit numerischen Simulationen verglichen und wir finden eine hervorragende Bestätigung des Skalierungsgesetzes für den inhomogenen Kibble Zureck Effekt[3]. [1] T. W. B. Kibble, Jour. Phys. A 9, 1387 (1976) und W. Zurek, Nat. 317, 505 (1985). [2] H. Kaufmann et al., accepted for publication in PRL, arxiv:1208.4040 [3] A. Del Campo, et al. PRL 105, 75701 (2010) und G. De Chiara, et al. NJP 12, 115003 (2010).

Q 6: Ultracold atoms and molecules

Time: Monday 11:00–12:30 Location: A 310

Group Report Q 6.1 Mon 11:00 A 310

Electric quantum walks — •Andrea Alberti, Maximilian Genske, Andreas Steffen, Noomen Belmechri, Wolfgang Alt, and Dieter Meschede — Institut für Angewandte Physik, Universität Bonn - Wegelerstr. 8, 53115 Bonn

Quantum walks represent the quantum motion of a particle on a lattice with a strictly local dynamics, and they constitute the quantum counterpart of classic random walks. Their dynamics is determined by periodically reiterating a set of discrete quantum operations. Single atoms in a spin-dependent optical lattice provide, e.g., spin-dependent displacements, spin rotations, and collisional phase shifts, which can be employed to experimentally implement quantum walks and to simulate the quantum evolution of complex physical systems.

We will report on the experimental realization of an electric quantum walk, which mimics the quantum transport of charged particles in a period potential in the presence of an external electric field. The continuous-time quantum dynamics of these systems – well known for leading to the Bloch oscillation phenomenon – is here stroboscopically approximated by a periodic sequence of basic discrete operations.

We are able to reproduce the mechanism of Bloch oscillations and to investigate the Landau-Zener tunneling between the two energy bands that govern the transport dynamics of quantum walks. We detected quantum resonances every time the Bloch period is chosen commensurate with duration of one step, forcing the walker to spread out ballistically. Off-resonance, we present a clear experimental signature that the walker remains localized instead.

Q 6.2 Mon 11:30 A 310

Ground state cooling of a single atom at the center of an optical cavity — •Andreas Reiserer, Christian Nölleke, Stephan Ritter, and Gerhard Rempe — Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Straße 1, 85748 Garching

The study of the dynamics and precise manipulation of physical systems at the quantum level requires full control over all relevant degrees of freedom. In this respect, single atoms in optical dipole traps are a well advanced system. In order to couple these atoms to single photons, optical cavities have proven very successful. However, for complete control of this coupling, the atoms have to be cooled to the ground state of the trapping potential.

In our experiment, a single neutral atom is deterministically localized at the center of an optical resonator of high finesse. Using a three-dimensional optical lattice with high intensities, we observe trap frequencies of several hundred kHz. This allows us to cool the atom to the three-dimensional ground state via Raman sideband cooling. Thus, our system is the first to achieve simultaneous experimental control over the motional, internal and radiative properties of a single atom.

Q 6.3 Mon 11:45 A 310

Feedback on a single atom using heterodyne detection — Christian Sames, Haytham Chibani, Christoph Hamsen, Anna Caroline Eckl, Paul Altin, •Tatjana Wilk, and Gerhard Rempe — Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Str. 1, D-85748 Garching

An optical cavity can be used as a kind of intensifier to study radiation features of an atom, which are hard to detect in free space, like squeezing [1]. Such experiments make use of strong coupling between atom and cavity mode. Experimentally, strong coupling requires the atom to be well localized in the cavity mode. This can be achieved using feedback on the atomic motion: since the atom-cavity coupling depends on the atomic position within the mode, the field of a probe beam transmitted through the cavity varies strongly when the atom moves. The intensity of an intracavity dipole trap can then be switched in synchronism with the atomic motion, leading to cooling and localization. In contrast to previous feedback experiments done with photon counting [2,3], feedback with heterodyne detection gives continuous information of the field leaking out of the cavity. In this talk we will present recent measurements that were enabled by this new feedback strategy. [1] A. Ourjoumtsev et al., Nature 474, 623 (2011). [2] A. Kubanek et al., Nature 462, 898 (2009). [3] M. Koch et al., Phys. Rev. Lett. 105, 173003 (2010).

Q 6.4 Mon 12:00 A 310

A raman laser system for adiabatic photo association of NaK molecules — •Diana Amaro, Nikolaus Buchheim, Zhenkai Lu, Tobias Schneider, Immanuel Bloch, and Christoph Gohle — Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Strasse 1, 85748 Garching

Ultra cold quantum gases with large dipolar interaction or large polarizability that are recently becoming available promise exciting new possibilities. Self assembled lattices of polarized particles supporting phonon modes will provide opportunities to simulate an even broader range of solid state physics phenomena [1]. New classes of many body phases (like super solids and stripe phases) are on the horizon and ferroelectric phases of highly polarizable systems are expected [2].

One such system is the NaK bialkali with a ground state dipole moment of 2.8 Debeye. In order to create these molecules at sufficiently high phase space density, an adiabatic route from a near degenerate mixture of sodium and potassium to the molecular electronic, rotational and vibrational ground state bridging 150THz is required. We have built a highly stable raman laser system by stabilizing two diode lasers to a ultra stable fabry perot transfer cavity.

[1] Pupillo, G., Micheli, A., Büchler, H. P., & Zoller, P. (2008). Condensed Matter Physics with Cold Polar Molecules. arXiv:0805.1896.

[2] Iskin, M., & Sá de Melo, C. (2007). Ultracold Heteronuclear Molecules and Ferroelectric Superfluids. Physical Review Letters, 99(11), 110402.

Q 6.5 Mon 12:15 A 310

Vacuum-Induced Coherence in Ultracold Molecules — •Sumanta Das[1,2], Arpita Rakshit[1], and Bimalendu Deb[1] — [1]Department of Material Sciences, IACS, Kolkata 700032, India — [2]Max Planck Institute for Nuclear Physics, Saupfercheckweg 1, 69117 Heidelberg, Germany

We show that coherence between two excited rovibrational states belonging to the same molecular electronic configuration arises quite naturally due to their interaction with the electromagnetic vacuum [1]. For initial preparation of a molecule in the desired rovibrational states, we propose to employ the method of ultracold photoassociation. Spontaneous decay of the excited molecule then gives rise to vacuum-induced coherence between the excited ro-vibrational states. We demonstrate theoretically an interesting interplay of effects due to vacuum-induced coherence and photoassociation. We apply our theory to photoassociation of bosonic ytterbium (^{174}Yb) atoms, which appear to be a promising system for exploring such interplay [2, 3]. The effects discussed here can be important for controlling decoherence and dissipation in molecular systems.

[1] S. Das, A. Rakshit and B. Deb, Phys. Rev. A **85**, 011401(R) (2012).

[2] S. Tojo *et al.*, Phys. Rev. Lett. **96**, 153201 (2006).

[3] M. Borkowski *et al.*, Phys. Rev. A **80**, 012715 (2009).

Q 7: Ultra-cold atoms, ions and BEC I (with A)

Time: Monday 11:00–12:30 Location: B 305

Invited Talk Q 7.1 Mon 11:00 B 305

Dynamics of Ultra-cold Atoms in Optical Lattices — •Sandro Wimberger — Institut für Theoretische Physik, Universität Heidelberg

Modern quantum and atom-optical experiments allow for an unprecedented control of microscopic degrees of freedom, not just in the initialization but also in the dynamical evolution of quantum states. This talk focuses on the dynamics of ultra-cold bosons in optical lattice structures. Experimental as well as theoretical results for two paradigm systems are reported: on (1) the interband transport in a tilted lattice, i.e. a realization of the famous Wannier-Stark problem, and (2) on the stability of the temporal evolution in kicked lattice potentials. General perspectives on future directions of our study of strongly correlated bosons in lattice structures conclude the talk.

Q 7.2 Mon 11:30 B 305

Interaction induced modification of tunnelling rates in a 1D tilted optical lattice — •Florian Meinert[1], Manfred Mark[1], Emil Kirilov[1], Katharina Lauber[1], Philipp Weinmann[1], Andrew Daley[2], and Hanns-Christoph Nägerl[1] — [1]Institut für Experimentalphysik, Universität Innsbruck — [2]Physics and Astronomy, University of Pittsburgh

Cold atoms confined in optical lattice potentials offer unique access to study condensed matter Hamiltonians, e.g. the bosonic Hubbard model. Magnetic Feshbach resonances provide high control and tunability of the interparticle on-site interaction strength allowing for the preparation of Mott insulating phases with both, attractive and repulsive interaction.

We study correlated tunnelling dynamics of degenerate bosonic Cs atoms prepared in one dimensional singly occupied Mott insulating chains. Subjecting the atoms to a linear potential gradient that is adiabatically ramped through resonance with the interaction energy results in a doublon-hole density wave order, a situation that maps onto the quantum phase transition from the paramagnetic to the antiferromagnetic state in the 1D transverse Ising model.

By quenching the system onto the phase transition point we initiate non-equilibrium tunnelling dynamics as detected in the number of created doubly occupied lattice sites. The observed coherent response of the system provides a direct measure of the tunnelling rate. We observe striking modification of this rate by interactions when tuned from attractive to repulsive.

Q 7.3 Mon 11:45 B 305

Strontium in an Optical Lattice as a Portable Frequency Reference — Ole Kock, Wei He, Lyndsie Smith, Huadon Cheng, Steven Johnson, Kai Kai, and •Yeshpal Singh — School of Physics and Astronomy, University of Birmingham, Edgbaston Park Road, Birmingham B15 2TT, UK

A major scientific development over the last decade, namely clocks based on optical rather than microwave transitions, has opened a new era in time/frequency metrology. Several Physics Nobel prizes (1997, 2001, 2005, 2012) were awarded for methods that have enabled optical clocks.In optical clocks the (laser) electromagnetic wave beats 10^15 times per second instead of 10^10 as in microwave clocks. Optical clocks have now achieved a performance significantly beyond that of the best microwave clocks, at a fractional frequency inaccuracy of 8.6 *10^-18. The essential techniques used in optical clocks are the confinement of the atoms to regions significantly smaller than the wavelength of light, provision of an environment as free of disturbing influences (magnetic and electric fields, residual gas, black-body fields) as possible, choice of adequate atomic species, and the narrowing of the spectral width of the clock laser to relative levels of 10^-15 and less. With the rapidly improving performance of optical clocks, in the future, most applications requiring the highest accuracy will require optical clocks. They cover the fields of fundamental physics (tests of General Relativity and its foundations), time and frequency metrology (comparison of distant terrestrial clocks, operation of a master clock in space).

Q 7.4 Mon 12:00 B 305

A novel 2D-confinement scheme for ultracold ^{40}K atoms — •Martin Reitter[1,2], Lucia Duca[1,2], Tracy Li[1,2], Josselin Bernardoff[1,2], Henrik Lüschen[1,2], Monika Schleier-Smith[1,2], Immanuel Bloch[1,2], and Ulrich Schneider[1,2] — [1]Fakultät für Physik, Ludwig-Maximilians-Universität, 80799 München, Germany — [2]Max-Planck-Institut für Quantenoptik, 85748 Garching, Germany

We report on a novel scheme for compressing an ultracold cloud of ^{40}K atoms into a single two-dimensional layer. The use of a single layer not only provides an analog to two-dimensional electron gases in condensed matter systems, but also allows for direct imaging of the atom cloud without the typical averaging effects due to the integration along the line-of-sight. A standard approach to compressing atoms into a single two-dimensional plane is to load them into a deep vertical lattice and remove atoms from all but one lattice plane. During this procedure, however, a significant number of atoms is lost. To overcome this disadvantage, we realize a vertical lattice with a dynamically variable lattice constant. By continuously changing the confinement, we will be able to compress almost all atoms held in a crossed-beam dipole trap into a single two-dimensional layer. Subjecting this two-dimensional system to an artificial gauge field will enable studies of topologically ordered states of fermions.

Q 7.5 Mon 12:15 B 305

Measuring and controlling quantum transport of heat in trapped-ion crystals — Alejandro Bermudez, •Martin Bruderer, and Martin B Plenio — Institut für Theoretische Physik, Albert-Einstein Allee 11, Universität Ulm, 89069 Ulm, Germany

Measuring heat flow through nanoscale systems poses formidable practical difficulties as there is no 'ampere meter' for heat. We propose to overcome this problem by realizing heat transport through a linear chain of trapped ions. Steady laser cooling of the chain edges to different temperatures induces a current of local vibrations (vibrons) across the bulk ions. We show how to efficiently measure and control this heat current (including fluctuations) by coupling vibrons to internal ion states, which are easily manipulated. That makes ion crystals an ideal tool for studying thermal quantum transport and, in particular, gives access to the expectedly large fluctuations in the bosonic current.

Q 8: Micromechanic oscillators II

Time: Monday 14:00–15:30 Location: F 142

Q 8.1 Mon 14:00 F 142

Dissipative opto-mechanics in a membrane interferometer — •Henning Kaufer, Andreas Sawadsky, Ramon Moghadas Nia, Sergey Tarabrin, Klemens Hammerer, and Roman Schnabel — Institut für Gravitationsphysik, Leibniz Universität Hannover and Max-Planck-Institut für Gravitationsphysik (Albert-Einstein-Institut), Callinstr. 38, 30167 Hannover, Germany

Opto-mechanical coupling can either be dispersive or dissipative. In the latter case, the movement of a mechanical oscillator rather changes the cavity linewidth than the cavity length. It was found that a signal-recycled Michelson-Sagnac interferometer with translucent, high-Q micromechanical oscillator is a topology that allows for the dissipative coupling mechanism to dominate over the dispersive coupling. The dissipative coupling features cooling in the unresolved sideband regime and some anomalous optical instability for a red and blue detuned cavity. In my talk, I will present the experimental setup and recent results.

Q 8.2 Mon 14:15 F 142

Cavity-Enhanced Long-Distance Coupling of an Atomic Ensemble to a Micromechanical Membrane — •Andreas Jöckel[1], Maria Korppi[1], Aline Faber[1], Matthew T. Rakher[1], Berit Vogell[2], Kai Stannigel[2], Peter Zoller[2], Klemens Hammerer[3], and Philipp Treutlein[1] — [1]Departement Physik, Universität Basel, Schweiz — [2]Universität Innsbruck, Österreich — [3]Universität Hannover, Deutschland

We present first experimental results on creating a hybrid quantum system where a dielectric membrane inside an optical cavity is coupled via a light field to a distant ultracold atomic ensemble trapped in free space. The coupling is mediated by a laser beam that couples to the cavity and creates an optical lattice for the atoms, thus coupling to the atomic center of mass motion. This coupling is enhanced by the cavity finesse as well as the square root of the number of atoms.

The system can be operated in two modes, where one can either observe coherent dynamics between the systems, or switch on a strong dissipation by cooling the atoms, thereby sympathetically cooling the membrane. The cooling scheme does not require resolved sidebands for the cavity, which relaxes a constraint present in standard optomechanical cavity cooling.

In a previous experiment [PRL 107, 223001(2011)] without a cavity we could demonstrate the bi-directional coupling of rubidium atoms to a SiN mechanical membrane oscillator. With the new system a substantial increase of the interaction is expected and even ground state cooling of a cryogenically pre-cooled membrane should be possible.

Q 8.3 Mon 14:30 F 142

Strong-coupling effects in dissipatively coupled optomechanical systems — •Talitha Weiss, Christoph Bruder, and Andreas Nunnenkamp — Department of Physics, University of Basel, Klingelbergstrasse 82, CH-4056 Basel, Switzerland

We study cavity optomechanical systems in which the position of a mechanical oscillator modulates both the resonance frequency (dispersive coupling) and the linewidth (dissipative coupling) of a cavity mode. Using a quantum noise approach we calculate the optical damping and the optically-induced frequency shift. We find that dissipatively coupled systems feature two parameter regions providing amplification and two parameter regions providing cooling. To investigate the strong-coupling regime, we solve the linearized equations of motion exactly and calculate the mechanical and optical spectra. In addition to signatures of normal-mode splitting that are similar to the case of purely dispersive coupling, the spectra contain a striking feature that we trace back to the Fano line shape of the force spectrum. Finally, we show that purely dissipative coupling can lead to optomechanically-induced transparency which will provide an experimentally convenient way to observe normal-mode splitting.

Q 8.4 Mon 14:45 F 142

Cavity Optomechanics with levitating Nanospheres — •Nikolai Kiesel, Florian Blaser, Uros Delic, David Grass, Rainer Kaltenbaek, and Markus Aspelmeyer — Vienna Center for Quantum Science and Technology (VCQ), Faculty of Physics, University of Vienna, A-1090 Vienna, Austria

Optically trapped nanospheres have been proposed as mechanical resonators for cavity optomechanics with great potential [1]: This approach promises, amongst others, optomechanical quantum information protocols at room temperature and fundamental quantum experiments with objects of up to 10^{10} amu [2]. These ideas require cavity optomechanical cooling and control of the nanospheres centre-of-mass motion. However, cavity cooling of such optically trapped and internally hot objects without internal level structure has not been experimentally achieved so far.

We present the experimental demonstration of a levitated nanosphere coupled to a high-finesse cavity and optomechanical readout and cooling of its center-of-mass motion.

Next steps towards operation in UHV and implementation of levitated ultra-high quality mechanical resonators in optical cavities will be dicussed.

[1] Romero-Isart O. et al., NJP 12, 33015 (2010), Chang D. et al. PNAS 107, 0912969107, (2009), Barker P, et al., PRA 81, 023826 (2010). [2] Romero-Isart, O et al., PRL, 107, 020405 (2011), Romero-Isart, O., PRA 84, 5 (2011), Kaltenbaek, R. et al., MAQRO, Exp. Astro., 1-42 (2012)

Q 8.5 Mon 15:00 F 142

Optomechanics beyond linearization: Two-phonon induced transparency — Kjetil Børkje[1], •Andreas Nunnenkamp[2], John D. Teufel[3], and Steven M. Girvin[4] — [1]Niels Bohr Institute, University of Copenhagen, Blegdamsvej 17, DK-2100 Copenhagen, Denmark — [2]Department of Physics, University of Basel, Klingelbergstrasse 82, CH-4056 Basel, Switzerland — [3]National Institute of Standards and Technology, Boulder, Colorado 80305, USA — [4]Departments of Physics and Applied Physics, Yale University, New Haven, Connecticut 06520, USA

We identify a novel signature of the intrinsic nonlinear interaction between light and mechanical motion in cavity optomechanical systems. This signature is observable in the resolved-sideband limit even if the cavity linewidth exceeds the optomechanical coupling rate. A strong laser drive red-detuned by twice the mechanical frequency from the cavity resonance frequency makes two-phonon processes resonant, which leads to a nonlinear version of optomechanically-induced transparency. This effect provides a new method of measuring the mean phonon number of the mechanical oscillator that is not susceptible to technical laser noise and should be observable with optomechanical coupling strengths that have already been realized in experiments.

Q 8.6 Mon 15:15 F 142

Continuous-time quantum state engineering in optomechanics — •Sebastian Hofer[1], Markus Aspelmeyer[1], and Klemens Hammerer[2] — [1]Vienna Center for Quantum Science and Technology, Faculty of Physics, University of Vienna, 1090 Vienna, Austria — [2]Institute for Theoretical Physics, Institute for Gravitational Physics, Leibniz University Hannover, 30167 Hannover, Germany

Control and state preparation of mechanical oscillators on the quantum level is one of the main goals of quantum optomechanics and has seen plenty of theoretical and experimental interest lately. Preparing a mechanical system in the ground state by side-band cooling has already been achieved. Recently cooling of mechanical motion has as well been demonstrated in a pulsed scheme, which also has the potential to prepare a mechanical squeezed states.

Building on our previous work which discussed optomechanical teleportation in the pulsed regime we here explore continuous-time mechanical state engineering. More specifically, we analyze a *continuous* quantum teleportation protocol which allows for teleportation of squeezed light states onto a mechanical oscillator by applying stochastic-master-equation methods developed in the context of continuous measurement and quantum control and estimation theory. We also show that with a similar scheme it is possible to generate continuous entanglement swapping between two oscillators. Furthermore we consider optomechanical feedback cooling in different parameter regimes and discuss its limitations.

Q 9: Photonics I

Time: Monday 14:00–16:00 Location: A 310

Q 9.1 Mon 14:00 A 310

Frequency Down-Conversion of Single Photons — •Andreas Lenhard[1], Sebastian Zaske[1], Christian Kessler[2], Jan Kettler[2], Carsten Arend[1], Christian Hepp[1], Roland Albrecht[1], Wolfgang-Michael Schulz[2], Michael Jetter[2], Peter Michler[2], and Christoph Becher[1] — [1]Universität des Saarlandes, FR 7.2 Experimentalphysik, Campus E2.6, 66123 Saarbrücken — [2]Institut für Halbleiteroptik und funktionelle Grenzflächen and Research Center SCoPE, Universität Stuttgart, 70569 Stuttgart

Establishing a quantum network over existing fiber transmission lines requires photons at low-loss telecommunication wavelengths, serving as flying qubits. To this end, photons generated by a quantum emitter in the red or near-infrared spectral region can be translated to the telecom bands via frequency down-conversion in a nonlinear medium using a strong mixing wave.

We report on the frequency down-conversion of single photons emitted by an InP/GaInP quantum dot at 710 nm to the telecom O-band at 1310 nm via difference frequency generation [1]. The strong pump field is generated by an optical parametric oscillator and mixed with the single photons in a PPLN waveguide. With an over-all conversion efficiency above 30% we were able to measure the second-order correlation function of the photons before and after conversion and prove the conservation of the single photon statistics. Furthermore, the temporal and coherence properties are also shown to be preserved.

1. Zaske et al., Phys. Rev. Lett. **109**, 147404 (2012)

Q 9.2 Mon 14:15 A 310

Coupling of single colour centres to photonic crystal cavities in monocrystalline diamond — •Janine Riedrich-Möller[1], Laura Kipfstuhl[1], Sébastien Pezzagna[2], Jan Meijer[2], Martin Fischer[3], Stefan Gsell[3], Matthias Schreck[3], and Christoph Becher[1] — [1]Experimentalphysik 7.2, Universität des Saarlandes, Germany — [2]Rubion, Ruhr-Universität Bochum, Germany — [3]Experimentalphysik IV, Universität Augsburg, Germany

The deterministic coupling of single quantum emitters to photonic crystal cavities is considered as an important step towards integrated solid-state devices for quantum information processing. As single emitters, colour centres in diamond, e.g. nitrogen- (NV) or silicon-vacancy (SiV) centres have attracted significant interest due to their extraordinary properties like long spin coherence times or narrow bandwidth emission, respectively. For controlled coupling of a single defect centre to photonic crystal cavities several challenges have to overcome, e.g. exact emitter positioning and alignment of the dipole moment with respect to the cavity electric field as well as cavity tuning methods. Here we present two strategies towards deterministic coupling of single colour centres to photonic crystal cavities fabricated in monocrystalline diamond. In the first approach, we locate a single SiV centre in a diamond thin film and etch a photonic structure around the emitter via focused ion beam milling. After the fabrication, the cavity modes are tuned into resonance with the zero phonon line of a single SiV centre. In the second approach, the photonic crystal cavity is fabricated first and NV centres are subsequently implanted at the cavity centre.

Q 9.3 Mon 14:30 A 310

Atomic defects in silicon carbide LEDs as a perspective single photon source — •Franziska Fuchs[1], Victor Soltamov[2], Stefan Väth[1], Pavel Baranov[2], Eugeny Mokhov[2], Georgy Astakhov[1], and Vladimir Dyakonov[1,3] — [1]Experimental Physics VI, Julius Maximilian University of Würzburg, 97074 Würzburg — [2]Ioffe Physical-Technical Institute, St. Petersburg, 194021 Russia — [3]ZAE Bayern, 97074 Würzburg

Single photon sources, reliably emitting on demand, are necessary for e.g. optical quantum computers. For this purpose, several systems seem suitable, including atoms, molecules, quantum dots and color centers in diamond. But all these systems are difficult to implement, since they either only work at low temperatures, or do not emit at typical wavelengths used in existing telecommunication infrastructure. We suggest another system - silicon vacancy defects in silicon carbide, emitting photons in the near infrared [1]. We fabricated light emitting diodes based on intrinsic defects in silicon carbide. The room temperature electroluminescence reveals two strong emission bands in visible and NIR, the latter assigned to silicon vacancy defects. Our approach can be used to realize an electrically driven single photon source for quantum telecommunication.

[1]Riedel et al.: Resonant Addressing and Manipulation of Silicon Vacancy Qubits in Silicon Carbide, Phys. Rev. Lett.109,226402(2012)

Q 9.4 Mon 14:45 A 310

Three dimensional mapping of the local density of states using a single quantum emitter — •Philip Engel, Andreas W. Schell, and Oliver Benson — Nano-Optics, Institute of Physics, Humboldt-Universität zu Berlin, Newtonstraße 15, D-12489 Berlin

Understanding light matter interaction plays an important role in tailoring and engineering complex environments on the nanoscale. A fundamental requirement for this is knowledge of the local density of optical states (LDOS). We present a method which allows to map the LDOS in all three dimensions with sub-nanometer resolution. Due to Fermi's golden rule the LDOS can be directly measured via lifetime changes of an emitter. We use the nitrogen vacancy defect in nanodiamond as point-like probe glued onto the tip of an atomic force microscopy. This gives us the capability to measure the topography, the lifetime, and therefore the LDOS simultaneously.

Q 9.5 Mon 15:00 A 310

NV-centers as single-photon emitters integrated into three-dimensional laser-written micro-structures — •Andreas W. Schell[1], Johannes Kaschke[2], Joachim Fischer[2], Janik Wolters[1], Rico Henze[1], Martin Wegener[2], and Oliver Benson[1] — [1]AG Nanooptik, Humboldt-Universität zu Berlin, Germany — [2]Institut für Angewandte Physik, Karlsruhe Institute of Technology (KIT), Germany

Future quantum-optical experiments and applications will likely require on-chip integration of micro-optical structures and single-photon emitters. Here, we show the direct integration of nitrogen-vacancy centers (NV centers) in nanodiamonds into various three-dimensional photonic structures by means of two-photon direct laser writing [1]. This technique enables manufacturing micro-optical structures of nearly arbitrary shape. The nanodiamonds are integrated by mixing them into the photoresist prior to its exposure. To exemplify the strength of this approach, we demonstrate efficient coupling of NV centers serving as single-photon sources to waveguides and whispering-gallery-mode optical micro-resonators.

[1] A.W. Schell et al. arXiv:1209.2036 (2012)

Q 9.6 Mon 15:15 A 310

A molecular – atomic hybrid system — •Petr Siyushev[1], Guilherme Stein[1], Jörg Wrachtrup[1,2], and Ilja Gerhardt[1,2] — [1]3. Physics Institute and Research Center SCoPE, University of Stuttgart, 70569 Stuttgart, Germany — [2]Max Planck Institute for Solid State Research, 70569 Stuttgart, Germany

Single photon sources (SPSs) are a key element for quantum information processing (QIP). Among other systems, single molecules are one of the promising candidates due to their high brightness and the possibility to generate single photons on demand [1]. Another crucial point for realization QIP is a quantum memory and atoms constitute a good media for its realization [2]. Here we present recent results in combining single molecule spectroscopy with the spectroscopy on the atomic vapor. A high-brightness molecule based SPS at the Sodium D-line is shown as well as slowed down photons in a Na-vapor cell. In addition, atomic vapor, serving as a very narrow notch filter, allows for an increased detection efficiency in comparison with commercial interference filters.

[1] B. Lounis and W. E. Moerner, Nature **407**, 491 (2000) [2] D. F. Phillips, A. Fleischhauer, A. Mair R. L. Walsworth, and M. D. Lukin, Phys. Rev. Lett. **86**, 783 (2001)

Q 9.7 Mon 15:30 A 310

Coupling color centers in diamond to fiber based Fabry-Pérot microcavities — •Hanno Kaupp[1,2], Christian Deutsch[1,2], Roland Albrecht[3], Elke Neu[4], Christoph Becher[3], Jakob Reichel[5], Theodor W. Hänsch[1,2], and David Hunger[1,2] — [1]Ludwigs-Maximilians-Universität München — [2]Max-Planck Institut für Quantenoptik, Garching — [3]Universität des Saarlandes — [4]Universität Basel — [5]Laboratoire Kastler Brossel, E.N.S, Paris

Optical fibers with machined and coated end facets can serve as high reflectivity mirrors to build low loss optical resonators with free space access. Such microcavities feature a very small mode volume on the order of a few tens of cubic wavelengths and a very large Finesse of up to 10^5, corresponding to quality factors of several millions. The resulting Purcell factor can ideally be as high as 10^4. This can involve a dramatic increase of the emission rate of an emitter inside the cavity.

We use the microcavities to couple color centers in diamond to the cavity. First results of coupling nitrogen-vacancy center (NV) ensembles to the cavity will be discussed. We demonstrate cavity enhanced emission and quantify the effective Purcell factor by analyzing optical spectra. The observed enhancement can be modeled with an effective Purcell factor taking the fast dephasing of the NV center into account.

In contrast to the broad spectral emission characteristics of NV centers, the silicon-vacancy (SiV) center in diamond can exhibit an emission linewidth of below 1 nm at room temperature. This holds promise to achieve much larger effective Purcell factors and emission rates. We will show first steps towards coupling SiV centers to microcavities.

Q 9.8 Mon 15:45 A 310

Photonic Rutherford Scattering — •Markus Selmke and Frank Cichos — Universität Leipzig, molecular nanophotonics

We show that the quantum mechanical (QM) description of Rutherford scattering has a photonic counterpart in a new form of single particle photothermal (PT) microscopy. Using a split detector we provide experimental evidence, that photons are deflected by a photonic potential which is created by a local refractive index change around a laser-heated absorbing nanoparticle. The deflection experienced is shown to be the analog to the deflection of a massive particle wave-packet in unscreened (spin-less) Coulomb scattering. The experimentally found focal detection geometry reveals an adjustable lateral split sub-volume feature which allows new correlation-based 3D-velocimetry experiments of absorbing nanoparticles with ultra-high sensitivity. Further, a framing of the whole spectrum of phenomena in PT single particle microscopy into the well-known QM scattering framework is hereby achieved.

Q 10: Precision measurements and metrology II

Time: Monday 14:00–15:45 Location: F 128

Group Report Q 10.1 Mon 14:00 F 128

Miniaturized laser systems for precision measurement applications — •Markus Krutzik[1], Achim Peters[1,2], Andreas Wicht[2], Ernst Rasel[3], Klaus Sengstock[4], and The LASUS Team[1,2,3,4] — [1]Institut für Physik, HU Berlin — [2]Ferdinand-Braun-Insitut, Leibniz Institut für Höchstfrequenztechnik, Berlin — [3]Institut für Quantenoptik, LU Hannover — [4]Institut für Laserphysik, U Hamburg

Rapid progress in the field of ultra cold quantum gases has led to the development of new measurement tools with unprecedented precision such as high performance optical clocks and matter wave interferometers. Their ultimate performance can only be reached in space by providing access to unperturbed long evolution times and low-noise environments, altogether leading to outperform existing inertial sensors in accuracy and precision. Space-borne experiments in particular, but also those instruments targeting practical applications on ground, depend to a large degree on the availability of robust, compact and energy-efficient laser system technology. We present the development of a new generation of compact laser systems specifically optimized for precision applications on sounding rockets and satellites.

This work is supported by the German Space Agency DLR with funds provided by the Federal Ministry of Economics and Technology (BMWi) under grant numbers DLR 50 WM 1131-1137, 1237-1240, 1141 and 50QT1201.

Q 10.2 Mon 14:30 F 128

High resolution Sagnac atom interferometer — •Gunnar Tackmann, Peter Berg, Sven Abend, Teresa Feld, Katja Baxmann, Paul Kaebert, Christian Schubert, Wolfgang Ertmer, and Ernst M. Rasel — Institut für Quantenoptik, Leibniz Universität Hannover

We present a compact dual source cold-atom gyroscope with flat parabolic atomic trajectories in which an area of 19 mm^2 is realised on a baseline of 13.7 cm. This gyroscope resolves a rotation rate of $5.3{\cdot}10^{-7}$ rad/s at one second, mainly limited by inertial noise, and reaches a final sensitivity of $3{\cdot}10^{-8}$ rad/s. We introduce ways to further improve the stability of the device and to increase its sensitivity to the 10^{-9} rad/s regime by monitoring the rotational noise with auxiliary seismic sensors.

This work is supported by the DFG, the cluster of excellence QUEST, and IQS.

Q 10.3 Mon 14:45 F 128

High sensitivity temperature measuerements on the nanometer scale — •Philipp Neumann[1], Florian Dolde[1], Ingmar Jakobi[1], Gerald Waldherr[1], Rolf Reuter[1], Junichi Isoya[2], and Jörg Wrachtrup[1] — [1]3. Physikalisches Institut, Universität Stuttgart — [2]Graduate School of Library, Information and Media Studies, University of Tsukuba, Japan

Here we demonstrate a novel method to measure temperatures with a sensitivity of ~ 10 mK/$\sqrt{Hz}$ and nanometer spatial resolution. Its temperature application range is at least from 120 K to 600 K and includes ambient conditions. It is therefore interesting for material and lifescience. We employ a single optically active paramagnetic defect in a nanometer size diamond, namely the nitrogen-vacancy center. More precisely the spin state can be read out optically and its energy levels depends on temperature among others. We have developed a novel technique to circumvent the main detrimental effects to achieve the stated sensitivity.

Q 10.4 Mon 15:00 F 128

Spectroscopy of the clock transition in ^{171}Yb with a transportable setup — •Tobias Franzen, Charbel Abou Jaoudeh, Gregor Mura, Axel Görlitz, Heiko Luckmann, Alexander Nevsky, Ingo Ernsting, and Stephan Schiller — Institut für Experimentalphysik, HHU Düsseldorf, Universitätsstr. 1, 40225 Düsseldorf

Optical lattice clocks based on elements with two valence electrons are strong competitors in the quest for next generation time and frequency standard. While promising results have already been obtained on several stationary setups using Sr and Yb, transportable clocks are desirable for both performance evaluation and applications.

In the framework of the Space Optical Clocks 2 project, we are developing a transportable Yb lattice clock demonstrator. Our setup is based on diode and fiber lasers and features an intra-vacuum enhancement resonator to allow the formation of a large volume lattice using moderate laser power.

Here we present first results of spectroscopy of the $^1S_0 \rightarrow {}^3P_0$ transition in ^{171}Yb confined in an one dimensional optical lattice, a first evaluation of systematics and ongoing work towards competitive clock operation as well as more compact and robust subsystems.

Q 10.5 Mon 15:15 F 128

Compact mode-locked diode laser system for highly accurate frequency comparisons — •Heike Christopher[1,2], Evgeny Kovalchuk[1], Achim Peters[1,2], and the LASUS Team[1,2,3,4] — [1]Institut für Physik, HU Berlin — [2]Ferdinand-Braun-Insitut, Leibniz-Institut für Höchstfrequenztechnik Berlin — [3]Institut für Quantenoptik, LU Hannover — [4]Institut für Laserphysik, Universität Hamburg

We have developed a compact mode-locked diode laser system designed to generate an optical frequency comb spanning the wavelength range from 767 nm to 780 nm. It will thus allow highly accurate frequency comparisons in microgravity experiments testing the Einstein equivalence principle (EEP) for Rubidium and Potassium quantum gases.

The passively mode-locked semiconductor laser system is configured as an extended-cavity laser, allowing for high flexibility in optimizing performance parameters to match the application requirements. The intra-cavity output of the two-section ridge-waveguide (RW) laser diode, consisting of a short saturable absorber and a long gain section, is collimated and reflected by a dielectric mirror. The group velocity dispersion (GVD) of this mirror can be adjusted to provide optimal performance by compensating the laser diode dispersion. Here we present the current status of our work and discuss options for further improvements.

This 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 50WM1237-1240.

Q 10.6 Mon 15:30 F 128

Broadband femtosecond filtering cavities for quantum limited projective metrology — •Roman Schmeissner, Valerian Thiel, Jonathan Roslund, Claude Fabre, and Nicolas Treps — Laboratoire Kastler Brossel, 4 Place Jussieu, 75252 Paris cedex 05, France

We have shown theoretically that balanced homodyne detection with a temporally shaped local oscillator extracts timing information and any other parameter of femtosecond(fs)-pulses with ultimate sensitivity [1]. To reach limits predicted by information theory, the scheme requires a laser beam that is quantum-limited in amplitude and phase. We propose to use optical cavities: they are intrinsic, passive low-pass filters that address frequency scales difficult to reach with active feedback mechanisms. Similar systems are used for broadband spectroscopy [2,3]. We construct and characterize a readily implementable filtering cavity that is simultaneously resonant over 100nm. This exceptional broadband property enables a wide range of applications from parameter estimation to ultra-precise spectroscopy. When seeded with a 25fs frequency comb, intensity and phase noise are reduced by up to 10dB at and below the relaxation oscillation band at 1MHz. Furthermore, noise quadrature interconversion enables qualitative identification of phase noise at sidebands above 100kHz. In conclusion, a frequency comb that is quantum limited in amplitude and phase for frequencies larger than 500kHz is obtained from a commercial Ti:Sa laser system.

[1] B. Lamine et al., Phys. Rev. Lett. 101, 2008, 123601, 1-4 [2] Ch. Gohle et al., Phys. Rev. Lett. 100, 2008, 1-4 [3] M.J. Thorpe et al., Optics Express 16, 2008, 2387-2397

Q 11: Quantum effects: QED

Time: Monday 14:00–16:00 Location: F 342

Group Report Q 11.1 Mon 14:00 F 342

Strong-Field QED Processes in Short Intense Laser Pulses — •Daniel Seipt[1,2], Tobias Nousch[1,2], Andreas Otto[1,2], Alexander I. Titov[1,3], and Burkhard Kämpfer[1,2] — [1]Helmholtz-Zentrum Dresden-Rossendorf, POB 510119, 01314 Dresden, Germany — [2]TU Dresden, Institut für Theoretische Physik, 01062 Dresden, Germany — [3]Bogoliubov Laboratory of Theoretical Physics, JINR, Dubna 141980, Russia

Strong-field QED processes in intense laser fields are presently of great interest in view of upcoming high-intensity laser facilities such as ELI. In this talk I will present recent results of our group on strong-field QED processes such as high-intensity one- and two-photon Compton scattering [1,2] as well as the cross channel pair production processes [3]. These processes are described using QED in the Furry picture with laser dressed Volkov states. The effects of the short laser pulse length of a few tens of femtoseconds are discussed. Furthermore, results for the dynamical Schwinger effect in time dependent electric fields as well as the modification weak interaction processes in intense laser fields are presented [4].

[1] D. Seipt and B. Kämpfer, Phys. Rev. A **83**, 022101 (2011). [2] D. Seipt and B. Kämpfer, Phys. Rev. D **85**, 101701 (2012). [3] T. Nousch, D. Seipt, B. Kämpfer and A. I. Titov, Phys. Lett. B **715**, 246 (2012). [4] A. I. Titov, B. Kämpfer, H. Takabe and A. Hosaka, Phys. Rev. D **83**, 053008 (2011).

Q 11.2 Mon 14:30 F 342

Collapse-revival dynamics in strongly laser-driven electrons — •Oleg Skoromnik[1], Iliya Feranchuk[2], and Christoph Keitel[1] — [1]Max Planck Institute for Nuclear Physics, Heidelberg, Germany — [2]Belarusian State University, Minsk, Belarus

The relativistic quantum dynamics of an electron in an intense single-mode quantized electromagnetic field is investigated with special emphasis on the spin degree of freedom. In addition to fast spin oscillations at the laser frequency, a second time scale is identified due to the intensity dependent emissions and absorptions of field quanta. In analogy to the well-known phenomenon in atoms at moderate laser intensity, we put forward the conditions of collapses and revivals for the spin evolution in laser-driven electrons starting at feasible 10^{18}W/cm^2, arXiv:1209.1939.

Q 11.3 Mon 14:45 F 342

Stochasticity effects in quantum radiation-reaction — •Norman Neitz and Antonino Di Piazza — Max-Planck-Institut für Kernphysik, Saupfercheckweg 1, D-69117 Heidelberg

Radiation-reaction effects in the collision of a strong laser pulse with a thin plasma foil have been shown to reduce the energy spread of the generated ion beam in the classical regime [1]. Here, we study the evolution of the energy distribution of an electron beam colliding with an intense laser pulse via a kinetic approach [2] in the framework of strong-field QED [3], and show that in the quantum regime radiation-reaction effects induce the opposite effect, i.e., the electron beam spreads out after interacting with the laser pulse. We identify the physical origin of this opposite tendency in the intrinsic stochasticity of quantum photon emission and then of quantum radiation-reaction [4]. Our numerical simulations indicate that the experimental investigation of the predicted effects of stochasticity is in principle feasible with present technology.

[1] M. Tamburini et al., New. J. Phys. **12**, 123005 (2010).
[2] V. N. Baier, V. M. Katkov and V. M. Strakhovenko, "Electromagnetic processes at high energies in oriented single crystals" (World Scientific, Singapore, 1998).
[3] A. Di Piazza *et al.*, Rev. Mod. Phys. **84**, 1177 (2012).
[4] N. Neitz and A. Di Piazza, to be submitted.

Q 11.4 Mon 15:00 F 342

Photonic Coupling of Cold Molecules at Large Distances — •Harald R. Haakh, Sanli Faez, and Vahid Sandoghdar — MPI for the Science of Light, Erlangen, Germany

Recent theoretical studies have shown that tightly confined guided optical modes can facilitate the strong coupling of individual quantum emitters to these modes. In particular, plasmonic waveguides, tapered optical fibers and slot dielectric waveguides have been considered for such studies, whereby the latter have the advantage of not suffering from propagation loss.

In this presentation, we extend these platforms to the coherent interaction of several molecules at large separations via the guided mode of an optical fiber with a nanoscopic core diameter. We consider the interaction at strong and weak excitation and discuss how the high degree of control made possible by the large spatial dimensions allows for controlled switching of the nonlinear scattering of photon wave packets. Furthermore, we investigate the impact of dephasing in the solid state.

Q 11.5 Mon 15:15 F 342

Coherent interaction of single quantum emitters in a one-dimensional waveguide — Sanli Faez, •Pierre Türschmann, Stephan Götzinger, and Vahid Sandoghdar — Max Planck Institute for the Science of Light and Friedrich Alexander University, Erlangen, Germany

The coherent interaction of propagating photons and single emitters has become of great interest during the last years because of its potential application in quantum information science. Recently, several theoretical and experimental studies have considered the coupling of atoms to guided modes. Such a system is expected to show intriguing new bound states of light and matter. In our laboratory, we investigate these phenomena by using organic molecules embedded in an organic matrix that is placed in the core of a hollow fiber. At cryogenic temperatures of 1.4 K the scattering cross section of the emitters approaches their theoretical limit, which is comparable with the fiber mode cross section, thus allowing an efficient interaction with the guided photons. We present first results of the coherent coupling of single molecules to the fiber mode and discuss various ideas that exploit this interaction.

Q 11.6 Mon 15:30 F 342

Dynamischer Schwinger-Effekt: Paarproduktion in zeitabhängigen elektrischen Feldern — •Andreas Otto[1,2], Daniel Seipt[1,2], Tobias Nousch[1,2] und Burkhard Kämpfer[1,2] —

[1]Helmholtz-Zentrum Dresden-Rossendorf, PF 510119, 01314 Dresden, Germany — [2]Institut für theoretische Physik, TU Dresden, 01062 Dresden, Germany

In den Antinoden mehrerer überlagerter linear polarisierter Laserpulse entstehen starke periodische elektrische Felder mit einer Homogenitätslänge, die sehr viel größer ist, als die Compton-Wellenläge von Elektronen und Positronen. Für ultra-starke Laserpulse entsteht somit die Möglichkeit der Elektron-Positron-Paarerzeugung durch den dynamischen Schwinger-Effekt, der insbesondere als Ausgangspunkt der Entwicklung von Lawinen weiterer Paare derzeit intensiv untersucht wird. In dem Vortrag werden Simulationen des dynamischen Schwinger-Effektes vorgestellt und verschiedene durch die beiden Parameter (Feldfrequenz und Feldstärke) bestimmte Regime für zeitlich ausgedehnte Laserpulse untersucht. Neben der Dynamik der Phasenraumverteilung der Quasiteilchen ist vor allem die Paaranzahl im asymptotischen Endzustand bei zeitlich begrenzten Laserpulsen von Interesse. Es werden Resultate für verschiedene Einhüllende von ultrastarken und ultra-kurzen Laserpulsen erläutert.

Q 11.7 Mon 15:45 F 342

Pair production in short intense laser pulses near threshold — •Tobias Nousch[1,2], Daniel Seipt[1,2], Burkhart Kaempfer[1,2], and Alexander I. Titov[3] — [1]Helmholtz-Zentrum Dresden-Rossendorf, POB 510119, 01314 Dresden, Germany — [2]TU Dresden, Institut für Theoretische Physik, 01062 Dresden, Germany — [3]Bogoliubov Laboratory of Theoretical Physics, JINR, Dubna 141980, Russia

We study finite-size effects in the process of e^+e^- pair production via the non-linear Breit-Wheeler process in ultra short laser pulses. Based on the Nikishov-Ritus method we use laser dressed electron and positron wave functions to derive the differential and total pair production cross section, focusing on the effects of a finite pulse duration. For short laser pulses with very few oscillations of the electromagnetic field we find an increase of the pair production rate below the perturbative weak-field threshold. The strong enhancement below the weak-field threshold is traced back to the finite bandwidth of the laser pulse. A folding model accounts for the interplay of the frequency spectrum and the intensity distribution in the course of the pulse.

Q 12: Quantum gases: Bosons I

Time: Monday 14:00–16:00 Location: E 001

Group Report Q 12.1 Mon 14:00 E 001

Intensity correlations of a Bose-Einstein condensate of photons in a dye-filled microcavity — •Julian Schmitt, Tobias Damm, David Dung, Cesar Cabrera, Frank Vewinger, Jan Klaers, and Martin Weitz — Institut für Angwandte Physik, Universität Bonn, Wegelerstraße 8, 53115 Bonn

We have measured second-order time correlations within a Bose-Einstein condensate of photons inside a dye-filled optical microcavity. In our experiment, photons are thermally equilibrated by multiple absorption-fluorescence cycles in a dye medium, which constitutes both a heat bath and a particle reservoir [1]. Due to the excitation exchange between the photon gas and the dye molecule reservoir, grand canonical experimental conditions are expected to be realized in the system [2]. Under these conditions, unusually large fluctuations of the condensate number (fluctuation catastrophe) are expected [3], where the photon number distribution is Bose-Einstein-like. We experimentally observe a bunching of the condensed photons, which we attribute as evidence for a grand canonical BEC regime. On the other hand, for large condensate fractions due to the finite size of the molecular reservoir a transition to the usual canonical condensate regime occurs, for which Poissonian number fluctuations lead to second order coherence. Our observations are in agreement with theoretical predictions.

[1] J. Klaers, J. Schmitt, F. Vewinger, M. Weitz, Nature **468**, 545(2010)
[2] J. Klaers, J. Schmitt, T. Damm, F. Vewinger, M. Weitz, Phys. Rev. Lett. **108**, 160403 (2012)
[3] e.g. R. Ziff, G. Uhlenbeck, M. Kac, Phys. Rep. **32**, 169 (1977)

Q 12.2 Mon 14:30 E 001

Non-Equilibrium Criticality of Driven Open Many-Body Quantum Systems — •Lukas M. Sieberer[1], Ehud Altman[2], Sebastian D. Huber[3], and Sebastian Diehl[1,4] — [1]Institute for Theoretical Physics, University of Innsbruck, 6020 Innsbruck, Austria — [2]Department of Condensed Matter Physics, Weizmann Institute of Science, Rehovot 76100, Israel — [3]Institute for Theoretical Physics, ETH Zurich, 8093 Zurich, Switzerland — [4]Institute for Quantum Optics and Quantum Information of the Austrian Academy of Sciences, 6020 Innsbruck, Austria

We investigate non-equilibrium phase transitions in an open bosonic many-body system with local single-particle incoherent pump and two-body loss. This model is naturally realized in a wide range of experimental contexts, such as cold atoms with optical Feshbach resonances or exciton-polariton condensates. Universal critical behavior in such a driven-dissipative system is characterized in three spatial dimensions by thermalization at low frequencies and the fadeout of reversible dynamics at long lengthscales according to a scaling law which features a new non-equilibrium critical exponent. We discuss prospects of probing this exponent in experiments.

Q 12.3 Mon 14:45 E 001

The quantum degenerate regime of driven ideal quantum gases in contact with a thermal bath — •Daniel Vorberg[1,2], Roland Ketzmerick[1,2], and André Eckardt[1] — [1]Max-Planck-Institut für Physik komplexer Systeme, Nöthnitzer Str. 38, 01387 Dresden — [2]Institut für Theoretische Physik, Technische Universität Dresden, 01062 Dresden

Time-periodically driven quantum systems (Floquet systems) that are weakly coupled to a thermal bath possess a time-periodic non-equilibrium steady state. This state is described by a density operator that is diagonal in the basis of Floquet states, that depends on the details of the coupling to the bath, and that generically violates detailed balance. We study ideal Floquet gases consisting of many non-interacting indistinguishable particles and investigate the influence of the bosonic or fermionic quantum statistic. To this end we consider generic one-dimensional model systems with regular and chaotic Floquet states and study their steady state using quantum-jump Monte Carlo simulations. We find that the density operator is generally not of Gaussian form, implying non-trivial occupation number correlations that deviate from Wick's decomposition. However, these deviations are found to be small and a mean-field theory based on a Gaussian ansatz still provides a good approximation to the exact steady state. We find quantum degenerate regimes where the respective quantum statistics leads to Bose condensation or the emergence of a Fermi edge.

Q 12.4 Mon 15:00 E 001

Environmentally induced dispersion of otherwise flat-band systems — •Albert Verdeny Vilalta and Andreas Mielke — Institut für Theoretische Physik, Universität Heidelberg, D-69120 Heidelberg, Germany

We investigate the experimental realization of bosonic condensed matter systems with a flat lowest energy band. Such systems can be obtained in optical lattices where shaking permits to engineer the hopping matrix element of the Bose Hubbard model. Since flat band systems are especially sensitive to perturbations, we consider the shaken Bose-Hubbard model coupled linearly to to a bosonic bath (driven Hubbard-Holstein model) so as to take environmental corrections into account. Using the flow equation method of infinitesimal unitary transformations, we construct the effective Hamiltonian of this system. We investigate the changes of its energy spectrum caused by the environment coupling and find a small dispersion as opposed to a perfectly flat band.

Q 12.5 Mon 15:15 E 001

Non-thermal fixed points in a two-component Bose gas across the miscible–immiscible transition — •Markus Karl[1,2], Boris Nowak[1,2], and Thomas Gasenzer[1,2] — [1]Institut für Theoretische Physik, Ruprecht-Karls-Universität Heidelberg, Philosophenweg 16, 69120 Heidelberg — [2]ExtreMe Matter Institute EMMI, GSI Helmholtzzentrum für Schwerionenforschung GmbH, Planckstraße 1, 64291 Darmstadt, Germany

We present a numerical analysis of non-thermal fixed points in an ultracold two-component Bose gas in two spatial dimensions across the miscible–immiscible transition. Unstable initial conditions are used to drive the system away from equilibrium, aiming for the excitation of topological defects such as domain structures and vortices, and their influence on the intermediate and late time evolution of the system is studied. Thereby a special focus is set on transient turbulent states, which are signaled by the emergence of quasi-stationary scaling laws in the occupation spectrum, $n(k) \sim k^{-\zeta}$. We find such quasi-stationary states far from equilibrium, so-called non-thermal fixed points, in all parameter regimes, *i.e.* in the miscible and the immiscible regime as well as at the transition point, accompanied by steady scaling laws with different scaling exponents, ζ, for the momentum distributions, which we are able to identify with the natural defect structures in the respective regimes.

Q 12.6 Mon 15:30 E 001

One-dimensional many-body quantum transport of Bose-Einstein condensates: a Truncated Wigner Approach — •Julien Dujardin[1], Arturo Argüelles[1], Alejandro Saenz[2], and Peter Schlagheck[1] — [1]Département de Physique, Université de Liège, 4000 Liège, Belgium — [2]Institut für Physik, Humboldt-Universität zu Berlin, 12489 Berlin, Germany

We study the transport properties of an ultracold gas of Bose-Einstein condensed atoms that is coupled from a magnetic trap into a one-dimensional waveguide. Our central motivation in the context of such guided atom lasers [1] is to explore the role of atom-atom interaction in many-body transport processes across finite scattering regions resembling tunnel junctions or quantum dots. Our theoretical approach to solve this problem is based on the Truncated Wigner Method [2] for which we assume the system to consist of two semi-infinite non-interacting leads and a finite interacting scattering region. The condensed and non-condensed fractions of the atomic density, the current, and the transmission in the steady-state regime are computed and compared with mean-field predictions as well as with numerical results obtained with the matrix-product state (MPS) method.

[1] W. Guerin et al., Phys. Rev. Lett. 97, 200402 (2006).
[2] C. W. Gardiner et al., J. Phys. B 35, 1555 (2002); A. Sinatra et al., J. Phys. B. 35, 3599 (2002) .

Q 12.7 Mon 15:45 E 001

Parametric resonance in Bose-Einstein condensates — Will Cairncross[1] and •Axel Pelster[2] — [1]Department of Physics, Queen's University at Kingston, Canada — [2]Fachbereich Physik, Technische Universität Kaiserslautern, Germany

We conduct a detailed stability analysis for Bose-Einstein condensates (BECs) in a harmonic trap under parametric excitation by periodic modulation of the s-wave scattering length [1]. To this end we follow Ref. [2] and obtain at first equations of motion for the radial and axial widths of the condensate using a Gaussian variational ansatz for the Gross-Pitaevskii condensate wave function. Linearizing about the equilibrium positions, we obtain a system of coupled Mathieu equations, the stability of which has been studied extensively [3,4]. We carry out an analytic stability analysis for the Mathieu equations, and compare with numerical results for the nonlinear equations of motion. We find qualitative agreement between the Mathieu analytics and the nonlinear numerics, and conclude that the previously unstable (stable) equilibrium of a BEC might be stabilized (destabilized) by parametric excitation.

[1] W. Cairncross and A. Pelster, `arXiv:1209.3148`
[2] I. Vidanovic, A. Balaz, H. Al-Jibbouri, and A. Pelster, Phys. Rev. A **84**, 013618 (2011)
[3] J. Slane and S. Tragesser, Nonl. Dyn. Syst. Th. **11**, 183 (2011)
[4] J. Hansen, Arch. Appl. Mech. **55**, 463 (1985)

Q 13: Quantum information: Concepts and methods I

Time: Monday 14:00–16:00 Location: E 214

Q 13.1 Mon 14:00 E 214

Effective theories from missing information — •Cedric Beny and Tobias Osborne — Leibniz Universität Hannover

Our ability to probe the real worlds is always limited by experimental constraints such as the precision of our instruments, or our inability to fully control a system's environment. It is remarkable that the resulting imperfect data nevertheless contains strong regularities which can be understood in terms of effective laws.

I will present recent results towards the development of systematic methods to define such effective theories using tools from quantum information theory. In particular, I will examine decoherence and renormalization as phenomena giving rise to a classical effective field theory from a quantum theory.

Q 13.2 Mon 14:15 E 214

Bell inequalities from variable elimination methods — •Costantino Budroni[1] and Adan Cabello[2] — [1]Naturwissenschaftlich-Technische Fakultät, Universität Siegen, D-57068 Siegen,Germany — [2]Departamento de Física Aplicada II, Universidad de Sevilla, E-41012 Sevilla, Spain

Complete sets of tight Bell inequalities are necessary and sufficient conditions for the existence of local hidden variable models describing a given measurement scenario. They are facets of Pitowsky's correlation polytope and are usually obtained from its extreme points by solving the hull problem. While there are algorithms that find all the facets of a given correlation polytope, the time required to compute them grows exponentially as the number of settings increases. This method has therefore been applied only to simple cases with a reduced number of settings.

In this talk an alternative method based on a combination of algebraic results on extensions of measures and variable elimination methods, e.g., the Fourier-Motzkin method, will be presented. Non-trivial cases where our method overcomes some of the computational difficulties associated with the hull problem will be discussed.

Q 13.3 Mon 14:30 E 214

Non-linear genuine multiparty entanglement witness and its application to graph states — •Junyi Wu[1], Hermann Kampermann[1], Dagmar Bruss[1], Claude Klockl[2], and Marcus Huber[3] — [1]Institute for Theoretical Physics III, Heinrich-Heine-University Dusseldorf, D-40225 Dusseldorf, Germany — [2]University of Vienna, Faculty of Mathematics, Nordbergstrae 15, 1090 Wien, Austria — [3]University of Bristol, Department of Mathematics, Bristol, BS8 1TW, U.K.

In [1] we introduced a general non-linear witness by lower bounding a genuine multipartite entanglement (GME) measure. The witness is experimentally efficient to implement since only a few off-diagonal and diagonal density operator elements are needed. However, its detection capabilities are basis dependent. Because it is not straightforward to construct an optimal non-linear GME-witness for a given target state, we develop techniques to construct an optimal non-linear GME-witness, and investigate its application to graph states with noise.

[1] Jun-Yi Wu, Hermann Kampermann, Dagmar Bruß, Claude Klockl, and Marcus Huber. Phys. Rev. A, 86:022319, Aug 2012.

Q 13.4 Mon 14:45 E 214

Extremal properties of the variance and the quantum Fisher information — •Géza Tóth[1,2,3] and Dénes Petz[4] — [1]Theoretical Physics, University of the Basque Country UPV/EHU, E-48080 Bilbao, Spain — [2]IKERBASQUE, Basque Foundation for Science, E-48011 Bilbao, Spain — [3]Wigner Research Centre for Physics, H-1525 Budapest, Hungary — [4]Alfréd Rényi Institute of Mathematics, Reáltanoda utca 13-15, H-1051 Budapest, Hungary

We show that the variance is its own concave roof. For rank-2 density matrices and operators with zero diagonal elements in the eigenbasis of the density matrix, we show analytically that the quantum Fisher information is 4 times the convex roof of the variance. Strong numerical evidence suggests that the quantum Fisher information is very close to the convex roof even for operators with nonzero diagonal elements or density matrices with a rank larger than 2. Hence, we conjecture that the quantum Fisher information is 4 times the convex roof of the variance even for the general case.

Q 13.5 Mon 15:00 E 214

Quantitative two-qutrit entanglement — 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, 48080 Bilbao, Spain — [3]IKERBASQUE, Basque Foundation for Science, 48011 Bilbao, Spain

We introduce the new concept of axisymmetric bipartite states. For $d \times d$-dimensional systems these states form a two-parameter family of nontrivial mixed states that include the isotropic states. We present exact quantitative results for class-specific entanglement as well as for the negativity and I-concurrence of two-qutrit axisymmetric states. These results have interesting applications such as for quantitative witnesses [1] of class-specific entanglement in arbitrary two-qutrit states and as device-independent witness for the number of entangled dimensions.

[1] C. Eltschka and J. Siewert, Sci. Rep. **2**, 942 (2012).

Q 13.6 Mon 15:15 E 214

Wick's theorem for matrix product states — •Robert Hübener[1], Andrea Mari[1,2,3], and Jens Eisert[1] — [1]Freie Universität Berlin — [2]Universität Potsdam — [3]Consiglio Nazionale delle Ricerche Pisa

Matrix product states and their continuous analogues are variational classes of states that capture quantum many-body systems or quantum fields with low entanglement; they are at the basis of the density-matrix renormalization group method and continuous variants thereof. In this talk we show that, generically, N-point functions of arbitrary operators in discrete and continuous translation invariant matrix product states are completely characterized by the corresponding two- and three-point functions. Aside from having important consequences for the structure of correlations in quantum states with low entanglement, this result provides a new way of reconstructing unknown states from correlation measurements e.g. for one-dimensional continuous systems of cold atoms. We argue that such a relation of correlation functions may help in devising perturbative approaches to interacting theories.

Q 13.7 Mon 15:30 E 214

Multiparticle negativity - a computable entanglement monotone for mixed states — •Martin Hofmann, Tobias Moroder, and Otfried Gühne — Naturwissenschaftlich-Technische Fakultät, Universität Siegen, Walter-Flex-Straße 3, 57068 Siegen, Germany

The detection of genuine multiparticle entanglement in composite systems of three or more particles is a challenging task and many results known so far, can be applied to pure states only.

One way to detect entanglement of multiparticle mixed states is given in [1]. The main idea of the authors is to try to decompose a mixed state into a convex combination of PPT states. If this can not be done for the state in question, then it is clearly genuine multiparticle entangled and there exists an entanglement witness detecting the state. This idea then finally leads to a computable entanglement monotone, which is based on semidefinite programing.

In our work we analytically investigate monogamy relations for this entanglement monotone. Additionally, we relate the monotone to a mixed state convex roof of the negativity.

[1] B. Jungnitsch *et al.*, Phys. Rev. Lett. **106**, 190502 (2011)

Q 13.8 Mon 15:45 E 214

SL-invariant measures in higher local dimensions — •Andreas Osterloh — Theoretische Physik (AG Schützhold), Universität Duisburg-Essen, Lotharstrasse 1, 47048 Duisburg, Germany.

We write the SL-invariant operator, the determinant, in terms of antilinear expectation values of the local $SL(d, \mathbb{C})$, thereby extending the mechanism for qubits to qudits. We outline the method on spin 1, and spin 3/2 explicitely, and generalize the method to higher spin. There is an odd-even discrepancy: whereas for half odd integer spin a situation similar to that observed in qubits is observed, for integer spin the outcome is an asymmetric invariant of doubled polynomial degree. The corresponding conditions for genuinely entangled spins carry over directly from the qubit case.

Q 14: Ultra-cold atoms, ions and BEC II (with A)

Time: Monday 14:00–16:00 Location: F 428

Q 14.1 Mon 14:00 F 428

Observing the Drop of Resistance in the Flow of a Superfluid Fermi Gas — •David Stadler, Sebastian Krinner, Jakob Meineke, Jean-Philippe Brantut, and Tilman Esslinger — Institute for Quantum Electronics, ETH Zurich

The ability of particles to flow with very low resistance is a distinctive character of a superfluid or superconducting state and led to its discovery in the last century. While the particle flow in liquid Helium or superconducting materials is essential to identify superfluidity or superconductivity, an analogous measurement has not been performed with superfluids based on ultracold Fermi gases. Here we report on the direct measurement of the conduction properties of strongly interacting fermions, and the observation of the celebrated drop of resistance associated with the onset of superfluidity. We observe variations of the atomic current over several orders of magnitude by varying the depth of the trapping potential in a narrow channel, which connects two atomic reservoirs. We relate the intrinsic conduction properties to thermodynamic functions in a model-independent way, making use of high-resolution in-situ imaging in combination with current measurements. Our results show that, similar to solid-state systems, current and resistance measurements in quantum gases are a sensitive probe to explore many-body physics. The presented method is closely analogous to the operation of a solid-state field-effect transistor. It can be applied as a probe for optical lattices and disordered systems, and paves the way towards the modeling of complex superconducting devices.

Q 14.2 Mon 14:15 F 428

Ultracold fermions in two and three dimensions — •Igor Boettcher[1], Sebastian Diehl[2,3], Jan Pawlowski[1,4], and Christof Wetterich[1] — [1]Institut fuer Theoretische Physik, Universitaet Heidelberg — [2]Institut fuer Theoretische Physik, Universitaet Innsbruck — [3]IQOQI, Innsbruck — [4]ExtreMe Matter Insitute EMMI, GSI Darmstadt

The increasing experimental advances in realizing ultracold atom ensembles constitute an unprecedented possibility for testing and constraining predictions from quantum field theory. Key observables in equilibrium are the equation of state and the phase diagram of the system. I will present results on the BCS-BEC crossover of two-component ultracold fermions in both two and three dimensions, obtained with the Functional RG. We aim at quantitative precision. For this purpose we incorporate renormalization effects like the Contact, which is related to the high energy behavior of the momentum distribution of particles, and study its influence on the thermodynamics. The two-dimensional case is particularly interesting due to strong quantum fluctuations and can be realized in experiment with highly anisotropic traps.

Q 14.3 Mon 14:30 F 428

A SU(N) symmetric Fermi degenerate gas of ytterbium for lattice many-body physics — •F. Scazza, C. Hofrichter, P. C. De Groot, M. Höfer, C. Schweizer, E. Davis, I. Bloch, and S. Fölling — MPI für Quantenoptik, Hans-Kopfermann-Strasse 1, 85748 Garching and Ludwig-Maximilians-Universität, Schellingstrasse 4, 80799 München, Germany

Ytterbium and other alkaline-earth-like atoms have some peculiar properties compared to alkali atoms which make them very attractive in the context of quantum simulation with ultracold atoms, especially in the presence of periodic potentials such as optical lattices.

Ytterbium possesses a metastable excited state which can be used to implement state-dependent optical lattices, enabling the simulation of new complex types of many-body Hamiltonians, e.g. the Kondo lattice model. In addition, the high nuclear spin of the fermionic ^{173}Yb, which is highly decoupled from the electronic state, gives rise to an enlarged SU(N) symmetry of the many-body Hamiltonian.

We describe preparation and detection of the nuclear and electronic spin state populations of a degenerate Fermi gas of Yb in the "magic lattice", used for coupling to the $^3P_0$ metastable state via a narrow line "clock" laser on the doubly forbidden clock transition.

Q 14.4 Mon 14:45 F 428

Two-component few-fermion mixtures in a one-dimensional trap — •Ioannis Brouzos and Peter Schmelcher — Zentrum für Optische Quantentechnologien, Universität Hamburg

We explore a few-fermion mixture consisting of two components which are repulsively interacting and confined in a one-dimensional harmonic trap. Different scenarios of population imbalance ranging from the completely imbalanced case where the physics of a single impurity in the Fermi-sea is discussed to the partially imbalanced and equal population configurations are investigated. For the numerical calculations the multi-configurational time-dependent Hartree (MCTDH) method is employed, extending its application to few-fermion systems. Apart from numerical calculations we generalize our Ansatz for a correlated pair wave-function proposed in [1] for bosons to mixtures of fermions. From weak to strong coupling between the components the energies, the densities and the correlation properties of one-dimensional systems change vastly. The numerical and analytical treatments are in good agreement with respect to the description of this crossover. We show that for equal populations each pair of different component atoms splits into two single peaks in the density while for partial imbalance additional peaks and plateaus arise for very strong interaction strengths. The case of a single impurity atom shows rich behaviour of the energy and density as we approach fermionization, and is directly connected to recent experiments.

[1] I. Brouzos and P. Schmelcher, PRL 108, 045301 (2012).

Q 14.5 Mon 15:00 F 428

Measurements on first and second sound in a unitary Fermi gas — •Leonid A. Sidorenkov[1,2], Meng Khoon Tey[1,2], Rudolf Grimm[1,2], Yan-Hua Hou[3], Lev Pitaevskii[3,4], and Sandro Stringari[3] — [1]Institut für Quantenoptik und Quanteninformation (IQOQI), Österreichische Akademie der Wissenschaften, 6020 Innsbruck, Austria — [2]Institut für Experimentalphysik, Universität Innsbruck, 6020 Innsbruck, Austria — [3]Dipartimento di Fisica, Universitá di Trento and INO-CNR BEC Center, 38123 Povo, Italy — [4]Kapitza Institute for Physical Problems RAS, 119334 Moscow, Russia

We report on the propagation of first- and second-sound-like excitations in a highly elongated Fermi gas with unitarity-limited interactions around the critical temperature for superfluidity. Our measurements on first sound are in excellent agreement with calculations based on the recently measured equation of state (EoS) of the unitary Fermi gas for the whole temperature range explored. Given the available knowledge of thermodynamic quantities from the EoS, we investigate second-sound-like excitations in the unitary Fermi gas, and their connection to the superfluid hydrodynamics. Observation of these second-sound-like excitations offers, in analogy to superfluid helium, a direct access to the local superfluid density. This quantity cannot be obtained in EoS measuremens and requires additional knowledge of the elementary excitation spectrum of the unitary Fermi gas.

Q 14.6 Mon 15:15 F 428

Attractive atom-dimer interaction on the repulsive side of a ^{6}Li-^{40}K Feshbach resonance — •Michael Jag[1,2], Matteo Zaccanti[1], Marko Cetina[1], Rianne Lous[1], Dmitri Petrov[3], Jesper Levinsen[4], Florian Schreck[1], and Rudolf Grimm[1,2] — [1]IQOQI, Österreichische Akademie der Wissenschaften, Innsbruck, Austria — [2]Inst. für Experimentalphysik, Universität Innsbruck, Innsbruck, Austria — [3]LPTMS, CNRS, Université Paris Sud, Orsay, France — [4]Cavendish Laboratory, Cambridge, UK

Mass imbalance in strongly interacting mixtures of ultracold fermions is predicted to lead to new pairing phenomena and quantum phases. We investigate a mass-imbalanced ^{6}Li-^{40}K Fermi-Fermi mixture in the regime of strong interactions on the repulsive side of an interspecies Feshbach resonance. We find that, for a sufficiently strong repulsive s-wave interaction, the ^{40}K atoms and the ^{6}Li^{40}K dimers interact attractively, which is in strong contrast to the mass-balanced case. This surprising behavior is related to the existence of a $\uparrow\uparrow\downarrow$ trimer state in $\uparrow\downarrow$ Fermi-Fermi mixtures with a mass ratio $m_\uparrow/m_\downarrow > 8.2$. For lower mass ratios (i.e. $m_{\rm K}/m_{\rm Li} = 6.64$) this trimer state turns into a p-wave atom-dimer scattering resonance. Here, we present our experimental results on interactions in a resonantly interacting atom-dimer mixture. Employing radio-frequency spectroscopy over a range of temperatures and interaction strengths, we confirm the presence of a strong attraction on the repulsive side of a Feshbach resonance, in good agreement with theory.

Q 14.7 Mon 15:30 F 428

Towards optical trapping of a single Ba$^+$ ion — •Michael Zugenmaier, Thomas Huber, Alexander Lambrecht, Julian Schmidt, and Tobias Schaetz — Albert-Ludwigs Universität Freiburg

In 2010 our group demonstrated the trapping of an Mg$^+$ ion in an optical dipole trap [1,2]. The lifetime in the optical potential was limited by heating due to photon recoils out of the optical field, detuned by only $7000\,\Gamma$ (depth $\sim$40 mK).

We are setting up a new experiment to trap a Ba$^+$ ion in a far off-resonance dipole trap. At first the Ba$^+$ ion is trapped and cooled in a linear Paul trap. The Ba$^+$ ion will then be transferred into an optical dipole trap which will be provided by a focussed laser at 532 nm. Using a far-detuned trapping laser of enhanced power features a comparable depth of the potential ($\sim$20 mK) while minimizing the photon scattering rate and will result in longer trapping durations.

The results of this experiment will be our first step towards the trapping of a Ba$^+$ ion and Rb atoms in one common trap. Combining the optically trapped ion with atoms in the same optical trap might allow us sympathetically cool the ion and to enter the regime of ultracold chemistry, where quantum phenomena are predicted to dominate.

[1] Ch. Schneider et al., Nat. Phot. 4, 772-775 (2010)
[2] M. Enderlein et al., Phys. Rev. Lett. 109, 233004 (2012)

Q 14.8 Mon 15:45 F 428

A single ion coupled to an optical fibre cavity — •Matthias Steiner[1], Hendrik-Marten Meyer[1], Christian Deutsch[2], Jakob Reichel[2], and Michael Köhl[1] — [1]Department of Physics, University of Cambridge, Cavendish Laboratory, Cambridge, United Kingdom — [2]Laboratoire Kastler-Brossel, ENS/UPMC-Paris 6/CNRS, F-75005 Paris, France

The development of an efficient ion-photon interface is a major challenge which needs to be overcome to realize large scale ion-based quantum networks. Such an interface could consist of a single ion coupled to a high finesse optical cavity. Existing ion-cavity systems operate in a regime, where the coupling of light and ion is smaller than the excited state decay rate[1]. In order to enhance the coupling, smaller cavity mode volumes must be used.

We report on the realization of a combined trapped-ion and optical cavity system, in which a single Yb$^+$ ion is confined by a micron-scale ion trap inside a 230 μm-long optical fibre cavity. We characterize the spatial ion-cavity coupling and measure the ion-cavity coupling strength using a cavity-stimulated Λ-transition [2]. Owing to the small mode volume, the coherent coupling strength between the ion and a single photon exceeds the natural decay rate of the dipole moment. Our results demonstrate that stable trapping of single ions in close vicinity of dielectric surfaces does not impose fundamental problems, even at room temperature.

[1] G. R. Guthöhrlein et al., Nature, 414, (2001).
[2] M. Steiner et al, arXiv:1211.0050.

Q 15: Matter-wave optics

Time: Monday 16:30–18:45 Location: F 142

Group Report Q 15.1 Mon 16:30 F 142

Atom chip based matter wave interferometry at the Bremen drop tower — •Hauke Müntinga[1], Claus Lämmerzahl[1], and The QUANTUS Team[1,2,3,4,5,6,7,8,9] — [1]ZARM, Universität Bremen — [2]Institut für Quantenoptik, LU Hannover — [3]Institut für Physik, HU Berlin — [4]Institut für Laser-Physik, Universität Hamburg — [5]Institut für Quantenphysik, Universität Ulm — [6]Institut für angewandte Physik, TU Darmstadt — [7]MUARC, University of Birmingham — [8]FBH, Berlin — [9]MPQ, Garching

The growing interest in microgravity platforms for AI is motivated by the prospect of performing high precision tests of fundamental gravitational effects, e.g. the WEP. The QUANTUS-I experiment has demonstrated the feasibility of operating delicate quantum optical experiments in a demanding environment and constitutes the first step towards space. In over 400 free fall experiments, the preparation, the free evolution [1] and the coherence of the condensate on macroscopic time scales have been studied. To this end, a matter wave interferometer using Bragg diffraction was implemented in our atom chip based setup and combined with a δ kick cooling scheme to slow the expansion of the clouds. With an asymmetrical Mach Zehnder scheme, contrast in the output ports was observed up to a total time in the interferometer of 677 ms. The QUANTUS project is supported by the German Space Agency DLR with funds provided by the Federal Ministry of Economics and Technology (BMWi) under grant number DLR 50WM1131-1137.

[1] T. van Zoest et al., Science 328, 1540 (2010).

Q 15.2 Mon 17:00 F 142

Charged matter-waves: Towards quantum interference applications with ions and charged molecules — •Alexander Rembold, Georg Schütz, Andreas Pooch, and Alexander Stibor — Physikalisches Institut, Tübingen, Germany

Realizing an ion interferometer opens up possibilities for new experiments in connection with Aharonov-Bohm physics. The large experience for guiding and detecting charged particles can be adopted from electron interferometry. We present the design and the current status in the construction of the first reliable, stable and intensive ion-interferometer for helium ions, based on [1]. In our setup a new technique allows for a coherent ion emission from a pyramidal shaped single-atom tip. The beam is separated and recombined by a fine charged biprism wire. The longitudinal coherence is adjusted by a Wien-filter and the interference pattern is detected after a quadrupole magnification by a delayline detector. Such a novel interferometer combines the advantages of electron, atom and molecule interferometry: efficient emission and detection, good beam guiding and the study of structure dependent effects, especially connected to the magnetic Aharonov-Bohm effect. As it will be proposed, the lower velocity of the ions compared to electrons allows the first direct proof of the electrostatic Aharonov-Bohm effect. The described interferometer can potentially be used to interfere particles with significantly higher masses, such as organic molecules.

[1] F. Hasselbach and U. Maier, 1999 Quantum Coherence and Decoherence, ISQM, Tokyo, p. 299

Q 15.3 Mon 17:15 F 142

Towards a test of Einstein's equivalence principle using a Rb-K atom interferometer — •Dennis Schlippert, Jonas Hartwig, Ulrich Velte, Henning Albers, Jonas Matthias, Wolfgang Ertmer, and Ernst Rasel — Institut für Quantenoptik and Centre for Quantum Engineering and Space-Time Research - QUEST, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover, Germany

We report on our work directed towards a dual species matter-wave interferometer for performing a differential measurement of the acceleration of free falling ^{87}Rb and ^{39}K atoms to test Einstein's equivalence principle (universality of free fall). According to the minimal Standard Model Extension such a test is very sensitive to composition based equivalence principle violating effects and complementary to classical tests. We will show the enviromental noise limited performance of the single species Rb gravimeter ($7.84 \cdot 10^{-6}\mathrm{m/s^2}/\sqrt{\mathrm{Hz}}$ and $3.86 \cdot 10^{-8}\mathrm{m/s^2}$ @ 49152 s) and the progress of the implementation of the K gravimeter. Moreover, we discuss possibilities to either match the interferometers' sensitivities or to match their free evolution times resulting in high common noise rejection.

Q 15.4 Mon 17:30 F 142

Gravity gradient corrections in μ-gravity. — •Luis Fernando Barragan Gil, Oliver Gabel, and Reinhold Walser — Institut für Angewandte Physik, TU-Darmstadt, Hochschulstr. 4a, 64289 Darmstadt

The realization of Bose-Einstein condensates in μ-gravity conditions, at the ZARM drop tower in Bremen by the QUANTUS collaboration [1,2], has opened the possibility to measure corrections to local gravitational field of the Earth beyond the linear Earth's acceleration (g) [3,4]. This is known as the gravity gradient correction and it is the next dominan contribution found in classical newtonian Physics as well as in general relativistic view of gravity.

We analyse a matter-wave interferometer for coherent states and thermal ensembles in the presence of the harmonic corrections to the gravitational potential. In this work, we use the formalism of generalized squeezed states and compare the results for various experimental observables as interference fringe spacing.

[1] Quantus Collaboration *http://www.iqo.uni-hannover.de/quantus.html*
[2] van Zoest, T. et al. *Bose-Einstein Condensation in Microgravity*, Science, **328**, 1540-1543 (2010)
[3] Dimopoulos, S. et al. *General Relativistic effects in atom interferometry*, Phys. Rev. D, **78** 042003 (2008)
[4] Kasevich, M. A. and Chu, S.*Atom Interferometry Using Stimulated Raman Transitions*,phys. Rev. D, **67**, 181-184 (1991)

Q 15.5 Mon 17:45 F 142

Theoretical description of QUANTUS experiments on interferometry with BECs in microgravity — •Wolfgang Zeller[1], Enno Giese[1], Endre Kajari[1,2], Stephan Kleinert[1], Vincenzo Tamma[1], Albert Roura[1], Wolfgang P. Schleich[1], and the QUANTUS Team[1,3,4,5,6,7,8,9,10] — [1]Institut für Quantenphysik, Universität Ulm — [2]Theoretische Physik, Universität des Saarlandes — [3]Institut für Quantenoptik, LU Hannover — [4]ZARM, Universität Bremen — [5]Institut für Physik, HU Berlin — [6]Institut für Laser-Physik, Universität Hamburg — [7]Institut für angewandte Physik, TU Darmstadt — [8]Midlands Ultracold Atom Research Centre, University of Birmingham, UK — [9]FBH, Berlin — [10]MPQ, Garching

The pioneering QUANTUS experiments merge microgravity environments with matter-wave interferometry using Bose-Einstein condensates (BECs). Recent experiments have realized a time-asymmetric Mach-Zehnder interferometer that produces in every shot an interference pattern in the density profile. We employ a time-dependent generalization of the Thomas-Fermi approximation [1], which accurately describes the expansion of the BEC in microgravity [2], to provide a simple theoretical explanation of all the relevant features observed in the experiments.

The QUANTUS project is supported by the German Space Agency DLR with funds provided by the Federal Ministry of Economics and Technology (BMWi) under grant number 50WM1136.

[1] Y. Castin and R. Dum, Phys. Rev. Lett. 77, 5315 (1996).
[2] T. van Zoest et al., Science 328, 1540 (2010).

Q 15.6 Mon 18:00 F 142

Physical insights into the time-dependent Thomas-Fermi approximation for Bose-Einstein Condensates — •Vincenzo Tamma, Wolfgang Zeller, Enno Giese, Stephan Kleinert, Albert Roura, Wolfgang P. Schleich, and the QUANTUS Team — Institut für Quantenphysik, Universität Ulm

We unravel the physical properties of the time-dependent Thomas-Fermi (TF) regime [1] describing the time evolution of an expanding BEC for an at most quadratic potential. In particular, we study in such a regime the time evolution behavior of the phase and of the modulus of the wave function. We provide physical insight into the validity of the TF approximation depending on the experimental conditions. At the same time we apply perturbation theory in order to obtain corrections to both the phase and modulus that are relevant in different experimental situations. The obtained results have important applications in experiments exploiting long-time BEC evolution leading to interferometry and, in particular, in the experiments performed within the QUANTUS collaboration measuring quantum interference of BEC in microgravity [2].

The QUANTUS project is supported by the German Space Agency DLR with funds provided by the Federal Ministry of Economics and Technology (BMWi) under grant number 50WM1136.

[1] Y. Castin and R. Dum, Phys. Rev. Lett. 77, 5315 (1996).
[2] T. van Zoest et al., Science 328, 1540 (2010).

Q 15.7 Mon 18:15 F 142

Representation-free description of matter wave interferometry — •Stephan Kleinert[1], Wolfgang Zeller[1], Enno Giese[1], Vincenzo Tamma[1], Albert Roura[1], Endre Kajari[2], Wolfgang P. Schleich[1], and the QUANTUS Team[1,3,4,5,6,7,8,9,10] — [1]Institut für Quantenphysik, Universität Ulm, D-89081 Ulm, Germany — [2]Theoretische Physik, Universität des Saarlandes, D-66041 Saarbrücken, Germany — [3]Institut für Quantenoptik, LU Hannover — [4]ZARM, Universität Bremen — [5]Institut für Physik, HU Berlin — [6]Institut für Laser-Physik, Universität Hamburg — [7]Institut für angewandte Physik, TU Darmstadt — [8]MUARC, University of Birmingham, UK — [9]FBH, Berlin — [10]MPQ, Garching

In the late 20th century progress in the coherent manipulation of atoms enabled the use of atom interferometers for high-precision measurements [1,2]. They play a central role in state-of-the-art clocks, inertial sensors and gravimeters.

Our talk provides a compact and versatile description of matter wave interferometry solely based on operator algebra. We present a straightforward method for determining the phase-shift for general multi-loop interferometers taking into account the local gravitational acceleration, gravity gradient and rotation of the device.

The QUANTUS project is supported by the German Space Agency (DLR) with funds provided by the Federal Ministry of Economics and Technology (BMWi) under grant number 50WM1136.

[1] C. J. Bordé, Physics Letters A 140, 10 (1989).
[2] M. Kasevich and S. Chu, Phys. Rev. Lett. 67, 181 (1991).

Q 15.8 Mon 18:30 F 142

Overcoming loss of contrast in atom interferometry due to gravity gradients — •Albert Roura, Wolfgang Zeller, Wolfgang P. Schleich, and the QUANTUS Team — Institut für Quantenphysik, Universität Ulm

Long-time atom interferometry in drop towers, sounding rockets and space missions is required for high-precision measurements of fundamental physical properties, including tests of the equivalence principle. Such measurements rely on the dependence of the phase shift between the two branches of a Mach-Zehnder interferometer as a function of the interrogation time and the corresponding oscillations in the integrated atom density at each exit port. For long times, however, gravity gradients cause the classical trajectories associated with the two branches not to close in phase space, which leads to a spatially dependent phase shift between the two overlapping wave-packets and a fringe-pattern density profile at the exit ports. This in turn implies a loss of contrast in the oscillations of the total number of atoms at each port and a reduction of the interferometer's sensitivity. Here we present a strategy for overcoming such loss of contrast which is very simple to implement.

The QUANTUS project is supported by the German Space Agency (DLR) with funds provided by the Federal Ministry of Economics and Technology (BMWi) under grant number 50WM1136.

Q 16: Photonics II

Time: Monday 16:30–18:30 Location: A 310

Q 16.1 Mon 16:30 A 310

Experimental demonstration and control of pulsed modulation — •Maximilian Brinkmann, Michael Kues, and Carsten Fallnich — Institut für Angewandte Physik, Westfälische Wilhelms-Universität, Corrensstr. 2, 48149 Münster

Modulation instability refers to the process in which a weak perturbation of an electromagnetic wave is exponentially amplified due to a nonlinear phase matching condition. The process is known to affect cw-signals in optical fibers and leads to the generation of multiple sidebands symmetrically spaced around the pump frequency. The effect also plays an important role in the initial stage of fiber supercontinuum (SC) generation with pulsed laser sources. However, so far only one pair of sidebands has been observed using pulsed laser sources, namely at the maxima of the gain curve. Here we report the generation of multiple sidebands in a microstructured fiber using only a short (few ps) chirped pump pulse in combination with a frequency-shifted weak seed pulse acting as a perturbation. The seed pulse is extracted from a prior formed SC. The generated sidebands have a minimum 3-dB linewidth of 2 THz, span over the whole parametric gain-spectrum of the pump (more than 300 THz) and can be shifted as close to the pump as 10 THz. The exact frequency and power of the sidebands can be simply controlled via the power and frequency of the seed. Thereby this technique bears the potential to be used as a multiwavelength laser pulse source. The experimental results agree with simulations based on the nonlinear Schrödinger equation and with analytic expressions.

Q 16.2 Mon 16:45 A 310

Exploring whispering-gallery modes in rolled-up vertical microcavities — •Stefan Böttner[1], Shilong Li[1], Matthew R. Jorgensen[1], and Oliver G. Schmidt[1,2] — [1]Institute for Integrative Nanosciences, IFW Dresden, Helmholtzstr. 20, 01069 Dresden, Germany — [2]Material Systems for Nanoelectronics, Chemnitz University of Technology, Reichenhainer Str. 70, 09107 Chemnitz, Germany

Vertically rolled-up microcavities (VRUMs), have a fascinating resonator geometry that confines light in a vertical plane. By carefully designing patterns before roll-up using standard photolithography, the VRUM shape can be tuned to facilitate axial light confinement and a reduction of optical losses to the substrate, both enhancing the optical quality factor [1, 2]. Furthermore VRUMs can be fabricated in large scales and integrated fabrication is, in principle, possible. Their thin walls lead to evanescent fields useful for a variety of applications such as microfluidic sensing or wavelength filtering in optical data processing.

In this talk we present fabrication methods of nontoxic low refractive index SiO_2 VRUMs and corresponding optical measurements. We detect optical resonances with high quality factors of more than 5000 using a photoluminescence setup [2]. In a second approach we use evanescently coupled tapered fibers to investigate optical properties at 1550 nm far from the photoluminescence of the VRUMs. This method is also favorable for integrated applications.

[1] Ch. Strelow et al., Phys. Rev. B. **85**, 155329 (2012).
[2] S. Böttner et al., Opt. Lett. **37**, 5136 (2012).

Q 16.3 Mon 17:00 A 310

Directional emission of dielectric disks with a finite scatterer in the THz regime — •J. Evers[1], S. I. Schmid[1], S. Preu[2], F. Sedlmeir[3,4], G. Leuchs[3,4], and H. G. L. Schwefel[3,4] — [1]Max-Planck-Institut für Kernphysik, Saupfercheckweg 1, D-69117 Heidelberg — [2]Lehrstuhl für Angewandte Physik, Universität Erlangen-Nürnberg, D-91058 Erlangen — [3]Institut für Optik, Information und Photonik, Universität Erlangen-Nürnberg, D-91058 Erlangen — [4]Max-Planck-Institut für die Physik des Lichts, D-91058 Erlangen

Directional emission of a whispering gallery mode resonator perturbed by a small hole acting as a scatterer in the vicinity of the resonator edge is discussed. We model the setup using finite-difference time-domain (FDTD) calculations of the electromagnetic field in a spatial region containing the resonator, but not the detector placed at larger distance in the far field. We then extrapolate the detection signal based on a Poynting vector analysis of the FDTD data. The numerical predictions agree well to experimental data obtained with cm scale resonators in the Terahertz domain.

Q 16.4 Mon 17:15 A 310

Chemical surface protection of optical microfibres examined with Raman spectroscopy — •Jan Hartung, Marcel Spurny, Wolfgang Alt, and Dieter Meschede — Institut für Angewandte Physik, Universität Bonn

The strong evanescent field of tapered optical microfibres makes them an excellent tool for light-matter interaction experiments. However, their high sensitivities to surface adsorbed molecules impose a problem: Microfibre transmission can be strongly influenced by surface adsorbates and chemical reaction of dangling bonds with the surrounding medium, especially in a chemically aggressive environment such as hot caesium vapour.

We present a method for surface passivation of tapered optical microfibres by silylation with methyl chlorosilanes and the examination of our microfibre samples with Raman spectroscopy before and after the treatment. This chemical surface passivation extends the range of environments in which optical microfibres can be used.

Q 16.5 Mon 17:30 A 310

Soliton molecules: possibility of fibre-optic transmission of two bits per clock period — •Alexander Hause, Philipp Rohrmann, and Fedor Mitschke — Universität Rostock, Institut für Physik, Universitätsplatz 3, 18051 Rostock

New concepts of optical data transmission are demanded in the near future. Most common coding principles rely on transmitting weak light pulses to avoid perturbations arising from fiber nonlinearity. In contrast we propose a soliton-based concept which includes nonlinear effects in dispersion-managed fibers. Using trains of solitons also known as soliton molecules it is possible to have more symbols for a new coding scheme available. Recently we succeeded to show the existence of a two- and three-soliton molecule in a proof-of-principle experiment[1]. With this achievement it is shown to be possible to transmit 2 bits of information in a single clock cycle.

Here we present experimental results and comparisons with numerical data. The multi-soliton input states are created using a pulse

shaper. Parameter scans reveal molecule properties. Finally a full amplitude and phase reconstruction of the soliton molecules is done with a homemade FROG setup. We obtain a good agreement between experimental and numerical results.
[1] P. Rohrmann et al., Scientific Reports **2**, 866 (2012)

Q 16.6 Mon 17:45 A 310

On the possible creation of short intense pulses from a family of solutions of the NLSE — •Christoph Mahnke and Fedor Mitschke — Institut für Physik, Universität Rostock

The Nonlinear Schrödinger equation (NLSE) governs the propagation of light fields in optical fibers. We consider a family of solutions including the Akhmediev Breather (AB), the Peregrine soliton (PS), and the Kuznetzov-Ma soliton (KM). Despite being known for a long time, the existence of PS and KM were confirmed in experiments just recently [2,3]. All three solutions share the property that their field consists of a cw part with a modulation on top of it. This combination leads to a growth of the modulation up to a culmination value during propagation, and subsequent decay. The AB and the KM have in common that the modulation exhibits an infinitely broad extent in one coordinate (time or space) but is localized in the other. The PS case is a transition between these two and is localized in both time and space.

We investigate whether it is possible to utilize the growth of the modulation to create short, powerful pulses from the culmination state. We present a technique to isolate the amplified modulation by splitting and recombining the field with suitable time and phase shifts. We discuss the properties of the extracted pulses and the limitations of our method.

[1] N.N. Akhmediev, V.I. Korneev, Th. Math. Phys. 69, 1089 (1986)
[2] B. Kibler et al., Nature Physics 6, 790 (2010)
[3] B. Kibler et al., Scientific Reports 2, article number 463 (2012)

Q 16.7 Mon 18:00 A 310

Kicked Rotor Dynamics in Optical Fibers — •Felix Ziegler, Marius Blaesing, and Sandro Wimberger — Institut für Theoretische Physik, Philosophenweg 19, 69120 Heidelberg

A new perspective of the well-known quantum kicked rotor model is offered by recent experiments investigating the dynamics of optical signals in fibers with nonlinearities. We consider the properties of a kicked particle wave function in position space in order to explain experimental data. The wave function is calculated by a modulation integral over the quasimomentum, which results from Bloch's theorem. For small kicking parameters the wave function shows a continuous dependence on the kicking strength. This can be explained by a tunnelling process of a particle in the ground band in a periodic potential. For higher values of the kicking strength the dynamics of the wave function exhibit a more interesting behaviour. The survival probability of the wave packet to stay in the central zone of the periodic potential shows either localisation or delocalisation depending on the kicking strength. This is in good qualitative accordance with the experiment. To explain this phenomenon, we use the fact that the kicking period corresponds to the effective $\hbar$. Semi-classical and quantum mechanical properties of the system are analysed with respect to tunnelling processes and classical phase space structures.

Q 16.8 Mon 18:15 A 310

Probing Planck's Law for a Silica Nanofiber — •Christian Wuttke and Arno Rauschenbeutel — VCQ TU Wien - Atominstitut, Stadionallee 2, A-1020 Wien

We investigate the thermalization via heat radiation of a silica fiber with a diameter smaller than the thermal wavelength. The temperature change of the subwavelength-diameter fiber is determined through a measurement of its optical path length in conjunction with an ab initio thermodynamic model of the fiber structure. The results differ significantly from the predictions of Planck's law based on the spectral emissivity of silica. Excellent agreement is obtained with a theoretical model that considers heat radiation as a volumetric effect and that takes the emitter shape and size relative to the emission wavelength into account. These results are of fundamental interest, may lead to technical applications, and can contribute to improved models of the earth's climate system

Q 17: Quantum effects: Interference and correlations

Time: Monday 16:30–18:30 Location: F 342

Group Report Q 17.1 Mon 16:30 F 342

Two-photon interference and complementarity with bright twin beams — Dirk Puhlmann, Axel Heuer, •Carsten Henkel, and Ralf Menzel — Institute of Physics and Astronomy, Universität Potsdam

We discuss experiments performed with bright twin beams produced by spontaneous parametric down-conversion (SPDC) from pump beams in different spatial modes. Two-photon interferences are observed both in polarization and spatially, inserting a Mach-Zehnder interferometer in the signal beam. Our setups are designed to favor conditions where the single-photon signal shows no contrast because *Welcher Weg* information is available from the idler photon [1, 2]. In the case of a pump mode of odd symmetry (TEM_{01}), we have observed double-slit interference in a mixed coincidence signal (signal far-field, idler near-field), although the strong position correlation in near-near coincidences suggests that the idler carries *Welcher Weg* information [3]. The interpretation of these results touches upon complementarity, nonlocality in delayed-choice experiments [4], and our understanding of two-photon quantum mechanics [5].

[1] T. J. Herzog & al, Phys. Rev. Lett. **75** (1995) 3034
[2] B.-G. Englert, Phys. Rev. Lett. **77** (1996) 2154
[3] R. Menzel, D. Puhlmann, A. Heuer, and W. P. Schleich, Proc. Natl. Acad. Sci. USA **109** (2012) 9314
[4] A. Peruzzo & al, Science **338** (2012) 634; F. Kaiser & al, Science **338** (2012) 63
[5] M. H. Rubin, & al, Phys. Rev. A **50** (1994) 5122

Q 17.2 Mon 17:00 F 342

Probing Quantum Coherence in Quantum Arrays — •Javier Almeida[1], Pieter C. de Groot[2], Susana F. Huelga[1], Alexandra Liguori[1], and Martin B. Plenio[1] — [1]Ulm Universität, Ulm, Baden-Württemberg — [2]Max Planck Institut fur Quantenoptik, Garching (München), Bayern.

We discuss how the observation of population localization effects in periodically driven systems can be used to quantify the presence of quantum coherence in interacting qubit arrays. Essential for our proposal is the fact that these localization effects persist beyond tight-binding Hamiltonian models. This result is of special practical relevance in those situations where direct system probing using tomographic schemes becomes infeasible beyond a very small number of qubits. As a proof of principle, we study analytically a Hamiltonian system consisting of a chain of superconducting flux qubits under the effect of a periodic driving. We provide extensive numerical support of our results in the simple case of a two-qubits chain. For this system we also study the robustness of the scheme against different types of noise and disorder. We show that localization effects underpinned by quantum coherent interactions should be observable within realistic parameter regimes in chains with a larger number of qubits.

Q 17.3 Mon 17:15 F 342

Bosonic behavior of entangled fermions — •Malte C. Tichy[1], Peter Alexander Bouvrie[2], and Klaus Mølmer[1] — [1]Lundbeck Foundation Theoretical Center for Quantum System Research, Department of Physics and Astronomy, University of Aarhus, DK-8000 Aarhus C, Denmark — [2]Departamento de Física Atómica, Molecular y Nuclear and Instituto Carlos I de Física Teórica y Computacional, Universidad de Granada, E-18071 Granada, Spain

Two bound, entangled fermions form a composite boson, which can be treated as an elementary boson as long as the Pauli principle remains irrelevant. The bosonic character of the composite is intimately linked to the entanglement of the fermions: Large entanglement implies good bosonic properties [1]. The deviation from perfect bosonic behavior manifests itself in the statistical properties of the composites and in their collective interference. As a consequence, the counting statistics exhibited by composites allow one to infer the form of the two-fermion wave-function [2]. Bosonic behavior can thus be used as a probe for the underlying structure of composite particles without directly accessing their constituents.

[1] M.C. Tichy, P.A. Bouvrie, K. Mølmer, Phys. Rev. A 86, 042317 (2012).

[2] M.C. Tichy, P.A. Bouvrie, K. Mølmer, arxiv:1209.3610, Phys. Rev. Lett., in press.

Q 17.4 Mon 17:30 F 342

Two-photon spectra — •Elena del Valle[1], Alejandro Gonzalez-Tudela[2], Fabrice P. Laussy[2], Carlos Tejedor[2], and Michael J. Hartmann[1] — [1]Technische Universität München, Germany — [2]Universidad Autónoma de Madrid, Spain

We apply our recently developed theory of frequency-filtered and time-resolved N-photon correlations [1] to study the two-photon spectra of a variety of systems of increasing complexity: single mode emitters and the various combinations that arise from their coupling. We consider both the linear and nonlinear regimes under incoherent excitation [2]. We find that even the simplest systems display a rich dynamics of emission, not accessible by simple single photon spectroscopy. In the strong coupling regime, novel two-photon emission processes involving virtual states are revealed which can be exploited for two-photon state generation [3].

[1] Theory of frequency-filtered and time-resolved N-photon correlations, E. del Valle, A. Gonzalez-Tudela, F. P. Laussy, C. Tejedor and M. J. Hartmann. Phys. Rev. Lett. 109, 183601 (2012)

[2] Two-photon spectra of quantum emitters, A. Gonzalez-Tudela, F. P. Laussy, C. Tejedor, M. J. Hartmann, E. del Valle. arXiv:1211.5592 (2012)

[3] Distilling one, two and entangled pairs of photons from a quantum dot with cavity QED effects and spectral filtering, E. del Valle. arXiv:1210.5272 (2012)

Q 17.5 Mon 17:45 F 342

Many-particle quantum walks in disordered media — •Felix R. Anger[1,2], Sibylle Braungardt[2], and Andreas Buchleitner[2] — [1]Fakultät für Physik, Ludwig-Maximilians-Universität München — [2]Physikalisches Institut, Albert-Ludwigs-Universität Freiburg

The problem of many-particle transport through disordered media lies at the heart of a multitude of physical processes. We study quantum walks on a biased beam splitter array as a simple model for the time evolution of many-particle states in a disordered potential. Using a general expression for the particle number correlation functions, we characterize the transport properties of such systems by investigating the dependence of localization phenomena on the number of injected particles as well as on their entanglement.

Q 17.6 Mon 18:00 F 342

Einzelphotonen-Interferenz durch induzierte Kohärenz bei parametrischer Fluoreszenz — •Sebastian Raabe, Axel Heuer und Ralf Menzel — Universität Potsdam, Institut für Physik und Astronomie, Karl-Liebknecht-Str. 24/25, 14476 Potsdam

Die bei parametrischer Fluoreszenz erzeugten Photonen eines Photonenpaares besitzen eine zueinander feste Phasenbeziehung, die durch synchrones Pumpen und Strahlüberlagerung auf ein zweites Photonenpaar aufgeprägt werden kann. In einem experimentellen Aufbau wurden so Photonenpaare aus zwei unterschiedlichen Quellen durch induzierte Kohärenz zur Interferenz gebracht [1,2].

Der Vortrag wird darauf eingehen, wie die induzierte Kohärenz durch den stimulierten oder den spontanen Prozess der parametrischen Floureszenz realisiert wurde. Es wird dargestellt welchen Einfluss die Strahlungsleistung des Pump- und Signallichts sowie die spektrale Breite des Signallichts auf die Sichtbarkeit der Einzelphotonen-Interferenz hat.

[1] L.J. Wang, X.Y. Zou and L. Mandel, Phys. Rev. A 44 4614 (1991)

[2] L.J. Wang, X.Y. Zou and L. Mandel, J. Opt. Soc. Am.B, Vol.8 No.5 (1991)

Q 17.7 Mon 18:15 F 342

Collective strong coupling in multimode cavity QED — •Arne Wickenbrock[1], Michael Hemmerling[2], Gordon R.M. Robb[2], Clive Emery[3], and Ferruccio Renzoni[1] — [1]University College London, London, UK — [2]University of Strathclyde, Glasgow, UK — [3]Technische Universitaet Berlin, Berlin, Germany

We study an atom-cavity system in which the cavity has several degenerate transverse modes. Mode-resolved cavity transmission spectroscopy reveals well-resolved atom-cavity resonances for several cavity modes, a signature of collective strong coupling for the different modes. Furthermore, the experiment shows that the cavity modes are coupled via the atomic ensemble contained in the cavity. The experimental observations are supported by numerical analysis. The work paves the way to the use of interacting degenerate modes in cavity-based quantum information processing.

Q 18: Quantum gases: Mixtures, spinor gases, disorder effects

Time: Monday 16:30–18:15 Location: E 001

Q 18.1 Mon 16:30 E 001

Entangling two distinguishable matter-wave bright solitons via collisions — Bettina Gertjerenken[1], Thomas Billam[2], Caroline Blackley[3], Ruth Le Sueur[3], Lev Khaykovich[4], Simon Cornish[5], and •Christoph Weiss[5] — [1]Institut für Physik,Carl von Ossietzky Universität, D-26111 Oldenburg, Germany — [2]Jack Dodd Center for Quantum Technology, Department of Physics, University of Otago, Dunedin 9016, New Zealand — [3]Joint Quantum Centre (JQC) Durham–Newcastle, Department of Chemistry, Durham University, Durham DH1 3LE, United Kingdom — [4]Department of Physics, Bar-Ilan University, Ramat-Gan, 52900 Israel — [5]Joint Quantum Centre (JQC) Durham–Newcastle, Department of Physics, Durham University, Durham DH1 3LE, United Kingdom

We investigate numerically the collisions of two distinguishable quantum matter-wave bright solitons in a one-dimensional harmonic trap. We show that such collisions can be used to generate mesoscopic Bell states which can reliably be distinguished from statistical mixtures. Calculation of the relevant s-wave scattering lengths reveals that such states could potentially be realized in quantum-degenerate mixtures of ^{85}Rb and ^{133}Cs. In addition to fully quantum simulations for two distinguishable dimers, we use a mean-field description supplemented by a stochastic treatment of quantum fluctuations in the soliton's center of mass: We demonstrate the validity of this approach by comparison to an effective potential treatment of the quantum many-particle problem.

Q 18.2 Mon 16:45 E 001

Quantum depletion of Bose-Einstein condensates in random lattice potentials — •Christopher Gaul[1,2] and Cord A. Müller[3] — [1]GISC, Departamento de Física de Materiales, Universidad Complutense, E-28040 Madrid, Spain — [2]CEI Campus Moncloa, UCM-UPM, Madrid — [3]Centre for Quantum Technologies, National University of Singapore, Singapore 117543, Singapore

We develop an inhomogeneous Bogoliubov theory for bosons on a tight-binding lattice [1]. In the first step, this consists in determining the condensate deformation caused by a weak external disorder potential. Then, the momentum distribution of quantum fluctuations around the deformed ground state is obtained via weak-disorder perturbation theory, and finally the resulting quantum depletion is calculated. As in the continuous case [2], the depletion due to the external potential, or potential depletion for short, is a small correction to the homogeneous depletion, validating our inhomogeneous Bogoliubov theory. Scattering due to disorder is strongest when the energy shell touches the Brillouin zone (BZ) edges. In the continuous limit, i.e., far away from the edges of the BZ, we reproduce previous results [2].

[1] arXiv:1209.5446. [2] New J. Phys., **14**, 075025 (2012).

Q 18.3 Mon 17:00 E 001

Observation of interspecies ^{6}Li -^{133}Cs Feshbach resonances — •Rico Pires[1], Marc Repp[1], Juris Ulmanis[1], Robert Heck[1], Eva Kuhnle[1], Matthias Weidemüller[1], and Eberhard Tiemann[2] — [1]Physikalisches Institut, Ruprecht- Karls Universität Heidelberg, Germany — [2]Institut für Quantenoptik, Leibniz Universität Hannover, Germany

We will present the measurement of 19 interspecies Feshbach resonances in an ultracold Bose-Fermi mixture of ^{6}Li and ^{133}Cs in the energetically lowest spin states [1]. The resonances are assigned to s- and p-wave molecular channels by a coupled-channels calculation, which precisely reproduces all observed resonances. The undressed Asymptotic Bound State Model does not yield the same level of accuracy. Several broad s-wave resonances provide prospects to create fermionic LiCs molecules with a large dipole moment via Feshbach association followed by stimulated Raman passage. With two 60 G broad resonances, this system is a promising candidate for the observation of a series of Efimov resonances, due to the small Efimov scaling factor of 4.88. As two of the s-wave resonances overlap with a zero crossing of the Cs scattering length, the mixture also offers prospects for the observations of polarons.

[1] M. Repp et al., accepted for publication in Phys. Rev. A (R) (2012)

Q 18.4 Mon 17:15 E 001

An ultracold mixture of metastable helium and rubidium — Hari Prasad Mishra, Adonis Flores, Wim Vassen, and •Steven Knoop — LaserLaB, Department of Physics and Astronomy, VU University Amsterdam, The Netherlands

We are setting up an experiment to produce an ultracold atomic mixture of metastable triplet He (^{3}He* or ^{4}He*) and ^{87}Rb. Our main motivation is the observation of heteronuclear Efimov trimers, where the large mass ratio results in a much reduced scaling factor between successive Efimov states, compared to the homonuclear case. Our strategy to reach an ultracold mixture starts with a two-species 3D-MOT, loaded from a Zeeman slower (He*) and a 2D-MOT (Rb). Afterwards the mixture is transferred to a quadrupole magnetic trap (QMT) and a 1557-nm optical dipole trap for forced evaporative cooling of Rb and sympathetic cooling of He*. Recently we have realized the two-species 3D-MOT, in which we load 10^7 ^{4}He* and 10^9 ^{87}Rb atoms in a few seconds. After optical molasses and spin polarizing Rb, we transfer the ultracold mixture into the QMT. For the doubly spin-polarized mixture (^{4}He*: m_J=+1, ^{87}Rb: F=2, m_F=+2), Penning ionization is suppressed because of spin conservation [1]. First experiments will concentrate on Penning ionization, sympathetic cooling and Majorana loss of the ultracold mixture trapped in the QMT.

[1] L. J. Byron, R. G. Dall, Wu Rugway, A. G. Truscott, New. J. Phys. 12, 013004 (2010)

Q 18.5 Mon 17:30 E 001

Detection of Fisher information for mesoscopic quantum states — •Helmut Strobel[1], Wolfgang Muessel[1], Tilman Zibold[1], Luca Pezze[2], Eike Nicklas[1], Jiri Tomkovic[1], Ion Stroescu[1], Maxime Joos[1], Daniel Linnemann[1], David B. Hume[1], Augusto Smerzi[2], and Markus K. Oberthaler[1] — [1]Kirchhoff-Institut für Physik, Universität Heidelberg, Im Neuenheimer Feld 227, 69120 Heidelberg, Germany — [2]INO-CNR and LENS, Largo Fermi 6, I-50125 Firenze, Italy

A very general classification of quantum states is the quantum Fisher information. It can be calculated from the density matrix which is experimentally accessible by state tomography. For a mesoscopic number of particles full state tomography with the necessary precision cannot be implemented in our system. Instead, we use the fact that the Fisher information is the key parameter quantifying possible sensitivity beyond the standard quantum limit in a phase estimation protocol.

We will present the realization of collective states of binary Bose-Einstein condensates with about 350 atoms and the analysis of their interferometric performance which gives a lower bound on the Fisher information. Our method is able to show that the Fisher information surpasses the shot-noise limit in a regime where no spin squeezing is present and thus reveals multiparticle entanglement.

Q 18.6 Mon 17:45 E 001

Mesoscopic dynamics of ultracold atoms in random potentials — •Cord A. Müller — Centre for Quantum Technologies, National University of Singapore, 117543 Singapore

I will briefly review the nonequilibrium dynamics of ultracold matter waves in random potentials, which attracts currently vivid experimental and theoretical interest. The recent observation of coherent backscattering of cold atoms [1], precisely following the theoretical prediction [2], presently opens avenues for a more refined understanding of disorder-induced localisation dynamics, both in weak and strong disorder. After an initial phase of momentum isotropisation [3], a coherent Cooperon peak persists in the momentum distribution, and turns into a remarkable twin-peak signal at the onset of Anderson localisation [4], whose precise properties remain to be studied.

[1] F. Jendrzejewski et al., Phys. Rev. Lett. **109**, 195302 (2012)
[2] N. Cherroret et al., Phys. Rev. A **85**, 011604(R) (2012)
[3] T. Plisson, T. Bourdel, C.A. Müller, arXiv:1209.1477
[4] T. Karpiuk et al., Phys. Rev. Lett. **109**, 190601 (2012)

Q 18.7 Mon 18:00 E 001

polar bosons in 1D disordered optical lattices — •Xiaolong Deng[1], Roberta Citro[2], Edmond Orignac[3], Anna Minguzzi[4], and Luis Santos[1] — [1]ITP, Universitaet Hannover, Germany — [2]Department of Physics, University Salerno, Italy — [3]LPMMC, CNRS, Grenoble, France — [4]ENS, Lyon, France

The effects of disorder and quasi-disorder on the ground-state properties of ultra-cold polar bosons in optical lattices are very interesting. In this talk, we show the rich phase diagrams from the interplay between (quasi-)disorder and inter-site interactions. A uniform disorder leads to a Haldane-insulator phase with finite parity order, whereas the density-wave phase becomes a Bose-glass at very weak disorder. For quasi-disorder, the Haldane insulator connects with a gapped generalized incommensurate density wave without an intermediate critical region. In addition, a novel kind of topological phase in the model will be discussed.

Q 19: Quantum information: Quantum computers

Time: Monday 16:30–18:30 Location: E 214

Group Report Q 19.1 Mon 16:30 E 214

Interfacing Ions and Photons at the Single Quantum Level — •Matthias Keller, Michale Belayneh, Stephen Begley, Markus Vogt, and Hiroki Takahashi — University of Sussex

The complementary benefits of trapped ions and photons as carriers of quantum information make it appealing to combine them in a joint system. To interface the quantum states of ions and photons efficiently, we use calcium ions coupled to an optical high-finesse cavity. For strong ion-cavity coupling, deterministic transfer of quantum states between ions and photons is possible. Each basis state of the ion is linked with one polarization mode of the cavity. Through a partially transparent cavity mirror, a freely propagating photon is generated which can be used to distribute quantum information. For moderate coupling, quantum entanglement may be generated probabilistically. Ions coupled to two orthogonally polarized cavity modes are projected to an entangled state upon detection of photons emitted from the cavity with different polarization. The realization of these schemes requires the development of novel techniques to combine ion traps with miniature optical cavities, as the strength of the ion-photon coupling increases with shrinking cavity mode volume. We are presently testing two different setups, optimized for the respective interaction regimes mentioned above.

Q 19.2 Mon 17:00 E 214

Room temperature entanglement between single defect spins in diamond. — •Ingmar Jakobi[1], Florian Dolde[1], Boris Naydenov[1,2], Nan Zhao[1], Sébastien Pezzagna[3], Jan Meijer[3], Philipp Neumann[1], Fedor Jelezko[1,2], and Jörg Wrachtrup[1] — [1]3. Physikalisches Institut, Research Center SCoPE, and IQST, Universität Stuttgart, Germany — [2]Institut für Quantenoptik, and IQST, Universität Ulm, Germany — [3]RUBION, Ruhr Universität Bochum, 44780 Bochum, Germany

Entanglement is an important element of quantum technology providing new algorithms to quantum computers, the basis for quantum cryptography and increased sensitivity in quantum metrology.

Here we experimentally demonstrate entanglement between two single solid state spin quantum bits (qubits) at ambient conditions and present a method to preserve entangled states on a time-scale of milliseconds [1]. The qubits are associated with two engineered nitrogen-vacancy (NV) defect centers in diamond separated by a distance of 25 nm.

The experiments mark an important step towards a scalable room temperature quantum device.

[1] Dolde et al., Room temperature entanglement between distant single spins in diamond, arXiv:1212.2804, (2012)

Q 19.3 Mon 17:15 E 214

Collectively Enhanced Interactions in Solid-state Spin Qubits — •Hendrik Weimer — Institut für Theoretische Physik, Leibniz Universität Hannover

I will show how to engineer collective enhancement of dipolar interactions in random spin networks. While disordered interactions typically lead to localization of all eigenstates, the presence of a transverse magnetic field can result in the appearance of a single delocalized mode suitable for the mediation of long-range quantum logic between remote spin registers [1]. I will discuss a specific implementation based on nitrogen-vacancy defects in diamond.

[1] H. Weimer, N. Y. Yao, M. D. Lukin, arXiv:1210.3622 (2012).

Q 19.4 Mon 17:30 E 214

Precisely timing dissipative quantum information processing — •Michael Kastoryano[1], Jens Eisert[1], and Michael Wolf[2] — [1]FU Berlin — [2]TU München

Dissipative engineering constitutes a framework within which quantum information processing protocols are powered by system-environment interaction rather than by unitary dynamics alone. This framework embraces noise as a resource, and consequently, offers a number of advantages compared to one based on unitary dynamics alone, e.g., that the protocols are typically independent of the initial state of the system. However, the time in- dependent nature of this scheme makes it difficult to imagine precisely timed sequential operations, conditional measurements or error correction. In this work, we provide a path around these challenges, by introducing basic dissipative gadgets which allow us to precisely initiate, trigger and time dissipative operations, while keeping the system Liouvillian time-independent. These gadgets open up novel perspectives for thinking of timed dis- sipative quantum information processing. As an example, we sketch how measurement based computation can be simulated in the dissipative setting.

Q 19.5 Mon 17:45 E 214

Selfassembling hybrid diamond-biological quantum devices — •Andreas Albrecht[1], Alex Retzker[2], Guy Koplovitz[3], Fedor Jelezko[4], Shira Yochelis[3], Yuval Nevo[5], Oded Shoseyov[5], Yossi Paltiel[3], and Martin B Plenio[1] — [1]Institut für Theoretische Physik, Universität Ulm, Germany — [2]Racah Institute of Physics, The Hebrew University of Jerusalem, Israel — [3]Department of Applied Physics, The Hebrew University of Jerusalem, Israel — [4]Institut für Quantenoptik, Universität Ulm, Germany — [5]The Robert H. Smith Institute of Plant Sciences and Genetics in Agriculture, The Hebrew University of Jerusalem, Israel

Scalable arrangements of nitrogen vacancy centers (NV) in diamond remain an open key challenge on the way to efficient quantum information processing, quantum simulation and magnetic sensing applications at the quantum limit. Here we provide a solution for creating a scalable system of individually addressable NV centers based on the self-assembling capabilities of biological systems in combination with the bridging of the bio-nano interface by means of surface functionalized nanodiamonds. We provide a detailed theoretical analysis on the feasibility of multiqubit quantum operations in such systems, exploiting the significant dipolar coupling on the nanometer scale and address the problems of decoherence, imperfect couplings and the randomness of the NV symmetry axes. We show that this allows for the high-fidelity creation of entanglement, cluster states and quantum simulation applications. In addition we present the first experimental demonstration of connecting nanodiamonds with biological systems (SP1 complexes).

Q 19.6 Mon 18:00 E 214

A toolbox for measurement based quantum computation on encoded data — •Michael Zwerger[1], Wolfgang Dür[1], and Hans Jürgen Briegel[1,2] — [1]Institut für theoretische Physik, Universität Innsbruck, Österreich — [2]Institut für Quantenoptik und Quanteninformation, Innsbruck, Österreich

We propose a toolbox for measurement based quantum computation on encoded data. It consists of small elementary building blocks, which can perform encoding/decoding, a single qubit rotation and a two qubit gate. They can be combined via Bell measurements to achieve resource states that can perform quantum gates on encoded qubits and simultaneously quantum error correction. We also discuss possible realizations of the building blocks and measurement based quantum error correction with present day technology.

Q 19.7 Mon 18:15 E 214

Optimal control of single spins in diamond — •Florian Dolde[1], Ingmar Jakobi[1], Ya Wang[1], Ville Bergholm[2,5], Sebastien Pezzagna[3], Jan Meijer[3], Boris Naydenov[4], Fedor Jelezko[4], Philipp Neumann[1], Thomas Schulte-Herbrüggen[2], and Jörg Wrachtrup[1] — [1]3. Physikalisches Institut, Research Center SCoPE, and IQST, Universität Stuttgart, Germany — [2]Dept. Chemistry, Technical University Munich (TUM), D-85747 Garching, Germany — [3]RUBION, Ruhr Universität Bochum, 44780 Bochum, Germany — [4]Institut für Quantenoptik, and IQST, Universität Ulm, Germany — [5]Institute for Scientific Interchange Foundation (ISI), I-10126 Turin, Italy

Recent progress in the quantum information experiments with the Nitrogen-Vacancy center (NV) in diamond have allowed for entanglement of two NVs forming a starting point for a quantum register. However the demonstrated fidelity of 0.67 ± 0.04 is not practical for quantum algorithms. The low fidelity was attributed not to decoherence effects but to pulse errors in the entanglement protocol [1].

In this work we investigate the usage of optimal control to perform high fidelity quantum gates on the NV center. Optimal control quantum gates were used to create coherence on a single electron spin and to store electron spin coherence in a long living nuclear spin.

[1] arXiv:1212.2804

Q 20: Ultracold plasmas and Rydberg atoms

Time: Monday 16:30–18:45 Location: E 415

Group Report Q 20.1 Mon 16:30 E 415

Steady-state crystallization of Rydberg excitations in optically driven atomic ensembles — •Michael Höning[1], Dominik Muth[1], David Petrosyan[2], and Michael Fleischhauer[1] — [1]Fachbereich Physik und Landesforschungszentrum OPTIMAS, TU Kaiserslautern — [2]Institute of Electronic Structure and Laser, FORTH, GR-71110 Heraklion, Crete, Greece

We study the emergence of many-body correlations in strongly-interacting, driven dissipative systems. Specifically, we examine resonant optical excitations of Rydberg states of atoms interacting via long-range van der Waals potential employing exact numerical methods such as t-DMRG and semiclassical Monte-Carlo simulations. In a one-dimensional lattice of atoms with nearly complete blockade of simultaneous excitation at the adjacent sites, we find that, under appropriate (dark-state) driving, the atoms can develop finite-range crystalline order of Rydberg excitations. At higher atomic densities, all atoms within the blockade radius form "superatoms", each accommodating at most one Rydberg excitation. Under strong uniform driving, the saturation of superatoms leads to quasi-crystallization of Rydberg excitations whose correlations exhibit damped spatial oscillations. The behavior of the system can be approximated by an analytically soluble model based on a "hard-rod" interatomic potential.

Q 20.2 Mon 17:00 E 415

Spontaneous avalanche ionization of a strongly blockaded Rydberg gas — •Christoph S. Hofmann, Martin Robert-de Saint-Vincent, Hanna Schempp, Georg Günter, Shannon Whitlock, and Matthias Weidemüller — Physikalisches Institut, Universität Heidelberg, Philosophenweg 12, 69120 Heidelberg

We report the sudden and spontaneous evolution of an initially correlated gas of repulsively interacting Rydberg atoms to an ultracold plasma [1]. Under continuous laser coupling we create a Rydberg ensemble in the strong blockade regime, which at longer times undergoes an ionization avalanche. By combining optical imaging and ion detection, we access the full information on the dynamical evolution of the system, including the rapid increase in the number of ions and a sudden depletion of the Rydberg and ground state densities. Rydberg–Rydberg interactions are observed to strongly affect the dynamics of plasma formation. We use a coupled rate-equation model to describe our data and to reveal that the initial correlations of the Rydberg ensemble should persist through the avalanche. The latter would mitigate disorder-induced-heating [2], and offer a route to enter new strongly-coupled regimes.

[1] M. Robert-de Saint-Vincent *et al.* arXiv:1209.4728 (2012)
[2] M. Murillo PRL **87** 115003 (2001)

Q 20.3 Mon 17:15 E 415

Light propagation in strongly interacting Rydberg gases — •Martin Gärttner and Jörg Evers — Max-Planck-Institut für Kernphysik, Saupfercheckweg 1, 69117 Heidelberg

Electromagnetically induced transparency in Rydberg gases has proven a valuable tool for applications in non-linear optics. Recently, single photons and other non-classical states of light have been produced using light propagation through strongly interacting Rydberg gases. We present a model describing the propagation of a weak probe beam in the presence of a strong coupling beam, coupling to a strongly interacting Rydberg level. Our model is based on the rate equation ansatz [1,2] and includes the attenuation of the probe beam. We test our model by comparing to experimental results of the group of M. Weidemüller [3] covering a large range of atomic densities and to other state of the art models. We find that all properties but the excitation statistics are described well by the rate equation model, indicating that quantum correlations in the light field should be taken into account.

[1] C. Ates et *al.*, Phys. Rev. A 76, 013413 (2007)
[2] K. P. Heeg et *al.*, arXiv:1202.2779 (2012)
[3] C. Hofmann et *al.*, arXiv:1211.7265 (2012)

Q 20.4 Mon 17:30 E 415

Optical imaging of Rydberg atoms in dense atomic gases — •Georg Günter, Hanna Schempp, Martin Robert-de Saint-Vincent, Stephan Helmrich, Vladislav Gavryusev, Christoph Hofmann, Shannon Whitlock, and Matthias Weidemüller — Physikalisches Institut, Universität Heidelberg, Philosophenweg 12, 69120 Heidelberg

We experimentally investigate a new all-optical method to image Rydberg atoms embedded in dense atomic gases [1]. The method exploits strong interactions between the Rydberg atoms and highly polarizable excited states of the surrounding gas. The resulting level-shifts of the excited states are mapped via electromagnetically induced transparency on a strong optical transition, leading to absorption for many atoms surrounding each Rydberg impurity in an otherwise transparent gas. Using this novel technique we show single shot images of small numbers of Rydberg atoms. Furthermore we characterize the time resolution and state-selectivity of the method. This makes it a promising tool for dynamical studies of strongly correlated many-body states as well as transport phenomena in Rydberg aggregates.

[1] G. Günter et al Phys.Rev.Lett. 108, 013002 (2012)

Q 20.5 Mon 17:45 E 415

Crystallization of photons via light storage in Rydberg gases — Johannes Otterbach[1,2], •Matthias Moos[1], Dominik Muth[1], and Michael Fleischhauer[1] — [1]Fachbereich Physik and Forschungszentrum OPTIMAS, Technische Universität Kaiserslautern, 67663 Kaiserslautern, Germany — [2]Department of Physics, Harvard University, Cambridge, MA 02138, USA

Light exciting atoms to Rydberg states under conditions of electromagnetically induced transparency (EIT) can be described in terms of slow-light Rydberg-polaritons. The strong interaction mediated by the Rydberg atoms can give rise to crystallization of photons, i.e., to density waves with long-range power-law correlations. In an 1D setting the low-energy physics can be described by a Luttinger liquid model. When the corresponding Luttinger parameter K becomes smaller than $1/2$, the density wave dominates the correlations marking the onset of crystallization. We calculate the K parameter by DMRG simulations and compare it to analytic approximations. We find that under typical slow-light conditions K is much larger than $1/2$ and thus no crystalline order can emerge. However, storing the polaritons in a stationary spin wave by switching off the control laser the effective mass and thus the kinetic energy vanish and K approaches zero. If the storage is done sufficiently adiabatic, long range crystalline order can be generated. We analyze the dynamics of this build-up in terms of a time-dependent Luttinger theory and derive conditions for an optimal storage scenario.

Q 20.6 Mon 18:00 E 415

Binding by dissipation — •Hendrik Weimer — Institut für Theoretische Physik, Leibniz Universität Hannover

I will demonstrate how dissipative forces can act as a binding mechanism between two strongly interacting particles, even when the interaction potential is purely repulsive [1]. The bound state arises as a quasi-stationary state of the dynamical evolution of the system. This method also carries the potential to serve as a cooling mechanism for strongly interacting quantum gases. Finally, I will discuss a possible experimental realization with ultracold Rydberg atoms.

[1] M. Lemeshko, H. Weimer, arXiv:1211.4035 (2012).

Q 20.7 Mon 18:15 E 415

Rydberg Physics on the Millisecond Timescale — •Thomas Niederprüm, Tobias Massimo Weber, Torsten Manthey, Vera Guarrera, Giovanni Barontini, and Herwig Ott — Research Center Optimas, Technische Universität Kaiserslautern, 67663 Kaiserslautern, Germany

Several proposals have demonstrated that dressing ultracold atoms with highly excited Rydberg states can be an extremely powerful tool to tune the interactions among them. The changed interactions create a new equilibrium state for the system that is reached typically on a timescale of milliseconds. While the short time behavior of cold Rydberg gases, the so called frozen Rydberg gas, has been vastly studied in the past only little work has been done to understand the long time behavior of Rydberg excitations in cold atomic gases. This talk will give an overview on recent experiments in our group aiming to address this regime of Rydberg physics. The ionization of Rydberg atoms inside cold clouds turns out to be an important process in such experiments. Monitoring these ion signals and combining the Rydberg excitation with a Scanning Electron Microscope we are able to study blockade phenomena in samples with dimensions down to 500 nm inside of optical lattices. Furthermore the influence of high energetic electrons on the excitation of Rydberg atoms inside a BEC is reported.

Q 20.8 Mon 18:30 E 415

Sub-Poissonian statistics of Rydberg-interacting dark-state polaritons — •Hanna Schempp[1], Christoph S. Hofmann[1], Georg Günter[1], Martin Robert-de-Saint-Vincent[1], Martin Gärttner[2,3], Jörg Evers[2], Shannon Whitlock[1], and Matthias Weidemüller[1] — [1]Physikalisches Institut , Universität Heidelberg, Philosophenweg 12, 69120 Heidelberg, Germany — [2]Max-Planck-Institut für Kernphysik, Saupfercheckweg 1, 69117 Heidelberg, Germany — [3]Institut für Theoretische Physik, Universität Heidelberg, Philosophenweg 16, 69120 Heidelberg, Germany

Interfacing light and matter at the quantum level is at the heart of modern atomic and optical physics and enables new quantum technologies involving the manipulation of single photons and atoms. A prototypical atom-light interface is electromagnetically induced transparency, in which quantum interference gives rise to hybrid states of photons and atoms called dark-state polaritons. We have observed individual dark-state polaritons as they propagate through an ultracold atomic gas involving Rydberg states [1]. Strong long-range interactions between Rydberg atoms give rise to an effective interaction blockade for dark-state polaritons, which results in large optical nonlinearities and modified polariton number statistics. The observed statistical fluctuations drop well below the quantum noise limit indicating that photon correlations modified by the strong interactions have a significant back-action on the Rydberg atom statistics.

[1] C.S. Hofmann et al., arXiv:1211.7265

Q 21: DFG funding programs

Time: Monday 18:30–19:15 Location: F 303

Q 21.1 Mon 18:30 F 303

DFG Nachwuchsprogramme im Überblick — •Stefan Krückeberg — Deutsche Forschungsgemeinschaft, Bonn

In diesem Vortrag wird zunächst ein kurzer Gesamtüberblick über die Förderaktivitäten der Deutschen Forschungsgemeinschaft (DFG) gegeben. Danach werden diejenigen Programme im Detail vorgestellt, die für Nachwuchswissenschaftlerinnen und Nachwuchswissenschaftler besonders interessant sind: das Forschungsstipendium für einen Postdoc - Aufenthalt im Ausland, das Einwerben der Eigenen Stelle sowie die Nachwuchsgruppenleitung im Emmy Noether - Programm.

15 min. discussion

Q 22: Laser development: Solid state lasers I

Time: Tuesday 11:00–12:30 Location: F 142

Q 22.1 Tue 11:00 F 142

High power 2.4 mJ Thulium-doped large-pitch fiber oscillator — •Fabian Stutzki[1], Florian Jansen[1], Cesar Jauregui[1], Jens Limpert[1,2], and Andreas Tünnermann[1,2,3] — [1]Institute of Applied Physics, Abbe Center of Photonics, Friedrich-Schiller-Universität Jena, Albert-Einstein-Str. 15, 07745 Jena, Germany — [2]Helmholtz-Institute Jena, Fröbelstieg 3, 07743 Jena, Germany — [3]Fraunhofer Institute for Applied Optics and Precision Engineering, Albert-Einstein-Str. 7, 07745 Jena, Germany

Fiber lasers offer high average powers, near diffraction-limited beam qualities, high efficiencies and simple configurations. Therefore, they are the ideal tool for many laser applications. Nowadays, several biological, medical, spectroscopic and military applications demand for wavelengths in the near-infrared region, which are not directly accessible with well-established Ytterbium-based fiber technology. Therefore, the research interest has shifted to new dopands like Thulium, which allow for laser radiation around 2 mu. In this contribution, we report on a high pulse energy and high average power Q-switched Tm-doped fiber oscillator. The oscillator produces 2.4 mJ pulses with 33 W average power and nearly diffraction-limited beam quality. The pulse duration of 15 ns results in a pulse peak power of more than 150 kW, which is a new record for Tm-based fiber oscillators. This performance is enabled by a Tm-doped large-pitch fiber, which allows for large core diameters in combination with effective single-mode operation. We will discuss further scaling capabilities and limitations of Tm-based ultrafast fiber lasers.

Q 22.2 Tue 11:15 F 142

Er:YAG-Laser bei 1645 nm zum Spurengasnachweis — •Casey Schuett[1], Haro Fritsche[1], Oliver Lux[1], Xin Wang[1], Zhigang Zhao[1], Wolfgang Gries[2] und Hans Joachim Eichler[1] — [1]Institut für Optik und Atomare Physik, TU Berlin, Str. des 17. Juni 135, 10623 Berlin — [2]DirectPhotonics Industries GmbH, Max-Planck-Str. 3, 12489 Berlin

Resonant gepumpte, augensichere Er:YAG-Laser bei 1645 nm stellen vielversprechende Laserquellen für LIDAR-Anwendungen dar. Verschiedene Er:YAG-Lasersysteme wurden sowohl im kontinuierlichen, als auch im gütegeschalteten Betrieb aufgebaut. Resonantes Pumpen zeichnet sich durch eine hohe Quanteneffizienz aus und kann bei einer Pumpwellenlänge von 1455 nm, 1470 nm oder 1532 nm erreicht werden. Es handelt sich hierbei um einen Quasi-Zwei-Niveau-Laserprozess, welcher zu einer Ausgangsstrahlung bei 1617 nm oder 1645 nm führt. Als Pumpquelle dienen InP-basierte, wellenlängenstabilisierte Hochleistungs-Diodenlasermodule von DirectPhotonics (DPI) mit einer Linienbreite besser als 0,2 nm bei geringem Strahlparameterprodukt. Somit konnten eine kontinuierliche Ausgangsleistung von über 2,5 W, sowie Pulsenergien von 6,6 mJ erreicht werden. Die Frequenzstabilität ist sowohl im kontinuierlichen, als auch im Pulsbetrieb geringer als 100 MHz. Die verschiedenen Er:YAG-Lasersysteme wurden hinsichtlich ihrer Eignung zum Spurengasnachweis untersucht. Dazu wurden Methan-Absorptionsmessungen bei verschiedenen Drücken im Bereich von 1 bis 400 mbar mittels einer Multipass-Zelle durchgeführt.

Q 22.3 Tue 11:30 F 142

Diode-Pumped Broad-Band Joule-Class Yb:CaF$_2$ Laser Amplifiers — •Joachim Hein[1,2], Jörg Körner[2,3], Diethard Klöpfel[2], Reinhard Seifert[1], Hartmut Liebetrau[2], Martin Kahle[1], Thomas Töpfer[3,4], and Malte Kaluza[1,2] — [1]Helmholtz-Institut Jena, Fröbelstieg 3, 07743 Jena — [2]Institut für Optik und Quantenelektronik, FSU Jena, Max-Wien-Platz 1, 07743 Jena — [3]Lastronics GmbH, Winzerlaer Straße 2, 07745 Jena — [4]Hellma Materials GmbH, Moritz-von-Rohr-Straße 1, 07745 Jena

We report on the development of a burst mode laser system based on the active material Yb:CaF$_2$. Despite the advantageous characteristics of this material for diode-pumped femtosecond pulse amplification the low achievable gain requires a high energy density of the extraction beam, a well homogenized pump radiation, many extraction passes, and preferably low temperatures of the gain material. This is solved by a novel multipass architecture, energy extraction by a burst of pulses instead of a single pulse, and cryogenic cooling with liquid nitrogen. Laser simulation and the analysis of a couple of multipass schemes are presented. Starting with nJ pulses from a femtosecond oscillator a chain of three amplifiers boosts the energy of a burst of 50-500 pulses to the Joule level. Amplifiers are operated by pumping with laser diodes of 20 kW peak power at 10 Hz. This burst pulse structure is suitable for several experiments for instance in combination with pulsed accelerators. Nowadays Yb:CaF$_2$ crystals can be produced at very large sizes and high optical quality. Based on the reported schemes even larger laser systems that enter the kJ range are imaginable.

Q 22.4 Tue 11:45 F 142

Kanalwellenleitung in Fs-Laser-strukturierten Nd:LuAG-Dünnschichten — •Gunnar Just, Sebastian Heinrich, Sebastian Müller, Sven Waeselmann, Christian Kränkel und Günter Huber — Institut für Laser-Physik, Universität Hamburg

Die Kanalwellenleitergeometrie ist vielversprechend im Hinblick auf die Entwicklung kompakter und effizienter Lasersysteme. Seltenerd-dotierte $Lu_3Al_5O_{12}$-Wellenleiter stellen schmalbandige Emissionslinien und eine hohe optische Verstärkung in Aussicht. Mit dem Pulsed Laser Deposition Verfahren (PLD) wurden 2 μm dicke, einkristalline Nd(0,5 at.%):$Lu_3Al_5O_{12}$-Schichten (Nd:LuAG) auf YAG-Substraten gewachsen. Die Herstellungsparameter wurden durch Charakterisierung von gewachsenen Schichten mit Röntgen- bzw. Elektronenbeugung sowie Reflektometrie optimiert. Die laterale Strukturierung der Schichten erfolgte mit Femtosekunden-Laser-Pulsen bei einer Wellenlänge von 775 nm. Dies ermöglicht eine räumlich stark lokalisierte Ablation im μm-Bereich. Bei der Verwendung von linear und zirkular polarisiertem Licht mit Pulsenergien zwischen 300 nJ und 800 nJ wurden Strukturen mit einer Breite von 2 μm und einer Maximaltiefe von 1 μm geschrieben. Dabei zeigte sich eine homogenere Ablation bei Verwendung zirkular polarisierten Lichts. Verlustmessungen an Nd:LuAG-Kanalwellenleitern mit der Mode Propagation Loss Measurement - Methode unter Variation der Anregungswellenlänge ermöglichten die Ermittlung von Streu- und Absorptionsverlusten.

Q 22.5 Tue 12:00 F 142

Yb:Lu$_2$O$_3$-Scheibenlaser für den Einfrequenzbetrieb bei 1015 nm in verschiedener dynamisch stabiler Resonatorkonfiguration — •Sebastian Mades[1,2], Thomas Diehl[1,2], Andreas Koglbauer[1,2], Daniel Kolbe[1,2], Matthias Stappel[1,2], Ruth Steinborn[1,2] und Jochen Walz[1,2] — [1]Institut für Physik, Johannes Gutenberg-Universität, 55099 Mainz, Deutschland — [2]Helmholtz-Institut Mainz, Johannes Gutenberg-Universität, 55099 Mainz, Deutschland

Scheibenlaser haben sich durch ihre gute Strahlqualität bei hoher Ausgangsleistung aufgrund der Kühlmöglichkeit des aktiven Mediums bewährt.

Für den einfrequenten Grundmodenbetrieb bei 1015 nm, außerhalb der Hauptemissionslinie von 1030 nm, verspricht ein neuartiges Scheibenmaterial aus Ytterbium dotiertem Lutetiumoxid aufgrund seines höheren Emissionswirkungsquerschnitts bei dieser Wellenlänge Leistungsvorteile gegenüber den etablierten Yb:YAG-Scheibenlasern.

Der für die zweistufige Frequenzverdopplung zu 254 nm notwendige Einfrequenzbetrieb wird durch ein Lyotfilter und ein Etalon im Laserresonator erreicht. Für den optimalen transversalen Grundmodenbetrieb werden unterschiedliche Pumpfleckgrößen sowie dynamisch stabile lineare und gefaltete Resonatorgeometrien getestet. In diesem Zusammenhang wird auf die Vorteile von gefalteten Resonatoren bei sich ändernder Scheibenkrümmung und thermischen Linsen eingegangen.

Q 22.6 Tue 12:15 F 142

Faserbasierte Filterung von azimutal und radial polarisierter Strahlung — •Christoph Jocher[1], Cesar Jauregui[1], Christian Voigtländer[1], Fabian Stutzki[1], Stefan Nolte[1], Martin Becker[2], Manfred Rothhardt[2], Jens Limpert[1,3] und Andreas Tünnermann[1,3,4] — [1]Institute of Applied Physics, Abbe Center of Photonics, Friedrich-Schiller-Universität Jena, Albert-Einstein-Str. 15, 07745 Jena, Germany — [2]Institute of Photonic Technology, Albert-Einstein-Str. 9, 07745 Jena, Germany — [3]Helmholtz-Institute Jena, Fröbelstieg 3, 07743 Jena, Germany — [4]Fraunhofer Institute for Applied Optics and Precision Engineering, Albert-Einstein-Str. 7, 07745 Jena, Germany

Das Anwendungsfeld von azimutal und radial polarisierter Strahlung ist in den letzten Jahren stetig gewachsen. Hier stellen wir einen faserbasierten Modenfilter vor, der es uns ermöglicht örtlich veränderliche Polarisationen zu erzeugen. Es wird eine hoch-NA Faser verwendet, in der die Polarisationsentartung aufgehoben ist und Fasermoden mit radialer oder azimutaler Polarisation auftreten. Durch die Integration eines Faser-Bragg-Gitters werden diese bei unterschiedlichen Wellenlängen reflektiert und die radiale und azimutale Polarisation können durch eine einfache Wellenlängenfilterung selektiert werden. Dieser faserbasierte Ansatz ermöglicht einen vollständig faserintegrierten Aufbau für die Konversion eines bestehenden Strahles oder die Erzeugung innerhalb eines Faseroszillators.

Q 23: Quantum gases: Interaction effects II

Time: Tuesday 11:00–12:30 Location: E 001

Group Report Q 23.1 Tue 11:00 E 001

Cavity Quantum Electrodynamics with utracold atoms — •Hessam Habibian[1,2,3], Stefano Zippilli[4], André Winter[1], Simone Paganelli[2], Fabrizio Illuminati[4], Heiko Rieger[1], and Giovanna Morigi[1] — [1]Universität des Saarlandes, Germany — [2]Universitat Autonoma de Barcelona — [3]ICFO-The Institute of Photonic Sciences, Spain — [4]Universita degli Studi di Salerno, Italy

Bragg scattering by atoms in optical lattices has been demonstrated in several experiments. When the atoms are confined in an array inside a resonator, they can elastically scatter photons into the cavity. In this work we assume that the periodicity of the lattice is such that there is no elastic scattering into the cavity mode. In this limit, when the atoms are deep in the Mott-insulator phase, the light at the cavity output can be squeezed or anti-bunched, depending on the amplitude of the laser intensity. We also show that the stationary entanglement between light and spin-wave modes of the array can be generated. While for point-like atoms photon scattering into the cavity is suppressed, for sufficiently strong lasers quantum fluctuations can support the build-up of an intracavity field. Numerical simulations show that for large parameter regions cavity backaction forces the atoms into clusters with a local checkerboard density distribution. The clusters are phase locked one with another so to maximize the number of intracavity photons. This state can be revealed in a non-destructive way by measuring the light at the cavity output. We argue that this system constitutes a novel setting where quantum fluctuations give rise to effects usually associated with disorder.

Q 23.2 Tue 11:30 E 001

Spin and Photon Glasses in Open Quantum Systems — •Michael Buchhold[1], Philipp Strack[2], and Sebastian Diehl[1,3] — [1]Institute for Theoretical Physics, University of Innsbruck, A-6020 Innsbruck, Austria — [2]Department of Physics, Harvard University, Cambridge MA 02138 — [3]Institute for Quantum Optics and Quantum Information of the Austrian Academy of Sciences, A-6020 Innsbruck, Austria

Recent studies of strongly interacting atoms and photons in optical cavities have triggered the interest in open system realizations of the Dicke model of atomic qubits coupled to discrete photon cavity modes. In the framework of a non-equilibrium Keldysh path integral approach tailored to study open quantum systems with disorder, we analyze the open multi-mode Dicke model with variable atom-photon couplings and cavity photon loss. In spite of the dissipative nature of this model, we identify a spin glass phase as a possible steady state of the system. The glassy system shows low frequency thermalization and unusual spectral behavior of the atoms as well as a strong competition between relaxational and reversible dynamics close to the glass transition. As a main feature, the physical properties of the spin glass are completely mapped onto the photonic degrees of freedom, which, as we demonstrate, makes spin glass physics directly observable in cavity QED experiments.

Q 23.3 Tue 11:45 E 001

Intrinsic optical bistability in a cooperative Rydberg ensemble — •Christopher Carr, Ralf Ritter, Kevin Weatherill, and Charles Adams — Joint Quantum Centre (JQC), Durham University, Durham, England

We demonstrate a non-equilibrium phase transition in a cooperative Rydberg ensemble. A thermal Rydberg ensemble provides an ideal environment for studying cooperative effects which dominate when the number of atoms per cubic wavelength is large [1,2]. We perform a three-photon excitation scheme to Rydberg states in Caesium which allows us to obtain high Rydberg densities [3] and large transition wavelengths to nearby states.

The first-order non-equilibrium phase transition in the atom-light interaction occurs due to competition between a single-body response and a cooperative many-body response. Long-range correlations between Rydberg atoms arise due to virtual photon exchange in the dipole-dipole interaction. In the frequency domain, we observe a cooperative mean-field shift resulting in intrinsic optical bistability [4]. In the time domain, we observe a superradiant Rydberg cascade [5] due to cooperative emission.

[1] J. Keaveney et al., Phys. Rev. Lett. **108** 173601 (2012)
[2] J. Pritchard et al., Phys. Rev. Lett. **105** 193603 (2010)
[3] C. Carr et al., Opt. Lett. **37** 3858 (2012)
[4] M. Hehlen et al., Phys. Rev. Lett. **73** 1103 (1994)
[5] F. Gounand et al., J. Phys. B **12** 547 (1979)

Q 23.4 Tue 12:00 E 001

Bistability in Bose-Einstein condensates with attractive two-body and repulsive three-body contact interaction — Hamid Al-Jibbouri[1], •Antun Balaž[2], and Axel Pelster[3] — [1]Fachbereich Physik, Freie Universität Berlin, Germany — [2]SCL, Institute of Physics Belgrade, University of Belgrade, Serbia — [3]Fachbereich Physik, Technische Universität Kaiserslautern, Germany

The effects of three-body contact interactions on the properties of harmonically trapped Bose-Einstein condensates are usually quite small. Only in exceptional circumstances, e.g. in the presence of geometric resonances [1], such effects can reach the level of a few percent of two-body effects, and thus become experimentally observable. However, in the case of an attractive Bose-Einstein condensate, the repulsive three-body interaction can stabilize the system against collapse by increasing the critical number of atoms. Furthermore, motivated by Ref. [2], we show that the system parameters can be tuned in such a way that two stable equilibria coexist. Following Ref. [3] we use a variational approach and perform a detailed numerical analysis of the underlying cubic-quintic Gross-Pitaevskii equation to study the occurrence of a possible bistability.

[1] H. Al-Jibbouri, *et al.*, eprint `arXiv:1208.0991`
[2] A. Montina and F. T. Arecchi, Phys. Rev. A **66**, 013605 (2002)
[3] I. Vidanović, *et al.*, Phys. Rev. A **84**, 013618 (2011)

Q 23.5 Tue 12:15 E 001

Ionizing collisions of metastable neon in different spin states — •Jan Schütz, Alexander Martin, Sanah Altenburg, and Gerhard Birkl — Institut für Angewandte Physik, Technische Universität Darmstadt, Schlossgartenstraße 7, 64289 Darmstadt

Metastable rare-gas atoms (*Rg**) prepared by laser cooling techniques present a unique class of atoms for the investigation of cold and ultracold collisions. The extremely low kinetic energy ($\approx 10^{-10}$ eV) of the laser-cooled atoms stands in strong contrast to the high internal energy (≈ 15 eV) of the metastable state which enables Penning and associative ionizing collisions. For unpolarized *Rg** samples, these collisions lead to two-body loss rate coefficients up to 10^{-9} cm^3/s. Spin polarizing the atoms to a spin-stretched state suppresses the ionizing collisions. The amount of suppression, however, depends crucially on the details of the interaction.

We perform detailed investigations on the collisions of Ne*. To gain closer insight into the details of the suppression mechanisms, we investigate ionizing collisions for Ne* prepared in the individual $m_j = +2, +1$, and 0 sublevels of the metastable $^3P_2$ state and controllable mixtures of all five m_j-states. We apply two techniques, one based on RF induced Rabi oscillations and one based on STIRAP, to prepare the states. We present the resulting rate coefficients for the two bosonic isotopes ^{20}Ne and ^{22}Ne.

Q 24: Quantum information: Atoms and ions II

Time: Tuesday 11:00–12:30 Location: A 310

Group Report Q 24.1 Tue 11:00 A 310

Trajectory-Based Micro-Motion Compensation and Simulation of Long Distance Entanglement in a Segmented Trap — •M. Johanning[1], M. T. Baig[1], T. Collath[1], T. F. Gloger[1], D. Kaufmann[1], P. Kaufmann[1], M. Giampaolo[2], S. Zipilli[2], F. Illuminati[2], and Ch. Wunderlich[1] — [1]Faculty of Science and Technology, Dep. of Physics, University of Siegen, Walter Flex Str. 3, 57072 Siegen, Germany — [2]Dep. of Mathematics and Informatics, University of Salerno, 84084 Fisciano SA, Italia

We report on the minimization of micromotion in a segmented linear paul trap by analyzing equilibrium position trajectories under dc and rf variations. We discuss the modelling and analysis of such trajectories and introduce methods to speed up the local optimization process down to a few seconds. We give an estimate for the accuracy of the optimization procedure and compare to other methods.

Furthermore, we propose an experiment to demonstrate the presence of long distance entanglement (LDE) in such a trap. LDE refers to the occurrence of ground-state entanglement between the end spins of a spin chain, and can be used to implement a quantum bus [1]. By designing the axial trapping potential, the required relative coupling strengths can be realized; suitable XY interactions can be obtained using a sequence of microwave pulses. We discuss how to combine this with previous findings for the adiabatic preparation of the ground state of an XY spin chain which exhibits LDE, and we demonstrate numerically its feasibility with realistic parameters.

[1] S. M. Giampaolo, F. Illuminati, New J. Phys. 12, 025019 (2010)

Q 24.2 Tue 11:30 A 310

Effects of ion motion in photon-assisted entanglement creation — •Jozsef Zsolt Bernad, Holger Frydrych, and Gernot Alber — Institut für Angewandte Physik, TU Darmstadt, D-64289, Germany

We investigate ion motion as a source of decoherence in the implementation of a hybrid quantum repeater. Studying the dynamics of ion motion in the Lamb-Dicke regime we explore possibilities of entangling two distant material qubits, realized by the internal states of two ions, which interact resonantly with single-mode cavity fields. For the purpose of achieving entangled pairs with high fidelity and with high probability we use an optimal generalized field measurement which is capable of preparing entangled states by postselection. We show that the quality of the entanglement depends primarily on the trap frequency. High trap frequencies enhance the fidelity of the postselected entangled pairs. We also propose a set of dynamical decoupling schemes performed locally on the ions which can suppress ion motion induced decoherence independently from other decoherence sources.

Q 24.3 Tue 11:45 A 310

Operating 2D Arrays of Addressable Ion Traps — •Muir Kumph[1], Michael Niedermayr[1], Michael Brownnutt[1], and Rainer Blatt[1,2] — [1]Institut für Experimentalphysik, Universitäts Innsbruck Technickerstr 25, 6020 Innsbruck, Austria — [2]Institut für Quantenoptik und Quanteninformation, Österreichische Akademie der Wissenschaften, 6020 Innsbruck, Austria

Controlling interactions between ions in a one dimensional array of ion traps, via a segmented linear ion trap, is becoming standard technology. Extending these methods to two dimensions, however, is not trivial. The trapping and control of ^{40}Ca$^+$ ions in a 4 by 4 array of addressable planar-electrode ion traps is shown. Demonstration of micromotion minimization and estimates of the heating rate of the ions will be given.

Q 24.4 Tue 12:00 A 310

Transport- und Gatteroperationen zur skalierbaren Quanteninformationsverarbeitung — •Henning Kaufmann[1], Thomas Ruster[1], Andreas Walther[2], Max Hettrich[1], Kilian Singer[1], Ferdinand Schmidt-Kaler[1] und Ulrich Poschinger[1] — [1]QUANTUM, Institut für Physik, Universität Mainz, Staudingerweg 7, 55128 Mainz, Germany — [2]Department of Physics, Lund University, Box 118, SE-221 00 Lund

Das Ziel unserer Experimente ist die Realisierung von Quantenrechnungen mit Hilfe gefangener Ionen in segmentierten Mikro-Ionenfallen. Wir stellen den Fortschritt der Realisierung schneller Transportoperationen über makroskopische Distanzen innerhalb einer Zeitskala nahe der Fallenperiode vor. Diese Transportoperationen konnten für ein einzelnes Ion realisiert werden, wobei die verbliebene Bewegungsenergie nach dem Transport mit einer Genauigkeit unter dem Einzel-Quantenniveau kontrolliert werden kann [1]. Wir konnten ausserdem zeigen, dass ein Zustand welcher in Spin- und Bewegungszustand verschränkt ist, die Transportoperation überdauert. Schritte zur Demonstration der Skalierbarkeit dieses Ansatzes beinhalten die numerischen Modellierung der Transportoperationen mit hinreichender Präzision. Diese konnte in der erfolgreichen Übereinstimmung von gemessenen Verschiebungsamplituden mit numerischen Resultaten gezeigt werden [2]. Wir berichten desweiteren von der Realisierung des geometrischen Phasengatters und der Entwicklung kontrollierter Teilungsoperationen. [1] A. Walther et al. PRL **109**, 080501 (2012). [2] F. Ziesel et al., arxiv:1211.5490 , (2012). [3] D. Leibfried et al., Nature **422**, 412 (2003).

Q 24.5 Tue 12:15 A 310

Full solid angle imaging of a single ion — •Martin Fischer[1,2], Robert Maiwald[1,2], Andrea Golla[1,2], Marianne Bader[1,2], Markus Sondermann[1,2], and Gerd Leuchs[1,2] — [1]Max Planck Institute for the Science of Light, Erlangen, Germany — [2]Institute of Optics, Information and Photonics, University of Erlangen-Nuremberg, Erlangen, Germany

In most ion trapping experiments the geometry of the trap as well as application specific restrictions significantly reduce the solid angle under which the ion can be observed. In our setup we make use of an ion trap designed to minimize the obscured solid angle [1]. This trap is combined with a parabolic mirror covering 81 % of the solid angle providing us with a setup capable of imaging our single emitter with sub-wavelength resolution [2]. We report on the highest resolution in imaging a single atomic emitter. Furthermore our system shows high sensitivity to misalignment of the ion from the focus of the parabolic mirror making sub-wavelength displacements easily detectable.

[1] R. Maiwald *et al.*, Nature Physics **5**, 551 (2009)

[2] R. Maiwald *et al.*, Phys. Rev. A **86**, 043431 (2012).

Q 25: Quantum information: Quantum communication II

Time: Tuesday 11:00–12:15 Location: E 214

Q 25.1 Tue 11:00 E 214

A wavelength tunable quantum light-emitting diode — •Jiaxiang Zhang[1], Fei Ding[1], Eugenio Zallo[1], Santosh Kumar[1], Bianca Höfer[1], Rinaldo Trotta[2], Armando Rastelli[2], and Oliver G. Schmidt[1] — [1]Institute for Integrative Nanosciences, IFW-Dresden, Helmholtzstrasse 20, D-01069 Dresden, Germany — [2]Institute of Semiconductor and Solid State Physics, Johannes Kepler University Linz, Altenbergerstrasse 69, A-4040 Linz, Austria

It is desirable to have trigged quantum light sources that emit single photons with exactly the same wavelength in quamtum communication. Previous work has realized two photon interference of the emission from two remote self-assembled quantum dots (QDs).Here we demonstrate an electrically driven, wavelength tunable single-photon source utilizing self-assembled InAs/GaAs QDs embedded in a p-i-n light-emitting diode (LED). Triggered single-photon emission is realized by applying ultra-short electrical pulses to the LED, while the wavelength of the emitted single photons is precisely controlled ($>$ 10meV) by external biaxial stresses. We also characterize the decay dynamics of the excitonic states and the pulsed single-photon emission [g2(*)] in this device. Our technique therefore presents strong promise for the realization of two photon interference from separated electrically injected single-photon sources.

Q 25.2 Tue 11:15 E 214

Detector efficiency in Communication Complexity and Bell test experiments — •Michael Epping — Institut für Theoretische Physik III, Heinrich-Heine-Universität Düsseldorf, Universitätsstr. 1, 40225 Düsseldorf

Suppose several separated parties need to calculate a function f(x), but each party has only access to one part of the input x. The amount of communication (in bits) necessary for the parties in order to calculate f is the communication complexity of f (see [1] for a survey). Similarly, one can ask for the probability of successful calculation of f if the communication is restricted. The parties can increase this probability if they share a non-local state, while the communication remains classical[2,3]. In this talk a link between the detection efficiency necessary for a quantum advantage in the task described above and the detection loophole of a Bell test experiment is presented. This is, the detection loophole can be closed when the detectors allow for a quantum advantage in the communication complexity task.

[1] H. Buhrman, R. Cleve, S. Massar and R. Wolf, "Non-locality and Communication Complexity", arXiv:0907.3584 (2009)

[2] C. Brukner, M. Zukowski, J. Pan and A. Zeilinger, "Bell's inequalities and quantum communication complexity", Phys. Rev. Lett., 92:127901 (2004)

[3] M. Epping, "Quantenkommunikationskomplexität mit nichtidealen Detektoren", Master's thesis, University of Vienna, Austria (2012)

Q 25.3 Tue 11:30 E 214

Continuous-variable entanglement distillation and non-commutative central limit theorems — •Earl Campbell[1], Marco Genoni[2], and Jens Eisert[1] — [1]Dahlem Center for Complex Quantum Systems, Freie Universitaet Berlin, 14195 Berlin, Germany — [2]QOLS, Blackett Laboratory, Imperial College London, London SW7 2BW, UK

Entanglement distillation transforms weakly entangled noisy states into highly entangled states, a primitive to be used in quantum repeater schemes and other protocols designed for quantum communication and key distribution. In this work, we present a comprehensive framework for continuous-variable entanglement distillation schemes that convert noisy non-Gaussian states into Gaussian ones in many iterations of the protocol. Instances of these protocols include (a) the recursive Gaussifier protocol, (b) the temporally-reordered recursive Gaussifier protocol, and (c) the pumping Gaussifier protocol. The flexibility of these protocols give rise to several beneficial trade-offs related to success probabilities or memory requirements, which that can be adjusted to reflect experimental demands. Despite these protocols involving measurements, we relate the convergence in this protocols to new instances of non-commutative central limit theorems, in a formalism that we lay out in great detail. Implications of the findings for quantum repeater schemes are discussed.

Q 25.4 Tue 11:45 E 214

Air to Ground Quantum Key Distribution — •Markus Rau[1], Sebastian Nauerth[1], Florian Moll[2], Christian Fuchs[2], Joachim Horwath[2], Stefan Frick[1], and Harald Weinfurter[1,3] — [1]Ludwig-Maximilians-Universität, München — [2]Deutsches Zentrum für Luft- und Raumfahrt e.V., Weßling — [3]Max-Planck-Institut für Quantenoptik, München

Quantum key distribution provides a whole new level of information security. However for long range communication, links via satellites or other airborne systems are necessary. Here we report on an experiment combining recent advances in classical and in quantum optical technologies to demonstrate the feasibility of quantum key distribution from an airplane to ground. Major challenges solved in this experiment are the higher pointing requirements compared to classical free-space communication and the integration of the QKD hardware into an existing communication system, including the development of a precise polarization compensation technique to account for the relative rotations of airborne and ground station qubit encoding bases.

The flight tests have been performed linking the optical ground station of the DLR Oberpfaffenhofen with a Donier 228 airplane flying at a distance of 20 km at 290 km/h. The achieved key rate of 145 bits/s with a quantum bit error rate of 4.8 % proves that a BB84 key exchange can be performed with a fast moving airborne platform. Given the high angular speed our demonstration also clearly proves the feasibility of QKD to satellites, high altitude platforms or intercontinental planes.

Q 25.5 Tue 12:00 E 214

Long-distance QKD enhanced by quantum repeaters with atomic ensembles and heralded qubit amplifiers — •Silvestre Abruzzo[1], Sylvia Bratzik[1], Nadja K. Bernardes[2,3], Hermann Kampermann[1], Peter van Loock[2,3,4], and Dagmar Bruss[1] — [1]Institute for Theoretical Physics III, Heinrich-Heine-Universität Düsseldorf, Universitätsstr. 1, 40225 Düsseldorf, Germany — [2]Optical Quantum Information Theory Group, Max Planck Institute for the Science of Light, Günther-Scharowsky-Str. 1/Bau 24, 91058 Erlangen, Germany — [3]Institute of Theoretical Physics I, Universität Erlangen-Nürnberg, Staudtstr. 7/B2, 91058 Erlangen, Germany — [4]Institute of Physics, Johannes-Gutenberg Universität Mainz, Staudingerweg 7, 55128 Mainz, Germany

We analyze in the context of long-distance quantum key distribution a recent quantum repeater proposal based on atomic ensembles and linear optics[1]. We investigate the impact of important experimental parameters on the final secret key rate. These parameters include the source efficiency, detector click probability and the quantum memory retrieval efficiency [2]. Moreover, we investigate the optimal number of repeater stations given a specific fixed value of the imperfections.

[1] J. Minář et al, Phys. Rev. A 85, 032313 (2012)

[2] S. Abruzzo et al, arXiv:1208.2201

Q 26: Ultra-cold atoms, ions and BEC III (with A)

Time: Tuesday 11:00–12:30 Location: B 302

Q 26.1 Tue 11:00 B 302

Shedding light on three-body recombination in ultracold atomic gases — •Artjom Krükow[1], Arne Härter[1], Markus Deiss[1], Björn Drews[1], Eberhard Tiemann[2], and Johannes Hecker Denschlag[1] — [1]Institut für Quantenmaterie and Center for Integrated Quantum Science and Technology IQST, Universit ät Ulm, 89069 Ulm, Germany — [2]Institute of Quantum Optics, Leibniz Universität Hannover, 30167 Hannover, Germany

We investigate three-body recombination in an optically confined ultracold cloud of ^{87}Rb atoms, in which Rb_2 molecules are formed. We examine the distribution of the molecular quantum states that are populated in this process. For this we ionize the Rb_2 molecules in a 3-photon REMPI scheme with a narrow-linewidth laser at a wavelength of around 1064nm. Subsequently the ionized molecules are trapped in a linear Paul trap where they are detected with single particle sensitivity and virtually no background. As we scan the frequency of the ionization laser, we observe a dense spectrum of narrow resonance lines which contains the information on the final states populated in the recombination events. We can resolve vibrational, rotational and hyperfine levels of the triplet and singlet ground state molecules. We observe deeply bound states with binding energies up to 750 GHz $\times$ h. We expect this method to provide a pathway to understanding three-body recombination in ultracold atomic gases which so far lacks a full theoretical treatment.

Q 26.2 Tue 11:15 B 302

Transport spectroscopy in the Bose-Hubbard model — •Christian Nietner — Technische Universität Berlin

Motivated by recent experiments [1] we consider a Bose-Hubbard model with a single defect lattice site. This defect is weakly coupled to the surrounding which gives rise to bosonic currents through the defect. In order to describe these defect currents we develop a Lindblad master equation. We treat the remaining bosonic lattice as an effective bath for the defect and obtain a rate equation which depends on the 2-point correlation functions of the Bose-Hubbard model. To calculate these quantities we follow the approach outlined in Ref. [2]. Finally, we obtain defect currents which show signatures of the Mott phase and allow transport spectroscopy of the energy gap.

[1] T. Gericke, P. Würtz, D. Reitz, T. Langen et. al., Nature Physics **4**, 949 (2008)

[2] B. Bradlyn, F. E. A. dos Santos, and A. Pelster, Phys. Rev. A **79**, 013615 (2009)

Q 26.3 Tue 11:30 B 302

Interference effects in Fock space in Bose-Hubbard systems — •Thomas Engl[1], Juan Diego Urbina[1], Arturo Argüelles Parra[2], Julien Dujardin[2], Peter Schlagheck[2], and Klaus Richter[1] — [1]Universität Regensburg — [2]Universite de Liege

Semiclassical techniques have so far been applied mainly to single particle systems. For these systems they provide a powerful toolbox to study interference effects and allow analytical calculations even in the presence of classical chaos.

On the other hand there have been attempts to apply the semiclassical approximation to the Feynman path integral for bosonic quantum fields in coherent state representation. The resulting coherent state path integral however leads to complex actions which does not give clear insight in interference effects.

We have succeeded in finding a representation in which the semiclassical approximation leads to a van-Vleck propagator with real action and therefore shows interference in Fock space explicitly. We use this propagator to predict various interference effects for Bose-Hubbard systems in three different regimes of the ratio of interaction and hopping strength, and we show that the probability of return is enhanced due to interference.

Q 26.4 Tue 11:45 B 302

Optimal control of ultracold atomic quantum systems — •Antonio Negretti[1], Simone Montangero[2], Tommaso Calarco[2], Sandrine van Frank[3], Wolfgang Rohringer[3], Tarik Berrada[3], Thorsten Schumm[3], and Jörg Schmiedmayer[3] — [1]Zentrum für Optische Quantentechnologien, Universität Hamburg, Luruper Chaussee 149, 22761 Hamburg (Germany) — [2]Institut für Quanteninformationsverarbeitung, Universität Ulm, Albert-Einstein-Alle 11, 89069 Ulm (Germany) — [3]Atominstitut, Universität Wien, Stadionallee 2, 1020 Wien (Austria)

In the recent past, experiments with ultracold quantum gases have reached an extremely high degree of control, in which the manipulation and detection of single particles like atoms and ions have been demonstrated. For the purposes of quantum information processing and interferometry it is needed not only a high degree of control, but also that the desired quantum transformation is obtained as fast as possible. To this aim optimal control is a valuable resource to achieve high performance in the shortest possible time.

In my talk I shall present recent and very promising achievements in the optimized quantum dynamics of degenerate quasi 1D quantum Bose gases experiments.

Q 26.5 Tue 12:00 B 302

Excitation spectrum of supersolids with soft-core bosons — •Tommaso Macri, Fabio Cinti, Fabian Maucher, and Thomas Pohl — Max Planck Institute for the Physics of Complex Systems, Dresden, Germany

Motivated by recent experimental efforts to realize quantum phases of matter with cold atomic Rydberg gases, I will discuss the excitation spectrum of supersolids in a two dimensional bosonic system with soft-core interactions. Previous works showed an exceptional agreement between Monte Carlo simulations and a numerical mean-field approach.

I will present a variational analysis of the Gross-Pitaevskii equation with a non-local interaction term and show that we can quantitatively reproduce the superfluid-supersolid transition at finite interaction strength in agreement with Monte Carlo results. We then test the validity of this mean-field analysis perturbing the ground state wave function and looking at the spectrum of the corresponding Bogoliubov equations. This approach provides an intuitive physical insight to the low energy dynamics of the system and is validated through the comparison of our findings with recent Monte Carlo simulations.

Q 26.6 Tue 12:15 B 302

Eigenvalue structure of Bose-Einstein condensates in $\mathcal{PT}$-symmetric double-well potentials — •Dennis Dast, Daniel Haag, Holger Cartarius, Jörg Main, and Günter Wunner — 1. Institut für Theoretische Physik, Universität Stuttgart

Hamiltonians which obey parity-time ($\mathcal{PT}$) symmetry are a special class of non-Hermitian Hamiltonians that can have entirely real eigenvalue spectra in certain parameter regimes. We investigate a Bose-Einstein condensate in a realistic $\mathcal{PT}$-symmetric double-well potential where particles are removed in one well and coherently injected into the other well. The stationary solutions of the nonlinear Gross-Pitaevskii equation are calculated by variational and numerically exact methods. Special attention is drawn to the influence of the Gross-Pitaevskii nonlinearity. The system shows an unusual structure with two exceptional points which are analyzed by means of an analytic continuation.

Q 27: Ultrashort laser pulses: Generation I

Time: Tuesday 11:00–12:00 Location: F 342

Q 27.1 Tue 11:00 F 342

Plasma-based generation and control of a single few-cycle, high-energy and ultrahigh intensity laser pulse — •Matteo Tamburini[1], Antonino Di Piazza[1], Tatiana V. Liseykina[2], and Christoph H. Keitel[1] — [1]Max-Planck-Institut für Kernphysik, Saupfercheckweg 1, D-69117 Heidelberg, Germany — [2]Institut für Physik, Universität Rostock, D-18051 Rostock, Germany

A method based on the reflection of an ultraintense laser pulse by a counterpropagating laser-boosted relativistic ‘mirror’ is proposed for generating a single sub-three-cycle and multi-petawatt laser pulse [1]. The generated pulse can reach 10-joule-energy and a peak intensity exceeding 10^{23}W/cm^2 [1]. In addition, its carrier-envelope-phase can be tuned provided that the carrier-envelope-phase of initial counter-propagating pulse is controlled. Such laser pulse is suitable for probing and potentially controlling ultrarelativistic and nonlinear quantum electrodynamics processes in the yet unexplored regime of ultrashort duration, where qualitatively different features are expected [2]. Multi-dimensional PIC simulations show that the proposed set-up is feasible employing next-generation 10-PW laser systems [1,3].

[1] M. Tamburini *et al.*, arXiv:1208.0794 (2012).

[2] S. Meuren *et al.*, PRL **107**, 260401 (2011); A. I. Titov *et al.*, PRL **108**, 240406 (2012); F. Mackenroth *et al.*, PRA **83**, 032106 (2011); M.

Boca *et al.*, PRA **86**, 013414 (2012).
[3] A. Di Piazza *et al.*, RMP **84**, 1177 (2012); A. V. Korzhimanov *et al.*, Phys. Usp. **54**, 9 (2011).

Q 27.2 Tue 11:15 F 342

Repetitionsratenstabilisierung eines modengekoppelten Faserlasers durch optisch induzierte Brechungsindexänderung — •Steffen Rieger, Tim Hellwig, Till Walbaum und Carsten Fallnich — Institut für Angewandte Physik, Westfälische Wilhelms-Universität Münster, Deutschland

Wir präsentieren die Stabilisierung der Repetitionsrate eines modengekoppelten Erbiumfaserlasers mit optischen Mitteln. Hierzu wurde in den Laserresonator zusätzlich eine ytterbiumdotierte Glasfaser eingefügt, deren Brechungs- und Gruppenindex durch optisches Pumpen bei einer Wellenlänge von 976 nm kontrolliert werden konnte. Entsprechend ergab sich eine Änderung der optischen Resonatorlänge um bis zu $8\,\mu$m, die für eine rein optische Stabilisierung der Repetitionsrate auf 31,4 MHz über etwa 30 Minuten ausreichte. Eine weitere Erhöhung der optischen Weglängenänderung auf über $80\,\mu$m gelang durch die zusätzliche Variation der Temperatur der ytterbiumdotierten Faser. Dies ermöglichte eine weitgehende Unabhängigkeit von Umgebungstemperaturschwankungen auf größeren Zeitskalen und einen stabilen Betrieb über zwölf Stunden mit einer Allanabweichung von $2,5 \cdot 10^{-12}$ über eine Mittelungszeit von einer Sekunde.

Q 27.3 Tue 11:30 F 342

Einflüsse von räumlichen, zeitlichen, parasitären und kaskadierten nichtlinearen Effekten auf die Pulsformungsdynamik in Optisch-Parametrischen Verstärkern. — •Tino Lang[1,2], Anne Harth[1,2], Marcel Schultze[1] und Uwe Morgner[1,2] — [1]Institut für Quantenoptik, Leibniz Universität Hannover — [2]Centre for Quantum Engineering and Space-Time Research (QUEST)

In den letzten Jahren ist die Entwicklung speziell hochrepetierender ultra-breitbandiger OPAs stark vorangetrieben worden. Leider konnten mit den zur Verfügung stehenden mathematischen Modellen die überraschend großen Verstärkungsbandbreiten, besonders mehrfarbig gepumpter Systeme, und die speziellen spektralen Eigenschaften in verschiedenen nichtlinearen Geometrien nicht zufriedenstellend erklärt werden. Wir präsentieren ein neuartiges (2+1) - dimensionales Model zur systematischen Untersuchung der Pulsformungsdynamik in ultrabreitbandigen OPAs. Durch die Darstellung von Pumpe, Signal und Idler in zwei mathematischen Feldern ordentlicher- und außerordentlicher Polarisation, welche je eine räumliche und eine zeitliche Dimension enthalten, kann die nichtlineare Wechselwirkung mit nur zwei Differentialgleichungen vollständig beschrieben werden. Eine zusätzliche Gleichung berücksichtigt die Propagation der einzelnen spektralen Komponenten. Somit ist es möglich, die raum-zeitliche und spektrale Entwicklung aller wechselwirkenden Felder und deren Mischprodukte genau zu beobachten und die besagten spektralen und räumlichen Effekte anschaulich zu erklären. Wir vergleichen zudem diese Simulationsergebnisse mit aktuellen Messungen aus unseren Laboren.

Q 27.4 Tue 11:45 F 342

Broadly tunable femtosecond near- and mid-IR source by direct pumping of an OPA with a 7.4 W Yb:KGW oscillator — Joachim Krauth[1], •Tobias Steinle[1], Andy Steinmann[1], Robin Hegenbarth[1], Matteo Conforti[2], and Harald Giessen[1] — [1]4th Physics Institute and Research Center SCOPE, University of Stuttgart, Germany — [2]CNISM, Dipartimento di Ingegneria dell'Informazione, Università di Brescia, Italy

Tunable mid-infrared laser sources provide access to a versatile field of spectroscopic applications such as near-field and FTIR spectroscopy. In contrast to quantum cascade lasers, parametric light sources based on difference frequency generation, such as optical parametric amplifiers (OPAs) and optical parametric oscillators (OPOs), are able to provide broadly tunable spectra in the near- and mid-IR. We demonstrate a femtosecond OPA that generates more than half a watt of tunable near-IR (1380-1830 nm) and several hundred milliwatts in the mid-IR (2.4-4.2 μm) as well as milliwatt level mid-IR (4.9-9.3 μm) radiation. The OPA is directly pumped by a simple diode-pumped solid-state 7.4 W Yb:KGW oscillator at 41.7 MHz repetition rate, without the need for any amplifier or cavity dumping. We use 5 mm periodically poled lithium niobate (PPLN) and 2 mm GaSe as downconversion crystals and seed this process by a supercontinuum from a tapered fiber. Due to its simplicity and stability, the system is most suitable to replace more complex OPOs as tunable light sources. Simulations predict that using one nonlinear crystal as pre-amplifier to seed a second OPA process leads to even higher output power, conversion efficiency and stability.

Q 28: Fachverbandssitzung Quantenoptik

Time: Tuesday 13:00–14:00 Location: F 342

Fachverbandssitzung Quantenoptik

Q 29: Photonics III

Time: Tuesday 14:00–15:45 Location: F 342

Q 29.1 Tue 14:00 F 342

A resonator-based time-stretch oscilloscope with variable magnification and time-aperture — •Stefan Weber[1,2], Christoph Reinheimer[1,2], and Georg von Freymann[1,2] — [1]Fraunhofer Institute for Physical Measurement Techniques, Department Terahertz Measurement and Systems, 79110 Freiburg — [2]University of Kaiserslautern, Physics Department and Research Center OPTIMAS, 67663 Kaiserslautern

We present a resonator-based approach to time-stretch electrical signals with variable temporal magnification up to $M = 100$ and time-aperture up to 800 ps.

In contrast to the conventional linear time-stretch setups with fixed magnification [Chou, J. ; Boyraz, O. ; Solli, D. ; Jalali, B.: In: Applied Physics Letters 91 (2007)] an optical pulse of an broadband laser source $\Delta\lambda$ will be prechirped in a first dispersive fiber. This prechirped pulse will be modulated in an electro-optical modulator. The modulated optical pulse couples via a beam-combiner into a fiber-based resonator. In this resonator, a dispersive and Raman-active fiber as well as a Raman-amplifier are placed. The fiber stretches the pulse and amplifies the signal at the same time. This concept comprises a measurement system with short fibers and high possible stretch-factors. After every resonator round-trip, an adequate part of the power is coupled out using a switch and detected by a fast photo-diode. The achievable magnification M depends on the number of round-trips N. Hence, this approach provides different magnification factors with only one configuration: A time-stretch setup with variable temporal magnification.

Q 29.2 Tue 14:15 F 342

Linear and nonlinear characterization of optical liquids in the visible and near-infrared spectral region — •Stefan Kedenburg, Andy Steinmann, Timo Gissibl, Marius Vieweg, and Harald Giessen — 4th Physics Institute and Research Center SCOPE, University of Stuttgart

Liquid-filled fibers and optofluidic devices require infiltration with a variety of liquids whose linear and nonlinear optical properties are still not well known over a broad spectral range, particularly in the near-infrared.

Hence, dispersion and absorption properties have been determined for carbon disulfide, nitrobenzene, toluene, and carbon tetrachloride.

For the refractive index measurement a standard Abbe refractometer in combination with a white light laser and a technique to calculate correction terms to compensate for the dispersion of the glass prism has been used. New refractive index data and derived dispersion formulas between a wavelength of 500 nm and 1600 nm are presented in good agreement with sparsely existing reference data.

The absorption coefficient has been deduced from the difference of the losses of several identically prepared liquid filled glass cells or tubes of different lengths in the wavelength region between 500 nm and 1750 nm.

The nonlinear refractive index has been characterized by self-phase modulation in liquid-filled hollow core fibers.

Q 29.3 Tue 14:30 F 342

Interferometrische Messung von Fluktuationen der Parameter optischer Frequenzkämme — •Erik Benkler, Felix Rohde und Harald R. Telle — Physikalisch-Technische Bundesanstalt, D-38116 Braunschweig

Die Charakterisierung der Rauscheigenschaften modengekoppelter Laser liefert wichtige Informationen für messtechnische Anwendungen sowie für die Optimierung solcher Laser. Hierbei sind insbesondere Fluktuationen der korrelierten Parameter ihres kammförmigen Emissionsspektrums, d. h. der optischen Trägerfrequenz ν_c, der Repetitionsrate f_{rep}, und der carrier-envelope-Frequenz ν_{CEO} von Interesse. Trägerfrequenz-Fluktuationen können mittels eines nicht-balancierten Interferometers als Frequenzdiskriminator gemessen werden. In diesem Beitrag wird dieser Ansatz übertragen auf die Messung der entsprechenden Gruppeneigenschaft, d.h. auf die der f_{rep}-Fluktuationen. Hierzu werden die ν_c-Fluktuationen simultan bei zwei spektral möglichst weit auseinander liegenden Frequenzkamm-Intervallen interferometrisch gemessen. Mit der Kenntnis deren Frequenzabstands sowie der Korrelation zwischen den ν_c-, ν_{CEO}- und f_{rep}-Fluktuationen können dann die f_{rep}- bzw. ν_{CEO}-Fluktuationen berechnet werden. Durch die hier demonstrierte Messmethode, die bei einer hohen effektiven Oberwellenordnung von f_{rep} arbeitet, wird eine große Messempfindlichkeit erreicht, die im Prinzip nur durch das technische Rauschen (z. B. Akustik, inelastische Streuprozesse) der zur Verzögerung im Interferometer verwendeten Glasfaser begrenzt wird. Vorteilhaft ist außerdem, dass keine ultraschnellen Photodetektoren benötigt werden.

Q 29.4 Tue 14:45 F 342

Bandbreitenreduzierung der stimulierten Brillouin Streuung in einem mehrstufigen, faserbasierten System — •Stefan Preussler und Thomas Schneider — Institut für Hochfrequenztechnik, Hochschule für Telekommunikation Leipzig

Die stimulierte Brillouinstreuung (SBS) ist einer der dominierenden nichtlinearen Effekte in optischen Einmodenfaser. Im Laufe der Jahre hat sich die SBS von einem Störeffekt in der optische Telekommunikation zu einer hervorragenden Grundlage für viele potentielle Anwendungen entwickelt. Gerade in den letzten Jahren rückte die SBS in den Fokus einer ganzen Reihe von Forschungsaktivitäten. Die SBS wird zum Beispiel als Sensor für Temperatur und mechanische Belastung in Wellenleitern, für die Verzögerung und Speicherung von Licht, für ultra-hochauflösende Spektralanalyse und als Filter für Millimeter und Terahertz-Wellen verwendet, um nur einige zu nennen. Die meisten dieser Anwendungen nutzen die sehr schmale Bandbreite der SBS von 10 MHz. Die Form und die Bandbreite der SBS beeinflusst direkt die Grenzen der Anwendungen. Eine geringere Bandbreite ermöglicht demnach eine genauere Auflösungen bei der Spektroskopie und höhere Speicherzeiten bei der Lichtspeicherung. Hier präsentieren wir eine neue Methode, um die Bandbreite der SBS durch die Kaskadierung mehrerer Brillouin-Verstärker zu reduzieren. Die Theorie wird mit ersten Experimenten bestätigt und zeigt, mit einem 3-stufigen System, eine Verringerung der Bandbreite auf 5.8 MHz. Das entspricht einer Verringerung auf 56% der natürlichen Bandbreite im verwendeten Medium.

Q 29.5 Tue 15:00 F 342

Numerische Simulation der Konversion transversaler Moden mittels ultrakurzer Laserimpulse — •Till Walbaum, Tim Hellwig und Carsten Fallnich — Institut für Angewandte Physik, Westfälische Wilhelms-Universität Münster, Deutschland

In einer Mehrmodenfaser führen die unterschiedlichen Propagationskonstanten der transversalen Moden durch Interferenz zu einer räumlich strukturierten Intensitätsverteilung entlang der Faser. Der Kerr-Effekt erzeugt daraus bei hohen Intensitäten eine Brechungsindexmodulation, die die Eigenschaften eines langperiodischen Gitters hat [1]. Solch ein Gitter kann genutzt werden, um transversale Moden ineinander zu konvertieren. Wird ein ultrakurzer Puls zur Erzeugung des Gitters eingesetzt, so wird instantan nur ein mit dem Puls wandernder Gitterausschnitt geformt.

Wir präsentieren hier erstmals die numerische Simulation dieser Modenkonversion mit Hilfe ultrakurzer Pulse auf Basis gekoppelter nichtlinearer Schrödingergleichungen. Dabei werden die Einflüsse verschiedener Parameter wie Spitzenleistung, Phasenlage oder des zeitlichen Versatzes zwischen Schreib- und Testpuls auf das zeitliche und räumlichen Pulsprofil untersucht. Ferner wird auf Basis der optisch induzierten Modenkonversion die Realisierung eines optischen Schalters vorgestellt.

[1] N. Andermahr und C. Fallnich, Opt. Expr. **18**, 4411 (2010).

Q 29.6 Tue 15:15 F 342

Konversion transversaler Fasermoden mittels ultrakurzer Lichtimpulse — •Martin Schnack, Till Walbaum und Carsten Fallnich — Institut für Angewandte Physik, Westfälische Wilhelms-Universität Münster, Deutschland

In diesem Beitrag zeigen wir, dass sich die Konversion transversaler Moden einer Stufenindexfaser unter Verwendung ultrakurzer Lichtimpulse (fs-Impulse) experimentell realisieren lässt. Mit quasikontinuierlichem Licht (ns-Impulse) konnte Modenkonversion 2010 demonstriert werden [1]; fs-Impulse bieten nun den Vorteil nichtlineare Effekte gleicher Stärke, bei wesentlich geringeren mittleren Leistungen zu erzielen.

Das Prinzip funktioniert ohne dauerhafte Materialveränderung und basiert darauf, dass mit einem Schreibimpuls durch Mehrmodeninterferenz ein räumliches Intensitätsmuster in der Faser erzeugt wird, welches aufgrund des Kerr-Effektes in ein räumliches Brechungsindexmuster umgesetzt wird und so effektiv ein transientes, langperiodisches Gitter erzeugt. Ein Testimpuls erfährt an diesem Gitter eine Konversion seiner transversalen Moden. Die zeitliche Überlagerung der Impulse haben wir durch einen interferometrischen Aufbau sowie durch Kopropagation in der Faser sichergestellt. Anhand der Polarisation ließen sich Schreib- und Testimpulse am Faserausgang trennen, und wir konnten einen deutlichen Unterschied in der Modenzusammensetzung des Testimpulses bei aus- und eingeschaltetem Schreibimpuls messen.

[1] N. Andermahr und C. Fallnich, Opt. Exp. 18, S. 4411 (2010)

Q 29.7 Tue 15:30 F 342

Seltenerd-dotierte In_2O_3- und $InYO_3$-Schichten auf Sesquioxid-Substraten — •Sven H. Waeselmann[1], Sebastian Heinrich[1], Christian Kränkel[1,2] und Günter Huber[1,2] — [1]Institut für Laser-Physik, Universität Hamburg — [2]The Hamburg Centre for Ultrafast Imaging

Mit dem Pulsed Laser Deposition-Verfahren (PLD) wurden In_2O_3-Schichten auf verschiedenen Sesquioxiden gewachsen. Das PLD-Verfahren eignet sich aufgrund der hohen Energie der Plasmabestandteile zur Herstellung von dünnen, einkristallinen Schichten. In-Situ Untersuchungen mit Elektronenbeugung sowie ex-Situ Untersuchungen mit Röntgenbeugung und Rasterkraftmikroskopie zeigen epitaktisches Wachstum von Seltenerd-dotiertem In_2O_3 auf Lu_2O_3 bzw. Sc_2O_3. Spektroskopische Untersuchungen haben gezeigt, dass die Emissionsspektren von Nd-dotierten In_2O_3-Schichten denen von entsprechend dotierten Sesquioxid-Einkristallen ähneln. Durch die Beimischung von Y_2O_3 gelang es, gitterangepasste $InYO_3$-Schichten auf Lu_2O_3 zu wachsen, wobei sich durch den reduzierten Gitterfehler die Schichtqualität deutlich verbessert. Aufgrund des vergleichweise hohen Brechungsindexes von kristallinem In_2O_3 (ca. 3 bei 400 nm bzw. 2,5 bei 633 nm) sind photonische Anwendungen z.B. als Wellenleiter und als kristalline, dielektrische Spiegel interessant.

Q 30: Quantum effects

Time: Tuesday 14:00–16:00 Location: F 128

Group Report Q 30.1 Tue 14:00 F 128

Coherent delocalisation and transport efficiency in disordered, noisy networks — •Federico Levi, Björn Witt, and Florian Mintert — Freiburg Institute for Advanced Studies (FRIAS), Albert-Ludwigs-Universität Freiburg, Alberstr.19, 79104 Freiburg

We investigate the role of quantum coherence in excitation transport across noisy, disordered networks. Our goal is to understand the impact of constructive multi-path interference on the transport efficiency. Necessary condition for multi-path interference is the coherent delocalisation of the excitation over multiple network sites; to characterise the spatial extent of this delocalisation we introduce a notion of coherence length for discrete systems and present techniques to characterise it for mixed states. More specifically we construct a hierarchy of criteria which provide a sufficient condition for coherent delocalisation of an excitation over a given number of sites. With these tools we consider in particular the case of networks driven incoherently by a thermal light field, for which we quantify the excitation flux in a stationary state. Although those states are strongly mixed we can verify enhanced coherent delocalisation in networks that yield highly efficient transport.

Q 30.2 Tue 14:30 F 128

Enhancing the sensitivity of chemical magnetometers — •Markus Tiersch[1,2], Gian Giacomo Guerreschi[1,2], Ulrich E. Steiner[3], and Hans J. Briegel[1,2] — [1]University of Innsbruck, Austria — [2]Institute for Quantum Optics and Quantum Information, Innsbruck, Austria — [3]Fachbereich Chemie, University of Konstanz, Germany

Magnetic field effects of chemical reactions that are explained by the radical pair mechanism can be used for chemical magnetometry and constitute the basis of a primary hypothesis for animal magnetoreception. We propose a new experimental approach based on molecular photoswitches to achieve additional control of these chemical reactions at the level of the recombination dynamics, and thus to allow for short-time resolution of the spin dynamics. This proposal enables experiments to test some of the standard assumptions of the radical pair model, and it improves the sensitivity of a model system for a chemical magnetometer by two orders of magnitude. For the experimentally well-studied model system, where the radical pair is formed by pyrene (Py) with N,N-dimethylaniline (DMA), we discuss how signatures of entanglement can be used to measure magnetic fields.

Q 30.3 Tue 14:45 F 128

Decoherence-assisted transport in quantum critical systems — •Gian Luca Giorgi[1] and Thomas Busch[2] — [1]AG Theoretische Quantenphysik, Theoretische Physik, Universität des Saarlandes, D-66123 Saarbrücken, Germany and Department of Physics, University College Cork, Cork, Republic of Ireland — [2]Quantum Systems Unit, Okinawa Institute of Science and Technology, Okinawa 904-0411, Japan

A two-level system interacting with an external bath is unavoidably subject to coherence loss. On the other hand, decoherence can be used to enhance the transport properties between the two levels of the systems. The bath is modelled as an XY spin chain in the presence of an external magnetic field, and is subject to a quantum phase transition by changing the intensity of the external field itself.

Driving the bath from the paramagnetic towards the ferromagnetic region, the dynamics of the qubit is studied. The transition probability from the lower level to the upper level is enhanced by the bath, and this noise-assisted phenomenon is sensitive to the change of the quantum phase of the environment.

First, we discuss the case of an isotropic chain. In the zero-temperature case, the bath renormalizes the system Hamiltonian, making it possible to improve the transition probability. Even if the mechanism is more complicated, the same qualitative enhancement can be observed for finite temperatures regime and by releasing the isotropic assumption.

G. L. Giorgi and Th. Busch, Physical Review A 86, 052112 (2012)

Q 30.4 Tue 15:00 F 128

Centro-symmetric Hamiltonians foster quantum transport — •Mattia Walschaers[1,2], Roberto Mulet[1,3], and Andreas Buchleitner[1] — [1]Physikalisches Institut, Albert-Ludwigs-Universitat Freiburg, Freiburg, Germany — [2]Instituut voor theoretische fysica, KU Leuven, Leuven, Belgium — [3]Complex System Group, University of Havana, Havana, Cuba

We propose a model for fast and highly efficient quantum transport of excitations, through finite, disordered systems. The presented mechanism is statistically robust against configurational changes which alter the realization of disorder. We furthermore discuss the potential relevance of our findings for excitation transport in photosynthetic light harvesting complexes.

Q 30.5 Tue 15:15 F 128

Revisiting the spin in relativistic quantum mechanics — •Heiko Bauke[1], Sven Ahrens[1], Christoph H. Keitel[1], and Rainer Grobe[2] — [1]Max-Planck-Institut für Kernphysik, Saupfercheckweg 1, 69117 Heidelberg, Germany — [2]Intense Laser Physics Theory Unit and Department of Physics, Illinois State University, Normal, IL 61790-4560 USA

Recently, renewed interest in the fundamental aspects of the electron spin arose from the growing field of relativistic quantum information [1] and high precision measurements of the electron's magnetic dipole moment [2]. According to the formalism of quantum mechanics, some Hermitian operator corresponds to each measurable quantity, e. g. the spin. Though the spin is regarded as a fundamental property of the electron there is no universally accepted spin operator within the Dirac theory. We investigate the properties of different proposals for such an operator. It is demonstrated that most candidates are lacking some features which one might naturally expect for a spin angular momentum operator. We will argue that some operator suggested by Pryce [3], however, is an ideal candidate for a relativistic spin operator.

[1] A. Peres and D. R. Terno, Rev. Mod. Phys. **76**, 93 (2004); P. L. Saldanha and V. Vedral, N. J. Phys. **14**, 023041 (2012).

[2] D. Hanneke *et al.*, Phys. Rev. Lett. **100**, 120801 (2008); S. Sturm *et al.*, Phys. Rev. Lett. **107**, 023002 (2011).

[3] M. H. L. Pryce, Proceedings of the Royal Society A **150**, 166 (1935).

Q 30.6 Tue 15:30 F 128

Coherent coupling of a single molecule to a plasmonic nanoantenna — •Benjamin A. Gmeiner, Andreas Maser, Tobias Utikal, Stephan Götzinger, and Vahid Sandoghdar — Max Planck Institute for the Science of Light and Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU), D-91058 Erlangen, Germany

We report on a new experiment investigating the coherent coupling of single molecules to plasmonic antennas. So far, all experiments in the field of plasmonics have been limited to the study of the enhancement of the excitation, the modification of the spontaneous emission rate, or changes in the angular radiation pattern accessed via the red-shifted fluorescence detection. Theoretical reports [1] predict that striking effects such as transparency (cloaking) or ultrastrong absorption can take place if a light beam interacts coherently with the coupled system of a quantum emitter and a plasmonic structure. We combine cryogenic high-resolution spectroscopy with localization microscopy to identify and study single molecules coupled to gold nanospheres. We report on our latest findings and their interpretation as Fano resonances, which are expected to result from the interference between the broad particle plasmon resonance of the gold nanoparticle and the narrow resonance of the molecule.

[1] X-W. Chen, V. Sandoghdar, M. Agio, Coherent interaction of a metallic structure with a single quantum emitter: from super absorption to cloaking, submitted (arXiv:1211.2152v2)

Q 30.7 Tue 15:45 F 128

Observing the quantum Zeno effect of a single state spin — •Max Strauss, Janik Wolters, Niko Nikolay, Simon Schönfeld, and Oliver Benson — Nanooptik, Institut für Physik, Humboldt Universität zu Berlin, Newtonstraße 15,D-12489 Berlin, Germany

Nitrogen vacancy (NV) centres in diamond exhibit remarkable features, comparable to those of a trapped atom albeit being a genuine solid-state system. Intense research in recent years has sought to exploit these exceptional attributes for various applications ranging from quantum information to neurosciences. We report the experimental observation of the quantum Zeno effect in the radio frequency transition between two NV^- ground state spin levels (a spin 1 system) in nanodiamond using optical read-out techniques.

Q 31: Quantum gases: Optical lattices I

Time: Tuesday 14:00–16:15 Location: E 001

Group Report Q 31.1 Tue 14:00 E 001

Observation of critical behavior at the non-equilibrium Dicke phase transition — •Ferdinand Brennecke[1], Rafael Mottl[1], Renate Landig[1], Kristian Baumann[2], Tobias Donner[1], and Tilman Esslinger[1] — [1]Quantum Optics Group, ETH Zurich, Switzerland — [2]Department of Applied Physics, Stanford University

We experimentally study critical behavior of the Dicke phase transition, realized by Raman coupling motional degrees of freedom of a Bose-Einstein condensate to the field in a high-finesse optical cavity. We use the natural dissipation channel of the cavity to observe the incoherent fluctuation spectrum of the coupled system in real time. The corresponding measurement backaction introduces additional density fluctuations in the atomic gas and changes the critical behavior of the system. A correlation analysis of the light exiting the cavity reveals the diverging time scale of the fluctuation dynamics, in agreement with the experimentally observed mode softening in the excitation spectrum. We quantitatively compare our measurements with a theoretical model taking into account both cavity and atomic dissipation channels. Future directions of the experiment include Bose-Hubbard physics with cavity-mediated long-range interactions and self-organization in lower dimensions.

Q 31.2 Tue 14:30 E 001

Semiclassical Study of Intrinsic Photoconductivity of Ultracold Fermions in Optical Lattices — •Alexander Itin[1,2,3], Jannes Heinze[1], Jasper Simon Krauser[1], Nick Fläschner[1], Bastian Hundt[1], Sören Götze[1], Klaus Sengstock[1,2], Christoph Becker[1,2], and Ludwig Mathey[1,2] — [1]Institut für Laser-Physik, Universität Hamburg, Germany — [2]Zentrum für Optische Quantentechnologien, Universität Hamburg, Germany — [3]Space Research Institute, Moscow, Russia

We present theoretical analysis of recent experiments reported in [J. Heinze et al., arxiv::1208.4020v2]. Ultracold fermionic atoms in optical lattices were used to simulate the phenomenon of photoconductivity. Using amplitude modulations of the optical lattice, the analog of a persistent alternating photocurrent was induced in the atomic gas. A small fraction of the atoms was excited to the third band as a wavepacket with a well-defined quasimomentum, leaving a hole in the momentum distribution of atoms in the lowest band. The subsequent dynamics is due to an external harmonic trap. It was observed that the particle excitations in the third band exhibit long-lived oscillations with a frequency determined by the initial quasimomentum, while holes in the lowest band behave strikingly differently: an initial fast collapse was followed by periodic partial revivals. We explain both observations by a semiclassical approach to lattice dynamics. By using the Truncated Wigner Approximation and mapping the system onto a classical Hamiltonian resembling a nonlinear pendulum, both the long-lived particle oscillations and decaying hole revivals are understood quantitatively.

Q 31.3 Tue 14:45 E 001

Motional coherence of fermions immersed in a bosonic bath — •Raphael Scelle, Arno Trautmann, Tobias Rentrop, and Markus K. Oberthaler — Kirchhoff-Institut für Physik, Universität Heidelberg, Im Neuenheimer Feld 227, 69120 Heidelberg

We study the impact of a Bose Einstein condensate of sodium atoms on the motional coherence of lithium atoms. For this purpose the lithium atoms are exposed to a species-selective lattice potential which allows to prepare the lithium atoms in a motionally coherent state by control of the lattice position. We developed a spin echo technique in order to investigate the bath impact on the coherent evolution of the lithium atoms. The interaction between the two components induces a decay of the motional coherence and we extract the corresponding time scale by comparing the spin echo signal for freely evolving lithium atoms to the signal for atoms evolving within the bosonic bath. The observed coherence decay time is consistent with the time scale expected from relaxation measurements of motionally excited states.

Q 31.4 Tue 15:00 E 001

Collective modes of interacting bosons in artificial gauge fields — •Ivana Vidanovic, Ulf Bissbort, and Walter Hofstetter — Institut für Theoretische Physik, Johann Wolfgang Goethe-Universität, 60438 Frankfurt/Main, Germany

Rapid experimental progress in the realization of artificial magnetic fields for cold neutral atoms heads toward the creation and direct observation of exotic quantum states under highly controllable experimental conditions. By combining mean-field and beyond mean-field approaches, we explore the phase diagram of strongly interacting lattice bosons in an artificial magnetic field. We calculate the ground state properties and excitation spectra of various phases. To demonstrate how the physical quantities of our system can be detected in experiments, we perform numerical calculations of the systems non-equilibrium behaviour under realistic perturbations.

Q 31.5 Tue 15:15 E 001

Gapped chiral phases and spontaneous symmetry breaking for ultracold bosons in zig-zag optical lattices — •Sebastian Greschner, Luis Santos, and Temo Vekua — Institut für theoretische Physik, Leibniz Universität Hannover, Appelstr. 2, 30167 Hannover, Germany

Ultracold bosons in (quasi-)one-dimensional zig-zag optical lattices - apart from being a theoretically well controllable test-bed to study the properties of possible quantum simulators of quantum antiferromagnetism - exhibit a wealth of interesting physical phenomena some of which are particular for one-dimensional systems [1]. In this talk we present the full phase diagram of ultracold bosons in zig-zag optical lattices for non-integer fillings. We comment on how interactions lead to a competition between spontaneous symmetry breaking chiral SF and two-component SF phases and analyse the emergence of insulating phases as well as gapped chiral phases exhibiting both local currents as well as a finite excitation gap. Some issues of phase preparation and detection are discussed.

[1] S. Greschner et al., arXiv:1202.5386 (2012)

Q 31.6 Tue 15:30 E 001

Quantum simulation of curved spaces in optical lattices containing topological defects — •Nikodem Szpak — Fakultät für Physik, Universität Duisburg-Essen

We discuss the possibility of quantum simulation of relativistic fields living in curved spaces realized in optical lattices loaded with ultra-cold atoms. In the low energy regime their dynamics can be described by the Hubbard model which, under some circumstances, can be mapped onto a discrete version of a relativistic quantum field theory. Manipulation of the hopping constants and the lattice topology can lead to the coupling to an artificial Riemann-Cartan geometry containing curvature and torsion. We give examples of several lattice geometries and discuss the properties of the emergent curved spaces with the field theoretic effects, like scattering on curvature centers or vortices and birefringence on torsion lines.

Q 31.7 Tue 15:45 E 001

Impact of inhomogeneities on antiferromagnetism in cold atom systems — •Elena Gorelik and Nils Blümer — Institute of Physics, Johannes Gutenberg University, Mainz, Germany

The study of inhomogeneities in antiferromagnets (AF) is of considerable interest both in condensed matter physics and in the cold-atom context. In atomic clouds, the intrinsic inhomogeneity is due to the presence of a confinement potential, whereas in material context interfaces provide an example of the large-scale inhomogeneities. Localized inhomogeneities, in particular impurities, in both homogeneous and spacially variable background, play important role in the interplay of competing phases.

We employ the real-space extension of dynamical mean-field theory (RDMFT) combined with Hirsch-Fye quantum Monte Carlo (QMC) impurity solver [1,2] to explore the effect of single/multiple impurities on the formation of AF correlations. Both the dimensional aspects and the proximity effects are analyzed. In $d = 2$, RDMFT results are compared with those of direct calculations using the determinantal quantum Monte Carlo method.

[1] E. V. Gorelik, I. Titvinidze, W. Hofstetter, M. Snoek, and N. Blümer, Phys. Rev. Lett. **105**, 065301 (2010).

[2] N. Blümer and E. V. Gorelik, Comp. Phys. Comm. **182**, 115 (2011).

Q 31.8 Tue 16:00 E 001

Direct Measurement of the Zak phase in Topological Bloch Bands — •Marcos Atala[1,2], Monika Aidelsburger[1,2], Julio T. Barreiro[1,2], Dmitry Abanin[3], Takuya Kitagawa[3], Eugene Demler[3], and Immanuel Bloch[1,2] — [1]Fakultät für Physik, Ludwig-Maximilians-Universität, Schellingstr. 4, 80799 Munich, Germany — [2]Max Planck Institute of Quantum Optics, Hans-Kopfermann Str. 1, 85748 Garching, Germany — [3]Department of Physics, Harvard University, 17 Oxford Str., Cambridge, MA 02138, USA

In this talk I will present our latest results on the direct measurement of the Zak phase for a dimerized optical lattice, which models polyacetylene. The experimental protocol consists of a combination of Bloch oscillations and Ramsey interferometry from where we extract the Zak phase - the Berry phase acquired during an adiabatic motion of a particle across the Brillouin zone - which can be viewed as an invariant characterizing the topological properties of the band. This work establishes a new general approach for probing the topological structure of Bloch bands in optical lattices.

Q 32: Quantum information: Atoms and ions III

Time: Tuesday 14:00–16:00 Location: A 310

Group Report Q 32.1 Tue 14:00 A 310

Strong coupling between single atoms and non-transversal photons — •Jürgen Volz, Christian Junge, Danny O'Shea, and Arno Rauschenbeutel — Vienna Center for Quantum Science and Technology, TU Wien, Atominstitut, Stadionallee 2, A-1020 Wien, Austria

The interaction between single atoms and single photons lies at the heart of quantum optics and has been investigated in a number of groundbreaking experiments with high-finesse cavities confining the photons. In this context, whispering-gallery-mode (WGM) microresonators have recently demonstrated their high potential as quantum technological devices because they achieve ultra high quality factors and, at the same time, enable in- and out-coupling of light with near-unit efficiency using tapered fiber couplers.

Remarkably, photons in such resonators are in general not transversally polarized and the electric field amplitude can have a strong component in the direction of propagation. Here, we experimentally demonstrate that the presence of this longitudinal field component significantly alters the physics of light–matter interaction. As a model system, we strongly couple single ^{85}Rb atoms to an ultra high-Q bottle-microresonator — a novel type of WGM microresonator. Our spectroscopic data agrees well with the predictions of a generalized theoretical model which includes a full vectorial description of the resonator modes. As an application, we describe our progress towards the realization of a four-port device capable of coherently routing photons between two optical fibers coupled to the resonator mode.

Q 32.2 Tue 14:30 A 310

High fidelity state-selective detection by scattering laser light — •Sabine Wölk and Christof Wunderlich — Experimentelle Quantenoptik, Universität Siegen, Siegen, Germany

An important ingredient for experiments in quantum information science is efficient quantum state-selective detection. With trapped ions high fidelity, single-shot detection of qubit states by scattering and detecting near-resonant laser light is state-of-the-art. The fidelity of detection could be limited, because during the measurement process it is possible that the ion changes its state. This could happen, for example, through spontaneous emission or off-resonant excitations.

For ions, where only one of the qubit states can decay to the other state and then stays there, detection schemes exist that take this effect into account [1, 2]. However, for ions like $^{171}Yb^+$ both qubit states can be populated during detection. Therefore, we have to take into account that not only one but several state-changes are possible during one measurement. In this talk we present generalizations of existing measurement schemes to this type of ions, discuss new approaches, and present detailed simulations.

[1] A. H. Myerson et. al., Phys. Rev. Lett. **100**, 200502 (2008)
[2] B. Hemmerling et. al., New J. of Phys. **14**, 023043 (2012)

Q 32.3 Tue 14:45 A 310

Laser Quantum Control of ^{9}Be$^+$ Using an Optical Frequency Comb — •Anna-Greta Paschke[1], Malte Niemann[1], Timko Dubielzig[1], Martina Carsjens[1,2], Matthias Kohnen[2,1], and Christian Ospelkaus[1,2] — [1]Institut für Quantenoptik, Leibniz Universität Hannover — [2]PTB Braunschweig

A CPT symmetry test experiment based on a g-factor comparison between single trapped (anti-)protons is currently being designed in our group. We aim to overcome the main experimental challenge, single-shot state readout for single (anti-)protons, by transferring their spin states to a co-trapped "logic" ^{9}Be$^+$ ion for readout using quantum logic operations [Heinzen and Wineland, PRA **42**, 2977 (1990)].

At low magnetic fields, the required quantum logic operations on ^{9}Be$^+$ are typically carried out using stimulated Raman two-photon transitions driven by pairs of phase-coherent CW laser fields. Their detuning is near-resonant with the qubit splitting of typically only a few GHz. Our experiment requires a rather high magnetic field (>1 T). The resulting qubit splitting easily exceeds 28 GHz and renders the CW approach unattractive. We explore optical frequency combs [Hayes *et al.*, PRL **104**, 140501 (2010)] for driving stimulated Raman transitions in ^{9}Be$^+$. Here, a considerable experimental challenge arises from the small excited state fine structure splitting of ≈ 200 GHz, which requires a careful design of the comb's spectral properties. We discuss stimulated Rabi rates, spontaneous scattering rates, spectral compression and spectral pulse shaping in order to obtain an optimized spectrum.

Q 32.4 Tue 15:00 A 310

Controlled emission and absorption of single photons by two distant single ions — •Michael Schug[1], Jan Huwer[1,2], Christoph Kurz[1], Philipp Müller[1], and Jürgen Eschner[1] — [1]Universität des Saarlandes, Experimentalphysik, Campus E2 6, 66123 Saarbrücken, Germany — [2]ICFO - Institut de Ciences Fotoniques, Mediterranean Technology Park, 08860 Castelldefels (Barcelona), Spain

A prerequisite for the realization of a quantum network is controlled emission and absorption of single photons by a single atom. Here we present controlled quantum interaction between two remotely trapped calcium ions by single photons. We release a single photon with controlled temporal shape from the sender ion and transmit it over one meter distance to the receiver ion. There we detect photon absorption with a quantum jump scheme. In continuous photon generation mode, the absorption reduces significantly the lifetime of the long lived $D_{5/2}$ state at the receiver ion. For triggered photon generation, we observe coincidences between the quantum jump event and the emission trigger of a photon.

Q 32.5 Tue 15:15 A 310

Photon blockade meets electromagnetically induced transparency — •Haytham Chibani[1], Eden Figueroa[1], James Alves De Souza[2], Celso Jorge Villas Boas[2], and Gerhard Rempe[1] — [1]Max-Planck-Institute of Quantum Optics, Hans-Kopfermann-Str. 1, 85748 Garching, Germany — [2]Universidade Federal de São Carlos, Departamento de Física, 13565-905 - Sao Carlos, SP - Brasil

One of the outstanding goals of quantum optics is the realization of controllable nonlinearities at the level of single quanta of matter and light. Here, we theoretically study the optical control of the quantum dynamics of a system which merges single-atom, cavity quantum electrodynamics with electromagnetically induced transparency, namely a three-level atom strongly coupled to a high-finesse cavity. We explore the photon statistics of the light emitted from the cavity by calculating the equal-time second-order intensity correlation function $g^{(2)}(0)$. We find a rich structure in the behavior of $g^2(0)$ which ranges from strong anti-bunching ($g^{(2)}(0) \approx 0$) to strong bunching ($g^{(2)}(0) \approx 100$), and which can be optically tuned via the control field intensity. We also show that when the system is strongly driven, $g^2(0)$ shows two anti-bunching dips at different control field intensities resulting from a single photon and a two-photon blockade respectively. The observed quantum control paves the way towards the implementation of a novel quantum device which allows the switching and/or the attenuation of the amplitude noise of a laser beam.

Q 32.6 Tue 15:30 A 310

An optical resonator as a model for single-photon-single-atom absorption experiments — •Marianne Bader[1,2], Simon Heugel[1,2], Alexander Chekhov[1,3], Markus Sondermann[1,2], and Gerd Leuchs[1,2] — [1]Max Planck Institute for the Science of Light, Erlangen, Germany — [2]Institute of Optics, Information and Photonics, University of Erlangen-Nuremberg, Erlangen, Germany — [3]Department of Physics, M.V. Lomonosov Moscow State University, Russia

An optical resonator can be used as a model system for the dynamics of the interaction of a single photon and a two-level system. Following this comparison, the energy stored inside the resonator is an analogue to the probability for absorption of the photon by the two-level system. Both systems respond in a similar way to the temporal profile of the incident light field [1]. For both, resonators and two-level systems, an optimized process is achieved by using an exponential rising pulse with a time constant matching the lifetime of the system. Using such an optimal pulse shape, the above mentioned processes reach an unit efficiency under idealized conditions.

In this contribution, we present experiments on coupling to a resonator and discuss the influence of various pulse shapes to the energy storage efficiency.

[1] Heugel et al., Laser Physics 19 (2009)

Q 32.7 Tue 15:45 A 310

A reversible optical memory for twisted photons — •Dominik Maxein[1], Lucile Veissier[1], Adrien Nicolas[1], Lambert Giner[1], Alexandra S. Sheremet[2], Elisabeth Giacobino[1], and Julien Laurat[1] — [1]Laboratoire Kastler Brossel: Université Pierre et Marie Curie, École Normale Supérieure, and CNRS, 4 place Jussieu, 75252 Paris Cedex 05, France — [2]Department of Theoretical Physics, State Polytechnic University, 195251, St.-Petersburg, Russia

"Twisted" single-photons carrying an orbital angular momentum (OAM) are promising information carriers in various quantum information protocols. They indeed offer the possibility of encoding and processing of information in high-dimensional Hilbert spaces, thus potentially allowing for higher efficiencies and enhanced information capacity. To use these states in quantum networks, light-matter interfaces play a crucial role, e.g. the reversible mapping of OAM into and out of atomic memories. Seminal experiments in this direction with "bright" OAM-carrying beams have already been performed [Pugatch et al, PRL **98**, 203601 ('07) and Moretti et al, PRA **79**, 023825 ('09)]

Here, we report on a multimode optical memory for the storage and retreival of the OAM of light, for the first time at the single-photon level. The light is mapped into and out of a cold atomic ensemble, using the dynamic electromagnetically-induced transparency protocol. We use very faint light pulses in Laguerre-Gaussian modes as signal and show that the handedness of their helical phase structure is preserved. This opens the possibility to the storage of qubits encoded as superpositions of orbital angular momentum states.

Q 33: Quantum information: Concepts and methods II

Time: Tuesday 14:00–16:00 Location: E 214

Q 33.1 Tue 14:00 E 214

Stabilizer states are spherical 3-designs – with applications to quantum state discrimination — •Richard Kueng and David Gross — Universität Freiburg

A *complex spherical k-design* is a configuration of vectors which is "evenly distributed" on a sphere in the sense that it reproduces Haar measure up to kth moments. Here, we show that the set of all n-qubit stabilizer states forms a complex spherical 3-design in dimension 2^n. Stabilizer states had previously only been known to constitute 2-designs. The problem is reduced to the task of counting the number of stabilizer states with pre-described overlap with respect to a reference state. This, in turn, reduces to a counting problem in discrete symplectic vector spaces for which we find a simple formula.

We use the finding to answer an open problem posed by in [Matthews, Wehner, Winter, CMP 291 (2008)]: There, the loss of distinguishability suffered by quantum states as a result of a POVM measurement was analyzed. It had been shown that 4-designs (seen as POVMs) perform almost optimally, while 2-designs fall significantly short of this. The performance of 3-designs was left open. Using our explicit example, we find that, unfortunately, 3-designs do not outperform 2-designs.

Q 33.2 Tue 14:15 E 214

The Power of Combining Coherent Control with Switchable Noise — •Thomas Schulte-Herbrüggen[1] and Ville Bergholm[1,2] — [1]Dept. Chem., TU-München (TUM) — [2]Institute for Scientific Interchange Foundation (ISI), Torino

Adding bang-bang switchable noise on a single qubit (out of a total of n) on top of unitary control seems magic: this simple add-on suffices for transforming *any* initial quantum state into *any desired target state*.

We have extended our open-loop optimal control algorithm (dynamo) by such degrees of incoherent control so that these unprecedented reachable sets can systematically be exploited in experiments [1]. As illustrated for an ion trap experimental setting, open-loop control with noise switching can accomplish all state transfers one can get by the more complicated measurement-based closed-loop feedback schemes [2,3] requiring a resettable ancilla qubit.

[1] V. Bergholm and T. Schulte-Herbrüggen, arXiv/1206.4945 (2012)
[2] S. Lloyd and L. Viola, Phys. Rev. A **65**, 010101 (2001)
[3] J. Barreiro et al., Nature **470**, 486 (2011)

Q 33.3 Tue 14:30 E 214

Approximate Quantum Error Correction: optimal codes for independent and correlated errors — •Sol H. Jacobsen and Florian Mintert — Freiburg Institute for Advanced Studies, Albert-Ludwigs-University of Freiburg, Albertstr. 19, 79104 Freiburg, Germany

The reversibility of open system dynamics in practice depends on a separation of probability regimes in which high-probability errors are corrected at the expense of leaving lower-probability errors uncorrected whenever these occur, i.e. correcting only errors on single qubits in a quantum code. However, several important quantum information processing scenarios are not describable by a neat separation of probability regimes, and we investigate codes for optimal information protection when this is the case. We use entanglement dynamics to compare and evaluate the performance of different codes and present optimal codes for full noisy quantum channels in terms of minimum deviation from perfect correctability. We present N-qubit inequalities governing optimal codes for different probability regimes of errors and give explicit examples of significant improvement for some standard cases.

Q 33.4 Tue 14:45 E 214

Scalable Reconstruction Schemes for Quantum State Tomography — •Tillmann Baumgratz[1], Marcus Cramer[1], David Gross[2], and Martin B. Plenio[1] — [1]Institut für Theoretische Physik, Albert-Einstein-Allee 11, Universität Ulm, D-89069 Ulm, Germany — [2]Physikalisches Institut, Hermann-Herder-Straße 3, Albert-Ludwigs Universität Freiburg, 79104 Freiburg i.Br., Germany

The ability to store and manipulate interacting quantum many-body systems, such as linearly arranged ions in ion traps, photonic implementations, and cold atoms in optical lattices, enhanced rapidly during the last years. By now, the number of controllable particles in such systems has reached sizes for which conventional methods of quantum tomography fail due to both, experiment time and post-processing resources. We discuss applications of recently developed strategies [1,2] to reconstruct state representations which are fully determined by a small fraction of the informationally complete measurements. Experimentally relevant examples for ion-trap, photonic, and cold-gases setups will be presented.

[1] M. Cramer, M.B. Plenio, S.T. Flammia, R. Somma, D. Gross, S.D. Bartlett, O. Landon-Cardinal, D. Poulin and Y.-K. Liu, Nat. Commun. 1, 149 (2010).
[2] T. Baumgratz, D. Gross, M. Cramer and M.B. Plenio, arXiv:1207.0358.

Q 33.5 Tue 15:00 E 214

Quantum optical state reconstruction using weak values — •Joachim Fischbach and Matthias Freyberger — Institut für

Quantenphysik, Universität Ulm, D-89069 Ulm, Germany

Reconstructing the state of a given system is a fundamental problem in quantum mechanics. We show that the special form of weak values, first introduced by Aharonov, Albert, and Vaidman, can be elegantly used to reconstruct the quantum state of a mode of light. Particularly simple reconstruction relations are found for modulus and phase of the wave function. Finally, we present a numerical simulation of a possible experimental setup, that basically consists of a modified eight-port interferometer, and discuss the limitations of the scheme [1].

[1] J. Fischbach and M. Freyberger, Phys. Rev. A **86**, 052110 (2012)

Q 33.6 Tue 15:15 E 214

Progress on compressed sensing tomography — •Carlos Riofrio[1], Steven T. Flammia[2], David Gross[3], Yi-Kai Liu[4], and Jens Eisert[1] — [1]Dahlem Center for Complex Quantum Systems, Freie Universität Berlin, Germany — [2]School of Physics, University of Sydney — [3]Institute of Physics, University of Freiburg, Germany — [4]National Institute of Standards and Technology, Gaithersburg, MD, USA

Quantum tomography allows us to estimate the state of a quantum system by measuring different observables on identically prepared realizations. This is a time-consuming task that requires a large number of measurements. In practice, however, one is usually concerned with estimating the state of systems that are well described by pure or almost pure states, which are represented by fewer parameters than arbitrary states. In this context, special interest has been growing to develop more efficient methods to address system identification when the states are generically described by low rank density matrices. Such techniques, commonly known as compressed sensing, provably accomplish this task under the low rank assumption. In this talk, I will report on recent progress of the novel tomographic technique of compressed sensing and give examples of its application.

Q 33.7 Tue 15:30 E 214

Continuous time limit of repeated quantum observations — •Bernhard Neukirchen — Leibniz Universität Hannover, Institute of Theoretical Physics, Germany

We look at the continuous time evolution of open quantum systems in the Markovian approximation. The goal is to describe all the information we can obtain about the System by measurements of the environment.

Since this problem is very well understood for discrete time, we set up the continuous time description as a refinement limit of the discrete approach in the step length. This construction can be used to obtain a full quantum description of the field emitted by a driven isolated system, e.g. a cavity or quantum dot.

Q 33.8 Tue 15:45 E 214

Directly probing correlatedness in optical lattices — •Janina Gertis, Matthias Ohliger, and Jens Eisert — Freie Universität Berlin, Germany

Full tomography of a quantum state usually requires a large number of measurements. However, often times, one is mostly interested in some characteristics of the quantum state. In this context, we present a method to directly estimate a lower bound on the degree of correlatedness in a system of cold atoms in an optical lattice. We achieve this goal resorting only to minimal a-priori assumptions on the quantum state of the system. By using density distribution data from time of flight measurements, which is available with current technology in this type of systems, we calculate the second and fourth moments of the quantum state. We minimize the relative entropy between an arbitrary quantum state, with the same estimated moments, and an uncorrelated Gaussian reference state. As a result of the minimization, we obtain a lower bound for the actual relative entropy between the state of the system and the closest Gaussian reference state. We can thus detect strong correlations without having to do a full tomographic reconstruction on the quantum state of the system.

Q 34: Ultrashort laser pulses: Applications

Time: Tuesday 14:00–15:45 Location: F 142

Q 34.1 Tue 14:00 F 142

Strong-field photoemission from metal nanotips in experiment and theory — •Michael Krüger[1], Georg Wachter[2], Michael Förster[1], Christoph Lemell[2], Joachim Burgdörfer[2], and Peter Hommelhoff[1,3] — [1]Max-Planck-Institut für Quantenoptik, 85748 Garching bei München — [2]Institut für Theoretische Physik, Technische Universität Wien, A-1080 Wien, Austria — [3]Universität Erlangen-Nürnberg, 91058 Erlangen

Few-cycle laser-induced strong-field photoemission from metal nanotips has recently attracted a lot of interest because of new findings, for example the strong sensitivity of the photoemission on the carrier-envelope phase [1]. Here we show spectrally resolved measurements of strong-field photoemission from tungsten tips for different experimental parameters such as laser intensity and applied static field strength [1–3]. We present theory models, among them the semiclassical three-step model and a more sophisticated time-dependent density functional theory (TDDFT) simulation. Despite the complexity of the system due to its solid-state nature, the interpretation of the involved physics is conceptionally even simpler than in the atomic analogue. Unlike in the atomic case, the tip breaks the symmetry, hence the number of electron trajectories is reduced and whole trajectory classes are forbidden.

[1] M. Krüger, M. Schenk, P. Hommelhoff, *Nature* **475**, 78 (2011).
[2] G. Wachter et al., *Phys. Rev. B* **86**, 035402 (2012).
[3] M. Krüger et al., *New J. Phys.* **14**, 085019 (2012).

Q 34.2 Tue 14:15 F 142

Sub-diffraction-limited spatial resolution in CARS microscopy — Carsten Cleff[1], Petra Gross[1], Chris Lee[2], Kai Kruse[2], Willem Beeker[2], Herman Offerhaus[2], Jennifer Herek[2], Klaus Boller[2], and •Carsten Fallnich[1] — [1]WWU Münster, Münster, Germany — [2]University of Twente, Enschede, The Netherlands

Based on the density matrix formalism we investigate CARS signal suppression enabling spatial resolution below the diffraction limit. Pulsed control light fields are used to manipulate the population distribution of the CARS sample in order to achieve a saturable suppression of the CARS process. If the control light fields are applied with a donut-shaped beam profile the saturable suppression of CARS signal generation can be used to enhance the spatial resolution beyond the diffraction limit similar to STED microscopy. Using computer-generated test images we numerically demonstrate sub-diffraction-limited spatial resolution in CARS microscopy down to 18 nm.

[1] Cleff et al., PRA 86, 023825 (2012)

Q 34.3 Tue 14:30 F 142

Small-polaron based hologram recording with sub-ps laser pulses in thermally reduced $LiNbO_3$ — •Holger Badorreck, Stefan Nolte, Pia Baeune, Hauke Bruening, Andreas Buescher, Volker Dieckmann, and Mirco Imlau — School of Physics, Osnabrueck University, Germany

The recording of mixed amplitude and index gratings with fs-laser pulses is studied by means of spatially modulated small polaron densities in single crystals of lithium niobate. Small bound polarons, that appear in the majority of polar oxides, exhibit a tremendous potential for the research field of ultrafast photonics due to their unique optical features. Only recently, the possibility to apply small polarons for highly efficient recording of holograms was successfully demonstrated with single ns-laser pulses in thermally reduced $LiNbO_3$ (M. Imlau et al., Opt. Express 19, 15322 (2011)). However, the turnover of the widely established results on polaron formation, transport and recombination obtained with cw-light and ns-pulses to dynamic fs-holography has only rarely been addressed in literature. We present our first systematic studies on the recording of mixed holograms with single 100 fs laser pulses in samples with thermal pre-treatment. The results have been corrected for nonlinearities, such as the two photon absorption coefficient and the nonlinear refractive index, that superimpose the diffraction signal. An experimental approach to determine the dispersive features of the recorded holograms in a single measurement, called *ultrafast holographic spectroscopy* is deduced. Financial support by the DFG (IM 37/5, INST 190/137-1) is gratefully acknowledged.

Q 34.4 Tue 14:45 F 142

Controlling electron localization in H_2^+ with optical cycles —
•T. Rathje[1], A.M. Sayler[1], S. Zeng[2], P. Wustelt[1], B. Esry[2], and G.G. Paulus[1] — [1]Institute of Optics and Quantum Electronics and Helmholtz-Institute Jena, Max-Wien-Platz 1, 07743 Jena, Germany — [2]J.R. Macdonald Laboratory, Kansas State University, Manhattan Kansas, 66506 US

We report on measurements and calculations of the absolute phase effects in the photodissociation of the simplest molecule, H_2^+, with a 5-fs few-cycle laser pulse. Control of the localization of the electron between the two nuclei during the dissociation process is facilitated by ultra-short laser pulses. The H_2^+ molecule is generated with a duoplasmatron ion source. Compared to previous experiments using neutral molecules, our dissociation process is not preceded by an photoionization process through a laser pulse. This well collimated ion beam is perpendicular to and overlapped with the laser beam, focused to peak intensities up to $4x10^{14}$ W/cm^2. At the same time an accurate measurement of the absolute phase for every single laser shot is obtained with a phase-meter. The two dissociation fragments are recorded in coincidence with a position- and time-sensitive detector. In this way, a phase-resolved and kinematically complete measurement is realized from which the phase-dependence of the KER-spectra and electron localization can be determined. The experimental results agree well with 3D-TDSE calculations, that take nuclear vibration and rotation into account.

Q 34.5 Tue 15:00 F 142

Coherent Phonons in Graphite studied by Femtosecond Transmission Electron Diffraction —
•Christian Gerbig, Silvio Morgenstern, Vanessa Sporleder, Cristian Sarpe, Matthias Wollenhaupt, and Thomas Baumert — Universität Kassel, Institut für Physik and Center for Interdisciplinary Nanostructure Science and Technology (CINSaT), D-34132 Kassel, Germany

In carbon layered materials (graphite, graphene, carbon nanotubes) the electron subsystem, stimulated by high currents or optical excitations, is strongly coupled to a small set of optical phonons which limits the ballistic conductance. A detailed understanding of phonon decay mechanism is thus essential in improving the performance of carbon-based future electronic devices [1,2]. Time-resolved diffraction, using x-ray or electron probes, has become a promising technique to directly provide insights into dynamics at the molecular level with ultrafast precision [3,4]. We use a femtosecond transmission electron diffractometer to study the evolution of phonon decays in single crystalline graphite after ultrashort laser excitation. Our highly compact setup is well characterized [4] with excellent spatial-temporal resolution (coherence length > 8 nm, electron pulse duration < 200 fs). In this contribution the generation and decay of coherent acoustic phonons are discussed in dependence of film thickness down to few-layer graphene.

[1] T. Kampfrath et al., Phys. Rev. Lett. **95**, 187403 (2005)
[2] S. Schäfer *et al.*, New J. Phys. **13**, 063030 (2011)
[3] M. Chergui & A. H. Zewail, Chem. Phys. Chem. **10**, 28 (2009)
[4] G. Sciaini & R. J. D. Miller, Rep. Prog. Phys **74**, 096101 (2011)

Q 34.6 Tue 15:15 F 142

Nanoscale probing of optical field enhancement by electron rescattering —
•Sebastian Thomas[1], Michael Krüger[1], Michael Förster[1], Markus Schenk[1], and Peter Hommelhoff[1,2] — [1]Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Str. 1, 85748 Garching, Gemany — [2]Universität Erlangen-Nürnberg, Erwin-Rommel-Str. 1, 91058 Erlangen, Germany

The enhancement of optical electric fields in the vicinity of nanostructures enables the localization of electromagnetic energy on the nanoscale. We present a new method of measuring the local field with a resolution of 1 nm. Experimentally, we study the photoemission of electrons from a metal nanotip under laser illumination. In this setup, some of the emitted electrons return to and scatter from the tip surface within one optical cycle of the driving field [1]. By measuring the kinetic energy of these electrons, we obtain the enhanced field strength within 1 nm from the tip surface [2]. A comparison with the field strength we calculate from focal and laser parameters yields the field enhancement factor. Our results are in good agreement with Maxwell simulations.

The resolution of 1 nm is about an order of magnitude better than previous work [3] and close to the length scale of quantum plasmonics, where quantum mechanical effects near the tip surface are expected to reduce the local field strength [4]. We discuss the implications.

[1] M. Krüger, M. Schenk, P. Hommelhoff, Nature 475, 78 (2011)
[2] S. Thomas et al., arxiv:1209.5195 (2012)
[3] M. Raschke et al., ChemPhysChem 6, 2197 (2005)
[4] J. Zuloaga, E. Prodan, P. Nordlander, ACS Nano 4, 5269 (2010)

Q 34.7 Tue 15:30 F 142

Direct laser acceleration of non-relativistic electrons at a dielectric grating structure —
•John Breuer[1] and Peter Hommelhoff[1,2] — [1]Max-Planck-Institut für Quantenoptik, Garching bei München, Deutschland — [2]Department für Physik, Friedrich-Alexander-Universität Erlangen-Nürnberg, Erlangen, Deutschland

Direct laser acceleration using dielectric structures has been envisioned to revolutionize particle accelerators [1]. Grating structures can support very high acceleration gradients [2] and may therefore lead to much smaller accelerators that can operate at high repetition rates, with application in free electron lasers. We report a proof-of-concept experiment demonstrating the first observation of direct laser acceleration of non-relativistic electrons using an evanescent mode excited by Titanium:sapphire laser pulses at 800nm at a dielectric grating. This work also represents the first demonstration of realistically scalable laser acceleration. We observe a maximum acceleration gradient of 25 MeV/m that is already comparable to state-of-the-art acceleration structures of today's accelerators operated with radio frequency fields. For relativistic electrons about two orders of magnitude larger acceleration gradients are expected.

[1] J. Rosenzweig, A. Murokh, C. Pellegrini, PRL 74, 2467 (1995).
[2] T. Plettner, R. L. Byer et al., PRSTAB, 9, 111301 (2006).

Q 35: Poster I

Time: Tuesday 16:00–18:30 Location: Empore Lichthof

Q 35.1 Tue 16:00 Empore Lichthof

Geometric measure of entanglement of mixed three-qubit-GHZ-symmetric states —
•Lars Erik Buchholz, Tobias Moroder, and Otfried Gühne — Theoretische Quantenoptik, Universität Siegen, Department Physik, Emmy-Noether-Campus, Walter-Flex-Strasse 3, 57068 Siegen

Quantifying entanglement is one of the challenging tasks in quantum information theory. The simplest case containing entanglement is the two-qubit system. This was intensively studied and significant results were distilled out of it. Progressive achievements on the experimental sector makes a consideration of multipartite entanglement essential. This problem is not a trivial extension of the bipartite entanglement due to different types of entanglement classes. Consequently, there exists not just one measure but a variety of possible quantifiers.

To improve our understanding about this quantum phenomenon, one has started to investigate special cases, like the mixed GHZ-symmetric-three-qubit states of Ref. [1]. This set of states exposed to be interesting due to the fact that the GHZ-Class is a nontrivial class of genuine tripartite entanglement and because of its high symmetric properties. Partial results were already obtained in Ref. [2] like the "three-tangle" as a measure for the three particle entanglement. To complete our understanding of these states we give an explicit expression of the geometric measure of entanglement with respect to fully separable states as well as for the concurrence for this class of states.

[1] C. Eltschka and J. Siewert, PRL **108**, 020502 (2012)
[2] J. Siewert and C. Eltschka, PRL **108**, 230502 (2012)

Q 35.2 Tue 16:00 Empore Lichthof

Scaling of genuine multi particle entanglement close to a quantum phase transition —
•Martin Hofmann[1], Andreas Osterloh[2], and Otfried Gühne[1] — [1]Naturwissenschaftlich-Technische Fakultät, Universität Siegen, Walter-Flex-Straße 3, 57068 Siegen, Germany — [2]Institut für Theoretische Physik, Universität Duisburg-Essen, Lotharstraße 1, 47048 Duisburg, Germany

Quantum phase transitions (QPT), which occur at zero temperature as some physical parameter reaches its critical value, are caused by abrupt changes in the ground state of a many body system. These transitions have been investigated and predicted in many different systems one of which was the one dimensional Ising model in a transverse field [1]. In this work the authors discuss the effects of the QPT on the two-particle entanglement using a finite size scaling ansatz. They also reveal that contrary to the correlation length, which diverges at the QPT, the two particle entanglement stays short ranged.

We extend their work from the investigation of two-particle entanglement to genuine multiparticle entanglement in three and four particles reduced states using the computable entanglement monotone for multi particle entanglement arising from the approach of PPT mixtures [2]. Our results show that also multi particle entanglement stays short ranged and follows a scaling behavior as the number of particles in the spin chain is varied.

[1] A. Osterloh *et al.*, Nature **416**, 608-610 (2002).
[2] B. Jungnitsch *et al.*, Phys. Rev. Lett. **106**, 190502 (2011)

Q 35.3 Tue 16:00 Empore Lichthof

A universal measure for genuine multipartite entanglement — •Florian Sokoli and Gernot Alber — Institut für Angewandte Physik, Technische Universität Darmstadt

In addition to the standard concept of multipartite entanglement so called genuine multipartite entanglement has become an interesting and challenging field of reaserch. We provide a measure for quantifying genuine multipartite entanglement and several other types of entanglement based on Arvesons entanglement measure [1]. This measure is given by a norm and applies to all types of multipartite quantum states on finitely many finite dimensional Hilbert spaces. Furthermore, we propose an intuitive partial order relation on the set of all entanglement types and show that our measure is monotonous with respect to that order yielding a natural system of mutual estimations between the measures for different kinds of entanglement. Finally, we demonstrate how to reduce the computation of our measure for an arbitrary mixed state to its computation for a corresponding pure state on an enlarged system. This work is financially supported by the Center of Advanced Security Darmstadt.

[1] W. Arveson, Maximal vectors in Hilbert space and quantum entanglement, J. Funct. Analysis 256, 1476-1510 (2009) arXiv:0804.1140[math.OA]

Q 35.4 Tue 16:00 Empore Lichthof

Fixpoint Engineering for Markovian Open Quantum Systems — •Corey O'Meara[1], Gunther Dirr[2], and Thomas Schulte-Hebrüggen[1] — [1]Dept. Chem., TU-München — [2]Inst. Math., University of Würzburg

In quantum memories and practical quantum control, recent focus has been on steering the open quantum system into desired fixed points.

Here we give a complete picture of fixpoint sets arising under Markovian relaxation. For n-qubit systems, we parameterise *all* Lindblad generators sharing a desired fixed point. We also give a constructive overview how to make this fixed point unique. Building upon our classification thus facilitates to choose the simplest Markovian experimental implementation to arrive at any desired fixed point.

Q 35.5 Tue 16:00 Empore Lichthof

Adiabatic interaction representation and Floquet Theory: quantum state dynamics under periodic Hamiltonians with different energy scales — •Hermann Kampermann[1], Dagmar Bruss[1], Alex Bain[2], and Randall Dumont[2] — [1]Institut für theoretische Physik III, Heinrich-Heine-Universität Düsseldorf, 40225 Düsseldorf — [2]Department of Chemistry, McMaster University, Ontario, Canada

We consider a quantum system which evolves under a time-dependent periodic Hamiltonian. We focus on the situation that the Hamiltonian contains terms which have large energy splittings in comparison to the periodic frequency of the Hamiltonian. An adiabatic interaction basis in Floquet space is used which allows to calculate accurate frequency spectra for an observable of a given quantum state. We exemplify the power of this framework by calculating the magic-angle-spinning nuclear magnetic resonance spectra of a spin-$\frac{1}{2}$ nucleus dipolar coupled to spin-1 or spin-$\frac{3}{2}$ nuclei.

Q 35.6 Tue 16:00 Empore Lichthof

Pointer-based measurements of conjugate observables in a thermal environment — •Raoul Heese and Matthias Freyberger — Institut für Quantenphysik, Universität Ulm, D-89069 Ulm, Germany

Arthurs and Kelly's simultaneous measurements of conjugate observables involve two pointer systems which are coupled to a quantum system to be measured. This coupling leads to generalized versions of uncertainty relations. A more realistic treatment of this model has to take environmental effects into consideration which further disturb the measurement process. We therefore treat the pointer systems as particles under Brownian motion in a thermal bath. This approach will allow us to discuss damping and decoherence of quantum measurements.

Q 35.7 Tue 16:00 Empore Lichthof

Distilling N00N-like Components of Two-Mode Quantum States of Light — •Falk Töppel[1,2], Kirill Yu. Spasibko[3], Timur Sh. Iskhakov[1], Magdalena Stobińska[4,5], Maria V. Chekohva[1,2,3], and Gerd Leuchs[1,2] — [1]Max Planck Institute for the Science of Light, Günther-Scharowsky-Straße 1/Bldg. 24, 91058 Erlangen, Germany — [2]Institute for Optics, Information and Photonics, Universität Erlangen-Nürnberg, Staudtstraße 7/B2, 91058 Erlangen, Germany — [3]Department of Physics, M. V. Lomonosov Moscow State University, Leninskie Gory, 119991 Moscow, Russia — [4]Institute of Physics, Polish Academy of Sciences, Al. Lotników 32/46, 02-668 Warsaw, Poland — [5]Institute of Theoretical Physics and Astrophysics, University of Gdańsk, 80-952 Gdańsk, Poland

The set of efficiently produced quantum states of light is limited. Particularly difficult to produce are non-classical non-Gaussian superpositions. Nevertheless, with quantum state engineering certain properties of accessible states can be modified. We propose a filter that diminishes the contributions of components with approximately equal population to a two-mode quantum state of light. In return, N00N-like contributions to the quantum state are enhanced. The main feature of our method is that it works symmetrically on components with different mode occupation and thus does preserve superpositions. Furthermore, the filter is especially suitable for macroscopic states of light and can be implemented easily with beam splitters and photon detectors only. We discuss its applications to several quantum states and present first experimental results on the filters working principle.

Q 35.8 Tue 16:00 Empore Lichthof

Single calcium-40 ions as quantum memories for single-photon polarization — •Philipp Müller, Joyee Ghosh, and Jürgen Eschner — Quantenphotonik, Universität des Saarlandes, Campus E 2.6, 66123 Saarbrücken, Germany

The controlled transfer of quantum states from one system to another is a cornerstone in the realization of quantum networks.

Here we present an overview of several schemes of storing polarization states of single photons in single $^{40}Ca^+$ ions. We compare the requirements, efficiencies and possible applications of these schemes with respect to the preparation of the absorber state, the absorption process and its analysis. These schemes can be used to create and herald entanglement of two (distant) ions through entanglement swapping from photon pairs onto the ions [1].

[1] S. Lloyd *et al.*, PRL **87**, 167903 (2001)

Q 35.9 Tue 16:00 Empore Lichthof

Effects of stochastic noise on dynamical decoupling procedures — Jozsef Zsolt Bernad, •Holger Frydrych, and Gernot Alber — Institut für Angewandte Physik, Technische Universität Darmstadt, D-64289 Darmstadt

Dynamical decoupling is a well-established technique to protect quantum systems from unwanted influences of their environment by exercising active control. It has been used experimentally to drastically increase the lifetime of qubit states in various implementations. The efficiency of different dynamical decoupling schemes defines the lifetime. However, errors in control operations always limit this efficiency. We propose a stochastic model as a possible description of imperfect control pulses and discuss the impact of this kind of error on different decoupling schemes. In the limit of continuous control, i.e. if the number of pulses $N \to \infty$, we derive a stochastic differential equation for the evolution of the density operator of the controlled system and its environment. In the context of this modified time evolution we discuss possibilities of protecting qubit states against environmental noise.

Q 35.10 Tue 16:00 Empore Lichthof

Optimal control of entanglement under restrictions — •Thomas Stefan Häberle and Matthias Freyberger — Institut für Quantenphysik, Universität Ulm, D-89069 Ulm

We present a novel iterative algorithm with a special presearching step that can optimize the entanglement of a coupled quantum system while fulfilling restrictions of the control function. As an example we regard two atoms in a harmonic trap which interact via pointlike collisions. Our aim is to improve the entanglement at a fixed time by dynamically varying the trap frequency within a fixed interval. In order to get rid of the restrictions for the trap frequency, we use a suitable parametrization that transforms the optimization problem from a restricted to an unrestricted one. By applying the presearching step we get a reasonable initial guess for the optimal trap frequency. Finally, we use a standard method based on optimal control theory to further increase the entanglement.

Q 35.11 Tue 16:00 Empore Lichthof

Effects of entanglement on the measurement of phase shifts — •Simon Laibacher and Matthias Freyberger — Institut für Quantenphysik, Universität Ulm, D-89069 Ulm, Germany

It has recently been shown that a two-mode squeezed vacuum has the capability to yield phase uncertainties at, or even slightly below, the Heisenberg limit, when applied in conjunction with a parity measurement [1]. We show that this can also be achieved using a different measurement scheme that is based on homodyne detection in an eight port interferometer. In particular, we look at the effect of entanglement on the phase uncertainty by comparing our results for a displaced two-mode squeezed vacuum with the case where two separable single-mode squeezed states are used.

[1] P. M. Anisimov et al., Phys. Rev. Lett. **104**, 103602 (2010).

Q 35.12 Tue 16:00 Empore Lichthof

Quantum State Reconstruction with Weak Measurement — •Phuc Thanh Luu, Hermann Kampermann, and Dagmar Bruss — Heinrich-Heine-Universität, Institut für Theoretische Physik III, Universitätstr. 1, 40225 Düsseldorf

The estimation of quantum states has become a basic task in quantum information. Here, we propose an alternative scheme: quantum state reconstruction with weak measurement. By tuning the interaction strength between the system and the ancilla to the weak regime, we can obtain a small amount of information about the state and cause a slight disturbance on it. Thus, the scheme can be found useful for experiments that requires the measuring of quantum states as an intermediate stage in a process.

Q 35.13 Tue 16:00 Empore Lichthof

Influence of initial correlations on the dynamics of open quantum systems — •Simon Milz — Institut für theoretische Physik TU Dresden, Deutschland

We investigate the effects of initial system-bath correlations on the dynamics of open quantum systems. While the dynamics of a system initially uncorrelated with its environment is well-known to be completely positive, the reduced time evolution arising from a general system-bath initial state does not necessarily display this feature [1,2].

By investigating the open dynamics of low-dimensional systems, we aim to shed light on the crucial differences between the dynamics of correlated and uncorrelated initial states. Moreover a detailed examination of the general reduced dynamics and the subset of states it can be applied to is carried out.

[1] P. Pechukas, Phys. Rev. Lett. 73 (8) (1994) 1060.

[2] T.F. Jordan, A. Shaji, E.C.G. Sudarshan, Phys. Rev A. 70 (5) (2004) 052110.

Q 35.14 Tue 16:00 Empore Lichthof

Multi-mode cooling in anharmonic ion traps — •Regina Lechner[1], Philip Holz[1], Maximilian Harlander[1], Thomas Monz[1], Michael Brownnutt[1], and Rainer Blatt[1,2] — [1]Institut für Experimentalphysik, Universität Innsbruck, Technikerstraße 25, A-6020 Innsbruck, Austria — [2]Institut für Quantenoptik und Quanteninformation der Österreichischen Akademie der Wissenschaften, Technikerstraße 21a, A-6020 Innsbruck, Austria

The ultimate usefulness of quantum computation is strongly bound to scalability. One standard route towards scalable architectures is by miniaturizing and segmenting traps. With such traps being used in various groups throughout the community, longer ion chains came into the focus of interest. With increasing ion numbers within a chain the number of motional modes increases too. However, in order to make use of ions and the ions' motion as information carrier, a way to cool unwanted modes is required to circumvent decoherence and information loss.

We investigate EIT cooling for multi-mode cooling of ion chains, both in harmonic and anharmonic trapping potentials. Segmented traps allow the application of anharmonic potentials and thus the possibility to arrange ions within a chain equidistantly. This property is of particular interest for quantum simulations, where equidistant spacing would more closely resemble the natural structure of - for example - solids.

Q 35.15 Tue 16:00 Empore Lichthof

A scanning probe quantum processor using NV centres — •Andreas Brunner, Friedemann Reinhard, and Jörg Wrachtrup — 3. Physikalisches Institut und Forschungszentrum SCoPE, Universität Stuttgart, Germany

The nitrogen-vacancy (NV) colour centre in diamond has shown to be a promising candidate for applications in spin sensing [1] and quantum information [2]. This is due to its electron spin structure featuring long coherence times and allowing optical state readout.

We pursue the realisation of a scanning-probe quantum processor by combining a mobile NV read-write-head with a stationary array of solid state quits. The scanning probe consists of an NV placed in the tip of microfabricated diamond pillar. This structure equally acts as a photonic waveguide and enables highly efficient fluorescence readout.

Our planned setup for these experiments is presented including our progress on the fabrication of such scanning NV sensors.

[1] N. Zhao et al., Nature Nanotechnology **7**, 657-662 (2012)

[2] N. Mizuochi et al., Nature Photonics **6**, 299-303 (2012)

Q 35.16 Tue 16:00 Empore Lichthof

A two-dimensional quantum register of single-atom qubits in optical microtraps — •Malte Schlosser, Sascha Tichelmann, Moritz Hambach, and Gerhard Birkl — Institut für Angewandte Physik, Technische Universität Darmstadt, Schlossgartenstraße 7, 64289 Darmstadt, Germany

Optical dipole potentials such as arrays of focused laser beams provide flexible geometries for the synchronous investigation of multiple atomic quantum systems, as studied e.g. in the fields of quantum degenerate gases, quantum information processing, and quantum simulation with neutral atoms. In our work, we focus on the implementation of trapping geometries based on microfabricated optical elements. This approach allows us to develop flexible and integrable configurations for quantum state storage and manipulation, simultaneously targeting the important issues of single-site addressing and scalability.

We give an overview on the investigation of ^{85}Rb atoms in two-dimensional arrays of well over 100 individually addressable dipole traps featuring trap sizes and a tuneable site-separation in the single micrometer regime. Advanced schemes for atom number resolved detection with high efficiency and reliability allow us to probe small ensembles and even single atoms stored in the microtrap array. For single atom preparation we utilize light assisted collisions to improve loading efficiencies while eliminating multi-atom events. We present single-site resolved addressing of single spins in a reconfigurable fashion and discuss the feasibility of Rydberg based two-qubit gates in our setup.

Q 35.17 Tue 16:00 Empore Lichthof

Coherent Rydberg Excitation in Thermal Caesium Vapour — •Alban Urvoy, Fabian Ripka, Christian Veit, Tilman Pfau, and Robert Löw — 5. Physikalisches Institut, Universität Stuttgart, Pfaffenwaldring 57, 70550 Stuttgart Germany

Rydberg atoms are promising candidates for the realisation of quantum devices, making use of their long-range atom-atom interaction. The presence of van der Waals-type interaction among Rydberg states has recently been demonstrated in thermal Rubidium vapour using a pulsed amplifier [1]. In Caesium, the excitation scheme $6S_{1/2} \rightarrow 7P_{3/2} \rightarrow nS, nD$ has the advantage, compared to that in Rubidium, that the upper transition may be driven at a wavelength of approx. 1064 nm. At this wavelength it is possible to reach high laser powers with CW fibre amplifiers and we therefore can expand the work of [1] to longer time scales with the use of a Pockels cell. However due to the strong Doppler effect present in thermal vapours, the wavelength ratio between the two driving laser fields plays a crucial role in the system and has to be considered carefully.

In this three level ladder system in Cs, we present our results on the

coherence properties for the steady-state EIT spectroscopy as well as for the pulsed nanosecond regime.
[1] T. Baluktsian, B. Huber, et al., arXiv:1212.0690 [physics.atom-ph]

Q 35.18 Tue 16:00 Empore Lichthof
Towards quantum simulation of spin-ice dynamics — •Henning Kalis, Miriam Bujak, Manuel Mielenz, Ulrich Warring, and Tobias Schaetz — Albert-Ludwigs-Universität Freiburg, Physikalisches Institut, Hermann-Herder-Strasse 3, 79104 Freiburg, Germany

Geometrically frustrated systems exhibit a residual entropy due to their exponentially large number of degenerate classical groundstates. In analogy to the proton-disorder in commom water ice they are called *spin-ice*-systems, e.g. the triangular Ising-Model with nearest neighbor antiferromeagnetic exchange interactions. Although spin-ice systems are of interest for many years [1] little is known about the microscopic mechanisms governing their physics.
High fidelity quantum control of multiple spin systems have been implemented [2] with ions in linear Paul traps (e.g. quantum simulation of Ising-Models [3]). A novel type of surface electrode trap [4] may extend this degree of control to two dimensional trap arrays (lattices) and therefore we may gain insight of the microscopic dynamics of spin-ice systems.
We introduce the surface trap geometry and report on the current status of the experiment.
[1] G.H. Wannier, Phys. Rev. **79**, 357 (1950)
[2] Ch Schneider *et al.*, Rep. Prog. Phys. **75** 024401 (2012)
[3] A. Friedenauer *et al.*, Nature Physics **4**, 757 - 761 (2008)
[4] R. Schmied *et al.*, PRL **102**, 233002 (2009)

Q 35.19 Tue 16:00 Empore Lichthof
Wärmekraftmaschine mit einzelnen Ionen — •Johannes Rossnagel[1], Georg Jacob[1], Charlotte Degünther[1], Obinna Abah[2], Ferdinand Schmidt-Kaler[1], Eric Lutz[2,3] und Kilian Singer[1] — [1]QUANTUM, Institut für Physik, Universität Mainz, Staudingerweg 7, 55128 Mainz, Germany — [2]Institut für Physik, Universität Augsburg, D-86135 Augsburg, Germany — [3]Dahlem Center für komplexe Quantensysteme, Freie Universtiät Berlin, Arnimallee 14, D-14195 Berlin-Dahlem, Germany

Wir präsentieren einen realistischen Vorschlag für eine Nano-Wärmekraftmaschine mit einem einzelnen Ion als aktives Medium [1]. Um einen Otto-Kreisprozess zu realisieren, wird ein einzelnes Ion in einer linearen Paulfalle mit speziell geformten Elektroden gefangen und an Wärmebäder gekoppelt. Diese Wärmebäder können durch verstimmte Laserstrahlung oder elektronisches Rauschen erzeugt werden und heizen und kühlen die radiale Komponente des thermischen Zustands des Ions im Wechsel. Die zugeführte Wärme wird umgesetzt in eine kohärente Bewegung des Ions entlang der Fallenachse, aus der die erzeugte Leistung bestimmt werden kann. Mit Monte-Carlo Simulationen unter realistischen Bedingungen zeigen wir, dass Effizienzen von 30% bei maximaler Leistung erreicht werden können.
[1] O.Abah, J.Roßnagel, G.Jacob et. al, PRL 109, 203006 (2012).

Q 35.20 Tue 16:00 Empore Lichthof
Near-field Microwave Quantum Logic with Trapped Ions — •Martina Carsjens[1,2], Matthias Kohnen[1,2], Timko Dubielzig[1], Anna-Greta Paschke[1], Malte Niemann[1], and Christian Ospelkaus[1,2] — [1]QUEST, Institut für Quantenoptik, Leibniz Universität Hannover — [2]QUEST, PTB Braunschweig

Multi-qubit interactions for quantum information processing with trapped ions require a coupling between individual ion-qubits and a shared motional degree of freedom as a quantum bus. Recent experiments have shown how such interactions can be realized using microwave near-fields rather than the widely used laser fields. The near-field approach holds great promise for integration, simplification and operation fidelities. To achieve these goals, the structure supplying the microwave fields needs to be well understood and optimized. We report on efficient and accurate numerical simulations of microwave guiding structures. Furthermore, near-field manipulation requires close proximity of ion-qubits to conductors, where anomalous motional heating can be a significant source of decoherence. To suppress these detrimental effects in our experiments, we have developed a low-vibration closed-cycle cryogenic setup.

Q 35.21 Tue 16:00 Empore Lichthof
Heralded photonic interaction between distant single ions — •Christoph Kurz[1], Jan Huwer[1,2], Michael Schug[1], Philipp Müller[1], and Jürgen Eschner[1] — [1]Experimentalphysik, Universität des Saarlandes, Saarbrücken, Germany — [2]ICFO – The Institute of Photonic Sciences, Castelldefels (Barcelona), Spain

Single trapped atoms and ions offer a high level of control over their internal and external quantum state and are therefore ideal systems for implementations of quantum information processing. They also allow for the controlled emission and absorption of single photons as a resource in quantum communication and quantum networking.

We operate two independent linear Paul traps with single $^{40}Ca^+$ ions, which provides a highly modular setup for implementing quantum processing and communication tools. The ions interact over 1 m distance through emission and absorption of single resonant photons. Single-photon emission in the sender ion is continuous or triggered; absorption in the receiver is signaled by a quantum jump. Frequency, polarization, and temporal shape of the single photons are controlled by appropriate laser pulses [1].
[1] C. Kurz et al., arXiv:1211.5922

Q 35.22 Tue 16:00 Empore Lichthof
Towards a Loophole Free Bell Test with a Pair of Remotely Entangeld 87Rb-Atoms — •Kai Redeker[1], Daniel Burchardt[1], Norbert Ortegel[1], Julian Hofmann[1], Michael Krug[1], Markus Weber[1], Wenjamin Rosenfeld[2], and Harald Weinfurter[1,2] — [1]Fakultät für Physik, Ludwig-Maximilians-Universität München, D-80799 München, Germany — [2]Max-Planck Institut für Quantenoptik, D-85748 Garching, Germany

Bell's inequality allows to test the validity of local hidden variables theories. To perform a conclusive Bell test, one has to fulfill two major requirements: The state measurements of the entangled particles need to be highly efficient and space like separated.

We present progress towards an experiment which can fulfill both requirements. We use entanglement between single trapped atoms and single photons to create heralded entanglement between separated atoms [1]. The measurement including choosing a random setting and efficiently reading out the atomic state, will take less then one microsecond. This is achieved by state dependent ionization and subsequent detection of the ionization fragments [2]. We plan extending the distance between the atoms from now 20m to 400m to enable the space like separation of the measurements on the atoms. Together, this will enable to finally close the locality and the efficiency loophole in one experiment.
[1]J.Hofmann et al. Science 337, 72 (2012)
[2]F.Henkel et al. Phys. Rev. Lett 105 253001 (2010)

Q 35.23 Tue 16:00 Empore Lichthof
Effective Interaction between Light Pulses based on Storage in a Bose-Einstein Condensate — •Simon Baur, Christoph Vo, Stephan Riedl, Dominik Fauser, Daniel Tiarks, Gerhard Rempe, and Stephan Dürr — Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Str. 1, D-85748 Garching, Germany

Creating an interaction between single photons is a key step towards realizing a photonic quantum gate. In conventional optical materials nonlinearities are so weak that they become negligible on the single photon level. However, light pulses can be stored in cold atomic ensembles as atomic spin waves with high efficiency and converted back to light on demand [1]. Coherent interaction between spin waves can be introduced by collisions between ground-state atoms or by excitation to Rydberg states with a long-range interaction. We experimentally demonstrate that in a Bose-Einstein condensate of ^{87}Rb s-wave scattering betweeen ground-state atoms is sufficiently strong to realize a classical AND gate for classical light pulses [2]. We show that the gate operation is phase coherent, an essential prerequisite for extensions to a quantum logic gate. We further report on experimental progress towards implementing interactions between single photons by using the long-range dipole-dipole interaction between Rydberg atoms.
[1] M. Lettner et al. *Phys. Rev. Lett.* **106**, 210503 (2011)
[2] C. Vo et al. arXiv:1211.7240

Q 35.24 Tue 16:00 Empore Lichthof
Rydberganregung von lasergekühlten $^{40}Ca^+$ Ionen — •Lennart Pelzer, Thomas Feldker, Ferdinand Schmidt-Kaler, Daniel Kolbe, Matthias Stappel und Jochen Walz — Institut für Physik, Johannes Gutenberg Universität, Mainz

In Paulfallen gefangen, lasergekühlte Ionen gehören zu den vielversprechendsten Kandidaten für die Quanteninformationsverarbeitung. Eine Kombination dieser Technologie mit quantenlogischen Operationen durch Rydberganregung und der damit verbundenen Dipol-Blockade verspricht eine erweiterte Skalierbarkeit.

In unserem Experiment werden die $^{40}Ca^+$ Ionen in einer Paulfalle gefangen und gekühlt bevor sie in den metastabilen $3D_{5/2}$ Zustand gebracht werden, von wo sie mittels Laserlicht bei einer Wellenlänge von 122nm in den Rydbergzustand 67P angeregt und spektroskopisch untersucht werden sollen[1]. Weitergehende Ziele sind die Modifikation der Modenstruktur des Ionenkristalles durch Rydberganregung einzelner Ionen sowie die Erzeugung von Vielteilchen-Verschränkung in Ionenkristallen mittels Dipolblockade.

Wir präsentieren die experimentellen Fortschritte der letzten Zeit, insbesondere die Ionisation von $^{40}Ca^+$ durch den VUV-Laser und damit den ersten Nachweis einer Interaktion des VUV-Lasers mit den Ionen.

[1] F. Schmidt-Kaler, T. Feldker, D. Kolbe, J. Walz, M. Müller, P. Zoller, W. Li and I. Lesanovsky,"Rydberg excitation of trapped cold ions: a detailed case study", New J. Phys., 2011

Q 35.25 Tue 16:00 Empore Lichthof

Automatisierte Messverfahren für einen zukünftigen Ionenfallen-Quantencomputer — •Thomas Ruster[1], Henning Kaufmann[1], Andreas Walther[2], Claudia Warschburger[1], Max Hettrich[1], Kilian Singer[1], Ferdinand Schmidt-Kaler[1] und Ulrich Poschinger[1] — [1]QUANTUM, Institut für Physik, Universität Mainz, Staudingerweg 7, 55128 Mainz — [2]Department of Physics, Lund University, Box 118, SE-221 00 Lund

Der Betrieb einer Ionenfalle zur Quanteninformationsverarbeitung ist mit erheblichem Kalibrationsaufwand verbunden. Darunter fallen die Präparation und Detektion von Ionen, die Spektroskopie kohärenter Übergänge sowie die Kalibration von Pulsflächen und Gatterparametern. Gerade im Hinblick auf die Skalierbarkeit des Systems ist es unverzichtbar, diese Messungen effizient und automatisiert durchzuführen.

Zur effizienten fluoreszenzbasierten Zustandserkennung eines Ionenkristalls wurde ein Algorithmus nach dem Prinzip der Support Vector Machine implementiert. Ein Verfahren zur Korrektur von Auslesefehlern erlaubt die Umwandlung systematischer Fehler in der Präparation, beim Electron Shelving und in der Fluoreszenzauslese in statistische Fehler. Es wird gezeigt, wie die Anwendung des Verfahrens die gemessene Fidelität einer Gatteroperation zur Verschränkung zweier Ionen verbessert.

Darüber hinaus werden automatisierte Verfahren zur Bestimmung und Vorhersage von Laserfrequenzen und zur präzisen Kalibration von Pulsflächen vorgestellt.

Q 35.26 Tue 16:00 Empore Lichthof

Ein mikrostrukturiertes Resonator-Ionenfallensystem für CQED-Experimente — •Max Hettrich, Andreas Pfister, Marcel Salz und Ferdinand Schmidt-Kaler — Institut für Physik, Universität Mainz

Die starke Kopplung von Atomen und Photonen in CQED-Experimenten ist mit ultrakalten, neutralen Atomen und Rydbergatomen schon seit einiger Zeit Stand der Technik, mit Ionen in Paulfallen konnten Experimente in diesem Regime bisher jedoch noch nicht realisiert werden. Das Hauptproblem stellt hierbei die Nähe der Ionen zu den dielektrischen Spiegeloberflächen dar, welche sich durch das Streulicht der verwendeten Laser aufladen können, und so das Fallenpotential unkontrolliert ändern. In unserem Design, welches wir auf diesem Poster vorstellen, umgehen wir diesen Effekt, indem wir den Bereich, in dem das Ion mit Laserlicht von außen interagiert von dem Bereich räumlich trennen, in welchem das Ion mit dem optischen Resonator wechselwirkt. Zwischen beiden Bereichen kann das Ion schnell hin- und hertransportiert werden. Wir benutzen hierfür eine segmentierte, mikrostrukturierte Paulfalle und integrieren darin einen Faserresonator. Wir untersuchen die Formung der Faserendflächen mit einem FIB, um eine für unseren Aufbau optimierte Resonatorgeometrie zu realisieren. Die so entstehende Schnittstelle ermöglicht den Austausch von Quanteninformation zwischen Photonen und Ionen. Dies ist unter anderem ein entscheidender Baustein eines Quantenrepeaters zur Vergrößerung der maximalen Übertragungsstrecke von Quantenzuständen.

Q 35.27 Tue 16:00 Empore Lichthof

Tools for single-ion quantum state preparation and analysis — •Pascal Eich[1], Jan Huwer[1,2], Christoph Kurz[1], Philipp Müller[1], Michael Schug[1], and Jürgen Eschner[1] — [1]Universität des Saarlandes, Experimentalphysik, Campus E2 6, 66123 Saarbrücken, Germany — [2]ICFO – Institut de Ciències Fotòniques, Mediterranean Technology Park, 08860 Castelldefels (Barcelona), Spain

Reliable preparation and analysis of quantum states is essential for quantum information applications. Here we demonstrate the required tools for the manipulation of electronic states of a single $^{40}Ca^+$ ion in the context of quantum repeaters. In the $S_{1/2}$ ground state, we prepare one of the two Zeeman sublevels by optical pumping and create a coherent superposition using radio frequency pulses. The population in the $S_{1/2}$ Zeeman sublevels is coherently transferred to one of the Zeeman sublevels of the metastable $D_{5/2}$ state using a narrowband laser at 729 nm, either via the rapid adiabatic passage technique or by a Rabi pulse.

Q 35.28 Tue 16:00 Empore Lichthof

Präzise experimentelle Untersuchung planarer Ionenkristalle für Quantensimulationen — •Henning Kaufmann[1], Stefan Ulm[1], Georg Jacob[1], Ulrich Poschinger[1], Haggai Landa[2], Alex Retker[3], Martin Plenio[4] und Ferdinand Schmidt-Kaler[1] — [1]QUANTUM, Institut für Physik, Universität Mainz — [2]Tel-Aviv University — [3]The Hebrew University of Jerusalem — [4]Universität Ulm

Das Verständnis von Eigenmoden und Eigenfrequenzen großer zweidimensionaler Ionenkristalle bildet die Basis für die weitere Verwendung solcher Strukturen zur Quantensimulation [1]. Wir untersuchen gefangene planare Ionenkristalle experimentell [2]. Die theoretische Vorhersage der Ionenpositionen konnte mit einer relativen Genauigkeit von $4 \cdot 10^{-5}$ bestätigt werden. Durch Veränderung der an die Falle angelegten Spannungen kann der Anisotropieparameter verändert werden, welcher das Verhältnis von axialem zu radialem Einschluss angibt. Wir beobachten mehrere Strukturübergänge und bestimmen kritische Anisotropiewerte für diese Übergänge. Mit Hilfe von Seitenband-Spektroskopie werden die gemeinsamen Schwingungsmoden in der Zickzack-Konfiguration untersucht. Hierbei stimmen die Messdaten jedoch nicht mit gängigen Pseudopotential Berechnungen überein, erst die komplette Zeitentwicklung der Mathieu Gleichungen zeigt gute Übereinstimmung mit den experimentellen Daten. [1] A. Bermudez et al., NJP,**14**, 9, (2012). [2] H. Kaufmann et al., accepted for publication in PRL, arxiv:1208.4040

Q 35.29 Tue 16:00 Empore Lichthof

Simulating the spin-boson model in a Paul trap — •Govinda Clos, Martin Enderlein, Ulrich Warring, and Tobias Schaetz — Physikalisches Institut, Universität Freiburg, Hermann-Herder-Straße 3, D-79104 Freiburg, Germany

Employing a linear chain of several Mg-25 ions stored in a Paul trap, we aim to experimentally simulate the dynamics of the spin-boson model. Using different lasers and control protocols we can, e.g., cool the ions to the motional ground state ($\bar{n} < 0.03$) and manipulate their internal and external degrees of freedom. Two-photon stimulated Raman transitions enable coherent couplings between the hyperfine states of one ion (the simulated spin) and the set of axial vibrational modes of all ions in the chain. These modes represent a finite number of harmonic oscillators (the bosons).

Following a proposal by Porras *et al.* [1] and based on the simulations realized by Friedenauer *et al.* [2], our setup based on trapped ions and of finite size will permit to explore the different regimes of the model depending on the spectral density of the environment: *(i)* revivals of excitation and entanglement, *(ii)* the overdamped regime, and finally, *(iii)* localization, i.e., inhibition of spin/energy transfer due to the Quantum Zeno effect.

[1] Porras, D., Marquardt, F., von Delft, J. and Cirac, J. I., Phys. Rev. A **78**, 010101 (2008).

[2] A. Friedenauer, H. Schmitz, J. Glueckert, D. Porras and T. Schaetz, Nat. Phys. **4**, 757-761 (2008).

Q 35.30 Tue 16:00 Empore Lichthof

Nanofibers as light-matter interfaces for quantum networks — •Dominik Maxein, Baptiste Gouraud, Adrien Nicolas, Elisabeth Giacobino, and Julien Laurat — Laboratoire Kastler Brossel, Université P. et M. Curie, École Normale Supérieure, and CNRS, 4 place Jussieu, 75252 Paris Cedex 05, France

An interesting and emerging system for light-matter interfacing is the optical nanofiber, where light is guided by a “glass wire” with subwavelength diameter. The strong evanescent field can yield strong interactions between guided light modes and matter in the surroundings of the nanofiber. To hold an ensemble of atoms in the vicinity of the fiber, two-color optical dipole traps have been recently realized [Vetsch et al., PRL **104**, 203603 (2010) and Goban et al., PRL **109**, 033603 (2012))].

Our group focuses on the development of quantum memories in cold, neutral atom clouds. We are currently building a work bench for the production of nanofibers using the brushing flame technique, heating a small portion of the fiber and pulling in a well-controlled way. We will present the technological background and characterization for our system and the first obtained tapered fibers. Future applications will be discussed.

Q 35.31 Tue 16:00 Empore Lichthof

Toward quantum simulations in a triangular surface trap — •Miriam Bujak, Manuel Mielenz, Henning Kalis, Ulrich Warring, and Tobias Schaetz — Physikalisches Institut, Albert-Ludwigs Universität Freiburg

Ions confined in linear Paul traps have proven to be well suited for quantum information processing and quantum simulations [1-2]. While many proof-of-principle experiments have been realized in these traps with up to tens of ions [2], scalability of ion based quantum processors and simulators remains a major issue.

To overcome the limitations of one-dimensional linear Paul traps, novel two-dimensional surface traps for triangular arrays of ions have been proposed [3] and optimized [4]. While in this new approach the ions will be stored in individual minima of the potential, the mutual distances are kept small enough to provide sufficient coupling strength for quantum simulation experiments in two-dimensional lattices [5]. We report on the current status of the experimental setup.

[1] A. Friedenauer *et al.*, Nature Phys. **4**, 757-761 (2008)
[2] R. Islam *et al.*, Nature Comm. **2**, 377 (2011)
[3] T. Schaetz *et al.*, J. Mod. Optics **54**, 16-17 (2007)
[4] R. Schmied *et al.*, PRL **102**, 233002 (2009)
[5] Ch. Schneider *et al.*, Rep. Prog. Phys. **75**, 024401 (2012)

Q 35.32 Tue 16:00 Empore Lichthof

Radiofrequency Spectroscopy of a single ^{40}Ca^{+} Qubit — •Jens Welzel, Amado Bautista-Salvador, Niels Kurz, Rene Gerritsma, and Ferdinand Schmidt-Kaler — QUANTUM, Institut für Physik, Universität Mainz, Staudingerweg 7, 55128 Mainz, Germany

Miniaturized ion traps may offer a route towards scalable quantum computation and simulation. Such devices also allow the manipulation of ions via magnetic field gradients in the radiofrequency domain, thus avoiding the technological overhead of lasers [1]. Here, we report on experimental work on a planar ion trap designed to coherently manipulate ^{40}Ca^{+} ions via magnetic field gradients [2]. We performed radiofrequency spectroscopy [1] of a single ^{40}Ca^{+} ion in the presence of static currents. Additionally, by moving the ion 600 μm along the trap axis we measured the total static magnetic field which yields a gradient of 1.11 ± 0.18 T/m per Ampere along the trap axis. Oscillating currents may be employed to couple the spin of the ions to their motion. We anticipate gradients of 10 T/m per Ampere perpendicular to the trap axis. These fields may be used to engineer spin-spin interactions in an ion crystal [2]. The presented experiments also pave the way for the implementation of a laser-less sideband cooling and robust quantum gates based on oscillating magnetic field gradients in the radiofrequency regime.

[1] Johanning, M. et. al. Phys. Rev. Lett. **102**, 073004 (2009).
[2] Welzel, J. et. al. Eur. Phys. J. D **65**, 285−297 (2011).

Q 35.33 Tue 16:00 Empore Lichthof

Single ion saturation as efficiency measurement for light-matter interaction — •Robert Maiwald[1,2], Andrea Golla[1,2], Martin Fischer[1,2], Marianne Bader[1,2], Markus Sondermann[1,2], and Gerd Leuchs[1,2] — [1]Institut für Optik, Information und Photonik (IOIP), Universität Erlangen-Nürnberg, Erlangen — [2]Max-Planck-Institut für die Physik des Lichts (MPL), Erlangen

The characteristic answer of a two-level system to a resonantly exciting laser field can be used as a measurement for the efficiency of light-matter interaction, aiming at applications such as quantum memories and quantum networks. We follow a free space approach where the incoming light field is mode-matched to a linear dipole transition of a single atomic ion. For this purpose we prepare a spatially and temporally formed light mode that has – after focusing – an almost perfect overlap with the emission of a linear dipole [1]. With a specialized ion trap we place a single ^{174}Yb^{+} ion in the focus of a parabolic mirror covering 81 % of the solid angle surrounding the ion [2]. This set-up allows one to directly interface the tailored light mode with the single ion. We use the saturation of the ion's cooling transition as a measure for the light-matter interaction efficiency to characterize the quality of the incoming light mode and the spread of the parabolic mirror's focal spot. Additionally, imaging the ion's fluorescence via the parabolic mirror yields the highest resolution achieved so far with single ions.

[1] A. Golla *et al.*, Eur. Phys. J. D **66**, 190 (2012)
[2] R. Maiwald *et al.*, Phys. Rev. A **86**, 043431 (2012)

Q 35.34 Tue 16:00 Empore Lichthof

Trapping Yb+ ions in a segmented surface trap with integrated magnetic field gradient — •Peter Kunert, Daniel Georgen, Michael Johanning, and Christof Wunderlich — Universität Siegen, Naturwissenschaftlich-Technische Fakultät, Dept. Physik, 57068 Siegen, Deutschland

A promising approach for realizing complex ion trap-structures and -arrays are planar ion traps where all electrodes and current carrying elements are arranged in a quasi-2-dimensional structure. We demonstrate trapping of 172Yb+ ions in a surface ion trap in ultra high vacuum at 5*10^-11 mbar. Long storage times of several hours are achieved. We characterize the trap in terms of its secular frequencies and demonstrate deterministic transport of ions above the plane. A 60 um thin glass plate is mounted at 2.5 mm above and parallel to the trap surface. It is coated with a 100 nm thin indium tin oxide layer allowing for the application of a static electric potential. This serves to protect the trapped ion from stray fields possibly induced by particles at the chip surface and the detection viewport, to change the trapping height of the ion and increase the trap depth by applying a suitable voltage. The ITO layer transmits 68% of resonance fluorescence light near 369 nm. We present briefly the production process using different lithography and electroplating steps. The trap design includes current carrying electrodes to produce magnetic field gradients with different tuneable shapes at the ion position. The magnetic field gradients will permit addressing of ions in the frequency domain and allows to couple internal and external motion with an effective Lamb-Dicke parameter.

Q 35.35 Tue 16:00 Empore Lichthof

Time-resolved Bell-state measurement between photons from remote single atoms — •Andreas Neuzner, Christian Nölleke, Andreas Reiserer, Carolin Hahn, Gerhard Rempe, and Stephan Ritter — Max-Planck-Institut für Quantenoptik, 85748 Garching, Germany

Detecting the Bell-state of two particles via a combined measurement is the key technique for the implementation of quantum teleportation protocols that allow for the heralded transfer of quantum information over large distances. We investigate Bell-state measurement of the polarization state of two photons originating from cavity-based neutral-atom quantum memories in separate laboratories. Two-photon interference and polarization-sensitive detection allow us to unambigously detect two of the four Bell states. The photons are generated via a vacuum-stimulated Raman adiabatic passage (vSTIRAP). By adjusting parameters of this process, we can tailor properties of the photons like temporal envelope and center frequency. We choose a width of the photons' envelope that exceeds the temporal resolution of the detection setup by more than two orders of magnitude. We can thus distinguish the arrival-time difference of the two temporal envelopes from the detection time difference of two individual photon events. A technique to herald events with increased interference contrast is demonstrated. Combining the Bell-state measurement with the creation of atom-photon entanglement enables us to implement teleportation of atomic states over a distance of 21m.

Q 35.36 Tue 16:00 Empore Lichthof

Hyperfine Qubit in a Microstructured Ion Trap with Integrated Solenoids — •Timm F. Gloger, M. Tanveer Baig, Thomas Collath, Delia Kaufmann, Peter Kaufmann, Michael Johanning, and Christof Wunderlich — Universität Siegen, NT Fakultät, Department Physik, 57068 Siegen, Germany

We characterize a micro-structured segmented ion trap with integrated solenoids. Using the segmented DC electrode structure of the trap we shuttle and split strings of laser cooled ions along the trap axis and are able to design various trapping potentials.

The trap is operated with ions of two Ytterbium isotopes, ^{172}Yb^{+} and ^{171}Yb^{+}. We coherently manipulate a qubit implemented in the $|S_{1/2}, F=0\rangle \leftrightarrow |S_{1/2}, F=1\rangle$ hyperfine transistions of ^{171}Yb^{+} and use the qubit as a sensor to characterized the magnetic field along the trap axis.

The solenoids are used to create switchable magnetic field gradients that in turn allow for addressing trapped ions in frequency space and coupling the ions' motional and spin states. Furthermore, long range spin-spin coupling of the ions' internal states is induced by the gradient. These mechanisms are called **Ma**gnetic **G**radient **I**nduced **C**oupling, MAGIC.

Switchable gradients and the ability to shape the trapping potentials enable the custom design of spin-spin coupling constants useful for a variety of experiments in quantum information science.

Q 35.37 Tue 16:00 Empore Lichthof

Towards laser-machined optical cavities — •Manuel Uphoff, Manuel Brekenfeld, Johannes Lang, Stephan Ritter, and Gerhard Rempe — Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Straße 1, 85748 Garching, Germany

Single atoms strongly coupled to fiber-based, high-finesse optical cavities are a promising system for applications in quantum information processing. Fiber-based cavities allow for small mode volumes and a small system size thereby improving the scalability compared to conventional Fabry-Pérot resonators. The Bragg mirrors are directly coated onto the end facets of the fibers. This requires concave structures on the end facets. Their surface has to be spherical over a large area with the surface roughness as low as possible. We report on the fabrication of such fiber ends, machined with a CO_2-laser at a wavelength of 9.3 μm. This new wavelength enables unprecedented structure sizes approaching the diameter of the fiber. We achieve a residual surface roughness well below 0.3 nm rms and investigate effects of the laser polarization on the eccentricity of the surface. We plan to fabricate cavities from these fibers that will enable strong atom-cavity coupling. The progress towards this goal will be discussed.

Q 35.38 Tue 16:00 Empore Lichthof

Charakterisierung einer deterministischen Einzelionenquelle — •Georg Jacob, Sebastian Wolf, Stefan Ulm, Johannes Rossnagel, Charlotte Degünther, Ferdinand Schmidt-Kaler und Kilian Singer — QUANTUM, Institut für Physik, Universität Mainz, Staudingerweg 7, 55128 Mainz, Germany

Ionenquellen, wie sie in Ionenmikroskopen und Focused Ion Beams Verbreitung finden, emittieren in ein sehr kleines Phasenraumvolumen, was eine Fokussierung bis auf wenige Nanometer ermöglicht. Aufgrund ihrer inhärent statistischen Natur ist es diesen nicht möglich deterministisch einzelne Ionen zu extrahieren, was jedoch für eine Reihe von Anwendungen, wie z.B. das deterministische Erzeugen von NV-Farbzentren, unabdingbar ist. Zu diesem Zweck wurde eine deterministische Einzelionenquelle auf der Grundlage einer linearen Paul-Falle entwickelt [1]. Mit einer verbesserten Version dieser Einzelionen-Quelle erreichen wir mit einer Einzelschuss Folge von 3 Ionen/s eine Strahldivergenz 30 μrad bei einer Energie von $(1352,6 \pm 0,3)$ eV, was einer Geschwindigkeitsverteilung von ungefähr 8 m/s entspricht. Um diese Messergebnisse zu stützen und realistische Startparameter für ein anschließendes Fokussieren des Strahls mittels einer elektrostatischen Einzellinse zu erzeugen, wurden zusätzlich nummerische Simulationen durchgeführt [2]. Eine entsprechende Modellierung lässt sogar Fokussradien im Sub-Nanometerbereich erwarten.

[1] W. Schnitzler *et al.*, Phys. Rev. Lett. **102**, 070501 (2009)
[2] K. Singer *et al.*, RMP **82**, 2609 (2010)

Q 35.39 Tue 16:00 Empore Lichthof

A novel ion trap design: the fibre cane trap — •Andrea Golla[1,2], Alexander L. Chekhov[3], Robert Maiwald[1,2], Patrick Uebel[2], Markus Schmidt[2,4], Markus Sondermann[1,2], Philip Russell[1,2], and Gerd Leuchs[1,2] — [1]Institute of Optics, Information and Photonics, University of Erlangen-Nuremberg, Staudtstr. 7 B2, 91058 Erlangen — [2]Max Planck Institute for the Science of Light, Guenther-Scharowsky-Str. 1 Bldg. 24, 91058 Erlangen — [3]Department of Physics, M. V. Lomonosov Moscow State University, 119991 Moscow, Russia — [4]The Institute of Photonic Technology, Friedrich Schiller University Jena, Albert-Einstein-Str. 9, 07745 Jena

We present a novel ion trap design enabling large optical access. The design is a further development of the stylus trap [1] allowing for down scaling of the trap size. The new trap is realized using a fibre cane as mounting base enabling a simplified, highly precise installation of the trap electrodes while offering large mechanical stability. The manufacturing process of this fibre cane trap will be described and the constructed trap will be presented. Furthermore, results of simulations of the trap structure and future applications will be discussed.

[1] R. Maiwald et al., Nature Physics 5, 551 (2009)

Q 35.40 Tue 16:00 Empore Lichthof

Trapping of Topological-Structural Defects in Coulomb Crystals — •Manuel Mielenz[1], Jonathan Brox[1], Haggai Landa[2], Steffen Kahra[1], Guenther Leschhorn[1], Magnus Albert[1], Benni Reznik[2], and Tobias Schaetz[1] — [1]Physikalisches Institut, Albert-Ludwigs Universität Freiburg — [2]School of Physics and Astronomy, Tel-Aviv University

We study experimentally and theoretically structural defects which are formed during the transition from a laser cooled cloud to a Coulomb crystal, consisting of tens of ions in a linear radiofrequency trap. We demonstrate the creation of predicted topological defects ('kinks') [1, 2, 3] in purely two-dimensional crystals, and also find kinks which show novel dynamical features in a regime of parameters not considered before. The kinks are always observed at the centre of the trap, showing a large nonlinear localized excitation, and the probability of their occurrence surprisingly saturates at ~ 0.5. Simulations reveal a strong anharmonicity of the kink's internal mode of vibration, due to the kink's extension into three dimensions. As a consequence, the periodic Peierls-Nabarro potential experienced by a discrete kink becomes a globally confining potential, capable of trapping one cooled defect at the center of the crystal.

[1] H. Landa *et al.*, PRL **104**, 043004 (2010)
[2] Ch. Schneider *et al.*, Rep. Prog. Phys. **75**, 024401 (2012)
[3] M. Mielenz *et al.*, submitted to PRL

Q 35.41 Tue 16:00 Empore Lichthof

Controlled interactions of two ions with an optical cavity — •Konstantin Friebe[1], Bernardo Casabone[1], Andreas Stute[1], Birgit Brandstätter[1], Klemens Schüppert[1], Tracy Northup[1], and Rainer Blatt[1,2] — [1]Institut für Experimentalphysik, Universität Innsbruck, Technikerstraße 25, 6020 Innsbruck, Österreich — [2]Institut für Quantenoptik und Quanteninformation, Österreichische Akademie der Wissenschaften, Otto-Hittmair-Platz 1, 6020 Innsbruck, Österreich

We explore the integration of optical resonators and ion traps in the context of quantum networks. We have recently demonstrated entanglement between a single trapped ion and a cavity photon as well as state mapping from the ion to the polarization state of the photon. Here we present results with two trapped ions coupled to the same cavity mode. By changing the position of the ions in the cavity standing wave, the ions' respective coupling to the mode can be accurately controlled.

By encoding a single qubit across both ions, the coupling of the qubit to the cavity mode can be increased by a factor of $\sqrt{2}$, which enables higher fidelities for state mapping from the stationary qubit to a photon. We present our plans in this direction as well as a scheme for generation of photonic cluster states as resources for measurement-based quantum computation in our setup.

Q 35.42 Tue 16:00 Empore Lichthof

Dynamical quantum teleportation — •Christine Muschik[1], Eugene Polzik[2], and Ignacio Cirac[3] — [1]ICFO-Institut de Ciencies Fotoniques, Spain — [2]Niels Bohr Institute, Denmark — [3]Max-Planck-Institute, Germany

We introduce two protocols for inducing non-local dynamics between two separate parties. The first scheme allows for the engineering of an interaction between the two remote systems, while the second protocol induces a dynamics in one of the parties, which is controlled by the other one. Both schemes apply to continuous variable systems, run continuously in time and are based on instantaneous feedback.

Q 35.43 Tue 16:00 Empore Lichthof

Quantum sensing using vacuum forces — •Christine Muschik[1], Simon Moulieras[1], Kanupriya Sinha[2], Frank Koppens[1], Maciej Lewenstein[1], and Darrick Chang[1] — [1]ICFO-Institut de Ciencies Fotoniques, Spain — [2]University of Maryland, US

We propose a scheme, which harnesses quantum vacuum forces for practical applications. Casimir Forces become extremely strong at very short distances. We use this mechanism to coupling a quantum emitter to a suspended graphene membrane. This setup allows for an instantaneous and highly sensitive read-out the position of the graphene sheet, which has important applications for mass and force sensing. Since the coupling via the Casimir force is very strong, it is also a very valuable tool for engineering the quantum state of the membrane and for investigating the damping mechanisms of moving graphene in a hitherto inaccessible regime of precision.

Q 35.44 Tue 16:00 Empore Lichthof

Single atom cavity quantum electrodynamics with non-transversally polarized light fields — •Christian Junge, Danny O'Shea, Jürgen Volz, and Arno Rauschenbeutel — Vienna Center for Quantum Science and Technology, TU Wien, Atominstitut, Stadionallee 2, A-1020 Wien, Austria

Whispering-gallery-mode (WGM) microresonators are versatile devices for enhancing light–matter interaction. They combine ultra high quality factors and small mode volumes with near lossless in- and outcoupling of light via tapered fiber couplers. Here, we report on a cavity quantum electrodynamics (CQED) experiment in which single ^{85}Rb atoms interact in the strong coupling regime with a WGM in an ultra high-Q bottle microresonator. We present optical transmission spectra of our system that fundamentally deviate from the predictions of the established theoretical model for CQED in ring resonators. We identify the non-transversal character of the field of WGMs as the origin of this discrepancy. Excellent agreement is found between our data and the predictions of an extended theoretical model that accounts for the full vectorial description of the WGMs. Our studies demonstrate that the non-transversal character of WGMs allows one to realize a paradigmatic quantum system that is ideally suited for basic studies as well as for technological applications.

Q 35.45 Tue 16:00 Empore Lichthof

Weakening of superradiance due to dipole-dipole interactions — •François Damanet and John Martin — Institut de Physique Nucléaire, Atomique et de Spectroscopie, Université de Liège, Bât. B15, B - 4000 Liège, Belgium

Superradiance, known as the cooperative spontaneous emission of a directional light pulse by excited atoms placed in vacuum, has recently regained attention in the context of photon localization [1] and single photon cooperative emission [2]. The dissipative dynamics of the atoms is known to depend dramatically on the ratio between the typical interatomic distance and the atomic transition wavelength, notably because of dipole-dipole interactions [3]. In this work, we study the effects of these interactions on superradiance as in [4] by solving numerically the corresponding master equation. In particular, by averaging over many realizations of the randomly distributed atomic positions, we show that the decay of the radiated energy pulse height with the intensity of the dipolar coupling follows a power law.

[1] E. Ackermans, A. Gero & R. Kaiser, Phys. Rev. Lett. 101, 103602 (2008).
[2] R. Friedberg & J. T. Manassah, J. Phys. B 43, 035501 (2010).
[3] M. Gross & S. Haroche, Physics reports 93, 301-396 (1982).
[4] B. Coffey & R. Friedberg, Phys. Rev. A 17, 1033 (1978).

Q 35.46 Tue 16:00 Empore Lichthof

Decoherence of the Orientation state — •Timo Fischer and Klaus Hornberger — Universität Duisburg-Essen

We introduce a Lindblad master equation describing the decoherence of the orientation state of extended quantum objects, such as molecules. Using the Monte Carlo unravelling the master equation is analyzed numerically. We further determine the pointer states of the master equation, i.e. the pure states which are minimally affected by the environment. They result from the competition of two opposing effects, the dispersion caused by the coherent part of the dynamics and the localization induced by the interaction with the environment [1]. To this end, we solve an associated nonlinear equation for pointer states.

[1] Pointer basis induced by collisional decoherence, M. Busse and K. Hornberger, J. Phys. A **43** (2010)

Q 35.47 Tue 16:00 Empore Lichthof

Control and manipulation of the nuclear spin bath via continuous measurement and feedback — •Julia Michl[1], Christian Burk[1], Philipp Neumann[1], Jason Twamley[2], and Jörg Wrachtrup[1] — [1]3. Institute of Physics, University Stuttgart, D-70550 Stuttgart — [2]MQ Research Center for Quantum Science and Technology, Maquarie University, NSW 2109, Australia

The detailed control of the electron and surrounding nuclear spins of the nitrogen vacancy (NV) defect in diamond is of interest both for sensing applications as well as for quantum information processing. Detailed control of these spins is hampered by decoherence from the extended surrounding nuclear spin bath consisting of ^{13}C nuclear spins. Researchers have previously shown that it is possible to control quantum systems via pulsed measurements and feedback in optomechanics. We theoretically describe how a similar protocol can be implemented in the solid-state spin to allow the NV to manipulate the surrounding nuclear spin bath to achieve a complete purification of the bath, to prepare the bath in a fully polarized state or to prepare highly spin squeezed states of the bath. By achieving detail control over the surrounding nuclear spins allows for greatly extended spin dephasing times for the electron spin of the NV and the potential use of the spin squeezed bath for improved sensing.

Q 35.48 Tue 16:00 Empore Lichthof

Electron spin decoherence of divacancy defect center in silicon carbide nuclear spin baths — •Christian Burk[1], Julia Michl[1], Nan Zhao[2], and Jörg Wrachtrup[1] — [1]3. Physikalisches Institut, Universität Stuttgart, 70550 Stuttgart, Germany — [2]Beijing Computational Science Research Center, Beijing 100084, China

The neutral divacancy in silicon carbide is a defect center which can be controlled coherently. It is very similar to the well-known nitrogen-vacancy center in diamond, as it is also a paramagnetic defect center in a solid with a spin $S = 1$ ground state, and can be polarized via excitation into an excited state and an alternate decay path over a metastable singlet state, which also allows for optical readout. Thus it is a promising system for quantum information processing or as a magnetic probe for sensing. Since the defect center is embedded in a lattice consisting of carbon and silicon atoms, there can be stable spin bearing isotopes of these atoms. Those isotopes (^{13}C and ^{29}Si, both with spin $S = 1/2$) act as a source of decoherence. Since there are too many relevant interactions between the divacancy and the nuclear spins and the nuclear spins with each other to completely include them all in calculations, the nuclear spins are generally treated as an environment or more specifically as a nuclear spin bath for the central electron spin. To effectively manipulate a defect center, the effects that occur due to the interaction with its environment have to be understood. To overcome the limitation, that prevents a purely quantum mechanical treatment of the bath due to its size, a cluster correlation expansion for this system was applied.

Q 35.49 Tue 16:00 Empore Lichthof

König-digraph Interaction Model of Decoherence and Quantum Darwinism — •Nenad Balaneskovic[1], Gernot Alber[1], and Jaroslav Novotny[1,2] — [1]Institut für Angewandte Physik, Technische Universität Darmstadt, D-64289 Darmstadt, Germany — [2]Department of Physics, FNSPE, Czech Technical University in Prague, 115 19 Praha 1 - Stare Mesto, Czech Republic

We discuss characteristic properties of pure decoherence and Quantum Darwinism based on qubit-models of open systems interacting with their respective environment by iterated and randomly applied controlled-NOT-type operations. From the analytically determined asymptotic dynamics of the resulting quantum Markov chain the Quantum Darwinistic appearance of Classicality and its connection to König-digraph interaction models of pure decoherence can be investigated.

König-digraph interactions comprise environmental qubits which do not interact among themselves by unitary quantum operations and are thus suitable to physically describe objective quantum measurements performed on an open system by autonomous observers (environmental qubits). König-digraph interactions also account for the most efficient storage of the classical information about a system of interest into its environment. Since the efficiency of the mentioned information storage is also connected with the concept of Quantum Darwinism, we therefore address possible limits of Quantum Darwinism as a valid physical mechanism leading to the appearance of objective reality.

Q 35.50 Tue 16:00 Empore Lichthof

Pointer states of a marker particle in an ideal gas environment — •Lutz Sörgel and Klaus Hornberger — Fakultät für Physik, Universität Duisburg-Essen

We study a quantum test particle interacting with an ideal gas environment via collisions, an important system for understanding the quantum-to-classical transition of particle motion. We consider first the case of collisional decoherence (i.e. the limit of a very massive test particle) and then the general effect of collisions. The latter is described by the quantum linear Boltzmann equation [1], which accounts also for the friction and thermalization experienced by the test particle. An orthogonal unraveling of collisional decoherence shows that the emerging pointer states follow classical trajectories in phase space [2]. Based on that we aim at characterizing the pointer states of the quantum linear Boltzmann equation and finding their equations of motion.

[1] B. Vacchini, K. Hornberger, Phys. Rep. 478 (2009)
[2] M. Busse, K. Hornberger, J. Phys. A 43 (2010)

Q 35.51 Tue 16:00 Empore Lichthof

Non-equilibrium states of two oscillators coupled to separate baths — Giuseppe Cammarata[1], •Carsten Henkel[2], Benjamin Schäfer[3], and Illarion Dorofeyev[4] — [1]Institute of Mathematics, Universität Potsdam, Germany — [2]Institute of Physics and Astronomy, Universität Potsdam, Germany — [3]Universität Göttingen, Germany — [4]Russian Academy of Sciences, Nizhny Novgororod, Russia

Oscillators coupled to heat baths have a long tradition as models for dissipative systems in statistical and quantum mechanics [1]. We apply quantum Langevin equations to a system of two oscillators with a bilinear coupling [2]. Spectral representations for the mean energy of interaction and the covariance matrix of the canonical coordinates are derived and discussed [3]. Of particular interest are shifts in the eigenfrequencies as the coupling is increased, the thermal equilibrium situation and the quantum correlations between the oscillators if the attached baths have different temperatures. In addition, we provide a survey of quantization schemes starting from a classification of couplings between classical oscillators.

[1] P. Ullersma, Physica 32 (1966) 27-96; R. J. Rubin, Phys. Rev. 131 (1963) 964.
[2] J. P. Paz and A. J. Roncaglia, Phys. Rev. Lett. 100 (2008) 220401
[3] I. Dorofeyev, arXiv:1207.3881

Q 35.52 Tue 16:00 Empore Lichthof

Spatial decoherence of ions near surfaces — •Kristine Karstens and Stefan Scheel — Institut für Physik, Universität Rostock, 18051 Rostock, Germany

Decoherence is a fundamental mechanism that destroys quantum mechanical superpositions of quantum states. It provides a limiting factor in the ability to coherently manipulate quantum systems such as atoms or ions. One particular example is path decoherence of coherently split particle beams [1].

Here we derive an expression for the spatial decoherence rate of coherently split beams of ions near metallic and superconducting surfaces. Our investigation is based on the formalism of macroscopic quantum electrodynamics [2] and the decoherence functional [3]. We evaluate the contributions of the possible charge-charge, charge-dipole and dipole-dipole interactions between the particles and their mirror images [4].

[1] P. Sonnentag and F. Hasselbach, Phys. Rev. Lett. **98**, 200402 (2007).
[2] S. Scheel and S. Y. Buhmann, Acta Phys. Slov. **58**, 675 (2008).
[3] H.-P. Breuer and F. Petruccione, *The Theory of Open Quantum Systems*, Oxford University Press, Oxford (2002).
[4] S. Scheel and S. Y. Buhmann, Phys. Rev. A **85**, 030101 (2012).

Q 35.53 Tue 16:00 Empore Lichthof

Decoherence of driven quantum systems — Walter Strunz and •Nina Megier — Institut für Theoretische Physik, TU Dresden

Based on exactly solvable models we investigate qubit decoherence under influence of time depending driving. We compare our findings to the usual quantum optical master equations approaches and discuss implications for nonequilibrium thermodynamics.

Q 35.54 Tue 16:00 Empore Lichthof

Spectral diffusion measurements on the zero phonon line of single nitrogen-vacancy centers diamond — •Niko Nikolay, Max Strauss, Nikola Sadzak, Janik Wolters, and Oliver Benson — Humboldt Universität zu Berlin, Nano-optics, Berlin, Germany

Nitrogen-vacancy (NV) centers in diamond have proven to be a promising resource for quantum technology. In particular, the NV center in bulk diamond is attractive as a source of indistinguishable single photons, as it provides a narrow zero phonon line (ZPL) at the optical 3A * 3E transition at 638 nm [1]. Furthermore the ZPL can be used for spin measurements and entanglement experiments [2]. However, fast fluctuations of the transition line, known as spectral diffusion are a major problem. Performing photon-correlation interferometry measurements [3] we determine the time-scale of the spectral diffusion and gain further knowledge about the underlying processes in bulk diamond, as well as in nano diamonds. In the future, our results will help to tackle the problem of spectral diffusion of NV centers in diamond.

[1] Two-Photon Quantum Interference from Separate Nitrogen Vacancy Centers in Diamond, H. Bernien et al., Physical Review Letters 108, 1*5 (2012).
[2] Quantum entanglement between an optical photon and a solid-state spin qubit, E. Togan et al., Nature 466, 730*4 (2010).
[3] Measurement of the ultrafast spectral diffusion of the optical transition of nitrogen vacancy centers in nano- size diamond using correlation interferometry, J. Wolters et al., Physical Review Letters, in press, arXiv:1206.0852.

Q 35.55 Tue 16:00 Empore Lichthof

Implementation of a waveguide based source of polarization entangled photon pairs — •Xu Yang, Harald Herrmann, Abu Thomas, Wolfgang Sohler, and Christine Silberhorn — Universität Paderborn, Integrierte Quantenoptik, Warburger Str. 100, D-33098 Paderborn

We designed and demonstrate an integrated source of entangled photon pairs based on spontaneous parametric downconversion (PDC) in a periodically poled Ti:LiNbO3 waveguide with Type-II quasi-phase-matching. The waveguide consists of two specially tailored interlaced periodicities to allow for two different phase-matched PDC processes exhibiting identical non-degenerate frequencies, but interchanged polarizations for the signal and idler photons. Thus the direct generation of polarization entangled state can be obtained at the output of the waveguide. Using standard polarization maintaining fibers we compensated the temporal walk-off caused by the birefringence of the crystal. Subsequent wavelength dependent splitting of the photon pairs was implemented by using a fiber based coarse wavelength division multiplexer. We characterized the polarization entangled photon pair by performing the two-photon interference and observe a visibility as high as of 95%, and a measured value of 2.57*0.06 of the Bell's inequality, with a violation of more than 9 standard deviations.

Q 35.56 Tue 16:00 Empore Lichthof

Stabilizing entanglement against local dissipation — Simeon Sauer, •Clemens Gneiting, and Andreas Buchleitner — Albert-Ludwigs-Universität, Freiburg, Germany

Natural dissipative processes in multipartite quantum systems are mostly of local nature and therefore affect entanglement adversely. In their presence, initially highly entangled states generically evolve into at most weakly entangled states. We investigate by what means this detrimental process can be counteracted. It is shown that a suitable, dissipator-adapted static system Hamiltonian can preserve entanglement in the stationary state to a significant but limited extend. We then extend our analysis to the general class of periodically driven Hamiltonians and show that they are subject to similar limitations. Finally, we develop incoherent but local control strategies which overcome these limits.

Q 35.57 Tue 16:00 Empore Lichthof

Stochastic approach to thermal states in the reduced system space — •Richard Hartmann — Institut für theoretische Physik, TU Dresden, Germany

We investigate a stochastic method to calculate the reduced density operator of a system for a total thermal state of a coupled system + bath model. We use that a coherent state representation of the bath allows for a stochastic interpretation of the dynamic equation. This technique was developed by Diosi, Strunz et al. [1] to efficiently calculate the reduced system dynamics in a stochastic manner. The numerical solutions of the stochastic equation are examined for soluble systems and compared to their known analytical solutions. We investigate the connection between such thermal states and time evolved reduced system states which have been in long time interaction with the bath.

[1] L. Diosi, W. T. Strunz, Physics Letters A 235, 569*573 (1997).

Q 35.58 Tue 16:00 Empore Lichthof

Finite Temperature Simulations of Exciton Dynamics in Biological Structures — •Robert Rosenbach[1], Alex W. Chin[2], Javier Prior[3], Felipe Caycedo-Soler[1], Susana F. Huelga[1], and Martin B. Plenio[1] — [1]Institut für Theoretische Physik, Universität Ulm — [2]Theory of Condensed Matter Group, Cavendish Laboratory, University of Cambridge — [3]Departamento de Física Aplicada, Universidad Politécnica de Cartagena

The Time Evolving Density Matrix with Orthogonal Polynomial Algorithm (TEDOPA) is a numerically exact technique to simulate open quantum systems interacting with arbitrarily structured environments. The algorithm has been developed in order to analyse excitonically coupled systems in structures of biological relevance at physiological temperatures, though there is a wide range of applications in solid state physics as well.

These technical developments are illustrated, based upon its successful application to reproduce the experimental observation of long-lived coherences in the Fenna-Matthews-Olson complex. Further applications regarding similar harvesting pigment protein structures are also considered.

Q 35.59 Tue 16:00 Empore Lichthof

Energy transfer dynamics in structured environments — •Daniel Süss and Walter T. Strunz — Institut für Theoretische Physik, TU Dresden

We determine energy transfer dynamics in molecular aggregates influenced by a structured quantum environment using a stochastic Schrödinger equation approach to open quantum systems [1]. A solution is presented in terms of a hierarchy of pure-state equations motivated by the corresponding framework for density operators [2].

[1] J. Roden, A. Eisfeld, W. Wolff and W.T. Strunz, Phys. Rev. Lett. 103, 058301 (2009) [2] Y. Tanimura, J. Phys. Soc. Jpn. 75, 082001 (2006)

Q 35.60 Tue 16:00 Empore Lichthof

MAIUS - a Bose-Einstein-Condensate in a sounding rocket — •André Kubelka[1], Sven Herrmann[1], and the QUANTUS-TEAM[1,2,3,4,5,6,7,8,9] — [1]ZARM, Universität Bremen — [2]Institut für Quantenoptik, LU Hannover — [3]Institut für Physik, HU Berlin — [4]Institut für Laserphysik, Universität Hamburg — [5]Institut für Quantenphysik, Universität Ulm — [6]Institut für angewandte Physik, TU Darmstadt — [7]MUARC, University of Birmingham, UK — [8]FBH, Berlin — [9]DLR RY, Bremen

MAIUS will be an atom-optical experiment that will show the feasibility of experiments with ultra-cold quantum gases in microgravity in a sounding rocket. The MAIUS setup will be able to produce a sample of ultra-cold atoms on-board a sounding rocket of the type VSB-30 launched at Esrange, Sweden. It is designed to create a Bose-Einstein-Condensate of 10^5 ^{87}Rb-atoms in less than 5 s and to observe its evolution over periods on the order of a few seconds. In addition, the properties of the sample shall be probed using atom interferometric techniques. The laser fields and magnetic fields used for trapping and manipulating the atoms will be created by hardware specifically designed to meet the requirements of a rocket mission. Special attention is thereby also spent on the appropriate magnetic shielding. A three layer magnetic shield provides a high shielding factor for an undisturbed operation of the experiment.
The QUANTUS project is supported by the German Space Agency DLR with funds provided by the Federal Ministry of Economics and Technology (BMWi) under grant number DLR 50 WM 1135.

Q 35.61 Tue 16:00 Empore Lichthof

Compact electronics for laser system in microgravity — •Thijs Wendrich, Wolfgang Ertmer, and Ernst Maria Rasel — Leibniz Universität Hannover, Institut für Quantenoptik

Microgravity experiments with ultra cold degenerate quantum gases require very compact and robust apparatuses. The LASUS project develops miniaturized and robust diode lasers, optical modules and electronics for use in the drop tower in Bremen and in space. In this poster we present the FPGA-based electronics for a complete experiment, fitting in a volume of less than a few liters. These electronics allow for a fully automated laser locking system to enable long term operation without manual intervention outside the lab. The LASUS project is a collaboration of FBH Berlin, HU Berlin, U Hamburg and LU Hannover supported by the German Space Agency DLR with funds provided by the Federal Ministry of Economics and Technology (BMWi) under grant number 50WM1239.

Q 35.62 Tue 16:00 Empore Lichthof

A miniaturized, high flux BEC source for precision interferometry — •Jan Rudolph[1], Ernst Maria Rasel[1], and The QUANTUS Team[1,2,3,4,5,6,7,8,9] — [1]Institut für Quantenoptik, Leibniz Universität Hannover — [2]ZARM, Universität Bremen — [3]Institut für Physik, HU Berlin — [4]Institut für Laser-Physik, Universität Hamburg — [5]Institut für Quantenphysik, Universität Ulm — [6]Institut für angewandte Physik, TU Darmstadt — [7]MUARC, University of Birmingham — [8]FBH, Berlin — [9]MPQ, Garching

Atom chips have proven to be excellent sources for the fast production of ultra-cold gases due to their outstanding performance in evaporative cooling. However, the total number of atoms has previously been limited by the small volume of their magnetic traps. To overcome this restriction, we have developed a novel loading scheme that allows us to produce Bose-Einstein condensates of a few 10^5 ^{87}Rb atoms every two seconds. The apparatus is designed to be operated in microgravity at the drop tower in Bremen, where even higher numbers of atoms can be achieved in the absence of any gravitational sag.

Using the drop tower's catapult mode, our setup will perform atom interferometry during nine seconds in free fall. Thus, the fast loading scheme allows for interferometer sequences of up to seven seconds – interrogation times which are inaccessible for ground based devices.

The QUANTUS project is supported by the German Space Agency DLR with funds provided by the Federal Ministry of Economics and Technology (BMWi) under grant number DLR 50WM1131.

Q 35.63 Tue 16:00 Empore Lichthof

Analysis of electron-wave decoherence near a semiconducting surface — Regine Frank, •Thimo Böhl, Henrike Prochel, Alexander Rembold, and Alexander Stibor — Physikalisches Institut, Tübingen, Deutschland

Dissipation and localization effects lead to decoherence. Novel quantum devices, such as hybrid quantum systems, exist in the transition region between a pure quantum state and a classical object. Understanding the strength of distinct decoherence mechanisms is still a challenge, which needs to be solved to realize new technical applications in the quantum regime. Here we describe an experiment were electron wave decoherence is observed in a biprism interferometer in the vicinity of a semiconducting plate [1]. An electron beam is separated by a fine biprism wire and guided a few micrometers above a silicon waver where interference and naturally decoherence occurs. The separated electron states gain 'which-path' information, when the electron wave suffers dissipation or it is weakly localized at the surface of the silicon waver. It can be clearly observed, that the interference contrast decreases with smaller beam distances towards the surface. We compare the results to an 'ab inito' theoretical description of electronic interaction and decoherence above a semiconductor surface. Decoherence is perfectly suited for investigations of material properties, so it might be possible to distinguish surface effects from bulk influences by fine-tuning the distance of flight above the surface.

[1] P. Sonnentag and F. Hasselbach, PRL **98**, 200402 (2007)

Q 35.64 Tue 16:00 Empore Lichthof

Quantum optical experiments with charged matter-waves — •Annika Bräuer, Georg Schütz, Alexander Rembold, Andreas Pooch, Henrike Prochel, and Alexander Stibor — Physikalisches Institut, Tübingen, Germany

In the history of quantum optics most experiments have been performed with neutral particles or pointlike electrons. The advantage of neutral atoms and molecules is the possibility to manipulate their inner structure, e.g. with lasers or by thermic excitation. The benefit of electrons is their easy manipulation. Both characteristics can be combined by performing interferometry experiments with ions and charged molecules. We present the setup and current status of the first stable ion biprism-interferometer based on [1] and propose novel quantum optical experiments in connection with the ion structure dependency in the magnetic and electrostatic Aharonov-Bohm effects. Helium ions are thereby field emitted from a novel single atom tip. They are separated and combined by an electrostatic biprism. Such interferometers have interesting technical prospects as highly sensitive detectors for rotation and acceleration. We additionally propose an experiment, where a charged particle biprism-interferometer can be used to measure the energy distribution of coherent field emitted electrons from a fine superconducting niobium tip. These sources could potentially create extremely monochromatic and coherent electron beams.

[1] F. Hasselbach and U. Maier, 1999 Quantum Coherence and Decoherence, ISQM, Tokyo, p. 299

Q 35.65 Tue 16:00 Empore Lichthof

Ray tracing for matter-waves — •Mathias Schneider and Reinhold Walser — Institut für Angewandte Physik, TU Darmstadt

The development of quantum limited acceleration and rotation devices is a key research direction. In the context of ultra-cold matter-waves, whether thermal clouds or Bose-Einstein condensates, this is usually realized with interferometers. The design of high precision optical devices, in particular optical interferometers, does not rely on the full Maxwell's equations but only on efficient semi-classical ray tracing methods. In the same spirit, we approximate the dynamics interacting thermal clouds or Bose-Einstein condensates with a ray tracing formalism that is very suited for realistic experimental setups. We employ the effective single-particle Wigner function as a phase-space representation of the atom cloud. A major virtue of this formulation is that, once the distribution is known for the initial state, it can be calculated at arbitrary times by merely propagating its values along the phase-space flow. The trajectories comprising this flow can be considered the matter-wave rays. In addition to this ray aspect, the phase-space formulation leads to a simple approximation scheme for the interacting stationary state at finite temperature. This Lambert-approximation interpolates between the Thomas-Fermi approximation of strongly interacting gases and the Maxwell-Boltzmann distribution for ideal gases.

Q 35.66 Tue 16:00 Empore Lichthof

A low-noise optical dipole trap as a source for matter wave interferometry — •Jonas Matthias, Jonas Hartwig, Dennis Schlippert, Ulrich Velte, Henning Albers, Wolfgang Ertmer, and Ernst M. Rasel — Institut für Quantenoptik and Centre for Quantum Engineering and Space-Time Research - QUEST, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover, Germany

We present our intensity stabilization design for an optical dipole trap (ODT) at a wavelength of 2 μm using a Pockels cell and a digital feedback loop. Since the response of a Pockels cell and an analyzer is non-linear we implement a linear feedback and a linearization of the response function in a field programmable gate array (FPGA). This enables high feedback loop performance independent of the nonlinear response.

The low-noise ODT allows for control of the initial position of the cold atomic cloud with high repeatability as a source for matter wave interferometry. Applications include loading the ODT from a single species magneto-optical (MOT) trap as well as from a ^{87}Rb/^{39}K dual-species MOT.

Q 35.67 Tue 16:00 Empore Lichthof

Towards an inertial sensitive ^{39}K matter wave interferometer — •Henning Albers, Jonas Hartwig, Dennis Schlippert, Ulrich Velte, Jonas Matthias, Wolfgang Ertmer, and Ernst M. Rasel — Institut für Quantenoptik and Centre for Quantum Engineering and Space-Time Research - QUEST, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover, Germany

We report on our work directed towards a space-time enclosing ^{39}K matter-wave interferometer.

Due its relatively low atomic mass and the small excited state hyperfine splitting on the order of only few linewidths ^{39}K is rather hard to cool. Therefore we investigate methods for efficient sub-Doppler cooling, e.g. dark optical molasses techniques, UV-cooling and prospects of evaporative and/or sympathetic cooling in an optical dipole trap.

We employ a three-dimensional magneto-optical trap (3D-MOT) loaded from a 2D-MOT. Our laser system is based on lasers phase-locked to a spectroscopy-locked reference laser. Frequencies for cooling, repumping and detection, as well as the light for driving stimulated Raman-transitions are then generated using double-pass acousto-optical modulators yielding both simplicity and stability. Also, cooling and repumping light are amplified in the same tapered amplifiers with only low losses into sidebands due to four-wave mixing. The laser system provides a total of 3W output power. We discuss performing a differential measurement of the acceleration of free falling ^{87}Rb and ^{39}K atoms to test Einstein's equivalence principle (universality of free fall).

Q 35.68 Tue 16:00 Empore Lichthof

Tidal Corrections for Free Falling Relativistic Bose-Einstein Condensates — •Oliver Gabel and Reinhold Walser — Institut für Angewandte Physik, Technische Universität Darmstadt, Hochschulstr. 4a, 64289 Darmstadt

On Earth, the release of trapped Bose-Einstein condensates is usually an auxiliary tool for exploring the properties of matter waves. However, in the QUANTUS experiment [1] the exploration of free-fall physics in microgravity and the Einstein equivalence principle are at the centre of attention.

In a recent article [2], we have formulated a relativistic mean field theory for Bose-Einstein condensates in a given background metric. In this contribution we explore the dominant corrections of the field equation in the non-relativistic limit, i. e., the local tidal corrections, which constitute additional harmonic potentials around the centre of mass [3]. In particular, we evaluate the magnitude of the interferometric phase shift originating from this tidal potential.

[1] T. van Zoest et. Al., *Bose-Einstein Condensation in Microgravity*, Science, **328**, 1540 (2010).
[2] O. Gabel, and R. Walser, *Relativistic corrections to free falling Bose-Einstein condensates in micro-gravity*, submitted (2013)
[3] 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**, 63617 (2007).

Q 35.69 Tue 16:00 Empore Lichthof

Atom interferometry with Bose-Einstein condensates in microgravity — •André Wenzlawski[1], Patrick Windpassinger[1], Klaus Sengstock[1], and the Quantus team[1,2,3,4,5,6,7,8,9] — [1]Institut für Laser-Physik, Universität Hamburg — [2]Institut für Quantenoptik, Universität Hannover — [3]Institut für Physik, HU Berlin — [4]ZARM, Universität Bremen — [5]Institut für angewandte Physik, TU Darmstadt — [6]Institut für Quantenphysik, Universität Ulm — [7]MUARC, University of Birmingham, UK — [8]FBH, Berlin — [9]MPQ, Garching

Atom interferometers have emerged as a standard tool for highly precise inertial measurements. The achievable precision strongly depends on the interrogation time which is why a BEC with its narrow momentum distribution serves as an ideal source for these type of sensors. Since the first realization of a Bose-Einstein condensate in microgravity in the Bremen drop tower [1] we were able to observe the free expansion of ultra-cold atoms for up to 2s, which allows for the realization of matter wave interferometers of unprecedented sensitivities. Furhtermore we could demostrate a matter wave interferometer based on stimulated Bragg scattering with which we will show the feasibility of bringing BEC-based atom interferometry into microgravity.

The QUANTUS Project is supported by the German Space Agency (DLR) with funds provided by the Federal Ministry of Economics and Technology (BMWi) under grant number DLR 50WM1131-1137.

[1] T. van Zoest et al., Science **328**, 1540 (2010).

Q 35.70 Tue 16:00 Empore Lichthof

Laser stabilization to a frequency comb for an optical clock — •Nils Scharnhorst, Jannes B. Wübbena, Sana Amairi, and Piet O. Schmidt — QUEST Institute of Experimental Quantum Metrology, Physikalisch-Technische Bundesanstalt and Leibniz Universität Hannover, Bundesallee 100, D-38116 Braunschweig, Germany

The goal of our project is to build a transportable optical clock based on a single aluminium ion using quantum logic spectroscopy with a co-trapped calcium ion [1]. We give an overview of our clock and the required lasers for laser cooling and clock interrogation. Laser frequency stabilisation is performed by phase-locking all lasers to an optical frequency comb. The repetition rate of the frequency comb can either be locked to a maser, which is referenced to the caesium fountain at PTB, or to a cavity-stabilized laser. The beat signal between the frequency comb and each laser contains the noise of the offset beat, which is fundamentally limited by the feedback bandwidth to the frequency comb. In our scheme the offset beat is electronically subtracted from the beat signals, thus eliminating its noise contribution [2]. The repetition rate can be tightly locked to the reference signal through an intra-cavity electro-optical modulator in the frequency comb's oscillator.

For the stabilization of a laser to the frequency comb a combination of a phase-frequency comparator for slow frequencies and a PI-controller for fast frequencies improves the long-term stability of our laser-lock.

[1] P. O. Schmidt et al., Science 309, 749-752 (2005).
[2] J. Stenger et al., Phys. Rev. Lett. 88, 073601 (2002).

Q 35.71 Tue 16:00 Empore Lichthof

Laser system technology for quantum gas experiments on a sounding rocket — •Markus Krutzik[1], The LASUS Team[1,2,3,4], and The QUANTUS Team[1,2,3,4,5,6,7,8,9] — [1]Institut für Physik, HU Berlin — [2]Ferdinand-Braun-Insitut, Leibniz Institut für Höchstfrequenztechnik, Berlin — [3]Institut für Quantenoptik, LU Hannover — [4]Institut für Laserphysik, U Hamburg — [5]ZARM, U Bremen — [6]Institut für Quantenphysik, U Ulm — [7]MPQ, Garchin — [8]Institut für angewandte Physik, TU Darmstadt — [9]Midlands Ultracold Atom Research Centre, University of Birmingham, UK

Autonomous experiments with ultra cold quantum gases on microgravity platforms can place fundamental physics in a unique position to adress some of the most significant questions of modern science, such as testing the weak equivalence principle. As an important next stepping stone with regard to space qualification, MAIUS aims at realizing Bose-Einstein condensates and investigating its coherence properties onboard a double-stage sounding rocket. In this poster, we present the current status of our laser system in detail. Special challenges in the construction are posed by the extreme environment, putting stringent requirements in terms of robustness, miniaturization and redundancy. All critical subsystems successfully passed mechanical vibration tests, that simulate the mechanical loads of a sounding rocket launch.

The QUANTUS and LASUS project are supported by the German Space Agency DLR with funds provided by the Federal Ministry of Economics and Technology (BMWi) under grant numbers DLR 50 WM 1131-1137 and 1237-1240.

Q 35.72 Tue 16:00 Empore Lichthof

A compact laser system for dual species atom interferometry — Christoph Grzeschik[1], •Kai Lampmann[1,2], Max Schiemangk[1,2], Markus Krutzik[1], Achim Peters[1,2], and The QUANTUS Team[1,2,3,4,5,6,7,8,9] — [1]Institut für Physik, HU Berlin — [2]Ferdinand-Braun-Institut, Leibniz-Institut für Höchstfrequenztechnik, Berlin — [3]Institut für Quantenoptik, LU Hannover — [4]Institut für Laserphysik, U Hamburg — [5]ZARM, U Bremen — [6]Institut für Quantenphysik, U Ulm — [7]MPQ, München — [8]Institut für angewandte Physik, TU Darmstadt — [9]Midlands Ultracold Atom Research Centre, University of Birmingham, UK

We present a compact and integrated laser system for dual-species interferometry being capable of testing the universality of free fall with rubidium and potassium atoms in microgravity. The setup is built around a set of hybrid-integrated master-oscillator power-amplifier modules consisting of a distributed feedback laser diode, coupled into a tapered amplifier, providing output power in the Watt range and an intrinsic linewidth below 200 kHz. Results from several catapult launches at the droptower in Bremen with acceleration loads up to 50 g demonstrate the stability and ruggedness of the complete system. We discuss the electro-optical properties in detail, including the implementation and performance of compact laser electronics and FPGA-based digital frequency locking circuits.

The QUANTUS project is supported by the German Space Agency DLR with funds provided by the Federal Ministry of Economics and Technology (BMWi) under grant numbers DLR 50WM 1131-1137.

Q 35.73 Tue 16:00 Empore Lichthof

Zerodur based laser systems for precision measurements in micro-gravity — •Mona Rafipoor[1], Hannes Duncker[1], and the LASUS Team[1,2,3,4] — [1]Institut für Laser-Physik, U Hamburg — [2]Institut für Physik, HU Berlin — [3]Ferdinand-Braun-Institut, Berlin — [4]Institut für Quantenoptik, LU Hannover

Ballistic rockets provide several minutes of micro-gravity and thereby promise to improve the precision of interferometric measurements with matter waves. However, a rocket launch poses stringent requirements on the employed components in terms of thermal and mechanical stress yet to be met by commercial products. To pave the way for the next generation of quantum precision experiments in micro-gravity, e.g. on sounding rockets, we developed laser system technology based on Zerodur within the project Lasus. The components and integrated systems benefit from the vanishing thermal expansion of Zerodur and its mechanical robustness.

The LASUS project is supported by the German Space Agency DLR with funds provided by the Federal Ministry of Economics and Technology (BMWi) under grant number 50WM1238.

Q 35.74 Tue 16:00 Empore Lichthof

CASI Cold Atom Gyroscope Experiment — •Sven Abend, Peter Berg, Gunnar Tackmann, Katja Baxmann, Teresa Feld, Paul Kaebert, Christian Schubert, Wolfgang Ertmer, and Ernst M. Rasel — Institut für Quantenoptik, Leibniz Universität Hannover

We report on recent progress of the Cold Atom Sagnac Interferometer (CASI) experiment at Leibniz Universtity of Hannover. This experiment demonstrates the use of cold atomic ensembles to measure ultra-slow rotations via the Sagnac effect with a sensitivity of $5.3\ 10^{-7}$rad/s. Atomic superposition states enclose areas as large as 19 mm^2 on a rather short baseline of 13.7 cm. We present several methods of modulating the interferometric phase via the reference mirrors and therefore a precise tool to compensate drift behaviours of the sensor. A careful analysis should allow to overcome our current limitation of $3\ 10^{-8}$rad/s and to measure Earth's rotation rate at the 10^{-9} rad/s level. This work is supported by the DFG, the cluster of excellence QUEST, and IQS.

Q 35.75 Tue 16:00 Empore Lichthof

Projekt FOKUS (Faserlaserbasierter Optischer Kammgenerator unter Schwerelosigkeit) — •Tobias Wilken[1,2], Matthias Lezius[2], Theodor W. Hänsch[1], Ronald Holzwarth[1,2], Anja Kohfeldt[3], Andreas Wicht[3], Hannes Duncker[4], Ortwin Hellmig[4], Patrick Windpassinger[4], Klaus Sengstock[4], Vladimir Schkolnik[5], Markus Krutzik[5] und Achim Peters[3,5] — [1]MPQ, Garching — [2]Menlosystems GmbH, Martinsried — [3]FBH, Berlin — [4]UHH, Hamburg — [5]HUB, Berlin

Im April 2013 wird im Rahmen des Projektes FOKUS die Technologiereife eines Frequenzkammes auf der Höhenforschungsrakete TEXUS 51 demonstriert und ein Test zur Universalität der gravitativen Rotverschiebung durchgeführt. Dieses Prinzip besagt, dass zwei Uhren in einem veränderlichen Gravitationspotential synchron gehen, unabhängig von ihrem inneren Aufbau. Das Experiment besteht aus einem Frequenzkamm, der auf einen Radiofrequenzübergang in Rubidium stabilisiert ist und einem mikrointegrierten DFB-Diodenlaser, welcher auf einen optischen Übergang in Rubidium stabilisiert ist. Während des Raketenflugs werden beide Uhren bei ihrem gemeinsamen Flug durch das Schwerefeld der Erde durch eine Schwebungsmessung von Kamm und Diodenlaser verglichen. Der raketentaugliche Frequenzkamm wurde gemeinsam vom MPQ und Menlosystems GmbH entwickelt. Der Diodenlaser und die Spektroskopie wurden von FBH, UHH und HUB im Rahmen des DLR-Projekts LASUS entwickelt.
Gefördert von DLR und BMWi (50WM0934 und 50WM1237-1240)

Q 35.76 Tue 16:00 Empore Lichthof

Compact apparatus for an Ytterbium lattice clock — •Gregor Mura, Charbel Abou Jaoudeh, Tobias Franzen, and Axel Görlitz — Institut für Experimentalphysik, HHU Düsseldorf, Universitätsstr. 1, 40225 Düsseldorf

Optical clocks using neutral atoms hold the promise to eventually reach an inaccuracy at a level of 10^{-18}. So far stationary optical lattice clocks have been demonstrated for Yb, Sr and Hg. In the framework of the Space Optical Clocks 2 project we are developing a transportable Yb lattice clock demonstrator. Here we present current developments of subsystems which are intended to improve the transportability. These include basically all laser systems in particular the cooling lasers at 399 nm and 556 nm.

Q 35.77 Tue 16:00 Empore Lichthof

Towards a test of the Universality of Free Fall of atoms in microgravity — •Christian Vogt, Sascha Kulas, Andreas Resch, and Sven Herrmann — ZARM, Universität Bremen, Am Fallturm, 28259 Bremen

Matter wave interferometry today is an established tool to perform precision measurements in fundamental physics. One of the main limiting factors in such experiments is the finite free evolution time available to matter waves in a laboratory setup. Thus, the extended free fall time which can be achieved in a microgravity environment is expected to be of great benefit to future matter wave precision measurements. First promising results towards this have been achieved by the QUANTUS collaboration in recent years [1]. Within the PRIMUS project (Präzisions-Interferometrie unter Schwerelosigkeit) we aim to further explore this potential in a dedicated drop tower experiment. Therefore, we are currently setting up a dual species interferometer to compare the free fall of 87Rb and 39K atoms. Here, we present the current status of this experiment and discuss the perspectives and attainable sensitivity of such a free fall test in the Bremen Drop Tower. 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 1142.

[1] T. van Zoest et al., "Bose-Einstein condensation in microgravity", Science, vol 328, no. 5985, p. 1540, 2010

Q 35.78 Tue 16:00 Empore Lichthof

An iodine frequency reference with 10^{-15} stability for space applications — •Klaus Döringshoff[1], Julia Pahl[1], Christian

Marciniak[1], Moritz Nagel[1], Evgeny V. Kovalchuk[1], Johannes Stühler[2], Thilo Schuldt[2,3,4], Claus Braxmaier[3,4], and Achim Peters[1] — [1]Humboldt-Universität zu Berlin, Institutfür Physik — [2]University of Applied Sciences Konstanz(HTWG), Institute of Optical Systems — [3]University Bremen, Center for Applied Space Technology and Microgravity (ZARM) — [4]DLR Institute for Space Systems (Bremen)

Future space missions related to fundamental science, earth observation, and navigation and ranging require ultra-stable optical frequency references. Iodine references for laser stabilization have the potential to be developed space compatible on a relatively short time scale, while featuring frequency stabilities superior to other references like hydrogen masers.

We present a semi-monolithic, glass ceramic setup realized with an adhesive bonding technology, featuring a frequency stability of $8 \cdot 10^{-15}$ at 1 s averaging down to $2 \cdot 10^{-15}$ at 100 s.

Further, we report on the development of an engineering model utilizing a compact multi-pass gas cell. This setup will undergo environmental testing, including vibration tests and thermal cycling.

This work is supported by the German Space Agency DLR with funds provided by the Federal Ministry of Economics and Technology (BMWi) under grant numbers 50 QT 1102 and 50 QT 1201.

Q 35.79 Tue 16:00 Empore Lichthof

Magnetic sensing using nitrogen-vacancy centres in diamond nanocrystals — •Helena Knowles, Dhiren Kara, and Mete Atature — University of Cambridge, United Kingdom

Nitrogen-vacancy (NV) centres in diamond are point defects in the diamond lattice that form an electronic spin state $S = 1$ with sublevels $m_s = 0$ and ± 1 that are Zeeman shifted in a magnetic field. This spin can be initialised and read out optically, and driven coherently with a microwave field. Ramsey type interferometry then enables the detection of magnetic fields at the site of the NV defect.

Compared to NV centres in ultra-pure bulk diamond, nanodiamonds have a higher concentration of spins surrounding the defect reducing the coherence time of the NV spin and its sensitivity as a magnetometer. However, due to their small spatial extent and the possibility of precise positioning of the crystal on the nanometre scale, NV centres in nanocrystals provide the ideal system for high precision spatially resolved magnetometry. We demonstrate the ability to move 15 nm diameter nanocrystals containing single NV defects using an atomic force microscope. We then perform multi-pulse decoupling sequences and extract magnetic field sensitivities of 0.5 μT $/\sqrt{\text{Hz}}$ in the shot noise limit.

Q 35.80 Tue 16:00 Empore Lichthof

Optical traps for a magnesium frequency standard — •Klaus Zipfel, André Kulosa, Steffen Rühmann, Dominika Fim, Temmo Wübbena, André Pape, Wolfgang Ertmer, and Ernst Rasel — Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover, Germany

Optical atomic clocks offer a significantly higher accuracy and stability compared to microwave atomic clocks and thus will allow more precise frequency measurements. As alkaline earth element magnesium features narrow transitions suitable for an optical atomic clock.

State-of-the-art optical clocks with neutral atoms rely on atoms trapped in an optical lattice at the magic wavelength. For magnesium, loading the optical lattice directly from a magneto optical trap (MOT) is not possible because of high temperatures and ionization losses from the upper ^3D_j MOT-states induced by the lattice light. This requires an optical dipole trap at 1064 nm as intermediate step, which is continuously loaded. The technical setup and performance of both optical traps will be presented in detail.

Q 35.81 Tue 16:00 Empore Lichthof

The mobile atom interferometer GAIN: towards low noise absolute gravity measurements — •Christian Freier, Matthias Hauth, Vladimir Schkolnik, Alexander Senger, Malte Schmidt, and Achim Peters — Humboldt-Universität zu Berlin, Institut für Physik, AG Optische Metrologie, Newtonstr. 15, 12489 Berlin

GAIN (Gravimetric Atom Interferometer) is a mobile atom gravimeter, based on interfering ensembles of laser cooled 87Rb atoms in an atomic fountain configuration. It is specifically designed to show the potential of atom interferometry for mobile gravity measurements in the context of geodesy and geophysics.

In order to compete or surpass current state-of-the-art absolute gravimeters, measurement noise caused by environmental vibrations has to be carefully removed. Furthermore, various systematic effects have to be taken into account to come to a reliable absolute value for g.

This contribution will focus on an active vibration isolation which increased the sensitivity of the atom gravimeter to about $2 \times 10^{-8}\text{g}/\sqrt{\text{Hz}}$, and the implementation of a tip/tilt mirror system to eliminate Coriolis effect offsets and actively stabilize the measurement axis of the instrument within a few μrad.

Q 35.82 Tue 16:00 Empore Lichthof

Ein hochstabiler Lokaloszillator mit einer Instabilität von 10^{*16} in 1s für eine optische Neutralatomuhr basierend auf Magnesium — •Steffen Rühmann, André Kulosa, Dominika Fim, Klaus Zipfel, Temmo Wübbena, André Pape, Wolfgang Ertmer und Ernst Rasel — Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover, Germany

Essentiell für die Abfrage eines schmalbandigen atomaren Übergangs für eine optische Atomuhr ist ein hochstabiler optischer Lokaloszillator. Kernstück eines solchen Oszillators ist gewöhnlich ein gegen akustische und thermische Störfaktoren isolierter Resonator hoher Längenstabilität. Am Institut für Quantenoptik (IQ) wurde ein derartiger Oszillator mit einer Stabilität von $5 \cdot 10^{-16}$ in 1s entwickelt und aufgebaut. Sein Licht wird nach Frequenzverdopplung zur Spektroskopie des stark verbotenen Übergangs $^1S_0 \rightarrow ^3P_0$ von neutralem Magnesium-24 genutzt. Wir untersuchten inwieweit die Rauscheigenschaften bei der fundamentalen Wellenlänge durch Einsatz der resonanten Frequenzverdopplung modifiziert werden. Eine weitere Erhöhung der Stabilität ist im Prinzip mit längeren Resonatoren vorstellbar. Wir diskutieren den extremen Fall, die exzellente Kurzzeitstabilität eines Gravitationswellendetektors zu nutzen.

Q 35.83 Tue 16:00 Empore Lichthof

Performance of a cooling method by quadratic coupling at high temperatures — •Zhijiao Deng[1,2,3], Yong Li[2], Ming Gao[1], and Chunwang Wu[1] — [1]Department of Physics, College of Science, National University of Defense Technology, Changsha 410073, People's Republic of China — [2]Beijing Computational Science Research Center, Beijing 100084, People's Republic of China — [3]Institute for Theoretical Physics, Universität Erlangen-Nürnberg, Staudtstraße 7, 91058 Erlangen, Germany

Cooling mechanical resonators to a quantum regime at high temperatures is important in terms of exploring and applying their quantum effects unrestricted by low environmental temperatures. It has been suggested by M. Bhattacharya et al. [Phys. Rev. A 77, 033819 (2008)] that quadratic coupling could be used to help cool a membrane in membrane-in-the-middle optomechanical systems (MMOSs) at room temperature to a state with a mean phonon number smaller than 1. We found that its cooling effect is actually overestimated because of the unconsidered factor that it is limited by the small frequency difference between the quadratically coupled cavity mode and its neighboring mode, which imposes an upper bound on the input trapping laser power. Here we have concretely investigated the performance of this cooling method by a more rigorous calculation. Our calculation shows that the cooling effect is indeed ultimately limited by the input trapping laser power, but one can still cool a membrane close to a quantum regime at 77 K with parameters approaching experimental values.

Q 35.84 Tue 16:00 Empore Lichthof

A new setup for interfacing ultracold atoms with micromechanical oscillators — •Aline Faber, Maria Korppi, Andreas Jöckel, Tobias Kampschulte, Matthew Rakher, and Philipp Treutlein — Departement Physik, Klingelbergstrasse 82, 4056 Basel, Schweiz

Ultracold atomic ensembles and mechanical oscillators have recently-attracted much interest as candidates for a hybrid quantum system. We aim to couple the motion of laser-cooled atoms to the vibrations of a micromechanical membrane in a single-sided cavity. The coupling is mediated over a long distance by a laser beam, which is reflected off the cavity and creates an optical lattice for the atoms. It is enhanced by the cavity finesse as well as the square root of the number of atoms. Such a coupling can e.g. be used to sympathetically cool the membrane by laser cooling the atoms.

Here we present a new experimental setup, with which we want to enhance the bidirectional coupling observed in an earlier experiment without a cavity [1]. Besides placing the membrane in a cavity, the new setup allows to create larger ultracold atomic clouds at higher loading rates. Furthermore, a transverse lattice will suppress light-assisted collisions between atoms in the presence of the coupling laser light. With these improvements we expect to increase the coupling rate by several orders of magnitude and to observe substantial cooling of the membrane's thermal motion.

[1] S. Camerer, M. Korppi et al., PRL 107, 223001 (2011)

Q 35.85 Tue 16:00 Empore Lichthof

Nonlinear response of an optomechanical system studied via the noise power spectrum — •Gotthold Fläschner[1,2], Kai Ruschmeier[1], Mohammad Reza Bakhtiari[2], Alexander Schwarz[1], Roland Wiesendanger[1], and Michael Thorwart[2] — [1]Institute of Applied Physics and Center of Microstructure Research, University of Hamburg, Jungiusstrasse 11, 20355 Hamburg, Germany — [2]I. Institute of Theoretical Physics, University of Hamburg, Jungiusstrasse 9, 20355 Hamburg, Germany

Utilizing a fiber optical Fabry-Perot interferometer is one way to detect the cantilever deflection in an atomic force microscopy set-up. Cantilever and fiber end form a low finesse cavity. The temperature of such a cantilever, which constitutes a micron sized mechanical oscillator, can be in principle determined by recording the power spectral density.

However, in the current experiment with a metal-coated cantilever, the spectral response function differs from the simple Lorentzian shape. In particular, its line shape is asymmetric and even shows antiresonant behavior due to the coupling of cavity and oscillator. We attribute this effect to a subtle interplay of different noises, which generates a nontrivial response of this nonlinear system. We analyze a tractable theoretical model and compare its predictions with experimental data. Its implications on accurate temperature measurement schemes are discussed.

Q 35.86 Tue 16:00 Empore Lichthof

Towards coupling a BEC to a micromechanical oscillator — •Andreas Bick[1], Christina Staarmann[1], Philipp Christoph[1], Philip Rothfos[1], Patrick Windpassinger[1], Christoph Becker[1], Klaus Sengstock[1], Hai Zhong[2], Gotthold Fläschner[2], Alexander Schwarz[2], and Roland Wiesendanger[2] — [1]Zentrum für Optische Quantentechnologien, Universität Hamburg, Deutschland — [2]Institut für Angewandte Physik, Universität Hamburg, Deutschland

The study of quantum hybrid systems is an emergent field of quantum optics with many potential applications in e.g. quantum communication or in the search for quantum behavior of macroscopic objects. In this poster we present our progress towards a new hybrid quantum system experiment, which aims at coupling ultracold atoms to micromechanical oscillators. In a first experiment we will couple a high-Q micromechanical membrane located inside a fiber fabry-perot cavity to a Rubidium BEC via an optical lattice. As a promising starting point to reach the ground state of the oscillator the fiber cavity - membrane setup will be cooled to temperatures around 30mK inside a dilution cryostat. On the long-term also short range (e.g. magnetic) interactions can be realized by creating Rubidium BEC inside the cryostat. This work is supported by the Landesexzellenzinitiative Hamburg, the Joachim Herz Stiftung and the ERC Advanced Grant "FURORE".

Q 35.87 Tue 16:00 Empore Lichthof

Synchronization dynamics in arrays of optomechanical oscillators — •Roland Lauter[1], Max Ludwig[1], Christian Brendel[1], and Florian Marquardt[1,2] — [1]Friedrich-Alexander-Universität Erlangen-Nürnberg, Staudtstr. 7, D-91058 Erlangen, Germany — [2]Max Planck Institute for the Science of Light, Günther-Scharowsky-Str. 1/Bau 24, D-91058 Erlangen, Germany

We consider 1d and 2d arrays of coupled optomechanical oscillators. Each of those consists of a laser-driven optical mode coupled to a mechanical mode, and it can be driven into a state of self-sustained mechanical oscillations. We analyze the dynamics of the phase field characterizing those oscillations. In the absence of noise, we find that there can be either vortex structures or spatiotemporal chaos in the phase field, depending on the system parameters. In the presence of noise (e.g. thermal or quantum fluctuations), the phase-phase correlator decays as a function of distance. We analyze this behaviour using both numerical simulations and simplified models.

Q 35.88 Tue 16:00 Empore Lichthof

Optomechanical state reconstruction using Kalman filtering — •Jason Hoelscher-Obermaier[1], Sebastian G. Hofer[1], Witlef Wiezcorek[1], Karoline Siquans[1], Ralf Riedinger[1], Garrett D. Cole[1], Klemens Hammerer[2], and Markus Aspelmeyer[1] — [1]Vienna Center for Quantum Science and Technology, Faculty of Physics, University of Vienna, 1090 Vienna, Austria — [2]Institute for Theoretical Physics, Institute for Gravitational Physics, Leibniz University Hannover, 30167 Hannover, Germany

Optomechanics uses light to control the state of a vibrational mode of a massive mechanical object. To verify the success of optomechanical protocols, the joint state of mechanical mode and light field needs to be measured. The mechanical mode can be measured only indirectly, however, by measuring the light which has interacted with it.

Kalman filtering allows for the reconstruction of the joint state of the light field and the mechanical mode from measurements on the light field alone. The Kalman filter relies on a system model and a measurement model to provide an optimal estimate of the full state of the system. We illustrate this method for our cavity-optomechanical setup. To this end, we perform homodyne detection on the driving beam after interaction with the mechanical mode, and postprocess the results using the Kalman filter. Since the Kalman filter is based on the full system dynamics (quantum Langevin equations for the interacting optomechanical system together with a model of the detection setup), no further simplifying assumptions (such as weak optomechanical coupling or adiabaticity) enter.

Q 35.89 Tue 16:00 Empore Lichthof

Laser theory for opotomechanical limit cycles in the quantum regime — •Niels Lörch and Klemens Hammerer — Institute for Theoretical Physics, Leibniz University, 30167 Hannover, Germany

We study the dynamics of an optomechanical system consisting of a driven optical cavity that is coupled to a mechanical oscillator via radiation pressure force. In such systems the classical nonlinear dynamics can give rise to self-induced oscillations. We use laser theory to derive an effective equation of motion to study the quantum properties of these oscillations.

Q 35.90 Tue 16:00 Empore Lichthof

Cavity cooling and trapping of levitated nanospheres — •Florian Blaser, Nikolai Kiesel, Uros Delic, David Grass, Rainer Kaltenbaek, and Markus Aspelmeyer — Vienna Center for Quantum Science and Technology (VCQ), Faculty of Physics, University of Vienna, Boltzmanngasse 5, A-1090 Vienna, Austria

Levitated optomechanical systems have been recently put forward [1] as test systems in fundamental quantum experiments [2]. A necessary ingredient of these experiments is cooling of the center-of-mass motion of the levitated object to the ground state. We report on the first experimental demonstration of cavity cooling of levitated nanospheres. In our experiment, a silica nanosphere of 10^{10} amu is trapped in a Fabry-Perot cavity. The sphere's center-of-mass motion is linearly coupled to one of the modes of the cavity, allowing for sideband-resolved optomechanical cooling. Cooling rates of up to 26 kHz and optomechanical interaction close to the strong coupling regime have been observed. Currently, ultra-high Q operation at low pressures is inhibited by particle loss. We will discuss a transverse feedback cooling that will lift this limitation and pave the way towards ground state cooling.

[1] Romero-Isart, O. et al. NJP 12, 33015 (2010), Chang D. et al. PNAS 107, 0912969107, (2009), Barker P, et al. PRA 81, 023826 (2010).

[2] Romero-Isart, O. et al. PRL 107, 020405 (2011), Romero-Isart, O. PRA 84, 5 (2011), Kaltenbaek, R. et al., MAQRO, Exp. Astro. 1 42 (2012)

Q 35.91 Tue 16:00 Empore Lichthof

A tomography formalism for reconstructing the magnetodielectric properties from quantum interference — •Johannes Fiedler and Stefan Scheel — Uni Rostock, Institut für Physik, Rostock, Germany

Wave properties of particles are known from fundamental experiments, like the double-slit interference of electrons, done by Young and Fresnel. This effects can be described by the wave-particle duality with the de Broglie wavelength of a matter wave, $\lambda = \frac{h}{p}$. Similar experiments with neutral atoms and molecules [1,2] have shown an additional effect, that matter waves are accumulating phases depending on the grating distance. These phases are facilitated by the Casimir-Polder potential between scatterer and particles, which results from the fluctuations of the quantized electromagnetic field [3]. Here we will present a possible route towards reconstructing the electromagnetic response properties of grating material by scattering tomography.

[1] Grisenti, Schoellkopf, Toennies et al. Phys. Rev. Lett. (2000). [2] T. Juffmann et al. Nature Nanotechnology 7, 297 (2012). [3] S. Scheel and S. Y. Buhmann, Acta Phys. Slov. 58, 657 (2008).

Q 35.92 Tue 16:00 Empore Lichthof

Aharonov-Casher effect for dark state polaritons — •Vladimir Djokic, Frank Vewinger, and Martin Weitz — Wegelerstr. 8, D-53115 Bonn, Germany

Dark state polaritons, quasiparticles with a photonic contribution and an atomic spin-wave component, exhibit a nonvanishing effective magnetic moment due to the spin-wave contribution. As has been pointed out by Aharonov and Casher, magnetic moments can lead to a topological phase shift when the particle is moving around a charged wire, the Aharonov-Casher phase.

We report on the status of an ongoing experiment aiming at a measure of the Aharonov-Casher phase in dark state polaritons in Rb 87. This set up allows the measurement of the differential phase shift between two polariton components, making the system robust against perturbations.

Q 35.93 Tue 16:00 Empore Lichthof

Experimental Investigation of Quantum Correlations in Multipartite Systems — •Vanessa Chille[1,2], Christian Peuntinger[1,2], Ladislav Mista[4], Niall Quinn[3], Natalia Korolkova[3], Christoph Marquardt[1,2], and Gerd Leuchs[1,2] — [1]Max Planck Institute for the Science of Light, Günther-Scharowsky-Straße 1, 91058 Erlangen, Germany — [2]Institute of Optics, Information and Photonics, University Erlangen-Nuremberg, Germany — [3]School of Physics and Astronomy, University of St. Andrews, North Haugh, St. Andrews KY16 9SS, United Kingdom — [4]Deparment of Optics, Palacky University, 17. listopadu 50, 772 07 Olomouc, Czech Republic

We study quantum correlations in a dissipative quantum system. A special focus lies on quantum discord and entanglement. A two-mode Gaussian mixed state is prepared by modulating a polarization squeezed state and mixing it with the vacuum mode. We measure the covariance matrix in dependence on the dissipation in one of the modes and examine the amount of quantum discord. The quantum discord changes as a side effect of the changes in local entropy caused by the dissipation which corresponds to a coupling of the system to the environment. These experiments serve also as a preparatory study for the experimental implementation of a distribution of continuous-variable entanglement by separable Gaussian states. The scheme uses quantum discord to distribute entanglement between two distant modes by a third separable auxiliary mode.

Q 35.94 Tue 16:00 Empore Lichthof

Multifractality of quantum wave packets — •John Martin[1], Ignacio Garcia-Mata[2,3], Olivier Giraud[4], and Bertrand Georgeot[5,6] — [1]Institut de Physique Nucléaire, Atomique et de Spectroscopie, Université de Liège, Bât. B15, B - 4000 Liège, Belgium — [2]Instituto de Investigaciones Fisicas de Mar del Plata, CONICET-UNMdP, Funes 3350, B7602AYL Mar del Plata, Argentina — [3]Consejo Nacional de Investigaciones Científicas y Tecnológicas, Buenos Aires, Argentina — [4]LPTMS, CNRS and Université Paris-Sud, UMR 8626, Bât. 100, 91405 Orsay, France — [5]Université de Toulouse, UPS, Laboratoire de Physique Théorique (IRSAMC), F-31062 Toulouse, France — [6]CNRS, LPT (IRSAMC), F-31062 Toulouse, France

We study the multifractality of individual wave packets in a periodically kicked system through a combination of numerical and analytical works. We consider a version of the mathematical Ruijsenaars-Schneider model and reinterpreted it physically in order to describe the spreading with time of quantum wave packets in a system where multifractality can be tuned by varying a parameter [1]. We compare different methods to measure the multifractality of wave packets and identify the best one. We find the multifractality to decrease with time until it reaches an asymptotic limit, which is different from the multifractality of eigenvectors but related to it, as is the rate of the decrease. Our results could guide the study of experimental situations where multifractality is present in quantum systems.

[1] I. Garcia-Mata, J. Martin, O. Giraud, B. Georgeot, Phys. Rev. E 86, 056215 (2012).

Q 35.95 Tue 16:00 Empore Lichthof

Highly non-classical symmetric states of an N-qubit system — •Dorian Baguette and John Martin — Institut de Physique Nucléaire, Atomique et de Spectroscopie, Université de Liège, Bât. B15, B - 4000 Liège, Belgium

A host of applications of quantum phenomena, such as quantum information processing and quantum-enhanced measurements, rely on the non-classical nature of quantum states[1]. In this work, we study two measures of non-classicality for pure symmetric N-qubit states : Wehrl participation ratio and Wehrl entropy. We focus more particularly on the identification of the most non-classical symmetric states with respect to these measures and on their nice geometrical properties in the Majorana representation[2]. The scaling of these measures with the number of qubits is also investigated. We show that the quest for the most non-classical symmetric states is somehow related to J. J. Thomson's century-old problem of the minimum energy configuration of charges on the surface of a sphere.

[1] C. Anastopoulos, Phys. Rev. D 59, 045001 (1998).

[2] I. Bengtsson & K. Zyczkowski, Geometry of Quantum States, Cambridge University Press (2006).

Q 35.96 Tue 16:00 Empore Lichthof

Lasing Without Inversion in Quecksilber — •Benjamin Rein und Thomas Walther — TU Darmstadt, Institut für Angewandte Physik, AG Laser und Quantenoptik, Schlossgartenstr. 7, D-64289 Darmstadt

Die Entwicklung von cw-Lasern im Wellenlängenbereich der VUV-Strahlung und darunter ist aufgrund der für die Besetzungsinversion benötigten Pumpleistung, die mit der 4ten Potenz der Frequenz der Laserstrahlung ansteigt, technisch stark eingeschränkt und wird zumeist unter der Ausnutzung nicht-linearer Effekte realisiert.

Lasing Without Inversion ist eine Technik die auf der kohärenten Anregung atomarer Übergänge beruht und einen alternativen Ansatz bietet. Durch destruktive Interferenz zweier Anregungswege wird die Absorption auf dem Laserübergang unterdrückt und erlaubt Lasertätigkeit mit nur wenigen angeregten Atomen.

Quecksilber besitzt Übergänge bei 253,7 nm und 185 nm mit denen sich LWI gewinnbringend einsetzen lässt. Es wird der aktuelle Stand des LWI Experiments bei 253,7 nm vorgestellt. Die benötigten Wellenlängen von 435,8 nm und 546,1 nm werden durch die effiziente Verdopplung von External Cavity Diode Lasern mittels KNbO3- bzw. LiNbO3-Kristall erzeugt. Ein weiterer ECDL bei 404,7 nm, dessen Linienbreite durch weißes Rauschen künstlich erhöht wird, dient als inkohärente Pumpe. Bei allen Lasersystemen handelt es sich um Eigenentwicklungen.

Q 35.97 Tue 16:00 Empore Lichthof

Lasing without inversion in the ultra violet regime — •Martin Sturm and Reinhold Walser — Institut für angewandte Physik, TU Darmstadt

Lasing without inversion on the basis of atomic coherence effects is a promising approach to continuous wave lasing in the ultra violet regime since the threshold pumping power for population inversion scales with ω^4 to ω^6 [1]. Despite successful proof of principle experiments, no lasing without inversion in the ultra violet regime has been realized until now.

In 1999 Fry et al. [2] proposed a lasing without inversion experiment based on the so called 'double-dark' scheme in a four level system. This setup allows Doppler-free lasing on 253 nm in Hg. We investigate this scheme theoretically: technical noise of pump lasers, the geometry of laser medium, the resonator design. This analysis is in cooperation with an experiment performed by B. Rein in the research group of Th. Walther at the Institute of Applied Physics/TU Darmstadt. The current status of this considerations is presented.

[1] J. Mompart and R. Corbalan, "Lasing without inversion", Journal of Optics B **3**, R7-R24 (2000)

[2] E. Fry, M. Lukin, T. Walther and G. Welch, "Four-level atomic coherence and cw VUV lasers", Optics Communications **179**, 499-504 (1999)

Q 35.98 Tue 16:00 Empore Lichthof

Hybrid coherent light: modeling quantum dot superluminescent diodes — •Franziska Friedrich and Reinhold Walser — Institute for Applied Physics, TU Darmstadt, Germany

Quantum dot superluminescent diodes show unusual light characteristics. On the one hand they are spectrally broad (THz) like a thermal light source, when considering the first order field correlation function. On the other hand, they exhibit a suppressed second order intensity noise spectrum like a coherent laser. This novel state of the electromagnetic field is called hybrid coherent light [1,2,3]. It is a interesting topic for fundamental research and has high potential for applications, e.g. in medical diagnostics.
In collaboration with the experimental group of Prof. W. Elsäßer (IAP/TUD) we developed a basic model of the diode to describe the emitted light and its correlation properties.

References :
[1] M. Blazek et al., Optics Express **17**, 16 (2009)
[2] M. Blazek, W. Elsäßer, Phys. Rev. A **84**, 063840 (2011)
[3] M. Blazek, W. Elsäßer IEEE, J. Quantum Electron. **48**, 12 (2012)

Q 35.99 Tue 16:00 Empore Lichthof

A miniaturized electron gun for microwave electron guiding — •Dominik Ehberger[1], Jakob Hammer[1], Johannes Hoffrogge[1], and Peter Hommelhoff[1,2] — [1]Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Straße 1, 85748 Garching — [2]Friedrich-Alexander-Universität Erlangen-Nürnberg, Erwin-Rommel-Str. 1, 91058 Erlangen

The realization of microwave guiding structures for electrons on micro-fabricated chips [1] enables new experiments in the context of guided matter-wave interferometry and controlled electron-electron or electron-surface interaction studies.

In addition to the spatial confinement of electrons guided in a planar AC-quadrupole guide (linear Paul trap), temporal control is feasible by implementation of a laser-based electron gun. Short blue laser pulses at 400 nm focused on a sharp tungsten tip drive electron emission with high efficiency. Since the emitted electron pulse length and repetition rate are directly linked to the laser pulse length and repetition rate, this set-up is well suited for synchronization with the microwave field. Here we present our ongoing experimental efforts on the realization and characterization of a fast, laser-triggered electron source. Such a miniaturized electron gun in combination with a microwave guide and suitable electron optics should allow tailoring of matter-waves with defined temporal and spatial properties for injection into the guiding potential.

[1] J. Hoffrogge, R. Fröhlich, M. Kasevich and P. Hommelhoff, *Phys. Rev. Lett.* **106**, 193001 (2011).

Q 36: Ultra-cold atoms, ions and BEC IV (with A)

Time: Wednesday 11:00–12:30 Location: F 428

Q 36.1 Wed 11:00 F 428

Mott-insulator state of ultracold atoms in optical lattices: comparison of exact numerical results with controlled approximations — •Konstantin Krutitsky, Friedemann Queisser, Patrick Navez, and Ralf Schützhold — Fakultät für Physik, Universität Duisburg-Essen, Duisburg, Germany

A wide class of phenomena for ultra-cold atoms in deep optical lattices is well described by the Bose-Hubbard model. Using exact numerical and approximate analytical methods, we have studied the ground-state energy, probabilities of the occupation numbers of the individual lattice sites, two-point correlation functions, and the excitation spectrum, in the Mott-insulator regime. Exact results are obtained for one-dimensional lattices up to 14 sites and for two-dimensional lattices of 3x3 sites. They are compared with the fourth order expansion in the ratio of the tunneling rate J and the interaction constant U valid in an arbitrary dimensions and the inverse coordination number 1/Z valid for arbitrary interaction strengths. The zeroth order in 1/Z is equivalent to the Gutzwiller mean field [3]. In one dimension, numerical data nearly coincide with perturbation theory in J/U whereas the first-order results in 1/Z deviate a bit for increasing J. In two dimensions, the 1/Z expansion is already superior to the J/U expansion, and should become even better in three and higher dimensions.

[1] J.K.Freericks and H.Monien, Phys.Rev.B 53, 2691 (1996).
[2] F.Queisser, K.V.Krutitsky, P.Navez, R.Schützhold, arXiv:1203.2164.
[3] S.Sachdev, Quantum phase transitions, Cambridge University Press, 2001.

Q 36.2 Wed 11:15 F 428

Density waves in dipolar Bose-Einstein condensates — •Alexandru Nicolin — Horia Hulubei National Institute for Physics and Nuclear Engineering, Magurele, Romania

Density waves in cigar-shaped dipolar Bose-Einstein condensates are analysed by variational means and we show analytically how the dipole-dipole interaction between the atoms generates a roton-maxon excitation spectrum. A simple model is used to derive the effective equations which describe the emergence of the density waves.

Q 36.3 Wed 11:30 F 428

Mode Entanglement in Systems of Massive, Indistinguishable Bosons — •Felix Binder[1], Libby Heaney[2], Dieter Jaksch[1,2], and Vlatko Vedral[1,2,3] — [1]Clarendon Laboratory, Department of Physics, University of Oxford, Parks Road, Oxford OX1 3PU, UK — [2]Center for Quantum Technologies, National University of Singapore, 3 Science Drive2, 117543, Singapore — [3]Department of Physics, National University of Singapore, 2 Science Drive 3, 117542, Singapore

The standard notion of entanglement breaks down in systems of indistinguishable particles due to a loss of the tensor product structure of Hilbert space. Nevertheless, second quantisation allows us to describe entanglement between spatial modes which arises naturally in Bose-Einstein condensates or optical lattices.

Under particle-number superselection rules the only basis for the description of these systems is the mode-occupation basis, where it is possible to study and quantise correlations, for example via their relation to the visibility of interference fringes and the single-particle reduced density matrix.

In order to genuinely detect or harness entanglement, however, it is ultimately necessary to locally overcome the particle-number superselection rules by providing a suitable reference frame. It will be shown how this is possible using a BEC reservoir as the reference frame and a proposed implementation scheme for an optical lattice system will be described. This scheme could be used to experimentally test entanglement between modes of massive, indistinguishable bosons for the first time.

Q 36.4 Wed 11:45 F 428

Dynamics of Bose-Einstein condensates in $\mathcal{PT}$-symmetric double-well potentials — •Daniel Haag, Dennis Dast, Holger Cartarius, and Günter Wunner — 1. Institut für Theoretische Physik, Universität Stuttgart

The study of non-Hermitian Hamiltonians has attracted large attention in recent years. A special class of such systems are described by non-Hermitian but $\mathcal{PT}$-symmetric Hamiltonians that can have entirely real spectra. In general, non-Hermitian systems do not conserve the norm of a wave packet, which has a severe effect on the dynamics of nonlinear systems such as Bose-Einstein condensates described by the Gross-Pitaevskii equation. We investigate the stability of the eigenstates and solve the time-dependent GPE for a $\mathcal{PT}$-symmetric double well, where in one well particles are removed while particles are coherently injected into the other.

Q 36.5 Wed 12:00 F 428

Superfluidity with disorder in a quantum gas thin film — •Sebastian Krinner, David Stadler, Jakob Meineke, Jean-Philippe Brantut, and Tilman Esslinger — Institute for Quantum Electronics, ETH Zürich, Switzerland

We investigate the properties of a strongly interacting, superfluid gas of $^6Li_2$ Feshbach molecules forming a thin film confined in a quasi two-dimensional channel with a tunable random potential, creating a microscopic disorder. We measure the atomic current and extract the resistance of the film in a two-terminal configuration, and identify a superfluid state at low disorder strength, which evolves into a normal, poorly conducting state for strong disorder. The transition takes place when the chemical potential reaches the percolation threshold of the disorder.

The evolution of the conduction properties contrasts with the smooth behavior of the density and compressibility across the transition, measured in-situ at equilibrium. These features suggest the emergence of a glass-like phase at strong disorder.

Q 36.6 Wed 12:15 F 428

Three-body recombination in a quasi-two-dimensional quantum gas — •Bo Huang[1], Alessandro Zenesini[1], Martin Berninger[1], Hanns-Christoph Nägerl[1], Francesca Ferlaino[1], and Rudolf Grimm[1,2] — [1]Institut für Experimentalphysik und Zentrum für Quantenphysik, Universität Innsbruck, 6020 Innsbruck, Austria — [2]Institut für Quantenoptik und Quanteninformation (IQOQI), Österreichische Akademie der Wissenschaften, 6020 Innsbruck, Austria

Collisional properties of interacting particles can dramatically change when the dimensionality of the system is reduced. One intriguing example is the disappearance of the weakly bound trimers known as Efimov states in two dimensions. Many open questions remain about the details of the crossover from three to two dimensions and how the Efimov-related three-body recombination losses are affected. We use ultracold cesium atoms trapped tightly in a harmonic potential along one spatial direction to realize a quasi-two-dimensional system with tunable confinement and tunable interactions. In our latest results, we succeed to trace a smooth transition of the three-body recombination rate from a three-dimensional to a nearly two-dimensional system, in good agreement with recent theoretical models.

Q 37: Laser applications: Spectroscopy

Time: Wednesday 14:00–15:15 Location: F 142

Q 37.1 Wed 14:00 F 142

Zeeman Effect on Single Silicon-Vacancy Color Centers in Diamond — •Christian Hepp[1], Tina Müller[2], Benjamin Pingault[2], Victor Waselowski[3], Elke Neu[1], Jeronimo Maze[3], Mete Atatüre[2], and Christoph Becher[1] — [1]FR 7.2 - Experimentalphysik, Universität des Saarlandes, 66123 Saarbrücken, Germany — [2]Atomic, Mesoscopic and Optical Physics Group, Cavendish Laboratory, University of Cambridge, JJ Thomson Ave, Cambridge CB3 0HE, United Kingdom — [3]Faculty of Physics, Pontificia Universidad Catolica, Vicuna Mackenna 4860, Santiago 7820436, Chile

We present spectroscopic measurements of the fine structure splitting of single negatively charged silicon-vacancy color centers (SiV^-) in diamond under the influence of high magnetic fields. The single centers have either been created in-situ in isolated CVD nanodiamonds on an iridium surface or, in an advanced approach, have been implanted into a high quality single crystalline diamond with solid immersion lenses fabricated by focused ion beam milling. The SiV^- zero phonon line shows a four line fine structure at liquid helium temperature which is attributed to optical transitions between both split ground and excited states. In the magnetic field, the Zeeman effect splits these states further giving rise to a complex pattern of up to 16 spectral lines with varying splitting strength. We discuss this splitting using a model based on a group theoretical approach for the SiV center in trigonal symmetry, which suggests a spin state S = 1/2 and takes into account distortions due to the crystal strain present in the nanodiamonds.

Q 37.2 Wed 14:15 F 142

Interferometric Femtosecond Stimulated Raman Scattering — •Sven Dobner[1], Carsten Cleff[1], Carsten Fallnich[1], and Petra Gross[2] — [1]Institut für Angewandte Physik, Westfälische Wilhelms-Universität, 48149 Münster — [2]Institut für Physik, Carl von Ossietzky Universität, 26129 Oldenburg, Deutschland

We present an optical method for background suppression in femtosecond stimulated Raman spectroscopy (FSRS) based on linear interferometry [1]. An unbalanced Sagnac interferometer reaches an unprecedented background reduction of 17 dB over a broad bandwidth of 60 THz (2000 cm^{-1}) and thereby increases the signal-to-background ratio in the measurement. The interferometric measurement does not reduce the Raman signal to a simple loss signature in the spectrum, but reveals the phase shift, gathered within the nonlinear interaction, as a dispersive lineshape, which is recreated with a simple Lorentzian oscillator model.

[1] Dobner et al., J. Chem. Phys. 137, 174201 (2012)

Q 37.3 Wed 14:30 F 142

Femtosecond characterization of an easily accesible charge transfer system — •Torben Villnow[1], Gerald Ryseck[1], Sarah Bay[2], Vidisha Rai-Constapel[3], Thomas J.J. Müller[2], and Peter Gilch[1] — [1]HHU Düsseldorf, Universitätsstr. 1, 40225 Düsseldorf, AG Femtosekundenspektroskopie — [2]LS Prof. Dr. T.J.J. Müller — [3]LS Prof. Dr. C. Marian

With regard to applications in (organic) photovoltaics numerous intramolecular donor-acceptor systems have been synthesized and characterized. The D-A system (sb078) studied here consists of a phenothiazine donor and anthrachinone acceptor moiety. The moieties are linked by an α-aminoacylamide bridge. Linkage relies on an Ugi-reaction which renders sb078 and related compounds easily synthetically accessible. Electron transfer properties of sb078 have been characterized by means of femtosecond transient absorption spectroscopy. Strong evidence for the very rapid formation of a charge separated state originating from the excited singlet and triplet state of anthrachinone is observed. Even though the singlet dominated charge separated state rapidly decays, the triplet phased state persist for more than 3 ns (range limited by the set-up).

Q 37.4 Wed 14:45 F 142

TDLAS Luftfeuchtemessungen mit extrem kurzer Zelle — •Alexander Hartmann[1], Robert Weigel[1] und Rainer Strzoda[2] — [1]Friedrich-Alexander-Universitaet Erlangen-Nuernberg, Lehrstuhl fuer technische Elektronik, Cauerstrasse 9, 91058 Erlangen — [2]Siemens AG,Corporate Technology, Otto-Hahn-Ring 6, 81739 Muenchen

Diodenlaserspektroskopie für Gaskonzentrationsmessungen ermöglicht Sensoren mit hoher Stabilität, hoher Sensitivität sowie hoher Gasselektivität. Die notwendige Länge der optischen Zelle schränkt jedoch die Anwendung für kompakte Sensoren stark ein. Halbleiterlaser im Wellenlängenbereich um 1.85 μm sowie die dort auftretenden, starken Wasserabsorptionslinien bieten die Möglichkeit, Luftfeuchtesensoren mit optischen Pfaden kleiner 3 cm aufzubauen. Die maximale Auflösung kurzer Zellen ist neben Rauscheffekten auch durch optische Interferenzen, bedingt durch Mehrfachreflexion an gegenüberstehenden Oberflächen, begrenzt. In der vorliegenden Studie hat sich gezeigt, dass sich in diesen Zellen lediglich eine dominante Interferenzschwingung bildet. Basierend auf der Analyse des Fourier-Spektrums, stellen wir eine Methode vor, diese optischen Störungen aus dem Absorptionssignal zu eliminieren. Durch geeignete Wahl des Messfensters, besteht die Möglichkeit die Interferenzschwingung auf eine gewählte Harmonische zu legen, die Abweichung zu korrigieren und die Absorptionslinie ohne Störung zu rekonstruieren. Stabile Absorptionsergebnisse mit Abweichungen kleiner $2 * 10^{-4}$, entspricht ca. 1% relativer Luftfeuchte, gegenüber Phasenänderung der Interferenz und einer Interferenzamplitude von ca. 30% relativ zur Signalstärke wurden damit erzielt.

Q 37.5 Wed 15:00 F 142

Two-photon excited fluorescence utilizing thermal light — •Andreas Jechow[1,2], Henning Kurzke[1], Axel Heuer[1], Michael Seefeldt[1], and Ralf Menzel[1] — [1]Universität Potsdam, Institut für Physik und Astronomie, Photonik, Karl-Liebknecht-Str. 24-25, Haus 28, 14476 Potsdam — [2]Centre for Quantum Dynamics, Griffith University, Brisbane, Australia

Two-photon excited fluorescence (TPEF) is a standard technique in modern microscopy. Due to the low two-photon absorption (TPA) cross section these experiments are typically performed using pulsed laser emission at relatively high intensities, which can lead to photodamage of the probe. Several proposals towards an enhancement of TPA exist including the use of two entangled photons, or biphotons [1].

Here, we utilize thermal light from a fiber-coupled super luminescence diode to demonstrate enhanced TPEF with three common fluorophores that can be used as marker molecules in microscopy. We detected TPEF with powers less than 50 μW and find that the TPA rate for chaotic light is directly proportional to the measured degree of second-order coherence (DSOC), as predicted by theory.

[1] A. Jechow, A. Heuer, and R. Menzel, "High brightness, tunable biphoton source at 976 nm for quantum spectroscopy," Opt. Express 16, 13439-13449 (2008)

Q 38: Precision measurements and metrology III

Time: Wednesday 14:00–16:00 Location: E 001

Group Report Q 38.1 Wed 14:00 E 001

Status of the LISA mission — •Gerhard Heinzel — Max-Planck-Institut für Gravitationsphysik (Albert-Einstein-Institut) Hannover

LISA is a planned gravitational wave detector in space, under intensive study since more than a decade. Recent changes in the programmatic situation at NASA and ESA have required a redefinition of the mission, to save cost. This talk give an overview of the new mission design and its current status.

Q 38.2 Wed 14:30 E 001

LISA Pathfinder: Vorbereitung des Betriebs im Orbit — •Heather Audley, Martin Hewitson, Natalia Korsakova, Jens Reiche, Gerhard Heinzel und Karsten Danzmann — Max Planck Institute für Gravitationsphysik/AEI, Hannover

LISA (Laser Interferometer Space Antenna) ist der erste weltraumbasierte Gravitationswellendetektor, der beabsichtigt, Quellen im Frequenzbereich von 0.1 mHz bis 1 Hz zu erfassen. Die Haupttechnologien, die auf der Erde nicht getestet werden, werden mit der Vorgängermission LISA Pathfinder überprüft. Hierzu gehören die Kontrolle der Testmassen im schwerelosen Raum, Interferometrie auf Picometer-Level sowie Tests der Micro-Newton-Antriebsdüsen. Dieser Beitrag gibt einen Überblick der LISA Pathfinder Mission und hebt speziell die neuesten Ergebnisse, Entwicklungen und die Vorbereitung des Betriebs im Orbit hervor.

Q 38.3 Wed 14:45 E 001

Towards the Quantum Limit: Update from the AEI 10-meter Prototype — •Tobin Fricke and The AEI 10 meter Prototype team — Max Planck Institute for Gravitational Physics (Albert Einstein Institute)

Future gravitational wave detectors will be limited in sensitivity by quantum radiation pressure noise and quantum shot noise. At the AEI 10-meter prototype facility we are building a Fabry-Perot Michelson interferometer designed to meet the Standard Quantum Limit (SQL) at 200 Hz, allowing investigation into techniques to surpass this limit. One technical challenge is the use of marginally stable optical cavities. I will describe the status of the 10-meter project with a focus on an initial configuration that will allow us to gain early experience with marginally stable cavities.

Q 38.4 Wed 15:00 E 001

GRACE Follow-on - Ein Überblick — •Gunnar Stede, Daniel Schütze, Vitali Müller, Alexander Görth, Christoph Mardt, Oliver Gerberding, Benjamin Sheard, Gerhard Heinzel und Karsten Danzmann — Albert-Einstein-Institut Hannover, Max-Planck-Institut für Gravitationspyhsik und Institut für Gravitationsphysik der Universität Hannover

GRACE (Gravity Recovery And Climate Experiment) isteine sehr erfolgreiche Mission, welche seit 10 Jahren das Schwerefeld der Erde mit Hilfe einer Abstandsmessung zweier hintereinander herfliegenden Satelliten bestimmt. Das aus der Abstandsmessung berechnete Schwerefeld hilft zum Beispiel dabei geodynamische und hydrologische Prozesse besser zu verstehen, kommt aber auch in anderen wissenschaftlichen Bereichen wie der Ozeanografie zum Einsatz. Aufgrund des großen Erfolges und des hohen wissenschaftlichen Interesses ist eine Nachfolgemission für 2017 geplant. Zusätzlich zum aktuell benutzten Mikrowelleninterferometer, welches auch bei der Nachfolgemission das primäre Messinstrument ist, werden die Satelliten um ein Laserinterferometer ergänzt, um die Abstandsmessung zu verbessern. Hier geben wir einen Überblick über die Mission, sowie über die Technologien und Konzepte, welche für das Laserinterferometer zur Zeit am Albert Einstein Institut Hannover entwickelt werden.

Q 38.5 Wed 15:15 E 001

Gravity measurements with the mobile atom-interferometer GAIN — •Matthias Hauth, Christian Freier, Vladimir Schkolnik, Alexander Senger, Malte Schmidt, and Achim Peters — Humboldt-Universität zu Berlin, Institut für Physik, AG Optische Metrologie, Newtonstr. 15, 12489 Berlin

The Gravimetric Atom Interferometer (GAIN) uses ensembles of laser cooled ^{87}Rb atoms to determine the gravitational acceleration with a targeted accuracy of a few parts in 10^{10}g. The atoms interfere in a Mach-Zehnder type interferometer realized by means of Raman transitions between the hyperfine ground states.

Here we introduce our experimental setup and different sub-systems, which allow for characterization and reduction of systematic effects like e.g. the Coriolis effect of the Earth, vibrational noise and $\mu-$radian tilts of the experiment.

We also present our latest measurement campaigns, where we have reached a sensitivity of $3 \cdot 10^{-8} g/\sqrt{Hz}$, compare them to data taken with classical gravimeters and give an outlook to future improvements and measurement campaigns.

Q 38.6 Wed 15:30 E 001

Suspension Platform Interferometer für das AEI 10 m-Prototypinterferometer — •Sina Köhlenbeck for the AEI 10m Prototype Team — Max-Planck-Institut für Gravitationsphysik (Albert-Einstein-Institut) und Institut für Gravitationsphysik der Leibniz Universität Hannover, 30167 Hannover, Deutschland

Am AEI in Hannover wird momentan das 10 m-Prototypinterferometer aufgebaut. In einem 100 m^3 umfassenden Ultrahochvakuumsystem wird ein Michelson-Interferometer mit Fabry-Perot Resonatoren in den Interferometerarmen installiert, dessen Empfindlichkeit im Messband nur noch durch Quantenrauschen limitiert sein wird. Diese physikalische Grenze nennt man das Standard Quanten Limit. Die klassischen Rauschquellen, wie seismisches Rauschen, müssen zu diesem Zweck vom Interferometer entkoppelt oder hinreichend reduziert werden. Dazu werden die optischen Komponenten auf drei seismisch isolierten optischen Tischen aufgebaut. Diese werden durch interferometrische Messungen zueinander stabilisiert um eine gemeinsame Arbeitsplattform zu erzeugen. Für die differentielle Stabilisierung der optischen Tische wurde das Suspension Platform Interferometer (SPI) entwickelt. Im Frequenzband von 10 mHz bis 10 Hz muss die Sensitivität des SPI dazu 100 pm/$\sqrt{\text{Hz}}$ in der longitudinalen Weglängenänderung und 10 nrad/$\sqrt{\text{Hz}}$ in der Winkeländerung zwischen den optischen Tischen erreichen. Das Design und die Umsetzung des SPI werden vorgestellt.

Q 38.7 Wed 15:45 E 001

Seismic isolation for the 10 m Prototype — •Gerald Bergmann for the AEI 10m Prototype Team — Leibniz Universität Hannover — MPG für Gravitationsphysik (AEI)

A 10 m arm length prototype interferometer is currently being setup at the AEI in Hannover, Germany. This facility will not only be used for developing novel techniques for future gravitational wave detectors, but furthermore it will provide a platform for high precision experiments such as measuring the standard quantum limit (SQL) of interferometry. To achieve the high requirements on displacement noise for these experiments a very good isolation from seismic motion is required.
Here we present the pre-isolation stage for the 10 m prototype interferometer based on a set of passively isolated optical tables. Geometric anti-spring filters provide vertical isolation, attenuation in the horizontal direction is provided by inverted pendulum legs. Several sensors and a Suspension Platform Interferometer will be used to measure the residual table motion. These signals will be used to control the tables at and below their fundamental resonances. Attenuation of more than 70 dB below 10 Hz was shown in first experiments with purely mechanically passive isolation. Currently two out of three tables are installed in the interferometer vacuum envelope.

Q 39: Quantum effects: Light scattering and propagation

Time: Wednesday 14:00–16:00 Location: F 342

Q 39.1 Wed 14:00 F 342

Diffractionless image propagation without absorption — •lida zhang and jörg evers — Max-Planck-Institut für Kernphysik, Saupfercheckweg 1, D-69117 Heidelberg, Germany

Recently, Firstenberg et al. have proposed and experimentally demonstrated a novel method to eliminate diffraction of a probe field carrying an arbitrary image in a thermal atomic medium[1,2]. Their method takes advantage of the thermal atomic motion and collisions. Control fields are applied such that momentum space components of the probe beam exhibits stronger coupling to the atoms moving in the opposite direction such that they are effectively carried back towards the main axis. But while this method eliminates the diffraction of the probe field, it necessarily involves strong absorption, and therefore is impractical.

Here we propose an enhanced scheme in which images encoded onto a probe field can be propagated diffractionless without absorption. An additional incoherent pump field is employed which together with the coupling fields generates additional atomic coherences such that gain is established for the probe. This way, the absorption of the probe due to single-photon absorption can be compensated by the gain. Based on this setup, prospects for various applications are discussed.

[1] O. Firstenberg, M. Shuker, N. Davidson, and A. Ron, Phys. Rev. Lett. 102, 043601 (2009).

[2] O. Firstenberg, P. London, M. Shuker, A. Ron and N. Davidson, Nature Phys. 5, 665 (2009).

Q 39.2 Wed 14:15 F 342

Conservation of Energy in Coherent Backscattering of Light — •Angelika Knothe and Thomas Wellens — Physikalisches Institut, Albert-Ludwigs-Universität Freiburg

We investigate the phenomenon of coherent backscattering of light, an interference effect that is observed when light propagates in disordered media in the presence of a boundary interface. Up to this day, it is not yet well-known what are the processes that allow this effect to occur without violating the law of conservation of total energy. [1]

We analyze in detail the processes at the origin of coherent backscattering as well as their relation to the mechanism that gives rise to the effect of weak localization. In the frame of a full description treating jointly these interference effects in random media, we are able to provide an explanation of the mechanism ensuring energy conservation.

[1] S. Fiebig *et al.*, Europhys. Lett. **81** 64004 (2008)

Q 39.3 Wed 14:30 F 342

The Quantum Nature of Random Lasers — •Regine Frank — Institut für Theoretsiche Physik, Universität Tübingen

Within this talk we present quantitative theoretical results for the quantum coherence of random laser light. The coherence is derived within a closed framework of diagrammatic quantum field theory coupled to a laser rate equation system. Furthermore, it is demonstrated how the ratio between classical coherence and quantum coherence can be tuned by dissipation. Decoherence effects are responsible for the lasing spot diameter on the one hand, but it can be derived quantitatively how the quantum nature of random lasers suffers due to decoherence.

Q 39.4 Wed 14:45 F 342

Photon-photon scattering in collisions of laser pulses — •Ben King[1] and Christoph H. Keitel[2] — [1]Ludwig-Maximilians-Universität, Theresienstraße 37, 80333 München, Germany — [2]Max-Planck-Institut für Kernphysik, Saupfercheckweg 1, 69117 Heidelberg

Motivated by recent interest in building higher-intensity laser facilities [1, 2], we investigate the possibility of measuring the predicted phenomenon of elastic vacuum photon-photon scattering with a single 10 PW optical laser beam split into two Gaussian-focused pulses with arbitrary impact geometry [3], extending previous work [4-5]. By calculating the number of photons scattered into regions of high signal-to-noise ratio, we find that the elastic process should be measurable with such a set-up, and if these pulses are sub-cycle, the frequency-shifting, vacuum four-wave mixing process could be measurable too.

[1] http://www.extreme-light-infrastructure.eu, Extreme Light Infrastructure (2012)

[2] http://www.xcels.iapras.ru, eXawatt Center for Extreme Light Studies (2012)

[3] B. King and C. H. Keitel, New J. Phys. **14**, 103002 (2012)

[4] B. King, A. Di Piazza and C. H. Keitel, Nature Photon. **4**, 92–94 (2010)

[5] A. Di Piazza, K. Z. Hatsagortsyan and C. H. Keitel, Phys. Rev. Lett. **97**, 083603 (2006)

Q 39.5 Wed 15:00 F 342

Nonlinear double Compton scattering in the full ultrarelativistic quantum regime — •Felix Mackenroth and Antonino Di Piazza — Max-Planck-Institut für Kernphysik, Saupfercheckweg 1, 69117 Heidelberg

An electron scattered from a high-intensity laser field may emit more than one photon. The simplest effect of this type is the emission of two photons [1], labeled nonlinear double Compton scattering (NDCS). We present a detailed analysis of NDCS in an ultra-strong laser field taking the effects of the laser field into account exactly and allowing for an arbitrary temporal laser field shape. We put particular emphasis on the parameter regime where nonlinear and quantum effects such as photon recoil significantly affect the emission pattern. It is demonstrated that due to recoil the energies of the emitted photons are no longer independent. This dependence is explained in terms of a semiclassical model, based on the possibility of assigning separate classical trajectories to the electron in the laser field before and after each quantum photon emission [2]. By virtue of the developed model we identify an experimentally feasible detection scheme for NDCS in the full quantum regime. The accessibility of this regime with already available plasma-based electron accelerator and laser technology is demonstrated by a numerical analysis.

[1] E. Lötstedt and U.D. Jentschura, Phys. Rev. Lett. **103**, 110404 (2009).

[2] F. Mackenroth and A. Di Piazza, submitted (see arXiv:1208.3424).

Q 39.6 Wed 15:15 F 342

An optical diode made from a "moving" photonic crystal — •Jörg Evers[1,2], Da-Wei Wang[2,4], Hai-Tao Zhou[2], Miao-Jun Guo[2], Jun-Xiang Zhang[2], and Shi-Yao Zhu[2,3,4] — [1]Max-Planck-Institut für Kernphysik, Saupfercheckweg 1, 69117 Heidelberg — [2]Beijing Computational Science Research Centre, Beijing 100084, China — [3]State Key Laboratory of Quantum Optics and Quantum Optics Devices, Institute of Opto-Electronics, Shanxi University, Taiyuan 030006, China — [4]Centre of Optics Sciences and Department of Physics, The Chinese University of Hong Kong, Hong Kong, China

Optical diodes controlling the flow of light are of principal significance for optical information processing. They transmit light from an input to an output, but not in reverse direction. This breaking of time reversal symmetry is conventionally achieved via Faraday or non-linear effects. Here we propose an all-optical optical diode which requires neither magnetic fields nor strong input fields. It is based on a "moving" photonic crystal generated in a three-level electromagnetically-induced-transparency medium in which the refractive-index of a weak probe is modulated by the moving periodic intensity of a strong standing coupling field with two detuned counter-propagating components. Due to the Doppler effect, the frequency range of the crystal's band gap for the probe co-propagating with the moving crystal is shifted from that for the counter-propagating probe. This mechanism is experimentally demonstrated in a room temperature Cs vapour cell.

Q 39.7 Wed 15:30 F 342

Statistical Properties of Photons in the Ultrastrong Coupling Regime — •Alessandro Ridolfo[1], Salvatore Savasta[2], and Michael J. Hartmann[1] — [1]Physik Department, Technische Universität München, James-Franck-Strasse, 85748 Garching, Germany — [2]Dipartimento di Fisica e Scienze della Terra, Universitá di Messina, Viale F. Stagno d'Alcontres 31, 98166 Messina, Italy

We present calculations for photon coincidence counting statistics in the ultrastrong coupling regime, where the strength of the interaction between an emitter and the cavity photons becomes comparable to the transition frequency of the emitter or the resonance frequency of the cavity mode. In such a regime of interaction, the usual normal order correlation functions fail to describe the output photon statistics. Exploiting the correct input-output relations within a suitable Master Equation approach, we are able to propose correlation functions that are valid for arbitrary degrees of light-matter interaction. In particular, here we focus on the photon blockade effect [1] and the emission of non-classical light from thermal systems [2], whose standard scenario is significantly modified for ultrastrong coupling.

[1] A. Ridolfo, M. Leib, S. Savasta, and M.J. Hartmann, Phys. Rev. Lett. 109, 193602 (2012)
[2] A. Ridolfo, S. Savasta, and M.J. Hartmann, arXiv:1212.1280 (2012)

Q 39.8 Wed 15:45 F 342

Coherent backscattering of intense laser light by cold Sr atoms - a diagrammatic pump-probe approach — •Andreas Ketterer, Vyacheslav Shatokhin, and Andreas Buchleitner — Physikalisches Institut Albert-Ludwigs-Universität Freiburg, Germany

The diagrammatic pump-probe approach is a promising method to study coherent transport of intense laser light in cold atomic clouds [1]. It expresses the multiple scattering signal in terms of single atom responses, and thus avoids the problem of the exponential growth of the Hilbert space dimension with an increasing number of atoms. In this talk we will show how to construct arbitrary single-atom building blocks for atoms with internal degeneracy, and present numerical results for triple scattering from Sr atoms.

[1] T. Wellens et al., Phys. Rev. A **82**, 013832 (2010)

Q 40: Quantum gases: Optical lattices II

Time: Wednesday 14:00–15:45 Location: A 310

Q 40.1 Wed 14:00 A 310

Expansion dynamics of interacting bosons in homogeneous lattices in one and two dimensions — •Jens Philipp Ronzheimer[1,2], Michael Schreiber[1,2], Simon Braun[1,2], Sean S. Hodgman[1,2], Stephan Langer[2,3], Ian P. McCulloch[4], Fabian Heidrich-Meisner[2,5], Immanuel Bloch[1,2], and Ulrich Schneider[1,2] — [1]LMU München — [2]MPQ Garching — [3]University of Pittsburgh, USA — [4]University of Queensland, Brisbane, Australia — [5]Universität Erlangen-Nürnberg, Erlangen

We study out-of-equilibrium dynamics and transport properties of interacting many-body systems using ultracold atoms in optical lattices. Specifically, we investigate the expansion dynamics of initially localized bosons in homogeneous 1D and 2D Hubbard systems. We find that the fastest, ballistic expansions occur in the integrable limits of the system. In 1D, these are both the non-interacting case as well as the hard-core regime, i.e. the strongly-interacting limits in the absence of doubly or higher occupancies. Any deviation from these limits, either through finite interactions or the admixture of double occupancies in the initial state for strong interactions, significantly slows down the expansion. In 2D, the strongly interacting limit is fundamentally different: Here, the system expands ballistically only in the non-interacting case, while all interactions lead to strongly diffusive behavior. By controlling the tunneling along individual lattice axes, we can gradually change the dimensionality of the system from 1D to 2D. In the strongly interacting case, we observe how the initially ballistic dynamics in a 1D system turn diffusive when additional degrees of freedom become available.

Q 40.2 Wed 14:15 A 310

Mean-field theory for extended Bose-Hubbard model with hard-core bosons — •Mathias May[1], Nicolas Gheeraert[2], Shai Chester[3], Sebastian Eggert[4], and Axel Pelster[4] — [1]Institut für Theoretische Physik, Freie Universität Berlin, Germany — [2]Institute of Theoretical Physics, University of Edinburgh, UK — [3]Physics Department, Columbia University, USA — [4]Fachbereich Physik, Technische Universität Kaiserslautern, Germany

We solve the extended Bose-Hubbard Model with hard-core bosons within mean-field theory for both a quadratic and a triangular lattice. To this end the nearest neighbor terms involving both interaction and hopping are factorized into a mean field and an operator. Assuming additionally a natural division of the lattice into sublattices, we yield a much simpler two- or three-site mean-field Hamiltonian for the quadratic and triangular lattice, respectively. Considering an on-site hard-core interaction allows each site to be occupied by at most one boson, thus the two- or three-site mean-field Hamiltonian reduces to a 4x4- or 8x8-matrix. The resulting energy eigenvalues have to be extremized with respect to the order parameters, which represent the condensate density and the average number of particles for each of the sublattices. As a result we obtain a mean-field phase diagram, which consists of a Mott insulator phase, a density wave phase, a superfluid phase and, for the triangular lattice, also of a supersolid phase. Finally, we determine whether the respective transition lines in the phase diagram are of first or second order and compare our results with recent quantum Monte Carlo simulations.

Q 40.3 Wed 14:30 A 310

Coherent coupling of Bloch bands in an optical lattice — •Christoph Sträter and Andre Eckardt — Max-Planck-Insuitut für Physik komplexer Systeme, 01387 Dresden, Germany

Ultracold quantum gases in optical lattices potentials have gained a lot of attention as a versatile tool for engineering many-body lattice physics under extremely clean and tunable conditions. In the interesting tight-binding regime of deep lattices, where a description in terms of Hubbard-type models applies, the lowest Bloch band is energetically well separated from excited bands. Therefore, orbital degrees of freedom belonging to excited bands are usually frozen out. Methods that have been used experimentally to include orbital freedom are a π-pulse like population transfer to the excited band via Raman coupling [1] and the rapid ramping of superlattice structures [2], both approaches involve considerable heating. Another scheme consists in using the sublattice orbital degree of freedom of special lattice geometries [3]. We are proposing a different method, namely to coherently couple energetically distant bands by employing an external time-periodic force. Such an approach allows to open the orbital freedom adiabatically in different ways under highly tunable conditions. We derive effective time-independent Hubbard models describing the band-coupled system. Within this framework we study the melting of a bosonic Mott-isulator as a result of the coherent band coupling.

[1] T. Müller, S. Fölling, A. Widera, and I. Bloch, PRL 99, 200405 (2007) [2] G. Wirth, M. Ölschläger, and A. Hemmerich, Nature Phys. 7, 147 (2011) [3] P. Soltan-Panahi et al., Nature Phys. 8, 71 (2012)

Q 40.4 Wed 14:45 A 310

Breathing mode in Bose-Hubbard chain with a harmonic trapping potential. — •Wladimir Tschischik, Masud Haque, and Roderich Moessner — Max-Planck-Institut für Physik komplexer Systeme, Dresden

Bosons in the continuum and bosons in optical lattices are both well-studied systems. We investigate the breathing mode of harmonically trapped bosons in the Bose-Hubbard (lattice) model at low fillings, seeking to connect to known results from Gross-Pitaevskii theory for continuum bosons. In 1D systems where there is no true Bose condensation, comparison with Bose-Hubbard dynamics is a particularly stringent test of the Gross-Pitaevskii description, which assumes a condensate. Using several numerical methods, we demonstrate that there is an intermediate interaction regime, between a ”free-boson” limit and a ”free-fermion” limit, in which the Bose-Hubbard breathing mode frequency approaches the Gross-Pitaevskii prediction.

Q 40.5 Wed 15:00 A 310

An Efficient Approach to Calculating Wannier States and Extension to Inhomogeneous Systems — •Ulf Bissbort and Walter Hofstetter — ITP, Goethe-Universität Frankfurt

Wannier states are a fundamental and central constituent to the construction of many-body models, as they are restricted to the single-particle Hilbert subspace of the respective band, while minimizing the spatial spread. Although simple in their initial definition as discrete Fourier transforms of the Bloch states, their actual computation amounts to a non-trivial high-dimensional minimization problem of the spatial variance as a complex phases of the single-particle Bloch state. Various involved techniques have been devised to efficiently treat this minimization problem, which quickly becomes numerically demanding for all but the simplest lattice geometries. We present an alternative approach, which allows for an efficient numerical calculation of the maximally localized Wannier states and entirely circumvents the pitfalls associated with the minimization technique, such as getting stuck in local minima. The computational effort scales favorably with increasing dimensions and lattice geometries in comparison to the minimization technique. Furthermore it allows for the first clear and unambiguous definition of Wannier states in inhomogeneous systems.

Q 40.6 Wed 15:15 A 310

A new lattice setup for a three-component Fermi gas — •Mathias Neidig, Martin Ries, Andre N. Wenz, Puneet Murthy, Thomas Lompe, and Selim Jochim — Physikalisches Institut, Ruprecht-Karls-Universität Heidelberg

Strongly interacting degenerate three-component Fermi gases are expected to show interesting many-body physics such as the formation of an atomic colour superfluid. However, studying such systems has so far been inhibited by large three-body loss rates. This limitation could be overcome via quantum Zeno loss blocking in a periodic potential. In this talk we present our progress towards realizing a three-component system in a single layer two-dimensional optical lattice.

We have transferred a quantum degenerate two-component gas of ^{6}Li atoms from an optical dipole trap into a stack of pancake shaped potentials with a spacing of about $4\,\mu$m which are formed by the interference pattern of two far off-resonant beams. Using tomographic radio frequency spectroscopy, we can show that we load the atoms into less than five pancakes. In the next step we will optimize this transfer such that we load only one pancake. By adding perpendicular lattice beams and transferring atoms into the third accessible hyperfine state we should then be able to produce a stable, strongly interacting three-component Fermi gas.

Q 40.7 Wed 15:30 A 310

Emergence of coherence in optical lattices — •Simon Braun[1,2], Sean Hodgman[1,2], Michael Schreiber[1,2], Philipp Ronzheimer[1,2], Daniel Garbe[1,2], Immanuel Bloch[1,2], and Ulrich Schneider[1,2] — [1]Ludwig-Maximilians-Universität München — [2]Max-Planck-Institut für Quantenoptik, Garching

Superfluidity in bosonic systems is fundamentally connected with the existence of long-range phase coherence. While this relationship is a well-established concept for equilibrium states also in optical lattices, much less is known about the dynamical emergence of coherence when the superfluid regime is entered. We present a detailed experimental study on how coherence of ultracold bosonic atoms in an optical lattice emerges when crossing the transition from the Mott insulating into the superfluid regime. We analyze the coherence length established in the system in dependence of the transition rate over the phase transition. We find a distinct symmetry between positive and negative temperature states at minimum and maximum kinetic energy, respectively, proving that the dynamics is independent of any residual non-local correlations in the initial Mott insulator. We investigate the behavior in different dimensions and also in an alternative scheme where coherence emerges in a static system after an initial quench.

Q 41: Quantum information: Concepts and methods III

Time: Wednesday 14:00–16:00 Location: E 214

Group Report Q 41.1 Wed 14:00 E 214

Quantum contextuality: state-independent inequalities, dimension witnesses, and challenges for new experiments — •Matthias Kleinmann[1], Jochen Szangolies[1], Costantino Budroni[1], Otfried Gühne[1], Adán Cabello[2], and Jan-Åke Larsson[3] — [1]Universität Siegen, D-57068 Siegen, Germany — [2]Universidad de Sevilla, E-41012 Sevilla, Spain — [3]Linköpings Universitet, SE-58183 Linköping, Sweden

Quantum mechanics cannot be explained by a non-contextual classical theory. This fact was pioneered by Kochen and Specker and is one of the fundamental features of quantum measurements. In a non-contextual classical theory, the outcome of a measurement must be independent of the measurement context, i.e., independent of any other measurements that are performed along with it. But quantum mechanics does not obey this rule, as can be shown by the violation of a non-contextuality inequality. Such inequalities are a natural generalization of Bell inequalities and in particular it is possible to find non-contextuality inequalities that are violated for *any* quantum state, even the completely mixed state. In this talk, recent results will be summarized, in particular the construction of the most fundamental state-independent inequality and the dimension-dependence of the violation of a non-contextuality inequality. Despite quantum contextuality has been demonstrated in several experiments, many questions and challenges remain open and shall also be outlined in this talk.

Q 41.2 Wed 14:30 E 214

Concept for a remote, balanced receiver for quantum key distribution — •Jan Gniesmer, Vitus Händchen, Tobias Eberle, and Roman Schnabel — Institut für Gravitationsphysik, Leibniz Universität Hannover and Max-Planck-Institut für Gravitationsphysik (Albert-Einstein-Institut), Callinstr. 38, 30167 Hannover, Germany

Entanglement-based continuous variable quantum key distribution networks rely on the efficient distribution and detection of quadrature entangled states. The distribution can be realized by coupling entangled states of light at 1550nm to optical fibers. This has been previously realized for squeezed states with high efficiency [Mehmet 2010]. In this talk I will present a scheme for distributing entangled states through 1km of fiber and measuring their quadrature amplitudes with balanced homodyne detection. This stand-alone receiver requires a phase lock of its local oscillator and polarization control of the distributed states.

Q 41.3 Wed 14:45 E 214

Simulation of sparse qubit systems — •Robert Zeier — Technische Universität München, Department Chemie, Lichtenbergstr. 4, 85747 Garching

We simulate the effect of unitary transformations on multi-qubit systems. The memory requirements arising from a exponentially growing state space are managed by assuming that the density matrix stays sparse during the simulation. We replace the customary matrix exponentiation with optimized computations in structure-constant Lie algebras. This allows us to better account for efficiency and sparsity while increasing the number of qubits. We present computer experiments with several tens of qubits and explore applications to the simulation of quantum algorithms.

Q 41.4 Wed 15:00 E 214

Robustness of quantum memories based on Majorana zero modes — Leonardo Mazza[1,2], •Matteo Rizzi[1,3], Mikhail Lukin[4], and Ignacio Cirac[1] — [1]Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Strasse 1, D-85748 Garching, Germany — [2]Scuola Normale Superiore, piazza dei Cavalieri 7, I-56127, Pisa, Italy — [3]Institut für Physik, Johannes-Gutenberg-Universität Mainz, Staudingerweg 7, D-55128 Mainz, Germany — [4]Physics Department, Harvard University, Cambridge, Massachusetts 02138, USA

We analyze the quantum memory based on a Kitaev chain containing Majorana zero modes in the presence of perturbations. We first derive a closed expression for the fidelity of the best recovery operation acting on the memory after the storage time and aimed at retrieving the initial encoded information. We then apply it to study the robustness of the memory to Hamiltonian (time-dependent) perturbations, as well as to particle losses. In the first case, the memory time grows exponentially with the system size only when the perturbed Hamiltonian is within the topological phase, and even if the perturbation contains frequencies that lie well above the gap. At the same time, the memory is unstable to particle losses.

Q 41.5 Wed 15:15 E 214

Quantum Circuit Implementation of Cyclic Mutually Unbiased Bases — •Ulrich Seyfarth, Niklas Dittmann, and Gernot Alber — Institut für Angewandte Physik, Technische Universität Darmstadt, 64289 Darmstadt, Germany

Complete sets of mutually unbiased bases (MUBs) play an important role in the areas of quantum state tomography and quantum cryptography. Sets which can be generated cyclically may eliminate certain side-channel attacks. To profit from the advantages of these MUBs we propose a method for deriving a quantum circuit that implements the generator of a set into an experimental setup. For some dimensions this circuit is minimal. The presented method is in principle applicable for a larger set of operations and generalizes recently published results [1]. Financial support by CASED is acknowledged.

[1] U. Seyfarth and K. S. Ranade, Phys. Rev. A 84, 042327 (2011)

Q 41.6 Wed 15:30 E 214

Quantum Walks with Nonorthogonal Position States — •Robert Matjeschk[1], Andre Ahlbrecht[1], Martin Enderlein[2], Christopher Cedzich[1], Albert H. Werner[1], Michael Keyl[3], Tobias Schaetz[2], and Reinhard F. Werner[1] — [1]Institut für Theoretische Physik, Leibniz Universität Hannover, Appelstr. 2, 30167 Hannover, Germany — [2]Albert-Ludwigs-Universität Freiburg, Physikalisches Institut, Hermann-Herder-Str. 3, 79104 Freiburg, Germany — [3]ISI Foundation, Via Alassio 11/c, 10126 Torino - Italy

Quantum walks have by now been realized in a large variety of different physical settings. In some of these, particularly with trapped ions, the walk is implemented in phase space, where the corresponding position states are not orthogonal. We develop a general description of such a quantum walk and show how to map it into a standard one with orthogonal states, thereby making available all the tools developed for the latter. This enables a variety of experiments, which can be implemented with smaller step sizes and more steps. Tuning the non-orthogonality allows for an easy preparation of extended states such as momentum eigenstates, which travel at a well-defined speed with low dispersion. We introduce a method to adjust their velocity by momentum shifts, which allows to experimentally probe the dispersion relation, providing a benchmarking tool for the quantum walk, and to investigate intriguing effects such as the analog of Bloch oscillations.

Q 41.7 Wed 15:45 E 214

Quasi phase-locking without a phase reference — •Christian R. Müller[1,2], Petr Marek[3], Radim Filip[3], 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, Germany — [3]Department of Optics, Palacký University, Olomouc, Czech Republic

The common approach to lock the phases of two quantum states is to individually couple them to a phase reference, e.g. a bright local oscillator, which can then directly be locked. However, if a bright phase reference cannot be provided the phase information is typically insufficient to stabilize the relative phase. We show that the phases of the quantum states can still be aligned to, in principle, arbitrary accuracy by allowing for probabilistic operation. This is achieved by measuring the freely drifting interference of the weak phase references by a photon number resolving detector and heralding the locked states based on the detected number of photons. Interestingly, not only the phase but all other degrees of freedom are also locked.

Q 42: Ultra-cold atoms, ions and BEC V (with A)

Time: Wednesday 14:00–16:00 Location: B 302

Invited Talk Q 42.1 Wed 14:00 B 302

Dipolar Physics with Ultracold Atomic Magnets — •Ferlaino Francesca — Institut für Experimentalphysik Universität Innsbruck Technikerstraße 25 6020 Innsbruck, Austria

We report on the production of the first Bose-Einstein condensate of erbium [1]. Erbium is a very special multi-valence-electron atom, belonging to the lanthanide series. It possesses a strongly magnetic dipolar character, a rich energy level diagram, and various isotopes, among which one has a fermionic nature. Despite the complex atomic properties of such unconventional species, we find a surprisingly simple and efficient approach to reach quantum degeneracy by means of laser cooling on a narrow-line transition and standard evaporative cooling techniques. We observe favorable scattering properties of 168Er, resulting in remarkably high evaporation efficiency and in a large number of Feshbach resonances at very low magnetic field values. We recently employed a Feshbach resonance to magnetically associate Er_2 Feshbach molecules, which are of extreme dipolar character. Our observations make Er a dream system for ultracold quantum gas experiments.

[1] K. Aikawa, A. Frisch, M. Mark, S. Baier, A. Rietzler, R. Grimm, and F. Ferlaino, Bose-Einstein Condensation of Erbium, Phys. Rev. Lett. 108, 210401 (2012).

Q 42.2 Wed 14:30 B 302

Novel resonant states in three-body problem — •Maxim A. Efremov[1], Lev Plimak[1,2], and Wolfgang P. Schleich[1] — [1]Institut für Quantenphysik and and Center for Integrated Quantum Science and Technology (IQST), Universität Ulm, 89069 Ulm, Germany — [2]Max-Born-Institut, 12489 Berlin, Germnay

We consider the bound states of a three-body system consisting of a light particle and two heavy ones when the heavy-light short-range interaction potential has a resonance corresponding to the non-zero orbital momentum. Within the Born-Oppenheimer approach we suggest a novel method to find the effective potential between the heavy particles by a self-consistent scattering of a light particle by two heavy ones. In the case of the exact resonance in the p-wave scattering the effective potential is shown to be attractive and long-range, namely it decreases as the third power of inter-atomic distance. Moreover, the range and power of the potential, as well as the number of the bound states are determined mainly by the mass ratio of the heavy and light particles and the parameters of the heavy-light short-range potential.

Q 42.3 Wed 14:45 B 302

Quantum Phases of Soft-Core Dipolar Bosons in Optical Lattices — •Sebnem Günes Söyler[1], Daniel Grimmer[2], and Barbara Capogrosso-Sansone[2] — [1]Max Planck Institute for the Physics of Complex Systems, Dresden, Germany — [2]University of Oklahoma, Norman, USA

We perform quantum Monte Carlo simulations of a system of soft-core ultracold bosonic atoms with dipolar interactions, confined in a two dimensional optical lattice. We consider long range isotropic repulsive interactions which refers to dipoles are alligned perpendicular to the plane. We calculate the ground state phase diagram for a parameter range that exhibits various solids, superfluid and supersolid phases. We also present finite temperature results and discuss the experimental feasibility of such phases.

Q 42.4 Wed 15:00 B 302

Ultracold Lattice Gases with Periodically Modulated Interactions — •Akos Rapp, Xiaolong Deng, and Luis Santos — Institut für Theoretische Physik, Leibniz Universität, 30167 Hannover

We show that a time-dependent magnetic field inducing a periodically modulated scattering length may lead to interesting novel scenarios for cold gases in optical lattices, characterized by a nonlinear hopping depending on the number difference at neighboring sites. We discuss the rich physics introduced by this hopping, including pair superfluidity, exactly defect-free Mott-insulator states for finite hopping, and pure holon and doublon superfluids. We also address experimental detection, showing that the introduced nonlinear hopping may lead in harmonically trapped gases to abrupt drops in the density profile marking the interface between different superfluid regions.

Q 42.5 Wed 15:15 B 302

Coherent Backscattering of Ultracold Atoms — •Fred Jendrzejewski[1,3], Kilian Müller[1], Jeremie Richard[1], Philippe Bouyer[2], Alain Aspect[1], and Vincent Josse[1] — [1]Laboratoire Charles Fabry, Palaiseau, France — [2]LP2N, Talence, France — [3]Joint Quantum Institute, Gaithersburg, USA

Quantum interference effects play a fundamental role in our understanding of quantum transport through disordered media, as it can lead to the suppression of transport, i.e. Anderson Localization. Recently it became possible to directly observe Anderson Localization with ultracold atoms. Convincing as they are, none of these experiments includes a direct evidence of the role of coherence.

For weak disorder, a first order manifestation of coherence is the phenomenon of coherent backscattering (CBS), i.e. the enhancement of the scattering probability in the backward direction, due to a quantum interference of amplitudes associated with two opposite multiple scattering paths.

In this talk, I present our work on the direct observation of such a CBS peak. Launching atoms with a well-defined momentum in a laser speckle disordered potential, we follow the progressive build up of the momentum scattering pattern, consisting of a ring associated with multiple elastic scattering, and the CBS peak in the backward direction. The observation of the CBS peak is a smoking gun of the existence of quantum coherence in quantum transport in disordered media.

Q 42.6 Wed 15:30 B 302

Sympathetic cooling of OH^--ions using Rb atoms in a MOT — •Bastian Höltkemeier[1], Matthias Weidemüller[1], Thorsten Best[2], and Roland Wester[2] — [1]Physikalisches Institut, Im Neuenheimer Feld 226, 69120 Heidelberg — [2]Institut f. Ionenphysik und Angewandte Physik, Technikerstr. 25/3, 6020 Innsbruck

Based on previous experiments on ion-atom reactions, we present a new setup to investigate the interaction of ultracold rubidium atoms in a Dark-SPOT and mass-selected OH^--water clusters. The ions are trapped in an octupole RF-trap consisting of thin wires instead of metal rods to give maximum optical access.

As a first step we have performed numerical simulations using SimIon to investigate the possibility to sympathetically cool the OH^- ions using the ultracold rubidium atoms. These simualtions suggest, that with our trap configuration cooling by at least one order of magnitude can be achived. As an outlook we will report on the current status of the experiment and possible future applications.

Q 42.7 Wed 15:45 B 302

Photoassociation near the intercombination line of ^{40}Ca — •Max Kahmann[1], Oliver Appel[1], Eberhard Tiemann[2], Fritz Riehle[1], and Uwe Sterr[1] — [1]Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig, Welfengarten 1, 30167 Hannover — [2]Institut für Quatenoptik, Universität Hannover, Welfengarten 1, 30167 Hannover

We have measured for the first time photoassociation resonances in the narrow-line system $^1S_0$ + $^3P_1$. We use about 10^5 calcium atoms that are trapped and evaporatively cooled to about 1 μK in a crossed optical dipole trap at a density of 10^{13} cm^{-3}. Precisely tunable laser light is produced by offset locking a diode laser to a laser which is resonant to the atomic line. The light is applied for typically 1 s to the trapped atoms and the trap loss is observed from absorption images of the atomic cloud. In a range of up to 25 GHz below the asymptote we have observed 6 photoassociation resonances in the two molecular potentials $\Omega = 0$ and $\Omega = 1$ correlating to the $^3P_1$ + $^1S_0$ asymptote. In both the $\Omega = 0$ and 1 excited states we observe a Zeeman splitting.

A theoretical model was developed in order to describe the Zeeman splitting and the energy of the bound molecular states in both potentials. The data helps to improve our knowledge of the molecular parameters and the dispersion coefficients and allows the use of low-loss optical Feshbach resonances to manipulate the atomic scattering length.

Q 43: Poster II

Time: Wednesday 16:00–18:30 Location: Empore Lichthof

Q 43.1 Wed 16:00 Empore Lichthof

Ho:YLF Laser mit direkter Anregung durch einen GaSb-Laserdiodenstack bei 1940 nm — Karsten Scholle, •Felix Gatzemeier, Samir Lamrini, Peter Fuhrberg und Philipp Kopmann — LISA laser products OHG, Max-Planck-Str. 1, 37191 Katlenburg

Lasersysteme im Wellenlängenbereich um 2100 nm sind aufgrund ihrer Eigenschaften vielfältig einsetzbar, z. B. in der Medizin, der Kunststoffbearbeitung oder der Messtechnik. Außerdem können sie zur Anregung von optisch parametrischen Oszillatoren für die nichtlineare Frequenzkonversion in den mittelinfraroten Wellenlängenbereich genutzt werden. Ho:YLF Laser mit ihrer hohen Strahlqualität und polarisierten Emission eignen sich besonders gut für diese Anwendungen. Die richtungsabhängige Absorption des Kristalls kann bei der Anregung durch Laserdioden optimal ausgenutzt werden.

Bisher wurden Ho:YLF Laser immer mit Tm-Festkörper- oder Faserlasern angeregt, was zu komplexen Gesamtsystemen mit geringer Effizienz führt. Wir präsentieren einen Ho:YLF Hochleistungslaser, der erstmals mithilfe eines GaSb-basierten Laserdiodenstacks resonant angeregt wurde. Dabei wurden eine maximale Ausgangsleistung von 11,6 W und ein differentieller Wirkungsgrad von 25 % erzielt (0 °C Kristalltemperatur). Bei Raumtemperatur betrug die Ausgangsleistung bis zu 8,7 W. Die Emissionswellenlänge des Lasers war abhängig vom Auskoppelgrad und lag zwischen 2100 nm und 2060 nm.

Q 43.2 Wed 16:00 Empore Lichthof

Ein regenerativer Zweifarben-Ti:Sa Verstärker für ein Triplett-Solvatationsdynamik Experiment — •Carl Böhmer[1], Vincenzo Talluto[1], Thomas Walther[1] und Thomas Blochowicz[2] — [1]Institut für Angewandte Physik, Technische Universität Darmstadt, Schlossgartenstr. 7, 64289 Darmstadt — [2]Institut für Festkörperphysik, Technische Universität Darmstadt, Hochschulstraße 8, 64289 Darmstadt

Die Triplett-Solvatationsdynamik ist eine Methode, mit der Relaxation in unterkühlten Flüssigkeiten nahe des Glasübergangs untersucht werden kann. Hierzu wird der Flüssigkeit ein Farbstoff beigemischt, welcher mittels eines UV-Laserpulses in einen langlebigen Triplettzustand angeregt wird. Über den zeitlichen Verlauf der Emissionswellenlänge des Farbstoffes kann die Relaxation der Solvatationshülle in einem Zeitbereich von 0.1 ms bis 1 s verfolgt werden. Je nach Farbstoff kann dabei eine dielektrische oder mechanische Response auf die Anregung des Farbstoffmoleküls beobachtet werden.

Um den nutzbaren Zeitbereich zu vergrößern, wird ein regenerativer Zweifarben-Ti:Sa Verstärker aufgebaut. Hiermit werden synchrone Pulse bei 320 nm und 940 nm erzeugt, mit denen eine stimulierte Besetzung des Triplettzustands möglich werden soll. Diese Methode verspricht hohe Transfereffizienzen in den Triplettzustand, wodurch der nutzbare Zeitbereich besonders zu kurzen Zeiten hin erweitert wird. Wir präsentieren erste Spezifikationen des Lasersystems sowie aktuelle Messungen.

Q 43.3 Wed 16:00 Empore Lichthof

Spectroscopy and self-pulsed red and orange laser operation of Sm^{3+} doped $LiLuF_4$ crystals — •Philip Werner Metz[1], Francesca Moglia[1], Sebastian Müller[1], Fabian Reichert[1], Daniel-Timo Marzahl[1], Nils-Owe Hansen[1], Matthias Fechner[1], Christian Kränkel[1,2], and Günter Huber[1,2] — [1]Universität Hamburg, Institut für Laser-Physik — [2]The Hamburg Center for Ultrafast Imaging

Most solid state lasers with emission wavelengths in the visible spectral region were so far based on nonlinear processes. In the recent years the development of new excitation sources emitting in the blue spectral region, e.g. InGaN-laser diodes and frequency doubled optically pumped semiconductor lasers (2ω-OPSL), have opened access to solid state lasers emitting directly in the visible spectral region. The most common ion for visible laser radiation within the rare earths is the praseodymium ion. However there are a couple of other rare earth ions with absorption lines in the blue spectral region which might support short wavelength laser operation. In this contribution we present spectroscopic investigations and our first results of laser experiments with Sm^{3+}:$LiLuF_4$ crystals. The lasers were continuously pumped by a 2ω-OPSL at a wavelength of 479 nm and emitted irregular pulses in the kHz range at wavelengths of 605 nm, and 640 nm with average output powers up to 30 mW and puls durations of several μs. The repetition rates of the lasers grow almost linear with the absorbed pump power while the pulse shapes remain almost constant, indicating a pulse mechanism comparable to a passive Q-switch.

Q 43.4 Wed 16:00 Empore Lichthof

Ein Brillouin-LIDAR zur Messung von Temperaturprofilen im Ozean: Fortschritte am gepulsten Faserverstärker — •David Rupp, Andreas Rudolf und Thomas Walther — Institut für Angewandte Physik, AG Laser und Quantenoptik, Technische Universität Darmstadt, Schlossgartenstr. 7, 64289 Darmstadt

Als Alternative zu kontaktbasierten Messverfahren entwickelt unsere Arbeitsgruppe ein flugtaugliches LIDAR-System zur Messung von Wassertemperaturprofilen im Ozean. Das Messprinzip basiert auf der

Detektion von spontaner Brillouin-Streuung, welche eine temperaturabhängige Spektralverschiebung gegenüber dem eingestrahlten Licht aufweist.

Die verwendete Laserquelle muss schmalbandige ns-Laserpulse im grünen Spektralbereich bereitstellen. Hierfür entwickeln wir einen Ytterbium-dotieren Faserverstärker mit anschließender Frequenzverdopplung. Die Wellenlänge ist durch unseren atomaren Detektor auf Basis von Rubidium auf 543 nm vorgegeben.

Aus der kontinuierlichen, vorverstärkten Seed-Strahlung eines ECDLs werden mittels elektro-optischer Modulatoren fourier-limierte 10 ns-Pulse mit einer maximalen Wiederholrate von 5 kHz ausgeschnitten. Anschließend werden die Pulse in drei Yb-dotieren Fasern mit jeweils steigendem Kerndurchmesser verstärkt. Die beiden letzten Stufen besitzen photonische Kristallstruktur und zeigen keinerlei Limitierung durch nichtlineare Effekte. Abschließend erfolgt effiziente Frequenzverdopplung in einem KTP-Kristall. Die derzeit maximal erreichbare Pulsenergie liegt im dreistelligen μJ-Bereich.

Q 43.5 Wed 16:00 Empore Lichthof

Vollständig festkörperbasierter Ar^+-Laserersatz — •Tobias Beck, Benjamin Rein und Thomas Walther — TU Darmstadt, Institut für Angewandte Physik, Laser und Quantenoptik, Schlossgartenstraße 7, 64289 Darmstadt

Vorgestellt wird eine Laserquelle, die bereits erfolgreich zur Kühlung relativistischer Ionen am Experimentierspeicherring der GSI eingesetzt wurde. Die Ausgangsleistung des Faserverstärkers beträgt bis zu 12 W bei 1029 nm. Die so erzeugte Strahlung kann spektral bis zu 26 GHz in 5 ms modensprungfrei abgestimmt werden. Bei einer Scanrate von 1 kHz kann stabil bis zu 4 GHz weit gescannt werden. Die Zentralwellenlänge lässt sich außerdem leicht um mehrere nm verschieben. Die Linienbreite beträgt unter 1 MHz. Anschließend wird durch Frequenzverdopplung in einem Überhöhungsresonator mit einem LBO-Kristall die Zielwellenlänge von 514 nm erreicht. Die Konversionseffizienz beträgt bereits bei einer IR-Leistung von $3,5$ W über 50 %. Das System wird mit Hilfe eines Offset-Locks auf eine externe Referenz absolut in seiner Frequenz stabilisiert. Zusätzlich ist es möglich mittels eines weiteren Überhöhungsresonators und einem BBO-Kristall die Frequenz auf 257 nm zu verdoppeln. Dabei wurden bisher Leistungen von bis zu 200 mW im UV-Bereich erzielt. Die so erzeugte UV-Strahlung lässt sich um 12 GHz in 25 ms abstimmen.

Q 43.6 Wed 16:00 Empore Lichthof

Universeller, VCSEL-geseedeter Ti:Sa Laser mit großer spektraler Abdeckung — •Tobias Krebs, Thorsten Führer und Thomas Walther — Technische Universität Darmstadt, Institut für Angewandte Physik, Schlossgartenstr. 7, 64289 Darmstadt

Eine VSCEL-Diode (Vertical Cavity Surface Emitting Laser) bei 850 nm wird als Injection-Seeder für einen Titan:Saphir-Laser verwendet. Pumpquelle ist ein kommerzieller, gepulster Nd:YAG-Laser. Der Resonator, bestehend aus zwei Spiegeln, dem Ti:Sa-Kristall und einem Prisma, wird mittels Polarisations-Spektroskopie nach Hänsch-Couillaud automatisch auf die Seedwellenlänge resonant gehalten. Durch den Einsatz der MEMS-Technologie (Micro-Electro-Mechanical System) bei VCSELn lässt sich prinzipiell ein modenspruchfreier Durchstimmbereich von 50 nm erreichen. Ziel des Projekts ist es, diesen weiten Durchstimmbereich auf den Ti:Sa-Laser zu übertragen, wodurch eine Verstärkung der schwachen Ausgangsleistung des VCSELs erreicht wird. In Verbindung mit nichtlinearen Konversionsschritten ist es dann möglich, den gesamten Spektralbereich von 190 nm bis 6000 nm abzudecken. Es soll der aktuelle Stand des Projekts vorgestellt werden.

Q 43.7 Wed 16:00 Empore Lichthof

Detailed investigations on novel TBR-diode-lasers in external resonators — •Mario Niebuhr, Christof Zink, Danilo Skoczowsky, Axel Heuer, and Ralf Menzel — Universität Potsdam, Institut für Physik und Astronomie, Photonik, Karl-Liebknecht-Straße 24-25, Haus 28, 14476 Potsdam

Laser diodes are cheap and effective light sources. They generally lack high output powers due to the small active volume and the corresponding low damage threshold. Within a reasonable scope one can therefore extend the active region. Such broad area laser diodes exhibit higher optical output powers up to tens of watts, but suffer from poor beam quality because of diminished mode selection.

Introducing a Transversal-Bragg-Resonance-(TBR-)grating alongside the core region results in a variable propagation loss depending on the transversal mode structure itself. One can thereby stimulate specific low loss resonance modes by using an external resonator assembly.

We were able to achieve transversal single mode operation with a quasi diffraction limited beam using TBR-diodes with various core geometries. The corresponding experimental results and the influence of the external resonator will be discussed. Furthermore computer simulations will be presented to understand the emission characteristics and obtain suggestions for improvements.

Q 43.8 Wed 16:00 Empore Lichthof

Development of a narrowband laser system for spectroscopy of ultra cold mercury — •Anika Trautmann[1], Holger John[1], Sascha Tichelmann[2], and Thomas Walther[1] — [1]Technische Universität Darmstadt, Institut für Angewandte Physik, Laser- und Quantenoptik, Schlossgartenstraße 7, 64289 Darmstadt — [2]Technische Universität Darmstadt, Institut für Angewandte Physik, Atome - Photonen - Quanten, Schlossgartenstraße 7, 64289 Darmstadt

Ultra cold neutral mercury trapped in an optical lattice lock has potential for a new time standard. A narrowband laser system with high stability on the $^1S_0$ - $^3P_0$ clock transition is required. We are working towards the realization of such a system. It is based on an external-cavity diode laser at 1062.4 nm which employs a low budget 4 nm broad interference-filter with a max. transition of 40%. Its output power is increased by amplification in an fiber amplifier. Subsequently, the wavelength of the clock transition at 265.6 nm will be reached by non-linear frequency conversion. The current state of the project will be presented.

Q 43.9 Wed 16:00 Empore Lichthof

Collective Spontaneous Emission from a System of Quantum Dots — •Wildan Abdussalam[1] and Paweł Machnikowski[2] — [1]Max Planck Institute for the Physics of Complex Systems, Nöthnitzer strasse 38, d-01187 Dresden, Germany — [2]Institute of Physics, Wrocław University of Technology, 50-370 Wrocław, Poland

We study the spontaneous emission from a regular lateral array or a randomly distributed ensemble of quantum dots under strong excitation (full inversion) conditions. We focus on the similarities and differences between the cases of random and regular arrangement of the dots and show that there is very little difference between the evolution of luminescence in these two cases, both for identical dots and for a realistically inhomogeneously broadened ensemble. This means that the enhanced emission or superradiance effect is not due to accidental clustering of pairs of dots. Moreover, we point out that observation of an enhanced emission under weak excitation does not prove that true superradiance will develop in a fully inverted system.

Q 43.10 Wed 16:00 Empore Lichthof

VUV generation in a hollow core fiber — •Andreas Koglbauer[1], Thomas Diehl[1,2], Daniel Kolbe[1,2], Matthias Stappel[1,2], Ruth Steinborn[1,2], and Jochen Walz[1,2] — [1]Johannes Gutenberg-Universität Mainz, 55099 Mainz — [2]Helmholtz-Institut Mainz, J.J.-Becher-Weg 36, 55128 Mainz

For future laser cooling of anti-hydrogen as well as quantum information processing with Rydberg ions, there is a need for a strong continuous vacuum ultraviolet (VUV) laser source in the region of 121-123 nm. Non-degenerate four-wave mixing (FWM) in metal vapors is a well-established method for VUV generation. Utilizing multi-photon resonances of the nonlinear medium, we recently demonstrated an important improvement in the mixing efficiency in mercury [1,2]. Further power enhancement can be achieved with an elongated interaction region of the fundamental beams, by confining the light in a vapor filled hollow core fiber.

We present a study of possible phase-matching scenarios and their associated VUV efficiencies, considering dispersion and losses due to the medium as well as the fiber. A gain of more than three orders of magnitude in the output power should be feasible. A sufficient mercury vapor within the fiber is demonstrated via absorption spectroscopy on the $6^1S - 6^3P$ transition in mercury transverse through the fiber, as well as the observation of two-photon resonance with longitudinally coupled beams.

[1] arXiv:1209.1519 (2012)
[2] Phys. Rev. Lett. 109, 063901 (2012)

Q 43.11 Wed 16:00 Empore Lichthof

Vierwellenmischen in einer mit Hg-Dampf gefüllten Hohlfaser zur Erzeugung von VUV-Strahlung — •Thomas Diehl[1,2], Andreas Koglbauer[1], Daniel Kolbe[1,2], Matthias Stappel[1,2], Ruth Steinborn[1,2] und Jochen Walz[1,2] — [1]Johannes Gutenberg-

Universität Mainz, D-55099 Mainz — [2]Helmholtz-Institut Mainz, J.J.-Becher-Weg 36, 55128 Mainz

Eine leistungsstarke und kontinuierliche Laserquelle im vakuumultravioletten (VUV) Bereich wird u.a. für zukünftige Präzisionsexperimente an gefangenem Anti-Wasserstoff benötigt. Die Erzeugung dieser Strahlung erreichen wir über einen Vierwellenmischprozess in Quecksilberdampf. Durch dreifach resonantes Vierwellenmischen mit fokussierten Gaußstrahlen ist es uns gelungen, eine leistungsstarke und effiziente kontinuierliche Laserquelle im Bereich um 121 nm zu verwirklichen [1].

Eine Hohlfaser bietet die Möglichkeit, den Wechselwirkungsbereich der Laserlichtfelder mit dem nichtlinearen Medium von ca. 1 mm, beim Vierwellenmischen mit fokussierten Gaußstrahlen, auf einige cm zu verlängern. Aus theoretischen Rechnungen geht hervor, dass dabei eine Effizienzsteigerung um drei Größenordnungen möglich ist.

Wir präsentieren den aktuellen Stand des Experiments sowie die jüngsten Ergebnisse beim Vierwellenmischen in einer dampfgefüllten Hohlfaser.

[1] Phys. Rev. Lett. 109, 063901 (2012)

Q 43.12 Wed 16:00 Empore Lichthof

High repetition rate continuously tunable near-IR and mid-IR nanosecond optical parametric oscillator — •Jens Bethge[1], Mateusz Ibek[1], Sophie Kröger[2], Hartmut Zimmermann[3], and Edlef Büttner[1] — [1]Angewandte Physik & Elektronik GmbH, Berlin, Germany — [2]Hochschule für Technik und Wirtschaft, Berlin, Germany — [3]Crystal Laser Systems GmbH, Berlin, Germany

Optical Parametric Oscillators (OPOs) with nanosecond pulse duration are of vital interest for applications in, e.g., chemistry, biology, and life-science. Most common systems provide a few 10 ns pulse duration and only some 10 Hz repetition rate, limiting the photon throughput in most experiments. We demonstrate a system with less than 2 ns pulse duration and up to 15 kHz repetition rate providing access to a new measurement regime. Using a passively Q-switched diode pumped pump laser at a wavelength of 1064 nm results in a cost effective system with an integrated pump laser and a small footprint. Further, the repetition rate can be freely tuned down to a few Hz or single shot operation. The presented cavity features a periodically poled magnesium oxide doped lithiumniobate crystal with a FAN-out design allowing for fast continuous tuning. Tuning in the near-IR spectral region from 1400-1970 nm (Signal wave) and in the mid-IR region from 2200-4200 nm (Idler wave) is demonstrated by tuning the crystal position only. Pulse energies of up to 4 uJ are measured, i.e., peak powers of more than 2 kW for the Signal.

Q 43.13 Wed 16:00 Empore Lichthof

Femtosecond-laser written waveguides in KTP for type II second harmonic generation — •Sebastian Müller[1], Thomas Calmano[1], Manuel Kirchen[1], Christian Kränkel[1,2], Carlota Canalias[3], Fredrik Laurell[3], and Günter Huber[1,2] — [1]Universität Hamburg, Institut für Laser-Physik, Hamburg, Germany — [2]The Hamburg Center for Ultrafast Imaging, Hamburg, Germany — [3]Department of Applied Physics, KTH, Albanova, Stockholm, Sweden

$KTiOPO_4$ (KTP) is a very suitable material for nonlinear optics due to a number of favorable properties like high nonlinear optical coefficients, wide transparency, good mechanical properties and strong resistance to visible light. It exhibits an extraordinary wide phasematching bandwidth for noncritical Type II frequency doubling of fundamental wavelengths around 1 μm. The technique of fs-laser writing gives the possibility to produce waveguiding structures in various active and passive dielectric media with the advantage of light confinement over long distances. In this contribution we present our results of efficient second harmonic generation in KTP waveguides. The waveguides were produced by writing double track structures in a 9.5 mm long z-cut KTP sample. Structures written with a track spacing of 22 μm enabled waveguiding of low loss ($<$ 0.8 dB/cm) circular single modes. 1.3 mW of light at a wavelength of 540.4 nm were achieved by frequency doubling the output of an Yb-fiber laser. This led, compared to the launched power of 126 mW to a normalized conversion efficiency of 9.1%/(Wcm^2).

Q 43.14 Wed 16:00 Empore Lichthof

Four-wave mixing in a three-color cavity — •Peter Micke[1,2], Thomas Diehl[1,2], Andreas Koglbauer[1,2], Daniel Kolbe[1,2], Matthias Stappel[1,2], Ruth Steinborn[1,2], and Jochen Walz[1,2] — [1]Johannes Gutenberg-Universität Mainz, 55099 Mainz — [2]Helmholtz-Institut Mainz, 55099 Mainz

Continuous coherent vacuum ultraviolet (VUV) radiation has fascinating applications. Radiation at Lyman-α (121,6 nm) is needed for future laser cooling of antihydrogen in experiments to test the fundamental symmetry between matter and antimatter. Radiation at slightly longer wavelengths can be used for Rydberg excitation of trapped ions in quantum information processing.

We use solid-state laser systems to produce continuous coherent VUV radiation by four-wave sum-frequency mixing (FWM) in Hg vapor. We plan to boost the VUV yield by enhancing the power of the fundamental beams at 254 nm, 408 nm, and 545 nm in a three-color cavity. A small Hg vapor cell is placed in the common focus of the cavity. Brewster prisms are used to split the three beams into separate collimated cavity return paths for coupling and stabilization. Previous experiments have been limited by a residual deposition on the vacuum side of the Hg cell windows, induced by the fundamental beam at 254 nm. This ruins the enhancement of the cavity. We are presently constructing a miniature cryogenic trap to avoid this problem in the future.

Q 43.15 Wed 16:00 Empore Lichthof

Whispering gallery mode resonators made from BBO — Guoping Lin[1], •Josef Urban Fürst[1,2], Dmitry Strekalov[1], Ivan Grudinin[1], and Nan Yu[1] — [1]Jet Propulsion Laboratory, California Institute of Technology. Pasadena, California, USA — [2]Institut für Optik, Information und Photonik, Universität Erlangen-Nürnberg. Erlangen, Germany

We demonstrate the first whispering gallery resonators made from the nonlinear crystal beta barium borate. Quality factors were measured at various optical wavelengths and they exceeded 10^8 in the ultraviolet wavelength regime. From these measurements we inferred new upper bounds for the absorption coefficients of beta barium borate at 1560 nm, 980 nm and 370 nm. Additionally, the polarization properties of the resonances in this angle-cut birefringent resonator were characterized. With these measurements, we laid the basis to combine the outstanding properties of whispering gallery resonators with the nonlinear optical properties of beta barium borate. This offers novel applications for whispering gallery resonators in nonlinear optics in the ultraviolet wavelength regime.

Q 43.16 Wed 16:00 Empore Lichthof

Sensitive measurements of atmospheric absorption spectra in the cavity of a broadband Cr:forsterite laser — •Svetlana Kuznetsova, Peter Fjodorow, Klaus Sengstock, and Valeri Baev — Institut für Laser-Physik, Universität Hamburg, Luruper Chaussee 149, 22761 Hamburg, Germany

Chromium doped forsterite lasers are of high interest for molecular spectroscopy due to their broad emission, ranging from 1.1 to 1.4 μm [1]. We demonstrate a broadband Cr:forsterite laser around 1.26 μm, pumped by an Yb-doped fiber laser with variable pulse duration. We performed intracavity absorption measurements with this laser and achieved an effective absorption path length of about 1000 km. The laser system can be applied for simultaneous sensitive measurements of various atmospheric molecules, e.g., O_2, H_2O, CO_2, CH_4, N_2O and HO_2. Some pollutants, such as HF and HCl can be measured with a sub ppb sensitivity as well.

This project is supported by DFG within GRK1355.

[1]. I. McKinnie et al, Appl Opt. 36, 4985 (1997)

Q 43.17 Wed 16:00 Empore Lichthof

A sample-free calibration method for quantitative Raman spectroscopy of hydrogen isotopologues — Magnus Schlösser[1], •Simone Rupp[1], Hendrik Seitz[1], Sebastian Fischer[1], Beate Bornschein[1], Timothy M. James[2], and Helmut H. Telle[2] — [1]Institute for Technical Physics, Tritium Laboratory Karlsruhe, Karlsruhe Institute of Technology, Germany — [2]Department of Physics, Swansea University, United Kingdom

Accurate composition measurements of gaseous samples of hydrogen isotopologues (H_2, D_2, T_2, HD, HT, DT) are of high importance in various fields of research. One example is the KArlsruhe TRItium Neutrino Experiment (KATRIN), which uses a gaseous tritium source as β-emitter for a high-sensitivity measurement of the neutrino mass. Impurities of all other hydrogen isotopologues are present in the T_2-source; their concentrations have to be measured accurately in order to minimize systematic uncertainties in the neutrino mass measurement.

Raman spectroscopy is a favorable technique for composition measurements, allowing for non-contact, in-line and multispecies gas analysis with high sensitivity. The quantitative analysis of Raman spectra requires a calibration of the Raman system employed. This poster presents a sample-free calibration method which allows to determine the calibration factors for all six hydrogen isotopologues. The approach makes use of theoretical Raman signal amplitudes, i.e. it combines theoretical Raman intensities with a measurement of the spectral sensitivity of the Raman system. The obtained results were successfully verified by an independent calibration method using gas samples.

Q 43.18 Wed 16:00 Empore Lichthof

Photoluminescence excitation and spectral hole burning spectroscopy of silicon-vacancy centers in diamond — •Carsten Arend[1], Hadwig Sternschulte[2], Doris Steinmüller-Nethl[2], and Christoph Becher[1] — [1]Universität des Saarlandes, Experimentalphysik, D-66123 Saarbrücken — [2]rho-BeSt Coating Hartstoffbeschichtungs GmbH, 6020 Innsbruck

Silicon-vacancy (SiV) centers in diamond are promising sources for single photons because they provide narrow zero-phonon-lines (ZPLs) in the near infrared (738 nm), high photostability, weak phonon coupling and high brightness [1]. At cryogenic temperatures, the ZPL shows a four line fine structure due to the doubly split ground and excited states. We here report on the results of photoluminescence excitation (PLE) spectroscopy where we scan a narrow-band laser across the fine structure lines and detect fluorescence on the phonon sidebands. We measure linewidths and splittings of an ensemble of SiV centers in a high quality, homoepitaxial CVD film and obtain linewidths of about 10 GHz as compared to a lifetime limited width in the order of 0.1 GHz. This difference arises from the inhomogeneous broadening of the transitions caused by spectral diffusion. We report on spectral hole burning spectroscopy which enables measurement of the homogeneous linewidth.
[1] E. Neu et al., New. J. Phys. 13, 025012 (2011)

Q 43.19 Wed 16:00 Empore Lichthof

Stimulierte Raman-Streuung mit einem schnell durchstimmbaren nicht-kollinearen optisch-parametrischen Oszillator — •Claudia Hoffmann[1], Tino Lang[1,2] und Uwe Morgner[1,2,3] — [1]Institut für Quanten Optik, Leibniz Universität Hannover — [2]Quest, Hannover — [3]Laserzentrum Hannover e.V.

Wir präsentieren die schnelle und empfindliche Erfassung breitbandiger Raman-Spektren mit Hilfe der Stimulierten Raman-Streuung (SRS). Nichtlineare Raman-Spektroskopie weist eine sehr viel höhere Empfindlichkeit auf als klassische Raman-Spektroskopie und erlaubt somit prinzipiell eine schnellere Erfassung solcher Spektren. Eine maßgebliche Einflussgröße für die erreichbare Aufnahmegeschwindigkeit ist die Durchstimmgeschwindigkeit der Lichtquelle. In unserem Experiment wird ein ultra-breitbandig phasenangepasster nicht-kollinearer optisch-parametrischer Oszillator eingesetzt, der durch Änderung der Resonatorlänge durchgestimmt wird. Gepumpt wird der Oszillator von einem frequenzverdoppelten Yb:KLu$(WO_4)_2$-Scheibenoszillator bei einer Repetitionsrate von 34 MHz. Mit einer durchschnittlich erhältlichen Ausgangsleistung von über 2W sind die Ausgangspulse über einen weiten spektralen Bereich von 650 nm bis 1200 nm durchstimmbar. Wird dieser Puls als Pump-Puls zusammen mit einem direkt vom Laser gelieferten Stokes-Puls bei 1030 nm räumlich und zeitlich überlagert, so lassen sich damit SRS-Spektren mit Videoraten über den Bereich von 3600 cm^{-1} bis 700 cm^{-1} erzeugen. So können transiente chemische Prozesse verfolgt werden.

Q 43.20 Wed 16:00 Empore Lichthof

Robust, frequency-stable and accurate mid-IR laser spectrometer in the $5-12$ μm spectral range based on combining QCLs and optical frequency metrology using upconversion in orientation-patterned GaAs — •Michael Hansen[1], Ingo Ernsting[1], Stephan Schiller[1], Sergey Vasilyev[1], and Arnaud Grisard[2] — [1]Heinrich-Heine-Universität Düsseldorf, Institut für Experimentalphysik, Universitätsstr. 1, 40225 Düsseldorf — [2]Thales Research and Technology, France

We demonstrate a robust and simple method for measurement, stabilization and tuning of the frequency of cw mid-infrared (MIR) lasers, in particular of quantum cascade lasers, allowing implementation of flexible and "turn-key" spectrometers for a range of high-resolution spectroscopic tasks. The MIR laser wave is upconverted by sum-frequency generation in an orientation-patterned GaAs crystal with the output of a standard high-power cw 1.5 μm fiber laser, subsequent amplification of the sum-frequency wave, Continuous measurements of this wave's and the fiber laser's frequency by a standard Er:fiber frequency comb provide signals allowing frequency control of the MIR laser. The proof of principle is performed with a quantum cascade laser at 5.4 μm, which is upconverted to 1.2 μm. The absolute QCL frequency is determined with 100 kHz-level inaccuracy relative to an atomic frequency reference. Frequency stabilization to sub-10 kHz level, controlled frequency tuning and long-term stability are demonstrated.

Q 43.21 Wed 16:00 Empore Lichthof

Tm/Ho codoped fiber laser for sensitive intracavity absorption spectroscopy — •Peter Fjodorow, Ortwin Hellmig, Svetlana Kuznetsova, Klaus Sengstock, and Valeri Baev — Institut für Laserphysik, Universität Hamburg, Germany

The simultaneous incorporation of Thulium and Holmium ions into laser materials, not only gives the possibility to build up a laser source emitting in the spectral range of 1.8 - 2.2 μm [1], where many molecules show strong absorption, but it also enables the use of easily available diode lasers at 800 nm as pump sources.

We demonstrate a broadband Tm/Ho silica fiber laser, tunable by an intracavity lens and emitting in the above mentioned spectral region. By performing intracavity absorption measurements with this laser system, various gases, such as H_2O, CO_2, N_2O, CH_4, NO, NH_3, HCl, HBr and C_2H_2, can be simultaneously detected with a ppb sensitivity and without the need for clean samples. The recording time for the emission spectrum of an individual laser pulse can be set to 50 μs, allowing to perform very sensitive *in situ* measurements of nonstationary processes. This laser system can be applied, e.g. for environmental and medical purposes, as well as for the study of combustion processes.

This project is supported by DFG within GRK 1355.

Q 43.22 Wed 16:00 Empore Lichthof

Cancer cell therapy by upcoversion UV emission from Pr:YAG nanoparticles — Kangwei Xia[1], •Gengxu Chen[1,2], Andrea Zappe[1], Rolf Reuter[1], Rainer Stöhr[1], Tugrul Inal[1], Jan Meijer[3], Roman Kolesov[1], and Jörg Wrachtrup[1] — [1]3. Physikalisches Institut, Universität Stuttgart, Pfaffenwaldring 57, Stuttgart, D-70569, Germany — [2]State Key Laboratory of Precision Spectroscopy, East China Normal University, Shanghai, 200062, China — [3]RUBION, Ruhr-Universität Bochum, Bochum, D-44780, Germany

Recently, rare-earth ions doped inorganic crystals have been introduced into cellular microscopic studies as new types of biomarkers due to optical upconversion process [1]. Furthermore, optical upconversion process in rare-earth doped materials can produce ultraviolet (UV) emission with visible or even infrared excitation. If such nanoparticles are located inside living cells, the cells will be killed by the UV emission with an appropriate excitation on the nanoparticles [2]. Here, we demonstrated the apoptosis of the HeLa cells incubated in a buffer containing Pr:YAG nanoparticles, which is on account of the photochemical effect caused by upconversion UV emission of Pr:YAG nanoparticles [2,3]. Our study might pave a way to novel methods of laser-assisted cancer treatment.

Reference [1] F. Wang and X. Liu, Chem. Soc. Rev. 38, 976-989 (2009) [2] R. Kolesov, K. Xia, R. Reuter, R. Stöhr, A. Zappe, J.Meijer, P.R. Hemmer, and J.Wrachtrup, Nat. Commun. 3:1029 doi: 10.1038/ncomms2034 (2012). [3] R. Kolesov, R. Reuter, K. Xia, R. Stöhr, A. Zappe, and J. Wrachtrup, Phys. Rev. B 84, 153413 (2011)

Q 43.23 Wed 16:00 Empore Lichthof

Design of ultrafast fluorescence spectroscopy for axial resolution of fluorophore distribution with low numerical apertures for ophthalmologic application — •Maximilian Gräfe[1], Andreas Hoffmann[1], and Christian Spielmann[1,2] — [1]Institut für Optik und Quantenelektronik, Abbe Zentrum für Photonik, Friedrich-Schiller-Universität Jena, Max-Wien-Platz 1, 07743 Jena — [2]Helmholzinstitut Jena, Fröbelstieg 3, 07743 Jena

A new method for resolving the fluorophore distribution along the propagation direction of a laserbeam is presented. For reaching spatial resolution of several tens of micrometers the time dependent fluorescence signal is sampled in the femtosecond-regime by using a technique similar to fluorescence upconversion applying optical parametric amplification. Thus this approach is applicable to fluorescence spectroscopy in the human eye.

The overall aim is to develope a method, which does not need high numerical apertures as it is necessary in confocal scanning systems.

Q 43.24 Wed 16:00 Empore Lichthof

Sample environments to image single molecules at the Euro-

pean XFEL Facility — Charlotte Uetrecht[1,2], •Sadia Bari[1], and Joachim Schulz[1] — [1]Sample Environment, European XFEL GmbH, Hamburg, Germany — [2]Molecular Biophysics, Uppsala University, Uppsala, Sweden

Recent success in femtosecond X-ray protein nano-crystallography and imaging of single mimivirus particles demonstrate the prospects of free-electron lasers (FEL) for biophysics. X-ray FELs provide much higher peak powers than any synchrotron source. Due to the short fs pulses, diffraction patterns of a sample can be recorded before damaging occurs. Thereby, the major bottleneck in structural biology to obtain large high quality crystals may be overcome. Since the sample is destroyed by the X-ray pulse, a full dataset is recorded from constantly replenished sample. The technique can also be used to study structural changes in bioparticles in a time-resolved manner. We develop methodology for efficient delivery and X-ray interaction of bio-samples at European XFEL. The two methods currently available for this purpose, a liquid jet and an aerodynamic lens, both suffer from high sample consumption. Native mass spectrometry (MS) has a high potential to overcome this problem. Furthermore, it allows online separation of species from a mixture. Therefore, it is especially suited to selectively investigate the structures of reaction intermediates. We show an introduction to established sample delivery techniques, native MS in general and first considerations how such a spectrometer can be integrated at the SPB-instrument.

Q 43.25 Wed 16:00 Empore Lichthof

3D super resolution upconversion microscopy of praseodymium-doped yttrium aluminum garnet — •Tugrul Inal, Rainer Stöhr, Roman Kolesov, Rolf Reuter, and Jörg Wrachtrup — 3. Physikalisches Institut and Stuttgart Research Center of Photonic Engineering (SCoPE), Universität Stuttgart, Pfaffenwaldring 57, 70569 Stuttgart, Germany

Super resolution fluorescence microscopy has caught great attention due to providing an optical resolution beyond the Abbe diffraction limit. Several diffraction unlimited techniques such as stimulated emission depletion (STED) and ground state depletion (GSD) microscopy have been developed for that purpose [1].

In previous work, we have demonstrated super-resolution upconversion microscopy of praseodymium-doped yttrium aluminum garnet (Pr:YAG) nanoparticles.This technique provides background-free imaging due to ultraviolet upconverted fluorescence of Pr:YAG nanoparticles [2].Combining the upconversion properties with a super-resolution optical microscopy technique similar to STED, yields to a lateral resolution of approximately 40 nm which is of the order of the size of the particles under study.

In this contribution, we discuss an additional improvement to the technique by increasing also the axial resolution far beyond the diffraction limit. Using the appropriate phase retardation plates, a resolution of approximately 40 nm in all three dimensions is achieved.

[1] Hell, S. W. et.al. Science 316, 1153-1158(2007) [2] Kolesov, R. et al. Phys. Rev. B 84, 153413 (2011)

Q 43.26 Wed 16:00 Empore Lichthof

Spectroscopic in-situ traceability for absolute distance interferometry — Günther Prellinger, Karl Meiners-Hagen, and •Florian Pollinger — Physikalisch-Technische Bundesanstalt (PTB), Bundesallee 100, 38116 Braunschweig, Germany

A popular approach to absolute distance measurements with interferometric accuracy is the so-called variable synthetic wavelength interferometry. The absolute length is deduced by the analysis of the phase shift of an interferometer signal observed during a defined frequency variation of the laser source. The accuracy of this method depends, inter alia, on the knowledge of the frequency change. Usually, technical references like Fabry-Perot interferometers or calibrated reference interferometers are used. Their stability and accuracy limits the uncertainty of the method today, in particular for the application in non-cooperative environments. In the presented study, Doppler-free iodine absorption spectroscopy is applied to determine the frequency change. A high-speed spectroscopic detection system has been realised capable of measurement times below 10 μs per absorption line. Thus, in-situ spectroscopic monitoring of the spectroscopic frequency markers can be performed in parallel to the interferometric phase measurement. First experiments indicate an achievable relative uncertainty better than 5×10^{-9} for the position of the frequency markers.

The project is funded by the DFG under grant PO1560/1-1.

Q 43.27 Wed 16:00 Empore Lichthof

An x-ray split and delay-unit for the European XFEL — •Sebastian Roling[1], Stefan Braun[2], Peter Gawlitza[2], Liubov Samoylova[3], Björn Siemer[1], Harald Sinn[3], Frank Siewert[4], Frank Wahlert[1], Michael Wöstmann[1], and Helmut Zacharias[1] — [1]Physikalisches Institut WWU Münster, Wilhelm-Klemm Straße 10, 48149 Münster — [2]Fraunhofer Institut IWS, Winterbergstraße 28, 01277 Dresden — [3]European XFEL GmbH, Alber-Einstein-Ring 19, 22761 — [4]HZB, Albert-Einstein-Straße 15, 12489 Berlin

For the European XFEL an x-ray split- and delay-unit (SDU) is built covering photon energies from 5 keV up to 20 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. The set-up is based on geometric wavefront beam splitting. The x-ray FEL pulses will be split by a sharp edge of a silicon mirror coated with Mo/B_4C multilayers for photon energies above 10 keV and W/B_4C below 10 keV. Both partial beams will 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. At a photon energy of 20 keV the reflectance of a Mo/B_4C multilayer coating with a multilayer period of 3.2 nm and $N = 200$ layers under a Bragg-angle of 0.57° amounts to $R = 0.92$. For a photon energy of 5 keV the reflectance of a W/B_4C coating with a multilayer period of 4 nm is $R = 0.73$. Because of the different incidence angles, the path lengths of the beams will vary as a function of wavelength between $\pm$ 3.7 ps at 20 keV and up to $\pm$ 40 ps at 5 keV.

Q 43.28 Wed 16:00 Empore Lichthof

Pulse compression and characterization of spectra supporting nearly single cycle pulses in the visible — •José Andrade[1,2], Anne Harth[1,3], Marcel Schultze[1], Claudia Hoffmann[1], Stefan Rausch[1,3], Thomas Binhammer[4], and Uwe Morgner[1,3,5] — [1]Institut für Quantenoptik, Leibniz Universität Hannover, Hannover, Germany — [2]Grupo de Lasers e Plasmas, Instituto de Plasmas e Fusão Nuclear, Instituto Superior Técnico, Lisboa, Portugal — [3]Quest: Center for Quantum Engineering and Space-Time Research, Hannover, Germany — [4]VENTEON Laser Technologies GmbH, Garbsen, Germany — [5]Lazer Zentrum Hannover, Hannover, Germany

We present a pulse compression scheme for the characterization and shaping of a two-colour pumped optical parametric chirped pulse amplified (OPCPA) laser system with spectra comprising of 1.5 octaves (from 430nm-1300nm; Fourier limit: sub-3 fs). A prism and an LCD spatial light modulator in a 4-f scheme is the base of our setup. Multiphoton intrapulse interference phase scan (MIIPS) is based on such an apparatus and is the most promising method to control the spectral phase. The study of the range of the needed specifications is being conducted, where theoretical simulations have been performed. This method has the advantage of both characterizing and compressing a pulse simultaneously through the use of a relatively simple setup.

Q 43.29 Wed 16:00 Empore Lichthof

Ultrakurzpulsoszillatoren der nächsten Generation — •Bernhard Kreipe[1], Jana Kampmann[1], Luise Beichert[1], Moritz Emons[1], Marcel Schultze[1] und Uwe Morgner[1,2] — [1]Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover — [2]Centre for Quantum Engineering and Space-Time Research (QUEST), Welfengarten 1, 30167 Hannover

Wir präsentieren Arbeiten zur Leistungs- und Energieskalierung gepulster Hochleistungsoszillatoren mit Pulsdauern im Bereich einiger 100 fs über Multikristall-Konzepte.

Durch das Hintereinanderschalten mehrerer Basismodule, bestehend aus je einem Yb:CALGO-Laserkristall mit Pumpelement in einer „zero-q“-Konfiguration, ist eine einfache Skalierung im Bereich der modengekoppelten Laseroszillatoren möglich. Neben der Reduzierung der thermischen Effekte durch die Aufteilung der Pumpleistung wird bei diesem Konzept insbesondere auch der Umlaufkleinsignalgewinn erhöht. In Kombination mit einer Auskopplung über Cavity-Dumping sollten damit bei 1 MHz Repetitionsrate hohe Pulsenergien im Bereich von 20 μJ direkt aus einem Oszillator möglich sein.

Q 43.30 Wed 16:00 Empore Lichthof

Hollow fiber pulse compressor for multi-mJ laser pulses — •Timo Rohrlapper[1], Martin Kretschmar[1,2], Peter Simon[3], Uwe Morgner[1,2,4], Milutin Kovacev[1,2], and Tamas Nagy[1,3] — [1]Leibniz Universität Hannover, Institut für Quantenoptik, Welfengarten 1, Hannover — [2]QUEST, Centre for Quantum Engineering and Space-Time Research, Welfengarten 1, Hannover — [3]Laser-Laboratorium Göttingen e.V., Hans-Adolf-Krebs-Weg 1, 37077 Göttingen — [4]Laser Zentrum Hannover e.V., Hollerithallee 8, Hannover

Lasers delivering few-cycle pulses (< 5 fs) play a prominent role in contemporary ultrafast science. Such lasers usually incorporate a spectral broadening stage, most frequently a hollow fiber compressor. Although this is an established technique which works well to sub-mJ pulses, it is still a great challenge to extend it to multi-mJ pulse energies. Such an energy scaling requires long hollow fibers. With our novel stretched flexible hollow fiber concept we can freely scale the length of the waveguide. Here we present the first experimental results of spectral broadening of ~2 mJ pulses with such fibers. By using a 3-m long fiber of 450 micron inner diameter filled with helium we could generate an octave-spanning spectrum with 1.5 mJ pulse energy giving a very high energy transmission of ~70%. The achieved spectral width supports 3.4 fs pulse duration.

Q 43.31 Wed 16:00 Empore Lichthof

Oberflächen-Plasmon-Polaritonen auf eindimensionalen Metallgittern nach Einstrahlung eines optischen Femtosekunden-Impulses — •Jens Bethge[1] und Roland Müller[2] — [1]Angewandte Physik & Elektronik GmbH, Berlin — [2]Max-Born-Institut, Berlin

Die Wechselwirkung zwischen Licht und strukturierten Metallfilmen ist in den letzten Jahren Gegenstand zahlreicher experimenteller und theoretischer Untersuchungen. Der Schwerpunkt dieser Arbeiten liegt auf dem Studium von Plasmon-Polaritonen auf Metalloberflächen. Wir stellen Ergebnisse theoretischer Untersuchungen vor, die den zeitlichen und räumlichen Verlauf des Lichtfeldes in optischen Transmissionsgittern nach Anregung mit einem 10fs Impuls beschreiben, vorausgesetzt, die Schlitzbreite der Gitter sei klein gegen die Lichtwellenlänge. Es werden zwei Modelle diskutiert: 1) Ein freistehendes Gitter und 2) ein Gitter auf einem dielektrischen Substrat. Im ersten Fall stimmen die Resonanzen der Plasmon-Polaritonen auf der Ober- und Unterseite des Metallgitters überein, während im letzteren die entsprechenden Resonanzstellen mit zunehmendem Brechungsindex im Substrat weiter auseinanderrücken. Dies führt zu unterschiedlich starker Kopplung zwischen den Feldern auf der Ober - und Unterseite in beiden Gittermodellen. Die Rechnungen zeigen deutliche Unterschiede in den Abklingkonstanten der Feldamplituden sowie stark differierende Transmissions-Spektren für die beiden Gittertypen. Ferner enthält die Arbeit Aussagen zur spektralen Dynamik im Nah- und Fernfeldbereich der Gitter.

Q 43.32 Wed 16:00 Empore Lichthof

Gepulste-Laser-Deposition von nichtlinearen Schichten und Charakterisierung mittels Erzeugung der dritten Harmonischen — •Mathias Hoffmann[1] und Uwe Morgner[1,2] — [1]Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover — [2]Laser Zentrum Hannover, Hollerithallee 8, 30419 Hannover

Mit Hilfe der gepulsten Laserdeposition (engl.: Pulsed Laser Deposition - PLD) können eine Vielzahl von Materialien als Schichten bzw. Schichtstrukturen deponiert werden. Bei der Schichtherstellung wird der Materialabtrag mit einem ns-Laser (1064 nm, 25 ns, 40kHz) durchgeführt. Deponiert werden Kupferoxid (CuO), Germanium (Ge), Silizium (Si) und Zinksulfid (ZnS) auf amorphe Substrate. Die entstandenen Schichten werden hinsichtlich ihrer Tauglichkeit als nichtlineares Medium als Frequenzverdreifacher untersucht. Hierzu wird mit Hilfe eines fs-Lasers die Frequenzverdreifachte erzeugt und mit der dritten Harmonischen erzeugt am Quarzglas verglichen. Mögliche Anwendung dieser Schichten besteht in der Frequenzverdreifachung spektral breitbandiger Pulse zur Pulscharakterisierung. In diesem Beitrag werden aktuelle Ergebnisse hinsichtlich der Schichtparameter (Material, Schichtdicke) für die Frequenzverdreifachung präsentiert.

Q 43.33 Wed 16:00 Empore Lichthof

Generation of Functional Structures in Dielectrics on Nanometer Scale via Shaped Femtosecond Laser Pulses — •Nadine Götte[1], Cristian Sarpe[1], Jens Köhler[1], Dirk Otto[1], Lars Englert[1], Thomas Kusserow[2], Tamara Meinl[2], Yousuf Khan[2], Hartmut Hillmer[2], Matthias Wollenhaupt[1], and Thomas Baumert[1] — [1]University of Kassel, Institute of Physics and CINSaT, D–34132 Kassel, Germany — [2]University of Kassel, Institute of Nanostructure Technologies and Analytics and CINSaT, D–34132 Kassel, Germany

In our experimental setup temporal shaped infrared femtosecond laser pulses are used for high precision laser processing of wide band gap dielectrics. By applying double pulses with certain interpulse delay or temporal asymmetric pulse trains ablation structures can be generated well below the diffraction limit [1–3].

Here we investigate functional structures on 100 nm scale by direct laser writing to demonstrate the potential for applications in nanophotonics. This includes the fabrication of spectral filters based on Fano resonances.

[1] L. Englert *et al.* Opt. Express **15**, 17855–17862, (2007)
[2] M. Wollenhaupt *et al.*, JLMN, **4**, 144–151 (2009)
[3] L. Englert *et al.*, J. Laser Appl., **24**, 042002 (2012)

Q 43.34 Wed 16:00 Empore Lichthof

Real time observation of transient electron density in water irradiated with tailored femtosecond laser pulses — Cristian Sarpe, Jens Köhler, Thomas Winkler, •Bastian Zielinski, Nadine Götte, Jutta Mildner, Matthias Wollenhaupt, and Thomas Baumert — University of Kassel, Institute of Physics and CINSaT, D–34132 Kassel, Germany

Ionization mechanisms in water irradiated with bandwidth-limited and temporally asymmetric femtosecond laser pulses are investigated via ultrafast spectral interferometry [1]. By using a novel common-path interferometer with an enlarged temporal measurement window we observe directly the dynamics of a free electron plasma generated by shaped pulses. We proved that a temporally asymmetric pulse and its time reversed counterpart address multiphoton and avalanche ionization mechanisms in a different fashion as suggested for solid dielectrics [2,3]. Positive third-order dispersion shaped pulses produce a much higher free electron density than negative ones at the same fluence, instantaneous frequency and focusing conditions. From the experimental data obtained after irradiation with bandwidth-limited and shaped pulses the multiphoton and avalanche coefficients were determined using a generic rate equation [4].

[1] C. Sarpe *et al.* New. J. Phys. **14**, 075021, (2012)
[2] L. Englert *et al.* Opt. Express **15**, 17855, (2007)
[3] L. Englert *et al.*, Appl. Phys. A **92**, 749, (2009)
[4] J. Noack and A. Vogel *et al.*, IEEE J. of Quantum Electron. **35**, 1156, (1999)

Q 43.35 Wed 16:00 Empore Lichthof

Laserinduced heating of thin graphite and SAM-graphene monitored by Ultrafst Electron Diffration — •Silvio Morgenstern, Christian Gerbig, Cristian Sarpe, Matthias Wollenhaupt, and Thomas Baumert — Universität Kassel, Institut für Physik und Center of Interdisciplinary Nanostructure Science and Technology (CINSaT), D-34132 Kassel, Germany

Ultrafast Electron Diffraction (UED) has lately become one of the most promising techniques to directly provide insights into fundamental dynamics in solids at the microscopic level on the pico- to subpicosecond timescale [1,2].

In this contribution we present our UED-setup to reach a high spatial and temporal resolution. Additionally we present first results in time-resolved diffraction experiments on thin graphite and SAM-graphene [3] and compare these with results from CVD-graphene [4].

[1] M. Chergui & A. H. Zewail, Chem. Phys. Chem. 10, 28 (2009)
[2] C.T. Hebeisen et.al., Optic Letters Vol. 31, No. 23, 3517 (2006)
[3] A. Turchanin et.al.,ACS Nano Vol.5, No.5, 3896 (2011)
[4] M. Schäfer et.al., New J. Phys. 13, 063030 (2011)

Q 43.36 Wed 16:00 Empore Lichthof

Erzeugung Harmonischer Strahlung mit Goldnanoantennen — •Monika Noack[1,2], Nils Pfullmann[1,2], Christian Waltermann[1,2], Milutin Kovacev[1,2], Vanessa Knittel[3], Alfred Leitenstorfer[3], Dieter Akemeier[4], Andreas Hütten[4] und Uwe Morgner[1,2] — [1]QUEST Centre for Quantum Engineering and Space-Time Research — [2]Institut für Quantenoptik, Leibniz Universität Hannover — [3]Department of Physics and Center for Applied Photonics, University of Konstanz — [4]Thin Films & Physics of Nanostructures, Department of Physics, Bielefeld University

Nanoantennen aus Metall zeigen im optischen Bereich ähnliche Eigenschaften wie Antennen im Radiofrequenz-Bereich. Durch eine passend gewählte Geometrie kann eine Überhöhung des elektrischen Feldes um mehrere Größenordnungen in einem kleinen Volumen erreicht werden. Die Feldstärken können dabei so hoch werden, dass die Erzeugung Hoher Harmonischer Strahlung (HHG) durch Spülung der Strukturen mit Gas demonstriert wurde. Wir zeigen unsere Experimente zur Wechselwirkung ultrakurzer Laserpulse mit unterschiedlichen Geometrien von Nanoantennen sowie deren Simulation mittels der FDTD-

Methode einschließlich des Temperaturverhaltens der verwendeten Antennen. Durch die Charakterisierung der verwendeten Gasdüse ist die Gasdichte sehr genau bekannt. Für die Erzeugung von HHG ist im Wechselwirkungsbereich der Antennen eine hohe Gasdichte notwendig. In einem Xenon- Gasstrahl wurden vergleichbare Photonenzahlen sowohl für die Wellenlänge der siebten Harmonischen des eingestrahlten Lasers als auch der Plasmalinien von Xenon gemessen.

Q 43.37 Wed 16:00 Empore Lichthof

Two-photon absorption and nonlinear refractive index in nominally undoped, thermally reduced $LiNbO_3$ — Holger Badorreck, •Stefan Nolte, Pia Baeune, and Mirco Imlau — School of Physics, Osnabrueck University, Germany

The two photon absorption coefficient β and the nonlinear index of refraction n_2 are determined in nominally undoped, thermally reduced $LiNbO_3$ single crystals by means of the z-scan technique. The crystals under investigation have become attractive for ultrafast photonics due to their unique photosensitive features over a huge timescale ranging from 100 fs to a few ms. It is well established that small bound Nb_{Li}^{4+} and Nb_{Li}^{4+}:Nb_{Nb}^{4+} polarons are at the origin of the photosensitivity and allow for visionary applications such as ultrafast holography (cf. e.g. M. Imlau et al. Opt. Express 19, 15322 (2011)). However, a non-neglectable impact of the small polaron density on the nonlinear electric susceptibility of third order can be expected, as well, that has not been studied, so far. We present our results on nominally undoped $LiNbO_3$ with thermal pre-treatment and compare our findings with untreated samples. An increase of the nonlinear electric susceptibility is distinguishable and is discussed in the frame of band-edge shifts due to alterations in the crystals' stoichiometry. We further discuss the impact of beam profile applied for the z-scan technique. Here, a spatial filtering with focusing mirrors has been realized to obtain a spatially trimmed Airy profile.

Financial support by the DFG (IM 37/5, INST 190/137-1) is gratefully acknowledged.

Q 43.38 Wed 16:00 Empore Lichthof

Stereo-Graphic Above-Threshold Ionization with 1.8 μm Few-Cycle Laser Pulses — •M. Möller[1], B. E. Schmidt[2], A. M. Sayler[1], G. Vampa[3], F. Legare[2], D. M. Villeneuve[3], G. G. Paulus[1], and P. B. Corkum[3] — [1]Helmholtz Institut Jena, Institut für Optik und Quantenelektronik, Max-Wien-Platz 1, 07743 Jena — [2]INRS,-EMT, 1650 Boulevard Lionel-Boulet, Varennes, Qc, J3X1S2, Canada — [3]JASLab, University of Ottawa/NRC, 100 Sussex Drive, Ottawa, Ontario K1A 0R6, Canada

Stereo-graphic above-threshold ionization (SATI) hase been the first phenomenon to show carrier-envelope phase (CEP) effects. It is now frequently used to characterize the CEP in strong-field light-matter interaction. So far, the concepts of the SATI-based CEP measurement have been established for pulses with a center wavelength around 800 nm. Here we present preliminary results from SATI measurements with passively CEP stable few-cycle pulses in the infrared spectral region around 1.8 μm. The CEP was continously ramped over more than 8 hours while the energy-dependent SATI spectra were recorded. The results show stronger CEP effects than reported previously particularly for the so-called direct electrons with energies around $2\,U_P$. In addition, large CEP-induced asymmetries for the left-right electron yield are found.

Q 43.39 Wed 16:00 Empore Lichthof

Ion Momentum Distributions from Strong-field Ionization of Atomic Ions using Linear and Elliptical Polarized Laser Light — •P. Wustelt[1], M. Möller[1,2], T. Rathje[1,2], D. Hoff[1,2], S. Trotsenko[2,3], Th. Stöhlker[1,2,3], A.M Sayler[1,2], and G.G. Paulus[1,2] — [1]Institute of Optics and Quantum Electronics Friedrich Schiller University Jena Germany — [2]Helmholtz Institute Jena, Germany — [3]GSI, Darmstadt, Germany

We investigate the multi-electron dynamics in strong field ionization with linear and elliptical polarized laser light. In contrast to linear polarization, for elliptically polarized many-cycle pulses, the final ion momentum distribution provides complete information on the ionization field strength as well as the ionization time. Elliptical polarization also allows one to suppress non-sequential ionization and determine the release times for subsequent ionizations, thereby probing electron correlation mechanisms not predicted by semi-classical tunneling models of sequential ionization. Moreover, starting from different initial charge states of the same atom allows us to isolate the effects of each ionization step. Here we present measurements of strong-field ionization of atomic ion beam targets (He^+, Ne^{n+}, Ar^{n+}, Xe^{n+}). The photoionized nuclei from the fast, transversally cold ion beam are detected using a position- and time-sensitive detector, which measures the momentum distribution and separates the initial and final charge states in space and time. In order to gain theoretical insight into the ionization dynamics, classical trajectory Monte-Carlo simulations are performed.

Q 43.40 Wed 16:00 Empore Lichthof

Characterization of supersonic gas jets as targets for laser-plasma interaction experiments — •Thomas Gangolf[1], Michael Schnell[1], Björn Landgraf[1,2], and Christian Spielmann[1,2] — [1]Institut für Optik und Quantenelektronik, Abbe Center of Photonics, Friedrich-Schiller-Universität Jena, Max-Wien-Platz 1, 07743 Jena, Germany — [2]Helmholtz-Institut Jena, Fröbelstieg 3, 07743 Jena, Germany

For studies of high power laser matter interaction, jets of neutral gases are widely used as targets for ultrashort pulses[1]. For the needs of a given experiment, a specifically tailored neutral gas density can be obtained from a particularly designed nozzle. In this contribution, we present a setup for the characterization of non-axisymmetric gas jet targets. We use a tomographic approach to measure the full 3D density profile and its temporal evolution by performing phase shift measurements with a Mach-Zehnder interferometer [2]. Additionally, we have carried out numerical simulations by solving the Navier-Stokes equations with a commercial computational fluid dynamics code. We have characterized divergent nozzles with different cross-sections. The realized supersonic gas jets have the expected plateau-like density profile. In this contribution we also report on successful laser wakefield acceleration experiments with rectangular shaped nozzles as well as about recent experiments studying the plasma dynamics with non-collinear laser beams in gas jets with elliptic cross-section.

[1] M. Schnell et al., Phys. Rev. Lett. **108**, 075001 (2012)
[2] B. Landgraf et al., Rev. Sci. Instrum. **82**, 083106 (2011)

Q 43.41 Wed 16:00 Empore Lichthof

Recombination effects in dielectrics irradiated with ultrashort intense laser pulses — •Nils Brouwer and Bärbel Rethfeld — TU Kaiserslautern, Erwin-Schrödinger-Straße 46, 67663 Kaiserslautern, Deutschland

Ultrashort laser pulses of high intensity are of increasing importance in material processing and fundamental research. In order to control or avoid laser damage to transparent dielectrics, a proper understanding of the involved microscopic processes is necessary. When modeling laser-excited dielectrics to trace dielectric breakdown, the valence band is often assumed to be fully occupied during the laser excitation. While this assumption certainly holds if the free electron density is several orders of magnitude below the valence band electron density, at high laser intensities its validity has to be examined, since recombination effects as Auger recombination can have a significant influence on the energy and particle density even on the subpicosecond timescale, if a considerable fraction of valence band states is unoccupied.

We extended our previous Boltzmann approach [1, 2] with an equation to model valence band dynamics and included collision integrals for Auger recombination. We present results for the free electron density, the free electron energy density and the phonon energy density with and without valence band dynamics.

[1] A. Kaiser, B. Rethfeld, M. Vicanek, G. Simon, *Phys. Rev. B* **61**, 11437 (2000)
[2] B. Rethfeld, H. Krutsch , D.H.H. Hoffmann, *Contrib. Plasma Phys.* **50**, 16 (2010)

Q 43.42 Wed 16:00 Empore Lichthof

Correlation measurements on single ultrashort light pulses — •Alexander Jänicke[1,2], Michael Förtsch[1,2], Jan Korger[1,2], Christoffer Wittmann[1,2], Christoph Marquardt[1,2], and Gerd Leuchs[1,2] — [1]Max-Planck Institute for the Science of Light, Erlangen — [2]Institute for Optics, Information and Photonics, University Erlangen-Nuremberg

The generation of non-classical states of light in higher order spatial modes can potentially increase the information capacity in quantum communication. Therefore we study the quantum properties of single ultrashort pulses using a highly efficient CCD camera.

We demonstrate that the repetition rate of a Ti:Sapphire laser can artificially be reduced to 1 Hz by a two-stage pulse picker design. This allows sampling of individual pulses on the CCD camera. We have realized a balanced detection scheme and studied intensity variances. Early experimental results indicate a shot noise limited measurement system.

This provides the basis for further studies of the spectral and spatial quantum properties of single ultrashort pulses. In particular, we want to measure non-classical correlations induced by the Kerr nonlinearity of a photonic crystal fiber. We will report on the latest results.

Q 43.43 Wed 16:00 Empore Lichthof

Controlling the dynamics of a single atom interacting with a high-finesse cavity — •Katharina Rojan[1], Daniel Reich[2], Christiane Koch[2], and Giovanna Morigi[1] — [1]Universität des Saarlandes, 66123 Saarbrücken — [2]Universität Kassel, 34132 Kassel

Quantum state preparation of the electromagnetic field is a prerequisite for quantum networks. In microwave cavity quantum electrodynamics the field can be manipulated by atomic beams which cross the resonator. We consider the question, how to prepare an arbitrary target state of the cavity by means of the interaction with a single atom, assuming that both cavity and atom can be driven by external fields. The problem draws on the proposal of [1], who showed that in principle this can be realized with a suitably tailored time-dependent Hamiltonian. We identify the time-dependent dynamics which is required in order to achieve a set of target states in the fastest time using Optimal Control Theory, in particular Krotov's method [2].

[1] C.K. Law and J.H. Eberly, Phys. Rev. Lett. **76**, 1055 (1996)
[2] D.M. Reich, M. Ndong, and C.P. Koch, J. Chem. Phys. **136**, 104103 (2012)

Q 43.44 Wed 16:00 Empore Lichthof

Cavity Quantum Electrodynamics in an Ellipsoidal Cavity — •Nils Griebe, József Z. Bernád, and Gernot Alber — Institut für Angewandte Physik, Technische Universität Darmstadt, 64289 Darmstadt, Germany

We discuss the dynamics of two two-level systems located in the foci of an ellipsoidal cavity which are coupled resonantly to a single photon of the radiation field inside this cavity. With the help of semiclassical methods a photonic path representation of the time evolution operator is developed. It is particulary well suited for describing the resonant photon exchange and modifications of the spontaneous decay process between both atoms inside the ellipsoidal cavity. In the limit of infinite separation of both foci our results reduce to the ones of a parabolic cavity.

Q 43.45 Wed 16:00 Empore Lichthof

Photon wave packet dynamics and resonant atom-photon interaction inside a parabolic cavity — •Johan David Eggers, József Zsolt Bernád, and Gernot Alber — Institut für Angewandte Physik, Technische Universität Darmstadt, D-64289 Darmstadt

The evolution of a single-photon electromagnetic wave packet is investigated, which is generated by a spontaneously decaying two-level system located at the focus of a parabolic half-open cavity with ideally conducting walls. In the rotating wave and dipole approximation a multiple scattering formalism is developed which represents relevant quantum mechanical probability amplitudes as sums of contributions of photonic paths in the cavity which have been scattered by the two-level system repeatedly. This photon-path representation is particularly well suited for describing the photonic wave packet dynamics in the semiclassical limit of small photonic wave lengths. Furthermore, it gives physical insight into the nature of the quantum electrodynamical light-matter interaction and its modification by boundary conditions.

This work is supported by the BMBF-project QuORep.

Q 43.46 Wed 16:00 Empore Lichthof

all-optical light beam steering beyond the paraxial approximation — •lida zhang[1], Tarak N. Dey[2], and Joerg Evers[1] — [1]Max-Planck-Institut f\"{u}r Kernphysik, Saupfercheckweg 1, D-69117 Heidelberg — [2]Department of Physics, Indian Institute of Technology Guwahati, Guwahati 781 039, Assam, India

We discuss all-optical steering of an optical beam. For this, we study light propagation in a suitable atomic medium driven beyond the paraxial approximation. Control fields are chosen such that they in essence optically create waveguide-like structures in the medium which allow to propagate the probe beam in a controlled way. We show that a branched waveguide can be implemented by employing control fields consisting of two parallel and one tilted Gaussian beams. This way, an input probe beam can be distributed between two output ports in an optically controlled way. The switching between the output ports can be controlled via the properties of the tilted coupling field. Interestingly, we find significant deviations from calculations in paraxial approximation already for light propagating in a single optically generated waveguide.

Q 43.47 Wed 16:00 Empore Lichthof

Coherent pulse propagation in nuclear media — •Xiangjin Kong and Adriana Pálffy — Max-Planck-Institut für Kernphysik, Saupfercheckweg 1, 69117 Heidelberg

Moving towards quantum interactions in the x-ray regime, new physical systems come into play, e.g., nuclei with low-lying collective states naturally arise as candidates for x-ray quantum optics studies. The coupling of nuclei with the radiation field is however significantly weaker than for atoms. For low x-ray intensities, this can lead to the delocalized excitation of a single nucleus. However, as long as elastic, recoil-free scattering of the incident light occurs, the contributions of all potential scatterers (nuclei) are spatially in phase in the forward direction and interfere coherently [1]. Thus the time evolution of the forward scattering response does not follow a natural exponential decay as expected for fluorescence involving a single-scattering event, but exhibits pronounced intensity modulations characteristic for the coherent resonant pulse propagation [1].

Here we investigate the situation of two counterpropagating resonant x-ray fields incident on a nuclear sample and the spatial distribution of the nuclear excitation probability. The coherent propagation in one direction can be under certain conditions controlled by the second counterpropagating pulse. This is a first step towards the study of coherent nuclear excitation in an x-ray cavity using x-ray mirrors at normal incidence [2].

[1] U. van Bürck, Hyperfine Interact. 123/124, 483 (1999).
[2] Y. Shvyd'ko *et al.*, Nature Photon. 5, 539 (2011).

Q 43.48 Wed 16:00 Empore Lichthof

Absorption and emission of a NV center coupled to an optical cavity — •Ralf Betzholz, Marc Bienert, and Giovanna Morigi — Theoretische Physik, Universität des Saarlandes, D-66123, Germany

We study a nitrogen vacancy center in a diamond crystal coupled to a single mode optical cavity. In particular the interaction of the electronic degree of freedom to bulk acoustic phonons is investigated. Starting from a Hamiltonian that includes the Jaynes-Cummings interaction and the Spin-Boson model a Master equation is derived that treats the spin-phonon interaction in a non-Markovian way. In order to model the absorption and emission spectra the population of the ground state and the excited state are calculated. In the calculations different forms of the spectral function, which represents the coupling of the excited state to the phonon modes, are taken into account. Furthermore, the influence of the cavity is investigated and the dependence of the absorption and emission behaviour on the temperature is studied.

Q 43.49 Wed 16:00 Empore Lichthof

Numerical treatment of non-linear effects on light propagation arising from vacuum polarisation — •Patrick Böhl, Ben King, and Hartmut Ruhl — Ludwig-Maximilians-Universität München, Theresienstr. 37, 80333 München

The upcoming availability of high-intensity laser facilities such as ELI [1] and XCELS [2], offer the possibility to test the predictions of QED in the non-linear regime. One such prominent prediction is the interaction of light with the polarised vacuum, which can be described by the so-called "Euler-Heisenberg" effective field theory. The resulting corrections to the classical Maxwell theory can be expanded in E/E_{cr} where $E_{cr} \approx 10^{16}$ V/cm is the critical field strength. We solve numerically, for the first time, the resulting implicit, non-linear equations of motion to lowest order in E/E_{cr}. The results describe light propagation at very high intensities and potentially hint at an ultimate limit of laser beam focussing due to the refractive interaction with the quantum vacuum.

[1] http://www.extreme-light-infrastructure.eu, Extreme Light Infrastructure (2012)
[2] http://www.xcels.iapras.ru, eXawatt Center for Extreme Light Studies (2012)

Q 43.50 Wed 16:00 Empore Lichthof

Speckle instabilities in non-linear disordered media —

•Felix Eckert, Andreas Buchleitner, and Thomas Wellens — Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, Hermann-Herder-Str. 3a, 79104 Freiburg

We study the emergence of instable, i.e. non stationary, behavior in disordered samples of non-linear point scatterers illuminated by a stationary monochromatic wave [1]. We perform a stability analysis of the system to determine the threshold-non-linearity where instable behavior sets in. We find that the position of the threshold depends crucially on the non-linear model we impose. This varying behavior of the different models can be qualitatively explained by a system composed of only two non-linear scatterers. We also examine coherent back scattering from non-linear scatterers and analyze to what extent this interference effect occurring in linear as well as in non-linear random media persists in the instable regime.

[1] B. Grémaud, T. Wellens, Phys.Rev.Lett. **104**, 133901 (2010)

Q 43.51 Wed 16:00 Empore Lichthof

Energy and phase dependence of the stability of three pulse soliton molecules in dispersion managed optical fibers — •Philipp Rohrmann, Alexander Hause, and Fedor Mitschke — Universität Rostock, Institut für Physik, Universitätsplatz 3, 18051 Rostock

It has been shown that solitons in dispersion managed optical fiber can form bound states, the so called soliton molecules. Such bound states may be used as additional symbols for nonbinary coding. In addition to the known case of the two-soliton molecule, an experimental verification of a three-soliton molecule was reported recently [1].

Here we present an experimental investigation of the stability of such three-soliton molecules for different pulse energies and relative phases. The pulse parameters of triple pulses were adjusted with a pulse shaping setup. These triple pulses were launched into a dispersion managed fiber; the output shape was measured with a cross correlation setup.

The energy range in which the formation of the molecule happens could be shown. We could also demonstrate that the stability of the molecule directly depends on the relative phase of the pulses; a stable propagation of the three-pulse molecules can be seen only for anti-phase pulses. The experimental data confirm the previous numerical work by our group.

[1] P. Rohrmann et al., Scientific Reports **2**, 866 (2012)

Q 43.52 Wed 16:00 Empore Lichthof

Comparison of Nelder-Mead Simplex and Genetic Algorithm Methods for Optimization of Soliton Molecules — •Sonia Gholami, Philipp Rohrmann, Alexander Hause, and Fedor Mitschke — Universität Rostock, Institut für Physik, Universitätsplatz 3, 18051 Rostock

There are several suggestions to further increase the data rate in optical data transmission. The use of solitons, particularly robust short pulses, is generally considered to be restricted to binary coding. Recently soliton molecules, i.e. bound pairs and triplets of solitons have been observed in experiments [1]. Together with ordinary solitons they allow quaternary coding.

In order to find the best shape of these compounds we evaluate their changes of shape during propagation, in other words compare shapes at input and output of a dispersion-managed fiber, with the goal of minimizing the difference. Information about this difference is then fed back to the initial pulse compound shape, in order to obtain an automatic optimization. This involves an algorithm for which we compare a Nelder-Mead simplex method and a genetic algorithm. We numerically test the optimization on known cases and proceed to more complex ones. We present a comparison of the algorithms in terms of speed and quality of convergence to the best shape.

[1] P. Rohrmann et al., Scientific Reports **2**, 866 (2012)

Q 43.53 Wed 16:00 Empore Lichthof

Optomechanical Crystals in Diamond — •Felix Guldner, Laura Kipfstuhl, and Christoph Becher — Universität des Saarlandes, Experimentalphysik, 66123 Saarbrücken

The realization of photonic crystal microcavities in diamond has successfully been demonstrated, both in simulation and fabrication. Generally, photonic crystals confining light can at the same time be designed as phononic crystals confining mechanical vibrations. The simultaneous localization of optical and acoustical modes in a single structure allows for optomechanical coupling due to the photoelastic effect and shifting material boundaries.

Its extraordinary mechanical properties, in particular its high Young's modulus, make diamond a very promising candidate for the realization of an optomechanical system with acoustical resonances in the range of few 10 GHz. Possible applications for these optomechanical crystals are manifold and reach from the area of quantum information science to high-precision measurements in sensing.

In a first step, we perform FDTD and FEM simulations to develop a design for optomechanical crystals capable of localizing both optical and acoustical modes. We outline methods for calculating and improving the coupling between these modes.

Q 43.54 Wed 16:00 Empore Lichthof

Preparation and spectral characterization of emitter-doped crystals on nanofibers — •David Papencordt, Ariane Stiebeiner, Moritz Numrich, and Arno Rauschenbeutel — VCQ, TU Wien – Atominstitut, Stadionallee 2, 1020 Wien, Austria

Tapered optical fibers with a nanofiber waist have proven to be a highly sensitive tool for surface spectroscopy which exhibits numerous advantages [1,2]. A possible route towards extending the range of applications to the single-molecule level is to deposit dye-doped organic crystals of sub-micron size onto the nanofiber section in order to interface them with the fiber-guided light via the evanescent field surrounding the nanofiber. We present and compare different ways of growing and depositing such crystals. In order to study crystal growth and guest-host interactions in the crystal, we carry out fluorescence and fluorescence excitation spectroscopy. This is achieved by exciting the crystals via the nanofiber while recording the fluorescence light which is coupled back into the fiber-guided mode. Measurements under cryogenic conditions allow us to reduce the homogeneous spectral broadening, a necessary prerequisite for spectrally addressing molecules out of the inhomogeneously broadened ensemble. As a first important step towards single molecule spectroscopy, we observed the statistical fine structure arising from the Poissonian fluctuations of the number of addressed molecules per spectral interval.

[1] F. Warken et al., Opt. Express, **15**, 11952 (2007)
[2] A. Stiebeiner et al., Opt. Express, **17**, 21704 (2009)

Q 43.55 Wed 16:00 Empore Lichthof

Fiber Fabry-Perot Cavities for CQED using Rb atoms — •Jose C. Gallego, Sutapa Ghosh, Miguel Martinez-Dorantes, Natalie Thau, Wolfgang Alt, Marcel Spurny, and Dieter Meschede — Institut für Angewandte Physik, Universität Bonn, Wegelerstraße 8, 53115 Bonn

CQED experiments rely on the coherent coupling of single or multiple atoms with an optical field inside a resonator. Recently a novel type of fiber-based cavities was presented, where the facet of optical fibers is machined with a CO_2-laser and coated with a dielectric to act as concave mirrors [1]. This kind of cavity provides much smaller mode waists (in the order of $5\mu m$) and thus stronger atomic coupling ($\frac{g}{\kappa} = 20$) as compared to conventional Fabry-Perot cavities. Here we present our first results on the fabrication and characterization of these cavities using our CO_2-laser setup.

[1] D Hunger *et al* 2010 *New J. Phys* **12** 065038.

Q 43.56 Wed 16:00 Empore Lichthof

Dual-polarity metalens based on plasmonic nanoantennas — Xianzhong Chen[1], Lingling Huang[1,2], •Holger Mühlenbernd[3], Guixin Li[4], Benfeng Bai[2], Qiaofeng Tan[2], Guofan Jin[2], Cheng-Wei Qiu[5], Shuang Zhang[1], and Thomas Zentgraf[3] — [1]School of Physics and Astronomy, University of Birmingham, Birmingham B15 2TT, UK — [2]State Key Laboratory of Precision Measurement Technology and Instruments, Tsinghua University, Beijing 100084, China — [3]Department of Physics, University of Paderborn, Warburger Straße 100, D-33098 Paderborn, Germany — [4]Department of Physics, Hong Kong Baptist University, Hong Kong — [5]Department of Electrical and Computer Engineering, National University of Singapore, 4 Engineering Drive 3, Singapore 117576, Singapore

The refractive index profile and surface topography dictate the functionality of a lens. Therefore the properties of the lenses are fixed during the fabrication process and cannot be altered. Here, ultrathin metalenses based on plasmonic nanoantennas can provide a solution. For such metalenses it is necessary to use a more generalized form of Snell's law, which contains an additional phase-change due to the plasmonic resonators. By controlling the position of the plasmonic resonators, it is possible to control the spatial phase-change of the incident beam. With this we are able to design ultrathin lenses with dispersionless behavior and specific focal length. Furthermore, we will show that the phase change depends on the polarization state of the incoming light. This opens the possibility to design lenses which can be switched from convex to concave.

Q 43.57 Wed 16:00 Empore Lichthof

A Cavity Nanoscope — •Matthias Mader[1,2], Hanno Kaupp[1,2], Thomas Hümmer[1,2], Jakob Reichel[3], Theodor W. Hänsch[1,2], and David Hunger[1,2] — [1]Ludwig-Maximilians-Universität München, Schellingstraße 4, 80799 München — [2]Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Straße 1, 85748 Garching — [3]Laboratoire Kastler-Brossel, ENS, CNRS, UPMC, 24 rue Lhomond, 75005 Paris

We present a novel tool for extremely sensitive and spatially resolved absorption spectroscopy on nanoscale objects. To boost sensitivity, multiple interactions of probe light with an object are realized by placing the sample inside an high finesse scanning optical microcavity. It is based on a laser machined and mirror-coated end facet of a single mode fiber and a macroscopic plane mirror forming a fully tunable open access Fabry-Perot cavity [1]. Scanning the sample placed on the plane mirror through the microscopic cavity mode yields a spatially resolved map of absorptivity of the sample.

We show first proof-of-principle experiments with single gold nanospheres. We demonstrate polarization sensitive absorption measurements as well as measurements on dispersive and birefringent effects of the samples.

[1] D. Hunger, T. Steinmetz, Y. Colombe, C.Deutsch, T. W. Hänsch and J. Reichel *A fiber Fabry-Perot Cavity with high finesse*, New J. Phys. **12**, pp. 065038(2010)

Q 43.58 Wed 16:00 Empore Lichthof

Photonic time-stretch system for high-frequency nonrepetitive electrical signals — •Christoph Reinheimer[1,2], Stefan Weber[1,2], and Georg von Freymann[1,2] — [1]Fraunhofer Institute for Physical Measurement Techniques, Department Terahertz Measurement and Systems, 79110 Freiburg, Germany — [2]University of Kaiserslautern, Physics Department and Research Center OPTIMAS, 67663 Kaiserslautern, Germany

We present a time-stretch system for the measurement of high-frequency electrical signals. The time information of these signals is mapped to the frequency spectrum of a pre-chirped laser pulse using an electro-optical modulator. [Chou, J.; Boyraz, O.; Solli, D.; Jalali, B.: Appl.Phys.Lett. 91, 161105 (2007)] A dispersive fiber element is used to stretch the optical signal to allow for measurement with standard fast photo-diodes and oscilloscopes. A variable temporal magnification up to a factor of 100 and a variable time-aperture up to 880 ps can be achieved by using a resonator geometry for the second dispersive fiber. Signal reconstruction is done by means of an optical back-propagation algorithm. [Stigwall, J.; Galt, S.: J. Lightwave Technol. 25, 3017 (2007)]

Q 43.59 Wed 16:00 Empore Lichthof

High-resolution microscopy and spectroscopy of rare-earth doped crystals for single ion detection — Tobias Utikal, •Emanuel Eichhammer, Stephan Götzinger, and Vahid Sandoghdar — Max-Planck-Institute for the Science of Light and Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU), D-91058 Erlangen, Germany

Rare-earth ion doped crystals have been considered for quantum memory applications due to their narrow spectral features and long spin coherence lifetimes on the order of seconds. While previous studies have worked with large ensembles of ions, many quantum information processing algorithms would benefit from control at the level of single material qubits. In our laboratory, we aim to spectrally isolate single praseodymium ions doped in an yttrium orthosilicate crystal. To address homogeneous linewidths below 100 kHz within an inhomogeneous band of 1 GHz, we have built a frequency-stabilized tunable laser system operating at 488 nm. In addition, we exploit various techniques of high-resolution microscopy to record the faint signal associated with transition lifetimes in the 100 μs. We present spectroscopic data and microscopic images of the system at hand and our progress towards the detection and spectroscopy of single ions.

Q 43.60 Wed 16:00 Empore Lichthof

Buried Rb-exchanged waveguides in KTP — •Christof Eigner, Helge Rütz, Olga Driesner, Raimund Ricken, Hubertus Suche, and Christine Silberhorn — Universität Paderborn, Integrierte Quantenoptik, Warburger Str. 100, D-33098 Paderborn

Waveguides fabricated by Rb-ion-exchange in Potassiumtytanylphosphate (KTP) allow for highly efficient $\chi^{(2)}$- processes like parametric down-conversion (PDC) within the whole transparency range of KTP. Guiding in both, TM- and TE-polarization, together with a periodic poling, allows for a variety of quasi-phase matching.

We have expanded the usual waveguide fabrication process by a subsequent surface-near reversed exchange of Rb against K to achieve a buried index profile. To our knowledge, this is the first report on fabrication and characterization of such buried Rb-exchanged waveguides in KTP.

The buried index profile results in symmetrized mode-field distributions which offer several advantages: improved overlap of the mode-fields for $\chi^{(2)}$-processes, reduced influence of surface imperfections on the scattering losses, enhanced fiber-coupling efficiencies and an improved control over single-mode guiding. We characterize the waveguides in terms of propagation losses and non-critically phasematched type-II second harmonic generation. In addition, first results of electric field induced periodic poling of buried Rb-exchanged waveguides are presented.

Q 43.61 Wed 16:00 Empore Lichthof

Regeneration of QPSK signals using phase-sensitive amplification by dual-pump four-wave-mixing process — •Birgit Stiller[1,2], Georgy Onishchukov[1], Bernhard Schmauss[3], and Gerd Leuchs[1,2] — [1]Max Planck Institute for the Science of Light, Erlangen — [2]Institute of Optics, Information and Photonics, University Erlangen — [3]Chair for Microwave Engineering, University Erlangen

For the growing demand on higher capacity in fiber-optic communication systems, advanced modulation formats provide a promising solution for significant capacity gains. One of these is multi-level phase-shift keying. Since phase-encoded signals are sensitive also to phase noise, induced by i.e. amplified spontaneous emission or nonlinear phase noise, the regeneration of phase (and amplitude) of the signal is crucial for long-haul transmission systems. In this work, we investigate numerically phase-sensitive amplification of the quadrature phase-shift keyed (QPSK) signal. A four-wave mixing (FWM) scheme with two phase-conjugated pumps, which are equally spaced around the QPSK signal, is used. The pumps are produced by an additional FWM process in another highly nonlinear fiber (HNLF). Dependence of regenerator performance on HNLF parameters has been investigated for 40 Gbaud transmission.

Q 43.62 Wed 16:00 Empore Lichthof

Optical modulator based on electro-optically induced waveguides — •Martin Blasl, Haldor Hartwig, Kirstin Bornhorst, and Florenta Costache — Fraunhofer Institute for Photonic Microsystems, Maria-Reiche-Str. 2, 01109 Dresden, Germany

Optical modulators are used to dynamically control the power of signals transmitted in optical fibre networks.

We report on a new design of an optical modulator based on electro-optically induced waveguides (EOIW) in isotropic phase nematic liquid crystals. These materials exhibit, just above their clearing temperature, unusually high electro-optical Kerr coefficients and therefore they are particularly suitable for this EOIW concept.

We fabricated an EOIW based optical modulator-chip by means of silicon technology. The chip assembly includes structured wafers bonded together and enclosing in between a liquid crystal layer. The bottom wafer comprises stripe aluminium electrodes, which define the induced waveguide region, as well as V-grooves for precise fibre to EOIW coupling.

For the modulator chip, we demonstrate a modulation bandwidth (-3 dB) of 5 MHz and an extinction ratio of 12 dB. The insertion loss is 3 dB, which is in agreement with FEM-simulations. Additionally, we analysed the influence of voltage induced phase transition on the performance of the chip.

Q 43.63 Wed 16:00 Empore Lichthof

Optimising single-photon collection efficiency using three-dimensional laser-written structures — •Tanja Neumer[1], Andreas W. Schell[1], Oliver Benson[1], Johannes Kaschke[2], Joachim Fischer[2], and Martin Wegener[2] — [1]Nano-Optics, Institute of Physics, Humboldt-Universität zu Berlin, Newtonstraße 15, D-12489 Berlin, Germany — [2]Wegener Group, Institue for Applied Physics, Karlsruher Institut für Technologie, Wolfgang-Gaede-Straße 1, D-76131 Karlsruhe

Efficient extraction of single photons from solid-state emitters in high-index materials is a major challenge for integrated quantum technologies. We introduce a novel approach to enhance collection efficiencies of single-photons emitted from nanodiamonds using tailored solid immersion lenses (SILs). First, we describe farfield intensity distributions calculated by finite-difference time domain (FDTD) simulations targeting high collection efficiencies for microscope objectives with low numerical aperture. Then we introduce the fabrication technique of the structures which is based on the method of direct laser lithography in a photoresist. This resist can be mixed with nanodiamonds containing single nitrogen-vacancy centres as single-photon emitters. We present experimental results demonstrating the feasibility of our approach [1].

[1] Andreas W. Schell, Johannes Kaschke, Joachim Fischer, Rico Henze, Janik Wolters, Martin Wegener, Oliver Benson, arXiv:1209.2036 (2012)

Q 43.64 Wed 16:00 Empore Lichthof

Carbon Nanotube spectroscopy in optical microcavities — •Thomas Hümmer[1,2], Hanno Kaupp[1,2], Matthias S. Hofmann[1], Jonathan Noe[1], Alexander Högele[1], Theodor W. Hänsch[1,2], and David Hunger[1,2] — [1]Ludwig-Maximilians-Universität München, Deutschland — [2]Max-Planck Institut für Quantenoptik, Garching, Deutschland

We use fiber-based Fabry-Perot optical microcavities[1] with mode volumes down to a few tens of wavelengths cubed and high quality factors up to 10^7 to study single-walled carbon nanotubes (SWCNTs). Very recent progress in the growth of freestanding narrow-diameter SWCNTs has demonstrated that this system can show exceptional fluorescence properties, including a strong optical dipole transition, single photon emission characteristics, and close to Fourier limited linewidth[2]. Placing nanotubes inside an optical microcavity promises ultimative sensitivity for absorption spectroscopy and strong Purcell enhancement of fluorescence emission. Harnessing the full tunability and open access of fiber-based microcavities allows us to address a variety of CNTs at different locations and wavelengths with a single cavity. We show first experimental results on cavity enhanced spectroscopy of individual SWCNTs and discuss the potential for cavity QED with this system.

[1] Hunger, Reichel et al., NJP 12, 065038 (2010)
[2] Hofmann, Högele et al., arXiv: 1209.3429 (2012)

Q 43.65 Wed 16:00 Empore Lichthof

Realization of a fiber based microcavity for coupling a single N-V center in diamond — •Alexander Bommer[1], Roland Albrecht[1], Christian Deutsch[2], Jakob Reichel[2], and Christoph Becher[1] — [1]Fachrichtung 7.2, (Experimentalphysik), Universität des Saarlandes, Campus E2.6, 66123 Saarbrücken — [2]Laboratoire Kastler Brossel, ENS/UPMC-Paris 6/CNRS, 24 rue Lhomond, 75005 Paris, France

The coupling of color centers in diamonds to optical cavities is an important technology for realizing light-matter interfaces in many quantum information protocols. We here investigate coupling of single N-V-centers in nanodiamonds to fiber based micro-cavities. The cavity consists of a fiber mirror and a plane mirror with a length of $<5\mu m$. The fiber mirror is produced by laser machining a fiber facet to yield a spherical imprint with radii of curvature of about $80\mu m$ and depths of $1\mu m$ with a sub-nm surface roughness, followed by deposition of a dielectric mirror stack [1]. Nanodiamonds containing single N-V-centers have been spin coated onto the plane mirror which is mounted in thermal contact with the cold finger of a liquid helium flow cryostat. At room temperature we observe phonon assisted emission of photons into the cavity mode and realize a single photon source tunable over the entire NV-emission spectrum. Theoretical simulations of the coupled emitter-cavity system predict that cooling of the nanodiamonds will allow to observe Purcell enhanced emission of the Zero-Phonon Line into the cavity mode.

[1] D. Hunger et al.,New J. Phys. 12, 065038 (2010)

Q 43.66 Wed 16:00 Empore Lichthof

Light propagation in an atomic ensemble — •Susanne Blum and Giovanna Morigi — Universität des Saarlandes, Saarbrücken, Germany

A theoretical description of the dynamics of propagation of single photons in a EIT medium is developed. The model includes quantum noise within a Heisenberg-Langevin formalism. Applications for single-photon frequency conversion are discussed.

Q 43.67 Wed 16:00 Empore Lichthof

Stationary non-classical states of a two mode cavity — •Christian Arenz[1,2], Melanie Rolles[1,3], and Giovanna Morigi[1] — [1]Saarland University — [2]Aberystwyth University — [3]University of Luxembourg

The dynamics of the electromagnetic field of a high-finesse resonator is studied, when it interacts with individual atoms of a beam [1]. These dynamics are well modeled by a Jaynes-Cummings type of Hamiltonian. In the strong coupling regime it was shown that trapping states of one field mode can be observed for well defined interaction times [2,3]. Depending on the initial state of the atoms this leads to asymptotic states of the cavity field dynamics that have non-classical features [4].
In this work we consider the energy levels of the atoms in a V-type configuration, where the dipoles are resonantly coupled to two field modes. We show that for well defined interaction times a trapping condition similar to the one mode case can be defined. We determine the asymptotic state of the field dynamics if the atoms that are injected into the cavity are prepared in a coherent superposition of their excited levels. We show that the asymptotic state is a pure entangled state and characterize its properties.

[1] S. Haroche et. al., Nature 455, 510 (2008)
[2] H. Walther et. al., Phys.Rev. Lett. 82, 3795 (1999).
[3] P. Meystre et. al., J. Opt. Soc, 3, 906 (1986).
[4] John J. Slosser et. al., Phys. Rev. Lett. 63, 934 (1989).

Q 43.68 Wed 16:00 Empore Lichthof

Approximate quantum error correction for generalized amplitude damping errors with graph-theoretic considerations — •carlo cafaro[1,2,3] and peter van loock[1,2,3] — [1]Max Planck Institute for the Science of Light, Guenther-Scharowsky-Str. 1/Bldg. 24, D-91058 Erlangen, Germany — [2]Institute of Optics, Information and Photonics, University of Erlangen-Nuremberg, Staudtstr. 7/B2, D- 91058 Erlangen, Germany — [3]Institute of Physics, University of Mainz, Staudingerweg 7, 55128 Mainz, Germany

We extend the analysis of approximate quantum error correction schemes to generalized amplitude damping errors. We present an analytical investigation of the performance of the five and seven-qubit CSS quantum stabilizer codes and compare it to that of a quantum code obtained via concatenation of the quantum dual rail code with the perfect four-qubit quantum erasure code. The performance of these schemes is quantified by means of the entanglement fidelity as function of the photon loss probability and the nonvanishing environmental temperature. In addition, knowing that every stabilizer code is locally equivalent to a graph code and that every codeword stabilized code can be described by a graph and a classical code, we construct novel mathematical graphs that realize both the standard Leung's et al. four-qubit code and its extension, the proposed eight-qubit quantum concatenated code. Finally, the role that these channel-adapted mathematical graphs may play in approximate quantum error correction is discussed.

Q 43.69 Wed 16:00 Empore Lichthof

Photon triplet generation in a photonic crystal fibre — •Andrea Cavanna, Felix Just, Bhaskar Kanseri, John Travers, Xin Jiang, Nicolas Joly, Maria V. Chekhova, Gerd Leuchs, and Philip Russell — Max Planck Institute for the Science of Light, Günther-Scharowsky-Str. 1, 91058 Erlangen

One of the challenging tasks in quantum optics is the creation of entangled photon triplets in Greenberger-Horne-Zeilinger (GHZ) states. Although several schemes for the production of three photon entangled states have been implemented, the photons lack the unique correlations that GHZ states offer and that make them essential in many quantum information and quantum computation protocols. We are working on the implementation of a source for GHZ states utilising the third-order nonlinearity in a microstructured photonic crystal fibre. Direct down-conversion from visible light at 532nm to triplets at 1596nm will be achieved by means of intermodal phasematching. This approach allows the efficiency to be increased by many orders of magnitude due to the much smaller confinement of the fields and the increased interaction length compared to a bulk crystal source. In order to verify the optimum fibre parameters for this specific phasematching, we are observing the inverse process, namely third harmonic generation. Guided by these results, a fibre specifically custom-designed for this purpose will be fabricated.

Q 43.70 Wed 16:00 Empore Lichthof

Single Photon Source with a Diamond Nanocrystal and

an Optical Nanofiber — •Lars Liebermeister[1], Fabian Petersen[1], Daniel Burchardt[1], Juliane Hermelbracht[1], Toshiyuki Tashima[1,2], Markus Weber[1], Ariane Stiebeiner[3], Arno Rauschenbeutel[3], and Harald Weinfurter[1,2] — [1]Ludwig-Maximilians-Universität, München — [2]Max-Planck-Institut für Quantenoptik, Garching — [3]Technische Universität Wien - Atominstitut, Wien, Austria

The development of high yield single photon sources is crucial for applications in quantum information as well as for experiments on the foundations of quantum physics. The NV-center in diamond is a promising solid state candidate. By using nanodiamonds this emitter can easily be coupled to integrated nano-optical and plasmonic [1] structures. Our approach is to utilize efficient coupling of fluorescence of a single NV-center to the evanescent field of an optical nanofiber [2].

Using a dip-pen technique we deposited few diamond nanorystals in the evanescent field of a nanofiber. When optically excited we observe fluorescence of few NV-centers (hosted in a single crystal) into the guided mode of the fiber. The measured antibunching of the photon statistics indicates its non-classical character. As no clean single photon emission into the fiber has been observed so far, we have set-up a new hybrid microscope (confocal microscope combined with an AFM) which allows us to optically preselect and position single nano-crystals onto the nanofiber. We report on the current experimental progress.

[1] PRL 106, 096801 (2011) [2] PRA 72(3), 032509 (2005)

Q 43.71 Wed 16:00 Empore Lichthof

Extractable squeezing from a degenerate waveguide PDC source — •Thomas Dirmeier[1,2], Nitin Jain[1,2], Georg Harder[3], Gerd Leuchs[1,2], Christoph Marquardt[1,2], and Christine Silberhorn[1,3] — [1]Max-Planck-Institut für die Physik des Lichts, Günther-Scharowsky-Str.1 Bau 24, 91058 Erlangen — [2]Institut für Optik, Information und Photonik, Friedrich-Alexander-Universität Erlangen-Nürnberg, Staudtstraße 7, 91058 Erlangen — [3]Integrierte Quantenoptik, Universität Paderborn, Warburgerstraße 100, 33098 Paderborn

A Parametric down-conversion (PDC) source is known to be a robust and versatile tool for the generation of states of photon pairs. It has recently been demonstrated that waveguide-embedded PDC sources are able to produce highly indistinguishable and pure photon pairs. In a continuous-variable picture, this corresponds to a single two-mode squeezed state. As a benchmark for future experiments, we record the attainable single-mode squeezing and analyze the remaining state impurities to characterize the extractable squeezing.

Q 43.72 Wed 16:00 Empore Lichthof

Multi-photon interference with pseudo-thermal light — •Florian Nägele, Simeon Müller, and Vincenzo Tamma — Institut für Quantenphysik, Universität Ulm

Multi-photon interference [1] with pseudo-thermal light is a promising new field of research that received increasing attention in recent years. Chen et al. have simulated Bell correlations and Franson-type correlations with a pseudo-thermal source [2,3]. We give a detailed theoretical description of such experiments, in order to describe the main physical aspects behind two-photon interference. Moreover, we generalize such a description to different experimental situations. Our analysis will lead us to the study of multi-photon interferometers of higher orders and the possibilities to exploit such schemes for quantum information processing.

[1] Yanhua Shih, An Introduction to Quantum Optics: Photon and Biphoton Physics, Taylor and Francis (2011), Boca Raton, FL

[2] H. Chen, et al., New J. Phys. 13, 083018 (2011)

[3] H. Chen, et al., private communication

Q 43.73 Wed 16:00 Empore Lichthof

Continuous-variable entanglement between different degrees of freedom in cylindrically polarized modes of light — •Stefan Berg-Johansen[1,2], Christian Gabriel[1,2], Ioannes Rigas[1,2], Andrea Aiello[1,2], Peter van Loock[1,2,3], Ulrik Andersen[1,2,4], Christoph Marquardt[1,2], and Gerd Leuchs[1,2] — [1]Max Planck Institute for the Science of Light, Guenther-Scharowsky-Str. 1/Bldg. 24, D-91058 Erlangen, Germany — [2]Institute of Optics, Information and Photonics, University of Erlangen-Nuremberg, Staudtstr. 7/B2, D-91058 Erlangen, Germany — [3]Institute of Physics, University of Mainz, Staudingerweg 7, 55128 Mainz, Germany — [4]Department of Physics, Technical University of Denmark, 2800 Kongens Lyngby, Denmark

Lately it has been shown that cylindrically polarized modes of light exhibit entanglement between the spatial and polarization degrees of freedom when undergoing quadrature squeezing [1]. This arises from a classical inseparability of the associated fields. Apart from being of fundamental interest, this hybrid entanglement can be used to generate multipartite entangled states for one-way quantum computing which are addressable via the spatial degree of freedom in addition to polarization [2]. We show how hybrid entanglement can be accessed experimentally [3] and give an account of progress towards its verification.

[1] C. Gabriel et al., Phys. Rev. Lett. **106**, 060502 (2011)

[2] I. Rigas, C. Gabriel et al., arXiv:1210.5188 (2012)

[3] C. Gabriel et al., Eur. Phys. J. D **66**, 172 (2012)

Q 43.74 Wed 16:00 Empore Lichthof

Experimental generation of photon-number squeezing in complex spatio-polarization modes with a spatial light modulator — •Marion Semmler[1,2], Stefan Berg-Johansen[1,2], Christian Gabriel[1,2], Peter Banzer[1,2], Andrea Aiello[1,2], Christoph Marquardt[1,2], and Gerd Leuchs[1,2] — [1]Max Planck Institute for the Science of Light, Guenther-Scharowsky-Str. 1, D-91058 Erlangen, Germany — [2]Institute of Optics, Information and Photonics, University Erlangen-Nuremberg, Staudtstr. 7/B2, D-91058 Erlangen, Germany

We report on the generation of photon-number squeezing in higher-order spatio-polarization modes of light. Using a phase-only spatial light modulator, we transform squeezed Gaussian modes into higher-order Laguerre-Gaussian, Hermite-Gaussian and Bessel beams. By appropriate superposition of orthogonal polarizations, beams with a complex spatio-polarization pattern can be achieved. The implementation is straightforward and in particular does not rely on interferometry. The mode conversion is shown to preserve any non-classicality present in the initial Gaussian mode up to linear losses. We thus demonstrate photon number squeezing of more than -1.0 dB in a wide range of higher-order modes.

Q 43.75 Wed 16:00 Empore Lichthof

Ultra-low Noise Quantum Interconnect at Room Temperature — •Josef Schupp[1], Eden Figueroa[1,2], Tobias Latka[1], Andreas Neuzner[1], Christian Nölleke[1], Andreas Reiserer[1], Stephan Ritter[1], and Gerhard Rempe[1] — [1]Max-Planck-Institut fuer Quantenoptik, Hans-Kopfermann-Str. 1, D-85748 Garching, Germany — [2]Department of Physics and Astronomy, Stony Brook University, Stony Brook, New York 11794-3800, USA

The development of a simple and inexpensive platform for interconnecting light and matter at the quantum level has recently emerged as one of the key challenges of quantum engineering. Although elementary quantum memory capabilities have already been shown using ensembles of cold atoms [1] or single atoms in optical cavities [2], a scalable-friendly architecture might still require room temperature operation [3]. Here we use an ensemble of Rb atoms in the gaseous state and store light pulses at the single-photon level using EIT to demonstrate that even in a common vapor cell it is possible to achieve quantum-level operation with ultra-low background noise. We have obtained a measured signal-to-background noise ratio of 3.5, which is the first time this figure of merit has been lifted beyond unity for experiments with room temperature operation. In addition, we also show the capabilities of the system to arbitrarily tailor the temporal properties of the retrieved single-photon-level pulses.

[1] A. I. Lvovsky *et al.*, Nature Photonics 3, 706 (2009).

[2] H. Specht *et al.*, Nature 473, 190 (2011).

[3] I. Novikova *et al.*, Laser and Photonics Reviews 6, 333 (2012).

Q 43.76 Wed 16:00 Empore Lichthof

Bestimmung der Detektionseffizienz von Silizium Single-Photon Avalanche Diode — •Helmuth Hofer, Silke Peters, Waldemar Schmunk und Stefan Kück — Physikalisch-Technische Bundesanstalt, Bundesallee 100, D-38116 Braunschweig

Silizium Single-Photon Avalanche Dioden (Si-SPAD) werden zur Detektion einzelner Photonen heutzutage in vielen Bereichen, wie z.B. in der Quanteninformationstechnologie, eingesetzt. Die rückgeführte Bestimmung der Detektionseffizienz, eines der wichtigsten Parameter, auf das Normal für die optische Strahlungsleistung (das Kryoradiometer) fehlte aber bisher. In diesem Beitrag stellen wir ein an der Physikalisch-Technischen Bundesanstalt (PTB) entwickeltes Messverfahren zu ihrer Bestimmung vor, das eine lückenlose Kalibrierkette sicherstellt. Dabei wird die Strahlung eines definiert abgeschwächten Diodenlasers bei einer Wellenlänge von 770 nm verwendet. Die Detektionseffizienz ergibt sich aus der mit einem Si-SPAD gemessenen Photonenzählrate. Letztere wird mit der einfallenden Strahlungsleistung verglichen, die mittels einer zuvor gegen das Kryoradiometer kalibrierten Silizium-Photodiode und kalibrierten Abschwächern bestimmt wurde. Insbesondere wird dabei die Photonenstatistik der einfallenden Laserstrahlung berücksichtigt, welche einen Einfluss auf die gemessene Photonenzählrate hat. Neben dem Kalibrierverfahren wird eine detaillierte Analyse der Messunsicherheit vorgestellt; diese liegt derzeit im Bereich von ca.1%.

Q 43.77 Wed 16:00 Empore Lichthof

Free Space Quantum Communication using Continuous Polarization Variables — •Bettina Heim[1,2], Christian Peuntinger[1,2], Christoffer Wittmann[1,2], Christoph Marquardt[1,2], and Gerd Leuchs[1,2] — [1]MPI for the Science of Light, Günther-Scharowsky-Str. 1 / bldg. 24, Erlangen — [2]Institute of Optics, Information and Photonics, University of Erlangen-Nuremberg, Staudtstraße 7 / B2, Erlangen

We present our experimental work on quantum communication using an atmospheric channel of 1.6 km in an urban environment. In a prepare-and-measure setup, we encode information into continuous polarization states. The signal states are measured using homodyne detection with the help of a local oscillator. Both, signal and local oscillator, are sent through the free-space quantum channel, polarization multiplexed and occupying the same spatial mode. This leads to an excellent interference at the detection and an auto-compensation of the phase fluctuations introduced by the channel. In addition, the local oscillator acts as a spatial and spectral filter which easily enables daylight operation. Currently, we are testing a protocol for continuous variable quantum key distribution (CVQKD) with discrete modulation of four signal states in terms of the channel's key properties, attenuation and excess noise. Those turned out to be low enough to pave the way towards free space CVQKD.

Q 43.78 Wed 16:00 Empore Lichthof

Key rates for practical quantum key distribution protocols — •Florian Köppen[1], Tobias Moroder[1], Norbert Lütkenhaus[2], and Otfried Gühne[1] — [1]Theoretische Quantenoptik, Department Physik, Universität Siegen — [2]Institute for Quantum Computing, Waterloo

Quantum key distribution, the method to provide secure communication, represents one of the cornerstone applications of quantum information and it has already evolved into its own research field. While the possible key rates of a generic quantum key distribution protocol are already fairly well known, its exact evaluation can often be quite tricky and cumbersome, in particular for practical implementations where one often needs to consider additional deviations between the ideal protocol and its realization. Moreover since these rates are often bounded analytically it is not clear whether one really evaluates the maximal possible rate or just a, possibly bad, lower bound of it.

In this work we develop a general method to overcome this drawback by using numerical techniques in the form of non-linear convex optimization. Via this powerful tool one can then start analysing the exact predicted rates of various different protocols. As a primary application we investigate the behaviour of implementations of the Bennett-Brassard protocol, where the weak coherent laser pulses still possess a global phase. This is in contrast to standard considerations of this protocol where the phase is assumed to be randomized and thus inaccessible to the eavesdropper; an effect which can drastically change the key rate behaviour.

Q 43.79 Wed 16:00 Empore Lichthof

Distribution of squeezed states over an atmospheric channel — •Christian Peuntinger[1,2], Bettina Heim[1,2], Christian Gabriel[1,2], Christoph Marquardt[1,2], and Gerd Leuchs[1,2] — [1]Max-Planck-Institut für die Physik des Lichts, Günther-Scharowsky-Str. 1 / Bau 24, 91058 Erlangen, Deutschland — [2]Friedrich-Alexander-Universität Erlangen-Nürnberg, Staudtstr. 7 / B2, 91058 Erlangen, Deutschland

We experimentally investigate the transmission of squeezing through an atmospheric channel of 1.6 km length in an urban environment. At the sender we prepare bright polarization squeezed states of light with a noise reduction of almost 3 dB relative to shot noise. We use polarization encoding as it is well suited for atmospheric transmission. We also apply a purification protocol taking into account the channel transmission to counteract the channel fluctuations. Thus we observe 1 dB of squeezing at the receiver, which is in good agreement with the attenuation of the channel.

Q 43.80 Wed 16:00 Empore Lichthof

Dynamical quantum repeater using cavity-QED evolution and coherent light — •Denis Gonta[1] and Peter van Loock[2] — [1]Institut für Optik, Information und Photonik, Friedrich-Alexander-Universität Erlangen-Nürnberg, Staudtstrasse 7, 91058 Erlangen — [2]Institut für Physik, Johannes Gutenberg-Universität Mainz, Staudingerweg 7, 55128 Mainz

In the framework of cavity QED, we propose an efficient quantum repeater that uses coherent light and chains of atoms coupled to optical cavities. In contrast to conventional schemes, we completely avoid quantum gates and exploit solely the cavity-QED evolution for entanglement purification and swapping protocols. The entanglement distribution between the repeater nodes is realized with the help of pulses of coherent light. In our previous paper [1], we already proposed a high-fidelity protocol to purify a bipartite entangled state using the evolution of atomic chains coupled to optical cavities. Here, we incorporate this purification protocol into our extended scheme that, together with the entanglement distribution and swapping protocols, yields an efficient and experimentally feasible quantum repeater for long-distance quantum communication.

[1] D. Gonta and P. van Loock, Phys. Rev. A 86, 052312 (2012).

Q 43.81 Wed 16:00 Empore Lichthof

Wave form and spectral properties of single photons emitted by a single atom — •Tristan Tentrup, Jürgen Eschner, and Giovanna Morigi — Saarland University, Saarbrücken, Germany

Quantum networks require the controlled interaction of stationary and flying qubits, implemented for example by single ions that emit [1] and absorb [2] single photons. This requires the characterization and the possibility to tailor the wave form and spectrum of the photons emitted by single emitters. The wave packet and Fourier spectrum of a photon emitted by a single atom is theoretically characterized under several conditions. We consider in particular the situation when the atom is driven by a laser pulse of different spectral forms, or when it is excited by a single photon generated by a second emitter.

[1] M. Almendros *et al.*, Phys. Rev. Lett **103**, 213601 (2009); C. Kurz *et al.*, arXiv:1211.5922.
[2] N. Piro *et al.*, Nature Physics **7**, 17 (2011).

Q 43.82 Wed 16:00 Empore Lichthof

Error correction for CV-QKD with entangled squeezed states — •Jörg Duhme[1], Reinhard Werner[1], and Fabian Furrer[2] — [1]Institut für theoretische Physik, Leibniz Universität Hannover — [2]Department of Physics, University of Tokio

Common error corretion schemes like for example cascade and LDPC codes have been investigated and optimized for years. Since the alphabet on which these schemes operate has dimension two (that is the classical bit) they are not suited for the post processing required by the protocol proposed by Furrer et al. This protocol being secure against coherent attacks is designed for entanglement based QKD using squeezed gaussian states. But the error correction schemes mentioned above additionally do not exploit the gaussian characteristics of this protocol. We present first ideas for an error correction operating on an alphabet of almost arbitrary dimension explicitely designed for gaussian protocols.

Q 43.83 Wed 16:00 Empore Lichthof

SPDC-basierte Einzelphotonenquellen für Anwendungen in der Quanteninformation — •Sabine Euler[1,2], Pascal Notz[1] und Thomas Walther[1,2] — [1]Institut für Angewandte Physik, TU Darmstadt, Schlossgartenstraße 7, D-64289 Darmstadt — [2]CASED, Mornewegstraße 32, D-64293 Darmstadt

In periodisch gepoltem KTP werden durch einen temperaturstabilisierten cw-gepumpten Typ-II-PDC-Prozess degenerierte Photonenpaare um 808 nm erzeugt. Der Verlauf der Hong-Ou-Mandel-Interferenzen für verschiedene Kristalltemperaturen lässt auf eine Verschränkung der Photonen im entarteten Fall schließen.

Die Photonenquelle bildet die Grundlage für zwei verschiedene Anwendungen: In einem ersten Experiment wird ein QKD-Setup entsprechend dem BB84-Protokoll implementiert, die Einzelphotonenquelle wird für das Sender-Modul verwendet. Die Photonenpräparation erfolgt dabei durch die Verwendung von Strahlteilerwürfeln rein passiv. Ziel des zweiten Experimentes ist es, durch Rückkopplung eines der

SPDC-Photonen in den Kristall in einem stimulierten Prozess zwei identische Photonen zu erzeugen, die anschließend an einem polarisierenden Strahlteiler ausgekoppelt und nachgewiesen werden können. Der aktuelle Stand beider Experimente wird präsentiert.

Q 43.84 Wed 16:00 Empore Lichthof

Four-wave mixing's effect on EIT propagation: spontaneous emission and vacuum noise — •Christopher O'Brien, Nikolai Lauk, and Michael Fleischhauer — Fachbereich Physik, Technische Universität Kaiserslautern

In electromagnetically induced transparency (EIT), a propagating signal field resonant with an optical transition is coupled in a Λ scheme by a strong resonant laser driving an adjacent transition, quantum interference then makes the medium transparent to the signal. In many EIT experiments, the driving laser also acts as a far-detuned field on the signal transition, which for high optical depth causes a four-wave mixing (FWM) process. The far-detuned field generates a new co-propagating idler field which along with the driving field moves population into the excited state, giving gain for the signal field. The presence of gain introduces noise on the signal field, due to both spontaneous emission as well as a vacuum contribution of the idler. To find analytic expressions for the noise, we solve the Maxwell-Bloch equations for the propagating field operator in a EIT FWM medium. We can then discuss the effect of FWM on EIT experiments, such as those done for EIT based quantum memories.

Q 43.85 Wed 16:00 Empore Lichthof

A High-Speed Quantum Random Number Generator Based on the Vacuum State — Bastian Hacker[1,2], Christian Gabriel[1,2], Christoffer Wittmann[1,2], Wolfgang Maurer[3], Metin Sabuncu[5,1], •Imran Khan[1,2], Elanor Huntington[4], Christoph Marquardt[1,2], and Gerd Leuchs[1,2] — [1]Max Planck Institute for the Science of Light, 91058 Erlangen Germany — [2]Institute of Optics, Information and Photonics, University Erlangen-Nuremberg, 91058 Erlangen, Germany — [3]Siemens AG, Corporate Technology, 81739 Munich, Germany — [4]School of Engineering and Information Technology, University College, The University of New South Wales, Canberra ACT 2600, Australia — [5]Department of Electrical and Electronics Engineering, Dokuz Eylül University, Tinaztepe, Buca, 35160 Izmir, Turkey

Quantum random number generators are based on the inherent statistical nature of the quantum mechanical measurement process. In principle this allows for the extraction of unique random numbers from, in our case, a measurement of the quantum optical vacuum state. However, in practice, the detection process introduces electronic noise which modifies the measured signal. We apply spectral filtering to get rid of parasitic frequencies and apply a special binning technique to convert the measured signal to a string of random bits. We then evaluate the entropy of each frequency bin. Later, a one-way hashing function may be applied to limit the information content to quantum effects. A high-speed detector and the new bit extraction method allow for a random bit extraction speed in the GBit/s range.

Q 43.86 Wed 16:00 Empore Lichthof

Femtosecond laser written waveguides for integrated quantum optics modules — •Gwenaelle Vest[1,2], Stefan Frick[1], Markus Rau[1], Henning Weier[2], Harald Weinfurter[1,3], and Roberto Osellame[4] — [1]Fakultät für Physik, Ludwig-Maximilians-Universität, 80799 München, Germany — [2]qutools GmbH, 80539 München, Germany — [3]Max-Planck-Institut für Quantenoptik, 85748 Garching, Germany — [4]Dipartimento di Fisica, Politecnico di Milano, 20133 Milano, Italy

Integrated optics has enabled small, fast and low power consuming communication devices. Further developments could lead to compact and stable platforms for manipulating quantum states, thereby boosting daily life implementation of quantum information processing. In this context femtosecond laser writing has emerged as a powerful fabrication tool, allowing cost-effective, single-step, rapid prototyping of two- and three-dimensional photonic microstructures [1].

Here we consider single-mode waveguide arrays and directional couplers written in borosilicate glass. We study the evolution of polarization encoded qubits in such structures, through birefringence and splitting ratio measurements at 850 nm. We characterize the mode size and investigate packaging solutions to ensure optimal in- coupling and light collection. The total system has a footprint of only a few cubic centimeters.

[1] Della Valle, G. et al. , J. Opt. A, Pure Appl. Opt. 11(1), 013001 (2009)

Q 43.87 Wed 16:00 Empore Lichthof

Metrologische Charakterisierung von Einzelphotonendetektoren — •Silke Peters, Helmuth Hofer, Waldemar Schmunk und Stefan Kück — Physikalisch-Technische Bundesanstalt, Bundesallee 100, D-38116 Braunschweig

Mit der kommerziellen Verfügbarkeit von Quantenkommunikationssystemen (QKD-Systeme) könnte der Einsatz von quantenkryptographischen Schlüsseln zukünftig die sichere Übertragung von Daten gewährleisten. Eine wesentliche Voraussetzung für die Nutzung von QKD-Systemen im Alltag ist unter anderem eine umfassende metrologische Charakterisierung ihrer optischen Komponenten: Einzelphotonenquelle, Übertragungskanal und Einzelphotonendetektor. In diesem Beitrag stellen wir erste Messergebnisse zu einer rückgeführten Bestimmung zweier solcher Parameter, der Totzeit und des Jitters von InGaAs Single-Photon Avalanche Dioden (SPAD) vor. Zur Messung ersterer erzeugen zwei auf Einzelphotonenlevel abgeschwächte Laser eine Abfolge von zeitlich zueinander verzögerten Lichtpulsen. Die Totzeit ergibt sich aus der Wahrscheinlichkeit beide Pulse abhängig von der variablen Zeitverzögerung gleichzeitige zu detektieren. Der Jitter des Detektors wird entsprechend der Standardmethode aus der vollen Halbwertsbreite der Instrumente-Antwortfunktion der SPAD bestimmt, die durch die zeitliche Korrelation von vielen Detektionsereignissen mit dem Triggersignal des Lasers gemessen wird. Bei beiden Messverfahren wird die Genauigkeit des Taktsignals, des Triggers sowie die Unsicherheit des elektronischen Zählers mittels eines Frequenznormals rückgeführt. Ebenso wird eine detaillierte Messunsicherheitsanalyse vorgestellt.

Q 43.88 Wed 16:00 Empore Lichthof

Towards a down-conversion source of positively spectrally correlated and decorrelated photon pairs at telecom wavelength — •Thomas Lutz[1,2], Piotr Kolenderski[1,3], and Thomas Jennewein[1] — [1]University of Waterloo, Institute for Quantum Computing, Waterloo, Canada — [2]Universitaet Ulm — [3]Nicolaus Copernicus University, Torun, Poland

The frequency correlation (or decorrelation) of photon pairs is of great importance in long-range quantum communications and photonic quantum computing. We experimentally characterize a spontaneous parametric down conversion (SPDC) source, based on Beta*-Barium Borate (BBO) crystal cut for type-II phase matching at 1550 nm which has the capability to emit photons with positive or no spectral correlations. Our system employs a carefully designed detection method exploiting two InGaAs detectors.

Q 44: Laser development: Solid state lasers II

Time: Thursday 11:00–12:30 Location: F 128

Q 44.1 Thu 11:00 F 128

A 2.1-Watts Intracavity-frequency-doubled All-solid-state Light Source at 671 nm for Laser Cooling of Lithium — •Andrea Bergschneider[1,2], Ulrich Eismann[1], Christophe Salomon[1], and Frederic Chevy[1] — [1]Laboratoire Kastler Brossel, ENS, UPMC, CNRS UMR 8552, 24 rue Lhomond, 75231 Paris, France — [2]Physikalisches Institut der Universität Heidelberg

Lithium atoms are one of the most versatile species used for research on quantum gases. We present an all-solid-state laser source developed for laser cooling on the Lithium D-lines. It is based on a diode-pumped, neodymium-doped orthovanadate ($Nd:YVO_4$) ring laser operating at 1342 nm frequency doubled with periodically poled KTP [1]. Our second generation laser source is intracavity doubled and emits up to 2.1 W of single-frequency light at 671 nm. We develop a simple theory for the efficient implementation of intracavity second harmonic generation, and its application to our system allows us to obtain nonlinear conversion efficiencies of up to 88%. The second-harmonic wavelength can be tuned over 0.5 nm, and mode-hop-free scanning over more than 6 GHz is demonstrated, corresponding to about ten times the laser cavity free spectral range.

[1] U. Eismann et al., Appl. Phys. B 106 (2012)

Q 44.2 Thu 11:15 F 128

Mode instabilities in high-power fiber lasers and amplifiers — •Hans-Jürgen Otto[1], Florian Janse[1], Fabian Stutzki[1], Cesar Jauregui[1], Jens Limpert[1,2], and Andreas Tünnermann[1,2,3] — [1]Friedrich-Schiller-Universität Jena, Institute of Applied Physics, Albert-Einstein-Str. 15, 07745 Jena, Germany — [2]Helmholtz-Institute Jena, Fröbelstieg 3, 07743 Jena, Germany — [3]Fraunhofer Institute for Applied Optics and Precision Engineering, Albert-Einstein-Str. 7, 07745 Jena, Germany

Currently, the onset of so-called mode instabilities (MI) in state-of-the-art high power fiber lasers and amplifiers is the most limiting effect for further output power scaling. A former stable Gaussian-like beam profile becomes temporally instable and simultaneously the beam quality reduces when a certain power threshold is reached. These phenomena can be observed in all types of fiber lasers and amplifiers. Hence, the investigation of MI is of fundamental importance for the high power fiber lasers and amplifiers of tomorrow. We will present our recent experimental results by showing slow motion videos of MI measured by a high speed camera ($>$ 20.000 images per second). It can be seen that MI are related to a fluctuation of the intermodal phase and amplitude of several involved modes. Moreover we give a theoretical explanation of the effect. MI are caused by a mostly thermally induced long period grating due to the beating of fiber modes. Finally, we show a novel active stabilization scheme to tremendously increase quality and stability of the MI affected beam at output power levels more than three times the typical power threshold of the laser system.

Q 44.3 Thu 11:30 F 128

Kontinuierliches UV-Lasersystem bei 254 nm durch Frequenzvervierfachung eines Stickstoff-gekühlten Faserverstärkers bei 1015 nm — •Ruth Steinborn[1,2], Thomas Diehl[1,2], Andreas Koglbauer[1,2], Daniel Kolbe[1,2], Matthias Stappel[1,2] und Jochen Walz[1,2] — [1]Institut für Physik, Johannes Gutenberg-Universität, 55099 Mainz, Deutschland — [2]Helmholtz-Institut Mainz, Johannes Gutenberg-Universität Mainz, 55099 Mainz, Deutschland

Ytterbium-Faserlaser/-verstärker sind eine bewährte, vielseitige und zuverlässige Laserquelle im Wellenlängenbereich von 1050 nm bis 1110 nm.

Für kürzere Wellenlängen steigt der Absorptionsquerschnitt an und beschränkt den Laserbetrieb. Durch Kühlung zu kryogenen Temperaturen lässt sich die Absorption im Bereich von 1000 nm bis 1050 nm deutlich reduzieren. Dieser Effekt wird ausgenutzt um einen Faserverstärker bei 1015 nm zu betreiben. Dazu wird ein Diodenlasersystem in einer auf 77 K gekühlten Ytterbium-Faser verstärkt.

Mit diesem System werden Ausgangsleistungen von über 5 W erreicht. Der Einfluss unterschiedlicher Fasertypen auf Polarisationsstabilität und ASE-Entwicklung (amplified spontaneous emission) wurde untersucht.

Das verstärkte Licht wird mit einem LBO- und einem BBO-Kristall jeweils in einem Überhöhungsresonator auf 254 nm frequenzvervierfacht. Diese Wellenlänge entspricht dem $6^1S_0 \rightarrow 6^3P_1$ Übergang in Quecksilber.

Q 44.4 Thu 11:45 F 128

Spektroskopische Eigenschaften von Dy^{3+}:$SrAl_{12}O_{19}$ im sichtbaren Spektralbereich — •Daniel-Timo Marzahl[1], Philip Werner Metz[1], Fabian Reichert[1], Matthias Fechner[1] und Günter Huber[1,2] — [1]Universität Hamburg, Institut für Laser-Physik, Hamburg, Germany — [2]The Hamburg Centre for Ultrafast Imaging, Hamburg, Germany

Laser mit Emissionen im sichtbaren Spektralbereich finden Anwendung in beispielsweise der Medizin, der Biophotonik und der Spektroskopie. Das trivalente Dysprosium-Ion (Dy^{3+}) besitzt mehrere strahlende Übergänge vom blauen bis in den tiefroten Spektralbereich. Lasertätigkeit von Dy^{3+}:YAG im sichtbaren Spektralbereich konnte vor Kurzem gezeigt werden [1].

Das Wirtsmaterial $SrAl_{12}O_{19}$ besticht durch seine sehr guten thermomechanischen Eigenschaften [2]. Im sichtbaren Spektralbereich konnte kürzlich effiziente Lasertätigkeit mit Pr^{3+} dotiertem $SrAl_{12}O_{19}$ gezeigt werden [2]. Im Weiteren wurde in unserem Labor auch Dy^{3+} dotiertes $SrAl_{12}O_{19}$ nach dem Czochralski-Verfahren gezüchtet.

In diesem Beitrag berichten wir von den spektroskopischen Untersuchungen an Dy^{3+}:$SrAl_{12}O_{19}$ mit Hinblick auf seine Eignung als Lasermaterial für den sichtbaren Spektralbereich. Im blauen Spektralbereich liegt die stärkste Grundzustandsabsorption bei 453,5 nm. Aus dem angeregten Niveau $^4F_{9/2}$ findet starke Emission bei 571,0 nm statt.

[1] S. R. Bowman *et al.*, Optics Express 20 (2012), 12906ff
[2] M. Fechner *et al.*, Applied Physics B 102 (2011), 731ff

Q 44.5 Thu 12:00 F 128

Fabrication of distributed feedback dye lasers by direct femtosecond laser writing — •Wolfgang Horn, Sebastian Kroesen, and Cornelia Denz — Institut für Angewandte Physik, Corrensstr. 2-4, 48149 Münster

In this presentation, we report the fabrication of organic distributed feedback (DFB) lasers in Rhodamin-6G-doped SU-8 negative tone photoresist by direct femtosecond laser writing.

Micro- and nanometer sized elements in photopolymers by nonlinear absorption of femtosecond radiation offers many benefits for integrated lab-on-a-chip devices. The most attractive aspect of femtosecond direct laser writing is the feasibility to create almost arbitrary three-dimensional structures by translating the host material under the laser focal point. This method allows for fabrication of light emitting devices for biophotonic and microfluidic applications with a high spatial resolution and a polymerized voxel size below the cubic wavelength of the focused femtosecond pulses.

The DFB lasers are realized by point-by-point exposure incorporating a low-order Bragg grating. A quarter-wave phase shift is included in the center of the grating section to obtain single mode operation. Different lasing wavelengths are demonstrated by varying the pitch of the feedback grating. Spectral emission, threshold and lifetime characterization is performed by pumping the laser with a pulsed, frequency double Nd:YAG laser.

Q 44.6 Thu 12:15 F 128

Analyse von Modulationsseitenbändern mit einem Mach-Zehnder-Interferometer — •Philipp Jahn, Henrik Tünnermann, Dietmar Kracht, Jörg Neumann und Peter Wessels — Laser Zentrum Hannover e.V., Hollerithallee 8, D-30419 Hannover

Die Ausgangsleistung von einfrequenten Faserverstärkern ist in der Regel durch stimulierte Brillouin-Streuung (SBS) limitiert. Breitbandige Laserstrahlung hat hingegen eine höhere Leistungsschwelle, ab der SBS einsetzt. Daher kann durch Aufprägen von Phasenmodulationsseitenbändern eine größere Ausgangsleistung erreicht werden, weil so das Erreichen der Schwelle für SBS vermieden werden kann. Für Anwendungen, die schmalbandige Laserstrahlung erfordern, muss das modulierte, verstärkte Licht zur Reduktion der spektralen Breite wieder korrekt demoduliert werden. Für diese Demodulation der verstärkten Laserstrahlung ist die Detektion der Modulationsseitenbänder entscheidend. Hier zeigen wir ein Verfahren zur präzisen Charakterisierung der Modulationsseitenbänder. Dazu wird Laserlicht aus einem nicht-planaren Ringoszillator mit einem EOM sinusförmig phasenmoduliert. Dieses phasenmodulierte Licht wird in ein faserbasiertes Mach-Zehnder-Interferometer eingekoppelt. Die Summe und die Differenz der an den Interferometerausgängen detektierten Signale werden analysiert. Mit den Informationen über die Amplitude und Phasenlage der Seitenbänder soll die nach der Verstärkung resultierende Phasen- und Amplitudenmodulation komplett rekonstruiert werden. Dieses Wissen soll dann dazu genutzt werden, das verstärkte Licht so zu demodulieren, dass wieder ein möglichst einfrequentes Signal entsteht.

Q 45: Quantum gases: Bosons II

Time: Thursday 11:00–12:30 Location: F 342

Q 45.1 Thu 11:00 F 342

Scattering bright solitons: quantum versus mean-field behavior — •Bettina Gertjerenken[1] and Christoph Weiss[2] — [1]Institut für Physik, Carl von Ossietzky Universität Oldenburg, D-26111 Oldenburg, Germany — [2]Department of Physics, Durham University, Durham DH1 3LE, United Kingdom

We investigate scattering bright solitons of a potential using both analytical and numerical methods. Our paper focuses on low kinetic energies for which differences between the mean-field description via the Gross-Pitaevskii equation (GPE) and the quantum behavior are particularly large. On the N-particle quantum level, adding an additional harmonic confinement leads to a simple signature to distinguish quantum superpositions from statistical mixtures. While the non-linear character of the GPE does not allow quantum superpositions, the splitting of GPE-solitons takes place only partially. When the potential strength is increased, the fraction of the soliton which is transmitted or reflected jumps non-continuously. We explain these jumps via energy-conservation and interpret them as indications for quantum superpositions on the N-particle level. On the GPE-level, we also investigate the transition from this stepwise behavior to the continuous case.

Q 45.2 Thu 11:15 F 342

Roton confinement in a trapped dipolar Bose-Einstein condensate — Mattia Jona Lasinio, •Kazimierz Łakomy, and Luis Santos — Institut für Theoretische Physik, Leibniz Universität, Hannover, Appelstrasse 2, D-30167 Hannover, Germany

Roton-like excitations constitute the key feature of dipolar gases, linking these systems to superfluid Helium. We show that the inherent locality of the roton spectrum in a trapped dipolar condensate results in the spatial confinement of rotons. As a result, roton instability leads to the appearance of localized density patterns which, depending on parameters of the system and fluctuations, can acquire the form of concentric rings. The localized modulational instability gives rise to a peculiar post-collapse dynamics which lacks the typical d-wave symmetry, characteristic for the global collapses in a dipolar condensate. Moreover, induced roton instability may be employed to create a gas of trapped roton excitations, with characteristic persistent density modulations confined in the center of the trap. Other consequences of the local roton spectrum are also discussed, including local susceptibility against a perturbation of the condensate, which leads to an inhomogeneous vortex lattice.

Q 45.3 Thu 11:30 F 342

Particles, holes and solitons: a matrix product state approach — •Tobias Osborne[1], Damian Draxler[2], Jutho Haegeman[3], Vid Stojevic[2], Laurens Vanderstraeten[3], and Frank Verstraete[2] — [1]Leibniz Universität Hannover, Institute of Theoretical Physics and Riemann center for geometry and physics, Appelstrasse 2, D-30167 Hannover, Germany — [2]Vienna Center for Quantum Science, Universität Wien, Boltzmanngasse 5, A-1090 Wien, Austria — [3]Ghent University, Department of Physics and Astronomy, Krijgslaan 281- S9, B-9000 Ghent, Belgium

We introduce a variational method for calculating dispersion relations of translation invariant (1+1)-dimensional quantum field theories. The method is based on continuous matrix product states and can be implemented efficiently. We study the Lieb-Liniger model as a benchmark where, despite criticality, excellent agreement with the exact solution is found, including, clear solitonic effects in Lieb's Type II excitation. In addition, a non-integrable model is studied where a U(1)-symmetry breaking term is added to the Lieb-Liniger Hamiltonian. For this model we find evidence of a non-trivial bound-state excitation in the dispersion relation.

Q 45.4 Thu 11:45 F 342

Compact mixture of degenerate quantum gases — •Katerine Posso-Trujillo, Holger Ahlers, Ernst M. Rasel, and Naceur Gaaloul — Institut für Quantenoptik, Leibniz Universität Hannover

Recent proposals in atom optics rely on long-lived samples of ultra-cold matter. Having compact sources (no more than mm range in radius) is necessary to prevent decoherence over long times and more strictly dephasing due to the spatial extension of the sample. A possible solution is to use the δ-kick technique to collimate the expanding BEC source, however this technique has to be adapted to the case of a quantum mixture.
During this talk, we will provide a clear method for preparing a mixture of ^{85}Rb/^{87}Rb which stays compact for several seconds.
The recipe includes the production of a miscible and stable mixture of the two Rb isotopes. The δ-kick cooling of both with realistic parameters of magnetic fields used, and laser beams.

Q 45.5 Thu 12:00 F 342

Solitonic states far from equilibrium — •Sebastian Erne[1,2], Boris Nowak[1,2], and Thomas Gasenzer[1,2] — [1]Institut für Theoretische Physik, Ruprecht-Karls-Universität Heidelberg, Philosophenweg 16, 69120 Heidelberg — [2]ExtreMe Matter Institute EMMI, GSI Helmholtzzentrum für Schwerionenforschung GmbH, Planckstraße 1, 64291 Darmstadt, Germany

The dynamics of an ultracold Bose gas far from equilibrium in one spatial dimension is analysed in the context of quasi-stationary solitonic states. We analytically describe the state within a model of randomly distributed solitons and address the possibilities for new experimental observations via statistical simulations using the classical field equations. Focus is placed on the one particle momentum distribution, concerning the appearance of transient power-laws, characteristic multi-peak structures for small momenta in a finite size system, and it's measurement in focus through the free expansion of the gas. Further, the influence of solitons on the density-density correlation after free expansion are addressed. Different scenarios including an anharmonicity of the trapping potential and the influence of temperature in the quasi-condensate regime are discussed. The results give detailed insight into the dynamics of solitons in these systems.

Q 45.6 Thu 12:15 F 342

A novel experiment for coupling quantum gases to various optical cavities — •Julian Leonard, Moonjoo Lee, Leigh Martin, Christian Zosel, Tilman Esslinger, and Tobias Donner — Institut for Quantum Electronics

We present the design and current status of a novel experimental system aiming at coupling a Bose-Einstein condensate (BEC) to optical cavities. At the heart of the apparatus is an interchangeable science platform which can house the cavities as well as a lens for high-resolution imaging of the atoms. This platform can be rapidly inserted into the vacuum chamber through a loadlock chamber, from which it is transferred into a vibration-isolated docking station. There we have excellent optical, thermal and electrical access from the outside while maintaining high stability and reproducibility in position.

The BEC is generated from a cloud of laser-cooled 87-Rb atoms which is first loaded into a hybrid trap and then optically transported into the cavity setup. Here it is transferred into a crossed dipole trap and evaporatively cooled down to quantum degeneracy.

This novel approach opens up the possibility to use a single apparatus to study the coupling of quantum gases with various cavity geometries such as crossed cavities, multimode cavities or setups involving mechanical membranes. With these systems, we aim to explore the dynamics of ultracold atoms in self-generated optical potentials, where novel phases of matter and light are predicted to appear.

Q 46: Quantum information: Concepts and methods IV

Time: Thursday 11:00–12:45 Location: E 001

Q 46.1 Thu 11:00 E 001

Are General Quantum Correlations Monogamous? — •Alexander Streltsov[1], Gerardo Adesso[2], Marco Piani[3], and Dagmar Bruss[1] — [1]Institut für Theoretische Physik III, Heinrich-Heine-Universität Düsseldorf — [2]School of Mathematical Sciences, University of Nottingham — [3]Institute for Quantum Computing and Department of Physics and Astronomy, University of Waterloo

Quantum entanglement and quantum nonlocality are known to exhibit monogamy; that is, they obey strong constraints on how they can be distributed among multipartite systems. Quantum correlations that comprise and go beyond entanglement are quantified by, e.g., quantum discord. It was observed recently that for some states quantum discord is not monogamous. We prove, in general, that any measure of correlations that is monogamous for all states and satisfies reasonable basic properties must vanish for all separable states: only entanglement measures can be strictly monogamous. Monogamy of other than entanglement measures can still be satisfied for special, restricted cases: we prove that the geometric measure of discord satisfies the monogamy inequality on all pure states of three qubits. See also Phys. Rev. Lett. 109, 050503 (2012)

Q 46.2 Thu 11:15 E 001

Device independent entanglement quantification — •Tobias Moroder[1], Jean-Daniel Bancal[2], Yeong-Cherng Liang[2], Martin Hofmann[1], and Otfried Gühne[1] — [1]Theoretische Quantenoptik, Department Physik, Universität Siegen — [2]Group of Applied Physics, University of Geneva

Most experiments require a rather precise characterization of the employed equipment or of the underlying model generating the data. However and presumably quite surprising at first, many tasks in quantum information processing can be made completely independent of this necessity. This has become the beauty of device independence, and there is a variety of tasks which have been investigated more thoroughly recently, including, for instance, different entanglement verification schemes or witnesses of the underlying quantum dimension.

We present a method for device independent entanglement quantification for the bi- and multipartite case, which directly provides non-trivial information about the underlying quantum dimension or the type of entanglement. This becomes possible by a novel technique to device independently characterize correlations if the quantum state has for instance a positive partial transpose or a biseparable structure. With this technique we additionally derive bounds on the maximal violation of a Bell inequality if the underlying state is PPT (and thus bound) entangled, which provides new insights into the bipartite Peres conjecture.

Q 46.3 Thu 11:30 E 001

Multipartite entanglement and high precision metrology — •Géza Tóth — Theoretical Physics, University of the Basque Country UPV/EHU, E-48080 Bilbao, Spain — IKERBASQUE, Basque Foundation for Science, E-48011 Bilbao, Spain — Wigner Research Center for Physics, H-1525 Budapest, Hungary

We present several entanglement criteria in terms of the quantum Fisher information that help to relate various forms of multipartite entanglement to the sensitivity of phase estimation. We show that genuine multipartite entanglement is necessary to reach the maximum sensitivity in some very general metrological tasks using a two-arm linear interferometer. We also show that it is needed to reach the maximum average sensitivity in a certain combination of such metrological tasks.

Q 46.4 Thu 11:45 E 001

A quantitative witness for Greenberger-Horne-Zeilinger entanglement — •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, 48080 Bilbao, Spain — [3]IKERBASQUE, Basque Foundation for Science, 48011 Bilbao, Spain

Along with the vast progress in experimental quantum technologies there is an increasing demand for the quantification of entanglement between three or more quantum systems. Theory still does not provide adequate tools for this purpose. We provide a simple procedure to quantify Greenberger-Horne-Zeilinger-type multipartite entanglement in arbitrary three-qubit states [1]. The method is based on the recently introduced GHZ symmetry [2] and exact results for the states which are invariant under this symmetry [3], and generally gives a good lower bound to the three-tangle. A generalization both to more parties and to higher-dimensional systems is possible.

[1] C. Eltschka, J. Siewert. Sci. Rep. 2, 942 (2012)
[2] C. Eltschka, J. Siewert, PRL 108, 020502 (2012)
[3] J. Siewert, C. Eltschka, PRL 108, 230502 (2012)

Q 46.5 Thu 12:00 E 001

A classification scheme of pure multipartite states — Markus Johansson[1,3], •Andreas Osterloh[2], Marie Ericsson[3], and Eric Sjöqvist[3] — [1]Centre for Quantum Technologies, National University of Singapore, 3 Science Drive 2, 117543 Singapore, Singapore. — [2]Fakultät für Physik, Universität Duisburg-Essen, Lotharstr. 1, 47048 Duisburg, Germany. — [3]Department of Quantum Chemistry, Uppsala University, Box 518, Se-751 20 Uppsala, Sweden.

We present a classification scheme based on balancedness of a state. Since the c-balanced states classify the SL-semistable states, a-balanced states are the bridge towards those states, which are characterized by unbalanced states. Together with U-invariants of bi-degree (m, n) which are known to have a topological phase, we have a complete characterization scheme from maximal genuinely entangled states that are representatives of the SL group $(2n, 0)$ down to the SU group (n, n). As a by-product we distill generalizations to the W-state, states that are entangled, but contain only globally distributed entanglement of parts of the systems.

Q 46.6 Thu 12:15 E 001

Non-Contextual Evolution: Generalizing and Testing the Kochen-Specker Theorem — •Jochen Szangolies, Matthias Kleinmann, and Otfried Gühne — Naturwissenschaftlich-Technische Fakultät, Walter-Flex-Str. 3, Universität Siegen

The Kochen-Specker theorem establishes the impossibility of completing quantum mechanics using noncontextual hidden variables. However, its experimental testability has been subject to some controversy. A reason for this is that (non-)contextuality in the Kochen-Specker sense is only applicable in the case of perfectly compatible observables. However, in real experiments, this cannot be achieved. We address this problem by introducing a generalized notion of noncontextuality that applies to a system subject to stochastic noncontextual evolution, and thus, is applicable even in the case of incompatible observables. This can be seen as a combination of the ideas behind the Leggett-Garg and Kochen-Specker 'no-go' results. On these grounds we then propose inequalities that are obeyed by any noncontextually evolving system, but violated by quantum mechanics. Since the class of hidden variable theories we consider includes the Kochen-Specker noncontextual ones, observing such a violation implies an experimental test of the Kochen-Specker theorem free from the problem of compatibility.

Q 46.7 Thu 12:30 E 001

Quantum phase space and its entropies — •Kedar S. Ranade — Institut für Quantenphysik, Universität Ulm

Quantum phase space functions are known to be an alternative representation of quantum mechanics, which in some sense appears to be more "classical" than the usual Hilbert space formalism with density matrices and operators. Similar to the concept of Shannon and von-Neumann entropies on probability distributions or density matrices, the Wehrl and Rényi-Wehrl entropies make use of the so-called Husimi-Kano phase space function. Certain analogues of these functions exist for the Wigner function. In this talk we give an overview on these concepts and their interpretation and discuss how relations between different phase space functions may be exploited to give new insights.

Q 47: Ultra-cold atoms, ions and BEC VI (with A)

Time: Thursday 11:00–12:30 Location: B 305

Q 47.1 Thu 11:00 B 305

Experimental observation of universal scaling at a quantum phase transition — •Eike Nicklas, Moritz Höfer, Wolfgang Müssel, Helmut Strobel, Ion Stroescu, Jiri Tomkovic, Maxime Joos, Daniel Linnemann, David B Hume, and Markus K Oberthaler — Kirchhoff-Institut für Physik, Heidelberg, Germany

A prominent feature of phase transitions is a universal scaling in the divergence of characteristic length and time scales when approaching a critical point. Here we report on the experimental observation of such scaling close to a quantum phase transition in a one-dimensional binary condensate of Rubidium. The quantum phase transition is realized by a microwave dressing field transforming the system from immiscible to miscible, where the distance to the critical point can be well controlled via the amplitude of the dressing field. We investigate the dynamics of in-situ spin-spin correlations and observe scaling behaviour of the correlation length. Both the deduced critical coupling strength and the power law exponent are consistent with theoretical predictions.

Q 47.2 Thu 11:15 B 305

Coupled l-wave confinement-induced resonances in cylindrically symmetric waveguides — •Panagiotis Giannakeas[1], Fotios Diakonos[2], and Peter Schmelcher[1] — [1]Zentrum für Optische Quantentechnologien, Universität Hamburg, Luruper Chaussee 149, 22761 Hamburg, Germany — [2]Department of Physics, University of Athens, GR-15771 Athens, Greece

A semi-analytical approach to atomic waveguide scattering for harmonic confinement is developed taking into account all partial waves. As a consequence l-wave confinement-induced resonances are formed being coupled to each other due to the confinement. The corresponding resonance condition is obtained analytically using the K-matrix formalism. Atomic scattering is described by transition diagrams which depict all relevant processes the atoms undergo during the collision. Our analytical results are compared to corresponding numerical data and show very good agreement.

Q 47.3 Thu 11:30 B 305

Evaporative cooling and thermalization in one-dimensional Bose gases — •Bernhard Rauer, Tim Langen, Michael Gring, Max Kuhnert, David Adu Smith, Remi Geiger, and Jörg Schmiedmayer — Vienna Center for Quantum Science and Technology, Atominstitut, Technische Universität (TU) Wien, Stadionallee 2, 1020 Vienna, Austria.

We experimentally study the process of evaporative cooling for a one-dimensional (1D) Bose gas in the quasi-condensate regime. While this process is well understood for 3D systems, evaporative cooling in 1D is strongly affected by the discrete level structure of the trap and the strongly inhibited thermalization. Consequently, the exact mechanism is still the subject of theoretical debate. The problem is closely related to our ongoing effort to understand relaxation and thermalization in a 1D quantum gases. The current status of this investigation will be presented.

Q 47.4 Thu 11:45 B 305

Hermitian four-well potential as a realization of a $\mathcal{PT}$ symmetric system — •Manuel Kreibich, Jörg Main, and Günter Wunner — 1. Institut für Theoretische Physik, Universität Stuttgart, Pfaffenwaldring 57, 70550 Stuttgart, Germany

A $\mathcal{PT}$ symmetric Bose-Einstein condensate can be theoretically described using a complex optical potential, however, the experimental realization of such an optical potential describing the coherent in- and outcoupling of particles is a nontrivial task.

As an alternative, we propose an experiment for a quantum mechanical realization of a $\mathcal{PT}$ symmetric system. The $\mathcal{PT}$ symmetric currents of a two-well system are implemented by coupling two additional wells to the system, which act as particle reservoirs. In terms of a simple four-mode model we derive conditions under which the two middle wells of the Hermitian four-well system behave *exactly* as the two wells of the $\mathcal{PT}$ symmetric system. We apply these conditions to calculate stationary solutions and oscillatory dynamics. By means of frozen Gaussian wave packets we relate the Gross-Pitaevskii equation to the four-mode model and give parameters required for the external potential, which provides approximate conditions for a realistic experimental setup.

Q 47.5 Thu 12:00 B 305

The impact of spatial correlation on the tunneling dynamics of few-boson mixtures — •Lushuai Cao, Ioannis Brouzos, Budhaditya Chatterjee, and Peter Schmelcher — Zentrum für Optische Quantentechnologien, Universität Hamburg, Germany

We investigate the tunneling properties of a two-species few-boson mixture in a one dimensional triple well and harmonic trap. The mixture is prepared in an initial state with a strong spatial correlation for one species and a complete localization for the other species. We observe a correlation induced tunneling process in the weak interspecies interaction regime. The onset of the interspecies interaction disturbs the spatial correlation of one species and induces tunneling among the correlated wells. The corresponding tunneling properties can be controlled by the spatial correlations with an underlying mechanism which is inherently different from the well known resonant tunneling process. We also observe the correlated tunneling of both species in the intermediate interspecies interaction regime and the tunneling via higher band states for strong interactions.

Q 47.6 Thu 12:15 B 305

Thermally induced coherent collapse of dipolar Bose-Einstein condensates — •Andrej Junginger[1], Jörg Main[1], Günter Wunner[1], and Thomas Bartsch[2] — [1]1. Institut für Theoretische Physik, Universität Stuttgart, Germany — [2]Department of Mathematical Sciences, Loughborough University, UK

We investigate Bose-Einstein condensates (BECs) with additional anisotropic and long-range dipolar interaction at finite temperature. The ground state of such a system is metastable and one decay mechanism is the BEC's coherent collapse due to collective thermal excitations. With focus on the latter and as an alternative to solving the Hartree-Fock-Bogoliubov equations, we make use of a variational approach to calculate the corresponding decay rates at temperatures small compared to the critical temperature. Within this variational approach, the collectively excited states of the condensates which form the “activated complex” are accessible. Using a normal form expansion of the equations of motion and the energy functional, the variational parameters can be mapped to classical phase space which allows for the application of transition-state theory. We show that the collapse dynamics of the dipolar BEC breaks the symmetry of the external trap if it is confined cylindrically symmetrical and present thermal decay rates for different temperatures of the quantum gas obtained from a variational ansatz using coupled Gaussian orbitals.

Q 48: Ultracold atoms: Traps and cooling

Time: Thursday 11:00–12:30 Location: A 310

Q 48.1 Thu 11:00 A 310

Laser cooling of dense atomic gases by collisional redistribution of radiation — •Anne Sass, Ralf Forge, Peter Moroshkin, and Martin Weitz — Institut für Angewandte Physik der Universität Bonn, Wegelerstraße 8, 53115 Bonn

We study laser cooling of atomic gases by collisional redistribution of fluorescence, a technique applicable to ultradense atomic ensembles of alkali atoms at a few hundred bar of buffer gas pressure. The cooled gas has a density of more than ten orders of magnitude above the typical values in Doppler cooling experiments of dilute atomic gases. In frequent collisions with noble gas atoms in the dense gas system, the energy levels of the alkali atoms are shifted, and absorption of far red detuned incident radiation becomes feasible. The subsequent spontaneous decay occurs close to the unperturbed resonance frequency, leading to a redistribution of the fluorescence. The emitted photons have a higher energy than the incident ones, and the dense atomic ensemble is cooled. We here report on recent experiments of a Rb-noble gas mixture and on the dependency of the cooling effect as a function of different experimental parameters, e.g. buffer gas pressure and incident laser power. For the future, we expect that redistribution laser cooling can also be applied to molecular gas samples.

Q 48.2 Thu 11:15 A 310

Building and Characterising a 2D-MOT as a Source of Cold Atoms — •Benjamin Gänger, Michael Bauer, Farina Kindermann, Shrabana Chakrabarti, and Artur Widera — TU Kaiserslautern, FB Physik, Erwin-Schrödinger-Str. 46, 67663 Kaiserslautern, Germany

Analysing the interaction of a single Cs atom with a cloud of ultracold Rb atoms requires many repetitions of the experimental cycle to obtain sufficient statistics. Therefore a high repetition rate is desirable which is limited by the time needed to initially trap and evaporatively cool a gas of atoms. As a first step towards a fast production of an ultracold cloud of atoms a 3D magneto-optical trap (MOT) is loaded by a beam of precooled Rb atoms from a 2D-MOT. For short loading cycles a high loading rate is intended. The designed cooling-laser setup provides up to 5 W optical output distributed over a 3D-MOT and a 2D-MOT with a 110 mm elongated cooling volume. Applying an additional push beam the loading rate reaches up to 10^9 atoms/s. In this setup a steady-state atom number of 2×10^9 atoms is achieved in about 2 seconds. We present an overview of the current setup and first results of the characterisation.

Q 48.3 Thu 11:30 A 310

EIT-control of single-atom motion in an optical cavity — •Tobias Kampschulte[1], Wolfgang Alt[1], Sebastian Manz[1], Miguel Martinez-Dorantes[1], René Reimann[1], Seokchan Yoon[1], Dieter Meschede[1], Marc Bienert[2], and Giovanna Morigi[2] — [1]Institut für Angewandte Physik, Universität Bonn, Wegelerstrasse 8, 53115 Bonn — [2]Theoretische Physik, Universität des Saarlandes, 66123 Saarbrücken

We demonstrate cooling of the motion of a single atom confined by a dipole trap inside a high-finesse optical resonator. Cooling of the vibrational motion results from EIT-like interference in an atomic Λ-type configuration, where one transition is strongly coupled to the cavity mode and the other is driven by an external control laser. Good qualitative agreement with the theoretical predictions is found for the explored parameter ranges. The role of the cavity in the cooling dynamics is confirmed by means of a direct comparison with EIT-cooling performed in the dipole trap in free space. These results set the basis to the realization of an efficient photonic interface based on single atoms.

Q 48.4 Thu 11:45 A 310

Efficient demagnetization cooling and its limits — •Valentin V Volchkov, Jahn Rührig, Matthias Wenzel, Tilman Pfau, and Axel Griesmaier — 5. Physikalisches Institut, Universität Stuttgart, Pfaffenwaldring 57, Stuttgart, 70569 , Germany

Demagnetization cooling of an atomic sample arises from laser cooling of the internal degree of freedom (optical pumping) and the rethermalization of the internal and the external degrees of freedom via dipolar relaxation [1]. It is a cooling scheme that was proposed by Kastler already in 1950 [2] and demonstrated in a proof of principle experiment in 2006 [3]. Here, we present the extension of this work to a larger temperature range. Deep optical potential and strong confinement are used to start the demagnetization cooling at a temperature of $T \approx 100\mu K$. Active magnetic field stabilization allows to circumvent limitation associated with magnetic field fluctuations at temperatures $T < 10\mu K$. Finally, we discuss the reabsorption of scattered light and its effect on the lowest attainable temperature with this technique.

[1]:S. Hensler, A. Greiner, J. Stuhler and T. Pfau, Europhys. Lett. **71**, 918 (2005)

[2]:A. Kastler, Le Journal de Physique et le Radium **11**, 255 (1950).

[3]:M. Fattori, T. Koch, S. Goetz, A. Griesmaier, S. Hensler, J. Stuhler, T. Pfau, Nature Physics **2**, 765 (2006)

Q 48.5 Thu 12:00 A 310

Hardware-in-the-Loop simulation of a strongly coupled atom-cavity system — •Maria Bernard-Schwarz[1], Tatjana Wilk[2], and Martin Gröschl[3] — [1]National Instruments, Germany — [2]MPQ, Germany — [3]TU Wien, Austria

The question whether classical concepts can be adapted to the quantum world is explored. The Hardware-in-the-Loop (HiL) approach is a common tool in industry to test a part of a system before implementing it into the real device. The HiL simulation acts like the real system and is used as a substitute during the development of the control algorithm. The advantage hereby is that the algorithm can be tested and modified even before any part of the real device exists. The system of interest is a strongly coupled atom-cavity system. There are two different specifications to control, first the motion of a two-level atom inside the cavity and second, the internal states of several multilevel atoms in the cavity. For these demands a performance of the HiL simulation of the atom-cavity system in the sub-microsecond range is required. In both cases high performance computing with the help of different platforms such as Real-Time processor, FPGA (Field Programmable Gate Array) and GPU (Graphical Processor Unit) is accomplished. The HiL simulation tools are available within the software platform LabVIEW which is also the platform of the experimental control system. The HiL simulation reproduces the dependency of the photon counts on the atomic position, which is the basis for feedback control on the atomic position.

Q 48.6 Thu 12:15 A 310

Electron guiding on a surface-electrode microwave chip — •Jakob Hammer[1], Johannes Hoffrogge[1], Dominik Ehberger[1], and Peter Hommelhoff[1,2] — [1]Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Straße 1, 85748 Garching — [2]Friedrich-Alexander-Universität Erlangen-Nürnberg, 91058 Erlangen

We investigate the guiding of electrons in a miniaturized planar AC-quadrupole guide (linear Paul trap) [1]. Electrons propagating freely along electrodes on a micro-fabricated chip experience a tight transverse harmonic confinement. For our parameters the quantum mechanical ground state of the guiding potential is still resolvable by electron optics. This encourages experiments to prepare electron matter-waves in the transverse motional ground state by matching the wavefunction of an incident electron with the ground state of the microwave guide.

Here we report on our ongoing experimental efforts. We use a single-atom tip electron emitter, a point source producing an exceptionally bright and fully coherent electron beam, to inject electrons into the guide. For collimation of the emitted electron wave packet we have fabricated a micron-scale electrostatic lens. Efficient ground state coupling requires a spot size of 100 nm and an angular spread of 1 mrad of the incoming electron wavefunction. We present the current status of the experiment as well as results from numerical optimization of the electrode layout, which aims at the adiabatic injection of electrons and the design of more complex structures like beam splitting elements.

[1] J. Hoffrogge, R. Fröhlich, M. Kasevich and P. Hommelhoff , Phys. Rev. Lett. 106, 193001 (2011).

Q 49: Ultrashort laser pulses: Generation II

Time: Thursday 11:00–12:30 Location: F 142

Group Report Q 49.1 Thu 11:00 F 142

Novel opportunities with intense mid-IR pulses: Self-compression to the 3-cycle regime and broadest coherent supercontinuum source — Matthias Baudisch[1], •Michael Hemmer[1], Alexandre Thai[1], Francisco Silva[1], Dane Austin[1], Arnaud Couairon[2], Daniele Faccio[3], and Jens Biegert[1,4] — [1]ICFO Institut de Ciencies Fotoniques, 08860 Castelldefels, Barcelona, Spain — [2]Centre de Physique Theorique, Ecole Polytechnique, CNRS UMR 7644, F-91128 Palaiseau Cedex, France — [3]Heriot-Watt University, Edinburgh Campus, Edinburgh EH14 4AS, United Kingdom — [4]ICREA Institucio Catalana de Recerca i Estudis Avançats, 08010 Barcelona, Spain

Availability of intense few-cycle pulses in the mid-IR allows scrutinizing strong field and attoscience phenomena in the deep tunneling regime.

We present first results from anomalous nonlinear propagation and filamentation in solid state media. We observe coherent supercontinuum generation from filamentary propagation in YAG avoiding the ubiquitous chaotic pulse breakup and loss of coherence. The resulting 3.3 octave-spanning spectrum is the broadest demonstrated, and coherent, supercontinuum generated in bulk [1]. Furthermore, the intricate pulse propagation dynamics results in stable temporal self-compression from 70 fs at 3100 nm to 32 fs which correspond to the sub-3-optical-cycle regime. The self-compression is surprisingly efficient (80%) and extremely stable; we observe a pulse-to-pulse stability of 0.8% rms. Numerical simulations and experimental results show excellent agreement.

Q 49.2 Thu 11:30 F 142

Beating the astigmatism in laser focusing and collimation with off-axis spherical mirrors — •Emanuel Wittmann, Niko Heinrichs, Elias Eckert, and Eberhard Riedle — LS für BioMolekulare Optik, LMU München

A central issue in ultrafast optics is the need to focus and collimate pulses with a very wide spectrum without diffractive elements. Diffractive lenses introduce an unacceptable chirp and also chromatic aberrations. Theoretically parabolic mirrors would be ideal. However, their optical quality is far inferior to spherical mirrors and the off-axis parabolics are only useful in the IR. We show that a combination of a concave and a convex spherical mirror with suitable ratio of radii of curvature can focus and collimate ultrafast pulses without any detectable astigmatism. This is found at angles where a single spherical mirror already introduces a large aberration. The new possibility is highly interesting for the collimation of NOPA seed continua generated in bulk materials and the beam management in 2D-UV spectroscopy. It renders for the first time undistorted short wavelength and duration pulses in the interaction region. In the talk the theoretical background, the implementations as well as the characterization of the spatial beam evolution are discussed. Ongoing measurements on the quality of the resulting phasefronts will conclude the presentation.

Q 49.3 Thu 11:45 F 142

High-order harmonic generation in laser-induced plasma plumes at 1 kHz repetition rate — •Jiaan Zheng[1], Michael Wöstmann[1], Henrik Witte[1], Helmut Zacharias[1], and Rashid A. Ganeev[2] — [1]Physikalisches Institut, Westfälische Wilhelms-Universität, Wilhelm-Klemm-Str.10, 48149 Münster, Germany — [2]Institute of Ion, Plasma, and Laser Technologies, Academy of Sciences of Uzbekistan, Akademgorodok 33, Dormon Yoli Street, Tashkent 100125, Uzbekistan

High-order harmonic generation (HHG) of ultra-short laser pulses in laser-induced plasmas for generation of extreme ultraviolet radiation is reported. Laser-generated silver and tin plasma plumes are produced by an amplified Ti:sapphire laser system, which provides pulse energies up to 5 mJ at a duration of 35fs and 1 kHz repetition rate. The HHG output is characterized with regard to the target design, the pre-pulse energy and pre-pulse duration. The time delay between the pre-pulse for plasma generation and the main pulse for efficient HHG was optimized. Influences of a main pulse chirp and an additional second harmonic field in the main pulse on the HHG spectra are studied.

Q 49.4 Thu 12:00 F 142

A broadband milliwatt-level mid-infrared source for near-field microscopy applications — •Robin Hegenbarth[1], Andy Steinmann[1], Sergey Sarkisov[2], Stefan Mastel[3], Sergiu Amarie[3], Andreas Huber[3], and Harald Giessen[1] — [1]4th Physics Institute and Research Center SCoPE, University of Stuttgart, Stuttgart, Germany — [2]Siberian Physical and Technical Institute of Tomsk State University, Tomsk, Russia — [3]Neaspec GmbH, Planegg, Germany

We demonstrate the generation of broadband mid-infrared radiation by difference-frequency mixing of two signal wavelengths of a femtosecond dual-signal-wavelength optical parametric oscillator (OPO). The OPO is pumped by a mode-locked Yb:KGW laser with 530 fs pulse duration and 7.4 W average output power and employs a 1 mm long MgO:PPLN crystal with 31 μm poling period. With a total intracavity group delay dispersion equal to zero at 1740 nm wavelength the OPO generates two different signal wavelengths that are mixed in an extracavity GaSe or $AgGaSe_2$ crystal. The polarizations of the OPO signals were adjusted to enable a type-II phase-matching process. This system generates up to 4.3 mW average mid-infrared power. Its spectra can be tuned between 10.5 μm and 16.5 μm (952 cm^{-1} - 606 cm^{-1}) with more than 50 cm^{-1} spectral bandwidth. We combined this system with a scattering-type SNOM and show near-field spectra on gold and near-field scans of Si-doped GaN nanowires.

Q 49.5 Thu 12:15 F 142

Rauscharmes, CEP stabilisiertes OPCPA System — •Jan Matyschok[1], Thomas Binhammer[2], Oliver Prochnow[2], Stefan Rausch[1,2], Piotr Rudawski[3], Cord L. Arnold[3], Anne L'Huillier[3] und Uwe Morgner[1,4,5] — [1]Institut für Quantenoptik, Leibniz Universität Hannover, D-30167 Hannover — [2]Venteon Laser Technologies GmbH, D-30827 Garbsen — [3]Department of Physics, Lund University, SE-221 00 Lund — [4]Quest: Center for Quantum Engineering and Space-Time Research, D-30167 Hannover — [5]Laser Zentrum Hannover e.V., D-30419 Hannover

Wir präsentieren ein zweistufiges, nichtkollineares OPCPA System bei einer Repetitionsrate von 200 kHz. Als Seedquelle kommt ein CEP stabilisierter Titan:Saphir-Oszillator (VENTEON | PULSE : ONE OPCPA SEED) zum Einsatz. Dieser liefert neben dem breitbandigen Spektrum, das Pulsdauern $<$ 6 fs unterstützt, gleichzeitig und ohne zusätzliche externe Verbreiterung hinreichend Leistung bei 1030 nm, um damit einen Faserverstärker zu seeden. Mit den frequenzverdoppelten Ausgangspulsen wird ein zweistufiger parametrischer Verstärker gepumpt, um die ursprüngliche Pulsenergie von 2 nJ auf mehr als 10 μJ zu verstärken. Die Ausgangsleistung von mehr als 2 Watt, bei einer Pulsdauer von 6,3 fs, weist ohne zusätzliche Stabilisierung ein rms Rauschen von 0,35 % über 100 Minuten auf. Langsame CEP-Drifts können durch eine zweite Regelschleife ausgeglichen werden. Durch das geringe Amplitudenrauschen, sowie der stabilen CE-Phase bei einer Pulsspitzenleistung von 800 MW, eignet sich dieses OPCPA-System hervorragend für die Erzeugung von hoher harmonischer Strahlung.

Q 50: Laser applications

Time: Thursday 14:00–16:00 Location: F 142

Group Report Q 50.1 Thu 14:00 F 142

Vortschritte im GEO-HF Upgrade Programm — •Christoph Affeldt — AEI Hannover

Seid 2009 befindet sich der Gravitationwellendetektor GEO 600 in einer Upgrade Phase, die den Namen GEO-HF trägt. Neben Änderungen im Read-out, Modifikationen der Signal Recycling Konfiguration und der Implementation von gequetschtem Licht, ist die Erhöhung der Lichtleistung ein zentraler Punkt des GEO-HF Upgrades. Letzteres stellt aktuell den Scherpunkt der laufenden Arbeiten da, nicht zuletzt, da die übrigen Punkte weitgehend erfolgreich abgeschlossen sind. In meinen Vortrag werde ich über die Erfolge, in den einzelnen Punkten des GEO-HF Upgrades berichten und im Schwerpunkt auf die verschiedenen Aspekte der Herausforderungen eingehen, die die Erhöhung der Lichtleistung mit sich bringt.

Q 50.2 Thu 14:30 F 142

Thermal lens measurement in commonly used optical components — •Christina Bogan[1], Patrick Kwee[2], Sabina Huttner[3], Stefan Hild[3], Benno Willke[1], and Karsten Danzmann[1] — [1]Albert-Einstein-Institut Hannover — [2]Massachusetts Institute of Technology — [3]University of Glasgow

Thermal lensing is a known effect in optical experiments, which is caused by the absorption in transmissive optics and scales with the laser power. The temperature dependent refractive index in combination with the non-uniform temperature profile in transmitive optics acts on a beam like a lens and is called thermal lens.

We developed a measurement method which allows to determine thermal lensing in commonly used optical components. The beam influenced by the thermal lens is expanded into the eigenmodes of an optical cavity and the modal content in the eigenbasis of the cavity is analyzed. The measured quantity depends neither on beam parameters nor on the position of the optical component under investigation. We demonstrated that this method agrees with a measurement of the relative beam size change performed with a camera including a test with a lens with known focal length.

We measured the thermal lens of different optical components, including an acousto-optic modulator whose thermal lens had a focal lens of more than 7000 m for a laser power of 1 W. These tiny effects are hardly measureable with other methods.

Q 50.3 Thu 14:45 F 142

Tomographiespektroskopie — •Robert Scharner[1], Michael Böhm[2], Oliver Henneberg[1], Mike Schwank[3], Oliver Reich[2] und Hans-Gerd Löhmannsröben[2] — [1]Universität Potsdam, Institut für Physik und Astronomie — [2]Universität Potsdam, Institut für Chemie — [3]Eidg. Forschungsanstalt WSL, Birmensdorf, Schweiz

Mit optischer Spektroskopie kann man Gaskonzentrationen von verschiedenen Gasgemischen untersuchen. Obwohl es hierzu zahlreiche Verfahren gibt, können nur wenige dieser Verfahren zur ortsaufgelösten Bestimmung der Gaskonzentrationen über lange Zeiten und im Feldmaßstab verwendet werden. Mit der hier vorgestellten Kombination aus Tomographie und Spektroskopie ist es möglich, großräumige Messungen, verbunden mit einer hohen Ortsauflösung ohne Störung der Messumgebung durchzuführen. Aus verschiedenen Richtungen aufgenommene Spektren ergeben zusammen Informationen über die Verteilung und Konzentration von Gasen in einem Areal mit einem Durchmesser von mehreren 100 m. Durch das an die Computertomographie angelehnte Verfahren erzielt man eine hohe Ortsauflösung, wohingegen die optische Spektroskopie selektiv die einzelnen Gaskomponenten nachweisen kann.

Gezeigt werden erste Ergebnisse zur Umsetzung eines Messpfades auf dem offenen Feld über größere Entfernungen. Dabei wird systematisch die geeignete Strahlführung für verschiedene Teleskopanordnungen untersucht.

Q 50.4 Thu 15:00 F 142

Ein Brillouin-LIDAR zur Messung von Temperaturprofilen im Ozean: Labor-Demonstration des Gesamtsystems — •Andreas Rudolf, David Rupp und Thomas Walther — Institut für Angewandte Physik, AG Laser und Quantenoptik, Technische Universität Darmstadt, Schlossgartenstr. 7, 64289 Darmstadt

Zur lasergestützten Messung von vertikalen Wassertemperaturverläufen im Ozean entwickeln wir ein portables, robustes LIDAR-Fernerkundungssystem. Als Messindikator dient aktiv erzeugte, spontane Brillouin-Streuung, welche eine temperaturabhängige Spektralverschiebung gegenüber dem eingestrahlten Licht aufweist.

Das LIDAR-System besteht aus zwei Hauptkomponenten: Die Laserquelle wird durch einen Ytterbium-dotierten, frequenzverdoppelten Faserverstärker realisiert. Als Detektor kommt ein Kantenfilter auf Basis von Rubidium (ESFADOF) zum Einsatz.

Die jüngsten Entwicklungsfortschritte beider Komponenten haben es uns nun erstmals ermöglicht, die Funktionalität des Gesamtsystems unter Laborbedingungen erfolgreich zu demonstrieren. Hierzu wurden zwei homogen temperierbare Wasserreservoirs mit einer Länge von je 1m hintereinander geschaltet und die zeitlich veränderte Temperaturstufe ortsaufgelöst mit dem LIDAR-System gemessen.

Q 50.5 Thu 15:15 F 142

Entwicklung einer Optical Ground Support Equipment Einheit für die GRACE follow-on Mission — •Alexander Görth[1], Oliver Gerberding[1], Christoph Mahrdt[1], Vitali Müller[1], Daniel Schütze[1], Benjamin Sheard[1], Gunnar Stede[1], Jose Sanjuan[2], Martin Gohlke[2,3], Claus Braxmaier[2], Gerhard Heinzel[1], Karsten Danzmann[1] und Kolja Nicklaus[4] — [1]Albert-Einstein-Institut Hannover/Max-Planck-Institut für Gravitationsphysik, Hannover, Germany — [2]Deutsches Zentrum für Luft- und Raumfahrt, Bremen, Germany — [3]Astrium GmbH, Immenstaad, Germany — [4]SpaceTech GmbH Immenstaad, Germany

Im Jahr 2017 wird eine Nachfolgemission zur erfolgreichen NASA/DLR Mission GRACE (Gravity Recovery And Climate Experiment) starten. Seit 2002 gewinnen die beiden GRACE Satelliten über gegenseitige Abstandsmessungen mit Hilfe eines Mikrowelleninterferometers Informationen über die räumliche und zeitliche Änderung des Gravitationsfelds der Erde. Für die GRACE Follow-on Mission wird zusätzlich ein Laser Ranging Instrument (LRI) entwickelt, welches die Abstandsbestimmung mit einer um zwei Größenordnungen höheren Genauigkeit ermöglichen soll. Zur Überprüfung der Funktionalität des LRI in den fertiggestellten Satelliten wird eine Optical Ground Support Equipment (OGSE) Einheit benötigt. Die OGSE Einheit wird zunächst die optische Verbindung der Satelliten im Orbit simulieren, wodurch wir in der Lage sein werden die unterschiedlichen Operationsmodi des LRI zu überprüfen. Wir werden sowohl die optische Verbindung der Satelliten, als auch die Funktionsweise der OGSE Einheit erläutern.

Q 50.6 Thu 15:30 F 142

A high power beam in high-order Laguerre-Gauss mode — •Christina Bogan[1], Ludovico Carbone[2], Andreas Freise[2], Benno Willke[1], and Karsten Danzmann[1] — [1]Albert-Einstein-Institut Hannover — [2]University of Birmingham

One approach to generate hgh-order Laguerre-Gauss modes with high efficiency and purity is the use of a transmitting phase plate illuminated with a laser beam in the fundamental mode. In contrast to other methods this method has the advantage of being siutable with high laser powers. However it is less flexible than for example a mode generation with an Spatial-Light-Modulator.

In this talk we present the generation of a high power helical LG_{33} mode. This mode was spatially filtered by a linear cavity. The mode conversion was observed for laser powers up to 140 W sent to the phase plate. Cavity scans showed that about 75 % of the power in the beam was in order-nine modes. The intensity pattern measured in transmission of the locked cavity was found to consist to more than 95 % of the helical LG_{33} mode. Therefore we could demonstrate a helical LG_{33} mode with a laser power of 82.6 W.

Q 50.7 Thu 15:45 F 142

Frequenzstabilisierung von Lasersystemen zur Rydberganregung von Calciumionen — •Patrick Bachor[1,2], Daniel Kolbe[1,2], Matthias Stappel[1,2], Thomas Feldker[1] und Jochen Walz[1,2] — [1]Institut für Physik, Johannes Gutenberg-Universität Mainz, 55099 Mainz, Deutschland — [2]Helmholtz-Institut Mainz, Johannes Gutenberg-Universität Mainz, 55099 Mainz, Deutschland

Ein vielversprechender Ansatz für einen skalierbaren Quantencomputer ist die Verwendung des Rydberg-Blockademechanismus, bei gespeicherten Calciumionen in einer Paulfalle [1]. Die benötigte Wellenlänge für den Übergang vom $3D_{5/2}$ Zustand in ein Rydbergniveau mit Hauptquantenzahl n = 67 liegt im Vakuum-Ultra-Violetten-Bereich bei 123 nm. Diese Wellenlänge kann durch einen Vier-Wellen-Mischprozess dreier fundamentaler Wellenlängen effizient erzeugt werden [2]. Die fundamentalen Wellenlängen werden durch Frequenzkonversion von infraroten Lasern bei 1015 nm, 1110 nm und 816 nm erzeugt. Wegen der schmalen Linienbreite des Rydbergniveaus ist es essentiell, dass das fundamentale Laserlicht eine Linienbreite im kHz-Bereich aufweist, was mit einer aktiven Frequenzstabilisierung erreicht werden kann. Um diese zu realisieren werden die drei Grundwellenlängen mit der Pound-Drever-Hall Methode auf einen ULE-Referenz-Resonator stabilisiert. Um die erreichte Linienbreite abzuschätzen, wird eine verzögerte selbst-heterodyne Messung mit einem Schwebungssignal zweier gleicher, unabhängiger Laser verglichen. Es wird der aktuelle Stand der Frequenzstabilisierung präsentiert. [1] F. Schmidt-Kaler et.al., NJP 13, (2011) 075014, [2] D. Kolbe et.al., PRL 109, (2012) 063901

Q 51: Precision measurements and metrology IV

Time: Thursday 14:00–16:00 Location: F 128

Group Report Q 51.1 Thu 14:00 F 128

A prototype optical bench for the Laser Interferometer Space Antenna — •Michael Tröbs and the LISA Optical Bench Team — Albert Einstein Institute, Callinstrasse 38, 30167 Hannover, Germany

The Laser Interferometer Space Antenna (LISA), aims to detect gravitational-waves at mHz frequencies. It consists of three spacecraft forming an equilateral triangle in an Earth-like orbit around the sun. Drag-free test masses define the arms of a Michelson interferometer that is implemented by mutual laser links between the satellites in a transponder configuration. Each LISA satellite carries optical benches, one for each test mass, that measure the distance to the local test mass and to the remote optical bench on the distant satellite. In addition, the optical bench includes an acquisition sensor and mechanisms for laser redundancy switching.

Currently, an elegant bread board of the optical bench is developed and will be characterized. This requires to complete externally the two interferometers mentioned above by simulators – a test mass simulator and a telescope simulator. We will give an overview of the test infrastructure including the simulators, the interferometer readout, the laser systems and the data acquisition.

Q 51.2 Thu 14:30 F 128

Micro-Newton thruster and test facility development — •Franz Georg Hey[1,2], Andreas Keller[1], Ulrich Johann[1], Claus Braxmaier[1,3,4], Martin Tajmar[2], and Dennis Weise[1] — [1]Astrium GmbH - Satellites — [2]Technische Universität Dresden — [3]Universität Bremen — [4]Deutsches Zentrum für Luft- und Raumfahrt

For future space missions especially with multi satellite configuration like the New Gravitational Wave Observatory, a highly precise attitude control system is required. The High Efficiency Multistage Plasma Thruster (HEMP-T) could be an adequate attitude actuator for these mission scenarios. In parallel to the development of suitable thrusters, also the setup of suitable test infrastructure for measurement of μN thrust noise levels is of crucial importance to understand such systems.

We present the development status of the micro-Newton HEMP-T as well as the status of the developed micro-Newton thrust balance. The developed, integrated and tested thrust balance consists of an optical read out, a calibration device, and the measurement pendulum itself. A heterodyne interferometer is used as optical read out. To measure the tilt of the pendulum, differential wave front sensing is used. The whole interferometer- and the mechanical balance setup is in a total symmetric configuration to enable a common-mode rejection of different noise sources. The calibration was accomplished with an electro static comb. The developed thrust balance has a resolution of $10\,\mu\text{N}/\sqrt{Hz}$ by a measured pendulum translation of few nanometers. Moreover we present the results of an experimental comparison of different HEMP-T configurations.

Q 51.3 Thu 14:45 F 128

Ground-based characterisation of the LISA Pathfinder optical measurement system — •Andreas Wittchen, Martin Hewitson, Heather Audley, Natalia Korsakova, Gerhard Heinzel, and Karsten Danzmann — Max-Planck Institut/AEI Hannover

A space-based gravitational wave detector, the laser interferometer space antenna (LISA), is currently being developed. LISA consists of three identical satellites, forming an equilateral triangle with million kilometre armlengths. To develop and test key technologies required, a test satellite, LISA Pathfinder, will be launched. This satellite contains a pair of free-floating test masses. The distance between the test masses will be precisely measured interferometrically. One of the key components of the measurement system is the optical bench, consisting of four interferometers. An engineering model optical bench is available at the Albert Einstein Institute, Hannover. It is currently used for system characterisation experiments, and will be integrated in a ground based test bed for use during in-flight operations. In this contribution the optical bench will be introduced and the current preparations for the mission are explained.

Q 51.4 Thu 15:00 F 128

MAIUS - a rocket-based matter-wave interferometer — •Stephan Tobias Seidel[1], Ernst Maria Rasel[1], and The Quantus-Team[1,2,3,4,5,6,7,8,9] — [1]Institut für Quantenoptik, LU Hannover — [2]ZARM, Universität Bremen — [3]Institut für Physik, HU Berlin — [4]Institut für Laser-Physik, Universität Hamburg — [5]Institut für Quantenphysik, Universität Ulm — [6]Institut für angewandte Physik, TU Darmstadt — [7]MUARC, University of Birmingham — [8]FBH, Berlin — [9]MPQ, Garching

A central goal of modern physics is the test of fundamental principles of nature with ever increasing precision. One of these contains of a differential measurement on freely falling ultra-cold clouds of two atomic species and thus using atom interferometry to test the weak equivalence principle in the quantum domain. By performing such an experiment in a weightless environment the precision of the interferometer can be considerably increased. With the QUANTUS experiments operating in the drop tower Bremen we were able to realize the first BEC based interferometer in microgravity. As a next step towards the transfer of such a system in space, either on board the ISS or as a dedicated satellite mission, a chip-based atom interferometer operating on a sounding rocket is currently being built. The success of this project would mark a major advancement towards a precise measurement of the equivalence principle with a space-born atom interferometer.

The QUANTUS project is supported by the German Space Agency DLR with funds provided by the Federal Ministry of Economics and Technology (BMWi) under grant number DLR 50WM1131.

Q 51.5 Thu 15:15 F 128

Breadboard model of the LISA Phasemeter — •Oliver Gerberding, Simon Barke, Joachim Kullmann, Ioury Bykov, Juan Josè Esteban Degaldo, Gerhard Heinzel, and Karsten Danzmann — Max-Planck-Institute for Gravitational Physics (Albert-Einstein-Institute) and Leibniz University of Hannover, Callinstraße 38, 30167 Hannover, Germany

The detection of gravitational waves in the sub-Hz regime will allow insight into the dynamics of galactic objects, like mergers of ultra-massiv black holes. For this purpose the space-born gravitational wave detector LISA is planned, which uses precision heterodyne laser interferometry as main measurement technology.

A breadboard model for the phase readout system of these interferometers (Phasemeter) is currently under development as an ESA project by a collaboration between the Albert-Einstein Institute, the Technical University of Denmark and Axcon Aps. The breadboard is designed to demonstrate all functions for operating a complete LISA-like metrology system, to meet all performance requirements for a future mission and to study the effort of bringing the design to space qualification.

Here we will present a system overview and the current status of testing and development of the breadboard. This includes phase readout with $1\mu\text{cycle}/\sqrt{\text{Hz}}$ performance, clock noise transfer, inter-satellite ranging and communication, laser frequency control and acquisition.

Q 51.6 Thu 15:30 F 128

Laser frequency stabilisation for the AEI 10m Prototype Interferometer — •Manuela Hanke for the AEI 10 m Prototype team — Leibniz Universität Hannover und MPG für Gravitationsphysik (AEI)

The 10 m Prototype facility, currently being set up at the AEI Hannover, will provide a testbed for very sensitve interferometric experiments. One ambitious goal of this project is to reach and subsequently even surpass the standard quantum limit in a detection band around 200 Hz with a 10 m arm length Michelson interferometer. In order to pursue such an avenue, the laser source must be extremely well stabilised. The laser source was chosen to be one of the 35 W lasers used to drive the km-scale gravitational wave observatories, LIGO and GEO 600. A fully suspended triangular ring cavity of finesse ca. 5000 will be used as a frequency reference for the stabilisation of the laser. The aim of this project, the so-called frequency reference cavity, is to reach a level of laser frequency fluctuations of better than 10^{-5} Hz/sqrt(Hz) in the detection band, centered around 200 Hz. Therefore we need to reduce the frequency noise by a factor of 10^7. The main goal is to make a sufficiently stabilised laser beam available for the AEI 10 m Prototype Interferometer, with a duty cycle that is not limiting the operation of the core instrument by any means. In this talk I will show the motivation for a frequency stabilisation and present the layout and the status of the reference cavity.

Q 51.7 Thu 15:45 F 128

Development of photoreceivers for space-based interferometry — •Germán Fernández, Gerhard Heinzel, and Karsten Danzmann — Max Planck Institute for Gravitational Physics/AEI, Hannover

The photoreceiver is a basic element in laser interferometry systems presented in space-based missions such as Lisa Pathfinder or GRACE. The special requirements demaded by those systems rule out any commercial solution for the photoreceiver. Therefore, new photoreceiver designs have been developed and characterized in the Max Planck Institute for Gravitational Physics, Hannover, focusing the efforts on the bandwidth and noise performance. Additionally, a high-accuracy measurement system was configured to perform scans of the photodiodes' surface, which allow a real understanding of the spatial response of those devices.

Q 52: Quantum gases: Fermions

Time: Thursday 14:00–15:45 Location: F 342

Group Report Q 52.1 Thu 14:00 F 342

Dynamical Properties of High-Spin Fermionic Quantum Gases — •Jasper Simon Krauser, Jannes Heinze, Nick Fläschner, Klaus Sengstock, and Christoph Becker — Universität Hamburg, Institut für Laserphysik, Luruper Chaussee 149, 22761 Hamburg, Germany

Ultracold fermions with large spin provide ideal model systems for high-spin magnetic properties beyond conventional electronic magnetism. Here, we report on extensive studies of fundamental spin and spin-spatial excitations in high-spin Fermi mixtures: Coherent multi-flavour spin dynamics in bulk systems and in 3d optical lattices, multi-component spin waves as well as the tuning of spin interactions via Feshbach resonances. As a key result we find that ultralow temperatures are essential for the coherent nature of spin dynamics. For our observations we find excellent agreement with theoretical models. Our results open new perspectives for further studies of high-spin magnetic properties such as $S > 1/2$ Mott insulators or color superfluidity. This work is supported by DFG within FOR 801.

Q 52.2 Thu 14:30 F 342

A Single Impurity in a Finite Fermi Gas — •Andre N. Wenz, Gerhard Zürn, Simon Murmann, Vincent Klinkhamer, Andrea Bergschneider, Thomas Lompe, and Selim Jochim — Physikalisches Institut, Ruprecht-Karls-Universität Heidelberg

We have studied ultracold fermionic few-particle systems consisting of one single impurity atom and an increasing number of majority atoms in another spin state. Starting from one atom in each spin state we observe the convergence of the normalized interaction energy towards a many-body limit by increasing the number of atoms one by one.

We realize this with a system of fermionic ^{6}Li atoms trapped in a quasi 1D optical dipole potential. In this system we can tune the strength of the repulsive interaction between the impurity and the majority atoms using a confinement induced resonance and probe the system by radio-frequency spectroscopy. This allows us to measure the interaction energy as a function of the number of majority atoms. We find that the interaction energy for a two particle system with one atom per spin state is very well described by the analytic theory by T. Busch et al. (Found. of Phys. 28, 549 (1998)). For an increasing number of majority atoms the interaction energy shows good agreement with numerical few-body calculations. For more than three majority atoms the normalized interaction energy quickly converges to a many-body limit. This limit is close to the prediction from an analytic model describing a single impurity in a bath of fermions which we obtain by adapting the homogeneous solution of McGuire (JMP 6, 432 (1965)) to the trapped system.

Q 52.3 Thu 14:45 F 342

Self-bound one-dimensional dipolar Fermi gases — •Frank Deuretzbacher[1], Georg M. Bruun[2], Mattia Jona-Lasinio[1], Christopher J. Pethick[3], Stephanie M. Reimann[4], and Luis Santos[1] — [1]Institut für Theoretische Physik, Leibniz Universität Hannover, Appelstr. 2, 30167 Hannover, Germany — [2]Department of Physics and Astronomy, University of Aarhus, Ny Munkegade, 8000 Aarhus, Denmark — [3]The Niels Bohr International Academy, The Niels Bohr Institute, Blegdamsvej 17, 2100 Copenhagen, Denmark — [4]Mathematical Physics, LTH, Lund University, 22100 Lund, Sweden

Dipolar Fermi gases open qualitatively novel scenarios compared to non-dipolar systems. We show that when the dipole moment is strong enough, self-bound single-component Fermi clouds may be possible in quasi-one-dimensional geometries due to the competition between the attractive dipole-dipole interaction and the Fermi pressure. By means of the Thomas-Fermi-Dirac approximation we establish the universal conditions for the existence of these states, showing that they are reachable in future experiments with ultra-cold polar molecules.

Q 52.4 Thu 15:00 F 342

Observation of Ferromagnetic Spin Correlations in a 1D Fermi System — •Simon Murmann, Andre N. Wenz, Vincent Klinkhamer, Andrea Bergschneider, Gerhard Zürn, Thomas Lompe, and Selim Jochim — Physikalisches Institut der Universität Heidelberg

We have studied spin correlations of quasi 1D spin $\frac{1}{2}$ systems. Starting with a ground state system of three to five ultracold ^{6}Li atoms, we use a Feshbach resonance to introduce repulsive interactions between the particles. After an adiabatic ramp across the resonance the particles end up in metastable states which have higher energies than states of spin-polarized samples with the same atom number. For systems satisfying this criterion the Stoner model predicts a transition to a ferromagnetic state. As a probe for the spin correlations, one particle is allowed to escape from the trap and the z-component of the total spin, as well as the energy of the remaining atoms is measured.

For weak repulsive interactions no significant fraction of prepared systems end up in a spin-polarized final state. This anticorrelation between the spins decreases with increasing repulsion. When crossing the Feshbach resonance to the metastable branch the number of spin-polarized systems is strongly enhanced, indicating the presence of strong ferromagnetic correlations.

Q 52.5 Thu 15:15 F 342

Quenching into the quantum AF]{Quenching into the quantum antiferromagnetic phase of ultra-cold fermions — •Monika Ojekhile, Robert Höppner, Ludwig Mathey, and Henning Moritz — University of Hamburg

The quantum anti-ferromagnetic phase of the two-dimensional Heisenberg model is one of the quintessential phases of many-body physics. To create and study this phase experimentally in ultra-cold fermionic atoms is one of the main challenges in the field of ultra-cold atoms. One important obstacle in these experiments are the high-entropy edge regions in the atomic trap, which can lead to substantial heating of the sample when the system is manipulated in a slow, adiabatic manner to create the phase.*Here, we study if and how this phase can be created by a fast quench instead. We consider several realistic quenches of the lattice parameters and external fields, as well as*several initial states, as ingredients of the quench.*We estimate the amount of excitations created in the quench using spin wave theory, and thereby*determine what the optimal strategy is to reach the quantum anti-ferromagnetic phase.

Q 52.6 Thu 15:30 F 342

Production of Ultracold Gases of Ytterbium in a 2D-/3D-MOT Setup — •Sören Dörscher, Alexander Thobe, Bastian Hundt, André Kochanke, Christoph Becker, and Klaus Sengstock — Zentrum für Optische Quantentechnologien, Universität Hamburg, Luruper Chaussee 149, 22761 Hamburg, Germany

Quantum gases of two-electron atoms are an exciting new branch within the field of ultracold atoms. Due to their complex level structure and unique features new phenomena such as SU(N)-symmetric spin Hamiltonians, artificial gauge fields or the Kondo lattice model can be studied.

Here we report on a novel experimental setup to produce quantum degenerate Yb gases based on a 2D-/3D-MOT scheme without use of a Zeeman slower. The 2D-MOT operated on the strong $^1S_0 - {}^1P_1$ transition captures Yb directly from a thermal beam of atoms and loads a 3D-MOT on the narrow $^1S_0 - {}^3P_1$ intercombination transition. Subsequently, atoms are transferred into a crossed optical dipole trap and evaporatively cooled to quantum degeneracy. We routinely produce Bose-Einstein condensates of ^{174}Yb with $1 \cdot 10^5$ atoms and degenerate Fermi gases of the spin-5/2 isotope ^{173}Yb with typically $2 \cdot 10^4$ particles at $T/T_F = 0.35$. We then prepare and study the ultracold gases in a triangular optical lattice by spectroscopy on the ultranarrow $^1S_0 - {}^3P_0$ transition.

This work is supported by the DFG within the SFB 925 and GRK 1355 and the EU FET-Open Scheme (iSense).

Q 53: Quantum information: Atoms and ions IV

Time: Thursday 14:00–16:00 Location: A 310

Group Report Q 53.1 Thu 14:00 A 310
Quantum technologies based on NV center in diamond — •Jianming Cai[1], Boris Naydenov[2], Liam McGuinness[2], Paz London[2], Kay Jahnke[2], Jochen Scheuer[2], Rainer Pfeiffer[2], Alex Retzker[1], Fedor Jelezko[2], and Martin Plenio[1] — [1]Institute of Theoretical Physics,Ulm University — [2]Institut für Quantenoptik, Ulm University

In this talk, I will report our recent developments on various applications of NV center in diamond. In particular, we propose a new architecture for a scalable quantum simulator, which consists of strongly-interacting nuclear spins attached to the diamond surface by its direct chemical treatment, or by means of a functionalized graphene sheet. The initialization, control and read-out of this quantum simulator can be accomplished with nitrogen-vacancy centers implanted in diamond. The system can be engineered to simulate a wide variety of interesting strongly-correlated models with long-range dipole-dipole interactions. We also explore the possibility of using NV center in diamond as a nano-scale sensor to probe the structural and dynamical processes in chemistry/biology.

Q 53.2 Thu 14:30 A 310
Trapping of Topological-Structural Defects in Coulomb Crystals — •Jonathan Brox[1], Haggai Landa[2], Manuel Mielenz[1], Benni Reznik[2], and Tobias Schaetz[1] — [1]Atom-, Molekül- und optische Physik, Physikalisches Institut, Universität Freiburg, Hermann-Herder-Str. 3, 79104 Freiburg — [2]School of Physics and Astronomy, Raymond and Beverly Sackler Faculty of Exact Sciences, Tel-Aviv University, Tel-Aviv 69978, Israel

We study experimentally and theoretically structural defects which are formed during the transition from a laser cooled cloud to a Coulomb crystal, consisting of tens of ions in a linear radiofrequency trap. We demonstrate the creation of predicted topological defects ('kinks') in purely two-dimensional crystals [1], and also find kinks which show novel dynamical features in a regime of parameters not considered before. The kinks are always observed at the centre of the trap, showing a large nonlinear localized excitation, and the probability of their occurrence surprisingly saturates at ~ 0.5. Simulations reveal a strong anharmonicity of the kink's internal mode of vibration, due to the kink's extension into three dimensions. As a consequence, the periodic Peierls-Nabarro potential experienced by a discrete kink becomes a globally confining potential, capable of trapping one cooled defect at the center of the crystal.

[1] H. Landa et al., Phys. Rev. Lett. **104**, 043004 (2010)

Q 53.3 Thu 14:45 A 310
Quantun non demolition measurement and entanglement of multiple nuclear spins in diamond — •Gerald Waldherr, Sebastian Zaiser, Ya Wang, Philipp Neumann, and Jörg Wrachtrup — 3. Physikalisches Institut, Uni Stuttgart

QND measurement of a nitrogen nuclear spin associated with the nitrogen vacancy (NV) defect in diamond has previously been demonstrated [1]. Here, we will show that QND measurement of certain nearby ^{13}C nuclear spins can also be performed. Additionally, we can use the interaction with the NV electron spin to entangle these nuclear spins with each other, to demonstrate basic quantum information processing tasks.

[1] P. Neumann, J. Beck, M. Steiner, F. Rempp, H. Fedder, P. R. Hemmer, J. Wrachtrup, and F. Jelezko, Science 329, 542 (2010)

Q 53.4 Thu 15:00 A 310
Quantum sensing using vacuum forces — •Christine Muschik[1], Simon Moulieras[1], Kanupriya Sinha[2], Frank Koppens[1], Maciej Lewenstein[1], and Darrick Chang[1] — [1]ICFO-Institut de Ciencies Fotoniques, Spain — [2]University of Maryland, US

We propose a scheme, which harnesses quantum vacuum forces for practical applications. Casimir Forces become extremely strong at very short distances. We use this mechanism to coupling a quantum emitter to a suspended graphene membrane. This setup allows for an instantaneous and highly sensitive read-out the position of the graphene sheet, which has important applications for mass and force sensing. Since the coupling via the Casimir force is very strong, it is also a very valuable tool for engineering the quantum state of the membrane and for investigating the damping mechanisms of moving graphene in a hitherto inaccessible regime of precision.

Q 53.5 Thu 15:15 A 310
Microwave sideband cooling of trapped ions using a static magnetic gradient — •Andrés F. Varón, Benedikt Scharfenberger, Christian Piltz, Anastasiya Khromova, and Christof Wunderlich — Universität Siegen, NT Fakultät, Department Physik, 57068 Siegen, Germany

We report on microwave sideband cooling of trapped $^{171}Yb^{+}$ ions. Different to laser cooling, microwave sideband cooling requires an additional mechanism that allows to couple internal states of a trapped ion with its vibrational states. This is done in the presence of a static magnetic field gradient created by two permanent magnets. Cooling is achieved by repetitions of the following two steps: First, microwave radiation, tuned to the red sideband of the hyperfine transition F=0 $\leftrightarrow$ F=1 in the electronic ground state $S_{1/2}$ of $^{171}Yb^{+}$, excites the ion reducing the phonon number by one. Second, laser light exciting the $S_{1/2}$, F=1 $\leftrightarrow$ $P_{1/2}$, F=1 dipole allowed resonance pumps the ion back to the initial F=0 state but with a phonon less. The trap is characterized by an axial trapping frequency of 121 kHz. We systematically measure the final ion temperature for different microwave and laser intensities. For the optimized set of parameters we show a reduction of more than one order of magnitude on the mean phonon occupation number from $\langle n \rangle = 176 \pm 30$ to $\langle n \rangle = 4 \pm 4$ achieving temperatures close to the ground state.

Q 53.6 Thu 15:30 A 310
Multi-site single-atom qubit manipulation in a 2D quantum register — •Sascha Tichelmann, Malte Schlosser, Moritz Hambach, and Gerhard Birkl — Institut für Angewandte Physik, Technische Universität Darmstadt, Schlossgartenstraße 7, 64289 Darmstadt, Germany

The ability to synchronously probe multi-component quantum systems in multi-site architectures is fostering some of the most active research in the investigation of ultra-cold atomic quantum systems for quantum information processing (QIP). For this purpose, we have introduced the application of micro-fabricated optical elements for atom optics and QIP with atoms. We present recent progress towards the realization of a scalable architecture for QIP using neutral atoms in two-dimensional (2D) arrays of optical microtraps as qubit registers. This approach is simultaneously targeting the important issues of single-site addressability and scalability, and provides versatile configurations for quantum state storage, manipulation, and retrieval. We report on the implementation of a quantum register with well over 100 sites featuring trap sizes and a tuneable site separation in the single micrometer regime. Individual ^{85}Rb atoms serve as carriers for quantum information. The atom number at each site can be initialized to 1 with sup-poissonian statistics by applying an atom number filtering process based on light assisted collisions. In each experimental realization, we prepare exactly one atom in more than 50 sites. We present single-site resolved addressing of single spins in a reconfigurable fashion and discuss the feasibility of Rydberg based two-qubit gates in our setup.

Q 53.7 Thu 15:45 A 310
Topological defect formation and dynamics of symmetry breaking in ion Coulomb crystals — •Jonas Keller[1], Karsten Pyka[1], Heather L. Partner[1], Ramil Nigmatullin[2], Tobias Burgermeister[1], Martin B. Plenio[2], Alex Retzker[3], Wojciech Zurek[4], Adolfo del Campo[4], and Tanja E. Mehlstäubler[1] — [1]Physikalisch-Technische Bundesanstalt, Braunschweig — [2]Institut für Theoretische Physik, Universität Ulm — [3]Racah Institute of Physics, The Hebrew University of Jerusalem — [4]Theoretical Division, Los Alamos National Laboratory

Structural defects in ion Coulomb crystals (kinks) have been proposed for studies of quantum-mechanical effects with solitons and as carriers of quantum information [1]. Defects form when a symmetry breaking phase transition is crossed and the finite speed of information prevents different regions from coordinating the choice of the symmetry broken state. In our case, the second-order phase transition from the linear to the zigzag configuration of a Coulomb crystal is driven by quenching the radial trapping potential. We demonstrated the creation of stable kinks and present experimental results on kink dynamics and losses. These allowed a quantitative verification of the power law scaling of kink density with the quench time as predicted by the paradigmatic Kibble-Zurek mechanism [2]. This theory applies to phase transitions in a wide range of fields, from cosmology to solid state physics and vortices in superfluids.

[1] Landa *et al.*, *Phys. Rev. Lett.* **104**, 043004 (2010)
[2] Pyka *et al.*, *arXiv*:1211.7005 (2012)

Q 54: Quantum information: Photons and nonclassical light I

Time: Thursday 14:00–16:00 Location: E 001

Group Report Q 54.1 Thu 14:00 E 001

Ultrafast multi-mode quantum optics — •Andreas Christ[1], Benjamin Brecht[1], Georg Harder[1], Vahid Ansari[1], Kaisa Laiho[1], Andreas Eckstein[2], and Christine Silberhorn[1] — [1]Applied Physics, University of Paderborn, Warburger Straße 100, 33098 Paderborn, Germany — [2]Equipe DON, Laboratoire Matériaux et Phénomènes Quantiques, Université Paris Diderot-Paris 7

Ultrafast single-mode quantum states of light constitute a basic building block for quantum enhanced applications. For quantum networking applications, people usually consider the combined use of several distinct sources to enlarge the available Hilbert space. As an alternative we harness the intrinsic multi-mode structure of high dimensional ultrafast quantum states, which, for example, enables multiplexed quantum communication protocols.

As a first step, we present the creation of multi-mode pulsed quantum states of light, based on ultrafast waveguided parametric down-conversion (PDC). Engineering the PDC process enables us to excite a tuneable number of ultrafast modes.

Secondly, in order to characterize the number of emitted modes and to benchmark our sources we introduce broadband correlation function measurements and show how they are able to resolve the multi-mode nature of the created quantum states.

Finally, it is essential for further applications to individually address the different pulse modes. Here we discuss quantum pulse gates, based on engineered ultrafast frequency conversion processes, which are able to separate individual pulse modes from multi-mode quantum states.

Q 54.2 Thu 14:30 E 001

Realization of quantum up-conversion of squeezed light from 1550 nm to 532 nm — •Petrissa Zell[1], Christina E. Vollmer[1], Christoph Baune[1], Aiko Samblowski[1], Jaromír Fiurášek[2], and Roman Schnabel[1] — [1]Institut für Gravitationsphysik, Leibniz Universität Hannover and Max-Planck-Institut für Gravitationsphysik (Albert-Einstein-Institut), Callinstr. 38, 30167 Hannover, Germany — [2]Department of Optics, Palacký University, 17. listopadu 50, 77200 Olomouc, Czech Republic

Frequency conversion of non-classical light provides a considerable amount of applications in the field of quantum information and quantum metrology. An example of quantum metrology is the sensitivity enhancement of gravitational wave detectors using squeezed vacuum states of light as it was recently accomplished in GEO 600 at a wavelength of 1064 nm. In principle, reducing the detector's wavelength to the optical regime yields a further enhancement of its sensitivity. Here we report on the generation of a continuous-wave squeezed vacuum state at 532 nm via frequency up-conversion of a squeezed vacuum state at 1550 nm. The up-conversion is realized by means of a doubly resonant optical parametric oscillator, exploiting a strong 810 nm pump field. With this method we achieved a non-classical noise reduction of 1.5 dB at 532 nm, and introduce the possibility to up-convert entangled states as well as single photons.

Q 54.3 Thu 14:45 E 001

Near-Unity Collection Efficiency of Single Photons from a Solid-State Emitter — Thomas J.K. Brenner, •Xiao-Liu Chu, Stephan Götzinger, and Vahid Sandoghdar — Max Planck Institut für die Physik des Lichts, Erlangen, Germany

Recently, we described a theoretical method for constructing a planar metallo-dielectric antenna that exhibits 99% collection efficiency. The antenna design consists of a multilayer architecture with stepwise change in the refractive index across the structure. Single photons emitted by a quantum emitter sandwiched in between the high and low refractive index layers are channeled into the middle layer (n2), from where they leak down into the high refractive index substrate (sapphire, n1=1.78) at angles determined by arcsin(n2/n1). The emitted photons are then collected by using a conventional microscope objective. Here we report on the experimental realization of this proposal using single colloidal quantum dots (CdS/CdSe) as sources of single photons. This system serves as a stable and ultra-bright source of single photons that is highly desirable for a variety of applications such as quantum communication, quantum cryptography, shot-noise-free detection and spectroscopy.

Q 54.4 Thu 15:00 E 001

Wavelength tunability of a triply resonant whispering gallery optical parametric oscillator — •Gerhard Schunk, Michael Förtsch, Josef Fürst, Dmitry Strekalov, Florian Sedlmeir, Harald Schwefel, Christoph Marquardt, and Gerd Leuchs — Max Planck Institute for the Science of Light, Institute for Optics, Information and Photonics, University Erlangen-Nuremberg, Erlangen, Germany

Lithium Niobate whispering gallery mode resonators (WGMR) offer high finesse and small mode volume leading to strong field enhancement for all wavelengths within the transparency window of the medium. Hence, optical parametric oscillators (OPO) based on WGMRs offer high efficiency as well as high stability and control over wavelength and bandwidth.

The process of parametric down conversion (PDC) has been demonstrated in a z-cut WGMR near the degenerate emission at 1064 nm [1,2,3]. The ongoing project aims for the analysis of wavelength tuning in this triply resonant OPO for applications in quantum optics. In particular, the focus lies on bridging the gap between atomic transitions (resonant idler photon) and telecom wavelengths (signal photon).

Q 54.5 Thu 15:15 E 001

Spectral and spatial correlations of PDC in waveguide arrays — •Regina Kruse, Fabian Katzschmann, Andreas Christ, Kaisa Laiho, and Christine Silberhorn — Universität Paderborn, Integrierte Quantenoptik, Warburger Str. 100, D-33098 Paderborn

Integrated optical devices form a compact and easy to manipulate basis for all types of optical applications. Especially weakly coupled waveguide arrays offer the advantage of highly stable interferometric experiments, which can be used for optical simulations of solid state systems. In the non-linear regime, localization effects like solitons can be observed [1]. Here, we investigate in detail the spectral and spatial correlations of parametric down-conversion (PDC) in waveguide arrays [2], which have been studied extensively in the context of classical optics and quantum walks [3,4]. We pay special attention to the engineering of hyperentangled multimode quantum states in the spectral and spatial degree of freedom, which allow for scalable and robust quantum information applications.

[1] H. S. Eisenberg et al. PRL 81 (3383), 1998
[2] A. Solntsev et al., PRL 108 (023601), 2012
[3] A. Peruzzo et al., Science 329 (1500), 2010
[4] L. Sansoni et al. PRL 108 (010502), (2012)

Q 54.6 Thu 15:30 E 001

An Efficient Integrated Two-Color Source for Heralded Single Photons — •Stephan Krapick, Harald Herrmann, Viktor Quiring, Benjamin Brecht, Hubertus Suche, and Christine Silberhorn — Universität Paderborn, Integrated Quantum Optics Group, Warburger Straße 100, 33098 Paderborn

We report on an integrated source for heralded single photons at telecom wavelength based on a type-I parametric down-conversion (PDC) process inside Titanium-indiffused periodically poled Lithium Niobate waveguides (Ti:PPLN). The on-chip integration of a passive directional coupler allows for excellent spectral separation of the generated signal and idler photons. Measurements of the heralded single photons prove a preparation efficiency of 60 % and coincidence-to-accidentals-ratios of up to 7400. For the low pump power regime we obtain a conditioned second order auto-correlation function of $g^{(2)}(0) = 0.004$ indicating almost pure photon pair generation. The high brightness of our source was concluded from the high average photon number generated per pump pulse of $\langle n_{\mathrm{pulse}}\rangle = 0.24$ at power levels below 100 μW.

Q 54.7 Thu 15:45 E 001

Quantum noise for Faraday light-matter interfaces — •Denis Vasilyev and Klemens Hammerer — Leibniz University Hanover, 30167 Hanover, Germany

In light-matter interfaces based on the Faraday effect, quite a number of quantum information protocols have been successfully demonstrated. In order to further increase the performance and fidelities achieved in these protocols, a deeper understanding of the relevant noise and decoherence processes needs to be gained. In this paper, we provide for the first time a complete description of the decoherence from spontaneous emission. We derive from first principles the effects of photons being spontaneously emitted into unobserved modes. Our results relate the resulting decay and noise terms in effective equations of motion for collective atomic spins and the forward-propagating light modes to the full atomic level structure. We illustrate and apply our results to the case of a quantum memory protocol. Our results can be applied to any alkali atoms, and the general approach taken in this paper can be applied to light-matter interfaces and quantum memories based on different mechanisms.

Q 55: Ultra-cold atoms, ions and BEC VII (with A)

Time: Thursday 14:00–16:00 Location: B 305

Q 55.1 Thu 14:00 B 305

Magneto-optical trapping of dysprosium — •Thomas Maier, Holger Kadau, Matthias Schmitt, Michaela Nickel, Axel Griesmaier, and Tilman Pfau — 5. Physikalisches Institut, Universität Stuttgart, Pfaffenwaldring 57, 70569 Stuttgart, Germany

Strongly dipolar quantum gases enable the observation of many-body phenomena with anisotropic, long-range interaction. Rotonic features, 2D stable solitons and the supersolid state are some of the exotic many-body phenomena predicted for such quantum gases. Recent generation of degenerated bosonic [1] and fermionic dysprosium [2] and bosonic erbium [3], both elements with large magnetic dipole moment, are promising candidates to observe these mentioned effects.

We report on progress in our experiment to achieve degenerate dysprosium quantum gases. Dysprosium is the element with the highest magnetic moment and offers a non-spherical symmetric groundstate $^5\mathrm{I}_8$. In the present stage, we realized a magneto-optical trap (MOT) for dysprosium on a broad cooling transition at 421 nm. Future perspectives are to implement a narrow-line MOT on the 626 nm cooling transition, similar to the work in [3].

[1] M. Lu *et al.*, Phys. Rev. Lett. **107**, 190401 (2011)
[2] M. Lu *et al.*, Phys. Rev. Lett. **108**, 215301 (2012)
[3] K. Aikawa *et al.*, Phys. Rev. Lett. **108**, 210401 (2012)

Q 55.2 Thu 14:15 B 305

Dissipative Binding of Lattice Bosons through Distance-Selective Pair Loss — Cenap Ates, Beatriz Olmos, •Weibin Li, and Igor Lesanovsky — School of Physics and Astronomy, The University of Nottingham, Nottingham NG7 2RD, United Kingdom

We show that in a gas of ultracold atoms distance selective two-body loss can be engineered via the resonant laser excitation of atom pairs to interacting electronic states. In an optical lattice this leads to a dissipative master equation dynamics with Lindblad jump operators that annihilate atom pairs with a specific interparticle distance. In conjunction with coherent hopping between lattice sites this unusual dissipation mechanism leads to the formation of coherent long-lived complexes that can even exhibit an internal level structure which is strongly coupled to their external motion. We analyze this counterintuitive phenomenon in detail in a system of hard-core bosons. While current research has established that dissipation in general can lead to the emergence of coherent features in many-body systems our work shows that strong nonlocal dissipation can effectuate a binding mechanism for particles.

Q 55.3 Thu 14:30 B 305

Atomic Coherence in a Superconducting Coplanar Resonator — •Patrizia Weiss, Helge Hattermann, Simon Bernon, Daniel Bothner, Martin Knufinke, Reinhold Kleiner, Dieter Koelle, and József Fortágh — Physikalisches Institut and CQ Center for Collective Quantum Phenomena and their Applications, Eberhard-Karls-Universität Tübingen, Auf der Morgenstelle 14, D-72076 Tübingen, Germany

Superconducting devices have proved suitable for fast qubit operations and quantum gates. However, their coherence times are still limited to a few μs. Therefore hybrid quantum systems have attracted considerable interest. One promising system is composed of superconductors and cold atoms, in which the atomic ensemble takes the role of a quantum memory and is coupled to a superconducting resonator that acts as a quantum bus.

Here we report on the preparation and coherence times of atomic ensembles in a superconducting coplanar resonator on an atom chip. The superconducting structures are based on niobium thin films at 4.2 K. Atoms are trapped by persistent currents in the resonator ground planes. We are able to produce large BECs of up to 10^6 atoms. The coherence of atomic superposition states is investigated by means of Ramsey interferometry. We find atomic coherence times on the order of $T_2 \sim 10$ s. We report on progress towards coupling of the atoms to the mode of a cavity.

Q 55.4 Thu 14:45 B 305

Millikelvin System for Cold Atom Superconductor Hybrid Quantum Devices — •Florian Jessen, Martin Knufinke, Petra Vergien, Malte Reinschmidt, Helge Hattermann, Simon Bernon, Simon Bell, Daniel Cano, Dieter Kölle, Reinhold Kleiner, and József Fortágh — Center for Collective Quantum Phenomena, Eberhard Karls Universität Tübingen, Auf der Morgenstelle 14, 72076 Tübingen

Hybrid quantum systems based on ultracold atoms and superconducting devices are promising candidates for fundamental physics as well as quantum information especially superconducting quantum circuits require millikelvin temperatures for their operation and sufficiently long coherence time. Towards realisation of the cold atom/superconductor quantum interface we installed cold atoms setup into a delution refrigerator reaching a base temperature of 50mK. We report on the operation of this system.

Q 55.5 Thu 15:00 B 305

Semiclassical dynamics of ultracold Bosons in multiple wells — •Lena Simon and Walter Strunz — Institut für theoretische Physik, TU Dresden

We aim to shed light on the transition from a nonequilibrium to an equilibrium state of an interacting bosonic manybody system. We investigate the dynamics of an ensemble of Bosons in a multiple well potential, which has been initially set up in a nonequilibrium state. The Bosons display interesting dynamics, gouverned by the interplay of tunneling and the interaction amongst the particles. The dynamics are investigated by solving the full Schroedinger equation for a Bose-Hubbard-model, and by means of the so called (semiclassical) Herman-Kluk propagator. The results are also compared to the often applied mean-field approximation.

Q 55.6 Thu 15:15 B 305

Noise correlations of two-dimensional Bose gases — •Vijay Pal Singh and Ludwig Mathey — Zentrum fuer Optische Quantentechnologien and Institut fuer Laserphysik, Universitaet Hamburg, D-22761 Hamburg, Germany

We analyze the density-density correlations of the expanding clouds of weakly interacting two-dimensional (2D) Bose gases below and above the Berezinskii-Kosterlitz-Thouless (BKT) transition. Such a system has two thermal phases in equilibrium, defined through the long-range order of the two-point correlation function. In the course of a time-of-flight expansion, both thermal and quantum fluctuations present in the trapped system transform into density fluctuations. The spectrum of density distributions shows an oscillatory shape controlled only by the scaling exponent of the quasi-condensed phase (below the transition) and by the correlation length (above the transition). This exponent can be extracted by analyzing the evolution of the spectrum of density distributions as a function of the expansion time. The positions of the spectral peaks show a scaling behavior with the expansion time. How these features can be extracted in experiment will be discussed as well.

Q 55.7 Thu 15:30 B 305

Quasi-particle excitation spectra of general quantum lattice systems via the 1/Z expansion — •Patrick Navez, Konstantin Krutitsky, Friedemann Queisser, and Ralf Schützhold — Fakultät für Physik, Universität Duisburg-Essen, Duisburg, Germany

We investigate general quantum lattice systems such as the Bose and Fermi Hubbard models or the Heisenberg spin model using the 1/Z expansion method [1,2] where Z is the coordination number. This method provides a general framework for deriving linearized equations of motion for quasi-particle excitation operators, which yield the excitation spectra, for example. Their solutions determine the one-site reduced density matrix and the two-sites reduced correlation density matrix, which are given in terms of bilinear expectation values of the quasi-particle excitation operators (displaying the quantum fluctuations). We illustrate the powerfulness of these general concepts for several examples such as particle-hole operators in the Mott phase of the Bose and Fermi Hubbard models (which lower the ground state energy by virtual tunneling) or the Heisenberg model (where virtual magnon excitations of opposite spin reduce antiferromagnetism) and compare our findings with the results found in the literature.

1 P. Navez, R. Schützhold, Phys. Rev. A 82, 063603 (2010)

2 F. Queisser, K. Krutitsky, P. Navez, R. Schützhold, arXiv:1203.2164

Q 55.8 Thu 15:45 B 305

Local Detection of Quantum Gases in Real Time — •Peter Federsel, Markus Stecker, Simon Bell, Hannah Schefzyk, Andreas Günther, and József Fortágh — Physikalisches Institut, Universität Tübingen, Deutschland

In this talk, we describe a novel scheme for local single-atom detection in trapped clouds of ultracold atoms. The scheme is based on local field ionization of atoms and subsequent ion detection. The ionization takes place in the locally enhanced near-field at the tip of a charged nanowire. Field strengths of up to 10^{10} V/m can be achieved, sufficient for field ionization of nearby rubidium atoms. The detection scheme is fully compatible to state-of-the-art atomchip experiments and includes ion-optics for extracting and guiding the ions to the sensitive single ion detector. We will show first results on this new detection scheme, including measurements on the tips field enhancement, characterization of the ion optics and field-ionization of thermal atoms.

Q 56: Poster III

Time: Thursday 16:00–18:30 Location: Empore Lichthof

Q 56.1 Thu 16:00 Empore Lichthof

Development of a laser system for coupling quantum gases with optical cavities — •Moonjoo Lee, Julian Leonard, Leigh Martin, Christian Zosel, Tilman Esslinger, and Tobias Donner — Institute for Quantum Electronics, ETH Zürich

Quantum gases coupled with high-finesse optical cavities opened a new way in exploring quantum many-body systems with long-range interactions. Extreme coupling rates on the order of GHz are achievable in these systems, but demand for lasers sources with wide range tunability while having very narrow linewidths.

We employ two diode lasers, one of them to probe/pump the system at 780 nm and the other to lock cavities at 830 nm. The absolute frequency of the probe laser is offset locked onto a frequency comb. Frequency stabilization to linewidths below 50 kHz is achieved by locking both lasers onto a transfer cavity. The frequency of the stabilized lasers are tunable by several GHz via wideband electro-optic modulators and one sideband is filtered out by using a cleaning cavity.

We are also presenting our progress in fabricating crossed high-finesse cavities which offer possibilities for nondestructive probing of quantum phases and for the realization of the multimode Dicke Hamiltonian.

Q 56.2 Thu 16:00 Empore Lichthof

Cavity assited momentum transfer in a Bose-Einstein condensate — •Hans Kessler, Jens Klinder, Matthias Wolke, Hannes Winter, and Andreas Hemmerich — ILP, Universität Hamburg

Conventional laser cooling relies on repeated electronic excitations by near-resonant light, which constrains its area of application to a selected number of atomic species prepared at moderate parti- cle densities. Optical cavities with a Purcell factor exceeding unity allow to implement laser cooling schemes using off-resonant light-scattering, which avoid the limitations imposed by spontaneous emis- sion. Here, we report on an atom-cavity system, combining a Purcell factor around 40 with a cavity bandwidth (9 kHz) below the recoil frequency associated with the kinetic energy transfer in a single pho- ton scattering event (14 kHz). This lets us access a yet unexplored fundamental quantum mechanical regime of atom-cavity interactions, in which the atomic motion can be manipulated by targeted dissi- pation with sub-recoil resolution. We demonstrate cavity-induced heating of a of 87Rb Bose-Einstein condensate and subsequent cooling at particle densities and temperatures incompatible with conven- tional laser cooling.

Q 56.3 Thu 16:00 Empore Lichthof

Nonthermal Fixed Points and Superfluid Turbulence in an Ultracold Bose Gas — Sebastian Erne[1,2], •Markus Karl[1,2], Steven Mathey[1,2], Boris Nowak[1,2], Nikolai Philipp[1,2], Jan Schole[1,2], and Thomas Gasenzer[1,2] — [1]Institut für Theoretische Physik, Ruprecht-Karls-Universität Heidelberg, Philosophenweg 16, 69120 Heidelberg — [2]ExtreMe Matter Institute EMMI, GSI Helmholtzzentrum für Schwerionenforschung GmbH, Planckstraße 1, 64291 Darmstadt, Germany

Turbulence appears in situations in which, *e.g.*, an energy flux goes from large to small scales where finally the energy is dissipated. As a result the distribution of occupation numbers of excitations follows a power law with a universal critical exponent. The situation can be described as a nonthermal fixed point of the dynamical equations. Single-particle momentum spectra for a dynamically evolving Bose gas are analysed using semi-classical simulations and quantum-field theoretic methods based on effective-action techniques. These give information about possible universal scaling behaviour. The connection of this scaling with the appearance of topological excitations such as solitons and vortices in one-component gases and domain walls and spin textures in multi-component systems is discussed. For the one-dimensional case, a random-soliton model provides analytical results for the spectra, and their relation to those found in a field-theory approach to strong wave turbulence is discussed. The results open a view on a possibility to study nonthermal fixed points and superfluid turbulence in experiment without the necessity of detecting solitons and vortices in situ.

Q 56.4 Thu 16:00 Empore Lichthof

The Multi-Layer Multi-Configuration Time-Dependent Hartree Method for Ultra-Cold Bosons — •Sven Krönke[1,2], Lushuai Cao[1,2], Oriol Vendrell[2,3], and Peter Schmelcher[1,2] — [1]Zentrum für Optische Quantentechnologien, Universität Hamburg, Germany — [2]The Hamburg Centre for Ultrafast Imaging, Germany — [3]Center for Free-Electron Laser Science, DESY, Hamburg, Germany

We develop and apply the multi-layer multi-configuration time-dependent Hartree method for bosons (ML-MCTDHB), which represents a highly flexible tool for investigating the quantum many-body dynamics of ultra-cold bosonic multi-species systems out of equilibrium in arbitrary dimensions.

Being an ab initio method for solving the time-dependent Schrödinger equation, ML-MCTDHB takes all correlations into account. The multi-layer feature of ML-MCTDHB allows for tailoring the wave function ansatz in order to describe intra- and inter-species correlations accurately and efficiently. To show the beneficial scaling and the efficiency of the method, we explore the correlated dynamics of three species tunneling in a double well trap. We demonstrate and analyze in detail the build up of inter- and intra-species correlations in the course of the quantum dynamics as well as signatures of equilibration.

Q 56.5 Thu 16:00 Empore Lichthof

Non-equilibrium Functional Renormalization for Driven Open Many-Body Quantum Systems — •Lukas M. Sieberer[1], Ehud Altman[2], Sebastian D. Huber[3], and Sebastian Diehl[1,4] — [1]Institute for Theoretical Physics, University of Innsbruck, 6020 Innsbruck, Austria — [2]Department of Condensed Matter Physics, Weizmann Institute of Science, Rehovot 76100, Israel — [3]Institute for Theoretical Physics, ETH Zurich, 8093 Zurich, Switzerland — [4]Institute for Quantum Optics and Quantum Information of the Austrian Academy of Sciences, 6020 Innsbruck, Austria

We study phase transitions in bosonic driven-dissipative systems with competing dissipative and unitary dynamics, describing a natural long-wavelength model for pumped quantum systems such as exciton-polariton condensates or cold atomic systems with optical Feshbach resonances. In three spatial dimensions, these systems thermalize at low frequencies and exhibit universal critical behavior governed by an interacting Wilson-Fisher fixed point. We identify a new and independent non-equilibrium critical exponent, measuring the fade-out of the microscopic competition of unitary and dissipative dynamics.

The starting point of our analysis is a description of the driven-dissipative dynamics by a Markovian many-body master equation which we map to a Keldysh functional integral partition function. The Keldysh technique provides an excellent framework to put into practice a functional renormalization group approach for the study of criticality in non-equilibrium stationary states.

Q 56.6 Thu 16:00 Empore Lichthof

Exchange-driven crystallization of Rydberg-dressed atoms — •Fabio Cinti[1], Massimo Boninsegni[2], Nils Henkel[1], and Thomas Pohl[1] — [1]Max Planck Institute for the Physics of Complex Systems, 01187 Dresden, Germany — [2]Department of Physics, University of Alberta, Edmonton, Alberta, Canada T6G 2J1

We study the physics of Bosonic atoms with long-range interactions, induced by optical dressing to high-lying Rydberg states. Using first-principle quantum Monte Carlo techniques, we construct the finite-temperature phase diagram, which is shown to be universal over a wide range of experimentally relevant parameters that promote superfluid, supersolid as well as insulating crystal phases. Surprisingly, we find that quantum exchange, which commonly tends to cause delocalization, stabilizes the crystalline phase as compared to an analogous quantum system composed distinguishable particles. We provide an intuitive picture for the mechanism behind this unexpected behavior and draw a connection to the peculiar shape of the interaction potential induced by Rydberg-dressing.

Q 56.7 Thu 16:00 Empore Lichthof

Evolution of Bose-Einstein condensates in a gravitational cavity — •Javed Akram[1] and Axel Pelster[2] — [1]Fachbereich Physik, Freie Universität Berlin, Germany — [2]Fachbereich Physik, Technische Universität Kaiserslautern, Germany

We investigate both the static and dynamic properties of weakly interacting Bose-Einstein condensates (BEC) in an one-dimensional gravitational cavity. There the effect of gravity is compensated by an exponentially decaying potential, which is created by the total internal reflection of an incident laser beam from the surface of a dielectric serving as a mirror for the atoms. By solving the underlying Gross-Pitaevskii equation with a variational Gaussian condensate wave function, we derive a coupled set of differential equations for the width and the height of the condensate. By considering small deflections around the respective equilibrium positions, we determine the collective excitations of the BEC. Furthermore, we analyze how the BEC cloud expands ballistically due to gravity after switching off the evanescent laser field.

Q 56.8 Thu 16:00 Empore Lichthof

Supersolidity in rotating Rydberg-dressed Bose-Einstein condensates — •Nils Henkel[1], Fabio Cinti[1], Piyush Jain[2], Guido Pupillo[3,4], and Thomas Pohl[1] — [1]Max Planck Institute for the Physics of Complex Systems, Dresden — [2]Department of Physics, University of Alberta, Edmonton, Alberta, Canada — [3]IQOQI and Institute for Theoretical Physics, University of Innsbruck, 6020 Innsbruck, Austria — [4]ISIS and IPCMS, Université de Strasbourg and CNRS, Strasbourg, France

We study two-dimensionally confined Bose-Einstein condensates in which long-range soft-core interactions are induced by optical dressing to high-lying Rydberg states [1]. Based on Quantum Monte Carlo simulations, we demonstrate that this system facilitates the preparation of supersolid states and show that many of their features can be described within a simplified mean field approach. Using the latter we investigate the rotation-induced formation of vortex structures [2]. Our calculations reveal an interesting interplay of length scales of the supersolid crystal and the vortex lattice which leads to a rich spectrum of spatial patterns. For certain parameters we find a commensurate vortex lattice superimposed on the underlying supersolid crystal, which provides an experimental means to probe superfluidity and thereby to verify supersolidity in such systems.

[1] N. Henkel, R. Nath and T. Pohl, Phys. Rev. Lett. **106**, 195302 (2010)
[2] N. Henkel et al., Phys. Rev. Lett. **108**, 265301 (2012)

Q 56.9 Thu 16:00 Empore Lichthof

Periodic Potentials for photon gases in dye-filled optical microcavities — •Tobias Damm, David Dung, Julian Schmitt, Cesar Cabrera, Frank Vewinger, Jan Klaers, and Martin Weitz — Institut für Angewandte Physik, Universität Bonn

In earlier works of our group, a thermalized photon gas and a transition to a Bose-Einstein condensate of photons has been realized in a dye-filled optical microcavity. A number-conserving thermalization of the photon gas in this system is achieved by repeated absorption and emission processes of dye-molecules.
Here we report on a method to imprint a spatially periodic or even arbitrary confining potential onto the photon gas. We add a second dye species with very low quantum efficiency whose absorption is spectrally shifted from the observed spectral regime of the condensate. By spatially controlled optical irradiation with a laser beam tuned to the absorption resonance of the "heating" dye, a variable modulation of the refrective index inside the cavity is achieved due to the thermo-optical effect. With this method double-well potentials as well as periodic lattices seem to be possible, and we plan to investigate Josephson oscillation and the Mott Insulator with effectively interacting photon gases in the medium.

Q 56.10 Thu 16:00 Empore Lichthof

Bogoliubov modes at the edge of a BEC — Aboulaye Diallo and •Carsten Henkel — Institute of Physics and Astronomy, Universität Potsdam

The quantum field theory of Bose-Einstein condensed gases can be efficiently built from the solutions to the Bogoliubov-de Gennes (BdG) equations. Indeed, they provide the quantum depletion of the condensate at zero temperature, the density of thermally excited particles, and higher correlation properties like the anomalous average. We study BdG solutions at the edge of a condensate, as a generalization of the wave mechanics in a linear potential. The condensate is described by a generalized Airy function (second Painlevé transcendant) that connects smoothly to the Thomas-Fermi profile [1]. The BdG equations are solved numerically and compared to the local density approximation. We apply symplectic techniques from Hamiltonian mechanics to enforce physical (stable) solutions. The scattering phase of the BdG modes helps to clarify the role of the potential well near the condensate boundary that appears in the Hartree-Fock approximation.

[1] F. Dalfovo, L. Pitaevskii, and S. Stringari, *Phys. Rev. A* **54** (1996) 4213; D. Margetis, *Phys. Rev. A* **61** (2000) 055601.

Q 56.11 Thu 16:00 Empore Lichthof

Characterization of solitonic states in a trapped ultracold Bose gas — •Sebastian Erne[1,2], Boris Nowak[1,2], and Thomas Gasenzer[1,2] — [1]Institut für Theoretische Physik, Ruprecht-Karls-Universität Heidelberg, Philosophenweg 16, 69120 Heidelberg — [2]ExtreMe Matter Institute EMMI, GSI Helmholtzzentrum für Schwerionenforschung GmbH, Planckstraße 1, 64291 Darmstadt, Germany

We study the dynamics of solitonic excitations in a finite size ultracold Bose gas out of equilibrium in one spatial dimension and propose an interpretation of this state in terms of turbulence. Of particular interest are non-trivial finite size effects found in the momentum distribution, in the form of characteristic multi-peak structures. We analytically describe the state within a model of randomly distributed solitons and address the possibilities for an experimental observation of the solitonic state via statistical simulations using the classical field equations. Different scenarios including an anharmonicity of the trapping potential and the measurement of the one particle momentum distribution through the free expansion of the gas are discussed. The results give detailed insight into the dynamics of solitons in these systems.

Q 56.12 Thu 16:00 Empore Lichthof

Dynamics of quantum-systems with localized dissipation — •Andreas Vogler, Ralf Labouvie, Felix Stubenrauch, Giovanni Barontini, Vera Guarrera, and Herwig Ott — Research Center OPTIMAS, Fachbereich Physik, Technische Universität Kaiserslautern

This Poster addresses the experimental investigation of various quantum systems, subjected to localized dissipative defects.

In our experiment, we are employing a tightly focussed scanning electron-beam, which ionizes atoms of an atomic cloud by electron-impact ionization. The produced ions are then extracted by means of electrostatic optics and detected. This allows us to probe atomic density distributions with high temporal and spatial resolution. Furthermore, the electron-beam is a versatile tool to manipulate the atomic ensemble. It yields the possibility for localized dissipative defects and the preparation of non-equilibrium states. The obtained ion-signal shows the system's reaction on the defect, and allows to measure pair-correlations and Zeno-like behaviour. In addition, subsequently obtained density-profiles allow for a in-vivo investigation. We probe various quantum-systems, ranging from weakly interacting BECs to strongly interacting 1D gases in optical lattices.

Q 56.13 Thu 16:00 Empore Lichthof

Towards local probing of ultracold Fermi gases — •Jonas Siegl, Kai Morgener, Wolf Weimer, Klaus Hueck und Henning Moritz — Institut für Laserphysik, Universität Hamburg Luruper Chaussee 149, 22761 Hamburg

Ultracold fermionic gases are an ideal model system for the study of quantum many-body phenomena. Of particular interest are two-dimensional strongly correlated systems which can exhibit superfluidity and Berezinskii-Kosterlitz-Thouless-type transitions.

Here we present our new experimental setup aimed at studying two-dimensional strongly interacting Fermi gases. Lithium atoms are laser-cooled and transferred into a resonator enhanced dipole trap. Due to the large volume and depth of this resonator trap, we achieve transfer efficiencies of up to 50%. For final evaporative cooling to quantum degeneracy, we transfer the atoms into a running wave dipole trap.

The atoms will be studied and controlled with a high resolution imaging system for which we have achieved a resolution of 660nm. The current status of the experiment will be presented.

Q 56.14 Thu 16:00 Empore Lichthof

Towards ultracold fermions in a 2D honeycomb lattice — •Thomas Paintner, Daniel Hoffman, Tobias Lupfer, Wladimir Schoch, Wolfgang Limmer, Benjamin Deissler und Johannes Hecker Denschlag — Universität Ulm, Institut für Quantenmaterie, Albert-Einstein-Allee 45, 89081 Ulm

We are setting up a new experiment with ultracold fermionic atoms in a two-dimensional honeycomb lattice to investigate intriguing phenomena which are either related to relativistic quantum physics(e.g. Zitterbewegung, Klein tunnelling) or to condensed matter physics (quantum criticality, quantum spin liquid). This system has the underlying geometry of graphene, but can be tuned and controlled in a much greater range. In the experiment, a degenerate Fermi gas of ^{6}Li will be created after laser cooling in a magneto-optical trap (MOT) and subsequent evaporative cooling in the vicinity of a Feshbach resonance in a strong optical dipole trap. The atoms will then be transferred optically into a glass cell, where they will be loaded into a two-dimensional honeycomb potential. We plan to use a site-resolved imaging technique in order to manipulate the particles and analyze their distribution in the lattice. We will show the experimental progress towards a degenerate Fermi gas.

Q 56.15 Thu 16:00 Empore Lichthof

A Versatile Setup for the Investigation of Ytterbium Quantum Gases — •A. Thobe, S. Dörscher, B. Hundt, A. Kochanke, C. Becker, and K. Sengstock — Zentrum für Optische Quantentechnologien, Universität Hamburg, Luruper Chaussee 149, 22761 Hamburg, Germany

Quantum gases of alkaline-earth like atoms such as Calcium, Strontium and Ytterbium (Yb) open up exciting new possibilities for the study of many body physics in optical lattices, ranging from SU(N) symmetric spin Hamiltonians to the Kondo Lattice Model. Here, we present a new setup for the investigation of bosonic and fermionic Yb quantum gases in a triangular optical lattice. This is the first apparatus to prepare quantum gases of an alkaline earth like element in a 2D/3D-MOT scheme. Atoms from the 2D-MOT, operating on the broad $^1S_0 \to {}^1P_1$ transtition, are directly loaded into the 3D-MOT operating on a narrow intercombination line. The atoms are then loaded into a crossed dipole trap, where they are evaporatively cooled to quantum degeneracy. With this setup we routinely produce BECs of $1 \cdot 10^5$ atoms and Fermi gases of $2 \cdot 10^4$ atoms at $T/T_F = 0.35$. Moreover, we report on an ultrastable laser system for precision spectroscopy on the ultranarrow $^1S_0 \to {}^3P_0$ clock transition in Yb. This laser will serve as a versatile tool for interaction sensing and selective addressing of atoms in a wavelength tunable, state selective, triangular optical lattice, which we are currently implementing.

This work is supported by DFG within SFB 925 and GrK 1355, as well as EU FETOpen (iSense).

Q 56.16 Thu 16:00 Empore Lichthof

Characterization of a new broad Feshbach Resonance in 40K — •Maria Langbecker, Dominik Vogel, Jasper Simon Krauser, Nick Fläschner, Jannes Heinze, Sören Götze, Klaus Sengstock, and Christoph Becker — Universität Hamburg, Institut für Laser-Physik, Luruper Chaussee 149, 22761 Hamburg, Germany

Quantum gases offer a wide range of applications in the field of quantum simulation due to the high tunability of crucial system parameters. One important tool are Feshbach resonances which can be used to widely control the interaction between atoms by tuning their scattering lengths.

Here we report on different methods to characterize the position, width and zero crossing of a new broad Feshbach resonance in 40 K in a spin mixture of mf = +1/2, -1/2. We identify the resonance position to be centered at 389 G with a width of 26 G. We compare loss measurements with molecule formation and the emergence of spin waves. We find that our spin-wave meassurements constitute a well suited method to determine the position as well as the zero crossing of a Feshbach resonance.

Our results open the route for future studies of high-spin mixtures of fermionic Potassium. This work is supported by DFG within FOR 801.

Q 56.17 Thu 16:00 Empore Lichthof

Single-branch theory of ultracold Fermi gases with artificial Rashba spin-orbit coupling — Daniel Maldonado-Mundo, •Manuel Valiente, and Patrik Ohberg — SUPA, IPaQs, Heriot-Watt University, Edinburgh, UK

We consider interacting ultracold fermions subject to Rashba spin-orbit coupling. We construct a single-branch interacting theory for the Fermi gas when the system is dilute enough so that the positive helicity branch is not occupied at all in the non-interacting ground state. We show that the theory is renormalizable in perturbation theory and therefore yields a model of polarized fermions that avoids a multi-channel treatment of the problem. Our results open the path towards a much more straightforward approach to the many-body physics of cold atoms subject to artificial vector potentials.

Q 56.18 Thu 16:00 Empore Lichthof

A K-Rb setup for studying Fermions in optical flux lattices — •Lucia Duca[1,2], Tracy Li[1,2], Monika Schleier-Smith[1,2], Martin Reitter[1,2], Josselin Bernardoff[1,2], Hendrik Lüschen[1,2], Martin Boll[1,2], Jens Phillip Ronzheimer[1,2], Immanuel Bloch[1,2], and Ulrich Schneider[1,2] — [1]Fakultät für Physik, Ludwig-Maximilians-Universität, 80799 München, Germany — [2]Max-Planck-Institut für Quantenoptik, 85748 Garching, Germany

We present an apparatus for studying a two-dimensional degenerate Fermi gas in the presence of a strong artificial magnetic field. In this double species experiment, fermonic ^{40}K atoms are first sympathetically cooled to quantum degeneracy in a bath of bosonic ^{87}Rb atoms. The fermions are then adiabatically compressed into a single layer of a 1D-lattice, creating an isolated 2D system.

The artificial magnetic field will be realized by means of an optical flux lattice [1], which combines a spatially varying Raman coupling with a spin-dependent potential. Their combination produces a magnetic length on the order of the optical wavelength. This high-magnetic-flux system is a good candidate to access the quantum Hall regime with ultracold atoms.

We present our plans for implementing the optical flux lattice and characterizing its topological character by probing its band structure.

The current status of this experimental setup and our novel 2D lattice configuration are also presented.

[1] N.R. Cooper, Phys. Rev. Lett. 106, 175301 (2011).

Q 56.19 Thu 16:00 Empore Lichthof

Correlations in one dimensional few-fermion systems — •Gerhard Zürn[1], Andre N. Wenz[1], Simon Murmann[1], Vincent Klinkhamer[1], Andrea Bergschneider[1], Thomas Lompe[1,2], and Selim Jochim[1,2] — [1]Physikalisches Institut Universität Heidelberg — [2]ExtreMe Matter Institute EMMI, GSI Darmstadt

We present experiments on few-fermion systems of ^{6}Li atoms in quasi one dimensionally confining potentials with tunable interaction. In one measurement we perform radio frequency spectroscopy to measure the energy of a single impurity particle interacting repulsively with a defined number of identical majority particles of different spin ($|\downarrow\uparrow \cdots \uparrow\rangle$). We study the crossover from a few-particle system to a many-particle system by adding majority particles one by one. We observe that already four majority particles are enough to describe the properties of the impurity by that of a polaron-like particle, i.e. by a single impurity dressed by a 1D Fermi sea. We have also performed measurements in the so-called super-Tonks regime and studied spin correlations in these systems. We have found strong indications that the system exhibits ferromagnetic correlations. Investigating attractively interacting systems we observe that for increasing interaction strength the pair correlations in the system increases. This correlation leads to a strong odd-even effect of the single particle dissociation energy similar to the one observed for nuclei.

Q 56.20 Thu 16:00 Empore Lichthof

Exploring Few-fermion Systems in a Tunable Potential — •Andrea Bergschneider, Vincent Klinkhamer, Simon Murmann, Gerhard Zürn, Thomas Lompe, and Selim Jochim — Physikalisches Institut der Universität Heidelberg

In the past two years we have built up an experimental setup to deterministically prepare small ensembles of ultracold fermions in a well-defined quantum state and use it to explore the physics of quasi-1D few-fermion systems [1, 2].

Here, we present a new setup featuring a high-resolution objective and a two-dimensional acousto-optic deflector. This upgrade gives us the capability to dynamically vary the shape of the trapping potential. We can change the aspect ratio of the confinement from quasi-1D or quasi-2D to 3D and hence continuously investigate the energetic shell structures in few-particle systems as a function of dimensionality and interaction strength. The new setup also allows the creation of multiple-well potentials and thus the investigation of few-site Hubbard physics as a bottom-up approach towards quantum magnetism.

[1] F. Serwane et al., Science 332 (336) (2011)
[2] G. Zürn et al., PRL 108, 075303 (2012)

Q 56.21 Thu 16:00 Empore Lichthof

Setup for an ultracold Bose-Fermi mixture of ^{133}Cs and ^{6}Li — •Stephan Häfner, Marc Repp, Rico Pires, Juris Ulmanis, Robert Heck, Arthur Schönhals, Eva Kuhnle, and Matthias Weidemüller — Physikalisches Institut, Ruprecht- Karls-Universität Heidelberg, Heidelberg, Germany

A mixture of ultracold ^{133}Cs and ^{6}Li atoms and molecules close to quantum degeneracy permits to study many different aspects of few and many body physics. Feshbach resonances provide a precise tunability of interspecies interactions [1]. The LiCs mixture is a particulary promising candidate to observe Efimov states [2], since it has a small universal scaling factor. Besides, the LiCs dimer has the largest dipole moment of 5.5 Debye of all stable alkali combinations [3], which can be exploited to form dipolar molecules via Feshbach association and study dipolar effects.

In this poster we will present the experimental approach and the current status of our experimental apparatus for cooling and trapping of fermionic Li and bosonic Cs atoms. The present procedure combines various cooling methods, including double species Zeeman slowing, Raman sideband cooling and forced evaporation out of an optical dipole trap that allows to prepare a Bose-Fermi mixture at microklevin temperatures.

[1] M. Repp et al., Phys. Rev. A, in press
[2] E. Braaten and H.-W. Hammer, Annals of Physics 322, 120 (2007)
[3] J. Deiglmayr et al., Phys. Rev. A 82, 032503 (2010)

Q 56.22 Thu 16:00 Empore Lichthof

Feshbach Resonances of ^{6}Li and ^{133}Cs — •Arthur Schönhals[1], Marc Repp[1], Rico Pires[1], Juris Ulmanis[1], Stephan Häfner[1], Robert Heck[1], Eva Kuhnle[1], Matthias Weidemüller[1], and Eberhard Tiemann[2] — [1]Physikalisches Institut, Ruprecht-Karls Universität Heidelberg, Germany — [2]Institut für Quantenoptik, Leibniz Universität Hannover, Germany

In this poster we present the first observation of interspecies Feshbach resonances of an ultracold Bose-Fermi mixture of ^{6}Li and ^{133}Cs in their energetically lowest spin states [1]. The mixture was prepared and loaded into an optical dipole trap, where resonances were detected as spin selective atom losses. In this way nineteen loss features could be observed and were assigned to s-and p-wave resonances by using a coupled-channel calculation. In addition, the results were compared with the Asymptotic Bound State Model.

Several of the s-wave resonances offer prospects for the investigation of a series of Efimov states, for which the mixture of ^{6}Li and ^{133}Cs is an excellent candidate due to the large mass ratio of $m_{Cs}/m_{Li} = 22$ that results in an universal scaling factor of 4.88 for $^{133}Cs_2{}^6Li$ [2,3].

[1] M.Repp et al., accepted for publication in Phys. Rev. A. (R), (2012)
[2] J. P. D'Incao & B.D. Esry, Phys. Rev. A **73**, 030703 (2006)
[3] E.Braaten and H.-W. Hammer, Annals of Physics **322**, 120 (2007)

Q 56.23 Thu 16:00 Empore Lichthof

Light induced spin-orbit coupling for ultra-cold neutral atoms — •Felix Kösel, Sebastian Bode, Michael Schmidt, Holger Ahlers, Katerine Posso Trujillo, Naceur Gaaloul, and Ernst M. Rasel — Institut für Quantenoptik, Hannover, Deutschland

We present the experimental efforts we pursue towards engineering a 2D spin-orbit-coupling [1] of a neutral Rubidium Bose-Einstein condensate (BEC). Using multiple Raman transitions to couple cyclically three hyperfine Zeeman states of the atoms, an effective gauge field is predicted to be created which resembles the one occurring in spintronic systems [2]. Such an artificial interaction could be used to build advanced solid state simulators with non-Abelian character in a versatile cold-atom system. The first experimental steps realized to build a BEC machine featuring a hybrid source concept [3] are presented. Possible experimental issues that could prevent a successful implementation or signature detection are discussed.

[1] Y.-J. Lin, K. Jiménez-García, and I. B. Spielman, Nature (London) 471, 83-86 (2011). [2] H. C. Koo et al., Science 325, 1515 (2009). [3] Y.-J. Lin, A. R. Perry, R. L. Compton, I. B. Spielman, and J. V. Porto, Phys. Rev. A 79, 063631 (2009).

Q 56.24 Thu 16:00 Empore Lichthof

Matter-wave scattering from interacting ultracold bosons in optical lattices — •Klaus Mayer, Alberto Rodriguez, and Andreas Buchleitner — Institut f. Physik, Universität Freiburg, Germany

We study matter-wave scattering from a system of ultracold bosons in a one-dimensional optical lattice, described by a Bose-Hubbard Hamiltonian. The phase transition from the superfluid state to the Mott Insulator is clearly displayed in the decay of the inelastic component of the scattering cross-section for increasing onsite interaction U [1]. In order to understand the role of interactions in this process, we perform a Bogoliubov expansion for small U and obtain an analytical expression for the cross-section in the weakly-interacting regime. We identify the different contributions to the inelastic scattering signal in terms of one- and two-quasiparticle excitations above the condensate in the superfluid phase. To support the analytical description, we present numerical results obtained from exact diagonalization methods.

[1] S. Sanders, F. Mintert, E. Heller, Phys. Rev. Lett. **105**, 035301 (2010)

Q 56.25 Thu 16:00 Empore Lichthof

Non-equilibrium Self-energy-functional theory and conserving approximations — •Felix Hofmann and Michael Potthoff — I. Institut für Theoretische Physik – Universität Hamburg, Hamburg, Deutschland

The self-energy-functional theory [1] provides a general framework for the systematic construction of non-perturbative, thermodynamically consistent approximations in order to study strongly correlated systems in the thermodynamical limit in and out of equilibrium and proves to respect certain conservation laws [2]. On the space of self-energies a functional can be constructed which is stationary at the physical self-energy and equals the physical grand canonical potential when evaluated at the latter. Without approximating the (formally unknown) functional, the variational principle can be evaluated by restricting the self-energies to a subspace of (numerically) solvable reference systems. This is done self consistently, such that the results are obtained in the thermodynamical limit. By choosing appropriate classes of reference systems, theories like variational-cluster-approach (VCA) and dynamical-mean-field-theory (DMFT) can be derived from SFT as well as improved variants. Likewise, SFT allows for studying phases and phase transitions (by numerical means) as for example the Mott metal-insulator transition, magnetic phase transitions or the transition from antiferromagnetic to the superconducting phase in Hubbard-like and spin models.

[1] M. Potthoff, AIP Conf. Proc. 1419, pp. 199-258 (2011)
[2] F. Hofmann and M. Potthoff, to be published

Q 56.26 Thu 16:00 Empore Lichthof

Orbital Physics with Ultracold Atoms in Higher Bands of an Optical Lattice — •Thorge Kock, Arne Ewerbeck, Robert Büchner, Matthias Ölschläger, Georg Wirth, and Andreas Hemmerich — Institut für Laser-Physik, Universität Hamburg, Luruper Chaussee 149, 22761 Hamburg, Germany

Atoms trapped in optical lattices have been used successfully to study many-body phenomena. However, the shape that bosonic ground-state wavefunctions can take is limited, apparently compromising the usefulness of this approach. Such limitations, however, do not apply to excited states of bosons. The study of atomic superfluids realized in higher Bloch bands, where orbital degrees of freedom are essential, can bring the world of optical lattices closer to relevant condensed matter systems. We discuss our observations of extremely long coherence times, chiral superfluid order and topological features in higher bands in a square optical lattice.

Q 56.27 Thu 16:00 Empore Lichthof

Bloch oscillations of particles with long-range interactions — •Christopher Gaul[1,2], Antonio Rodriguez[3], Rodrigo P. A. Lima[4], and Francisco Domínguez-Adame[1] — [1]GISC, Departamento de Física de Materiales, Universidad Complutense, E-28040 Madrid, Spain — [2]CEI Campus Moncloa, UCM-UPM, Madrid — [3]GISC, Departamento de Matemática Aplicada y Estadística, Universidad Politécnica, E-28040 Madrid, Spain — [4]Instituto de Física, Universidade Federal de Alagoas, Maceió, AL 57072-970, Brazil

As the two-particle problem has traditionally provided valuable insights into the full many-body phenomena, we study two particles in a lattice potential subject to an external field and to a long-range interaction. Using the semiclassical approximation, we find chaotic behavior in general, limited by several regular regimes: (i) Bloch oscillations in the relative motion, driven by the interaction, (ii) open trajectories, and (iii) independent oscillations of far away particles, driven by the external field.

Q 56.28 Thu 16:00 Empore Lichthof

Anisotropic superfluidity of bosons in optical Kagome superlattice — Tao Wang[1,2], Xue-Feng Zhang[1], •Axel Pelster[1], and Sebastian Eggert[1] — [1]Fachbereich Physik, Technische Universität Kaiserslautern, Germany — [2]Harbin Insititute of Technology, Harbin, China

We study the quantum phase transitions for the extended Bose-Hubbard model with bosons on a Kagome superlattice which can be implemented by enhancing the long wavelength laser in one direction of the optical lattice [1]. To this end we combine the virtues of a Mean-Field theory with the Laudau theory of Ref. [2] and work out a multi-component effective potential method. By comparing the corresponding analytic results with extensive quantum Monte-Carlo simulations, we find that several striped solids emerge in this system. Due to the blockade effect of such a striped order, the resulting superfluid density turns out to be anisotropic and thus, reveals its tensional property [3]. Finally, we discuss the complete quantum phase diagram.

[1] G.-B. Jo, J. Guzman, C. K. Thomas, P. Hosur, A. Vishwanath, and D. M. Stamper-Kurn, Phys. Rev. Lett. **108**, 045305 (2012)
[2] F. E. A. dos Santos and A. Pelster, Phys. Rev. A **79**, 013614 (2009)
[3] M. Ueda, *Fundamentals and New Frontiers of Bose-Einstein Condensation* (World Scientific, Singapore, 2010)

Q 56.29 Thu 16:00 Empore Lichthof

Quasirelativistic atomic Bose-Einstein Condensate in an Optical Lattice — •Martin Leder, Christopher Grossert, Tobias Salger, Sebastian Kling, and Martin Weitz — Institute for Applied Physics, University of Bonn, Germany

A proof-of-principle experiment simulating effects predicted by relativistic wave equations with ultracold atoms in a bichromatic optical lattice that allows for a tailoring of the dispersion relation is reported [1]. In this lattice, for specific choices of the relativistic phases and amplitudes of the lattice harmonics the dispersion relation in the region between the first and the second excited band becomes linear, as known for ultrarelativistic particles. One can show that the dynamics can be described by an effective one-dimensional Dirac equation [2].

We experimentally observe the analog of Klein-Tunneling, the penetration of relativistic particles through a potential barrier without the exponential damping that is characteristic for nonrelativistic quantum tunneling [3]. Both linear (relativistic) and quadratic (nonrelativistic) dispersion relations are investigated, and significant barrier transmission is only observed for the relativistic case.

References
[1] T. Salger, C. Grossert, S. Kling, and M. Weitz, Phys. Rev. Lett. 107, 240401 (2011)
[2] D. Witthaut, T. Salger, S. Kling, C. Grossert, and M. Weitz, Phys. Rev A 84, 033601 (2011)
[3] O. Klein, Z.Physik 53, pp. 157-165 (1929)

Q 56.30 Thu 16:00 Empore Lichthof

Spin interactions in ultracold many-body systems — •Johannes Zeiher[1], Peter Schauss[1], Takeshi Fukuhara[1], Sebastian Hild[1], Marc Cheneau[1], Manuel Endres[1], Christian Gross[1], Stefan Kuhr[3], and Immanuel Bloch[1,2] — [1]Max-Planck-Institut für Quantenoptik, 85748 Garching, Germany — [2]Fakultät für Physik, Ludwig-Maximilians-Universität München, 80799 München, Germany — [3]University of Strathclyde, Department of Physics, SUPA, Glasgow G4 0NG, United Kingdom

Spin Hamiltonians are used to explain a variety of different phenomena in solid state physics. Quantum simulation of such systems with ultracold gases promises deeper insight in the emerging physics.

Here we report on the realization of two kinds of effective spin Hamiltonians with ultracold Rubidium atoms in optical lattices.

Single site resolved detection enabled the direct measurement of a single spin impurity immersed into a bath of opposite spins. The measurement revealed coherent superexchange dynamics in the Heisenberg regime as well as evidence for polaronic behavior in the superfluid regime.

In a second experiment we used Rydberg atoms to realize long-range interacting effective spin systems. By high resolution optical detection we observed the emergence of spatially ordered patterns upon laser excitation of a dense 2D gas. The results pave the way towards quantum simulation of novel long-range interacting quantum systems with ultracold atoms.

Q 56.31 Thu 16:00 Empore Lichthof

Direct Measurement of the Zak phase in Topological Bloch Bands — •Monika Aidelsburger[1,2], Marcos Atala[1,2], Julio T. Barreiro[1,2], Dmitry Abanin[3], Takuya Kitagawa[3], Eugene Demler[3], and Immanuel Bloch[1,2] — [1]Fakultät für Physik, Ludwig-Maximilians-Universität, Schellingstr. 4, 80799 Munich, Germany — [2]Max-Planck Institute of Quantum Optics, Hans-Kopfermann Str. 1, 85748 Garching, Germany — [3]Department of Physics, Harvard University, 17 Oxford Str., Cambridge, MA 02138, USA

Geometric phases can characterize the topological properties of Bloch bands. In one-dimensional periodic potentials the topological invariant is given by the Zak phase – the Berry phase acquired during an adiabatic motion of a particle across the Brillouin zone. Here we will present the direct measurement of the Zak phase for a dimerized optical lattice, which models polyacetylene. The experimental protocol consists of a combination of Bloch oscillations and Ramsey interferometry. This work establishes a new general approach for probing the topological structure of Bloch bands in optical lattices.

Q 56.32 Thu 16:00 Empore Lichthof

Experimental Realization of Strong Effective Magnetic Fields with Ultracold Atoms in Optical Superlattices — •Marcos Atala[1,2], Monika Aidelsburger[1,2], Yu Ao Chen[1,2], Sylvain Nascimbène[3], Stefan Trotzky[1,2], and Immanuel Bloch[1,2] — [1]Fakultät für Physik, Ludwig-Maximilians-Universität, Schellingstr. 4, 80799 Munich, Germany — [2]Max Planck Institute of Quantum Optics, Hans-Kopfermann Str. 1, 85748 Garching, Germany

— [3]Laboratoire Kastler Brossel, CNRS, UPMC, Ecole Normale Supérieure, 24 rue Lhomond, 75005 Paris, France

Ultracold atoms in optical lattices are promising candidates to study quantum many-body phenomena, such as the integer or fractional quantum Hall effect. Here we report about the experimental realization of strong effective magnetic fields, on the order of one flux quantum per plaquette, with ultracold atoms using photon assisted tunneling in an optical superlattice. When hopping in the lattice, the accumulated phase shift by an atom is equivalent to the Aharonov-Bohm phase of a charged particle exposed to a large staggered magnetic field. We studied the nature of the ground state from ist momentum distribution and observed that the frustration induced by the magnetic field can lead to a degenerate ground state for noninteracting particles. A local measurement performed in a lattice of isolated plaquettes directly revealed the quantum cyclotron orbit of a single atom exposed to the magnetic field.

Q 56.33 Thu 16:00 Empore Lichthof

Intrinsic Photoconductivity of Ultracold Fermions in Optical Lattices — •Jannes Heinze[1], Jasper Simon Krauser[1], Nick Fläschner[1], Bastian Hundt[1], Sören Götze[1], Alexander Itin[1,2,3], Ludwig Mathey[1,2], Klaus Sengstock[1,2], and Christoph Becker[1,2] — [1]Institut für Laser-Physik, Universität Hamburg, Luruper Chaussee 149, 22761 Hamburg, Germany — [2]Zentrum für Optische Quantentechnologien, Universität Hamburg, Luruper Chaussee 149, 22761 Hamburg, Germany — [3]Space Research Institute, Russian Academy of Sciences, Moscow, Russia

Photoconductivity describes the change of a material's conductivity following an excitation with photons. If the photon energy is resonant with a band transition, electrons are excited from the valence band to the conduction band and an initial insulator becomes conducting. We present measurements of an analog to a persistent alternating photocurrent in an ultracold gas of fermionic atoms in an optical lattice (arXiv:1208.4020). A small fraction of the atoms is excited to the second excited band using lattice amplitude modulation, leaving holes in the lowest band. Both hole and particle excitations have a defined quasimomentum. The subsequent dynamics is induced and sustained by an external harmonic confinement. While atoms in the excited band exhibit long-lived oscillations with a momentum dependent frequency a strikingly different behavior is observed for holes in the lowest band. An initial fast collapse is followed by subsequent periodic revivals. Both observations are fully explained by mapping the system onto a nonlinear pendulum. This work is supported by DFG within FOR801.

Q 56.34 Thu 16:00 Empore Lichthof

Ultracold fermions in honeycomb optical lattices — •Thomas Uehlinger[1], Daniel Greif[1], Gregor Jotzu[1], Leticia Tarruell[1,2], and Tilman Esslinger[1] — [1]Institute for Quantum Electronics, ETH Zurich, 8093 Zurich, Switzerland — [2]LP2N UMR 5298, Univ. Bordeaux 1, Institut d'Optique and CNRS, 351 cours de la Libération, 33405 Talence, France

Ultracold Fermi gases have emerged as a versatile tool to simulate condensed matter phenomena. For example, the control of interactions in optical lattices has lead to the observation of Mott insulating phases. However, the topology of the lattice is equally important for the proper- ties of a solid. A prime example is the honeycomb lattice of graphene, where the presence of topological defects in momentum space - the Dirac points - leads to extraordinary transport properties.

We report on the investigation of Dirac points of a quantum degenerate Fermi gas of ^{40}K atoms confined in the honeycomb structure of an optical lattice with tunable topology. The lattice is created by superimposing a square lattice with an interfering superlattice, which can be continuously adjusted to create square, triangular, dimer und honeycomb structures. The band structure is studied in detail using Bloch oscillations, particularly addressing the double passing of the two Dirac points. We also report on the investigation of the effect of interactions when loading a two-component repulsively interacting Fermi gas into the newly accessible lattice geometries.

Q 56.35 Thu 16:00 Empore Lichthof

Negative absolute temperature and out-of-equilibrium dynamics of interacting bosons in optical lattices — •Michael Schreiber[1,2], Simon Braun[1,2], Jens Philipp Ronzheimer[1,2], Daniel Garbe[1,2], Sean Hodgman[1,2], Immanuel Bloch[1,2], and Ulrich Schneider[1,2] — [1]LMU München — [2]MPQ Garching

Absolute temperature is usually bound to be strictly positive. However, in systems with an upper energy bound, negative absolute temperature states are possible, in which the occupation probability of states increases with their energy. We realised a negative absolute temperature state for motional degrees of freedom using ultracold bosonic ^{39}K atoms in an optical lattice.

This new state strikingly revealed itself by strong occupation peaks at maximum kinetic energy. We found that the negative absolute temperature state is as stable as the corresponding positive temperature state. We also studied how coherence emerges in a slow quench from an incoherent attractive Mott insulator at negative temperature and compared it to the positive temperature case.

Additionally, we investigated the out-of-equilibrium expansion dynamics of interacting bosons in one- and two-dimensional Hubbard systems. We found that the fastest, ballistic expansions occur in the integrable limits. For non-integrable systems the expansion slows down significantly as diffusive dynamics set in.

Q 56.36 Thu 16:00 Empore Lichthof

Superexchange dynamics of ultracold high-spin fermions — •Ole Jürgensen, Dirk-Sören Lühmann, and Klaus Sengstock — Institut für Laserphysik, Universität Hamburg

Superexchange interactions are of fundamental relevance for quantum magnetism and are believed to play an important role in high-T_c superconductivity.

We theoretically study the dynamics of high-spin fermions loaded in a one-dimensional optical lattice. In shallow lattices, spin-changing collisions allow for the melting of an initially prepared two-component band-insulator. The exact time evolution shows that particle-number fluctuations are strongly suppressed in shallow lattices and the dynamics is goverened by spin-exchange processes.

This unique system therefore allows for the direct study of superexchange interactions with high amplitudes in the abscence of direct tunneling processes.

Q 56.37 Thu 16:00 Empore Lichthof

Quantum magnetism of ultracold fermions in an optical lattice — •Gregor Jotzu[1], Daniel Greif[1], Thomas Uehlinger[1], Leticia Tarruell[1,2], and Tilman Esslinger[1] — [1]Institute for Quantum Electronics, ETH Zurich, 8093 Zurich, Switzerland — [2]2 LP2N UMR 5298, Univ. Bordeaux 1, Institut d'Optique and CNRS, 351 cours de la Lib

Interactions between electrons lead to fascinating magnetic phenomena including antiferromagnets, RVB states and spin liquids. However, even simple model hamiltonians for these interactions have proven notoriously difficult to solve. Ultracold fermions in optical lattices have emerged as a new tool to investigate such models, including the the celebrated Fermi-Hubbard hamiltonian. Whilst charge-ordering in systems simulating this models has been successfully investigated, magnetic order could so far not be observed due to the low temperatures required. Here we present the first observation of quantum magnetism of fermions in an optical lattice. Local order appears when loading a low-temperature gas into the lattice and is detected by projecting pairs of neighbouring sites on a singlet or triplet wavefunction. Using a tunable geometry lattice, we create dimerized and anisotropic cubic lattices. There the exchange energy of certain links is stronger, which drastically enhances magnetic correlations between sites they connect. We investigate the dependence of the correlations on the entropy and geometry of the system. In the regime where a second order high-temperature series is still reliable, we find good agreement with theory.

Q 56.38 Thu 16:00 Empore Lichthof

Interferometric optical lattice for higher bands of ultracold quantum gases — •Raphael Eichberger, Matthias Ölschläger, Georg Wirth, and Andreas Hemmerich — Institut für Laserphysik, Universität Hamburg, Luruper Chaussee 149, 22761 Hamburg, Germany

We present a new setup of a bipartite optical square lattice for ultracold quantum gases. The symmetrie of the lattice potential depends on the time phase difference between two optical standing waves and the individual intensity of the four involved laser beams. To achieve the full control of these parameters we build up a new kind of Michelson-Interferometer.

With this interferometric optical lattice we want to excite ultracold atoms - Bosons and Fermions - into higher bands and study new interesting many body phenomena. Here, we report on basic ideas and our recent progress.

Q 56.39 Thu 16:00 Empore Lichthof

Glass Physics in Open Quantum Systems: A Keldysh Path Integral Approach — •Michael Buchhold[1], Philipp Strack[2], and Sebastian Diehl[1,3] — [1]Institute for Theoretical Physics, University of Innsbruck, A-6020 Innsbruck, Austria — [2]Department of Physics, Harvard University, Cambridge MA 02138 — [3]Institute for Quantum Optics and Quantum Information of the Austrian Academy of Sciences, A-6020 Innsbruck, Austria

We investigate non-equilibrium phase transitions in an open cavity system with random atom-photon couplings and cavity photon loss. This system shows normal and superradiant phases, as well as a transition to an atomic spin glass phase for fluctuating atom-photon couplings. The physical behavior close to the glass transition reflects the strong competition between relaxational and reversible dynamics, including low frequency thermalization and the non-equilibrium scaling behavior at the transition.

For a theoretical describtion, we develop a functional integral approach in Keldysh framework, tailored to describe steady state properties and non-equilibrium time-evolution for open quantum many-body systems. This approach allows to combine the strengths of functional integral methods, including perfect access to critical phenomena in large systems, with well established methods from quantum optics, as for instance the input-output formalism and further detection schemes. This is used to show how the above mentioned results can be detected in cavity QED experiments.

Q 56.40 Thu 16:00 Empore Lichthof

Coherent excitation of interacting Rydberg gases at room temperature — •Andreas Kölle, Bernhard Huber, Thomas Baluktsian, Robert Löw, and Tilman Pfau — 5. Physikalisches Institut, Universität Stuttgart

Glass cells filled with thermal rubidium vapor are proposed to be promising candidates for a large variety of quantum devices. These devices are based on a long range Rydberg-Rydberg interaction which has been demonstrated in various ultra cold experiments. In order to translate these results to a hot ensemble of atoms, effects like reduced life time and atomic motion have to be taken into account.

We present evidence for van-der Waals interaction between Rydberg atoms in thermal vapor. Using a pulsed two-photon excitation scheme on the ns time scale we overcome problems of thermal motion on the order of the interaction length and limited coherence time. The resulting Rabi oscillations are compared to a simple 3 - level single atom model including a dephasing due to the Rydberg-Rydberg interaction.

In addition we present results on merging the pulsed excitation with a four-wave-mixing scheme resulting in a pulsed coherent light source. Our progress towards the creation of non classical light based on Rydberg interaction will be shown.

Q 56.41 Thu 16:00 Empore Lichthof

Macroscopic quantum tunneling of Bose-Einstein condensates — •Torsten Schwidder, Matin Kaufmann, Holger Cartarius, Jörg Main, and Günter Wunner — 1. Institut für Theoretische Physik, Uni Stuttgart

Macroscopic quantum tunneling of Bose-Einstein condensates is investigated using a Gaussian variational ansatz. The quantum statistical decay of the condensate wave function is examined by means of a semiclassical approximation to Feynman's path integral formalism, considering only the Euclidean action of the bounce trajectory and fluctuations around it. The imaginary time dynamics is described by a set of coupled differential equations for the Gaussian parameters, and the bounce trajectory is determined using a multi-shooting algorithm. Furthermore, the contributions of the fluctuations are obtained from the eigenvalues of the monodromy matrix. We discuss various methods for calculating the fluctuation determinant.

Q 56.42 Thu 16:00 Empore Lichthof

A versatile quantum gas mixture experiments for investigation of non-linear physics — •Alexander Grote, Markus Pfau, Harald Blazy, Juliette Simonet, Patrick Windpassinger, and Klaus Sengstock — Institut für Laserphysik, Universität Hamburg, 22761 Hamburg, Germany

Solitons are among the most studied excitations within a wide range of nonlinear systems. Stabilized by a balance between dispersion and nonlinearity, solitons are wave packets that exhibit some exceptional generic features such as form stability and particle-like properties. Research with ultracold quantum gases provides a sophisticated toolbox to produce very pure and well-controllable nonlinear systems that offer unique possibilities to study soliton dynamics. We report here on the phase imprinting technique allowing for the creation of dark solitons in a ^{87}Rb condensate.

Our experimental apparatus is capable to realize degenerated mixtures of bosonic (^{87}Rb or ^{39}K) and fermionic (^{40}K) species, which also allow for multi-component quantum gases with mixed statistics. This novel experimental setup allows to develop external collaborations within the guest program of Center of Quantum Technologies (ZOQ - Hamburg). The apparatus also plays a central role in the education of undergraduate students at the Universität Hamburg allowing to get an attractive insight into the latest development in quantum optics. This work is supported by Universität Hamburg , ZOQ and Studiengebühren UHH.

Q 56.43 Thu 16:00 Empore Lichthof

Breakdown of Kohn theorem near Feshbach resonance — •Hamid Al-Jibbouri[1] and Axel Pelster[2] — [1]Fachbereich Physik, Freie Universität Berlin, Germany — [2]Fachbereich Physik, Technische Universität Kaiserslautern, Germany

We study the collective excitation modes of a harmonically trapped Bose-Einstein condensate in the vicinity of a Feshbach resonance at zero temperature [1]. To this end we solve the underlying Gross-Pitaevskii equation by using a Gaussian variational approach and obtain the coupled set of ordinary differential equations for the widths and the center of mass of the condensate. A linearization shows that the dipole mode frequency changes when the bias magnetic field approaches the Feshbach resonance.

[1] E. R. F. Ramos, F. E. A. dos Santos, M. A. Caracanhas, and V. S. Bagnato, Phys. Rev. A **85**, 033608 (2012)

Q 56.44 Thu 16:00 Empore Lichthof

Bose-Einstein condensation in compact astrophysical objects — •Christine Gruber[1] and Axel Pelster[2] — [1]Fachbereich Physik, Freie Universität Berlin, Germany — [2]Fachbereich Physik, Technische Universität Kaiserslautern, Germany

We discuss the possible occurrence of Bose-Einstein condensates (BECs) in astrophysical contexts, i.e. in compact objects such as neutron stars and white dwarfs. As unlikely as it may seem, conditions in such environments allow for the formation of BECs due to a favorable combination of temperature and density. To this end it is of interest to investigate the condensation of bosonic particles under the influence of gravitational interactions in the framework of a Hartree-Fock theory. Results can be compared to observations through the predicted density profiles and masses of the objects.

[1] O.G. Benvenuto and M.A. Vito, J. Cosmol. Astropart. Phys. **2**, 033 (2011)

[2] P. Chavanis and T. Harko, Phys. Rev. D **86**, 064011 (2012)

Q 56.45 Thu 16:00 Empore Lichthof

Dipolar Bose-Einstein condensates with periodically modulated contact interaction — •Branko Nikolić[1], Antun Balaž[2], and Axel Pelster[3] — [1]Fachbereich Physik, Freie Universität Berlin, Germany — [2]SCL, Institute of Physics Belgrade, University of Belgrade, Serbia — [3]Fachbereich Physik, Technische Universität Kaiserslautern, Germany

Harmonically trapped Bose-Einstein condensates (BECs) with a sufficiently strong dipolar interaction possess both a stable and an unstable equilibrium. Following Ref. [1] we investigate how the stability of both equilibria change under parametric excitation by a periodic modulation of the s-wave scattering length [2]. To this end we perform both an analytical linear and a numerical nonlinear stability analysis for the Thomas-Fermi solution of the underlying Gross-Pitaevskii equation [3]. We find that parametric excitation can stabilize a previously unstable dipolar BEC and vice versa. We even find indications that bistability may exist for a certain choice of driving amplitude and frequency.

[1] W. Cairncross and A. Pelster, eprint `arXiv:1209.3148`

[2] S.E. Pollack, *et al.*, Phys. Rev. A **81**, 053627 (2010)

[3] D.H.J. O'Dell, S. Giovanazzi, and C. Eberlein, Phys. Rev. Lett. **92**, 250401 (2004)

Q 56.46 Thu 16:00 Empore Lichthof

Elastic and inelastic collisions of single neutral impurity atoms immersed in an ultracold cloud — •Farina

Kindermann[1,2], Nicolas Spethmann[1,2], Dieter Meschede[2], and Artur Widera[1] — [1]FB Physik, TU Kaiserslautern, Erwin Schrödinger Str. 46, 67663 Kaiserslautern — [2]Institut für angewandte Physik, Universität Bonn, Wegelerstr. 8, 53115 Bonn

Recently hybrid systems immersing single atoms in a many body system have been a subject of intense interest. Here we present an example of controlled doping of an ultracold Rubidium cloud with single neutral Cesium impurity atoms. We observe thermalization of 'hot' Cs atoms by elastic interaction with an ultracold Rb gas, employing different schemes of measuring the impurities' energy distribution. Inelastic collisions are restricted to a single three-body recombination channel allowing us to precisely determine the three-body loss coefficient in good agreement with theory.

The poster will present details of the experimental setup, sequence and data analysis needed to extract the interspecies scattering length and three-body loss coefficient from the thermalization dynamics and loss rates measured.

Q 56.47 Thu 16:00 Empore Lichthof

Spin waves and Collisional Frequency Shifts of Trapped-Atom Clocks — Wilfried Maineult[1], Christian Deutsch[2], Kurt Gibble[3], Jakob Reichel[2], and •Peter Rosenbusch[1] — [1]LNE-SYRTE, Observatoire de Paris, France — [2]LKB, Ecole Normale Supérieure, Paris, France — [3]Pennsylvania State University, USA

The indistinguishability of identical particles is most fundamental to quantum statistics. It imposes exchange (anti-)symmetry and leads to intriguing phenomena like Bose attraction and Pauli pressure. We study the exchange interactions in a trapped atom clock on a chip (TACC). The clock, designed to operate with magnetically trapped ^{87}Rb atoms aims at stability 10 times better than commercial clocks.

Contrary to standard atomic clocks, where the atoms are in free flight, the trap increases the density $10^4\times$ and hence the effects of interactions. In addition, we reach ultra-low temperatures, where interactions become purely s-wave. Under these ideal conditions, we have observed the opening of an energy gap between the symmetric and anti-symmetric 2-body-wavefunction describing colliding atoms. The energy gap inhibits dephasing such that extraordinarily long coherences times (58 s) can be reached [PRL 105, 020401 (2010), PRL 106, 240801 (2011)]. Here we present a direct spectroscopic measurement of the energy gap and demonstrate its inextricable link with spin waves [PRL 109, 020407 (2012)]. We also demonstrate a counter-intuitive dependence of the clock frequency on the area of the 2nd pulse in Ramsey spectroscopy. Our findings are equally relevant to optical lattice clocks and quantum information processing with small-ensemble qubits.

Q 56.48 Thu 16:00 Empore Lichthof

Stability of Rotating Bose Gases at Finite Temperature — •Holger Hauptmann[1,2], Patrick Navez[2], Holger Kantz[1], and Walter T. Strunz[2] — [1]Max-Planck-Institut für Physik komplexer Systeme, Dresden — [2]Technische Universität Dresden

We investigate the stability of the relative motion between a Bose-Einstein condensate and its thermal cloud for a gas with repulsive self-interaction at finite temperature in a harmonic trap. The thermal cloud is described by a semi-classical Bose-Einstein distribution. The condensate obeys the Gross-Pitaevskii equation. Stirring the system at low frequencies leads to a rotation of the thermal cloud with a resting condensate. We are looking for the critical angular velocity between condensate and thermal cloud for which the system becomes unstable.

Q 56.49 Thu 16:00 Empore Lichthof

Absorption and Transfer properties of quantum aggregates under the influence of Lévy-stable disorder — •Sebastian Möbius[1], Sebastiaan M. Vlaming[1,2], Victor A. Malyshev[2], Jasper Knoester[2], and Alexander Eisfeld[1] — [1]Max Planck Institute for Physics of Complex Systems, Nöthnitzer Strasse 38, D-01187 Dresden, Germany — [2]Centre for Theoretical Physics and Zernike Institute for Advanced Materials, University of Groningen, Nijenborgh 4, 9747 AG Groningen, The Netherlands

Molecular aggregates exhibit extraordinary absorption properties, depending on their geometrical conformation and inter-monomeric coupling. The shape of the narrow absorption band for J-aggregates can be well described by diagonal Gaussian static disorder for individual site energies. Aggregates consisting of large molecules are usually embedded in complex environments, making it impossible to separate individual contribution to the energy fluctuations.

Recent developments in generating and trapping highly excited Rydberg atoms, allow for quantum simulations of molecular aggregates. By controlling the environment, e.g. a polar background gas, static disorder besides Gaussian can be studied. We analyze on how the environment generates disorder distributions with heavy tails, so called Lévy-stable distributions. We also show that the Lévy distributions lead to even a broadening of the absorption band [1] as well as a subdiffusive exciton transfer.

[1] A. Eisfeld, S.M. Vlaming, V.A. Malyshev, J. Knoester, PRL **105**, 137402 (2010)

Q 56.50 Thu 16:00 Empore Lichthof

Numerical solutions of Gross-Pitaevskii equation for a disordered Bose condensed gas — •Tama Khellil[1], Antun Balaž[2], and Axel Pelster[3] — [1]Fachbereich Physik, Freie Universität Berlin, Germany — [2]SCL, Institute of Physics Belgrade, University of Belgrade, Serbia — [3]Fachbereich Physik, Technische Universität Kaiserslautern, Germany

We present a numerical study of a Bose-condensed gas in a harmonic trapping potential and a Gaussian-distributed disorder potential in one dimension at zero temperature. The underlying Gross-Pitaevskii equation for the condensate wave function represents a nonlinear, partial differential equation and is difficult to solve exactly. Using a computer program [1] that solves the time-independent Gross–Pitaevskii equation in one space dimension in a harmonic trap using the imaginary-time propagation, we are able to obtain its numerical solution for each realization of the disorder potential. Performing disorder ensemble averages we have access to both the condensate density and to the density of disconnected local mini-condensates in the respective minima of the disorder potential [2]. Our study is performed for different values of the disorder strength and the correlation length of the disorder, so that we can study the influence of both of them on the numerical solutions. For small disorder strengths we reproduce the seminal results of Huang and Meng for a Bogoliubov theory of dirty bosons.

[1] D. Vudragović, I. Vidanović, A. Balaž, P. Muruganandam, and S. Adhikari, Comput. Phys. Commun. **183**, 2021 (2012)
[2] R. Graham and A. Pelster, Int. J. Bif. Chaos **19**, 2745 (2009)

Q 56.51 Thu 16:00 Empore Lichthof

Controlled engineering of extended states in disordered systems — •Alberto Rodriguez[1], Arunava Chakrabarti[2], and Rudolf A. Römer[3] — [1]Physikalisches Institut, Albert-Ludwigs Universität Freiburg,Hermann-Herder Strasse 3, D-79104, Freiburg, Germany — [2]Department of Physics, University of Kalyani, Kalyani, West Bengal-741 235, India — [3]Department of Physics and Centre for Scientific Computing, University of Warwick, Coventry, CV4 7AL, United Kingdom

We describe how to engineer wavefunction delocalization in disordered systems modelled by tight-binding Hamiltonians in $d > 1$ dimensions. We show analytically that a simple product structure for the random onsite potential energies, together with suitably chosen hopping strengths, allows a resonant scattering process leading to ballistic transport along one direction, and a controlled coexistence of extended Bloch states and anisotropically localized states in the spectrum. We demonstrate that these features persist in the thermodynamic limit for a continuous range of the system parameters. Numerical results support these findings and highlight the robustness of the extended regime with respect to deviations from the exact resonance condition for finite systems. The localization and transport properties of the system can be engineered almost at will and independently in each direction. This study gives rise to the possibility of designing disordered potentials that work as switching devices and band-pass filters for quantum waves, such as matter waves in optical lattices. [Phys. Rev. B 86, 085119 (2012)]

Q 56.52 Thu 16:00 Empore Lichthof

Scattering of the spin-orbit coupled ultra-cold atoms — •Gediminas Juzeliunas[1], Julius Ruseckas[1], Rytis Jursenas[1], and Ian Spielman[2] — [1]Institute of Theoretical Physics and Astronomy, Vilnius University, A. Gostatuto 12, LT-01108 Vilnius, Lithuania — [2]Joint Quantum Institute, National Institute of Standards and Technology, and University of Maryland, Gaithersburg, MD 20899, USA

Over the last several years there has been a substantial increase of interest in artificial gauge fields and spin-orbit coupling for electrically neutral atoms [1-3]. The spin-orbit coupling with equal Rashba and Dresselhaus contributions has been recently implemented experimentally [4]. Here we consider manifestations of such a spin-orbit coupling for scattering of ultra-could atoms at the impurity sites [5]. In particular, we show that the spin-orbit coupling can lead to both suppression or enhancement of the atomic backward scattering. Additionally we have analysed the impurity-induced bound states for the spin-orbit coupled atoms.

[1] M. Lewenstein, A. Sanpera, V. Ahufinger, B. Damski, A. S. De and U. Sen, Adv. Phys. 56, 243 (2007). [2] I. Bloch, J. Dalibard and W. Zwerger, Rev. Mod. Phys. 80, 885 (2008). [3] J. Dalibard, F. Gerbier, G. Juzeliunas and P. Öhberg, Rev. Mod. Phys. 83, 1523 (2011). [4] Y.-J. Lin, K. Jimenez-Garcia and I. B. Spielman, Nature (London) 471, 83 (2011). [5] J. Ruseckas, R. Jursenas, G. Juzeliunas and I.B. Spielman, in preparation.

Q 56.53 Thu 16:00 Empore Lichthof

Multiple scattering of interacting bosons in random potentials — Tobias Geiger, •Thomas Wellens, and Andreas Buchleitner — Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, Germnay

We microscopically derive a theory for scattering of N atoms – with all atoms initially prepared in the same single-particle momentum eigenstate – from a three dimensional random disorder potential in the presence of two-body interactions. Starting from an exact diagrammatic expansion of the N-particle transition amplitude, we identify those combinations of diagrams which – in the case of a weak random potential (mean free path much larger than wavelength) – survive the disorder average, and sum up the remaining series of ladder and crossed diagrams non-perturbatively in the strength of the particle-particle interaction. We show that the latter leads to a relaxation of the individual particles' energies towards a Maxwell-Boltzmann distribution as the particles diffuse throughout the random potential [1]. As interferential correction to diffusive transport, we furthermore consider the phenomenon of coherent backscattering and analyze how this coherent effect is modified by interactions.

[1] T. Geiger, T. Wellens, and A. Buchleitner, Phys. Rev. Lett. **109**, 030601 (2012)

Q 56.54 Thu 16:00 Empore Lichthof

Semiclassical theory for laser-driven atoms in optical cavities — •Stefan Schütz[1], Hessam Habibian[1,2], and Giovanna Morigi[1] — [1]Theoretische Physik, Universität des Saarlandes, D-66041 Saarbrücken, Germany — [2]Grup d'Óptica, Universitat Autònoma de Barcelona, E-08193 Bellaterra, Barcelona, Spain

We theoretically study the formation of self-organized structures of atoms, whose dipolar transition is driven by a laser and also couples to the optical mode of a high-finesse cavity. Self-organization in the cavity field emerges due to the mechanical forces of the cavity photons on the atoms, whereby the cavity field is sustained by the photons scattered by the atoms from the laser and hence depends on the atomic position. We consider the semiclassical model in [1], which is used when the laser is well above the self-organization threshold, and identify the limits of validity. We then extend the theoretical description to a Fokker-Planck equation which is valid below threshold, when the intracavity photon number is low. In this regime we analyze the dynamics of cavity cooling, and determine the final temperatures and cooling rates.

[1] P. Domokos et al., J.Phys. B: At. Mol. Opt. Phys. **34** 187-198 (2001)

[2] J.K.Asbóth, P. Domokos, H. Ritsch, and A. Vukics, Phys. Rev. A **72**, 053417 (2005)

Q 56.55 Thu 16:00 Empore Lichthof

ac Stark shift of a cesium atom in a two-color nanofiber-based atom trap — •Fam Le Kien, Philipp Schneeweiss, and Arno Rauschenbeutel — VCQ, TU Wien - Atominstitut, Stadionallee 2, 1020 Wien, Austria

An atom exposed to an intense far-detuned light field experiences shifts of its energy levels. In general, these light shifts (ac Stark shifts) depend not only on the dynamical polarizability of the atomic state but also on the polarization of the light field. Here, we present central results of a systematic derivation of the ac Stark shift induced by a far-off-resonance light field of arbitrary polarization. These results are in particular relevant when theoretically describing the optical trapping of atoms using near-fields or nonparaxial light beams which in general lead to nontrivial polarization patterns.

When applying this light-shift formalism to cesium atoms in a two-color nanofiber-based optical trap, we find Zeeman-state-dependent optical trapping potentials. The state dependence is a consequence of the effective magnetic field which results from the vector polarizability of the atomic ground state in conjunction with the residual ellipticity of the nanofiber-guided trapping light fields. Using an external (real) magnetic offset field, we observe a spatial displacement of the trapping potential that can be continuously controlled. We propose to exploit this behavior for microwave control and cooling of the atomic motional states. For this purpose, we calculate the Franck-Condon factors between vibrational levels and show that an implementation of these microwave operations appears experimentally feasible.

Q 56.56 Thu 16:00 Empore Lichthof

Towards redistribution laser cooling of molecular gases: Production of candidate molecule SrH by laser ablation. — Philipp Simon, •Lars Weller, Anne Sass, Peter Moroshkin, and Martin Weitz — Institut für Angewandte Physik, Universität Bonn, Bonn, Germany

Laser cooling by collisional redistribution of radiation is a powerful novel technique suitable for cooling of very dense and hot gases. It has been successfully applied for cooling alkali-metal vapours mixed with rare gases at high pressure. Here we report on the progress of our project aiming at the demonstration of the redistribution cooling in a molecular gas. The strontium monohydride molecule SrH possesses a strong near-infrared electronic transition XΣ - AΠ with a highly diagonal Franck-Condon structure that makes it a good candidate for laser cooling. We produce SrH by laser ablation of strontium dihydride in a pressurized rare gas atmosphere. The composition of the ablation plasma plume is analyzed by measuring its emission spectrum. The achieved concentration of SrH molecules and its dynamics following the ablation laser pulse is studied as a function of the buffer gas pressure and the laser intensity.

Q 56.57 Thu 16:00 Empore Lichthof

Transition from ion chain to zigzag configuration in a box like potential — •Andrea Klumpp and Peter Schmelcher — ZOQ University of Hamburg

Self-organizing processes are an interesting subject of physical research. These can be investigate by studing ultracold charged particles in a trap [1]. In numerical calculation of the classical ground state configurations of such trapped particles, the so called Coulomb or Wigner crystals, an harmonic potential $\phi_{eff} = \nu_1 x^2 + \nu_2 y^2 + \nu_3 z^2$ is used as a first approximation for the effective potential of the trap [2]. Thus, for the harmonic potential a number of studies exist for the ground state of the trapped particles and for the phase transition between different formations [3,4]. In order to improve the usually applied approximation we start to model the spatial limits of a trap using a box like potential $\Phi(z) = -\frac{V0}{1+(z/l)^m}$ with the length l of the trap in axial direction and an harmonic potential perpendicular to the axis.

Using this more realistic potential we varied the parameter m governing the box-type behaviour of the potential. We present the results of calculations for the one dimensional Wigner crystal configurations and the transition from ion chain to zigzag formation in the box like potential and compared the results with the purely harmonic confinement [4].

[1] R.Blumel,et all Nature 334,309 (1988)
[2] W.Paul Rev.Mod.Phys. 62,3(1990)
[3] P.Ludwig,S.Kosse, M.Bonitz Phys. Rev.E 71,046403 (2005)
[4] E.Shimshoni, G.Morigi,S. Fishmann PRL 106, 010401 (2011)

Q 56.58 Thu 16:00 Empore Lichthof

A CO_2-laser optical dipole trap for ultracold erbium atoms — •Henning Brammer, Jens Ulitzsch, Matthias Rehberger, and Martin Weitz — Institut für Angewandte Physik, Universität Bonn

The erbium atom has a $4f^{12}6s^2\ {}^3H_6$ electronic ground state with a large angular momentum of $L = 5$. So far, most atomic quantum gases have been realized with a sperical symmetric ($L = 0$) S-ground state configuration, for which in far detuned laser fields with detuning above the upper state fine structure splitting the trapping potential is determined by the scalar electronic polarizability. For an erbium quantum gas with its $L > 0$ ground state, the trapping potential also for far detuned dissipation-less trapping laser fields becomes dependent on the internal atomic state (i.e. spin). We report on progress in an ongoing experiment directed at the generation of an atomic erbium Bose-Einstein condensate by evaporative cooling in a quasistatic optical dipole trap generated by the focused beam derived from a CO_2-laser operating near 10.6μm wavelength. The atoms are loaded into the dipole trap from a magneto-optical trap (MOT), which itself is loaded from a Zeeman-slowed atomic beam. For the MOT, the experiment uses a single laser frequency tuned to the red of the 400.91nm cooling transition. No repumping radiation is required for the MOT operation, despite the complex energy level structure of the erbium atom.

Q 56.59 Thu 16:00 Empore Lichthof

EIT-control of single-atom motion in an optical cavity — •Tobias Kampschulte[1], Wolfgang Alt[1], Sebastian Manz[1], Miguel Martinez-Dorantes[1], René Reimann[1], Seokchan Yoon[1], Dieter Meschede[1], Marc Bienert[2], and Giovanna Morigi[2] — [1]Institut für Angewandte Physik, Universität Bonn, Wegelerstrasse 8, 53115 Bonn — [2]Theoretische Physik, Universität des Saarlandes, 66123 Saarbrücken

We demonstrate cooling of the motion of a single atom confined by a dipole trap inside a high-finesse optical resonator. Cooling of the vibrational motion results from EIT-like interference in an atomic Λ-type configuration, where one transition is strongly coupled to the cavity mode and the other is driven by an external control laser. Good qualitative agreement with the theoretical predictions is found for the explored parameter ranges. The role of the cavity in the cooling dynamics is confirmed by means of a direct comparison with EIT-cooling performed in the dipole trap in free space. These results set the basis to the realization of an efficient photonic interface based on single atoms.

Q 56.60 Thu 16:00 Empore Lichthof

Sequential loading of a conservative potential — •Ilka Geisel[1], Jan Mahnke[1], Carsten Klempt[1], Wolfgang Ertmer[1], and Kai Cordes[2] — [1]Institut für Quantenoptik, Leibniz Universität Hannover — [2]Institut für Informationsverarbeitung, Leibniz Universität Hannover

We investigate guiding and trapping of rubidium atoms on a mesoscopic chip structure with millimeter-scale wires.

This structure is used to create a quadrupole field for a magneto-optical trap, a magnetic guide and a flexible magnetic trapping potential. In our experiments, the guide allows us to transport cold atoms into a region that provides better vacuum conditions and very effective stray light protection. It is therefore particularly well suited to simultaneously trap and collect atoms.

We show that our control of the local magnetic fields and the effective light shielding enable us to load another MOT without significantly reducing the lifetime of previously trapped atoms. We present first results on sequential loading mechanisms with regard to continuous loading of a conservative potential [1].

[1] Continuous loading of a non-dissipative atom trap C. F. Roos et al 2003 Europhys. Lett. 61 187

Q 56.61 Thu 16:00 Empore Lichthof

Surface-electrode microwave structures for electron guiding — •Johannes Hoffrogge[1], Jakob Hammer[1], and Peter Hommelhoff[1,2] — [1]MPI für Quantenoptik, 85748 Garching — [2]Friedrich-Alexander-Universität Erlangen-Nürnberg, 91058 Erlangen

We study the guiding of free electrons in a planar microwave quadrupole guide [1]. The surface-electrode structure is driven at microwave frequencies, which allows tight radial confinement. This results in transverse trap frequencies of up to several hundred MHz and enables the precise control of slow electrons at 1-10 eV by means of purely electric fields. We experimentally and numerically study the dynamics of the electrons and their dependence on the microwave drive parameters. Upon coupling into the guide, the electron trajectories show strong dependence on the microwave phase and fringing electric fields. We therefore present a numerically optimized electrode layout that provides an adiabatic passage of the electron beam into the guide. We also discuss more complex electrode structures like beam splitting elements for guided electrons, as well as designs with electrodes that are larger than the drive wavelength. These require to consider traveling wave effects in the electrode layout [2]. Finally, the combination of an electron guide with a single atom tip electron source should allow the direct preparation of electrons in low-lying quantum states of the transverse harmonic oscillator potential. This would enable new guided matter-wave experiments with electrons.

[1]J. Hoffrogge, *et al. Phys. Rev. Lett.* **106**, 193001 (2011).
[2]J. Hoffrogge, P. Hommelhoff, *New. J. Phys* **13**, 095012 (2011).

Q 56.62 Thu 16:00 Empore Lichthof

Novel paths to phase-space density increase in dipolar atomic gases — Valentin Volchkov, •Jahn Rührig, Matthias Wenzel, Axel Griesmaier, and Tilman Pfau — 5. Physikalisches Institut, Universität Stuttgart, Germany

We present novel paths that we use to increase the phase-space density in a continuously loaded atomic trap. Following the argumentation in [2] we extend our previous work [1] by applying RF radiation during the loading. We discuss how this leads to an increase of the steady state PSD during the continuous process and faster loading. In pulsed operation, we increase the phase-space density by use of the dipolar nature of ^{52}Cr which allows demagnetization cooling [3] and avoids losses connected to evaporative cooling. Starting in an up to now unaccessed temperature regime of $T \approx 100\mu K$ we aim for the production of large dipolar BECs with high repetition rates. The realization of an active magnetic field stabilization on the level of $100\mu G$ per axis enables us to circumvent the previously explored limits set by transversal stray fields with respect to the laser used for optical pumping during the demagnetization.

[1]: M. Falkenau, V. V. Volchkov, J. Rührig, A. Griesmaier and T. Pfau, Phys. Rev. Lett. **106**, 163002 (2011)
[2]: M. Falkenau, V. V. Volchkov, J. Rührig, H. Gorniaczyk, A. Griesmaier, Phys. Rev. A **85**, 023412 (2012)
[3]: M. Fattori, T. Koch, S. Goetz, A. Griesmaier, S. Hensler, J. Stuhler, T. Pfau, Nature Physics **2**, 765 (2006)

Q 56.63 Thu 16:00 Empore Lichthof

Laser cooling of Iron atoms — •Nicolas Huet, Stéphanie Krins, and Thierry Bastin — Institut de Physique Nucléaire, Atomique et de Spectroscopie, Université de Liège, Belgium

We report on the first laser cooling of Iron atoms. Our laser cooling setup makes use of 2 UV laser radiation sent colinearly in a 0.8 m Zeeman slower. One laser is meant for optical pumping of the Iron atoms from the ground state to the lowest energy metastable state. The second laser cools down the atoms using a quasi-perfect closed transition from the optical pumped metastable state. The velocity distribution at the exit of the Zeeman slower is obtained from a probe laser crossing the atom beam at an angle of 50 degrees. The fluorescence light is detected using a photomultiplier tube coupled with a boxcar analyzer. The Iron atom beam is produced with a commercial effusion cell working at around 1950 K. Our laser radiations are stabilized using standard saturated-absorption signals in both an Iron hollow cathode absorption cell and an Iodine cell. We will present our experimental setup, as well as the first evidences of cooled down Iron atoms at the exit of the Zeeman slower.

Q 56.64 Thu 16:00 Empore Lichthof

Phase-Locked Raman Laser Systems Based on Interference Filter ECDLs for Coherent Hyperfine State Manipulation — •Jan Phieler, Michael Bauer, Shrabana Chakrabarti, Philipp Franzreb, Benjamin Gänger, Farina Kindermann, and Artur Widera — Technische Universität Kaiserslautern, FB Physik, Erwin-Schrödinger-Str. 46, 67663 Kaiserslautern, Germany

We report on the construction of phase-locked Raman laser systems for Rb and Cs atoms in a two-species cold atom experiment in order to enable resolved sideband cooling of tightly bound atoms to the quantum mechanical ground state of optical dipole traps as well as controlled preparation of different hyperfine states.

Interference filter stabilized extended cavity diode lasers at wavelengths of 780 and 852 nm form the laser sources of both systems and provide superior stability and narrow linewidth. Driving coherent Raman transitions between the hyperfine substates of the Rb and Cs groundstates requires two phase coherent laser beams. This coherence is achieved by phase-locking the beat-note of the lasers to an external reference oscillator by means of a high speed digital phase frequency discriminator circuit.

We present meaurements on the basic properties of the systems, including passive stability and regulation circuit performance, and report on the current status of integrating them in our experiment.

Q 56.65 Thu 16:00 Empore Lichthof

Optical traps for combining an ultracold Rb gas and single Cs atoms — •Philipp Franzreb, Michael Bauer, Shrabana Chakrabarti, Benjamin Gänger, Farina Kindermann, Jan Phieler, and Artur Widera — Technische Universität Kaiserslautern

Experiments combining single neutral atoms with a many body system require many repetitions of the experimental cycle to obtain significant statistics. Hence it is important to achieve short cycle times with a high production rate of the Bose-Einstein condensate (BEC).

In this poster experimental outline and current status of our optical dipole trap system for a rapid all-optical Rb BEC production and the combination with single Cs atoms is discussed. From a 3D MOT Rb atoms are loaded into a single beam trap, where evaporation is supported due to a crossed beam configuration. Trapping and controlled immersion of single Cs atoms is possible with the aid of an optical lattice formed by an additional anti parallel beam.

Q 56.66 Thu 16:00 Empore Lichthof

Coherence properties of cold cesium atomic spins in a nanofiber-based dipole trap — •Rudolf Mitsch, Daniel Reitz, Clément Sayrin, Philipp Schneeweiss, and Arno Rauschenbeutel — Vienna Center for Quantum Science and Technology, TU Wien, Atominstitut, Stadionallee 2, 1020 Wien, Austria

The possibility to efficiently store quantum information over extended periods of time is a prerequisite for quantum protocols. Here, we present the first experimental characterization of the coherence properties of nanofiber-trapped atoms. In our system, neutral Cs atoms are trapped in a two-color evanescent field surrounding a subwavelength-diameter optical fiber. The atoms are localized in an one-dimensional optical lattice only 200 nm above the dielectric surface [1]. This close proximity and the strong polarization gradients of nanofiber-guided light fields are prone to cause decoherence. In order to investigate these effects, a resonant microwave field is used to drive the $m_F = 0 \rightarrow 0$ clock-transition between the two hyperfine ground states. Ramsey interferometry on this transition yields inhomogeneous dephasing times of about $T_2^* = 500\,\mu$s, whereas spin echo measurements result in homogeneous dephasing times of up to $T_2' = 2$ ms. These long coherence times are compatible with the implementation of more complex quantum operations, thereby paving the road towards establishing nanofiber-based traps for cold atoms as a building block in a quantum network.

[1] E. Vetsch *et al.*, Phys. Rev. Lett. **104**, 203603 (2010).

Q 56.67 Thu 16:00 Empore Lichthof

Reflection spectroscopy on laser-cooled atoms trapped around an optical nanofiber — •Bernhard Albrecht, Igor Mazets, Rudolf Mitsch, Daniel Reitz, Clément Sayrin, Philipp Schneeweiss, and Arno Rauschenbeutel — Vienna Center for Quantum Science and Technology, TU Wien, Atominstitut, Stadionallee 2, A-1020 Wien, Austria

Tapered optical fibers with a waist diameter smaller than the optical wavelength have recently been used to trap and optically interface laser-cooled cesium atoms [1,2]. In addition to their potential as a building block in a quantum network, nanofiber-trapped atoms are a promising model system for fundamental investigations on light-matter interaction. Here, we report on our latest experimental results on reflection spectroscopy of cesium atoms trapped in a one-dimensional optical lattice about 200 nm above the nanofiber surface. The atoms are randomly loaded into this lattice while the collisional blockade effect limits the number of atoms per trapping site to one at most. Reflection spectra are taken in regimes dominated by coherent and by incoherent scattering. The data is well described by a model that considers radiation transfer in a non-linear inhomogeneous medium. Our results contribute to the deeper understanding of light propagation through complex atomic media and are an important step towards cavity QED with atomic mirrors [3].

[1] E. Vetsch *et al.*, Phys. Rev. Lett **104**, 203603 (2010).
[2] E. Vetsch *et al.*, IEEE J. Quantum Electron **18**, 1763 (2012).
[3] D. E. Chang *et al.*, New J. Phys. **14**, 063003 (2012).

Q 56.68 Thu 16:00 Empore Lichthof

Heterodyne spectroscopy of single atom motional states inside a high-finesse cavity — •Natalie Thau, Wolfgang Alt, Tobias Kampschulte, Sebastian Manz, René Reimann, Seokchan Yoon, and Dieter Meschede — Institut für Angewandte Physik der Universität Bonn, Wegelerstr. 8, 53115 Bonn

Tight control and knowledge of the motional states of single atoms are a prerequisite for many experiments connected to the field of quantum information. In our system insight to the motional states of single atoms coupled to a high finesse optical resonator is gained by the means of optical heterodyne detection. Measuring the beat signal between a fixed-frequency local oscillator beam and the light interacting with the coupled atoms, we are able to map the atomic motional state to the frequency domain in a non-destructive way. Analysing the spectra we discuss different experimental imperfections and estimate the intra-cavity atomic temperature within the frame of a simple model.

Q 56.69 Thu 16:00 Empore Lichthof

2D Discrete Quantum Simulator — •Stefan Brakhane, Carsten Robens, Andrea Alberti, Wolfgang Alt, and Dieter Meschede — Institut für Angewandte Physik der Universität Bonn,Wegelerstr. 8,53115 Bonn

Coherent control of individual atoms in optical lattices have recently proven to be a key asset in simulating physical phenomena, spanning from quantum transport effects typical of solid state physics to artificial gauge fields.

Our planed apparatus features a 2D optical lattice with polarization controlled state-dependent transport, a high numerical aperture imaging system (NA = 0.92) enabling single site detection and addressing by means of highly-focused steering laser beams, and high magnetic field gradient to act as spin-dependent force.

We report on the current status of the experiment and on the development of a dodecagonal ultra-high vacuum glass cell with minimal bifrefringence allowing for optimal polarization control inside the vacuum.

Q 56.70 Thu 16:00 Empore Lichthof

Optical imaging of thermal and condensed gases — •Cristina Gherasim, Soenke Beck, and Reinhold Walser — Institute for Applied Physics, TU Darmstadt, Germany

Absorption imaging is the standard way of observing trapped atomic gases. From the two dimensional column integrated densities, one obtains optical images on CCD devices after propagation through an optical system, i.e. abberated lenses, $\lambda/4$ plates, vacuum windows, beam splitters etc. In order to assess the fidelity of optically measured particle densities, we analyze the performance of realistic imaging setups for thermal clouds and strongly interacting Bose-Einstein condensates. Using optical design software we model the optical setup of the QUANTUS experiment [1] with geometric ray tracing and wave optics. We compare the 2D density of the atomic cloud with its optical image $n^{2D} = \log{(I_o^{vac}/I_o^{BEC})}/(2\alpha)$ [2].

[1] T. van Zoest et al, Science, **328**, 1540 (2010).
[2] W. Ketterle, D.S. Durfee and D.M. Stamper-Kurn, Proceedings of the International School of Physics "Enrico Fermi" Course CXL (1999)

Acknowledgments: This project is supported by the Deutsche Luft und Raumfahrt Agentur (DLR Grant: 50 WM 1137).

Q 56.71 Thu 16:00 Empore Lichthof

Precision imaging of interfering matter waves — •Sönke Beck, Cristina Gherasim, and Reinhold Walser — Institut für angewandte Physik, Technische Universität Darmstadt, Hochschulstr. 4A, 64289 Darmstadt, Germany

We investigate the limitations of optical imaging for cold thermal clouds and Bose-Einstein condensates. An optimized imaging system is crucial to perform high precision measurements [1]. Within the paraxial approximation of wave optics, we have calculated the image of an absorptive-dispersive ($\chi = \chi' + i\chi''$) atomic cloud after propagating through an ideal lens system with finite aperture. This shows the limitations of the standard formula for imaging the column integrated density $\tilde{n}$ of dilute clouds, $\tilde{n} = \ln(I_{\rm vac}/I_{\rm cloud})/k_0\chi''$ ($I_{\rm vac}$, $I_{\rm cloud}$ image intensities without and with cloud, k_0 free-space wave number) [2]. The results are particularly relevant for diffraction limited structures of interfering Bose-Einstein condensates in a matter wave interferometer as realized in QUANTUS [3].

References:
[1] T. van Zoest et al., Science **328**, 1540 (2010)
[2] W. Ketterle et al., Proceedings of the International School of Physics “Enrico Fermi” (1999)
[3] J. Rudolf et al., Microgravity Sci. Technol. **23**, 287 (2011)

Q 56.72 Thu 16:00 Empore Lichthof

Non-adiabatic quantum state control in few-well few-atom systems — •Malte C. Tichy, Mads Kock Pedersen, Klaus Mølmer, and Jacob F. Sherson — Lundbeck Foundation Theoretical Center for Quantum System Research, Department of Physics and Astronomy, University of Aarhus, DK-8000 Aarhus C, Denmark

A scheme for arbitrary unitary control of ensembles of interacting bosonic atoms in two-well systems is presented, which uses a discrete sequence of local potential variations as the only control parameter. Exact solutions, readily available for infinite interaction strength, are used as a starting point for numerical optimization yielding high-fidelity procedures to arbitrarily manipulate quantum states. We thereby combine universal but artificially constrained "bang-bang" quantum control with the Euler-decomposition of large unitary matrices to yield a practical powerful scheme. We demonstrate the efficiency of our proposal with non-adiabatic population transfer, N00N-state creation, and transistor-like, conditional evolution of several atoms.

Q 56.73 Thu 16:00 Empore Lichthof

Towards coherent interaction between single neutral atoms and a BEC — •Michael Bauer, Shrabana Chakrabarti, Philipp Franzreb, Benjamin Gänger, Farina Kindermann, Nicolas Spethmann, and Artur Widera — Technische Universität Kaiserslautern

Combining a single neutral atom with a quantum many body system, such as a Bose-Einstein condensate (BEC) poses a challenge, not only due to the different temperatures of both systems realized in experiments so far, but also because of the different measurement statistics and typical sequence durations. Studying the interaction of a single atom with a BEC requires many repetitions of the experimental cycle to obtain sufficient statistics. Thus it is essential to achieve short measuring times and therefore a high production rate of the BEC. Here we present a concept and first characterizations for a new setup capable of breeding an all optical BEC in a few seconds and immersing single atoms into the ultracold quantum system.

Our setup will feature mechanisms for independently manipulating and detecting both single atoms and the BEC, thereby providing an unrivaled level of control over impurities in a quantum gas. Possible research directions include the investigation of coherent impurity physics and the creation and characterization of polarons in a BEC. The poster will review the current status of the experiment.

Q 56.74 Thu 16:00 Empore Lichthof

A single atom in a 3D optical lattice strongly coupled to an optical cavity — •Stephan Ritter, Andreas Reiserer, Christian Nölleke, and Gerhard Rempe — Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Straße 1, 85748 Garching, Germany

Single atoms in optical cavities have proven ideal for the reversible interconversion and storage of quantum information and therefore make excellent quantum network nodes. Despite these successes, position and momentum of the atom has so far escaped complete control. As a consequence, the atom-cavity coupling strength is neither maximal nor constant. This limits the fidelity and in particular the efficiency of interconversion and other quantum information processing protocols. To solve this problem, we demonstrate deterministic localization of a single atom in a three-dimensional optical lattice with the resonator as one of the lattice axes. By shifting the standing-wave potential formed by one of the lattice beams, we place the atom at the center of the cavity mode. This allows us to reach the strong-coupling regime of cavity QED manifested by a clearly resolved normal-mode splitting even for a moderate cavity finesse. The use of high intensities along all three axes gives adjustable trap frequencies of a few hundred kHz, such that the atom is tightly confined to the Lamb-Dicke regime. This enables Raman sideband cooling to the ground state of the three-dimensional lattice potential.

Q 56.75 Thu 16:00 Empore Lichthof

Counting mesoscopic atom numbers — •Ion Stroescu, Maxime Joos, David B. Hume, Wolfgang Müssel, Helmut Strobel, Jiri Tomkovic, Eike Nicklas, Daniel Linnemann, and Markus K. Oberthaler — Kirchhoff-Institut für Physik, Heidelberg, Germany

Many cold atom experiments rely on precise atom number detection. Especially in the context of quantum atom optics experiments that exhibit effects at the quantum level. Here we investigate the limits of atom number counting via resonant fluorescence imaging for mesoscopic samples of trapped atoms. We characterize the precision of these fluorescence measurements beginning from the single atom level up to more than one hundred. Spatial resolution potentially enables the simultaneous detection of atom numbers in two different magnetic sub-states. This capability enables future experiments with highly entangled states of mesoscopic Bose-Einstein condensates going beyond spin squeezed states.

Q 56.76 Thu 16:00 Empore Lichthof

Towards a miniaturized setup for single photon storage in an ensemble of neutral Rb atoms — •Sutapa Ghosh, Jose C. Gallego, Miguel Martinez-Dorantes, Wolfgang Alt, Marcel Spurny, and Dieter Meschede — Institut für Angewandte Physik, Universität Bonn, Wegelerstraße 8, 53115 Bonn

We present our progress in setting up a miniaturized CQED experiment for single photon storage in an ensemble of neutral Rb atoms. Rb atoms are trapped and cooled using a miniaturized MOT and transfered into a fiber-based optical cavity using our conveyor belt technique, where they are trapped in a 3D optical lattice (comprising a 2D optical lattice and the cavity field). This leads to strong localization of the atoms inside the resonator. The MOT is imaged from two perpendicular sides, giving a quasi-3D impression of the extension and position of the MOT.

Q 56.77 Thu 16:00 Empore Lichthof

A spectral approach to the tunneling decay of two interacting bosons — •Stefan Hunn[1], Klaus Zimmermann[1], Moritz Hiller[2,1], and Andreas Buchleitner[1] — [1]Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, Hermann-Herder-Str. 3, 79104 Freiburg — [2]Institute for Theoretical Physics, Vienna University of Technology, Wiedner Hauptstraße 8-10/136, 1040 Vienna, Austria

We study the microscopic dynamics of two interacting, ultracold bosons in a one- dimensional double-well potential, through the numerically exact diagonalization of the many-body Hamiltonian. With the particles initially prepared in the left well, we increase the width of the right well in subsequent trap realizations and witness how the tunneling oscillations evolve into particle loss. In this closed system, we analyze the spectral signatures of single- and two-particle tunneling for the entire range of repulsive interactions. We conclude that for comparable widths of the two wells, correlated tunneling of a boson pair may be realized for specific system parameters. In contrast, the decay process (corresponding to a broad right well) is dominated by uncorrelated single-particle decay.

Q 56.78 Thu 16:00 Empore Lichthof

Timing control system for cold atom experiments based on a Cortex ARM platform — •Daniel Mayer[1], Felix Schmidt[1], Carsten Lippe[1], Tobias Lausch[1], Nicolas Spethmann[1,2], and Artur Widera[1] — [1]Fachbereich Physik, TU Kaiserslautern, Erwin-Schrödinger-Str. 46, 67663 Kaiserslautern — [2]Department of Physics, University of California Berkley, California, 94720 USA

Precise timing of laser pulses or magnetic fields, for example, are crucial in experiments working with ultracold atoms. We present a timing system featuring a time resolution of .1 microseconds, minimal flank spacing of 1 microsecond, and up to several hundred digital channels, based on standard Cortex ARM processors on a cheap LPC-Expresso platform. The software frontend to create the sequence is programmed in python using QtGui. In order enable maximum automation of the experiment, the software offers a control panel to create basic variables and functions for any repetition of a sequence. Furthermore a small web-server programmed in cpp provides access to the basic functionality of the hardware system. Once created, the sequence is transferred to a master processor, which distributes the signal to eight slave processors, each having 32 digital channels. All processors are locked to a Rb frequency standard, which provides exact relative timing between them and allows for a scalable number of slaves. Additionally the hardware offers a manual mode in order obtain quasi-real-time control over any connected device.

The poster will present details of the hardware design as well as the basic software used to control the timing system.

Q 56.79 Thu 16:00 Empore Lichthof

Cryogenic fiber amplifier for optical trapping of neutral mercury — •Holger John, Patrick Villwock, and Thomas Walther — Technische Universität Darmstadt, Institut für Angewandte Physik, Laser- und Quantenoptik, 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 in relatively high natural abundance. On the one hand the fermionic isotopes could be used to develop a new time-standard based on a lattice optical clock employing the $^1S_0$ - $^3P_0$ transition at 265.6 nm. Another interesting venue is the formation of ultra cold Hg-dimers employing photo-association and achieving vibrational cooling by employing a special pumping scheme.

The requirements for trapping neutral mercury are given by the cooling transition with a linewidth of 1.27 MHz at a wavelength of 253.7 nm. Our approach is to twice frequency double a Yb:disc laser with the fundamental wavelength of 1014.8 nm. In the recent past we have successfully trapped the bosonic ^{202}Hg as well as the fermionic ^{199}Hg isotopes and have performed first temperature measurement.

Our goal is to increase the reproducibility of our setup by substituting the thin-disc laser with a Yb doped fiber amplified ECDL. We will report on the status of the experiments.

Q 56.80 Thu 16:00 Empore Lichthof

Disordered gases of two level Rydberg atoms — •Martin Gärttner[1,2], Thomas Gasenzer[2], and Jörg Evers[1] — [1]Max-Planck-Institut für Kernphysik, Saupfercheckweg 1, 69117 Heidelberg — [2]Institut für Theoretische Physik, Universität Heidelberg, Philosophenweg 16, 69120 Heidelberg

Exciting atoms to high lying Rydberg states leads to extreme properties, most important of which are their long life-times and the long range interactions among them. For ensembles of Rydberg atoms various appications in quantum optics, quantum information and solid state physics have been proposed and implemted. We study the coherent dynamics of a finite laser-driven cloud of ultra-cold Rydberg atoms by calculating the time evolution from the full many body Hamiltonian. Using the frozen gas approximation and treating the atoms as effective two level systems, we identify effects of finite size and finite density leading to modifications of the predicted parameter scaling of the excited fraction. Also, we analyze the influence of resonant excitation channels in the case of two-photon detuned excitation lasers. We thereby study the buildup of strong correlations and crystal-like structures and discuss potential applications of these features.

Q 56.81 Thu 16:00 Empore Lichthof

Modelling many-body Rydberg interactions — •David Schönleber, Martin Gärttner, and Jörg Evers — Max-Planck-Institut für Kernphysik, Saupfercheckweg 1, 69117 Heidelberg

In the field of Rydberg physics, basically two approaches to modelling many-body interactions exist, namely the approach to solve the many-body Schrödinger equation and the approach to solve effective models such as rate equations. While the first approach includes exact correlation effects which the latter neglects, it does not include reservoir effects such as damping. We develop methods to augment the exact many-body Hamiltonian approach with the ability to model reservoir effects e.g. by implementing quantum jumps via Monte Carlo techniques [1], aiming to enlarge the field of validity of the Schrödinger equation approach. Consequently, the scope of the methods developed is studied with respect to the conventional models.

[1] K. Mølmer *et al*, J. Opt. Soc. Am. B 10, 524-538 (1993)

Q 56.82 Thu 16:00 Empore Lichthof

Conical Intersections and exitation transport in flexible Rydberg aggregates — •Karsten Leonhardt, Sebastian Wüster, and Jan Michael Rost — Max Planck Institute for the Physics of Complex Systems

Transport of electronic excitation is a very important mechanism in nature, e.g. Photosynthesis [1]. It was shown that in linear flexible Rydberg aggregates [2] localized excitons connects the electronic excitation and entanglement transport with atomic motion [3,4]. Here we show that Rydberg systems also allow reflection of the excitation transport by fixing the positions of the last atoms in the aggregate. Further we extend the setup to a 2D arrangement to get access to Conical intersections. We use this feature to create entanglement of atomic motion.

References

[1] R. van Grondelle,V.I. Novoderezhkin, *Phys. Chem. Chem. Phys.* **8**, 793 (2006).
[2] C. Ates, A. Eisfeld, J-M. Rost, *New. J. Phys.* **10**, 045030 (2008).
[3] S. Wüster, C. Ates, A. Eisfeld, J-M. Rost, *Phys. Rev. Lett.* **105**, 195392 (2010).
[4] S. Möbius, S. Wüster, C. Ates, A. Eisfeld, J-M. Rost, *J. Phys. B.* **44**, 184011 (2011).
[5] S. Wüster, A. Eisfeld, J-M. Rost, *Phys. Rev. Lett.* **106**, 153002 (2011).

Q 56.83 Thu 16:00 Empore Lichthof

Towards Imaging Single Rydberg Atoms via Electromagnetically Induced Transparency — •Stephan Helmrich, Georg Günter, Hanna Schempp, Christoph S. Hofmann, Vladislav Gavryusev, Martin Robert-de-Saint-Vincent, Shannon Whitlock, and Matthias Weidemüller — Physikalisches Institut, Universität Heidelberg, Im Neuenheimer Feld 226, 69120 Heidelberg

Electromagnetically induced transparency of Rydberg atoms presents the unique possibility to image individual Rydberg atoms immersed in a dense atomic gas and to study their spatial correlations. In our recent proposal [1] the level shifts induced by the Rydberg atoms to the surrounding gas are utilized to provide sensitive, single-shot absorption images of individual Rydberg atoms.

To experimentally realize this idea we require quasi-1D or 2D trapping geometries and a high resolution imaging system capable of resolving single Rydberg blockade spheres. Therefore we designed and implemented a diffraction limited imaging system taking maximum advantage of the present experimental setup. Additionally we optimized critical experimental parameters including atomic density and exposure time to achieve the highest possible signal-to-noise ratio and spatial resolution. We will present our experimental progress towards imaging single Rydberg atoms.

[1] G. Günter et al., Phys. Rev. Lett. 108, 013002 (2012)

Q 56.84 Thu 16:00 Empore Lichthof

Study of Rydberg-surface interactions in thermal atomic vapor — •Ralf Ritter, Daniel Barredo, Robert Löw, and Tilman Pfau — 5. Physikalisches Institut, Universität Stuttgart, 70569 Stuttgart, Germany

The coherent control of strong interactions between Rydberg atoms hold great promise for the manipulation of quantum information. In ultracold experiments several results have already been achieved to proof the basic concepts for this intention. However, thermal atomic vapor cells offer an attractive alternative in terms of scalability for practical devices [1]. For the successful applicability of this approach, decoherence effects with nearby walls need to be investigated and minimized.

In our work, we study the Rydberg atom-surface interaction in a UHV environment as a function of surface composition, corrugation, and temperature for different Rydberg states, atomic species and buffer gases. We will present the versatile setup we utilize for this project and discuss the current status of the experiment.

[1] H. Kübler et al., Nature Photon. 4, 112-116 (2010)

Q 56.85 Thu 16:00 Empore Lichthof

Electric field optimization of a Rydberg atom experiment — •Maximilian Argus, Hanna Schempp, Georg Günter, Shannon Whitlock, and Matthias Weidelmueller — Physikalisches Institut Universitaet Heidelberg, Im Neuenheimer Feld 226, 69120 Heidelberg Germany

Modern experiments with ultracold Rydberg atoms with application to many body physics and quantum information science, demand a high level of experimental sophistication. In particular, Rydberg atoms are highly polarizable, therefore special care must be taken to control external electric fields. In our experiment this is possible using a structure hosting >10 individually controllable electrodes. However, finding the optimal control voltages can be a challenging task, further complicated by incomplete knowledge of the underlying charge distributions, including possible patch fields.

To overcome this challenge we have applied evolutionary algorithms, a group of powerful search heuristics, to optimize the overall performance of our experiment. Focussing on two problems: cancellation of electric fields and and optimum guiding of field ionized Rydberg atoms to a MCP detector, we asses the performance of several algorithms with competing requirements of noise robustness and fast convergence. Future applications to controlling quantum state evolution and engineering strongly correlated many body systems of interacting Rydberg atoms will be considered.

Q 56.86 Thu 16:00 Empore Lichthof

Strongly interacting single photons in an ultra-cold Ryberg gas — •Hannes Gorniaczyk, Christoph Tresp, and Sebastian Hofferberth — 5. Physikalisches Institut, Universität Stuttgart, Deutschland

Strong photon-photon coupling can be achieved in highly nonlinear media such as Rydberg atoms under the condition of electromagnetically induced transparency. Such a system enables the implementation of fundamental building blocks for photonic quantum information processing. More fundamentally, the underlying interacting Ryberg polaritons form a novel strongly correlated many-body system with widely tunable parameters.

We are currently constructing an experimental setup for Rydberg excitation in an optically dense medium of ultra-cold ^{87}Rb atoms in a crossed optical dipole trap. With excitation lasers focussed smaller than the Rydberg blockade radius a one-dimensional system of Rydberg-polaritons can be realized. This system is suited to create non-classical light, in particular to create and absorb single photons in a deterministic way.

Q 56.87 Thu 16:00 Empore Lichthof

Fractional quantum Hall physics for Rydberg-dressed atoms in artificial magnetic fields — Fabian Grusdt[1,2] and •Michael Fleischhauer[1] — [1]Department of Physics and research center OPTIMAS, University of Kaiserslautern, Germany — [2]Graduate School Materials Science in Mainz, Staudinger Weg 9, 55128 Mainz, Germany

We study ultracold Rydberg-dressed Bose gases in the lowest Landau level (LLL) generated by artificial gauge fields. The characteristics of the Rydberg interaction gives rise to interesting many-body ground states different from standard LLL fractional quantum Hall physics. The non-local but rapidly decreasing interaction potential favors crystalline ground states for very dilute systems. While a simple Wigner crystal becomes energetically favorable compared to the Laughlin liquid for filling fractions $\nu < 1/12$, a correlated crystal of composite particles emerges already for $\nu \leq 1/6$. The presence of a new length scale, the Rydberg blockade radius a_B, gives rise to a bubble crystal phase when the average particle distance becomes less than a_B and $\nu \lesssim 1/4$. For larger fillings indications for strongly correlated, non-Abelian cluster liquids are found.

Q 56.88 Thu 16:00 Empore Lichthof

Rydberg Polaritons — •Johannes Otterbach[1,2], Matthias Moos[2], Dominik Muth[2], and Michael Fleischhauer[2] — [1]Physics Department, Harvard University, Cambridge, MA 02138, USA — [2]Fachbereich Physik and Forschungszentrum OPTIMAS, Technische Universität Kaiserslautern, 67663 Kaiserslautern, Germany

The near resonant interaction of light fields with three-level atoms involving a Rydberg state under conditions of electromagnetically induced transparency (EIT) can be described in terms of strongly interacting quasi-particles, termed Rydberg polaritons. An effective many-body model for dark and bright Rydberg polaritons is introduced and compared to recent experiments. The low energy physics of a 1D gas of dark Rydberg polaritons is discussed in terms of a Luttinger liquid model and numerical DMRG simulations. The generation of non-classical photon states with e.g. sub-poissonian number statistics and long-range crystalline order is discussed.

Q 56.89 Thu 16:00 Empore Lichthof

Quantum-classical lifetimes of Rydberg molecules — •Andrej Junginger, Jörg Main, and Günter Wunner — 1. Institut für Theoretische Physik, Universität Stuttgart, Germany

A remarkable property of Rydberg atoms is the possibility to create molecules formed by a scattering process of a highly excited Rydberg electron and an atom in the ground state. Besides the good agreement between theory [1] and the experiment [2] concerning the vibrational states of the molecule, the experimental observations yield the astonishing feature that the lifetime of the molecule is clearly reduced as compared to the bare Rydberg atom [3]. With focus on this yet unexplained observation, we investigate the vibrational ground state of the molecule in a quantum-classical framework. We show that the Rydberg wave function is continuously detuned by the presence of the moving ground state atom and that the timescale on which the detuning significantly exceeds the natural linewidth is in good agreement with the observed reduced lifetimes of the Rydberg molecule.

[1] C. H. Greene et al , Phys. Rev. Lett. 85, 2458 (2000).
[2] V. Bendkowsky et al, Nature 458, 1005, (2009).
[3] B. Butscher et al , J. Phys. B 44, 184004 (2011).

Q 56.90 Thu 16:00 Empore Lichthof

Towards ultracold polar NaK molecules — •Matthias W. Gempel, Torben A. Schulze, Torsten Hartmann, Maurice Petzold, Janis Wöhler, and Silke Ospelkaus — Institut für Quantenoptik, Universität Hannover

Quantum degenerate gases of polar molecules are promising candidates for the realization of strongly correlated quantum many body systems. Particularly promising in this respect is a quantum gas of NaK molecules.

In its groundstate NaK has large electric dipole moment of -2.579 Debye [J. Chem. Phys. 129, 064309 (2008)]. Furthermore, chemical reactions of the form $NaK + NaK \rightarrow Na_2 + K_2$ are expected to be endothermic and therefore suppressed at ultra low temperatures [PRA 81, 060703(R) (2010)]. As a consequence quantum gases of NaK molecules are expected to be stable at ultracold temperatures.

On this poster, we will present our progress towards a quantum degenerate gas of NaK molecules. In particular, we will present the design and the current status of our experimental apparatus.

Q 56.91 Thu 16:00 Empore Lichthof

Collisions of ultracold fermionic molecules: Averaged rates and state-changing collisions — •A. Pikovski[1], M. Klawunn[2], A. Recati[2], and L. Santos[1] — [1]Institut für theoretische Physik, Leibniz Universität Hannover, Germany — [2]INO-CNR BEC Center and Dipartimento di Fisica, Università di Trento, Italy

At very low temperatures, effects of quantum statistics play an important role in interparticle collisions. We study ensemble-averaged collision rates for a two-component gas of fermions, with possibly different masses, particle densities, and temperatures, for general two-body collisions. The results give an understanding of how the experimentally measured rates depend on the system parameters. [arXiv:1211.6613]

A concrete example of ultracold collisions are state-changing collisions in ultracold polar molecules in a bilayer geometry. If the molecules in each layer are initially prepared in a different rotational state, we show that the inter-layer dipole-dipole interaction induces a swap of the rotational state of molecules in different layers in two-body collisions. Remarkably, for optically trapped highly reactive molecules like KRb, such state swaps lead to losses by chemical reactions, and hence the state-changing collisions can be observed by monitoring the molecule number. [Phys. Rev. A 84, 061605(R) (2011)]

Q 56.92 Thu 16:00 Empore Lichthof

Two-Photon-Spectroscopy of YbRb - Towards paramagnetic molecules — •Cristian Bruni, Frank Münchow, Maximilian Madalinski, and Axel Görlitz — Institut für Experimentalphysik, HHU Düsseldorf, 40225 Düsseldorf

Ultracold heteronuclear molecules offer fascinating perspectives ranging from ultracold chemistry to novel interactions in quantum gases. Here we report on the spectroscopic investigation of vibrational levels in the electronic ground state of YbRb which is an important step towards the realization of YbRb ground state molecules [1]. Using two-photon photoassociation spectroscopy in laser-cooled mixtures of ^{87}Rb and various Yb isotopes we are able to determine the binding energies of weakly-bound vibrational levels and the positions of possible magnetic Feshbach resonances. Recent theoretical work suggest that also in mixtures of alkali and spin-singlet atoms magnetic Feshbach resonances could be experimentally accessible [2]. From additional investigations by means of Autler-Townes spectroscopy we obtain information on the transition rates between vibrational levels of different electronic molecular states.

[1] F. Münchow, C. Bruni, M. Madalinski, and A. Görlitz. Two-photon photoassociation spectroscopy of heteronuclear YbRb. PCCP,13(42):18734 - 18737, (2011).
[2] Piotr S. Zuchowski, J. Aldegunde, and Jeremy M. Hutson. Ultracold RbSr molecules can be formed by magnetoassociation. Phys.Rev. Lett., 105(15):153201, (2010).

Q 56.93 Thu 16:00 Empore Lichthof

Magnetic field dependence of collisions in ultracold YbRb mixtures — •Fabian Wolf, Cristian Bruni, Ali Al-Masoudi, Arnd Obert, Kira Borkowski, and Axel Görlitz — Institut für Experimentalphysik, HHU Düsseldorf, 40225 Düsseldorf

Due to its paramagnetic ground state YbRb is an interesting candidate for the realization of dipolar molecules with additional degrees of freedom. Exploration of magnetically tunable collision properties may eventually offer the possibility to associate ultracold atoms to molecules via Feshbach association. Recent theoretical work suggest that in mixtures of alkali and spin-singlet atoms a coupling between the entrance channel and the bound state channels exists [2]. This coupling leads to the existence of narrow Feshbach resonances. Via two-photon photoassociation spectroscopy the binding energies of weakly bound vibrational levels in YbRb were determined [1] and the positions of possible magnetic Feshbach resonances were predicted. Here we report on the current status of the experiment where we measure the atom loss in an optically trapped YbRb mixture under the influence of a tunable magnetic field.

[1] F.Münchow, C. Bruni, M. Madalinski, and A. Görlitz. Two-photon photoassociation spectroscopy of heteronuclear YbRb. PCCP, 13(42):18734 - 18737, (2011).
[2] Piotr S. Zuchowski, J. Aldegunde, and Jeremy M. Hutson. Ul-

tracold RbSr molecules can be formed by magnetoassociation. Phys. Rev. Lett., 105(15):153201, (2010).

Q 56.94 Thu 16:00 Empore Lichthof

Zur Gültigkeit der adiabatischen Näherung im getriebenen Zwei-Niveau-System — •Ralf Saplata und Carsten Henkel — Universität Potsdam

Wir untersuchen ein getriebenes Zwei-Niveau-System (Rabi-Modell), für das der Einfluss der RWA auf die Berry-Phase kontrovers diskutiert wurde [1]. Obwohl die entsprechenden Kriterien [2] formal erfüllt sind, ist es nicht klar, ob die adiabatische Näherung angewendet werden darf [3]. Zur Interpretation der Berry-Phase untersuchen wir die Entwicklung des Zustands auf der Bloch-Kugel. Alternativ wird die Zeitentwicklung an Hand von numerischen Lösungen einer Differentialgleichung vom Hill-Mathieu-Typ diskutiert, wobei wir Floquet-Matrizen verwenden, um kurze und lange Zeitskalen zu überbrücken.

[1] J.Larson,Phys.Rev.Lett.108,033601(2012)
[2] A.Messiah,Quantum Mechanics,Vol.2,North-
Holland Pub. Co. Amsterdam (1962)
[3] K.P.Marzlin and B.C.Sanders, Phys.Rev.Lett.93, 160408(2004)

Q 56.95 Thu 16:00 Empore Lichthof

On the Electrons in the Quantum Free-Electron Laser — •Rainer Endrich[1], Enno Giese[1], Peter Kling[1], Matthias Knobl[1], Paul Preiss[1,2], Wolfgang P. Schleich[1], Roland Sauerbrey[2], and Muhammad S. Zubairy[3] — [1]Institut für Quantenphysik and Center for Integrated Quantum Science and Technology (IQ^{ST}), Universität Ulm, Albert-Einstein-Allee 11, D-89081, Germany — [2]Helmholtz-Zentrum Dresden-Rossendorf eV, D-01328 Dresden, Germany — [3]Institute for Quantum Science and Engineering, Department of Physics and Astronomy, Texas A&M University, College Station, Texas 77843, USA

Free-Electron Lasers (FEL) provide coherent and widely tunable radiation of high brilliance. Most theoretical descriptions are based on classical physics in agreement with experimental results. However, an FEL working the quantum regime is within reach at the Research Center Dresden-Rossendorf. Substantial theoretical progress has been made to understand quantum effects which are usually suppressed in the classical regime and therefore ignored. This includes two-level behavior, recoil effects, phase diffusion and much more. Based on our earlier work, we take a closer look at the density matrix of the joint system of laser field and electron beam. By this way we analyze the center-of-mass motion of the electrons and show how bunching emerges in the low-gain regime as well as the hole-burning effect.

Q 56.96 Thu 16:00 Empore Lichthof

Towards an interaction-free measurement with electrons — •Sebastian Thomas[1], Jakob Hammer[1], Johannes Hoffrogge[1], and Peter Hommelhoff[1,2] — [1]Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Str. 1, 85748 Garching, Gemany — [2]Universität Erlangen-Nürnberg, Erwin-Rommel-Str. 1, 91058 Erlangen, Germany

Exploiting wave-particle duality, it is possible to determine the position of an object without affecting it in any way. This phenomenon is called an "interaction-free measurement" [1]. It can be realized with a single-photon source coupled into a Mach-Zehnder interferometer, where the presence of an object in one of the paths becomes noticeable as it prevents interference at the interferometer exit.

Recently, an interaction-free measurement setup has been proposed with electrons instead of photons [2]. This way, a new type of electron microscope might be constructed, in which samples receive a greatly reduced radiation dose. We discuss general features of interaction-free measurements as well as different approaches towards the realization of such a measurement with electrons. In particular, we investigate the effect of semi-transparent samples, and we consider the application of a linear microwave guide of low-energy electrons [3] for interaction-free measurements.

[1] P. Kwiat, H. Weinfurter, T. Herzog, A. Zeilinger, M. Kasevich, Phys. Rev. Lett. 74, 4763 (1995)
[2] W. Putnam, M. Yanik, Phys. Rev. A 80, 040902 (2009)
[3] J. Hoffrogge, R. Fröhlich, M. Kasevich, P. Hommelhoff, Phys. Rev. Lett. 106, 193001

Q 56.97 Thu 16:00 Empore Lichthof

Relativistic aspects of the free-electron laser in the quantum limit — •Peter Kling[2], Roland Sauerbrey[1], Muhammad S. Zubairy[3], Rainer Endrich[2], Enno Giese[2], Matthias Knobl[2], Paul Preiss[1,2], and Wolfgang P. Schleich[2] — [1]Helmholtz-Zentrum Dresden-Rossendorf e V, D-01328 Dresden, Germany — [2]Institut für Quantenphysik and Center for Integrated Science and Technology, Universität Ulm, Albert-Einstein-Allee 11, D-89081 Ulm, Germany — [3]Institute for Quantum Science and Engineering, Department of Physics and Astronomy, Texas A&M University, College Station, Texas 77843, USA

Free-electron laser (FEL) devices are radiation sources with a wide tunability ranging from far-infrared up to X-rays. All existing FELs can be described by classical electrodynamics. However, due to experimental progress in the last years a new regime, the so-called quantum regime seems to be in reach.

Here recoil effects become important and a Jaynes-Cummings-like behavior between the radiation and the center-of-mass motion arises. Within our approach we investigate its emergence as well as its properties. In contrast to earlier approaches based on quantum mechanics in a co-moving reference frame we stay in the laboratory frame and use quantum electrodynamics.

Q 56.98 Thu 16:00 Empore Lichthof

Quantum tunnelling from a metastable potential: the driven Morse potential — •Harald Losert, Karl Vogel, and Wolfgang P. Schleich — Institut für Quantenphysik, Universität Ulm, D-89069 Ulm, Germany

We study the behaviour of a particle in a Morse potential under the influence of an external force. We have chosen the Morse potential as an example for an anharmonic potential since the eigenvalues, eigenfunctions and dipole matrix elements can be calculated analytically. Based on these results we solve the time-dependent Schrödinger equation for the driven system numerically.

In the first step we use a time-dependent external force to induce transitions from the ground state to an excited state, for example to an energy eigenstate. In the second step we apply a constant external force to enable quantum tunneling through an energy barrier whose height can be tuned by changing the external force. We investigate quantum tunnelling for various excited states, in particular energy eigenstates.

Q 56.99 Thu 16:00 Empore Lichthof

Comparison of phase space dynamics of Kopenhagen and Causal interpretations of Quantum Mechanics — •Christoph Tempel and Wolfgang P. Schleich — Institut f\"ur Quantenphysik, Universit\"at Ulm, D-89069 Ulm

Recent publications pursue the attempt to reconstruct Bohm trajectories experimentally utilizing the technique of weak measurements. We study the phase space dynamics of a specific double slit setup in terms of the Bohm de-Broglie formulation of quantum mechanics.

We want to compare the results of those Bohmian phase space dynamics to the usual quantum mechanical phase space formulation with the Wigner function as a quasi probability density.

Q 57: Laser development: Nonlinear effects

Time: Friday 11:00–12:30 Location: F 128

Q 57.1 Fri 11:00 F 128

1.3-mW tunable and narrow-band continuous-wave light source at 191 nm — Matthias Scholz[1], Dmitrijs Opalevs[1], •Jürgen Stuhler[1], Patrick Leisching[1], Wilhelm Kaenders[1], Guiling Wang[2], Xiaoyang Wang[2], Rukang Li[2], and Chuangtian Chen[2] — [1]TOPTICA Photonics AG, 82166 Gräfelfing, Germany — [2]Beijing Center for Crystal Growth and Development, Chinese Academy of Sciences, Beijing 100190, China

We present a cw narrow linewidth deep-UV source at 191 nm, consisting of a grating-stabilized diode laser which is frequency-quadrupled by two consecutive second harmonic generation (SHG) stages. In the first SHG stage, the fundamental light at 764 nm is resonantly enhanced and frequency doubled to 382 nm in a lithium triborate (LBO) crystal. The resulting uv light is beam shaped and enhanced in the second SHG stage. Using the novel crystal potassium fluoroborato-beryllate (KBBF) [1], an output power of up to 1.3 mW at 191 nm is achieved [2]. The linewidth of the laser output at 191 nm (1570 THz) is estimated to be below 300 kHz (1 km coherence length). Automatic fine tuning of the laser up to 40 GHz and coarse wavelength changes of 1 nm are possible. Similar techniques should provide wavelengths between 165 nm and 205 nm. The demonstrated light source is a unique tool for deep-UV metrology, photoemission spectroscopy, or atomic spectroscopy.

[1] C. Chen et al., Appl. Phys. B 97, 9-25 (2009).
[2] M. Scholz et al., Opt. Express 20, No. 17, 18659-18664 (2012).

Q 57.2 Fri 11:15 F 128

Kaskadierter Raman-Faserlaser mit 5W Ausgangsleistung bei 1480nm — •Michael Steinke, Emil Schreiber, Dietmar Kracht, Jörg Neumann und Peter Wessels — Laser Zentrum Hannover

Wellenlängen um 1480nm eignen sich hervorragend, um Er-dotierte Systeme zu pumpen, da beispielsweise durch den kleineren Quantendefekt eine höhere Effizienz als bei der Verwendung von typischen Pumpwellenlängen um 975nm erreicht werden kann. Ausgehend von einem 30W Yb-Faserlaser, dessen Ausgangswellenlänge von 1117nm durch den Raman-Effekt in insgesamt fünf Schritten verschoben wurde, konnte eine Ausgangsleistung von 5W bei 1480nm realisiert werden. Dazu wurden eine Faser mit hoher Raman-Verstärkung und Faser-Bragg-Gitter zur Realisierung von Resonatoren bei den einzelnen Raman-Ordnungen verwendet. Optimiert wurde das System mit Hilfe einer genauen numerischen Analyse. Unsere numerischen Ergebnisse zeigen zusätzlich, dass die Ausgangsleistung des Systems unter Verwendung von verlustfreieren Resonatoren in Zukunft noch auf über 10W gesteigert werden kann.

Q 57.3 Fri 11:30 F 128

Isotopenphasenangepasstes Vierwellenmischen in Quecksilber zur Erzeugung von kontinuierlicher VUV-Strahlung — •Matthias Stappel[1,2], Thomas Diehl[1,2], Andreas Koglbauer[1,2], Daniel Kolbe[1,2], Ruth Steinborn[1,2] und Jochen Walz[1,2] — [1]Institut für Physik, Johannes Gutenberg-Universität Mainz, 55099 Mainz, Deutschland — [2]Helmholtz-Institut Mainz, Johannes Gutenberg-Universität mainz, 55099 Mainz, Deutschland

Vierwellenmischen in Quecksilber ist eine etablierte Methode zur Erzeugung von kohärenter kontinuierlicher vakuum-ultravioletter (VUV) Strahlung. Von experimentellem Interesse ist VUV Strahlung bei 121 nm, dem Lyman-α Übergang in Wasserstoff. Diese Wellenlänge lässt sich effizient durch Vierwellenischen von drei fundamentalen Laserfeldern bei 254 nm, 408 nm und 540 nm in Quecksilberdampf erzeugen [1]. Im Fall von nahresonantem Vierwellenmischen lässt sich die nichtlineare Suszeptibilität stark erhöhen. Jedoch hat eine Einphotonenresonanz starken Einfluss auf die Dispersion und somit auf die Phasenanpassung des Vierwellenmischens. Wir zeigen wie durch das Ausnutzten der Isotopenaufspaltung von Quecksilber die Phasenanpassungsbedingung auch im nahresonanten Fall erfüllt werden kann und welchen Einfluss die 6^1S-6^3P Resonanz auf die Mischeffizienz hat.

[1] Kolbe et al., PRL 109, 063901 (2012)

Q 57.4 Fri 11:45 F 128

Charakterisierung von Flüstergalerieresonatoren aus Lithiumniobat im nahen und mittleren Infrarot — •Markus Leidinger, Karsten Buse und Ingo Breunig — Institut für Mikrosystemtechnik - IMTEK , Albert-Ludwigs-Universität Freiburg, Georges-Köhler-Alle 102, 79110 Freiburg

Flüstergalerieresonatoren stellen einen monolithischen Resonatortyp dar, der aufgrund seiner hohen Güte eine starke Intensitätsüberhöhung erlaubt. Dies macht ihn besonders für nichtlinear-optische Prozesse wie Frequenzkonversion interessant. Als Material bietet sich aufgrund seiner hohen optischen Nichtlinearität zweiter Ordnung und seiner geringen Absorption in einem weiten spektralen Bereich Lithiumniobat an. Bisher wurden Flüstergalerieresonatoren aus Lithiumniobat lediglich im Wellenlängenbereich von 488 bis 1560 nm hinsichtlich ihrer Güte untersucht. Theoretische Arbeiten sagen die höchste Güte, also die effizienteste Frequenzkonversion, um 2000 nm Wellenlänge vorher. Mit Hilfe eines modensprungfrei durchstimmbaren optisch parametrischen Oszillators (OPO) machen wir uns ebendiesen Wellenlängenbereich zugänglich, um Flüstergalerieresonatoren aus Lithiumniobat dort zu charakterisieren. Weiter werden aus den gemessenen Gütewerten die Absorption in Lithiumniobat im nahen und mittleren Infrarot bestimmt, wozu bisher aufgrund der hohen Transparenz wenige zuverlässige Daten vorliegen.

Q 57.5 Fri 12:00 F 128

Flüstergalerieresonatoren: Blau-gepumpte optisch-parametrische Oszillation in Lithiumniobat — •Christoph Werner, Tobias Beckmann, Karsten Buse und Ingo Breunig — Institut für Mikrosystemtechnik - IMTEK, Albert-Ludwigs-Universität Freiburg, Georges-Köhler-Alle 102, 79110 Freiburg

Wir stellen einen optisch-parametrischen Oszillator in Millimeter großen Flüstergalerien aus Lithiumniobat vor, der bei 488 nm Wellenlänge gepumpt wird. Die erzeugte Signalwellenlänge kann mit der Temperatur von 715 nm bis 865 nm durchgestimmt werden. Die Idlerwellenlänge reicht von 1121 nm bis 1536 nm. Die Konversionseffizienz liegt im Prozentbereich bei einer Pumpschwelle unter 0,2 mW. Weitere Miniaturisierung verspricht eine höhere Effizienz und eine niedrigere Pumpschwelle. Durch verkürzen der Pumpwellenlänge ist eine Durchstimmbarkeit bis ins Grüne zu erwarten.

Q 57.6 Fri 12:15 F 128

Quantum and Classical description of Light: Mie - Resonances and Non-Linear Effects — Anton Lebedev, Stephanie Mühlheim, Marius Dommermuth, Roland Speith, and •Regine Frank — Institut für Theoretsiche Physik, Universität Tübingen

Within this talk we present the interplay of the classical description of the intrinsic nonlinearity of random lasers, as e.g. Mie resonances with the quantum nature of random lasing emission. We show, how exactly the Mie resonanance as such introduces a controversially discussed spectral separation of random laser modes whereas spatial coexistence is possible.

Q 58: Precision measurements and metrology V

Time: Friday 11:00–12:30 Location: E 001

Q 58.1 Fri 11:00 E 001

Spektroskopie des optischen $^1S_0$-$^3P_0$ Uhrenübergangs von Magnesium nahe der magischen Wellenlänge — •Steffen Rühmann, André Kulosa, Dominika Fim, Klaus Zipfel, Temmo Wübbena, André Pape, Wolfgang Ertmer und Ernst Rasel — Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover, Germany

Magnesium ist ein interessanter Kandidat für die Präzisionsspektroskopie in optischen Gittern [Katori, Nature 435, 321-324, 2005]. Es besitzt eine der geringsten Sensitivitäten auf die Schwarzkörperstrahlung, welche die Performance aktueller Neutralatomuhren limitiert. Wir berichten über die Speicherung von Magnesium in einem optischen Gitter bei der sogenannten magischen Wellenlänge, bei der die differentielle Frequenzverschiebung durch den AC-Stark-Effekt des stark verbotenen Uhrenübergangs $^1S_0$-$^3P_0$ in erster Ordnung unterdrückt wird. Dies erlaubt es erstmalig diesen Übergang direkt anzuregen. Erste Ergebnisse zur Spektroskopie werden präsentiert.

Q 58.2 Fri 11:15 E 001

Ultra-stable Cryogenic Optical Sapphire Cavities – Towards a Thermal Noise Limited Frequency Stability $< 3 \cdot 10^{-17}$ — •Moritz Nagel, Katharina Möhle, Klaus Döringshoff, Sylvia Schikora, Evgeny Kovalchuk, and Achim Peters — Humboldt-Universität zu Berlin, Institut für Physik, AG Optische Metrologie, Newtonstr. 15, 12489 Berlin

Many experimental and technical applications, e.g. optical atomic clocks, demand ultra-stable cavity systems for laser frequency stabilization. Nowadays, the main limiting factor in frequency stability for room temperature resonators has been identified to be the displacement noise within the resonator substrates and mirror coatings due to thermal noise. A rather straightforward method to reduce the influence of thermal noise is to cool down the resonators to cryogenic temperatures. Following this approach, we present a design and first measurements for an ultra-stable cryogenically cooled sapphire optical cavity system, with a prospective thermal noise limited frequency stability better than $3 \cdot 10^{-17}$.

Q 58.3 Fri 11:30 E 001

Coherence transfer for the generation of x-ray frequency combs — •Stefano M. Cavaletto[1], Zoltán Harman[1,2], Christian Buth[3], and Christoph H. Keitel[1] — [1]Max-Planck-Institut für Kernphysik, Heidelberg, Germany — [2]ExtreMe Matter Institute (EMMI), Darmstadt, Germany — [3]Argonne National Laboratory, Argonne, IL, USA

Optical frequency combs had a revolutionary impact on precision spectroscopy and metrology. The spectrum of a frequency comb, consisting of evenly spaced lines, is the result of an infinite train of femtosecond pulses produced in a mode-locked ultrafast laser. Recently, frequency-comb technology was extended to the extreme-ultraviolet spectral regime via high-harmonic generation in a femtosecond-enhancement cavity [1]. We propose an optical scheme to transfer the coherence of a driving, optical frequency comb to the radiation emitted by transitions of higher frequencies. The comb structure we predict in the emitted x-ray spectrum might eventually represent an alternative scheme for x-ray-comb generation, able to overcome the frequency limitations of present HHG-based methods.

[1] A. Cingöz et al., Nature 482, 68 (2012).

Q 58.4 Fri 11:45 E 001

Coherence-Enhanced Optical Determination of the ^{229}Th Isomeric Transition — •Sumanta Das, Wen-Te Liao, Christoph H. Keitel, and Adriana Pálffy — Max Planck Institute for Nuclear Physics, Heidelberg

The 7.8 eV isomeric transition in ^{229}Th [1] is a promising candidate for next generation frequency standards. The advantages of this nuclear transition are its very narrow width, the stability with respect to external perturbations and an accessible frequency within the VUV region. However, a direct measurement of the transition energy has not yet been possible, due to the weak fluorescence signal and the lack of an unmistakable signature for the nuclear excitation.

Here we investigate the effect of coherent light propagation on the excitation and fluorescence signal of the isomeric transition [2]. The transient superradiant behaviour for the nuclear fluorescence in a crystal lattice environment in the forward direction can be exploited to enhance the signal and reduce data collecting time. Furthermore, we put forward a quantum optics scheme based on quantum interference induced by two coherent fields coupling three nuclear levels as a novel way to identify the isomeric transition energy [2]. The proposed setup provides a clear signature for the nuclear excitation and an enhanced precision in the optical determination of the transition frequency compared to a direct fluorescence experiment using only one field.

[1] B. R. Beck *et al.*, Phys. Rev. Lett. 98, 142501 (2007).
[2] W.-T. Liao, S. Das, C. H. Keitel and A. Pálffy, Phys. Rev. Lett., in press (2012).

Q 58.5 Fri 12:00 E 001

An optical feedback frequency stabilized laser tuned by single-sideband modulation — •Johannes Burkart and Samir Kassi — Laboratoire Interdisciplinaire de Physique (LIPhy), UMR5588 CNRS/Université Joseph Fourier Grenoble, 38402 Saint Martin d'Hères, France

Stable, narrow and tunable laser sources are indispensable for molecular lineshape metrology.

Our novel approach consists in stabilizing a distributed feedback diode laser to an ultrastable V-shaped reference cavity by optical feedback self-locking. This limits the laser's frequency drifts to the order of a few hertz per second and reduces its linewidth by several orders of magnitude.

The second key innovation consists in shifting the laser frequency with millihertz precision using an integrated electro-optic Mach-Zehnder modulator. By successive laser locking to adjacent reference cavity modes this technique allows continuous frequency tuning over more than one terahertz.

Combined with cavity ring-down spectroscopy, this new setup will pave the way to an accurate determination of the Boltzmann constant as well as optical precision measurements of isotopic ratios for atmospheric and climate sciences.

Q 58.6 Fri 12:15 E 001

Optical Frequency Transfer over 1840 km Fiber Link - Bridging Continental Distances — •Stefan Droste[1], Katharina Predehl[1], Thomas Udem[1], Theodor W. Hänsch[1], Ronald Holzwarth[1], Sebastian Raupach[2], Filip Ozimek[2], Harald Schnatz[2], and Gesine Grosche[2] — [1]Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Str. 1, 85748 Garching — [2]Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig

The increasing performance of optical frequency standards calls for new methods of transferring highly stable optical frequencies. Well established satellite-based frequency dissemination techniques do not reach the required stability set by state-of-the-art frequency standards. Recently, a lot of work has been put into investigating fiber links as a possible medium for transferring optical frequencies. We established a fiber connection between the two institutes Max Planck Institute of Quantum Optics (MPQ) in Garching and the Physikalisch-Technische Bundesanstalt (PTB) in Braunschweig. In a loop configuration we transferred an optical carrier frequency at 194 THz over a 1840 km long fiber link. Doppler shifts introduced by the fiber link lead to a degradation of the optical signal. After applying a correction signal to compensate for the fiber noise we could demonstrate that optical frequencies can be transferred over nearly 2000 km with a stability and accuracy that surpasses the requirements for comparing modern optical frequency standards by more than one order of magnitude.

Q 59: Quantum gases: Optical lattices III

Time: Friday 11:00–12:30 Location: F 342

Q 59.1 Fri 11:00 F 342

Mott transitions in the half-filled SU(2M) symmetric Hubbard model — •Nils Blümer and Elena Gorelik — Institute of Physics, Johannes Gutenberg University, Mainz, Germany

The SU(N) symmetric Hubbard model with total degeneracy $N > 2$ has recently gained direct physical relevance in the context of ultracold earth alkali atoms. A Mott insulating state has already been observed in a SU(6) symmetric system of fermionic ytterbium atoms (^{173}Yb) on a cubic optical lattice [1], opening the door to detailed experimental investigations of Mott metal-insulator transitions in SU(N) symmetric Hubbard models (with $N > 2$). This breakthrough clearly calls for corresponding theory data in the full relevant range of N.

We compute static properties of the Hubbard model in the SU(2M) symmetric limit for up to $M = 8$ bands at half filling within dynamical mean-field theory, using the numerically exact multigrid Hirsch-Fye quantum Monte Carlo approach. Based on this unbiased data, we establish scaling laws which predict the phase boundaries of the paramagnetic Mott metal-insulator transition at arbitrary orbital degeneracy M with high accuracy.

[1] S. Taie, R. Yamazaki, S. Sugawa, and Y. Takahashi, Nature Physics **8**, 825 (2012).

Q 59.2 Fri 11:15 F 342

Quantum dynamics of a single, mobile spin impurity — •Takeshi Fukuhara[1], Adrian Kantian[2], Manuel Endres[1], Marc Cheneau[1], Peter Schauss[1], Sebastian Hild[1], David Bellem[1], Ulrich Schollwöck[3], Thierry Giamarchi[2], Christian Gross[1], Immanuel Bloch[1,3], and Stefan Kuhr[4] — [1]Max-Planck-Institut für Quantenoptik, 85748 Garching, Germany — [2]DPMC-MaNEP, University of Geneva, 24 Quai Ernest-Ansermet, 1211 Geneva, Switzerland — [3]Fakultät für Physik, Ludwig-Maximilians-Universität München, 80799 München, Germany — [4]University of Strathclyde, Department of Physics, SUPA, Glasgow G4 0NG, United Kingdom

Quantum magnetism plays an important role in many materials such as transition metal oxides and cuprate superconductors. One of its elementary processes is the propagation of spin excitations. Here we study the quantum dynamics of a deterministically created spin-impurity atom, as it propagates in a one-dimensional lattice system. We probe the full spatial probability distribution of the impurity at different times using single-site-resolved imaging of bosonic atoms in an optical lattice. In the Mott-insulating regime, a post-selection of the data allows to reduce the effect of temperature, giving access to a space- and time-resolved measurement of the quantum-coherent propagation of a magnetic excitation in the Heisenberg model. Extending the study to the bath's superfluid regime, we determine quantitatively how the bath affects the motion of the impurity, showing evidence of polaronic behaviour.

Q 59.3 Fri 11:30 F 342

Creation and dynamics of remote spin-entangled pairs in the expansion of strongly correlated fermionic atoms — •Stefan Kessler[1], Ian McCulloch[2], and Florian Marquardt[1,3] — [1]Institute for Theoretical Physics, Friedrich-Alexander-Universität Erlangen-Nürnberg, Erlangen, Germany — [2]School of Physical Sciences, University of Queensland, Brisbane, Australia — [3]Max Planck Institute for the Science of Light, Erlangen, Germany

We consider the nonequilibrium dynamics of an interacting spin-$\frac{1}{2}$ fermionic gas in a one-dimensional optical lattice after switching off the confining potential. In particular, we study the creation and the time evolution of spatially separated, spin-entangled fermionic pairs. This results in entanglement between pairs of singly occupied lattice sites across the cloud, which we quantify by the concurrence. The time-dependent density-matrix renormalization group is used to simulate the time evolution and evaluate the two-site correlation functions, from which the concurrence is calculated. We find that the entangled fermionic pairs are found at different locations, depending on the onsite interaction strength. Moreover, we briefly discuss the prospects of experimentally observing these phenomena by measuring the spin-entanglement using single-site and spin-dependent detection of the particle number.

Q 59.4 Fri 11:45 F 342

Observation of Ising symmetry breaking in a triangular optical lattice — •Christoph Ölschläger[1], Julian Struck[1], Malte Weinberg[1], Juliette Simonet[1], Robert Höppner[1], Ludwig Mathey[1], Philipp Hauke[2], Maciej Lewenstein[2], André Eckardt[3], Patrick Windpassinger[1], and Klaus Sengstock[1] — [1]Institut für Laserphysik, Universität Hamburg, Germany — [2]ICFO - Institut de Ciències Fotòniques, Castelldefels, Spain — [3]MPI für Physik komplexer Systeme, Dresden, Germany

Ultracold quantum gases in optical lattices are well suited to investigate and simulate systems connected to solid state physics. Here we report on the experimental realization of ultracold atoms in a triangular lattice with an emergent discrete Ising (Z2) and continuous (U(1)) symmetry by engineering fully tunable artificial staggered gauge fields via lattice shaking. For staggered pi-fluxes the ground state is twofold degenerate and we observe a thermally driven phase transition between an unordered (paramagnetic-like) state and an ordered (ferromagnetic-like) state, where the system shows a spontaneous magnetization. Via the full control over the flux strength, it is in addition possible to lift the degeneracy on purpose, e.g. to break the Ising symmetry, and thus measure the magnetization depending on the field and temperature. This can be viewed as in close analogy to a classical Ising-spin model in an external homogeneous magnetic field showing characteristic magnetization dependences below and above a critical temperature.
We acknowledge support from the Deutsche Forschungsgemeinschaft within SFB925 and FOR801.

Q 59.5 Fri 12:00 F 342

Quantum magnetism of ultracold fermions in an optical lattice — •Thomas Uehlinger[1], Daniel Greif[1], Gregor Jotzu[1], Leticia Tarruell[1,2], and Tilman Esslinger[1] — [1]Institute for Quantum Electronics, ETH Zurich, 8093 Zurich, Switzerland — [2]LP2N UMR 5298, Univ. Bordeaux 1, Institut d'Optique and CNRS, 351 cours de la Libération, 33405 Talence, France

Quantum magnetism is a fundamental phenomenon in condensed matter physics, which manifests itself for example in antiferromagnets or spin-liquids and is believed to play a crucial role in high-temperature superconductivity. Remarkably, even simple models of the underlying many-body physics are often intractable with state-of-the-art theoretical methods. While ultracold atoms in optical lattices have been successfully used to investigate simple condensed matter model systems, the regime of quantum magnetism could so far not be accessed due to the low temperatures required.

We report on the first observation of quantum magnetism of a Fermi gas in an optical lattice. The key to obtaining and detecting the short-range magnetic order is a tunable geometry optical lattice set to either a dimerized or an anisotropic simple cubic geometry. For a low-temperature gas we find magnetic correlations on neighbouring sites, which manifest as an excess number of singlets as compared to triplets consisting of two atoms with opposite spins. For the anisotropic lattice, we determine the transverse spin correlator from the singlet-triplet imbalance and observe antiferromagnetic correlations along one spatial axis.

Q 59.6 Fri 12:15 F 342

Monte-Carlo simulation of frustrated magnetic phases of ultracold bosonic atoms in an optical lattice — •Robert Höppner and Ludwig Mathey — Zentrum für Optische Quantentechnologien/Institut für Laser-Physik, Hamburg, Germany

Recent experiments have demonstrated that ultracold Rubidium-87 atoms in frustrated optical lattices can be used to simulate classical magnetism (1). Here, we use classical Monte-Carlo to understand the equilibrium phase diagram of such systems. We consider a frustrated triangular lattice in which the tunnelling energy in two spatial directions is negative, and is complex in the third spatial direction. We model the bosonic field by using a thermally fluctuating complex field. We obtain several observables, such as the momentum space distribution of the atoms, both above and below the critical point, and the chirality of the state. We discuss the relevance of our results to experiments.

[1] Struck, J., et al. (2011). Quantum simulation of frustrated classical magnetism in triangular optical lattices. Science, 333 (6045)

Q 60: Quantum effects: Entanglement and decoherence I

Time: Friday 11:00–12:30 Location: A 310

Group Report Q 60.1 Fri 11:00 A 310

Energetic consequences of pure decoherence in ultrafast collisions — •C. Aris Dreismann[1], Evan MacA. Gray[2,3], and Tom P. Blach[4] — [1]Institute of Chemistry, TU Berlin — [2]Griffith University, Brisbane, Australia — [3]Queensland Micro- and Nanotechnology Centre — [4]Queensland University of Technology, Brisbane, Australia

We consider the dynamics of open quantum systems exhibiting pure decoherence (without disipation) as described by the well known master equations of the so-called Lindblad form. They ensure positivity of the system's reduced density operator, but they also exhibit an unexpected feature: an intrinsic increase of the system's energy [1]. Recently this effect of decoherence has been theoretically shown [2,3] to be of more general character, under the condition that the characteristic time of the process is sufficient short. Here we report first experimental evidence of this surprising effect, in the frame of attosecond neutron Compton scattering (NCS) from protons and deuterons (of gaseous H2 and D2 at 40 K) [4]. Additionally we provide a qualitative theoretical understanding of the experimental results [4]. The observations stand in blatant contradiction to conventional theory, which is based on the Golden Rule and in which quantum correlations [5] and decoherence between probe particle and scatterer play no role.

[1] L. E. Ballentine, Phys. Rev. A 43 (1991) 9. [2] L. S. Schulman and B. Gaveau, Phys. Rev. Lett. 97 (2006) 240405. [3] N. Erez et al., Nature 452 (2008) 724. [4] C. A. C.-Dreismann, E. MacA. Gray and T. P. Blach, AIP Advances 1 (2011) 022118; and Nucl. Instr. Meth. A 676 (2012) 120. [5] K. Modi et al., Rev. Mod. Phys. 84 (2012) 1655.

Q 60.2 Fri 11:30 A 310

Robust entangled qutrit states in atmospheric turbulence — •Tobias Brünner[1] and Filippus Stef Roux[2] — [1]Institute of Physics, Albert-Ludwigs University of Freiburg, Hermann-Herder Str.

3, 79104 Freiburg, Germany — [2]CSIR National Laster Centre, P.O. Box 395, Pretoria 0001, South Africa

We consider propagation of entangled photon pairs through atmospheric turbulence, and seek for the entangled qutrit states that are most robust against entanglement decay. Performing optimization of the initial state, we obtain expressions for bipartite qutrit states that retain their initial entanglement longer than the initially maximally entangled states. (arxiv.org/abs/1211.3203)

Q 60.3 Fri 11:45 A 310

Adaptive Resummation of Open Quantum Dynamics — •Felix Lucas[1,2] and Klaus Hornberger[1,2] — [1]Max Planck Institute for the Physics of Complex Systems, Nöthnitzer Straße 38, 01187 Dresden, Germany — [2]University of Duisburg-Essen, Faculty of Physics, Lotharstraße 1-21, 47057 Duisburg, Germany

We introduce a scheme for obtaining analytic approximations to the evolution of Markovian open quantum systems based on the lowest orders of a highly convergent, generalized Dyson series. The expansion is performed in terms of the number of environment-induced quantum jumps, and its rapid convergence is ensured by a resummation that makes use of adaptive transformations of the jump operators. The resulting lowest order terms can be evaluated analytically and provide an effective description of the full open system dynamics. The power of this approach is demonstrated by means of two examples: a free particle, reflected upon detection and the Landau-Zener system in the presence of dephasing. The derived approximations are asymptotically exact and show errors on the per mil level.

Q 60.4 Fri 12:00 A 310

Quantum trajectory description of entanglement dynamics — •Ivonne Guevara[1,2] and Carlos Viviescas[1] — [1]Departamento de Física, Universidad Nacional de Colombia, Carrera 30 No.45-03, Bogotá D.C., Colombia — [2]Centre for Quantum Dynamics, Griffith University, Brisbane, Queensland 4111, Australia

We present and overview of the characterization of the dynamical evolution of entanglement in open quantum system by means of diffusive quantum trajectories. We show how this method allows for a complete description of this phenomenon providing deterministic evolution equations for some experimentally relevant cases, and excellent upper bounds for the entanglement dynamics in some other cases. Remarkably, for a family of entanglement measures, all the information of the entanglement dynamics can be recovered from a single trajectory. For some of the cases considered we propose quantum optical experimental setups which allow for a real time measurement of the entanglement time evolution.

Q 60.5 Fri 12:15 A 310

Entanglement evolution of two entangled OAM photons under the effect of atmospheric turbulence — •Nina Leonhard, Vyacheslav Shatokhin, and Andreas Buchleitner — Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, Germany

Quantum information can be encoded into wave fronts of photons carrying orbital angular momentum (OAM), with an experimentally achieved Hilbert space dimension of several hundred [1]. As such, photons with OAM are very promising for free-space quantum communication. However, free-space links are intrinsically noisy due to atmospheric turbulence, causing distortion of the photon's wave fronts and deterioration of quantum information. In this talk we will discuss the impact of the atmospheric turbulence on the propagation of two OAM-entangled qudits.

[1] R. Fickler et al., Science, **338**, 6107 (2012)

Q 61: Quantum information: Atoms and ions V

Time: Friday 11:00–12:30 Location: E 214

Q 61.1 Fri 11:00 E 214

Heralded entanglement between solid-state qubits separated by 3 meters — •Hannes Bernien[1], Bas Hensen[1], Wolfgang Pfaff[1], Gerwin Koolstra[1], Machiel Blok[1], Lucio Robledo[1], Lilian Childress[2], Tim Taminiau[1], Matthew Markham[3], Daniel Twitchen[3], and Ronald Hanson[1] — [1]Kavli Institute of Nanoscience Delft, The Netherlands — [2]McGill University, Department of Physics, Montreal, Canada — [3]Element Six, Ltd., Ascot, United Kingdom

Here we present our most recent results towards the realization of scalable quantum networks with solid-state qubits. We have entangled two spin qubits in diamond, each associated with a nitrogen vacancy center in diamond [1]. The two diamonds reside in separate setups three meters apart from each other. With no direct interaction between the two spins to mediate the entanglement, we make use of a scheme based on quantum measurements: we perform a joint measurement on photons emitted by the NV centers that are entangled with the electron spins. The detection of the photons projects the spins into an entangled state. We verify the generated entanglement by single-shot readout of the spin qubits in different bases and correlating the results.

These results open the door to a range of exciting opportunities. For instance, the remote entanglement can be extended to nuclear spins near the NV center. Our recent experiments demonstrate robust methods for initializing, controlling and entangling nuclear spins by using the electron spin as an ancilla [2,3].

[1] H. Bernien et al., in preparation. [2] T. van der Sar et al., Nature 484, 82 (2012). [3] W. Pfaff et al., Nature Physics (2012).

Q 61.2 Fri 11:15 E 214

Dynamical quantum teleportation — •Christine Muschik[1], Eugene Polzik[2], and Ignacio Cirac[3] — [1]ICFO-Institut de Ciencies Fotoniques, Spain — [2]Niels Bohr Institute, Denmark — [3]Max-Planck-Institute, Germany

We introduce two protocols for inducing non-local dynamics between two separate parties. The first scheme allows for the engineering of an interaction between the two remote systems, while the second protocol induces a dynamics in one of the parties, which is controlled by the other one. Both schemes apply to continuous variable systems, run continuously in time and are based on instantaneous feedback.

Q 61.3 Fri 11:30 E 214

Quantum teleportation of a polarization state of a weak laser pulse to a single atom — •Daniel Burchardt[1], Norbert Ortegel[1], Kai Redeker[1], Julian Hofmann[1], Michael Krug[1], Markus Weber[1], Wenjamin Rosenfeld[1,2], and Harald Weinfurter[1,2] — [1]Ludwig-Maximilians-Universität, München — [2]Max-Planck-Institut für Quantenoptik, Garching

Quantum teleportation enables to transfer the quantum state of a particle to a remote location without sending the particle itself. Here, we report on teleportation of the polarization state of an attenuated laser pulse to a single ^{87}Rb atom stored in an optical dipole trap over a distance of 20 m. In a first step the atomic Zeeman state is entangled with the polarization state of a single photon[1]. The emitted photon interferes with the polarized photon of the laser pulse on a beam splitter enabling a Bell state measurement. This projects the atom to one of four well-defined states depending on the outcome of the Bell state measurement. To achieve a sufficient fidelity one has to ensure that the interfering photons are indistinguishable in all degrees of freedom except polarization. Additionally the Poissonian distribution of the laser source gives rise to a non-vanishing probability for multi-photon pulses. We determine the fidelity of the teleportation process by evaluating the density matrix of the new atomic state. This demonstrates e.g. the possibility of writing quantum states into a remote quantum memory.

[1] J. Volz et al., *Phys. Rev. Lett.*, 2006.

Q 61.4 Fri 11:45 E 214

Efficient teleportation between remote single-atom quantum memories — •Christian Nölleke, Andreas Neuzner, Andreas Reiserer, Carolin Hahn, Gerhard Rempe, and Stephan Ritter — Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Straße 1, 85748 Garching

Teleportation is a prerequisite for the transfer of quantum information over large distances when the losses inherent in any quantum channel preclude a direct transfer. We demonstrate teleportation between two single-atom quantum memories in distant laboratories. By implementing a time-resolved photonic Bell-state measurement (BSM), which is based on two-photon quantum inference, we achieve a teleportation fidelity of 88%, largely determined by our entanglement fidelity. The problem of limited photon collection efficiency in free space is overcome by trapping each atom in an optical cavity. Compared to previous experiments with remote single material qubits, our approach boosts the overall efficiency by almost five orders of magnitude. This results in success probabilities not predominantly limited by the photon generation and collection efficiency but by the transmission and detection losses inherent in the photonic BSM.

Q 61.5 Fri 12:00 E 214

Entanglement quantification by neutron scattering — •Oliver Marty[1], Michael Epping[2], Hermann Kampermann[2], Dagmar Bruss[2], Martin Plenio[1], and Marcus Cramer[1] — [1]Institut f. Theoretische Physik, Universtität Ulm, Ulm, Germany — [2]Institute f. Theoretische Physik III, Heinrich-Heine Universität Düsseldorf, Düsseldorf, Germany

We present studies about the quantification of the entanglement contained in large samples of magnetic materials by structure factor measurements – a standard tool in analysing condensed matter systems. We discuss experimentally relevant models (such as Heisenberg [1], Majumdar-Ghosh and XY models) in different geometries and with different spin numbers. For those, lower bounds to entanglement measures can be read off directly from the cross section obtained in neutron-scattering experiments.

[1] N.B. Christensen *et al.*, Proc. Natl. Acad. Sci. USA, **104**, 15264 (2007)

Q 61.6 Fri 12:15 E 214

Fast and efficient detection of Zeeman states of ^{87}Rb via ionization — •Michael Krug[1], Daniel Burchardt[1], Norbert Ortegel[1], Kai Redecker[1], Julian Hofmann[1], Wenjamin Rosenfeld[1,2], and Harald Weinfurter[1,2] — [1]Ludwig-Maximilians-Universität, München — [2]Max-Planck-Institut für Quantenoptik, Garching

Current experiments in quantum information such as quantum repeaters and atomic quantum computers rely on the capability to read out qubits fast and efficiently. Here we present a novel readout scheme for a qubit encoded in (degenerate) Zeeman states of a single ^{87}Rb atom that fulfills these requirements.

In detail we use a two-photon transition with the first photon resonant to the D_1-line and the second at a wavelength of 445 nm to ionize the atom within 500 ns. For evaluating the scheme we generate entanglement between a spontaneously emitted photon and the Zeeman state of the atom. By measuring the polarisation of the photon we project the atom onto a selected superposition of Zeeman states. This superposition is directly ionized without lifting the degeneracy where the measurement basis is defined by the polarization of the D_1-light. We achieve a read out fidelity of the atom-photon state of 0.95 ± 0.03. Together with the implementation of channel electron multipliers[1] and the generation of entanglement between two separated atoms[2] this will be a key ingredient towards a loophole free test of Bell's inequality.

[1] F. Henkel et al., *Phys. Rev. Lett.* 105, 253001 (2010)
[2] J. Hofmann et al., *Science*, 337, 72 (2012)

Q 62: Ultracold atoms: Manipulation and detection

Time: Friday 11:00–12:30 Location: F 142

Q 62.1 Fri 11:00 F 142

Direct synthesis of light polarization for state-dependent transport of atoms — •Carsten Robens, Andreas Steffen, Anna Hambitzer, Noomen Belmechri, Andrea Alberti, Wolfgang Alt, and Dieter Meschede — Institut für Angewandte Physik der Universität Bonn,Wegelerstr. 8,53115 Bonn

Coherent control of individual atoms in optical lattices have recently proven to be a key asset in simulating physical phenomena, spanning from quantum transport effects typical of solid state physics to artificial gauge fields.

We report on a new approach to transport neutral atoms state-dependently in a spin-dependent optical lattice. The scheme is based on direct synthesis of light polarization by employing RF sources integrated with acousto-optic modulators for phase control.

The optical lattice is formed by superimposing two circularly polarized lattices. An optical phase-locked loop allows us to control with interferometric precision the phase difference between the two lattices. The phase directly corresponds to the relative displacement of the two lattices.

Applying this method to a digital atom interferometer [1], we envisage macroscopic splitting over spatial distances up to 10mm, about a million times larger than the size of each component of the split atom.

[1] A. Steffen, A. Alberti, W. Alt, N. Belmechri, S. Hild, M. Karski, A. Widera and D. Meschede, PNAS109, 9770 (2012)

Q 62.2 Fri 11:15 F 142

Coherent manipulation of cold cesium atoms in a nanofiber-based two-color dipole trap — •Daniel Reitz, Rudolf Mitsch, Clement Sayrin, Philipp Schneeweiss, and Arno Rauschenbeutel — Vienna Center for Quantum Science and Technology, TU Wien, Atominstitut, Stadionallee 2, A-1020 Wien, Austria

We have recently demonstrated a new experimental platform for trapping and optically interfacing laser-cooled cesium atoms. The scheme uses a two-color evanescent field surrounding an optical nanofiber to localize the atoms in a one-dimensional optical lattice 200 nm above the nanofiber surface. In order to use this fiber-coupled ensemble of trapped atoms for applications in the context of quantum communication and quantum information processing, non-classical states of the atomic spins have to be prepared and should live long enough to allow one to apply successive quantum gates. The close proximity of the trapped atoms to the nanofiber surface and the strong polarization gradients of nanofiber-guided light fields are potentially important sources of decoherence. Here, we present our latest experimental results on the coherence properties of atomic spins in our nanofiber-based trap. Using a microwave field to drive the clock transition, we determine inhomogeneous and homogeneous dephasing times by Ramsey and spin echo techniques, respectively. Our results constitute the first measurement of the coherence properties of atoms trapped in the vicinity of a nanofiber and represent a fundamental step towards establishing nanofiber-based traps for cold atoms as a building block in a quantum network.

Q 62.3 Fri 11:30 F 142

Atom lens without chromatic aberrations — •Maxim A. Efremov[1], Polina V. Mironova[2], and Wolfgang P. Schleich[1] — [1]Institut für Quantenphysik and Center for Integrated Quantum Science and Technology (IQST), Universität Ulm, 89081 Ulm, Germany — [2]Theoretische Quantendynamik, Institut für Angewandte Physik, Technische Universität Darmstadt, 64289 Darmstadt

We propose a lens for atoms with reduced chromatic aberrations and calculate its focal length and spot size. In our scheme a two-level atom interacts with a near-resonant standing light wave formed by two running waves of slightly different wave vectors, and a far-detuned running wave propagating perpendicular to the standing wave. We show that within the Raman-Nath approximation and for an adiabatically slow atom-light interaction, the phase acquired by the atom is independent of the incident atomic velocity.

Q 62.4 Fri 11:45 F 142

Optomechanics with an atomic array in a cavity — •Oxana Mishina and Giovanna Morigi — Theoretische Physik, Universität des Saarlandes, D-66041 Saarbrücken, Germany

Cold atomic ensembles inside an optical cavities are good candidates for exploring quantum aspects of optomechanical coupling. An interesting perspective emerges in the configuration when the atoms are confined by an external periodic potential inside a high-finesse resonator. We present a theoretical model describing the optomechanical coupling of the atomic array with a single mode light in a cavity and investigate cooling of the atomic motion to the ground state of the individual wells. We reproduce the dynamics observed in [1]. Moreover, we investigate further experimental regimes and find that arrays with tens of atoms can be cooled down to the ground state within few milliseconds for accessible experimental parameters. These results set the starting point for the exploration of the light-phonon interface and possibly novel quantum states of motion.

[1] Optomechanical Cavity Cooling of an Atomic Ensemble M.H., Schleier-Smith, I.D. Leroux, H. Zhang, M.A. Van Camp, and V. Vuletić, Phys. Rev. Lett. 107, 143005 (2011)

Q 62.5 Fri 12:00 F 142

Heterodyne spectroscopy of single atom motional states inside a high-finesse cavity — •René Reimann, Wolfgang Alt, Tobias Kampschulte, Sebastian Manz, Natalie Thau, Seokchan Yoon, and Dieter Meschede — Institut für Angewandte Physik der Universität Bonn, Wegelerstr. 8, 53115 Bonn

Tight control and knowledge of the motional states of single atoms are a prerequisite for many experiments connected to the field of quantum information. In our system insight to the motional states of single atoms coupled to a high finesse optical resonator is gained by the means of optical heterodyne detection. Measuring the beat signal between a fixed-frequency local oscillator beam and the light interacting with the coupled atoms, we are able to map the atomic motional state to the frequency domain in a non-destructive way. Analysing the spectra we discuss different experimental imperfections and estimate the intra-cavity atomic temperature within the frame of a simple model.

Q 62.6 Fri 12:15 F 142

Optimal control of effective Hamiltonians — •Albert Verdeny Vilalta[1], Cord A. Müller[2], and Florian Mintert[1] — [1]Freiburg Institute for Advanced Studies, Albert-Ludwigs University of Freiburg, Freiburg 79104, Germany — [2]Centre for Quantum Technologies, National University of Singapore, Singapore 117543, Singapore

Periodically driven Hamiltonians can be approximately described by a time-independent effective Hamiltonian if the driving is sufficiently fast. There exist, however, many different drivings that result in the same effective Hamiltonian. Using optimal control techniques, we investigate which driving yields the best approximation to the dynamics induced by a desired effective Hamiltonian. The viability of our approach is proven for the simplest example of a driven three-level Lambda system, and shall ultimately help to improve the precision of quantum simulations.

Q 63: Photonics IV

Time: Friday 14:00–16:00 Location: F 128

Q 63.1 Fri 14:00 F 128

On-chip optical isolation based on non-reciprocal resonant delocalization effects — •Ramy El-ganainy[1], Pradeep Kumar[2], and Miguel Levy[2] — [1]Max Planck Institute for the Physics of Complex Systems, Nothnitzer street 38, 01187 Dresden, Germany — [2]Department of Physics, Michigan Technological University, Houghton, Michigan 49931

Optical isolators are very essential components in most optical systems. These devices operate as optical diodes- allowing light to propagate only in one direction and block any reflected signal. We propose a novel optical isolator device design that is based on integrated optics waveguide technology. The proposed device consists a modulated optical Bloch lattice that exhibits a refractive index ramp and periodic coupling constants between next neighbor optical channels along the propagation direction. Non-reciprocal resonant delocalization effects are introduced in these structures by depositing magnetic cover layer on top of the waveguides. Our analytical and numerical results show that large bandwidth high isolation ratios of -45 dB can be achieved at the telecommunication wavelength

Q 63.2 Fri 14:15 F 128

High Aspect Ratio Micro-Rod Arrays as 2D Photonic Crystal Structures — •Christian Kraeh[1], Markus Schieber[2], Alexandru Popescu[2], Harry Hedler[2], Martin Zeitlmair[1], and Jonathan Finley[1] — [1]Walter Schottky Institut, Technische Universität München, 85748 Garching — [2]Siemens AG, Corporate Technology, 81739 München

We are developing novel photonic crystal structures made of high aspect ratio micro-rod arrays. The fabrication of these rods is based on the creation of macroporous Si by a wet-chemical etching technique and subsequent filling of the pores and selective etching of the Si substrate. Due to their high aspect ratio the rods exhibit almost ideal 2D optical properties. Simulations show that they can be used as optical bandgap materials.

A potential application of these structures is a photonic crystal based gas detection system in which the photonic crystal is used to reduce the optical absorption path.

Q 63.3 Fri 14:30 F 128

Photonic Crystals for Improved Light Extraction from Scintillators: Impact of Scintillator Parameters — •Christof Thalhammer[1], Alexandru Popescu[2], Harry Hedler[2], and Thoralf Niendorf[1] — [1]Berlin Ultrahigh Field Facility (B.U.F.F.), Max-Delbrueck Center für Molekulare Medizin, Berlin — [2]Corporate Technology, Siemens AG, München

Photonic crystals bear the potential to improve the light extraction from scintillator crystals used in high energy physics and medical imaging applications. Because of their periodic structure with dimensions in the range of the wavelength of incident light, photonic crystals can manipulate photon propagation in a significant way. In this study, Rigorous Coupled Wave Analysis has been used in conjunction with Monte Carlo simulations to investigate the performance of two-dimensional photonic crystal coatings for various scintillator configurations, including different geometries and crystal wrappings. Their impact on the detector performance is discussed and preparations of the experimental verification are presented.

Q 63.4 Fri 14:45 F 128

Effect of Domain Shape on Noncollinear Second-Harmonic Emission in Disordered Quadratic Media — •Markus Passlick[1], Mousa Ayoub[1], Philip Roedig[1], Kaloian Koynov[2], Jörg Imbrock[1], and Cornelia Denz[1] — [1]Institut für Angewandte Physik Westfälische Wilhelms-Universität Münster, 48149 Münster, Germany — [2]Max Planck Institut für Polymerforschung, 55128 Mainz, Germany

Nonlinear parametric processes are known to depend critically on phase matching between the phase velocities of the interacting waves. Phase matching is mostly achieved using conventional methods like crystal birefringence in homogeneous nonlinear optical media, or quasi-phase matching technique in periodically poled media. Recently, randomly structured multi-domain media have attracted a lot of interest for frequency conversion, because they allow a tunable phase-matched second-harmonic generation (SHG) practically in the whole transparency range of the crystal. However, these applications require adapted methods of phase matching. In this contribution, we study the role of the individual ferroelectric domain shape in SH emission in strontium barium niobate (SBN). The noncollinearly emitted SH signal is scanned in the far-field at different incident angles for different domain size distributions. This offers a possibility to retrieve the distribution of the Fourier coefficients, corresponding to the spatial domain distribution and the domain shape. Based on microscopic images of domain structures in SBN, domain patterns are simulated, the SH intensities are calculated, and finally compared with the measurements.

Q 63.5 Fri 15:00 F 128

Polarization of Random-Lasing Modes under Weak Localization — •Sebastian Knitter, Michael Kues, Michael Haidl, and Carsten Fallnich — Westfälische Wilhelms-Universität Münster

When the diffusive losses induced by strong scattering in a random optical medium are compensated by gain, a recurrent stimulated amplification can arise. The resulting coherent light field is often referred to as “Random-Lasing” (RL) and is associated with narrow peaks atop the regular fluorescence spectrum of the amplifying component [1].

By using a novel single-shot spectro-polarimetric technique [2], we have shown earlier how the emission polarization of weakly scattering organic-dye RL can be manipulated [3] (mean free path $l_t > 100$ μm). Our most recent study however, is concerned with RL modes in the weakly-localized regime (l_t of a few μm). Here a static assembly of Zinc oxide nanoparticles was used to provide strong scattering and amplification at the same time.

An excitation of the medium with ps-pulses at 355 nm lead to sharp RL modes, which reproduced very well in spectrum and polarization over more than 2000 pump-laser shots. The exact shape of the emission spectra was characteristic to any given sample position. Also the RL mode-polarization and spectrum were strongly affected by the pump polarization, as expected from FDTD-simulations.

[1] H. Cao et al., Journal of Physics A, 38 (2005)
[2] S. Knitter et al., Opt. Lett., 36, 16 (2011)
[3] S. Knitter et al., Opt. Lett., 37, 17 (2012)

Q 63.6 Fri 15:15 F 128

Numerische Untersuchungen zu anisotrop verstärkten laseraktiven randomisierten Medien — •Michael Haidl, Michael Kues, Sebastian Knitter und Carsten Fallnich — Institut für Angewandte Physik, Westfälische Wilhelms-Universität, Münster, Deutschland

In konventionellen Lasern formen Spiegel zur optischen Rückkopplung einen Resonator, der durch optische Verstärkung aufgrund von stimulierter Emission entdämpft und zur Oszillation angeregt wird. Bei Random Lasern erfolgt die Rückkopplung z.B. durch streuende Partikel.

Mittels einer dreidimensionalen numerischen Simulation konnte erstmals der Einfluss anisotroper Verstärkung, wie sie etwa in flüssigen Farbstoffen [1] oder Halbleitermaterialien wie Zink-Oxid [2] existiert, auf Emissionsspektren sowie die Polarisation spektraler Moden von Random Lasern berechnet werden. Die Spektren zeigen eine Abhängigkeit von der Anisotropie der Verstärkung, die im Experiment über die Polarisation der Pumpstrahlung eingeht und eingestellt werden kann. Experimentelle Ergebnisse [1] konnten mit Hilfe der numerischen Untersuchungen bestätigt werden. Darüber hinaus wurden klare Unterschiede im Verhalten der Polarisation spektraler Moden zwischen dem diffusiven und dem schwach lokalisierten Regime festgestellt.

[1] S. Knitter *et al.*, Optics Letters **37**, 17 (2012)
[2] R. Klucker *et al.*, Phys. Stat. Sol. (b) **45**, 265 (1971)

Q 63.7 Fri 15:30 F 128

Anderson localization in optically induced photonic random structures — •Sebastian Brake, Martin Boguslawski, Patrick Rose, and Cornelia Denz — Institut für Angewandte Physik and Center for Nonlinear Science (CeNoS), Westfälische Wilhelms-Universität Münster, 48149 Münster, Germany

Anderson localization is one of the most intriguing effects in solid state physics where an electron may be localized in dependence on the disorder of the surrounding crystal lattice. Since the effect is based on wave phenomena, Anderson localization has recently been discovered for light waves in several systems as e.g. random granular media.

In this contribution, we demonstrate light localization in optically induced two-dimensional photonic random lattice structures. Using the so-called optical induction technique, we are able to create reconfigurable refractive index patterns in a nonlinear optical medium. In contrast to previous realizations, our approach is based on a computer-controlled spatial light modulator that is used to generate structured nondiffracting beams with a tremendous flexibility. This class of beams that provides complex transverse intensity structures while being invariant in the direction of propagation is the foundation of our flexible approach for the generation of complex random structures.

We report our results on the experimental observation of Anderson localization in these structures and show how the localization can be controlled. We find that the localization length depends both on the strength of the refractive index modulation as well as on the structural size of the induced photonic random structure.

Q 63.8 Fri 15:45 F 128

3D Photonic Crystals from Rolled Membranes — •Silvia Giudicatti, Matthew R. Jorgensen, and Oliver G. Schmidt — Institute for Integrative Nanosciences, IFW-Dresden, Helmholtzstrasse 20, D-01069 Dresden, Germany

Photonic crystals are periodically patterned dielectric materials which allow the control of light thanks to forbidden frequencies ranges (photonic band gaps). Their properties make them interesting candidates for a large number of applications, such as the control of spontaneous emission for light amplification, lasing, quantum information, photovoltaics and photocatalysis. In particular, 3D photonic crystals promise to offer unprecedented opportunities. However, their fabrication requires sophisticated methods that mainly allow the preparation of devices suitable for applications in the near infrared and longer wavelengths. Regarding visible frequencies, examples are limited to partial band gap materials and those templated from biological samples.

We propose 3D photonic crystals achieved by applying rolled-up technology to pre-patterned 2D membranes. A combined control of the structural parameters such as the membrane thickness and composition, the geometry of the 2D lattice and the rolling direction makes a variety of crystal families accessible. Among them, the diamond structure can also be obtained. A theoretical investigation has been carried out to identify the structural parameters resulting in the best band gap. The effects of the finite size as well as the bending have been also considered. The results of the theoretical analysis will be presented together with some preliminary tests for the system fabrication.

Q 64: Precision measurements and metrology VI

Time: Friday 14:00–15:45 Location: E 001

Q 64.1 Fri 14:00 E 001

A long reference cavity with contribution from thermal noise to frequency instability of below 10^{-16} — •Sebastian Häfner, Stefan Vogt, Stephan Falke, Christian Lisdat, and Uwe Sterr — Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig

The stability of current optical clocks is limited through the short-term stability of the interrogation laser. Here, we will focus on the reference cavity of the clock laser system, whose mechanical length stability provides the frequency stability of the clock laser. The length stability of well designed and operated cavities is limited by the Brownian motion of the materials, especially of the mirrors. This influence can be reduced by using longer cavities at the cost of a higher sensitivity to vibrations and more difficult thermal control.

Our laser system uses a 47.7 cm long ULE high finesse cavity which is to our knowledge the longest cavity ever used for frequency stabilization of a laser, with expected frequency instability from thermal noise of $\Delta\nu/\nu = 8 \cdot 10^{-17}$. We have designed a new cavity mounting which shows a measured acceleration sensitivity of $\Delta l/l = 4 \cdot 10^{-11}/g$ and a precision temperature control system with expected temperature instability of below 10 μK. To fully benefit from the cavities stability, we are planing to control all fluctuations of the optical path length from the end mirror of the cavity to the experiment. This work is supported by the Centre for Quantum Engineering and Space-Time Research (QUEST) and EU through the Space Optical Clocks (SOC2) project.

Q 64.2 Fri 14:15 E 001

Laser ranging for GRACE follow-on — •Daniel Schütze, Gunnar Stede, Vitali Müller, Alexander Görth, Oliver Gerberding, Christoph Mahrdt, Benjamin Sheard, Gerhard Heinzel, and Karsten Danzmann — Max Planck Institute for Gravitational Physics / Albert Einstein Institute Hanover

The joint NASA/DLR mission GRACE (Gravity Recovery and Climate Experiment) successfully collects data about spatial and temporal variations in the gravity field of the earth using satellite-to-satellite tracking via microwave ranging. A GRACE follow-on mission will be launched in 2017. In addition to the conventional microwave ranging system, the GRACE follow-on satellites will also contain a laser ranging instrument to improve the inter-satellite distance measurements. This laser ranging instrument employs heterodyne interferometry with a receiver-transponder principle and phasemeter readout making use of LISA technologies. Essential parts of the laser ranging instrument are a triple mirror assembly to establish an off-axis roundtrip path between the satellites and a steering mirror setup to account for satellite pointing. A laboratory test setup of the GRACE follow-on interferometer is presented with which these key components are tested.

Q 64.3 Fri 14:30 E 001

General Astigmatic Gaussian Beam Model — •Evgenia Kochkina, Dennis Schmelzer, Gudrun Wanner, Gerhard

Heinzel, and Karsten Danzmann — Albert Einstein Institute, Hannover

Optical simulations for space interferometers require accurate beam models in order to predict all interesting effects. In many cases circular or elliptical (simple astigmatic) Gaussian beams are sufficient. When a beam is transformed (reflected or refracted) at a curved interface the plane of incidence is defined by the beam direction and the local normal vector to the interface at the point of incidence. This definition is purely geometrical and doesn't account for physical beam properties, such as intensity or phase distribution. If we assume that the transformed beam is elliptical, we need one of it's semi-axes to lie in plane of incidence in order to use simple astigmatic beam model. In a general 3D case it's not necessarily true. When both semi-axes of the beam ellipse do not lie in the plane of incidence, beam transformations can be described using the general astigmatic Gaussian beam model. Such beams have been described in the literature. To our knowledge however there is no available software implementation or a complete general astigmatic Gaussian model description. We will report on our investigations of the general astigmatic Gaussian beam model, it's implementation in the software and the experiments to verify the simulation results.

Q 64.4 Fri 14:45 E 001

Ultra-stable 39.5 cm long optical cavity with reduced thermal noise — •Sana Amairi and Piet O. Schmidt — QUEST, PTB, Braunschweig , Germany

We are currently setting up an aluminium quantum logic optical clock. $^{27}Al^+$ has been chosen as the clock ion since it has a narrow 8 mHz clock transition at 267 nm which exhibits no electric quadruple shift and a low sensitivity to black-body radiation. The $^{27}Al^+$ clock ion is be trapped together with a $^{40}Ca^+$ ion which is used for sympathetic cooling and internal state detection of the clock ion. The quantum projection noise limited stability $\sigma_y(\tau)$ for Al^+ is in the order of $1 \times 10^{-16}/\sqrt{\tau}$. This stability can only be achieved with an interrogation laser with a sufficiently small linewidth, thermal noise-limited instability and drift. The dominant thermal noise contribution to relative frequency instability in state-of-the art optical cavities comes from the mirror coatings. It scales with the inverse length of the cavity and the inverse square of the laser beam radius on the mirrors, which also increases with the length. Therefore, we have set up a long (39.5 cm) ultra-stable optical cavity made of a ULE spacer and fused silica mirrors. We have performed finite element simulations to estimate a thermal noise limited instability of 7×10^{-17} for such a cavity [1]. Furthermore, we have performed numerical simulations to find optimum support points together with allowed machining tolerances and required force balancing. Besides theoretical estimates, we present first experiments towards the characterization of the cavity. Ref[1]:ArXiv:submit/0614173

Q 64.5 Fri 15:00 E 001

Digital unterstützte heterodyn Interferometrie — •Katharina-Sophie Isleif, Sina Köhlenbeck, Oliver Gerberding, Stefan Gossler, Gerhard Heinzel und Karsten Danzmann — Albert-Einstein-Institut Hannover, Max-Planck-Institut für Gravitationspyhsik und Institut für Gravitationsphysik der Universität Hannover, Callinstraße 38, 30167 Hannover, Deutschland

Heterodyne Laserinterferometrie ist eine der wichtigsten Technologien für präzise Längenänderungsmessungen, die bereits bei den Missionen LISA und LISA Pathfinder zur Anwendung kommt. Digital unterstützte heterodyne Interferometrie ist eine Erweiterung hiervon. Hier wird eine digital erzeugte binäre Pseudozufallszahlenfolge auf die Phase des Lichts in einem Interferometerarm mit Hilfe eines EOM's moduliert. Durch anschließende digitale Decodierung mit derselben Pseudozufallszahlenfolge mit unterschiedlichen Verzögerungen können die Laufwege mehrerer Laserstrahlen eines Strahlenganges separiert werden. Dadurch wird es möglich, mehrere Interferometer gemeinsam auszulesen und die Messempfindlichkeit durch Unterdrückung gemeinsamer Rauschquellen signifikant zu verbessern. Momentan wird am Albert Einstein Institut in Hannover an einem bestehenden Aufbau geforscht, der diese Technologie bereits verwendet.

In diesem Vortrag wird der aktuelle Stand des Interferometers vorgestellt. Die bisher erreichte Messempfindlichkeit beträgt $3\mathrm{pm}/\sqrt{\mathrm{Hz}}$ bei 10Hz. Indem der bisher verwendete Laser auf einen frequenzstabileren iodstabilisierten Laser gelockt wird, erwarten wir eine Verbesserung der Sensitivität unterhalb 10Hz.

Q 64.6 Fri 15:15 E 001

Coating thermal noise interferometer — •Tobias Westphal and the AEI 10m Prototype team — Max-Planck-Institute for Gravitational Physics (Albert-Einstein-Institut) and Leibniz University Hannover

Coating thermal noise (CTN) is getting a more and more significant noise source for high precision experiments and metrology. It arises from mechanical losses in the dielectric coatings applied to mirrors to achieve high reflectivity. Deeper understanding and verification of its theory requires direct (off-resonant) observation.

The AEI 10 m Prototype facility is probably the best suited environment for this kind of experiment in a frequency range of special importance for earth bound gravitational wave detectors. A pre-isolated platform shows three to four orders of magnitude attenuated seismic noise inside ultra-high vacuum. Up to 10 W highly stabilized (frequency as well as amplitude) laser power at 1064 nm will be available for experiments.

In this talk the CTN- interferometer being at the transition from design to construction phase will be presented. The range solely limited by CTN is designed to reach from 10 Hz to about 50 kHz, limited by seismic noise at low frequencies and shot noise (photon counting noise) at high frequencies.

Q 64.7 Fri 15:30 E 001

Control of optical cavities in light-shining-through-a-wall experiments — •Robin Baehre — Max-Planck-Institute for Gravitational Physics (Albert-Einstein-Institute), Callinstr. 38, 30167 Hannover, Germany

Light-shining-through-a-wall (LSW) experiments are a straightforward approach to laboratory searches for weakly interacting sub-eV particles (WISPs), which are considered as a viable candidate for cold dark matter. WISPs, which exhibit coupling to a photon field, can be produced from a laser beam, which is shone on a solid wall. Due to their weak coupling to ordinary matter, WISPs can transverse the wall, which is opaque to photons, and can reconvert into photons afterwards and consequently be detected by a photon detector. LSW experiments often suffer from the fact that WISP fluxes produced in the laboratory are much smaller than those from astronomical sources. However, LSW searches can be considerably improved by fully exploiting the benefits of using coherent laser light to the production and regeneration process. Using optical resonators on the production and regeneration side helps to probe for very small WISP-photon couplings and to explore the parameter space that can be deduced from observations of anomalous white dwarf cooling and transparency of the universe to TeV photons. I will focus my tak on the optical design of ALPS-II with the implementation of production and regeneration resonator and explain how the demanding requirements on spatial and spectral stability can be fulfilled by application of optical precision measurement and control with picometer accuracy.

Q 65: Quantum gases: Bosons III

Time: Friday 14:00–16:00 Location: F 342

Group Report Q 65.1 Fri 14:00 F 342

Laser cooling to quantum degeneracy — •Simon Stellmer[1], Benjamin Pasquiou[1], Alex Bayerle[1,2], Slava Tzanova[1], Florian Vogl[2], Rudolf Grimm[1,2], and Florian Schreck[1] — [1]Institut für Quantenoptik und Quanteninformation, Innsbruck, Austria — [2]Institut für Experimentalphysik und Forschungszentrum für Quantenphysik, Innsbruck, Austria

So far, every cooling method capable of reaching BEC in dilute gases relied on evaporative cooling as the last and crucial cooling stage. Laser cooling to BEC has been strongly discussed middle of the 1990s, but the experimental capabilities of that time were insufficient to reach this goal. Choosing strontium as the atomic species allows for a new approach.

We prepare a sample of ^{84}Sr atoms in a large-volume *reservoir* dipole trap, constantly illuminated by cooling light on the narrow intercombination line that fixes the temperature to 800 nK. The density in the central region of the gas is increased by ramping up a *dimple* dipole trap. At the same time, we apply a *transparency* beam to this region of the sample. This beam is blue-detuned from a transition originating from the upper cooling state and selectively shifts this state out of resonance by 10^3 linewidths. Elastic collisions lead to a rapid accumulation of atoms in the dimple and ensure thermalization between the dimple and reservoir regions. A BEC of 10^5 atoms forms on a timescale of a few 10 ms. Laser cooling is the only cooling mechanism involved, while elastic collisions are indispensable for thermalization. This work holds prospects for the generation of a continuous atom laser.

Q 65.2 Fri 14:30 F 342

Universality of the Unitary-Limited Three-Body Loss Rate in Bosonic Systems — •Ulrich Eismann[1,2], Li-Chung Ha[1], Logan Clark[1], Eric Hazlett[1], Shih-Huang Tung[1], and Cheng Chin[1] — [1]The James Franck Institute and Department of Physics, University of Chicago, Chicago, IL 60637, USA — [2]Laboratoire Kastler Brossel, ENS, UPMC, CNRS UMR 8552, 24 rue Lhomond, 75231 Paris, France

In recent years, the tunability of quantum gases has become an standard experimental tool. It is established by exploiting magnetic Feshbach resonances in alkali atom collisions. In bosonic systems, however, strong interactions are accompanied by enhanced three-body loss, which therefore is an important practical limitation for tuning. However, apart from being a nuisance, three-body loss itself represents an important observable, and can be used to probe nonclassical correlations and few-body physics like the Efimov effect [1].

We present measurements of the temperature-dependent three-body loss rate in ultracold Bose gases at unitarity, where the two-body scattering amplitude becomes resonant. Experimentally, we exploit the d-wave Feshbach resonance near 48 G in the lowest hyperfine ground state of cesium-133. We confirm former measurements performed in the lithium-7 system [2] on a more than ten times higher temperature scale, providing evidence of universality of the unitary three-body loss rate. Given our excellent signal-to noise ratio, we discuss the experimental observability of Efimov-like oscillations in the loss spectrum.

[1] V. Efimov, Phys. Lett. B **33**, 563 (1970).
[2] U. Eismann, Ph.D. thesis, Université P. et M. Curie (2012).

Q 65.3 Fri 14:45 F 342

Density correlation of a mixture of ultracold atoms in an optical lattice — •Vladislav Gavryusev[1,2,3], Stefano Conclave[1,2], Giacomo Lamporesi[1,2], Devang Naik[1,2], Francesco Minardi[1,2], and Massimo Inguscio[1,2] — [1]LENS-European Laboratory for Non-Linear Spectroscopy and Dipartimento di Fisica, Universitá di Firenze, via N. Carrara 1, IT-50019 Sesto Fiorentino-Firenze, Italy — [2]CNR-INO, via G. Sansone 1, IT-50019 Sesto Fiorentino-Firenze, Italy — [3]Physikalisches Institut, Universitatät Heidelberg, Philosophenweg 12, 69120 Heidelberg, Germany

At LENS we have an experimental apparatus that can produce a double Bose-Einstein condensate of ^{87}Rb and ^{41}K atoms and trap it in a 3D optical lattice. The atomic sample is well described by the double species Bose-Hubbard model and its parameters can be experimentally controlled with great precision by varying the power of the trapping laser and by applying magnetic fields. We are interested in the arrangement of the atoms in the lattice and for this we require diagnostic methods that can access the relevant observables. We make use of the Hanbury Brown and Twiss effect, which, if there is a regular ordering of the atoms in the lattice, leads to the presence of a correlation in the fluctuations of the atomic density, caused by the quantum statistics of bosonic particles. Different orderings lead to different correlation patterns, allowing to discriminate "ferromagnetic" and "antiferromagnetic" phases. We validated our technique by studying the single species case and now we are making progress on applying this method to the double species case.

Q 65.4 Fri 15:00 F 342

Correlations of photonic BEC in a micro resonator — •Tobias Rexin[1], Carsten Henkel[2], and Axel Pelster[3] — [1]Zentrum für Optische Quantentechnologien and Institut für Laserphysik,Universität Hamburg, 22761 Hamburg, Germany — [2]Institut für Physik und Astronomie, Universität Potsdam, 14469 Germany — [3]Fachbereich Physik, Technische Universität Kaiserslautern, 67663 Kaiserslautern, Germany

Light confined in a microcavity [1] is described by Maxwell's equations with appropriate boundary conditions. A careful analysis of the corresponding boundary value problem in suitable coordinates provides a systematic approach to determine the underlying mode functions for the cavity photon field. In paraxial approximation this three-dimensional microcavity problem can be reduced to an effective two-dimensional trapped massive Bose gas which supports the heuristic derivation of Ref. [2]. The obtained quantized photon field with its mode structure can be used to determine various thermodynamic and statistical quantities such as critical particle number and correlation functions. In particular we present the correlation for the cavity photons at finite temperature.

[1] J. Klaers, F. Vewinger, and M. Weitz, Nature Physics 6, 512 (2010).
[2] J. Klaers, J. Schmitt, F. Vewinger, and M. Weitz, Nature 468, 545 (2010).

Q 65.5 Fri 15:15 F 342

Defect-induced supersolidy with soft-core Bosons — •Fabio Cinti[1], Tommaso Macri[1], Wolfgang Lechner[2], Guido Pupillo[3], and Thomas Pohl[1] — [1]Max Planck Institute for the Physics of Complex Systems, 01187 Dresden, Germany — [2]IQOQI and Institute for Theoretical Physics, University of Innsbruck, 6020 Innsbruck, Austria — [3]ISIS (UMR 7006) and IPCMS (UMR 7504), Universite' de Strasbourg and CNRS, Strasbourg, France

More than 40 years after its conjecture by Andreev, Lifshitz and Chester the possible existence of continuous-space supersolids due to delocalized zero-point defects still remains under active debate. Here we show that soft-core Bosons confined to two-dimensions give rise to the emergence of this elusive state. We present a detailed study of the zero-temperature phase-diagram in the strongly coupled regime and identify conditions for defect-induced supersolidity, i.e. for the formation of an incommensurate crystal in the ground state of the system. In addition to displaying supersolidity the phase diagram shows a rich structure and contains other interesting phases, such as commensurate supersolid.

Q 65.6 Fri 15:30 F 342

Thermodynamics of ultracold Bose gases at a dimensional crossover — •Ralf Labouvie, Andreas Vogler, Vera Guarrera, and Herwig Ott — Research Center OPTIMAS, TU Kaiserslautern, 67663 Kaiserslautern

We have studied the thermodynamics of ultracold Bose gases in the crossover from a three-dimensional to a one-dimensional regime.

In our experiment, we use a focussed electron-beam to probe in situ atomic density distributions with high temporal and spatial resolution. Starting with a Bose-Einstein-Condensate in a single beam optical dipole trap we can create one-dimensional systems by loading the atoms in a two-dimensional blue-detuned optical lattice. With increasing strength of the lattices we go from a three-dimensional into a one-dimensional system. Furthermore we tune the interaction strengths of the one-dimensional quantum-gases from weak (quasi-condensate) to strong (Tonks-Girardeau). By measuring the density profiles and applying an inverse Abel-Transformation we extract the equation of states of these systems and characterize the crossover from the three-dimensional to the one-dimensional regime.

Q 65.7 Fri 15:45 F 342

Coherence properties of Bose-Einstein condensates in an optical storage ring — •Johannes Küber[1], Thomas Lauber[1], Felix Schmaltz[1], Jordi Mompart[2], and Gerhard Birkl[1] — [1]Institut für Angewandte Physik, Technische Universität Darmstadt, Schlossgartenstraße 7, 64289 Darmstadt — [2]Departament de Física, Universitat Autònoma de Barcelona, E-08193 Bellaterra, Spain

We present experiments with Bose-Einstein condensates (BEC) performed in an optical storage ring.

The optical storage ring is a combination of a blue detuned double-ring trapping potential which is formed by conical refraction and a red detuned lightsheet potential which supports the atoms against gravity. The ring shaped trapping potential is created by a birefringent crystal which is appropriately polished and aligned along one of the optical axes. The resulting image in the focal plane resembles two bright rings with a dark ring in between. The trapping potential is loaded with an all-optical BEC created with an multi-mode fiber laser at 1070nm.

The experiments performed in the optical trapping potential show that a coherent transport in this novel structure is possible. The measured coherence length of $(2.53 \pm 0.75)\mu m$ of a wave packet traveling in the potential resembles the coherence length of a BEC at rest after condensation. Additionally we show different loading techniques of the ring and ongoing analysis of interferometric measurements of BEC in our ring shaped potential.

Q 66: Quantum effects: Entanglement and decoherence II

Time: Friday 14:00–15:45 Location: A 310

Group Report Q 66.1 Fri 14:00 A 310

Entanglement between two defects mediated by a surrounding chain — •Bruno G. Taketani[1], Thomás Fogarty[2], Endre Kajari[1], Pierre Wendenbaum[1,3], Alexander Wolf[1], Dragi Karevski[3], Thomas Busch[2], and Giovanna Morigi[1,4] — [1]Universität des Saarlandes, Saarbrücken, Germany — [2]University College Cork, Cork, Ireland — [3]Université de Lorraine, Nancy, France — [4]Universitat Autònoma de Barcelona, Bellaterra, Spain

Bath-mediated entanglement between two objects refers to the generation of entanglement between two physical systems which originates from the coupling with a common reservoir. Examples have been reported showing situations where the generated entanglement is stationary. An open question is how stationary entanglement, generated by the coupling with a bath scales with the distance between the objects. We consider this question by analysing two impurity defects embedded in a crystal structure, like an array of ions in a Paul trap. Entanglement is found for sufficiently cold chains and for a certain class of initial, separable states of the defects. It results from the interplay between localized modes which involve the defects and the interposed ions, it is independent of the chain size, and decays slowly with the distance between the defects. These dynamics can be observed in systems exhibiting spatial order: viable realizations are optical lattices, optomechanical systems, or cavity arrays in circuit QED.

These studies are then extended to the case in which instead of oscillators one considers a spin chain embedding two defect spins.

Q 66.2 Fri 14:30 A 310

Smooth Optimal Control of Nitrogen-Vacancy Centers — •Björn Bartels[1], Tobias Nöbauer[2], Johannes Majer[2], and Florian Mintert[1] — [1]Freiburg Institute for Advanced Studies, Albert-Ludwigs-Universität Freiburg, Albertstr. 19, 79104 Freiburg, Germany — [2]Vienna Center for Quantum Science and Technology, Atominstitut, Technische Universität (TU) Wien, Stadionallee 2, 1020 Vienna, Austria

We present pulse shaping techniques that allow us to control ensembles of NV centers with external time-dependent fields that contain only a few predefined frequency components. By doing this, we respond to experimental challenges in implementing the broad band pulses typically generated with existing optimal control algorithms. With our approach we target the design of control pulses for the manipulation of ensembles of NV centers and the interaction of such ensembles with microwave cavities. We construct high fidelity pulses that cope with inhomogeneous broadening in the ensemble as well as inhomogeneity in the control field itself.

Q 66.3 Fri 14:45 A 310

Dissipative preparation of steady-state multipartite entanglement — •Cecilia Cormick, Alejandro Bermudez, Susana F. Huelga, and Martin B. Plenio — Universität Ulm, Institut für Theoretische Physik, Ulm, Germany

We propose a method to create multipartite-entangled states of spin systems by means of engineered dissipative processes. The model we consider consists of a spin chain along which excitations are allowed to hop, while the on-site energy can be shifted by the coupling to a harmonic oscillator. We show that for small chains, by damping the harmonic oscillator the system can be driven towards an entangled asymptotic state which corresponds to the ground state of an XX spin chain with transverse field. We discuss the role of non-Markovianity of the environment and propose an implementation using ions in a linear trap.

Q 66.4 Fri 15:00 A 310

Quantum-Dense Read-Out for Interferometric Measurements — •Melanie Meinders, Sebastian Steinlechner, Jöran Bauchrowitz, Helge Müller-Ebhardt, Karsten Danzmann, and Roman Schnabel — Institut für Gravitationsphysik, Leibniz Universität Hannover and Max-Planck-Institut für Gravitationsphysik (Albert-Einstein-Institut), Callinstr. 38, 30167 Hannover, Germany

The sensitivity of interferometric measurements is affected by scattered, frequency shifted photons, so-called parasitic interferences [1]. In gravitational-wave detectors, parasitic interferences are possibly already a limiting factor in the lower audio-band. Future detectors that use higher laser powers will even be stronger disturbed by this kind of noise. In this talk we present a new read-out scheme which allows for the detection of two orthogonal quadratures with uncertainties below that of the meter's ground state. In contrast to science signals in the phase quadrature, parasitic signals due to scattered light have an arbitrary orientation in phase space. Therefore, our read-out scheme can be utilized to identify such signals. The scheme uses entangled, two-mode-squeezed states of light and was experimentally demonstrated on the basis of a table-top Michelson interferometer. In our setup a non-classical noise suppression of ~6dB was achieved in both quadratures.

[1] H. Vahlbruch, S. Chelkowski, K. Danzmann, R. Schnabel, Quantum engineering of squeezed states for quantum communication and metrology, New J. Phys. 9, 371 (2007).

Q 66.5 Fri 15:15 A 310

Dissipative Preparation of Spin Squeezed Atomic Ensembles in a Steady State — •Johannes Otterbach[1], Emanuele Dalla Torre[1], Eugene Demler[1], Vladan Vuletic[2], and Mikhail Lukin[1] — [1]Physics Department, Harvard University — [2]Physics Department, Massachussetts Institute of Technology

Spin squeezed states have attracted substantial interest over the last decades from fundamental and application points of view to study many-body entanglement and improve high-precision spectroscopy. One limiting factor for squeezing is the coupling to the environment which usually has detrimental effects on the generation and entanglement fidelity of these states. Here we present a scheme for the deterministic generation of spin squeezed states in coherently driven atomic ensemble of effective spin-1/2 particles collectively interacting with a strongly decaying cavity mode, thus turning dissipation into a resource for entanglement. We show that there exists a dark-state of the cavity dissipation exhibiting squeezing bounded only by the Heisenberg limit and calculate the timescale to reach this state. Upon taking spontaneous atomic scattering into account we find that the steady state is unique and independent of the initial state, and thus squeezing is generated by optical pumping. Finally we determine the general scaling of the squeezing as a function of the single-atom cooperativity and the number of atoms.

Q 66.6 Fri 15:30 A 310

Entanglement of two trapped ions via an optical resonator — •Bernardo Casabone[1], Konstantin Friebe[1], Andreas Stute[1], Birgit Brandstätter[1], Klemens Schueppert[1], Tracy Northup[1], and Rainer Blatt[1,2] — [1]Institut für Experimentalphysik, Universität Innsbruck, Technikerstrasse 25, 6020 Innsbruck, Austria — [2]Institut für Quantenoptik und Quanteninformation, Österreichische Akademie der Wissenschaften, Otto-Hittmair-Platz 1, 6020 Innsbruck, Austria

It is often proposed to use cavities at nodes of quantum networks as they provide a natural interface between matter and light. By working with just a few trapped ions, one can explore the cavity-mediated interactions between multiple particles while still enjoying the degree of control available in single-ion experiments. We present results of entanglement between two $^{40}Ca^{+}$ ions via coupling to the same mode of a resonator. The ions are stored in a linear ion trap and coupled to two degenerate polarization modes of a high-finesse optical resonator. A single photon is generated in one of the two polarization modes from each ion using a bichromatic Raman transition. By detecting one photon in each polarization mode the two ions are projected onto an entangled state. Entanglement is detected using parity oscillations. A fidelity up to $(92.7 \pm 2.7)\%$ with respect to the maximally entangled Bell state $\sqrt{1/2}(|10\rangle + |01\rangle)$ is reported. The results illustrate precise control of the ions' position in the standing wave and hence of the ion-cavity coupling.

Q 67: Quantum information: Concepts and methods V

Time: Friday 14:00–16:00 Location: E 214

Q 67.1 Fri 14:00 E 214

External vs internal spin squeezing. How to tell them apart? — Giuseppe Vitagliano[1], •Zoltan Zimboras[1], Philipp Hyllus[1], Inigo Egusquiza[1], 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

Spin squeezing with collective angular momentum operators is studied for an ensemble of atoms with a local spin larger than 1/2. In these systems, unlike the case of spin-1/2 ensembles, it is possible to carry out *internal spin squeezing*: only the local spin of each atom is squeezed, while there is no correlation between the atoms. We discuss the possibility of introducing entanglement conditions that can identify whether the ensemble of atoms is in such an internal squeezed state or there is genuine inter-particle spin squeezing, which we term *external squeezing*. Also the detection of internal and external squeezing with possible collective measurements in actual experiments is addressed.

Q 67.2 Fri 14:15 E 214

Area Laws for thermal free fermions — •Michael Kastoryano[1], Jens Eisert[1], and Holger Bernigau[2] — [1]FU Berlin — [2]MPI für Mathematik, Leipzig

We introduce a framework allowing to compute the mutual information, showing an area law, as well as the complete spectra of reduced states of translationally invariant free fermionic lattice systems in Gibbs states in a rigorous and asymptoti- cally exact fashion. The framework introduced develops new methods for computing determinants of Toeplitz operators with smooth symbols, and allows for considering Toeplitz matrices the entries of which depend on the physical system size. The expres- sions derived constitute a setting for studying the interplay of ground state scaling of entanglement entropies and temperature effects, showing that only at extremely low temperatures, signatures of criticality can be seen. As an example, we discuss the sit- uations of the XX in one dimension and free fermionic models on the torus in higher dimensions in detail. We highlight in particular the dependence of the mutual informa- tion scaling like the logarithm of the inverse temperature, constituting an exponential improvement over known general bounds derived from the extremality of the free en- ergy.

Q 67.3 Fri 14:30 E 214

Witnessing genuine entanglement from local information: possible, but hard — Alexandre Lopes, •Panagiotis Papanastasiou, and David Gross — University of Freiburg

It has recently been observed [M. Walter et al, arXiv:1208.0365] that in some instances, strong statements about multi-particle entanglement can be deduced from single-site information alone. The conceptually simplest case concerns the presence of *genuine entanglement*: It has been shown that certain local density matrices are compatible only with a global state that is not bi-separable (assuming it is close to pure). Here, we analyze the *computational complexity* of this task. We show that, while there are many efficiently solvable instances, the general problem is NP-hard. This leaves us with the situation that few, easily obtainable physical measurements may be sufficient to witness many-body entanglement – but that the classical post-processing is intractable. To the best of our knowledge, this is the first natural instance of a *pure state* entanglement problem that has been proven to be hard.

Q 67.4 Fri 14:45 E 214

Quantum Transport Enhancement by Time-Reversal Symmetry Breaking — Zoltan Zimboras[1,2], •Mauro Faccin[2], Zoltan Kadar[2], James Whitfield[2,3], Ben Lanyon[4], and Jacob Biamonte[2] — [1]Theoretical Physics, University of the Basque Country UPV/EHU, E-48080 Bilbao, Spain — [2]Institute for Scientific Interchange Foundation, Via Alassio 11/c, 10126 Torino, Italy — [3]Vienna Center For Quantum Science and Technology, Boltzmanngasse 5 1090 Vienna, Austria — [4]Institut für Quantenoptik und Quanteninformation, Otto-Hittmair-Platz 21a 6020 Innsbruck, Austria

Quantum mechanics still provides new unexpected effects when considering the transport of energy and information. Models of continuous time quantum walks, which implicitly use time-reversal symmetric Hamiltonians, have been intensely used to investigate the effectiveness of transport. Here we show how breaking time-reversal symmetry in this model can enable directional control, enhancement, and suppression of quantum transport. Examples ranging from exciton transport to complex networks are presented. This opens new prospects for more efficient methods to transport energy and information.

Q 67.5 Fri 15:00 E 214

SU(d) squeezing and entanglement in systems of d-level particles — •Giuseppe Vitagliano[1], Philipp Hyllus[1], Zoltan Zimboras[1], Inigo Luis Egusquiza[1], 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

We discuss the problem of finding inequalities useful to detect entanglement in systems of particles with a spin j higher than 1/2. We derive a set of inequalities based on the first two moments of collective quantities different from the angular momentum operators, like the $su(2j+1)$ generators G_k. We study the states that saturate and violate the inequalities and compute the tolerance of the conditions to white noise. We compare our criteria to other entanglement conditions, such as the PPT condition and show that our criteria can detect bound entangled states. Finally, inequalities that can detect genuine k-particle entanglement are also derived.

[1] G. Vitagliano, P. Hyllus, I.L. Egusquiza, and G. Tóth, Phys. Rev. Lett. 107, 240502 (2011).

Q 67.6 Fri 15:15 E 214

Optimized entanglement witnesses for Dicke states — •Marcel Bergmann and Otfried Gühne — Naturwissenschaftlich-Technische Fakultät, Universität Siegen, Department Physik, Walter-Flex-Straße 3, D-57068 Siegen

Quantum entanglement is an important ressource for applications in quantum information processing like quantum teleportation and cryptography. Moreover, the number of particles that can be entangled experimentally using polarized photons or ion traps has been significantly enlarged. Therefore, criteria to decide the question whether a given multiparticle state is entangled or not have to be improved.

Our approach to this problem uses the notion of PPT mixtures [1] which form an approximation to the set of biseparable states. With this method, entanglement witnesses can be obtained in a natural manner via linear semidefinite programming. In our contribution, we will present analytical results for entanglement witnesses for Dicke states. This allows to overcome the limitations of convex optimization.

[1] B. Jungnitsch et al., Phys. Rev. Lett. 106, 190502 (2011).

Q 67.7 Fri 15:30 E 214

Improved contraction schemes for Projected Entangled Pair States — •Michael Lubasch, Juan Ignacio Cirac, and Mari-Carmen Bañuls — Max Planck Institute of Quantum Optics, Hans-Kopfermann-Strasse 1, 85748 Garching, Germany

Projected Entangled Pair States (PEPS) represent the natural generalization of Matrix Product States (MPS) in higher dimensions. The strength of MPS in the numerical simulation of 1D quantum many-body systems is well established, as they are the variational class of states underlying the Density Matrix Renormalization Group and the latter is nowadays considered numerically exact for systems comprising hundreds of quantum particles. In algorithms based on MPS or PEPS, the bond dimension D of the state determines the number of variational parameters and the computational cost. While bond dimensions on the order of hundreds and thousands are feasible with MPS, standard 2D PEPS algorithms are limited to values in the range 2 to 6 due to the much worse scaling of the computational cost with D. Recently, a new algorithm based on an alternative contraction has been proposed [1] that reduces this cost significantly. It resorts to the single-layer picture where the contraction is done in ket and bra separately. We investigate the advantages and disadvantages of this algorithm which can be understood in terms of the PEPS's boundary approximation [2].

[1] I. Pižorn, L. Wang, and F. Verstraete, Phys. Rev. A **83**, 052321

(2011).
[2] J. I. Cirac, D. Poilblanc, N. Schuch, and F. Verstraete, Phys. Rev. B **83**, 245134 (2011).

Q 67.8 Fri 15:45 E 214

Efficient State Analysis and Entanglement Detection — •C. Schwemmer[1,2], G. Tóth[3,4,5], D. Richart[1,2], T. Moroder[6], W. Laskowski[7], L. Knips[1,2], O. Gühne[6], and H. Weinfurter[1,2] — [1]MPI für Quantenoptik, D-85748 Garching — [2]Ludwig-Maximilians-Universität, D-80797 München — [3]University of the Basque Country, E-48080 Bilbao — [4]IKERBASQUE, E-48011 Bilbao — [5]Wigner Research Centre, H-1525 Budapest — [6]Universität Siegen, D-57068 Siegen — [7]University of Gdańsk, PL-80-952 Gdańsk

Multi-partite entangled quantum states offer great opportunities with potential applications in quantum information processing. Therefore, practical tools for entanglement detection and characterization are needed. However, conventional state tomography suffers from an exponentially increasing measurement effort with the number of qubits. In contrast, low rank or symmetric states like W, Dicke or GHZ states enable tomographic analysis at polynomial effort [1,2]. Here, we apply these schemes to experimentally analyze four and six photon symmetric Dicke states. For data processing a fitting algorithm based on convex optimization is used offering significant improvements in terms of speed and accuracy [3]. It is further studied how the principle of correlation complementarity can be applied to detected entanglement with few measurements and to speed up quantum state tomography [4].

[1] Tóth et al., Phys. Rev. Lett. **105**, 250403 (2010)
[2] Gross et al., Phys. Rev. Lett. **105**, 150401 (2010)
[3] Moroder et al., New J. Phys. **14**, 105001 (2012)
[4] Laskowski et al., Phys. Rev. Lett. **108**, 240501 (2012)

Q 68: Quantum information: Photons and nonclassical light II

Time: Friday 14:00–16:00 Location: F 142

Q 68.1 Fri 14:00 F 142

Interfacing UV and telecommunication wavelengths — •Helge Rütz, Hubertus Suche, and Christine Silberhorn — Universität Paderborn, Integrierte Quantenoptik, Warburger Str. 100, D-33098 Paderborn

While trapped ions and other promising candidates for stationary qubit systems in quantum information applications can only be addressed in the UV and visible spectral region, efficient long distance photonic state transfer is restricted to telecommunication wavelengths. This spectral gap can however be bridged by Frequency Conversion.

Here, we focus on a coherent Frequency Conversion interface for quantum states of light between trapped ions at 369.5 nm and telecommunication wavelengths around 1310 nm. A single-pass quasi-phasematched second-order nonlinear interaction with a strong cw-pump field at 515 nm in a periodically poled waveguide allows for the upconversion of infrared- as well as the downconversion of UV-light. Conceptual and experimental details of this interface are given and its potential for quantum information technology is discussed.

Q 68.2 Fri 14:15 F 142

Click statistics of strongly illuminated systems of on-off detectors — •Johannes Kröger[1], Thomas Ahrens[1], Jan Sperling[2], Boris Hage[3], and Heinrich Stolz[1] — [1]AG Halbleiteroptik, Institut für Physik, Universität Rostock — [2]AG Theoretische Quantenoptik, Institut für Physik, Universität Rostock — [3]AG Experimentelle Quantenoptik, Institut für Physik, Universität Rostock

We present experimental results from measurements with systems of on-off detectors, i. e. an array of single photon detectors (SPDs), where the examined intensities of the incident coherent light field include mean photon numbers per SPD being significantly higher than one. Thus probabilities for multiple photon events on one SPD become eminent. This is contrary to the common method of preparing the experimental setup in a way that the probability of detecting one photon per single detector is $\ll 1$. We compare the obtained click statistics, which include up to 80 distinguishable simultaneous clicks, with the theoretically predicted click statistics, based on the calculations of J. Sperling, W. Vogel and G.S. Agarwal, for the case of a coherent light field. These calculations and our experimental verification render it possible to obtain useful information about the state of a light field, while the detector system is strongly illuminated, thus minimizing undesired effects due to attenuation of the intensity.

Q 68.3 Fri 14:30 F 142

A Versatile Photon Pair Source for Quantum Circuits — •Vahid Ansari, Georg Harder, Benjamin Brecht, and Christine Silberhorn — Applied Physics, University of Paderborn, Warburger Straße 100, 33098 Paderborn, Germany

Efficient generation of indistinguishable single photons in pure quantum states is key to many applications in quantum information processing. We present an ultrafast pulsed parametric down conversion (PDC) source based on a degenerate type-II PDC in a PP-KTP waveguide at telecommunication wavelengths. As such, our highly efficient source generates close to perfect single-mode photon pairs with indistinguishable mode properties. As a measure of indistinguishability we observe Hong-Ou-Mandel interference between signal and idler with a visibility of 95.6%, without narrow-band filtering. We further demonstrate the purity of signal and idler by HOM interference between signal/idler and a weak coherent field. The results are in excellent agreement to the spectral and modal characterization as well as to theory.

Q 68.4 Fri 14:45 F 142

Phase-locked indistinguishable flying qubits from a quantum dot — •Carsten H. H. Schulte, Clemens Matthiesen, Martin Geller, Claire Le Gall, Jack Hansom, Zhengyong Li, and Mete Atatüre — Cavendish Laboratory, University of Cambridge, Cambridge CB3 0HE, United Kingdom

Optically active spins in self-assembled InAs quantum dots (QDs) represent one of many promising qubit candidates for quantum information processing. The entanglement of individual spins constitutes the smallest unit of a distributed quantum network and can be realised through quantum interference of flying qubits, i.e. photons emitted by the QD. For this, ideally indistinguishable photons from separate QDs are needed, the generation of which has proved challenging due to dephasing of the used optical QD transitions. Resonance fluorescence in the Heitler regime circumvents environment-induced dephasing and delivers single photons with a coherence well above the Fourier transform limit of the QD transition, the spectral shape of the photons being solely tailored by the excitation laser [1]. Using optical heterodyning, we demonstrate that QD photons and exciting laser field are phase-locked on a timescale exceeding 3 seconds. Exploiting this degree of mutual coherence we spectrally shape the emitted photons by modulating the excitation laser. Finally, successively emitted photons generated phase-locked to the excitation laser are proven to be fundamentally indistinguishable in Hong-Ou-Mandel interferometry [2].

[1] Matthiesen *et al.*, Phys. Rev. Lett. **108**, 093602 (2012).
[2] Matthiesen *et al.*, arXiv:1208.1689 [quant-ph] (2012).

Q 68.5 Fri 15:00 F 142

Quantification of nonclassicality — •Melanie Mraz, Jan Sperling, Werner Vogel, and Boris Hage — Universität Rostock, Institut für Physik, Rostock, Deutschland

At the beginning of the 20th century the discussion on physics beyond the classical regime started. This was the hour of birth of quantum physics and, with Einstein's description of the photoelectric effect, of quantum optics. Even the physicists had problems to understand nonclassical quantum phenomena, because of its non-intuitive properties. So, why further struggling?

Nonclassical states have an advantage over classical states for various applications. Only one example is the quantum teleportation which would be unthinkable without nonclassical states. Hence, it is of a fundamental interest to study properties of nonclassical quantum states. It is already possible to say if a state is nonclassical or not, but how can we decide how much nonclassicality is in our system?

We propose a degree of nonclassicality being a nonclassicality measure. It is determined by the decomposition of a quantum state into superpositions of coherent states. On the one hand, coherent states resembles the behavior of a classical harmonic oscillator most closely. On the other hand, the more quantum superpositions of coherent states are needed, the more quantum interferences arise. A method for such a decomposition of quantum states is presented and the degree of nonclassicality is determined for different states. We apply our method to typical nonclassical states, such as the compass state and the squeezed vacuum state.

Q 68.6 Fri 15:15 F 142

Entangling photons via the quantum Zeno effect — •Nicolai ten Brinke, Andreas Osterloh, and Ralf Schüztzhold — Fakultät für Physik, Universität Duisburg-Essen, Lotharstraße 1, D-47057 Duisburg, Germany

The quantum Zeno effect describes the inhibition of quantum evolution by frequent measurements. In this talk, we propose a scheme for entangling two given photons based on this effect. We consider a linear-optics set-up with an absorber medium whose two-photon absorption rate $\xi_{2\gamma}$ exceeds the one-photon loss rate $\xi_{1\gamma}$. In order to reach an error probability $P_{\rm error}$, we need $\xi_{1\gamma}/\xi_{2\gamma} < 2P_{\rm error}^2/\pi^2$ [1], which is a factor of 64 better than previous approaches, e.g., [2]. Since typical media have $\xi_{2\gamma} < \xi_{1\gamma}$, we discuss mechanisms for enhancing two-photon absorption as compared to one-photon loss. In particular, we present a mechanism which envisages three-level systems where the middle level is meta-stable (Λ-system). In this case, $\xi_{1\gamma}$ is more strongly reduced than $\xi_{2\gamma}$ and thus it should be possible to achieve $\xi_{2\gamma}/\xi_{1\gamma} \gg 1$. In conclusion, although our scheme poses serious experimental challenges, we find that a two-photon gate with an error probability $P_{\rm error}$ below 25% might be feasible using present-day technology [3].

[1] N. ten Brinke, A. Osterloh, and R. Schützhold, Phys. Rev. A **84**, 022317 (2011).

[2] J. D. Franson, B. C. Jacobs, and T. B. Pittman, Phys. Rev. A **70**, 062302 (2004).

[3] N. ten Brinke, A. Osterloh, and R. Schützhold, arXiv:1212.1309.

Q 68.7 Fri 15:30 F 142

Entanglement distribution by separable states — •Daniela Schulze[1], Christina E. Vollmer[1], Tobias Eberle[1], Vitus Händchen[1], Jaromír Fiurášek[2], and Roman Schnabel[1] — [1]Institut für Gravitationsphysik, Leibniz Universität Hannover and Max-Planck-Institut für Gravitationsphysik (Albert-Einstein-Institut), Callinstr. 38, 30167 Hannover, Germany — [2]Department of Optics, Palacký University, 17. listopadu 50, 77200 Olomouc, Czech Republic

Distribution of entanglement between two parties - Alice and Bob - is an essential step for most quantum information protocols. Usually, entanglement is distributed directly by exchanging entangled subsystems between the individual parties. However, it has been shown in [1] that it is possible to establish entanglement between two parties by exchanging an ancilla mode C, which is neither entangled with Alice's mode A, nor with Bob's mode B. We report on the experimental realization of a scheme for entanglement distribution by separable states on the basis of continuous variables. Our scheme relies on a specific three-mode Gaussian state where parts of the entanglement structure are initially hidden by correlated noise and later restored via quantum interference.

[1] T. Cubitt, F. Verstraete, W. Dür, and J. Cirac. Separable States Can Be Used To Distribute Entanglement. Physical Review Letters, 91(3):1-4, July 2003.

Q 68.8 Fri 15:45 F 142

Efficient Reconstruction of Qudit Entangled States — •Daniel L. Richart[1,2], Christian Schwemmer[1,2], Wieslaw Laskowski[1,2,3], and Harald Weinfurter[1,2] — [1]Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Str.1 D-85748 Garching, Germany — [2]Ludwig-Maximilians-Universität, Schellingstr. 4, D-80797 München, Germany — [3]Instytut Fizyki Teoretycznej i Astrofizyki, Uniwersytet Gdánski, PL-80-952 Gdánsk, Poland

Qudit states offer significant advantages with respect to qubit states regarding their application in the field of quantum communication and computation. However, the measurement effort necessary to tomographically reconstruct their quantum states scales with $4^{log(d)/log(2)}$ with d denoting the dimension of the qudit state. Here, we present experimental results on the efficient tomographic reconstruction of qudit entangled states with dimensions up to 2x8 using the energy-time degree of freedom [1,2]. Two different methods based on low rank quantum state tomography [3] and on correlation complementarity [4] are compared regarding their efficiency.

[1] J.D. Franson et al., PRL 62, 2205 (1989) [2] D. Richart et al., Appl. Phys. B 106, 543 (2012) [3] D. Gross et al., PRL 105 150401 (2010) [4] W. Laskowski et al., PRL 108, 240501 (2012)