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

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Overview of Sessions

Sessions

Q 1.1–1.10	Mon	10:30–13:00	HSZ 02	**Micro Mechanical Oscillator 1**
Q 2.1–2.10	Mon	10:30–13:00	HÜL 386	**Quantum Gases: Bosons 1**
Q 3.1–3.10	Mon	10:30–13:00	BAR Schön	**Cold Molecules 1**
Q 4.1–4.9	Mon	10:30–12:45	BAR 106	**Ultra-cold atoms, ions and BEC I**
Q 5.1–5.10	Mon	10:30–13:00	SCH 251	**Ultracold Atoms: Manipulation and Detection**
Q 6.1–6.9	Mon	10:30–13:00	SCH A01	**Quantum Effects: Light Scattering and Propagation**
Q 7.1–7.10	Mon	10:30–13:00	SCH A118	**Quantum Information: Concepts and Methods 1**
Q 8.1–8.10	Mon	10:30–13:00	SCH A215	**Photonics 1**
Q 9.1–9.3	Mon	14:30–15:15	HSZ 02	**Micro Mechanical Oscillator 2**
Q 10.1–10.6	Mon	14:30–16:00	HÜL 386	**Quantum Gases: Bosons 2**
Q 11.1–11.5	Mon	14:30–16:00	BAR Schön	**Quantum Information: Atoms and Ions 1**
Q 12.1–12.6	Mon	14:30–16:00	SCH A118	**Quantum Information: Concepts and Methods 2**
Q 13.1–13.6	Mon	14:30–16:00	SCH A215	**Laserentwicklung: Festkörperlaser 1**
Q 14.1–14.6	Mon	14:30–16:00	SCH 251	**Ultrakurze Laserpulse: Erzeugung 1**
Q 15.1–15.92	Mon	16:30–19:30	P1	**Poster 1: Quanteninformation, Quanteneffekte, Laserentwicklung, Laseranwendungen, Ultrakurze Pulse, Photonik**
Q 16.1–16.9	Tue	10:30–13:00	HSZ 02	**Solid State Photon Sources**
Q 17.1–17.9	Tue	10:30–12:45	BAR Schön	**Fermi Quantum Gas**
Q 18.1–18.9	Tue	10:30–12:45	BAR 106	**Ultra-cold atoms, ions and BEC II**
Q 19.1–19.9	Tue	10:30–13:00	HÜL 386	**Quantum Gases: Miscellaneous**
Q 20.1–20.10	Tue	10:30–13:00	SCH A118	**Quantum Information: Concepts and Methods 3**
Q 21.1–21.9	Tue	10:30–12:45	SCH A215	**Laserentwicklung: Festkörperlaser 2**
Q 22.1–22.10	Tue	10:30–13:00	SCH A01	**Ultrakurze Laserpulse: Anwendungen 1**
Q 23.1–23.60	Tue	18:00–21:00	P1	**Poster 2: Intersectional Session**
Q 24.1–24.10	Wed	10:30–13:00	HSZ 02	**Quantum Gases: Opt. Lattice 1**
Q 25.1–25.10	Wed	10:30–13:00	BAR Schön	**Matter Wave Optics**
Q 26.1–26.9	Wed	10:30–13:00	HÜL 386	**Quantum Information: Atoms and Ions 2**
Q 27.1–27.8	Wed	10:30–12:45	BAR 106	**Ultra-cold atoms, ions and BEC III**
Q 28.1–28.9	Wed	10:30–12:45	SCH A01	**Quantum Information: Quantum Communication 1**
Q 29.1–29.10	Wed	10:30–13:00	SCH 251	**Laserentwicklung: Nichtlineare Effekte 1**
Q 30.1–30.10	Wed	10:30–13:00	SCH A118	**Photonics 2**
Q 31.1–31.6	Wed	14:30–16:00	HSZ 02	**Quantum Gases: Opt. Lattice 2**
Q 32.1–32.7	Wed	14:30–16:15	HÜL 386	**Quantum Information: Atoms and Ions 3**
Q 33.1–33.6	Wed	14:30–16:00	SCH A118	**Quantum Information: Quantum Communication 2**
Q 34.1–34.6	Wed	14:30–16:00	BAR Schön	**Cold Molecules II**
Q 35.1–35.6	Wed	14:30–16:00	SCH A01	**Ultrakurze Laserpulse: Anwendungen 2**
Q 36.1–36.6	Wed	14:30–16:00	SCH 251	**Laseranwendungen und Photonik 1**
Q 37.1–37.7	Wed	16:30–18:15	BAR Schön	**Cold Molecules III**
Q 38.1–38.6	Wed	16:30–18:00	BAR 205	**Ultra-cold atoms, ions and BEC IV**
Q 39.1–39.7	Wed	16:30–18:15	TOE 317	**Quantum Control**
Q 40.1–40.6	Wed	16:30–18:00	HSZ 02	**Transport and Localization of interacting Bosons 1**
Q 41.1–41.6	Wed	16:30–18:00	HÜL 386	**Precision Measurement and Metrology 1**
Q 42.1–42.5	Wed	16:30–17:45	SCH 251	**Laserentwicklung: Festkörperlaser 3**

Q 43.1–43.4	Wed	16:30–17:30	SCH A118	**Laseranwendungen und Photonik 2**
Q 44.1–44.9	Thu	10:30–13:00	HSZ 02	**Quantum Optics of Solid State Photon Sources**
Q 45.1–45.9	Thu	10:30–13:00	HÜL 386	**Precision Measurement and Metrology 2**
Q 46.1–46.10	Thu	10:30–13:00	BAR 106	**Ultra-cold atoms, ions and BEC V**
Q 47.1–47.9	Thu	10:30–12:45	BAR Schön	**Quantum Information: Quantum Computer**
Q 48.1–48.9	Thu	10:30–12:45	SCH 251	**Quantum Gases: Effects of Interactions**
Q 49.1–49.10	Thu	10:30–13:00	SCH A215	**Laseranwendungen: Laserspektroskopie**
Q 50.1–50.10	Thu	10:30–13:00	SCH A01	**Quantum Effects: Entanglement and Decoherence**
Q 51.1–51.6	Thu	14:30–16:00	SCH A118	**Ultracold Atoms: Trapping and Cooling 1**
Q 52.1–52.6	Thu	14:30–16:00	HÜL 386	**Precision Measurement and Metrology 3**
Q 53.1–53.6	Thu	14:30–16:00	SCH 251	**Quantum Information: Photons and Nonclassical Light 1**
Q 54.1–54.6	Thu	14:30–16:00	SCH A01	**Quantum Effects: QED**
Q 55.1–55.6	Thu	14:30–16:00	BAR Schön	**Transport and Localization of interacting Bosons 2**
Q 56.1–56.5	Thu	14:30–15:45	SCH A215	**Ultrakurze Laserpulse: Anwendungen 3**
Q 57.1–57.109	Thu	16:30–19:30	P1	**Poster 3: Quantengase, Ultrakalte Atome, Ultrakalte Moleküle, Materiewellen Optik, Präzisionsmessungen, Metrologie**
Q 58.1–58.10	Fri	10:30–13:00	HSZ 02	**Ultracold Atoms: Trapping and Cooling 2**
Q 59.1–59.9	Fri	10:30–12:45	SCH A01	**Quantum Effects: Interference and Correlations**
Q 60.1–60.7	Fri	10:30–12:15	SCH 251	**Quantum Information: Photons and Nonclassical Light 2**
Q 61.1–61.10	Fri	10:30–13:00	SCH A118	**Quantum Information: Concepts and Methods 4**
Q 62.1–62.9	Fri	10:30–13:00	HÜL 386	**Laseranwendungen: Lebenswiss. und Umweltphys.**
Q 63.1–63.9	Fri	10:30–12:45	SCH A215	**Ultrakurze Laserpulse: Erzeugung und Anwendungen 2**

Jahrestreffen des Fachverbands Quantenoptik und Photonik

Mittwoch, 13:30–14:15 in Raum SCH251

- Bericht des Fachverbandsleiters
- Vorstellung des Sektionssprechers
- Verschiedenes

Q 1: Micro Mechanical Oscillator 1

Time: Monday 10:30–13:00 Location: HSZ 02

Q 1.1 Mon 10:30 HSZ 02

Listening to the Quantum Drum: Mechanics in its Ground State — •Tobias Donner[1,2], John Teufel[3], Ray Simmonds[3], and Konrad Lehnert[2] — [1]Institute for Quantum Electronics, ETH Zurich, CH-8093 Zurich, Switzerland — [2]JILA, University of Colorado and National Institute of Standards and Technology, Boulder, CO 80309, USA — [3]National Institute of Standards and Technology, Boulder, CO 80305, USA

A mechanical resonator is a physicist's most tangible example of a harmonic oscillator. If cooled to sufficiently low temperatures a mechanical oscillator is expected to behave differently to our classical perception of reality. Examples include entanglement and superposition states where a macroscopic, human made object can be in two places at once. Observing the quantum behavior of a mechanical oscillator is challenging because it is difficult both to prepare the oscillator in a pure quantum state of motion and to detect those states. I will present experiments in which we couple the motion of a micro-fabricated oscillator to the microwave field in a superconducting high-Q resonant circuit. The displacement of the oscillator imprints a phase modulation on the microwave field which we detect with a nearly shot-noise limited interferometer. We employ the radiation pressure force of the microwave photons to cool the mechanical oscillator to its motional ground state.

Q 1.2 Mon 10:45 HSZ 02

Optomechanical Coupling of Ultracold Atoms and a Membrane Oscillator — •Maria Korppi[1,2,3], Andreas Jöckel[1], Stephan Camerer[2,3], David Hunger[2,3], Theodor W. Hänsch[2,3], and Philipp Treutlein[1,2,3] — [1]Universität Basel, Switzerland — [2]Ludwig-Maximilians-Universität, München, Germany — [3]Max-Planck-Institut für Quantenoptik, Garching, Germany

We report the recent results of our experiment, where we couple a single mode of a high-Q membrane-oscillator to the motion of laser-cooled atoms in an optical lattice. The optical lattice is formed by retroreflection of a laserbeam from the membrane surface. The coupling is mediated by power modulation of the lattice beam due to the vibrations of the atoms in the lattice. If the trap frequency of the atoms in the lattice is matched to the eigenfrequency of the membrane, we observe resonant energy transfer between the two systems.

In the long term, such coupling mechanism could be exploited to develop hybrid quantum systems between atoms and solid-state devices. As another intriguing perspective, a new generation of optical lattice experiment is in sight, where the mirrors creating the laser standing waves are micromechanical oscillators interacting with the atoms on a quantum level.

Q 1.3 Mon 11:00 HSZ 02

Tuning the quality factor of a miromechanical membrane oscillator — •Andreas Jöckel[1], Maria Korppi[1,2,3], Stephan Camerer[2,3], Matthias Mader[2], David Hunger[2,3], Theodor W. Hänsch[2,3], and Philipp Treutlein[1,2,3] — [1]Departement Physik, Universität Basel, Switzerland — [2]Ludwig-Maximilians-Universität, München, Germany — [3]Max-Planck-Institut für Quantenoptik, Garching, Germany

We report on the characterization and tuning of the mechanical modes of high-Q SiN-membrane oscillators. Such membranes are used in many optomechanical experiments and have Q-factors up to 10^7 with frequencies in the hundreds of kHz regime and masses of a few ng, resulting in rather large ground state and thermal amplitudes.

We show that the membrane eigenfrequencies can be tuned by locally heating the membranes with laser light, resulting in a release of intrinsic stress. The frequencies of several modes were measured with a Michelson interferometer. We observe that the Q-factor changes dramatically while tuning and reveals resonances in the mechanical dissipation, which allows us to tune the Q-factor over two orders of magnitude. With this technique we achieve an improvement over the bare membrane Q-factor.

Another way of improving the properties of these membranes lies in structuring them with a focused ion beam (FIB) in order to reduce their mass, or applying mirrors to increase the reflectivity.

Q 1.4 Mon 11:15 HSZ 02

A closed-cycle dilution refrigerator with free-space and fiber optical access for quantum optomechanics experiments at 20mK — •Witlef Wieczorek[1], Simon Gröblacher[1], Matthias Bühler[2], Peter Christ[2], Jens Höhne[2], Doreen Wernicke[2,3], and Markus Aspelmeyer[1] — [1]University of Vienna, Faculty of Physics, A-1090 Vienna, Austria — [2]VeriCold Technologies GmbH, Bahnhofstr. 21, D-85737 Ismaning, Germany — [3]Entropy GmbH, Gmundner Str. 37a, D-81379 Munich, Germany

We report on the operation of a closed-cycle dilution refrigerator for quantum optomechanics experiments at 20mK. The sample chamber of the dilution fridge is optically accessible both via optical windows as well as optical fibers, allowing us to perform a variety of optical experiments at low temperatures. It is designed to vibrationally isolate the sample chamber allowing for stable operation of a high-finesse optical cavity. This enables us to perform cavity-optomechanics experiments at ultra-low temperatures.

Q 1.5 Mon 11:30 HSZ 02

Optomechanical cooling close to the ground state — •Rémi Rivière[1], Stefan Weis[1,2], Samuel Deléglise[1,2], Emanuel Gavartin[2], Olivier Arcizet[3], Albert Schliesser[1,2], and Tobias Kippenberg[1,2] — [1]Max-Planck-Institut für Quantenoptik, 85748 Garching, Germany — [2]Ecole Polytechnique Fédérale de Lausanne (EPFL), 1015 Lausanne, Switzerland — [3]Institut Néel, 38042 Grenoble, France

Optomechanical cooling of a mechanical oscillator mediated by the radiation pressure of the light enables preparing a macroscopic system in its quantum ground state. In our experiment, the vehicle used is a silica microtoroid resonator, hosting both optical and mechanical degrees of freedom within the same device. Combining both cryogenic and optomechanical cooling, we demonstrate an occupancy as low as 9 ± 1 phonons, for which limitations to further phonon occupation reduction are only technical. The forthcoming ground state will then enable the study of quantum effects in a macro-object.

Q 1.6 Mon 11:45 HSZ 02

Cavity optomechanics with nonlinear mechanical resonators in the quantum regime — •Simon Rips, Martin Kiffner, Ignacio Wilson-Rae, and Michael Hartmann — Technische Universität München, Germany

The coupling of light and a mechanical resonator within an optomechanical setup can have significant effects on both the light field inside the cavity and the motion of the mechanical resonator. A prominent example is the cavity assisted side-band cooling of the mechanical motion, leading to low phonon occupation and thereby inducing the quantum regime.

Here, we consider the physics of a nonlinear mechanical resonator, coupled to different cavity modes that are each driven by a detuned laser. We show that the mechanical nonlinearity can be used to prepare a *nonclassical steady state* of mechanical motion. The nonclassicality criterion we use is the appearance of a negative Wigner function.

The open coupled quantum system is treated analytically with the projection operator technique. By tracing out the cavity modes, a master equation for the mechanical motion is derived. The structure of that master equation allows to understand the underlying physics and thereby to identify parameters (especially for detuning) that will produce the nonclassical steady state. The results are verified in a numerical treatment of the full coupled optomechanical system.

Q 1.7 Mon 12:00 HSZ 02

Stochastically activated opto-mechanical coupling — •Andrea Mari and Jens Eisert — Institute of Physics and Astronomy, University of Potsdam, 14476 Potsdam, Germany

We study the effect of stochastic noise on the standard opto-mechanical setup: an optical cavity with a vibrating mirror. We show how to engineer an effective bath for the mechanical resonator by using only incoherent thermal light. Thanks to the non-linear interaction Hamiltonian, optical stochastic noise can activate the coupling between a mechanical mode of the mirror and an optical mode of the cavity. This interaction can generate several non-trivial effects, e.g. the counter-intuitive process of cooling with thermal noise. This is another instance - different from stochastic resonance - where somewhat counterintuitively, incoherent noise helps to generate coherent quantum effects.

Q 1.8 Mon 12:15 HSZ 02

Optomechanically Induced Transparency — •Stefan Weis[1,2], Rémi Rivière[2], Samuel Deléglise[1,2], Emanuel Gavartin[1], Olivier Arcizet[3], Albert Schliesser[1,2], and Tobias Kippenberg[1,2] — [1]Ecole Polytechnique Fédérale de Lausanne (EPFL), 1015 Lausanne, Switzerland — [2]Max-Planck-Institut für Quantenoptik, 85748 Garching, Germany — [3]Institut Néel, 38042 Grenoble, France

Electromagnetically induced transparency is a quantum interference effect observed in atoms and molecules, in which the optical response of an atomic medium is controlled by an electromagnetic field. We demonstrate a form of induced transparency enabled by radiation-pressure coupling of an optical and a mechanical mode. A control optical beam tuned to a sideband transition of a micro-optomechanical system leads to destructive interference for the excitation of an intracavity probe field, inducing a tunable transparency window for the probe beam. Optomechanically induced transparency may be used for slowing and on-chip storage of light pulses via microfabricated optomechanical arrays.

Q 1.9 Mon 12:30 HSZ 02

Quantum dynamics in optomechanical arrays — •Florian Marquardt[1,2], Max Ludwig[1], Georg Heinrich[1], Andreas Kronwald[1], Michael Schmidt[1], Jiang Qian[3], and Björn Kubala[1] — [1]Institut für Theoretische Physik, Universität Erlangen-Nürnberg — [2]Max-Planck Institut für die Physik des Lichts — [3]Arnold Sommerfeld Center, Center for NanoScience, Department Physik, LMU München

Optomechanical arrays consist of a number of localized vibrational and optical modes coupled to each other via radiation forces. First versions of such structures have been realized recently based on photonic crystal designs. Future setups are projected to enter the quantum regime. We present our theoretical analysis of the linear and nonlinear quantum dynamics of interacting photons and phonons in such arrays.

Q 1.10 Mon 12:45 HSZ 02

Shot noise limited displacement measurement of a high Q micromechanical oscillator below the peak value of the SQL — •Henning Kaufer, Daniel Friedrich, Andreas Sawadsky, Tobias Westphal, Kazuhiro Yamamoto, and Roman Schnabel — Albert-Einstein-Institut, MPI für Gravitationsphysik, QUEST, Leibniz Universität Hannover

The standard quantum limit (SQL) is a classical limit for measurement precision of a test mass position. Using a SiN membrane with a Q-factor of 10^6 and a mass of 100 ng we achieved a displacement sensitivity of $3 \cdot 10^{-16}$ m/$\sqrt{\text{Hz}}$ in a Michelson-Sagnac interferometer and thereby beat the peak value of the SQL at resonance. The interferometer topology allows implementation of advanced interferometer techniques such as power- or signal recycling. The latter can enhance the displacement sensitivity by a factor of 10 in the first step and reveal thermal noise of the oscillator over a broad frequency range.

Q 2: Quantum Gases: Bosons 1

Time: Monday 10:30–13:00 Location: HÜL 386

Q 2.1 Mon 10:30 HÜL 386

Two-point density correlations of quasicondensates in free expansion — •Stephanie Manz, Robert Bücker, Thomas Betz, Christian Koller, Igor Mazets, Aurelién Perrin, Thorsten Schumm, and Jörg Schmiedmayer — Atominstitut, TU Wien

We measure the two-point density correlation function of freely expanding quasicondensates in the weakly interacting quasi-one-dimensional (1D) regime. While initially suppressed in the trap, density fluctuations emerge gradually during expansion as a result of initial phase fluctuations present in the trapped quasicondensate. Asymptotically, they are governed by the thermal coherence length of the system. Our measurements take place in an intermediate regime where density correlations are related to near-field diffraction effects and anomalous correlations play an important role. Comparison with a recent theoretical approaches yields good agreement with our experimental results and shows that density correlations can be used for thermometry of quasicondensates. New results testing this method on samples with low atom numbers will be presented as well.

Q 2.2 Mon 10:45 HÜL 386

From Rotating Atomic Rings to Quantum Hall States — Marco Roncaglia[1], •Matteo Rizzi[2], and Jean Dalibard[3] — [1]Dipartimento di Fisica del Politecnico, corso Duca degli Abruzzi 24, I-10129, Torino, Italy — [2]Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Str. 1, D-85748, Garching, Germany — [3]Laboratoire Kastler Brossel, CNRS, UPMC, École normale supe*rieure, 24 rue Lhomond, 75005 Paris, France

Considerable efforts are currently devoted to prepare ultracold neutral atoms in the emblematic strongly correlated quantum Hall regime. The routes followed so far essentially rely on thermodynamics, i.e. imposing the proper Hamiltonian and cooling the system towards its ground state. In rapidly rotating 2D harmonic traps the role of transverse magnetic field is played by the angular velocity. The required huge angular momentum can be obtained only for spinning frequencies extremely near to deconfinement limit; consequently, the prescribed control turns out to be far too stringent.

Here we propose to follow instead a dynamic path starting from the gas confined in a rotating ring by a repulsive "plug" laser. The large moment of inertia of the fluid facilitates the access to states with a large angular momentum, corresponding to a giant vortex. The "plug" is then adiabatically removed, leaving only an harmonic confinement on. We provide clear numerical evidence that for a relatively broad range of initial angular frequencies, the giant vortex state is adiabatically connected to the bosonic $\nu = 1/2$ Laughlin state. We discuss the scaling to many particles and the robustness against trap defects.

Q 2.3 Mon 11:00 HÜL 386

Bose-Einstein condensates in optical micro-potentials — •Johannes Küber, Thomas Lauber, Martin Hasch, Oliver Wille, and Gerhard Birkl — Institut für Angewandte Physik, Technische Universität Darmstadt, Schlossgartenstraße 7, 64289 Darmstadt

Our experiment provides an approach for the coherent manipulation and transport of atoms in optical potentials. We prepare an all-optical Bose-Einstein Condensate (BEC) of 25000 Rb atoms in a crossed optical dipole trap at 1070nm.

Our experiment allows us to create different attractive and repulsive trapping potentials by using miniaturized lenses. Furthermore we can combine these potentials to complex geometries like one dimensional resonators, disk-shaped potentials or toroidal potentials. A one-dimensional optical lattice gives us the ability to control the momentum of atoms loaded into these guiding structures.

In a first set of experiments we demonstrated an interferometer in a one-dimensional waveguide. Therefore we stored the atoms in the waveguide and create a coherent superposition of momentum states with the 1D lattice. In another set of experiments we loaded a BEC in a ring shaped attractive potential and used the ring as a guiding structure for accelerated atoms.

Q 2.4 Mon 11:15 HÜL 386

Bogoliubov theory of disordered Bose-Einstein condensates — •Christopher Gaul[1] and Cord A. Müller[2] — [1]GISC, Departamento de Física de Materiales, Universidad Complutense, E-28040 Madrid, Spain — [2]Centre for Quantum Technologies, National University of Singapore, Singapore 117543, Singapore

We describe repulsively interacting Bose-Einstein condensates in spatially correlated disorder potentials of arbitrary dimension. The first effect of disorder is to deform the mean-field condensate. Secondly, the quantum excitation spectrum and condensate population are affected. By a saddle-point expansion of the many-body Hamiltonian around the deformed mean-field ground state, we find the fundamental quadratic Hamiltonian of quantum fluctuations, in a basis where excitations remain always orthogonal to the deformed condensate. Via Bogoliubov-Nambu perturbation theory, we compute the effective excitation dispersion, including the disorder-corrected sound velocity and

localization lengths. Finally, we are able to calculate analytically, for the first time and in all dimensions, the true disorder-induced quantum depletion, i.e. the fraction of particles out of the deformed condensate, which is found to depend strongly on the disorder correlation.

C. Gaul and C.A. Müller, arXiv:1009.5448

Q 2.5 Mon 11:30 HÜL 386

Bose-Einstein condensation of photons in an optical microcavity — •Jan Klärs, Julian Schmitt, Frank Vewinger, and Martin Weitz — Institut für Angewandte Physik, Universität Bonn

Bose-Einstein condensation has been observed in several physical systems, including cold atomic gases and solid-state quasiparticles. However the most omnipresent Bose gas, blackbody radiation, does not show BEC. In such systems the photon number is not conserved when the temperature of the photon gas is varied; at low temperatures, photons disappear in the cavity walls instead of occupying the cavity ground state. A number-conserving thermalization process was experimentally observed for a two-dimensional photon gas in a dye-filled optical microcavity [1]. Here we report the observation of a Bose-Einstein condensate of photons in this system [2]. The cavity mirrors provide both a confining potential and a non-vanishing effective photon mass, making the system formally equivalent to a two-dimensional gas of trapped, massive bosons. The photons thermalize to the temperature of the dye solution (room temperature) by multiple scattering with the dye molecules. Upon increasing the photon density, we observe the following BEC signatures: the photon energies have a Bose-Einstein distribution including a massively populated ground-state mode; the phase transition occurs at the expected photon density and exhibits the predicted dependence on cavity geometry; and the ground-state mode emerges even for a spatially displaced pump spot.

[1] J. Klaers, F. Vewinger and M. Weitz, *Nature Phys.* **6**, 512 (2010)
[2] J. Klaers et al., *Nature* **468**, 545 (2010)

Q 2.6 Mon 11:45 HÜL 386

Quantum phases of polar bosons in ladder-like lattices — •Xiaolong Deng and Luis Santos — ITP, Uni. Hannover, Appelstr. 2, D-30167 Hannover

We study the ground-state properties of polar bosons (e.g. polar bosonic molecules) loaded in ladder-like lattices. By means of DMRG simulations we determine numerically various ground-state correlation functions. We characterize various quantum phases, including pair supersolid, pair superfluid and various Haldane insulator phases for different interaction regimes, and identify the phase diagram for different fillings. Additionally, we also investigate the entanglement spectrum in such a two-lag ladder with 1/2 filling.

Q 2.7 Mon 12:00 HÜL 386

Probing carbon nanotube with cold gases — •Mathias Schneider and Reinhold Walser — Institut für Angewandte Physik, TU Darmstadt

The interaction of carbon nanotubes with cold gases has many unknowns. In particular, the interaction potentials and loss rates are under intense investigations (cf Casimir-Polder potential). In this contribution we would like to ask the inverse question and obtain potential shapes from observed loss rates.

In the case of Bose condensed gases we use superfluid hydrodynamics in a perturbative limit (linear response) to calculate the particle loss rate for certain potential shapes. This model incorporates two basic features. First, the nanotube attracts atoms nearby through a very short ranged attractive potential. Second, inelastic collisions between the nanotube and condensed atoms surrounding it lead to particle loss. Quantities of interest are the density profile of the condensate, the evolution of the ground state occupation number and how these are connected to basic parameters like two body interaction strength, the atom-object collision rate, etc.

Q 2.8 Mon 12:15 HÜL 386

Scaling laws of turbulent ultracold bosons — •Boris Nowak[1,2], Maximilian Schmidt[1,2], Jan Schole[1,2], Denes Sexty[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

Turbulent dynamics in an ultracold Bose gas, in two and three spatial dimensions, is analysed by means of statistical simulations using the classical field equation. A special focus is set on the infrared regime of large-scale excitations following universal power-law distributions distinctly different from those of commonly known weak wave-turbulence phenomena. The infrared power laws which have been predicted within an analytic field-theoretic approach based on the 2PI effective action, are discussed in comparison to the well-known Kolmogorov scaling of vortical motion. These phenomena of strong turbulence should in principle be observable with ultracold atomic gases.

Q 2.9 Mon 12:30 HÜL 386

Transition to quasi-condensation in a low-D Bose gas — •Carsten Henkel[1], Antonio Negretti[2], Stuart P. Cockburn[3], and Nikolaos Proukakis[3] — [1]Universität Potsdam, Germany — [2]Universität Ulm, Germany — [3]Newcastle University, U.K.

We analyze a dilute Bose gas in a one-dimensional trap, using a modified mean field theory based on the Popov approximation [1]. This has been successfully applied to describe density profiles and the border between a quasi-condensate (qc) regime and a non-degenerate gas. We provide simple formulas in an intermediate temperature range for the qc fraction and the total density. A critical chemical potential that delimits the qc and normal phases is identified, and the possibility of a phase transition is explored. We discuss the role of the quantum pressure in a trap and of a renormalized two-body interaction in smoothing out the qc border.

[1] Al Khawaja & al, *Phys. Rev. A* **66** (2002) 013615; Proukakis, *Phys. Rev. A* **74** (2006) 053617

Q 2.10 Mon 12:45 HÜL 386

Numerical simulations on space-time lattices for macroscopic quantum tunneling of Bose-Einstein condensates with attractive 1/r-interaction — •Pascal Wieland, Jörg Main, and Günter Wunner — 1. Institut für Theoretische Physik, Universität Stuttgart

For a special laser-configuration one can induce a self-trapped BEC with an attractive 1/r-interaction which can be described by the Gross-Pitaevskii equation (GPE). Those BECs can collapse due to macroscopic quantum tunneling. The tunneling rate can be calculated with the Euclidean action of the bounce trajectory. We search for the numerical exact bounce trajectory by simulations on a space-time lattice. The time propagation is computed via a split-operator method and the continuity conditions for all time steps are determined using a Newton algorithm.

Q 3: Cold Molecules 1

Time: Monday 10:30–13:00 Location: BAR Schön

Q 3.1 Mon 10:30 BAR Schön

Ultracold and dense samples of ground-state molecules — •Johann Georg Danzl, Manfred Mark, Elmar Haller, Lukas Reichsöllner, and Hanns-Christoph Nägerl — Institut für Experimentalphysik, Universität Innsbruck, Innsbruck, Austria

We produce ultracold and dense samples of rovibrational ground state (RGS) molecules near quantum degeneracy in the presence of an optical lattice. We first associate Cs_2 Feshbach dimer molecules out of a lattice-based Mott-insulator state loaded from an atomic Bose-Einstein condensate (BEC) of Cs atoms and then coherently transfer the molecules to the RGS by a four-photon STIRAP process. We discuss improvements to reach higher transfer efficiencies and the next steps towards the production of a BEC of dimer molecules. The work is supported by the Austrian Science Fund FWF in the framework of project P 21555-N20.

Q 3.2 Mon 10:45 BAR Schön

Bogoliubov Theory of Dipolar Bose-Einstein Condensates — •Aristeu R. P. Lima[1] and Axel Pelster[2] — [1]Institut für Theoretische Physik, Freie Universität Berlin, Arnimallee 14, 14195 Berlin, Germany — [2]Fachbereich Physik, Universität Duisburg-Essen, Lotharstrasse 1, 47048 Duisburg, Germany

Nowadays, Bose-Einstein condensates with a weak anisotropic and long-range dipole-dipole interaction, such as ^{52}Cr condensates, are considered to be relatively well understood in terms of the Gross-Pitaevskii mean-field theory. Howerever, for highly magnetic atoms, such as dysprosium, or for strongly polar heteronuclear molecules, as for instance ^{40}K-^{87}Rb, quantum fluctuations in dipolar condensates could become relevant. To this end, we discuss at first the Lee-Huang-Yang correction to the sound velocity of a homogeneous dipolar condensate as derived from the Bogoliubov theory. In order to take the harmonic trapping potential into account, we extend our calculations with the help of the Bogoliubov-de Gennes theory. Thereby, we make use of the local density approximation to derive the Bogoliubov spectrum analytically, from which we determine then physical quantities of interest such as the condensate depletion and the quantum corrections to the low-lying excitation frequencies as well as to the time-of flight dynamics. Due to the delicate interplay between the dipolar interaction and the condensate geometry, we find that the influence of the quantum fluctuations can be strongly affected by the trap aspect ratio. Therefore, we are quite optimistic that future experiments will detect these beyond mean-field effects.

Q 3.3 Mon 11:00 BAR Schön

Semiclassical model for the formation of Rydberg molecules — •Andrej Junginger, Jörg Main, and Günter Wunner — 1. Institut für Theoretische Physik, Universität Stuttgart

In cold gases ultra-long range Rydberg molecules have been predicted theoretically [1] and recently observed experimentally [2]. The bond is caused by a scattering process of the Rydberg electron at the ground state atom. In a mean-field approximation this can be explained by a Fermi pseudo-potential which well describes the bound states but, as a conservative potential, is not able to explain the process of capturing the ground state atom.

We present a new model based on scattering theory and a semiclassical approximation which is capable of describing the formation of the Rydberg molecule by decelerating the ground state atom. From the infinite set of Kepler ellipses we select a finite number passing through the ground state atom. At the position of the latter the ellipses are approximated by plane waves, and the s-wave scattering of the Rydberg electron at the ground state atom then leads to a dissipative force. Solving the classical equations of motion, we find that a ground state atom with kinetic energy $E_{\mathrm{kin}} > 0$ in the order of the magnitude of the binding energy will always be decelerated. Depending on the initial conditions it can even come to rest, so that this dissipative process may play an important role in the formation of the Rydberg molecule.

[1] C. H. Green *et al.*, *Phys. Rev. Lett.* **85**, 2458 (2000).
[2] V. Bendkowsky *et al.*, *Nature* **458**, 1005 (2009).

Q 3.4 Mon 11:15 BAR Schön

Optical Manipulation of Large Molecule Beams for Molecule Interference — •Paul Venn and Hendrik Ulbricht — School of Physics and Astronomy, University of Southampton, Highfield, SO17 1BJ, UK

A challenge of molecule interferometry is being able to create intense beams of large molecules, which are typically created through sublimation in a furnace. In order to increase the intensity of the beam reaching our Talbot-Lau interferometer a molecular lens is proposed. This lensing effect relies on creating an off-resonant Stark shift in the target molecule species through the interaction with an intense laser beam directed perpendicular to the molecular beam. This lensing effect has previously been observed for light molecules such as CS2 and I2, and the effect is scalable up to much larger masses due to the non-resonant interaction. Simulations have been carried out modelling the lensing effect for our interferometer using a femtosecond pulsed Ti:Sa laser with 50kW peak power. From this we expect to observe a 25% increase in detected signal for a thermal beam of C60 using a single laser beam acting as a cylindrical molecular lens. For more highly polarizable molecules such as H2TPP we expect to be able to observe the focal spot of the lens without the need for preliminary cooling of the molecule beam. It is hoped that this lensing effect can be used on more massive fluro-fullerene molecules to allow us to measure interference for molecules of masses of up to 10,000amu. We will report on theoretical simulations as well as on experiments on this effect.

Q 3.5 Mon 11:30 BAR Schön

Low temperature studies of molecules in solid state using an optical nanofiber — •Ariane Stiebeiner, Nils Konken, David Papencordt, Ruth Garcia-Fernandez, and Arno Rauschenbeutel — Technische Universität Wien - Atominstitut, Stadionallee 2, 1020 Wien, Austria

Molecules in solids have proven to be a versatile system for studying quantum optical effects and for realizing single photon sources. Coupling the emitters to optical nanofibers further enhances the potential of this system. The strong radial confinement and the pronounced evanescent field of the guided light in optical nanofibers yield a high excitation and emission collection efficiency [1, 2]. We present low temperature studies on terrylene doped p-terphenyl crystals on the nanofiber waist of a tapered optical fiber. The high sensitivity of our method should allow us to perform single molecule spectroscopy and to realize an all-fiber-based single photon source.

We gratefully acknowledge financial support by the Volkswagen Foundation (Lichtenberg Professorship), the ESF (European Young Investigator Award), and the EC (STREP "CHIMONO").

[1] F. Warken et al., Optics Express, Vol. 15, 19, 11952-11958 (2007)
[2] A. Stiebeiner et al., Optics Express, Vol. 17, 24, 21704-21711 (2009)

Q 3.6 Mon 11:45 BAR Schön

Low Temperature Studies on Single Molecules interacting with Plasmonic Structures — •Bernhard Grotz[1], Ilja Gerhardt[1,2], Petr Siyushev[1], Fedor Jelezko[1], and Jörg Wrachtrup[1] — [1]3rd Physics Institute and Research Center SCoPE, Universität Stuttgart, Germany — [2]Max Planck Institute for Solid State Research, Stuttgart, Germany

When light interacts with metal surfaces it excites electrons which can form propagating excitation waves called surface plasmon polaritons (SPP). These collective electronic excitations allow for many applications due to their ability to produce electric fields, localized to sub-wavelength scales. It was shown that the emission of single quantum systems like e.g. quantum dots [1] or nitrogen vacancy centres in diamond [2] can be used to generate propagating single surface plasmon polaritons. In the frame of large scale quantum networks, further conceived experiments incooperate the incoupling of single narrow-band emitters to plasmons. Such single emitters could be organic dye molecules serving as an element of e.g. a quantum phase gate. Here we present first experimental results on the coupling of single organic molecules to silver nanowires at cryogenic temperatures.

[1] A. V. Akimov, A. Mukherjee, C. L. Yu, D. E. Chang, A. S. Zibrov, P. R. Hemmer, H. Park & M. D. Lukin, Nature 450, 402-406 (2007)
[2] R. Kolesov, B. Grotz, G. Balasubramanian, R. J. Stöhr, A. A. L. Nicolet, P. R. Hemmer, F. Jelezko & J. Wrachtrup, Nature Physics 5, 470-474 (2009)

Q 3.7 Mon 12:00 BAR Schön

Interlayer superfluidity and scattering in bilayer systems of polar molecules — •Alexander Pikovski[1], Michael Klawunn[1,2], G. V. Shlyapnikov[3], and Luis Santos[1] — [1]Institut für Theoretische Physik, Leibniz Universität Hannover, Appelstr. 2, 30167 Hannover, Germany — [2]INO-CNR BEC Center and Dipartimento di Fisica, Università di Trento, 38123 Povo, Italy — [3]Laboratoire de Physique Théorique et Modèles Statistiques, Université Paris Sud, CNRS, 91405 Orsay, France

We consider fermionic polar molecules in a bilayer geometry. The dipole-dipole interaction between molecules of different layers leads to the emergence of interlayer superfluids. The superfluid regimes range from BCS-like fermionic superfluidity to BEC of interlayer dimers. The system shows unusual two-dimensional scattering behaviour [M. Klawunn et al., Phys. Rev. A **82**, 044701 (2010)] and exhibits a peculiar BCS-BEC crossover [A. Pikovski et al., Phys. Rev. Lett. **105**, 215302 (2010)].

Q 3.8 Mon 12:15 BAR Schön

Controlling a Shape Resonance with Non-resonant Laser Light — •Ruzin Aganoglu[1], Mikhail Lemeshko[2], Bretislav Friedrich[2], Rosario González-Férez[3], and Christiane P. Koch[1,4] — [1]Freie Universität Berlin, Institut für Theoretische Physik — [2]Fritz-Haber-Institut der Max-Planck-Gesellschaft, Berlin — [3]Universidad de Granada, Facultad de Ciencias, Spain — [4]Universität Kassel, Institut für Physik

A shape resonance is a metastable state that arises from trapping of a part of the scattering wavefunction by the centrifugal barrier. It corresponds to an enhanced pair density of atoms at short internuclear separations, which can be useful for making molecules from atom pairs. For atoms confined in an atom trap, the pair density will be enhanced if the energy width of the resonance matches the atom trap temperature. Herein, we seek to control the energy of a shape resonance by making use of non-resonant laser light. Nonresonant light couples to the polarizability anisotropy of an atom pair and thereby modifies its rotational and vibrational states. We study the effect on the pair density of rubidium and strontium atoms as a function of the pulse duration and intensity of the nonresonant light.

Q 3.9 Mon 12:30 BAR Schön

Near-threshold vibrational bound states in long-range molecules — •Tim-Oliver Müller and Harald Friedrich — Physik Department, TU München, Germany

Interatomic potentials with attractive tails asymptotically vanishing as $-1/r^{\alpha}$ (with $\alpha > 2$) support at most a finite number of vibrational bound states, and their energies E_v are related to their quantum numbers v via a quantization rule $v_{\rm D} - v = F(E_v)$, where $v_{\rm D}$ is the – not necessarily integer – *threshold quantum number*. At near-threshold energies the *quantization function* $F(E)$ is predominantly determined by a contribution $F_{\rm tail}(E)$ stemming from the potential's tail, which is a universal function depending only on the power α. Quantum effects are important near the dissociation threshold and $F(E)$ differs significantly from the widely used semiclassical expression derived by LeRoy and Bernstein [1]. Explicit analytical expressions for $F_{\rm tail}$ have been presented for to the van der Waals interaction between two neutral polarizable atoms or molecules ($\alpha = 6$) [2] as well as for the dispersion energy occuring in certain diatomic molecular ions ($\alpha = 4$) [3] and recently also for the power $\alpha = 3$ [4], which corresponds to the resonant dipole-dipole interaction between two identical atoms in a homonuclear dimer. Applications to sodium dimers show the importance of correctly including quantum effects near threshold.

[1] R. J. LeRoy and R. B. Bernstein, *J. Chem. Phys* **52**, 3869 (1970).
[2] P. Raab and H. Friedrich, *Phys. Rev. A* **78**, 022707 (2008).
[3] P. Raab and H. Friedrich, *Phys. Rev. A* **80**, 052705 (2009).
[4] T.-O. Müller and H. Friedrich, submitted to *Phys. Rev. A.*

Q 3.10 Mon 12:45 BAR Schön

Quantum reflection and localization in bound systems — •Elias Diesen[1] and Jan-Michael Rost[2] — [1]Max-Planck-Institut für Physik komplexer Systeme — [2]Max-Planck-Institut für Physik komplexer Systeme

The phenomenon of quantum reflection is briefly presented and compared to the situation where a similar shape of the underlying potential causes localization of eigenstates in a confining potential. The relation of both these quantum phenomena to the breakdown of semiclassical (WKB) dynamics is discussed. A few physical systems that show such behaviour are presented, among them the ultracold Rydberg dimer, consisting of a ground state and a Rydberg atom [1]. Due to the current rapid development of experimental techniques for the ultracold regime, these phenomena should become more and more accessible to direct experimental investigation.

[1] V. Bendkowsky etal., Phys. Rev. Lett. 105, 163201 (2010).

Q 4: Ultra-cold atoms, ions and BEC I

Time: Monday 10:30–12:45 Location: BAR 106

Q 4.1 Mon 10:30 BAR 106

Scattering of a polarizable atom by an absorbing nanowire — •Martin Fink, Johannes Eiglsperger, Harald Friedrich, and Javier Madroñero — Physik Department (T30a), TU München, Germany

In view of the intense attention currently given to systems involving nanotubes at very low temeratures, we study the fundamental process of scattering a cold, polarizable atom by an infinite cylindrical conducting wire. We formulate a method offering a practicable way of numerically calculating the exact nonretarded electrostatic van der Waals potential with any desired accuracy, see Ref. [1]. Using this method, we are able to calculate numerically the scattering properties for an absorbing nanowire by assuming incoming boundary conditions at the surface. We present calculations, e.g. of the s-wave scattering length which characterizes the behaviour of these properties in the near-threshold region. This is the first calculation of atom-wire scattering, which is based on a theoretically founded potential and on the two-dimensional nature of the problem.

[1] M. Fink et al., Physical Review A **81**, 062714 (2010).

Q 4.2 Mon 10:45 BAR 106

Universality of s-wave scattering phase shifts beyond the effective-range expansion — •Alexander Kaiser, Tim-Oliver Müller, and Harald Friedrich — Physik Department, TU München, Germany

The properties of scattering states at low energies in deep potentials with a homogeneous attractive tail $V(r) = -\hbar^2\beta_\alpha^{\alpha-2}/(2\mu r^\alpha)$ with $\alpha > 2$ are strongly related to the location of the bound states just below the dissociation threshold. It has been shown that the non-integer part $\Delta_{\rm th}$ of the threshold quantum number determines the scattering length [1] as well as the semiclassical behaviour [2] of the scattering phase shift at intermediate energies. With a new method we derived a formula for the scattering phase shift, accurately describing the whole energy range from threshold to the semiclassical regime, $\tan(\delta_0) = A_s/A_c \sin(\phi_s - \phi_{\rm sr})/\cos(\phi_s - \phi_{\rm sr})$, where A_s/A_c, ϕ_s and ϕ_c are universal functions of energy, which depend on the potential tail (i.e. α) alone and $\phi_{\rm sr}$ contains a single parameter $\Delta_{\rm th}$, accounting for all short range effects. The bound states below threshold are given by the quantization function [3], $F_{\rm tail}(E_n) = n_{\rm th} - n$, so that the whole energy spectrum around the dissociation threshold is determined by the scattering length.

[1] G. Gribakin and V. Flambaum, *Phys. Rev. A* **48**, 546 (1993).
[2] G. Gribakin et al., *Phys. Rev. A* **59**, 1998 (1999).
[3] P. Raab and H. Friedrich, *Phys. Rev. A* **7**8, 022707 (2008).

Q 4.3 Mon 11:00 BAR 106

Three bosons in two dimensions — •Kerstin Helfrich and Hans-Werner Hammer — HISKP(Theorie) und BCTP, Universität Bonn

In this talk I discuss two-dimensional atomic gases exhibiting a large two-body scattering length. In an effective field theory framework we are able to calculate observables up to next-to-leading order, i.e. with the inclusion of the two-body effective range. We are especially interested in three-body observables such as the binding energies, the atom-dimer scattering length and the three-body recombination rate.

Q 4.4 Mon 11:15 BAR 106

Interaction Driven Interband Tunneling of Bosons in the Triple Well — •Lushuai Cao[1], Ioannis Brouzos[1], Sascha Zöllner[2], and Peter Schmelcher[1] — [1]Zentrum für Optische Quantentechnologien, Luruper Chaussee 149, D-22761 Hamburg, Germany — [2]Niels Bohr International Academy, Niels Bohr Institute, Blegdamsvej 17, DK-2100 Copenhagen, Denmark

We study the tunneling of a small ensemble of strongly repulsive bosons in a one-dimensional triple-well potential. The usual treatment within the single-band approximation suggests suppression of tunneling in the strong interaction regime. However, we show that several windows of enhanced tunneling are opened in this regime. This enhanced tunneling results from higher band contributions, and has the character of interband tunneling. It can give rise to various tunneling processes, such as single-boson tunneling and two-boson correlated tunneling of the ensemble of bosons, and is robust against deformations of the triple well potential. We introduce a basis of generalized number states including all contributing bands to explain the interband tunneling, and demonstrate various processes of interband tunneling and its robustness by numerically exact calculation.

Q 4.5 Mon 11:30 BAR 106

A fundamental limit to spin-exchange optical pumping of ^{3}He nuclei — •H.R. Sadeghpour, T.V. Tscherbul, P. Zhang, and A. Dalgarno — ITAMP, Harvard-Smithsonian CfA, Cambridge, MA 02138

The existence of a fundamental limit to the efficiency of spin-exchange optical pumping of ^{3}He nuclei by collisions with spin-polarized alkali-metal atoms is established. Using accurate *ab initio* calculations of molecular interactions and scattering properties, requiring no adjustable parameters, it is demonstrated that attainable polarization of ^{3}He nuclei by spin-exchange collisions with K atoms is limited by the anisotropic hyperfine interaction. The theory is specifically applied to the spin-exchange between potassium and ^{3}He. In a complementary calculation, it is suggested that it may be possible to overcome this limit by using atomic silver (Ag) as a collision partner in spin-exchange optical pumping experiments.

Q 4.6 Mon 11:45 BAR 106

Rotons and Supersolids in Rydberg-dressed BECs — •Nils Henkel and Thomas Pohl — Max Planck Institute for the Physics of Complex Systems, Nöthnitzer Straße 38, 01187 Dresden

We study a BEC where atoms are off-resonantly coupled to high Rydberg states with strong van der Waals interaction. We find that this leads to effective ground state interactions which, in turn, lead to the formation of a crystalline structure in the BEC. Comparisons to Quantum Monte Carlo simulations at finite temperatures demonstrate the survival of a significant superfluid fraction, i.e. the emergence of a Supersolid state in the BEC. This excellent agreement proves the applicability of our Mean-Field theory. Therefore, we then extend our Mean-Field investigation to rotating BECs and find similar structures as in the stationary case. There appears however a nontrivial competition between supersolid order and an Abrikosov vortex lattice due to rotation. Shedding light on this competition, the resulting phase diagram will be discussed.

Q 4.7 Mon 12:00 BAR 106

Mesoscopic Transport of Ultracold Atoms in Optical Lattices — •Martin Bruderer and Wolfgang Belzig — Fachbereich Physik, Universität Konstanz, D-78457 Konstanz, Germany

Transport of quantum gases is attracting considerable attention, both on a theoretical and experimental level, in part because ultracold atoms confined to optical lattices can be coherently manipulated and detected on microscopic scales. In particular, substantial technological progress has opened the way for a bottom-up approach to mesoscopic transport in optical lattices, in which case the coherence in certain parts of the system is deliberately destroyed. We show based on a specific setup, namely two incoherent atomic reservoirs connected by a short optical lattice, that mesoscopic phenomena such as, e.g., phonon assisted transport, coherent suppression of tunneling and non-adiabatic quantum pumping can be realized with ultracold atoms. For our analysis in the tight-binding regime we use the non-equilibrium Green's functions formalism extended to include the time dependence of the reservoirs.

Q 4.8 Mon 12:15 BAR 106

Phase diagrams for spin-1 bosons in an optical lattice — •Ming-Chiang Chung[1,2] and Sungkit Yip[2] — [1]Physics Division, National Center for Theoretical Science, Hsinchu, 30013, Taiwan — [2]Institute of Physics, Academia Sinica, Taipei 11529, Taiwan

The phase diagrams of a polar spin-1 Bose gas in a three-dimensional optical lattice with linear and quadratic Zeeman effects both at zero and finite temperatures are obtained within mean-field theory. The phase diagrams can be regrouped to two different parameter regimes depending on the magnitude of the quadratic Zeeman effect Q. For large Q, only a first-order phase transition from the nematic (NM) phase to the fully magnetic (FM) phase is found, while in the case of small Q, a first-order phase transition from the nematic phase to the partially magnetic (PM) phase, plus a second-order phase transition from the PM phase to the FM phase is obtained. If a net magnetization in the system exists, the first-order phase transition causes a coexistence of two phases and phase separation: for large Q, NM and FM phases and for small Q, NM and PM phases. The phase diagrams in terms of net magnetization are also obtained

Q 4.9 Mon 12:30 BAR 106

Magnetism and Phase Separation in SU(3) Symmetric Multi-species Fermi Mixtures — •Irakli Titvinidze[1], Antonio Privitera[1,2], Soon-Yong Chang[3,4], Sebastian Diehl[3], Mikhail Baranov[3], Andrew Daley[3], and Walter Hofstetter[1] — [1]Institut für Theoretische Physik, Goethe-Universität, Frankfurt am Main, Germany — [2]Dipartimento di Fisica, Università di Roma La Sapienza, Roma, Italy — [3]IQOQI of the Austrian Academy of Sciences, Innsbruck, Austria, — [4]Department of Physics, The Ohio State University, Columbus, OH 43210, USA

We study the phase diagram of a SU(3) symmetric mixture of three-species fermions in a lattice with attractive interactions and the effect on the mixture of an effective three-body constraint induced by three-body losses. We address the properties of the system in $D \geq 2$ by using dynamical mean-field theory and variational Monte Carlo techniques. The phase diagram of the model shows a strong interplay between magnetism and superfluidity. In the absence of three-body constraint (no losses), the system undergoes a phase transition from a color superfluid phase to a trionic phase, which shows additional charge density modulations at half-filling. Outside of the particle-hole symmetric point the color superfluid phase has always a finite polarization, leading to phase separation in systems where the total number of particles in each species is conserved. The three-body constraint strongly disfavors the trionic phase, stabilizing a (fully magnetized) color superfluid phase also at strong coupling. With increase of the temperature we observe a transition to a non-magnetized $SU(3)$ Fermi liquid phase.

Q 5: Ultracold Atoms: Manipulation and Detection

Time: Monday 10:30–13:00 Location: SCH 251

Q 5.1 Mon 10:30 SCH 251

Single-spin addressing in an atomic Mott insulator — •C. Weitenberg, M. Endres, J. F. Sherson, M. Cheneau, P. Schauss, T. Fukuhara, I. Bloch, and S. Kuhr — Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Str. 1, D-85748 Garching

The quest to address single sites of an optical lattice has a longstanding history in the field of ultracold atoms. Here we report on the achievement of full two-dimensional single-site spin control in an optical lattice with sub-diffraction limited spatial resolution. We use the differential light shift of a tightly focused laser beam to shift selected atoms into resonance with a microwave field. Starting from a Mott insulator with unity filling we are able to create arbitrary spin patterns. To demonstrate that our scheme leaves most of the atoms in the motional ground state, we observe the one-dimensional tunneling dynamics of the addressed atoms and discriminate the dynamics of the ground state and the first excited band. Our scheme opens the path to a wide range of novel applications from quantum dynamics of spin impurities, entropy transport, implementation of novel cooling schemes, and engineering of quantum many-body phases to quantum information processing.

Q 5.2 Mon 10:45 SCH 251

Feedback control of the hyperfine ground states of neutral atoms in an optical cavity — •Stefan Brakhane[1], Wolfgang Alt[1], Miguel Martinez-Dorantes[1], Tobias Kampschulte[1], René Reimann[1], Artur Widera[1,2], and Dieter Meschede[1] — [1]Institut für Angewandte Physik der Universität Bonn, Wegelerstr. 8, 53115 Bonn — [2]Fachbereich Physik der TU Kaiserslautern, Erwin-Schrödinger-Str., 67663 Kaiserslautern

Detection and manipulation of atomic spin states is essential for many experimental realizations of quantum gates. Feedback schemes to stabilize the states and their superpositions can counteract perturbations caused by the environment.

In our experiment we deduce the atomic spin state of one or two Caesium atoms by measuring the transmission of a probe laser through a high-finesse cavity. Depending on the number of atoms in the hyperfine state that strongly couples to the cavity, the resonance of the cavity is shifted and the probe laser transmission is decreased. We employ a Bayesian update formalism to obtain time-dependent probabilities for the atomic states of one and two atoms [1].

I will present an experimental implementation using a digital signal processor which allows us to determine the atomic spin state in real-time. First experimental results of an extension to a feedback loop for the preparation and stabilization of atomic states will be shown.

[1] S. Reick, K. Mølmer *et al.*, J. Opt. Soc. Am. B **27**, A152 (2010)

Q 5.3 Mon 11:00 SCH 251

Measurement of the atom number distribution in an optical tweezer using single photon counting — •Andreas Fuhrmanek, Ronan Bourgain, Yvan Sortais, Philippe Grangier, and Antoine Browaeys — Institut d'Optique, RD 128 Campus Polytechnique, 91127 Palaiseau Cedex, France

In this talk I will present our experimental realisation of an atom counting method that allows us to reconstruct the atom number distribution inside a dipole trap and to measure the average atom number precisely. This method relies on counting single photon events on an intensified CCD camera when resonant light is sent on the atoms. We deduce the atom number distribution by analyzing the photon number distribution obtained over a series of images. This technique is a useful alternative to fluorescence or absorption methods, that may underestimate the atom number in dense samples due to photon reabsorption processes.

Q 5.4 Mon 11:15 SCH 251

Imaging of microwave fields using ultracold atoms — •Pascal Böhi[1], Max Riedel[1], Theodor Hänsch[2], and Philipp Treutlein[1] — [1]Departement Physik, Universität Basel, Klingelbergstrasse 82, 4056 Basel, Switzerland — [2]Max-Planck-Institut für Quantenoptik and Ludwig-Maximilians-Universität, München, Germany

Clouds of ultracold atoms are used as highly sensitive, tunable and non-invasive probes for microwave field imaging with micrometer spatial resolution. The microwave magnetic field drives Rabi oscillations on atomic hyperfine transitions which are read out using state-selective absorption imaging. It is possible to fully reconstruct the microwave magnetic field, including the microwave phase distribution. We use this method to determine the microwave near-field distribution around a coplanar waveguide which is integrated on an atom chip. We compare the extracted microwave field to simulations to deduce the microwave current distribution on the waveguide.
[1] P. Böhi *et al.*, Appl. Phys. Lett. **97**, 051101 (2010).

Q 5.5 Mon 11:30 SCH 251

Feedback Cooling of a Single Neutral Atom — •Christian Sames, Markus Koch, Maximilian Balbach, Haytham Chibani, Alexander Kubanek, Alexei Ourjoumtsev, Pepijn Pinkse, Karim Murr, Tatjana Wilk, and Gerhard Rempe — Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Str. 1, D-85748 Garching, Germany

Feedback is a powerful tool to control the evolution of classical systems. Fast electronics enables its extension towards the quantum domain, namely the control of the motion of a single neutral atom inside a high-finesse optical resonator. The atom is trapped in an optical dipole trap and interacts strongly with a single mode of the resonator. The interaction strength determines the resonance condition of the coupled system, depending on the atomic position, and hence governs the intensity of a transmitted probe beam. We analyze the flux of the transmitted photons which carries information about the atomic position and velocity, and alter the dipole force in such a way that it counteracts the atomic motion [1]. With this feedback technique we enhance the storage time of the atom in the resonator by at least 2 orders of magnitude, reaching values of more than 17 seconds with an average of more than 1 second. Additionally, we demonstrate cooling of the single atom by this technique to a temperature of about 160 μK [2]. Feedback cooling of a single atom hence rivals state-of-the-art laser cooling with the advantage that much less optical access is required.

[1] A. Kubanek et al., Nature 462, 898 (2009).
[2] M. Koch et al., Phys. Rev. Lett. 105, 173003 (2010).

Q 5.6 Mon 11:45 SCH 251

Particle counting statistics of time dependent fields — •Sibylle Braungardt[1], Mirta Rodrígues[2], Aditi Sen[3], Ujjwal Sen[3], Roy J. Glauber[4], and Maciej Lewenstein[1] — [1]ICFO - Institut de Ciències Fotòniques, Av. del Canal Olímpic s/n, 08860 Castelldefels (Barcelona), Spain — [2]Instituto de Estructura de la Materia, CSIC, C/Serrano 121, 28006 Madrid, Spain — [3]Harish-Chandra Research Institute, Chhatnag Road, Jhunsi, Allahabad 211 019, India — [4]Lyman Laboratory, Physics Department, Harvard University, 02138 Cambridge, MA, U.S.A.

Since the beginnings of quantum optics, photon counting has been used as an important tool to characterize quantum states of light. The counting distribution is typically calculated using the quantum Mandel formula [1]. Likewise, the counting statistics of atoms can give insight into the quantum properties of many-body states of ultracold atomic gases. A wide range of experimental setups with cold atoms require a time and space dependent treatment of the counting process. The quantum Mandel formula treats time in a perturbative way, and generally does not give the correct behavior for time dependent systems. We derive a non-perturbative formula for the counting distribution and apply it to different experimental situations of ultracold atoms.

[1] R.J. Glauber, in Quantum Optics and Electronics, eds. B. DeWitt, C. Blandin, and C. Cohen-Tannoudji, pp. 63-185, Gordon and Breach, New York, (1965).

Q 5.7 Mon 12:00 SCH 251

Shortcut to adiabatic passage in two- and three-level atoms — •Andreas Ruschhaupt — Institut für Theoretische Physik, Leibniz Universität Hannover, Appelstraße 2, 30167 Hannover, Germany

We propose a method to speed up adiabatic passage techniques in two-level and three-level atoms extending to the short-time domain their robustness. It supplements or substitutes the standard laser beam setups with auxiliary pulses that steer the system along the adiabatic path. Compared to other strategies such as composite pulses or the original adiabatic techniques, it provides a fast and robust approach to population control.

Ref.: X. Chen, I. Lizuain, A. Ruschhaupt, D. Guéry-Odelin, and J. G. Muga, Phys. Rev. Lett. 105, 123003 (2010)

Q 5.8 Mon 12:15 SCH 251

Coherent control of atoms using STIRAP: Two realistic systems. — •Tadhg Morgan, Brian O'Sullivan, and Thomas Busch — Physics Department, University College Cork, Co. Cork, Ireland

Developing strategies for coherent control of quantum states is one of the keys for successful engineering of quantum mechanical structures or quantum information processors in the future. Due to the fragile nature of quantum states these techniques need to be, most importantly, fault tolerant and lead to high fidelities. One class of techniques that can achieve this are so-called adiabatic techniques and their use in optical systems has been widely investigated in the past. Recently, it has been shown that similar techniques can, in principle, be used to prepare and process quantum states of single atoms and that, in particular, the counter-intuitive STIRAP process is an excellent candidate for the coherent movement of ultra-cold atoms. As atomic traps are currently not at the technologically advanced state where they can easily be moved in space we propose two realistic setups in which STIRAP can be observed, an atomchip with three current carrying wires and triple well radio frequency potential. We show that both systems provide high fidelity STIRAP and also that the radio frequency potential allows us to extend the application of the STIRAP technique a cloud of interacting atoms.

Q 5.9 Mon 12:30 SCH 251

Improved detection of small atom numbers through image processing — •Caspar Ockeloen[1,2], Atreju Tauschinksy[1], Robert Spreeuw[1], and Shannon Whitlock[1,3] — [1]University of Amsterdam, The Netherlands — [2]Universität Basel, Switzerland — [3]Universität Heidelberg, Germany

We demonstrate improved detection of small trapped atomic ensembles through advanced post-processing and optimal analysis of absorption images. These techniques provide the basis to improve the readout of trapped atom interferometers to the quantum limit or to better resolve number/spin-squeezing and entanglement between small atomic ensembles. A fringe removal algorithm reduces imaging noise to the fundamental photon-shot-noise level and proves beneficial even in the absence of fringes. A maximum-likelihood estimator is then derived for optimal atom-number estimation and is applied to real experimental data to measure the population differences and intrinsic atom shot-noise between spatially separated ensembles each comprising between 10 and 2000 atoms. The combined techniques improve our signal-to-noise by a factor of 3, to a minimum resolvable population difference of 17 atoms, close to our ultimate detection limit.

Q 5.10 Mon 12:45 SCH 251

Control of refractive index and motion of a single atom by quantum interference — •Tobias Kampschulte[1], Wolfgang Alt[1], Stefan Brakhane[1], Martin Eckstein[1,2], Miguel Martinez-Dorantes[1], René Reimann[1], Artur Widera[1,3], and Dieter Meschede[1] — [1]Institut für Angewandte Physik der Universität Bonn, Wegelerstr. 8, 53115 Bonn — [2]Max-Born-Institut, Abteilung A2, Max-Born-Str. 2 A, 12489 Berlin — [3]Fachbereich Physik der TU Kaiserslautern, Erwin-Schrödinger-Str., 67663 Kaiserslautern

The properties of an optically probed atomic medium can be changed dramatically by coherent interaction with a near-resonant control light field. I will present our experimental results on the elementary case of electromagnetically induced transparency (EIT) with a single neutral atom inside an optical cavity probed by a weak field [1]. We have observed modification of the dispersive and absorptive properties of a single atom by changing the frequency of the control light field in the off-resonant regime.

In this regime, the creation of a transparency window close to a narrow absorption peak can give rise to a sub-Doppler cooling mechanism. I will present the observation of strong cooling and heating effects in the vicinity of the two-photon resonance. The cooling increases the storage time of our atoms twenty-fold to about 16 seconds. Recent investigations of this effect outside the cavity using microwave sideband spectroscopy have revealed that a large fraction of atoms is cooled to the axial ground state of the trap.

[1] T. Kampschulte *et al.*, Phys. Rev. Lett. **105**, 153603 (2010)

Q 6: Quantum Effects: Light Scattering and Propagation

Time: Monday 10:30–13:00 Location: SCH A01

Q 6.1 Mon 10:30 SCH A01

Multiple scattering of photons on disordered atomic samples: localization vs. nonlinearity — •Ralf Blattmann, Felix Eckert, Jochen Zimmermann, Vyacheslav Shatokhin, Thomas Wellens, and Andreas Buchleitner — Physikalisches Institut, Universität Freiburg, Hermann-Herder-Str. 3 , 79104 Freiburg

When single photons are multiply scattered inside a disordered cloud of cold atoms, interference between different scattering paths manifests themselves in weak and strong localization effects such as coherent backscattering and – in the most extreme case – even a complete suppression of classical diffusion. At higher laser intensities, however, nonlinear and inelastic multi-photon scattering events must be taken into account, and compete with the coherent transport effects mentioned above. First, we show – by means of diagrammatic scattering theory – that the coherent backscattering peak is reduced, or even inverted, for classical light propagating in a nonlinear disordered medium, and generalize these results to the regime of strong localization. In addition to the nonlinearity, we then address inelastic scattering resulting from the interaction of atoms with the quantized radiation field. In particular, we will analyze scattering of intense laser light by two atoms with degenerate energy levels. Finally, we consider coherent propagation of one and two photons in a one-dimensional disordered chain of two-level atoms, where – in contrast to 3D – recurrent scattering cannot be neglected.

Q 6.2 Mon 11:00 SCH A01

Highly resonant spin noise spectroscopy at the D_2 rubidium transition — •Hauke Horn[1], Ernst Rasel[2], Luis Santos[3], Michael Oestreich[1], and Jens Hübner[1] — [1]Institute for Solid State Physics, Leibniz University Hannover, Appelstr. 2, 30167 Hannover, Germany — [2]Institut für Quantenoptik, Leibniz University Hannover, Welfengarten 1, 30167 Hannover, Germany — [3]Institute for Theoretical Physics, Leibniz University Hannover, Appelstr. 2, 30167 Hannover, Germany

We measure the fluctuating magnetization noise of an ensemble of non-interacting rubidium atoms with high sensitivity Faraday rotation spectroscopy. This measurement technique called spin noise spectroscopy allows us to probe the equilibrium spin dynamics of our sample. In spin noise spectroscopy, a magnetic field is applied in Voigt geometry to modulate the occurring spin noise with the Larmor frequency $\omega_L = g_I \mu_B B/\hbar$ with atom g–factor g_I, Bohr magneton μ_B and magnetic field B. Usually, the laser is widely detuned from optical resonances to avoid unwanted excitation effects (as e.g. carrier heating in semiconductors).

Here, we probe the Faraday rotation noise under resonant and non-resonant conditions in terms of non-linear magneto–optics. We tune the laser ±10 GHz around the Rb D_2-transition and see a clear signature of coherent couplings of the participating electronic levels and explain it fully by extended Bloch equations including all D_2 hyperfine states as well as homogeneous and inhomogeneous processes like pressure broadening of the resonances and diffusion of the atoms.

Q 6.3 Mon 11:15 SCH A01

Creation of Strongly Correlated States for Photons using Rydberg Interactions — Johannes Otterbach[1], Alexey V. Gorskov[2], •Thomas Pohl[3], Mikhail D. Lukin[4], and Michael Fleischhauer[1] — [1]Fachbereich Physik & Forschungszentrum OPTIMAS, TU Kaiserslautern — [2]Physics Department, California Institute of Technology, Pasadena, CA, USA — [3]Max-Planck-Institut für Physik komplexer Systeme, Dresden — [4]Physics Department, Harvard University, Cambridge, MA, USA

Due to their strong long-range interaction and high level of controllability Rydberg-atoms are especially well suited for applications in quantum-information [1]. We study the interaction of single- or few-photon pulses in a coherently driven ensemble of Rydberg atoms exhibiting a ladder-like linkage pattern. Under conditions of electromagnetically induced transparency the photons form quasi-particles, so-called dark-state polaritons [2]. We investigate the effect of the strong Rydberg interactions on the polaritons. In particular we discuss two-particle correlations which are shown to decay very quickly to zero within the so-called blockade radius if the lower transition is close to resonance. Away from resonance temporary two-polariton bound states are formed. On length scales large compared to the blockade radius the Rydberg polaritons experience a repulsive interaction. Finally we discuss the formation of strongly correlated many-photon states.

[1] M. Saffman et al., Rev. Mod. Phys. 82, 2313 (2010).
[2] M. Fleischhauer et al., Rev. Mod. Phys. 77, 633 (2005).

Q 6.4 Mon 11:30 SCH A01

Suppression of stimulated Brillouin scattering in a photonic crystal fiber with periodically-varied core diameter — •Birgit Stiller[1], Michaël Delqué[1], Min Won Lee[1], Alexandre Kudlinski[2], Hervé Maillotte[1], and Thibaut Sylvestre[1] — [1]Institut FEMTO-ST, Université de Franche-Comté, 25030 Besançon, France — [2]Université Lille 1, IRCICA, Laboratoire PhLAM, 59655 Villeneuve d'Ascq, France

Suppression of stimulated Brillouin scattering (SBS) in optical fibers is of particular interest for telecommunication and fiber laser applications. For this purpose we designed a photonic crystal fiber with periodically varying size of the air-hole-structure by 7% while keeping a low attenuation coefficient. We experimentally demonstrate 7 dB improvement in SBS suppression compared to a homogenous fiber. The fiber under test was characterized by using Brillouin echoes distributed sensing technique where the periodic variation of the Brillouin frequency shift is demonstrated. Additionally guided acoustic wave Brillouin scattering was investigated in this fiber and compared to numerical simulations of a full-vectorial finite element method based on the scanning electron microscope image of the fiber cross section.

Q 6.5 Mon 11:45 SCH A01

Photon-Phonon Interaction in Hollow-Core Photonic Crystal Fibers — •Wenjia Zhong, Bettina Heim, Dominique Elser, Christoph Marquardt, and Gerd Leuchs — MPI für die Physik des Lichts, Erlangen, Germany

In hollow-core photonic crystal fibers (HCPCF) light travels in the central air core surrounded by a photonic-bandgap structure.

We performed quantum-noise-limited measurements in a HCPCF and observed polarization noise at sideband frequencies in the MHz range when using a pulsed laser. The observation shows that although the light has small overlap with the silica material, there exists excess polarization noise.

The agreement of the experimental findings with finite element method simulations of the acoustic vibrational modes of the HCPCF shows that the polarization noise is induced by thermally excited acoustic vibrations of the photonic crystal structure of the HCPCF.

Q 6.6 Mon 12:00 SCH A01

Wavefield Back-Propagation in High-Resolution X-ray Holography with a Movable Field of View — •Erik Guehrs[1], Christian Günther[2], Bastian Pfau[1], Torbjörn Rander[1], Stefan Schaffert[1], William Schlotter[3], and Stefan Eisebitt[1] — [1]TU-Berlin — [2]Helmholtz-Zentrum Berlin — [3]Centre for Free-

Electron Laser Science, Universität Hamburg

Mask-based Fourier transform holography (FTH) is used to record images of biological objects with 2.2 nm X-ray wavelength. The holography mask and the object are separated from each other allowing us to move the field of view of the sample. Due to the separation of the holography mask and the sample on different X-ray support membranes, a gap between both windows of several 10s of microns typically exists which can be due to misalignment or dust or is desired to protect the sample from direct contact. The depth of field, thus limits the gap size for which sharp images of the sample can be reconstructed using a 2D Fourier Transform of the hologram. In this contribution, we systematically investigate the imaging and reconstruction conditions for mask-sample separations up to 400 μm. We demonstrate the feasibility to combine FTH and wavefield backpropagation to obtain a focused image even for large separations and discuss the limitations of our approach which are mainly associated with Fresnel illumination. In particular for high-resolution imaging with soft X-rays and the associated small fields of view below 2 μm, our approach is crucial in order to obtain diffraction limited resolution combined with experimental ease regarding the scanning setup.

Q 6.7 Mon 12:15 SCH A01

Collective multi-mode effects in quantum optics — •Bojan Skerlak[1,2], Matthias Liertzer[3], Stefan Rotter[3], and Hakan Türeci[1,2] — [1]Department of Electrical Engineering, Princeton University, USA — [2]Institute for Quantum Electronics, ETH Zürich, Switzerland — [3]Institute for Theoretical Physics, TU Vienna, Austria

Controlling the photon emission of quantum systems is at the heart of a number of fields ranging from quantum information processing to single-molecule spectroscopy. A way to tune the spontaneous emission rate and directionality of a quantum emitter is to place it in a suitably designed photonic structure. Much of the earlier work has focused here on the resonant coupling of the emitter to a single, carefully chosen mode of this photonic structure with favorable emission properties, while the coupling to the rest of the modes of the photonic environment is regarded as a parasitic influence. This approach results in stringent requirements on the spectral and spatial overlap of the emitter and the resonant mode in question. Here we investigate the opposite approach: coupling an emitter to a large number of modes of a cavity. In particular, we show how this multi-mode coupling can be engineered to lead via interference to a robust collective enhancement of directionality which is more pronounced than that of each mode.

Q 6.8 Mon 12:30 SCH A01

Single-Slit Focusing and its Representations — •Emerson Sadurni[1], William Case[2], and Wolfgang Schleich[1] — [1]Institut fuer Quantenphysik, Ulm Universitaet, Albert-Einstein Allee 11 89081 Ulm - Germany — [2]Department of Physics, Grinnell College, P.O. Box 805, Grinnell, Iowa 50112

We have found that under free Schroedinger propagation a real-valued square wave packet shrinks rather than expands for very short times. The amplitude is enhanced by an approximate factor of 1.8. This is also the case when a two dimensional electromagnetic wave of constant phase hits a single slit and focuses around the optical axis in the near-field region. We give several descriptions of the problem, covering its many aspects from different (but equivalent) points of view: Wigner functions, fractality, suitable focusing measures et cetera.

Q 6.9 Mon 12:45 SCH A01

Optical control of the relativistic x-ray resonance fluorescence spectrum — •Octavian Postavaru[1,2], Zoltán Harman[1,2], and Christoph H. Keitel[1] — [1]Max Planck Institute for Nuclear Physics, Saupfercheckweg 1, 69117 Heidelberg, Germany — [2]ExtreMe Matter Institute EMMI, Planckstrasse 1, 64291 Darmstadt, Germany

Resonance fluorescence of laser-driven highly charged ions is studied in the relativistic regime by solving the time-dependent master equation in a multi-level model [1]. Our ab initio approach based on the Dirac equation allows for investigating highly relativistic ions, and, consequently, provides a sensitive means to test correlated relativistic dynamics, bound-state quantum electrodynamic phenomena and nuclear effects by applying coherent light with x-ray frequencies. Atomic dipole or multipole moments may be determined to unprecedented accuracy by measuring the fluorescence spectrum narrowed by quantum interference due to an additional optical driving.

[1] O. Postavaru, Z. Harman, C. H. Keitel, arxiv.org/abs/1011.6416

Q 7: Quantum Information: Concepts and Methods 1

Time: Monday 10:30–13:00 Location: SCH A118

Q 7.1 Mon 10:30 SCH A118

Verifying W-entanglement — •Hermann Kampermann[1], Otfried Gühne[2], Colin Wilmott[1], and Dagmar Bruss[1] — [1]Theoretische Physik III, Universität Düsseldorf — [2]Fachbereich Physik, Universität Siegen

We present a simple algorithm for finding specific decompositions of mixed density operators. The pure states in such decompositions belong to the same SLOCC entanglement class. This procedure can help to prove separability or to characterize specific types of entanglement. We use this algorithm to verify for some three qubit states W-type entanglement, i.e. states which can be written as a convex combination of pure W-states and which are genuine multipartite entangled.

Q 7.2 Mon 10:45 SCH A118

Linking a distance measure of entanglement to its convex roof — •Alexander Streltsov, Hermann Kampermann, and Dagmar Bruss — Heinrich-Heine-Universität Düsseldorf, Institut für Theoretische Physik III, D-40225 Düsseldorf

An important problem in quantum information theory is the quantification of entanglement in multipartite mixed quantum states. We establish a new connection between the geometric measure of entanglement and a distance measure of entanglement. A direct application of our result provides a closed expression for the Bures measure of entanglement of two qubits. We also prove that the number of elements in an optimal decomposition with respect to the geometric measure of entanglement is bounded from above by the Caratheodory bound, and we find necessary conditions for the structure of an optimal decomposition. Further we present a new algorithm for an upper bound of the geometric measure of entanglement. See also arXiv:1006.3077 [quant-ph]

Q 7.3 Mon 11:00 SCH A118

Evolution equation of entanglement for multi-qubit systems — •Michael Siomau[1,2] and Stephan Fritzsche[3,4] — [1]Max-Planck-Institut fuer Kernphysik, Postfach 103980, D-69029 Heidelberg, Germany — [2]Physikalisches Institut, Heidelberg Universitaet, D-69120 Heidelberg, Germany — [3]Department of Physical Sciences, P.O.Box 3000, Fin-90014 University of Oulu, Finland — [4]GSI Helmholtzzentrum fuer Schwerionenforschung, D-64291 Darmstadt, Germany

Typically, the time evolution of entanglement of a system is deduced from studying its state evolution under the influence of decoherence. Instead of making explicit use of the state evolution for the analysis of the entanglement dynamics of a given system, Konrad et al. [1] recently derived an evolution equation of entanglement for a two-qubit system that provides a direct relationship between the initial and the final entanglement of the system when one of its qubits is subjected to an arbitrary noise. We have extended this concept towards multi-qubit systems under the same assumption that just one of the qubits undergoes the action of a noisy channel. In this contribution, we suggest and discuss an evolution equation of entanglement for a lower bound for multi-qubit concurrence [2].

[1] T.Konrad et al., Nature Phys. 4, 99 (2008).
[2] M.Siomau and S.Fritzsche, arXiv:1011.5348v1.

Q 7.4 Mon 11:15 SCH A118

Multi-partite entanglement in a driven qubit network — •Simeon Sauer[1], Florian Mintert[1,2], and Andreas Buchleitner[1] — [1]Physikalisches Institut, Albert-Ludwigs-Universität, Hermann-Herder-Str. 3, D-79104 Freiburg, Germany — [2]Freiburg Institute for Advanced Studies, Albert-Ludwigs-Universität Freiburg, Albertstraße 19, D-79104 Freiburg, Germany

As demonstrated recently [1,2], periodic driving of a composite quantum system can induce entanglement that significantly exceeds the threshold of the static case. Alike general resonance phenomena this enhancement of entanglement occurs for very specific amplitudes and frequencies of the driving fields.

We aim to develop a general understanding of the underlying mechanisms. To this end, we consider a multi-partite quantum system that consists of several weakly coupled spins and study the interplay of periodic driving and multi-partite entanglement within the Floquet picture; *i.e.* we identify the dressed states of the driven system and quantify their entanglement by means of a multi-partite entanglement measure. Indeed, at well-defined values of the driving frequency and amplitude, we find a resonant behavior of entanglement. The occurrence of these resonances can be understood in terms of the single particle Floquet spectra only, what permits to predict resonances without solving the underlying many-body problem.

[1] Galve *et al.*, Phys. Rev. A 79, 032332 (2009).
[2] Cai *et al.*, Phys. Rev. E 82, 021921 (2010).

Q 7.5 Mon 11:30 SCH A118

Quantification of entanglement and polynomial invariants of homogeneous degree 4 — Christopher Eltschka[1], Thierry Bastin[2], Andreas Osterloh[3], and •Jens Siewert[4,5] — [1]Institut für Theoretische Physik, Universität Regensburg, D-93040 Regensburg, Germany — [2]Institut de Physique Nucléaire, atomique et de Spectrosopie, Université de Liège, 4000 Liège, Belgium — [3]Fakultät für Physik, Universität Duisburg-Essen, 47048 Duisburg, Germany — [4]Departamento de Química Física, Universidad del País Vasco, 48080 Bilbao, Spain — [5]Ikerbasque, Basque Foundation for Science, 48011 Bilbao, Spain

The N-tangle of Wong and Christensen [1] (which for $N = 3$ is the three-tangle) gives the simplest $SL(2,C)^{\otimes N}$-invariant polynomial of homogeneous degree 4. The relevance of degree-4 polynomials for entanglement classification and quantification is increasing with the possibility of polynomial SLOCC classifications [2]. Extending a well-known theorem [3] we prove that all such polynomials naturally lead to degree-4 entanglement monotones. By focusing on four qubits we show how various degree-4 polynomial invariants introduced by different authors can be put into a common framework. Surprisingly, the invariants defined by Luque and Thibon [4] have a precise physical meaning, and have generalizations to multi-qubit and even multi-qudit systems.

[1] A. Wong and N. Christensen, Phys. Rev. A **63**, 044301 (2001).
[2] O. Viehmann, C. Eltschka, and J. Siewert, unpublished.
[3] F. Verstraete *et al.*, Phys. Rev. A **68**, 012103 (2003).
[4] J.-G. Luque and J.-Y. Thibon, Phys. Rev. A **67**, 042303 (2003).

Q 7.6 Mon 11:45 SCH A118

Maximizing entanglement with numerically optimized pulse design — •Fabian Bohnet-Waldraff[1], Florian Mintert[2], Uwe Sanders[3], Steffen Glaser[3], and Andreas Buchleitner[1] — [1]Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, Hermann-Herder-Str. 3, 79104 Freiburg — [2]Freiburg Institute for Advanced Studies (FRIAS), Albert-Ludwigs-Universität Freiburg, Albertstraße 19, 79104 Freiburg — [3]Department of Chemistry, Technical University of Munich, D-85747 Garching

The design of optimal pulse shapes, e.g. by means of the GRAPE algorithm [1], permits the accurate preparation of general quantum states. On the other hand, there are vital advantages in optimizing entanglement itself (as quantified, e.g. by a suitable entanglement measure) [2] rather than the fidelity with respect to a given entangled state. Like most techniques from optimal control theory, the GRAPE algorithm has been designed to target a specific state and, therefore, is not necessarily applicable to an entanglement measure as a target functional, since such measures are not maximized by a unique state. We discuss how GRAPE can be extended accordingly such that it permits the optimization of many-body entanglement in noisy environments. As a specific situation we apply this framework to nitrogen vacancy centers in diamond.

[1] N. Khaneja, T. Reiss, C. Kehlet, T. Schulte-Herbrüggen, S. J. Glaser, J. Magn. Reson. **172**, 296-305 (2005).
[2] F. Platzer, F. Mintert, A. Buchleitner, PRL **105**, 020501 (2010).

Q 7.7 Mon 12:00 SCH A118

On Hybrid Entanglement — •Karsten Kreis[1,2] and Peter van Loock[1,2] — [1]OQI, MPL, Erlangen, Germany — [2]Institute of Theoretical Physics I, Uni Erlangen-Nuremberg, Erlangen, Germany

In this talk, we define hybrid entanglement as entanglement between a discrete-variable quantum system and an infinite-dimensional, continuous-variable quantum system. A classification scheme is given leading to a distinction between pure hybrid entangled states, mixed hybrid entangled states (those effectively supported by an overall finite-dimensional Hilbert space), and so-called truly hybrid entangled states (those which cannot be described in an overall finite-dimensional Hilbert space). Physically relevant examples for states of either regime are presented and entanglement witnessing as well as quantification are discussed. Regarding witnessing the well-known inseparability criteria by Shchukin and Vogel play a crucial role [1]. Quantification may be accomplished by describing the states in finite-dimensional subspaces and employing discrete-variable measures such as the logarithmic negativity. [1] E. Shchukin and W. Vogel, Phys. Rev. Lett. 95, 230502 (2005).

Q 7.8 Mon 12:15 SCH A118

Entanglement of four-qubit mixed states quantified with polynomial invariants — •Christopher Eltschka[1], Oliver Viehmann[2], and Jens Siewert[3,4] — [1]Institut für Theoretische Physik, Universität Regensburg, Regensburg, Germany — [2]Physics Department, ASC, and CeNS, Ludwig-Maximilians-Universität, München, Germany — [3]Departamento de Química Física, Universidad del País Vasco - Euskal Herriko Unibertsitatea, Bilbao, Spain — [4]Ikerbasque, Basque Foundation for Science, Bilbao, Spain

Recent work [1, 2] underlines the importance of polynomial SL invariants for classification and quantification of multipartite entanglement. For mixed states, the corresponding monotones are defined through convex-roof extension. In addition to the difficulties of calculating the convex roof, starting with four qubits there exists a continuum of monotones to choose from.

We study the mixed state entanglement of GHZ diagonal states of four qubits by calculating selected monotones. We discuss the implications for the classification of mixed state entanglement and compare with other criteria for entanglement in multipartite mixed states [3].

[1] Gour G., Phys. Rev. Lett. 105, 190504 (2010)
[2] Viehmann O., Eltschka C. and Siewert J., unpublished
[3] Gühne O. and Seevinck M., New J. Phys. 12, 053002 (2010)

Q 7.9 Mon 12:30 SCH A118

Entanglement verification with realistic measurement devices via squash models — •Tobias Moroder[1], Otfried Gühne[1,2], Normand Beaudry[3], Marco Piani[4], and Norbert Lütkenhaus[4] — [1]Institute for Quantum Optics and Quantum Information, Innsbruck, Austria — [2]Department of Physics, University of Siegen, Germany — [3]Institute for Theoretical Physics, ETH Zurich, Switzerland — [4]Institute for Quantum Computing, Waterloo, Canada

Many protocols and experiments in quantum information science are described in terms of simple measurements on qubits. However, in a real implementation, the exact description is more difficult and more complicated observables are used. The question arises whether a claim of entanglement in the simplified description still holds, if the difference between the realistic and simplified model is taken into account.

We show that a positive entanglement statement remains valid if a certain linear map connecting the two measurement models exists. For entanglement verification this map only needs to be positive, but not necessarily completely positive as required in tasks like quantum key distribution, where this idea called squash model is already quite common. However this offers the possibility to employ this technique even for measurement setups which do not possess a completely positive squash model. The well-known polarization measurement using only threshold detectors, which is extensively used in optical experiments, represents a physical relevant example for which this new technique can indeed be applied.

Q 7.10 Mon 12:45 SCH A118

Shifting entanglement from states to observables — •Kedar Ranade[1] and Nathan Harshman[2,1] — [1]Institut für Quantenphysik, Universität Ulm, 89069 Ulm — [2]Department of Physics, American University, Washington DC

We illustrate that for any pure state on a finite-dimensional Hilbert space we can construct observables that induce a tensor product structure such that the amount of entanglement of the state may take arbitrary values. In particular, we provide an example of how to construct observables on a d-dimensional system such that an arbitrary known pure state can be treated as maximally entangled. In effect, we show how entanglement properties can be shifted from states to observables.

Q 8: Photonics 1

Time: Monday 10:30–13:00 Location: SCH A215

Q 8.1 Mon 10:30 SCH A215

Geometric Spin Hall Effect of Light — •Jan Korger[1,2], Andrea Aiello[1,2], Christian Gabriel[1,2], Peter Banzer[1,2], Tobias Kolb[1,2], Christoph Marquardt[1,2], and Gerd Leuchs[1,2] — [1]MPI für die Physik des Lichts, Erlangen, Deutschland — [2]Institut für Optik, Information und Photonik, Universität Erlangen-Nürnberg, Deutschland

We describe a novel fundamental optical phenomenon and report on experimental progress towards its verification.

The Geometric Spin Hall Effect of Light amounts to a multiple wavelengths shift of a light beam's position [A. Aiello et. al., Phys Rev Lett **103**, 100401 (2009)]. This displacement depends on the properties of the light beam such as the state of polarization and the geometry of the detection system.

The effect occurs whenever a projection is perfomed on the light field which breaks the symmetry of the beam's internal structure. We show that a suitable projection can be implemented using a tilted polarizer. A setup using a commercial polarizer in a configuration suitable to measure the predicted shift will be discussed.

Q 8.2 Mon 10:45 SCH A215

Einfache, variable Speicherung optischer Daten bis zu 800ns — •Stefan Preussler, Kambiz Jamshidi, Andrzej Wiatrek und Thomas Schneider — Institut für Hochfrequenztechnik, Hochschule für Telekommunikation Leipzig

Eine Schlüsseltechnologie für rein optische Netzwerke der Zukunft ist die Speicherung optischer Datenpakete. Bisher wurden dafür klassische Slow-Light Systeme und auch die sogenannte conversion/dispersion Methode genutzt. Slow-Light Systeme erlauben die Verzögerung um nur wenige Bit, während dispersion/conversion Systeme einen extrem großen Aufwand mit durchstimmbaren Lasern und Filtern sowie einer aufwändigen Dispersionskompensation benötigen. Eine völlig andere Methode ist die Quasi-Lichtspeicherung (QLS). Die QLS basiert auf der Filterung des Spektrums. Dabei wird das Frequenzspektrum des Eingangssignals mit einem Frequenzkamm multipliziert, so dass mehrere Kopien des Eingangssignals im Zeitbereich entstehen. Mit einem optischen Schalter können die Kopien beliebig ausgeschnitten werden. Die QLS kann für die nahezu verzerrungsfreie, variable Speicherung von Datenpaketen in optischen Fasern verwendet werden. Die mit der QLS einfach einstellbare Speicherung ermöglicht allerdings nur maximale Speicherzeiten bis 100ns.

In diesem Beitrag zeigen wir die drastische Steigerung der durchstimmbaren QLS Speicherzeiten durch den Aufbau in einer Schleife. Wir diskutieren unsere Methode, zeigen experimentelle Ergebnisse und gehen auf ein neues Verfahren zur Senkung der Verzerrung ein.

Q 8.3 Mon 11:00 SCH A215

A photon diode made from linear optical materials — •Jörg Evers[1], Keyu Xia[1], and Shi-Yao Zhu[2] — [1]Max-Planck-Institut für Kernphysik, Heidelberg, Germany — [2]Computational Science Research Center, Beijing, China

We discuss methods to achieve a photon diode using simple setups relying on linear optical materials only. The diode is a fundamental building block for all-optical communication or computation infrastructures with two ports which transmits light entering from one side, but blocks light entering from the other side. Our implementations do not require any external fields, non-linear materials, or magneto-optical effects, and therefore are scalable and compatible with on-chip operation. The operation is demenstrated both using quantum mechanical coupled mode theory and full time-dependent numerical solutions of the underlying Maxwell equations to verify the operation of our device.

Q 8.4 Mon 11:15 SCH A215

Frequency-to-time conversion: A method to easily manipulate the spectrum of optical pulses — •Kambiz Jamshidi and Thomas Schneider — Institut für Hochfrequenztechnik, Hochschule für Telekommunikation, Leipzig, Germany

Frequency-to-time conversion (FTTC) has been successfully used for pulse shaping, packet header recognition, jitter compensation, and packet compression. A dispersive media maps the spectrum of the input signal to the time domain. This is named FTTC and occurs due to the frequency dependent delay property of the dispersion. Linear mapping between the frequency and time domain is obtained if the dispersive media shows pure second order dispersion. FTTC can be implemented via off the shelf components in photonics like: arrayed waveguide gratings, chirped fiber Bragg gratings, photonic crystal structures or even a spool of optical fiber.

In this talk, we will investigate the limitations of this technique and present new applications of FTTC like delaying the optical pulses and dispersion compensation. Several tens of thousands of fractional bits delay is possible by using FTTC. Also, easily tunable dispersion trimming in long haul transmission systems and reconfigurable all optical filters can be realized via this technique.

Q 8.5 Mon 11:30 SCH A215

Multisolitonen unter Einfluss des Raman-Effekts — •Alexander Hause, Philipp Rohrmann, Haldor Hartwig und Fedor Mitschke — Universität Rostock, Institut für Physik, Universitätsplatz 3, 18051 Rostock

Es wurde kürzlich bei Experimenten an photonischen Kristallfasern beobachtet, dass sich Paare von Solitonen bilden können, die gemeinsam erheblich Raman-verschoben werden [1].

Zum Einen analysieren wir die Wechselwirkung benachbarter Solitonen und finden, dass es zwei qualitativ verschiedene Typen von Solitonenpaaren gibt, bei denen eine Ausbreitung mit nahezu gleichbleibendem Abstand möglich ist. Kennzeichnend ist eine unterschiedliche Dynamik der relativen Phase [2]. Zum Anderen konnten wir im Experiment mittels Pulsformung geeignete Eingangspulse erzeugen, mit denen der Nachweis eines Typs dieser Paare bereits gelang.

Die Vorhersagen des Modells wurden mit numerischen Simulationen und den Resultaten des Experiments verglichen und zeigen eine gute Übereinstimmung.

[1] A. Podlipensky et al., JOSA B **25**, 2049 (2008)
[2] A. Hause et al., Opt. Lett. **35**, 2167-2169 (2010)

Q 8.6 Mon 11:45 SCH A215

Observation of spontaneous Raman scattering in 220nm Silicon-on-Insulator (SOI) waveguides — •Shaimaa Mahdi[1], Sha Wang[1], Aws Al-Saadi[1], Bülent A. Franke[1], Viktor Lisinetskii[2], Sigurd Schrader[2], Stefan Meister[1], and Hans J. Eichler[1] — [1]Technische Unuversität Berlin, Institut für Optik und Atomare Physik, Berlin, Germany — [2]Technische Hochschule Wildau (FH), Institut für Plasma- und Lasertechnik, Wildau, Germany

The prospect of silicon acting as an active optical material with the possibility of amplification and lasing has been the driving force behind the research of Raman scattering in Silicon-on-Insulator (SOI) waveguides. We report the observation of spontaneous Raman scattering in 220nm SOI strip waveguides with a width of 2μm and a length of 2cm. Raman scattering was investigated for two different pump wavelengths at 1341nm and 1455nm. The coupling efficiency was estimated to be about 10%. The spontaneous Raman spectrum was measured by an optical spectrum analyzer. The first order Raman peak was measured at about 1441.4nm by using a pump wavelength of 1341nm, which corresponds to a Raman shift of 15.6THz. The FWHM of the Raman peak was about 100GHz. Maximum Raman output of 90pW at 1441.4nm was obtained with a pump power of 22mW. Also the polarization dependency of the pump source was studied. Laser-induced damage threshold of the silicon waveguide facets is critical, therefore the facet preparation is important. A new method of preparation of silicon waveguides will be presented using fs laser pulses at 800nm with a repetition rate of 1kHz.

Q 8.7 Mon 12:00 SCH A215

z-Scan Characterization of Zwitterionic Chromophores for Optoelectronic Switching — •Ulrich Skrzypczak[1], Grant V. M. Williams[2], Stefaan Janseens[2], M. Delower H. Bhuiyan[2], Manuela Miclea[1], and Stefan Schweizer[1,3] — [1]Centre for Innovation Competence SiLi-nano®, Martin Luther University of Halle-Wittenberg, Karl-Freiherr-von-Fritsch-Str. 3, 06120 Halle (Saale) — [2]Industrial Research Ltd., P.O. Box 31310, Lower Hutt 5040, New Zealand — [3]Fraunhofer Center for Silicon Photovoltaics, Walter-Hülse-Str. 1, 06120 Halle (Saale)

Materials with high nonlinear optical (NLO) susceptibilities are being actively researched for a range applications that include optical switches, reconfigurable add/drop multiplexers, wavelength switching devices, and THz emitters and detectors. Devices using conventional solid-state compounds are frequently limited by their high power requirements caused by their relatively weak NLO response. In contrast, organic chromophores can provide a NLO response that is several orders of magnitude larger. A number of NLO chromophores have recently been synthesized and optimized for a large 2nd order NLO figure of merit. However, the 3rd order NLO response is not known. For this reason, 3rd order NLO experiments have been performed on films containing amorphous polycarbonate and zwitterionic chromophores. The NLO refractive index and the two-photon absorption coefficient were determined by analyzing the results from z-scan measurements. The 3rd order NLO figure of merit is comparable to that of organic compounds specifically optimized for a NLO refractive index.

Q 8.8 Mon 12:15 SCH A215

Imaging in 3D the scattering pattern of plasmonic nanostructures by digital heterodyne holography — •Sarah Yasmine Suck[1,2], Stéphane Collin[3], Yannick De Wilde[1], and Gilles Tessier[1] — [1]Institut Langevin, ESPCI ParisTech, CNRS, 10 rue Vauquelin, 75231 Paris, France — [2]Fondation Pierre-Gilles de Gennes pour la Recherche, 29 rue d'Ulm, 75005 Paris, France — [3]CNRS-LPN, Route de Nozay, 91460 Marcoussis, France

Nanoantennas are the direct extension of conventional radio and microwave antennas to the visible frequency range and can be used to convert optical radiation into localized energy and resonantly enhance light scattering. Here, we present a highly sensitive full-field imaging technique based on digital heterodyne holography which allows measuring both amplitude and phase for the 3D mapping of light scattered by plasmonic nanostructures at specific resonance wavelengths.

Various gold nanostructures, i.e. chains of nanodisks, single nanorods and nanodimers, were fabricated on a glass substrate with different lengths and spacings. After a spectroscopic study, the 3D far field phase and amplitude distributions of those antennas at resonance were measured at two laser wavelengths (λ1=658nm and λ2=785nm), and the 3D cartography of the scattered light of the nanostructures is reconstructed. As an example, using this technique we identify typical features of a nanodisk chain in resonant configuration: appearance of angular radiation lobes and a strong forward scattering perpendicular to the sample plane. Thus, this method provides an accurate spatial characterization of the signature of a nanostructure.

Q 8.9 Mon 12:30 SCH A215

SiO2 coated 1D-photonic crystal microcavities in ultra-small SOI waveguides — •Sebastian Kupijai[1], Bülent A. Franke[1], Aws Al-Saadi[1], Miroslaw Szczambura[1], Shaimaa Mahdi[1], Viachaslau Ksiandzou[2], Sigurd Schrader[2], Hans J. Eichler[1], and Stefan Meister[1] — [1]Technische Universität Berlin, Institut für Optik und Atomare Physik, Berlin, Germany — [2]Technische Fachhochschule Wildau, Institut für Plasma- und Lasertechnik, Wildau, Germany

Microcavity filters in ultra-small Silicon on Insulator (SOI) waveguides are investigated. The microcavities are formed by one-dimensional photonic crystals (1D-PhC) in a Fabry-Pérot structure, which are embedded in planar strip waveguides with 450nm width and 220nm height. The photonic crystal microcavities are fabricated in a CMOS environment using 248nm DUV lithography. An 1um-SiO2-cladding is coated on the waveguide structures by the chemical vapor deposition (CVD) technique. Different types of PhC microcavities on the SOI waveguides, for instance first and higher order cavities and multicavities were investigated. The effect of changes of the Fabry-Pérot filter parameter, like hole diameter, hole number and cavity length, on the transmission characteristics at the wavelengths around 1550nm will be presented. Additionally the findings will be compared with uncoated waveguide structures.

Q 8.10 Mon 12:45 SCH A215

Strategie zum Finden stabiler Solitonenzustände bei der Propagation in Glasfasern — •Philipp Rohrmann, Haldor Hartwig, Alexander Hause und Fedor Mitschke — Universität Rostock, Institut für Physik, Universitätsplatz 3, 18051 Rostock

Die derzeit in der Telekommunikation genutzten Glasfaserstrecken nutzen die materialbedingten Kapazitätsgrenzen fast vollständig aus. Gebundene Mehrsolitonenzustände, die in dispersionsalternierenden Glasfasern auftreten, bieten hier prinzipiell eine Möglichkeit zur Erweiterung der binären Kodierung und damit zu einer Erhöhung der Übertragungskapazität.

Unser Ziel ist es nun, solche Mehrsolitonenzustände zu ermitteln. Dazu sind numerische Simulationen kaum geeignet, da eine Suche in einem mehrdimensionalen Parameterraum extrem zeitaufwendig wäre. Vielmehr gehen wir einen anderen Weg: Ein Spatial Light Modulator wird zur Pulsformung eingesetzt; nach Durchlaufen der Glasfaser wird die Abweichung zwischen Eingangs- und Ausgangssignal aus der Kreuzkorrelation beider Pulse bestimmt. Mit einem genetischen Algorithmus werden die Pulsparameter so optimiert, dass Eingangs- und Ausgangspuls eine möglichst gute Übereinstimmung zeigen.

Diese Methode wurde bereits erfolgreich für bekannte Fälle numerisch getestet: Standardsolitonen, Solitonen in dispersionsalternierender Faser, Solitonenmoleküle. Als nächster Schritt soll sie auch im Experiment umgesetzt werden, und schließlich sollen damit auch bislang unbekannte Solitonenzustände gefunden werden.

Q 9: Micro Mechanical Oscillator 2

Time: Monday 14:30–15:15 Location: HSZ 02

Q 9.1 Mon 14:30 HSZ 02

Synchronization in optomechanical arrays — •Georg Heinrich[1], Max Ludwig[1], Jiang Qian[2], Björn Kubala[1], and Florian Marquardt[1,3] — [1]Institute for Theoretical Physics, University of Erlangen-Nuremberg, Germany — [2]Department of Physics, LMU Munich, Germany — [3]Max Planck Institute for the Science of Light, Erlangen, Germany

The motion of nano- and optomechanical systems can be coupled to electromagnetic fields. Beside the ultimate goal to measure and control the quantum state of mechanical motion, these systems allow to study elaborate dynamics due to the light-mechanics interaction. Recent developments have demonstrated systems comprising several coupled optical and vibrational modes, such as optomechanical crystals. Here we investigate the collective dynamics of arrays of coupled optomechanical cells, each consisting of a laser-driven optical and a mechanical mode. Beyond a certain threshold of the laser input power, each cell shows a Hopf bifurcation towards a regime of self-induced oscillations. We show that the phases of many such cells, even with different bare initial frequencies, can lock to each other, synchronizing the dynamics to a collective oscillation frequency. We present different regimes for the dynamics and describe the system in terms of an effective Kuramoto model. This allows to connect our optomechanical results to the general field of nonlinear science where synchronization constitutes an important, universal feature finding applications in fields ranging from physics over chemistry to biology.

Q 9.2 Mon 14:45 HSZ 02

Optomechanical entanglement and teleportation in a pulsed scheme — •Sebastian Hofer[1,2], Markus Aspelmeyer[1], and Klemens Hammerer[2] — [1]Faculty of Physics, University of Vienna, Austria — [2]Institute for Theoretical Physics and Institute for Gravitational Physics, Leibniz University Hannover, Germany

We analyze the creation of optomechanical EPR entanglement in a pulsed scheme. Furthermore we apply the standard CV teleportation protocol to optomechanical systems, analyze its Fidelity under the influence of thermal noise and determine the optimal parameter regime.

Q 9.3 Mon 15:00 HSZ 02

Quantum theory of light scattering for dielectric objects in optical cavities — •Anika C. Pflanzer, Oriol Romero-Isart, and J. Ignacio Cirac — Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Strasse 1, 85748 Garching, Germany

We develop a full quantum theory to describe the coupling of light to the motion of general dielectric objects in high-finesse optical cavities. In particular, we derive a master equation to describe the center-of-mass motion of the dielectric object, the cavity mode and their coupling to the other modes of the electromagnetic field via photon scattering. Focusing on massive particles here, this general theory is in particular applied to the recent proposal of using an optically levitating dielectric as a cavity opto-mechanical system [1,2]. Furthermore, we explore the range of applicability of this theory with respect to the size of the dielectric object and investigate limitations on possible cavity-cooling schemes. By comparing our findings to results from classical Mie scattering theory, we investigate differences arising from a fully quantum mechanical treatment of the system.

[1]Romero-Isart, New J. Phys. 12:033015 (2010)
[2]Romero-Isart, Pflanzer et al., arXiv:1010.3109 (2010)

Q 10: Quantum Gases: Bosons 2

Time: Monday 14:30–16:00 Location: HÜL 386

Q 10.1 Mon 14:30 HÜL 386

Non-Equilibrium Dynamics of 1d Bose Gases Studied via Quantum Noise Distributions — •Tim Langen, Michael Gring, Maximilian Kuhnert, David Alexander Smith, and Jörg Schmiedmayer — Atominstitut, Technische Universität Wien, 1020 Wien, Österreich

The non-equilibrium dynamics of many-body quantum systems is at the center of many fundamental questions such as decoherence, phase transitions and transport phenomena. Here we present a first test of the use of quantum noise distributions to study the dynamics of such systems. We employ a coherently split one-dimensional ultracold Bose gas, which provides a highly non-equilibrium state that is easily accessible and offers a striking example of the effects of interactions on correlated many-body systems. By mapping noise distributions at different length scales of the system, we demonstrate that the multimode character and enhanced role of fluctuations in one-dimensional systems play a dramatic role in the resultant non-equilibrium dynamics.

Q 10.2 Mon 14:45 HÜL 386

Quantum superpositions of Bose-Einstein condensates and periodic shaking — •Christoph Weiss — Institut für Physik, Universität Oldenburg, 26111 Oldenburg

Quantum superpositions of ultra-cold atoms are investigated for periodically shaken systems [1-3]. The focus of the talk will lie on how to distinguish quantum superpositions from statistical mixtures. All proposals would start with Bose-Einstein condensates.

[1] C. Weiss and N. Teichmann. Differences between mean-field dynamics and N-particle quantum dynamics as a signature of entanglement. Phys. Rev. Lett., 100:140408, 2008.
[2] B. Gertjerenken, S. Arlinghaus, N. Teichmann, and C. Weiss. Reproducible mesoscopic superpositions of Bose-Einstein condensates and mean-field chaos. Phys. Rev. A, 82:023620, 2010.
[3] K. Stiebler, B. Gertjerenken, N. Teichmann, and C. Weiss. Spatial two-particle quantum superpositions in periodically driven three-well potentials. Submitted to J. Phys. B, 2010.

Q 10.3 Mon 15:00 HÜL 386

Open Bose-Hubbard model: Beyond the mean-field approximation — •Georgios Kordas[1], Dirk Witthaut[2], and Sandro Wimberger[1] — [1]Institut für Theoretische Physik, Universität Heidelberg, Philosophenweg 19, D-69120 Heidelberg, Germany — [2]Max-Plank-Institute for Dynamics and Self-Organization, D-37073 Göttingen, Germany

We investigate the dissipative dynamics of bosonic quantum gases, beyond the mean-field approximation. To this end we use a Bose-Einstein condensate in an optical lattice subject to localized particle dissipation and phase noise. Our starting point is the full many-body dynamics, which is described by a master equation. We use this equation to derive the generalized mean-field and Bogoliubov backreaction approximations. The second method is taking into account higher-order correlation functions, so it gives a much better simulation of the many-body dynamics than the mean-field approach. As it will be shown the localized particle dissipation leads to surprising dynamics, since it can suppress the decay and restore the coherence of a Bose-Einstein condensate.

Q 10.4 Mon 15:15 HÜL 386

Solitons and solitons' filaments in an array of one-dimensional dipolar condensates. — •Kazimierz Łakomy[1], Rejish Nath[2], and Luis Santos[1] — [1]Institut für Theoretische Physik, Leibniz Universität Hannover, Appelstrasse 2, 30167 Hannover, Germany — [2]Max Planck Institute for the Physics of Complex Systems, Nöthnitzer Strasse 38, 01187 Dresden, Germany

Dipolar ultracold gases offer broad spectrum of novel physical phenomena due to the long-range and anisotropic character of the dipole-dipole interactions. The effects of the interactions are particularly relevant to what concerns the nonlinear properties of dipolar Bose Einstein condensates. In this talk, we will focus on the physics of one-dimensional solitons. After presenting some new properties of the solitons in dipolar gases, we will discuss the possibility of achieving solitons' filaments in an array of dipolar condensates. Even in the case of the absence of a hopping between the sites of the array, the inter-site attractive dipole-dipole interactions are shown to introduce an inter-soliton attractive potential that leads to the formation of solitons' filaments. We analyze this possibility for realistic systems with condensates of chromium and polar molecules, and discuss possible ways to probe the filaments.

Q 10.5 Mon 15:30 HÜL 386

Dissipative defects in ultracold quantum gases — •Matthias Scholl, Arne Ewerbeck, Andreas Vogler, Peter Würtz, Vera Guarrera, Giovanni Barontini, and Herwig Ott — Fachbereich Physik, Universität Kaiserslautern

We study the evolution of a Bose-Einstein condensate subjected to a local dissipative defect. In our experiment, we locally remove atoms from the cloud by ionizing them with a focussed electron beam. By analyzing the time resolved ion signal, we explore the decay dynamics of the BEC. Theoretically, we model the decay by a numerical simulation of the Gross-Pitaevskii equation with an imaginary potential.

Q 10.6 Mon 15:45 HÜL 386

Turbulent dynamics of ultracold bosons — •Jan Schole[1,2], Maximilian Schmidt[1,2], Boris Nowak[1,2], Denes Sexty[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

Turbulent dynamics in an ultracold Bose gas, in one, two and three spatial dimensions, is analysed by means of statistical simulations using the classical field equation. A special focus is set on the time-evolution of characteristic quantities such as the energy and velocity distributions, vortical density and spectral function. The results give insight into the dynamics of an ultracold Bose gas in the quantum turbulent regime.

Q 11: Quantum Information: Atoms and Ions 1

Time: Monday 14:30–16:00 Location: BAR Schön

Q 11.1 Mon 14:30 BAR Schön

Remote Entanglement between a Single Atom and a Bose-Einstein Condensate — •Matthias Lettner, Martin Mücke, Stefan Riedl, Christoph Vo, Carolin Hahn, Simon Baur, Jörg Bochmann, Stephan Ritter, Stephan Dürr, and Gerhard Rempe — Max Planck-Institut für Quantenoptik, Hans Kopfermann Str.1, 85748 Garching

Entanglement has been recognised as a puzzling yet central element of quantum physics with applications envisioned in many fields like quantum computing and quantum networking. In the latter field photons will act as flying qubits for the entanglement of remote atomic systems. Here we report on the experimental demonstration of entanglement between a single atom located inside a high-finesse optical cavity and a Bose-Einstein condensate (BEC). To this end we generate a single photon in the atom-cavity system, entangling the photon polarisation with the atomic spin state. The photon is transported to a different laboratory, where it is stored in a BEC employing electromagnetically induced transparency (EIT). This converts the atom-photon entanglement into remote matter-matter entanglement. Subsequently we map the matter-matter entanglement onto photon-photon entanglement. The resulting two-photon state is found to have high fidelity with a maximally-entangled Bell state proving that entanglement survives all described mapping procedures. We determine the lifetime of the remote matter-matter entanglement and discuss decoherence mechanisms.

Q 11.2 Mon 15:00 BAR Schön

Single atom-photon interfaces with strongly focused optical modes — •Gleb Maslennikov[1], Syed Abdullah Aljunid[1], Jian-Wei Lee[1], Martin Paesold[2], Dao Hoang Lan[1], Kadir Durak[1], Brenda Chng[1], and Christian Kurtsiefer[1] — [1]Centre for Quantum Technologies / Dept. of Physics, National University of Singapore — [2]ETH, Zurich

Interaction of light with single atoms forms the basic building block in many scenarios for the exchange of quantum information between different physical carriers, for the implementation of simple quantum logic devices, and for a better understanding of localizable single photon states. Complementary to the well-known approach of optical field enhancement with cavities we investigate field enhancement due to strong focusing of an optical mode. With this, we have seen significant extinction, optical phase shifts, which eventually should allow for significant interaction between photons [1-3]. We discuss our experimental progress on atom localization, atomic excitation probabilities under weak optical pulses and an anaclastic cavity-lens geometry for optical field enhancement at the atom with a very high optical coupling between probing and detection modes.

[1] M. K. Tey, et al., Nature Physics **4** 924 (2008)
[2] S.A. Aljunid et al., Phys. Rev. Lett. **103**, 153601 (2009)
[3] S.A. Aljunid et al., arXiv:1006.2191 (2010)

Q 11.3 Mon 15:15 BAR Schön

Entanglement-preserving absorption of single photons by a single atom — •Michael Schug[2], Jan Huwer[1,2], Joyee Ghosh[1,2], Nicolas Piro[1], Marc Almendros[1], Felix Rohde[1], Carsten Schuck[1], Francois Dubin[1], and Jürgen Eschner[1,2] — [1]ICFO - Institut de Ciences Fotoniques, Mediterranean Technology Park, 08860 Castelldefels (Barcelona), Spain — [2]Universität des Saarlandes, Experimentalphysik, Campus E2.6, 66123 Saarbrücken

We observe the absorption of single down-conversion photons by a single $^{40}Ca^+$ ion, heralded by the detection of the partner photons. A photon absorption event induces a quantum jump in the ion, detected as a sudden change in its fluorescence rate. The correlation function of the quantum jumps and the arrival times of the partner photons reveals the coincidence between the two events [1]. Additionally, we observe that the polarization entanglement of the photons is preserved in the absoprtion process. This shows the potential of the method as a tool in quantum optical information technology.

[1] N.Piro et al., DOI: 10.1038/NPHYS1805

Q 11.4 Mon 15:30 BAR Schön

Entanglement Distribution with an Atom-Cavity-System — •Carolin Hahn, Martin Mücke, Jörg Bochmann, Andreas Neuzner, Stephan Ritter, and Gerhard Rempe — Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Str. 1, 85748 Garching

The deterministic generation and distribution of entanglement is one of the key ingredients for applications in quantum information science. In our system, a single Rubidium atom is quasi-permanently trapped inside a high-finesse optical cavity. Using this atom and a suitable energy-level scheme to produce a single photon entangles the polarization state of the emitted photon with the Zeeman-state of the atom. After a chosen time $\Delta\tau$, the atomic state is mapped onto the polarization of a second photon, thus generating a maximally entangled photon pair. Technical improvements have increased the entanglement lifetime of our Zeeman qubit by more than one order of magnitude, now exceeding $\Delta\tau = 150\mu s$. So far, these experiments have been studied on the ^{87}Rb D_2-line at 780 nm. However, the prospect of interfacing our system e.g. with atomic systems, poses a strong incentive to implement a similar scheme on the D_1-line at 795 nm. In addition, the involved excited state provides a much cleaner level scheme and therefore allows for higher fidelities with the desired entangled state. We report on the extension of the protocol to the D_1-line. A detailed comparison of the system's performance with respect to fidelity and photon generation efficiency at the two different wavelengths will be given and future applications will be discussed.

Q 11.5 Mon 15:45 BAR Schön

Entangling two single atoms at remote locations — •Julian Hofmann[1], Norbert Ortegel[1], Michael Krug[1], Florian Henkel[1], Wenjamin Rosenfeld[1,2], Markus Weber[1], and Harald Weinfurter[1,2] — [1]Department für Physik der LMU, München — [2]Max-Planck Institut für Quantenoptik, Garching

Entanglement between distant atomic quantum memories is a key resource for future applications in quantum communication. Here we present our recent progress on establishing entanglement between two single Rb-87 atoms over a large distance.

For this purpose we have set up two independently operating atomic traps situated in two neighboring laboratories separated by 20 meter. On each side we capture a single neutral Rb-87 atom in an optical dipole trap and generate a spin-entangled state [1] between the atom and a photon. The emitted photons are collected with high-NA objectives into single-mode optical fibers and guided to the same 50-50 fiber beam-splitter where we observe their interference. This setup allows us to detect two of four maximally entangled Bell states, thereby projecting the two atoms into an entangled state.

Here we report the progress towards the verification of the entanglement between the two distant atoms.

[1] J. Volz, et al. Phys. Rev. Lett. 96, 030404 (2006).

Q 12: Quantum Information: Concepts and Methods 2

Time: Monday 14:30–16:00 Location: SCH A118

Q 12.1 Mon 14:30 SCH A118

Poincaré sphere representation for classical inseparable states of the electromagnetic field — •Annemarie Holleczek[1,2], Andrea Aiello[1,2], Christian Gabriel[1,2], Christoph Marquardt[1,2], and Gerd Leuchs[1,2] — [1]Max Planck Institute for the Science of Light, Günter-Scharowsky-Str. 1/Bau 24, 91058 Erlangen, Germany — [2]Institute for Optics, Information and Photonics, University of Erlangen-Nuremberg, Staudtstr. 7/B2, 91058 Erlangen, Germany

Cylindrically polarized modes (CPMs) of the electromagnetic field are very intriguing objects as they combine a complex polarization pattern with a complex spatial pattern. We investigate theoretical subtleties underlying their structure, in particular, a thorough theoretical description for spatio-polarization modes is developed. We show that two hybrid Poincaré spheres can be introduced to represent simultaneously the polarization and the spatial degrees of freedom of CPMs in accordance with conventional ways of displaying properties of optical beams, such as the Poincaré sphere for polarization. Possible mode-to-mode transformations accomplishable with the help of conventional polarization and spatial phase retarders are shown within this representation.

Q 12.2 Mon 14:45 SCH A118

Solving frustration-free spin models — •Niel de Beaudrap[1], Matthias Ohliger[1], Tobias J. Osborne[2], and Jens Eisert[1] — [1]Universität Potsdam, Institut für Physik und Astronomie, Karl-Liebknecht-Strasse 24/25 14476 Potsdam — [2]Leibniz Universität Hannover, Institut für Theoretische Physik, Appelstraße 2, 30167 Hannover, Germany

We show that ground states of unfrustrated quantum spin-1/2 systems on general lattices satisfy an entanglement area law, provided that the Hamiltonian can be decomposed into nearest-neighbor interaction terms which have entangled excited states. The ground state manifold can be efficiently described as the image of a low-dimensional subspace of low Schmidt measure, under an efficiently contractible tree-tensor network. This structure gives rise to the possibility of efficiently simulating the complete ground space (which is in general degenerate). We also show how our approach gives rise to an ansatz class useful for the simulation of almost frustration-free models in a simple fashion, outperforming mean field theory.

Q 12.3 Mon 15:00 SCH A118

Measures of Quantum Decoherence — •Julius Helm and Walter T. Strunz — Institut für Theoretische Physik, TU Dresden, 01062 Dresden

For practical purposes decoherence may often be well described on basis of a stochastic Hamiltonian. Yet, for systems of two qubits or more it is known that true quantum decoherence exists, that is, decoherence due to growing entanglement between the system and its quantum environment. While the former may be described using random unitary (RU) channels, there are quantum decoherence channels of which no RU representation can be found [1,2]. We study measures of the quantumness of a decoherence channel, that is, the norm distance to the convex set of random unitary channels.

[1] L. Landau and R.F. Streater, Lin. Alg. Appl. 193, 107 (1993).
[2] J. Helm and W.T. Strunz, Phys. Rev. A 80, 042108 (2009).

Q 12.4 Mon 15:15 SCH A118

Control of many body quantum systems — •Simone Montangero — Ulm university

We present recent results on control of many body quantum systems, in particular the control of quantum phase transition dynamics and of coherent transport in open systems such as FMO complexes.

Q 12.5 Mon 15:30 SCH A118

Polynomial invariants for discrimination and classification of four-qubit entanglement — •Oliver Viehmann[1], Christopher Eltschka[2], and Jens Siewert[3,4] — [1]Physics Department, ASC, and CeNS, Ludwig-Maximilians-Universität, München, Germany — [2]Institut für Theoretische Physik, Universität Regensburg, Regensburg, Germany — [3]Departamento de Química Física, Universidad del País Vasco – Euskal Herriko Unibertsitatea, Bilbao, Spain — [4]Ikerbasque, Basque Foundation for Science, Bilbao, Spain

It is well known that the number of entanglement classes in SLOCC (stochastic local operations and classical communication) classifications increases with the number of qubits and is already infinite for four qubits [1]. Bearing in mind the rapid evolution of experimental technology, criteria for explicitly discriminating and classifying pure states of four and more qubits are highly desirable and therefore in the focus of intense theoretical research.

We develop a general criterion for the discrimination of pure N-partite entangled states in terms of polynomial $SL(d,\mathbb{C})^{\otimes N}$ invariants. By means of this criterion, existing SLOCC classifications of four-qubit entanglement are reproduced. Based on this we propose a polynomial classification scheme in which families are identified through “tangle patterns”, thus bringing together qualitative and quantitative description of entanglement.

[1] W. Dür, G. Vidal, and J.I. Cirac, Phys. Rev. A **62**, 062314 (2000).

Q 12.6 Mon 15:45 SCH A118

Driving-enhanced multi-partite entanglement in a qubit network — •Simeon Sauer[1], Florian Mintert[1,2], and Andreas Buchleitner[1] — [1]Physikalisches Institut, Albert-Ludwigs-Universität, Hermann-Herder-Str. 3, D-79104 Freiburg, Germany — [2]Freiburg Institute for Advanced Studies, Albert-Ludwigs-Universität Freiburg, Albertstraße 19, D-79104 Freiburg, Germany

Periodically driving a composite quantum system can have beneficial influence on its entanglement dynamics, if the driving parameters are suitably chosen. This fact was investigated recently for the case of bipartite entanglement in several *open* quantum systems. Yet, a general understanding of when and why entanglement is enhanced by periodic driving is not present. Furthermore, not much is know for the case of multi-partite entanglement so far.

To develop such understanding, in the presented work we consider a *closed* multi-partite quantum system, consisting of several weakly coupled qubits, and study the interplay of periodic driving and multipartite entanglement therein. To this end, we identify the dressed states of the driven system in the Floquet picture and and quantify their entanglement by means of a multi-partite entanglement measure. Indeed, at certain values of the driving frequency and amplitude, we find a resonant behavior of entanglement. The occurrence of these resonances in parameter space coincides with avoided crossings in the Floquet spectrum. This fact enables us to explain the underlying mechanism that leads to the resonances and to predict them from the single particle Floquet spectrum only.

Q 13: Laserentwicklung: Festkörperlaser 1

Time: Monday 14:30–16:00 Location: SCH A215

Q 13.1 Mon 14:30 SCH A215

Oberflächenstrukturierung von Sesquioxid-Wellenleiterschichten mittels ultrakurzer Laser Pulse — •Sebastian Heinrich, Thomas Calmano, Jörg Siebenmorgen, Klaus Petermann und Günter Huber — Institut für Laser-Physik, Universität Hamburg

Die Kanalwellenleiter-Geometrie ist vielversprechend im Hinblick auf die Entwicklung kompakter Lasersysteme. Infolge der hervorragenden thermomechanischen und optischen Eigenschaften stellen optisch aktive Sesquioxid-Wellenleiter schmale Emissionslinien, hohe Frequenzstabilität und eine hohe optische Verstärkung in Aussicht.

Eine Strukturierung von Wellenleiterschichten mittels ultrakurzer Laser Pulse ermöglicht, im Vergleich zu Strukturierungsmethoden wie dem reaktiven Ionenätzen, eine räumlich stark lokalisierte Materialmodifikation in einem Arbeitsschritt.

Mit dem Pulsed Laser Deposition-Verfahren wurden Seltenerd-dotierte Y_2O_3-Schichten auf Saphir-Substraten gewachsen. Spektroskopische Untersuchungen zeigten, dass die Emissionsspektren, bis auf eine geringe Verbreiterung, gut mit den Spektren entsprechend dotierter Y_2O_3-Volumenkristalle übereinstimmen.

Die auf Laserablation basierende Strukturierung erfolgte mit einem stark auf die Oberfläche einer 2 μm dicken Tm(2,5at.%):Y_2O_3-Schicht fokussiertem fs-Laser. Mit Pulsenergien von 150 nJ und Pulsdauern von ca. 150 fs wurden auf diese Weise Strukturen mit einer Breite von ca. 1 μm und einer Tiefe von ca. 0,4 μm geschrieben. Homogener Materialabtrag konnte bei Pulswiederholraten von 1 kHz und Verfahrgeschwindigkeiten von bis zu 400 μm/s erzielt werden.

Q 13.2 Mon 14:45 SCH A215

Wellenlängenstabilisierter Tm-Faserlaser bei 1983 nm — •Samir Lamrini[1,2], Philipp Koopmann[1], Karsten Scholle[1], Michael Schäfer[1], Jens Thomas[3], Christian Voigtländer[3], Stefan Nolte[3], Peter Fuhrberg[1] und Martin Hofmann[2] — [1]LISA laser products, Katlenburg-Lindau — [2]Lehrstuhl für Photonik und Terahertztechnologie, Ruhr-Universität Bochum — [3]Institut für Angewandte Physik, Friedrich-Schiller-Universität Jena

Laser, die im Wellenlängenbereich um 2 μm emittieren, sind aufgrund ihrer Eigenschaften vielfältig einsetzbar, z. B. in der Medizin, Messtechnik oder als Pumpquellen für OPOs im mittleren Infrarotbereich. Viele dieser Anwendungen erfordern neben hohen Ausgangsleistungen mit hoher Strahlqualität ein schmalbandiges Laserspektrum. Diese Anforderungen sind mit diodengepumpten Tm-Faserlasern wesentlich einfacher zu realisieren als mit herkömmlichen Festkörperlasern. Für die Realisierung eines wellenlängenstabilisierten Tm-Faserlasers wurde ein hochreflektierendes Faser Bragg Gitter für 1983 nm mithilfe eines Ti:Saphir-Femtosekundenlasers direkt in den Kern der aktiven Faser geschrieben. Verlustbehaftete Spleißstellen bleiben somit erspart. Mit einer Singlemode-Faser (10/125 μm, NA = 0,46) wurden im diodengepumpten Betrieb 9,1 W Ausgangsleistung bei einer Schwelle von 1 W erreicht. Bei maximaler Ausgangsleistung wurden lediglich 215 mW in die entgegengesetze Richtung emittiert, was vielversprechend für ein all-fiber System ist. Die Gesamteffizienz (optisch-optisch) betrug 38 % bei einem differentiellen Wirkungsgrad von 42 %. Das Laserspektrum bei 1983 nm hatte eine Halbwertsbreite von 0,5 nm.

Q 13.3 Mon 15:00 SCH A215

Thermo-Optical Aberrations of the Gain Medium of an Yb:YAG Thin-Disk Laser — •Julian Perchermeier, Sven Verpoort, and Ulrich Wittrock — Muenster University of Applied Sciences, Photonics Laboratory, Stegerwaldstr. 39, 48565 Steinfurt, Germany

We present interferometric measurements of the thermo-optical aberrations of an Ytterbium doped YAG thin-disk laser. The thin-disk laser concept itself was invented to minimize thermal aberrations induced by the active laser medium. The top-hat pump spot, which has a homogeneous intensity distribution, causes a strong temperature gradient in radial direction at the border to the unpumped region of the disk. This temperature distribution leads to diffraction losses which are detrimental for an efficient laser operation, especially with fundamental mode laser operation. Since the light circulates about 20 times inside the resonator, the resonator is very sensitive to thermo-optical aberrations. To measure these small aberrations, we use a phase-shifting Twyman-Green interferometer with a high resolution. We measured the thermo-optical aberrations of the thin-disk for different pump powers with and without lasing operation. The results will allow us to manufacture a custom-made deformable mirror to compensate for the measured thermo-optical aberrations of the thin-disk in a future step.

Q 13.4 Mon 15:15 SCH A215

Frequenzstabilisierung von Laseroszillatoren mit Hilfe von Verstärkungsgittern in Nd:YAG — •Roland Ullmann[1], Robert Elsner[1], Axel Heuer[1], Martin Ostermeyer[1,2] und Ralf Menzel[1] — [1]Universität Potsdam, Institut für Physik und Astronomie, Karl-Liebknecht-Str. 24-25, 14476 Potsdam — [2]IBL Innovative Berlin Laser GmbH, Am Schlangengraben 16, 13597 Berlin

Wir präsentieren ein Schema für eine passive, frequenzstarre Verkopplung eines cw-Seedlasers mit einem gepulsten Ringoszillator basierend auf holografischen Verstärkungsgittern. Längenverstimmungen des Ringoszillators von der Frequenz des Seedlasers werden durch die variable Phasenlage des Gitters automatisch kompensiert. Die hohe spektrale und räumliche Selektivität ermöglicht darüber hinaus die einfache Realisierung von single-mode Betrieb. Zudem wirkt das Verstärkungsgitter als phasenkonjugierendes Element [1], welches Phasenstörungen im Resonator effektiv korrigiert. Gleichzeitig wird durch die transiente Natur des Gitters ein passiver Güteschalter realisiert.

Es wurden numerische Rechnungen in ein und zwei räumlichen Dimensionen zur quantitativen Beschreibung der Resonatordynamik duchgeführt. Gleichzeitig wurde mit einem vereinfachten Aufbau das Verstärkungsgitter erzeugt und charakterisiert.

Referenzen: [1] M. J. Damzen, R. P. M. Green, and K. S. Syed, Opt. Lett. 20, 1704- (1995)

Q 13.5 Mon 15:30 SCH A215

Verlustprozesse in hoch Yb-dotierten oxidischen Lasermaterialien: Untersuchungen zur Photoleitung und ihrer Temperaturabhängigkeit — •Ulrike Wolters, Uwe Kelling, Henning Kühn, Susanne Fredrich-Thornton, Klaus Petermann und Günter Huber — Institut für Laserphysik, Universität Hamburg

Yb-dotierte Oxide lassen aufgrund des einfachen Energieniveauschemas des Yb^{3+}-Ions interne Verlustprozesse wie Kreuzrelaxation, Upconversion oder ESA nicht erwarten. Dennoch ist durch Messung der Photoleitfähigkeit dieser Lasermaterialien nachgewiesen worden, dass bei Bestrahlung von Einkristallen mit der Yb-Pumpwellenlänge von 940 nm freie Ladungsträger erzeugt werden. Das Auftreten eines Photostroms konnte in verschiedenen Wirtsgittern auf die Anwesenheit von Yb-Ionen zurückgeführt werden und zeigt eine nichtlineare Abhängigkeit von der Dichte angeregter Ionen. Diskutiert wird ein Upconversionmechanismus, der Ladungsträger in ein stromführendes Band anhebt. Die beobachtete Photoleitfähigkeit lässt einen Zusammenhang zu Verlustprozessen in Yb-dotierten Scheibenlasern vermuten, welche von Anregungsdichte, Dotierungskonzentration und der Temperatur abhängen. Zur weiteren Klärung dieses Zusammenhangs sind temperaturabhängige Photoleitfähigkeitsmessungen durchgeführt worden, deren Ergebnisse vorgestellt werden.

Q 13.6 Mon 15:45 SCH A215

A new laser source for trapping Lithium — •Ulrich Eismann[1], Frédéric Chevy[1], Fabrice Gerbier[1], Gérard Trénec[2], Jacques Vigué[2], and Christophe Salomon[1] — [1]Laboratoire Kastler Brossel, CNRS UMR 8552, UPMC, École Normale Supérieure, 24 rue Lhomond, 75231 Paris, France — [2]Laboratoire Collisions Agrégats Réactivité, CNRS UMR 5589 - Université Paul Sabatier Toulouse 3, Route de Narbonne, 31062 Toulouse Cedex, France

We present an all solid-state laser source emitting 660 mW of narrowband 671 nm light frequency-locked to the Lithium D-line transitions.

The design is based on a diode-pumped solid state Nd:YVO_4 ring laser, operating on the $^4F_{3/2} \rightarrow {}^4I_{13/2}$ transition near 1342 nm. The infrared light is subsequently frequency doubled in an enhancement cavity using periodically poled Potassium Titanyl Phosphate (ppKTP). Optical-to-optical efficiencies of up to 80% are obtained, resulting in a diffraction-limited beam.

We demonstrate the suitability of this stable, robust, spectrally narrow and frequency-stabilized light source for laser cooling of Lithium atoms.

Q 14: Ultrakurze Laserpulse: Erzeugung 1

Time: Monday 14:30–16:00 Location: SCH 251

Q 14.1 Mon 14:30 SCH 251

Ultrakurze 120 μJ Laserpulse durch kohärentes Kombinieren zweier Faserverstärker — •Sven Breitkopf[1], Enrico Seise[1,3], Arno Klenke[1], Marco Plötner[2], Jens Limpert[1,2,3] und Andreas Tünnermann[1,2,3] — [1]Institut für Angewandte Physik, Friedrich Schiller Universität Jena, Albert-Einstein-Str. 15, 07745 Jena — [2]Fraunhofer Institut für Angewandte Optik und Feinmechanik, Albert-Einstein-Str. 7, 07745 Jena — [3]Helmholtz-Institut Jena, Max-Wien-Platz 1, 07743 Jena

Das Konzept des kohärenten Kombinierens ultrakurzer Laserpulse eröffnet neue Möglichkeiten der Leistungsskalierung von Lasersystemen, über die Grenzen des verwendeten Verstärkerkonzepts hinaus. Dabei wird ein Strahl zunächst in N Kanäle aufgeteilt, um diese nach anschließender Verstärkung wieder kohärent zu kombinieren. Das Prinzip ist universell und völlig unabhängig vom verwendeten Verstärkertyp nutzbar.

In einem Experiment mit zwei Kanälen wurde das Konzept umgesetzt. Die Strahlaufspaltung in dem aktiv stabilisierten Mach-Zehnder-Interferometer, wurde durch polarisationsabhängige Strahlteiler umgesetzt. Nach der Verstärkung in Yb-dotierten Fasern erfolgte die Rekombination. So wurden 120 μJ-Pulse mit einer Pulsdauer von 800 fs erzeugt, wohingegen die Kanäle einzeln komprimiert lediglich 66 μJ Pulsenergie lieferten. Die Kombinationseffizienz betrug somit 91 %.

Es werden die grundlegende Theorie, sowie experimentelle Herausforderungen und Messergebnisse des kohärenten Kombinierens ultrakurzer Pulse präsentiert.

Q 14.2 Mon 14:45 SCH 251

Development of a laser-based XUV source on the μJ level — •Wolfram Helml[1], Gilad Marcus[1], Laszlo Veisz[1], Reinhard Kienberger[2], and Ferenc Krausz[1,3] — [1]Max-Planck-Institut f. Quantenoptik, Hans-Kopfermann-Str. 1, 85748 Garching, Deutschland — [2]TU München, James-Franck-Str. 1, 85748 Garching, Deutschland — [3]Ludwig-Maximilians-Universität München, 85748 Garching, Deutschland

High-harmonic generation has over the last decade been established as the method of choice to produce coherent XUV radiation with subfemtosecond duration. One of the main issues that hinders the applicability of this technique to a large number of experiments, including for instance highly anticipated XUV pump - XUV probe measurements, is the relatively low efficiency of the process and subsequent low flux of the generated XUV photons.

We have built up an HHG beamline, based on a high-energy (100 mJ), ultrashort ($\sim$ 8 fs) OPCPA system and a very long focal-length geometry, that allows us to fully exploit the power of the IR laser. We measured the resulting XUV intensity with a Zr-coated photo diode and demonstrate a flux of 10^{10} photons at an energy of 100 eV, corresponding to $\sim 2.24 \times 10^{-4}$ mJ per pulse. First tests with a multiple-nozzle quasi-phase-matching scheme to further enhance the yield have been conducted and show very promising results to increase the XUV intensity above the μJ level.

Q 14.3 Mon 15:00 SCH 251

High-Harmonic Generation source for seeding FLASH — •M. Mittenzwey[1], A. Azima[1], J. Boedewadt[1], F. Curbis[1], H. Delsim-Hashemi[1], M. Drescher[1], U. Hipp[1], T. Maltezopoulos[1], V. Miltchev[1], M. Rehders[1], J. Roensch-Schulenburg[1], J. Rossbach[1], R. Tarkeshian[1], M. Wieland[1], S. Bajt[2], S. Duesterer[2], J. Feldhaus[2], T. Laarmann[2], H. Schlarb[2], S. Khan[3], and R. Ischebeck[4] — [1]University of Hamburg — [2]DESY, Hamburg — [3]DELTA, Dortmund — [4]PSI, Villigen, Switzerland

The Free electron LASer in Hamburg (FLASH) is currently operated in the self-amplified spontaneous emission mode (SASE), producing photons in the XUV range. Due to the statistical nature of SASE the radiation shows intensity and spectral pulse-to-pulse fluctuations. Moreover, the electron acceleration process introduces arrival time fluctuations of the electron bunch at the undulator entrance, which leads to a temporal jitter of the XUV pulses. In order to reduce these fluctuations a seeding scheme for the electron bunch can be used. To this end, XUV seed pulses from a High-Harmonic Generation (HHG) source will be overlapped in space and time with the electron bunches. In this case the amplification process takes place within the seed pulse length leading to a radiation without temporal jitter, lower intensity- and spectral fluctuations, and full control over the pulse length. In this contribution the general design and first results of the seeding experiment at FLASH will be presented. In particular the HHG source will be explained in detail. This work is supported by the Federal Ministry of Education and Research under contract 05 ES7GU1.

Q 14.4 Mon 15:15 SCH 251

Prepulse suppression in a Multi-10-TW diode-pumped Yb:Glass laser — •Sebastian Keppler[1], Ragnar Bödefeld[1,2], Marco Hornung[1,2], Alexander Sävert[1], Joachim Hein[1], and Malte Christoph Kaluza[1,2] — [1]Institute of Optics and Quantum Electronics, FSU Jena — [2]Helmholtz-Institut Jena

High energy short-pulse laser systems often consist of an oscillator and a certain number of regenerative amplifiers. The repetition rate of such laser systems is some orders of magnitude lower than the repetition rate of the oscillator. Pulse picking systems employing the technique of polarization gating are widely used for this purpose.

Due to the limited extinction ratio of the polarizers and the remaining birefringence of the PC, the polarization contrast of a pulse picker could practically not be increased beyond a certain value. A small part of the pulse train ($\sim 10^{-3}$) will leak into the subsequent regenerative amplifier cavity.

By synchronizing the round trip times, this prepulse could be shifted in time underneath the intensity pedestal of the main pulse. At the time the postpulse arrives at the injection TFP of the second amplifier, the main pulse is also there. Hence, the latter could be hidden in the pedestal of the main pulse.

Q 14.5 Mon 15:30 SCH 251

Compact 7.4 W femtosecond oscillator for white-light generation and nonlinear microscopy — •Andy Steinmann, Bernd Metzger, Robin Hegenbarth, and Harald Giessen — 4th Physics Institute and Research Center SCOPE, University of Stuttgart

Compact femtosecond laser oscillators with high average powers and MHz repetition rates are essential laser sources for a lot of applications in science. In this contribution we present a passively mode-locked two-crystal Yb:KGW oscillator delivering 7.4 W average power at a repetition rate of 41.7 MHz and 425 fs pulse duration.

With this simple, reliable, and cost efficient laser source we demonstrate nonlinear experiments such as the generation of high-power white-light pulses in tapered fibers or pumping of an optical parametric oscillator, which generates a signal power up to 2 W with femtosecond pulses tunable in a wavelength range from 1.45 to 1.88 μm.

Q 14.6 Mon 15:45 SCH 251

Non-collinear Optical Parametric Chirped-Pulse Amplification of ultrashort pulses at 20 k-Hz — •Wataru Kobayashi[1], Jiaan Zheng[1], Thomas Haman[1], Markus Lührmann[2], Johannes A. L'huilier[2], Richard Wallenstein[2], and Helmut Zacharias[1] — [1]Physikalisches Institut, Westfälische Wilhelms-Universität, Wilhelm-Klemm-Str.10, 48149 Münster, Germany — [2]TU Kaiserslautern, Fachbereich Physik, Erwin-Schrödinger-Str.46, 67663 Kaiserslautern, Germany

We present a non-collinear optical parametric chirped-pulse amplification (NOPCPA) system generating sub-20 fs, 150 μJ optical pulses at a repetition rate of 20 kHz. A Kerr-lens mode-locked Ti:sapphire oscillator generates 7fs, 2 nJ seed pulses at a repetition rate of 80 MHz. A frequency-doubled mode-locked Nd:YVO_4 amplifier is employed as a pump source [1]. The pump laser is synchronized with the seed oscillator and generates 250 ps, 1.25 mJ pulses at the wavelength of 532 nm operating at 20 kHz repetition rate. A grism pair induces negative 2nd-and 3rd-order dispersion and stretches the seed pulse to about 100 ps. An acousto-optic programmable dispersive filter (AOPDF) follows the stretcher to compensate for the higher order dispersion. A three-stage optical parametric amplification (OPA) based on type I phase matching in BBO amplifies the seed up to 150 μJ. The seed pulses are compressed to sub-20 fs by use of Brewster-angle-cut SF57 glass blocks and a fused silica glass block.

[1] M. Lührmann, C. Theobald, R. Wallenstein, J. A. L'huillier, Opt. Exp. 17, 22761 (2009)

Q 15: Poster 1: Quanteninformation, Quanteneffekte, Laserentwicklung, Laseranwendungen, Ultrakurze Pulse, Photonik

Time: Monday 16:30–19:30 Location: P1

Q 15.1 Mon 16:30 P1

Characterization of THz generation by ionizing two-color pulses — •Christian Koehler[1], Eduardo Cabrera[1], Ihar Babushkin[2], Joachim Herrmann[3], and Stefan Skupin[1,4] — [1]Max-Planck-Institute for the Physics of Complex Systems, Dresden, Germany — [2]Weierstraß-Institut für Angewandte Analysis und Stochastik, Berlin, Germany — [3]Max-Born-Institut für Nichtlineare Optik und Kurzzeitspektroskopie, Berlin, Germany — [4]Friedrich-Schiller-University, Institute of Condensed Matter Theory and Solid State Optics, Jena, Germany

We present a theoretical and numerical investigation of the mechanisms responsible for the THz generation by ionizing two-color laser pulses. In that setup, a laser pulse containing a fundamental and its second harmonic frequency is focused into a gas, where the generated electrons are accelerated by the laser field and thus build up a current. That current in turn partly radiates in the THz range. To elucidate the underlying processes, numerical simulations using Forward Maxwell as well as Finite Difference Time Domain schemes are used and supported by analytical calculations. We explain how angularly resolved THz spectra depend on laser pump frequencies, phase relation between fundamental and second harmonic, and the plasma geometry.

Q 15.2 Mon 16:30 P1

Hochfrequenz-Lasersysteme für die Quelle polarisierter Elektronen am Darmstädter S-DALINAC — •Martin Espig, Joachim Enders, Janina Lindemann, Markus Roth, Fabian Schneider, Markus Wagner, Antje Weber und Benjamin Zwicker — Institut für Kernphysik, Darmstadt, Deutschland

Am Darmstädter supraleitenden Elektronenlinearbeschleuniger S-DALINAC können nun durch Bestrahlung einer Strained-superlattice-GaAs-Photokathode mit zirkularpolarisiertem Laserlicht polarisierte Elektronen für Experimente erzeugt werden. Um den erzeugten Elektronenstrahl an die Hochfrequenzbeschleunigung anzupassen, soll der Laser der Photoelektronenquelle mit einer Repetitionsrate von 3 GHz bei Pulslängen im Bereich weniger ps gepulst werden. Wir berichten über Untersuchungen an Diodenlasersystemen, u.a. VCSEL-Systemen für die künftige Verwendung an der polarisierten Quelle.

Gefördert durch die DFG im Rahmen des SFB 634.

Q 15.3 Mon 16:30 P1

Characterization of the laser-induced enhanced absorbance due to etching with LESAL — •Martin Erhardt and Klaus Zimmer — Permoser Str. 15

High-quality etching of transparent materials for applications in micro- and nano-structuring as well as in precision engineering is still a challenge for current laser processing techniques. Laser Etching at a Surface-Adsorbed Layer (LESAL) is an advanced laser processing method applying a gaseous absorber at the backside of the processed sample. Material processing with the LESAL method is particularly characterized by a low etching rate (< 1 nm/pulse) and a very low surface roughness of down to 0.4 nm rms. In previous studies LESAL was investigated in terms of the influence of different laser parameters like fluence, wavelength, pulse duration, and pulse number on the etching rate and the achieved surface qualities. This work is addressed to study the laser-induced alterations of LESAL-processed fused silica surfaces by means by investigating the optical properties. For this purpose depth-resolved transmission measurements were done in the UV/Vis wavelength range of laser-etched areas. The results were correlated with the used laser parameters. The obtained results are of basic interest to reveal the etching mechanism, to clarify the role of the near-surface modification at LESAL and to provide input data for simulations of the LESAL process.

Q 15.4 Mon 16:30 P1

Laser generated x-ray beams from a table-top source — •Michael Schnell[1], Christian Peth[2], Björn Landgraf[1,3], Tobias Thiele[2], Thomas Königstein[2], Timur Kudyakov[2], Alexander Sävert[1], Maria Reuter[1], Bernhard Hidding[2], Monika Toncian[2], Toma Toncian[2], Matle Kaluza[1,3], Georg Pretzler[2], Oswald Willi[2], and Christian Spielmann[1,3] — [1]Institut für Optik und Quantenelektronik, Friedrich-Schiller Universität Jena, Max-Wien-Platz 1, 07743 Jena, Germany — [2]Institut für Laser- und Plasmaphysik, Heinrich-Heine Universität Düsseldorf, Universitätsstraße 1, 40225 Düsseldorf, Germany — [3]Helmholtzinstitut Jena, Helmholtzweg 4, 07743 Jena, Germany

The use of ultra intense laser pulses to excite plasma waves with a relativistic phase velocity is a possible route to the development of compact particle accelerators. Quasimonoenergetic electron beams with energies from 0.1 to 1 GeV have been reliably generated. In addition these compact particle accelerators are sources of intense x-rays with peak brilliances comparable to "3rd generation" synchrotrons.

In this poster we present measured x-ray betatron spectra recorded in Düsseldorf and Jena with maximum emission at serveral keV. The spectra were taken in single photon counting mode and are in good agreement with theoretical simulations. Furthermore we used the "knife-edge" technique for an estimation of the betatron source size.

Q 15.5 Mon 16:30 P1

Multimodaler Aufbau zur Kombination von OCT und CARS mit einem Ultrakurzpuls-Titan:Saphir-Laser — •Claudia Hoffmann[1], Bernd Hofer[2,3], Sara Rey[3,4], Angelika Unterhuber[2,3], Wolfgang Drexler[2,3] und Uwe Morgner[1] — [1]Institut für Quantenoptik, Leibniz Universität Hannover, Deutschland — [2]Medizinische Universität Wien, Zentrum für medizinische Physik und Biomedizintechnik, AKH Wien, Österreich — [3]Biomedical Imaging Group, School of Optometry and Vision Sciences, Cardiff University, Cardiff, UK — [4]School of Biosciences, Cardiff University, UK

Optische Kohärenz-Tomographie (OCT) ist ein nichtinvasives interferometrisches Bildgebungsverfahren, mit dem in vivo hoch aufgelöste Tiefenschnitte von Mikrostrukturen erstellt werden können. Bei der kohärenten Anti-Stokes Raman Streuung (CARS) handelt es sich um eine nichtlineare spektroskopische Technik, die auf Grund eines Vierwellen-Mischprozesses molekulare Informationen zugänglich macht.

Um die Funktionalität optischer Kohärenz-Tomographie in Hinblick auf die Detektion des molekularen Fingerabdrucks einer Probe zu erweitern, wurde ein multimodaler Aufbau entwickelt. Bei diesem wird ein Ultrakurzpuls-Titan:Saphir-Laser verwendet, um in Kombination mit einem spektralen Pulsformer hoch aufgelöste OCT-Aufnahmen und die Erzeugung eines CARS-Signals zu ermöglichen.

Wir präsentieren Messungen verschiedener Proben mit diesem multimodalen Setup.

Q 15.6 Mon 16:30 P1

Kinetic description of laser-induced dielectric breakdown of insulators — •Nils Brouwer[1], Oliver Brenk[1], Helena Krutsch[2], Dieter H. H. Hoffmann[2], and Bärbel Rethfeld[1] — [1]Technische Universität Kaiserslautern, Deutschland — [2]Technische Universität Darmstadt, Deutschland

Ultrashort laser pulses of high intensity are of increasing importance in material processing and fundamental research. A proper understanding of the involved microscopic processes in condensed matter induced by laser irradiation is needed for enhanced controllability and to avoid damage to lenses. Transparent dielectrics may become opaque when being irradiated with intense laser beams, due to the creation of free electrons. We use the Boltzmann equation for a kinetic modelling of the microscopic collision processes determining the materials' response. In order to investigate the change of optical parameters, like the dielectric function and the reflectivity, we extended a former model [1] by a dynamic calculation of the internal laser field. The contributions of impact ionization and strong electric field ionization to the total free electron density are calculated for fused silica. We trace dielectric breakdown initiated by the increasing free electron density. In addition, we calculate the energy transfer to the lattice obtaining a damage threshold for lattice melting.

[1] A. Kaiser, B. Rethfeld, M. Vicanek and G. Simon, *Phys. Rev. B* **61**, 11437 (2000)

Q 15.7 Mon 16:30 P1

Preparation of free-standing single and few-layer Graphene for Ultrafast Electron Diffraction experiments — •Silvio Morgenstern, Christian Gerbig, Cristian Sarpe, Matthias Wollenhaupt, and Thomas Baumert — University of Kassel, Institute of Physics and Center of Interdisciplinary Nanostructure Science and Technology (CINSaT), D-34132 Kassel, Germany

Graphene is a recently discovered material with unique properties arising from its 2D crystal lattice [1]. The preparation and characterization of single- and few-layer graphene (SLG/FLG) with various methods on different substrates [1,2] as well as free-standing membrans [3] is a highly active field of research. The investigation of structural dynamics in graphene after ultrashort laser excitation should bring new insights in its mechanical and optical properties.
In this contribution we present first results on the preparation of free-standing SLG/FLG and the direct observation of optically induced lattice heating in these material using Ultrafast Electron Diffraction [4]. In addition, we show improvements and a new approach of our setup, leading to an enhanced spatial and temporal resolution.

[1] A. K. Geim & K. S. Novoselov, Nature Materials **6**, 183 (2007)
[2] S. Park & R. S. Rouff, Nature Nanotechnology **4**, 217 (2009)
[3] J. C. Meyer *et al.*, Appl. Phys. Lett. **92**, 123110 (2008)
[4] M. Chergui & A. H. Zewail, Chem. Phys. Chem. **10**, 28 (2009)

Q 15.8 Mon 16:30 P1

Spectroscopy and coherent control of colloidal semiconductor nanocrystals by phase-shaped femtosecond laserpulses — •Roland Wilcken, Martin Ruge, Matthias Wollenhaupt, and Thomas Baumert — University of Kassel, Institute for Physics and CINSaT, Heinrich-Plett-Str. 40, D-34132 Kassel, Germany

The interaction of a quantum system with the electric field of an ultrashort, shaped laser pulse is one of the key aspect in coherent control. Semiconductor nanocrystals - or quantum dots (QDs) - are often considered as artificial atoms with discrete energy levels but obeying bulk semiconductor properties like confined lattice vibrations as well. Several control schemes are well established for atomic and molecular transitions [1]. The aim is the adaption of control strategies based on experiences gained on atoms and molecules. The synthesis of QDs consisting of different semiconductors, e.g. PbS or CdX (X = S, Se, Te), is done by chemical hot-injection methods with the ability to tailor the size, shape and structure. In this way the optical properties can be tuned over a wide range by changing the quantum confinement. The ligand-stabilized QDs, dispersed in hexane, are used for experiments at room temperature. In a pump-probe setup collinear double pulse sequences are applied, generated by a high resolution polarization pulse shaper. The transmitted light intensity as well as the photoluminescence are detected. First results on the excitation dynamics and the related vibrational features in the nanocrystals are shown. The photoluminescence signal for a variety of different pulse shapes is measured.
[1] M. Wollenhaupt et al., Annu. Rev. Phys. Chem., 56, 25-56 (2005)

Q 15.9 Mon 16:30 P1

High Power THz Generation in a Thin Lithium Niobate Slab

using a Non-Collinear Cherenkov-Type Geometry — •Ulrich Arthur Fromme, Benjamin Ewers, Maik Scheller, Sangam Chatterjee, and Martin Koch — Department of Physics and Material Sciences Center, Philipps-Universität Marburg, Renthof 5, D 35032 Marburg

In the field of non-linear terahertz (THz) spectroscopy, there is a growing demand for THz emitters strong enough to induce significant nonlinear effects. But since the optically gated THz antennas usually used to generate THz pulses already saturate at moderate laser intensities, they cannot convert extremely high pump energies efficiently. Another method to achieve strong THz emission is optical rectification, a $\chi^{(2)}$ process which generates strong THz radiation at high laser pump powers. In this work, lithium niobate ($LiNbO_3$) is used to convert intense pulses of infrared light into THz waves. A simple thin slab of bulk $LiNbO_3$ is illuminated with the light of a regenerative Ti:Sapphire amplifier system in a non-collinear Cherenkov-type geometry. To overcome the total reflection of the THz waves at the $LiNbO_3$-air interface, a silicon prism is contacted to the crystals surface. Using an additional diffractive grating to tilt the lasers wave front allows for phase matching between the optical and the THz pulses in the utilized geometry. Thus, conversion efficiencies up to 10^{-4} and peak electric fields strengths of $50\frac{kV}{cm}$ are obtained at pump pulse energies of $450\mu J$. We investigate the effect of changing the tilt angle of the wave on the generated THz amplitude and spectrum.

Q 15.10 Mon 16:30 P1

Erzeugung von Nanostrukturen durch 2-Photonen-Polymerisation mit einem sub-10-fs-MHz-NOPA — •Moritz Emons[1], Guido Palmer[1], Marcel Schultze[1], Kotaro Obata[2], Boris Chichkov[2] und Uwe Morgner[1,2] — [1]Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover — [2]Laser Zentrum Hannover, Hollerithallee 8, 30419 Hannover

Wir präsentieren die ersten Ergebnisse von Nanostrukturierung mittels Zwei-Photonen-Polymerisation (2PP) durch die Verwendung eines nicht-kollinearen parametrischen Verstärkers (NOPA), welcher Pulse mit Dauern von weniger als 10 fs erzeugt. Die realisierbaren Nanostrukturen können weit unter den Beugungsbegrenzungen aus der klassischen Optik liegen, was im wesentlichen dadurch gegeben ist, dass die verwendete Strahlquelle mit ihren besonderen zeitlichen und energetischen Eigenschaften zur Verfügung steht. Das 2PP-Verfahren ermöglicht eine weitgehend flexible räumliche Gestaltung der Energiedeposition im Material, wodurch eine dreidimensionale Strukturierung im Volumen ermöglicht wird, die gezielt auf die Erfordernisse technischer und biomedizinischer Fragestellungen angepasst werden kann. Anhand dieses Posters sollen die erzielten Ergebnisse mit denen anderer Lasersysteme verglichen werden.

Q 15.11 Mon 16:30 P1

A high repetition rate High Harmonic Generation source for coherent XUV microscopy and electron spectroscopy — •Jürgen Schmidt[1], Christian Späth[1], Michael Hofstetter[2], Soo Hoon Chew[1], Alexander Guggenmos[2], Mihael Kranjec[1], and Ulf Kleineberg[1,2] — [1]Fakultät für Physik, Ludwig-Maximilians-Universität München, 85748 Garching, Germany — [2]Max-Planck-Institut für Quantenoptik, 85748 Garching, Germany

Laser driven high harmonic sources have established as versatile instruments for fundamental research in the EUV, XUV and SXR wavelength range. Due to their outstanding properties like coherence, the possibility of locking them to the driving laser pulse and of generating sub-fs pulses, they are inevitable for ultrafast pump-probe experiments and improved applications such as the lens-less coherent diffraction imaging XUV microscopy. In our setup we seeded, to our knowledge for the first time, a HHG gas source with a 10 kHz repetition rate Ti:Sa laser system with pulses of 5 fs duration and 0.2 mJ energy. Having high rep rates in the harmonics is very desirable regarding integration time e.g. for scanning microscopic schemes or often even indispensible for detector types which barely can handle multi-hit events, e.g. delayline detectors. Experiments and applications relying on those detectors/schemes could only poorly performed so far with today's available HHG sources at repetition rates below 1 kHz. We characterized the harmonic output of our system by means of a XUV flat field spectrometer and tested its potential and limits with respect to harmonic selectivity, energy-range/cut-off tunability and conversion efficiency.

Q 15.12 Mon 16:30 P1

Interferometrische Vermessung von Laser-erzeugten Plasmen zur Elektronenbeschleunigung — •Maria Reuter, Alexander Sävert, Ajay Kawshik Arunachalam, Michael Schnell, Maria Nicolai, Christina Widmann, Björn Landgraf, Oliver Jäckel, Christian Spielmann, Gerhard G. Paulus und Malte C. Kaluza — Institut für Optik und Quantenelektronik, Jena

Laser-erzeugte Plasmen stellen aufgrund der mit ihrer Hilfe erzeugbaren immensen elektrischen Felder eine mögliche Alternative für konventionelle Beschleunigersysteme dar. Um die Parameter der erzeugten Teilchenstrahlung so genau wie möglich kontrollieren zu können, ist eine genaue Beobachtung der bei der Beschleunigung auftretenden Prozesse notwendig. Eine Möglichkeit stellt die Verwendung eines kurzen, synchronisierten optischen Probestrahls dar. Am JETI-Lasersystem des IOQ wurde ein solcher Probestrahl aufgebaut. Mithilfe von Interferometrie konnte u.a. die zeitliche Entwicklung der Plasmadichte bestimmt werden. Dabei wird über die Phase des Probestrahls die Brechungsindexverteilung entlang seines Weges durch das Plasma aufgenommen. Die Interferogramme können anschließend bezüglich ihrer Phaseninformation ausgewertet werden, um die Elektronendichteverteilung des Plasmas zu erhalten. Im Rahmen eines Experiments zur Elektronenbeschleunigung am JETI-Laser wurden relativistische Elektronenpulse erzeugt und in einem Spektrometer detektiert. Gleichzeitig wurde die Plasmadichte interferometrisch bestimmt. Über den Vergleich der Energiespektren mit den Interferogrammen können Informationen über den Beschleunigungsprozess gewonnen werden.

Q 15.13 Mon 16:30 P1

Einfluss der experimentellen Parameter auf die Stabilität der Laser-Wakefield-Beschleunigung von Elektronen — •Maria Nicolai, Christina Widmann, Alexander Sävert, Michael Schnell, Maria Reuter, Oliver Jäckel, Christian Spielmann, Gerhard G. Paulus und Malte C. Kaluza — Institut für Optik und Quantenelektronik, Friedrich-Schiller-Universität, 07743 Jena

In den letzten Jahren wurden wichtige Fortschritte im Bereich der Laser-Wakefield-Beschleunigung erzielt. Durch die starken elektrischen Felder, die eine durch einen intensiven Laserpuls erzeugte Plasmawelle zur Verfügung stellen kann, können Elektronen auf relativ kurzen Distanzen auf relativistische Energien beschleunigt werden. So konnten Elektronenpulse innerhalb von wenigen Millimetern auf Energien im GeV-Bereich beschleunigt werden. Die Stabilität, gerade im Hinblick auf Energie, Bandbreite und Richtung, muss aber noch verbessert werden, um die laserbeschleunigten Elektronen für Anwendungen interessant zu machen. Da der Beschleunigungsprozess oft nichtlinear von den Anfangsbedingungen abhängt, haben wir mit den JETI-Laser-System am IOQ in Jena Untersuchungen durchgeführt, wie sich die Eigenschaften der Elektronenpulse in Abhängigkeit von den experimentellen Parametern ändern. Die Einflüsse der Elektronendichte, der Laserenergie, der Pulsdauer und der Pulsfrontverkippung auf die Elektronenenergie, die Richtungsstabilität und die Reproduzierbarkeit werden präsentiert.

Q 15.14 Mon 16:30 P1

Time Resolved Electron Diffraction of a Charge Density Wave — •Eichberger Maximilian[1], Schäfer Hanjo[1], Krumova Marina[1], Beyer Markus[1], Demsar Jure[1], Moriena Gustavo[2], Sciaini German[2], and Miller Dwayne[2] — [1]Universität Konstanz, Germany — [2]University of Toronto, Canada

We employed femtosecond electron diffraction (FED) and all-optical pump probe experiments on the 2D charge density wave (CDW) system 1T-TaS_2, studying the order parameter relaxation therein. The data suggest an optically induced suppression of the CDW within ~250 fs, followed by a purely electronic relaxation which is faster than ~100 fs. The order parameter of the CDW however, recovers on a timescale of several picoseconds which can be directly assessed by the FED data and also indirectly by the undertaken all-optical pump probe experiments.

Q 15.15 Mon 16:30 P1

Broadband polarization control and preservation for scanning near-field optical microscopy — •Christoph Zeh[1], Ron Spittel[2], Sonja Unger[2], Jörg Opitz[1], Bernd Köhler[1], Johannes Kirchhof[2], Hartmut Bartelt[2], and Lukas M. Eng[3] — [1]Fraunhofer Institut für Zerstörungsfreie Prüfverfahren IZFP, Institutsteil Dresden, Maria-Reiche-Str. 2, 01109, Dresden — [2]Institut für Photonische Technologien, Albert-Einstein-Str. 9, 07745 Jena, Deutschland — [3]Institut für Angewandte Photophysik, Technische Universität Dresden, 01062 Dresden, Deutschland

To achieve high throughput with apertureless fiber probes for scanning near-field optical microscopy (SNOM) radial polarized, non-fundamental fiber modes can be used. A radial polarized fiber mode can be converted efficiently into a propagating surface plasmon mode on the metal coating of the probe, leading to a highly focused spot at the tip apex. Since for our index-tailored fiber (ITF) the first higher order modes have well separated effective indices, mode coupling due to external stress (e.g. bending, twist) is suppressed. This allows for transmitting radial and other complex states of polarization through the fiber for SNOM and many other applications. Here, we show how we can control the state of polarization of non-fundamental modes in an ITF by selective mode excitation using mechanical long period gratings. A mayor advantage of the ITF is its broad wavelength range of 1000 nm to 1600 nm. We will show first results of translating this behavior from infrared to visible wavelength.

Q 15.16 Mon 16:30 P1

Finite element modeling of high-Q microcavities — •Dominik Floess[1], Tobias Grossmann[1,2], Mario Hauser[1], Saskia Becker[1], Torsten Beck[1], Timo Mappes[2], and Heinz Kalt[1] — [1]Institut für Angewandte Physik, Karlsruhe Institute of Technology (KIT), 76128 Karlsruhe, Germany — [2]Institut für Mikrostrukturtechnik, Karlsruhe Institute of Technology (KIT), 76128 Karlsruhe, Germany

We report on simulations of high-Q microcavities using the JCMresonance-module of the software JCMsuite, which is based on the time-harmonic finite element method. The simulations enable optimization of the device performance by studying geometry variations and allow for understanding of measured mode spectra by visualization of the spatial distribution of whispering gallery modes (WGMs) and their corresponding Q factors.

The eigenfrequencies are computed by solving Maxwell's equations on a finite number of elements using an adaptive refinement technique of the mesh. Due to the radial symmetry of the resonator, the eigenvalue problem is effectively two dimensional. In contrast to many numerical methods carried out in the time domain, this method efficiently allows for the exact analysis of Q factors, eigenfrequencies and field distributions.

First results show the analysis of the modestructure and Q factors of high-Q conical polymeric microcavities, a promising photonic structure for label-free molecule detection. The simulation results predict Q factors above 100 million in the visible sprectral region.

Q 15.17 Mon 16:30 P1

Accurate generation of polarization-shaped femtosecond laser pulses with zeptosecond precision — Jens Köhler, Tim Bayer, Cristian Sarpe, •Tom Bolze, Matthias Wollenhaupt, and Thomas Baumert — Universität Kassel, Institut für Physik und CINSaT, Heinrich-Plett-Str. 40, D-34132 Kassel, Germany

Femtosecond laser pulse shaping is the key technology in quantum control. In particular, polarization-shaped pulses are of current interest, because they exploit the vectorial aspects of light-matter interaction, i.e. they are well-suited for 3D coherent control. We demonstrate realization of *accurately* generated polarization-shaped pulses delivering full control over the polarization state in the interaction region of a vacuum chamber employing photoelectron imaging spectroscopy [1]. Currently, we extend the application of our polarization-shaping capabilities to the generation of "designer" free-electron wave packets characterized by 3D tomographic reconstruction [2]. In addition, we have investigated the *precision* achievable in the generation of a pulse pair by making use of phase- and amplitude modulation of femtosecond laser pulses. To this end, we study the interference signal of two temporally delayed pulses as well as ultrafast switching of photoelectron spectra via Photon-Locking by temporal phase discontinuities [3]. Our results show, that the pulse-to-pulse delay and the relative temporal phase can be controlled with *zeptosecond precision.*

[1] M. Wollenhaupt et al., Applied Physics B, 95(2), 245–259, (2009)
[2] M. Wollenhaupt et al., Applied Physics B, 95(4), 647–651, (2009)
[3] M. Wollenhaupt et al., Phys. Rev. A, 73(6), 063409, (2006)

Q 15.18 Mon 16:30 P1

Adhering and coupling emitter-doped organic crystals to optical nanofibers — •David Papencordt, Ariane Stiebeiner, Nils Konken, Ruth Garcia-Fernandez, and Arno Rauschenbeutel — Technische Universität Wien - Atominstitut, Stadionallee 2, 1020 Wien, Austria

Optical nanofibers have proven to be an extremly sensitive tool for spectroscopy of particles near or on the fiber surface [1, 2]. Here, we present our results on adhering emitter-doped organic crystals to the nanofiber waist of a tapered optical fiber. The emitted fluorescence light is coupled into the guided mode of the fiber, allowing us to spectroscopically study crystal growth and guest-host interactions in the crystals. Additional information can be obtained by performing such measurements under cryogenic conditions. In particular, it should be possible to realize nanofiber-based spectrosopy at the single molecule level.

We gratefully acknowledge financial support by the Volkswagen Foundation (Lichtenberg Professorship), the ESF (European Young Investigator Award), and the EC (STREP "CHIMONO").

[1] F. Warken et al., Optics Express, Vol. 15, 19, 11952-11958 (2007)
[2] A. Stiebeiner et al., Optics Express, Vol. 17, 24, 21704-21711 (2009)

Q 15.19 Mon 16:30 P1

Phase behaviour of electro-optic liquid crystals-oil blends — •Kirstin Bornhorst, Martin Blasl, and Florenta Costache — Fraunhofer Institut for Photonic Microsystems, Maria-Reiche-Str. 2, 01109 Dresden, Germany

New blends with high electro-optic (EO) constants are created by mixing the thermotropic liquid crystals 4-cyano-4*-n-alkylbiphenyle (nCB) with immersion oils. EO effect in blends occurs in their nematic as well as their isotropic phases. We study the optical, thermal and morphological changes of the new blends in view of possible applications for dynamic EO waveguides and compare them to pure nCBs.

The phase transition behaviour of pure n-CBs (n = 4-7) and nCB-oil blends was analysed as a function of oil concentration by DSC and their corresponding changes in morphology with polarized optical microscopy. For all blends we observed that the nematic-isotrop transition temperature, T_{NI}, as well as the crystalline-nematic transition temperature, T_{CN}, shift largely toward lower temperatures with increasing oil concentration. For instance, T_{NI} in the 5CB-oil blend was found to be 17 °C lower than that of pure 5CB. Additionally, we observed significant texture changes in the blends.

The isotropic phase for 5CB- and 6CB-oil blends occurs at room temperature. Interestingly, the nematic phase of 5CB-oil blend exists over a much wider temperature range as compared to that of pure 5CB. We will show that this can considerably help the temperature stabilization requirements of the EO waveguide device.

Q 15.20 Mon 16:30 P1

Enhanced single photon emissions from nitrogen-vacancy centers in diamond — •Moritz Eyer[1], Helmut Fedder[1], Merle Becker[1], Robert Rossbach[2], Daniel Richter[2], Michael Jetter[2], Peter Michler[2], Fedor Jelezko[1], and Jörg Wrachtrup[1] — [1]3. Physikalisches Institut, Universität Stuttgart — [2]Institut für Halbleiteroptik und Funktionelle Grenzflächen, Universität Stuttgart

Nitrogen-Vacancy (NV) centers in nano diamonds or bulk diamonds are a promising source for single photon emissions, which is stable even at room temperature. This opens the door to a great field of applications such as quantum computing, nano sensing and optical imaging below the diffraction limit. Our goal is to increase the photon yield of these emissions by using specially created structures of the diamond material and its surroundings. The resonant coupling to plasmonic structures and micro layer cavities are promising proposals in order to both increase the excitation rate and decrease the lifetime of the excited NV centers and to enhance the emitted field without losing their character as a quantum mechanic single photon process.

The necessary measurements are realized by using Fluorescence Lifetime Imaging Microscopy (FLIM) and antibunching measurements attached to a confocal microscope. Enhanced single phtoton emission from NV centers holds promise for applications in quantum cryptography, nondeterministic quantum computation based on indistinguishable photons, as well as entanglement generation of distant NV spin qubits.

Q 15.21 Mon 16:30 P1

Direct evaluation of the spatio-temporal coherence properties of free electron laser pulses at FLASH — •Sebastian Roling[1], Michael Wöstmann[1], Rolf Mitzner[2], Björn Siemer[1], Kai Tiedtke[3], and Helmut Zacharias[1] — [1]Westfälische Wilhelms-Universität Münster, Wilhelm Klemm Str. 10, 48149 Münster — [2]Helmholtz-Zentrum Berlin für Materialien und Energie, A.-Einstein-Str. 15, 12489 Berlin — [3]Deutsches Elektronen-Synchrotron, DESY, Notkestraße 85, 22607 Hamburg

The spatio-temporal behaviour of the mutual coherence of soft x-ray free electron laser pulses at FLASH is measured at 32 nm, 25.8 nm, 24 nm, 19 nm, 13 nm, 8 nm and 8 nm as third harmonic of 24 nm wavelength setting. Two time-delayed partial beams are directly interfered on a CCD camera. Both pulses are derived from the same optical source by wavefront beam splitting at a sharp mirror edge in a beam splitter and delay unit (autocorrelator). The delay of one partial beam reveals a coherence time of about 6 fs at 24 nm and 2.9 fs at 8 nm. A decrease of coherence time with decreasing wavelength scaling with $\lambda^{2/3}$ is found, in agreement with FEL theory. The spatial coherence was measured by increasing the overlap angle between the two partial beams, which increases the distance Δx_d between the interfering points of the beam. With increasing Δx_d the visibility shows a Gaussian-like decrease, as expected. A transverse coherence length of 2.3 mm (rms) at the entrance of the autocorrelator is observed, where the beam size is 2.5 mm (rms).

Q 15.22 Mon 16:30 P1

Fabrication and characterization of low-loss waveguides in lithium niobate — •Benjamin Weigand[1], Andreas Lenhard[1], Mareike Stolze[2], Felix Rübel[2], Sandra Wolff[3], Johannes L'huillier[2], and Christoph Becher[1] — [1]Universität des Saarlandes, FR 7.2 Experimentalphysik, Campus E2.6, 66123 Saarbrücken — [2]Photonik-Zentrum Kaiserslautern e.V., Kohlenhofstr. 10, 67663 Kaiserslautern — [3]Nano+Bio Center, Erwin-Schrödinger-Str. Geb. 13, 67663 Kaiserslautern

Waveguides in $LiNbO_3$ find widespread applications in the fields of optical data transmission and quantum communication. In recent years ridge waveguide structures have attracted increasing interest as they offer significant advantages: the high refractive index contrast of ridge waveguides leads to both, strong mode confinement and mode overlap and thus to enhanced interaction of guided light fields. Furthermore, transmission losses are kept to a minimum. Our approach for fabrication of ridge waveguides is based on ultra-short laser pulse ablation, reactive ion etching or combinations of both methods. We compare waveguides produced with the different techniques and report on experimental investigations of transmission losses. We develop numerical models for designing waveguides with maximum mode overlap and minimum transmission losses and compare their predictions with the experimental results. Possible applications for the waveguide structures investigated here are experiments towards frequency conversion of single photons into the telecom band.

Q 15.23 Mon 16:30 P1

Cold atom cavity quantum electrodynamics experiments with ultra-high Q whispering-gallery-mode bottle microresonators — •Danny O'Shea, Christian Junge, Sebastian Nickel, Christian Hauswald, Konstantin Friebe, and Arno Rauschenbeutel — Technische Universität Wien - Atominstitut, Stadionallee 2, 1020 Wien, Austria

We describe an apparatus to deliver cold rubidium atoms to a nanofiber-coupled whispering-gallery-mode bottle microresonator using an atomic fountain. We actively stabilize the frequency of the ultra-high Q resonator mode (Q>100 million) to less than 10% of its linewidth. Moreover, the resonator-nanofiber separation is actively stabilized to a fraction of the resonant wavelength. This represents an important advancement for cavity quantum electrodynamic experiments with monolithic microresonators. On the cold atom side, we show that our atomic fountain creates a moving molasses for cold rubidium atoms with a temperature of 5–10 μK. The turning point of the parabolic trajectory of the atoms can be precisely controlled using an acousto-optic modulator driven by a digital synthesizer. Finally, our progress toward coupling atoms to a mode of the bottle resonator is presented.

Financial support by the DFG, the Volkswagen Foundation, and the ESF is gratefully acknowledged.

Q 15.24 Mon 16:30 P1

Full active stabilization of an evanescently coupled ultra-high Q whispering-gallery-mode microresonator-nanofiber system — •Christian Junge, Danny O'Shea, Sebastian Nickel, Konstantin Friebe, and Arno Rauschenbeutel — Technische Universität Wien - Atominstitut, Stadionallee 2, 1020 Wien, Austria

We have experimentally solved the issue of operating an ultra-high Q whispering-gallery-mode microresonator under highly stable and reproducible conditions concerning both its resonance frequency and the evanescent in- and out-coupling of light by means of an optical nanofiber. For this purpose, we have implemented a double Pound-Drever-Hall scheme that allows us to derive two unambiguous error signals. Using these signals, we actively stabilize the resonator frequency to an external reference while, simultaneously, the resonator-nanofiber gap and thus the evanescent in- and out-coupling of light is actively stabilized to a fixed value. We characterize the performance of our method and demonstrate that it also works under ultra-high vacuum conditions. These results are highly relevant for the use of whispering-gallery-mode bottle microresonators in cavity quantum electrodynamics experiments.

Financial support by the DFG, the Volkswagen Foundation, and the ESF is gratefully acknowledged.

Q 15.25 Mon 16:30 P1

Single optical microfibre interferometer — •Konstantin Karapetyan, Wolfgang Alt, Fabian Bruse, and Dieter Meschede — Institut für Angewandte Physik, Universität Bonn, Wegelerstr. 8, 53115, Bonn, Germany

Over the last seven years, optical microfibres (OMF) with a diameter on the order of 100...1000 nm operating in the strong guiding regime have been investigated and applied in various fields of physics and photonics, including evanescent field spectroscopy, atom trapping and nonlinear optics. In this work we present a single OMF interferometer—a monolithic single-fibre device for dispersive sensing. It uses the down-taper of an OMF as a beam splitter and the up-taper as a beam recombiner, as in a Mach-Zehnder interferometer. The two arms are realized here by two different transverse modes guided in the waist of the OMF. Details of the design, manufacturing and testing of this device as well as our first results on dispersive sensing of liquids, molecules and atoms are presented.

Q 15.26 Mon 16:30 P1

Point-by-point Inscription of Bragg Gratings in Coated Standard Telecommunication Fibers Using Infrared Femtosecond Laser Pulses — Jörg Burgmeier[1], Günter Flachenecker[2], •Markus Thiel[1], and Wolfgang Schade[1,2] — [1]Institut für Energieforschung und Physikalische Technologien der TU Clausthal, EnergieCampus, Am Stollen 19 , 38640 Goslar — [2]Fraunhofer Heinrich Hertz Institute, Fibre Optical Sensor Systems, EnergieCampus, Am Stollen 19, 38640 Goslar

Writing of fibre Bragg gratings (FBG) in non-photosensitized single mode fibres by femtosecond laser pulses has attracted significant interest in the recent past. The core and the cladding of a standard telecommunication fibre consist of fused silica, which is transparent in the near infrared spectral region. The interaction between laser pulses and the material is taking place by multiphoton absorption. In the interaction area a change of the refractive index takes place. A grating is created by periodical modification of the refractive index in the fibre. Generally the coating of the fibre has to be removed for this fabrication technique. In our approach the use of a tightly focussing objective lens in combination with a transparent polymer coating allows the inscription of FBGs without removing the coating. Due to the presence of a protecting polymer, the robustness of the resulting device could be improved, which is of great importance for various applications. A prototype of a FBG sensor system for monitoring stress being effective on power cables will be presented, too.

Q 15.27 Mon 16:30 P1

Development of low-loss silicon rib waveguides with 4 microns height — •Harald Richter[1], René Eisermann[1], Mirko Fraschke[1], Lars Zimmermann[1,2], Katrin Schulz[1], Marco Lisker[1], Wolfgang Höppner[1], Jürgen Drews[1], Georg Winzer[2], and Bernd Tillack[1,2] — [1]IHP Frankfurt, Im Technologiepark 25, 15236 Frankfurt (Oder) — [2]Technische Universität Berlin, HFT 4, Einsteinufer 25

There has been an increased interest in silicon as a material for use in integrated optoelectronics. Silicon-on-insulator (SOI) waveguides are very promising for realization of photonic integrated circuits. The transport of light by a waveguide is one main reason for light intensity loss. The minimization of propagation loss is the main goal in waveguide fabrication process development. Silicon roughness, critical dimension stability and side wall slope angles determine the silicon waveguide quality essentially. The present work is focused on the development of a manufacturing process for silicon rib waveguides with 4 microns height. Different hard mask layer stacks for the deep silicon etch process were tested and optimized. Experiments have shown the mask opening step is significant for high-quality silicon waveguides.

For the following silicon dry etch process an HBr/SF6 chemistry was chosen for fabrication of rib waveguide with sidewall slope angles between 89° and 90° and minimal sidewall roughness. Propagation loss values less than 0.3 dB/cm verify the technological manufacturing process quality.

Q 15.28 Mon 16:30 P1

Processing of Small Integrated Optical Spectrometer Devices with Femtosecond Laser Pulses — •Markus Thiel[1], Günter Flachenecker[2], Jörg Burgmeier[1], and Wolfgang Schade[1,2] — [1]Institut für Energieforschung und Physikalische Technologien der TU Clausthal, EnergieCampus, Am Stollen 19 , 38640 Goslar — [2]Fraunhofer Heinrich Hertz Institute, Fibre Optical Sensor Systems, EnergieCampus, Am Stollen 19, 38640 Goslar

Compact miniature spectrometers have, due to their advantage of size and cost-efficiency, increasing significants in networks based on fibre optics like telecommunication or dispersed optical sensor systems. Here we show first results of a spectrometer, which is processed directly into glass with femtosecond laser pulses. The design is a spatial heterodyne spectrometer, based on an array of Mach-Zehnder interferometers.[1] Fundamental parameters for processing waveguide structures are discussed and future applications for sensor networks are outlined. The design of the spectrometer is compared with conventional arrayed waveguide gratings.

References:

M. Florjanczyk, P. Cheben, S. Janz, A. Scott, B. Solheim, D. Xu, OPTICS EXPRESS, 15, 18176 (2007)

Q 15.29 Mon 16:30 P1

Tailoring the Single Photon Emission from Nitrogen-Vacancy Centres using Metallic Structures — •Merle Becker[1], Daniel Dregely[2], Helmut Fedder[1], Fedor Jelezko[1], Harald Giessen[2], and Jörg Wrachtrup[1] — [1]3. Physikalisches Institut, Universität Stuttgart, 70550 Stuttgart — [2]4. Physikalisches Institut, Universität Stuttgart, 70550 Stuttgart

The nitrogen-vacancy (NV) centre is a promising single photon source in the solid state. Control over NV centre emission properties as well as surface plasmon propagation is important for many quantum applications including quantum repeaters and single photon transistors. This implies efficient coupling of the NV centre to guided modes of the electrical field. One possible approach is to concentrate optical fields at the NV centre location. These strong fields can be obtained by metallic antenna structures. We investigate field enhancement and increased decay rate of the NV centre, both being indications of strong electrical fields, for different metallic antenna structures.

Q 15.30 Mon 16:30 P1

Phase-preserving amplitude regeneration of quadrature-amplitude-modulated signals — •Tobias Röthlingshöfer[1,2,3], Georgy Onishchukov[2,3], Bernhard Schmauss[3,4], and Gerd Leuchs[1,2,3] — [1]Institute of Optics, Information and Photonics, University Erlangen — [2]Max Planck Institute for the Science of Light — [3]Erlangen Graduate School in Advanced Optical Technologies (SAOT) — [4]Chair for Microwave Engineering, University Erlangen

Quadrature amplitude modulation (QAM), a combination of amplitude and phase-shift keying, has often been suggested to increase the spectral efficiency in optical communication systems.

Its main problem is a higher sensitivity to amplitude and phase noise. Amplitude noise can be converted into nonlinear phase noise in the transmission fiber due to the Gordon-Mollenauer effect which is usually the major limiting factor for phase-encoded transmission. As the regeneration of the signal phase is complex, phase-preserving amplitude regeneration can be used to reduce amplitude fluctuations, which are the origin of nonlinear phase noise. Such phase-preserving amplitude regeneration of signals with phase-shift keying has been demonstrated using a nonlinear amplifying loop mirror (NALM). Due to its periodic behavior of the power transfer characteristic, this regenerator type is a promising candidate for multilevel phase-preserving amplitude regeneration as well.

A comparison of different NALM modifications and their performance for phase-preserving amplitude regeneration of QAM formats is presented.

Q 15.31 Mon 16:30 P1

Digital plasmonics — Bergin Gjonaj[1], •Jochen Aulbach[1], Patrick M. Johnson[1], Allard P. Mosk[2], Laurens Kuipers[1], and Ad Lagendijk[1] — [1]FOM Institute for Atomic and Molecular Physics AMOLF, Science Park 113, 1098 XG Amsterdam, The Netherlands — [2]Complex Photonic Systems, MESA+ Institute, University of Twente, Post Office Box 217, NL-7500 AE Enschede, The Netherlands

We control the wavefronts of Surface Plasmon Polaritons (SPP) on nanohole arrays using a digital spatial light modulator. Optimizing the plasmonic phases via feedback we focus SPPs at a freely pre-chosen point on the surface of the array with high resolution. Digital addressing of SPPs without mechanical motion will enable novel interdisciplinary applications of advanced plasmonic devices in cell microscopy, optical data storage and sensing.

Q 15.32 Mon 16:30 P1

Taper design for high Q factors in hybrid photonic wire slot microcavities — •Clemens Schriever, Christian Bohley, and Jörg Schilling — Zentrum für Innovationskompetenz SiLi-nano, Martin-Luther-Universität Halle Wittenberg

An outstanding property of photonic crystals is their ability to confine light in a small volume. Microcavities with huge quality factors (Q-factors) can be created in such a way enabling a strong light matter interaction. These cavities were commonly produced by introducing defects into planar 2D photonic crystals by removing or shifting single pores. Recently, there is a growing interest in 1D photonic crystal microcavities realized by etching periodic pore chains into photonic wires. Here, possible designs of slotted photonic wire microcavities are numerically investigated, which allow intensive light matter interaction. In contrast to solid microcavities, here the microcavity consists of a slot etched into the waveguide at the cavity position. The slot can be locally infiltrated and offers the possibility to be used as a device for sensing or nonlinear optical applications or as an optical nano probe. The Q factor of the device can be enhanced by a proper design of a tapering region between the mirrors and the cavity. These tapers can be designed to match the electric field distribution of the cavity mode to the field of the evanescent Bloch mode in the mirror, thus reducing scattering losses. We have adapted the design concept for solid cavities and modified it for the case of an infiltrated hybrid slot photonic waveguide. For a linear taper of pore position and radius, this leads to a Q factor of about 35000.

Q 15.33 Mon 16:30 P1

Towards magnetic levitation in opto-mechanics — •Jonas Schmöle — Quantum Optics, Quantum Nanophysics, Quantum Information; Faculty of Physics, University of Vienna, Austria

Diamagnetic suspension allows the creation of freely levitating objects, which might serve as high quality mechanical oscillators. We explore the feasibility of magnetic levitation in combination with cavity optomechanics and we discuss possible experimental challenges.

Q 15.34 Mon 16:30 P1

Lichtstreuung an einem atomaren Dipol in einem optomechanischen Resonator — •Daniel Breyer, Giovanna Morigi und Marc Bienert — Theoretische Quantenphysik, Universität des Saarlandes, 66041 Saarbrücken

Wir untersuchen die elementare Wechselwirkung in einem optomechanischen System, welches aus einem optischen Resonator besteht, der über den Strahlungsdruck mit einem mechanischen Oszillator wechselwirkt und dessen elektromagnetisches Feld an einen Dipolübergang eines Atoms koppelt. Die Schwerpunktsposition des Atoms ist fest vorgegeben, während die Bewegung des mechanischen Oszillators, des elektrischen Feldes und des elektronischen Freiheitsgrades quantenmechanisch behandelt wird. Die Form des Hamiltonoperators für das gekoppelte System wird mit Hilfe des Lagrange- und Hamiltonformalismus ausgehend von den klassischen Bewegungsleichungen abgeleitet.

Mit Hilfe der gefundenen Wechselwirkungsterme wird die Streuung einzelner Photonen eines Lasers untersucht, der das Atom treibt. Wir beschränken uns auf den Fall, in dem die Breite des Wellenpaketes des mechanischen Oszillators viel kleiner ist als die Dimension des optischen Resonators, und nur eine Mode des elektromagnetischen Feldes relevant ist. Wir konzentrieren uns auf Streuprozesse, die den Zustand des mechanischen Resonators verändern, und untersuchen verschiedene Wechselwirkungsmechanismen. Anhand der Ergebnisse geben wir einen Ausblick, wie die Manipulation oder die Charakterisierung des Bewegungszustands des mechanischen Oszillators erreicht werden kann.

Q 15.35 Mon 16:30 P1

A table-top demonstration of radiation pressure — •Dilek

Demir, Garrett D. Cole, and Markus Aspelmeyer — Fakultät Physik, Universität Wien, Boltzmanngasse 5, A-1090 Wien, AUSTRIA

The observation of the momentum transfer of light, i.e. radiation pressure, goes back to the seminal experiments by Lebedew and by Nichols and Hull in the early 20th century. Up to now, all experimental demonstrations of this effect rely on a well-shielded experimental environment that is operated in vacuum. In this presentation we describe a simple table-top experiment that illustrates the momentum transfer between light and a suspended mechanical mirror under ambient conditions. Our work is enabled by the development of millimeter-sized cantilevers of high reflectivity ($> 99.98\%$), very low spring constant (< 0.001 N/m) and very low levels of optical absorption (< 100 ppm). Using these devices in an optical lever arrangement we unambiguously demonstrate radiation pressure effects while operating in air, at room temperature and with only modest(< 10 mW) laser power.

Q 15.36 Mon 16:30 P1

Light-induced entanglement between vibrational modes in nanostructures — •Michael Schmidt[1], Max Ludwig[1], and Florian Marquardt[1,2] — [1]Institut für Theoretische Physik, Universität Erlangen-Nürnberg, Staudtstrasse 7, D-91058 Erlangen, Germany — [2]Max Planck Institute for the Science of Light, Günter-Scharowsky-Strasse 1/Bau 24, D-91058 Erlangen, Germany

Novel photonic crystal structures with localized vibrational modes (optomechanical crystals) can be used to strongly couple a trapped light field to its mechanical degrees of freedom. Such structures are a versatile example of an optomechanical system. Recent experiments aim towards the quantum ground state of the vibrational modes. In our theoretical work, we show that entanglement between distinct vibrational modes can be achieved by intensity modulation of the driving laser.

Q 15.37 Mon 16:30 P1

Effects of ultrastrong light-mechanics coupling — •Andreas Kronwald[1], Max Ludwig[1], and Florian Marquardt[1,2] — [1]Institut für Theoretische Physik, Universität Erlangen-Nürnberg, Staudtstrasse 7, D-91058 Erlangen, Germany — [2]Max Planck Institute for the Science of Light, Günter-Scharowsky-Strasse 1/Bau 24, D-91058 Erlangen, Germany

A generic optomechanical system consists of a mechanical degree of freedom coupled to a laser-driven photonic mode. Recent experiments aim towards the quantum regime of mechanical motion. In addition, there is a trend towards strongly enhanced light-mechanics coupling. Here we show first theoretical predictions for the ultrastrong coupling regime, where single photons in the cavity are able to strongly affect the mechanical system.

Q 15.38 Mon 16:30 P1

Dipole force driven mechanical oscillation of a silica nanofiber — •Christian Wuttke, Christian Wagner, and Arno Rauschenbeutel — Technische Universität Wien - Atominstitut, Stadionallee 2, A-1020 Wien

We present experimental results on the excitation of mechanical modes in an optical nanofiber by light-induced dipole forces. The nanofiber has a diameter of 500 nm and is realized as the waist of a tapered optical fiber, fabricated from a standard optical glass fiber in a heat-and-pull process. By sending near infrared light through such a nanofiber, a strong evanescent field builds up in its vicinity.

When a second nanofiber is inserted into this evanescent field, the coupling results in an optical dipole force between the fibers. By periodically modulating the intensity of the light, we excite a mechanical oscillation of the fibers. This oscillation can then be detected by the change of the light field coupling caused by the oscillation. Using this method, we observe mechanical resonances at frequencies of several hundred kHz. We examine the dependence of the mechanical quality factors of the resonances on the pressure of the gas atmosphere surrounding the fibers and find values exceeding 10^5 for pressures up to the mbar range. This shows that silica nanofibers are interesting devices for quantum optomechanics applications.

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Q 15.39 Mon 16:30 P1

One- and Two-Photon Scattering in a Disordered 1D Quantum System — •Jochen Zimmermann, Thomas Wellens, and Andreas Buchleitner — Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, Hermann-Herder-Str. 3, 79108 Freiburg

We present our findings on the scattering of one and two photons in a 1D system of two level atoms with binary disorder. For the single-photon case, the scattering matrix is mapped onto the corresponding transfer matrix [1]. Anderson localization and recurrent phases are observed numerically as well as analytically, using a selfconsistent equation for the phase relation.

On the other hand, localization of two photons is still an open problem. Our special interest lies in the role of inelastic scattering events, which occur each time both photons meet at the same atom. We present first perturbative results for the scattering amplitudes of two photons by two atoms and discuss their implication for the construction of a two photon transfer matrix approach.

[1] C. J. Lambert and M. F. Thorpe. Random T-matrix approach to one-dimensional localization. Phys. Rev. B, 27(2):715-726, Jan 1983

Q 15.40 Mon 16:30 P1

Faserverstärker basierter Ersatz für einen Ar^+-Laser — •Benjamin Rein, Tobias Beck und Thomas Walther — TU Darmstadt, Institut für Angewandte Physik, Laser und Quantenoptik, Schloßgartenstraße 7, D-64289 Darmstadt

Es wird ein schmalbandiges und weit abstimmbares Lasersystem vorgestellt, dass bei einer Wellenlänge von 514,5 nm emittiert und als Ersatz für Ar^+-Laser eingesetzt werden kann. Die spektralen Eigenschaften des Lasersystems werden durch die Seedquelle vorgegeben, welche als External Cavity Diode Laser realisiert wurde. Die eingesetzte, leistungsstarke Laserdiode emittiert bei 1029 nm und kann durch ein auf Polarisationsspektroskopie basierendes Locking-Verfahren auch ohne AR-Beschichtung modensprungfrei über einen Bereich von 26 GHz mit hohen Scanfrequenzen von bis zu 400 Hz abgestimmt werden. Die Seedstrahlung wird durch eine Yb-dotierte, polarisationserhaltende Faser auf bis zu 10 W verstärkt, um in einer anschließenden Intracavity-Frequenzverdopplung die Zielwellenlänge zu erreichen.

Q 15.41 Mon 16:30 P1

Diodengepumpte Femtosekunden-Laser geschriebene Kanal-Wellenleiterlaser in Yb:YAG-Kristallen — •Thomas Calmano, Jörg Siebenmorgen, Klaus Petermann und Günter Huber — Universität Hamburg, Institut für Laser-Physik, Hamburg

Durch die Fokussierung von fs-Laserpulsen in dielektrische Medien kann aufgrund nichtlinearer Absorptionsprozesse eine Volumenstrukturierung im μm Bereich erfolgen. In Yb:YAG Kristallen führt eine Zerstörung der kristallinen Struktur im Fokus des fs-Lasers aufgrund des elasto-optischen Effektes zu einer lokalen spannungsinduzierten Erhöhung des Brechungsindexes in der Umgebung des modifizierten Bereiches. Dieser Effekt wurde genutzt um Wellenleiter in Yb:YAG zu schreiben. Durch Verfahren des Kristalls unter dem Fokus der Probe wurden Spurpaare geschrieben, zwischen denen Wellenleitung möglich ist. Die Rückkopplung aufgrund der Fresnel Reflexion an den Endflächen der Wellenleiter von ca. 9% in den Wellenleiter ist ausreichend, um Laseroszillation zu ermöglichen. Dies entspricht einem Auskoppelgrad von 99%. Als Pumpquelle für die Laserexperimente diente eine Single-Mode Laserdiode mit einer Ausgangsleistung von 300 mW bei einer Wellenlänge von 940 nm. Mit dem Yb:YAG Wellenleiterlaser konnte eine maximale Ausgangsleistung von 43 mW und ein differentieller Wirkungsgrad von $\eta_s = 51\%$ bezüglich einfallender Pumpleistung erreicht werden. Die Schwellpumpleistung betrug 183 mW. Ein Vergleich mit Experimenten bei denen ein Ti:Saphir Laser als Pumpquelle verwendet wurde zeigt, dass der Wellenleiterlaser für beide Pumpquellen nahezu dasselbe Verhalten im Bereich nahe der Laserschwelle zeigt.

Q 15.42 Mon 16:30 P1

Er^{3+}-Doped YVO_4 Laser Emitting around 1.6 μm — Christian Brandt, •Francesca Moglia, Klaus Petermann, and Günter Huber — Institut of Laser-Physics, Luruper Chaussee 149, 22761 Hamburg, Germany

Resonantly inband pumped Er^{3+}-doped solid-state lasers offer the opportunity for efficient operation around 1.6 μm wavelength. These lasers in the eye-safe region are interesting for medical applications, telecommunication, and remote sensing. In particular for remote measurements of CO_2 using the DIAL (Differential Absorption Lidar) technique an efficient laser is needed at appropriate absorption bands of the CO_2 molecule at 1579 nm or 1603 nm.

Resonantly inband pumping an Er(1.1 at.%):YVO_4 crystal by a fiber laser at 1536 nm results in a maximum slope efficiency with respect to the absorbed pump power of 57.9%. For the maximum pump power of about 8 W a maximum laser output power of 2.3 W was achieved. Depending on the output coupler transmission the free running laser oscillated between 1603 and 1608 nm. By using a birefringent filter the laser wavelength could be tuned from 1578.8 to 1582.3 nm and from 1601.4 to 1607.8 nm, covering two suitable wavelengths for CO_2 DIAL application. Between these tuning bands the laser also oscillated at 1594 nm.

Q 15.43 Mon 16:30 P1

Ein universeller, VCSEL-geseedeter ns-Ti:Sa Laser mit (fourierlimitierten Pulsen und) großer spektraler Abdeckung — •Suleiman Amiri, Simon Metzendorf, Thorsten Führer, Alexander Bertz und Thomas Walther — Technische Universität Darmstadt, Institut für Angewandte Physik, Schlossgartenstr. 7 64289 Darmstadt

Ein Titan:Saphir-Laser wird durch einen frequenzverdoppelten Nd:YAG-Laser gepulst betrieben und emittiert im Wellenlängenbereich von 670 nm bis 1100 nm, wobei das Maximum bei 780 nm liegt. Um Pulse nahe am Fourierlimit zu erzeugen, wird der Ti:Saphir-Laser durch einen schmalbandigen Halbleiterlaser geseedet, wobei die Stabilisierung des Resonators auf die Seedwellenlänge über Polarisations-Spektroskopie nach Hänsch-Couillaud erfolgt. Der Resonator ist in einer Dreieckskonfiguration aufgebaut und ermöglicht eine kurze Buildup-Zeit von 21 ns bei einem FSR von 1GHz. Dies ermöglicht es durch SFG und DFG ein Spektrum von 190nm bis 6000nm zu erschließen. In einem weiteren Schritt soll das Injection-Seeding durch eine MEMS-VCSEL-Diode realisiert werden, welcher bei einer Zentrallwellenlänge von 850 nm über 20 nm modensprungfrei abstimmbar ist.

Q 15.44 Mon 16:30 P1

Effiziente Pr^{3+}:YLF-Laser im Dauerstrich-Betrieb bei den Wellenlängen 522,6 nm, 545,9 nm, 607,2 nm und 639,5 nm — •Teoman Gün, Philip Metz und Günter Huber — Universität Hamburg, Institut für Laser-Physik

Seit der Entwicklung von InGaN-Laserdioden (LD) im blauen Spektralbereich gehören Praseodym-dotierte $LiYF_4$ (YLF)-Kristalle zu den effizientesten Festkörperlasermaterialien im sichtbaren Spektralbereich. In diesem Beitrag werden die aktuellsten Ergebnisse zu LDn-gepumpten Pr^{3+}-Lasern vorgestellt. Dabei konnten, ausgehend von Pr^{3+}:YLF-Kristallen mit einer Dotierungskonzentration von 0,5 at.% und einer Länge von 2,9 mm, im sichtbaren Spektralbereich maximale Ausgangsleistungen von bis zu 938 mW bei einem differentiellen Wirkungsgrad von 63,6 % erreicht werden. Für die Laserexperimente im Dauerstrichbetrieb wurden einfach gefaltete Resonatoren aufgebaut und der Pr^{3+}:YLF-Laserkristall über zwei LDn mit je 1 W Ausgangsleistung beidseitig gepumpt. Zum Fokussieren des Pumpstrahls wurden zwei Linsen mit je 40 mm Brennweite genutzt um einen möglichst guten Überlapp zwischen Pump- und Lasermode zu realisieren. Bei einer absorbierten Pumpleistung von etwa 1,5 W konnten maximale Laserausgangsleistungen von 773 mW bei 522,6 nm, 384 mW bei 545,9 nm, 418 mW bei 607,2 nm und 938 mW bei 639,5 nm generiert werden. Die dabei erreichten maximalen differentiellen Wirkungsgrade für die entsprechenden Wellenlängen betrugen 61,5 %, 52,1 %, 32,0 % und 63,6 %. Die Beugungsmaßzahl des Laserübergangs bei 522,6 nm wurde zu $M_x^2 \approx M_y^2 \approx 1{,}1$ bestimmt.

Q 15.45 Mon 16:30 P1

mode interaction in ZnO random lasers — •Janos Sartor, Daniel Schneider, Felix Eilers, Dirk Silber, Claus Klingshirn, and Heinz Kalt — Institut für Angewandte Physik, Karlsruhe Institute of Technology (KIT) 76128 Karlsruhe (Germany)

Random lasing is a phenomenon found in strongly scattering materials that provide sufficient optical gain. Optically pumped ZnO powder with a mean grain size in the order of the wavelength is such a system and provides excellent conditions to examine random lasing activity. In this system optical modes with different degrees of localization can be observed. Our work concentrates on the characterization of single random lasing modes and their interactions. In samples of reduced size the strong fluctuations typical for random lasers can be suppressed and almost stable emission from single modes can be observed. However at higher excitation densities additional modes appear influencing the formerly stable modes. Once multiple modes begin to lase at the same time, fluctuations of spectral mode positions are observed. This behavior can be explained by carrier density fluctuations caused by spatially overlapping modes.

Q 15.46 Mon 16:30 P1

Aktive Regelung und Kontrolle der Linienbreite eines ECDLs — •Thorsten Führer und Thomas Walther — TU Darmstadt, Institut für Angewandte Physik, AG Laser und Quantenoptik, Schlossgartenstr. 7, D-64289 Darmstadt

Laserdioden mit externem Resonator (ECDL) ermöglichen große Durchstimmbereiche und weisen niedrige spektrale Linienbreiten auf. Für viele Bereiche, beispielsweise in der Sensorik oder der Präzisionsspektroskopie, sind ECDLs daher unverzichtbar. Es wird ein aktives Stabilisierungsverfahren präsentiert, das neben dem Erreichen großer modensprungfreier Durchstimmbereiche die Möglichkeit bietet, die Linienbreite des ECDLs zu minimieren und während des Abstimmens sowie im Betrieb bei einer fixen Wellenlänge konstant zu halten. Darüber hinaus lässt sich die Linienbreite innerhalb gewisser Schranken beliebig einstellen. Das Verfahren nutzt den Polarisationszustand des ECDLs als Fehlersignal für einen geschlossenen Regelkreis, der die Resonanz des Gesamtsystems aufrecht erhält.

Basierend auf der Technik der selbst-heterodynen Detektion werden Messungen präsentiert, die eine Aufschlüsselung der Linienbreite in verschiedene Rauschtypen ermöglichen. Der Einfluss des Stabilisierungsverfahrens auf den jeweiligen Typus wird diskutiert.

Q 15.47 Mon 16:30 P1

Effect of detuning in Fourier domain mode locked lasers on the performance of optical coherence tomography — •Lars Kirsten, Julia Walther, Peter Cimalla, Sven Meissner, Mirko Mehner, and Edmund Koch — Dresden University of Technology, Faculty of Medicine Carl Gustav Carus, Clinical Sensoring and Monitoring, Fetscherstraße 74, 01307 Dresden, Germany

Optical coherence tomography (OCT) is an interferometric imaging technique, generally used in medical diagnostics, providing cross-sectional and volumetric images of tissue with a spatial resolution of a few micrometers [1]. Broadband wavelength sweeps are required for swept source Fourier domain OCT to detect the interference spectrum time encodedly. For achieving high repetition rates, Fourier domain mode locked (FDML) lasers [2] have been introduced. In contrast to conventional ring lasers, a long single mode fiber (km) is additionally inserted in the ring resonator yielding a relatively long round trip time (μs). Synchronously to the round trip, a Fabry-Perot filter is tuned periodically over the wavelength range of the amplifier in the ring laser. The presented FDML laser provides wavelength sweeps in the 1300 nm range with repetition rates of 50 kHz and 123 kHz. The laser performance is significantly affected by detuning the sweep frequency of the Fabry-Perot filter against the optical round trip frequency. The influence of detuning on OCT performance, especially on the SNR, is demonstrated.

[1] D. Huang et al. Science 254, 1178-1181 (1991)
[2] R. Huber et al. Optics Express 14, 3225-3237 (2006)

Q 15.48 Mon 16:30 P1

Induzierte spontane Lasertätigkeit in Quecksilber durch Zweiphotonenanregung — •Daniel Kolbe, Andreas Koglbauer, Ruth Steinborn und Jochen Walz — Institut für Physik, Johannes Gutenberg-Universität Mainz und Helmholtz-Institut Mainz, D-55099 Mainz

Die geringe Anregungswahrscheinlichkeit bei einer Zweiphotonenresonanz stellt eine Herausforderung dar, diesen Prozess als Pumpmechanismus zum Laserbetrieb zu nutzen. Die nötigen Pumpintensitäten werden meist nur durch gepulste Quellen erreicht. Hier wird von spontaner Lasertätigkeit auf dem 7^1S–6^1S Übergang in Quecksilber mit kontinuierlichen Pumplasern berichtet. Durch die Wahl der Verstimmung zum intermediärem 6^3P Niveau kann die Zweiphotonenanregung stark erhöht werden und die Laserschwelle kann bereits bei wenigen 100 mW Pumpleistung überwunden werden. Durch Veränderung der Leistungen kann isotopenselektive Lasertätigkeit beobachtet werden.

Q 15.49 Mon 16:30 P1

Dauerstrich optisch parametrischer Oszillator zur Erzeugung von Terahertzstrahlung und Kombination mit einem Photomischer zur kohärenten Detektion* — •Jens Kiessling, Rosita Sowade, Karsten Buse und Ingo Breunig — Physikalisches Institut, Universität Bonn, Wegelerstr. 8, 53115 Bonn

Wir stellen einen durchstimmbaren optisch parametrischen Oszillator vor, der auf periodisch gepoltem Lithiumniobat basiert und kontinuierliche Terahertzstrahlung um 1,4 THz mittels eines kaskadierten optisch parametrischen Prozesses erzeugt. Die Leistung der Terahertz-

Strahlung liegt im Mikrowatt-Bereich. In Kombination mit einem Photomischer wird die Terahertzstrahlung kohärent nachgewiesen, was die simultane Bestimmung von Amplituden- und Phaseninformationen des Terahertzlichts ermöglicht.

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Q 15.50 Mon 16:30 P1

Unequal spacing of attosecond pulse trains from relativistic surface high harmonic generation — •Jana Bierbach[1], Christian Rödel[1,4], Michael Behmke[2], Daniel an der Brügge[3], Martin Heyer[1], Matthias Kübel[1], Monika Toncian[2], Dirk Hemmers[2], Oliver Jäckel[1,4], Toma Toncian[2], Oswald Willi[2], Alexander Pukhov[3], Georg Pretzler[2], and Gerhard Paulus[1,4] — [1]Institut für Optik und Quantenelektronik, Friedrich-Schiller-Universität Jena — [2]Institut für Laser- und Plasmaphysik, Heinrich-Heine Universität Düsseldorf — [3]Institut für Theoretische Physik, Heinrich-Heine Universität Düsseldorf — [4]Helmholtz-Institut Jena

The interaction of an intense ultrashort laser pulse with a solid density plasma leads to the emission of XUV attosecond pulses within each laser cycle. The process is very sensitive to the laser pulse contrast and the plasma scale length. We observe a strong influence of pre-plasma conditions on the spectral fine structure of high harmonic spectra. The modifications were realized by an adjustable contrast enhancement using different plasma mirror targets. While in the case of high contrast sharp harmonic lines are obtained, an intermediate contrast leads to a strongly modulated spectrum. These modulations can be explained by an unequal pulse spacing in the attosecond pulse train due to a positive linear chirp caused by the cycle averaged motion of the electron plasma surface. A simple analytical model can describe this temporal denting effect and is in good agreement with Particle-In-Cell simulations and the experiment.

Q 15.51 Mon 16:30 P1

Efficiency of surface high harmonic radiation generated with a table-top terawatt laser — •Silvio Fuchs[1,3], Christian Rödel[1,3], Michael Behmke[2], Erich Eckner[1,3], Jana Bierbach[1,3], Wolfgang Ziegler[1,3], Oliver Jäckel[1,3], Georg Pretzler[2], and Gerhard Paulus[1,3] — [1]Institut für Optik und Quantenelektronik, Friedrich-Schiller-Universität Jena — [2]Institut für Laser- und Plasmaphysik, Heinrich-Heine Universität Düsseldorf — [3]Helmholtz-Institut Jena

High harmonic radiation generated on solid surfaces is a promising source of intense XUV radiation. When terawatt laser pulses are focused with high temporal contrast on a glass target to relativistic intensities of 10^{19} W/cm^2, the plasma-vacuum boundary and the electrons therein quiver due to the oscillating electric field of the driving laser pulse. The generated plasma oscillations cause two different generation mechanisms of surface high harmonics that contribute to the observed high harmonic spectra. We determined the efficiency of single high harmonic lines from laser-solid interaction as a function of the incident laser energy for the first time. The 17^{th} harmonic, assigned to the CWE mechanism, has a pulse energy of $\approx 1-10\ \mu J$. Relativistic surface harmonics (ROM) contain 100 nJ and 20 nJ for the 21^{st} and 25^{th} harmonic respectively. The conversion efficiency for CWE harmonics is 10^{-5}. The relativistic harmonics have a conversion efficiency of 10^{-7} (21^{st}) to 10^{-8}(25^{th}). A comparison with efficiencies that are obtained using Particle-In-Cell simulations shows good agreement for our experimental parameters.

Q 15.52 Mon 16:30 P1

Gekoppelte Ringresonatoren mit Tapered Amplifier und miniaturisiertem SHG Resonator zur effizienten Frequenzverdopplung auf 488 nm — •Danilo Skoczowsky, Andreas Jechow, Axel Heuer und Ralf Menzel — Universität Potsdam, Institut für Physik und Astronomie, Photonik, Karl-Liebknecht-Straße 24-25, Haus 28, 14476 Potsdam

Die effiziente Erzeugung von sichtbarer Laserstrahlung ist für viele Anwendungen von hohem Interesse. Neben der direkten Erzeugung beispielsweise mit Laserdioden ist die Frequenzverdopplung von infraroter Laserstrahlung nach wie vor eine gängige Technik. Wird die Intensität der Grundwelle mit Hilfe eines Resonators überhöht, so kann der Verdopplungsprozess deutlich effizienter gestaltet werden. Diese Technik erfordert jedoch eine Stabilisierung der Frequenz des Pumplasers mit der Resonanzfrequenz des hochvergüteten Resonators oder umgekehrt. Vorgestellt wird ein neues, passives Kopplungskonzept basierend auf einem Tapered Amplifier in einer ringförmigen Resonatoranordnung, an den ein zweiter, miniaturisierter Ringresonator gekoppelt ist. Dieser ist hochvergütet ausgeführt und enthält einen periodisch gepolten, nichtlinearen Kristall zur Frequenzverdopplung. Beide Resonatoren sind ohne eine aktive Regelung rein optisch gekoppelt. Es konnten bisher über 300 mW blaues Licht bei 488 nm generiert werden. Das blaue Licht ist nahezu beugungsbegrenzt und hat eine Bandbreite von 50 MHz. Die Emission ist zeitlich stabil mit Fluktuationen $< 1\%$.

Q 15.53 Mon 16:30 P1

Thomson backscattering on laser-accelerated relativistic electron sheets — •Stephan Kuschel[1,2], Christian Rödel[1,2], Athena Paz[1,2], Oliver Jäckel[1,2], Malte Kaluza[1,2], and Gerhard Paulus[1,2] — [1]Institut für Optik und Quantenelektronik, Friedrich-Schiller-Universität Jena — [2]Helmholtz-Institut Jena

High-intensity femtosecond laser pulses open the way to ultra-short particle sources with relativistic energies. When a short laser pulse interacts with a counter-propagating electron bunch, the Thomson backscattering frequency is Doppler upshifted by $4\gamma^2$ times the laser frequency. Since both the electron bunch and the optical pulse have a duration in the femtosecond domain, the scattered radiation is a promising ultra-short XUV source. An all-optical compact particle and photon source was set up for this purpose using a 30-fs 40-TW laser. An electron bunch with MeV electron temperature was created by focusing the TW pulses on a thin metal foil after enhancing the pulse contrast by means of a plasma mirror. A temporally delayed probe pulse was focused on the counter-propagating electron bunch. The XUV emission recorded with an XUV spectrometer showed a clear dependence on the delay. The yield of the XUV radiation and its spectral shape are in agreement with theoretical predictions. The XUV signal which is attributed to Thomson backscattering gives rise to an electron temperature of about 1-3 MeV which is consistent with former experimental findings and theoretical predictions.

Q 15.54 Mon 16:30 P1

Continuous wave Lyman-α (121.56 nm) generation by four-wave mixing in mercury — •Matthias Sattler, Daniel Kolbe, Andreas Koglbauer, Thomas Diehl, Matthias Stappel, Anna Beczkowiak, and Jochen Walz — Institut für Physik, Johannes Gutenberg-Universität Mainz und Helmholtz Institut Mainz, D-55099 Mainz

For future precision experiments on antihydrogen, laser cooling of the magnetically trapped atoms down to milliKelvin range is essential. We present the generation of Lyman-α light on the cooling transition at 121.56 nm wavelength by sum frequency four-wave mixing (FWM) in mercury vapor using solid-state laser systems. The current status of projects for power enhancement and stability improvement is presented. This includes the design of powerful fundamental laser systems like a 30 W Yb:YAG fiber amplifier (1091 nm) and a Yb:Lu_2O_3 disk laser (1015 nm). Additionally FWM in a three color enhancement cavity and a hollow core fiber is investigated.

Q 15.55 Mon 16:30 P1

Frequency-Quadrupled 285nm Diode Laser System for Photoionization of Mg using LBO as a Second Harmonic Generation Crystal — •Stephan Duewel, Martin Enderlein, Thomas Huber, Johannes Stroehle, Christian Schneider, and Tobias Schaetz — MPI für Quantenoptik

Trapped Mg ions have shown to be a good candidate for quantum simulations[1,2]. Ionization using electron bombardment has turned out to be disadvantageous causing long time degradation of trapping conditions. In our current setup, Mg ions are produced out of a thermal atomic beam by a photoionization laser system generating several mW of 285nm single mode laser light via one SHG resonator from a dye laser at 570nm. However, dye lasers and their optical pumps are expensive and work intensive to maintain and operate. An alternative is frequencyquadrupling of a diode laser at 1140nm, previously realized using periodically poled LiNbO3 in the first SHG cavity[3]. We report on an all solid state frequency-quadrupling system pumped by a diode laser at 1140nm, using an LBO crystal for SHG in the first resonator. Despite its low non-linear coefficient of only 0.82pm/V, we are currently able to achieve 9.5mW at 570nm from a pump power of 70mW and optimize the system for a doubling efficiency of 20% of the first SHG at a pump power of 100mW. This should provide on the order of 0.5mW at 280nm, sufficient for efficient photoionization.

[1] A. Friedenauer et al., Nat. Phys. 4, 757-761 (2008)
[2] H. Schmitz et al., Phys. Rev. Lett. 103, 090504 (2009)
[3] D. Nigg, Master's thesis, Universität Innsbruck (2009)

Q 15.56 Mon 16:30 P1

Intracavity absorption spectroscopy with an Er^{3+}-doped fiber ring laser — •Peter Fjodorow, Luis Leal, Benjamin Löhden, Klaus Sengstock, and Valeri Baev — Institut für Laser-Physik, Universität Hamburg, Luruper Chaussee 149, 22761 Hamburg

Laser intracavity absorption spectroscopy is a very effective way to enhance the sensitivity of absorption measurements. With this technique, a sample of narrow-line absorption is placed into the cavity of a broadband laser, e.g. a fiber laser. The laser light passes through the absorber many times, and the absorption signal appears in the output spectrum, as in a multipass cell. The highest sensitivity is achieved with a cw laser, and it is limited by nonlinear mode coupling. e.g. by the spatial inhomogeneity of the laser gain and by stimulated Brillouin scattering. We report here on an experimental setup for sensitive absorption measurements based on a broadband Er^{3+}-doped fiber unidirectional ring laser. In this laser the complete elimination of the spatial gain inhomogeneity, reduction of stimulated Brillouin scattering in the fiber and decrease of spectral noise has been demonstrated. The sensitivity achieved with this laser is approximately one order of magnitude higher compared to the linear laser configuration with similar parameters [1] and corresponds to the effective absorption path length of over 500 km. This system can be used for the detection of trace gases and for environmental or medical applications.

[1] B. Löhden, S. Kuznetsova, K. Sengstock, V. M. Baev, A. Goldman, S. Cheskis, and B. Pálsdóttir, Appl. Phys. B, DOI 10.1007/s00340-010-3995-9 (2010).

Q 15.57 Mon 16:30 P1

Aufbau eines Integrated-Cavity-Output-Spektrometers im mittleren Infrarot — •Lars Czerwinski, Kathrin Heinrich, Marcus Sowa und Peter Hering — Institut für Lasermedizin, Universitätsklinikum Düsseldorf, Universitätsstr. 1, 40225Düsseldorf

Die Integrated-Cavity-Output-Spektroskopie (ICOS) ist eine Weiterentwicklung der Absorptionspektroskpie, die mit Hilfe eines optischen Resonators die Wechselwirkungsstrecke zwischen Laserlicht und absorbierendem Medium verlängert, um die Nachweisgrenze zu verbessern. Das Spektrometer wurde neu aufgebaut und soll dem hochempfindlichen Nachweis von Stickstoffmonoxid (NO) dienen. NO besitzt eine bedeutende medizinische Relevanz bei der Regulation des Blutdrucks, bei der Kommunikation von Nervenzellen, bei der Zerstörung von Krankheitserregern und anderen physiologischen Prozessen. Das hier vorgestellte Spektrometer wird mittels eines Quantenkaskadenlasers (QCL) betrieben, der mit einem Peltier-Element gekühlt wird und bei einer Wellenlänge von 5,3 μm emittiert. Die Verwendung eines QCL ermöglicht die Realisierung eines kompakten Systems mit technisch minimalen Aufwand für die Spurengasanalytik. Das Spektrometer erreicht bei einer Allan-Varianz-Messung eine minimale rauschäquivalente Absorption von $8{,}4 \cdot 10^{-7}\,\mathrm{cm}^{-1}$ bei einer Integrationszeit von 270 Sekunden. Dies entspricht einer rauschäquivalenten Konzentration von 355,9 ppb ^{14}NO.

Im Rahmen eines Posters sollen der Aufbau des Spektrometers und erste Ergebnisse präsentiert werden.

Q 15.58 Mon 16:30 P1

Flow measurements by the phase-resolved Doppler OCT and the signal power decrease in Spectral Domain OCT — •Julia Walther and Edmund Koch — Clinical Sensoring and Monitoring, Faculty of Medicine Carl Gustav Carus, Dresden University of Technology, Fetscherstr. 74, 01307 Dresden, Germany

Optical Coherence Tomography (OCT) is a non-invasive, contactless imaging modality in medical diagnosis and biomedical research providing cross-sectional images of internal structures of highly scattering samples with micrometer resolution. Spectral Domain OCT (SD OCT), based on the spectrometer analysis of the interference signal, is gaining considerable interest due to its high sensitivity and high image acquisition speed. Nowadays, SD OCT structural imaging is extended with functional studies for the determination of physiology and functional impairment of diseases. The phase-resolved Doppler method is based on the linear relation of the phase difference of adjacent interference signals and the axial sample velocity and is often used to measure blood flow velocities in small vessels. Unfortunately, this technique can be inflamed due to high sample velocities during the integration time resulting in a signal power decrease of the backscattering signal. We propose to take advantage of the signal damping for the quantification of high flow velocities at which the standard Doppler OCT does not work any longer. Furthermore, a combination of the established Doppler OCT and the numerically simulated signal damping due to obliquely moved scatterers is presented for an in vitro 1% Intralipid flow phantom study.

Q 15.59 Mon 16:30 P1

High-resolution Optical Nanospectrometers for Medical Applications using Substrate Conformal Imprint Lithography as Novel 3D Fabrication Technique — •Alla Albrecht, Xiaolin Wang, Hanh H. Mai, Timo Schotzko, Imran Memon, Martin Bartels, and Hartmut Hillmer — Institute of Nanostructure Technologies and Analytics, University of Kassel, 34132 Kassel, Germany

Optical spectroscopy has become one of the most prevalent characterization methods used in a wide array of field applications such as medical health-care. The most important challenge facing the construction of spectrometers is their miniaturization and integration into mobile devices. This pocket-size spectrometry will enable a long-time self-monitoring of the user's state of health in a non-invasive way.

Due to the fact that the miniaturization of grating-based spectrometers has reached its limits, they need to be replaced by novel approaches, e.g. by Fabry-Pérot (FP) based spectrometers combined with Nanoimprint Technology. We have successfully implemented a new methodology of fabricating miniaturized spectrometers (Nanospectrometers) with 3D filter-arrays of different cavity heights with high vertical resolution by only one single process step. For a detection of a broad spectral range, multiple DBRs (Distributed Bragg Reflectors) with different physical heights are obligatory. The novel Substrate Conformal Imprint Lithography (SCIL) affords to print on those cascade structured surfaces. Nanospectrometers, as fabricated at the INA, are low in cost, very robust and show a very high optical resolution ($\lambda/\Delta\lambda$) up to 500 and thus, having a great potential for the commercial market.

Q 15.60 Mon 16:30 P1

Novel Technology for Highly Sensitive Gas Sensors — •Sven Blom, Mahamoud Ahmad, Jyoti Shrestha, Nico Storch, Usman Masud, Sandra Schink, Basim Kudhair, and Hartmut Hillmer — Institute of Nanostructure Technologies and Analytics, University of Kassel, 34132 Kassel, Germany

Modern industrial and medical applications require precise sensing of substances, e.g. pollutants or biomarkers. Commercially available sensors are very cost intensive and due to their size hard to handle or to implement. Moreover, size-reduced sensors do not reach the required sensitivity. A novel technology sensor system, developed at the INA, has the potential to combine miniaturization, high sensitivity and a low cost production.

The concept of our optical system is the reaction of a semiconductor laser to slight variation of its resonator parameters. For a very high sensitivity a two mode laser-system is used, in which both modes are brought into an artificial intensity equilibrium. One of the two modes is tuned to a characteristic absorption line of the substance to be analyzed. Even an extremely small amount of molecules introduced into the resonator results in an intensity difference which is coevally correlated to the gas concentration.

Conventional gas sensors require a photomultiplier. In contrast, our system measures the mode competition by means of "relative intensity noise" (RIN). This electrical evaluation also enables the miniaturization of our system. Due to this and the possibility to tailor this sensor for individual substances, the application field becomes very broad.

Q 15.61 Mon 16:30 P1

Laser-induced front side etching of fused silica with KrF excimer laser using thin metal layers — •Pierre Lorenz and Klaus Zimmer — Leibniz-Institut für Oberflächenmodifizierung e. V., Permoserstraße 15, 04318 Leipzig, Germany

Laser-induced front side etching is a method for laser etching of transparent materials using thin absorber layers. This approach is a straight forward advancement of the backside etching techniques. Within this study the etching of fused silica with different thin metal layers as absorbers is presented using nanosecond KrF excimer laser radiation (λ = 248 nm, 25 ns pulses, 10 Hz). The laser fluence, the number of pulses, the absorber material, as well as the layer thickness were varied. As metallic absorber materials chrome, aluminium, silver, titanium, as well as molybdenum were used with different layer thicknesses from 2 nm to 250 nm. Furthermore, the laser fluence was altered from below the metal ablation threshold up to 10 J/cm^2 and the surface was processed with different pulse numbers up to 10 pulses. The treated fused silica was analysed with microscopic (white-light interferometry, scanning electron microscopy (SEM)) and spectroscopic methods (X-ray photoelectron spectroscopy (XPS), energy dispersive X-ray spectroscopy (EDX)). An etching depth up to 500 nm with well-defined etching regions can be achieved.

Q 15.62 Mon 16:30 P1

Carrier-envelope phase stabilized 9.3 fs, 0.54 mJ pulses at 1.8 μm — Ding Wang[1], •Canhua Xu[1], Liwei Song[1], Chuang Li[1], Chuanmei Zhang[1], Yansui Huang[1], Xiaowei Chen[1,2], Yuxin Leng[1], Ruxin Li[1], and Zhizhan Xu[1] — [1]State Key Laboratory of High Field Laser Physics, Shanghai Institute of Optics and Fine Mechanics, Chinese Academy of Sciences, Shanghai 201800, China — [2]Laboratoire d'Optique Appliquee, ENSTA ParisTech, Ecole Polytechnique, CNRS, 91761 Palaiseau Cedex, France

Generation of 0.54 mJ, 9.3 fs pulses at 1.8 μm with a controlled waveform comprised of $\tilde{1}.5$ optical cycles is demonstrated. The 1.27 mJ, 40 fs seed pulses from a passive carrier-envelope-phase (CEP) stabilized optical parametric amplifier are spectrally broadened in an argon-filled hollow-core fiber, subsequently compressed through linear propagation in a glass plate in the anomalous dispersion regime. The reservation of the pulse CEP stabilization is also demonstrated, with the drift error of the compressed pulses of 0.516rad (rms), comparable to the incident pulses.

Q 15.63 Mon 16:30 P1

New Beamline for applied High Harmonics Spectroscopy — •Jochen Vieker, Hatem Dachraoui, Martin Michelswirth, Tobias Milde, and Ulrich Heinzmann — Molecular and Surface Physics, University of Bielefeld

Spectroscopy of High Harmonic Generation (HHG) on laserfield-aligned molecules using femtosecond lightsources has become popular over the last years, due to its ability of probing molecular dynamics. A new beamline with a pulsed gas jet HHG-target, followed by a toroidal mirror based spectrometer was recently put into operation. The beam is generated by a 50Hz Ti:Sa lasersystem (804nm), producing 50fs, 15mJ pulses.

Q 15.64 Mon 16:30 P1

Untersuchungen zur spektralen Emissionscharakteristik von PLD deponierten laseraktiven Materialien — •Mathias Hoffmann[1], Stefan Schrameyer[2], Mark Gyamfi[1], Holger Blaschke[2], Detlev Ristau[2] 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. Als laseraktives Material wurden die Materialien Nd:YAG und Nd:Glas verwendet und auf hochwertigen Quarzglassubstraten deponiert. In diesem Beitrag werden aktuelle Ergebnisse und der Projektstand der PLD vorgestellt. Darüber hinaus wurden als wesentlicher Bestandteil der Charakterisierung die spektralen Emissionseigenschaften der Proben untersucht. Dabei deuten die Resultate der Fluoreszenzmessungen auf eine nichtlineare Frequenzkonversion der generierten Emissionen im Schichtmaterial hin.

Q 15.65 Mon 16:30 P1

Ultrashort laser pulse characterization based on a pulse shaping device — •Stefanie Züllighoven, Jens Köhler, Tillmann Kalas, Cristian Sarpe, Matthias Wollenhaupt, and Thomas Baumert — University of Kassel, Institute of Physics and Center of Interdisciplinary Nanostructure Science and Technology (CINSaT), Heinrich-Plett-Str. 40, D- 34132 Kassel, Germany

Femtosecond (fs) laser pulse shaping is a key technology often used in the fields of fs spectroscopy and ultrafast laser control. In order to characterize ultrashort laser pulses typically autoccorrelation (AC), crosscorrelation (CC) and spectrogram based techniques are employed. A common feature of all these pulse measurement methods is the use of an interferometric setup. In this contribution we present our scheme to combine these two approaches. Our pulse shaper consists of a standard 4f-zero dispersion compressor setup and a double layer liquid crystal spatial light modulator allowing for independent spectral phase and amplitude modulation. This device provides the possibility to simultaneously generate complex-shaped laser pulses and to mimic the interferometer needed for their characterization [1].

We present results on measurements and simulations of collinear AC as well as CC traces and their spectrally resolved counterparts, i.e. FROG and X-FROG spectrograms. In addition, we utilize Fourier techniques to extract the non-collinear information of the collinear measurements [2].

[1] A. Galler and T. Feurer, Appl. Phys. B 90, 427 (2008)
[2] I. Amat-Roldan *et al.*, Optics Express 12, 1169 (2004)

Q 15.66 Mon 16:30 P1

New kind of single-shot pulse length measurement of intense few-cycle laser pulses — •T. Rathje[1], A. M. Sayler[1], W. Müller[1], C. Kürbis[1], K. Rühle[1], G. Stibenz[2], and G. G. Paulus[1] — [1]Institut für Optik und Quantenelektronik and Helmholtz Institut Jena, Max-Wien-Platz 1, 07743 Jena, Germany — [2]APE GmbH, Plauener Str. 163-165, 13053 Berlin, Germany

Intense few-cycle (4–8 fs) laser pulses at 790 nm are now being used in a wide variety of application, including the production of attosecond extrem-ultraviolet (XUV) pulses. Since these experiments are sensitive to the electric field of the laser light, the characterization of the waveform is critical for the understanding and control of these interactions. We present a new technique to determine the pulse length by using a stereographic laser-induced above-threshold ionization (ATI) measurement of Xe, i.e. the same technique that provides precise, real-time, every-single-shot carrier-envelope phase measurement of ultrashort laser pulses. By comparing the left and right electron time-of-flight signals in the stereographic ATI apparatus we can calculate the asymmetry of the lasers electric field in real-time for every individual laser shot. This asymmetry increases when the pulse length decreases and vice versa. The corresponding relationship allows us to determine the temporal waveform of every single pulse in a kHz pulse train within the Gaussian pulse approximation. For calibration we used a few-cycle spectral phase interferometer for direct electric-field reconstruction (SPIDER). Our measurements roughly agree with calculations done using quantitative rescattering theory (QRS).

Q 15.67 Mon 16:30 P1

Single-shot carrier-envelope phase tagged non-sequential double ionization of argon in intense 4-fs laser fields — •A. M. Sayler[1], T. Rathje[1], W. Müller[1], K. Rühle[1], G. G. Paulus[1], Nora G. Johnson[2,3], O. Herrwerth[2], A. Wirth[2], S. De[3], I. Ben-Itzhak[3], M. Lezius[2], B. Bergues[2], A. Senftleben[4], C. D. Schröter[4], R. Moshammer[4], J. Ullrich[4], K. J. Betsch[5], R. R. Jones[5], and M. Kling[2,3] — [1]Institut für Optik und Quantenelektronik and Helmholtz Institut Jena, Max-Wien-Platz 1, 07743 Jena, Germany — [2]Max-Planck-Institut für Quantenoptik, Garching 85748, Germany — [3]Kansas State University, Manhattan, KS 66506, USA — [4]Max-Planck-Institut für Kernphysik, Heidelberg, 69117, Germany — [5]University of Virginia, Charlottesville, VA 22904, USA

Single-shot carrier envelope phase (CEP) tagging has been utilized in a cold-target recoil-ion momentum spectroscopy (COLTRIMS) measurement of ultra-short laser-induced non-sequential double ionization (NSDI) of argon. This novel technique facilitates an unprecedented level of stability, longevity, and precision in the determination of CEP dependence and, in general, shows great promise for utilization in a wide variety of CEP sensitive measurements. Here we find that the yield of Ar^{2+} in 4 fs laser fields at 750 nm and an intensity of 1.6×10^{14} W/cm^2 shows a strong CEP dependence which compares with recent theoretical predictions employing quantitative rescattering (QRS) theory. Additionally, the Ar^{2+} momentum, along the laser polarization axis, is strongly influenced by the CEP.

Q 15.68 Mon 16:30 P1

Precision measurement of carrier-envelope phase dependent ATI spectra for the noble gases using phase-tagging technique — •Dominik Hoff, Stefan Fasold, Tim Rathje, Walter Müller, Klaus Rühle, A. M. Sayler, and G. G. Paulus — Institut für Optik und Quantenelektronik and Helmholtz Institut Jena, Max-Wien-Platz 1, 07743 Jena, Germany

Presented are the carrier-envelope phase (CEP) and energy dependent ATI spectra for Xenon, Argon, and Neon. This data was obtained using a phase tagging technique which is based on a novel, robust, real-time, every-single-shot technique for determining the carrier-envelope phase via a stereographic ATI setup. The CEP is calculated and output within ∼20 μs of the laser interaction and this information is then used to tag ATI data of several noble gases to investigate their dependence on the relative CEP. Additionally the relative phase was kept constant for all targets, thus the relationship between the ATI phase dependencies is revealed. This phase measurement also enables the

tagging of any other event-mode experiment run in parallel with the phase determination to get a relative dependence of these experiments from the corresponding CEP of the pulse.

Q 15.69 Mon 16:30 P1

Pulsformer für Pulsspektren mit 1,5 Oktaven von VIS bis NIR — •Anne Harth[1,2], Marcel Schultze[1,2], Stefan Rausch[1,2] und Uwe Morgner[1,2] — [1]Institut für Quantenoptik, Leibniz Universität Hannover, Hannover, Germany — [2]QUEST: Centre for Quantum Engineering and Space-Time Research, Hannover, Germany

Die zeitliche Pulsformung im fs-Bereich erfordert die Manipulation der spektralen Phase eines Pulsspektrums und somit einen Fourierwechsel vom Zeit- in den Frequenzraum. Dies wird üblicherweise durch einen 4f-Aufbau realisiert, in dessen Fokus ein LC-Display steht. Entsprechende Pulsformer werden bereits in vielen Gebieten verwendet, wie der kohärenten Kontrolle chemischer Prozesse (coherent control), der Erzeugung fourierlimitierter Pulse oder auch der Pulscharakterisierung (MIIPS).

Wir präsentieren einen Pulsformer für ein 1,5 Oktaven breites Spektrum (450 nm - 1,1 μm) basierend auf einem breitbandigen LC-Display und zwei hochbrechende Prismen zur Frequenzaufspaltung.

Q 15.70 Mon 16:30 P1

Frequency comb stabilization with zero phase slip frequency for high repetition rate carrier envelope sensitive experiments — •Matthias Hensen, Christian Strüber, and Walter Pfeiffer — Fakultät für Physik, Universität Bielefeld, Universitätsstr. 25, 33615 Bielefeld, Germany

In the regime of few-cycle laser pulses light-matter interaction becomes sensitive to the absolute phase of the electric field. The stabilization and control of this carrier envelope phase (CEP) made it for example possible to extend the time-resolution in laser spectroscopy to the attosecond regime. Most present experiments rely on amplified pulses and thus it suffices to stabilize the frequency comb modulo a constant phase slip frequency, commonly chosen as one quarter of the oscillator repetition rate. However, this limits the applicability of CEP stabilized lasers in experiments using directly the high repetition rate oscillator pulses. To overcome this limitation we have built a f-2f interferometer in which the fundamental-arm is shifted in frequency by an acousto-optic modulator. Using a commercial phase locking control electronics this allows stabilizing the CEP at zero phase slip frequency. Long term CEP stabilization of <7 fs laser pulses with a rms phase noise of 130 mrad is achieved for closed-loop operation.

Q 15.71 Mon 16:30 P1

Monochromatizing a Femtosecond High-Order Harmonic VUV Photon Source with Reflective Off-Axis Zone Plates — •Mateusz Ibek[1], Torsten Leitner[1], Alexander Firsov[2], Alexei Erko[2], and Philippe Wernet[1] — [1]Institute for Methods and Instrumentation for Synchrotron Radiation Research, Helmholtz-Zentrum Berlin — [2]Institute for Nanometer Optics and Technology, Helmholtz-Zentrum Berlin

Conventional grazing incidence grating monochromators pose major disadvantages to monochromatizing femtosecond pulses in the vacuum ultraviolet (VUV) photon energy range. Their transmission efficiency is very low and they increase the pulse duration considerably. Additionally, the efficiency further decreases with every optical element added to a given setup. Using the laser-based high-harmonic generation (HHG) setup at HZB/BESSYII we have characterized the properties of off-axis reflection zone plates (RZP) for simultaneously monochromatizing and focusing a femtosecond VUV photon source. Our setup generates 50 fs pulses and here we used photon energies between 15 and 30 eV. Three RZPs, each designed for a specific harmonic were etched on a gold coated plane substrate. Here we present the proof of principle of such a system, its spectral resolution and focal characteristics among others. The results show clearly that the RZPs besides being cheaper and easier to manufacture have a higher efficiency and good energy resolution. Furthermore, we demonstrate how with these RZPs one can easily trade in dispersion (spectral resolution) versus pulse broadening online to adapt these parameters.

Q 15.72 Mon 16:30 P1

Optical vortex supercontinuum and topological charge transfer — •Peter Hansinger[1,2], Alexander Dreischuh[1,3], Georgi Maleshkov[3], and Gerhard Georg Paulus[1,2] — [1]Institut für Optik und Quantenelektronik, Friedrich-Schiller-Universität Jena, Max-Wien-Platz 1, 07743 Jena, Germany — [2]Helmholtz-Institut Jena, Helmholtzweg 4, 07743 Jena, Germany — [3]Department of Quantum Electronics, Sofia University, 5 James Bourchier Blvd., Sofia-1164, Bulgaria

Optical vortices, also known as screw dislocations, are singular points within the phase of a light beam. The phase varies by a multiple of 2π over the angular coordinate ϕ, and is therefore undefined in the center and the intensity becomes zero at this point. Such donut beams have become useful e.g. in optical micromanipulation as so-called optical tweezers. Particularly interesting is the generation of optical vortices in broadband coherent continua, such as ultrashort pulses.

To date, most experiments aimed to generate a broad spectral distribution first (e.g. in photonic crystal fibers) and subsequently impose the phase singularity onto the generated white-light beam. Only recently, supercontinuum has been generated directly with an optical vortex beam in calcium fluoride glass.

We have conducted measurements with an optical vortex beam in Argon gas, which serves as a nonlinear Kerr medium. During propagation, inhomogeneities in the beam profile initiate filamentation and supercontinuum generation. Despite strong background beam modulation, the vortex phase is preserved in a broad spectral range.

Q 15.73 Mon 16:30 P1

Low-threshold conical microcavity dye lasers — •Saskia Becker[1], Tobias Grossmann[1,2], Mario Hauser[1], Dominik Floess[1], Torsten Beck[1], Timo Mappes[2], and Heinz Kalt[1] — [1]Institut für Angewandte Physik, Karlsruhe Institute of Technology (KIT),76128 Karlsruhe, Germany — [2]Institut für Mikrostrukturtechnik, Karlsruhe Institute of Technology (KIT), 76128 Karlsruhe, Germany

We report on utilizing high-Q polymeric conical microresonators for the development of low-threshold lasers operating in the visible spectral region. This type of laser is promising for the development of highly integrated photonic circuits or lab-on-chip systems.

The microcavities are made of low loss, thermoplastic polymer poly(methyl methacrylate) (PMMA), directly processed on a silicon substrate and possess cavity Q factors above two million in the 1300 nm wavelength region. By integrating a large oscillator strength gain material, e.g. the dye molecule rhodamine 6G, into the polymeric host matrix, laser thresholds as low as 3 nJ per pulse are observed under quasi-stationary pumping conditions. By varying the dye concentration, laser emission wavelengths can be spectrally tuned. This effect can be explained using a standard model of a dye lasing in a Fabry-Perot cavity.

Q 15.74 Mon 16:30 P1

Toroid microcavity based frequency combs for optical telecommunication — •Marcel Dornbusch[1], Florian Bach[2], Mario Hauser[1], Jörg Pfeifle[2], Torsten Beck[1], Tobias Grossmann[1], Christian Koos[2], and Heinz Kalt[1] — [1]Institute of Applied Physics, Karlsruhe Institute of Technology (KIT), Karlsruhe, Germany — [2]Institute of Photonics and Quantum Electronics, Karlsruhe Institute of Technology (KIT), Karlsruhe, Germany

Optical frequency comb generation has been demonstrated using various high-Q whispering gallery mode microcavities made of different nonlinear media. Such combs can be used as integrated light sources for ultra-high speed optical data transmission based on modulation of each individual frequency line. This application requires a comb with a multitude of equally strong, equidistant lines spaced apart 100 GHz or less.

A simulation to investigate the required resonator properties is presented. It is based on the nonlinear Schrödinger equation. The model parameters such as the effective mode area and the nonlinearity parameter are computed numerically with the help of a finite element mode solver.

Additionally, we investigate the fabrication process of glass toroid microcavities on a silicon chip setting value on the specifications of size, quality factor and mode area obtained in the simulation.

Q 15.75 Mon 16:30 P1

Photonic Phase Gate via an Exchange of Fermionic Spin Waves in a Spin Chain — •Johannes Otterbach[1], Alexey V. Gorskov[2], Eugene Demler[3], Michael Flesichhauer[1], and Mikhail D. Lukin[3] — [1]Fachbereich Physik & Forschungszentrum OPTIMAS, TU Kaiserslautern — [2]Physics Department, California Institute of Technology, Pasadena, CA, USA — [3]Physics Department, Harvard University, Cambridge, MA, USA

We propose a new protocol for implementing the two-qubit photonic phase gate. In our approach [1], the phase is acquired by mapping two single photons into atomic excitations with fermionic character and exchanging their positions. This scheme provides a robust phase shift in thus the relative acquired phase is exactly π, independent of any fine tuning of parameters. The fermionic excitations are realized as spin waves in a spin chain, while photon storage techniques provide the interface between the photons and the spin waves. Experimental systems suitable for implementing the gate and possible imperfections are discussed.

[1] A. V. Gorshkov et al., Phys. Rev. Lett. 105, 060502 (2010).

Q 15.76 Mon 16:30 P1

Radiative corrections in strong field QED in intense laser fields — •Sebastian Meuren and Antonino Di Piazza — Max-Planck-Institut für Kernphysik, Saupfercheckweg 1, D-69117 Heidelberg

We investigate radiative corrections to electron states in a background plane-wave laser field [1]. At the tree level, electrons are described by Volkov states, which are solutions of the Dirac equation in a plane-wave field. However, the interaction of the electron with its own electromagnetic field leads to “radiative” modifications of the states [2,3]. We investigate these quantum corrections by solving the Dirac-Schwinger equation perturbatively in a constant-crossed field and in a linearly-polarized plane wave field. To this end we present a new derivation of the mass operator entering the Dirac-Schwinger equation for a constant-crossed field. Finally, experimental possibilities of measuring these radiative corrections are discussed.

[1] S. Meuren and A. Di Piazza, in preparation.
[2] V. I. Ritus, Journal of Russian Laser Research **6**, 497 (1985).
[3] V. N. Baier, M. Katkov, V. M. Strakhovenko, Electromagnetic Processes at High Energies in Oriented Single Crystals (World Scientific, Singapore, 1998).

Q 15.77 Mon 16:30 P1

Robustness of trapping states in microwave cavity QED. — •Christian Arenz and Giovanna Morigi — Theoretische Physik, Universität des Saarlandes

Trapping states are fixed points of the dynamics of the mode of a high-Q resonator coupled with a beam of atoms [2, 3]. Such states are found in the strong coupling regime and for well defined interaction times. In [1] it was shown that, when the atoms are prepared in a coherent superposition of ground and excited state, the corresponding trapping state can be a "Schrödinger-cat" state of the cavity field, provided that the atomic velocity is appropriately selected.
We study both analytically and numerically the stability of trapping states for different initial states of the driving atoms, as a function of the velocity distribution of the atoms, of their arrival rate, and of the photon storage time in the cavity field. Furthermore we determine the fidelity of preparing these states for experimentally accessible parameters [2, 3].

[1] J. Slosser, P. Meystre, and S. Braunstein Phys. Rev. Lett. 63, 934 (1989) (1986).
[2] M. Weidinger, B.T.H. Varcoe, R. Heerlein, and H. Walther, Phys. Rev. Lett. 82, 3795 (1999).
[3] J.M. Raimond, M. Brune, S. Haroche, Rev. Mod. Phys. 73, 565 (2001).

Q 15.78 Mon 16:30 P1

An optical cavity with a strongly focused mode — •Kadir Durak, Syed Abdullah Aljunid, Brenda Chng, Gleb Maslennikov, and Christian Kurtsiefer — Centre for Quantum Technologies / Dept. of Physics, National University of Singapore

Electrical field enhancement with optical cavities is a common method to observe strong coupling between atoms and photons for efficient quantum interfaces. Commonly, free-space cavities for such experiments have paraxial field modes, but additional field enhancement can be accpomplished by placing the atoms in focused cavity modes [1]. We investigate an anaclastic cavity lens configuration [2], which provides strong coupling with a moderate finesse cavity and allow for efficient matching to Gaussian modes outside the cavity[3]. We report on our progress for mode characterization and alignment of such a nearly-critical resonator.

[1] S.E. Morrin, C.C. Yu, T.W. Mossberg, Phys. Rev. Lett. **73** 1489 (1994).
[2] Ibn Sahl, On burning mirrors and lenses. Baghdad (984).
[3] S.A. Aljunid et al., arXiv:1006.2191v1 / J. Mod. Opt. (2010)

Q 15.79 Mon 16:30 P1

Theoretical aspects of the QFEL — •Rainer Endrich[1], Enno Giese[1], Matthias Knobl[1], Paul Preiss[1,2], Roland Sauerbrey[2], and Wolfgang P. Schleich[1] — [1]Institut für Quantenphysik, Universität Ulm, 89069 Ulm, Germany — [2]Forschungszentrum Dresden-Rossendrof, 01314 Dresden, Germany

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, in the near future an FEL working in the quantum regime is within reach at the Research Center Dresden-Rossendorf. Some theoretical progress has been made so far to understand quantum effects which are usually suppressed in the classical regime and therefore ignored. This includes two-level photon transitions, significant 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. In this way we will analyze the behavior of both systems and, in particular, the photon statistics of the field and the microbunching of the electrons with the corresponding reduced density matrices.

Q 15.80 Mon 16:30 P1

Storing the collective positronium atoms with laser field — •Ni Cui, Mihai Macovei, Karen Z. Hatsagortsyan, and Christoph H. Keitel — Max-Planck-Institut für Kernphysik, Saupfercheckweg 1, 69117 Heidelberg, Germany

Different from ordinary atoms, positronium(Ps) atoms in the ground states are unstable, and annihilate by γ emission. Populating the excited states of Ps atoms is an efficient way to increase the annihilation lifetime with resonant excitation by laser field [1]. If the inter-particle intervals among Ps atoms is small on a scale given by the relevant transition wavelength, collective effects have large influence on the annihilation probabilities in an assembly of Ps atoms. The numerical results show that, both superradiance and subradiance phenomena are present in the cooperative spontaneous evolutions of two-state (1S-2P) Ps atoms with initially suitable preparation by optical pumping. Then, for the collective three-state (1S-2P-3D) Ps atoms excited by resonant laser field, we find that the Ps atoms could be stored in the upper state with an extended lifetime by a factor much longer than independent Ps atoms.

[1] F. H. M. Faisal and P. S. Ray, J Phys. B: At. Mol. Phys. 14, L715 (1981); A. Karlson and M. H. Mittleman, J Phys. B: At. Mol. Phys. 29, 4609 (1996).

Q 15.81 Mon 16:30 P1

Plasmon-mediated interaction and level shifts of atoms: a Green's function approach — •David Dzsotjan[1,2] and Michael Fleischhauer[1] — [1]TU Kaiserslautern, Kaiserslautern, Germany — [2]RMKI-KFKI, Budapest, Hungary

We investigate the long-range coupling of individual atoms placed close to metallic nanowires. Putting the emitter close to the surface of a thin wire, a strong Purcell effect can be observed due to the extremely small transverse mode area of the surface plasmon modes: the emitter will decay into guided surface plasmon modes of the wire with a rate exceeding that of free space by a large factor. Placing a pair of emitters along the wire, we observe a strong, wire- mediated long-range interaction between the emitters. As a result, super- and subradiance can occur over distances large compared to the resonant wavelength. The states with enhanced or suppressed decay rate are the symmetric or anti-symmetric Dicke states. Besides the modification of decay rates, dipole-dipole shifts emerge due to the wire-mediated interaction, which we calculate explicitly. Coupling more atoms to a wire network with a nontrivial coupling topology leads to interesting entangled subradiant states of the system.

Q 15.82 Mon 16:30 P1

Time-Continuous Measurements and Non-Markovian Open Quantum Systems — •Sven Krönke and Walter T. Strunz — Institut für Theoretische Physik, TU Dresden, Zellescher Weg 17, 01069 Dresden

Both Markovian and non-Markovian open quantum systems can be described by means of Monte Carlo methods: The reduced density operator of the open system can be obtained by averaging over many solutions of a stochastic Schrödinger equation. In the Markovian case, where the environment has no memory at all, it is moreover possible to really generate those solutions in an experiment by time-continuously monitoring the environment (e.g. by homo-/heterodyne detection). This offers the possibility to non-demolition measurements: By observing many identical copies of the system and averaging over the measurement outcomes, the influence of the measurements on the open system dynamics is removed.

This contribution deals with the question whether or not it is feasible to find such measurement schemes even in the non-Markovian regime, where the coupling between the system and its environment is not necessarily small and the environment has a finite memory.

Q 15.83 Mon 16:30 P1

Dynamical cooling of a single-reservoir open quantum system via optimal control — •Rebecca Schmidt, Jürgen T. Stockburger, and Joachim Ankerhold — Institut für Theoretische Physik, Universität Ulm, Albert Einstein-Allee 11, 89069 Ulm

The coherent optimal control of noisy and open quantum systems is critical in tailored-matter such as quantum information processing. We investigate this type of control problem using the exact description of the dynamics of open quantum systems given by stochastic Liouville-von Neumann equations [1], and generalizing Krotov's iterative algorithm. We apply this formalism to an harmonic oszillator coupled to an ohmic bath. Performing optimal control on this system, allows us to cool translational motion with a single thermal reservoir and without involving internal degrees of freedom [2].

[1] Stockburger, J.T. and Grabert, H., Phys. Rev. Lett. **88**, 170407 (2002)

[2] Schmidt, R., Negretti, A., Ankerhold, J., Calarco, T. and Stockburger, J.T., arXiv:1010.0940 (2010)

Q 15.84 Mon 16:30 P1

Entanglement of motion with optimal control — •Thomas Stefan Häberle and Matthias Freyberger — Institut für Quantenphysik, Universität Ulm, 89069 Ulm

We discuss two compact particles in a harmonic trap which interact via pointlike collisions. The interaction can be modelled by a δ-potential in the relative coordinate of the particles. Each collision will dynamically entangle the motion of the particles by a certain amount. Therefore, the time evolution of entanglement will show a step-like behaviour. Our aim is to optimize the corresponding von-Neumann-entropy at an arbitrarily fixed time by dynamically varying the trap frequency. Hence we apply a special form of Krotov's method for optimal control problems which guarantees monotone convergence even for non-linear functionals.

Q 15.85 Mon 16:30 P1

Bose-Einstein Condensation and QND Measurements in a Crossed Optical Cavity — •Ralf Kohlhaas[1], Thomas Vanderbruggen[1], Simon Bernon[1], Andrea Bertoldi[1], Philipp Bouyer[1], Arnaud Landragin[2], and Alain Aspect[1] — [1]Laboratoire Charles-Fabry de l'Institut d'Optique, CNRS and Univ. Paris-Sud, Campus Polytechnique, RD 128, F-91127 Palaiseau, FRANCE — [2]LNE-SYRTE, Observatoire de Paris, CNRS, UPMC, 61 avenue de l'Observatoire, 75014 Paris, FRANCE

The atomic shot noise level is a limit for the sensitivity of atom interferometers and can be overcome with the use of non-classical atomic states such as spin squeezed states. In this context, we investigate the generation of such states by quantum non-demolition measurements in a high-finesse optical cavity. Recent progress in the all-optical trapping and evaporation in a crossed optical cavity and a first characterization of the non destructive heterodyne detection scheme is reported.

Q 15.86 Mon 16:30 P1

Entanglement Control via Magnetic Fields in Solid Systems — •Vivian França and Andreas Buchleitner — Physikalisches Institut, Albert-Ludwigs-Universität, Hermann-Herder-Str. 3, Freiburg, Germany

Entanglement, one of the most intriguing characteristics of Quantum Mechanics, is considered an important key in Quantum Information Theory. Among several possible systems, solids are good candidates for the development of devices for quantum information processes. While in condensed matter physics the Hubbard model has been largely used for describing properties of many-body systems, only recently entanglement studies have been performed in the one-dimensional Hubbard model. In homogeneous systems many interesting properties were analised, however previous investigations showed that the inhomogeneities present in real-life systems in general destroy the degree of entanglement in the system [1]. Here we use Density Functional Theory techniques for investigating the impact of spin imbalanced population and external magnetic fields onto the entanglement of inhomogeneous systems. In particular two inhomogeneous systems are investigated: chains with disordered impurities and harmonically confined chains, which can simulate for example cold atoms in optical lattices. Our preliminary results for the confined chains show that, although the degree of entanglement for the homogeneous case can not be recovered, it is possible to increase the entanglement degree by a factor of as much as 5 via the application of magnetic fields.

[1] V. V. França and K. Capelle, Phys. Rev. Lett. 100, 070403 (2008).

Q 15.87 Mon 16:30 P1

Photosynthesis and quantum mechanical transport processes — •Dominic Wörner and Jörg Evers — Max-Planck-Institut für Kernphysik, Heidelberg, Germany

Recent experimental results on quantum effects in photosynthetic units motivate the study of quantum mechanical transport processes, in particular also under the influence of decoherence. Here, we present results on such transport models. In particular, we focus on the evolution of correlations throughout the transport and on possible implementations of biologically relevant transport configurations in light scattering setups accessible in the lab.

Q 15.88 Mon 16:30 P1

Self-focusing and defocusing of twisted light in non-linear media. — •Anita Thakur[1,2] and Jamal Berakdar[2] — [1]Max Planck Institute of Microstructure Physics, Weinberg 2, 06120 Halle(Saale) — [2]Institut für Physik, Martin-Luther Universität Halle-Wittenberg, Heinrich Damerow Str.4, 06120 Halle(Saale), Germany.

We study the self-focusing and defocusing of a light beam carrying angular momentum (called twisted light) propagating in a non-linear medium. We derive a differential equation for the beam width parameter f as a function of the propagation distance, angular frequency, beam waist and intensity of the beam. The method is based on the Wentzel-Kramers-Brillouin and the paraxial approximations. Analytical expressions for f are obtained, analyzed and illustrated for typical experimental situations.

Q 15.89 Mon 16:30 P1

Atom-Photon Entanglement in Cavity QED with a Single Calcium Ion — •Bernardo Casabone[1], Andreas Stute[1], Birgit Brandstätter[1], Diana Habicher[1], Johannes Ghetta[1], Andrew McClung[1], Tracy Northup[1], and Rainer Blatt[1,2] — [1]Institut für Experimentalphysik, Universität Innsbruck, Technikerstraße 25/4, 6020 Innsbruck, Austria — [2]Institut für Quantenoptik und Quanteninformation der Österreichischen Akademie der Wissenschaften, Otto-Hittmair-Platz 1, 6020 Innsbruck, Austria

A cavity QED system for atom-photon entanglement enables efficient collection of entangled photons; such a system could be used in a quantum network to remotely entangle atoms. Here, our progress toward entanglement in an optical cavity with a calcium ion is discussed.

A system consisting of a single trapped $^{40}Ca^+$ ion coupled to the mode of a high-finesse optical resonator is used. Intra-cavity photons are generated in a vacuum-stimulated Raman process between two atomic states driven by a laser and the cavity vacuum field. We have previously implemented a single-photon source on the $4P_{1/2} \leftrightarrow 3D_{3/2}$ transition; we now generate single photons on the $4P_{3/2} \leftrightarrow 3D_{5/2}$ transition. All Zeeman states are resolved in agreement with theoretical simulations. A laser on the narrow $4S_{1/2} \leftrightarrow 3D_{5/2}$ transition permits detection of individual Zeeman states. Coherent state manipulation on this transition enables characterization of an entangled atom-photon state.

We discuss our ion-photon entanglement scheme, including simultaneously driving two vacuum-stimulated Raman transitions.

Q 15.90 Mon 16:30 P1

Classical and quantum radiation reaction effects in intense laser fields — •Omri Har-Shemesh, Antonino Di Piazza, Karen Z. Hatsagortsyan, and Christoph H. Keitel — Max-Planck-Institut für Kernphysik, Saupfercheckweg 1, D-69117 Heidelberg (Germany)

A fundamental problem in classical electrodynamics (CED) is the so-called "radiation reaction" problem: classically, when a charged particle (an electron, for definiteness) is accelerated by an external field, it emits radiation and this emission changes the motion of the electron. In the realm of CED, the so-called Landau-Lifshitz (LL) describes the motion of an electron by including the effects of radiation reaction and it has not yet been tested experimentally. We explore a new regime of parameters in which, as predicted by the LL equation, the influence of radiation reaction on the electromagnetic spectra emitted by the electron is substantial [1]. What is the quantum analog of radiation reaction? In [2] we have answered this question and we have investigated the quantum radiation dominated regime, in which quantum recoil and radiation reaction effects both dominate the dynamics of the electron.

[1] A. Di Piazza, Lett. Math. Phys. **83**, 305 (2008); A. Di Piazza, K. Z. Hatsagortsyan, and C. H. Keitel, Phys. Rev. Lett. **102**, 254802 (2009).
[2] A. Di Piazza, K. Z. Hatsagortsyan, and C. H. Keitel, Phys. Rev. Lett. **105**, 220403 (2010).

Q 15.91 Mon 16:30 P1

Imaging, Addressing and State Detection of Two Ions in an Optical Cavity — •Diana Habicher[1], Andreas Stute[1], Bernardo Casabone[1], Birgit Brandstätter[1], Johannes Ghetta[1], Andrew McClung[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

Entangling two atoms via the mode of an optical cavity is a major goal of cavity quantum electrodynamics. Recent progress towards this goal is presented.

In the experiment, two $^{40}Ca^{+}$ ions are stored in a linear ion trap and coupled to the same mode of a high-finesse optical resonator. In order to evaluate the quantum state of the ions, one must implement state tomography, which requires both state detection and single-ion (addressed) rotations. For the necessary state detection, fluorescence detection methods have been implemented, using both a CCD camera and a PMT. To apply the rotations, a custom objective for a 729nm laser has been installed and single-ion addressing has been characterized. Finally, two possible methods to achieve entanglement are discussed.

Q 15.92 Mon 16:30 P1

Zeta States in Phase Space — •Cornelia Feiler and Wolfgang P. Schleich — Institute for Quantum Physics, Ulm University

In 1859 Bernhard Riemann mentioned in his seminal paper “Ueber die Anzahl der Primzahlen unter einer gegeben Grösse” [1], the by now famous conjecture: *all non-trivial zeros of the zeta function have real part one-half* without giving a proof for it. Although the Riemann hypothesis was studied by many famous mathematicians and lately was attacked by physicists, no rigorous proof exists today.

Our approach towards the Riemann zeta function takes advantage of the time evolution of two interacting quantum systems followed by a joint measurement. The states which reproduce the zeta function in the different parts of the complex plane inherit the properties of the different representations [2] of the zeta function. To understand their behavior we investigate the Wigner functions of these so-called zeta states.

[1] B. Riemann. Monatsbericht der Berliner Akademie, 1859.
[2] E. C. Titchmarsh. *The Theory of the Riemann Zeta-Function*. Oxford, Charlendon Press, 1967.

Q 16: Solid State Photon Sources

Time: Tuesday 10:30–13:00 Location: HSZ 02

Q 16.1 Tue 10:30 HSZ 02

Optical Processes in OLEDs: Molecular Photonics — •Michael Flämmich, Dirk Michaelis, and Norbert Danz — Fraunhofer Institute for Applied Optics and Precision Engineering, 07745 Jena, Germany

Following the OLED display market take-off, huge world wide efforts are spent to develop OLEDs towards competitive sources for general lighting applications. In this context, the light outcoupling problem is well known as the key parameter to improve OLED efficiency in order to tackle existing lighting schemes. From the optical point of view, the device performance is driven (i) by the architecture of the OLEDs layered system and (ii) by the internal features of the emissive material. Studies in recent years have shown that the latter attributes (which are the internal electroluminescence spectrum, the profile of the emission zone, the orientation of the transition dipole moments and the internal luminescence quantum efficiency q) can be determined in situ by measurements of the far-field emission pattern generated by active OLEDs (i.e. in electrical operation) and corresponding optical reverse simulations. Starting from basic considerations of the dipole radiation characteristics, we elaborate specifically how the orientation distribution of the dipole transition moments in the layered system can be analyzed in situ, providing insight into the internal photo-physical processes on the molecular scale of the emitter.

Q 16.2 Tue 11:00 HSZ 02

Single Photon Source with Diamond Nanocrystals on Tapered Optical Fibers — •Almut Tröller[1], Juliane Hermelbracht[1], Markus Weber[1], Wenjamin Rosenfeld[1], Ariane Stiebeiner[3], Arno Rauschenbeutel[3], James Rabeau[4], and Harald Weinfurter[1,2] — [1]Ludwig-Maximilians-Universität, München — [2]Max-Planck-Institut für Quantenoptik, Garching — [3]Johannes-Gutenberg-Universität, Mainz — [4]Macquarie University, Sydney

The development of reliable devices generating single photons is crucial for applications in quantum information as well as for fundamental experiments in quantum optics. Due to its properties the nitrogen-vacancy (NV) color center in diamond is considered a promising candidate for the implementation of such a device. Those properties include an optical transition at 637 nm with a fluorescence lifetime of 11.6 ns, high photostability and the possibility to work at room temperature.

However, the collection efficiency of the fluorescence light in bulk diamond is limited by the high refractive index of diamond. To resolve this issue we use diamond nanocrystals, which – being smaller than the wavelength of the fluorescence light – are not subject to refraction. In order to further enhance the single photon collection efficiency we aim at coupling the emission of a single NV center to the evanescent field of a tapered optical fiber. Here we present data on diamond nanocrystals containing NV centers and the first attempts towards their application to tapered fibers.

Q 16.3 Tue 11:15 HSZ 02

Fiber-integrated diamond-based single photon source — •Tim Schröder, Andreas Wolfgang Schell, Günter Kewes, Thomas Aichele, and Oliver Benson — Nano Optics Group, Institut für Physik, Humboldt-Universität zu Berlin, Newtonstr. 15, 12489 Berlin, Germany

The most direct approach to fabricate a reliable single photon source is to mount a single quantum emitter on an optical fibre. It integrates easily into fibre optic networks for quantum cryptography or quantum metrology applications . For the first time such a fibre-integrated single photon source operating at room temperature is demonstrated. It consists of a single nitrogen vacancy defect centre in a nanodiamond which is directly near-field coupled to the guiding modes of a commercial optical fibre. The coupling is achieved in a bottom-up approach by placing a pre-selected nanodiamond directly on the fibre facet. This configuration is ultra-stable and realignment-free. Its high photon collection efficiency is equivalent to a far-field collection via an objective with a numerical aperture of 0.82. Furthermore, simultaneous excitation of the single defect centre and recollection of its fluorescence light through the fibre is possible introducing a fibre-connected single emitter sensor.

Q 16.4 Tue 11:30 HSZ 02

Near-field infrared spectroscopy of single InAs quantum dots — Rainer Jacob[1], •Stephan Winnerl[1], Harald Schneider[1], Manfred Helm[1], Marc Tobias Wenzel[2], Hans-Georg v. Ribbeck[2], and Lukas M. Eng[2] — [1]Institut für Ionenstrahlphysik und Materialforschung, Helmholtz-Zentrum Dresden-Rossendorf, Postfach 51 01 19, 01314 Dresden, Germany — [2]Institut für Angewandte Photophysik, TU Dresden, George-Bähr-Straße 1, 01069 Dresden, Germany

Scattering-type scanning near-field optical microscopy (s-SNOM) is a versatile technique in optical sciences. It provides optical resolution in the nanometer range, while offering spectroscopic application when combined with a tunable light source. Here, we exploit the combination of a s-SNOM with a widely tunable free-electron laser. With this setup, we were able to perform optical spectroscopy of single InAs quantum dots by means of their near-field signature in the mid infrared. The sample was composed of a single layer of self-assembled InAs quantum dots that were capped by a 70 nm thick GaAs layer. In the s-SNOM-measurements we could obtain a clear near-field contrast between the dots and the surrounding medium at 10.2 um which corresponds to 120 meV. Another clear contrast could be obtained for 85 meV. Both signatures could be attributed to intersublevel transitions in the quantum dot [1]. To our knowledge this is the first time that an optical near-field signature of an intersublevel transition could be demonstrated at a single InAs quantum dot.

[1] P. Boucaud et al., C. R. Physique 9, 840 (2008)

Q 16.5 Tue 11:45 HSZ 02

Quantum-Dot Pyramidal Microcavities as Candidates for Electrically Pumped Efficient Single-Photon Sources — •Daniel Rülke, Christoph Reinheimer, Florian Stockmar, Daniel M. Schaadt, Heinz Kalt, and Michael Hetterich — Institut für Angewandte Physik and DFG Center for Functional Nanostructures, Karlsruhe Institute of Technology (KIT), Wolfgang-Gaede-Straße 1, 76131 Karlsruhe (Germany)

We have investigated InAs-QDs embedded in reversed pyramidal GaAs microcavities in order to fabricate optically and electrically pumped single-photon sources. As a great advantage of the pyramidal shape the total number of QDs inside the cavity can be controlled by the position of the QD layer during molecular-beam epitaxial growth. Thus, by placing the QD layer close to the tip of the reversed pyramid, a very low number of QDs in the cavity can be achieved, while the facets act as a retroreflector for the emitted light. The pyramidal cavities were fabricated by a a combination of e-beam lithography and a selective wet-chemical etching process. In order to pump QDs electrically they have been embedded in the intrinsic layer of a pin-junction and individual cavities have been connected via bridges to a larger contact pad. To this end, a second non-critical e-beam alignment step had to be added after the wet-chemical etching process before metalisation and a subsequent lift-off process.

Q 16.6 Tue 12:00 HSZ 02

Realisation of a robust and compact fibre-coupled diamond based single photon source implemented with gradient-index lenses — •Philip Engel, Tim Schröder, and Oliver Benson — Nano Optics Group, Institut für Physik, Humboldt-Universität zu Berlin, Newtonstr. 15, 12489 Berlin

Single photons play an important role for many quantum information technologies. Quantum cryptography schemes and other experiments with single photons have already been implemented in rather large laboratory setups. To reduce the size and cost and increase the scalability of such experiments we designed a diamond based single photon source which uses gradient-index (GRIN) lenses with integrated thin film filters to collect and couple single photons into a single-mode fibre. GRIN lenses can be fabricated in such a way that a collimated incoming beam has its focal plane overlaying with the surface of the lens where nanodiamonds containing single defect centres can be deposited via spin-coating. In this manner the GRIN lens serves as holder for single photon emitters as well as light collection objective. Furthermore a solid immersion lens like behaviour increases the emission of a dipole into the direction of the GRIN lens. Depending on the defect centre type we expect more than 100 kcts/s of fibre coupled single photons. This high count rate combined with its easy experimental realisation, moderate cost for components and its small dimensions of about 3 mm by 3 mm by 30 mm makes this device interesting for robust and low cost single photon implementations.

Q 16.7 Tue 12:15 HSZ 02

A spintronic circularly-polarized single-photon source — •Andreas Merz, Pablo Asshoff, Robin Schwerdt, Heinz Kalt, and Michael Hetterich — Karlsruhe Institute of Technology (KIT)

Diluted magnetic semiconductors (DMS) are among the most promising materials for efficient spin-injection into semiconductors. They are thus ideal materials for designing a spin-polarized single photon source pumped by an electrical current. As a model system we investigate a spin light-emitting diode with the DMS ZnMnSe and an InGaAs quantum dot as single photon source. With an applied magnetic field of 2 T, a pronounced spin-polarization of $\sim 65\,\%$ is achieved, while at $B = 6\,T$ it even approaches 95 %. Autocorrelation measurements in pulsed operation mode prove the light emitted being non-classical.

Q 16.8 Tue 12:30 HSZ 02

On-demand single photon source in (311)A GaAs quantum dots — •Snežana Lazić, Rudolf Hey, and Paulo Santos — Paul-Drude-Institut für Festkörperelektronik, Hausvogteiplatz 5–7, 10117 Berlin, Germany

We demonstrate the generation of single photons on demand using an acousto-electric effect in GaAs/AlGaAs quantum well (QW) grown by molecular beam epitaxy on pre-patterned (311)A GaAs substrates. In this process, a surface acoustic wave (SAW) is employed to control the transfer of carriers, photogenerated in the QW, to an array of quantum dots (QDs) embedded at well-defined positions within the high-mobility QW transport channel. The embedded QD arrays form during the growth at the edges of etched triangular trenches due to monolayer fluctuations of the QW thickness. The photoluminescence from these acoustically-pumped arrays of QDs consists of a series of sharp lines which are attributed to the recombination of carriers in discrete quantum states. Time-resolved studies show that the population of the emitting states within the array, as well as the subsequent emission of single photons is governed by the SAW. The photons are emitted when the electrons captured within the array recombine with holes brought in a subsequent SAW cycle. The mechanism for the emission of non-classical light from QD arrays was investigated by analyzing the statistics of the emitted photons using the Hanbury Brown and Twiss approach.

Q 16.9 Tue 12:45 HSZ 02

Tunnel Injection in Electrically Pumped Single Photon Emitters — •Alexander Dreismann[1], Murat Öztürk[1], Ole Hitzemann[1], Erik Stock[1], Waldemar Unrau[1], Askhat K. Bakarov[2], Aleksandr I. Toropov[2], Ilia A. Derebezov[2], Vladimir Haisler[2], and Dieter Bimberg[1] — [1]Institut für Festkörperphysik, TU-Berlin, 10623 Berlin, Germany — [2]Institute of Semiconductor Physics, 630090 Novosibirsk, Russia

Electrically pumped InGaAs/GaAs quantum dot (QD) based Resonant-Cavity LEDs (RC-LEDs) represent powerful semiconductor based single photon and potential entangled photon emitters with high out-coupling efficiencies as required for quantum key distribution [1]. To achieve high photon emission rates the exciton luminescence intensity should be as high as possible; in the case of entangled photon sources exciton and biexciton luminescence intensities should be comparable.

To optimize the operation of our RC-LED in this regard we investigate the dependence of the luminescence intensity on the applied bias as well as on the temperature. We observe resonant tunneling injection of charge carriers into the QDs before the flat band condition of the diode structure is reached [2]. The influence of the dark state of the exciton on the luminescence is studied by comparing experimental data with a rate equation model. This work was partly funded by the SFB 787.

[1] D. Bimberg et. al., IEEE Photonics Journal, 1, 58 (2009)
[2] A. Baumgartner et. al., Phys. Rev. Lett. accepted (2010)

Q 17: Fermi Quantum Gas

Time: Tuesday 10:30–12:45 Location: BAR Schön

Q 17.1 Tue 10:30 BAR Schön

Exploring Many-Body Interaction in a Strongly Interacting ^{6}Li-^{40}K Fermi-Fermi Mixture — •Christoph Kohstall[1,2], Andreas Trenkwalder[1], Matteo Zaccanti[1], Devang Naik[1], Andrei Sidorov[3], Florian Schreck[1], and Rudolf Grimm[1,2] — [1]Institut für Quantenoptik und Quanteninformation, Österreichische Akademie der Wissenschaften, Innsbruck, Austria — [2]Institut für Experimentalphysik und Zentrum für Quantenphysik, Universität Innsbruck, Innsbruck, Austria — [3]Swinburne University of Technology, Melbourne, Australia

We have realized the first strongly interacting ^{6}Li-^{40}K Fermi-Fermi mixture by means of an interspecies Feshbach resonance. Measurements on the expansion of this resonantly interacting Fermi-Fermi mixture reveal its collisionally hydrodynamic behavior [1]. In present experiments, we explore the many-body interaction by determining the interaction energy, which we extract from expansion measurements and from radio frequency spectroscopy. These studies will shed light on the formation dynamics of polarons or pseudo-gap pairs in the strongly interacting regime. An intriguing prospect is to individually control the optical potentials of the two components, opening the new possibility to investigate systems with selectively adjusted Fermi surfaces or with mixed dimensionality.

[1] A. Trenkwalder et al., arXiv:1011.5192 (2010).

Q 17.2 Tue 10:45 BAR Schön

Deterministic preparation and control of a few-fermion system — •Gerhard Zürn[1,2], Thomas Lompe[1,2,3], Timo Ottenstein[1,2,3], Martin Ries[1,2], Friedhelm Serwane[1,2,3], Andre Wenz[1,2], and Selim Jochim[1,2,3] — [1]Physikalisches Institut, Universität Heidelberg — [2]MPI für Kernphysik, Heidelberg — [3]ExtreMe Matter Institute EMMI, GSI, Darmstadt

Systems composed of only few interacting fermions are common in nature. The most prominent examples are atoms and nuclei. However, these systems have limited tunability. In contrast microscopic quantum systems consisting of ultracold atoms can provide tunable artificial atoms if they can be prepared in well defined quantum states. To prepare such systems we load a micrometer-sized trap from a shallow optical dipole trap containing a two-component degenerate Fermi gas. To control the number of atoms in the microtrap we spill the excess atoms from the upper levels of the microtrap potential by applying a magnetic field gradient. Using this technique, we have prepared ground state samples of one to ten atoms with fidelities of $\sim 90\%$. Due to the tunability of the interaction strength our system is suited for quantum simulation with fully controlled few-body systems.

Q 17.3 Tue 11:00 BAR Schön

Local observation of density and fluctuations in a trapped Fermi gas — •David Stadler[1], Torben Müller[1], Bruno Zimmermann[1], Jakob Meineke[1], Jean-Philippe Brantut[1], Henning Moritz[2], and Tilman Esslinger[1] — [1]Institut für Quantenelektronik, ETH Zürich, Schweiz — [2]Institut für Laser-Physik, Universität Hamburg, Deutschland

We present in-situ observations of density and density fluctuations in a two-component Fermi gas of Lithium atoms.

These observations are performed in an apparatus, which features two microscope objectives, allowing high-resolution (about 1 micrometer) in-situ optical detection of the cloud. By measuring the number of atoms in small regions of the cloud on many realisations of the experiment, we locally measure the mean and the variance of the atomic density. For a non-degenerate, weakly interacting gas, we observe density fluctuations proportional to the mean cloud density (atomic shot-noise), in agreement with classical statistics. In a degenerate, weakly interacting fermi gas, we observe a strong reduction of density fluctuations compared to the classical limit. This represents a direct manifestation of Fermi-Dirac statistics, complementary to the Hanbury-Brown and Twiss observations performed with cold atoms after time-of-flight.

In addition we present an interferometric detection scheme that allows to extend fluctuation measurements to the magnetic properties of a two-component Fermi gas.

Q 17.4 Tue 11:15 BAR Schön

Impurities in a 2D Fermi Gas — •Sascha Zöllner[1], Georg M. Bruun[2], and Christopher J. Pethick[1] — [1]Niels Bohr Institute, Copenhagen, Denmark — [2]Aarhus University, Aarhus, Denmark

We study an impurity atom in a two-dimensional (2D) Fermi gas using variational wave functions for (i) an impurity dressed by particle-hole excitations (a so-called polaron) and (ii) a dimer consisting of the impurity and a majority atom. In contrast to 3D, where similar calculations predict a sharp transition to a dimer state with increasing interspecies attraction, the 2D polaron ansatz always gives a lower energy. However, the exact solution for a heavy impurity reveals that both a two-body bound state and distortions of the Fermi sea are crucial. This reflects the importance of particle-hole pairs in lower dimensions and makes simple variational calculations unreliable. Moreover, we show that the energy of an impurity gives important information about its dressing cloud, and what can be learned about the more general case of many (fermionic or bosonic) impurities.

Q 17.5 Tue 11:30 BAR Schön

The density profile of interacting Fermions in a one-dimensional optical trap — Stefan Söffing and •Sebastian Eggert — Fachbereich Physik und Research Center OPTIMAS, Univ. Kaiserslautern, Germany

The density distribution of the Hubbard model in a one-dimensional external harmonic potential is investigated in order to study the effect of the confining trap. The broadening of the Fermion cloud with increasing interaction is analyzed in detailed, which can be described by a surprisingly simple scaling form. Strong superimposed "Friedel" oscillations are always present despite the absence of any hard wall boundaries. The wavelength of the dominant oscillation changes with interaction, which indicates the crossover to a spin-incoherent regime. We present an analytical formula, which describes the behavior of the oscillations very well for all interactions strengths and in return gives some insight for the use of bosonization in a trapping potential.

Q 17.6 Tue 11:45 BAR Schön

Double-degenerate Bose-Fermi mixture of strontium — •Simon Stellmer[1,2], Meng Khoon Tey[1], Mark Parigger[1,2], Rudolf Grimm[1,2], and Florian Schreck[1] — [1]Institut für Quantenoptik und Quanteninformation, 6020 Innsbruck, Austria — [2]Institut für Experimentalphysik und Zentrum für Quantenphysik, Universität Innsbruck, 6020 Innsbruck, Austria

We report on the achievement of a double-degenerate Bose-Fermi mixture of strontium. A sample of fermionic ^{87}Sr atoms is spin-polarized and sympathetically cooled by interisotope collisions with the bosonic isotope ^{84}Sr. At the end of evaporation, 2×10^4 ^{87}Sr atoms at a degeneracy of $T/T_F = 0.30(5)$ co-exist with a BEC of ^{84}Sr. Fermions with two valence electrons have a rich electronic structure, which comprises metastable states, narrow intercombination lines, and a nuclear spin that can be as large as 9/2 in ^{87}Sr. These properties are at the heart of recent proposals for quantum simulation, especially the study of $SU(N)$ magnetism. Loading the fermions into a lattice is the next step towards the realization of such systems. Furthermore, we report on BEC of ^{86}Sr with an unusually large scattering length of $\sim 800\, a_0$.

Q 17.7 Tue 12:00 BAR Schön

Radio-Frequency Association of Efimov Trimers — •Thomas Lompe[1,2,3], Timo Ottenstein[1,2,3], Friedhelm Serwane[1,2,3], Andre Wenz[1,2], Gerhard Zürn[1,2] und Selim Jochim[1,2,3] — [1]Physikalisches Institut, Ruprecht-Karls-Universität Heidelberg, Germany — [2]Max-Planck-Institut für Kernphysik, Saupfercheckweg 1, 69117 Heidelberg, Germany — [3]ExtreMe Matter Institute EMMI, GSI Helmholtzzentrum für Schwerionenforschung, Darmstadt, Germany

Since the first signatures of Efimov states were found in the rate of inelastic collisions of an ultracold atomic gas, such systems have been used to study Efimov physics with great success. However, until recently experiments have been limited to observations of the crossings of Efimov states with the continuum. In this talk we report on the first direct observation of an Efimov state with RF association spectroscopy. We have measured the binding energy of this Efimov state as a function of interaction strength and found good agreement with theoretical predictions. This work opens the door for both precision studies and coherent manipulation of Efimov trimers.

Q 17.8 Tue 12:15 BAR Schön

Loschmidt Echo of a Trapped Fermi Gas — •Thomas Fogarty[1], Thomas Busch[1], and John Goold[2] — [1]Physics Department, University College Cork, Ireland — [2]Department of Atomic & Laser Physics, Clarendon Laboratory, University of Oxford

The process of decoherence in quantum systems is an substantial area of study with implications for quantum computing. This importance has led to a rich area of study that encompasses decoherence in spin environments. It has been shown that the coherence of a qubit coupled to an environment directly influences the entanglement of the qubit with the environment and can result in quantum phase transitions. Here we study the decoherence of a one dimensional Fermi gas in a harmonic trap undergoing a sudden perturbation. The decoherence is studied by calculating the Loschmidt echo which is the overlap of the initial state evolving according to two different hamiltonians, one with and one without the perturbation. We show that revivals of the coherence occur based on the trap frequency of the harmonic oscillator and that the decoherence is directly influenced by the Anderson orthogonality catastrophe. Anderson proved that the overlap of two many body ground states tends to zero as the number of fermions are increased and here we provide detailed analysis of the catastrophe and derive a perturbative scheme which holds for a small perturbation.

Q 17.9 Tue 12:30 BAR Schön

Far-From-Equilibrium Dynamics of Ultracold Fermi Gases — •Matthias Kronenwett[1,2], Sebastian Bock[1,2], and Thomas Gasenzer[1,2] — [1]Institut für theoretische Physik, Philosophenweg 16, 69120 Heidelberg — [2]ExtreMe Matter Institute EMMI, GSI Helmholtzzentrum für Schwerionenforschung GmbH, Planckstr. 1, 64291 Darmstadt

Equilibration of an isolated Fermi gas in one spatial dimension after an interaction quench is studied. Evaluating Kadanoff-Baym dynamic equations for correlation functions obtained from the two-particle-irreducible effective action in nonperturbative approximation, the gas is seen to evolve to states characterized by thermal as well as nonthermal momentum distributions, depending on the assumed initial conditions. At sufficiently low total energies a violation of the fluctuation-dissipation relation in the tail of the Fermi-Dirac distribution indicates equilibration to a nonthermal state.

Q 18: Ultra-cold atoms, ions and BEC II

Time: Tuesday 10:30–12:45 Location: BAR 106

Q 18.1 Tue 10:30 BAR 106

Feshbach resonances of harmonically trapped atoms — •Philipp-Immanuel Schneider, Yulian V. Vanne, and Alejandro Saenz — AG Moderne Optik, Humboldt-Universität zu Berlin, Newtonstraße 15, 12489 Berlin

Confined ultracold atoms with their interaction controlled by a magnetic Feshbach resonance (MFR) have vast and intriguing applications e.g. for studying new phases of matter, performing quantum information processing, or simulating condensed matter Hamiltonians. Employing a short-range two-channel description we derive an analytic model of atoms in isotropic and anisotropic harmonic traps at an MFR. On this basis we obtain an analytic expression for the admixture of the resonant bound state and a parameterization of the energy-dependent scattering length which differs from the one previously employed [1]. We validate the model by comparison to full numerical calculations for ^{6}Li-^{87}Rb and explain quantitatively the experimental observation of a resonance shift of trapped gases and of trap-induced molecules in exited bands and band gaps of an optical lattice.

[1] Z. Idziaszek and T. Calarco, Phys.Rev.A **74**, 022712 (2006).

[2] P.-I. Schneider, Y. V. Vanne, and A. Saenz, eprint arXiv:1005.5306

Q 18.2 Tue 10:45 BAR 106

an electron-ion crystal in a linear Paul trap — •Weibin Li and Igor Lesanovsky — School of Physics and Astronomy, The University of Nottingham, Nottingham NG7 2RD, UK

Trapping of charged particles has undergone significant advancements in the past decades. Today ions can be controlled with extreme precision in various traps at the quantum level. This has attracted enormous attentions, due to a broad variety of possible applications, for example, in precisions measurements and quantum computation. Traditional ion traps can confine either positively or negatively charged particles while the opposite charge is repelled. We demonstrate that a single electron can be trapped in the centre of a metastable doubly charged ion crystal in a linear Paul trap. A uniform magnetic field is applied in the axial direction, which tightly confines electron in the radial directions, and stabilises the system. At equilibrium, the system is approximated by coupled harmonic oscillators. We discuss the stability properties and the dynamics of the system. Our study illuminates possibilities for coherently manipulating oppositely charged particles simultaneously in linear Paul traps. This has the potential to highlight new perspectives for quantum simulators that use electrons as fundamental constituents and thus are of fundamental interest in condensed matter physics.

Q 18.3 Tue 11:00 BAR 106

Influence of reduced dimensionality on ultracold atoms — •Simon Sala[1,2] and Alejandro Saenz[1] — [1]Institut für Physik, Humboldt-Universität zu Berlin, Newtonstr. 15, 12489 Berlin — [2]Kirchhoff-Institut für Physik, Ruprecht-Karls Universität Heidelberg, Im Neuenheimer Feld 227, 69120 Heidelberg

Low-dimensional systems of ultracold atoms show unique quantum signatures which are not present in the three dimensional case. Two topical examples in the quasi 1D regime are the fermionization of Bosons, i.e. strongly repulsive Bosons acquire fermionic properties, and the appearance of a confinement-induced resonance (CIR)[1]. Recently both effects were experimentally observed [2,3]. Quasi one-dimensional systems are realized by a tight confinement in two spatial directions freezing out two degrees of freedom. We present a theoretical treatment of two atoms in quasi one-dimensional traps using a full six-dimensional exact diagonalization technique [4]. Coupling effects due to anharmonicity of the trapping potential and the resulting effects on a CIR are investigated. Especially the experimental observed [3] splitting of CIR positions in completely anisotropic traps is an open question we try to answer.

[1] M. Olshanii, Phys. Rev. Lett. **81**, 938 (1998)

[2] B. Paredes et al., Nature **429**, 277 (2004)

[3] Haller et al., Phys. Rev. Lett. **104**, 153202 (2010)

[4] S. Grishkevich, A. Saenz, Phys. Rev. A **80**, 013403 (2009)

Q 18.4 Tue 11:15 BAR 106

Single Cs Atoms Interacting with an Ultracold Rb Gas — •Nicolas Spethmann[1], Shincy John[1], Farina Kindermann[1], Amir Moqanaki[1], Claudia Weber[1], Dieter Meschede[1], and Artur Widera[2,1] — [1]Institut für Angewandte Physik, Wegelerstr. 8, 53115 Bonn — [2]Technische Universität Kaiserslautern, Fachbereich Physik, Erwin-Schrödinger-Str., 67663 Kaiserslautern

We immerse single Cs atoms into a many body systems consisting of cold and ultracold Rb gases in order to use the single Cs atom as a sensitive probe for inter-species interaction and as an agent to manipulate the quantum gas.

In order to study ground state collisions between a single Cs atom and a quantum degenerate Rb gas we have developed techniques to combine a quantum gas with a single trapped neutral atom. For this purpose, an optically trapped Rb BEC is prepared in the magnetic field insensitive $F = 1$, $m_F = 0$ state. Then single Cs atoms are loaded into a superimposed 1D-lattice, which exerts a strong potential for Cs atoms and a weak potential for Rb. At ultralow temperatures and with negligible scattering of photons, ground state collions between the single atom and the quantum gas determine the interaction. This enables (coherent) probing and manipulation of the BEC by the single atom. We will report on the ground state interactions between single Cs atoms and a quantum gas and our recent progress controlling the single atom inside the quantum gas.

Q 18.5 Tue 11:30 BAR 106

Probing an ultracold atomic crystal with matter waves — Bryce Gadway, Daniel Pertot, Jeremy Reeves, and •Dominik Schneble — Department of Physics & Astronomy, Stony Brook University, Stony Brook, NY 11794, USA

We explore the scattering of matter waves from ultracold atoms held in an optical lattice. By “shining” a one-dimensional Bose gas onto an atomic Mott insulator (target), we observe Bragg diffraction peaks that reveal the target’s crystalline structure. We find a systematic dependence of the Bragg intensity on the degree of atom localization, and recover a transition to coherent momentum and energy exchange (“Newton’s cradle”) in the limit of free target atoms. Neutral-atom diffraction can serve as a novel experimental technique for probing atomic many-body systems.

Q 18.6 Tue 11:45 BAR 106

Correlated phases of bosons in tilted, frustrated lattices — •Susanne Pielawa, Takuya Kitagawa, Erez Berg, and Subir Sachdev — Physics Department, Harvard University, Cambridge, MA 02138, USA

The search for correlated quantum phases of cold atoms in optical lattices has focused mainly on entangling the spin degrees of freedom on different lattice sites. We show that there are also rich possibilities for correlated phases in the density sector, and these are likely to be readily accessible by tilting Mott insulators into metastable states. It has been previously shown that a Mott insulator in a potential gradient undergoes an Ising quantum phase transition when the potential drop per lattice spacing is close to the repulsive interaction energy [1]. Here we theoretically study bosons in tilted, frustrated, two-dimensional lattices. The phases we find include phases with charge density order, a sliding Luttinger liquid phase, and a liquid-like ground state with no broken lattice symmetry.

[1] S. Sachdev, K. Sengupta, and S. M. Girvin, Phys. Rev. B 66, 075128 (2002).

Q 18.7 Tue 12:00 BAR 106

Injection locking of a trapped-ion phonon laser - the detection of ultraweak forces — •Sebastian Knünz[1], Maximilian Herrmann[1], Valentin Batteiger[1], Guido Saathoff[1], Kerry Vahala[2], Theodor W. Hänsch[1], and Thomas Udem[1] — [1]MPQ, Garching, Germany — [2]Caltec, Pasadena, USA

A single trapped ion, addressed by both a red-detuned cooling laser and a blue-detuned pump laser can exhibit stable oscillatory motion with a well defined threshold. We have shown that this oscillation is the result of stimulated emission of center-of-mass phonons, providing saturable amplification of the motion. We show that the dynamics of this "phonon laser" are surprisingly sensitive to external fields; we demonstrate phase synchronization ("injection locking") to an external signal by applying forces as weak as 5 yN (yocto=10^{-24}). This enormous sensitivity might allow the detection of the nuclear spin of a single atom or molecule.

Q 18.8 Tue 12:15 BAR 106

Nucleation of solitons in a quasi-1D Bose-Einstein condensate: the Kibble-Zurek mechanism — •Gor Nikoghosyan, Adolfo del Campo, Alex Retzker, and Martin Plenio — Institut für Theoretische Physik, Albert-Einstein Allee 11, Universität Ulm, D-89069 Ulm

Finite-rate cooling of a quasi-1D thermal atomic cloud leads to the spontaneous nucleation of solitons during Bose-Einstein condensation (BEC). We study whether the dynamics of the transition can be described in terms of equilibrium properties using the Kibble-Zurek mechanism (KZM), and simulate the process within the stochastic Gross-Pitaevskii equation. We propose a novel method to detect the density of solitons in a quasi-1D BEC. This method is based on the measurement of the second order correlation function which enables the detection of solitons without knowing their location. The dependence of the density of solitons on the cooling rate of the atomic cloud for realistic experimental conditions is numerically analyzed, and agrees with the KZM only when this is extended to account for the inhomogeneous nature of the condensation arising from the external trapping potential.

Q 18.9 Tue 12:30 BAR 106

Propagation of a wave-packet in a nonlinear and disordered medium in two dimensions — •Georg Schwiete[1] and Alexander Finkelstein[2] — [1]Dahlem Center for Complex Quantum Systems, Freie Universität Berlin, Germany — [2]Texas A&M University, College Station, USA

We develop an effective theory of wave-packet propagation in a nonlinear and disordered medium. The theory is formulated in terms of a nonlinear diffusion equation. Despite its apparent simplicity this equation describes novel phenomena which we refer to as "locked explosion" and "diffusive" collapse. The equation can be applied to such distinct physical systems as laser beams propagating in disordered photonic crystals or Bose-Einstein condensates expanding in a disordered environment.

Q 19: Quantum Gases: Miscellaneous

Time: Tuesday 10:30–13:00 Location: HÜL 386

Q 19.1 Tue 10:30 HÜL 386

Interacting ultracold bosons in optical lattices: Scattering and decoherence — •Hannah Venzl[1], Stefan Hunn[1], Scott Sanders[1], Tobias Zech[1], Lewin Stein[1,2], Florian Mintert[3], Moritz Hiller[1], and Andreas Buchleitner[1] — [1]Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, Hermann-Herder-Str. 3, 79104 Freiburg — [2]Technische Universität Berlin, Hardenbergstr. 36, 10623 Berlin — [3]Freiburg Institute for Advanced Studies (FRIAS), Albert-Ludwigs-Universität Freiburg, Albertstraße 19, 79104 Freiburg

Ultracold bosons in optical lattices provide a versatile testing ground to investigate complex quantum phenomena. In this talk, we address the implications of the inter-particle interactions from two complementary perspectives: On the one hand, we devise a matter-wave scattering approach and probe the system via the inelastic scattering cross section. Within the first-order Born approximation, we reveal unambigous traces of the Mott-insulator to superfluid phase transition. Beyond these ground-state properties, also the excitation spectrum of a BEC is probed. In the parameter regime where the interactions induce chaotic spectral statistics, we observe universal Ericson fluctuations with characteristic features rooted in the underlying mean-field equations.

On the other hand, we investigate how the spectral properties are reflected in the system’s dynamics: We find that the interactions lead to decoherence, which results in a fast and irreversible decay of Bloch oscillations, and obtain the corresponding decay rate from the local density of states.

Q 19.2 Tue 11:00 HÜL 386

Modulation of polariton condensates with acoustic periodic potentials — •Edgar Cerda[1], Dmitryi Krizhanovskii[2], Klaus Biermann[1], Michiel Wouters[3], Rudolf Hey[1], Paulo Santos[1], and Maurice Skolnick[2] — [1]Paul-Drude-Institut Berlin, Hausvogteiplatz 5-7, 10117 Berlin, Germany — [2]University of Sheffield, Sheffield S3 7RH, United Kingdom — [3]Ecole Polytechnique Fédérale de Lausanne, 1015 Lausanne, Switzerland

Exciton-polaritons are particles formed by the strong coupling between light and excitons in a semiconductor microcavity with embedded quantum wells (QWs). Being composite bosons in the dilute limite with very low mass, they are prone to condensation. In this work, we use surface acoustic waves (SAWs) propagating in a microcavity structure with QWs to create a periodic potential for polaritons by modulating the cavity thickness and the QW energy band gap. The modulation is realised with a SAW of wavelength $\lambda_{SAW} = 8\mu m$ propagating along a non-piezoelectric direction ([100]) of a (001)-GaAs microcavity. We investigate the effects of SAWs on the spatial coherence properties of exciton-polariton condensates. By increasing the applied power, the SAW modulation reduces the coherence length L_y in a controlled manner until the extended state is fragmented into weakly interacting wires confined at the valleys of the SAW wavefronts with width equal to $L_y = \lambda_{SAW}/2 = 4\mu m$. The decrease of L_y is understood in terms of the reduction of the tunneling coupling between adjacent wires and in the case of OPO, also by the spatial modulation of the pump.

Q 19.3 Tue 11:15 HÜL 386

Many-Body Effects on the Frustrated Diamond Chain — •Leonardo Mazza and Matteo Rizzi — Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Str. 1, 85748 Garching, Deutschland

We study the Bose-Hubbard model on a quasi-1D periodic structure of rhombi embedded in a homogeneous magnetic field, i.e. the so-called fully-frustrated Diamond Chain. The system is characterized by flat single-particle dispersion relations, i.e. by localization in the absence of disorder. Conversely, interactions tend to induce delocalization effects preserving on-site parity [Douçot and Vidal, Phys.Rev.Lett. 88,227005(2002)]. The phase diagram of the many-body problem is investigated by means of analytical and numerical approaches and it displays unconventional uncompressible phases, Bose glass and pairs quasi-condensate.

Q 19.4 Tue 11:30 HÜL 386

A single fermion in a Bose Josephson Junction — •Maximilian Rinck and Christoph Bruder — Deptartement Physik der Universität Basel, Klingelbergstr. 82, 4056 Basel, Schweiz

We consider the tunneling properties of a single fermionic impurity immersed in a Bose–Einstein condensate in a double-well potential. For strong boson–fermion interaction, we show the existence of a tunnel resonance where a large number of bosons and the fermion tunnel simultaneously. We give analytical expressions for the lineshape of the resonance using degenerate Brillouin–Wigner theory. We finally compute the time-dependent dynamics of the mixture. Using the fermionic tunnel resonances as beam splitter for wave-functions, we construct a Mach–Zehnder interferometer that allows complete population transfer from one well to the other by tilting the double-well potential and only taking into account the fermion's tunnel properties.

Q 19.5 Tue 11:45 HÜL 386

Nonclassical States of Matter generated by Parametric Amplification in a Spinor BEC — •Manuel Scherer[1], Bernd Lücke[1], Jan Peise[1], Jens Kruse[1], Oliver Topic[1], Frank Deuretzbacher[2], Wolfgang Ertmer[1], Luis Santos[2], Jan Arlt[3], and Carsten Klempt[1] — [1]Institut für Quantenoptik, Leibniz Universität Hannover — [2]Institut für Theoretische Physik, Leibniz Universität Hannover — [3]QUANTOP, Department of Physics and Astronomy, University of Aarhus

The two-mode Optical Parametric Amplifier is the standard tool in optics to realize number and phase squeezing in relative observables. We have shown that the spin dynamics in a Bose-Einstein condensate (BEC) with a spin degree of freedom can provide a two-mode parametric amplification of matter waves. At first, we report on the effects of phase sum squeezing on the spontaneous creation of spin patterns. Furthermore, the created matter waves show ultralow fluctuations in the relative atom number. We observe a variance of up to 8 dB below the shot noise limit at a total particle number of more than 10^4 atoms. By coupling the two created clouds via microwave pulses, we construct a beam splitter for these non-classical matter waves. We report on super-Poissonian fluctuations after the beam splitter, in agreement with the large fluctuations of the conjugate variable.
In the future, a second beam splitter will allow for closing the nonclassical interferometer with the prospect of a Heisenberg limited sensitivity.

Q 19.6 Tue 12:00 HÜL 386

Process-chain approach applied to the Bose-Hubbard model — •Dennis Hinrichs, Niklas Teichmann, and Martin Holthaus — Institut für Physik, Carl von Ossietzky Universität Oldenburg, 26111 Oldenburg

The process-chain approach is a powerful tool for carrying out perturbative calculations on many-body lattice systems in high order. In combination with the method of the effective potential, this technique permits us to determine the phase boundary marking the superfluid to Mott-insulator quantum phase transition for various lattice types with high accuracy [1]. Moreover, it will be shown that it also gives access to the superfluid density, and to critical exponents.

[1] N. Teichmann, D. Hinrichs, M. Holthaus, EPL 91, 10004 (2010)

Q 19.7 Tue 12:15 HÜL 386

Comparison of stochastic techniques for finite temperature Bose gases — Stuart Cockburn[1], •Antonio Negretti[2], Nikolaos Proukakis[1], and Carsten Henkel[3] — [1]School of Mathematics and Statistics, University of Newcastle upon Tyne, Newcastle upon Tyne, NE1 7RU, United Kingdom — [2]Institut für Quanteninformationsverarbeitung, Universität Ulm, Albert- Einstein-Allee 11, 89069 Ulm, Germany — [3]Institut für Physik und Astronomie, Universität Potsdam, Karl-Liebknecht-Str. 24-25, 14476 Potsdam, Germany

In this talk we analyze two stochastic approaches for describing weakly interacting, trapped quasi-one-dimensional Bose gases at finite temperatures: a number-conserving Bogoliubov (ncB) approach and a stochastic Gross-Pitaevskii equation (sGPe). Density profiles, correlation functions, and the condensate statistics are compared to predictions based upon alternative theories. Although the two stochastic methods are built on different thermodynamic ensembles (ncB: canonical, sGPe:grand-canonical), they yield the correct condensate statistics in a large BEC (strong enough particle interactions). For smaller systems, the sGPe results are prone to anomalously large number fluctuations, well-known for the grand-canonical, ideal Bose gas, whereas the ncB approach, due to thermal phase fluctuations, loses its validity at relatively low temperatures.

Q 19.8 Tue 12:30 HÜL 386

Non-abelian Gauge-field simulators with cold atoms — •Torben Schulze[1], Naceur Gaaloul[1], Holger Ahlers[1], Sebastian Bode[1], Felix Kösel[1], Vyacheslav Lebedev[1], Wolfgang Ertmer[1], Luis Santos[2], and Ernst Rasel[1] — [1]Institut für Quantenoptik, LU Hannover — [2]Institut für Theoretische Physik, LU Hannover

The study of strongly correlated regimes using cold-atom systems is a long-standing challenge for physicists. The charge neutrality of the atoms and the consequent absence of a Lorentz force are strong limitations to this end. The experimental realization of rotating degenerate quantum gases demonstrated the potential of atomic systems to simulate charged particles subject to a uniform magnetic field. However, due to centrifugal forces and technical issues this method turned out to be of limited use. Recently, several proposals showed that preparing coherent superpositions of Zeeman sub-states of atoms which evolve adiabatically in a laser field could drive the matter wave to acquire a Berry phase. This phase translates into a non-vanishing synthetic magnetic field which could be used to engineer a Lorentz force-like for atoms. We present a practical scheme where atomic populations of a degenerate spinor system are driven by appropriate laser arrangements leading to the appearance of gauge field structures. The use of realistic parameters and atomic spectral data make of this method a receipt to implement quantum simulators of gauge fields including the general class of non-abelian (non-commutative) gauges, so far never observed for atoms.

Q 19.9 Tue 12:45 HÜL 386

Strong-field-QED analogue on the lattice — Ralf Schützhold and •Nikodem Szpak — Fakultät für Physik, Universität Duisburg-Essen

We present a model describing cold atoms in an optical lattice which is capable of showing phenomena known from the strong field QED, like the Schwinger effect or adiabatic spontaneous pair creation. This requires re-derivation of an effective Fermi-Hubbard Hamiltonian from first principles. The main advantage of this analogue model is experimental accessibility of the strong field regime in contrast to the real QED.

Q 20: Quantum Information: Concepts and Methods 3

Time: Tuesday 10:30–13:00 Location: SCH A118

Q 20.1 Tue 10:30 SCH A118

Experimental investigation of the uncertainty principle using entangled photons — •Robert Prevedel[1], Deny Hamel[1], Roger Colbeck[2], Kent Fisher[1], and Kevin Resch[1] — [1]Institute for Quantum Computing, University of Waterloo, Waterloo, N2L 3G1, ON, Canada — [2]Perimeter Institute for Theoretical Physics, 31 Caroline Street North, Waterloo, Ontario N2L 2Y5, Canada

The uncertainty principle, first formulated by Heisenberg provides a fundamental limitation on an observer's ability to simultaneously predict the outcome when one of two measurements is performed on a quantum system. However, if the observer has access to a particle which is entangled with the system, his uncertainty is generally reduced: indeed, if the particle and system are maximally entangled, the observer can predict the outcome of both measurements precisely. This effect has recently been quantified by Berta et al. in a new, more general uncertainty relation. Here we perform experiments to probe the validity of this new inequality using entangled photon pairs. The behavior we find agrees with the predictions of quantum theory, satisfying the new uncertainty relation. An optical delay line that serves as a quantum memory, in combination with fast feed-forward allows an observer to gain more information and hence lower uncertainty about the outcome of an measurement than would be possible without the entanglement. This shows not only that the reduction in uncertainty caused by entanglement can be significant in practice, but also demonstrates the use of the inequality to witness entanglement.

Q 20.2 Tue 10:45 SCH A118

Reconstructing CV-Quantum Optical States by Compressed Sensing — •Vincent Nesme[1], Matthias Ohliger[1], David Gross[2], and Jens Eisert[1] — [1]Universität Potsdam, Institut für Physik und Astronomie (Haus 28) Karl-Liebknecht-Strasse 24/25 14476 Potsdam, Germany — [2]ETH Zürich, Theoretische Physik, Wolfgang-Pauli-Strasse 27, 8093 Zürich, Switzerland

The reconstruction of quantum states from measurement results is a challenging task both on the experimentalist and on the post-processing side. In recent work, compressed sensing has been used to reduce the number of measurements needed to reconstruct a state with rank r in a n-dimensional Hilbert space from $O(n^2)$ to $O(rn \log n)$ where the post-processing can be done efficiently with the help of semidefinite programming. We extend this result to tackle the reconstruction of a continuous-variable (CV) state of a quantum optical system. We discuss the recovery of the Wigner function both from homodyne-measurement and photon-counting and also address the question of resistance to noise.

Q 20.3 Tue 11:00 SCH A118

Taming multiparticle entanglement — •Bastian Jungnitsch[1], Tobias Moroder[1], and Otfried Gühne[1,2] — [1]Institut für Quantenoptik und Quanteninformation, Österreichische Akademie der Wissenschaften, Technikerstraße 21a, A-6020 Innsbruck, Austria — [2]Fachbereich Physik, Universität Siegen, Walter-Flex-Straße 3, D-57068 Siegen, Germany

Current experiments have succeeded in manipulating up to fourteen qubits [1], moving tasks like measurement-based quantum computation closer to the realm of possibility.

We present an approach to characterize genuine multiparticle entanglement using appropriate approximations in the space of quantum states [2]. This leads to a criterion for entanglement which can easily be calculated using semidefinite programming and improves all existing approaches significantly. Experimentally, it can also be evaluated when only some observables are measured. Furthermore, it results in a computable entanglement monotone for genuine multiparticle entanglement which reduces to the negativity in the bipartite case.

Based on this criterion, we develop an analytical approach for the entanglement detection in graph states. When specialized to, e.g., linear cluster states, this approach leads to witnesses whose white noise robustnesses approach unity exponentially fast with an increasing number of qubits.

[1] T. Monz et al., arXiv:1009.6126
[2] B. Jungnitsch, T. Moroder and O. Gühne, arXiv: 1010.6049

Q 20.4 Tue 11:15 SCH A118

Measuring entanglement in condensed matter systems — •Marcus Cramer[1], Martin Plenio[1,2], and Harald Wunderlich[1] — [1]Institut für Theoretische Physik, Universität Ulm, Germany — [2]QUOLS, Imperial College London, UK

We show how entanglement may be quantified in spin and cold atom many-body systems using standard experimental techniques only. The scheme requires no assumptions on the state in the laboratory and a lower bound to the entanglement can be read off directly from the scattering cross section of Neutrons deflected from solid state samples or the time-of-flight distribution of cold atoms in optical lattices, respectively. This removes a major obstacle which so far has prevented the direct and quantitative experimental study of genuine quantum correlations in many-body systems: The need for a full characterisation of the state to quantify the entanglement contained in it. Instead, the scheme presented here relies solely on global measurements that are routinely performed and is versatile enough to accommodate systems and measurements different from the ones we exemplify in this work.

Q 20.5 Tue 11:30 SCH A118

Entanglement detection in systems of spin-j particles with collective observables — •Giuseppe Vitagliano[1] and Géza Tóth[1,2,3] — [1]Theoretical Physics, The University of the Basque Country, E-48080 Bilbao, Spain — [2]IKERBASQUE, Basque Foundation for Science, E-48011 Bilbao, Spain — [3]Research Institute for Solid State Physics and Optics, H-1525 Budapest, Hungary

We discuss the problem of finding inequalities useful to detect entanglement in systems of particles with a spin higher than 1/2. We focus on uncertainty relations based on the knowledge of the first two moments of global observables, such as for example the total spin components. We compare the various inequalities obtained from the point of view of their usefulness to detect entanglement by characterizing the experimental effort needed and by studying the states that violate them.

Q 20.6 Tue 11:45 SCH A118

Volume law scaling of entanglement entropy in spin-1/2 chains. — •Giuseppe Vitagliano[1], Arnau Riera[2], and José Ignacio Latorre[3] — [1]Theoretical Physics, The University of the Basque Country, E-48080 Bilbao, Spain — [2]Institute of Physics and Astronomy, University of Potsdam, D-14476 Potsdam, Germany — [3]Department d' Estructura i Constituents de la Matéria, Universitat de Barcelona, E-08028 Barcelona, Spain

We address the question whether a Hamiltonian with only nearest neighbor interaction can have a highly entangled ground state, in the sense that it presents a volume law scaling of the block entanglement entropy. For typical quantum systems the block entanglement entropy of the ground state follows an area-law scaling, with a logarithmic violation for quantum critical models. Nevertheless, we explicitly construct a spin-1/2 chain Hamiltonian that has the expected properties, breaking the translational invariance of the model. Its ground state is characterized by an accumulation of singlet bonds across the half chain.This result is also related to the QMA completeness of the 1D local Hamiltonian problem.

Q 20.7 Tue 12:00 SCH A118

Robust and Fragile Entanglement in Qubit Environments — •Jaroslav Novotny[1,2], Gernot Alber[1], and Igor Jex[2] — [1]Institut für Angewandte Physik, Technische Universität Darmstadt, D-64289 Darmstadt, Germany — [2]Department of Physics, FNSPE CTU in Prague, Czech Republic

The asymptotic decoherence originating from iteratively applied random unitary couplings between distinguishable qubits of a quantum network is investigated. Within this framework the resulting asymptotic dynamics of a subsystem and its residual qubit environment is explored without any further simplifying assumptions concerning the coupling strength or the number of relevant couplings between subsystem and its environment or the numbers of qubits involved. The dependence of the resulting asymptotic decoherence and entanglement decay of the subsystem on the interaction topology and on the size and initial state of the environment is discussed. It is shown that there are two classes of entangled states whose asymptotic entanglement decay depends on the size of the surrounding qubit environment in a characteristic and completely different way. The asymptotic entanglement of members of the first class is destroyed already for a finite and usually very small number of environmental qubits. Besides this class of fragile entangled states there is also the second class of robustly entangled states whose entanglement is not destroyed completely for any finite size of the surrounding qubit environment. A simple analytical criterion is presented which is capable of distinguishing between these two classes in the case of two-qubit states.

Q 20.8 Tue 12:15 SCH A118

Permutationally Invariant Quantum Tomography — •Géza Tóth[1,2,3], Witlef Wieczorek[4,5], David Gross[6], Roland Krischek[4,5], Christian Schwemmer[4,5], and Harald Weinfurter[4,5] — [1]Theoretical Physics, The University of the Basque Country, E-48080 Bilbao, Spain — [2]IKERBASQUE, Basque Foundation for Science, E-48011 Bilbao, Spain — [3]Research Institute for Solid State Physics and Optics, H-1525 Budapest, Hungary — [4]Max-Planck-Institut für Quantenoptik, D-85748 Garching, Germany — [5]Fakultät für Physik, Ludwig-Maximilians-Universität, D-80799 Garching, Germany — [6]Institute for Theoretical Physics, Leibniz University Hannover, D-30167 Hannover, Germany

We present a scalable method for the tomography of large multi-qubit quantum registers. It acquires information about the permutationally invariant part of the density operator, which is a good approximation to the true state in many, relevant cases. Our method gives the best measurement strategy to minimize the experimental effort as well as to minimize the uncertainties of the reconstructed density matrix. We calculate the measurements needed for up to 14 qubits, and also compute the required total count, i.e., how many times the experiments have to be repeated for obtaining sufficiently low uncertainties. We note that the method has been implemented for the experimental tomography of a four-qubit symmetric Dicke state [1].

[1] See the talk by C. Schwemmer et al.

Q 20.9 Tue 12:30 SCH A118

Permutationally invariant tomography of a four qubit symmetric Dicke state — •Christian Schwemmer[1,2], Géza Tóth[3,4,5], Witlef Wieczorek[6], David Gross[7], Roland Krischek[1,2], and Harald Weinfurter[1,2] — [1]Max-Planck-Institut für Quantenoptik, D-85748 Garching — [2]Fakultät für Physik, Ludwig-Maximilians-Universität, D-80797 München — [3]Department of Theoretical Physics, The University of the Basque Country, E-48080 Bilbao — [4]IKERBASQUE, Basque Foundation for Science, E-48011 Bilbao — [5]Research Institute for Solid State Physics and Optics, Hungarian Academy of Sciences, H-1525 Budapest — [6]Faculty of Physics, University of Vienna, A-1090 Vienna — [7]Institute for Theoretical Physics, Leibniz University Hannover, D-30167 Hannover

Multi-partite entangled quantum states play an important role for many quantum information tasks. Therefore, efficient measurement schemes for characterizing these states are needed. As shown by Tóth et al. [1], when restricting to permutationally invariant states the measurement effort scales only quadratically with the number of qubits. Here, we present experimental results of the tomographic analysis of a photonic four qubit Dicke state. Instead of 81 basis settings for full tomography only 15 basis settings have to be measured. We investigate the possibility of permutationally invariant tomography for photonic systems with a larger number of qubits on the example of a six photon symmetric Dicke state. Due to the low count rates for such systems, full tomography is practically impossible.

[1] Tóth et al., Phys. Rev. Lett., in press; talk by Tóth

Q 20.10 Tue 12:45 SCH A118

Simulation of relativistic effects with ultracold atoms in bichromatic optical lattices — •Christopher Grossert, Tobias Salger, Sebastian Kling, and Martin Weitz — Institut für Angewandte Physik, Wegelerstr.8 , 53115 Bonn, Germany

We propose a scheme to simulate relativistic effects with ultracold rubidium atoms in bichromatic optical lattice potentials. In an earlier experiment, we have investigated the energy splitting betweeen the first and second excited Bloch band of a Fourier- synthesized lattice potential created by superimposing two lattice harmonics with different spatial periodicities [1]. Interestingly for specific values of the potential depths of the lattice harmonics, the energy dispersion for ultracold atoms shows a linear behaviour, where the dynamics of the particles can be described by the linear Dirac equation. We expect to observe relativistic effects like Klein tunneling, where ultrarelativistic particles penetrate a potential barrier without significant damping, regardless of the height and length of the barrier [2]. This effect has already been demonstrated in graphene, which shows a similar relativistic energy dispersion for free electrons [3]. More- over, we expect to be able to investigate effects predicted by the linear and non-linear Dirac equation.

References

[1] Salger, T. ; Geckeler, C. ; Kling, S. ; Weitz, M.: Phys. Rev. Lett. **99** 190405 (2007)
[2] Klein, O.: Z.Physik **53** 127 (1929)
[3] Stander, N. ; Huard, B. ; Goldhaber-Gordon, D.: Phys. Rev. Lett. **102** 026807 (2009)

Q 21: Laserentwicklung: Festkörperlaser 2

Time: Tuesday 10:30–12:45 Location: SCH A215

Q 21.1 Tue 10:30 SCH A215

Diodengepumpter Laserbetrieb von Tm:Sc_2O_3 bei 2116 nm — •Philipp Koopmann[1,2], Samir Lamrini[2], Karsten Scholle[2], Peter Fuhrberg[2], Klaus Petermann[1] und Günter Huber[1] — [1]Institut für Laser-Physik, Universität Hamburg, Germany — [2]LISA laser products, Katlenburg-Lindau, Germany

Auf Grund zahlreicher Anwendungen besteht ein wachsendes Interesse an Lasersystemen, deren Wellenlängen im Bereich um 2 μm liegen. Insbesondere für das Anregen von OPOs für den mittleren Infrarotbereich sind große Wellenlängen von Vorteil. Standardmäßig werden hierfür Holmium-Laser verwendet, welche wiederum von Thulium-Lasern gepumpt werden müssen. Eine Alternative wären diodengepumpte Thulium-Laser, deren Wellenlänge im langwelligen Bereich liegt. Auf Grund der großen Stark-Aufspaltung in Scandiumoxid liegen in Tm:Sc_2O_3 hohe Emissionswirkungsquerschnitte jenseits von 2,1 μm vor. Für die hier präsentierte Arbeit wurde ein Tm(1%):Sc_2O_3 Kristall nach dem HEM-Verfahren hergestellt und spektroskopisch untersucht. Verstärkungspeaks konnten bei 2120 nm und bei 1990 nm gefunden werden. In diodengepumpten Laserexperimenten ($\lambda_{\text{Pump}} = 796$ nm) konnte ein differentieller Wirkungsgrad von 41 % gegen die absorbierte Leistung erreicht werden. Die Laserschwelle lag deutlich unter 3 W und die maximale Ausgangsleistung betrug 26 W. Die Laserwellenlänge war mit 2116 nm noch größer als die von Ho:YLF (2050 nm) und Ho:YAG (2090 nm). In einem Experiment zur spektralen Durchstimmbarkeit des Lasers konnte ein Durchstimmbereich von 1975 nm bis 2168 nm erreicht werden.

Q 21.2 Tue 10:45 SCH A215

888 nm diode-pumped nanosecond Nd:YVO_4-highpower-laser at 1342 nm — •Florian Lenhardt[1], Achim Nebel[2], Ralf Knappe[2], Thorsten Bauer[3], Jürgen Bartschke[3], and Johannes L'huillier[1] — [1]Photonik-Zentrum Kaiserslautern e.V., Kohlenhofstrasse 10, 67663 Kaiserslautern — [2]Lumera Laser GmbH, Opelstrasse 10, 67661Kaiserslautern — [3]Xiton Photonics GmbH, Kohlenhofstrasse 10, 67663 Kaiserslautern

Compact and efficient diode pumped all-solid-state lasers operating in the infrared spectral region around 1.3 μm have important applications in fiber optics, medical treatment and scientific research. Moreover this wavelength is attractive for the display technology via harmonic generation into red (SHG) or blue radiation (THG). Among the different laser materials in particular the $^4F_{3/2} \rightarrow {}^4I_{13/2}$-transition of Nd doped laser materials is of great interest for this wavelength range. However the main limitation of 1342 nm Nd-lasers is the strong thermal load, due to the large quantum defect and excited state absorption (ESA). This finally results into a strong thermal lens. In this contribution we report on the design, development and optimization of a Nd:YVO_4 laser at 1342 nm pumped at 888 nm and actively Q-switched by an accusto optical modulator. The development leads to an average output power of 14 W with a pulse duration of 18 ns at a pulse repetition rate of 10 kHz, giving a peak power of 61 kW and pulse energy of 1.4 mJ. The pulses are very stable with pulse energy fluctuations less 0.5 % and the beam quality of the laser radiation is diffraction limited.

Q 21.3 Tue 11:00 SCH A215

46 W regenerative amplifier based on Nd:YVO$_4$ seeded by a gain switched diode laser — •Florian Harth[1], Markus Lührmann[1], Christian Theobald[1], Thorsten Ulm[1], Ralf Knappe[2], Achim Nebel[2], Andreas Klehr[3], Götz Erbert[3], and Johannes L'huillier[1] — [1]Photonik-Zentrum Kaiserslautern e.V., 67663 Kaiserslautern, Germany — [2]Lumera Laser GmbH, 67663 Kaiserslautern, Germany — [3]Ferdinand-Braun-Institut, Leibniz-Institut für Höchstfrequenztechnik, 12489 Berlin, Germany

We report on a Nd:YVO$_4$ regenerative amplifier, end pumped by 888 nm-diode lasers. The output power was about 46 W at adjustable repetition rates from 150 to 833 kHz with a M^2-factor of 1.2. The amplifier was seeded by a gain switched diode laser, generating pulses with a duration of 65 ps and a pulse energy of ~5 pJ. The high gain of the regenerative amplifier of ~70 dB provides amplified pulse energies as high as 180 μJ. Bifurcations of the pulse energy could be avoided without a pre-amplifier despite the low seed energy. Pulse amplitude fluctuations of only 1.2 % for 10,000 consecutive pulses were measured. The long term output power stability was 0.3 %. The laser combines the advantages of a small and efficient diode seed source with a reliable solid state regenerative amplifier, forming a compact, robust and powerful system. The gain switched seed diode delivers pulses on demand, rendering a pulse picker unnecessary. It is also insensitive against feedback, reducing requirements on isolation between seed diode and amplifier. This makes the laser an ideal source for applications in non-linear optics and high quality material processing.

Q 21.4 Tue 11:15 SCH A215

Yb:LiYF$_4$ als Scheibenlasermaterial — •Kolja Beil[1], Susanne T. Fredrich-Thornton[1], Christian Kränkel[1], Daniela Parisi[2], Klaus Petermann[1], Mauro Tonelli[2] und Günter Huber[1] — [1]Institut für Laser-Physik, Universität Hamburg, Deutschland — [2]NEST-Nanoscience Insitute-CNR, Dipartimento di Fisica, Pisa, Italien

Yb-dotiertes LiYF$_4$ (Yb:YLF) ist vor allem aufgrund seiner negativen thermo-optischen Koeffizienten, die die Ausprägung einer thermischen Linse unterdrücken, Gegenstand intensiver Forschung. Die lange Fluoreszenzlebensdauer von 2 ms wirkt sich überdies in relativ niedrigen Laserschwellen aus und die breiten Emissionsspektren ermöglichen sub-200-fs Pulse. Die Möglichkeit, effizienten Laserbetrieb auch bei, im Vergleich zu anderen Yb-dotierten Materialien, hohen Yb-Dotierungen zu realisieren macht Yb:YLF zu einem interessanten Material für den Scheibenlaserbetrieb, denn hohe Dotierungen erlauben geringere Scheibendicken und damit eine effizientere Kühlung. In dieser Arbeit wird erstmals Lasertätigkeit von Yb:YLF im Scheibenlaser demonstriert. In ersten Versuchen konnte mit einem 30% Yb-dotierten YLF Kristall eine Ausgangsleistung von 5.87 W erreicht werden, was unseres Wissens die höchste Leistung für dieses Material bei Raumtemperatur ist. Der maximale differentielle Wirkungsgrad betrug 42%. Da die Anregung mangels geeigneter Pumpquelle nicht im Maximum der Absorption stattfand und die Kristallbeschichtungen für Yb:YAG ausgelegt waren, ist zu erwarten, dass mit optimierten Parametern deutlich gesteigerte Effizienzen und Ausgangsleistungen erzielt werden können.

Q 21.5 Tue 11:30 SCH A215

Joule-level, room-temperature Yb:YAG and Yb:CaF$_2$ lasers — •Markus Loeser[1], Mathias Siebold[1], Franziska Kroll[1], Fabian Röser[1], Jörg Körner[2], Joachim Hein[2], Ulrich Schramm[1], and Roland Sauerbrey[1] — [1]Helmholtz-Centre Dresden Rossendorf, Bautzner Landstr. 400, 01328 Dresden, Germany — [2]Institute for Optics and Quantum Electronics, Max-Wien-Platz 1, 07743 Jena, Germany

Compact diode-pumped solid-state laser systems are envisioned to be an efficient approach for the direct generation of ultrahigh peak laser intensities at a high average power. At the Helmholtz-Centre Dresden Rossendorf a fully diode-pumped Petawatt laser system called PEnELOPE (**P**etawatt, **En**ergy **E**fficient **L**aser for **O**ptical **P**lasma **E**xperiments) with a pulse duration of 200 fs and a pulse energy of 200 J is planed to build. Here we present gain and efficiency measurements of a joule-level active mirror amplifier for the investigatin of the architecture of the main amplifier stages. A setup comprising of 4–16 extracting beams and a pump recovery configuration was employed in order to study the small-signal gain and the optical-to-optical conversion efficiency of an Ytterbium-doped amplifier using either Yb:YAG or Yb:CaF$_2$. Both the pump and the laser beams were relay-imaged at each pass. For seeding an Yb:YAG Q-switched regenerative amplifier with an output energy of 300 μJ and a pulse duration of 6 ns was pre-amplified up to 100 mJ.

Q 21.6 Tue 11:45 SCH A215

In der Wellenlänge umschaltbarer, gewinngeschalteter Pr^{3+}:LiYF$_4$-Laser — •Sebastian Müller, Nils-Owe Hansen, Ortwin Hellmig und Günter Huber — Universität Hamburg, Institut für Laserphysik

Das Energieniveau-Schema des dreiwertigen Praseodym-Ions erlaubt Laserbetrieb auf verschiedenen Wellenlängen im sichtbaren Spektralbereich. In diesem Beitrag wird ein Laser auf der Basis von Pr^{3+}:LiYF$_4$ vorgestellt, in welchem unter Pumpen mit einer blauen Laserdiode bei 444 nm simultan Lasertätigkeit bei 523 nm im grünen und 640 nm im roten Spektralbereich erzielt werden kann. Hiermit steht ein sehr kompaktes RGB-System zur Verfügung, welches einen großen Bereich der additiven Farbmischung abdeckt.

In diesem Lasersystem diente ein Fabry-Perot-Etalon als Auskoppelspiegel. Das Etalon wird aus einem Spiegelpaar mit variablem Luftspalt gebildet. Die Änderung dieses Luftspaltes mittels eines Piezoaktors ermöglichte eine schnelle Variation des Auskoppelgrades für die beiden Laserwellenlängen.

Zusätzlich wurden Untersuchungen zur Erzeugung gewinngeschalteter Laserpulse mittels Modulation der Pumpleistung durchgeführt. Dabei konnten Laserpulse von 300 ns Pulsdauer und einer Pulsspitzenleistung von 2,1 W bei 640 nm bzw. 670 ns Pulsdauer und 1,6 W Pulsspitzenleistung bei 523 nm erzeugt werden.

In Kombination mit der schnellen Variation des Auskoppelgrades lieferte das System gewinngeschaltete Laserpulse mit einer Repetitionsrate von 34 kHz, die nach jedem Puls die Wellenlänge wechselten.

Q 21.7 Tue 12:00 SCH A215

Faserverstärker basierter Ar-Ionen Laser Ersatz — •Tobias Beck, Benjamin Rein und Thomas Walther — TU Darmstadt, Institut für Angewandte Physik, Laser und Quantenoptik, Schlossgartenstraße 7, D-64289 Darmstadt

Wir stellen eine Laserquelle bei 1029 nm vor, die spektral bis zu 26 GHz modensprungfrei abgestimmt werden kann. Die Scanfrequenz beträgt dabei bis zu 400 Hz. Dank eines Yb-Faserverstärkers werden Ausgangsleistungen bis zu 10 W realisiert. Die Linienbreite beläuft sich auf einige 100 kHz. Um die Zielwellenlänge von 514 nm zu erreichen, wird das System in einem Überhöhungsresonator frequenzverdoppelt. Das System soll später eine effizientere Kühlung relativistischer Ionen ermöglichen.

Q 21.8 Tue 12:15 SCH A215

Frequenzverdopplung eines schmalbandigen Hochleistungsfaserverstärkers bei 1091 nm — •Matthias Stappel, Anna Beczkowiak, Thomas Diehl, Andreas Koglbauer, Daniel Kolbe, Matthias Sattler, Ruth Steinborn und Jochen Walz — Institut für Physik, Johannes Gutenberg-Universität Mainz und Helmholtz Institut Mainz, D-55099 Mainz

Ein kontinuierlicher Kühllaser bei einer Wellenlänge von 121,56 nm (Lyman-α Linie) ist die Vorraussetzung für zukünftige Präzissionsexperimente an Antiwasserstoff. Laserlicht bei einer Wellenlänge von 121,56 nm wird durch Summenfrequenzmischen von drei fundamentalen Lasern, darunter einer bei einer Wellenlänge von 545,5 nm, erzeugt. Hier wird der Aufbau eines Hochleistungslasersystems zur Erzeugung von Strahlung bei 545,5 nm vorgestellt. Ausgangspunkt ist eine Kombination aus einem schmalbandigen Ytterbium-Faserlaser bei 1091 nm (60 kHz Emissionsbandbreite) und einem zweistufigen Ytterbium-Faserverstärker. Damit konnte eine langzeitstabile Leistung von 30 W gezeigt werden. Das infrarote Lichtfeld soll anschließend in einem externen Überhöhungsresonator mit einem nichtlinearen Medium (LBO-Kristall) frequenzverdoppelt werden. Alternativ soll die Frequenzverdopplung im Einfachdurchgang in einem periodisch gepolten MgO:SLT-Kristall (Lithiumtantalat) durchgeführt werden. Die beiden Methoden zur Frequenzverdopplung werden verglichen und der derzeitige Stand des Gesamtsystems aus Faserverstärker und Frequenzverdopplung vorgestellt.

Q 21.9 Tue 12:30 SCH A215

Kompakte Dauerstrichlaser mit hohen Effizienzen im ultravioletten Spektralbereich — •Philip Metz, Teoman Gün und Günter Huber — Universität Hamburg, Institut für Laser-Physik

Die meisten Systeme zur Erzeugung kohärenter ultravioletter (UV) Dauerstrich-Strahlung basieren auf einer zweifachen Frequenzkonversion von im infraroten Spektralbereich emittierenden Lasern. Die Effizienz derartiger Systeme ist dadurch begrenzt, dass zumindest auf einen resonatorexternen Frequenzkonversionsschritt zurückgegriffen werden muss. Im Rahmen dieses Beitrages wird die Erzeugung kohärenten UV-Lichtes durch resonatorinterne Frequenzverdopplung von im sichtbaren Spektralbereich emittierenden Praseodym-Lasern im Dauerstrichbetrieb demonstriert. Hierfür wird ein Praseodym-dotierter $LiYF_4$-Kristall von zwei InGaN-Laserdioden mit jeweils etwa 1 W Ausgangsleistung um 444 nm gepumpt. In einem Fokus des zweifach gefalteten Resonators befand sich der nichtlineare Kristall. Die Frequenzverdopplung des roten Überganges bei 639,5 nm mittels eines 8 mm langen LBO-Kristalls lieferte 426 mW Ausgangsleistung bei 319,8 nm im mittleren UV-Bereich. Der grüne Übergang bei 522,6 nm wurde mittels eines 5 mm langen BBO-Kristalls in 261,3 nm-Strahlung im fernen UV-Bereich konvertiert. Die hierbei erzielte Ausgangsleistung betrug 356 mW. Bezogen auf die eingestrahlte Pumpleistung stellen diese kompakten Systeme UV-Quellen mit hohen Effizienzen von 21 % bzw. 18 % dar.

Q 22: Ultrakurze Laserpulse: Anwendungen 1

Time: Tuesday 10:30–13:00 Location: SCH A01

Q 22.1 Tue 10:30 SCH A01

Erzeugung Harmonischer Strahlung mit Goldnanoantennen — •Nils Pfullmann[1,2], Carsten Clever[1,2], Christian Waltermann[1,2], Milutin Kovacev[1,2], Tobias Hanke[3], Rudolf Bratschitsch[3], Alfred Leitenstorfer[3] 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

Nanoantennen aus Metall zeigen im optischen Bereich ähnliche Eigenschaften wie makroskopische 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 demonstriert wurde. Damit würden EUV-Pulse mit Multimegahertz-Repetitionsraten für viele Anwendungen zur Verfügung stehen. Wir zeigen unsere Experimente zur Wechselwirkung ultrakurzer Laserpulse mit unterschiedlichen Geometrien von Nanoantennen. Bisher konnte schon Strahlung mit niedriger harmonischer Ordnung erzeugt werden, und eine Abschätzung der Feldüberhöhung ist möglich. Dies gibt wichtige Hinweise für die Erzeugung Hoher Harmonischer Strahlung.

Q 22.2 Tue 10:45 SCH A01

Generation and characterization of femtosecond-laser induced nanostructures on thin gold films — •Conny Axel Hulverscheidt, Martin Reininghaus, and Dirk Wortmann — RWTH Aachen University, Lehrstuhl für Lasertechnik, Steinbachstr. 15, D-52074 Aachen

Femtosecond (fs)-laser radiation focused on a silicon substrate with a 60 nm thin gold film induces the formation of conical nanostructures, nanobumps and nanojets. Since the formation dynamics of these nanostructures are still not understood, the step for a theoretical understanding of this phenomenon has been done by means of Molecular Dynamics simulations. The comparison of theory and experiments with high temporal und spatial resolution gives an opportunity to have a microscopic view on the nanostructure formation kinetics. Therefore a pump-probe-experiment consisting of a combination of fs-laser and EUV-microscope is constructed. Time-resolved measurements in a pump-probe-setup require a reproducible generation of the nanobumps and nanojets. Additionally, debris or plasmageneration has to be avoided to prevent damage on the EUV-optics. The influence of the laser-parameters pulse-energy, pulse-duration and focus on the generation of nanobumps and nanojets is investigated. Previous experiments have shown that the morphology and thickness of the gold film has also an impact on the formation of nanostructures, thus its influence on the formation dynamics is determined. The laser-parameters and gold film characteristics define the required parameter window allowing ablation-free generation of nanobumps and nanojets.

Q 22.3 Tue 11:00 SCH A01

Zeptosecond precision pulse shaping — •Jens Köhler, Matthias Wollenhaupt, Tim Bayer, Cristian Sarpe, and Thomas Baumert — Universität Kassel, Institut für Physik und Center for Interdisciplinary Nanostructure Science and Technology (CINSaT), Heinrich-Plett-Str. 40, D-34132 Kassel, Germany

We investigate the temporal precision in the generation of an ultrashort laser pulse pair. To this end, we combine a femtosecond polarization pulse shaper [1] with a polarizer and employ two linear spectral phase masks to mimic an ultrastable common-path interferometer. In an all-optical experiment we study the interference signal resulting from two temporally delayed pulses. Our results demonstrate a 2σ-precision of 300 zs = 300×10^{-21} s in pulse-to-pulse delay. This corresponds to a variation of the optical path length in conventional delay stage based interferometers of 0.45 Å. In addition, we apply these precisely generated pulse pairs and furthermore pulse sequences generated by sinusoidal spectral phase modulation to strong-field quantum control. In a coherent electronic excitation experiment we show ultrafast switching of photoelectron spectra via Photon-Locking by temporal phase discontinuities [2,3] on the few attosecond timescale.

[1] M. Wollenhaupt et al., Applied Physics B, 95(2), 245–259, (2009)
[2] M. Wollenhaupt et al., Phys. Rev. A, 73(6), 063409, (2006)
[3] T. Bayer et al., J. Phys. B, 41, 074007, (2008)

Q 22.4 Tue 11:15 SCH A01

Parametervariation femtosekunden-geschriebener Wellenleiter in YAG-Kristallen — •Anna-Greta Paschke, Thomas Calmano, Jörg Siebenmorgen, Klaus Petermann und Günter Huber — Universität Hamburg, Institut für Laser-Physik, Hamburg

Durch die Bestrahlung mit ultrakurzen Laserpulsen können wellenleitende Strukturen in dielektrischen Materialien erzeugt werden.

In YAG-Kristallen wird aufgrund nichtlinearer Absorptionsprozesse im Fokus des fs-Laserpulses die kristalline Struktur zerstört. Das modifizierte Material übt Spannungen auf das umgebende Material aus. Dies führt dort aufgrund des elasto-optischen Effekts zu einer lokalen Erhöhung des Brechungsindex um $\Delta n \approx 10^{-3}$. Wird der Laserpuls in die Probe fokussiert und diese während der Bestrahlung verfahren, können im Kristall Doppelspuren aus zerstörtem Material erzeugt werden, in deren Zentrum die Führung von Licht möglich ist. Die Eigenschaften der Wellenleitung sind dabei von verschiedenen Parametern abhängig.

Um optimale Wellenleiter herzustellen wurden in undotierten YAG-Proben Doppelspuren mit unterschiedlichen Spurabständen, Verfahrgeschwindigkeiten und Pulsenergien geschrieben. Die Spurabstände variierten dabei zwischen $14\,\mu m$ und $30\,\mu m$, die Geschwindigkeiten zwischen $10\,\mu m/s$ und $100\,\mu m/s$ und für die Pulsenergien sind verschiedene Werte entsprechend der jeweiligen Zerstörschwelle gewählt worden. Die Untersuchung der erzeugten Strukturen erfolgte mit Hilfe lichtmikroskopischer Aufnahmen. Zur Charakterisierung der Wellenleiter wurden die Modenprofile aufgenommen und die Verluste untersucht. Diese liegen für die besten Wellenleiter im Bereich von 0,8 dB/cm.

Q 22.5 Tue 11:30 SCH A01

Superresolved femtosecond nanosurgery of cells — •Matthias Pospiech[1], Moritz Emons[1], Kai Kütemeyer[2], Alexander Heisterkamp[2], and Uwe Morgner[1,2] — [1]Leibniz Universität Hannover — [2]Laserzentrum Hannover e.V.

We report on femtosecond nanosurgery of fluorescent labeled structures in cells with a spatially superresolved laser beam. The focal spot width is reduced below the diffraction limit using phase filtering applied with a programmable phase modulator. These superresolved focal spots are analyzed theoretically and experimentally. Cutting of cell structures is performed within an inverted Microscope and high NA Objectives. A comprehensive statistical analysis of the resulting cuts is presented, which demonstrates an achievable average resolution enhancement of 30 %

Q 22.6 Tue 11:45 SCH A01

Combining fs-pulse tailoring and self-phase modulation for nonlinear microscopy — •Tillmann Kalas, Jens Köhler, Cristian Sarpe-Tudoran, Matthias Wollenhaupt, and Thomas

Baumert — University of Kassel, Institute of Physics and Center of Interdisciplinary Nanostructure Science and Technology (CINSaT), Heinrich-Plett-Str. 40, D- 34132 Kassel, Germany

Nonlinear label-free microscopy is a powerful tool for the investigation of physical and biological samples with high spatial resolution. Often intrinsic Second- or Third-Harmonic Generation as well as Coherent Anti-Stokes Raman Scattering is used as contrast mechanism.
We make use of fs pulse shaping in combination with self-phase modulation (SPM) in order to generate the nonlinear signals [1, 2]. Extending our previous studies [1], fs laser pulses are amplitude and phase modulated in a narrow spectral interval and focused into transparent samples. SPM leads to a redistribution of the power spectral density (PSD) depending on the nonlinear index of refraction. In particular the intensity of previously removed spectral components is recovered. Hence, observation of these intensities holds the possibility to distinguish between different materials. We demonstrate high nonlinear contrast and resolution in technical samples combining the fs pulse shaping technique with a commercial laser-scanning-microscope. Moreover, the influence of additional spectral phases on the self-phase modulated PSD is studied and results are given.

[1] A. Präkelt *et al.*: Appl. Phys. Lett. **87**(12), 121113(2005)
[2] M. C. Fischer *et al.*: Opt. Lett. **30**(12), ,1551(2005)

Q 22.7 Tue 12:00 SCH A01

Optimization of Characteristic X-Ray Emission Generated by sub-10-fs Laser Pulses — •Fabian Gaussmann, Dirk Hemmers, and Georg Pretzler — Institut für Laser- und Plasmaphysik, Heinrich-Heine-Universität Düsseldorf

We present the generation of characteristic Kα radiation in the energy range from 1.5 keV to 25 keV by focusing of few-cycle laser pulses (sub-10-fs pulse duration, intensity 10^{16} W/cm^2) on solid targets. The influence of various laser parameters was measured and discussed. One key parameter to optimize the x-ray emission is the control of the pre-plasma formation. For this purpose, we analyzed the influence of laser pre-pulses with an intensity of about 10^{14} W/cm^2 and a variable delay in the ps range. Two different techniques were used for the pre-pulse generation. First a spectral modulation of the laser beam with an acousto-optical modulator (DAZZLER) and second two beam-splitters in combination with a delay unit. The advantages as well as the disadvantages of both techniques are discussed. While a hydrodynamic code was used to estimate the pre-plasma formation, the laser absorption was calculated with a PIC simulation. Both numerical methods in combination with the experimental results provide a quantitative understanding of the x-ray generation.

Q 22.8 Tue 12:15 SCH A01

Ultra-broadband third-harmonic generation in fs-filamentation — •Tobias Vockerodt[1,3], Daniel Steingrube[1,3], Emilia Schulz[1,3], Milutin Kovačev[1,3], and Uwe Morgner[1,2,3] — [1]Institut für Quantenoptik, Leibniz Universität Hannover — [2]Laserzentrum Hannover e.V. — [3]QUEST Centre for Quantum Engineering and Space-Time Research, Hannover

Optical filamentation is a scheme often used for supercontinuum generation of short laser pulses as an alternative to gas filled hollow-core fibres. Filaments are well studied with respect to temporal and spectral evolution in the visible and infrared region. However, little attention has been given to the ultraviolet (UV) parts of the spectrum.

In this work, we present our studies of UV and third harmonic generation within a filament generated by a 35 fs, 800 nm laser pulse in argon. The filament is probed along its length by establishing an abrupt transition to vacuum by a pinhole. Amongst broadening of the fundamental pulse spectrum throughout the visible and near infrared, third harmonic (TH) generation extends the spectrum into the UV. The unperturbed filament emits TH off-axis on a cone around the filament core. However, if the filament is truncated, the TH conversion efficiency on-axis increases significantly and the TH spectrum broadens. The central part contains pulse energy of up to one microjoule, opening prospects for strong few-cycle-pulses in the UV.

Q 22.9 Tue 12:30 SCH A01

Application of the multiple rate equation — •Oliver Brenk, Nils Brouwer, and Bärbel Rethfeld — TU Kaiserslautern, 67663 Kaiserslautern, Germany

Material processing with ultrashort laser pulses is in the focus of experimental and theoretical research. The multiple rate equation, introduced in [1], is a tool to numerically simulate the effects of ultrashort laserpulse irradiation on dielectrics. The MRE allows to investigate the temporal evolution of the electronic density in the conduction band with very good agreement to a full kinetic approach [2] using Boltzman's equation, but with considerably less computational effort. We expanded the MRE model to include reflectivity at the surface and the recombination into Self-Trapped Excitons (STE-States). The reflectivity, depending on the electronic density, influences the laser intensity inside the material. STEs are localized electron-hole pairs formed by free electrons having recombined with localized holes, energetically lying between valence band and conduction band. Re-excitation out of these states is considered as well. We added a spatial dimension to the already implemented time evolution, in order to study the spatially resolved evolution of the electronic densities. Counting the absorbed laser photons allows us to estimate the absorbed energy per spatial layer.

[1] B. Rethfeld. Phys. Rev. Lett., 92:187401, 2004.
[2] A. Kaiser, B. Rethfeld, M. Vicanek, and G. Simon. Phys. Rev. B,61(17):11437*11450,2000.

Q 22.10 Tue 12:45 SCH A01

Monochromatizing a Femtosecond High-Order Harmonic VUV Photon Source with Reflective Off-Axis Zone Plates — •Mateusz Ibek[1], Torsten Leitner[1], Alexander Firsov[2], Alexei Erko[2], and Philippe Wernet[1] — [1]Institute for Methods and Instrumentation for Synchrotron Radiation Research, Helmholtz-Zentrum Berlin — [2]Institute for Nanometer Optics and Technology, Helmholtz-Zentrum Berlin

High-harmonic generation (HHG) of femtosecond lasers pave the way for such applications as table-top imaging and spectroscopy using femtosecond light pulses from the VUV to the x-ray range. Due to the comparably low output of HHG sources the necessity of efficient optical elements arises while the amount of said elements must be minimal. A solution is found with off-axis reflection zone plates (RZP). They allow focusing and monochromatizing the VUV and x-ray radiation with only one single element while preserving the pulse duration. At the HHG setup at HZB/BESSYII we have characterized the properties of RZPs for the monochromatization and focusing of a femtosecond VUV photon source. The setup is generating 50 fs pulses and here we used photon energies between 15 and 30 eV. Three RZPs were each calculated and designed for a specific harmonic wavelength on a gold coated plane substrate. As each RZP focuses a different wavelength to the same spot so this arrangement can be easily used to select and focus a desired laser high-order harmonic. The diffracted light i.e. focal point and spectrum was recorded on an x-ray CCD camera and spectral resolution and focal characteristics were determined.

Q 23: Poster 2: Intersectional Session

Time: Tuesday 18:00–21:00 Location: P1

Q 23.1 Tue 18:00 P1

Entanglement dynamics of multi-qubit states in single- and many-sided noisy channels — •Michael Siomau[1,2] and Stephan Fritzsche[3,4] — [1]Max-Planck-Institut fuer Kernphysik, Postfach 103980, D-69029 Heidelberg, Germany — [2]Physikalisches Institut, Heidelberg Universitaet, D-69120 Heidelberg, Germany — [3]Department of Physical Sciences, P.O.Box 3000, Fin-90014 University of Oulu, Finland — [4]GSI Helmholtzzentrum fuer Schwerionenforschung, D-64291 Darmstadt, Germany

We study the entanglement dynamics of a multi-qubit system which is initially prepared in a GHZ or a W state and undergoes the action of some noisy channel. We discuss both cases of single- and many-sided noisy channels, i.e. when just one or several qubits simultaneously being subject to local noise. As noise models for the influence of the environment we use the Pauli channels σ_x, σ_y and σ_z. The entanglement of the (mixed) states is quantified with a lower bound for multi-qubit concurrence as suggested recently by Li et al. [J. Phys. A **42**, 012312 (2009)]. We show that for a single-side channel, the loss of the entanglement of the multi-qubit system is independent on the initial state and the type of acting noise. For many-sided channels, however, there is a difference in the "speed of disentanglement" between the GHZ and the W states which, moreover, depends on the type of coupling noise.

Q 23.2 Tue 18:00 P1

Entanglement Dynamics in Harmonic Oscillator Chains — •Razmik Unanyan and Michael Fleischhauer — Fachbereich Physik und Forschungszentrum OPTIMAS, Technische Universität Kaiserslautern, D-67663 Kaiserslautern, Germany

We study the long-time evolution of the bipartite entanglement in translationally invariant gapped harmonic lattice systems with finite-range interactions. A lower bound for the von Neumann entropy is derived in terms of the purity of the reduced density matrix. It is shown that starting from an initially Gaussian state the entanglement entropy increases at least linearly in time. This implies that the dynamics of gapped (non-critical) harmonic lattice systems cannot be efficiently simulated by algorithms based on matrix-product decompositions of the quantum state.

Q 23.3 Tue 18:00 P1

Entanglement and Thouless time from coincidence measurements across disordered media — •Nicolas Cherroret and Andreas Buchleitner — Institute of Physics, Albert-Ludwigs University of Freiburg, Hermann-Herder-Str. 3, D-79104 Freiburg, Germany

When light propagates in a disordered medium, it generally experiences a diffusion process. In some cases however, when the disorder strength is increased, interference between multiple scattering paths may build up, which lead to non-vanishing intensity correlations between different points of the scattering sample. If this picture is today well understood in situations where the light is in a classical state, less is known about multiple scattering of non-classical light. We will investigate the propagation of a photon-pair, a strongly nonclassical state of light, in a disordered medium. We will show that interference contributions to the coincidence counting rate of the two transmitted photons contain information about the spectral entanglement of the pair, and about the dynamical properties of the medium. A possible experimental technique for accessing this information will be proposed.

Q 23.4 Tue 18:00 P1

Scalable quantum computation via local control of only two qubits — •Daniel Burgarth[1], Koji Maruyama[2], Michael Murphy[3], Simone Montangero[3], Tommaso Calarco[3], Franco Nori[2], and Martin Plenio[4] — [1]IMS and QOLS, Imperial College, London, United Kingdom — [2]Advanced Science Institute, The Institute of Physical and Chemical Research (RIKEN), Wako-shi, Japan — [3]Institut für Quanteninformationsverarbeitung, Universität Ulm — [4]Institut für Theoretische Physik, Universität Ulm

Recent experiments on solid state qubits have focused on the implementation of high-fidelity operations on two qubits. It may seem that scaling these experiments to say 30 qubits requires a further big step in controlling the qubits. We show that this is not the case: the control implemented today is enough to indirectly control the remaining qubits, which can therefore remain passive. The control we have on the two qubits is mediated by the system Hamiltonian in a scalable way. This is shown by quantum control. In order to compute the required control pulses in a scalable fashion, we had to find a trick to separate the complexity of the dynamics (required for universal quantum computation) from its simulability (required for quantum control).

Q 23.5 Tue 18:00 P1

Estimating mixed qudits: hedging and adaption — •Christof Happ, Florian Nägele, and Matthias Freyberger — Institut für Quantenphysik, Universität Ulm, D-89069 Ulm

Reconstruction of a completely unknown quantum state from limited resources, i. e. when only a small number of identically prepared states are available, is an important challenge in the field of quantum information. We present Monte-Carlo simulations of estimation processes for mixed qubits and qu*d*its (d-level states), that compare different estimation methods, namely standard maximum likelihood estimation and a modification of it, the so called hedged maximum likelihood estimation. The latter promises better estimation quality for mixed states. Additionally, we discuss adaptive methods to further improve estimation quality for this estimation schemes.

Q 23.6 Tue 18:00 P1

Cyclic Mutually Unbiased Bases and the Fibonacci Sequence — •Ulrich Seyfarth[1], Kedar Ranade[2], and Gernot Alber[1] — [1]Institut für Angewandte Physik, Technische Universität Darmstadt, 64289 Darmstadt, Germany — [2]Institut für Quantenphysik, Universität Ulm, Albert-Einstein-Allee 11, 89069 Ulm, Germany

The construction of mutually unbiased bases (MUBs) is of high interest in quantum information science. MUBs are called cyclic if they can be constructed by repeated applications of a single unitary operator. To get a deeper notion of how to contruct complete sets of cyclic MUBs in arbitrary dimensions it is important to explore their mathematical structure. Based on recent work [1] a connection between cyclic MUBs and the Fibonacci sequence is established. This connection enables one to find complete sets of cyclic MUBs in arbitrary even prime-power dimensions. Thereby, known properties of the Fibonacci sequence yield a simplified construction method conveying a better notion of complete sets of cyclic MUBs.

[1] O. Kern, K. S. Ranade and U. Seyfarth, J. Phys. A, 43, 275305 (2010)

Q 23.7 Tue 18:00 P1

Designing Ideal Hamiltonian Qubit Dynamics by Dynamical Recoupling — •Holger Frydrych and Gernot Alber — Institut für Angewandte Physik, Technische Universität Darmstadt, D-64289 Darmstadt

Dynamical recoupling is a powerful method for suppressing unwanted parts of an active Hamiltonian on a qubit network, provided one is able to control all relevant qubits appropriately. A general construction principle is presented for dynamical recoupling schemes which are capable of transforming a given qubit Hamiltonian into a desired ideal form. The necessary and sufficient conditions which have to be fulfilled by the Hamiltonian are discussed.

As an example it is demonstrated how a particular perfect-state-transfer Hamiltonian [1][2] can be designed by a dynamical recoupling scheme in a linear qubit chain governed by nearest-neighbour interactions.

References:

[1] G. M. Nikolopoulos et al. Eur. Phys. Lett. 65, 297 (2004)
[2] M. Christandl et al. Phys. Rev. Lett. 92, 187902 (2004)

Q 23.8 Tue 18:00 P1

Local Entropy Flow in Qubit Networks Under Random Controlled Unitary Transformations — •Jaroslav Novotny[1,2], Gernot Alber[1], and Igor Jex[2] — [1]Institut für Angewandte Physik, Technische Universität Darmstadt, D-64289 Darmstadt, Germany — [2]Department of Physics, FNSPE CTU in Prague, Czech Republic

The asymptotic dynamics of many-qubit quantum systems is investigated under iteratively applied random unitary transformations [1]. For a one-parameter family of controlled unitary transformations two main theorems are proved which characterize completely the dependence of this asymptotic dynamics on the topology of the interaction graph which encodes all possible qubit couplings. On the basis of these theorems the local entropy transport between an open quantum system and its environment are explored for strong non-Markovian couplings and for different sizes of the environment and different interaction topologies. In particular, the processes of thermalization and cooling of an open subsystem are investigated in detail. It is shown that both processes are possible if couplings between the subsystem and its environment act in both directions. If this condition is violated a successful realization of both processes is not possible.

References:

[1] J. Novotny, G. Alber, I. Jex, Cent. Eur. J. Phys. **8**, 1001 (2010).

Q 23.9 Tue 18:00 P1

Noise Spectrum Analysis at the NV center in diamond — •Konstantin Schukraft, Florian Rempp, Fedor Jelezko, and Jörg Wrachtrup — 3. Physikalisches Institut, Uni Stuttgart

Being able to extend the coherence time of quantum systems is very important not only for quantum computers, but also for high precision metrology applications. To efficiently decouple a system from its environment one needs to know that environment, characterised by the noise spectrum it generates. Since the noise spectrum isn't accessible directly in our case, we retrieve it via echo measurements. These are conducted with the NV centers electron spin; not only already an important measurement tool for the aforementioned high precision measurements, but also a candidate for high/room temperature quantum

computers.

Q 23.10 Tue 18:00 P1

Illustrating the Geometry of Quantum Channels — •Corey O'Meara[1], Gunther Dirr[2], and Thomas Schulte-Herbrüggen[1] — [1]Dept. Chem., TU-Munich, Germany — [2]Math. Inst., University of Würzburg, Germany

Standard Markovian quantum channels are elucidated geometrically in terms of (Lie)semigroups. We specify the respective tangent cones, i.e. Lie wedges, for a variety of open quantum system evolutions undergoing well known types of dissipative interactions with the environment.

In practice, such dissipative dynamics are inherent in many experimental implementations. The corresponding tangent cones which characterize the channels' time evolution subject to external controls in fact give illustrative insight into the differential geometry of open-system dynamics under Hamiltonian controls. Furthermore, this insight may subsequently be exploited to approximate the reachable sets of given initial quantum states.

Q 23.11 Tue 18:00 P1

Quantum information transfer with trapped-ion antennae — •Regina Lechner[1], Maximilian Harlander[1], Michael Brownnutt[1], Rainer Blatt[1,2], and Wolfgang Hänsel[1,2] — [1]Institut für Experimentalphysik, Universität Innsbruck, Technikerstraße 25, 6020 Innsbruck, Austria — [2]Institut für Quantenoptik und Quanteninformation der Österreichischen Akademie der Wissenschaften, Technikerstraße 21a, 6020 Innsbruck, Austria

To make trapped-ion quantum computing useful, scaling to many ions is imperative. One method of achieving this is to use miniaturized, segmented ion traps and by coupling ions trapped in separate wells[1]. A major obstacle to be overcome in implementing such techniques is to achieve gate operations that are much faster than the ion-heating rate which scales as d^{-4}, where d is the distance between the ions and the electrodes. As traps are miniaturized the gate speed increases, but so do the heating rates. We solve this problem by using multiple ions in each well as antennae to increase the dipole-dipole interaction. By using three ions in each of two wells, a 7-fold increase in interaction speed is observed compared with the case of a single pair of ions[2]. The experimental setup used to implement the double-well potential is described, focusing on the generation of the low-noise voltages required to achieve suitable ion stability, and for the reduction of technical-noise-induced ion heating. References [1] Cirac, J. I. & Zoller, P.; Nature 404, 579 (2000). [2] Harlander, M., Lechner, R., Brownnutt, M., Blatt, R. & Hänsel, W.; arXiv:1011.3639v2.

Q 23.12 Tue 18:00 P1

Measurement Based Quantum Computing with Optical Superlattices — •Alexander Kegeles[1], Mathis Friesdorf[1], Jonas Hörsch[1], Matthias Ohliger[1], David Gross[2], and Jens Eisert[1] — [1]Universität Potsdam, Institut für Physik und Astronomie, Karl-Liebknecht-Strasse 24/25, 14476 Potsdam, Germany — [2]ETH Zürich, Theoretische Physik, Wolfgang-Pauli-Strasse 27, 8093 Zürich, Switzerland

Measurement Based Quantum Computing (MBQC) is a very promising paradigm for the realization of a quantum computer, as it allows to separate the computation in the creation of an universal (independent of the performed algorithm) resource and the actual computing which is done by local measurements only. Possible resource states for single-qubit processing (quantum wires) and their couplings have already be classified using the formalism of Matrix Product States (MPS).

Cold atoms in optical super-lattices allow for controlled translationally invariant nearest-neighbor interaction between qubits, which can be described with the Margolus model of Quantum Cellular Automata (QCA). We explore the possibilities to create quantum wires with experimentally accessibly operations and discuss possible two-dimensional couplings.

Q 23.13 Tue 18:00 P1

Entanglement-Enhanced Classical Communication over a Noisy Classical Channel — •Robert Prevedel, Yang Lu, Will Matthews, Rainer Kaltenbaek, and Kevin Resch — Institute for Quantum Computing, University of Waterloo, Waterloo, N2L 3G1, ON, Canada

We present and experimentally demonstrate a communication protocol that employs shared entanglement to reduce errors when sending a bit over a particular noisy classical channel. Specifically, it is shown that, given a single use of this channel, one can transmit a bit with higher success probability when sender and receiver share entanglement compared to the best possible strategy when they do not. The experiment is realized using polarization-entangled photon pairs, whose quantum correlations play a critical role in both the encoding and decoding of the classical message. Experimentally, we find that a bit can be successfully transmitted with probability 0.891 ± 0.002, which is close to the theoretical maximum of $(2 + 2^{-1/2})/3 \approx 0.902$ and is significantly above the optimal classical strategy, which yields $5/6 \approx 0.833$.

Q 23.14 Tue 18:00 P1

Aufbau eines QKD-Setups mit passiver Zustandspräparation — •Tobias Diehl, Sabine Euler, Jan Hendrik Abel, Mathias Sinther und Thomas Walther — IAP, TU Darmstadt, Schlossgartenstraße 7, 64289 Darmstadt

Die Quantenkryptografie bietet eine Möglichkeit, einen zur Verwendung als One-Time-Pad geeigneten Schlüssel sicher zwischen den Übertragungspartnern auszutauschen. Das BB84-Protokoll bietet eine mögliche Realisierung, basierend auf der Präparation der Polarisation einzelner Photonen in zwei verschiedenen Basen. Zur Bereitstellung der einzelnen Photonen verwenden wir einen Typ-II SPDC-Prozess in einem PPKTP mit Wellenleiterstruktur. Ein Photon des erzeugten Paares dient dabei als Herald für das zweite, zur Übertragung verwendete, Photon. Um die beiden erforderlichen Basen zu realisieren, wird der Pumplaser bei 404 nm (cw) von beiden Seiten in den Kristall eingekoppelt. Eine geeignete Detektionseinheit aus einer Kombination aus Strahlteilerwürfeln und Photodioden macht es möglich, einzelne Photonen in verschiedenen Polarisationszuständen zu präparieren und angekündigt zu verschicken, ohne auf aktive Präparationseinheiten wie beispielsweise akusto-optische Modulatoren zurückzugreifen. Die klassische Kommunikationsstrecke, basierend auf einem gepulsten Laser, dient gleichzeitig der Strahlverfolgung und Justage des Empfängermoduls. Der aktuelle Stand des Projekts wird diskutiert.

Q 23.15 Tue 18:00 P1

Quantum Key Distribution on Hanover Campus — •Vitus Händchen[1], Tobias Eberle[1,3], Jörg Duhme[2,3], Torsten Franz[2], Roman Schnabel[1], and Reinhard Werner[2] — [1]Institut für Gravitationsphysik, Leibniz Universität Hannover und Max-Planck-Institut für Gravitationsphysik (Albert-Einstein-Institut) — [2]Institut für Theoretische Physik, Leibniz Universität Hannover — [3]QUEST Centre for Quantum Engineering and Space-Time Research, Leibniz Universität Hannover

We report on the planned experimental implementation of quantum key distribution on the campus of the Leibniz Universität Hannover. A fiber based continuous variable quantum cryptographic link will be established between the Albert-Einstein-Institute and the Institute of Quantum Optics, which are about 1 km apart. The link will be build with two-mode squeezed states at 1550 nm and standard telecommunication fibers. We present first experimental results concerning the generation of two-mode squeezing at 1550 nm. Furthermore the security of our scheme will be discussed and the expected secure key rates will be presented.

Q 23.16 Tue 18:00 P1

Efficient entanglement purification protocol using chains of atoms and optical cavities — •Denis Gonta and Peter van Loock — Optical Quantum Information Theory Group, Max Planck Institute for the Science of Light, Günther-Scharowsky-Str. 1, Bau 26, D-91058 Erlangen

In the framework of cavity QED, we propose an efficient scheme to purify bipartite entanglement by using short chains of atoms coupled to high-finesse optical cavities. In contrast to the conventional entanglement purification scheme [1], we avoid CNOT gates and reduce, therefore, complicated pulse sequences and superfluous qubit operations. Our interaction scheme works in a deterministic way, and together with entanglement distribution and swapping, yields an efficient quantum repeater protocol for long-distance quantum communication.

[1] C. H. Bennett et al., Phys. Rev. Lett. 76, 722 (1996);
C. H. Bennett et al., Phys. Rev. A 54, 3824 (1996).

Q 23.17 Tue 18:00 P1

Aufbau einer Zwei-Photonen-Quelle — •Sabine Euler, Mathias Sinther und Thomas Walther — TU Darmstadt, Institut für angewandte Physik, Schlossgartenstraße 7, 64289 Darmstadt

Durch einen Typ II SPDC-Prozess in PPKTP bei 404 nm werden zunächst zwei frequenzgleiche Photonen erzeugt, die sich nur in ihrer Polarisation unterscheiden. In einem zweiten Schritt wird eines dieser Photonen um 90° in seiner Polarisation gedreht und erneut in den Kristall eingekoppelt. Durch einen DFG-Prozess zwischen diesem rückgekoppelten Photon und einem Pumpphoton entstehen zwei identische Photonen, die an einem polarisierenden Strahlteiler ausgekoppelt und nach einem weiteren 50-50 Strahlteiler als koinzidente Ereignisse detektiert werden können. Ein weiteres, zu den beiden ersten Photonen senkrecht polarisiertes Photon kann erneut zur Rückkopplung verwendet werden. Der aktuelle Status des Experimentes wird diskutiert.

Q 23.18 Tue 18:00 P1

Quantum key distribution on Hanover Campus: Theory — •Jörg Duhme[1], Torsten Franz[1], Reinhard F. Werner[1], Vitus Händchen[2], Tobias Eberle[2], and Roman Schnabel[2] — [1]Leibniz Universität Hannover, Institut für Theoretische Physik, AG Quanteninformation — [2]Albert Einstein Institut, Quantum Interferometry

We report on the implementation of an entanglement-based quantum cryptograph on Hanover campus using squeezed gaussian states (continuous variables). This poster focuses on the theoretical aspects of this project. First available experimental data has been compared with the theoretical simulation of the experimental setup. We discuss the different sources of noise in the setup focusing especially on their impact on the key rate and the EPR-criterion. Furthermore we discuss the possible origins of memory effects in the experiment.

Q 23.19 Tue 18:00 P1

Laser-Assisted Bell Measurements and Spontaneous Decay Processes — •Jozsef Zsolt Bernad and Gernot Alber — Institut für Angewandte Physik, Technische Universität Darmstadt, D-64289 Darmstadt

Following the original suggestion of Briegel et al. [1] recently also alternative theoretical proposals of quantum repeaters have been developed in which the Bell-measurements required are implemented by different physical processes. The recent proposal for a quantum repeater based on continuous variables by van Loock et al. [2,3], for example, is based on Bell measurements which are performed with the help of off-resonant laser-induced couplings in the relevant material qubits. In this contribution the resulting realistic effects of spontaneous decay of the excited qubits are investigated and their influence on the quality of Bell measurements is explored. It constitutes a first step towards the development of appropriate error suppression methods which counteract the entanglement breaking tendencies of spontaneous decay processes.

[1] H. J. Briegel, W. Dür, J. I. Cirac, P. Zoller, Phys. Rev. Lett. 81, 5932 (1998).

[2]P. van Loock, T. D. Ladd, K. Sanaka, F. Yamaguchi, K. Nemoto, W. J. Munro, and Y. Yamamoto, Phys. Rev. Lett. 96, 240501 (2006).

[3]P. van Loock, N. Lütkenhaus, W. J. Munro, and K. Nemoto, Phys. Rev. A 78, 062319 (2008).

Q 23.20 Tue 18:00 P1

Fabrication and characterisation of tailored waveguide PDC sources in RPE:PPLN for quantum communication — •Stephan Krapick, Hubertus Suche, Harald Herrmann, Raimund Ricken, Viktor Quiring, Christine Silberhorn, and Wolfgang Sohler — Universität Paderborn - Department Physik - AG "Integrierte Quantenoptik", Warburger Str. 100, D-33098 Paderborn

Parametric down conversion (PDC) is a well established process for the generation of photon pairs. Due to their high brightness, the spatial mode confinement and most importantly the flexibility in wavelength of the generated photon pairs, PDC devices can be utilized as ideal sources to address various ionic quantum memories in quantum repeaters. We present the results of the preparation and characterisation of waveguides in periodically poled z-cut Lithium Niobate (PPLN). In order to exploit the large second order nonlinearity of Lithium Niobate, Type I quasi-phasematching is employed to enable photon pair generation. In the fabrication process of the waveguides the promising approach of reversed proton exchange (RPE) is used. This provides us with low-loss and high-efficiency waveguides of symmetrical mode intensity distributions, which allow extraordinary fiber coupling. Various parameters have been tested to tailor the fluorescence of a 532 nm pump at will, yielding the addressability of Nd(3+)- and Tm(3+)-Ions to be used in quantum memories.

Q 23.21 Tue 18:00 P1

Improving entanglement based quantum key distribution through turbulent atmosphere — •Bettina Heim[1,2,3], Chris Erven[3], Raymond Laflamme[3,4], Gregor Weihs[3,5], and Thomas Jennewein[3] — [1]Max Planck Institute for the Science of Light, Erlangen, Germany — [2]Institute of Optics, Information und Photonics, University of Erlangen-Nuremberg, Erlangen, Germany — [3]Institute for Quantum Computing, University of Waterloo, Waterloo, ON, Canada — [4]Perimeter Institute, Waterloo, Canada — [5]Institute for Experimental Physics, University of Innsbruck, Innsbruck, Austria

Within the framework of our free-space quantum key distribution system, we study influences of the turbulent atmosphere on entangled photons sent over a 1.3 km free-space link, and explore the possibility of optimizing the quantum transmisson in this situation. Entangled photons are created in a Sagnac configuration [1], using a periodically poled KTP non-linear optical crystal that is placed in an interferometer loop and pumped bi-directionally. One photon of each pair is detected locally, the other one is sent through the free-space channel. We specifically studied the effects of the atmospheric channel on the entanglement properties and the performance of our system under various losses and pump rates with a view to improving the signal-to-noise ratio of the system in order to increase the secret key rate. In the future, we intend to perform the same study with two independent free-space links. [2].

[1] C. Erven et al., QuantumCom2009, LNICST 36, 108-116, 2010.

[2] C. Erven et al., Opt. Exp. 16, 16840-16853 (2008).

Q 23.22 Tue 18:00 P1

Quantifying effective entanglement in a continuous-variables QKD system — •Imran Khan[1,2], Christoffer Wittmann[1,2], Nitin Jain[1,2], Josef Fürst[1,2], Nathan Killoran[3], Norbert Lütkenhaus[3], Christoph Marquardt[1,2], and Gerd Leuchs[1,2] — [1]Max-Planck-Institute für die Physik des Lichts, Günther-Scharowsky-Str. 1, 91058 Erlangen — [2]Institut für Optik, Information und Photonik, Universität Erlangen-Nürnberg, Staudtstraße 7/B2, 91058 Erlangen — [3]Institute for Quantum Computing, 200 University Ave. W.,Waterloo, ON N2L 3G1

We discuss a continuous-variables QKD system, where non-orthogonal coherent states are sent through a fiber-based quantum channel. The phase modulated signal is detected using simultaneous homodyne detection of conjugate quadratures. Evidence of quantum correlations in this raw data are a prerequisite for the production of a secure key. The quantum correlations can be modeled by effective entanglement. We have witnessed these correlations for a 2 km link. Our aim is to increase the channel length and quantify the effective entanglement.

Q 23.23 Tue 18:00 P1

Coherent Rydberg Excitation in Thermal Microcells — •Renate Daschner[1], Harald Kübler[1], Bernhard Huber[1], Thomas Baluktsian[1], Andreas Kölle[1], James P. Shaffer[2], Robert Löw[1], and Tilman Pfau[1] — [1]5. Physikalisches Institut, Universität Stuttgart, Germany — [2]Homer L. Dodge Department of Physics and Astronomy, The University of Oklahoma, USA

In order to create quantum devices based on the Rydberg blockade mechanism, it is necessary to have a confinement of the excitation volume to less than the blockade radius in a frozen gas of atoms; i.e. the excitation times need to be shorter than the timescales of the respective dephasing mechanisms.

While ultracold gases seem to be the obvious choice, our approach utilizes thermal atomic vapor in small glass cells [1] which offer multiple advantages like good optical access and scalability. Such a system can be realized by confining the atoms to geometries in the μm regime.

Decoherence effects like resonant interactions of the Rydberg atoms with polaritonic excitations in the glass have been studied and can be minimized by the appropriate choice of Rydberg states [2].

Using a bandwidth-limited pulsed laser system for the Rydberg excitation we observe coherent Rabi oscillations on the nanosecond timescale. We discuss future perspectives for Quantum information processing.

[1] Baluktsian, T., et. al. *Opt. Lett.* **35**, 1950 (2010)

[2] Kübler, H., et. al. *Nature Photon.* **4**, 112-116 (2010)

Q 23.24 Tue 18:00 P1

Towards an efficient quantum memory using atomic vapour — •Tobias Latka, Andreas Neuzner, Eden Figueroa, and Gerhard Rempe — Max-Planck-Institute of Quantum Optics, Hans-Kopfermann-Str. 1, 85748 Garching

One of the main challenges in the implementation of quantum memories is achievement of high retrieval efficiency. State of the art ex-

periments report efficiencies as high as 45% [1]. Nonetheless, higher values are required e.g. for the implementation of an efficient quantum repeater. A new approach based on off-resonant photon echoes in three-level atoms has paved the way for higher storage efficiencies [2]. We present our current results towards the implementation of such a device in Rubidium vapor. We discuss our simulations regarding the design of coils capable of producing the essential switchable linear field gradient required for the photon echoes generation, experimentally achievable efficiencies, and the future use of the system in combination with a cavity QED based source of single photons [3].

[1] I. Novikova, et al., Phys. Rev. A 78, 021802 (2008)
[2]M. Hosseini, et al., arXiv: 1009.0567v1 (2010).
[3] M. Hijlkema, et al., Nature Physics 3, 253 (2007).

Q 23.25 Tue 18:00 P1

A Bose-Einstein Condensate as Quantum Memory for Optical Polarisation Qubits — •Christoph Vo, Matthias Lettner, Martin Mücke, Stefan Riedl, Carolin Hahn, Simon Baur, Jörg Bochmann, Stephan Ritter, Stephan Dürr, and Gerhard Rempe — Max-Planck-Institute of Quantum Optics, Hans-Kopfermann-Str. 1, 85748 Garching

We present the experimental characterization of a quantum memory for optical polarisation qubits using electromagnetically induced transparency (EIT) in a Bose-Einstein condensate of ^{87}Rb atoms. Our system operates 70 MHz detuned from the D_1-line in a moderately-detuned Raman regime rather than the on-resonance EIT regime. Photonic polarisation qubits are mapped onto Zeeman qubits in the atomic system. Using classical light pulses, we performed a full quantum process tomography to determine the Müller matrix of the system.

To demonstrate the performance of our memory in the quantum regime, we stored a single photon of a polarisation-entangled Einstein-Podolsky-Rosen pair. After retrieving the stored photon from the memory we performed a quantum state tomography to determine the density matrix of the bi-partite system and found close resemblance with the original state. The fidelity of the retrieved state with respect to the maximally-entangled $|\Psi^-\rangle$ Bell state is found to be well above the classical limit of 0.5, showing the memory's suitability as building block of a quantum repeater for long-distance quantum communication.

Q 23.26 Tue 18:00 P1

Non-linear optics using single-atom cavity Electromagnetically Induced Transparency — •Eden Figueroa[1], Celso J. Villas-Boas[2], Stephan Ritter[1], and Gerhard Rempe[1] — [1]Max-Planck-Institute of Quantum Optics, Hans-Kopfermann-Str. 1, 85748 Garching — [2]Departamento de Fisica, Universidade Federal de São Carlos, 13565-905 São Carlos, SP, Brazil

A fundamental challenge for quantum optics is the realization of nonlinear systems capable of mediating strong interactions between light fields at the few- photon level. A promising avenue to achieve this goal is the combination of cavity Quantum Electrodynamics (cQED) and Electromagnetically Induced Transparency (EIT). Along these lines, a breakthrough has been achieved recently, as a new generation of experiments has reached the necessary conditions to observe EIT with single atoms [1]. Here we study this new phenomenon theoretically and explore possible realistic applications based upon the non-classical behaviour of the system, ranging from the coherent control of the photon statistics of incident beams, to its use as a photonic gate for quantum information purposes [2]. We will highlight future perspectives and possible strategies to implement these ideas with existing cQED setups.

[1] M. Mücke, et al., Nature 465, 755 (2010).
[2] Rebic et al., J. Opt. B: Quantum Semiclass. Opt. 1, 490 (1999).

Q 23.27 Tue 18:00 P1

Optical nanofibers in ion-traps — •Jan Petersen[1], Benjamin Ames[2], Michael Brownnutt[2], Rainer Blatt[2], and Arno Rauschenbeutel[1] — [1]Technische Universität Wien - Atominstitut, 1020 Wien, Austria — [2]Institut für Experimentalphysik, Unversität Innsbruck, 6020 Innsbruck, Austria

Atoms and molecules can be efficiently coupled to the intense evanescent light field around optical nanofibers. Such nanofibers are realised from standard optical fibers in a heat and pull process to produce a waist with a diameter of several 100 nm. Ion traps, on the other hand, are one of the most successful systems for manipulating single particles. Trapped ions can be confined for long durations and by tuning the electric trapping potentials one can adjust their position with a precision of a few nanometers.

We are planning to profit from the advantageous properties of both systems and set up an experiment, in which an optical nanofiber is integrated in an ion trap. With this setup one could probe the evanescent light field with an ion and also use the optical nanofiber to efficiently excite the ions and to collect their fluorescence. As the ion will have to be placed in close vicinity of the nanofiber surface (around 100 nm), charging effects of the fiber surface have to be minimized. We present results and discuss possibilities of coating the fibers to tackle this problem.

Financial support by ERA-Net Research Network "Nanofibre Optical Interfaces, (NOIs)", the Volkswagen Foundation (Lichtenberg Professorship) and the ESF (EURYI Award) is gratefully acknowledged.

Q 23.28 Tue 18:00 P1

Implementation of quantum error correction protocols in a small quantum register — •Matthias Nitsche, Matthias Steiner, Gerald Waldherr, Philipp Neumann, Fedor Jelezko, and Joerg Wrachtrup — 3. Physikalisches Institut, Universitaet Stuttgart, Pfaffenwaldring 57, D-70550, Germany

Electron spins associated with the nitrogen-vacancy (NV) defect in diamond are promising candidates for quantum information processing at room temperature. For practical applications, however, the quantum information stored in a spin qubit has to be protected from phase and bit-flip errors. Techniques like the encoding of quantum state in decoherence free subspaces or the application of error correction protocols involving proximal nuclear spins are discussed.

Q 23.29 Tue 18:00 P1

Quantum information processing with atoms in arrays of dipole potentials — •Sascha Tichelmann, Malte Schlosser, Jens Kruse, and Gerhard Birkl — Institut für Angewandte Physik, Technische Universität Darmstadt, Schlossgartenstraße 7, 64289 Darmstadt

Neutral atoms confined in two-dimensional multi-site potential geometries represent an important experimental approach towards quantum information processing. By using well separated optical micropotentials created by micro-fabricated lens arrays, we obtain highly controllable and scalable quantum systems with single-site addressability and long coherence times. Our microtrap array accesses the regime of collisional blockade, which allows us to prepare atom distributions with sub-Poissonian statistics.

We achieve a direct control of each trap by implementing a spatial light modulator to create arbitrary trap configurations as well as flexible, site-specific, but also parallelized initialization and coherent manipulation of small ensembles or single ^{85}Rb atoms. Towards the entanglement of qubits, we demonstrate the coherent transport of atomic quantum states in a shift register architecture. The shift sequence is based on loading, moving and reloading of two independently controllable microtrap arrays.

We also report on an experimental scheme compensating for the differential lightshift induced by the dipole traps. This "magic-wavelength" behavior results in a strong suppression of dephasing. The scheme is extendable to all alkali elements.

Q 23.30 Tue 18:00 P1

Spin-Spin interaction in impurity doped ion crystal — •Peter Ivanov, Amado Bautista-Salvador, Jens Welzel, Niels Kurz, Frank Ziesel, Max Hettrich, Ulrich Poschinger, and Ferdinand Schmidt-Kaler — Institut für Physik, Johannes Gutenberg-Universität Mainz, 55099 Mainz, Germany

For the simulation of magnetic quantum phase transitions, we consider the behavior of the effective spin-spin couplings in an ion crystal of $^{40}Ca^+$ $S = 1/2$ ions doped with high magnetic moment ions, such as Mn^+, which possess spin $S = 3$ in the electronic-ground state. Spin-spin interactions are tailored by employing an oscillating magnetic field with a strong gradient. The presence of ion species with $S > 1/2$ increases the strength of the effective spin-spin interaction which allows for observation of Schrodinger cat states of large size. Moreover, we discuss how the impurity doped ion crystal is suited for the investigation of quantum phase transitions and frustration effects in spin systems. First experimental steps in a specialized planar ion trap have been realized. We will report about the experimental and theoretical progress

Q 23.31 Tue 18:00 P1

Towards a universal, single-atom based quantum interconnect

— •Andreas Reiserer, Holger Specht, Christian Nölleke, Manuel Uphoff, Eden Figueroa, Stephan Ritter, and Gerhard Rempe — Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Str. 1, 85748 Garching

A prerequisite for the realization of quantum networks is a coherent interface between flying and stationary qubits. A promising candidate for such a device is a single atom that interacts with single photons via a high-finesse optical cavity. It has been shown that atom-cavity systems can be used for efficient and controlled single photon production via vacuum stimulated Raman transitions (vSTIRAP) between two atomic ground states. Here, we report on the reverse process - coherent absorption of single photons by a single atom. In our setup, we quasi-permanently trap a single Rb atom in a resonator in the intermediate coupling regime of cavity QED. We prepare the atom in the lower atomic hyperfine state (F=1). By adiabatically ramping down the power of a strong control laser pulse, we cause the atom to absorb a single photon out of a weak coherent probe pulse impinging on the cavity. In this process, the atom is transferred to the upper atomic ground state (F=2). After a finite storage time, a vSTIRAP is used to read out the stored excitation by producing a single photon. The current status towards the implementation of a quantum memory will be presented.

Q 23.32 Tue 18:00 P1

State manipulation of single atoms in a high-finesse optical cavity — •Manuel Uphoff, Christian Nölleke, Andreas Reiserer, Holger Specht, Eden Figueroa, Stephan Ritter, and Gerhard Rempe — Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Strasse 1, 85748 Garching

Single atoms trapped in a high-finesse optical cavity are an ideal candidate for the distribution of quantum information over a quantum network. Coherent manipulation of the atomic state allows single qubit rotations on the atom and the mapping of qubits to decoherence-free subspaces. Efficient state transfer by microwave radiation is prohibited in our atom-cavity system as the cavity assembly largely shields the long-wavelength radiation. Therefore stimulated Raman transitions with their sub-natural linewidth are best suited to drive transitions between hyper-fine states of atoms trapped in a high-finesse cavity. We report on near unity transfer of the population using π-pulses in 1 μs, which is much shorter than the lifetime of the atomic state. The effects of the geometry and polarisation of the Raman beams and their interplay with different Zeeman substates are investigated and future applications in detecting and manipulating the motional state of the atom will be discussed.

Q 23.33 Tue 18:00 P1

Qubit-Auslese mit einer EMCCD-Kamera — •Alex Wiens, Ulrich Poschinger, Andreas Walther, Frank Ziesel, Kilian Singer und Ferdinand Schmidt-Kaler — QUANTUM, Universität Mainz, Staudingerweg 7, 55128 Mainz

Die Auslese von atomaren Quantenbits erfolgt experimentell durch die Detektion von Resonanzfluoreszenz. Dabei wird der Zustand durch die Anzahl der detektierten Photonen in "hellöder "dunkel"klassifiziert, so dass die Güte dieser Zustandsdiskriminierung fundamental durch Schrotrauschen und Hintergrundlicht limitiert ist[1]. Wir benutzen eine EMCCD-Kamera, um mithilfe der Ortsauflösung festzustellen, inwieweit es möglich ist die optimale Güte der Diskriminierung zu erreichen [2]. Es werden Fluoreszenzmessungen an einem $^{40}Ca^+$ Ion benutzt, um den Ausleseprozess präzise zu modellieren. Auf dieser Basis werden verschiedene Zustandsklassifikationsalgorithmen in Simulationen verglichen.

[1] A.H. Myerson et al., Phys. Rev. Lett. 100, 200502 (2008).
[2] A.H. Burrell et al., Phys. Rev. A 81, 040302 (2010).

Q 23.34 Tue 18:00 P1

Interfacing Ions with Nanofibres — •Benjamin Ames[1], Michael Brownnutt[1], Jan Petersen[2], Arno Rauschenbeutel[2], and Rainer Blatt[1,3] — [1]Institut für Experimentalphysik, Uni. Innsbruck, Technikerstr. 25, 6020 Innsbruck, Austria — [2]Atominstitut, Technische Universität Wien, Stadionallee 2, 1020 Wien, Austria — [3]Institut für Quantenoptik und Quanteninformation, Österreichische Akademie der Wissenschaften, 6020 Innsbruck, Austria

Given the advances made in trapped-ion quantum information processing, ions make a natural choice of physical qubit in a register. By contrast, the ability to reliably transmit light over long distances makes photons a natural choice for flying qubits to connect the registers. It may be possible to couple these two systems by trapping ions in the evanescent field of a nanofibre.

Implementation of such an ion-fibre system is not without technical and physical challenges, particularly with regard to positional stability, and ion heating close to nanostructures. We describe an ion-trap/nanofibre system used to investigate such effects, and propose methods of observing coupling between ions and evanescent waves, even in the presence of such perturbations.

Q 23.35 Tue 18:00 P1

Aufbau zur Erzeugung von Mikrowellensignalen mit phasenkohärenter Frequenzumschaltung — •T. F. Gloger, M. Johanning, A. Khromova, Chr. Piltz, B. Scharfenberger, A. Varón und Chr. Wunderlich — Fachbereich Physik, Universität Siegen

In einer linearen Paul-Falle gespeicherte Ytterbium-Ionen lassen sich als Systeme zur Quantensimulation und -informationsverarbeitung nutzen. Geeignete Qubits werden in den langlebigen Hyperfeinzuständen $|S_{1/2}, F=0\rangle \leftrightarrow |S_{1/2}, F=1\rangle$ des $^{171}Yb^+$ Ion realisiert. Zur direkten Manipulation dieser Qubits wird ein Mikrowellenfeld mit einer Frequenz von etwa 12.6 GHz benötigt. Durch einen Magnetfeldgradienten entlang der Fallenachse werden Qubits in den zeemanaufgespaltenen Übergängen $|F=0\rangle \leftrightarrow |F=1, m_F=\pm 1\rangle$ einzeln im Frequenzraum adressierbar. Zur Quantenzustandsmanipulation mehrerer Ionen ist es notwendig, die Frequenz des elektromagnetischen Feldes phasenkohärent schalten zu können.

Wir erzeugen das benötigte Mikrowellensignal durch Mischen eines schmalbandigen Signals mit 12.568 GHz mit den Signalen zweier phasenkohärent schaltbarer Signalgeneratoren mit Frequenzen von 1-150 MHz in IQ-Konfiguration. Dies ermöglicht einen Adressierungsraum der Qubits von 300 MHz.

Der experimentelle Aufbau wird vorgestellt und hinsichtlich Frequenzstabilität, Amplitudenstabilität und Phasenrauschen charakterisiert. Darüber hinaus werden die Addressierung und Manipulation mehrerer $^{171}Yb^+$ Ionen in einer linearen Paul-Falle mit Magnetfeldgradient demonstriert.

Q 23.36 Tue 18:00 P1

Direct Characterization of Quantum Dynamics in a system of $^{40}Ca^+$ - ions — •Daniel Nigg[1], Julio T. Barreiro[1], Philipp Schindler[1], Thomas Monz[1], Michael Chwalla[1,2], Stefan Quint[1], Markus Hennrich[1], and Rainer Blatt[1,2] — [1]Institut für Experimentalphysik, Universität Innsbruck, Technikerstr. 25, 6020 Innsbruck, Austria — [2]Institut für Quantenoptik und Quanteninformation, Österreichische Akademie der Wissenschaften, Technikerstr. 21A, 6020 Innsbruck, Austria

Quantum process tomography (QPT) is an essential tool for characterizing a process in quantum information processing. Standard QPT requires a large number of measurements for various input states and measurement bases of the respective quantum system. Direct characterization of quantum dynamics (DCQD) can significantly reduce the number of measurements [1]. The process acting on a single qubit is characterized by entangling it initially with an auxiliary qubit and performing Bell-state measurements on the joint final state. An experimental realization of DCQD is reported in a system of $^{40}Ca^+$ ions confined in a linear Paul trap. The unitary processes $\sigma_{X,Y,Z}$ as well as phase and amplitude damping are characterized on a single qubit. DCQD allows determining the longitudinal and transversal relaxation times T_1 and T_2 of one or two qubits in a single measurement. Thus the system's spontaneous decay time (T_1) and dephasing time (T_2) are quantitatively analysed with a single experimental setting.

[1] M. Mosheni and D. A. Lidar, *Phys. Rev. Lett.*, 97:1-4, (2006).

Q 23.37 Tue 18:00 P1

Entangled photons at 780 nm and 795 nm from a single atom — •Joerg Bochmann, Martin Mücke, Carolin Hahn, Andreas Neuzner, Stephan Ritter, and Gerhard Rempe — Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Str. 1, 85748 Garching

Neutral atoms embedded in high-finesse optical cavities are well suited for applications in quantum information science. A prime example is entanglement of a single intra-cavity atom with a single emitted photon by means of a deterministic scheme [1]: A vacuum stimulated Raman adiabatic passage generates a photon whose polarization is entangled with the atomic spin state. After a chosen delay time, the atomic state can be mapped onto the polarization state of a second emitted photon. Crucial for applications of this scheme in quantum network experiments are achievable success rates, fidelities and coherence times.

Here, we report on significant improvements of these key parameters in our experiment and compare its performance on the D1 (795 nm) and D2 (780 nm) lines of Rubidium. We show that the fidelity with the desired Bell state is markedly increased when using the D1 line. Moreover, we are able to extend the coherence time of the atomic qubit by more than an order of magnitude, beyond 100 us. Further optimization strategies will be discussed.

[1] B. Weber et al., Phys. Rev. Lett. 102, 100 (2009).

Q 23.38 Tue 18:00 P1

Efficient single-mode fiber coupling of photons from a single ion — •Christoph Kurz[1], Jan Huwer[1,2], Michael Schug[1], José Brito[1], Philipp Müller[1], Joyee Ghosh[1,2], and Jürgen Eschner[1,2] — [1]Universität des Saarlandes, Experimentalphysik, Campus E2.6, 66123 Saarbrücken — [2]Institut de Ciències Fotòniques, Mediterranean Technology Park, 08860 Castelldefels (Barcelona)

We operate two independent linear Paul traps with single $^{40}Ca^{+}$ ions, which provides a highly modular setup for implementing quantum information processing and communication tools [1, 2]. In one application, a trapped ion is used to efficiently generate single photons, which are then coupled to a single-mode fiber. Here we present a significant improvement over previous measurements [1] by optimising the fiber coupling and making use of constructive interference of light from the ion and its mirror image.

[1] M. Almendros et al., PRL **103**, 213601 (2009)
[2] N. Piro et al., DOI: 10.1038/NPHYS1805

Q 23.39 Tue 18:00 P1

Fast and stable laser pulses using EOM for quantum information — •Stephan Quint[1], Daniel Nigg[1], Philipp Schindler[1], Markus Hennrich[1], and Rainer Blatt[1,2] — [1]Institut für Experimentalphysik, Universität Innsbruck, Technikerstr. 25, 6020 Innsbruck, Austria — [2]Institut für Quantenoptik und Quanteninformation, Österreichische Akademie der Wissenschaften, Technikerstr. 21A, 6020 Innsbruck, Austria

Technical developments in the field of quantum computing with trapped ions have made significant progress and allow one to perform single- and two-qubit quantum gates with fidelities of up to 99%. Further technological improvements are necessary to reduce the operational errors below the fault-tolerant threshold of 10^{-3} - 10^{-4}. One important source of errors are intensity fluctuations of the laser pulses used to manipulate the electrical and vibrational states of the ions. For quantum computer experiments with ions, acousto-optical modulators (AOM) are used to shape and tune these pulses. Unfortunately, thermal effects within the AOM crystal lead to intensity fluctuations of the laser intensity. This problem is overcome by using an electro-optical modulator (EOM) to shape the amplitude of the applied pulses. Besides better thermal stability, EOMs enable faster switching speeds than AOMs. An EOM, however, requires sophisticated control electronics to drive laser pulses and to compensate for drifts. In this presentation, the control electronics for generating laser pulses with an EOM is discussed and the use of this device for quantum information processing with trapped ions is reviewed.

Q 23.40 Tue 18:00 P1

Phase transitions in ion chains — •Luis Rico Pérez and James R. Anglin — Technische Universität Kaiserslautern, Germany

The interest in the understanding of the behavior of low dimensional cooled ion structures has recently grown due to the suggested possibility of using them to implement quantum information processors and simulators [1]. We identify and classify the different possible phase transitions of an ion chain depending on strength and asymmetry of the trapping potential. Our results for the regime where the line and zig-zag configurations are stable agrees with previous studies for homogeneous traps [2] and we extend this by considering also transitions to 3D structures as well.

[1] J. I. Cirac, P. Zoller, PRL 74, 4091 (1995); D. Leibfried et al, Nature 422, 412 (2003); D. Porras, J. I. Cirac, PRL 92, 207901 (2004)
[2] S. Fishman, G. De Chiara, T. Calarco, G. Morigi, PRB 77, 064111 (2008)

Q 23.41 Tue 18:00 P1

Entanglement between two remotely trapped atoms — •N. Ortegel[1], J. Hofmann[1], M. Krug[1], F. Henkel[1], W. Rosenfeld[1], M. Weber[1], and H. Weinfurter[1,2] — [1]Fakultät für Physik der LMU München, Schellingstr. 4/III, 80799 München — [2]Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Str. 1, 85748 Garching

Entangled atom-atom pairs can serve as basic elements in quantum communication schemes such as quantum repeaters. They can also be used to carry out fundamental tests of quantum mechanics such as tests of Bell's inequality.

In our experiment we generate an entangled pair of single atoms that are located in two independent optical dipole traps by using the entanglement-swapping protocol.

Here we present details of the main building blocks of this experiment: Creation of entanglement between the electronic spin state of an atom and the polarization state of a photon [1], distribution of atom-photon entanglement over a distance of 300 m via an actively stabilized optical fiber link [2], a Bell-state measurement of the two photons by two-photon interference at a fiber beam-splitter and finally a sub-microsecond readout scheme of the atomic state by state-selective ionization [3]. The latter promises to be fast and efficient enough to allow for a loophole-free test of Bell's inequality [4].

[1] J. Volz et al., PRL 96 (2006)
[2] W. Rosenfeld et al., PRL 101 (2008)
[3] F. Henkel et al., arXiv:1008.1910v2 (2010)
[4] W. Rosenfeld et al., Adv. Sci. Lett. 2, 469 (2009)

Q 23.42 Tue 18:00 P1

Towards quantum simulations in a two-dimensional lattice of ions — •Christian Schneider, Johannes Stroehle, Martin Enderlein, Thomas Huber, Stephan Duewel, and Tobias Schaetz — Max-Planck-Institut für Quantenoptik

Linear Paul traps have demonstrated to be a well-suited tool for quantum simulations [1,2]. General 2D interactions or large-scale systems can hardly be simulated in conventional Paul traps. Surface-electrode traps are a promising candidate to overcome some of these limitations and allow to design arbitrary trapping geometries [3].

We started a collaboration with Roman Schmied (Uni Basel), Didi Leibfried (NIST, Boulder) and Dave Moehring (Sandia National Labs) to investigate the feasibility of a surface-electrode trap providing a lattice of RF traps. We want to report on our progress in setting up a new experiment and visions for quantum simulations. A linear surface-electrode trap from Sandia National Labs has been successfully assembled into a vacuum system to test the integral parts of a new setup. Afterwards, we plan to substitute it by a first lattice trap with three trapping zones arranged in a triangle. The zones will have mutual distances of 40 μm and a height above the surface of 40 μm, which could already allow to achieve a sufficient coupling strength between the ions for first quantum simulation experiments in two dimensions.

[1] A. Friedenauer et al., Nat. Phys. 4, 757-761 (2008)
[2] H. Schmitz et al., PRL 103, 090504 (2009) and
F. Zähringer et al., PRL 104, 100503 (2010)
[3] R. Schmied et al., PRL 102, 233002 (2009)

Q 23.43 Tue 18:00 P1

Microstructured ion traps for microwave-based quantum information — •Muhammad Tanveer Baig, Thomas Collath, Michael Johanning, Delia Kaufmann, and Christof Wunderlich — Fachbereich Physik, Universität Siegen, 57068 Siegen

Ion trap based quantum computing has proven its prominent position for a future quantum computer and laser cooled ions held in microstructured segmented linear Paul traps (micro-traps) are particularly promising candidates. A large number of DC electrodes in micro-traps are very useful for shuttling and separating the trapped ions as well as for controlling the range and magnitude of the spin-spin coupling between the ions. We will use Magnetic Gradient Induced Coupling (MAGIC) to address individual trapped (Yb+) ion and do laser-less quantum information with microwave pulses controlling the qubits. Our recent setup provides a ceramic chip carrier; this acts as the mechanic base for the micro-structured trap chip and as a vacuum interconnect using thick film technology; furthermore it permits very short distances to low pass filtering circuits. A glass cap allows good optical and microwave access. The recent results will be presented.

Q 23.44 Tue 18:00 P1

Opical Trapping of an Ion - Results and Perspectives — •Thomas Huber, Martin Enderlein, Christian Schneider, Stephan Duewel, Johannes Stroehle, and Tobias Schaetz — MPI für Quantenoptik

The simulation of large quantum systems on conventional computers is impossible, since quantum behavior is not efficiently translatable in classical language. However, one could gain deeper insight into complex quantum dynamics via experimentally simulating the quantum behaviour of interest in quantum system, where some relevant parameters can be controlled and robust effects detected sufficiently well. One example is simulating quantum-spin systems with trapped ions and one approach among others to reach scalability might be to combine the advantages of trapped ions with optical lattices. As a first experimental step, we were able to trap an ion in an optical dipole trap. The measured lifetime of milliseconds allows for hundreds of oscillations within the optical potential. It is limited by heating due to photon scattering. In the near future, we plan to realize cooling to increase the lifetime and to investigate the limitations on the coherence times. Next to quantum simulations with several ions interacting via phonons like the simulation of the Ising Hamiltonian, a new class of quantum simulations might become accessible, based on the potentially intriguing interplay between neutral and charged particles in common optical lattices. Furthermore, confining an ion and atoms in one common optical dipole trap might allow to investigate ultra cold collisions without the limitations set by radio-frequency driven micro-motion.

Q 23.45 Tue 18:00 P1

Spin and spin-lattice relaxation in isotopically pure diamond — •Jan Honert[1], Helmut Fedder[1], Michael Klas[1], Junichi Isoya[3], Matthew Markham[2], Daniel Twitchen[2], Fedor Jelezko[1], and Jörg Wrachtrup[1] — [1]Universität Stuttgart, 70550 Stuttgart, Germany — [2]Element Six Ltd, King's Ride Park, Ascot SL5 8BP, UK — [3]Graduate School of Library, Information and Media Studies, University of Tsukuba, 1-2 Kasuga, Tsukuba, Ibaraki 305-8550, Japan

The Nitrogen-Vacancy defect in diamond is a promising solid-state spin qubit, that allows optical readout and coherent spin manipulation even at room temperature. One of the crucial properties with respect to spin based quantum applications is a long spin coherence time T2. In diamond, T2 is typically limited by coupling to 13C nuclear spins. Record T2 times reaching several ms were recently demonstrated using isotopically enriched (99.7% 12C) diamond. Under ideal conditions, the limit for T2 is set by spin-lattice relaxations that can reach tens of ms in typical samples. We study the spin and spin-lattice relaxation time in ultra pure isotopically enriched (up to 99.99%) diamonds. In addition to results from our magnetically shielded setup an overview of the current understanding of the contributing factors to the spin decoherence are presented.

Q 23.46 Tue 18:00 P1

Trapping of ions in a deep parabolic mirror — •Robert Maiwald[1,2], Andrea Golla[1,2], Benoît Chalopin[2], Martin Fischer[1,2], Alessandro S. Villar[2], Markus Sondermann[1,2], and Gerd Leuchs[1,2] — [1]Institut für Optik, Information und Photonik (IOIP), Universität Erlangen-Nürnberg, Staudtstr. 7/B2, 91058 Erlangen — [2]Max-Planck-Institut für die Physik des Lichts (MPL), Günther-Scharowsky-Str. 1/Bau 24, 91058 Erlangen

Due to its fundamental significance as well as its applicability to, e.g., quantum networks, a wide variety of investigations exists dealing with the efficient coupling of photons and matter. Whether it is atoms in a cavity, in or close to a fiber or a waveguide, all these methods employ some sort of coupling tool to match the profile of the electromagnetic field to the atomic transition. The aim of our research is to couple the light field to an atomic ion directly, i.e. in free space. This requires excitation from the full solid angle for optimal field-transition overlap.

Our solution to this problem is to trap an ion with a single tip ion trap with wide optical access, which is placed inside the focus of a deep parabolic mirror. We examine experimental issues like loading and cooling in such a geometry, micro-motion compensation, optimization of the focal position and detection schemes.

Q 23.47 Tue 18:00 P1

Towards Continuous Variable Quantum Information with trapped Ions — •Felix Just[1,2], Alessandro S. Villar[2], and Gerd Leuchs[1,2] — [1]Institut für Optik, Information und Photonik (IOIP), Universität Erlangen-Nürnberg, Staudtstr. 7/B2, 91058 Erlangen — [2]Max-Planck-Institut für die Physik des Lichts (MPL), Günther-Scharowsky-Str. 1/Bau 24, 91058 Erlangen

One approach to quantum information and quantum computation relies on physical systems with continuous degrees of freedom, or 'continuous variables'. In this context, one usually employs the quadratures of the light field as the physical implementation of quantum information. In this project, we investigate the preparation and manipulation of non-classical states using the vibrational modes (i.e. the position and momentum degrees of freedom) of a trapped Yb ion, which are formally identical to the quadratures of the electromagnetic field. The ionic internal degrees of freedom are utilised both for the readout of the motional state and for mediating interaction between different vibrational modes. We aim at preparing useful quantum states to demonstrate coherent control over a continuous variables system.

Q 23.48 Tue 18:00 P1

Generation of a light mode that couples efficiently to a dipole transition — •Andrea Golla[1,2], Benoît Chalopin[2], Robert Maiwald[1,2], Irina Harder[1], Markus Sondermann[1,2], and Gerd Leuchs[1,2] — [1]Institut für Optik, Information und Photonik (IOIP), Universität Erlangen-Nürnberg, Staudtstr. 7/B2, 91058 Erlangen — [2]Max-Planck-Institut für die Physik des Lichts (MPL), Günther-Scharowsky-Str. 1/Bau 24, 91058 Erlangen

For perfect coupling of light with an atomic transition the light field must be mode matched to the atomic radiation pattern. Localizing an atom with a linear dipole transition inside a deep parabolic mirror enables efficient absorption of a single-photon wave packet in free space. A linear dipole field radiated by the atom is transformed after reflecting off the parabolic mirror into a transverse mode very close to a radially polarized doughnut mode. We demonstrate the generation of such a mode at the transition wavelength with the optimum size for our focusing geometry, envisioning 98% overlap with the atomic dipole radiation.

Imperfections of the mirror surface induce errors on the phase front. We show that by inserting a phase plate fabricated to fit to the specific mirror these aberrations are corrected such that the focal intensity reaches more than 90% of the diffraction limited case.

For the perfect absorption of photons, also the temporal shape of the wave packet must be tailored to the transition, requiring an exponentially increasing envelope. This is achieved with the modulation of highly attenuated continuous wave laser beams.

Q 23.49 Tue 18:00 P1

Coherent spin dynamics in isotopically pure diamond — •Helmut Fedder[1], Jan Honert[1], Michael Klas[1], Florian Dolde[1], Junichi Isoya[3], Matthew Markham[2], Daniel Twitchen[2], Fedor Jelezko[1], and Jörg Wrachtrup[1] — [1]Universität Stuttgart, 70550 Stuttgart, Germany — [2]Element Six Ltd, Ascot, UK — [3]Graduate School of Library, Information and Media Studies, University of Tsukuba, 1-2 Kasuga, Tsukuba, Japan

Nitrogen-Vacancy (NV) centers in diamond are promising solid-state spin system for applications in quantum information and communication, that allow optical readout and coherent spin manipulation even at room temperature. Of pivotal importance for scalable NV based quantum architectures is a long spin coherence time in the diamond host material. In diamond, spin coherence is typically limited by coupling of the NV centers to adjacent 13C nuclear spins, that occurr with a natural abundance of 1.1%. Here we present our recent results towards ultralong coherent spin dynamics in isotopically pure diamond, and their application to magnetic-dipole type spin-spin entanglement. We find that spin coherence times get close to the limit set by spin-lattice relaxation. Complementary, we study the decoupling of the electron spin from magnetic fluctuations through |+> and |-> type excitations in 'dirty' diamond host material under zero magnetic field conditions. We give an account of the resulting perspectives for quantum gate operations using bias field switching.

Q 23.50 Tue 18:00 P1

Trapped ions as quantum bits: Essential numerical tools — •Kilian Singer[1], Ulrich G. Poschinger[1], Michael Murphy[2], Frank Ziesel[1], Tommaso Callarco[2], and Ferdinand Schmidt-Kaler[1] — [1]Universität Mainz, Staudingerweg 7, 55128 Mainz — [2]Universität Ulm, Albert-Einstein-Allee 11, 89069 Ulm

We present powerful numerical tools for the optimization of the external control of the motional and internal states of trapped neutral atoms, explicitly applied to the case of trapped laser-cooled ions in a segmented ion-trap [1]. We then solve inverse problems, when optimizing trapping potentials for ions. Optimizing a quantum gate is realized by the application of quantum optimal control techniques. The numerical methods presented can also be used to gain an intuitive understanding of quantum experiments with trapped ions by performing virtual simulated experiments on a personal computer [2].

[1] K. Singer, U. G. Poschinger, M. Murphy, P. Ivanov, F. Ziesel, T. Calarco, F. Schmidt-Kaler, Rev. Mod. Phys. 82, 2609 (2010). [2] http://kilian-singer.de/ent

Q 23.51 Tue 18:00 P1

Ultra-bright and compact fibre coupled single photon source based on a defect centre in diamond using a solid immersion lens — •Friedemann Gädeke, Tim Schröder, and Oliver Benson — AG Nano Optics, Institut für Physik, Humboldt Universität zu Berlin, Newtonstr. 15, 12489 Berlin

Single photons are fundamental elements for quantum information technologies such as quantum cryptography, quantum information storage and optical quantum computing. Colour centres in diamond have proven to be stable single photon sources and thus essential components for reliable and integrated quantum information technology. A key requirement for such applications is a large photon flux and a high efficiency. We present an ultra bright and very compact single photon source based on nitrogen-vacancy defect centres in nanodiamonds. To increase the photon flux we used a hemispheric solid immersion lens made of ZrO_2. The nanodiamonds were spin-coated on the flat surface of the solid immersion lens. We found stable count rates of up to 853 kcts/s and have access to more than 100 defect centres with count rates between 400 kcts/s and 500 kcts/s. We also found a blinking defect centre with a count rate of 2.4 Mcts/s for time intervals of several ten seconds at saturation intensity. At pulsed excitation with 10 MHz we got count rates of up to 221 kcts/s indicating a detection efficiency of 2.2 %. For flexible operation we intend to integrate excitation, collection and fibre coupling into a very compact device with a size of about 30 cm x 11 cm x 5 cm.

Q 23.52 Tue 18:00 P1

Quantum interference and non-locality of independent photons from disparate sources — •Ralph Wiegner[1], Joachim von Zanthier[1], and Girish Agarwal[2] — [1]Institut für Optik, Information und Photonik, Universität Erlangen-Nürnberg, Erlangen, Germany — [2]Department of Physics, Oklahoma State University, Stillwater, OK, USA

We quantitatively investigate the non-classicality and non-locality of a whole new class of mixed disparate quantum and semiquantum photon sources at the quantum-classical boundary (arXiv:1005.4176v1). The key quantity in our investigations is the visibility of the corresponding photon-photon correlation function. We present explicit results on the violations of the Cauchy-Schwarz inequality - which is a measure of nonclassicality - as well as of Bell-type inequalities for path correlations rather than for polarization correlations.

Q 23.53 Tue 18:00 P1

Interaction of two-level atoms with circularly polarized light — •Armen Hayrapetyan[1] and Stephan Fritzsche[2,3] — [1]Max-Planck-Institut für Kernphysik, Postfach 103980, D-69029 Heidelberg, Germany — [2]Department of Physics, P.O. Box 3000, Fin-90014 University of Oulu, Finland — [3]GSI Helmholtzzentrum für Schwerionenforschung, D-64291 Darmstadt, Germany

The interaction of two-level atoms with circular-polarized light is examined to explore how the polarization properties of the light affect the population dynamics of the atoms. Equations are presented and discussed for the probability amplitudes of the atomic levels. It is shown that the inversion in the population in two-level atoms depends on both, the space and time coordinates, and can be expressed in terms of the invariant phase of the light.

Q 23.54 Tue 18:00 P1

How well can photons change their colour - about the efficiency of single photon frequency down-conversion — •Susanne Blum[1], Georgina Olivares-Rentería[2,3], Carlo Ottaviani[3], Sebastian Zaske[1], Christoph Becher[1], and Giovanna Morigi[1,3] — [1]Universität des Saarlandes, Germany — [2]Universidad de Concepción, Chile — [3]Universitat Autònoma de Barcelona, Spain

Efficient single photon transmission in future quantum networks requires wavelengths in the low loss band of optical fibres. Currently most single photon sources do not emit in this spectral region, but rather in the red or near-infrared. We analyse theoretically the conversion efficiency of single photons into the low-loss band at 1550nm, when using difference frequency generation in a $\chi^{(2)}$ material. For this purpose we use Heisenberg-Langevin equations for the signal, idler, and pump fields, in the limit of a strong classical signal field. We consider the effects of quantum noise sources, e.g. photon loss in pump and idler modes, and photon generation at 1550nm due to optical parametric fluorescence. From this model we study the efficiency of the single photon down-conversion process by determining the value of intensity-intensity correlations at zero delay and the influence of quantum noise sources on photon correlation funtions.

Q 23.55 Tue 18:00 P1

Towards coupling of a single N-V center in diamond to a fiber based micro- cavity — •Roland Albrecht[1], Christian Deutsch[2], Jakob Reichel[2], Tim Schröder[3], Rico Henze[3], Oliver Benson[3], 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 — [3]Institut für Physik, AG Nanooptik, Humboldt-Universität zu Berlin, Newtonstraße 15, 12489 Berlin

Coupling a single N-V center in diamond to a micro-cavity is a crucial step towards sucessful implementation of many quantum information protocols.[1] We here investigate fiber based Fabry Perot cavities which consist of a flat dielectric mirror and an optical fiber. N-V centers in diamond nanocrystals are deposited onto the flat mirror by spin coating. This cavity design has several advantages: it is tunable, can be scanned transversally and is automatically fiber-coupled with very good efficiency. To achieve stable cavities, a concave impression has been produced on the fiber facet by laser machining prior to deposition of a dielectric coating. As a second approach for fabrication of the concave mirror we investigate focused ion beam milling of tapered fibers, allowing for enhanced design flexibility. Cavities using mirrors with radii of curvature of about 50 μm, with a finesse of up to 3000 and a length of 5 μm have been realized. We observe emission of a single N-V center into the fiber cavity.

[1] S. Prawer and A.D. Greentree, Science 320, 1601 (2008)

Q 23.56 Tue 18:00 P1

Optimal pulse shaping for excitation of single atoms in free-space. — •Dao Hoang Lan, Syed Abdullah Aljunid, Brenda Chng, Gleb Maslennikov, and Christian Kurtsiefer — Centre for Quantum Technologies / Dept. of Physics, National University of Singapore

Recent theoretical works suggest that an optimal excitation of single atoms can be performed by optical pulses that are time reversed replica of spontaneously emitted light [1,2]. In the time domain this would constitute a pulse with an envelope given by rising exponential function, followed by a fast drop. The time constant τ_c of such exponential pulse should correspond to the lifetime of atomic excited state. We present an experimental implementation based on an electronic circuit that allows to generate electrical pulses with $\tau_c = 27$ ns which is compatible to the D2 transition in ^{87}Rb. The output of the circuit is multiplied with an RF carrier at 1.5 GHz and the resulting product sent to a fast Electro-Optical Modulator to change the phase of a cw laser beam. One of the corresponding optical sidebands is selected by a filter cavity, effectively preparing an optical pulse with the desired exponential envelope and the corresponding Lorentzian spectrum. The scheme has a high on/off ratio for the optical pulses, since all the switching can be done by toggling the RF oscillator. We discuss the implementation of this scheme in free-space atom-photon interfaces.

[1] M. Stobinska, G. Alber and G. Leuchs, Euro. Phys. Lett **86**, 14007 (2009)
[2] Y. Wang, L. Sheridan and V. Scarani, arXiv:1010:4661v1 (2010)

Q 23.57 Tue 18:00 P1

Probing the Wigner function of pulsed single photons point-by-point — Kaisa Laiho[1], •Georg Harder[2], Katiuscia N. Cassemiro[1], David Gross[3], and Christine Silberhorn[1,2] — [1]MPI for the Science of Light, Erlangen, Germany — [2]Applied Physics, University of Paderborn, Germany — [3]Institute for Theoretical Physics, ETH Zürich, Switzerland

Quantum tomography is essential in different quantum optical applications. The standard technique, homodyne detection, allows the characterization of quantum states and processes in terms of the Wigner function. However, the determination of the properties at a single point in phase space with homodyne detection requires tomographical reconstruction, since the Heisenberg's uncertainty principle precludes the simultaneous measurement of non-commuting field quadratures.

Nevertheless, the evaluation of the Wigner function point-by-point is possible by measuring the mean value of parity operator. An all optical implementation of this *direct probing* scheme requires a realization of displacement operator and photon counter. We have implemented this scheme and measured the phase-averaged Wigner function of spectrally broadband, pulsed single photons at individual points in phase space [1]. Our results verify the non-classicality of the prepared single-photon state. Since the measurement is sensitive to all signal modes, it can uncover the single-mode properties of the signal in spatiotemporal degrees of freedom. Furthermore, it allows us to directly investigate the statistics of displaced states.

[1] K. Laiho, *et al.*, Arxiv:1010.1208 (2010)

Q 23.58 Tue 18:00 P1

An optimized 1560nm polarization squeezer for quantum information protocols — •Christian Gabriel[1,2], Joel F. Corney[3], Christoph Marquardt[1,2], and Gerd Leuchs[1,2] — [1]Max Planck Insitute for the Science of Light, Günther-Scharowsky-Strasse 1, D-91058 Erlangen, Germany — [2]Institute for Optics, Information and Photonics, University Erlangen-Nuremberg, Staudtstrasse 7/B2, D-91058 Erlangen, Germany — [3]ARC Centre of Excellence for Quantum-Atom Optics, School of Physical Sciences, The University of Queensland, Brisbane, QLD 4072, Australia

We investigate polarization squeezing with ultrashort pulses in optical fibers over a wide range of input energies, pulse lengths and fibre lengths. We present first experimental results of how an optimization of all these parameters gives rise to highly efficient polarization squeezing. The optimization is based on quantum mechanical simulations which reveal the influence of phase noise and Raman effects on the squeezing. This squeezing source can be used for quantum information protocols, ranging from squeezing and entanglement distillation to actual quantum communication with squeezed and entangled states over a realistic freespace link.

Q 23.59 Tue 18:00 P1

Einfluss der Photonenstatistik auf die Kalibrierung von Einzelphotonendetektoren — •Waldemar Schmunk, Silke Peters, Mark Rodenberger, Helmuth Hofer und Stefan Kück — Physikalisch-Technische Bundesanstalt, 38116 Braunschweig

In den sich rasch entwickelnden Anwendungsgebieten der Einzelphotonentechnik, wie z.B. der Quantenoptik und -kryptographie gewinnen radiometrische Fragestellungen zunehmend an Bedeutung. Dabei gehört die Detektionsseffizienz von Einzelphotonendetektoren zu den wichtigen Kenngrössen, welche unter anderem durch die Photonenstatistik des eingestrahlten Lichts beeinflusst wird. Denn im Gegensatz zu analogen registrieren digitale Detektoren das gleichzeitige Eintreffen mehrerer Photonen als ein Einphoton-Ereignis, was zu Fehleinschätzungen der gemessenen Detektionseffizienzen bei der Kalibrierung führen kann. Die Kalibrierung erfolgt hier mittels einer radiometrischen Methode aus dem Bereich der fasergekoppelten Detektoren. Untersucht wird der Einfluss der Photonenstatistik auf die Bestimmung der relativen Detektionseffizienz von SPADs. Eine Lampe, ein Laser sowie eine Einzelphotonenquelle ($g^{(2)}(0) = 0,15$) erzeugen die benötigte Strahlung. Übereinstimmend mit den Vorhersagen einer Modellierung zeigt sich, dass sich die mit Laser und Lampe gemessenen relativen Detektionseffizienzen von $0,165 \pm 0,002$ sowie $0,161 \pm 0,001$ signifikant von denen der nicht-klassischen Einzelphotonenquelle von $0,122 \pm 0,001$ unterscheiden. Die vorliegende Arbeit diskutiert in wie weit die Photonenstatistik für die gemessenen Abweichungen verantwortlich ist und gibt einen Ausblick auf die Realisierung einer absoluten Rückführung.

Q 23.60 Tue 18:00 P1

Correlation measurements on optical fields from a Whispering Gallery Mode Optical Parametric Oscillator — •Gerhard Schunk[1,2], Josef Fürst[1], Dmitry Strekalov[1,3], Michael Förtsch[1], Ulrik L. Anderson[1,4], Andrea Aiello[1], Christoph Marquardt[1], and Gerd Leuchs[1] — [1]Max Planck Institute for the Science of Light, Institute for Optics, Information and Photonics, University Erlangen-Nuremberg, Erlangen, Germany, — [2]Institut für Quantenphysik, Universität Ulm, D-89069 Ulm, Germany — [3]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California, USA — [4]Department of Physics, Technical University of Denmark, Kgs. Lyngby, Denmark

The second order optical nonlinear process of parametric down conversion (PDC) has successfully been demonstrated in a z-cut Lithium Niobate whispering gallery mode (WGM) resonator. Inherently, PDC affects the quantum properties of the interacting fields, where squeezing and entanglement can be observed. PDC becomes very efficient, in particular as our WGM resonator provides a high Q-factor and small optical mode volume. This makes WGM resonators attractive for applications like Quantum Information Processing and quantum sensing.

Our present focus is to study and optimize the quantum properties of the signal and idler beams in our above threshold WGM optical parametric oscillator. For this goal we work on the improvement of the detector design and aim for further investigations of the parameter space accessible in our WGM setup. We will report on the latest results of the project.

Q 24: Quantum Gases: Opt. Lattice 1

Time: Wednesday 10:30–13:00 Location: HSZ 02

Q 24.1 Wed 10:30 HSZ 02

Studying Quantum Many-Particle Systems on the Single-Atom Level — •M. Endres, C. Weitenberg, J. Sherson, M. Cheneau, P. Schauss, T. Fukuhara, I. Bloch, and S. Kuhr — Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Str. 1, D-85748 Garching

The reliable detection of single quantum particles has revolutionized the field of quantum optics and quantum information processing. For several years, researchers have aspired to extend such detection possibilities to larger-scale, strongly correlated quantum systems.

We report on fluorescence imaging of bosonic Mott insulators in an optical lattice with single-atom and single-site resolution[1]. From our images, we fully reconstruct the atom distribution on the lattice and identify individual excitations with high fidelity.

Furthermore we will present progress towards in-situ thermometry and the detection of coherent particle-hole excitations across the superfluid-to-Mott-insulator transition.

We plan to use our detection technique to study one dimensional quantum systems. In the Tonks-Girardeau regime, their strongly interacting nature can be revealed by the density-density correlation function, which should show a distinct anti-bunching of the particles.

[1] J. Sherson et al., Nature 467, 68 (2010)

Q 24.2 Wed 10:45 HSZ 02

A mulitband ground-state superfluid — •Parvis Soltan-Panahi, Julian Struck, Dirk-Sören Lühmann, Andreas Bick, Wiebke Plenkers, Rodolphe Le Targat, Patrick Windpassinger, and Klaus Sengstock — Institut für Laser-Physik, Universität Hamburg, Luruper Chaussee 149, 22761 Hamburg, Germany

Superfluid bosonic atoms confined in a 3D optical lattice are usually very well described by a single quasi-momentum state in the lowest Bloch band (s-band). In this regime, interaction effects are small and can mostly be treated at a mean-field level.

Here, we report on the experimental realization of an interaction induced mixing of the s- and p-band states in a shallow, spin-dependent hexagonal lattice in the superfluid regime. This novel phase occurs for a certain class of spin-mixtures and can be unambiguously determined by a clear reduction of the six-fold rotational symmetry to a three-fold symmetry of the many-body state in momentum space. Remarkably, the fully correlated two-particle interaction plays here the major role, which is usually only observed in strongly interacting systems.

We theoretically describe this novel mulit-band superfluid ground-state phase as a second-order quantum phase transition. This is characterized by a twisted quantum mechanical phase between s- and p-band superfluid fractions, which leads to the very characteristic momentum spectrum of the different spin-components.

Q 24.3 Wed 11:00 HSZ 02

Adiabatic generation of a Heisenberg antiferromagnet in an optical lattice — •Michael Lubasch[1], Valentin Murg[2], Mari-Carmen Bañuls[1], Juan Ignacio Cirac[1], Ulrich Schneider[3], and Immanuel Bloch[1,3] — [1]Max Planck Institute of Quantum Optics, Hans-Kopfermann-Strasse 1, 85748 Garching, Germany — [2]University of Vienna, Faculty of Physics, Boltzmanngasse 5, 1090 Vienna, Austria — [3]Ludwig-Maximilians-University Munich, Faculty of Physics, Schellingstrasse 4, 80799 Munich, Germany

Ultracold fermions in optical lattices hold the potential to be employed as a true quantum simulator of the Hubbard model and as such give us insight into high-T_c superconductivity. However, a main obstacle is still the low temperatures needed for the validity of the Hubbard model description.

Whereas a fermionic Mott state has already been realized in an optical lattice (R. Joerdens *et al.*, Nature **455**, 204 (2008); U. Schneider *et al.*, Science **322**, 1520 (2008)), the next challenge is the demonstration of magnetic order, present in an underlying Heisenberg antiferromagnet. However, a direct construction of this state is difficult because even lower temperatures are needed.

Alternatively, we may try to generate the antiferromagnetic state by means of adiabatic evolution from an easily preparable initial state. We numerically simulate our proposal via Matrix Product States (MPS) in 1D and Projected Entangled Pair States (PEPS) in 2D. We discuss the resulting time scales for the adiabatic evolution, the effect of defects in the initial state and the importance of a harmonic trap.

Q 24.4 Wed 11:15 HSZ 02

Complete devil's staircase and crystal–superfluid transitions in a dipolar XXZ spin chain: A trapped ion quantum simulation — •Philipp Hauke[1], Fernando M. Cucchietti[1], Mari-Carmen Bañuls[2], Alexander Müller-Hermes[2], J. Ignacio Cirac[2], and Maciej Lewenstein[1] — [1]ICFO – The Institute of Photonic Sciences, Mediterranean Technology Park, 08860 Castelldefels (Barcelona), Spain — [2]Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Str. 1, 85748 Garching, Germany

Systems with long-range interactions show such intriguing properties as the accommodation of many meta-stable states, supersolid phases, and counterintuitive thermodynamics. On the downside, this increased complexity hinders theoretical studies, making a quantum simulator for long-range models highly desirable. In [1], we propose a trapped-ion quantum simulation of hard-core bosons on a chain with dipolar off-site interaction and tunneling, equivalent to a dipolar XXZ spin-1/2 chain. We explore the rich phase diagram of this model employing perturbative mean-field theory, exact diagonalization, and quasi-exact numerical techniques (density-matrix renormalization group and infinite time evolving block decimation). We find that the complete devil's staircase – an infinite sequence of crystal states existing at vanishing tunneling – spreads to a succession of lobes similar to the Mott-lobes of Bose–Hubbard models. Inside the insulating lobes there appears – opposed to models with nearest-neighbor tunneling – a *quasi-supersolid*, a phase with diagonal long-range and off-diagonal quasi–long-range order. [1] Hauke *et al.*, New J. Phys. **12** (2010) 113037

Q 24.5 Wed 11:30 HSZ 02

Towards Plaquettes in Optical Superlattice — •Marcos Atala[1,2], Monika Aildesburger[1], Yu-Ao Chen[1,2], Sylvain Nascimbene[1,2], Stefan Trotzky[1], and Immanuel Bloch[1,2] — [1]Fakultät für Physik, Ludwig-Maximilian-Universität, Schellingstrasse 4, 80798 München, Germany — [2]Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Strasse 1, 85748 Garching, Germany

Superimposing two optical lattice potentials differing in periodicity by a factor of two creates a superlattice structure. Together with two orthogonal lattices it provides a generic system to study isolated double well physics. By removing one of the orthogonal lattices one could extend the system from coupled quantum dots to coupled tubes, which allows us to extend the study of few-body physics to many-body physics. In addition, by adding another superlattice potential perpendicular to the first one, an array of plaquettes is created. In this talk we will discuss about recent progress in such a system.

Q 24.6 Wed 11:45 HSZ 02

Three-body losses and three-body correlations in one-dimensional systems — •Elmar Haller, Manfred J. Mark, Johann G. Danzl, Lukas Reichsöllner, Mohamed Rabie, Oliver Krieglsteiner, Andreas Klinger, and Hanns-Christoph Nägerl — Institut für Experimentalphysik und Zentrum für Quantenphysik, Universität Innsbruck, Technikerstrasse 25, A-6020 Innsbruck, Austria

We load a Bose-Einstein condensate of cesium atoms into an array of tube-like 1D traps generated by a 2D optical lattice potential, and we control the interaction strength by means of a 1D confinement-induced resonance [1]. Unlike for ultracold atoms in 3D geometry, which show a dramatic increase of three-body losses in the proximity of a Feshbach resonance, we observe a strong suppression of three-body losses in 1D. This suppression originates from a strong reduction of the three-body correlation function g_3 at close distances in 1D. We find a reduction of g_3 by several orders of magnitude for an increasing interaction parameter γ. The scaling of $g_3(\gamma)$ is compared to theoretical predictions [2] [1] E. Haller, *et al.*, Phys. Rev. Lett. **104** 153203 (2010).

[2] D. Gangardt, and G. Shlyapnikov, Phys. Rev. Lett. **90** 10401 (2003).

Q 24.7 Wed 12:00 HSZ 02

Scanning electron microscopy of ultracold atoms — •Peter Würtz, Andreas Vogler, Arne Ewerbeck, Matthias Scholl, Giovanni Barontini, Vera Guarrera, and Herwig Ott — TU Kaiserslautern

We have adapted a scanning electron microscope for the study of ultracold quantum gases. The technique allows for in situ imaging of single atoms with a resolution of better than 150 nm. Thus, it can readily be applied to study quantum gases in optical lattices. The dissipative interaction of the electron beam with the atoms can be used to selectively remove atoms. In this way, one can create arbitrary patterns of occupied lattice sites. We were able to measure temporal pair correlations in a thermal gas, which demonstrates the single atom sensitivity of our detection method. The system is also an interesting experimental platform to study electron-atom scattering processes and cold ion-atom collisions.

Q 24.8 Wed 12:15 HSZ 02

Emulating Frustrated Magnetism in Triangular Optical Lattices — •Julian Struck, Christoph Ölschläger, Christina Staarmann, Parvis Soltan-Panahi, Rodolphe Le Targat, Patrick Windpassinger, and Klaus Sengstock — Institut für Laser-Physik, Universität Hamburg, 22761 Hamburg, Germany

We present the experimental realization of a quantum simulator for magnetism with ultracold quantum gases in optical lattices. It is possible to emulate magnetic interactions of a xy-model – interestingly with spinless bosons – by applying a time periodic acceleration to the lattice as proposed by Eckardt et al. [1]. Several different magnetic phases of this model have successfully been realized. The most interesting is the frustrated spiral phase which exhibits exotic properties like time-reversal and spontaneous symmetry breaking.

These first results open the perspective to extremely complex and yet not well understood phases like the spin-liquid in a quantum xy-model.

[1] A. Eckardt et al 2010 EPL 89 10010

Q 24.9 Wed 12:30 HSZ 02

The Dicke quantum phase transition in an optical cavity QED system — •Rafael Mottl[1], Kristian Baumann[1], Ferdinand Brennecke[1], Tobias Donner[1], Christine Guerlin[2], and Tilman Esslinger[1] — [1]Institute for Quantum Electronics, ETH Zurich, 8093 Zurich, Switzerland — [2]Thales Research and Technology, 91767 Palaiseau Cedex, France

The collective interaction of an ensemble of atoms with an electromagnetic field mode is of fundamental interest. A conceptually important model describing such a system is the Dicke model for which the existence of a quantum phase transition was predicted years ago. We have achieved its first experimental realization in an open system in which a Bose-Einstein condensate is coupled to an optical high-finesse cavity. The interaction between the condensate atoms is mediated by the field of the optical cavity and is of infinite range. Starting in a superfluid state, the self-organized phase which emerges at the phase transition is of supersolid character.

We map out the phase diagram which agrees quantitatively with the Dicke model prediction. The spontaneous symmetry breaking occuring at the quantum phase transition leads to the development of two initially degenerate ground states which are observed by a phase-sensitive detection of light leaking out of the cavity. Investigating the excitation spectrum below threshold by Bragg spectroscopy, we identify a vanishing energy gap when approaching the critical point - a precursor of the quantum phase transition.

Q 24.10 Wed 12:45 HSZ 02

Hierarchy of correlations in the Bose–Hubbard–Model — Ralf Schützhold, Patrick Navez, and •Markus Pater — Fakultät für Physik, Universität Duisburg-Essen, Lotharstaße 1, D-47057 Duisburg, Germany

We study the Bose–Hubbard–Model in terms of reduced density matrices of one ($\hat{\rho}_\mu$), two ($\hat{\rho}_{\mu\nu}$) and more lattice sites.

By complete induction, we prove a hierarchy of correlations such as

$\hat{\rho}^{\text{corr}}_{\mu\nu} = \hat{\rho}_{\mu\nu} - \hat{\rho}_{\mu}\hat{\rho}_{\nu}$.

For large coordination numbers $Z \gg 1$, the two-point correlation $\hat{\rho}^{\text{corr}}_{\mu\nu}$ is suppressed by $\hat{\rho}^{C}_{\mu\nu} = O\left(1/Z\right)$ while three-point correlators are suppressed by $O\left(1/Z^2\right)$ etc.

This facilitates a controlled analytical description of many–body quantum dynamics away from equilibrium.

We apply this approach to some physical example scenarios.

Q 25: Matter Wave Optics

Time: Wednesday 10:30–13:00 Location: BAR Schön

Q 25.1 Wed 10:30 BAR Schön

Quantum test of the equivalence principle with dual species atom interferometry — •Daniel Tiarks, Jonas Hartwig, Dennis Schlippert, Ulrich Velte, Maic Zaiser, Vyacheslav Lebedev, Ernst Rasel, and Wolfgang Ertmer — Institut für Quantenoptik, Hannover

The CAPRICE experiment is aiming for a test of the equivalence principle using atom interferometry with two atomic species. For this test we trap and cool rubidium and potassium atoms in a two-stage loading scheme using a 2D/3D MOT. Both atomic ensembles are then dropped for a simultaneous differential measurement of the Earth's gravitation g. This setup allows us to make systematic studies concerning the comparison of interferometry with bosonic and fermionic matter and the metrological comparison of two different gravimeters at the same place and in the same experimental environment. A very compact diode laser system is used for cooling and coherently manipulating the atomic clouds. We will show a characterisation of the present detection system as well as first studies of gravitational measurements using ^{87}Rb.

To guarantee well defined starting conditions the two species will be trapped in an optical dipole trap formed by a Thulium doped fiber laser with 50 W output power at a wavelength of 1960 nm. The special properties of this optical dipole trap allow for fast and efficient cooling.

Q 25.2 Wed 10:45 BAR Schön

Atom Interferometry in a mobile high-precision setup to measure local gravity — •Matthias Hauth, Malte Schmidt, Alexander Senger, Vladimir Schkolnik, Christian Freier, and Achim Peters — Humboldt-Universität zu Berlin, Institut für Physik, AG Optische Metrologie, Newtonstr. 15, 12489 Berlin

GAIN (Gravimetric Atom Interferometer) is a mobile gravimeter, based on interfering ensembles of laser cooled ^{87}Rb atoms in an atomic fountain configuration. The high-precision interferometer is designed to reach an accuracy of a few parts in 10^{10} for the measurement of local gravity, g.

We give an introduction into the working principle of our mobile atom interferometer based on a Raman-sequence driving the hyperfine transition of the ^{87}Rb ground state and report on our first move to another laboratory. Furthermore we present first gravity-measurements showing earth tides, the current status and steps planned for the future.

Q 25.3 Wed 11:00 BAR Schön

Matter wave interferometry: Molecular mass, complexity, dynamics and structure — •Sandra Eibenberger[1], Stefan Gerlich[1], Jens Tüxen[2], Stefan Nimmrichter[1], Marcel Mayor[2], and Markus Arndt[1] — [1]University of Vienna, Quantum Nanophysics, Austria — [2]University of Basel, Department of Chemistry, Switzerland

Kapitza-Dirac-Talbot-Lau interferometry is a versatile tool for studying the wave nature of massive and complex molecules.

De Broglie coherence is to first order only associated with the center-of-mass motion. In the presence of external perturbations, however, internal molecular properties, such as electric susceptibilities, polarizabilities or dipole moments become accessible without introducing genuine decoherence.

Recent experimental data from high-contrast interference measurements with massive and complex molecules are presented. The influence of molecular dynamics on de Broglie coherence and the distinction of structural isomers via quantum metrology are shown.

References:

M. Gring et al. Phys. Rev. A 81, 031604 (2010)

J. Tüxen et al. Chem. Commun. 46, 4145-4147 (2010)

S. Gerlich et al. Angewandte Chemie Int. Ed. 47, 6195-6198 (2008)

K. Hornberger et al. NJP 11, 043032 (2008)

Q 25.4 Wed 11:15 BAR Schön

Chip-based Bragg interferometry with Bose-Einstein condensates in microgravity — •Markus Krutzik[1], Achim Peters[1], and the QUANTUS Team[1,2,3,4,5,6,7,8,9] — [1]Institut für Physik, HU Berlin — [2]Institut für Quantenoptik, LU Hannover — [3]Institut für Laserphysik, Uni Hamburg — [4]ZARM, Uni Bremen — [5]Institut für Quantenphysik, Uni Ulm — [6]MPQ, München — [7]Institut für angewandte Physik, TU Darmstadt — [8]Midlands Ultracold Atom Research Centre, University of Birmingham, UK — [9]FBH, Berlin

The successful observation of Bose-Einstein-Condensation in microgravity was an important result towards operating dilute quantum gas experiments under extreme conditions (van Zoest et al., Science **328** 2010). In this talk we report on atom-optical experiments with a BEC produced in this apparatus, performed on ground as well as in free fall. The coherent manipulation of the ensemble is realized with stimulated Bragg diffraction as a splitting and recombination process. Using a simple interferometer composed of two Bragg pulses we investigated the phase-coherence of the ensemble by oberserving the spatial fringe pattern with free evolution times up to 500ms. In the near future we intend to realize multiphoton Mach-Zehnder topologies to achieve extremely large distances between the diffracted wave packets and even longer timescales within the sequence.

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 1131-1137.

Q 25.5 Wed 11:30 BAR Schön

Molecule Interferometer at Southampton — •Carola Szewc, Paul Venn, and Hendrik Ulbricht — University of Southampton, School of Physics and Astronomy, Highfield, SO17 1BJ, Southampton, United Kingdom

De Broglie interference experiments with large molecules are of interest to address fundamental physics related to limitations of quantum physics, but also for applications like molecule metrology as demonstrated by the Vienna group. We will report on our progress of setting up a vertical molecule Talbot-Lau interferometer at Southampton. This three material grating interferometer will enable interference and metrology experiments of particles of up to 10,000 amu (atomic mass units), which is an important intermediate step towards very massive particle interferences to attack the fundamental questions. Furthermore, that mass range is important for metrology experiments with organic molecules. While some analytic methods basing on molecule interference have been demonstrated - as the measurement of molecule's polarizability, dipole moments and molecular quantum interference lithography as a new bottom-up nanofabrication technique - other proposals on molecule sorting and single photon recoil spectroscopy are still waiting for experimental realization. Studies by our molecule interferometer include the mapping of the molecule distribution to extract the full information about the molecular quantum state by Wigner function tomography as well as the study of van der Waals/Casimir-Polder interactions between molecules and diffraction gratings.

Q 25.6 Wed 11:45 BAR Schön

Trapped atomic gravimeter for near-field force measurements — •Gunnar Tackmann, Quentin Beaufils, Bruno Pelle, Sophie Pélisson, Xiaolong Wang, Marie-Christine Angonin, Peter Wolf, and Franck Pereira Dos Santos — LNE-SYRTE, Observatoire de Paris, CNRS, UPMC, 61 avenue de l'Observatoire, 75014 Paris, France

The realization of matter-wave interferometry on neutral atoms in a vertical 1D lattice coupling the system's eigenstates, namely the

Wannier-Stark states, permits high precision measurements of the energy difference between the lattice wells. In addition to the absolute determination of the gravitational acceleration, this will allow the mapping of the Casimir-Polder potential between the neutral atoms and a macroscopic surface as well as to push the limits on possible derivations from Newtonian gravitation on short distances when performed in the vicinity of the retro-reflective lattice mirror's surface.

In the experiment Forca-G, such an interferometer is realized with ^{87}Rb atoms in a 532 nm lattice. In this talk, we present the current performance of the interferometer far from the mirror surface. Featuring long coherence times in the order of seconds, these measurements are currently limited by the trap lifetime.

This research is carried on within the project iSense, which acknowledges the financial support of the FET programme within the Seventh Framework Programme for Research of the European Commission, under FET-Open grant number: 250072. We also gratefully acknowledge support by Ville de Paris ("Emergence(s)" program) and IFRAF.

Q 25.7 Wed 12:00 BAR Schön

A dual species matter-wave interferometer in microgravity — •Jan Rudolph[1], Ernst Maria Rasel[1], and the QUANTUS Team[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

The QUANTUS-II apparatus is a matter-wave interferometer that is designed to operate in free fall with two atomic species simultaneously. This will enable us to perform differential measurements of ^{87}Rb and ^{40}K atoms and thus provide a test of the weak equivalence principle in the quantum domain. The experiment will be carried out in the microgravity environment of the drop tower in Bremen. Here our predecessor project QUANTUS has already demonstrated the feasibility of experiments with ultra-cold gases in free fall, realizing a Bose-Einstein condensate and subsequently observing its free evolution for up to one second. We aim to realise an apparatus that is even more compact, operates with a higher number of atoms, uses a more sophisticated atom chip and allows for twice the amount of time in microgravity. In this way we will take advantage of long free evolution 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 25.8 Wed 12:15 BAR Schön

Simple description of atom interferometry with Bose-Einstein condensates — •Endre Kajari[1,2], Stefan Arnold[2], Daniela Moll[2], Wolfgang P. Schleich[2], and the QUANTUS Team[3,4,5,6,7,8,9,10] — [1]Theoretische Physik, Universität des Saarlandes — [2]Institut für Quantenphysik, Universität Ulm — [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

In this talk we present the theoretical formalism used in the analysis of the long-time evolution of Bose-Einstein condensates in microgravity [1]. Starting from a natural generalization of the scaling approach [2] which addresses time-dependent rotating traps, we identify the range of application of this description, introduce a Hamilton formalism for the new dynamical variables, and point out the connection to the constants of motion of the Gross-Pitaevskii equation. Since this approach provides us with an accurate phase evolution of the macroscopic wave function as well, it represents a valuable tool for the description of atom interferometry with Bose-Einstein condensates.

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 1136.

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

Q 25.9 Wed 12:30 BAR Schön

Matter wave optics with Bose-Einstein condensates in microgravity — •Hauke Müntinga[1], Claus Lämmerzahl[1], and the QUANTUS Team[2,3,4,5,6,7,8,9,10] — [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]Midlands Ultracold Atom Research Centre, University of Birmingham, UK — [8]FBH, Berlin — [9]MPQ, Garching — [10]Laboratoire Kastler Brossel, ENS, Paris

In 2007 the first Bose-Einstein condensate in microgravity was realized by the QUANTUS collaboration in the ZARM drop tower in Bremen. In over 200 drops from a height of 110 m, our setup has proven the feasibility of operating delicate quantum optical experiments in demanding environments and allowed us to study the physics of ultra-cold quantum gases in previously inaccessible parameter regimes.

After examining the free evolution of the condensate for up to 1 s [1], we have now integrated a matter wave interferometer based on Bragg diffraction into out apparatus. In our talk we will describe the current setup and give an abstract of recent measurements addressing e.g. the phase evolution of the condensate on macroscopic time scales.

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.

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

Q 25.10 Wed 12:45 BAR Schön

Delta kick cooling: a method for fast adiabatic decompression and its applications to atom interferometry — •Andre Wenzlawski[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]Midlands Ultracold Atom Research Centre, University of Birmingham, UK — [8]FBH, Berlin — [9]MPQ, Garching

The first realization of a Bose-Einstein condensate in microgravity in 2007 paved the way for the observation of freely evolving ultra cold quantum gases on a much longer timescale than possible in any ground based experiment. We were able to observe a freely expanding BEC for up to 1 second [1] but for longer evolution times the atomic cloud got too thin to be detected efficiently.

To further increase the observation time the concept of delta kick cooling has been implemented in the experimental apparatus. This technique makes use of a magnetic lens and as a result the expansion of the BEC can be slowed down. In this talk I will report on the status of this project and on its applications to our goal to do atom interferometry in space.

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 50WM1133.

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

Q 26: Quantum Information: Atoms and Ions 2

Time: Wednesday 10:30–13:00 Location: HÜL 386

Q 26.1 Wed 10:30 HÜL 386

Scalable architecture for quantum information processing with neutral atoms — •Malte Schlosser, Sascha Tichelmann, Jens Kruse, and Gerhard Birkl — Institut für Angewandte Physik, Technische Universität Darmstadt, Schlossgartenstraße 7, 64289 Darmstadt

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 report on the investigation of ^{85}Rb atoms in two-dimensional arrays of individually addressable dipole traps featuring trap sizes and a tunable 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. Spatial light modulators and techniques for coherent quantum state transport complement our two-dimensional architecture of highly controllable atomic quantum systems.

Q 26.2 Wed 11:00 HÜL 386

Coherent Shaping of Photons using Electromagnetically Induced Transparency — •Andreas Neuzner, Eden Figueroa, and Gerhard Rempe — Max-Planck-Institute of Quantum Optics, Hans-Kopfermann-Str. 1, 85748 Garching

Over the last decade the effect of light-storage using electromagnetically induced transparency (EIT) has received extensive attention as a potential candidate for the realization of optical quantum memories. Towards this goal several milestones have been reached, for example, the storage and retrieval of single photons [1]. A key addition to these developments towards the implementation of future hybrid quantum networks is the full control over the temporal shape of the retrieved photon. We have set up an EIT-experiment based on a ^{87}Rb vapour cell, capable of storing weak classical pulses. In addition, a protocol to arbitrarily shape the envelope of the read-out light has been implemented [2]. We will also discuss the possibilities of this setup as a storage device for single photons generated from a cavity QED based source [3].

[1] M.D. Eisaman, et al., Nature 438, 837 (2005).
[2] I. Novikova, et al., Phys. Rev. Lett. 98, 243602 (2007).
[3] M. Hijlkema, et al., Nature Physics 3, 253 (2007).

Q 26.3 Wed 11:15 HÜL 386

Charge states of the nitrogen-vacancy center in diamond unraveled by single shot NMR — •Gerald Waldherr, Johannes Beck, Matthias Steiner, Philipp Neumann, Fedor Jelezko, and Jörg Wrachtrup — 3. Physikalisches Institut, Universität Stuttgart, 70550 Stuttgart, Deutschland

Nitrogen-vacany (NV) defects in diamond can be used for important applications such as quantum information processing at room temperature and magnetometry with atomic-scale resolution. The associated nitrogen nuclear spin is very robust even during laser illumination and ionization of the NV center and allows projective quantum nondemolition measurement of its state. Therefore, the nuclear spin can act as a probe for different electronic charge and spin states, due to their different hyperfine and quadrupole interactions. It turns out that under typical measurement conditions, the NV exists in two different charge states. Charge and spin state initialization can be achieved by optical pumping.

Q 26.4 Wed 11:30 HÜL 386

Heisenberg limited phase estimation of the electron spin of the the nitrogen-vacancy center in diamond — Ressa Said[1], Johannes Beck[2], Gerald Waldherr[2], •Philipp Neumann[2], Fedor Jelezko[2], Jason Twamley[1], and Jörg Wrachtrup[2] — [1]Macquarie University Sydney, Australia — [2]Universität Stuttgart

The exact determination of a quantum phase yields information about the corresponding Hamiltonian which is vital for quantum information processing or for metrology to name only two applications. Recently adaptive and non-adaptive quantum phase estimation sequencences have been introduced that scale like the Heisenberg limit and therefore beat the standard quantum limit. We show how these techniques can be implemented for quantum phase measurement of a single electron spin associated with the nitrogen-vacancy center in diamond. This system is a promising candidate for room temperature quantum information processing and magnetic field sensing with atomic resolution. Both applications greatly benefit from increased phase measurement speed.

Q 26.5 Wed 11:45 HÜL 386

Towards a single-atom quantum memory — •Christian Nölleke, Holger Specht, Andreas Reiserer, Manuel Uphoff, Eden Figueroa, Stephan Ritter, and Gerhard Rempe — Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Str. 1, 85748 Garching

The implementation of quantum networks composed of stationary nodes and photonic channels requires the development of quantum interconnects, featuring the coherent and reversible mapping of quantum information between light and matter. So far, these interfaces have largely been based upon the engineered exchange of information between photons and collective atomic excitations. A promising alternative is the development of an interface between a single quantum of light and a single particle of matter (e.g. single atoms). This approach has fundamental advantages as it allows for the individual manipulation of the atomic qubit and opens possibilities for in situ processing of stored qubits. We report on the current status of our experiment towards the most fundamental implementation of a quantum memory, based on a single neutral atom trapped inside a high-finesse optical cavity. This experiment is a major step in the development of a universal node of a quantum network, capable of fully controlled photon generation, qubit storage and with intriguing perspectives towards the development of quantum gates.

Q 26.6 Wed 12:00 HÜL 386

Kernspins kalter Ionen als Quantenregister — •Michael Johanning[1], Kunling Wang[2], Mang Feng[2] und Christof Wunderlich[1] — [1]Fachbereich Physik, Universität Siegen, 57068 Siegen — [2]State Key Laboratory of Magnetic Resonance and Atomic and Molecular Physics, Wuhan Institute of Physics and Mathematics, Chinese Academy of Sciences, Wuhan 430071, China

Wir schlagen einen neuen Implementierungsansatz zur Quanteninformationsverarbeitung vor, bei dem Qubits in Kern- und Elektronenspins einer kalten gespeicherten Ionenkette kodiert sind. Im Paschen-Back-Regime lassen sich in der Hochfeldnäherung die Kernspins gut vom dephasierenden Einfluss der Umgebung abschirmen und erlauben so lange Kohärenzzeiten, während man über die Manipulation der Elektronenspins eine hohe Güte bei Gatteroperationen und bei der Zustandsbestimmung erhält. Wir diskutieren effiziente Gatter und realistisch erreichbare Kopplungskonstanten, Gatterzeiten und -güten und stellen mögliche experimentelle Umsetzungen zur Erzeugung der nötigen hohen Magnetfelder und Gradienten vor.

Q 26.7 Wed 12:15 HÜL 386

Quantum computing with magnetic field insensitive dressed states — •I. Baumgart[1], N. Timoney[1], A. Retzker[2], A.F. Varón[1], M. Johanning[1], M. Plenio[2], and C. Wunderlich[1] — [1]Fachbereich Physik, Universität Siegen, 57068 Siegen — [2]Institute of Theoretical Physics, Universität Ulm, 89069 Ulm

Ion trap quantum computing or quantum simulations with easy to control and stable microwave sources instead of complex laser systems, require the use of Zeeman sub levels. Here, dephasing between magnetic field sensitive states, due to ambient magnetic field noise, shortens the coherence. By dressing magnetic field sensitive states with microwave fields we demonstrate theoretically and experimentally that the dressed states are long-lived and that fast universal quantum logic is possible with this approach. Experimentally we achieved, depending on the particular dressed state, an extension in coherence times between a factor of 4 and two orders of magnitude compare to bare states.

Using rf coupling, a dressed state and a magnetic field insensitive bare state can be used as a qubit. Multi-qubit gates can be very fast, since the carrier transition cancels by interference when tuning to a motional sideband. The advantage over the regular quantum computing scheme is that fast gates are possible even when the Lamb Dicke parameter is small.

Q 26.8 Wed 12:30 HÜL 386

Pulsed coherent Rydberg excitation in a thermal gas of Rb — •Bernhard Huber, Thomas Baluktsian, Andreas Kölle, Harald Kübler, Michael Schlagmüller, Renate Daschner, Alban Urvoy, Robert Löw, and Tilman Pfau — 5. Physikalisches Institut, Universität Stuttgart

The Rydberg blockade effect is a promising candidate for the realization of quantum devices. For this, fully coherent dynamics in the atom-light-system is required. Our approach utilizes thermal atomic vapor in a small glass cell which offers multiple advantages in terms of scalability and ease of use compared to ultracold atomic systems. However, the limited coherence time of a thermal gas requires excitation on the nanosecond timescale, corresponding to Rabi frequencies of up to 1 GHz.

In our setup a two-photon-excitation is used to address the Rydberg level via an intermediate state. In order to produce fast enough dynamics between the ground and Rydberg state the upper transition is driven by a bandwidth-limited pulsed laser amplifier.

We present time-resolved measurements of Rabi oscillations involving a Rydberg state in a thermal gas of Rb. This implies the feasibility of coherent control of thermal atomic systems including Rydberg levels.

Q 26.9 Wed 12:45 HÜL 386

Optimal Controlled Phasegates for Trapped Neutral Atoms at the Quantum Speed Limit — •Michael Goerz[1], Tommaso Calarco[2], and Christiane P. Koch[1,3] — [1]Institut für Theoretische Physik, Freie Universität Berlin, Germany — [2]Institut für Quanteninformationsverarbeitung, Universität Ulm, Germany — [3]Institut für Physik, Universität Kassel, Germany

We study controlled phasegates for ultracold atoms in an optical lattice. A shaped laser pulse drives transitions between the ground and electronically excited states where the atoms are subject to a long-range $1/R^3$ interaction. We fully account for this interaction and use optimal control theory to calculate the pulses. This allows us to determine the minimum pulse duration, respectively, gate time T that is required to obtain high fidelity. We find the gate time to be limited either by the interaction strength in the excited state or by the ground state vibrational motion in the trap. The latter needs to be resolved in order to fully restore the motional state of the atoms at the end of the gate.

Q 27: Ultra-cold atoms, ions and BEC III

Time: Wednesday 10:30–12:45 Location: BAR 106

Invited Talk Q 27.1 Wed 10:30 BAR 106

Ultracold chemistry and dipolar collisions in a quantum gas of polar molecules — •Silke Ospelkaus[1,2], Amodsen Chotia[2], Marcio de Miranda[2], Brian Neyenhuis[2], Kang-Kuen Ni[2], Dajun Wang[2], Jun Ye[2], and Deborah Jin[2] — [1]Institut fuer Quantenoptik und QUEST, Universitaet Hannover — [2]JILA, NIST and University of Colorado, Boulder, CO, USA

Ultracold polar molecular quantum gases promise to open new research directions ranging from the study of ultra-cold chemistry, precision measurements to novel quantum phase transitions. Based on the preparation of high-phase space density gases of polar KRb molecules [1,2,3], I will discuss the control of dipolar collisions and chemical reactions of polar molecules in a regime where quantum statistics, single scattering partial waves, and quantum threshold laws play a dominant role [4]. In particular, I will point out the crucial role of electric dipole-dipole interactions [5] and external confinement [6] in determining the chemical reaction rate. Finally, I will discuss prospects of reaching quantum degeneracy in bi-alkali samples of polar molecules and prospects for these systems as novel dipolar quantum many-body systems. [1] K. K. Ni, S. Ospelkaus, M. H. G. de Miranda, et al., Science 322, 231 (2008). [2] S. Ospelkaus, K. K. Ni, M. H. G. de Miranda, et al., Faraday Discussions 142, 351 (2009). [3] S. Ospelkaus, K. K. Ni, G. Quemener, et al., Phys. Rev. Lett. 104, 030402 (2010). [4] S. Ospelkaus, K. K. Ni, D. Wang, et al., Science 327, 853 (2010). [5] K. K. Ni, S. Ospelkaus, D. Wang, et al., Nature 464, 1324 (2010). [6] M. H. G. de Miranda, A. Chotia, B. Neyenhuis et al, arXiv: 1010.3731 (2010).

Q 27.2 Wed 11:00 BAR 106

Finite temperature interactions between cold atoms and nanostructures — Johannes Märkle, Benjamin Jetter, Philipp Schneeweiss, Michael Gierling, Gabriela Visanescu, Peter Federsel, Dieter Kern, Andreas Günther, József Fortagh, and •Thomas Judd — CQ Center for Collective Quantum Phenomena and their Applications, Eberhard-Karls-Universität Tübingen, Auf der Morgenstelle 14, D-72076 Tübingen, Germany

There is currently much interest in combining cold atoms with nanofabricated devices such as carbon nanotubes. Such research studies the interface between quantum gases and solid devices, and the interface between quantum and classical physics. It also provides insight into nanomachines, nanoelectronics, and macromolecular control. In such systems the role of temperature is important and related to quantum coherence properties.

Here we study quantum reflection and inelastic scattering of atoms from carbon nanotubes and show how cold atom experiments can extract information about nanostructures' van der Waals potentials. We also develop a novel finite temperature theory for cold atoms and study how solid structures may be used to cool and create coherence in quantum gases. We also explore the reverse case in which a cold atom cloud is used to cool solid objects.

Q 27.3 Wed 11:15 BAR 106

Dark solitons near the Mott-insulator–superfluid phase transition — •Konstantin Krutitsky[1], Jonas Larson[2,3], and Maciej Lewenstein[4,5] — [1]Fakultät für Physik der Universität Duisburg-Essen, Campus Duisburg, Lotharstraße 1, 47048 Duisburg, Germany — [2]NORDITA, 106 91 Stockholm, Sweden — [3]Department of Physics, Stockholm University, AlbaNova University Center, 106 91 Stockholm, Sweden — [4]ICFO-Institut de Ciències de Fotòniques, 008860 Castelldefels (Barcelona), Spain — [5]ICREA-Institució Catalana de Recerca i Estudis Avançats, Lluís Companys 23, 08010 Barcelona, Spain

Dark solitons of ultracold bosons in the vicinity of the Mott-insulator–superfluid phase transition are studied. Making use of the Gutzwiller ansatz we have found antisymmetric eigenstates corresponding to standing solitons, as well as propagating solitons created by phase imprinting. Near the phase boundary, superfluidity has either a particle or a hole character depending on the system parameters, which greatly affects the characteristics of both types of solitons. Within the insulating Mott regions, soliton solutions are prohibited by lack of phase coherence between the lattice sites. Linear and modulational stability show that the soliton solutions are sensitive to small perturbations and, therefore, unstable. In general, their lifetimes differ for on-site and off-site modes. For the on-site modes, there are small areas between the Mott-insulator regions where the lifetime is very large, and in particular much larger than that for the off-site modes.

Q 27.4 Wed 11:30 BAR 106

Overview of laser cooling of relativistic C3+ ion beams at ESR — •Michael Bussmann[1], Franziska Kroll[1], Markus Löser[1], Matthias Siebold[1], Ulrich Schramm[1], Weiqiang Wen[1,2,6], Daniel F.A. Winters[2,3], Tobias Beck[4], Benjamin Rein[4], Thomas Walther[4], Gerhard Birkl[4], Wilfried Nörtershäuser[2,5], Thomas Kühl[2], Christian Novotny[2,5], Christophor Kozhuharov[2], Christopher Geppert[2,5], Markus Steck[2], Christina Dimopoulou[2], Fritz Nolden[2], Xinwen Ma[6], and Thomas Stöhlker[2,3] — [1]Forschungszentrum Dresden-Rossendorf — [2]GSI Helmholtzzentrum für Schwerionenforschung GmbH — [3]Universität Heidelberg — [4]Technische Universität Darmstadt — [5]Universität Mainz — [6]Institute for Modern Physics, Chinese Academy of Science

We present an overview of the setup for all-optical cooling and beam diagnostics for relativistic C3+ ion beams at the Experimental Storage Ring (ESR) at GSI. With new optical diagnostics it is foreseen to improve the measurement of the longitudinal momentum spread of the beam by at least an order of magnitude. The new optical diagnostics together with the new Schottky diagnosis and beam profile monitor available at ESR will allow to access the complete phase space evolution of the beam inside the storage ring. With new laser systems developed for cooling beams with an initially large energy spread it will be possible to replace the electron cooler that was used to reduce the initial momentum spread of the ion beam.

Q 27.5 Wed 11:45 BAR 106

Stability and elementary excitations of a dipolar Bose gas in a 1D optical lattice — •Mattia Jona - Lasinio[1], Luis Santos[1], Stefan Mueller[1,2], Juliette Billy[2], Emanuel Henn[2], Holger Kadau[2], Philipp Weinmann[2], David Peter[2], and Tilman Pfau[2] — [1]ITP, Institut für Theoretische Physik, Leibniz Universität Hannover — [2]5. Physikalisches Institut, Universität Stuttgart

We consider a system of ultracold dipolar bosons in a 3D harmonic potential plus a 1D optical lattice along the weakest trapping direction.

We assume all dipoles to be aligned along the lattice direction. We investigate the stability of the system as a function of the lattice strength and we highlight the role played by the long range dipole-dipole interaction. By solving the Bogoliubov equations we also characterize the different types of instability emerging in the system. We compare our theoretical predictions with the stability of a Chromium (^{52}Cr) condensate, finding the experimental evidence of the dipole-dipole long range character.

Q 27.6 Wed 12:00 BAR 106

Stability of a Dipolar Quantum Gas in a 1D Optical Lattice — •Stefan Mueller[1,2], Juliette Billy[1], Emanuel Henn[1], Holger Kadau[1], Philipp Weinmann[1], David Peter[1], Mattia Jona Lasinio[2], Luis Santos[2], and Tilman Pfau[1] — [1]5. Physikalisches Institut, Universität Stuttgart — [2]Cluster of Excellence QUEST, Institut für Theoretische Physik, Leibniz Universität Hannover

We present first measurements on the stability of a BEC of chromium atoms in a 1D optical lattice. In a shallow lattice the trap aspect ratio of the underlying optical dipole trap (ODT) potential determines the critical scattering length [1]. However, in a deep lattice the system can be considered as a stack of pancake shape BECs, which individually are expected to be much more stable. We investigate the range from 0 to approx. 100 recoil energies lattice depth, observing a continuous decrease in the critical scattering length from +13 to -20 Bohr radii. Theoretical studies support significant intersite coupling via the long range dipole-dipole interactions.

[1] T.Koch *et al.*: Nature Physics **4**, 218 (2008)

Q 27.7 Wed 12:15 BAR 106

Controlled Charge Transport in lattice confined Alkaline-Earth Gases — •Rick Mukherjee[1], Alexander Eisfeld[1], Igor Lesanovsky[2], and Thomas Pohl[1] — [1]Max Planck Institute for the Physics of Complex Systems, Dresden, Germany — [2]School of Physics and Astronomy, The University of Nottingham, United Kingdom

We study the dynamics of an ion immersed in an optical lattice of ultracold atoms. Here, simultaneous trapping of atoms and ions is made possible though the use of alkaline-earth atoms. Focussing on Strontium, we present extensive calculations of the atomic structure of highly excited states, as well as of the properties of molecular ions composed of such two-electron atoms. Optical dressing to Rydberg states is shown to permit precise and detailed control of charge exchange between neighbouring lattice sites, thereby offering unique opportunities to steer coherent charge transport and implement, e.g. a range Holstein-Hubbard type Hamiltonians in optical lattices.

Q 27.8 Wed 12:30 BAR 106

Mixing and de-mixing of dressed condensates — •Eike Nicklas, Helmut Strobel, Christian Gross, Tilman Zibold, Jiri Tomkovic, and Markus K Oberthaler — Kirchhoff Institute for Physics, University of Heidelberg, Germany

Two component interacting Bose-Einstein condensates provide a versatile system for studying the dynamics of multicomponent quantum fluids. Here we report on a method for controlling the effective interactions that govern the miscibility of the system by dressing the two components with a linear coupling field. We experimentally investigate the demixing dynamics of a binary condensate consisting of two hyperfine states of Rubidium and compare the results with numerical simulations. A Feshbach resonance allows changing the miscibility parameter of the system. We observe suppression of demixing when the two components are dressed with a linear coupling and the effective miscibility can be controlled via the coupling strength. Furthermore, we find that a miscible system is destabilized when applying a driving field.

Q 28: Quantum Information: Quantum Communication 1

Time: Wednesday 10:30–12:45 Location: SCH A01

Q 28.1 Wed 10:30 SCH A01

Faked-state attacks on commercial quantum key distribution — •Nitin Jain[1,2], Lars Lydersen[3,4], Christoffer Wittmann[1,2], Carlos Wiechers[5], Dominique Elser[1,2], Christoph Marquardt[1,2], Vadim Makarov[3,4], Johannes Skaar[3,4], and Gerd Leuchs[1,2] — [1]Max Planck Institute for the Science of Light, Guenther-Scharowsky-Str. 1, Bau 24, 91058, Erlangen, Germany — [2]Institut fuer Optik, Information und Photonik, University of Erlangen-Nuremberg, Staudtstraße 7/B2, 91058, Erlangen, Germany — [3]Department of Electronics and Telecommunications, Norwegian University of Science and Technology, NO-7491 Trondheim, Norway — [4]University Graduate Center, NO-2027 Kjeller, Norway — [5]Departamento de Fisica, Campus Leon, Universidad de Guanajuato, Lomas del Bosque 103, Fracc. Lomas del Campestre, 37150, Leon, Gto, Mexico

We experimentally review an off-the-shelf commercial quantum key distribution system (QKD) from ID Quantique to identify loopholes and exploit vulnerabilities by simulating and performing attacks on it. In particular, we devise faked-state attacks against the avalanche photo diode (APD) based detectors of this QKD system. We have shown several successful proof-of-principle attacks through experiments and simulations.

Q 28.2 Wed 10:45 SCH A01

Highly Efficient Frequency Conversion at the Single Photon Level — Sebastian Zaske, •Andreas Lenhard, and Christoph Becher — Universität des Saarlandes, FR 7.2 Experimentalphysik, Campus E2.6, 66123 Saarbrücken

Much recent progress has been achieved in the fabrication of single photon emitters based on color centers in diamond, e.g., SiV-centers emitting at 738 nm [1]. However, efficient single photon transmission in future quantum networks requires wavelengths in the low loss band of optical fibers around 1550 nm. In order to bridge this wavelength gap we aim at frequency downconversion of single photons emitted from a SiV-center. As a first step we investigate difference frequency mixing of attenuated laser pulses at 738 nm with a strong continuous light field at 1404 nm in a ZnO-doped periodically poled $LiNbO_3$ ridge waveguide and yield converted photons at 1557 nm. An internal conversion efficiency exceeding 80% is achieved. Together with a high coupling efficiency of 93% into the waveguide at 738 nm this leads to an overall conversion efficiency of about 30% for our setup. We further investigate the noise properties of the mixing process by measuring the spectrum between 1450-1600 nm. The dominating noise source in our experiment is identified to be spontaneous (Stokes) Raman scattering induced by the strong pump field at 1404 nm.

[1] E. Neu, D. Steinmetz, J. Riedrich-Möller, S. Gsell, M. Fischer, M. Schreck, and C. Becher, "Single photon emission from silicon-vacancy centres in CVD-nano-diamonds on iridium," accepted for publication in New. J. Phys. (2010).

Q 28.3 Wed 11:00 SCH A01

Daylight Free Space Quantum Communication using Continuous Polarization Variables — •Christian Peuntinger[1,2], Bettina Heim[1,2], Christoffer Wittmann[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]Institut für Optik, Information und Photonik, Universität Erlangen-Nürnberg, Staudtstrasse 7 / B2, 91058 Erlangen, Deutschland

We present our experimental work on quantum communication using a free space quantum channel of 1.6km in an urban environment. In our prepare-and-measure setup, we perform binary encoding of continuous polarization states. The signal states are measured using homodyne detection with the help of a local oscillator (LO). Both, signal and LO, are sent through the free-space channel while occupying the same spatial mode. This leads to excellent interference at the detection and an auto-compensation of the phase fluctuations introduced by the channel. Additionally the LO automatically acts as a spatial and spectral filter of the signal, which allows for unrestrained daylight operation. We have compared Stokes measurements on the quantum states before and after passing the free space channel using different modulation patterns. This allows for investigation of the influences of the turbulent atmosphere on our quantum states. A main drawback when working with an atmospheric channel is spatial beam jitter. We studied these kind of effects in detail and will present methods to reduce their

impact.

Q 28.4 Wed 11:15 SCH A01

Broadband mode selector based on spectrally engineered sum frequency generation — •Benjamin Brecht[1], Andreas Eckstein[1,2], and Christine Silberhorn[1,2] — [1]Integrated Quantum Optics, Applied Physics, University of Paderborn, 33098 Paderborn — [2]Max Planck Institute for the Science of Light, 91058 Erlangen

We propose broadband mode selection, a method for accessing the spectrally broadband mode structure of ultrafast quantum states of light. This opens up a new degree of freedom for quantum information coding which was unitl now not practically accessible. Based on spectrally engineered sum frequency generation (SFG), it allows us to pick well-defined pulsed broadband modes from an ultrafast multi-mode state without destroying its coherent pulse characteristics. By shaping the pulse of the bright SFG pump beam, different orthogonal broadband modes matched to the intrinsic structure of the input state can be addressed individually, extracted spatially with near unit efficiency and interconverted into each other for later interference.

Q 28.5 Wed 11:30 SCH A01

The excitation of a two-level atom by a propagating light pulse — •Yimin Wang, Lana Sheridan, and Valerio Scarani — Centre for Quantum Technologies, Singapore

State mapping between atoms and photons, and photon-photon interactions play an important role in scalable quantum information processing. We consider the interaction of a two-level atom with a quantized *propagating* pulse in free space and study the probability $P_e(t)$ of finding the atom in the excited state at any time t. This probability is expected to depend on (i) the quantum state of the pulse field and (ii) the overlap between the pulse and the dipole pattern of the atomic spontaneous emission. In the full three-dimensional vector model for the field, we show that the second effect is captured by a single parameter $\Lambda \in [0, 8\pi/3]$, obtained by weighing the numerical aperture with the dipole pattern. Then $P_e(t)$ can be obtained by solving time-dependent Heisenberg-Langevin equations. We provide detailed solutions for both single-photon states and coherent states and for various shapes of the pulse. By optimizing the pulse bandwidth of each kind of pulse with specific shapes, the maximum excitation probability is shown respectively. The effect of mean photon numbers for coherent state pulse is also analyzed.

Reference

[1] G. Zumofen *et al.*, Phys. Rev. Lett. **101**, 180404 (2008).
[2] M. Stobińska *et al.*, Euro. Phys. Lett., **86**, 14007 (2009).
[3] M. K. Tey *et al.*, Nature Physics **4**, 924 (2008).
[4] Y. M. Wang *et al.*, arXiv: 1010.4661v1, (2010).

Q 28.6 Wed 11:45 SCH A01

Lenses as an Atom-Photon Interface: A Simple Model — •Colin Teo[1] and Valerio Scarani[1,2] — [1]Centre for Quantum Technologies, Singapore — [2]Department of Physics, National University of Singapore, Singapore

Strong interaction between the light field and an atom is often achieved with cavities. Recent experiments have used a different configuration: a propagating light field is strongly focused using a system of lenses, the atom being supposed to sit at the focal position. In reality, this last condition holds only up to some approximation; in particular, at any finite temperature, the atom position fluctuates. We present a formalism that describes the focalized field and the atom sitting at an arbitrary position. As a first application, we show that thermal fluctuations do account for the extinction data reported in [1].

References:

[1] M. K. Tey *et al.*, Nature Physics **4**, 924 (2008)
[2] M. K. Tey *et al.*, New Jour. Phys. **11**, 043011 (2009)

Q 28.7 Wed 12:00 SCH A01

Rate analysis for a hybrid quantum repeater — •Nadja Kolb Bernardes[1,2], Ludmila Praxmeyer[3], and Peter van Loock[1,2] — [1]OQI Group, MPL, Erlangen, Germany — [2]Institute of Theoretical Physics I, University Erlangen-Nuremberg, Erlangen, Germany — [3]Institute of Physics, Nicoulaus Copernicus University, Torun, Poland

We present a detailed rate analysis for a hybrid quantum repeater [1, 2] assuming perfect memories and using optimal probabilistic entanglement generation and deterministic swapping routines [3]. The hybrid quantum repeater protocol is based on atomic qubit-entanglement distribution through optical coherent-state communication. An exact, analytical formula for the rates of entanglement generation in quantum repeaters is derived, including a study on the impacts of entanglement purification and multiplexing strategies. More specifically, we consider scenarios with as little purification as possible and we show that for sufficiently low local losses, such purifications are still more powerful than multiplexing. In a possible experimental scenario, our hybrid system can create near-maximally entangled (F=0.98) pairs over a distance of 1280 km at rates of the order of 100 Hz.

[1] P. van Loock *et al.*, Phys. Rev. Lett. **96**, 240501 (2006).
[2] P. van Loock *et al.*, Phys. Rev. A **78**, 062319 (2008).
[3] N. K. Bernardes, L. Praxmeyer and P. van Loock, arXiv:1010.0106v1 (2010).

Q 28.8 Wed 12:15 SCH A01

Secret key rates in quantum key distribution using optimization of Rényi entropies — •Silvestre Abruzzo, Markus Mertz, Hermann Kampermann, and Dagmar Bruss — Heinrich-Heine-Universität Düsseldorf, Institut für Theoretische Physik III, Düsseldorf, Germany

The analysis of a quantum key distribution(QKD) protocol considering finite resources is a new research field. In this talk we will present a new bound for the secret key rate based on the optimization of Rényi entropies, and we will show how to estimate it for finite number of signals. We will explicitly calculate this bound for the symmetric six-state protocol and show that in comparison with other relevant approaches it leads to higher key rates.

Q 28.9 Wed 12:30 SCH A01

Experimental optimum unambiguous discrimination of two mixed single-photon states — •Gesine Steudle[1], Sebastian Knauer[1], Ulrike Herzog[1], Erik Stock[2], Dieter Bimberg[2], and Oliver Benson[1] — [1]Humbolt-Universität Berlin, AG Nanooptik, Newtonstr. 15, 12489 Berlin — [2]Technische Universität Berlin, Institut für Festkörperphysik, Hardenbergstr. 36, 10623 Berlin

The discrimination of quantum states [1,2] is a fundamental challenge in quantum communication. Particularly, the discrimination of two non-orthogonal quantum states can be performed unambiguously only at the expense of admitting inconclusive results.

In this contribution we present an experimental setup for optimum unambiguous discrimination between two non-orthogonal mixed states [3,4]. We show experimental results for two mixed single-photon states. The single photon source is based on Stranski-Krastanow-grown InAs dots which are embedded in a pin-junction to establish electrical pumping [5].

[1] J. A. Bergou et al., Lect. Notes Phys. 649, 417-465 (Springer, Berlin, 2004)
[2] S. M. Barnett and S. Croke, Adv. Opt. Photon. 1, 238-278 (2009)
[3] U. Herzog, Phys. Rev. A 75, 052309 (2007)
[4] U. Herzog and O. Benson, J. Mod. Opt. 56, 1362 (2009)
[5] A. Lochmann et al., Electron. Lett. 42, 774 (2006)

Q 29: Laserentwicklung: Nichtlineare Effekte 1

Time: Wednesday 10:30–13:00 Location: SCH 251

Q 29.1 Wed 10:30 SCH 251

Frequency Comb Generation in Crystalline Whispering-Gallery Mode Resonators — •Tobias Herr[1], Christine Wang[2], Pascal Del'Haye[2], Klaus Hartinger[3], Ronald Holzwarth[3], and Tobias Kippenberg[1,2] — [1]École Polytechnique Fédérale de Lausanne (EPFL), CH-1015 Lausanne, Switzerland — [2]Max-Planck-Instiut für Quantenoptik, D-85748 Garching, Germany — [3]Menlo Systems GmbH, Am Klopferspitz 19a, D-82152 Martinsried, Germany

We experimentally demonstrate frequency comb generation via four-wave mixing in ultra high-Q crystalline MgF2 whispering-gallery mode resonators. More than 800 comb lines with spacing of 43 GHz are observed, while the resonator is thermally self-locked to a 700mW continuous wave pump laser at 1556 nm. Cross-correlation measurements reveal well separated pulses in the time-domain output at the comb repetition rate.

Q 29.2 Wed 10:45 SCH 251

Superkontinuumserzeugung mit Rückkopplung — •Michael Kues, Nicoletta Brauckmann, Sven Dobner, Maximilian Brinkmann, Till Walbaum, Petra Gross und Carsten Fallnich — Institut für Angewandte Physik, Westfälische Wilhelms-Universität Münster, Corrensstr. 2, 48149 Münster

Superkontinua, die durch eine spektrale Verbreiterung eines ultrakurzen Laserimpulses in mikrostrukturierten Fasern erzeugt werden, finden in vielen Bereichen Anwendung und können durch Änderung der Pumpimpulsparameter sowie der Faserparameter beeinflusst werden. Um jedoch weitere Möglichkeiten für eine gezielte Beeinflussung nicht nur der spektralen Form sondern auch der zeitlichen Entwicklung der Superkontinua zu erhalten, verfolgen wir das Konzept der Superkontinuumserzeugung mit Rückkopplung. In diesem Beitrag wird ein System, bestehend aus einer mikrostrukturierten Faser in einem Ringresonator, synchron gepumpt mit Laserimpulsen, vorgestellt. Es werden sowohl numerische als auch experimentelle Ergebnisse präsentiert, wobei zwischen der Superkontinuumserzeugung mittels Solitonendynamiken und mittels Vier-Wellen-Mischen (FWM) unterschieden wird. Im ersten Fall können je nach Parameterwahl nichtlineare Dynamiken wie Periodenverdopplung, Grenzzyklen oder Chaos auftreten, die eine maßgebliche Beeinflussung des Frequenzkammes ermöglichen und stark von der Phase der Rückkopplung abhängig sind, wodurch eine Kontrolle dieser Dynamiken ermöglicht wird. Im zweiten Fall kann eine Verstärkung der Maxima des FWM sowie eine Verschiebung der Frequenz bei Variation der zeitlichen Verzögerung beobachtet werden.

Q 29.3 Wed 11:00 SCH 251

A Widely tunable XUV frequency comb source — •Dominik Z. Kandula[2], Tjeerd J. Pinkert[1], Christoph Gohle[3], Itan Barmes[1], Jonas Morgenweg[1], Wim Ubachs[1], and Kjeld S.E. Eikema[1] — [1]LaserLaB Amsterdam, Institute for Lasers Life and Biophotonics, Vrije Universiteit, De Boelelaan 1081, 1081HV Amsterdam, The Netherlands — [2]Max Born Institute, Max-Born Str. 2A, 12489 Berlin, Germany — [3]Ludwig-Maximilians-Universität, Schellingstrasse 4, 80799 München, Germany

A frequency comb in the extreme ultraviolet (XUV) spectral range is produced by means of high harmonic upconversion of two phase-locked infrared pulses. The IR-pulse pair originates from a frequency comb oscillator and is amplified to energies in the order of several mJ per pulse in a noncollinear optical parametric chirped pulse amplifier. The amplification scheme allows to select the wavelength and the bandwidth of the amplified IR-pulses in the range between 700nm and 1000nm. This enables to cover the entire spectral range from the 5th harmonic at 200nm, to at least the 15th harmonic at 50nm with the upconverted frequency comb.

The versatility of the system is demonstrated by recording direct frequency comb excitation signals in helium, neon and argon with visibilities of up to 62%, at wavelengths from 51.5 nm to 83.5 nm. Using the XUV frequency comb a new ground state energy of helium could be measured with 6 MHz accuracy, presenting the most accurate direct frequency measurement in the XUV to date.

Q 29.4 Wed 11:15 SCH 251

Optisch parametrischer Oszillator hoher mittlerer Leistung mit Femtosekunden-Pulsen und schnell durchstimmbarem Spektrum — •Tino Lang[1], Michael Jackstadt[1], Stefan Rausch[1], Thomas Binhammer[2], Guido Palmer[1] und Uwe Morgner[1] — [1]Institut für Quantenoptik, Leibniz Universität Hannover, Deutschland — [2]VENTEON Laser Technologies GmbH, Garbsen, Deutschland

Wir präsentieren einen optisch-parametrischen Oszillator (OPO), der mittels eines frequenz-verdoppelten modengekoppelten Yb:KLuW-Scheibenlasers gepumpt wird. Bei der Pumpwellenlänge von 515 nm stehen damit über 12 Watt Pumpleistung bei einer Puls-Wiederholrate von 34,7 MHz und Pulsdauern von 500 fs zur Verfügung. Bei dem OPO handelt es sich um einen linearen signal-resonanten Oszillator mit BBO als aktives Medium, welcher über einen piezobetriebenen Verschiebetisch an die Puls-Wiederholrate des Pumplasers angepasst werden kann. Über eine gezielte Verstimmung der beiden Wiederholraten können die erzeugten Femtosekunden-Pulse in einem Bereich von 700 nm bis 1000 nm spektral schnell durch gestimmt werden. Dabei konnten mittlere Leistungen bis zu 3 W erreicht werden.

Q 29.5 Wed 11:30 SCH 251

Saturable absorption and nonlinear refractive index in composites doped with metal nanoparticles — •Kwang-Hyon Kim, Anton Husakou, and Joachim Herrmann — Max Born Institute for Nonlinear Optics and Short Pulse Spectroscopy, Max-Born-Str. 2a, 12489 Berlin

Commonly applied saturable absorbers for passive mode-locking of lasers are semiconductors, especially multi-quantum wells. However, in the short wavelength range below 700 nm attractive saturable absorbers are still missing. In the present talk we demonstrate that composites doped with metal nanoparticles can provide the required photonic element. By using a modified self-consistent Maxwell-Garnett formalism for spherical nanoparticles and a generalization of the discrete-dipole formalism for particles with arbitrary shape we show that the total absorption coefficient exhibit strong saturation behaviour near the plasmon resonance with saturation intensities in the range of 10 MW/cm^2. The plasmon resonance can be shifted in a wide wavelength range by choosing nanoparticles of different size and shape. This paves the way to a new class of designable saturable absorbers in the wavelength range of 400∼700 nm, where standard types of saturable absorbers are hard to apply. In addition, we study also the nonlinear refractive index and the field enhancement factor in the considered composites.

Q 29.6 Wed 11:45 SCH 251

Messung des nichtlinear-optischen Koeffizienten von Lithiumniobat im Terahertz-Frequenzbereich* — •Rosita Sowade, Jens Kiessling, Karsten Buse und Ingo Breunig — Physikalisches Institut, Universität Bonn, Wegelerstr. 8, 53115 Bonn

Basierend auf kaskadierten parametrischen Prozessen konnten wir einen optisch parametrischen Oszillator realisieren, der in der Lage ist, Dauerstrich-Terahertzstrahlung zu erzeugen. Aus der Bestimmung der Schwelle für diese Prozesse ergibt sich für den effektiven nichtlinearen Koeffizienten bei 1,4 THz für magnesiumdotiertes Lithiumniobat der Wert 94 pm/V. Über die Durchstimmbarkeit der erzeugten Terahertzwelle erhalten wir zusätzlich die Temperaturabhängigkeit des Brechungsindex für Terahertzfrequenzen, 0,0013/K.

* Wir danken der Deutschen Forschungsgemeinschaft (FOR 557) und der Deutschen Telekom AG für finanzielle Unterstützung.

Q 29.7 Wed 12:00 SCH 251

Erzeugung durchstimmbarer Terahertzstrahlung mit einem optisch parametrischen Oszillator und resonatorinterner Differenzfrequenzerzeugung im Dauerstrichbetrieb* — •Florian Fuchs, Jens Kiessling, Karsten Buse und Ingo Breunig — Physikalisches Institut, Universität Bonn, Wegelerstr. 8, 53115 Bonn

Zur Erzeugung weit durchstimmbarer Terahertzstrahlung generieren wir zwei Signalwellen um 1,4 μm Wellenlänge in einem optisch parametrischen Oszillator mit einem periodisch gepolten Lithiumniobat-Kristall, der eine Doppelstruktur aufweist. Der Frequenzabstand dieser Wellen ist variabel von 0,5 – 5 THz einstellbar. Die Differenzfrequenzmischung findet phasenangepasst in einem zusätzlichen Lithiumniobatkristall statt, welcher in einem zweiten Fokus des Resonators platziert wird. Mit diesem Aufbau wurde eine Durchstimmbarkeit von 0,7 – 2 THz bei Terahertzleistungen bis zu 0,4 μW gezeigt.

* Wir danken der Deutschen Forschungsgemeinschaft (FOR 557) und der Deutschen Telekom AG für finanzielle Unterstützung.

Q 29.8 Wed 12:15 SCH 251

1.5 W Output Two-Color Femtosecond Optical Parametric Oscillator Pumped by a 7.4 W Femtosecond Yb:KGW Laser — •Robin Hegenbarth[1], Andy Steinmann[1], János Hebling[2], and Harald Giessen[1] — [1]4th Physics Institute, University of Stuttgart, Pfaffenwaldring 57, 70550 Stuttgart, Germany — [2]Department of Experimental Physics, University of Pécs, Ifjúság út 6, H-7624 Pécs, Hungary

We developed a singly resonant optical parametric oscillator synchronously pumped by an Yb:KGW laser. The OPO signal was generated in a 1 mm long MgO-doped periodically poled congruent lithium niobate (MgO:cPPLN) crystal. With 7.4 W average pump power, 42 MHz repetition rate, and 530 fs FWHM pump pulse duration we were able to achieve more than 1 W in several wavelength regions between 1445 and 1880 nm wavelength with FWHM pulse durations shorter than 600 fs. In particular, we achieved up to 1.5 W using 60 % output coupling rate. A peak in conversion efficiency could be observed at approximately 3 to 5 times threshold pump power. At higher pump power levels conversion efficiency was decreasing. Two-color operation occurred when the OPO was operated close to the point at which total cavity GDD was equal to zero. Due to large signal bandwidth and due to the fact that identical group delay occurred at two wavelengths, oscillation at two wavelengths was possible. This can be used for efficient difference frequency generation into the mid-IR region.

Q 29.9 Wed 12:30 SCH 251

Characterization and modelling of novel TBR laser diodes at 980 nm — •Chistof Zink, Danilo Skoczowsky, Andreas Jechow, Axel Heuer, and Ralf Menzel — Universität Potsdam, Institut für Physik und Astronomie, Photonik, Karl-Liebknecht-Straße 24–25, Haus 28, 14476 Potsdam

Broad area (BA) lasers are the most efficient light sources available, but suffer from poor beam quality due to the lack of tranversal mode selection. By incorporating a transverse Bragg grating into a BA laser diode it is possible to select one transversal mode. The resulting transverse Bragg resonance (TBR) waveguide can be designed to have a single transversal mode that is distributed throughout the entire width of the laser for efficient, stable and single transversal mode operation even at high output powers. In addition the modal gain at the desired lasing frequencies can be increased by designing the dispersion of the TBR modes. This concept promises higher output powers and improved efficiency compared to traditional index-guided laser diodes. Detailed measurements of several lasers with different dimensions and numbers of quantum wells will be presented. The TBR lasers were also operated in an external resonator which allows selecting different types of modes. Finally, a simple model will be introduced which describes the emission characteristics of the different lasers.

Q 29.10 Wed 12:45 SCH 251

Impact of injector length on interband cascade laser performance — •Robert Weih, Adam Bauer, Sven Höfling, Martin Kamp, Lukas Worschech, and Alfred Forchel — Technische Physik, University of Würzburg, Wilhelm-Conrad-Röntgen-Research Center for Complex Material Systems Am Hubland, D-97074 Würzburg, Germany

The interband cascade laser (ICL) is a novel type of unipolar semiconductor laser emitting in the mid-infrared wavelength range. Although the laser operation is driven by interband transitions between electron states and hole states, only electrons are injected. While travelling through a cascaded active region, these electrons generate multiple photons making the ICL a hybrid laser, combining advantages of diode lasers and QCLs. Whereas bipolar diode lasers utilize also interband transition, but within a pn-junction, QCLs are unipolar devices and thoroughly based on intersubband transitions between electron states.

In this work ICLs were grown by MBE and investigated via temperature dependent electro-optical measurements. It was found that shortening the chirped superlattice injector regions used for resonant tunnel injection of electrons into the type-II "W" active regions improves the laser performance significantly. Stepwise reduction of the injector length from 74nm to 49nm led to close to linear dependence between pulsed maximum operation temperatures and injector length, while threshold current figures could be reduced monotonically. Devices incorporating the optimized shortened injector layout reach operation temperatures exceeding 335K (pulsed) and 273K (cw).

Q 30: Photonics 2

Time: Wednesday 10:30–13:00 Location: SCH A118

Q 30.1 Wed 10:30 SCH A118

Sensing with coupled microcavity systems — •Sandra Isabelle Schmid and Jörg Evers — Max-Planck-Institut für Kernphysik, Heidelberg, Germany

In recent years microresonators have become more and more important for optical research. Their special properties as low loss rates and ultra high Q values offer a lot of advantages for applications and experiments. They can be used as optical filters or even as ultra fast switching devices [1,2].

We consider systems of coupled Whispering Gallery Mode (WGM) resonators. In such toroidal cavities WGM modes always occur in pairs of modes of the same frequency but opposite propagation directions. If another cavity or object is located very close to a resonator, an interaction via the evanescent field can take place. In our research we investigate the transmission and reflection properties of arrays built of microresonators. Our observables are the transmission and reflection intensities.

Moreover, we study systems consisting of microcavities coupled to nearby atoms. In [3] was shown, that a nearby two-level atom crucially influences the output fluxes of a single cavity. Therefore, we are interested in the impact of a nearby atom on an array of microcavities. We study the transmission and reflection spectra in detail and discuss possible applications.

[1] K. Vahala, Nature **424**, 839 (2003).
[2] M. A. Popovic et al., Optics Express **14**, 3 (2006).
[3] B. Dayan et al., Science **319**, 1062 (2008).

Q 30.2 Wed 10:45 SCH A118

Microcavity Biosensing: recent advances — •Frank Vollmer — Max Planck Institute for the Science of Light, Erlangen, Germany

Optical resonance is created by confining coherent light inside a miniature dielectric structure such that it interferes constructively. Ideally, such optical resonators (microcavities) would confine light indefinitely and real-world divergence from this condition is described by the finite cavity quality (Q) factor. Ultimate (absorption limited) Q-factors have been reported in microsphere whispering-gallery mode optical resonators where light is efficiently confined by total-internal reflection. The high Q-factor (up to 10^9) enables precise measurements of resonance frequency and changes thereof. Such changes occur, for example, due to the binding of molecules or particles to the outer surface of the microsphere cavity. Since microcavities can be immersed in a liquid without significant damping of the optical resonance, measurements of resonance frequency shifts have been exploited to construct ultra-sensitive label-free biosensor devices.

I will give an overview of our recent advances in microcavity biosensor development, which have resulted in an improvement of the detection capability down to the single particle (single virus) level. I will also highlight other modalities of microcavity biosensors, such as approaches that use resonant evanescent fields for nanoparticle trapping and manipulation, as well as for enhanced detection with plasmonic nanoparticles.

Q 30.3 Wed 11:00 SCH A118

Nonlinear Photonic Lattices based on Complex Nondiffracting Beams — •Falko Diebel, Patrick Rose, Martin Boguslawski, Julian Becker, and Cornelia Denz — Institut für Angewandte Physik and Center for Nonlinear Science (CeNoS), Westfälische Wilhelms-Universität Münster, 48149 Münster, Germany

The fascinating field of nonlinear light propagation in photonic lattices comprises a variety of effects caused by the interplay between periodicity and nonlinearity. Reams of recent publications account for the importance of this topic.

In particular, the technique of optical induction facilitates the creation of reconfigurable nonlinear photonic structures. In order to induce these one- or two-dimensional functional refractive index patterns, typically so-called nondiffracting beams are used. These beams are characterized by transversely modulated intensity patterns that are translation invariant in the direction of propagation. They can be expressed as solutions of the Helmholtz equation and – depending on the coordinate system – belong to different families, namely Bessel, Mathieu, Weber, and discrete nondiffracting beams.

In this contribution, we present a novel technique for the optical induction of all these complex photonic structures using only one spatial light modulator to manipulate the phase as well as the amplitude of the light field at the same time. The resulting lattices are subsequently analyzed in detail. These complex photonic structures are of particular interest since they offer exciting possibilities to engineer the diffraction properties of light and facilitate the existence of new soliton families.

Q 30.4 Wed 11:15 SCH A118

Femtosecond Induced Optical Elements In Fused Silica — •Janning Herrmann, Wolfgang Horn, and Cornelia Denz — Institut für Angewandte Physik, Westfälische Wilhelms-Universität Münster, 48149 Münster, Germany

Optical waveguides and large-scale integrated photonic devices, such as couplers, splitters, amplifiers and add-drop multiplexers are of increasing interest for today's high speed optical networks. One of the most attractive fabrication techniques for these devices is point-by-point ultra-fast laser writing of photonic structures that permit rapid prototyping by multiphoton absorption in otherwise nonphotosensitive technical glasses. Femtosecond induced refractive index modifications are long term stable, have true 3D capability, and exhibit a higher degree of freedom for the design of integrated photonic circuits compared to traditional procedures like mask-based lithography. We demonstrate writing of diffractive optical elements, single-mode waveguide couplers, three-dimensional splitters, and Mach-Zehnder interferometers. Fabricated prototypes are fiber-coupled to lightwave circuits to determine mode confinement and loss characteristics. We also produced waveguides with integrated Bragg-gratings for narrowband multichannel filters in the telecom waveband and characterized their reflection and transmission properties. The used point-by-point writing techniques allows to easily induce defects that break the symmetry of the lattice. Therefore, magnitude and phase response of the filter transfer function can be customized to achieve tailored phase modification of propagating signals.

Q 30.5 Wed 11:30 SCH A118

Spatial analysis of optically induced photonic lattices — •Sybille Niemeier, Patrick Rose, Martin Boguslawski, and Cornelia Denz — Institut für Angewandte Physik and Center for Nonlinear Science (CeNoS), Westfälische Wilhelms-Universität Münster, 48149 Münster, Germany

In optics, periodic refractive index structures have been utilized to demonstrate a multitude of fascinating nonlinear effects. These so-called photonic lattices may for instance be generated via optical induction in photorefractive crystals. The electro-optic properties of these crystals as e.g. strontium barium niobate allow for the generation of highly reconfigurable nonlinear refractive index patterns modulated in one, two, or three dimensions.

Up to now, only rather qualitative methods like waveguiding and Brillouin zone spectroscopy are used to analyze the spatial properties of optically induced lattices. In this contribution, we develop methods for a quantitative analysis of these structures. For birefringent materials, the exploitation of an induced birefringence modulation due to the anisotropy of the electro-optic coefficients is a very promising approach. Beneath, the measurement of the underlying band structure allows to infer information of the investigated photonic lattice structure as well.

These new approaches grant a well-grounded analysis of the induced refractive index structure, which will certainly lead to a better understanding of many sophisticated effects in photonic lattices such as discrete and vortex solitons, Zener tunneling, Bloch oscillations, or Anderson localization.

Q 30.6 Wed 11:45 SCH A118

Simulation and design of electro-optic modulator based on SOI waveguides — •Aws Al-Saadi[1], Bülent A. Franke[1], Miroslaw Szczambura[1], Sebastian Kupijai[1], Shaimaa Mahdi[1], Viachaslau Ksiandzou[2], Sigurd Schrader[2], Hans J. Eichler[1], and Stefan Meister[1] — [1]Technische Universität Berlin, Institut für Optik und Atomare Physik, Berlin, Germany — [2]Technische Fachhochschule Wildau, Institut für Plasma- und Lasertechnik, Wildau, Germany

We present the simulation and design of single-mode e-o modulators based on 1-D photonic crystal micro resonator fabricated in silicon-on-insulator (SOI) (220nm x 445nm) rib waveguides. The device operates by change the refractive index in the resonator microcavity region produce shifting in center wavelengthof the transmission peak. The refractive index in the microcavity is varied by using the free-carrier dispersion effect. The carrier density is modulated by a p-i-n diode formed about the microcavity. The change in refractive index as well as absorption produced from free carrier dispersion was included in the simulation to analyze the performance of the modulator. The device has been modeled and analyzed using 3D simulation software based on FDTD method.

Q 30.7 Wed 12:00 SCH A118

Linear and Nonlinear Measurements on Silicon-Organic Hybrid Waveguide Structures — •Peter W. Nolte, Clemens Schriever, and Jörg Schilling — Centre for Innovation Competence SiLi-nano, Martin-Luther-University Halle-Wittenberg, Germany

In the last years great efforts lead to a strong miniaturization of optical components, as several devices were realized on the silicon-on-insulator (SOI) platform which is completely compatible to CMOS technology. The very high refractive index contrast between the Si core (n=3.5) and the oxide cladding (n=1.45) and air (n=1), respectively, leads to a high confinement of light inside a waveguide. However, for many applications active devices exhibiting a nonlinear optical behavior are needed. One possible way to boost the nonlinear optical properties in integrated optics is the functionalization of SOI-structures. This is achieved by a combination of Silicon with strongly nonlinear organic materials such as dyes. SOI-ridge-waveguides have been fabricated using standard CMOS-processing and coated with molten dyes. Linear poperties like mode index and propagation losses are determined from a Fourier evaluation of the Fabry Perot oscillations of the transmission spectra. Finally the nonlinear properties of these devices have been studied by degenerated four-wave-mixing measurements.

Q 30.8 Wed 12:15 SCH A118

Electro-optical induced waveguides in isotropic phase liquid crystals-oil mixtures — •Martin Blasl, Kirstin Bornhorst, and Florenta Costache — Fraunhofer Institut for Photonic Microsystems, Maria-Reiche-Str. 2, 01109 Dresden, Germany

Optical multiplexers based on electro-optical (EO) materials are used to route signals in sensor applications. EO induced wave-guides are of interest for wavelength independent multi-mode and wavelength selective mono-mode operation and fast multiplexing.

Liquid crystals exhibit above their clear point (nematic-isotopic transition temperature) the second order EO effect. We created novel EO mixtures of 5CB liquid crystals-immersion oil with modified clear point as it was determined by DSC-technique.

The temperature dependent Kerr effect as well as the refractive indices were measured with a combined refractometric - interferometric technique. We observed that the Kerr activity is still present in the mixtures.

Designs of basic EO induced waveguides containing the new mixtures and various ITO-electrodes pathways were fabricated for switching, attenuation and deflection of light.

We show that dynamic optical waveguides with low insertion loss and bandwidth larger than kHz could be generated in the new mixtures for a broad temperature range.

We compare the measured optical guiding efficiency in the fabricated devices with FEM-simulations of designed EO induced waveguide devices using the measured Kerr constants.

Q 30.9 Wed 12:30 SCH A118

Control of light transmission through opaque scattering media in space and time — •Jochen Aulbach[1,2], Bergin Gjonaj[1], Patrick M. Johnson[1], Allard P. Mosk[3], and Ad Lagendijk[1] — [1]FOM Institute for Atomic and Molecular Physics AMOLF, Science Park 113, 1098 XG Amsterdam, The Netherlands — [2]Institut Langevin, ESPCI ParisTech, CNRS, 10 rue Vauquelin, 75231 Paris Cedex 05, France — [3]Complex Photonic Systems, MESA+ Institute, University of Twente, Post Office Box 217, NL-7500 AE Enschede, The Netherlands

We report the first experimental demonstration of combined spatial and temporal control of light trajectories through opaque media. This control is achieved by solely manipulating spatial degrees of freedom of the incident wave front. As an application, we demonstrate that the present approach is capable to form bandwidth-limited ultra-short pulses from the otherwise randomly transmitted light with a controllable interaction time of the pulses with the medium. Our approach provides a new tool for fundamental studies of light propagation in complex media and has potential for applications for coherent control, sensing and imaging in nano- and bio-photonics.

Q 30.10 Wed 12:45 SCH A118

Erzeugung von höheren räumlich transversalen Moden mittels eines "Spatial Light Moldulators" — •Dirk Puhlmann, Axel Heuer und Ralf Menzel — Universität Potsdam, Institut für Physik und Astronomie, Photonik, Karl-Liebknecht-Str. 24-25, 14476 Potsdam

Bei der Konzeption und Realisierung der meisten Lasersysteme wird ein möglichst perfekter Gaußstrahl angestrebt. Für Anwendungen in der Mikroskopie, der Quantenoptik und gegebenenfalls bei der Materialbearbeitung können höhere transversale Moden von Interesse sein. Für solche Versuche stehen aus den oben genannten Gründen kaum käufliche Quellen zur Verfügung. Ein Weg zur Lösung, ist die Umwandlung der TEM_00 Mode in entsprechend höhere transversale Moden mit Hilfe eines diffraktiven Elements. In diesem Vortrag präsentieren wir die Möglichkeiten der Erzeugung höherer räumlich transversaler Moden mit Hilfe eines "Spatial Light Modulator" (SLM), mit dem beliebige Gauss-Laguerre als auch Gauss-Hermite-Moden generiert werden können. Die Vor- und Nachteile dieser Methode werden diskutiert und vorgestellt.

Q 31: Quantum Gases: Opt. Lattice 2

Time: Wednesday 14:30–16:00 Location: HSZ 02

Q 31.1 Wed 14:30 HSZ 02

Probing nearest-neighbor correlations of ultracold fermions in an optical lattice — •Thomas Uehlinger, Daniel Greif, Leticia Tarruell, Robert Jördens, Gregor Jotzu, and Tilman Esslinger — Institute for Quantum Electronics, ETH Zurich, 8093 Zurich, Switzerland

We demonstrate a probe for nearest-neighbor correlations of fermionic quantum gases in optical lattices. It gives access to spin and density configurations of adjacent sites and relies on creating additional doubly occupied sites by perturbative lattice modulation. The measured correlations for different lattice temperatures are in good agreement with an *ab initio* calculation without any fitting parameters. This probe opens new prospects for studying the approach to magnetically ordered phases.

Q 31.2 Wed 14:45 HSZ 02

Momentum-resolved spectroscopy of ultracold fermions in optical lattices — •Jannes Heinze, Sören Götze, Jasper Simon Krauser, Bastian Hundt, Nick Fläschner, Dirk-Sören Lühmann, Christoph Becker, and Klaus Sengstock — Institut für Laser-Physik, Universität Hamburg

The periodic dispersion of electrons in crystals gives rise to many important phenomena in solid-state physics. To characterize such systems a measurement of the energies and fillings is required for the lowest bands. Ultracold fermionic atoms in optical lattices show essentially the same physics, however, with much better control over the system parameters. This includes especially the arbitrary tuning between different lattice depths: From weak to strong lattices, conductive and insulating phases can be realized. We present a spectroscopy method which is sensitive to both, form and filling of the different bands fully momentum-resolved. Thus, we can measure the full band structure and therefore extract very accurately all derived properties as e.g. the tunneling energy. The additional filling information allows in principle for the determination of the systems' phase. Our sensitivity is promising for the extension of these studies to observe interaction shifts due to additional bosonic atoms as well as changes in the densitiy of states for interacting fermionic gases.

Q 31.3 Wed 15:00 HSZ 02

Néel transition of lattice fermions in a harmonic trap: a real-space dynamical mean-field study — •Elena V. Gorelik[1], Irakli Titvinidze[2], Walter Hofstetter[2], Michiel Snoek[3], and Nils Blümer[1] — [1]Institute of Physics, Johannes Gutenberg University, Mainz, Germany — [2]Institute for Theoretical Physics, Johann Wolfgang Goethe University, Frankfurt, Germany — [3]Institute for Theoretical Physics, University of Amsterdam, The Netherlands

Ultracold atoms on optical lattices attract enormous interest as potential "quantum simulators" of condensed-matter systems. A missing link in this context is the realization of antiferromagnetic (AF) Néel phases: in spite of enormous experimental efforts, concentrating in particular on achieving lower temperatures, no AF signatures have been detected so far.

We extend the range of applicability of the recently developed real-space dynamical mean-field theory (DMFT) to the temperatures of experimental interest by combining it with a highly efficient quantum Monte Carlo algorithm [1]. We demonstrate that the onset of AF correlations at low temperatures is signaled, for interactions U > 10t, by a strongly enhanced double occupancy [2]. This signature is directly accessible experimentally and should be observable well above the critical temperature for long-range order. Dimensional aspects appear less relevant (and DMFT more accurate) than naively expected.

[1] N. Blümer and E. V. Gorelik, Comp. Phys. Comm. **182**, 115 (2011). [2] E. V. Gorelik, I. Titvinidze, W. Hofstetter, M. Snoek, and N. Blümer, Phys. Rev. Lett. **105**, 065301 (2010).

Q 31.4 Wed 15:15 HSZ 02

Occupation-dependent multi-band Hubbard models — •Ole Jürgensen, Dirk-Sören Lühmann, and Klaus Sengstock — Institut für Laser-Physik, Universität Hamburg, 22761 Hamburg, Germany

Typically, tunneling and interactions are competing processes in optical lattices, where the quantum phase transition to the Mott insulator is one of the most prominent examples. So far, often single band Bose-Hubbard models are used to study these systems theoretically. Recently it was pointed out that already for moderate parameters the interaction promotes particles to higher bands of the lattice which alters the energy gain connected with the tunneling significantly[1,2]. In bosonic systems, new quantum phases have been predicted for occupation-dependent tunneling.

Using a fully correlated treatment, we calculate the effective tunneling and on-site interactions in optical lattices for bosonic atoms and Bose-Fermi mixtures. The renormalized tunneling sums over all combinations of higher-band processes and shows substantial deviations from the uncorrelated tunneling. We introduce an occupation-dependent Hubbard model which effectively covers the role of higher-orbital physics.

The results obtained from our fully correlated calculation cast new light on the underlying processes and support the significance of occupation-dependent Hubbard models.

[1] D.-S. Lühmann et al., Phys. Rev. Lett. 101, 050402 (2008)
[2] T. Best et al., Phys. Rev. Lett. 102, 030408 (2009)

Q 31.5 Wed 15:30 HSZ 02

Probing Quantum Density Fluctuations of Ultracold Atoms with Matter Wave Optics — •Scott Sanderes, Florian Mintert, and Andreas Buchleitner — Albert-Ludwigs-Universität, Freiburg, Germany

In this talk, we discuss the utility of matter wave scattering as a means to probe quantum density fluctuations of ultracold bosons in an optical lattice. Such fluctuations are characteristic of the superfluid phase and vanish due to increased interactions in the Mott insulating phase. We employ an analytical treatment of the scattering and demonstrate that the fluctuations lead to incoherent processes, which we propose to observe via decoherence of the fringes in a Mach-Zender interferometer. In this way we extract the purely coherent part of the scattering. Further, we show that the quantum density fluctuations can also be extracted directly from the differential angular scattering cross section for an atomic beam scattered from the atoms in a lattice. Here we find an explicit dependence of the scale of the inelastic scattering on the quantum density fluctuations.

Q 31.6 Wed 15:45 HSZ 02

Resonance fluorescence as a precision test for single site addressability — •Peter Degenfeld-Schonburg, Martin Kiffner, and Michael Hartmann — Technische Universität München, Physik Department, James Franck Strasse, 85748 Garching, Germany

Pioneering methods in recent optical lattice experiments allow for addressing single atoms in individual sites of an optical lattice by focused laser beams. Inspired by this, we examine the resonance fluorescence spectrum of two-level atoms positioned in adjacent lattice sites, where a focused laser beam drives a single atom only. As compared to the case where the laser hits several atoms, the spectrum for single site addressing is no longer symmetric around the laser frequency. The shape of the spectrum of fluorescent light can therefore serve as a test for the precision of single site addressing. The effects we find can be attributed to a dipole-dipole interaction between the atoms due to mutual exchange of photons.

Q 32: Quantum Information: Atoms and Ions 3

Time: Wednesday 14:30–16:15 Location: HÜL 386

Q 32.1 Wed 14:30 HÜL 386

Quantum computation and simulation using dissipation — •Philipp Schindler[1], Julio T. Barreiro[1], Markus Müller[2,3], Daniel Nigg[1], Thomas Monz[1], Michael Chwalla[1,2], Markus Hennrich[1], Christian F. Roos[2], Volckmar Nebendahl[3], Peter Zoller[2,3], and Rainer Blatt[1,2] — [1]Institut für Experimentalphysik, Universität Innsbruck, Austria — [2]Institut für Quantenoptik und Quanteninformation, Österreichische Akademie der Wissenschaften, Innsbruck, Austria — [3]Institut für Theoretische Physik, Universität Innsbruck, Austria

In quantum information experiments, quantum systems are usually isolated from the environment and their dynamics is controlled coherently. On the other hand, engineering the dynamics of many particles by a controlled coupling to an environment opens new possibilities in quantum information and simulation experiments[1]. We report on several experiments combining the power of multi-qubit quantum gates and dissipative coupling to the environment in a $^{40}Ca^{+}$ ion trap quantum computer. For example, quantum error correction requires to dissipatively reset ancilla qubits. For this optical pumping is used thus enabling multiple steps of a quantum-error-correction algorithm. We further demonstrate a toolbox for simulating an open quantum system with up to five qubits exemplified by the dissipative preparation of entangled states. This work offers novel prospects for quantum simulation and computation by adding controlled dissipation to coherent operations.

[1] F. Verstraete, et. al., *Nature Phys.* **5**, 633 (2009)

Q 32.2 Wed 14:45 HÜL 386

Quantum information processing with trapped ions at NIST — •Christian Ospelkaus — NIST, 325 Broadway, Boulder, CO, USA — Present address: QUEST, Universität Hannover, Welfengarten 1, 30167 Hannover and PTB, Bundesallee 100, 38116 Braunschweig

Most current schemes for Quantum Information Processing (QIP) with trapped ions implement quantum logic gates through a *laser-induced* spin-dependent interaction between ions held in the *same* trap. We give an overview of the current effort and describe experiments which explore ideas beyond these well-established techniques. In particular, we demonstrate Coulomb coupling between two ions held in individual traps separated by 40 μm. We observe oscillations of energy between the two oscillators at the single quantum level. Beyond the fundamental relevance of this system of coupled quantized mechanical oscillators, these results open new experimental perspectives for quantum simulation, novel entangling schemes for QIP and for precision spectroscopy. In a second experiment, we demonstrate a microwave near-field approach to coherent quantum control of trapped ions. For quantum logic, this approach has several important potential advantages with respect to operation fidelity and reduced complexity. We demonstrate single-qubit rotations with π times of less than 20 ns, driven by microwave currents in the trap electrodes, motional sideband transitions induced by the near-field magnetic field gradient, and sideband cooling. We discuss applications to quantum logic, simulation and spectroscopy. This work has been supported by IARPA, DARPA, NSA, ONR, and the NIST Quantum Information Program.

Q 32.3 Wed 15:00 HÜL 386

High precision measurement techniques for improving the scalability of ion trap quantum computing — •Andreas Walther, Ulrich Poschinger, Frank Ziesel, Max Hettrich, Alex Wiens, Michael Schnorr, Jens Welzel, Kilian Singer, and Ferdinand Schmidt-Kaler — Institute of Physics, University of Mainz, Staudinger Weg 7, 55128 Mainz

Two techniques for advancing the state of quantum computing in ion traps are presented. Both results are important for improving future gate fidelities as well as scalability possibilities of the ion trap quantum computing concept. The first one is a novel homodyne detection of the interference between two parts of an ion wavepacket, where the motional state of the ion is entangled with its spin state. We use this technique to characterize the phase space trajectory of the ion with high enough accuracy to find deviations from the linear approximation to the spin dependent light force, leading to an extension of the current models of the system evoloution.

Secondly, we employ a single ion to measure a magnetic field gradient with a relative sensitivity of $\Delta B/B \sim 10^{-7}$ over a 100 μm distance, which is shown to be quantum shot noise limited. The compensation of gradients helps to increase the coherence time of qubits that are transported for the realization of scalable quantum information processsing.

Q 32.4 Wed 15:15 HÜL 386

Optical Ion Trapping - Cooling and Perspectives — •Martin Enderlein, Thomas Huber, Christian Schneider, Stephan Duewel, Johannes Stroehle, and Tobias Schaetz — Max-Planck-Institut für Quantenoptik, Garching, Germany

Atomic ions stored in a linear Paul trap is one of the experimental quantum systems which is best controllable and suffers least from decoherence, making it particularly suited for quantum information experiments. Recently we were able to demonstrate a proof of principle for a quantum simulator for quantum spin systems by making use of the long-range interaction between ions [1]. The motivation for a quantum simulator is to gain deeper insight into complex quantum dynamics (e.g. of a solid-state system) via experimentally simulating the quantum behaviour of interest in another, better controllable quantum system (e.g. trapped ions). In order to gain genuinely new insights one has to scale these simulations to particle numbers that cannot be handled efficiently on a classical computer. This, however, might not be possible in a linear trap. One approach is to combine the advantages of trapped ions with those of optical lattices. As a first experimental step, we were able to trap an ion in a deep optical dipole trap [2]. In the mean time we have been analyzing the system in more detail and have investigated several laser cooling schemes. These results are the basis for future experiments with the goal of 2D quantum simulations with ions, or ions and atoms, trapped in optical lattices.

[1] A. Friedenauer et al., Nat. Phys. 4 (2008), 757-761

[2] Ch. Schneider et al., Nat. Photonics 4 (2010), 772-775

Q 32.5 Wed 15:30 HÜL 386

Measuring the Magnetic induced J-coupling between two ions — •Anastasiya Khromova, Andrés Felipe Varón, Benedikt Scharfenberger, Christian Piltz, Timm Gloger, and Christof Wunderlich — Fachbereich Physik, Universität Siegen, Walter-Flex-Straße 3, 57068 Siegen

Two 171Yb+ ions are electrodynamically trapped in presence of a magnetic gradient field. This magnetic field not only allows to address the ions independently [1] but also accounts for an effective spin-spin coupling [2]. This interaction was measured in a linear Paul trap using spin echo techniques on Doppler-cooled ions.

The magnetic field gradient is produced by means of two permanent magnets with identical poles facing toward each other and reaches up to 17 T/m. Having the axial trap potentials in the range of hundred kilohertz we are able to measure coupling constants of a few tens of hertz. The measured values we obtained are in good agreement with the theoretical expectations.

[1] M. Johanning et al., Phys. Rev. Lett. 102, 073004 (2009).

[2] Chr.Wunderlich, Laser Physics at the Limits, p.261, (Springer, 2002), arXiv:quant-ph/0111158

Q 32.6 Wed 15:45 HÜL 386

Towards quantum simulations in a two-dimensional lattice of ions — •Johannes Stroehle, Christian Schneider, Martin Enderlein, Thomas Huber, Stephan Duewel, and Tobias Schaetz — Max-Planck-Institut für Quantenoptik

Linear Paul traps have demonstrated to be a well-suited tool for quantum simulations [1,2]. General 2D interactions or large-scale systems can hardly be simulated in conventional Paul traps. Surface-electrode traps are a promising candidate to overcome some of these limitations and allow to design arbitrary trapping geometries [3].

We started a collaboration with Roman Schmied (Uni Basel), Didi Leibfried (NIST, Boulder) and Dave Moehring (Sandia National Labs) to investigate the feasibility of a surface-electrode trap providing a lattice of RF traps. We want to report on our progress in setting up a new experiment and visions for quantum simulations. A linear surface-electrode trap from Sandia National Labs has been successfully assembled into a vacuum system to test the integral parts of a new setup. Afterwards, we plan to substitute it by a first lattice trap with three

trapping zones arranged in a triangle. The zones will have mutual distances of 40 μm and a height above the surface of 40 μm, which could already allow to achieve a sufficient coupling strength between the ions for first quantum simulation experiments in two dimensions.

[1] A. Friedenauer et al., Nat. Phys. 4, 757-761 (2008)
[2] H. Schmitz et al., PRL 103, 090504 (2009) and F. Zähringer et al., PRL 104, 100503 (2010)
[3] R. Schmied et al., PRL 102, 233002 (2009)

Q 32.7 Wed 16:00 HÜL 386

2D Arrays of RF-Addressable Ion Traps — •Muir Kumph[1], Michael Brownnutt[1], and Rainer Blatt[1,2] — [1]Insitut für Experimentalphysik, Innsbruck, Österreich — [2]Institut für Quantenoptik und Quanteninformation, Österreichische Akademie der Wissenschaften, Innsbruck, Österreich

The design and testing of 2 dimensional arrays of ion traps is described and analyzed. Each ion trap is a point-like Paul trap which confines the ion in all 3 dimensions. However, the RF voltage on each segmented, RF electrode can be independently varied, allowing ions in neighboring traps to be brought close to one another, thereby tuning the interaction between them. Varying the RF drive of the traps in the 2D array allows for pairwise interactions in more than one dimension and provides a possible avenue for massive scalability of quantum computation and quantum simulation with trapped ions.

Q 33: Quantum Information: Quantum Communication 2

Time: Wednesday 14:30–16:00 Location: SCH A118

Q 33.1 Wed 14:30 SCH A118

Quantum key distribution with finite resources: Coherent vs. Collective attacks — •Markus Mertz, Silvestre Abruzzo, Sylvia Bratzik, Hermann Kampermann, and Dagmar Bruss — Institut für Theoretische Physik III, Heinrich-Heine-Universität Düsseldorf, Germany

In QKD with finite resources it is known for the assumption of collective attacks, where the eavesdropper is forced to interact with each signal independently, how to quantify the length of a secure key. But for the most general attack (coherent attack), we have to adjust the security analysis. Based on the ideas of paper [1] we calculate the quantitative difference between coherent and collective attacks for the BB84 and the six-state protocol, with finite number of signals. Here, we use the smooth min entropy to bound the secure key rate.

[1] R. Renner, N. Gisin, and B. Kraus, Phys. Rev. A 72, 012332 (2005)

Q 33.2 Wed 14:45 SCH A118

Probabilistic Phase-Covariant Cloning of Coherent States — •Christian R. Müller[1,3], Christoffer Wittmann[1,3], Petr Marek[4], Radim Filip[4], Mario A. Usuga[2], Christoph Marquardt[1,3], Ulrik L. Andersen[1,2], and Gerd Leuchs[1,3] — [1]Max-Planck-Institut für die Physik des Lichts , Günther-Scharowsky-Str. 1 / Bau 24, 91058 Erlangen, Germany — [2]Department of Physics, Technical University of Denmark, Building 309, 2800 Lyngby, Denmark — [3]Institute for Optics, Information and Photonics, University Erlangen-Nuremberg, Staudtstr. 7/B2, 91058 Erlangen, Germany — [4]Department of Optics, Palacký University 17, listopadu 50, 772 07 Olomouc, Czech Republic

Duplicating an unknown quantum state with high fidelity is at the heart of many quantum information and quantum communication protocols. The laws of quantum mechanics impose strict bounds on the average fidelity that can be achieved deterministically. However, in a probabilistic regime one can overcome these bounds. We present the concept of a novel probabilistic quantum cloner for coherent state alphabets based on the phase concentration scheme presented in [1]. The scheme relies solely on phase-covariant displacements and photon counting ensuring a feasible and robust implementation. We show that our scheme surpasses the deterministic approach with the hitherto highest performance for phase-covariant alphabets [2].

[1] M.A. Usuga, C.R. Müller, C. Wittmann, P. Marek, R. Filip, C. Marquardt, G. Leuchs and U.L. Andersen, Nat. Phys. 6, 767 (2010).
[2] M.F. Sacchi, Phys. Rev. A 75, 042328 (2007)

Q 33.3 Wed 15:00 SCH A118

Squashing model and applications to quantum key distribution protocols — •Oleg Gittsovich[1], Varun Narasimhachar[1], Ruben Andrei Romero Alvarez[4], Normand Beaudry[5], Tobias Moroder[6], and Norbert Lütkenhaus[1,2,3] — [1]Institute for Quantum Computing & Department of Physics and Astronomy, University of Waterloo, 200 University Avenue West, N2L 3G1 Waterloo, Ontario, Canada — [2]Quantum Information Theory Group, Institute of Theoretical Physics I, University Erlangen-Nuremberg, Staudtstraße 7/B2, 91058 Erlangen, Germany — [3]Max Planck Institute for the Science of Light, Günther-Scharowsky-Straße 1/24, 91058 Erlangen, Germany — [4]Department of Physics, University of Toronto, Toronto, Ontario, M5S 3G4, Canada — [5]Institute for Theoretical Physics, ETH Zurich, 8093 Zurich, Switzerland — [6]Institut für Quantenoptik und Quanteninformation, Österreichische Akademie der Wissenschaften, Technikerstraße 21A, A-6020 Innsbruck, Austria

Measurements are one of the main ingredients in physics. The description of a particular measurement depends on a variety of factors. First, one has a measurement device, which is assumed to perform a measurement of some physical observable. Second, based on the knowledge what observable one wants to measure, a theoretical model for the device is constructed. This theoretical model is believed to describe the processing of the device faithfully. In this talk we address the question of device modeling and its application to the quantum key distribution (QKD) protocols.

Q 33.4 Wed 15:15 SCH A118

Analysis of the certification of quantum random number generators by Bell's theorem — •Rainer Plaga — Bundesamt für Sicherheit in der Informationstechnik (BSI), 53175 Bonn, Godesberger Allee 185-189

S.Pironio et al. describe a qualitatively novel method to certify quantum random number generators ("Random numbers certified by Bell's theorem" (Nature 464, 1021 (2010)). A qualitative simplification and/or improvement of the IT-security certification of a component which is as important for IT-security as random number generators is a potentially important new practical application of quantum information technology.

The new method is systematically compared to the standard "model based" approach recommended by the BSI for the certification of physical random number generators when it would be applied to Pironio et al.'s device. The possible advantages of and remaining problems with Pironio et al.'s methodology are discussed.

Q 33.5 Wed 15:30 SCH A118

Gaussian Errors and Gaussian Quantum Error Correction — •Ricardo Wickert[1,2] and Peter van Loock[1,2] — [1]Optical Quantum Information Theory Group, Max Planck Institute for the Science of Light, Erlangen, Germany — [2]Institute of Theoretical Physics I, Universität Erlangen-Nürnberg, Erlangen, Germany

In the context of optical Quantum Information Processing schemes, Gaussian operations are those most easily implemented in the laboratory. However, it has been recently proved that these operations are of no use in protecting Gaussian states from the ubiquitous class of Gaussian errors [1]. In this talk, we report on ongoing efforts towards understanding and characterizing these errors and their effect on continuous-variable entanglement resources [2]. We investigate the potential implementation of correction strategies within the Gaussian regime against errors of Gaussian character acting on quantum states of non-Gaussian nature [3], and also as a countermeasure to stochastic, non-Gaussian error models [4].

[1] J. Niset et al., Phys. Rev. Lett. 102, 120501 (2009)
[2] R. Wickert et al., Phys. Rev. A 81, 062344 (2010)
[3] R. Wickert and P. van Loock, in preparation
[4] P. van Loock, J. Mod. Optics 57, 19 (2010)

Q 33.6 Wed 15:45 SCH A118

Non-zero key rates for "small" numbers of signals using the min-entropy — •Sylvia Bratzik, Markus Mertz, Hermann Kampermann, and Dagmar Bruss — Institute for Theoretical

Physics III, Heinrich-Heine-Universität Düsseldorf, 40225 Düsseldorf, Germany

We calculate an achievable secret key rate for quantum key distribution with a finite number of signals, by evaluating the min-entropy explicitly [1]. The min-entropy can be expressed in terms of the guessing probability [2], which we calculate for different d-dimensional QKD protocols. We compare these key rates to previous approaches using the von Neumann entropy [3] and find non-zero key rates for only $10^4 - 10^5$ signals. An interesting conclusion can also be drawn from the additivity of the min-entropy and its relation to the guessing probability: for a set of symmetric tensor product states the optimal minimum-error discrimination (MED) measurement is the optimal MED measurement on each subsystem.

[1] S. Bratzik et al., arXiv:1011.1190 [quant-ph].
[2] R. König, R. Renner, and C. Schaffner, IEEE Trans. Inf. Th. **55**, 4337 (2009), arXiv:0807.1338 [quant-ph].
[3] R. Renner, Int. J. Quant. Inf. **6**, 1 (2008); V. Scarani and R. Renner, Phys. Rev. Lett. **100**, 200501 (2008); R. Cai and V. Scarani, New J. Phys. **11**, 045024 (2009).

Q 34: Cold Molecules II

Time: Wednesday 14:30–16:00 Location: BAR Schön

Q 34.1 Wed 14:30 BAR Schön

A Molecular Synchrotron — •Peter C. Zieger[1], Sebastiaan Y. T. van de Meerakker[1], Hendrick L. Bethlem[2], André J. A. van Roij[3], and Gerard Meijer[1] — [1]Fritz-Haber-Institut der Max-Planck-Gesellschaft, Berlin, Germany — [2]Laser Centre Vrije Universiteit, Amsterdam, The Netherlands — [3]Institute for Molecules and Materials, Radboud University Nijmegen, Nijmegen, The Netherlands

With a Stark decelerator it is possible to produce beams of cold neutral polar molecules with a tunable velocity that are well suited for molecular beam scattering studies. One can load these beams into a molecular synchrotron; this offers particularly interesting prospects for these kinds of scattering experiments. In principle, a storage ring allows for the confinement of multiple packets of molecules that repeatedly interact in a circle, thereby, significantly increasing the sensitivity of molecular collision experiments. We present a molecular synchrotron consisting of 40 straight hexapoles that allows the simultaneous confinement of multiple packets moving clockwise and counter clockwise. We will explain the operation principle of the synchrotron and present our latest experiment, where multiple molecular packets are confined over a flight length of one mile [1]. Recently a second Stark decelerator beamline was built to enable the injection of multiple counter-propagating packets in the synchrotron. These measurements epitomize the level of control that can now be achieved over molecular beams and brings a low-energy molecular collider within close reach.

[1] P.C. Zieger, S.Y.T. van de Meerakker, C.E. Heiner, H.L. Bethlem, A.J.A. van Roij, G. Meijer, PRL 105, 173001 (2010)

Q 34.2 Wed 14:45 BAR Schön

Millimeter wave control over neutral molecules in a Stark decelerator — •Mark Abel[1], Gabriele Santambrogio[1], Samuel Meek[1], Liam Duffy[2], and Gerard Meijer[1] — [1]Fritz-Haber-Institut der Max-Planck-Gesellschaft, 4-6 Faradayweg, 14195 Berlin — [2]Department of Chemistry and Biochemistry, University of North Carolina at Greensboro, Greensboro NC, 27402, USA

Stark- and Zeeman-based decelerators have shown much promise as a route to the full quantum state control of cold neutral molecular samples. Here, we combine Stark deceleration and trapping using a microstructured electrode array with internal state control using a coherent millimeter-wave source. The millimeter wave radiation is coupled to the molecules only microns from the trap electrodes, switching their quantum state. Such on-chip manipulations constitute an important step for future chip-based molecular devices.

Q 34.3 Wed 15:00 BAR Schön

Focusing metastable CO molecules with an elliptical electrostatic mirror — •Ana Isabel González Flórez, Gabriele Santambrogio, Samuel A. Meek, Horst Conrad, and Gerard Meijer — Fritz-Haber-Insitut der Max-Planck-Gesellschaft, Faradayweg 4-6, D-14195 Berlin, Germany

Focusing optics for polar molecules finds application in shaping, steering and confining molecular beams. Here we present an elliptical mirror for polar molecules consisting of an array of microscopic gold electrodes deposited on a glass substrate. Alternating voltages applied to the electrodes create a repulsive potential for polar molecules in low field seeking states. The equipotential lines are parallel to the substrate, which is bent in an elliptical shape, allowing to focus the molecules from one focal point into the other. The reflectivity of the mirror depends on the voltages applied, on the quantum state of the molecules, and on their velocity. The dependence of the focusing properties of the mirror on these three variables was studied and the results agree with our numerical simulations.

Q 34.4 Wed 15:15 BAR Schön

Multistage Zeeman Deceleration of Metastable Neon — •Michael Motsch, Alex W. Wiederkehr, Stephen D. Hogan, and Frédéric Merkt — Laboratorium für Physikalische Chemie, ETH Zürich, CH-8093, Switzerland

Multistage Zeeman deceleration exploits the interaction between paramagnetic atoms or molecules and pulsed magnetic fields to slow a supersonic beam of these particles in a phase-stable manner. We start by exciting Ne atoms to the metastable $^3P_2$ state with a DC discharge in the expansion region behind a pulsed gas nozzle. Using 91 deceleration solenoids, we slow Ne* atoms to velocities as low as 120 m/s, thereby removing up to 95 % of the initial kinetic energy. We characterize the cold sample of Ne* atoms with a time-of-flight technique, investigate the efficiency of the deceleration process, and discuss the possibility to extend the technique to other species.

Q 34.5 Wed 15:30 BAR Schön

The alternating-gradient m/μ-selector — •Stephan Putzke[1], Frank Filsinger[1], Jochen Küpper[1,2,3], and Gerard Meijer[1] — [1]Fritz-Haber-Institut der MPG, Berlin — [2]Center for Free-Electron Laser Science, DESY, Hamburg — [3]Universität Hamburg

Over the last years we have developed and applied methods for the manipulation of the motion of large and complex molecules. Because all states are high-field seeking at the relevant field strengths, alternating gradient (dynamic) focusing has to be applied [1]. Polar molecules in different quantum states or conformers, exhibiting a sufficently different Stark effect, can be filtered selectively. This method has been succesfully used for the conformer selection of 3-aminophenol in a m/μ-selector [2]. The resolution can be improved by changing the duty-cycle of the half-periods in the switching cycle [3].

Here we present results obtained with a newly set up second generation AG guide. We investigate the transmission of individual rotational quantum states of benzonitrile (C_7H_5N), a prototypical large polar molecule. The transmission and the m/μ-resolution are considerably improved by the new setup. It employs both, longer electrodes – allowing more switching cycles – and an improved alignment. It now becomes possible to filter almost all quantum states out of the beam and to prepare a nearly pure ground-state sample of benzonitrile.

[1] D. Auerbach et al., J. Chem. Phys. **45**, 2160 (1966); H. L. Bethlem et al., J. Phys. B **39**, R263 (2006)
[2] F. Filsinger et al., Phys. Rev. Lett. **100**, 133003 (2008)
[3] F. Filsinger et al., Phys. Rev. A **82**, 052513 (2010)

Q 34.6 Wed 15:45 BAR Schön

Microwave lens: Focusing properties and potential losses — •Simon Merz[1], Claudia Brieger[1], Gerard Meijer[1], and Melanie Schnell[2] — [1]Fritz-Haber-Institut der Max-Planck-Gesellschaft, D-14195 Berlin — [2]Max-Planck Advanced Study Group at CFEL, D-22607 Hamburg

To manipulate the motion of polar molecules in high-field-seeking states, which is important for molecules in their ground states and for basically all larger and more complex molecules, time-dependent methods such as AC focusing and trapping and alternating-gradient (AG) deceleration have to be employed. Besides electric fields, electromagnetic radiation can be used, such as laser and microwave fields.

We have recently demonstrated a microwave lens for polar molecules in high-field-seeking states [1] that can be used to focus molecules. We investigated the focusing properties as a function of the microwave mode structure, the microwave input power, the detuning and the molecules' velocity, and also studied some potential loss mechanisms. A detailed understanding is necessary for future experiments on microwave deceleration and trapping using an open Fabry-Pérot type resonator.

[1] H. Odashima et al. Microwave Lens for Polar Molecules. *Phys. Rev. Lett.*, 104:253001, 2010

Q 35: Ultrakurze Laserpulse: Anwendungen 2

Time: Wednesday 14:30–16:00 Location: SCH A01

Q 35.1 Wed 14:30 SCH A01

Ultrafast Lattice Heating in Graphite and few-layer Graphene monitored by Ultrafast Electron Diffraction — •Christian Gerbig, Silvio Morgenstern, Cristian Sarpe, Matthias Wollenhaupt, and Thomas Baumert — University of Kassel, Institute of Physics and 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 at the microscopic level and on the pico- to subpicosecond timescale [1]. The investigation of laser-induced structural dynamics in the recently discovered 2D material graphene via UED should bring new insights in its unique properties [2]. So far time-resolved electron crystallography has been used to study lattice vibrations and coherent motions of graphite sub-surfaces after photoexcitation [3,4].
In this contribution we present first results on the direct observation of transient lattice heating in free-standing graphite and few-layer graphene using UED. In addition, we show a new approach of our setup with the prospect to directly resolve coherent lattice motions.

[1] M. Chergui & A. H. Zewail, Chem. Phys. Chem. **10**, 28 (2009)
[2] A. K. Geim & K. S. Novoselov, Nature Materials **6**, 183 (2007)
[3] A. H. Zewail and coworkers, Phys. Rev. Lett. **100**, 035501 (2008)
[4] R. K. Raman *et al.*, Phys. Rev. Lett. **101**, 077401 (2008)

Q 35.2 Wed 14:45 SCH A01

Ultrafast electron kinetics in metals irradiated with femtosecond XUV laser pulses — •Nikita Medvedev[1,2] and Baerbel Rethfeld[1] — [1]Technical University of Kaiserslautern, Germany — [2]CFEL at DESY, Hamburg, Germany

Metals irradiated with ultrashort laser pulses undergo a photoabsorption by electrons in conduction band and by ionization of deep atomic shells if the photon energy is sufficient. The relaxation of this excited nonequilibrium electron ensemble leads to photoemission, which can be detected experimentally, and to a lattice heating with further observable material modifications. We present a theoretical study of the excited electronic subsystem in solid aluminum irradiated with XUV ($\sim$ 10 - 200 eV) femtosecond laser pulse ($\sim$ 10 fs), as produced by the FLASH (free electron laser in Hamburg). The Monte Carlo method is extended to take into account the electronic band structure and Pauli's principle for excited electrons, secondary ionization, Auger-decays [1,2]. The results show that excited electronic distribution has two branches: a low energy part as a slightly distorted Fermi-distribution and a long high energy tail. We compare the calculated electron distributions with the spectroscopy data obtained in first experiments with FLASH [3].

[1] N.Medvedev, B.Rethfeld, New J. Phys. 12, 073037 (2010)
[2] N.Medvedev, B.Rethfeld, AIP conf. Proc. 1278, 250 (2010)
[3] S. M. Vinko et al., Phys. Rev. Lett. 104, 225001 (2010)

Q 35.3 Wed 15:00 SCH A01

Dynamics of electrons in liquid water excited with ultrashort VUV laser pulse — •Klaus Huthmacher, Nikita Medvedev, and Bärbel Rethfeld — TU Kaiserslautern, Deutschland

In this work we present the theoretical study of the interaction of an ultrashort VUV laser pulse with liquid water. Incident photons ionize water molecules and lead to free electrons, which further create secondary electrons due to ionization and interact via elastic collisions with other water molecules. For the laser pulse we assume a gaussian shape with a FWHM of 10fs and an average photon energy of 50eV.
We use an extended Monte Carlo method [1] to track each free electron and its collisions event by event. In the first step we calculate the realized penetration depth of the photons. Next we evaluate the cross sections for the free electrons refering to ionization and elastic collisions. Furthermore we compute mean free paths and finally we get the energy loss due to elastic collisions or the energy transfer to secondary electrons due to ionization. All the secondary electrons are included in the simulation in the same manner.
As results we present time-, spatially- and energetically resolved electron distributions.

[1] N. Medvedev and B. Rethfeld
New Journal of Physics **12** (2010) 073037

Q 35.4 Wed 15:15 SCH A01

Visualisierung des Elektronen-Beschleunigungsprozesses bei der Laser-Wakefield-Beschleunigung — •Maria Nicolai[1], Hans-Peter Schlenvoigt[1], Stuart P. D. Mangles[2], Alexander G. R. Thomas[2], Aboobaker E. Dangor[2], Heinrich Schwoerer[1], Warren B. Mori[3], Zulfikar Najmudin[2], Karl M. Krushelnick[2], Alexander Sävert[1] und Malte C. Kaluza[1] — [1]Institut für Optik und Quantenelektronik, 07743 Jena — [2]Imperial College London — [3]UCLA Los Angeles

Bei der Wakefield-Beschleunigung werden durch einen intensiven Laser hohe elektrische Felder in einer Plasmawelle erzeugt. Dadurch können auf sehr kurzen Distanzen Elektronen auf relativistische Energien beschleunigt werden. Dieser Prozess konnte bisher nur über numerische Simulationen untersucht oder indirekt beobachtet werden.

In dem hier vorgestellten Experiment wurde eine Kombination aus Schattenbildern, Interferometrie und Polarimetrie verwendet, um die magnetischen Felder sichtbar zu machen, die die Elektronen und die Plasmawelle umgeben. Wenn ein linear polarisierter Probepuls einen Bereich im Plasma mit starken Magnetfeldern durchläuft, dann wird seine Polarisation durch den Faraday-Effekt gedreht. Diese Polarisationsdrehung wurde experimentell gemessen und daraus das magnetische Feld ermittelt, welches durch den Elektronenstrom erzeugt wurde. Durch die Veränderung der zeitlichen Verzögerung zwischen Haupt- und Probepuls konnte erstmals die zeitliche Entwicklung des Beschleunigungsprozesses mit hoher räumlicher und zeitlicher Auflösung untersucht werden.

Q 35.5 Wed 15:30 SCH A01

Photonic structure-based acceleration of non-relativistic electrons — •John Breuer and Peter Hommelhoff — Max-Planck-Institut für Quantenoptik, Garching, Deutschland

Laser-based electron acceleration is an intriguing tool for small-size particle accelerators, but also for precise temporal control of non-relativistic electrons. Our concept is based on periodic electric field reversal, thus the electrons are accelerated directly by the laser electric field (proposed in [1]). We illuminate a fused-silica transmission grating with Titanium:sapphire femtosecond pulses in order to excite evanescent spatial modes which propagate synchronously with 30 keV electrons. Numerical simulations show expected accelerating gradients of up to 60 MeV/m and an energy gain of around 300 eV at a distance of 100 nm away from the grating surface. We will describe our experimental setup, present first results and discuss possible applications.

[1] T. Plettner, R. L. Byer et al., PRSTAB, 9, 111301 (2006)

Q 35.6 Wed 15:45 SCH A01

Time-resolved amplified spontaneous emission in quantum dots — Jordi Gomis-Bresco[1], Sabine Dommers-Völkel[1], Oliver Schöps[1], •Yücel Kaptan[1], Olga Dyatlova[1], Dieter Bimberg[2], and Ulrike Woggon[1] — [1]Institut für Optik und Atomare Physik, Technische Universität Berlin, Straße des 17. Juni 135, 10623 Berlin, Germany — [2]Institut für Festkörperphysik, Technische Universität Berlin, Hardenbergstraße 36, 10623 Berlin, Germany

Complementary to prior pump-probe experiments the time-resolved amplified spontaneous emission (TRASE) of the excited state (ES) in

InGaAs quantum dots-in-a-well (DWELL) based semiconductor optical amplifiers (SOAs) is studied by utilizing a Streak Camera System. The natural advantage of this approach is that we are able to directly resolve the population dynamics of the ES after the amplification of an ultrashort 150fs pulse resonant to the ground state (GS). Conducting the TRASE measurement when saturating the SOA we observe a 10ps delay between the nonlinear GS pulse amplification and the subsequent ES population drop-off [1]. It is well-known from pump-probe experiments that the GS population recovers in the time range of a few picoseconds. Assuming a cascade-like relaxation path (2D barrier-ES-GS) a corresponding fast decrease in the intensity of the ES ASE should be visible in the measurements. Since our observed 10ps delay contradicts this expectation, we conclude the dominance of a direct capture relaxation path (2D barrier-GS) in electrically pumped DWELL structures. [1] J. Gomis-Bresco et al., Appl. Phys. Lett. (accepted)

Q 36: Laseranwendungen und Photonik 1

Time: Wednesday 14:30–16:00 Location: SCH 251

Q 36.1 Wed 14:30 SCH 251

Ein Drei-Farben-Überhöhungsresonator zur Erzeugung von Lyman-α-Strahlung — •Anna Beczkowiak, Daniel Kolbe, Andreas Koglbauer, Ruth Steinborn, Andreas Müllers, Thomas Diehl, Matthias Stappel, Matthias Sattler und Jochen Walz — Institut für Physik, Johannes-Gutenberg-Universität Mainz, 55099 Mainz und Helmholtz-Institut Mainz, 55099 Mainz

Für künftige Präzisionsexperimente an Antiwasserstoff ist ein kontinuierlicher Laser beim 1S-2P Kühlübergang mit einer Wellenlänge von 121,56 nm (Lyman-α) nötig. Diese Strahlung kann durch Summenfrequenzmischen von drei fundamentalen Strahlen in Quecksilber erzeugt werden (Vier-Wellen-Mischen). Die erzeugte Lyman-α-Leistung ist proportional zum Produkt der Leistungen der Fundamentallaser. Zur Steigerung der Leistung der einzelnen Fundamentalen werden die Laser in drei verschachtelten Resonatoren in Doppel-Z-Geometrie getrennt überhöht, deren fokussierte Arme mit Hilfe von Prismen überlagert sind. Für die Leistungen der einzelnen Strahlen wurde bereits eine relative Überhöhung von 50-100 erreicht. Eine Dampfzelle mit dem Quecksilberdampf zur Lyman-α-Erzeugung ist so im Resonator positioniert, dass sich die Foki der Fundamentallaser in der Dampfzone der Zelle überlagern. In diesem Vortrag wird der aktuelle Stand des Experiments vorgestellt.

Q 36.2 Wed 14:45 SCH 251

Optical mode structure of a harmonically mode-locked Yb femtosecond fiber laser — •Simon Herr[1,2], Tilo Steinmetz[1,2], Tobias Wilken[1], Martin Engelbrecht[2], Theodor W. Hänsch[1], Thomas Udem[1], and Ronald Holzwarth[1,2] — [1]Max-Planck-Institute for Quantum Optics, Hans-Kopfermann-Str. 1, 85748 Garching, Germany — [2]Menlo Systems GmbH, Am Klopferspitz 19a, 82152 Martinsried, Germany

Due to their ease of use, fiber lasers provide an excellent source for ultrashort pulses and are well suited for frequency comb generation. The need for an extended fiber section, however, restricts the repetition rate and the mode spacing of a fundamentally mode-locked fiber laser to about 1 GHz, thus limiting their potential for applications where even larger mode spacings are required such as the calibration of astronomical spectrographs. Passive harmonically mode-locked (HML) fiber lasers on the other hand have produced repetition rates up to 7.2 GHz and have recently been proposed for this application.

In this work we investigate the optical mode structure of a passive HML Yb femtosecond fiber laser and show that all modes are oscillating with equal intensity. This is possible when the the spectral phase follows a quadratic distribution and is favored over suppression of modes due to the inhomogeneously broadened gain of the laser. Our findings emphasize the need of a mode selection mechanism, such as a Fabry-Perot cavity, for frequency domain applications of passive HML lasers.

Q 36.3 Wed 15:00 SCH 251

Stimulierte Raman-Streuung und Raman-Laser mit Silizium bei tiefen Temperaturen — •Oliver Lux, Hanjo Rhee, Stefan Meister und Hans Joachim Eichler — Institut für Optik und Atomare Physik, TU Berlin, Straße des 17. Juni 135, 10623 Berlin

Wir demonstrieren Stimulierte Raman-Streuung (SRS) in Silizium-Einkristallen bei Temperaturen um 10 K. Die Vergrößerung der Bandlücke bei diesen tiefen Temperaturen reduziert deutlich die lineare Absorption der Strahlung eines Nd:YAG-Lasers mit einer Emissionswellenlänge von 1064 nm. Dies ermöglicht die Erzeugung höherer Stokes-Raman-Ordnungen mit einem modengekoppelten Nd:YAG-Pumplaser. Derselbe Laser wurde verwendet, um die Temperaturabhängigkeit der SRS-Schwelle für verschiedene Kristallorientierungen und Polarisationsrichtungen der Pumpstrahlung zu untersuchen. Dabei wurden neben reinem Silizium auch Proben mit einer Kodotierung aus Gold und Antimon analysiert.

Die Helium-gekühlten 3 cm-langen Silizium-Einkristalle wurden zudem als Raman-aktives Material für einen externen Resonator eingesetzt, welcher von einem gütegeschalteten Nd:YAG-Oszillator-Verstärker-System bei 1064 nm gepumpt wurde. Mit diesem erstmalig realisierten „bulk“-Silizium-Raman-Laser gelang die Erzeugung von Laserstrahlung bei 1127 nm mit einer Pulsspitzenleistung von etwa 30 kW.

Q 36.4 Wed 15:15 SCH 251

Durchstimmbare optisch parametrische Oszillation in Flüstergalerieresonatoren — •Tobias Beckmann, Heiko Linnenbank, Karsten Buse und Ingo Breunig — Physikalisches Institut, Universität Bonn, Wegelerstr. 8, 53115 Bonn

Optisch parametrische Oszillatoren sind weit durchstimmbare Quellen kohärenten Lichts. Durch Quasiphasenanpassung lässt sich der Prozess auf beliebige Wellenlängenbereiche ausdehnen. Um das Konzept auf einen Flüstergalerieresonator zu übertragen und dessen wellenlängenunabhängige Intensitätsüberhöhung zu nutzen, sind radial gepolte Strukturen notwendig, da sich hier das Licht auf einer Kreisbahn bewegt.

Ein Flüstergalerieresonator mit radialer Domänentruktur zur Quasiphasenanpassung optisch parametrischer Oszillationen mit 1040 nm Pumpwellenlänge wird realisiert. Der Oszillator ist durchstimmbar von 1780 bis 2070 nm und hat eine Schwelle von 6 mW.

*Wir danken der Deutschen Forschungsgemeinschaft (FOR 557) und der Deutschen Telekom AG für finanzielle Unterstützung.

Q 36.5 Wed 15:30 SCH 251

Towards nonlinear optics in a mercury-filled hollow core fiber — •Andreas Koglbauer, Anna Beczkowiak, Thomas Diehl, Daniel Kolbe, Andreas Müllers, Matthias Sattler, Matthias Stappel, Ruth Steinborn, and Jochen Walz — Institut für Physik, Johannes Gutenberg-Universität Mainz und Helmholtz Institut Mainz, 55099 Mainz

The generation of continuous coherent vacuum ultraviolet (VUV) light at 121.56 nm, the cooling transition in (anti-)hydrogen, is essential for future precision experiments with trapped antihydrogen. Due to the short wavelength, this is typically achieved by four-wave-mixing in vapors.

It has already been successfully demonstrated by sum-frequency-generation in mercury-vapor, which gives an output power of 0.4 nW [1]. One possibility to enhance the efficiency of this process is to stretch the interaction region. This can be achieved by confining the light in a vapor-filled hollow core fiber of several cm length.

We compare this approach to the mixing process with Gaussian beams and estimate the achievable VUV powers considering different fiber lengths and radii. Moreover we present the current status of the experiment, in particular the generation and detection of mercury vapor within the fiber.

[1] Optics Express, Vol. 17, Issue 14, pp. 11274-11280 (2009)

Q 36.6 Wed 15:45 SCH 251

Updates on our non-invasive method to determine the total hemoglobin mass — •Marcus Sowa and Peter Hering — Institut für Lasermedizin, Universitätsklinikum Düsseldorf, Universitätsstr. 1, 40225 Düsseldorf

At the last DPG conference we presented first results of our work on a method to determine the total hemoglobin mass (t-Hb) in the human body. This non-invasive method is based on breath analysis by means of Cavity Leak-Out Spectroscopy (CALOS).

Our CALOS system works in the mid-infrared region at a wavelength of about 5 μm. This enables us to perform isotopologue selective online measurements of the P25 transition of ^{13}CO at 1994.7 cm^{-1} without any cross sensitivities towards other relevant gases in the exhaled air. The advantage of the utilization of the rare isotopologue is the harmless amount of ^{13}CO needed for the inhalation process.

We will report on various improvements regarding our system e.g. the sensitivity and the measurement of the t-Hb mass. The temperature stabilization of our CALOS cavity is subject of a separate talk at this conference as well as the subject of blood analysis regarding the isotopologue selective measurement of carboxyhemoglobin.

Furthermore, we have conducted our experiment before and after a blood donation. This allows us to check wheter our method is sensitive enough to detect sudden changes in the t-Hb mass as they would occur e.g. with blood doping. The results of these measurements are very promising and will also be presented in the talk.

Q 37: Cold Molecules III

Time: Wednesday 16:30–18:15 Location: BAR Schön

Q 37.1 Wed 16:30 BAR Schön

Visible rovibrational spectroscopy of cold H_3^+ via chemical probing in a 22 pole trap — •Florian Grussie, Max Berg, Andreas Wolf, and Annemieke Petrignani — Max-Planck Institut für Kernphysik, Saupfercheckweg 1, 69117 Heidelberg

H_3^+ is the cornerstone of interstellar chemistry and the simplest triatomic molecule, therefore also of fundamental interest to experimental and theoretical physics. At the MPI for Nuclear Physics, spectroscopy on cold H_3^+ is performed in a cryogenic 22-pole radiofrequency trap using laser-induced reactions with argon as chemical probe. The chemical probing technique provides high sensitivity and a low background environment, so that transitions up to at least 6 orders of magnitude weaker than the fundamental (B_{21}=4.77 · 10^{23} $cm^{-3}J^{-1}s^{-1}$) can be observed. This high sensitivity is augmented by an efficient Daly detection system where each ion is amplified into a bunch of secondary electrons that are subsequently amplified into photons before being counted by a photomultiplier tube. This has allowed us to measure transitions from the two lowest rotational states of the H_3^+ vibrational ground state to, recently, final levels up to 16600 cm^{-1}, i.e., half the dissociation energy. To observe transitions to even higher levels, the already low background needs to be minimized further. The background originates from non-laser-induced probe ions and laser photons. The latter should be eliminated by a new detection system insensitive to our laser photons. The non-laser-induced ions can be minimized by injecting the argon chemical probing gas during laser excitation only, using a pulsed valve.

Q 37.2 Wed 16:45 BAR Schön

High resolution spectroscopy of Rb_2 triplet molecules — •Christoph Strauss[1,2], Tetsu Takekoshi[2], Florian Lang[2], Klaus Winkler[2], Rudolf Grimm[2,3], Marius Lysebo[4], Leif Veseth[4], Eberhard Tiemann[5], and Johannes Hecker Denschlag[1] — [1]Universität Ulm, Institut für Quantenmaterie, Albert-Einstein-Allee 45, D-89081 Ulm, Germany — [2]Institut für Experimentalphysik und Zentrum für Quantenphysik, Universität Innsbruck, A-6020 Innsbruck, Austria — [3]Institut für Quantenoptik und Quanteninformation der Österreichischen Akademie der Wissenschaften, A-6020 Innsbruck, Austria — [4]Department of Physics, University of Oslo, 0316 Oslo, Norway — [5]Gottfried Wilhelm Leibniz Universität Hannover, D-30167 Hannover, Germany

A detailed understanding of the molecular level structure is essential for future cold collision experiments of ultracold molecules such as Rb_2. We present a complete analysis of the triplet ground state $a^3\Sigma_u^+$ and the first excited triplet state $(1)^3\Sigma_g^+$ of Rubidium 87 discussing its vibrational, rotational, hyperfine and Zeeman structure. We perform laser spectroscopy on ultracold Feshbach molecules to obtain precision data with a typical resolution of a few tens of MHz. We can describe and understand the experimental spectra quite well using model Hamiltonians. As a result we obtain optimized $a^3\Sigma_u^+$ and the $X^1\Sigma_g^+$ Born-Oppenheimer potentials within a coupled channel model. We gain interesting insights on level mixing of singlet and triplet states, and obtain evidence that the hyperfine structure in these molecules depends weakly on the vibrational level.

Q 37.3 Wed 17:00 BAR Schön

Threshold photodetachment thermometry for cold molecular anions — •Alexander von Zastrow[1], Thorsten Best[1], Rico Otto[1], Stephanie Eisenbach[1], Martin Stei[3], Sebastian Trippel[1], Matthias Weidemüller[2], and Roland Wester[3] — [1]Physikalisches Institut, Universität Freiburg, Hermann-Herder-Str. 3, 79104 Freiburg — [2]Physikalisches Institut, Universität Heidelberg, Philosophenweg 12, 69120 Heidelberg — [3]Institut f. Ionenphysik und Angewandte Physik, Universität Innsbruck, Technikerstr. 25/3, A-6020 Innsbruck

During photodetachment an anion's excess electron is lifted from a bound to a continuum state. The cross section for this process reveals information about the internal structure of the anion and the neutral as well as long range electron-neutral interactions. One of the best studied molecular anions is OH^-. At threshold the photodetachment cross section is sensitive to the different occupied rotational levels. From their contribution to the cross section, the anions' rotational temperature can be derived. In our experiments ions are stored and sympathetically cooled in a 22-pole radiofrequency trap which can be operated between 8 K and 300 K. To determine the ions' rotational temperature, we measure the absolute photodetachment cross section using a previously reported laser depletion tomography method [1,2]. This will allow us to investigate the efficiency of collisional cooling of internal degrees of freedom in future experiments.

[1] S. Trippel *et al.*, Phys. Rev. Lett. 97, 193993 (2006)
[2] P. Hlavenka *et al.*, J. Chem. Phys. 130, 061105 (2009)

Q 37.4 Wed 17:15 BAR Schön

Interaction of cold atoms with molecular ions — •Anna Göritz[1], Johannes Deiglmayr[1], Thorsten Best[2], Rico Otto[2], Matthias Weidemüller[3], and Roland Wester[2] — [1]Physikalisches Institut, University of Freiburg, Germany — [2]Physikalisches Institut, University of Innsbruck, Austria — [3]Physikalisches Institut, University of Heidelberg, Germany

Sympathetic cooling of atomic and molecular ions by ultracold gases has recently gained significant interest[1]. For the investigation of a wider range of molecular ions high order multipole radio frequency (rf) traps in combination with helium buffer-gas cooling are an established tool. In order to reach lower temperatures it is intriguing to replace helium with laser-cooled atoms. To this aim we develop a new rf octopole trap with thin wire-electrodes, yielding high optical access to the trapping region. A vapour-loaded magneto-optical trap provides ultracold ^{85}Rb atoms. The design of the hybrid trap is chosen for optimally adapted density distributions of atoms and ions, where the latter is measured directly by photodetachment depletion tomography of anions. Here, we report on first results on the interaction of the trapped ions with ultracold rubidium. In particular we observe the inelastic collision $OH^-+Rb^*\rightarrow OH^-+Rb+E_{kin}$, leading to loss of ions from the trap. The prospects for sympathetic cooling of molecular ions by laser-cooled Rb are discussed.

[1] Christoph Zipkes et al., Nature 464, 388 (2010); Stefan Schmid et al., PRL 105, 133202 (2010); X. Tong et al., PRL 105, 143001 (2010)

Q 37.5 Wed 17:30 BAR Schön

Reaction of D^- with H_2 at low temperatures — •Stephanie Eisenbach[1], Rico Otto[1], Alexander von Zastrow[1], Thorsten Best[1,2], and Roland Wester[1,2] — [1]Physikalisches Institut, Universität Freiburg, Hermann-Herder-Str. 3, 79104 Freiburg — [2]Institut f. Ionenphysik und Angewandte Physik, Universität Innsbruck, Technikerstr. 25/3, A-6020 Innsbruck

Tunneling through barriers, one of the most fundamental processes in quantum mechanics, can be an important reaction mechanism for chemical reactions at low temperatures see e.g. $F+H_2$. Another example may be the isotope exchange reaction $D^-+H_2 \rightarrow H^-+HD$, with a reaction barrier height of 330 meV. This reaction can proceed over the barrier at high kinetic energies of the reactands [1]. In a 22-pole radio-frequency ion trap we can study reactions of buffer gas cooled molecular or atomic anions with neutral molecules down to 8 Kelvin temperature [2,3]. From these measurements an upper limit for the tunneling rate in H^-+D_2 is derived.

[1] E. Haufler, *et al.*, J. Phys. Chem. A **101**, 6441 (1997)
[2] R. Wester, J.Phys. B: At. Mol. Opt. Phys. **42**, 154001 (2009)
[3] R. Otto, *et al.*, PRL **101**, 063201 (2008)

Q 37.6 Wed 17:45 BAR Schön

Reactive Scattering with cold Molecules out of a RF Multipol Ion Trap — •Jonathan Brox[1], Rico Otto[1], Sebastian Trippel[1], Martin Stei[2], Thorsten Best[1], and Roland Wester[2] — [1]Physikalisches Institut, Universität Freiburg, Hermann-Herder-Str. 3, 79104 Freiburg — [2]Institut f. Ionenphysik und Angewandte Physik, Universität Innsbruck, Technikerstr. 25/3, A-6020 Innsbruck

Crossed beam experiments offer a maximum amount of information about the dynamics of a reactive collision. If the process involves a molecular ion its internal excitation is expected to influence the reaction. To control these internal degrees of freedom we combined our velocity map imaging setup with a multipol rf trap, which allows us to control the internal state distribution of the molecular ion. The trap can be operated in a temperature range from 100 to 400 K. The extraction out of the rf trap provides a translational energy distribution of 100meV FWHM. In this talk we will present first test measurements on reactive scattering of OH^- and CH_3I for relativ energies between 0.15eV and 3.0eV.

Q 37.7 Wed 18:00 BAR Schön

Manipulation of Polar Molecules in a Microstructured Electric Trap — •Barbara G.U. Englert, Manuel Mielenz, Christian Sommer, Josef Bayerl, Michael Motsch, Pepijn W.H. Pinkse, Martin Zeppenfeld, and Gerhard Rempe — Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Str. 1, 85748 Garching

Cold polar molecules offer exciting new possibilities for research in physics and chemistry, such as molecular precision spectroscopy or cold collision studies. For all of these experiments, long interaction times are essential. Additionally, homogeneous electric fields are desirable for laser addressing of individual molecular states or the control of chemical reactions. These requirements are assured by using a properly designed electric trap. In our experiment, molecules are confined between two capacitor plates which are microstructured with a suitable charged electrode array to avoid collisions with the plate surfaces [1]. A novel feature of our trap is that it is devided into two separate regions to which independent homogeneous fields can be applied, giving rise to a tunable potential step for the molecules. This allows for a controlled manipulation of the molecular motion. Latest experimental results towards the cooling of the molecular motion are presented.

[1] M. Zeppenfeld et al., Phys. Rev. A **80**, 041401(R) (2009).

Q 38: Ultra-cold atoms, ions and BEC IV

Time: Wednesday 16:30–18:00 Location: BAR 205

Q 38.1 Wed 16:30 BAR 205

Quantum dynamics of strongly interacting bosonic mixture. — •Budhaditya Chatterjee[1], Ioannis Brouzos[2], and Peter Schmelcher[2] — [1]Physikalisches Institut, Universität Heidelberg, Philosophenweg 12, 69120 Heidelberg, Germany — [2]Zentrum für Optische Quantentechnologien, Luruper Chaussee 149, 22761 Hamburg, Germany

We look at tunneling dynamics of strongly correlated bosonic mixture. The effect of the inter- and the intra-species interaction and their interplay is investigated using the numerically exact Multi-Configuration Time dependent Hartree (MCTDH) method. Dynamics is calculated for two initial configurations- complete population imbalanced state and phase separated state. Increasing the inter-species interaction leads to an exponential increase in the tunneling time period analogous to the quantum self-trapping for condensates. The increase of the intra-species repulsion elongates the tunneling period for small inter-species correlations while in the opposite case of stronger interaction it enhances the tunneling. These effects are explained by studying the spectra and the stationary states. The effect of higher particle number as well as number symmetry is discussed.

Q 38.2 Wed 16:45 BAR 205

Atomic homodyne detection of two mode squeezed states — •Helmut Strobel, Christian Gross, Eike Nicklas, Tilman Zibold, Jiri Tomkovic, and Markus K Oberthaler — Kirchhoff Institute for Physics, University of Heidelberg, Germany

In quantum optics homodyning is a very successful and widely used measurement technique that reveals the quadratures of the electric field. Its counterpart for Quantum Atom Optics, the measurement of the quadratures of a matter wave field, has not been realized so far. Here we present a homodyne measurement of the matter wave quadratures of two mode squeezed atomic quantum states produced by spin changing collisions in a Bose-Einstein condensate. Our measurements reveal strong correlation between the two largely occupied modes and show the existence of a non-vanishing pair phase, i.e. pair coherence. The observed noise level in the two mode quadratures is below the threshold expected for classical states and hence flags entanglement in the system.

Q 38.3 Wed 17:00 BAR 205

Observation of new Feshbach Resonances in Sodium-Lithium Mixtures — •Tobias Schuster, Raphael Scelle, Arno Trautmann, Steven Knoop, and Markus K. Oberthaler — Kirchhoff Institut für Physik, Universität Heidelberg, Im Neuenheimer Feld 227, 69120 Heidelberg

We report on studies of Feshbach resonances in an ultracold Bose-Fermi mixture of ^{23}Na and ^{6}Li. The experimentally observed spectra of resonances cover magnetic fields of more than 2kG and different spin channels. Our findings are explained in terms of the Asymptotic Bound-state Model, which gives a comprehensive explanation of our experimental results, differing substantially from previous theoretical predictions [1]. Possible applications of this ultracold Bose-Fermi mixture are discussed.

[1] M. Gacesa, P. Pellegrini, and R. Cote, Phys. Rev. A **78**, 010701(R) (2008)

Q 38.4 Wed 17:15 BAR 205

Spinor Bose-Einstein condensates in optical superlattices — •Andreas Wagner and Christoph Bruder — University of Basel

We examine spinor Bose-Einstein condensates in optical superlattices theoretically using a Bose-Hubbard hamiltonian which takes spin effects into account. Assuming that a small number of spin-one bosons is loaded in an optical potential, we study single-particle tunneling which occurs when one lattice site is ramped up relative to a neighbouring site. Spin-dependent effects modify the tunneling events in a qualitative and a quantitative way. We use a double-well potential as a unit cell of a one-dimensional superlattice and a four-well square-shaped potential as a unit cell of a two-dimensional superlattice. Homogeneous and inhomogeneous magnetic fields lead to spin-flip transitions and various other effects. E.g. it is possible for the four-well potential to observe spin-ordered states and non-trivial tunneling events, i.e. events at which at one site the particle number increases although the potential energy increases simultaneously. Finally, we investigate the bipartite entanglement between single sites and the remainder of the system and construct states of maximal entanglement.

Q 38.5 Wed 17:30 BAR 205

New Efimov resonances in an ultracold cesium gas — •Alessandro Zenesini[1], Martin Berninger[1], Bo Huang[1,2], Stefan Besler[1], Hanns-Christoph Nägerl[1], Francesca Ferlaino[1], and Rudolf Grimm[1,2] — [1]Institut für Experimentalphysik, Universität Innsbruck, 6020 Innsbruck, Austria — [2]Institut für Quantenoptik und Quanteninformation, Österreichische Akademie der Wissenschaften, 6020 Innsbruck, Austria

Efimov trimer states represent the paradigm of universality in few-body physics. Although these exotic three-body weakly-bound states have been experimentally investigated in an increasing number of ultracold atomic systems, many fundamental aspects remain unclear [1]. An intriguing open question is related to how short-range physics influences the Efimov effect in real systems. Short range contributions are commonly included in universal theory via a single parameter, known as "three-body parameter". An open question is whether this parameter is constant or whether it can vary significantly when Feshbach resonances are employed for interaction tuning. Cesium is a very promising candidate to address this issue because of the many broad and narrow Feshbach resonances with different partial-wave character. Our experimental results reveal new Efimov features close to different Feshbach resonances and shed new light on the three-body parameter.

[1] "Forty years of Efimov physics: How a bizarre prediction turned into a hot topic" F. Ferlaino and R. Grimm, Physics 3, 9 (2010)

Q 38.6 Wed 17:45 BAR 205

Structural Defects in Ion Chains by Quenching the External Potential: The Inhomogeneous Kibble-Zurek Mechanism — Giovanna Morigi[2], Adolfo Del Campo[1], Gabriele De Chiara[3], Martin Plenio[1], and •Alex Retzker[1] — [1]Universitaet Ulm, Ulm, Germany — [2]Universität des Saarlandes, Saarbrücken, Germany — [3]Universitat Autonoma de Barcelona, Barcelona, Spain

The nonequilibrium dynamics of an ion chain in a highly anisotropic trap is studied when the transverse trap frequency is quenched across the value at which the chain undergoes a continuous phase transition from a linear to a zigzag structure. Within Landau theory, an equation for the order parameter, corresponding to the transverse size of the zigzag structure, is determined when the vibrational motion is damped via laser cooling. The number of structural defects produced during a linear quench of the transverse trapping frequency is predicted and verified numerically. It is shown to obey the scaling predicted by the Kibble-Zurek mechanism, when extended to take into account the spatial inhomogeneities of the ion chain in a linear Paul trap.

Q 39: Quantum Control

Time: Wednesday 16:30–18:15 Location: TOE 317

Q 39.1 Wed 16:30 TOE 317

Direct mid-infrared femtosecond pulse shaping with a calomel acousto-optic programmable dispersive filter — •Patrick Nuernberger[2,4], Raman Maksimenka[1], Kevin F. Lee[2], Adeline Bonvalet[2], Thibault Vieille[1,2], Cestmir Barta[3], Miloš Klima[3], Thomas Oksenhendler[1], Pierre Tournois[1], Daniel Kaplan[1], and Manuel Joffre[2] — [1]FASTLITE, Centre scientifique d'Orsay - Bât. 503, 91401 Orsay, France — [2]Laboratoire d'Optique et Biosciences, Ecole Polytechnique, CNRS UMR 7645, INSERM U696, 91128 Palaiseau, France — [3]BBT Materials Processing, Doubicka 11, 184 00 Prague, Czech Republic — [4]Institut für Physikalische und Theoretische Chemie, Universität Würzburg, Am Hubland, 97074 Würzburg

Direct amplitude and phase shaping of mid-infrared femtosecond pulses is realized with a calomel-based acousto-optic programmable dispersive filter transparent between 0.4 and 20 μm. The shaped pulse electric field is fully characterized with high accuracy, using chirped-pulse upconversion and time-encoded arrangement spectral phase interferometry for direct electric field reconstruction techniques. Complex mid-infrared pulse shapes at a center wavelength of 4.9 μm are generated with a spectral resolution exceeding by more than a factor of 5 the reported experimental resolutions of calomel-based acousto-optic filters.

Q 39.2 Wed 16:45 TOE 317

Femtosecond Pulse-Shaping and Characterization in the Mid-Infrared — •Rene Costard, Christian Greve, Erik T. J. Nibbering, and Thomas Elsaesser — Max Born Institut für Nichtlineare Optik und Kurzzeitspektroskopie, Max Born Strasse 2A, D-12489 Berlin, Germany

Femtosecond mid-infrared (IR) pulses are now commonly used for nonlinear time-resolved vibrational spectroscopy. Pump-probe or multidimensional photon echo experiments of transient vibrational excitations allow for elucidation of anharmonic couplings and vibrational energy flow pathways. So far, these experiments have typically been performed using the output of a parametric frequency converter, with the central frequency of the IR pulses as experimental parameter. Controlling the amplitude and phase of these pulses, however, allow for a full coherent control of vibrational excitations in molecular systems. We present experimental results of amplitude and phase shaping of ultrashort pulses around 3 μm, which are generated by taking the idler output of an optical parametric amplifier using KTP, pumped by a Ti:sapphire chirped-pulse amplification system. Directing these pulses through a 4f setup with a germanium acousto-optic modulator in the Fourier plane, enables independent shaping of amplitude and phase to generate e.g. double pulses with adjustable time separation or arbitrarily chirped pulses. We fully characterize the amplitude and phase of these shaped mid-IR pulses by cross-correlation frequency-resolved optical gating (XFROG) with well-characterized 800 nm pulses.

Q 39.3 Wed 17:00 TOE 317

The von Neumann representation as a parameterization for polarization-shaped laser pulses — •Stefan Ruetzel[1], Anja Krischke[1], Tobias Brixner[1], and David J. Tannor[2] — [1]Institut für Physikalische und Theoretische Chemie, Universität Würzburg, Am Hubland, 97074 Würzburg — [2]Department of Chemical Physics, Weizmann Institute of Science, 76190 Rehovot, Israel

Polarization-shaped laser pulses offer a wide range of applications in femtosecond spectroscopy and coherent control. The description of such laser pulses is generally provided in time or frequency domain. Time–frequency descriptions descriptions were shown to be useful in the past but have been limited to linearly polarized fields. Here we introduce the von Neumann description as a parameterization for polarization-shaped laser pulses. The electric field is expanded in terms of Gaussian-shaped transform-limited subpulses located on a discrete time–frequency lattice, each with a specific polarization state. On the one hand this formalism can serve as a new description of polarization-shaped laser pulses, simplifying the interpretation of the time- and frequency-dependent polarization state of the light field. On the other hand the polarization state of the laser pulse can directly be defined in the joint time–frequency domain, which allows for an intuitive parameterization of such laser pulses with a reduced number of variables compared to common laser pulse descriptions. Possible applications for future experiments will be presented.

Q 39.4 Wed 17:15 TOE 317

Resonant Strong-Field Control of Electron Dynamics in K_2 — Tim Bayer, •Hendrike Braun, Cristian Sarpe, Matthias Wollenhaupt, and Thomas Baumert — University of Kassel, Institute of Physics and CINSaT, D-34132 Kassel, Germany

The strong-field control mechanism SPODS (Selective Population of Dressed States) has been demonstrated on atoms by using variously shaped femtosecond laserpulses [1,2,3]. The applicability of SPODS to the coherent control of molecules and chemical reactions was pointed out by wave packet calculations on K_2 [4]. Here, we present an experimental demonstration of the molecular strong-field control scheme proposed in [4]. Employing pulse sequences from sinusoidal and blurred step phase modulation respectively, we steer the molecular system, i.e. nuclear wave packet, from a well-defined ground state *via* a transient state of maximum electronic coherence towards a preselected target state. By exerting control on the dressed states of a resonant subsystem we are able to selectively adress different target channels within a manifold of final states with high efficiency. That is, the control of electronic coherences gives rise to effective manipulation of nucelar coherences. Since dressed state splittings in the order of several 100 meV are readily achieved experimentally, the devised SPODS control scheme offers prospect to various applications in femtochemistry.

[1] M. Wollenhaupt *et al.*, Phys. Rev. A **68**, 0154011 (2003)
[2] M. Wollenhaupt *et al.*, Phys. Rev. A **73**, 063409-1 (2006)
[3] T. Bayer *et al.*, Phys. Rev. Lett. **102**, 023004 (2009)
[4] M. Wollenhaupt *et al.*, JPPA **180**, 248 (2006)

Q 39.5 Wed 17:30 TOE 317

Product control of conical intersection driven photochemical reactions by steering electronic wavepackets — •Philipp von den Hoff and Regina de Vivie-Riedle — Department Chemie, Ludwig-Maximilians-Universität München, D-81377 München, Germany

Electrons and their dynamics are involved in bond breaking and formation, thus the idea to steer chemical reactions by localization of electronic wavepackets seems natural. The formation of a localized electronic wavepacket requires the superposition of two or more appropriate electronic states through e.g. an external electric field. The guiding of such an electronic wavepacket is only possible within the coherence time of the system. Here, we present a new UV-pump-IR-control scheme that allows us to control the product ratio of conical intersection driven photochemical reactions by steering an electronic wavepacket [1]. To test the proposed scheme, we constructed a two dimensional model system. Our calculations show, that we are able to steer the final product ratio very precisely by changing the carrier envelope phase of the control IR-pulse.

[1] P. von den Hoff, R. Siemering and R. de Vivie-Riedle, Ultrafast Phenomena XVII, Oxford University Press, (2010), in Press.

Q 39.6 Wed 17:45 TOE 317

Efficient and robust strong-field control of populationtransfer in sensitizer dyes with designed femtosecond laser pulses — Johannes Schneider, •Matthias Wollenhaupt, Andreas Winzenburg, Tim Bayer, Jens Köhler, Rüdiger Faust, and Thomas Baumert — University of Kassel, Institute of Physics and CINSaT, D-34132 Kassel, Germany

We demonstrate control of electronic population transfer in molecules with the help of shaped femtosecond laser pulses. To that end we investigate two photosensitizer dyes in solution being prepared in the triplet ground state. Excitation within the triplet system is followed by intersystem crossing and the corresponding singlet fluorescence is monitored as a measure of population transfer in the triplet system. We record control landscapes with respect to the fluorescence intensity on both dyes by a systematic variation of laser pulse shapes combining second order and third order dispersion. In the strong-field regime we find highly structured topologies with large areas of maximum or minimum population transfer being robust with respect to the applied laser intensities. We then compare our experimental results with simulations on generic molecular potentials by solving the TDSE for excitation with shaped pulses. The analysis of the regions of maximum or minimum population transfer reveals that coherent processes control the outcome of the excitation process. The physical mechanisms of joint motion of ground and excited state wave packets or population of an vibrational eigenstate in the excited state permits us to discuss the molecular dynamics in an atom-like picture.

Q 39.7 Wed 18:00 TOE 317

Prospects of Incoherent Control by Continuous Measurements — •Felix Platzer and Klaus Hornberger — Max Planck Institute for the Physics of Complex Systems, Nöthnitzer Straße 38, 01187 Dresden, Germany

In contrast to state-selective coherent control, which proves to be fragile when applied to large quantum systems such as poly-atomic molecules, incoherent dynamics induced by continuous measurements can provide a more robust means of steering quantum dynamics towards desired target states. Here, we demonstrate the potential use of non-selective measurements of position or, more generally, of configurational degrees of freedom of molecules, for the optimization of transition probabilities. Numerical simulations of wave packet dynamics in the presence of optimized position measurements are presented and their analytical description in terms of the corresponding master equation undertaken.

Q 40: Transport and Localization of interacting Bosons 1

Time: Wednesday 16:30–18:00 Location: HSZ 02

Q 40.1 Wed 16:30 HSZ 02

Observation of Absolute Negative Mobility in Driven Quantum Systems — •Tobias Salger[1], Sebastian Kling[1], Sergey Denisov[2], Alexey Ponomarev[2], Peter Hänggi[2], and Martin Weitz[1] — [1]Institut für Angewandte Physik, Wegelerstrasse 8, 53115 Bonn — [2]Institut für Physik, Universitätsstrasse 1, 86135 Augsburg

Here we report on the observation of absolute negative mobility (ANM) of a Bose-Einstein condensate in an ac-driven quantum system. This effect describes the paradoxial situation, when the motion of a particle is always in oppositve direction to an applied external gradient field. Based on successful experiments, demonstrating a directed motion of a Bose-Einstein condensate in a Hamiltonian quantum ratchet, we investigate the dynamics of atoms when exerted to an external bias field [1].

Up to now, the presence of strong decoherence mechanisms has been considered to be crucial for absolute negative mobility [2]. However here we demonstrate for the first time that this phenomenon can also be observed in a coherent quantum system. Our experimental results are in good agreement with a theoretical model, based on numerical simulations.

[1] T. Salger et al., Science **326**, 1241 (2009)
[2] A. Ros et al., Nature **436**, 928 (2005)

Q 40.2 Wed 16:45 HSZ 02

Direct observation of quasi-local relaxation with strongly correlated bosons in an optical lattice — •Stefan Trotzky[1,2,3], Yu-Ao Chen[1,2,3], Andreas Flesch[4], Ian P. McCulloch[5], Ulrich Schollwöck[1,6], Jens Eisert[6,7], and Immanuel Bloch[1,2,3] — [1]Ludwig-Maximilians Universität München — [2]MPI für Quantenoptik, Garching — [3]Johannes-Gutenberg Universität Mainz — [4]Forschungszentrum Jülich — [5]University of Queensland — [6]Institute for Advanced Study, Berlin — [7]Universität Potsdam

The question of how closed quantum systems far from equilibrium come to rest lies at the heart of statistical mechanics. We report the experimental observation of the relaxation dynamics of a one-dimensional bosonic density wave in an optical lattice. Using an optical superlattice, we are able to load Bose-Hubbard chains with each second lattice site occupied. Furthermore, the superlattice allows us to monitor the non-equilibrium dynamics emerging after rapidly switching on the tunnel coupling along the chain in terms of quasi-local densities, currents and correlations. We find a rapid relaxation of all these quantities to steady-state values compatible with those of a maximum entropy state. We compare the experimental results to parameter free time-dependent DMRG simulations, finding excellent agreement. The system thus can be seen as an accurate dynamical quantum simulator for the systematic study of equilibration phenomena in strongly correlated many-body systems.

Q 40.3 Wed 17:00 HSZ 02

Observation of subdiffusion of a disordered interacting system — •Eleonora Lucioni[1], Benjamin Deissler[1], Luca Tanzi[1], Chiara D'Errico[1], Giacomo Roati[1], Matteo Zaccanti[1,2], Michele Modugno[1,3], Massimo Inguscio[1], and Giovanni Modugno[1] — [1]LENS and Università di Firenze, and CNR-INO, Italy — [2]Institut für Quantenoptik und Quanteninformation, Innsbruck, Austria — [3]IKERBASQUE, Basque Foundation for Science, Bilbao, Spain

We study the transport dynamics of matter-waves in the presence of disorder and non-linearity. A Bose-Einstein Condensate of 39K atoms is let free to expand in a quasiperiodic lattice realized by superimposing two laser beams of incommensurate wavelength in standing wave configuration. By means of a broad magnetic Feshbach resonance it is possible to tune the scattering length between atoms at will. In the noninteracting case this system is an experimental realization of the Aubry-André model: if the disorder is strong enough, the system is localized and no expansion is permitted (Anderson localization).

The presence of a weak repulsive interaction allows the coupling between orthogonal localized single particle states and destroys localization. In this case we observe a change of shape of the atomic cloud during the expansion and a slow increase of the width σ of the sample that follows a subdiffusive law: $\sigma(t) \propto t^{\alpha}$, with $\alpha = 0.2 - 0.4$. We find that the exponent increases with the initial interaction energy and the localization length.

Q 40.4 Wed 17:15 HSZ 02

Coherent transport of a BEC in the presence of disorder and nonlinearity — •Tobias Geiger, Thomas Wellens, and Andreas Buchleitner — Physikalisches Institut der Universitaet Freiburg, Hermann-Herder-Str. 3, 79104 Freiburg

For a dilute cloud of weakly interacting ultracold bosons subject to a random disorder potential, the Gross-Pitaevskii equation, in its limits, produces reliable results. However, for increasing amounts of disorder and interaction, the stationary solution of the mean field description [1] – and eventually also the mean field description itself – breaks down.

In our approach, we treat the full bosonic N-body problem microscopically in a nonlinear scattering setup. By employing a diagrammatic technique relying on the assumption of a weakly scattering disorder potential [2], one is in principle able to sum up all different orders of the nonlinear scattering series.

Here, we present first preliminary results of different scattering orders and compare them to findings predicted by the Gross-Pitaevskii equation.

[1] T. Paul, M. Albert, P. Schlagheck, P. Leboeuf, and N. Pavloff, Phys. Rev. A **80**, 033615 (2009)

[2] T. Wellens and B. Grémaud, Phys. Rev. A **80**, 063827 (2009)

Q 40.5 Wed 17:30 HSZ 02

Interaction-based reduction of weak localization in coherent transport of Bose Einstein Condensates — •Josef Michl[1], Timo Hartmann[1], Juan Diego Urbina[1], Cyril Petitjean[2], Thomas Wellens[3], Peter Schlagheck[4], and Klaus Richter[1] — [1]Institute of Theoretical Physics, University of Regensburg, Germany — [2]SPSMS-INAC-CEA, Grenoble, France — [3]Physics Department, University of Fribourg, Switzerland — [4]Physics Department, University of Liège, Belgium

Based on the Gross-Pitaevskii-equation, we investigate reflection amplitudes and reflection probabilities in the transport of coherent bosonic matter waves through a fully-chaotic two-dimensional billiard-system. Like in the case of electronic transport, one can observe the effect of weak-localization in this setting. Our interest lies now in the influence of a weak interaction between particles on the weak-localization-peak and its behaviour in the presence of a weak magnetic field in the billiard.

Numerical results on this topic predict a reduction of the weak-localization-peak for small magnetic fields and a vanishing influence of the interaction with an increasing one. Trying to explain that, an analytical technique based on a semiclassical treatment in form of a diagrammatic perturbation theory in the parameter representing the interaction will be presented. Its results are compared to the numerical findings.

Q 40.6 Wed 17:45 HSZ 02

Anderson orthogonality catastrophe in ultracold quantum gases — •Daniel Kotik[1], Martina Hentschel[1], and Walter Strunz[2] — [1]Max-Planck-Institut für Physik komplexer Systeme, Nöthnitzer Straße 83, 01187 Dresden — [2]Institut für Theoretische Physik, TU Dresden, 01062 Dresden

Ultracold quantum gases have attracted a lot of attention in recent years, not least due to their exquisite experimental control and the resulting versatile possibilities to manipulate them.

Here, we study impurity potentials in ultracold bosonic quantum gases and specifically in their Bose-Einstein condensed phase, that result, e.g., from unavoidable defects contained in the material or from deliberately placed perturbations. Our emphasis will be on spatio-temporal perturbations that are suddenly switched-on and spatially localized, as can be realized by switching on an additional laser beam. The many-body response of the quantum gas to this impurity potential is studied numerically and analytically.

We will pay particular attention to the consideration of the bosonic analogue known from solid state theory as Anderson orthogonality catastrophe.

Q 41: Precision Measurement and Metrology 1

Time: Wednesday 16:30–18:00 Location: HÜL 386

Q 41.1 Wed 16:30 HÜL 386

Frequency standard based on the octupole transition in ^{171}Yb$^+$ — •Nils Huntemann, Maxim Okhapkin, Burghard Lipphard, Stefan Weyers, Christian Tamm, and Ekkehard Peik — Fachbereich Zeit und Frequenz, Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig, Germany

We present our results on the development of a new optical frequency standard based on the electric octupole (E3) transition $^2S_{1/2}(F = 0) \rightarrow {}^2F_{7/2}(F = 3)$ of a single trapped laser-cooled $^{171}Yb^+$ ion at 467 nm.

In comparison with a previously realized optical frequency standard in $^{171}Yb^+$ [Tamm *et al.*, Phys. Rev. A **80** 043403 (2009)] this E3 transition benefits from smaller systematic level shifts due to external fields and its negligible natural linewidth. Another important aspect of the new standard is its strong dependence on variations of the fine structure constant α.

A recently built probe laser system [Sherstov *et al.*, Phys. Rev. A **81** 021805(R) (2010)] and the use of a new efficient repump scheme allows to observe Fourier transform-limited linewidths below 7 Hz and a resonant excitation probability of more than 90 %.

We lock the probe laser frequency to the resonance signal of the E3 transition and use a real-time extrapolation scheme to eliminate the huge light shift induced by the probe field. The unperturbed transition frequency was measured by a comparison to a caesium fountain clock using a frequency comb generator. The resulting uncertainty was mainly limited by the systematic uncertainty of the fountain clock.

Q 41.2 Wed 16:45 HÜL 386

Optical Lattice Clock with ^{87}Sr — •Stephan Falke, Thomas Middelmann, Fritz Riehle, Uwe Sterr, and Christian Lisdat — Physikalisch-Technische Bundesanstalt (PTB), Bundesallee 100, 38116 Braunschweig, Germany

We present an absolute frequency measurement of the $5s^2\ {}^1S_0$ – $5s5p\ {}^3P_0$ transition of ^{87}Sr against the Cs fountain clock CsF1 at PTB. An ultrastable laser with a linewidth of about 1 Hz interrogates an ensemble of ultracold fermionic strontium atoms that are held in an optical lattice. The lattice laser is set to the magic wavelength at 813 nm. The trapping allows for Doppler-free spectroscopy and interrogation times of 90 ms. The interrogating laser is locked to the atoms by measuring the transition probability for the two extreme Zeeman components that show a Fourier linewidth of 10 Hz.

The systematics of the Sr system itself has been investigated using an alternating stabilization technique. It is found to be better than, both, the systematic and the statistical uncertainty of the Cs clock.

With the alternating stabilization scheme, we measured the magic wavelength for the optical lattice. This frequency is determind to the level of a few MHz.

By comparing the transition frequency for different densities we looked for the effect of collisions (density shift). Such shifts can at least be reduced to 3×10^{-17} for our experimental configuration.

The work is supported by the Centre for Quantum Engineering and Space-Time Research (QUEST), ESA, DLR, and the ERA-NET Plus Programme.

Q 41.3 Wed 17:00 HÜL 386

Towards an optical frequency standard based on cold neutral magnesium atoms in an optical lattice — •André P. Kulosa, André Pape, Temmo W. Wübbena, Jan Friebe, Matthias Riedmann, Hrishikesh Kelkar, Steffen Rühmann, Dominika Fim, Klaus H. Zipfel, Wolfgang Ertmer, and Ernst-M. Rasel — Leibniz Universität Hannover, Institut für Quantenoptik, Hannover

Optical clocks have exceeded today's best atomic microwave clocks in accuracy and stability. The alkaline earth atoms are promising candidates for possible future optical frequency standards. Magnesium shows an attractive benefit with its low sensitivity to black body radiation shift at room temperature, which is a limiting contribution to today's best optical clocks.

Our current magnesium frequency standard is based on cold free-falling atoms interrogated on the narrow intercombination line $^1S_0$ - $^3P_1$ using a Ramsey-Bordé-interferometer geometry.

We trap the bosonic isotope ^{24}Mg in an optical dipole trap at 1064 nm during a MOT-cooling stage in the triplet manifold. We are able to accumulate 10^5 atoms at a temperature of 100 μK in the dipole trap using a continuous loading scheme. The atoms will be transferred to an optical lattice at the magic wavelength which is predicted to be 463 nm. The power in the lattice is enhanced using a build-up cavity.

Q 41.4 Wed 17:15 HÜL 386

Precision measurement of the 1S-2S transition in atomic hy-

drogen — •Christian G. Parthey[1], Arthur Matveev[1], Janis Alnis[1], Axel Beyer[1], Nikolai Kolachevsky[1], Randolf Pohl[1], Thomas Udem[1], and Theodor W. Hänsch[1,2] — [1]Max-Planck-Institut für Quantenoptik, 85748 Garching — [2]Ludwig-Maximilians-Universität, 80799 München

Precision spectroscopy of the 1S-2S transition in atomic hydrogen has been used to test quantum electro dynamics (QED), determine the Rydberg constant and the proton charge radius. It can also be used to set limits on possible Lorentz-boost invariance violations. Here we report on a new measurement of the 1S-2S transition pushing the uncertainty to the 10^{-15} level.

Q 41.5 Wed 17:30 HÜL 386

Using ($\Delta F = 1, \Delta m_F = \pm 1$) transitions as a diagnostic tool for atomic fountain clocks — •Nils Nemitz, Vladislav Gerginov, Stefan Weyers, and Robert Wynands — Physikalisch-Technische Bundesanstalt, Braunschweig

Atomic caesium fountain clocks provide the most accurate realization of the SI second by making use of the $|F = 3, m_F = 0\rangle$ to $|F = 4, m_F = 0\rangle$ hyperfine transition.

A leading contribution to their uncertainty budget arises from the effects of phase gradients in the microwave cavity. A better understanding of the atomic distribution during each of the two cavity passages would help in putting stricter limits on this uncertainty.

We have recently investigated a new method of obtaining information on the center-of-mass position during either cavity passage for the fraction of atoms contributing to the actual frequency measurement. It is based on a position-dependent change of the $\Delta m = \pm 1$ spectra when the normally vertical quantization field is tilted slightly. This type of spectra is normally not investigated in fountain clocks.

We will present experimental evidence and an analytical model that promises an achievable accuracy of the measured center-of-mass position of better than 0.3 mm.

Q 41.6 Wed 17:45 HÜL 386

Laser spectroscopy of trapped thorium ions — •Óscar-Andrey Herrera-Sancho[1], Maxim Okhapkin[1], Kai Zimmermann[1], Alexey Taichenachev[2], Valeriy Yudin[2], Christian Tamm[1], and Ekkehard Peik[1] — [1]Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig, Germany — [2]Institute of Laser Physics, Siberian Branch of RAS, Novosibirsk 630090, Russia

In our experiment more than 10^5 $^{232}Th^+$ ions are stored in a linear Paul trap after creation by laser ablation from thorium metal. Single-frequency laser excitation in the complex spectrum of Th^+ poses the problem that spontaneous decay populates a number of metastable levels that are decoupled from the laser. Helium and Argon buffer gas are used for collisional cooling and quenching of those levels. We observe laser excitation of the strong resonance line at 401.9 nm with an extended-cavity diode laser and laser excitation of several other transitions around 400 nm and 270 nm with harmonics of a pico-second Ti:Sa laser. In a theoretical analysis we approximate the dense electronic level structure of Th^+ ions by just four levels: the ground state and an excited state are coupled by the primary laser, one metastable state is depopulated by a repumper laser and one level by collisions only. The model agrees with experimental results for the fluorescence rate as a function of the laser intensities and can be used to deduce populations and quenching rates. First investigations on two-photon excitation of the Th^+ electron shell to the energy range 7.8 eV of the nuclear transition of ^{229}Th are in progress.

Q 42: Laserentwicklung: Festkörperlaser 3

Time: Wednesday 16:30–17:45 Location: SCH 251

Q 42.1 Wed 16:30 SCH 251

Optische Verstärkung in Er^{3+}:Y_2O_3 Rippenwellenleitern — •Jonathan Thielmann, Sebastian Heinrich, Klaus Petermann und Günter Huber — Institut für Laserphysik, Universität Hamburg

Die Wellenleitergeometrie ist sehr vielversprechend im Hinblick auf die Entwicklung kompakter Lasersysteme. Sesquioxide weisen hervorragende thermomechanische Eigenschaften, wie z.B. ihre große Härte und ihre hohe Wärmeleitfähigkeit, auf. Zudem stellen kristalline Seltenerd-dotierte Sesquioxid-Wellenleiter schmale Emissionslinienbreiten, hohe Frequenzstabilität und eine hohe optische Verstärkung in Aussicht. Daher wurden mit dem Pulsed Laser Deposition-Verfahren Er^{3+}:Y_2O_3-Schichten auf Saphir-Substraten hergestellt. Spektroskopische Untersuchungen zeigten, dass die Emissionsspektren, bis auf eine geringe Verbreiterung, gut mit den Spektren von Er^{3+}:Y_2O_3-Volumenkristallen übereinstimmen. In einem 7,7 mm langen und 3 μm dicken (0,6at%) Erbium dotierten Wellenleiter konnte bei einer Wellenlänge von 1535 nm eine Verstärkung von 6,6 dB gemessen werden. Dies entspricht einer höheren Verstärkung, als den 5,9 dB/cm, die in einem einkristallinen Er^{3+}(0,6 at.%):$(Gd,Lu)_2O_3$-Rippenwellenleiter gemessen wurde [1]. Die Wellenleiterverluste wurden bei einer Wellenlänge von 940 nm zu einer oberen Grenze von 5,8 dB bestimmt. Bei höheren Wellenlängen werden deutlich geringere Verluste erwartet, so dass Laseremission der Rippenwellenleiter möglich sein sollte.

[1] A. Kahn et al., Journal of the Optical Society of America B **25** (11), 1850-1853 (2008)

Q 42.2 Wed 16:45 SCH 251

Erzeugung von 7 μJ Pulsenergie mit einem Zwei-Kristall Yb:KYW-Oszillator mit Cavity-Dumping — Guido Palmer[1], •Moritz Emons[1], Marcel Schultze[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

Wir stellen ein Chirped-Pulse-Oszillator (CPO)-System vor, welches mit zwei Yb:KYW-Kristallen betrieben wird und komprimierte Pulsdauern von 416 fs bei Ausgangsleistungen von 7 W und einer Repetitionsrate von 1 MHz generiert. Die erreichbare Spitzenleistung unter Berücksichtigung von Kompressorverlusten und Pulsform liegt bei 12 MW. Neben der externen Kompression der Pulse von Piko- auf Femtosekunden Pulsdauer wird auf die Untersuchungen der Auswirkungen der Nutzung von zwei Kristallen auf die Effizienz des Cavity-Dumpings, sowie die Einflüsse von Dispersion höherer Ordnung auf die erreichbaren Pulsdauern eingegangen. Darüber hinaus wird die Verstärkung der ps-Pulse aus dem Oszillator mittels eines nachfolgenden Faserverstärkers basierend auf einer Yb-dotierten rod-type-Faser diskutiert.

Q 42.3 Wed 17:00 SCH 251

Development of an all semiconductor laser system for ultrashort pulse generation — •Jan C. Balzer[1], Tobias Schlauch[1], Andreas Klehr[2], Götz Erbert[2], Günther Tränkle[2], and Martin R. Hofmann[1] — [1]Chair for Photonics and Terahertz Technology, Building ID 04/327, D-44780 Bochum, Germany — [2]Ferdinand Braun Institute, Gustav-Kirchhoff-Str. 4, D-12489 Berlin, Germany

Laser diodes are attractive sources for the generation of ultrashort pulses. These systems are particularly interesting as an alternative to conventional femtosecond lasers like Ti:sapphire lasers, which are rather complex and expensive. We present a compact all semiconductor laser system for femtosecond pulse generation. A two section electrically driven edge emitting dual quantum well mode-locked laser diode is used in an external cavity. With intracavity dispersion control the spectral bandwidth of our laser could be significantly increased. Due to the mainly quadratic spectral phase of the generated pulses an external pulse compressor allows us a reduction of the pulse duration down to 200 fs by compensating the linear chirp. In combination with a tapered amplifier a peak power in the kW range was realized. With these specifications our system is a cost efficient and compact alternative to commercial laser systems for ultrashort pulse generation. It has already been demonstrated that our system is capable to replace a commercial Ti:sapphire laser system in order to drive a terahertz time-domain spectrometer.

Q 42.4 Wed 17:15 SCH 251

Untersuchung der Specklereduktion bei inkohärent gekoppelten Diodenlasern im externen Resonator — •Antonio Saghati, Danilo Skoczowsky, Axel Heuer und Ralf Menzel — Universität Potsdam, Institut für Physik und Astronomie, Photonik, Karl-Liebknecht-Str. 24-25, Haus 28, 14476 Potsdam

Speckle sind störend bei diversen Anwendungen wie zum Beispiel in der Beleuchtung, der Linienprojektion oder der Displaytechnologie. Eine Möglichkeit Speckle zu reduzieren, ist die Erzeugung von mehreren unkorrelierten Specklemustern und deren Überlagerung.

Um dies zu realisieren, wurde ein Multiwellenlängenlaser aufgebaut. Die inkohärente Kopplung von Diodenlasern mittels „spectral beam combining“ (SBC) ermöglicht gleichzeitig eine gute Strahlqualität, eine Bandbreite von mehreren nm und eine hohe Ausgangsleistung zu erzielen.

Mit einem antireflex beschichteten streifenkontaktierten Breitstreifenlaser bestehend aus 40 „Emittern“ wurde mit SBC eine Ausgangsleistung von >400 mW, eine gute Strahlqualität von M^2<1,8 und eine spektrale Bandbreite von ≈25 nm realisiert. Der Einfluß der Bandbreite auf den Specklekontrast wurde bei verschiedenen Betriebsparametern untersucht.

Q 42.5 Wed 17:30 SCH 251

UV-Strahlquelle mittels Frequenzvervierfachung eines Faserverstärkers — •Daniel Rieländer, Tobias Beck, Mathias Sinther und Thomas Walther — Institut für Angewandte Physik, Technische Universität Darmstadt, Schlossgartenstr. 7, D-64289 Darmstadt

Wir stellen den aktuellen Stand der Entwicklung einer verstimmbaren, schmalbandigen Strahlquelle mit Zentralwellenlänge bei 254,1 nm vor. Diese Wellenlänge wird erreicht, indem ein Ytterbium-dotierter Faserverstärker bei 1016,4 nm betrieben wird und anschließend durch zweifache Frequenzverdopplung mittels nichtlinearer Kristalle in zwei Überhöhungsresonatoren auf 254,1 nm konvertiert wird. Der Faserverstärker wird durch einen verstimmbaren ECDL geseedet. Weiterhin wird eine polarisationserhaltende Faser verwendet und zur Verbesserung ihrer Absorptionseigenschaften mit flüssigem Stickstoff gekühlt. Die Überhöhungsresonatoren werden dabei durch das Hänsch-Couillaud-Locking stabilisiert. In späteren Experimenten kann die Strahlquelle an einer magnetooptischen Quecksilberfalle für Experimente zur Photoassoziation verwendet werden.

Q 43: Laseranwendungen und Photonik 2

Time: Wednesday 16:30–17:30 Location: SCH A118

Q 43.1 Wed 16:30 SCH A118

Photonic Crystal Halfhole-Microresonators on (220x450) nm SOI waveguides — •Bülent A. Franke[1], Aws Al-Saadi[1], Miroslaw Szczambura[1], Sebastian Kupijai[1], Shaimaa Mahdi[1], Viachaslau Ksiandzou[2], Sigurd Schrader[2], Hans J. Eichler[1], and Stefan Meister[1] — [1]Technische Universität Berlin, Institut für Optik und Atomare Physik, Berlin, Germany — [2]Technische Fachhochschule Wildau, Institut für Plasma- und Lasertechnik, Wildau, Germany

1D-photonic crystal halfhole Fabry-Pérot resonator based on Silicon-on-Insulator technology (SOI) will be presented. The microresonators in SOI waveguides are created by sinusoidal modulation of the waveguide width to realize Bragg mirror sections. The mirror regions are separated by a sub-micron spacer. The microresonators are manufactured by DUV-Lithography (248 nm) in a CMOS environment with 130 nm resolution. The waveguides as well as the width modulated mirror regions are designed using a single mask and are fabricated in a shallow trench process. Filters with different halfhole diameters, cavity length, and mirror refectivity was produced and investigated. Q-factors of up to 1500 could be observed around 1550 nm wavelength with an insertion loss of 3 dB. The results will be discussed and compared and simulated.

Q 43.2 Wed 16:45 SCH A118

Single optical microfibre interferometer — •Konstantin Karapetyan, Wolfgang Alt, Fabian Bruse, and Dieter Meschede — Institut für Angewandte Physik, Universität Bonn, Wegelerstr. 8, 53115, Bonn, Germany

Applications of optical microfibres (OMF)—optical fibres with a diameter on the order of 100...1000 nm operating in the strong guiding regime—have been proposed for evanescent field spectroscopy, atom trapping, nonlinear optics, and microparticle manipulation. Interferometers with an OMF in one or both arms have also been demonstrated. We present a single OMF-based interferometer. This device uses the down-taper of an OMF as a beam splitter and the up-taper as a beam recombiner, similar to a Mach-Zehnder interferometer. The two arms are realized here by the two lowest circular modes of the OMF, having different propagation constants. Due to their different mode field diameters, they experience specific absorptive and dispersive changes from materials in the evanescent field. We explain the design and manufacturing of such devices and show how they can be applied to a variety of experiments including the sensing of temperature, pressure and stretching, simultaneous measurement of absorption and dispersion of liquids, adsorbed and dissolved molecules, and free atoms.

Q 43.3 Wed 17:00 SCH A118

Applications of selectively liquid-filled photonic crystal fibers — •Timo Gissibl, Marius Vieweg, and Harald Giessen — 4th Physics Institute, University of Stuttgart, Pfaffenwaldring 57, 70569 Stuttgart, Germany

Photonic crystal fibers have been the subject of many research efforts due to their amazing characteristics, such as endless single-mode propagation, high nonlinearity, tunable dispersion, or high birefringence. We developed a unique technique to infiltrate liquids, metals, nanodiamonds, or gases into selected holes of photonic crystal fibers. Two-photon polymerization is used to selectively close the holes of such a fiber [1]. With this method we have the possibility to close microstructured fibers with any desired pattern and produce in this way tunable liquid-filled photonic crystal fibers for light propagation in two-dimensional discrete systems. As examples we show 19-strand large-mode-area liquid-filled fibers, as well as tunable highly-birefringent liquid-filled photonic crystal fibers.

[1] M. Vieweg, T. Gissibl, S. Pricking, B. T. Kuhlmey, D. C. Wu, B. J. Eggleton, and H. Giessen, ”Ultrafast nonlinear optofluidics in selectively liquid-filled photonic crystal fibers,” Opt. Express 18, 25232-25240 (2010).

Q 43.4 Wed 17:15 SCH A118

Tunable thin film Fabry-Pérot filters directly coated on the end-faces of optical fibers — •Dawid Schweda[1], Stefan Meister[1], Marcus Dziedzina[1], Ronny Juhre[1], Stefan Prorok[2], Manfred Eich[2], and Hans J. Eichler[1] — [1]Technische Universität Berlin, Institut für Optik und Atomare Physik, Berlin, Germany — [2]Technische Universität Hamburg-Harburg, Hamburg, Germany

Thin film Fabry-Pérot filters which act as narrow bandpass filters were directly coated on fiber end-faces to achieve a very high level of integration with a reduction of optical elements. Possible fields of application are sensing, monitoring and telecommunication. The Fabry-Pérot filters were realized as thin film dielectric Bragg mirrors in combination with an electro-optical (eo) polymer as the spacer material. Filter bandwidths of less than 1nm were achieved resulting in a Q-factor of more than 2200. With additionally integrated films of transparent conductive oxides used as electrodes, e.g. indium tin oxide (ITO), the filters become tunable. The initially poled and therefore anisotropic eo-polymer spacer performs a Pockels effect during the application of an electrical field, which leads to a change in the refractive index of the spacer. Low drive voltages of several volts, in dependency of the poling efficiency and the applicable field strength, already lead to a shift of the transmitted wavelength in the nanometer range. While in general any filter band can be achieved by the adjustment of the design parameters, focus have been taken on the telecommunication wavelength of 1550nm.

Q 44: Quantum Optics of Solid State Photon Sources

Time: Thursday 10:30–13:00 Location: HSZ 02

Q 44.1 Thu 10:30 HSZ 02

Solid state single photon sources based on color centers in diamond — •Elke Neu[1], David Steinmetz[1], Christian Hepp[1], Janine Riedrich-Möller[1], Roland Albrecht[1], Jan Meijer[2], Martin Fischer[3], Stefan Gsell[3], Matthias Schreck[3], and Christoph Becher[1] — [1]Universität des Saarlandes, FR 7.2 Experimentalphysik, D-66123 Saarbrücken — [2]RUBION, Ruhr-Universität Bochum, D-44780 Bochum — [3]Universität Augsburg, Lehrstuhl für Experimentalphysik 4, D-86135 Augsburg

Color centers in diamond are promising candidates for practical single photon sources due to room temperature operation and superior photostability. We observe single photon emission from various color centers, produced either by ion-implantation or in-situ doping during CVD-growth. Optimum results are obtained from Silicon-Vacancy (SiV)-centers in isolated nano-diamonds grown on Iridium layers. These centers feature emission predominantly (80-90 %) into the narrow (0.7 nm) zero-phonon-line and high brightness with up to 4.8 Mcps at saturation, thus being the brightest single color centers to date [1]. We observe for the first time the fine structure of a single SiV-center at cryogenic temperatures and perfom detailed spectroscopy investigating level structures, polarization and the influence of spectral diffusion. We discuss strategies for enhancing spectral and spatial emission properties by coupling color centers to micro-cavities e.g. fiber-based or photonic crystal cavities.

[1] E. Neu et al, ArXiv 1008.4736 accepted for publication in *New J. Phys.*

Q 44.2 Thu 11:00 HSZ 02

Quantum Light from a Whispering Gallery Resonator — •Josef Fürst[1], Dmitry Strekalov[2], Dominique Elser[1], Ulrik L. Andersen[1,3], Andrea Aiello[1], Christoph Marquardt[1], and Gerd Leuchs[1] — [1]Max Planck Institute for the Science of Light, Institute for Optics, Information and Photonics, University Erlangen-Nuremberg, Erlangen, Germany — [2]Jet Propulsion Laboratory, California lnstitute of Technology, Pasadena, USA — [3]Department of Physics, Technical University of Denmark, Kgs. Lyngby, Denmark

Optical subharmonic generation, also referred to as parametric down-conversion (PDC) is mediated by an optically nonlinear dielectric medium and connects an optical field to its subharmonic. In this process, one pump photon is converted to two subharmonic photons, called signal and idler. Enclosing the nonlinear medium in a cavity, the setup is called an optical parametric oscillator (OPO). We use a whispering gallery mode (WGM) resonator for our OPO. These WGM cavities offer high quality factors, that enhance the conversion efficiency of the nonlinear process. With a WGM resonator made from Lithium Niobate, we were able to show extremely efficient PDC in our WGM OPO. As the signal and idler photon pairs originate from one pump photon in PDC, they are strongly correlated in photon number. Investigating the quantum properties of the interacting light fields, while driving the OPO above the pump threshold, we observed nonclassical parametric light [1]. We plan to further investigate these quantum properties and will present the latest results.

[1] J. U. Fürst et al., arXiv:1008.0594v6 (2010)

Q 44.3 Thu 11:15 HSZ 02

Studying Photon Number Distributions of (NV-) Single-Photon Centres — •Waldemar Schmunk[1], Marco Gramegna[3], Giorgio Brida[3], Ivo P. Degiovanni[3], Marco Genovese[3], Helmuth Hofer[1], Stefan Kück[1], Lapo Lolli[3], Matteo G.A. Paris[4], Silke Peters[1], Mauro Rajteri[3], Mark Rodenberger[1], Andras Ruschhaupt[2], Emanuele Taralli[3], and Paolo Traina[3] — [1]Physikalisch-Technische Bundesanstalt, 38116 Braunschweig, Germany — [2]Leibniz Universität Hannover, 30167 Hannover, Germany — [3]L'Istituto Nazionale di Ricerca Metrologica INRIM, 10135 Torino, Italy — [4]Universita degli studi di Milano, 20122 Milano, Italy

Reconstruction of the optical density matrix provides information on photon number distributions of unknown quantum states. In the present work we focus on the photon statistics of different nitrogen vacancies centres in diamond. For that purpose, the diagonal elements of the density matrix were experimentally determined by using a transition-edge sensor (TES), which produces an output pulse proportional to the number of photons absorbed and is therefore capable to resolve the photon number. Additional measurements were performed by on/off-statistics using avalanche photodetection assisted by a maximum likelihood estimation. From the data of the two photon number resolving techniques, values of the second order correlation function $g^{(2)}(t=0)$ were determined and compared with the corresponding values measured by a Hanbury-Brown-Twiss interferometer. In the presentation, the three methods will be described and discussed in detail.

Q 44.4 Thu 11:30 HSZ 02

Realization of photonic crystal microcavities in single crystal diamond — •Janine Riedrich-Möller[1], Laura Kipfstuhl[1], Christian Hepp[1], Martin Fischer[2], Stefan Gsell[2], Matthias Schreck[2], and Christoph Becher[1] — [1]Universität des Saarlandes, Fachrichtung 7.2 (Experimentalphysik), Campus E2.6, 66123 Saarbrücken — [2]Universität Augsburg, Experimentalphysik IV, 86159 Augsburg

Microcavities in two-dimensional photonic crystal slabs allow to strongly confine light in volumes of about one cubic wavelength. They are expected to enable the realization of highly efficient emitters and control of spontaneous emission. Such photonic crystal microcavities are routinely fabricated in semiconductor materials. On the other hand, in recent years diamond has attracted significant interest as material for quantum information processing due to the extraordinary properties of optically active defect centers. These so called colour centers can be employed e.g. for cavity enhanced single photon sources that operate at room temperature or cavity-based atom-photon interfaces. We here investigate the fabrication of photonic crystal cavities in single crystalline diamond grown on an Iridium layer. We produce free-standing diamond membranes by dry-etching techniques and pattern them by focussed ion beam milling (FIB). We both realize 1D nanobeam cavities etched in a freestanding waveguide and 2D cavities with several missing holes in a triangular lattice. For the 2D cavities we experimentally obtain quality factors of Q = 300.

Q 44.5 Thu 11:45 HSZ 02

Photon blockade in a strongly coupled quantum-dot cavity system — •Thomas Volz, Andreas Reinhard, and Atac Imamoglu — Institute of Quantum Electronics, ETH Zurich, 8093 Zurich, Switzerland

A long-standing goal in the field of mesoscopic cavity quantum electrodynamics is the demonstration of photon blockade in a strongly coupled quantum-dot cavity system. While signatures of quantum correlations in resonant scattering have been observed previously, here we demonstrate for the first time strong photon blockade in such a device. Our system consists of a single self-assembled InGaAs quantum dot positioned at the field maximum of a photonic crystal L3 cavity (Q≈24000), leading to a coupling strength of g ≈ 150 μeV. In order to tune the cavity in resonance with the neutral quantum dot transition we employ a nitrogen tuning technique. We then probe the strongly coupled device with a resonant laser employing a cross-polarization technique to suppress the excitation-laser light. Due to strong classical blinking dynamics of the quantum dot we additionally use a repump laser to enhance the polariton signal. The photons scattered from the strongly-coupled system are analysed in a standard Hanbury-Brown-Twiss correlation setup. Due to the fast decay dynamics of the polaritons we carry out the experiment in pulsed mode. When the laser is resonant with the polaritons we observe strong antibunching - clear signature of photon blockade. Our results pave the way for the realization of non-linear photonic devices, such as a single-photon transistor or the quantum optical Josephson interferometer.

Q 44.6 Thu 12:00 HSZ 02

Deterministic Coupling of Individual Quantum Systems to Photonic Crystal Structures — Janik Wolters[1], •Andreas W. Schell[1], Günter Kewes[1], Nils Nüsse[2], Max Schoengen[2], Bernd Löchel[2], Michael Barth[1], and Oliver Benson[1] — [1]Nano-Optics, Institute of Physics, Humboldt-Universität zu Berlin, Newtonstr. 15, 12489 Berlin — [2]Operator Centre Microtechnology, Helmholtz-Centre Berlin for Materials and Energy, Albert-Einstein-Straße 15, 12489 Berlin

The controlled and scaleable coupling of single quantum emitters to photonic crystal structures is one of the main challenges on the way towards integrated solid-state devices for optical quantum information processing. We tackle this problem by using a hybrid approach, which combines lithographic fabrication techniques with nanomanipulation methods, allowing the deterministic coupling of arbitrary emitters or other nanoscopic objects to the optical modes of photonic crystal cavities. Here we present recent experimental results on the controlled coupling of the zero phonon line emission from a single NV-center in a nanodiamond to such cavities. Our approach is well suited for the creation of improved single photon sources and also complex photonic devices with several emitters coupled coherently via shared cavity modes.

Q 44.7 Thu 12:15 HSZ 02

Deterministic Coupling of Single Nitrogen Vacancy Centres in Diamond Nanocrystals to Bowtie Nanoantennas — •Günter Kewes, Andreas Schell, Thomas Aichele, and Oliver Benson — Humboldt-Universität zu Berlin, Institut für Physik, Nanooptik

Surface plasmons polaritons provide the opportunity to concentrate electromagnetic energy in volumes much smaller than the wavelength of a photon with equal frequency, i.e. focussing beyond Abbe's limit, therefore giving large interaction between light and matter. This can be exploited in the construction of optical antennas which are designed to concentrate excitation energy at an emitter's location and further enhance the emitters output.

We present the coupling of single nitrogen vacancy (NV) centres in nanodiamond with a gold nanoantenna. The NV centres were systematically rearranged through AFM nanomanipulation around the nanoantenna, resulting in maps of excited state lifetime reduction. These maps can give great insight into the near-field properties of such structures allowing for optimization of hybrid emitter-antenna systems. We observe that this reduction is not solely a fluorescence quenching effect, and an overall enchancement of the photon rate by a factor 2.2 was found.

Q 44.8 Thu 12:30 HSZ 02

Quantum key distribution using electrically triggered quantum dot-micropillar single photon sources — •Tobias Heindel[1], Markus Rau[2], Christian Schneider[1], Martin Fürst[2,3], Sebastian Nauerth[2,3], Matthias Lermer[1], Henning Weier[2,3], Stephan Reitzenstein[1], Sven Höfling[1], Martin Kamp[1], Harald Weinfurter[2,4], and Alfred Forchel[1] — [1]Technische Physik and Wilhelm Conrad Röntgen Research Center for Complex Material Systems, Universität Würzburg, Am Hubland, 97074 Würzburg, Germany — [2]Fakultät für Physik, Ludwig-Maximilians-Universität, 80799 Munich, Germany — [3]qutools GmbH, 80539 Munich, Germany — [4]Max-Planck-Institut für Quantenoptik, 85748 Garching, Germany

In 1984, Bennett and Brassard proposed a secret key-distribution protocol (BB84) that uses the quantum mechanical properties of single photons to avoid the possibility of eavesdropping on an encoded message. Due to the lack of efficient single photon sources however most quantum key distribution (QKD) experiments have been performed with strongly attenuated lasers. First experiments utilizing optically pumped solid state based single photon sources affirmed the great potential of QKD but still suffered from the drawbacks of this excitation scheme.

In this work we report on a QKD experiment using highly efficient electrically triggered quantum dot - micropillar single photon sources with $g^{(2)}(0)$-values below 0.5 and sifted key rates in the range of 10 kBit/s.

Q 44.9 Thu 12:45 HSZ 02

Generation of entangled photon pairs from the polariton ground state in a switchable optical cavity — •Adrian Auer and Guido Burkard — Department of Physics, University of Konstanz, D-78457 Konstanz, Germany

Intersubband cavity polaritons are the fundamental excitations of a planar microcavity embedding a sequence of doped quantum wells [1]. They arise from the interaction of cavity photons with intersubband excitations in the quantum wells. The ground state of the system, the polariton vacuum, contains a finite number of photons and, moreover, correlations of two photons having opposite in-plane wave vectors. It was proposed that these photons can be released by a non-adiabatic tuning of the light-matter interaction [1,2]. We theoretically investigate the polariton vacuum state in order to determine the entanglement between two photons, where we restrict our analysis to only two different modes. This could be carried out experimentally by a post-selective measurement. In this case we find that there is some entanglement for photon pairs having exactly opposite in-plane wave vectors which we quantify by the concurrence C. The amount of entanglement depends on the frequency of each photon and can be as high as $C = 0.7$ for experimentally reasonable values. The probability for a successful post-selection is determined to be on the order of 10^{-5}.

[1] C. Ciuti, G. Bastard and I. Carusotto, Phys Rev. B **72**, 115303 (2005).

[2] S. De Liberato, C. Ciuti and I. Carusotto, Phys. Rev. Lett. **98**, 103602 (2007).

Q 45: Precision Measurement and Metrology 2

Time: Thursday 10:30–13:00 Location: HÜL 386

Q 45.1 Thu 10:30 HÜL 386

Interferometrie für den Gravitationswellendetektor LISA — •Gerhard Heinzel — Max-Planck Institut für Gravitationsphysik (Albert-Einstein Institut) Hannover und QUEST, Leibniz Universität Hannover

Die ESA/NASA Mission LISA soll mittels Laserinterferometrie zwischen 3 Satelliten Gravitationswellen im Frequenzbereich zwischen 0.001 Hz und 1 Hz messen. Wichtige Teile der Laserinterferometrie werden zur Zeit im Labor entwickelt. In diesem Vortrag werden die Herausforderungen, Lösungsvorschläge und der Stand der Entwicklung im Labor zusammengefasst.

Q 45.2 Thu 11:00 HÜL 386

Realistic Test of a Transportable 1 Hz-Linewidth Laser — •Stefan Vogt[1], Christian Lisdat[1], Thomas Legero[1], Sebastian Häfner[1], Uwe Sterr[1], Ingo Ernsting[2], Alexander Nevsky[2], and Stephan Schiller[2] — [1]Physikalisch-Technische Bundesanstalt (PTB), Bundesallee 100, 38116 Braunschweig, Germany — [2]Institut für Experimentalphysik, Heinrich-Heine Universität Düsseldorf, 40225 Düsseldorf, Germany

Optical clocks based on trapped cold atoms are now outperforming the best microwave clocks. So far these clocks have been only available in dedicated laboratories. Operating them in space and on the ground at different locations would enable new studies and applications, like relativistic geodesy and improved fundamental physics tests. We present the setup of a transportable clock laser at 698 nm for a strontium lattice clock that was developed within the ESA/DLR project "Space Optical Clocks". A master-slave diode laser system is stabilized to a rigidly mounted optical reference cavity. For a realistic test, this setup was transported by truck over 400 km from Braunschweig to Düsseldorf, where the cavity-stabilized laser was compared to a stationary Yb-clock laser at 578 nm. The lasers were compared by a Ti:Sapphire frequency comb used as a transfer oscillator. This setup allowed generating a virtual beat between these lasers which showed a combined linewidth below 1 Hz. We will present the setup and discuss the ongoing activities towards a complete transportable optical clock. The work is supported by the Centre for Quantum Engineering and Space-Time Research (QUEST) and the ERA-NET Plus Programme.

Q 45.3 Thu 11:15 HÜL 386

Development of a cryogenic sub-Hz laser system for optical clocks — •Christian Hagemann[1], Thomas Kessler[1], Thomas Legero[1], Uwe Sterr[1], Fritz Riehle[1], Michael J. Martin[2], and Jun Ye[2] — [1]Physikalisch-Technische Bundesanstalt (PTB) and Centre for Quantum Engineering and Space-Time Research (QUEST), Bundesallee 100, 38116 Braunschweig, Germany — [2]JILA, NIST and University of Colorado, 440 UCB, Boulder, CO 80309-0440, USA

Today's best optical clocks are outperforming the best primary Cs frequency standards. The performance of such clocks is limited by the frequency stability of the lasers that are used to interrogate the atomic or ionic quantum transition used as the pendulum of the atomic clock. In such setups an interrogation laser is locked to a high performance cavity for frequency stabilization.

In the Centre of Excellence (QUEST) we have developed a novel single-crystal silicon cavity operated at a temperature of 120 K. We will present the current setup, comprising the cryostat and the laser system. We have observed a fractional instability of a few times 10^{-15} (1 s) limited by the thermal noise floor of the ULE type reference laser. The impact of possible noise sources such as mechanical vibrations, temperature drifts and thermal noise on the frequency stability will be discussed.

Q 45.4 Thu 11:30 HÜL 386

NV color centers for magnetic field sensing at the nanoscale — •Friedemann Reinhard[1], Bernhard Grotz[1], Gopalakrishnan Balasubramanian[1,3], Julia Tisler[1], Eike Oliver Schäfer-Nolte[1,2], Markus Ternes[2], Florian Rempp[1], Klaus Kern[2], Fedor Jelezko[1], and Jörg Wrachtrup[1] — [1]Universität Stuttgart, 3. Physikalisches Institut — [2]Max-Planck-Institut für Festkörperforschung, Stuttgart — [3]Max-Planck-Institut für biophysikalische Chemie, Göttingen

The NV color center in diamond can be used as a magnetic field sensor with sub-nanometer spatial resolution. This prospect arises from the fact that its spin sublevels are sensitive to magnetic fields, only ~1kHz wide and are accessible to pulsed optical-microwave precision spectroscopy.

I present our work towards such a scanning probe diamond nanomagnetometer, focussing on the study of centers, which have been created few nanometers below the diamond surface. We are using such centers to sense noise from surface spins and charges, testing advanced techniques like dynamic decoupling and double–resonance EPR spectroscopy.

Q 45.5 Thu 11:45 HÜL 386

The frequency reference cavity for the AEI 10m Prototype interferometer — •Fumiko Kawazoe[1], Alessandro Bertolini[1], Michael Born[1], Yanbei Chen[2], Katrin Dahl[1], Stefan Gossler[1], Christian Graef[1], Gerhard Heinzel[1], Stefan Hild[3], Sabina Huttner[3], Gerrit Kuehn[1], Harald Lueck[1], Kasem Mossavi[1], Roman Schnabel[1], Kentaro Somiya[4], Kenneth A. Strain[3], John R Taylor[1], Alexander Wanner[1], Tobias Westphal[1], Benno Willke[1], and Karsten Danzmann[1] — [1]Max-Planck-Institut fuer Gravitationsphysik, QUEST, and Leibniz Universitaet Hannover,30167 Hannover, Germany — [2]California Institute of Technology, Pasadena, CA 91125 — [3]University of Glasgow, Glasgow, G12 8QQ, UK — [4]Waseda Institute for Advanced Study,1-6-1 Nishi Waseda, Shinjuku-ku, Tokyo 169-8050, Japan

The AEI 10m Prototype Interferometer will run an interferometric experiment called the sub-SQL interferometer whose sensitivity is designed to reach and even surpass the Standard Quantum Limit. In order to achieve such a good sensitivity, it is required that the laser frequency noise is suppressed to a level of $10^{-4}\,\mathrm{Hz}/\sqrt{\mathrm{Hz}}$ at 20 Hz dropping to below $10^{-6}\,\mathrm{Hz}/\sqrt{\mathrm{Hz}}$ at 1 kHz. For this purpose we have designed a ~ 20 Hz round-trip optical cavity with each mirror individually suspended from a triple cascaded pendulum systems. By controlling the laser frequency to follow the reference cavity's supporting frequency, we aim to achieve the required level of frequency stability. Here, details of the reference cavity design and the according control loop are presented.

Q 45.6 Thu 12:00 HÜL 386

Frequency Combs for Calibration of High-Precision Astronomical Spectrographs — •Tobias Wilken[1], Tilo Steinmetz[1,2], Rafael Probst[1], Ronald Holzwarth[1,2], Theodor W. Hänsch[1], and Thomas Udem[1] — [1]Max-Planck-Institut für Quantenoptik, Garching — [2]Menlosystems GmbH, Martinsried

High precision spectrography in astronomy is at present limited by the available calibration sources. Frequency combs have have been proposed to be an optimal calibration source if they fulfill certain requirements with respect to their spectral bandwidth and mode spacing.

We have developed a frequency comb, based on an Yb-fiber laser which is filtered with Fabry-Perot cavities (FPCs) to have a mode spacing of > 10 GHz. After frequency doubling the comb, ~ 6 nm bandwidth at 526 nm are obtained and this comb was tested at the HARPS spectrograph in La Silla, Chile. This is to date the most precise instrument in the world. A calibration uncertainty limited by photon noise has been observed.

Currently we are working on broadening the optical spectrum to cover the bandwidth of the spectrograph. In this context, noise issues and the reamplification of modes which were initially suppressed by the FPCs need to be investigated in more detail. The latest results will be presented in this talk.

Q 45.7 Thu 12:15 HÜL 386

Hochpräzise Frequenzmetrologie über Glasfasernetzwerke — •Katharina Predehl[1,2], Ronald Holzwarth[1], Thomas Udem[1], Theodor W. Hänsch[1], Osama Terra[2], Gesine Grosche[2] und Harald Schnatz[2] — [1]Max-Planck-Institut für Quantenoptik, Garching — [2]Physikalisch-Technische Bundesanstalt, Braunschweig

Optische Atomuhren übertreffen herkömmliche Mikrowellenstandards in Stabilität und Genauigkeit inzwischen bei Weitem. Für diese Uhren existiert damit keine absolute Referenz mehr. Eine Charakterisierung wird im direkten Vergleich mit einer anderen optischen Uhr vorgenommen. Die typischen Entfernungen für solche Uhrenvergleiche zwischen zwei Instituen sind in Europa um die 1000 - 2000 km. Satellitenkommunkation scheidet hier als Übertragungstechnik aus, sie die geforderten Genauigkeiten nicht erreicht. Glasfasernetzwerke haben sich hingegen als wesentlich geeigneter herausgestellt: das Uhrensignal kann in der Faser sehr rauscharm übertragen werden.

PTB und MPQ haben einen 900 km langen Faserlink aufgebaut, um für die Präzisionsspektroskopie am MPQ hochpräzise Frequenzstandards zur Verfügung stellen zu können. Das Signal wird über 9 fernsteuerbare optische Verstärker übertragen und Schwankungen der Faserlänge werden über die gesamte Strecke aktiv kompensiert. Für das 200 THz-Signal erreichen wir eine Übertragungsstabilität von einem Hz pro Sekunde und eine Genauigkeit im Mikrohertz-Bereich (nach 10000 Sekunden). So erhalten wir am MPQ permanente CSF- Korrekturen für unsere rf- Referenzen und auch optische Signale können direkt mit einem Standard an der PTB verglichen werden.

Q 45.8 Thu 12:30 HÜL 386

Status of the development of LISA Pathfinder — •Jens Reiche, Antonio Francisco García Marín, Heather Audley, Gerhard Heinzel, and Karsten Danzmann — Max Planck Institute for Gravitational Physics (Albert Einstein Institute) Hannover and QUEST, Leibniz University Hannover

LISA Pathfinder is a dedicated technology demonstration mission for the joint ESA/ NASA Laser Interferometer Space Antenna (LISA) mission. LISA Pathfinder will presumably be launched in 2013. LISA is a planned gravitational wave observatory in the frequency range of 0.1 mHz to 1 Hz which is a complementary frequency band to the Earth based detectors. The launch of LISA is planned for 2020. LISA Pathfinder's goal is to demonstrate the key technologies of LISA such as spacecraft control with micronewton thrusters, test mass drag-free control, and precision laser interferometry between free-flying test masses. The talk will give an overview of the actual status of LISA Pathfinder and the payload including its subsystems. The hardware is built by a number of different institutes and industries. Challenges including their solutions and the status of the systems, their integration, verification and testing will be presented.

Q 45.9 Thu 12:45 HÜL 386

Transportable cavity-stabilized fibre laser at 1542 nm — •Thomas Legero, Thomas Kessler, Christian Hagemann, Gesine Grosche, and Harald Schnatz — Physikalisch-Technische Bundesanstalt and Centre for Quantum Engineering and Space-Time Research, Bundesallee 100, 38116 Braunschweig, Germany

Cavity-stabilized laser systems with sub-Hz line width are essential for high-resolution spectroscopy and optical frequency standards. In addition, their superior short term stability in the 10^{-15} regime makes them an excellent tool for referencing fs-frequency combs, optical microwave generation [1] or characterization of optical fibre links [2]. For operation along fibre links the system must be rigid and small enough to be transportable by a small van. We present a compact, cavity stabilized laser system based on a commercial fibre laser at a wavelength of 1542 nm. The cavity setup is designed to withstand typical accelerations during transportation. The complete laser system including the cavity and the electronics package fits into a 19-inch racksystem with a base of 60×60 cm^2 and a height of 1.50 m. Its short term stability of a few times 10^{-15} allows a varity of applications where a mobile highly stable refrence frequency is required.

[1] B. Lipphardt *et al.*, IEEE Trans. Instrum. Meas., **58**, 1258, (2009)

[2] O. Terra *et al.*, Appl. Phys. B, **97**, 541, (2009)

Q 46: Ultra-cold atoms, ions and BEC V

Time: Thursday 10:30–13:00 Location: BAR 106

Q 46.1 Thu 10:30 BAR 106

Supersolid Phase of Cold Fermionic Polar Molecules in 2D Optical Lattices — •Liang He and Walter Hofstetter — Institut für Theoretische Physik, Johann Wolfgang Goethe–Universität, 60438 Frankfurt/Main, Germany

The recent successful realization of a degenerate quantum gas of fermionic polar molecules of $^{40}K^{87}Rb$ [1] opens the door towards exploring the interesting many-body physics originating from the dipole-dipole interactions in fermionic systems. Here we investigate a system of ultra-cold fermionic polar molecules in a two-dimensional square lattice interacting via both the long-ranged dipole-dipole interaction and the short-ranged on-site attractive interaction. Singlet superfluid, charge density wave, and supersolid phases are found to exist in the system. We map out the zero temperature phase diagram and find that the supersolid phase is considerably stabilized by the dipole-dipole interaction and can thus exist over a large region of filling factors. At finite temperatures, we study the melting of the supersolid with increasing temperature, map out a finite temperature phase diagram of the system at a fixed filling factor, and determine the parameter region where the supersolid phase can be possibly observed in experiments.

[1] K.-K. Ni, S. Ospelkaus, M. H. G. de Miranda, A. Pe'er, B. Neyenhuis, J. J. Zirbel, S. Kotochigova, P. S. Julienne, D. S. Jin, and J. Ye, Science, **322**, 231 (2008).

Q 46.2 Thu 10:45 BAR 106

Fermi-Hubbard physics with ultracold fermions in optical lattices — •Daniel Greif, Leticia Tarruell, Thomas Uehlinger, Gregor Jotzu, and Tilman Esslinger — Institute for Quantum Electronics, ETH Zurich, Switzerland

The Fermi-Hubbard Hamiltonian is one of the key models for strongly correlated electrons in solid state systems and incorporates fascinating phenomena such as Mott-insulating behavior or spin ordered phases. Despite intense numerical effort, a number of questions still remains open, in particular on the low temperature phases where spin degrees of freedom start to play a role.

In our experiment we use a two-component Fermi gas loaded into an optical lattice to realize this simple model Hamiltonian. Currently several experiments are reaching out to access the regime of quantum magnetism. We report on recent progress of creation and characterization of low entropy states in the lattice.

Q 46.3 Thu 11:00 BAR 106

Generalized Hartree-Fock Theory for Interacting Fermions in Lattices: Numerical Methods — •Christina Kraus and Ignacio Cirac — Max-Planck Institut für Quantenoptik, Garching

We present numerical methods to solve the Generalized Hartree-Fock theory for fermionic systems in lattices, both in thermal equilibrium and out of equilibrium. Specifically, we show how to determine the covariance matrix corresponding to the Fermionic Gaussian state that optimally approximates the quantum state of the fermions. The methods apply to relatively large systems, since their complexity only scales quadratically with the number of lattice sites. Moreover, they are specially suited to describe inhomogenous systems, as those typically found in recent experiments with atoms in optical lattices, at least in the weak interaction regime. As a benchmark, we have applied them to the two-dimensional Hubbard model on a 10x10 lattice with and without an external confinement.

Q 46.4 Thu 11:15 BAR 106

Quantum-noise quenching in quantum tweezers — •Stefano Zippilli[1,2,3], Bernd Mohring[4], Eric Lutz[5], Giovanna Morigi[1,2], and Wolfgang Schleich[4] — [1]Departament de Física, Universitat Autònoma de Barcelona, E-08193 Bellaterra, Spain — [2]Theoretische Physik, Universität des Saarlandes, D-66041 Saarbrücken, Germany — [3]Fachbereich Physik and research center OPTIMAS, Technische Universität Kaiserslautern, D-67663 Kaiserslautern, Germany — [4]Institut für Quantenphysik, Universität Ulm, D-89081 Ulm, Germany — [5]Department of Physics, University of Augsburg, D-86135 Augsburg, Germany

The efficiency of extracting single atoms or molecules from an ultracold bosonic reservoir is theoretically investigated for a protocol based on lasers, coupling the hyperfine state in which the atoms form a condensate to another stable state, in which the atom experiences a tight potential in the regime of collisional blockade, the quantum tweezers. The transfer efficiency into the single-atom ground state of the tight trap is fundamentally limited by the collective modes of the condensate, which are thermally and dynamically excited and constitute the ultimate noise sources. This quantum noise can be quenched for sufficiently long laser pulses, thereby achieving high efficiencies, and showing that this protocol can be applied for quantum information processing based on tweezer traps for neutral atoms.

Q 46.5 Thu 11:30 BAR 106

Definite angular momentum and fragmentation in 3D attractive BECs — •Marios C. Tsatsos[1], Alexej I. Streltsov[1], Ofir E. Alon[1,2], and Lorenz S. Cederbaum[1] — [1]Theoretische Chemie, Physikalisch-Chemisches Institut, Universität Heidelberg, Im Neuenheimer Feld 229, D-69120 Heidelberg, Germany — [2]Department of Physics, University of Haifa at Oranim, Tivon 36006, Israel

We consider a 3D Bose-Einstein Condensate (BEC), with attractive interparticle interactions, embedded in a harmonic, spherically symmetric trap. This system is metastable only if the total number of bosons N and the interaction strength λ_0 do not exceed some critical values. Otherwise the system collapses. The Gross-Pitaevskii (GP) theory predicts the maximum (critical) number of bosons N_{cr}^{GP} that, for a given λ_0, can be loaded to the ground state of the system, without its collapse. But, what happens to the excited states? To investigate the structure and stability of these states we must go beyond GP theory; the excited states have definite values of angular momentum L, are highly fragmented and can support number of bosons much greater than N_{cr}^{GP}.

Q 46.6 Thu 11:45 BAR 106

Continuous Loading of a Conservative Trap from an Atomic Beam — •Markus Falkenau[1], Valentin Volchkov[1], Jahn Rührig[1], Axel Griesmaier[1,2], and Tilman Pfau[1] — [1]5. Physikalisches Institut, Universität Stuttgart, Germany — [2]Niels-Bohr Insitute, Copenhagen, Denmark

We present results on the fast accumulation of ^{52}Cr atoms in a conservative potential from a magnetically guided atomic beam. Without laser cooling on a cycling transition, a single dissipative step realized by optical pumping allows to load atoms at a rate of $2 \cdot 10^7 s^{-1}$ in the trap. Within less than 100 ms we reach the collisionally dense regime, from which we directly produce a Bose-Einstein condensate with subsequent evaporative cooling. This constitutes a new approach to degeneracy where, provided a slow beam of particles can be produced by some means, Bose-Einstein condensation can be reached for species without a cycling transition.

Q 46.7 Thu 12:00 BAR 106

Novel magnetic trap design for ultra-cold metastable helium atoms with large optical access — •Franz Sievers, Juliette Simonet, Sanjukta Roy, Jérôme Beugnon, Michèle Leduc, and Claude Cohen-Tannoudji — Laboratoire Kastler Brossel, École Normale Supérieure, 24 rue Lhomond, 75231 Paris, France

We present the design of a modified Cloverleaf-type Ioffe-Pritchard trap for Bose-Einstein condensation of ultra-cold atoms, compatible with in situ loading of the condensed gas into a three-dimensional optical lattice. The coil geometry offers optical access for three independent triplets of orthogonal laser beams that cross in the centre of the trap. Two are used for the magneto-optical trap and the projected three-dimensional optical lattice, respectively. Technical considerations of the trap design, as well as the electric circuitry for fast switching are reviewed. This set-up is intended to operate for metastable helium, but is also of practical interest for experiments with other species.

Q 46.8 Thu 12:15 BAR 106

Gauge fields for ultra-cold Ytterbium atoms — •Sebastian Krinner[1,2], Fabrice Gerbier[1], Jerôme Beugnon[1], and Jean Dalibard[1] — [1]Laboratoire Kastler Brossel, 24 rue Lhomond, 75005 Paris, France — [2]Institute for Quantum Electronics, ETH Zürich, Hönggerberg, CH-8093 Zürich, Switzerland

Cold atoms in optical lattices can serve as model systems for condensed matter physics. In our project we plan to investigate the rich physics of fractional quantum Hall phases. I will first briefly explain the core of the planned experiment, i.e. the implementation of a strong U(1)-like gauge field on cold Ytterbium atoms confined in a two-dimensional square lattice.

The second part focuses on the laser cooling of Yb. It consists of Zeeman slowing of an atomic beam using the strong singlet transition at 399nm and subsequent magneto-optical trapping using the green intercombination line at 556nm. Both laser wavelengths are produced via the technique of second-harmonic generation. As a showcase I will treat the generation of the 556nm light relying on intra-cavity frequency doubling of a 2W fiber laser at 1112nm. The output power of 1.2W corresponds to 80% efficiency and suggests an alternative to dye lasers.

Q 46.9 Thu 12:30 BAR 106

Radiofrequency spectroscopy of a strongly interacting two-dimensional Fermi gas — •Bernd Fröhlich, Michael Feld, Enrico Vogt, Marco Koschorreck, and Michael Köhl — Cavendish Laboratory, University of Cambridge, JJ Thomson Avenue, Cambridge CB3 0HE

We have realized and studied a strongly interacting two-component atomic Fermi gas confined to two spatial dimensions using an optical lattice. Using radio-frequency spectroscopy we measure the interaction energy of the gas. We find that the strong confinement to two dimensions induces scattering resonances and leads to the existence of confinement-induced molecules which have no counterpart in three dimensions.

Q 46.10 Thu 12:45 BAR 106

Large coordination number expansion for a lattice Bose gas — •Patrick Navez[1], Ralf Schützhold[2], and Konstantin Krutitsky[2] — [1]Institut für Theoretische Physik, TU Dresden, D-01062 Dresden, Germany — [2]Fakultät für Physik, Universität Duisburg-Essen, Lotharstrasse 1, D-47057 Duisburg, Germany

We establish a set of hierarchy equations describing the time evolution of the N-points spatial correlation reduced density matrix in a lattice Bose gas. This set of equations is solved through a 1/z expansion where z is the coordination number i.e. number of interaction of a site with its nearest neighbors. The leading order of this expansion corresponds to the time-dependent Gutzwiller mean field approach that is used to describe the Bragg scattering in the superfluid regime. The next order contribution includes the correlations between sites. We illustrate how these correlations appear in the process of a ultra fast sweeping from a deep Mott regime to the superfluid regime.

Q 47: Quantum Information: Quantum Computer

Time: Thursday 10:30–12:45 Location: BAR Schön

Q 47.1 Thu 10:30 BAR Schön

Digital quantum simulation with trapped ions — Benjamin P. Lanyon[1,2], •Cornelius Hempel[1,2], Markus Müller[1,3], Florian Zähringer[1,2], Markus Rambach[2], René Gerritsma[1], Philipp Schindler[2], Daniel Nigg[2], Julio T. Barreiro[2], Markus Hennrich[2], Rainer Blatt[1,2], and Christian F. Roos[1] — [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 — [3]Institut für Theoretische Physik, Universität Innsbruck, Technikerstr. 25, 6020 Innsbruck, Austria

A universal quantum simulator is a highly controllable quantum system that can be programmed to efficiently simulate the dynamics of any other quantum system with local interactions. The long term goal is to use such a device to gain new insights into quantum systems, which are believed to be permanently beyond the calculating power of the conventional classical model of information processing. Quantum simulations performed to date have been 'analog', whereas in this work we demonstrate an alternative and potentially more powerful approach known as digital quantum simulation [1]. We use a system of trapped ions, on which a finite set of coherent operations is performed, to simulate a range of different systems of interacting spin-1/2 particles, including the Ising, XY and Heisenberg models. Using complex stroboscopic sequences of up to 80 coherent operations, we achieve accurate digital simulations of both time-independent and time-dependent dynamics. [1] Lloyd, S., Science 273, 1073 (1996).

Q 47.2 Thu 10:45 BAR Schön

Quantum memories based on engineered dissipation — •Fernando Pastawski, Lucas Clemente, and Ignacio Cirac — Max-Planck-Institut für Quantenoptik Hans-Kopfermann-Str. 1 D-85748 Garching, Germany

Storing quantum information for long times without disruptions is a major requirement for most quantum information technologies. A very appealing approach is to use *self-correcting* Hamiltonians, i.e. tailoring local interactions among the qubits such that when the system is weakly coupled to a cold bath the thermalization process takes a long time. Here we propose an alternative but more powerful approach in which the coupling to a bath is engineered, so that dissipation protects the encoded qubit against more general kinds of errors. We show that the method can be implemented locally in four dimensional lattice geometries by means of a toric code, and propose a simple 2D set-up for proof of principle experiments.

Q 47.3 Thu 11:00 BAR Schön

Deterministic entanglement of ions in separate traps — •Maximilian Harlander[1], Regina Lechner[1], Michael Brownnutt[1], Wolfgang Hänsel[1,2], and Rainer Blatt[1,2] — [1]Institut für Experimentalphysik, Universität Innsbruck — [2]Institut für Quantunoptik und Quanteninformationsbearbeitung, Innsbruck

Trapped-ion systems are a promising candidate to experimentally realize a powerful quantum information processor. A major challenge achieving this goal is scaling such systems to large numbers of ions. In 2000 Cirac and Zoller presented a route to interconnect neighbouring, independently trapped ions by using the small dipole moment of their oscillations as a quantum-mechanical link. Since the dipole-dipole interaction strength between ions at distance d scales with $1/d^3$, microfabrication techniques are neccessary to create separate potential wells at distances at the scale of tens of microns. The experimental demonstration of quantum information exchange is reported between ions in two potential wells separated by $54\,\mu$m. This enables possible schemes to provide entangling gates between two trapping zones, using a Mølmer-Sørensen type interaction.

Q 47.4 Thu 11:15 BAR Schön

Coherent Photon Conversion enabling Nonlinear Optical Quantum Computing — Nathan K. Langford[1,2], •Sven Ramelow[1,2], Robert Prevedel[1,2], William J. Munro[3], Gerard J. Milburn[4], and Anton Zeilinger[1,2] — [1]University of Vienna, Austria — [2]IQOQI Vienna, ÖAW, Austria — [3]NTT Laboratories, Japan — [4]University of Queensland, Australia

Photonic systems offer many advantages for quantum information technologies such as minimal decoherence and almost trivial single qubit operations. The key unresolved challenges for a working optical quantum computer are scaleable on-demand single photon sources; deterministic two-photon interactions; and near 100%-efficient detection. Here, we introduce a novel four-wave mixing process called coherent photon conversion (CPC). This process potential provides a very wide range of tools for optical quantum information processing and promises to enable scalable sources, efficient detection and deterministic entangling gates. The CPC process is a pumped $\chi(3)$ interaction inducing an effective $\chi(2)$ nonlinearity which is enhanced by the pump power. With a single-photon input and high enough effective nonlinearity deterministic photon doubling can be achieved - one key element in our scheme. We present first experiments with photonic crystal fibers that demonstrate the four-colour nonlinear process underlying CPC. We observe correlated photon-pair production at the predicted wavelengths, experimentally characterise the enhancement of the interaction strength by varying the pump power and discuss how to reach the near-deterministic regime with current technology.

Q 47.5 Thu 11:30 BAR Schön

Scalable Architecture for a Room Temperature Solid-State

Quantum Information Processor — Norman Y. Yao[1], Liang Jiang[2], Alexey V. Gorshkov[2], Peter Maurer[1], •Geza Giedke[3], J. Ignacio Cirac[3], and Mikhail D. Lukin[1] — [1]Physics Department, Harvard University, Cambridge, MA 02138, USA — [2]Institute for Quantum Information, California Institute of Technology, Pasadena, CA 91125, USA — [3]Max-Planck-Institut für Quantenoptik, D-85748 Garching, Germany

We propose and analyze an architecture for a scalable, solid-state quantum information processor capable of operating at or near room temperature. Our approach is based upon recent experimental advances involving Nitrogen-Vacancy color centers in diamond. The architecture involves a hierarchy of control at successive length scales and makes use of nuclear-spin quantum memory and dark-spin chains to couple different NV senters. The architecture is applicable to realistic conditions which include disorder and relevant decoherence mechanisms.

Q 47.6 Thu 11:45 BAR Schön

Controlling qubit arrays with XXZ Heisenberg interaction by acting on a single qubit — •Vladimir M. Stojanovic[1], Rahel Heule[1], Christoph Bruder[1], and Daniel Burgarth[2] — [1]Department of Physics, University of Basel, Switzerland — [2]Institute for Mathematical Sciences, Imperial College London, United Kingdom

With the aim of exploring local quantum control in arrays of interacting qubits, we study anisotropic XXZ Heisenberg spin-1/2 chains with control fields acting on one of the end spins. In this work, which hinges on a recent Lie-algebraic result pertaining to the local controllability of spin chains with "always-on" interactions, we determine piecewise-constant control pulses corresponding to optimal fidelities for quantum gates such as spin-flip, controlled-NOT, and square-root-of-SWAP. We find the minimal times for realizing different gates depending on the anisotropy parameter of the model, showing that the shortest gate times are reached for particular values of this parameter larger than unity. To study the influence of possible imperfections in anticipated implementations of qubit arrays, we analyse the robustness of the obtained gate fidelities to random variations in the control-field amplitudes and finite rise time of the pulses. Finally, we discuss the implications of our findings for superconducting charge-qubit arrays.

Q 47.7 Thu 12:00 BAR Schön

Continuous-variable quantum logic gate decompositions — •Seckin Sefi and Peter van Loock — Max Planck Institute for the Science of Light, Erlangen, Germany

We will present a general and efficient method for decomposing an arbitrary exponential operator of bosonic mode operators into a set of universal logic gates [1]. Our work is mainly oriented towards the field of continuous-variable quantum computation, but our results might have implications on any field that incorporates exponential operator decompositions such as quantum control, discrete-variable quantum computation or Hamiltonian simulation. We will also discuss possible optical experimental implementations.

[1]arXiv:quant-ph/1010.0326

Q 47.8 Thu 12:15 BAR Schön

Holonomic quantum computing using symmetry-protected topological order — •Joseph M. Renes[1], Akimasa Miyake[2], Gavin K. Brennen[3], and Stephen D. Bartlett[4] — [1]TU Darmstadt, Darmstadt, Germany — [2]Perimeter Institute, Waterloo, Canada — [3]Macquarie University, Sydney, Australia — [4]University of Sydney, Sydney, Australia

We propose an architecture for performing holonomic quantum computation via local adiabatic control of at most two-body nearest-neighbor interactions. Logical qubits are constructed from the degenerate gapped ground states of Haldane phase spin-1 chains, and logical gates are executed by manipulating the boundary spins. The computational scheme inherits significant robustness to disorder and noise from the symmetry-protected topological order of the Haldane phase. Similarity to the circuit model provides a means of ensuring fault-tolerance, and the architecture could feasibly be implemented with current state of the art technology. We illustrate this by describing an implementation based on ultracold polar molecules trapped in optical lattices.

Q 47.9 Thu 12:30 BAR Schön

Catalysis and activation of magic states in fault tolerant architectures — •Earl Campbell — Institute of Physics and Astronomy, University of Potsdam, 14476 Potsdam, Germany

Fault tolerance techniques enable quantum computers to operate despite noise. In many architectures, fault tolerant quantum computing is achieved by a combination of fault tolerant coherent dynamics, preparation of cold qubits in an appropriate quantum state, and measurements. Typically, the fault tolerance coherent dynamics can be simulated efficiently by a classical computer, as they are within the so-called Clifford group. To promote the device beyond a classical computer, cold qubits must be available in a "magic state", which is a suitable nonstabilizer state. These magic states constitute a resource for driving the fault tolerant quantum computation, and are consumed throughout the computation. Here we propose novel protocols that exploit multiple species of magic states in surprising ways, providing insights into a comprehensive resource theory of magic states. Our protocols provide examples of previously unobserved phenomena that are analogous to catalysis and activation well known in entanglement theory. Magic state catalysis demonstrates that catalytic resources can enable useful transformations without depleting the resource. The phenomena of magic state activation exploits bound magic states, which appear to be computationally inert when they are the only available resource. However, our protocols show that bound resources can be utilized when accompanied by an activating resource.

Q 48: Quantum Gases: Effects of Interactions

Time: Thursday 10:30–12:45 Location: SCH 251

Q 48.1 Thu 10:30 SCH 251

Charge exchange reactions between a single ^{138}Ba^{+} ion and an ultracold sample of neutral ^{87}Rb atoms — •Arne Härter, Artjom Krükow, Stefan Schmid, Wolfgang Schnitzler, and Johannes Hecker Denschlag — Universität Ulm, Institut für Quantenmaterie, Albert-Einstein-Allee 45, D-89069 Ulm, Deutschland

Using a novel hybrid apparatus which allows for the simultaneous trapping of laser-cooled ions and ultracold neutral atoms, we investigate the interaction of a single trapped ^{138}Ba^{+} ion with an optically confined atomic sample of ^{87}Rb atoms [1]. After initially trapping the Ba^{+} ion in a linear Paul trap, it is then injected into the Rb cloud, giving rise to elastic and inelastic collisions. In the latter case, we mainly observe charge exchange reactions of the type $\mathrm{Ba}^{+} + \mathrm{Rb} \rightarrow \mathrm{Ba} + \mathrm{Rb}^{+}$, which are studied as a function of various parameters such as the interaction time and the density of the atomic sample. Understanding the dynamics of such reactions could allow for the realization of a charged quantum gas, which offers intriguing perspectives for a variety of novel experiments, such as charge transport in the ultracold domain [2], the formation of novel atom-ion bound states [3], polaron-type physics [4] or the production of cold, charged molecules in a well-defined quantum state [5].

[1] S. Schmid *et al.*, Phys. Rev. Lett. **105**, 133202 (2010)
[2] R. Côté, Phys. Rev. Lett. **85**, 5316 (2000)
[3] R. Côté *et al.*, Phys. Rev. Lett. **89**, 093001 (2002)
[4] F. M. Cucchietti *et al.*, Phys. Rev. Lett. **96**, 210401 (2006)
[5] P. F. Staanum *et al.*, Nature Phys. **6**, 271 (2010)

Q 48.2 Thu 10:45 SCH 251

Dipolar Bose-Einstein Condensates with Weak Disorder — •Christian Krumnow[1] and Axel Pelster[2] — [1]Institut für Theoretische Physik, Freie Universität Berlin, Arnimallee 14, 14195 Berlin, Germany — [2]Fachbereich Physik, Universität Duisburg-Essen, Lotharstrasse 1, 47048 Duisburg, Germany

We consider a homogeneous dipolar Bose-Einstein condensate in the presence of weak quenched disorder within mean-field theory. By solving perturbatively at first the underlying Gross-Pitaevskii equation and performing then disorder ensemble averages, we derive the disorder-induced depletion of the condensate density. Furthermore, we obtain the result that the anisotropy of the two-particle interaction is passed on to both the superfluid density and the sound velocity at zero temperature. For a small dipolar interaction the superfluid depletion for a motion parallel or perpendicular to the dipoles is larger than the condensate depletion in accordance with the Huang-Meng theory of Bose-Einstein condensates with pure contact interaction [1]. For a sufficiently strong dipolar interaction, however, the superfluid depletion for a motion parallel to the dipoles becomes smaller than the condensate depletion. This astonishing finding supports that the tiny Bose-Einstein condensates, which are localized in the respective minima of the random potential, have a finite localization time [2].

[1] K. Huang and H. F. Meng, Phys. Rev. Lett. **69**, 644 (1992).
[2] R. Graham and A. Pelster, Int. J. Bif. Chaos **19**, 2745 (2009).

Q 48.3 Thu 11:00 SCH 251

Nonlocal quantum superposition states via scattering of a bright quantum matter wave soliton — •Bettina Gertjerenken and Christoph Weiss — Institute of Physics, Carl von Ossietzky University, 26111 Oldenburg, Germany

Scattering of a quantum matter wave soliton on a barrier in a one-dimensional geometry can lead to mesoscopic quantum superposition states [1]. On the two-particle level the mathematically justified effective potential approach [1] can be numerically compared with the exact quantum dynamics and an excellent agreement for an experimentally realistic approximately Gaussian potential has already been shown [2]. Further investigations of the effective potential approach will be presented.

[1] C. Weiss and Y. Castin, Phys. Rev. Lett. 102, 010403 (2009).
[2] C. Weiss, Laser Phys. 20, 665 (2010).

Q 48.4 Thu 11:15 SCH 251

Homogeneous Bose-Einstein Condensate with Weak Disorder — •Vladimir Luković[1], Antun Balaž[1], and Axel Pelster[2] — [1]Scientific Computing Laboratory, Institute of Physics Belgrade, University of Belgrade, Pregrevica 118, 11080 Belgrade, Serbia — [2]Fachbereich Physik, Universität Duisburg-Essen, Lotharstrasse 1, 47048 Duisburg, Germany

We determine the thermodynamic properties of a homogeneous superfluid dilute Bose gas in presence of weak quenched disorder. To this end we solve perturbatively the underlying Gross-Pitaevskii equation and perform then disorder ensemble averages for the respective physical quantities of interest. In the first order with respect to the disorder we reproduce the seminal results of Huang and Meng, which were originally derived within a Bogoliubov theory around a disorder averaged background field [1]. Afterwards, we determine both the condensate and the superfluid depletion as well as the equation of state and the sound velocity also in the subsequent second order and evaluate them for different disorder correlation functions.

[1] K. Huang and H. F. Meng, Phys. Rev. Lett. **69**, 644 (1992).

Q 48.5 Thu 11:30 SCH 251

Towards coherent control of collisions in metastable neon — •Jan Schütz, Alexander Martin, Thomas Feldker, Holger John, and Gerhard Birkl — Institut für Angewandte Physik, Technische Universität Darmstadt, Schlossgartenstraße 7, 64289 Darmstadt

We investigate the collisional interactions of laser cooled, metastable neon (Ne*). The most remarkable feature of Ne* is its high internal energy. Since the internal energy exceeds half of the ionization energy it enables ionizing collisions, namely Penning and associative ionization. The resulting ions as well as Ne* can be detected with high efficiency and accurate time resolution using electron multipliers. This enables us to gain a close insight into collisional interactions.

We are exploring a method to manipulate the ionization cross-sections by preparing the atoms in superposition states of $^3P_2$ Zeeman sublevels. Due to the interference of different collision channels this is proposed to modify the cross-sections of Penning and associative ionization for certain superpositions. We prepare the desired superposition states using radio frequency pulses in combination with the AC Stark shift of a laser. We report on the status of the experiment.

Q 48.6 Thu 11:45 SCH 251

Variational calculations for anisotropic solitons in dipolar Bose-Einstein condensates — •Rüdiger Eichler, Jörg Main, and Günter Wunner — 1. Institut für Theoretische Physik, Universität Stuttgart, Germany

We present variational calculations using a Gaussian trial function to calculate the ground state of the Gross-Pitaevskii equation and to describe the dynamics of the quasi-two-dimensional solitons in dipolar Bose-Einstein condensates. Furthermore we extend the ansatz to a linear superposition of Gaussians improving the results for the ground state to exact agreement with numerical grid calculations using imaginary time and split-operator method. We are able to give boundaries for the scattering length and estimate the temperature at which the solitons would be stable in a future experiment. By dynamical calculations with coupled Gaussians we are able to describe the rather complex behavior of the thermally excited solitons. The discovery of dynamically stabilized solitons indicates the existence of such BECs at experimentally accessible temperatures.

Q 48.7 Thu 12:00 SCH 251

Stability of Bose-Einstein condensates: Variational and numerical approach — •Manuel Kreibich, Jörg Main, and Günter Wunner — 1. Institut für Theoretische Physik, Universität Stuttgart

We analyze the stability of Bose-Einstein condensates by two methods: First by solving the Bogoliubov-de Gennes equations which yields the numerically exact stability eigenvalues. Second with the ansatz of coupled Gaussians within the framework of the time dependent variational principle. For the lowest eigenvalues we find good agreement. However, not all Bogoliubov eigenmodes can be described by the simple ansatz of coupled Gaussians. We modify the original ansatz in such a way that the complete Bogoliubov eigenspectrum can be obtained.

Q 48.8 Thu 12:15 SCH 251

Multi-shooting algorithm for the calculation of the bounce trajectory in Bose-Einstein condensates with attractive 1/r-interaction — •Kai Marquardt, Jörg Main, and Günter Wunner — 1. Institut für Theoretische Physik, Universität Stuttgart

Bose-Einstein condensates of cold dilute atomic gases with attractive 1/r-interaction are well described by the Gross-Pitaevskii equation (GP). We solve the GP by a time-dependent variational principle using an ansatz of superimposed Gaussians. The condensates can decay from the metastable ground state into a collapsing state due to macroscopic quantum tunneling. To determine the tunneling rates we calculate the bounce trajectory in imaginary time by a multi-shooting algorithm.

Q 48.9 Thu 12:30 SCH 251

Macroscopic quantum tunnelling and bounce solutions of Bose-Einstein condensates with dipolar interaction — •Torsten Schwidder, Jörg Main, and Günter Wunner — 1. Institut für Theoretische Physik, Universität Stuttgart

Macroscopic quantum tunnelling is discussed for Bose-Einstein condensates with dipolar interaction. The decay of a metastable groundstate into a collapsing wave function is investigated in a time-dependent variational approach to the nonlinear Gross-Pitaevskii equation. For a superposition of Gaussian wave functions the bounce trajectory is computed in imaginary time using a multi-shooting algorithm and tunnelling rates are calculated.

Q 49: Laseranwendungen: Laserspektroskopie

Time: Thursday 10:30–13:00 Location: SCH A215

Q 49.1 Thu 10:30 SCH A215

Interferometrically readout micro tuning forks applied in photoacoustic spectroscopy — •Michael Köhring[1], Martin Angelmahr[1], and Wolfgang Schade[1,2] — [1]Fraunhofer Heinrich Hertz Institute, Am Stollen 19, 38640 Goslar — [2]Clausthal University of Technology, Institut für Energieforschung und Physikalische Technologien, Am Stollen 19, 38640 Goslar

Photoacoustic spectroscopy is an important part of today's optical sensor techniques for insitu trace gas analysis. The usage of a micro tuning fork as detector for the optically induced acoustic waves enables a remarkable miniaturisation of the sensor system. Due to the high resonance frequency of the micro tuning fork and its small bandwidth, the influence of ambient noise can be neglected. Consequently, no reference measurement is required and an open cell design is considerable.

A new technique is presented, in which the tuning fork's deflection is readout interferometrically without the utilization of the piezoelectric effect applied in the so-called QEPAS technology (quartz-enhanced photoacoustic spectroscopy). A comparison between both techniques is drawn resulting in equivalent detection sensitivities limited by the tuning fork's thermal noise.

The interferometric readout leads to another step of miniaturisation and offers complete fiber-coupled photoacoustic trace gas sensors without the need of any energy source or electrical components at the sensor head. First measurements with this new generation of fiber-coupled trace gas sensors are presented.

Q 49.2 Thu 10:45 SCH A215

pH dependence of the absorption and emission behaviour of lumiflavin in aqueous solution — Amit Tyagi and •Alfons Penzkofer — Fakultät für Physik, Universität Regensburg, Universitätsstrasse 31, D-93053 Regensburg, Germany

The spectroscopic behaviour of lumiflavin (LF) in aqueous solutions of pH range -1.08 to 14.6 is studied. Absorption spectra, fluorescence quantum distributions, quantum yields and lifetimes are determined. The ionisation stage of ground-state LF changes from cationic (LFH_2^+) at low pH ($pK_c \approx 0.38$) via neutral (LFH) to anionic (LF^-) at high pH ($pK_a \approx 10.8$). The cationic, neutral, and anionic forms are identified by their different absorption spectra. LFH in neutral aqueous solution is reasonably fluorescent (fluorescence quantum yield $\phi_F = 0.29$, fluorescence lifetime $\tau_F = 5.2$ ns), while LF^- is weakly fluorescent ($\phi_F = 0.0042$, $\tau_F = 90$ ps), and LFH_2^+ is nearly non-fluorescent ($\phi_F \approx 3.6 \times 10^{-5}$, $\tau_F \approx 0.4$ ps).

In the ground state a pH dependent thermodynamic equilibration of cationic, neutral and anionic lumiflavin exists by reaction with H_2O, H_3O^+ and OH^-. For lumiflavin in aqueous solution in the excited state no equilibrium distributions are reached between the cationic, neutral, and anionic forms. Some neutral excited lumiflavin transforms to the cationic ground-state form at low pH by intermolecular photo-induced proton transfer from H_3O^+ to LFH*. At high pH no photo-induced intermolecular proton transfer takes place.

Q 49.3 Thu 11:00 SCH A215

Laser Raman Spektroskopie an Tritium für KATRIN — •Sebastian Fischer — für die KATRIN Kollaboration, Karlsruher Institut für Technologie, ITEP - Tritiumlabor, Karlsruhe, Deutschland

Das KArlsruher TRItium Neutrino-Experiment KATRIN untersucht das Energiespektrum des Tritium β-Zerfalls nahe dem Endpunkt von 18,6 keV. Dies ermöglicht eine modellunabhängige Bestimmung der Neutrinomasse. KATRIN verwendet dazu eine fensterlose molekulare gasförmige Tritiumquelle und ein elektrostatisches Spektrometer.

Zum Erreichen der Sensitivität von 0,2 eV/c^2 (90% CL) ist es erforderlich, die Tritiumkonzentration im eingespeisten Gas kontinuierlich über Zeiträume von typischerweise 60 Tagen mit einer Präzision von 0,1 % zu überwachen. Die Überwachung des Gaszusammensetzung erfolgt mit dem LAser-RAman-System LARA am Tritiumlabor Karlsruhe, das in Zusammenarbeit mit der Universität Swansesa (Wales) entwickelt wurde. Für Wasserstoff-Isotopologe (T_2, HT, DT, H_2, D_2, HD) wird innerhalb von 100 s Messzeit die erforderliche Präzision von 0,1 % und eine Nachweisgrenze (3σ) von 0,03 mbar erreicht [1].

In diesem Vortrag wird das Prinzip und der Aufbau des LARA-Systems vorgestellt, sowie aktuelle Ergebnisse präsentiert.

Gefördert vom BMBF unter Förderkennzeichen 05A08VK2 und von der DFG im Sonderforschungsbereich SFB/Transregio 27 "Neutrinos and Beyond".

[1] M. Schlösser et al., *Design Implications for Laser Raman Measurement Systems for Tritium Sample-Analysis, Accountancy or Process-Control Applications*, Tritium 2010 (Nara, Japan).

Q 49.4 Thu 11:15 SCH A215

Direction-selective optical limiting in bi-layer glass-metal nanocomposites — •Sabitha Mohan and Gerhard Seifert — Physics Institute, Martin-Luther-Universität Halle-Wittenberg, von-Danckelmann-Platz 3, 06120 Halle (Saale)

We have studied the optical nonlinearity of a glass-metal nanocomposite containing spherical silver nanoparticles in a thin surface layer of a few micrometers only. The remainder of the sample thickness of 1 mm consists of the pure soda-lime glass substrate. Femtosecond z-scan experiments have been performed using a Ti:Sa laser (wavelength λ=800nm, pulse duration τ=80fs, repetition rate 1kHz) as excitation source. This wavelength is suited for two-photon absorption by the Ag nanoparticle's surface Plasmon resonance (at 410nm), while the glass UV absorption requires at least three photons to be absorbed simultaneously. Irradiating the sample first from the substrate, then from the particle layer side, we found a highly directionally selective nonlinear transmission. When the laser beam enters the sample from the substrate side, the nonlinear absorption is enhanced by five orders of magnitude compared to irradiation from the particle side. It is shown by careful theoretical modelling that this optical diode-like behaviour can be explained by self-focusing effects in the glass substrate. In one direction, the pertinent intensity increase upon passing the substrate leads to strongly enhanced two-photon absorption in the particle layer; while in the other direction three-photon absorption in the glass remains negligible.

Q 49.5 Thu 11:30 SCH A215

Off-beam QEPAS with divergent light sources — •Stefan Böttger[1], Ulrike Willer[1], Martin Angelmahr[2], and Wolfgang Schade[1,2] — [1]Clausthal University of Technology, Energie-Forschungszentrum Niedersachsen, EnergieCampus, Am Stollen 19, 38640 Goslar — [2]Fraunhofer Heinrich Hertz Institute, EnergieCampus, Am Stollen 19, 38640 Goslar

Photoacoustics is an established method of spectroscopy. Eight years ago the application of quartz tuning forks as resonant sensor elements found its way into the photoacoustic spectroscopy known as QEPAS (quartz-enhanced photoacoustic spectroscopy). The high Q-factor of the tuning fork leads to high achievable sensitivities combined with small sensor dimensions. Since the introduction of QEPAS various configurations and applications have been found. However, the submillimeter diameter of the acoustic resonator demanded for laser sources with excellent beam quality so far. In a new approach, the so-called off-beam resonator design, the tuning fork is no longer positioned in the beam path. Since the light only needs to penetrate the acoustic resonator its geometry can be adapted according to the light source. This enables to utilize low beam quality light sources like high-power laser diodes or LEDs. In this investigation we present the detection of ozone with off-beam QEPAS using different divergent light sources.

Q 49.6 Thu 11:45 SCH A215

Temperaturstabilisierung einer Cavity-Leak-Out-Spektroskopie-Messzelle — •Lars Czerwinski, Kathrin Heinrich, Marcus Sowa und Peter Hering — Institut für Lasermedizin, Universitätsklinikum Düsseldorf, Universitätsstr. 1, 40225 Düsseldorf

Die Cavity-Leak-Out-Spektroskopie (CALOS) ist eine ausgezeichnete Methode für die isotopenselektive Analyse von Spurengasen. CALOS ist eine Weiterentwicklung der Absorptionspektroskpie, wobei mit Hilfe eines optischen Resonators die Wechselwirkungsstrecke zwischen Laserlicht und absorbierendem Medium verlängert wird, um die Nachweisgrenze zu verbessern. Bei der Vermessung von verschiedenen Spurengasen unterliegt die Messzelle den thermischen Bedingungen im Labor. Die Temperaturänderungen können dort bis zu ± 0,5 °C pro Stunde betragen. Dies hat eine Längenänderung der Invar-Messzelle von bis zu 1 μm zu Folge. Die Resonanzlinie der Messzelle ändert dabei um bis zu 40 MHz. Eine gezielte Isolierung der Messzelle erfolgte mittels eines Plexiglasgehäuses und Styropor, sowie dem Einsatz einer Wasserkühlung die im Bereich von − 20 °C bis + 40 °C arbeitet. Bei einem Vergleich der Allan-Varianz-Messungen des Systems wird eine Optimierung der Integrationszeit von 51 s - ohne - auf 109 s - mit Temperaturstabilisierung - erreicht. Die minimale rauschäquivalente Absorption konnte von $1{,}61 \cdot 10^{-10}$ cm^{-1} auf $1{,}03 \cdot 10^{-10}$ cm^{-1} verbessert werden.

Im Rahmen eines Vortrags sollen der Aufbau und erste Ergebnisse präsentiert werden.

Q 49.7 Thu 12:00 SCH A215

Stabilisierung von Hochleistungslasern für Präzisionsinterferometrie — •Patrick Kwee, Christina Bogan, Tobias Meier, Jan Põld, Benno Willke und Karsten Danzmann — Albert-Einstein-Institut Hannover

Erst durch den Einsatz von stabilisierten Lasern können viele Präzisionsexperimente ihre hohe Empfindlichkeit erreichen. Eine der höchsten Anforderungen an das Lasersystem werden heute von interferometrischen Gravitationswellendetektoren gesetzt. Diese verlangen robuste, zuverlässige Laser mit Ausgangsleistungen im Bereich von über 100 W bei exzellenter Strahlqualität und gleichzeitig extrem hoher Stabilität aller Laserstrahlparameter, die nur durch aufwändige aktive und passive Stabilisierungen erreicht werden kann.

Die Stabilisierung des 1064 nm Nd:YAG Hochleistungs-Lasersystems für den Gravitationswellendetektor *Advanced LIGO* wird vorgestellt. Dieses umfassend stabilisierte System liefert einen Laserstrahl mit mehr als 98.8% TEM_{00} Mode, relativen Leistungsfluktuationen von $10^{-8}\,Hz^{-1/2}$, relativen Strahllagefluktuationen von $10^{-6}\,Hz^{-1/2}$ und Frequenzfluktuationen im Bereich $1\,Hz\,Hz^{-1/2}$. Eine Charakterisierung dieses Lasersystems sowie weiterführende Laserstabilisierungs- und Hochleistungs-Frequenzverdopplungsexperimente der Lasergruppe des Albert-Einstein-Instituts Hannover werden präsentiert.

Q 49.8 Thu 12:15 SCH A215

LISA Pathfinder Optical Metrology System Modelling — •Natalia Korsakova, Martin Hewitson, Gerhard Heinzel, and Karsten Danzmann — Max-Planck Institut for Gravitational Physics (Albert-Einstein Insitut) Hannover and QUEST, Leibniz University Hannover, Callinstraße 36, 30167 Hannover

LISA Pathfinder is the technology demonstration space mission for LISA (Laser Interferometer Space Antenna). One of the main objectives of LISA Pathfinder is to demonstrate drag-free control of the space craft. LTPDA (LISA Technology Package Data Analysis) models the system and the control using state-space modelling. In this talk I will discuss the open-loop model for the optical metrology system and compare simulations to data from the real system. This model considers separately the optical part of the interferometer, the phasemeter and the following data processing of the measurements, which allows us to account for the different noise sources which arise in each of the subsystems of the optical metrology system.

Q 49.9 Thu 12:30 SCH A215

Methoden zur Prozessierung von Ramanspektren — •Magnus Schlösser[1], Timothy James[2], Richard Lewis[2] und Helmut Telle[2] — [1]für die KATRIN Kollaboration, Karlsruher Institut für Technologie, ITEP - Tritiumlabor, Karlsruhe, Deutschland — [2]University of Swansea, Wales, UK

Ramanspektroskopie eignet sich als Methode zur Inline-Bestimmung der Tritiumreinheit in Gasen aus Wasserstoffisotopologen ($T_2, DT, D_2, HT, HD, H_2$) in Anwendungen am Brennstoffkreislauf eines Fusionsreaktors (wie ITER) oder in Tritium-Neutrinomassenexperimenten (wie KATRIN). Auf Grund des starken Isotopieeffektes der Wasserstoffisotopologen sind die reinen Vibrationsanregungen deutlich von einander getrennt und eignen sich somit zur quantitativen Analyse von Gasmischungen.

Nach der Aufnahme von Rohdaten von der CCD sind weitere Prozessschritte nötig bevor die Zusammensetzung aus den Ramanlinien bestimmt werden kann. In diesem Vortrag wird der Einfluß der Methode der Datenauslese auf das CCD-Rauschen vorgestellt. Dies hat wiederum direkten Einfluß auf die Möglichkeit Abbildungsfehler des Spektrometers (Astigmatismus) zu beheben. Weiterhin werden zwei verschiedene Methoden vorgestellt, um durch kosmische Strahlung induzierte Lesefehler zu korrigieren. Außerdem werden Methoden vorgestellt, um die eigentlichen Spektrallinien von parasitären Untergrund zu trennen.

Gefördert vom BMBF unter Förderkennzeichen 05A08VK2 und von der DFG im SFB/Transregio 27 "Neutrinos and Beyond".

Q 49.10 Thu 12:45 SCH A215

Aufbau einer Anlage zur Herstellung von optischen Faserkomponenten mittels eines CO2-Laser — •Felix Wichmann[1,2], Thomas Theeg[1,2], Hendrik Gebauer[1], Katharina Hausmann[1,2], Hakan Sayinc[1,2], Lars Richter[1], Jörg Neumann[1,2] und Dietmar Kracht[1,2] — [1]Laser Zentrum Hannover e.V., Hollerithallee 8, 30419 Hannover — [2]Centre for Quantum Engineering and Space-Time Research (QUEST), Welfengarten 1, 30167 Hannover

In faserbasierten Lasersystemen werden hohe optische Leistungen innerhalb kleinster Faserkerndurchmesser geführt. Die dabei auftretenden Intensitäten können zur Zerstörung der Endfläche oder der gesamten Faser führen. Mit Hilfe angespleißter Endkappen (meist Quarzglaszylinder) kann das Licht aus dem Faserkern austreten und innerhalb der Endkappe divergieren. Dadurch sinkt die Intensität am Übergang Glas-Luft und einer Zerstörung der Faserendfläche wird vorgebeugt. In unserem Beitrag präsentieren wir einen Aufbau zum Spleißen von Fasern an Quarzglaszylinder mit einem CO2-Laser. Durch eine computergestützte Steuerung konnte die mit einem Pyrometer gemessene Oberflächentemperatur der Endkappen durch Variation der Laserleistung geregelt werden. Auf diese Weise können beliebige Temperaturverläufe realisiert werden, die auf Grund der Regelung unabhängig von Schwankungen der Laserleistung sind. Im Gegensatz zu kommerziell erhältlichen Spleißsystemen erlaubt der entwickelte Spleißprozess die Verwendung unterschiedlichster Faser- und Endkappen-Kombinationen.

Q 50: Quantum Effects: Entanglement and Decoherence

Time: Thursday 10:30–13:00 Location: SCH A01

Q 50.1 Thu 10:30 SCH A01

Treatment of genuine quantum effects in the initial energy excitation propagation in light harvesting complexes — •Markus Tiersch[1,2], Hans J. Briegel[1,2], and Sandu Popescu[3,4] — [1]Institut für Theoretische Physik, Universität Innsbruck, Austria — [2]Institut für Quantenoptik und Quanteninformation, Österreichische Akademie der Wissenhschaften, Innsbruck, Austria — [3]H. H. Wills Physics Laboratory, University of Bristol, U.K. — [4]Hewlett-Packard Laboratories, Bristol, U.K.

The studies of the initial energy excitation propagation in light-harvesting proteins, in particular in the Fenna-Matthews-Olson protein complex, have recently been enriched with the discussion of quantum-coherent excitation transfer and genuine quantum effects such as entanglement. The presence of quantum-coherent energy transfer and quantum entanglement during excitation transfer have been linked to an improved energy transport efficiency in light harvesting complexes.

In this presentation, we investigate the theoretical modeling that underlies the excitation transfer dynamics in light harvesting complexes, and we elucidate its impact on genuine quantum effects such as entanglement.

Q 50.2 Thu 10:45 SCH A01

Long-distance entanglement between two harmonic oscillators via a quantum reservoir — •Endre Kajari[1,2], Alexander Wolf[2], Gabriele De Chiara[3,5], Eric Lutz[4], and Giovanna Morigi[1,5] — [1]Theoretische Physik, Universität des Saarlandes, D-66041 Saarberücken, Germany — [2]Institut für Quantenphysik, Universität Ulm, D-89069 Ulm, Germany — [3]Grup de Física Teorica, Departament de Física, Universitat Autònoma de Barcelona, E-08193 Bellaterra, Spain — [4]Department of Physics, University of Augsburg, D-86135 Augsburg, Germany — [5]Grup d'Òptica, Departament de Física, Universitat Autònoma de Barcelona, E-08193 Bellaterra, Spain

We discuss the creation of entanglement between two harmonic oscillators that interact via a common reservoir consisting of a chain of harmonic oscillators with nearest-neighbor coupling. The oscillators are initially prepared in squeezed states with squeezing parameter r, whereas the chain starts from a thermal state at temperature T. The entanglement between the oscillators is studied as a function of r and T using the logarithmic negativity. We first identify a parameter regime in which the chain acts as an Ohmic environment and recover a long time behavior of the entanglement that is qualitatively in agreement with the predictions of [1]. When the oscillators couple to two separate sites of the chain, decoherence free subspaces support quasi-stationary quantum correlations between the oscillators for certain frequency ranges. The requirements for long-distance entanglement are identified and possible experimental realizations are envisaged.

[1] J. P. Paz, A. J. Roncaglia, Phys. Rev. Lett. **100**, 220401 (2008).

Q 50.3 Thu 11:00 SCH A01

Effects of retardation on sudden death and revival of entanglement — •Qurrat Ul-ain[1], Zbigniew Ficek[2], and Jörg Evers[1] — [1]Max-Planck-Institut für Kernphysik, Heidelberg, Germany — [2]The National Centre for Mathematics and Physics, King Abdulaziz City for Science and Technology, Riyadh, Saudi Arabia

In the standard setup of atoms coupled to a cavity, a finite time is required by light to travel between the atoms and the cavity boundaries. In suitable parameter regimes, these retardation effects can affect the time evolution of the combined system of atoms and cavity field to a large degree [1].

Here, we study the effects of retardation on the entanglement dynamics of a system of two two-level atoms placed inside a one-dimensional ring cavity. For this, we calculate the time evolution of the concurrence [2], which quantifies the entanglement between the two atoms. We indentify suitable parameter ranges for the study of retardation effects, analyze sudden death and revival of entanglement [3] in the presence of retardation, and interpret the obtained results in terms of the traveling time of light between the atoms and the cavity mirrors.

[1] E. V. Goldstein and P. Meystre, Phys. Rev. A **56**, 5135 (1997).
[2] W. K. Wootters, Phys. Rev. Lett. **80**, 2245 (1998).
[3] T. Yu and J. H. Eberly, Phys. Rev. Lett. **93**, 140404 (2004).

Q 50.4 Thu 11:15 SCH A01

Unconditional Preparation of Bound Entanglement — •Aiko Samblowski[1], James DiGuglielmo[1], Boris Hage[1], Carlos Pineda[2,3], Jens Eisert[3,4], and Roman Schnabel[1] — [1]Institut für Gravitationsphysik, Leibniz Universität Hannover und Max-Planck Institut für Gravitationsphysik (Albert-Einstein-Institut), 30167 Hannover, Germany — [2]Instituto de Física, Universidad Nacional Autónoma de México, México — [3]Institute of Physics and Astronomy, University of Potsdam, 14476 Potsdam, Germany — [4]Institute for Advanced Study Berlin, 14193 Berlin, Germany

Among the possibly most fascinating aspects of quantum entanglement is that it comes in "free" and "bound" instances. In contrast to free entanglement it is not possible to distill bound entangled states.Their existence hence certifies an intrinsic irreversibility of entanglement in nature and suggests a connection with thermodynamics.

A first experimental unconditional preparation and detection of a bound entangled state of light [1] will be presented in this talk. The focus will be set on the realization and results of our experiment that continuously produced a continuous-variable (CV) bound entangled state with an extraordinary significance of more than ten standard deviations away from both separability and distillability. This platform allows the efficient preparation of multi-mode entangled states of light with various applications in quantum information, quantum state engineering and metrology.

[1] J. DiGuglielmo, A. Samblowski, B. Hage, C. Pineda, J. Eisert and R. Schnabel, arXiv:1006.4651 (2010)

Q 50.5 Thu 11:30 SCH A01

Task-dependent control of open quantum systems — •Jens Clausen — Institut für Quantenoptik und Quanteninformation, Innsbruck, Austria

We consider the evolution of an open quantum system to second order in its coupling to a bath and describe the effect of a controlled time-dependence of the system Hamiltonian on a chosen function of the system state at a fixed time. This function defines a task quantity to be optimized such as fidelity, purity, or entanglement. If the time-dependence of the system Hamiltonian is fast enough to be comparable or shorter than the response-time of the bath, then the resulting non-Markovian dynamics allows to optimize the chosen task quantity. This implies on the one hand protecting a desired unitary system evolution from bath-induced decoherence but on the other hand also allows to use the system-bath coupling to realize a desired non-unitary effect on the system. Joint work with G. Bensky and G. Kurizki.

Q 50.6 Thu 11:45 SCH A01

Entanglement Control with Measures Optimized on the Fly — •Mark Girard and Florian Mintert — Freiburg Institute of Advanced Studies, Albert-Ludwigs-Universität Freiburg, Albertstraße 19, 79104 Freiburg

We develop optimal time-dependent control fields that drive many-body quantum systems into states that maximize genuine multipartite entanglement. We build on techniques [1] to derive such control fields that have recently been derived to optimize entanglement as characterized by an approximate entanglement measure. This quantity, however, cannot accurately recognize genuine multipartite entanglement. To overcome this, we employ a recently derived criterion [2] to identify genuine many-body entanglement. Similar to typical entanglement measures, its evaluation requires an optimization. Thus we have two optimizations to solve, one for the control fields and one for the separability criterion. We investigate how both of these can be addressed simultaneously with the same techniques.

[1]Felix Platzer, Florian Mintert and Andreas Buchleitner, Phys. Rev. Lett., **105**, 020501 (2010)

[2]Marcus Huber, Florian Mintert, and Andreas Gabriel, Beatrix Hiesmayr, Phys. Rev. Lett., **104**, 210501 (2010)

Q 50.7 Thu 12:00 SCH A01

Environment-assisted entanglement in a Penning trap — •Michael Genkin and Alexander Eisfeld — MPIPKS, Dresden, Germany

Penning traps are known as an excellent tool for high precision measurements on charged particles since decades. More recently, however, also their potential in quantum information related applications was pointed out. Motivated by the recent proposals to store quantum information in the spatial degrees of freedom, we study theoretically the possibility of environment-assisted entanglement of the axial and cyclotron motion of a single charged particle in an ideal Penning trap, as the separability of the modes which is normally assumed for an ideal trap cannot be taken for granted in the presence of an environment. The dynamics is treated in the framework of a master equation with linear coupling to the environment, while the emergence of entanglement is monitored by means of the positive partial transpose criterion. Our results strongly suggest that weak environmental coupling of the axial and cyclotron degrees of freedom does not lead to entanglement at experimentally realistic temperatures, since detrimental thermalization appears to be dominant in this regime. The conclusion is supported by observation of entanglement at unrealisticly low temperatures; In this context, we also briefly address the interplay with decoherence which is known to grow with increasing temperature.

Q 50.8 Thu 12:15 SCH A01

Collisional decoherence in the non-Markovian regime — •Federico Levi[1,2] and Bassano Vacchini[1] — [1]Università degli Studi di Milano, Dipartimento di Fisica, Via Celoria 16, 20133 Milano, Italy. — [2]Freiburg Institute for Advanced Studies (FRIAS), Albert-Ludwigs-Universität Freiburg, Albertstr. 19, 79104 Freiburg

The issue of collisional decoherence is addressed theoretically in the framework of the theory of open quantum systems. With reference to the well-known experiments involving mesoscopic particles flying through a two slit interferometer in controlled pressure conditions [1], a test particle drifting through a gas can be described by means of the quantum linear Boltzmann equation [2]. If dissipative effects are neglected in order to focus on the suppression of the contrast of interference fringes generated by the action of decoherence, and if the Markovian approximation is performed, the dynamics can be described as a sequence of scattering events given by random momentum kicks. We show how these dynamics are immediately characterized by means of classical stochastic counting processes, and how a distribution of the scatterings in time following a so-called renewal processes generate strong non-Markovian dynamics. The non-Markovian dynamics thus obtained are analyzed in the strong and weak decoherence regimes and are compared with the Markovian case.

[1] K.Hornberger *et al.*, Phys. Rev. Lett. **90**, 160401 (2003).
[2] B. Vacchini and K. Hornberger, Phys. Rep. **478**, 71-120 (2009).

Q 50.9 Thu 12:30 SCH A01

Noise assisted long time entanglement for non-Markovian interactions — •Ines de Vega and Susana Huelga — Insitute of Theoretical Physics, University of Ulm

Noise is an ubiquitous phenomena in physical systems, and it is normally associated with a loss of quantum coherence, and hence entanglement, in the system. This picture was modified some years ago, when it was discovered that under particular conditions, a certain quantity of Markovian noise in the system can actually build entanglement in the long time limit. In this presentation, we extend this analysis to non-Markovian environments, and observe how the building of entanglement is strongly modified by the bath memory effects. Our analysis is based on the so-called stochastic Schrödinger equations, which allow the generation of a complete positive density matrix of the system, as it is required in order to measure properties such as entanglement.

Q 50.10 Thu 12:45 SCH A01

Spontaneous decay into a BEC near a surface — •Carsten Henkel and Jürgen Schiefele — Universität Potsdam

The spontaneous emission rate of an excited two-level atom placed in a Bose-Einstein condensate of ground-state atoms is enhanced by bosonic stimulation. The magnitude of the effect depends on the overlap between the atomic wave functions and the wavevector of the photon involved in the decay. We present calculations based on a quantum field theory of the atom-photon interaction that illustrate the importance of two- and four-point correlation functions of the ground-state field for the Bose enhancement [1].

For an excited atom prepared in a wavepacket, the transition rate to the ground state can be increased under optimum conditions by a factor $N/10$ where N is the atom number in the BEC. The effect can be used to amplify the small distance-dependent oscillations of the decay rate of an excited atom near an interface.

[1] PLA, 2010 (in press), doi:10.1016/j.physleta.2010.11.058.

Q 51: Ultracold Atoms: Trapping and Cooling 1

Time: Thursday 14:30–16:00 Location: SCH A118

Q 51.1 Thu 14:30 SCH A118

Experiments on atoms trapped in a two-color-dipole trap — •Rudolf Mitsch[1], Daniel Reitz[1], Melanie Müller[1], Samuel T. Dawkins[2], and Arno Rauschenbeutel[1] — [1]Technische Universität Wien - Atominstitut, Stadionallee 2, A-1020 Wien — [2]Johannes Gutenberg-Universität Mainz, AG QUANTUM, D-55099 Mainz

Our recent results on trapping laser-cooled cesium atoms around a subwavelength-diameter optical nanofiber will be presented. The atoms are localized in a dipole trap formed by a two-color evanescent field surrounding the optical nanofiber. The atoms are detected by sending a weak resonant probe beam through the nanofiber that couples to the atoms via the evanescent field. We can observe the light-matter-coupling by either measuring the absorption or the phase shift experienced by the probe light. Furthermore, we demonstrate that the off resonant measurements are non-destructive with respect to the number of trapped atoms. Finally, we present first results on Autler-Townes state splitting and electromagnetically induced transparency. These results open the route towards the manipulation and storage of light with coherently prepared fiber-coupled atomic ensembles. Potential applications include fiber-coupled quantum memories and quatum repeaters as well as many-body physics with light-matter quasi-particles.

Financial support by the Volkswagen Foundation, the ESF and the FWF Doctoral Programme CoQuS is gratefully acknowledged.

Q 51.2 Thu 14:45 SCH A118

AC-Stark shift and photoionization of Rydberg atoms in an optical dipole trap — •Tobias Weber[1], Frank Markert[1], Peter Würtz[1], Andreas Koglbauer[2], Tatjana Gericke[1], Andreas Vogler[1], and Herwig Ott[1] — [1]Fachbereich Physik, Universität Kaiserslautern — [2]Institut für Physik, Universität Mainz

We present the measurement of the AC-Stark shift of the $14D_{5/2}$ Rydberg state of rubidium 87 in an optical dipole trap formed by a focussed CO_2-laser. We find good quantitative agreement with the model of a free electron experiencing a ponderomotive potential in the light field. In order to reproduce the observed spectra we take into account the broadening of the Rydberg state due to photoionization and extract the corresponding cross-section.

Q 51.3 Thu 15:00 SCH A118

EIT cooling of an atom in optical resonators — •Marc Bienert and Giovanna Morigi — Theoretische Quantenphysik, Universität des Saarlandes, 66041 Saarbrücken, Germany

We consider a single, harmonically trapped atom in an optical resonator. The internal level configuration of the atom is Λ-shaped. One of the dipole transitions is coupled to a strong laser field, whereas the other transition interacts with the quantised light field of the optical resonator. The resonator is additionally pumped by a weak probe laser. Similar configurations have been used recently to demonstrate electromagnetically induced transparency of a single atom [1]. We investigate the mechanical effects of the radiation acting on the atomic motional degree of freedom. The analysis is performed in the Lamb-Dicke limit. We investigate several cooling mechanisms occurring in this configuration, among them an analog to EIT cooling in free space and cavity sideband cooling. Further cooling schemes which rely on quantum interference can be identified. Finally, we compare our findings with experimental results which show alternating cooling and heating areas around two-photon resonance [2].

[1] M. Mücke et al., Nature **465**, 755 (2010)
[2] T. Kampschulte et al., Phys. Rev. Lett. **105**, 153603 (2010)

Q 51.4 Thu 15:15 SCH A118

Trapping ions with lasers — •Cecilia Cormick and Giovanna Morigi — Theoretische Physik, Universität des Saarlandes, D-66041 Saarbrücken, Germany

This work theoretically addresses the physics underlying the trapping of an ionized atom with a single valence electron by means of lasers. In our model, the coupling between the ion and the electromagnetic field includes the charge monopole and the internal dipole, within a multipolar expansion of the interaction Hamiltonian. Specifically, we perform a Power-Zienau-Woolley transformation, taking into account the motion of the center of mass. The net charge produces a correction in the atomic dipole which is of order m_e/M with m_e the electron mass and M the total mass of the ion. With respect to neutral atoms, there is also an extra coupling to the laser field which can be approximated by that of the monopole located at the position of the center of mass. These additional effects, however, are shown to be very small compared to the dominant dipolar trapping term, and we can conclude that the effect of the net charge on dipolar trapping is negligible.

Q 51.5 Thu 15:30 SCH A118

Quantum jumps triggered by atomic motion — Mauricio Torres[1], •Marc Bienert[1,2], Stefano Zippilli[3,4], and Giovanna Morigi[2,3] — [1]Instituto de Ciencias Físicas, Universidad Nacional Autónoma de México, Cuernavaca, Morelos, Mexico — [2]Theoretische Quantenphysik, Universität des Saarlandes, 66041 Saarbrücken, Germany — [3]Departament de Física, Universitat Autònoma de Barcelona, E 08193 Bellaterra, Spain — [4]Fachbereich Physik and research center OPTIMAS, Technische Universität Kaiserslautern, 67663 Kaiserslautern, Germany

We theoretically study the occurrence of quantum jumps in the resonance fluorescence of a trapped atom. In our approach the atom is laser cooled in a configuration of levels such that the occurrence of a quantum jump is associated to a change of the vibrational center-of-mass motion by one phonon. The statistics of the occurrence of the dark fluorescence period is studied as a function of the physical parameters and the corresponding features in the spectrum of resonance fluorescence are identified. We discuss the information which can be extracted on the atomic motion from the observation of a quantum jump in the considered setup.

Q 51.6 Thu 15:45 SCH A118

Neuartige Transportoperationen in planaren und dreidimensionalen Paulfallen mittels variabler Radiofrequenzamplituden — •Andreas Kehlberger[1], Stefan Ulm[1], Georg Jacob[1], Todd Karin[2], Isabela Le Bras[2], Nikos Daniilidis[2], Hartmut Häffner[2], Ferdinand Schmidt-Kaler[1] und Kilian Singer[1] — [1]Institut für Physik, Johannes Gutenberg Universität Mainz, Staudinger Weg 7, 55128 Mainz, Germany — [2]Department of Physics, University of California, 366 LeConte Hall #7300, Berkeley, CA 94720-7300, USA

Bisherige Paulfallen sind in der Lage mittels variabler DC Potentiale Ionen und Ionenketten entlang einer Fallenachse zu positionieren und Ionenkristalle zu trennen. Mittels variabler Radiofrequenzamplituden können wir diese Operationen nun auf alle drei Dimensionen ausdehnen. Wir präsentieren optimierte planare[1] und drei dimensionale Fallengeometrien um Ionen auf eine genau definierte Position zu platzieren. Desweiteren erläutern wir numerische Methoden um entsprechende Kalkulationen durchzuführen. Die Methoden berücksichtigen experimentelle Vorgaben und sind in der Lage anhand der Felder die benötigten Radiofrequenz Spannungen und Ionentrajektorien für gewünschte Transportoperationen zu optimieren.

Refrences

1. T. Karin, I. Le Bras , A. Kehlberger , K. Singer , N. Daniilidis, H. Häffner, arXiv:1011.6116 (2010)

Q 52: Precision Measurement and Metrology 3

Time: Thursday 14:30–16:00 Location: HÜL 386

Q 52.1 Thu 14:30 HÜL 386

Fluorescent Nanodiamonds for Fluorescence Resonance Energy Transfer Imaging and Magnetometry — •Julia Tisler[1], Gopalakrishnan Balasubramanian[1], Jean-Paul Boudou[2], Patrick Curmi[2], Rolf Reuter[1], Boris Naydenov[1], Anke Lämmle[1], Fedor Jelezko[1], and Jörg Wrachtrup[1] — [1]3.Physikalisches Institut, Universität, Germany — [2]Université d'Evry, France

Matchless photostability, magnetic resonance at room temperature combined with chemical inertness and excellent biocompatibility, put nanodiamonds with color centers in the focus of interest for new high resolution microscopy methods. An example for such color center is the NV-center. Through progress in irradiation and milling we achieved fluorescent nanodiamonds with sizes below 4 nm [1]. Recent research showed that even very small nanodiamonds with NV-center retain their optical and spin properties [2]. Based on these new findings novel high resolution imaging could be performed by field gradient magnetometry and FRET. With the new particles it is now within reach for magnetometry to get below the already achieved magnetic field limit of 5 mT [3]. Also first successful experiments of FRET between fluorescent nanodiamonds (FRET donator) and quencher molecules of fluorescent dyes (FRET acceptor) have been done.

[1] Boudou J.P. (2009) Nanotechnology [2] Tisler J. (2009) ACS Nano [3] Balasubramanian G. (2008) Nature

Q 52.2 Thu 14:45 HÜL 386

Readout of satellite-satellite interferometer with 200km arms and nm precision — •Oliver Gerberding, Benjamin Sheard, Ioury Bykov, Joachim Kullmann, Gerhard Heinzel, and Karsten Danzmann — Max-Planck Institut for Gravitational Physics (Albert-Einstein Insitut) Hannover and QUEST, Leibniz University Hannover

In current geodesy mission like GRACE, Earth's gravity field is determined by measuring the precise variations in distance between two satellites in low Earth orbit. To improve this distance measurement, laser interferometry is the most promising candidate. A heterodyne interferometer between the satellites allows to measure their relative pointing and their distance variations with nm precision. The core of such an interferometer is the electronic phase readout system, called phasemeter. It tracks the phase with the required precision, while the heterodyne frequency is changing due to Doppler shifts introduced by relative satellite movements. The design of such a phasemeter is a very challenging task, since it needs to be able to handle technical noise, laser frequency noise and shot noise from receiving only a small amount of light.

Here we present our prototype design for such a phasemeter, able to measure heterodyne frequencies between 1 and 40MHz, and we show results from performance simulations and experiments.

Q 52.3 Thu 15:00 HÜL 386

Enhancing the angular tolerance of resonant waveguide gratings — •Stefanie Kroker, Frank Brückner, Ernst-Bernhard Kley, and Andreas Tünnermann — Friedrich-Schiller-Universität, Institut für Angewandte Physik, Max-Wien-Platz 1, 07743 Jena

We present a novel concept to increase the angular tolerance of resonant waveguide gratings by stacking two resonant structures on top of each other. It is demonstrated that reflectivites close to unitiy can be reached over the entire angular spectrum by this double T-shaped grating configuration. The principles of our new approach can be used for gratings made of two different materials but also to realize monolithic silicon structures with similar properties. We illustrate that the functionality of the device can be understood by a decomposition into separated elements. Our concept might have applications as new diffractive-reflective optical components with low coating thermal noise in the field of high precision metrology.

Q 52.4 Thu 15:15 HÜL 386

Michelson-interferometer with 3-port-grating-coupled arm-resonators — •Maximilian Wimmer, Michael Britzger, Daniel Friedrich, Björn Hemb, Karsten Danzmann, and Roman Schnabel — Albert-Einstein-Institut Hannover, Max- Planck-Institut für Gravitationsphysik und Centre for Quantum Engineering and Space-Time Research (QUEST), Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover, Germany

In high precision interferometers such as gravitational wave detectors the maximization of circulating light power is one way to increase the signal to noise ratio. Stronger light fields will also increase thermooptic effects in the transmissive beamsplitters and cavity-couplers that are used in these interferometers. The direct approach to avoid these effects is the change to all-reflective optics. We present the realization of an Interferometer with diffractively coupled arm-resonators using so-called 3-port diffraction gratings and the first results of the signal response measurements.

Q 52.5 Thu 15:30 HÜL 386

The AEI 10m Prototype Interferometer — •Tobias Westphal for the 10m prototype team — A. Einstein Inst., QUEST, Leibnitz Univ. Hannover

A 10m Prototype Interferometer is currently being set up at the AEI in Hannover, Germany. Among the main objectives are the demonstration of novel techniques for future generations of GW detectors, as well as building an instrument operating at and beyond the standard quantum limit of interferometry for 100g test masses.

For the pre-isolation of the experimental setup three seismically isolated optical tables inside a large (ca. $100m^3$) ultra-high vacuum envelope are set up. The differential motion of these tables will be stabilised via a set of Mach-Zehnder interferometers. All relevant optical components will be mounted on top of these isolated tables by means of multiple-cascaded pendulum suspensions. A suspended triangular ring cavity with a finesse of ca. 7300 will, in conjunction with a molecular iodine reference, serve as a frequency reference for the stabilisation of the 35W Nd:YAG laser. The main instrument is a 10m Michelson interferometer with Fabry-Perot cavities in the arms. The end mirrors will be made of Khalili-style Fabry-Perot cavities to minimise the effective coating thermal noise. The design of the interferometer is done such that the sum of all classical noises lies well below the sum of quantum noise in a frequency band around 100Hz. The layout, status, and progress of the AEI 10m prototype will be given in this talk.

Q 52.6 Thu 15:45 HÜL 386

LISA Pathfinder: Flight Model testing of the Optical Metrology System — •Heather Audley, Antonio Garcia Marin, Jens Reiche, Miquel Nofrarias, Anneke Monsky, Ingo Diepholz, Martin Hewitson, Frank Steier, Gerhard Heinzel, and Karsten Danzmann — AEI/Leibniz Universitaet Hannover, Deutschland

The Laser Interferometer Space Antenna (LISA) is a joint ESA-NASA mission for the first space-borne gravitational wave detector. LISA aims to detect sources in the 0.1 mHz to 1 Hz range. Core technologies required for the LISA mission that cannot be tested on-ground will be tested with a precursor satellite, LISA Pathfinder. The past year has seen great progress towards the expected 2013 launch of LISA Pathfinder. This contribution presents an overview of the results of the successful Flight Model test campaigns. These results and associated test procedures will be utilised directly in planning the in-flight operations and the mission Experimental Master Plan. Additionally, they allow valuable testing of data analysis methods using the custom developed MATLAB based LTP data analysis (LTPDA) toolbox.

Q 53: Quantum Information: Photons and Nonclassical Light 1

Time: Thursday 14:30–16:00 Location: SCH 251

Q 53.1 Thu 14:30 SCH 251

Experimental Qudit Entanglement — •Daniel L. Richart[1,2], Yvo Fischer[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

Entangled qudits, i.e. entangled higher dimensional states, have been proven to offer potential applications in the field of quantum computation and communication, e.g. for the implementation of more efficient quantum gates and more secure Quantum Key Distribution schemes. We make use of a scalable scheme using unbalanced interferometers to encode energy-time entangled [1] qudits first on a 2x4 dimensional Hilbert space. We experimentally demonstrate entanglement between both ququats by performing a Bell test [2], and further characterize them by dimension and state witnesses. Potential applications in the field of quantum metrology are discussed.

[1] J.D. Franson et al., PRL 62, 2205 (1989) [2] Vertesi et al., PRL 104, 060401 (2010)

Q 53.2 Thu 14:45 SCH 251

Testing spectral modes in parametric downconversion — •Malte Avenhaus[1], Andreas Christ[2], Katiúscia N. Cassemiro[1], and Chrstine Silberhorn[1,2] — [1]Max-Planck Institute for the Science of Light, Erlangen, Germany — [2]University of Paderborn, Applied Physics, Paderborn, Germany

Parametric downconversion has found wide application in quantum optics. Great effort has recently been attributed to generate states with either a very large number of modes, or to design PDC sources that work in the single mode regime. While the first approach offers a large extent of spectral entanglement, the latter can be used to implement pure heralded single photon sources.

For characterizing these sources recent focus was based on gaining an operational value that estimates the number of modes from specific measurements on the output state. Here, we focus on a way to directly access the spectral structure of the modes generated, by seeding the source with a spectrally shaped coherent beam.

Q 53.3 Thu 15:00 SCH 251

Useful multiparticle entanglement applied for sub shot noise phase estimation — •Roland Krischek[1,2], Christian Schwemmer[1,2], Witlef Wieczorek[1,2,3], Harald Weinfurter[1,2], Philipp Hyllus[4], Luca Pezzé[5], and Augusto Smerzi[4] — [1]Max-Planck-Institut für Quantenoptik, D-85748 Garching, Germany, — [2]Fakultät für Physik, Ludwig-Maximilians-Universität München, D-80799 München, Germany — [3]University of Vienna, Faculty of Physics, Boltzmanngasse 5, A-1090 Vienna, Austria — [4]BEC-CNR-INFM and Dipartimento di Fisica, Università di Trento, I-38050 Povo, Italy — [5]Laboratoire Charles Fabry de l'Institut d'Optique, F-91403 Orsay Cedex, France

The goal of quantum enhanced metrology is to develop methods to improve the precision of measurements using non-classical resources. To this aim, a parameter, for example, a phase shift has to be determined with a precision beyond the classical shot noise limit. In general, quantum correlations are necessary but not sufficient to achieve measurement sensitivities beyond the shot noise limit. Therefore we developed theoretically and demonstrated experimentally for a 4 photon symmetric Dicke state the condition to recognize useful multiparticle entanglement for the estimation of an unknown phase shift. We implemented a maximum likelihood as well as a Bayesian phase estimation protocol and demonstrate the enhanced sensitivity obtained for an entangled symmetric Dicke state.

Q 53.4 Thu 15:15 SCH 251

Near-unity collection efficiency of single photons using a planar dielectric antenna — •Kwanggeol Lee, Xuewen Chen, Hadi Eghlidi, Philipp Kukura, Alois Renn, Vahid Sandoghdar, and Stephan Götzinger — Laboratory of Physical Chemistry, ETH Zürich, CH-8093 Zürich, Switzerland

Single-photon sources have been discussed as the building blocks of quantum cryptography, optical quantum computation, spectroscopy, and metrology. However, the feasibility of these proposals depends on the availability of single photons with a high fidelity. For sources based on single emitters, this implies near-unity collection efficiency into well-defined modes. Some of the current state-of-the-art efforts aimed at achieving these criteria have been demonstrated, but despite an impressive progress the results still fall short. In particular, a collection efficiency of 38% were reported using microresonators[1], while a nanowire device reached an efficiency of 72% at cryogenic temperatures[2]. Here we report on a broad-band room-temperature scheme, which uses a layered dielectric structure for tailoring the angular emission of a single oriented molecule such that more than 96% of the emitted photons are collected with a microscope objective, leading to recorded photon count rates of about 50 MHz[3]. Our approach is wavelength insensitive and compatible with cryogenic experiments and can therefore be extended to other solid state emitters, including defect centers in diamond and semiconductor quantum dots. [1] S. Strauf et al. Naure Photon. 1, 704-708 (2007). [2] J. Claudon et al. Nature Photon. 4, 174-177 (2010). [3] K-G. Lee et al. Nature Photon., to appear.

Q 53.5 Thu 15:30 SCH 251

Towards experiments with atoms in coupled cavity arrays — Guillaume Lepert[1], Michael Trupke[2], •Michael Hartmann[3], Martin Plenio[4], and Ed Hinds[1] — [1]Centre for Cold Matter, Imperial College, Prince Consort Road, London SW7 2BW, United Kingdom — [2]Technische Universität Wien - Atominstitut, Stadionallee 2, 1020 Wien, Austria — [3]Technische Universität München, Physik Department, James-Franck-Strasse, 85748 Garching, Germany — [4]Universität Ulm, Institut für Theoretische Physik, Albert-Einstein-Allee 11, 89069 Ulm, Germany

The physics of coupled quantum emitters or strongly interacting polaritons in arrays of coupled cavities has attracted considerable interest in recent years. Yet experimental realisations, in particular with optical photons, are still scarce. Here we describe a technologically viable platform for experiments with atoms or other quantum emitters in coupled optical cavity arrays. The envisaged solution requires only existing fabrication techniques and realistic performance parameters. The device uses open Fabry-Perot micro-cavities to couple to the emitters. The central innovation of this design is to connect the microcavities via evanescently-coupled resonators on a photonic waveguide chip. Based on these premises we present a theoretical analysis of two possible experiments and discuss further, more advanced applications.

Q 53.6 Thu 15:45 SCH 251

Spectroscopy of a single molecule with a stream of lifetime-limited single photons — Yves Rezus, •Samuel Walt, Gert Zumofen, Alois Renn, Stephan Götzinger, and Vahid Sandoghdar — ETH Zürich, Laboratory of Physical Chemistry (LPC), 8093 Zürich, Switzerland

An important elementary process in quantum information processing is the transfer of a single excitation between two quantum emitters. We report on the first realization of such an experiment in a direct fashion, where lifetime-limited single photons emitted by a single molecule are used as the source for the coherent excitation and spectroscopy of a second single molecule at a distance of more than 2m.

Q 54: Quantum Effects: QED

Time: Thursday 14:30–16:00 Location: SCH A01

Q 54.1 Thu 14:30 SCH A01

Observation of squeezed light with one atom — alexei ourjoumtsev, alexander kubanek, markus koch, christian sames, pepijn pinkse, gerhard rempe, and •karim murr — Max-Planck-Institut fuer Quantenoptik, Hans-Kopfermann-Str. 1, 85748 Garching

For a coherent or vacuum state of the electromagnetic field, the quantum uncertainties of its fluctuating electric and magnetic components are equal and minimize the Heisenberg's uncertainty relation. It is nowadays possible to reduce the value of one of the uncertainties below the vacuum level at the expense of increasing the other. Such "squeezed" states are so far generated using macroscopic media only, such as atomic vapours, optical fibres or non-linear crystals.

That a single atom can produce squeezed light has been predicted almost 30 years ago by Walls and Zoller. However, it has been foreseen by Mandel in 1982 that the squeezing generated by one atom would be "at least an order of magnitude more difficult" to observe than antibunching. Despite experimental efforts, single-atom squeezing has escaped observation.

We observe squeezed near-infrared light generated by a single neutral atom trapped inside a high-finesse optical cavity. With an excitation beam containing on average only 2 photons per system's lifetime, the measured field quadratures clearly present a phase-dependent nonclassical response. I will discuss the history on the theory of single-atom squeezing as well as our experiment for a broad audience.

Q 54.2 Thu 14:45 SCH A01

Observation of time-dependent, third-order correlations in cavity QED — •Markus Koch, Christian Sames, Maximilian Balbach, Haytham Chibani, Alexander Kubanek, Tatjana Wilk, Karim Murr, and Gerhard Rempe — Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Str. 1, 85748 Garching

A single two-level atom strongly coupled to a high-finesse cavity is a text book example of a dissipative quantum system, ideally suited to study fundamental effects of light-matter interaction. We probe its dynamics by evaluating time-dependent correlation functions of the light that is emitted from the system when it is driven by a probe beam. We present measurements of the second-order correlation function showing both vacuum Rabi oscillations, i.e. the coherent exchange of single photons between the atom and the cavity mode, and the coherent exchange of energy between the driving laser and the coupled atom-cavity system. Furthermore, we introduce third-order correlation functions as a new tool to observe effects involving the correlated emission of three photons. We find evidence for the coherent emission and reabsorption of single photons in the presence of another photon and show that the fluctuations of the transmitted intensity are asymmetric in time.

Q 54.3 Thu 15:00 SCH A01

Observation of the Collective Lambshift in Single-Photon Superradiance — •Ralf Röhlsberger[1], Kai Schlage[1], Balaram Sahoo[1], Sebastien Couet[2], and Rudolf Rüffer[3] — [1]DESY, Notkestr. 85, 22607 Hamburg — [2]KU Leuven, Celestijnenlaan 200D, 3001 Leuven, Belgium — [3]ESRF, 38043 Grenoble Cedex, France

The interaction of many identical two-level atoms with a common radiation field leads to a profound modification of the temporal, directional and spectral characteristics of their collective emission compared to that of a single atom. A prominent example is the phenomenon of superradiance that manifests as a strong acceleration of the collective spontaneous emission [1]. Later it was predicted that the superradiant emission goes along with a radiative shift of the transition energy, the collective Lamb shift (CLS) [2,3]. In the optical regime, however, this shift appeared to be extremely difficult to observe due to its small magnitude and atom-atom interactions masking it. In the x-ray regime, these effects can be neglected. Thus, we used pulsed 14.4 keV synchrotron radiation to resonantly excite ensembles of ^{57}Fe Mössbauer atoms into a purely superradiant state [4]. For that purpose the atoms were embedded into a planar solid-state cavity. Spectral analysis of the cooperative emission revealed the CLS as predicted. Applications for the analysis of cooperative emission in general will be discussed.

[1] R. H. Dicke, Phys. Rev. 93, 99 (1954). [2] R. Friedberg, S. R. Hartmann, and J. T. Manassah, Phys. Rep. C 7, 101 (1973). [3] M. O. Scully, Phys. Rev. Lett. 102, 143601 (2009). [4] R. Röhlsberger, K. Schlage, B. Sahoo, S. Couet and R. Rüffer, Science 328, 1248 (2010).

Q 54.4 Thu 15:15 SCH A01

Temperature invariance of Casimir–Polder potentials — •Stefan Yoshi Buhmann[1], Simen Ådnøy Ellingsen[2], and Stefan Scheel[1] — [1]Quantum Optics and Laser Science, Blackett Laboratory, Imperial College London, Prince Consort Road, London SW7 2AZ, United Kingdom — [2]Department of Energy and Process Engineering, Norwegian University of Science and Technology, N-7491 Trondheim, Norway

It is commonly assumed that thermal photons have an impact on the Casimir–Polder interaction of an atom with a surface. In particular, one would expect the potential of molecules or Rydberg atoms with low-frequency transitions to be very sensitive to temperature changes, because the thermal photon number for such transitions is very large even at room temperature.

In contrast to these expectations, we demonstrate that the potential of an atom in an energy eigenstate at nonretarded distance from a metal surface is temperature-invariant over the whole range from zero to room temperature and beyond [1]. As demonstrated for an infinite plate, this is due to strong cancellations of contributions from virtual and evanescent photons, leaving a temperature-invariant total potential. We are able to prove that more generally, temperature-invariance holds for metal bodies for arbitrary shapes [2].

[1] S. Å. Ellingsen, S. Y. Buhmann and S. Scheel, Phys. Rev. Lett. **104**, 223003 (2010).
[2] S. Y. Buhmann, S. Å. Ellingsen and S. Scheel, in preparation (2010).

Q 54.5 Thu 15:30 SCH A01

Theory of the QFEL — •Paul Preiss[1,2], Matthias Knobl[2], Roland Sauerbrey[1], and Wolfgang P. Schleich[2] — [1]Forschungszentrum Dresden-Rossendorf, 01314 Dresden, Germany — [2]Institut für Quantenphysik, Universität Ulm, 89069 Ulm, Germany

Having served as a coherent light source with a widely tunable wave length the free-electron laser has become interesting for theoratical physicists once more. New developments in accelerator and laser physics raise hope for the so-called QFEL, a free-electron laser operating in the quantum mechanical regime, e. g. at the Research Center Rossendorf in Dresden.

We develop a fully quantized one-particle theory for the dynamics of the interaction between the electron and the wiggler and laser field. Our results obtained for the quantum mechanical regime are reminiscent of dynamics in two-level systems. Compared to such a two-level system with one internal degree of freedom (e. g. an atom with a ground and one excited state) the state of our system is mainly determined by the momentum of the electron in the co-moving Bambini-Renieri frame. In contrast to the classical regime here the electron propagating through the wiggler field can only emit or absorb one single photon. Transitions including the emission or absorption of many photons are significantly suppressed.

Q 54.6 Thu 15:45 SCH A01

Feynman diagrams for dispersion interactions — •Harald Haakh, Juergen Schiefele, and Carsten Henkel — Institut für Physik und Astronomie, Universität Potsdam, Germany

Diagrammatic techniques have been used for a long time in perturbative calculations of dispersion interactions between atoms or molecules such as the Casimir-Polder or van-der-Waals interaction [1] and atomic (or molecular) QED, as in the Lamb shift and the calculation of radiative lifetimes. Using the multipolar coupling scheme and Feynman-ordered diagrams rather than retarded graphs, significantly reduces the number of graphs required for calculating the T-matrix. The formalism presented in Ref. [2] offers a rich toolbox that can be applied to different situations reaching from few-body interactions to Bose-Einstein condensates. It is possible to include macroscopic bodies and atomic wave packets, relevant for quantum gases in modern microtraps. Interesting applications involve entangled states or systems out of thermal equilibrium. Resonant contributions arise from the interaction of excited molecules and are supposed to play an important role in molecular biology [3].

[1] D.P. Craig and T. Thirunamachandran, Molecular Quantum Electrodynamics (Dover, 1998)

[2] J. Schiefele and C. Henkel, Phys. Rev. A **82**, 023605 (2010), J. Schiefele and C. Henkel, Phys. Lett. A (2010), doi:10.1016/j.physleta.2010.11.058, arXiv:1011.4428,

[3] H. Fröhlich, Proc. Nat. Acad. Sci. USA **72**, 4211 (1975).

Q 55: Transport and Localization of interacting Bosons 2

Time: Thursday 14:30–16:00 Location: BAR Schön

Q 55.1 Thu 14:30 BAR Schön

Interband dynamics in a many-body Wannier-Stark system — •Carlos Parra Murillo[1], Javier Madroñero[2], and Sandro Wimberger[1] — [1]Institut fuer theoretische Physik, Heidelberg University, D-69120, Heidelberg, Germany — [2]Physik Department, Technische Universitaet Muenchen, D-85747 Garching, Germany

In the last years the dynamics of ultracold atoms, in particular Bose condensates loaded into optical lattices, have become amply studied in view of interesting phenomena like Landau-Zener tunnelling, resonantly enhanced tunnelling (RET) and Bloch oscillations. Regular and chaotic regimes can be reached by varying the parameters in the many-body description of ultracold bosons [1]. We present results obtained by studying the dynamical properties of a two-band Bose-Hubbard Hamiltonian for a one-dimensional tilted optical lattice [2]. We compare the interband dynamics for the single particle limit and for the fully interacting system, by computing the average occupation of the upper band. The spectral properties (avoided crossings) provide a comprehensive understanding of the dynamics close to RET as a control parameter is varied and the number of particles is increased. The dynamical correlations between the bands imply interesting perspectives for state-of-the-art experiments with ultracold bosons.

[1] A. Tomadin, R. Mannella, and S. Wimberger, Phys. Rev. Lett. 98, 130402 (2007). [2] P. Ploetz, J. Madroñero, and S. Wimberger, J. Phys. B 43, 081001(FTC) (2010).

Q 55.2 Thu 14:45 BAR Schön

Stability and decay of Bloch oscillations in Bose-Einstein condensates with time-dependent atom-atom interactions — •Christopher Gaul[1], Elena Díaz[1,2], Cord A. Müller[3], Rodrigo Lima[4], and Francisco Domínguez-Adame[1] — [1]GISC, Departamento de Física de Materiales, Universidad Complutense, E-28040 Madrid, Spain — [2]Institute for Materials Science, Technische Universität Dresden, D-01062 Dresden, Germany — [3]Centre for Quantum Technologies, National University of Singapore, Singapore 117543, Singapore — [4]Instituto de Física, Universidade Federal de Alagoas, Maceió AL 57072-970, Brazil

Bose-Einstein condensates in tilted optical lattices allow the observation of Bloch oscillations (BOs). Generically, the interaction leads to dephasing and to the decay of the wave packet. By means of Feshbach resonances, however, experimentalists can tune the s-wave scattering length to zero or modulate it in time. We investigate the effect of such time-managed interactions on BOs. Additionally to the noninteracting case and a solitonic solution, we find an infinite family of modulations that preserve the Bloch oscillating wave packet [1]. In these cases, the stability follows from a time-reversal argument. In the unstable cases, we employ a collective-coordinates ansatz and a stability analysis, in order to quantify the decay of the BOs. In particular we show that in presence of external perturbations, an additional modulation of the interaction can enhance the lifetime of the Bloch oscillation [2].

[1] Gaul et al. PRL 102, 255303 (2009)
[2] Díaz et al. PRA 81, 051607R (2010)

Q 55.3 Thu 15:00 BAR Schön

Wave packet surgery in driven optical lattices — •Stephan Arlinghaus and Martin Holthaus — Institut für Physik, Carl von Ossietzky Universität, D-26111 Oldenburg

The dynamics of particles in a periodic potential under the influence of homogeneous external forcing is governed by Bloch's acceleration theorem, provided the single-band approximation remains viable. However, interband transitions induced by strong time-periodic forces, which lie ouside the scope of this old approach, offer most interesting perspectives for coherent control. We show how a generalized acceleration theorem, based on the use of Floquet states, leads to novel control strategies, allowing one to selectively "cut out" certain parts from the particles' wave packets. Ultracold atoms in driven optical lattices provide experimentally accessible testing ground for these ideas.

Q 55.4 Thu 15:15 BAR Schön

Weak (anti-)localization of Bose-Einstein condensates in two-dimensional chaotic cavities: numerical results — •Timo Hartmann[1], Juan Diego Urbina[1], Klaus Richter[1], and Peter Schlagheck[2] — [1]Institute for Theoretical Physics, University of Regensburg, D-93040 Regensburg, Germany — [2]Département de Physique, Université de Liège, 4000 Liège, Belgium

The possibility to induce artificial magnetic gauge potentials for matter waves [1] and to create almost arbitrarily shaped confinement potentials [2] makes it now interesting and feasible to study coherent transport of Bose-Einstein condensates through various mesoscopic structures. Previous theoretical studies have focused on the question how coherent backscattering in disordered potentials is modified by the presence of the atom-atom interaction [3]. We now study the analogous scenario of weak localisation in ballistic billiard geometries which exhibit chaotic classical dynamics. To this end we numerically investigate the quasi-stationary propagation of a condensate through such structures within the mean-field approximation. The transmission is measured as a function of the magnetic gauge field and of the non-linearity. With increasing non-linearity an inversion of the weak-localisation peak is visible and its origin will be discussed.

[1] Y.-J. Lin et al., Phys. Rev. Lett. **102** 130401 (2009)
[2] K. Henderson et al., New J. Phys. **11**, 043030(2009)
[3] M. Hartung et al., Phys. Rev. Lett. **101**, 020603 (2008).

Q 55.5 Thu 15:30 BAR Schön

Destruction of localization in a nonlinear generalization of the quantum kicked rotor — •Goran Gligorić, Joshua Bodyfelt, and Sergej Flach — MPI für Physik komplexer Systeme

Quantum suppression of classically chaotic diffusion was first observed numerically in the quantum kicked rotor model. This phenomenon can be considered in many aspects as the dynamical version of Anderson localization in tight-binding disordered models [1]. In the case of the kicked rotor there is no true randomness and diffusion after an initial time interval appears, resulting from chaotic dynamics in the corresponding classical counterpart. The realization of Bose-Einstein condensates has opened a new opportunity for studying dynamical systems in the presence of many-body interactions. In the mean field approximation, these interactions can be represented by adding a quartic nonlinearity in the Schrödinger equation. Our aim is to utilize such a model, as introduced by Shepelyansky [2] in order to understand how nonlinearity generally affects the kicked rotor model. Particularly, we aim to understand the influence of nonlinearity on dynamical localization; of special concern is the possibility of a critical nonlinear strength above which localization is destroyed, and how this destruction comes about. Lastly, we will consider the corresponding anomalous subdiffusion law in this regime and test its universality.

[1] S. Fishman, D.R. Grempel and R.E. Prange, Phys. Rev. A 29 (1984) 1639
[2] D.L. Shepelyansky, Phys. Rev. Lett. 70 (1993) 1787

Q 55.6 Thu 15:45 BAR Schön

Localization of two interacting bosons in a random potential — •Dmitry Krimer[1,2], Ramaz Khomeriki[1,3], and Sergej Flach[1] — [1]Max Planck Institute for the Physics of Complex Systems, 01189 Dresden, Germany — [2]Institute for Theoretical Physics, University of Tuebingen, 72076 Tübingen — [3]Physics Department, Tbilisi State University, 0128 Tbilisi, Georgia

We study the dynamics of two interacting bosons in one-dimensional random lattices using the Bose-Hubbard model. In the absence of interaction all eigenstates are spatially localized and both particles follow the single particle dynamics corresponding to Anderson localization. Our study aims to clarify the interplay of disorder and interactions in few-body dynamics. In particular, we calculate the enhancement factor of the localization length l_2 in comparison to the single particle localization length l_1 for weak disorder performing rigorous numerical calculations. Previous studies based on the mapping of the two-particle problem onto a physically relevant matrix model contained different statements on this issue [1]. Our findings are in tact with predictions, which follow from the statistical properties of the overlap integrals of single particle eigenvectors [2].

[1] D.L. Shepelyansky, Phys. Rev. Lett. 73, 2607 (1994); K. Frahm, A. Müller-Groeling, J.-L. Pichard, D. Weinmann, Europhys. Lett., 31, 169 (1995)

[2] D.O. Krimer, S. Flach, Phys. Rev. E 82, 046221 (2010)

Q 56: Ultrakurze Laserpulse: Anwendungen 3

Time: Thursday 14:30–15:45 Location: SCH A215

Q 56.1 Thu 14:30 SCH A215

Role of Ferroelectric Domain Distribution and Shape in Čerenkov Second Harmonic Generation — •Philip Roedig, Mousa Ayoub, Jörg Imbrock, and Cornelia Denz — Institut für Angewandte Physik and Center for Nonlinear Science (CeNoS), Westfälische Wilhelms-Universität Münster, 48149 Münster, 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 by using conventional methods like crystal birefringence or quasi-phase matching (QPM) techniques.

Recently, it was pointed out that unpoled ferroelectric crystals can also be used for frequency conversion in nonlinear optics being considered as randomly structured domain media that allow e.g. for tunable phase-matched second-harmonic generation (SHG) practically in the whole transparency range of the crystal. Two characteristic emission configurations, namely planar and Čerenkov geometries, were suggested.

In this contribution, we systematically study the characteristics of Čerenkov second-harmonic generation in multi-domain χ^2 strontium barium niobate crystals by femtosecond laser pulses. Starting from an unpoled sample having a random domain distribution, different degrees of disorder are experimentally generated, offering a possibility to achieve deformation in the shape and distribution of the ferroelectric domains. This results in an enhancement of the efficiency conversion of such type of second harmonic generation and features remarkable modulations in the SH intensity emission patterns.

Q 56.2 Thu 14:45 SCH A215

Hystereseeffekte in einem Rückkoppelsystem zur Superkontinuumserzeugung — •John Wetzel, Nicoletta Brauckmann, Michael Kues, Petra Gross und Carsten Fallnich — Institut für Angewandte Physik, Westfälische Wilhelms-Universität, Münster, Deutschland

Bei der Erzeugung von Superkontinua wird schmalbandiges Licht durch das Zusammenwirken von Dispersion mit nichtlinearen Prozessen wie beispielsweise Selbstphasenmodulation, Vier-Wellen-Mischung und Raman-Streuung spektral verbreitert.

In unserem experimentellen Aufbau werden Superkontinua durch Einkopplung von Femtosekunden-Laserimpulsen aus einem Titan:Saphir-Laser in eine mikrostrukturierte Glasfaser innerhalb eines Ringresonators erzeugt. Durch die so realisierte optische Rückkopplung überlagern die Superkontinuumsimpulse mit den folgenden Pumpimpulsen, was zu wesentlichen Auswirkungen auf die Eigenschaften der erzeugten Superkontinua führt. Das System zeigt nichtlineare Dynamiken von stationären Zuständen über Periodenvervielfachung und Grenzzyklen bis hin zu chaotischem Verhalten. Die Einstellung dieser Dynamiken hängt stark von der Phase der Überlagerung ab, die über die Länge des Ringresonators eingestellt wird. Es wurde gezeigt, dass die Phase genutzt werden kann, um zwischen verschiedenen Systemzuständen definiert zu schalten.

Die hier präsentierten experimentellen und numerischen Ergebnisse zeigen, dass beim Wechsel zwischen verschiedenen Regimen nichtlinearer Dynamiken durch Phasenänderung Hystereseeffekte auftreten.

Q 56.3 Thu 15:00 SCH A215

Measuring the carrier-envelope phase of ultra-intense few-cycle laser pulses — •Felix Mackenroth, Antonino Di Piazza, and Christoph H. Keitel — Max-Planck-Institut für Kernphysik, Saupfercheckweg 1, D-69117 Heidelberg (Germany)

In order to produce ultra-strong laser fields tight temporal focussing of the laser field down to only a few cycles of the carrying electromagnetic wave is usually required. In such few-cycle pulses physical phenomena exhibit a dependence on the relative phase between the carrier wave and the envelope function, also known as the carrier-envelope phase (CEP). It is therefore desirable to have available a determination scheme for the CEP, which in principle can operate at arbitrarily high intensities. Conventional schemes based on atomic physics only allow determination of the CEP of laser fields with intensities up to about 10^{16} W/cm^2, which is well below already available peak laser intensities of the order of 10^{22} W/cm^2 [1]. We show that the CEP of such intense pulses can in principle be determined from the angular distribution of the photons emitted by an electron via multiphoton Compton scattering off the strong few-cycle laser pulse [2].

[1] V. Yanovsky et al., Opt. Express **3**, 16 (2008).
[2] F. Mackenroth, A. Di Piazza, and C. H. Keitel, Phys. Rev. Lett. **105**, 063903 (2010).

Q 56.4 Thu 15:15 SCH A215

A split operator method for the Klein-Gordon equation with applications to ultrashort laser-matter interaction — •Matthias Ruf, Heiko Bauke, and Christoph H. Keitel — Max-Planck-Institut für Kernphysik, Saupfercheckweg 1, D-69117 Heidelberg

The quantum dynamics of ultrashort high-intensity laser-matter interaction necessitate a relativistic treatment. Many problems may be treated by numerical means only. Here, we present a numerical scheme to solve the time evolution of the Klein-Gordon equation via the split operator method. Typical split operator methods act alternately in position and momentum space and, therefore, require the computation of a Fourier transform in each time step. In the two-component representation of the Klein-Gordon equation [1], however, the kinetic energy operator is nilpotent. This allows one to perform the split operator method for the Klein-Gordon equation entirely in position space and this way to avoid the computation of a Fourier transform.

We have implemented a position space split operator method [2] for the solution of the time-dependent Klein-Gordon equation with arbitrary electromagnetic fields. The parallel implementation is based on domain decomposition. In our presentation, we describe the computational details and address various physical applications, such as the ionization of highly charged hydrogenlike ions or electron-positron pair creation from vacuum.

[1] H. Feshbach and F. Villars, Rev. Mod. Phys. **30**, 24 (1958)
[2] M. Ruf, H. Bauke and C. H. Keitel, J. Comp. Phys. **228**, 9092 (2009)

Q 56.5 Thu 15:30 SCH A215

Light field control of electronic motion in condensed matter — •Agustin Schiffrin[1], Tim Paasch-Colberg[1,2], Daniel Gerstner[2], Nicholas Karpowicz[1], Sascha Mühlbrandt[2], Joachim Reichert[2], Johannes V. Barth[2], Reinhard Kienberger[1,2], Ralph Ernstorfer[1,2,3], and Ferenc Krausz[1,4] — [1]Max-Planck-Institut für Quantenoptik, Garching, Germany — [2]Technische Universität München, Germany — [3]Fritz-Haber-Institut, Berlin, Germany — [4]Ludwig-Maximilians-Universität, München, Germany

The advent of intense few-cycle near infrared (NIR) laser pulses with stable and tunable carrier envelope phase (CEP) has enabled the control of electromagnetic fields with attosecond time precision [1]. Here we aim at exploiting these few-cycle NIR optical fields with well-defined CEP to generate and control the motion of charge carriers within heterogeneous nanoscaled solid state interfaces. We demonstrate the generation of directly measurable photocurrents in unbiased gold-coated SiO_2 nanogaps, whose magnitude and directionality can be tuned with the laser CEP. This effect vanishes with the increase of the laser pulse duration. We claim that such phenomenon is the signature of optically induced electron tunneling at the metal-dielectric interface with subsequent acceleration of the charge carrier in the ultrashort laser field. This ultrafast current injection at a nanoscaled condensed matter system represents a first step towards femtosecond lightwave electronics.

[1] Baltuska, A. et al. "Attosecond control of electronic processes by intense light fields" Nature **421**, 611-615 (2003).

Q 57: Poster 3: Quantengase, Ultrakalte Atome, Ultrakalte Moleküle, Materiewellen Optik, Präzisionsmessungen, Metrologie

Time: Thursday 16:30–19:30 Location: P1

Q 57.1 Thu 16:30 P1

Weak Localisation with Short Loops — •Felix Eckert, Thomas Wellens, and Andreas Buchleitner — Physikalisches Institut, Albert-Ludwigs Universität, Freiburg, Germany

In multiply scattering weakly disordered media (i.e. the wavelength $\lambda \ll$ mean free path ℓ), the average wave intensity is known to obey a diffusion equation. It is also well understood that interference effects lead to reduction of the diffusion, termed "weak localisation" and expressed by a decrease of the diffusion coefficient. These interference effects can be explained in terms of pairs of counterpropagating loops interfering constructively, thus enhancing the probability of return.

In the usual approach, these loops are calculated within the diffusion approximation, thus completely neglecting short loops, i.e. loops that consist of only a few scattering events. We present a calculation of the weak localisation corrections treating the propagation inside the loops exactly thus accounting also for the short loops. We find that the leading order correction to the diffusion coefficient scales linearly in λ/ℓ as opposed to the $(\lambda/\ell)^2$ predicted by the usual approach.

Q 57.2 Thu 16:30 P1

Many boson- vs. many-fermion interference – differences and similarities — •Malte C. Tichy[1], Markus Tiersch[2], Florian Mintert[1,3], and Andreas Buchleitner[1] — [1]Physikalisches Institut - Universität Freiburg - Hermann-Herder-Str. 3 - D-79104 Freiburg — [2]Institute for Quantum Optics and Quantum Information - Austrian Academy of Sciences - Technikerstr. 21A - A-6020 Innsbruck, Austria — [3]Freiburg Institute for Advanced Studies - Universität Freiburg - Albertstr. 19 - D-79104 Freiburg

We discuss many-particle interference in the scattering of an arbitrary number of non-interacting bosons, fermions, or distinguishable particles within general scenarios. For the case of Fourier multiport beam splitters, a suppression law is derived [1] for both bosons and fermions, providing a generalization of the two-photon Hong-Ou-Mandel effect. In general, the intuitive dichotomy of bosons and fermions, known from the two-particle case, does, surprisingly, not prevail for more than two particles. The statistical behavior of identical particles – bunching for bosons and the Pauli principle for fermions – and many-particle interference that governs the particles' behavior in any scattering scenario need to be considered as two largely independent effects.

[1] M.C. Tichy et al., Phys. Rev. Lett. 104, 220405 (2010)

Q 57.3 Thu 16:30 P1

Nonlinear BEC Dynamics Induced by Harmonic Modulation of Atomic s-wave Scattering Length — •Ivana Vidanović[1], Antun Balaž[1], Hamed Al-Jibbouri[2], and Axel Pelster[3] — [1]Scientific Computing Laboratory, Institute of Physics Belgrade, University of Belgrade, Pregrevica 118, 11080 Belgrade, Serbia — [2]Institut für Theoretische Physik, Freie Universität Berlin, Arnimallee 14, 14195 Berlin, Germany — [3]Fachbereich Physik, Universität Duisburg-Essen, Lotharstrasse 1, 47048 Duisburg, Germany

In the recent experiment [1], a Bose-Einstein condensate of ^{7}Li has been excited by a harmonic modulation of the atomic s-wave scattering length via Feshbach resonance. Combining an analytical perturbative approach with numerical simulations we analyze the resulting nonlinear dynamics of the system on the mean-field Gross-Pitaevskii level. Our detailed results show the presence of higher harmonics and mode coupling. Most importantly, we also find significant shifts of the collective modes frequencies in the resonance region which are due to the nonlinearity of the system dynamics. Finally, we indicate how these frequency shifts could be measured in a future experiment.

[1] S. E. Pollack et. al., PRA **81**, 053627 (2010).

Q 57.4 Thu 16:30 P1

Exact Lieb-Liniger Dynamics — •Jan Zill[1,2], Matthias Kronenwett[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, Planckstr. 1, 64291 Darmstadt

A one-dimensional gas of Bosons with repulsive delta-function interactions is studied. The ground state and the (low lying) excitation spectrum for fixed particle numbers and different interaction strengths are computed numerically via the Bethe-Ansatz and an extended Fermi-Bose mapping. We aim to compute the time evolution of the momentum distribution for weak and strong interaction strength, as well as of other correlation functions. Since the Schrödinger equation is solved exactly, the results can be used as a benchmark for approximative analytical and numerical methods in quantum field theory.

Q 57.5 Thu 16:30 P1

Back reaction from Bogoliubov modes onto grey solitons — •Philip Walczak and James Anglin — TU Kaiserslautern, Erwin-Schrödinger-Str. 46, 67663 Kaiserslautern

In quasi-one-dimensional Bose-condensed gases one can observe the formation of so-called grey solitons in the semi-classical limit. These are large phase and amplitude slips occurring on healing length scales. The dynamics of grey solitons is described by the non-linear Gross-Pitaevskii equation. We have found the exact solutions of the linearized problem of small excitations around a general grey soliton background. These excitations can be viewed as traveling waves in a perfectly non-reflecting potential provided by the soliton. It can be seen that asymptotically the effect of the soliton on these modes is a wave number dependent phase shift. From momentum and energy conservation one can conclude that in turn the passage of the excitations must induce a finite spatial translation the soliton. We derive an analytical expression for this classical back reaction 'dragging' effect in the case of an initial Gaussian wave packet, which is in good agreement with numerical propagation under the full non-linear equation. We discuss differences between quantum and classical back reaction.

Q 57.6 Thu 16:30 P1

Towards the realization of an erbium atomic quantum gas — •Henning Brammer, Jens Ulitzsch, Riad Bourouis, 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 realized atomic quantum gases all have been realized with a spericall 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. In contrast, 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 have reported on progress in an ongoing experiment directed at the generation of an atomic erbium Bose-Einstein condensate by evaporative cooling in a far detuned optical dipole trap. In the present stage of the experiment, a magneto optical trap (MOT) for this rare earth metal atom has been realized, loaded from an effusive cell and decelerated by a Zeeman slower. 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 erbium and therefore the presence of several leak channels. This is attributed to the high magnetic moment of the erbium atom ($7\mu_B$), which allows a magnetic trapping of erbium atoms left in metastable energy levels in the MOT gradient magnetic field. Experimental data of the erbium MOT will be shown.

Q 57.7 Thu 16:30 P1

Dipole potentials for guided atom-optics — •Thomas Lauber, Johannes Küber, Martin Hasch, Oliver Wille, and Gerhard Birkl — Institut für Angewandte Physik, Technische Universität Darmstadt, Schlossgartenstraße 7, 64289 Darmstadt

We present our approach towards integrated atom-optics, which is based on the implementation of micro-fabricated optical elements for the shaping of dipole potentials. These elements are available in various designs like cylindrical lens arrays or a ring lens. They provide the advantage that the resulting light fields can be easily combined to create complex structures, like beam splitters or Mach-Zehnder like interferometers. The ring lens, which offers a toroidal trapping potential, is currently investigated. We present first experiments with a Bose-Einstein condensate loaded to and accelerated in linear wave guides and the ring shaped dipole potential.

For these experiments we use a BEC which is prepared all-optically in a crossed dipole trap generated by a 1070nm fibre laser. For coherent splitting and acceleration of the atoms we use a one-dimensional optical lattice. With this setup we are able to perform interferometric experiments for characterisation of the coherence properties in a wave guide.

We further show a possible scheme for an atom matter wave resonator with tunable mirror transmittance, which reveals long lifetimes and specific revival dynamics.

Q 57.8 Thu 16:30 P1

Scaling laws of turbulent ultracold bosons — •Boris Nowak[1,2], Maximilian Schmidt[1,2], Jan Schole[1,2], Denes Sexty[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

Turbulent dynamics in an ultracold Bose gas, in two and three spatial dimensions, is studied analytically and numerically. A special focus is set on the infrared regime of large-scale excitations following universal power-law distributions distinctly different from those of commonly known weak wave-turbulence phenomena. The infrared power laws which have been predicted within an analytic field-theoretic approach based on the 2PI effective action, are discussed in comparison to the well-known Kolmogorov scaling of vortical motion. These phenomena of strong turbulence should in principle be observable with ultracold atomic gases.

Q 57.9 Thu 16:30 P1

Critical dynamics of ultracold bosons in one dimension — •Maximilian Schmidt[1,2], Jan Schole[1,2], Boris Nowak[1,2], Denes Sexty[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

Critical dynamics in an ultracold Bose gas, in one spatial dimension, is analysed with respect to topological excitations and compared to quantum turbulence in two and three dimensions. A special focus is set on the time-evolution of characteristic quantities such as the energy and velocity distributions, soliton and vortex densities and the spectral function. The results give insight into the structure of stationary states of an ultracold Bose gas away from equilibrium.

Q 57.10 Thu 16:30 P1

Bose-Einstein condensation of a two-dimensional photon gas and prospects on its realization in solid-state materials — •Julian Schmitt, Jan Klaers, Frank Vewinger, and Martin Weitz — Institut für Angewandte Physik (IAP), Universität Bonn

Bose-Einstein condensation has been experimentally demonstrated in several physical systems, including cold atomic gases and solid-state quasiparticles. Owing to its vanishing chemical potential blackbody radiation does not collectively occupy the lowest energy mode when the temperature is lowered - but instead the photons disappear in the cavity walls. We describe a thermalized two-dimensional photon gas with a freely adjustable chemical potential based on a dye-filled microresonator. Thermalization to the temperature of the resonator is achieved by photon scattering off the dye molecules, and the cavity mirrors provide both an effective photon mass and a confining harmonic potential. This allows for Bose-Einstein condensation of photons, which is experimentally observed at sufficiently high photon densities. In more recent experiments, we have realized a thermalized photon gas in a solid state system. Dye molecules embedded in polymeric host matrices allow for multiple emission and reabsorption processes of the photons driving the system to thermal equilibrium, with the occupation of transversal modes being Boltzmann-like. In correspondence to our experiments carried out on the liquid dye solution, a spatial concentration effect of the light to the centre of the confining potential is observed. However, the experiment reveals a sensitive dependence of the spatial redistribution extent on the fluorescence quantum yield of the dye molecules.

Q 57.11 Thu 16:30 P1

Quantum - classical correspondence and break-down of second Josephson oscillations — •Martin P. Strzys and James R. Anglin — Technische Universität Kaiserslautern, FB Physik, 67663 Kaiserslautern, Germany

A simple four-mode Bose-Hubbard model with intrinsic time-scale separation can can be considered as a paradigm for mesoscopic quantum systems in thermal contact. Bogoliubov excitations of the two-mode subsystems thereby behave similarly to second sound phenomenons in liquid Helium II and perform second Josephson oscillations. We will illuminate the quantum classical correspondence and the range of validity of this theory.

Q 57.12 Thu 16:30 P1

Investigation of light-assisted collisions of ^{40}Ca — •Oliver Appel, Max Kahmann, Stephan Schulz, Sebastian Kraft, Fritz Riehle, and Uwe Sterr — Physikalisch-Technische Bundesanstalt (PTB), Bundesallee 100, 38116 Braunschweig

Quantum degenerate Calcium is an interesting candidate for atom interferometry and optical Feshbach resonances. Therefore it is necessary to investigate collisions involving at least one excited atom. We use photoassociation spectroscopy to search for bound molecular states near the $^1S_0$-$^3P_1$ asymptote. By optically coupling these bound states to the ground state we will be able to generate an optical Feshbach resonance. In contrast to magnetic Feshbach resonances these can be used to modify the scattering length on very small length scales.

To further understand collisions of unbound ^3P atoms we excite into the $^3P_1$ and $^3P_0$ states and study the coherence loss. The excitation to the long-lived $^3P_0$ state demands for an ultranarrow laser, which is being set up.

In this poster we will report on the current status of the experiment.
Our work is supported by the excellence cluster QUEST.

Q 57.13 Thu 16:30 P1

Low-dimensional physics on atom chips — •Anton Piccardo-Selg, Gal Aviv, Simon Goodall, Lucia Hackermüller, Thomas Fernholz, and Peter Krüger — School of Physics and Astronomy, University of Nottingham, NG7 2RD, United Kingdom

Atom chips allow for almost arbitrary trapping geometries for atomic ensembles by means of magnetic, electric, optical, microwave and radio-frequency potentials. Our research aims at the creation of multiply connected topologies, like rings, tori, and cylinders. These traps are used to investigate the low temperature behaviour of ultracold quantum gases when the dimensionality of the trapping geometry changes.

Our current atom chip generation will produce cylinder-symmetric traps by using a combination of dc and radio-frequency fields. Further to the investigation of low-dimensional systems the chip can be used to dynamically split an elongated cloud of ultracold atoms. This “unzipping” of the cloud is intended to be used as a quantum simulator for the dynamical Casimir effect. The current progress of the experimental setup will be presented.

Q 57.14 Thu 16:30 P1

Cold Heat - The Quantum Kinetic Theory of Collisionless Superfluid Internal Convection — •Lukas Gilz and James Anglin — TU Kaiserslautern, Kaiserslautern, Germany

When a superfluid is heated locally, condensate and non-condensate fractions flow in opposite directions. As if to rebut the 19th century conclusion that cold is merely absence of heat, condensate flows like a flux of cold, from cooler regions to hotter. Wereas this phenomenon of ”superfluid internal convection” is usually described within Landau’s phenomenological two fluid model, we obtain a more fundamental picture of internal convection by extending a standard master equation formulation of quantum kinetic theory to include two reservoirs of different temperatures. We find that internal convection occurs even in collisionless regimes and that coherent scattering is essential to the observation of a condensate flow. Besides computing estimates of particle-, energy- and entropy flow, we propose an experimental approach by which this behavior can be observed in trapped ultracold Bose gases.

Q 57.15 Thu 16:30 P1

Scattering Ultracold Atoms on Carbon Nanotubes — •Peter Federsel[1], Michael Gierling[1], Philip Schneeweiss[1], Gabriela Visanescu[1], Dieter Kern[2], Andreas Günther[1], and József Fortágh[1] — [1]Physikalisches Institut der Universität Tübingen Auf der Morgenstelle 14 D-72076 Tübingen — [2]Institut für Angewandte Physik Universität Tübingen Auf der Morgenstelle 10 D-72076 Tübingen

We measure the inelastic scattering cross section between ultracold rubidium atoms and carbon nanotubes. The measurement is done by

spatially overlapping ultracold thermal clouds and Bose-Einstein condensates with a single carbon nanotube and recording the atom loss. From the data we derive the velocity dependent scattering radius of the nanotube.

Q 57.16 Thu 16:30 P1

Interactions and crossovers between insulating phases of fermionic gases in optical lattices — •Victor Hugo Ferreira Bezerra[1], Flavio de Souza Nogueira[1], and Axel Pelster[2] — [1]Institut für Theoretische Physik, Freie Universität Berlin, Arnimallee 14, 14195 Berlin, Germany — [2]Fachbereich Physik, Universität Duisburg-Essen, Lotharstrasse 1, 47048 Duisburg, Germany

Recent experimental progress in the field of cold atoms has boosted a world-wide quest to simulate condensed matter problems within the realm of ultracold quantum gases in optical lattices. A considerable progress was achieved last years with the realization of a fermionic Mott insulator in an optical lattice. Several groups are now focusing experimental and theoretical efforts to realize the BEC-BCS crossover and different magnetic phases in optical lattices. In this work we investigate the phase structure for interacting fermions near a Feshbach resonance in two- and three-dimensional cubic lattices. To this end we have analyzed the underlying Hubbard-like model with a recently developed field-theoretic many-body technique to describe crossovers and transitions between the diferent phases related to superconducting and antiferromagnetic instabilities. In particular, we have calculated the quantum effective action and obtained in the strongly correlated regime a crossover between magnetic and charge ordered insulators. This crossover corresponds to the strongly correlated counterpart of the BCS-BEC crossover, which for our lattice model occurs in the weakly coupled regime.

Q 57.17 Thu 16:30 P1

A new setup for the study of strongly correlated low-dimensional systems — •Florian Wittkötter, Wolf Weimer, Kai Morgener, Niels Strohmaier, and Henning Moritz — Institut für Laser-Physik, Universität Hamburg, Luruper Chaussee 149, 22761 Hamburg

We present our new experimental setup for the study of low-dimensional Fermi gases with local control and readout. A gas of fermionic Lithium is cooled to quantum degeneracy and prepared between two microscope objectives. A novel ring resonator concept will be used for creating one-dimensional systems and the Fermi-Hubbard model. In combination with the excellent optical access this allows us to address non-equilibrium phenomena in strongly correlated systems.

Q 57.18 Thu 16:30 P1

Approaching a three-component Fermi gas in an optical lattice — •Martin Ries[1,2], Andre Wenz[1,2], Philipp Simon[1,2], Thomas Lompe[1,2], Friedhelm Serwane[1,2], Gerhard Zürn[1,2], and Selim Jochim[1,2] — [1]Physikalisches Institut, Universität Heidelberg — [2]Max-Planck-Institut für Kernphysik

We report on our progress towards the realization of a three-component Fermi gas of ^{6}Li atoms in a two-dimensional optical lattice. A three-component Fermi gas with its approximate SU(3) symmetry can serve as a simplified model system for QCD problems. In free space, however, the gas is not stable due to a large three-body loss rate. This issue can be overcome with the help of a lattice potential, which is predicted to block three-body losses and thus to stabilize the system.

We have set up a magneto-optical trap, from which precooled atoms will be transferred to an optical dipole trap and evaporatively be cooled to degeneracy. They will then be transferred into a two-dimensional optical lattice.

Q 57.19 Thu 16:30 P1

Bosons and fermions in three-dimensional optical lattices: Multi-band and nonlinear hopping corrections — •Alexander Mering and Michael Fleischhauer — Fachbereich Physik and research center OPTIMAS, Technische Universität Kaiserslautern

Recent experiments revealed the importance of higher-band effects for the Mott insulator – superfluid transition of ultracold bosonic atoms or mixtures of bosons and fermions in deep optical lattices [Best *et al.*, PRL **102**, 030408 (2009); Will *et al.*, Nature **465**, 197 (2010)]. In the present work, we derive an effective lowest-band Hamiltonian in 3D that generalizes the standard Bose-Fermi Hubbard model taking these effects into account within an adiabatic elimination scheme of virtual transitions to higher bands. Nonlinear corrections of the tunneling amplitudes mediated by interspecies interactions being neglected so far are shown to be of equal importance. Further more, a correct description of the lattice states in terms of the bare-lattice Wannier functions turns out to be essential in contrast to approximations such as harmonic oscillator states. Especially for repulsive interactions, our approach reveals the importance of the interplay between nonlinear and higher-band corrections for the understanding of the observed shift of the MI-SF transition.

Q 57.20 Thu 16:30 P1

Interacting instabilities in spin-orbit coupled one dimensional Spinor condensates — •Frank Zimmer, Andreas Jacob, and Rejish Nath — Max-Planck-Institut für Physik komplexer Systeme, Nöthnitzer Str. 38, 01187 Dresden

Homogeneous Bose Einstein condensates with repulsive short-range interactions are always stable against small perturbations. Once spin-orbit (SO) coupling is introduced they exhibit a finite momentum instability. Such an instability may lead to the formation of standing waves in 1D or vortex arrays in 2D, depending on the interactions in the system.

If interactions are attractive, in addition to the already existing unstable finite momentum modes, unstable low momentum phonon excitations occur. They emerge due to the SO coupling present in the system. Such a novel scenario in BECs is studied by means of Landau modulation equations. We discuss in detail the possible stable solutions associated with interacting instabilities.

Q 57.21 Thu 16:30 P1

Perspectives of Few Body Physics in an Ultracold Mixture of ^{6}Li and ^{133}Cs — •Romain Müller, Marc Repp, Rico Pires, Juris Ulmanis, Stefan Schmidt, Kristina Meyer, and Matthias Weidemüller — Physikalisches Institut, Ruprecht-Karls-Universität Heidelberg, Heidelberg, Germany

The ability to precisely control the interactions in a Bose-Fermi mixture of ^{133}Cs and ^{6}Li at phase-space densities close to quantum degeneracy results in the opportunity to study many different aspects of few- and many body physics in a system with the highest mass imbalance between alkali atoms.

To observe few body effects precise characterization and tuning of interspecies interactions via magnetic field (i.e. knowledge of *Feshbach resonances*) beetween ^{133}Cs and ^{6}Li are necessary. Additionally, the extremely large mass-difference of Li and Cs results in the smallest scaling factor of all alkali combinations for the appearance of universal Efimov states of 4.88 (in comparison to 22.7 for homo-nuclear mixtures) for $^{133}Cs_2{}^6Li$. A precise control over the scattering length enables the observation of a large series of this trimer states [1,2].

In this poster we present the structure of Feshbach resonances for a mixture of ^{133}Cs and ^{6}Li that is calculated using the Asymptotic-Bound-State model [3]. We discuss the experimental approach used to study Efimov physics and other few body effects in this mixture.

[1] E. Braaten and H.-W. Hammer, AnnPhys **322**, 120 (2007)
[2] K. Helfrich *et al.*, PRA **81**, 042715 (2010)
[3] T. G. Tiecke *et al.*, PRA **82**, 042712 (2010)

Q 57.22 Thu 16:30 P1

Non-abelian Gauge-field simulators with cold atoms — •Naceur Gaaloul[1], Torben Schulze[1], Holger Ahlers[1], Sebastian Bode[1], Felix Kösel[1], Vyacheslav Lebedev[1], Wolfgang Ertmer[1], Luis Santos[2], and Ernst Rasel[1] — [1]Institut für Quantenoptik, LU Hannover — [2]Institut für Theoretische Physik, LU Hannover

The study of strongly correlated regimes using cold-atom systems is a long-standing challenge for physicists. The charge neutrality of the atoms and the consequent absence of a Lorentz force are strong limitations to this end. The experimental realization of rotating degenerate quantum gases demonstrated the potential of atomic systems to simulate charged particles subject to a uniform magnetic field. However, due to centrifugal forces and technical issues this method turned out to be of limited use. Recently, several proposals showed that preparing coherent superpositions of Zeeman sub-states of atoms which evolve adiabatically in a laser field could drive the matter wave to acquire a Berry phase. This phase translates into a non-vanishing synthetic magnetic field which could be used to engineer a Lorentz force-like for atoms. We present a practical scheme where atomic populations of a degenerate spinor system are driven by appropriate laser arrangements leading to the appearance of gauge field structures. The use of realistic parameters and atomic spectral data make of this method a receipt to implement quantum simulators of gauge fields including the general class of non-abelian (non-commutative) gauges, so far never observed for atoms.

Q 57.23 Thu 16:30 P1

Towards Bose-Fermi mixtures in disordered optical lattices — •Mathis Baumert[1], Nadine Meyer[1,2], Michael Holynski[1], Marisa Perea Ortiz[1], Kai Bongs[1], and Jochen Kronjäger[1] — [1]University of Birmingham, School of Physics & Astronomy, Birmingham, United Kingdom — [2]Universität Hamburg, Institut für Laserphysik, Hamburg, Germany

We are presenting progress towards a new setup for a ^{87}Rb - ^{40}K quantum gas mixture experiment aiming for in situ single site resolution in order to investigate disorder effects in the phase diagram.

In this poster we present glueing techniques for glass-metal window seals. This allows the use of window ports without the use of flanges, significantly reducing the size of our vacuum chamber. This in conjunction with a newly developed ultra compact magnetic coil design allows for high magnetic fields (e.g. Feshbach resonances) being generated with comparably low power.

We also present simulations for optical lattices in 2D and possible realisations of arbitrary optical potentials via SLM techniques.

We acknowledge support by EPSRC under grants EP/E036473/1 and EP/H009914/1.

Q 57.24 Thu 16:30 P1

Spontaneous Breaking of Spatial and Spin Symmetry in Spinor Condensates — Manuel Scherer[1], Bernd Lücke[1], •Jan Peise[1], Garu Gebreyesus[2], Oliver Topic[1], Frank Deuretzbacher[2], Wolfgang Ertmer[1], Luis Santos[2], Jan Arlt[3], and Carsten Klempt[1] — [1]Institut für Quantenoptik, Leibniz Universität Hannover, 30167 Hannover, Germany — [2]Institut für Theoretische Physik, Leibniz Universität Hannover, 30167 Hannover, Germany — [3]QUANTOP, Department of Physics and Astronomy, University of Aarhus, 8000 Århus C, Denmark

Spin-changing collisions can be utilized as parametric amplification of quantum fluctuations, a fundamental mechanism for spontaneous symmetry breaking. We realize a parametric amplifier for spin modes by a spinor Bose-Einstein condensate, resulting in a twofold spontaneous breaking of spatial and spin symmetry in the amplified clouds. Our experiment provides a precise analysis of the amplification of spatial Bessel-like modes, and a detailed understanding of the twofold symmetry breaking. On magnetic resonances that create vortex-antivortex superpositions, we demonstrate that the cylindrical spatial symmetry is spontaneously broken. However, spin symmetry is preserved as a consequence of phase squeezing. If nondegenerate spin modes contribute to the amplification, quantum interferences produce spin-dependent density profiles and lead to spontaneously formed patterns in the longitudinal magnetization.

Q 57.25 Thu 16:30 P1

An atomic parametic amplifier for the production of non-classical States — Manuel Scherer[1], •Bernd Lücke[1], Jens Kruse[1], Jan Peise[1], Oliver Topic[1], Frank Deuretzbacher[2], Wolfgang Ertmer[1], Jan Arlt[3], Luis Santos[2], and Carsten Klempt[1] — [1]Institut für Quantenoptik, Leibniz Universität Hannover, — [2]Institut für Theoretische Physik, Leibniz Universität Hannover — [3]QUANTOP, Department of Physics and Astronomy, University of Aarhus

In optics, parametric amplification is one of the most important tools to prepare non-classical states and investigate phenomena like squeezing and entanglement. In our experiment, we expand this process to the field of ultra cold atoms where we observe non-classical states of matter.

We use the non-linearity of the interactions in Bose-Einstein-Condensates with a spin degree of freedom to generate two entangled ensembles of atoms in the magnetic states $m_F = \pm 1$. These ensembles are analog to the signal and idler beam of an optical parametric amplifier and thus show non-classical correlations.

One effect of these correlations is a reduced fluctuation of the population of the magnetic sub-states. We measured the corresponding variance to be well below the shot-noise limit. The measurements are consistent with the properties of a twin Fock-state with exactly the same number of atoms in both sub-states. Such twin-Fock states may be used to perform interferometric measurements at the Heisenberg-limit.

Q 57.26 Thu 16:30 P1

Quantum fluctuations in the time-dependent BCS-BEC crossover — •Bernhard M. Breid and James R. Anglin — Technische Universität Kaiserslautern, Germany

We report our theoretical results on various aspects connected with the time-dependent formation of a molecular BEC out of an atomic BCS state by a slow Feshbach sweep at zero temperature. In order to solve for the systems dynamics, we apply a path integral approach using adiabatic approximations to solve for an effective action for the molecules. We are then in a position to address questions like the non-adiabatic production of quasi-particles during the sweep and the effect of different sweep rates.

Q 57.27 Thu 16:30 P1

Quantum dynamics of few ultra-cold atoms in a periodically shaken optical superlattice — Martin Esmann, Kirsten Stiebler, Bettina Gertjerenken, Niklas Teichmann, and •Christoph Weiss — Institut für Physik, Universität Oldenburg, 26111 Oldenburg

Photon-assisted tunneling is investigated both numerically and analytically in periodically shaken superlattices. While fractional photon-assisted tunneling was previously shown to be a small effect [1-3], for few particles (cf. [4]) in each of the double wells of an optical superlattice it can actually be a leading order effect. Experimentally, this should be observable with the existing experimental setup of Ref. [4]. Two-particle Schrödinger cat-states in three-well lattices are also investigated.

[1] N. Teichmann, M. Esmann, and C. Weiss, Phys. Rev. A, 79:063620, 2009.

[2] E. Haller, R. Hart, M. J. Mark, J. G. Danzl, L. Reichsöllner, and H.-C. Nägerl, Phys. Rev. Lett., 104:200403, 2010.

[3] G. Lu, W. Hai, H. Zhong, and Q. Xie, Phys. Rev. A, 81:063423, 2010.

[4] P. Cheinet, S. Trotzky, M. Feld, U. Schnorrberger, M. Moreno-Cardoner, S. Fölling, and I. Bloch, Phys. Rev. Lett., 101:090404, 2008.

Q 57.28 Thu 16:30 P1

Quantum Phase Diagram for Bosons in Optical Lattices with On-Site Interaction Modulation — •Francisco Ednilson Alves dos Santos[1] and Axel Pelster[2] — [1]Institut für Theoretische Physik, Freie Universität Berlin, Arnimallee 14, 14195 Berlin, Germany — [2]Fachbereich Physik, Universität Duisburg-Essen, Lotharstrasse 1, 47048 Duisburg, Germany

In the seminal paper [1] Walter Kohn showed with the help of Floquet theory that periodic systems, which weakly interact with a heat bath, necessarily evolve towards an equilibrium. On this basis we generalize the Ginzburg-Landau theory for bosons in optical lattices [2,3] to a single-band Bose-Hubbard Hamiltonian where the on-site interaction is periodically modulated. This allows us to characterize the location of the quantum phase transition between the Mott insulator and the superfluid for such a periodically driven system.

[1] W. Kohn, J. Stat. Phys **103**, 417 (2001).

[2] F.E.A. dos Santos and A. Pelster, Phys. Rev. A **79**, 013614 (2009).

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

Q 57.29 Thu 16:30 P1

Magnetic phases of spinor quantum gases in hexagonal optical lattices — •Eva-Maria Richter[1], Dirk-Sören Lühmann[2], and Daniela Pfannkuche[1] — [1]I. Institut für Theoretische Physik, Universität Hamburg, Germany — [2]Institut für Laser-Physik, Universität Hamburg, Germany

Ultracold quantum gases in optical lattices have been established as a continuously growing field of research with various applications in different areas of science. While cubic lattices are theoretically and experimentally investigated in the majority of cases so far, our focus rests on spinor bosons in hexagonal lattices. By employing a triangular optical lattice with defined polarized laser beams, a hexagonal 'magnetic' optical lattice is created. Bosonic atoms in different spin quantum states are subject to different optical potentials, which depend on their internal state. Thus, the hexagonal optical lattice consists of two sublattices A and B, induced by the polarization which is mapped to an effectiv site dependent magnetic field. This leads to a spin de-

pendent Zeeman shift beetween the two sublattices. Starting from the Bose-Hubbard-Hamiltonian and within the framework of exact diagonalization for finite systems with periodic boundary conditions we investigate the different quantum phases depending on various lattice parameters and different particle numbers. We discriminate different phases by their corresponding pair-correlation functions. Phases with next-neighbour pairing are observed as well as antiferromagnetic ordering. We compare our numerical results with those of a meanfield approximation and with experiments.

Q 57.30 Thu 16:30 P1

Non-equilibrium dynamics in a Kondo lattice of ultracold fermionic alkaline-earth-metal atoms — •Sebastian Bock[1,2], Matthias Kronenwett[1,2], Michael Foss-Feig[3], Ana Maria Rey[3], and Thomas Gasenzer[1,2] — [1]Institut für theoretische Physik, Philosophenweg 16, 69120 Heidelberg — [2]ExtreMe Matter Institute EMMI, GSI Helmholtzzentrum für Schwerionenforschung GmbH, Planckstr. 1, 64291 Darmstadt — [3]JILA, University of Colorado, Boulder CO-80309, USA

We study the dynamics of ultracold Fermi gases far from thermal equilibrium. We employ a functional-integral approach based on the Schwinger-Keldysh closed time path integral to derive the two-particle irreducible (2PI) effective action. From this, the two-point correlation functions are determined self-consistently. The action is expanded in inverse powers of N, where N is the number of atomic hyperfine states. The dynamic equations are derived in next-to-leading order of this expansion. This approach reaches far beyond mean-field theory and includes quantum statistical aspects of equilibration dynamics. This formalism is especially suited to describe far-from-equilibrium dynamics in a Kondo lattice of ultracold fermionic alkaline-earth-metal atoms where N can be as large as 10.

Q 57.31 Thu 16:30 P1

Repulsiv gebundene Teilchenpaare aus Bosonen und Fermionen im optischen Gitter — •Eva Katharina Rafeld, Bernd Schmidt und Walter Hofstetter — Institut für Theoretische Physik, Goethe-Universität Frankfurt am Main

Wir untersuchen analytisch und numerisch das Phasendiagramm repulsiv und attraktiv gebundener Teilchenpaare in optischen Gittern, die aus verschiedenen Teilchensorten bestehen (z. B. zweikomponentige Fermionen, Boson-Fermion-Paare oder Paare aus verschiedenen Bosonen). Repulsiv gebundene Teilchenpaare, die aus gleichen Bosonen bestehen, wurden schon experimentell realisiert und auch theoretisch untersucht. Bei Teilchenpaaren, die aus verschiedenen Teilchensorten bestehen, hat man jedoch noch eine viel größere Flexibilität, die effektive Wechselwirkung zwischen den Paaren einzustellen. Wir leiten daher die effektiven Vielteilchen-Hamiltonoperatoren für die unterschiedlichen Teilchenpaare her. Da die effektiven Hamiltonoperatoren der Paare dem Spin-1/2 XXZ Modell äquivalent sind, ist es dank der Flexibilität der effektiven Wechselwirkung möglich, sämtliche Phasen, die das XXZ Model aufweist, auch bei den Teilchenpaaren zu beobachten. Im eindimensionalen Fall berechnen wir dazu Teilchenzahlverteilungen und Korrelationen der Paare im harmonischen Fallenpotential und im Kastenpotential mit Hilfe der Time Evolving Block Decimation (TEBD) Methode. Da das Phasendiagramm des Spin-1/2 XXZ Model in 1d analytisch exakt bekannt ist, erlaubt es uns eine vollständige und exakte Klassifizierung und Interpretation der Teilchenpaarverteilungen in 1d.

Q 57.32 Thu 16:30 P1

Quantum dynamics in the bosonic Josephson junction — •Moritz Hiller[1], Maya Chuchem[2], Katrina Smith-Mannschott[3,4], Tsampikos Kottos[3], Amichay Vardi[5,6], and Doron Cohen[2] — [1]Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, Hermann-Herder-Str. 3, 79104 Freiburg — [2]Department of Physics, Ben-Gurion University of the Negev, P.O.B. 653, Beer-Sheva 84105, Israel — [3]Department of Physics, Wesleyan University, Middletown, Connecticut 06459, USA — [4]MPI für Dynamik und Selbstorganisation, Bunsenstraße 10, 37073 Göttingen — [5]Department of Chemistry, Ben-Gurion University of the Negev, P.O.B. 653, Beer-Sheva 84105, Israel — [6]ITAMP, Harvard-Smithsonian CFA, 60 Garden St., Cambridge, Massachusetts 02138, USA

We employ a semiclassical picture to study dynamics in a bosonic Josephson junction with various initial conditions [1]. Phase-diffusion of coherent preparations in the Josephson regime is shown to depend on the initial relative phase between the two condensates. For initially incoherent condensates, we find a universal value for the buildup of coherence in the Josephson regime. In addition, we contrast two seemingly similar on-separatrix coherent preparations, finding striking differences in their convergence to classicality as the number of particles increases.

[1] M. Chuchem *et al.*, Phys. Rev. A **82**, 053617 (2010)

Q 57.33 Thu 16:30 P1

Spectral origin of decaying Bloch oscillations — •Hannah Venzl, Moritz Hiller, and Andreas Buchleitner — Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, Hermann-Herder-Str. 3, 79104 Freiburg

We study Bloch oscillations of ultracold bosonic atoms in tilted optical lattices. Our analysis is based on the Bose-Hubbard Hamiltonian amended by a static field term. For comparable values of the control parameters, namely the inter-atomic interaction, the tunneling coupling, and the static field, the system displays chaotic level statistics. In this regime, the Bloch oscillations exhibit an irreversible and fast decay. We show that the corresponding decay rate can be obtained from the spectral properties of the Hamiltonian by investigating the weighted distribution of frequencies appearing in the local density of states.

Q 57.34 Thu 16:30 P1

Realization of Tunable Tunneling Dynamics and New Phases in Triangular Optical Lattices — •Christoph Ölschläger, Julian Struck, Christina Staarmann, Parvis Soltan-Panahi, Rodolphe Le Targat, Patrick Windpassinger, and Klaus Sengstock — Institut für Laser-Physik, Universität Hamburg, 22761 Hamburg, Germany

Ultracold quantum gases in optical lattices are well suited to investigate and simulate systems known from other physical branches.

Here we report on the simulation of new non-ferromagnetic phases of spinless bosons in triangular lattices that can be described in analogy to magnetism in solid state physics. The additional degree of freedom in our system is the possibility to change the order and sign of the tunneling matrix elements between adjacent lattice sites. An independent control of the various tunneling parameters is achieved by a fast elliptical lattice acceleration. This is induced by frequency modulations of the lattice beams where the well adjustable modulation amplitudes determine the resulting tunneling dynamics.

First experimental observations and analysis of the different phases in the weakly interacting regime are presented. The excellent agreement between theoretical predictions (Eckardt et al. [1]) and the observed phases is promising to explore the strongly interacting regime and associated new quantum phases like a spin-liquid.

[1] A. Eckardt et al., EPL 89, 10010 (2010)

Q 57.35 Thu 16:30 P1

Local mean field in optical lattices — •Astrid E. Niederle and Heiko Rieger — Universität des Saarlandes, Germany

The properties of a Bose-Einstein condensate in an optical lattice are under investigation here and studied using local mean-field theory [2]: By definition of the so called superfluid order parameter, the high dimensional Hamiltonian describing the system can be decomposed in a sum of on-site Hamiltonians. This on-site Hamiltonian forms the starting point for our investigations, in order to investigate the system in different dimensions and various geometries. Through a detailed study of the groundstate properties we observe the competing phases. The Mott lobes separate the insulating from the superfluid phase and in the presence of disorder [1] the Bose glass appears in between. Moreover this investigations in local mean-field theory can be carefully expanded to the hole spectrum in order to study time dependent effects.

[1] J. Kisker and H. Rieger, Phys. Rev. B 55, 11981 (1997)
[2] P. Buonsante, A. Vezzani, Phys. Rev. A 70, 033608 (2004)

Q 57.36 Thu 16:30 P1

Effective occupation-dependent tunneling in optical lattices — •Maria Langbecker, Ole Jürgensen, Dirk-Sören Lühmann, and Klaus Sengstock — Institut für Laser-Physik, Universität Hamburg, 22761 Hamburg, Germany

Usually, atoms in optical lattices are described by single-band Hubbard models. The admixture of higher bands caused by interactions leads to non-negligible changes of the tunneling matrix elements. As a consequence the tunneling process becomes explicitly occupation-dependent which gives rise to an effective Hubbard Hamiltonian and novel exciting quantum phases.

We calculate the effective tunneling in optical lattices using a mean-field approach solely dependent on the occupation number of higher orbitals. This simple effective picture already gives results that compare well with the fully correlated treatment and visualizes intuitively the impact of higher-band tunneling processes. Even for few particles per lattice site, the effective tunneling differs notably from the single-band tunneling for both purely bosonic systems and boson-fermion mixtures.

The results demonstrate, in general, the important role of higher-band processes in optical lattices.

Q 57.37 Thu 16:30 P1

Quantum Many-Body Systems on the Single-Atom Level — •P. Schauss, C. Weitenberg, M. Endres, J. F. Sherson, M. Cheneau, T. Fukuhara, I. Bloch, and S. Kuhr — Max- Planck-Institut für Quantenoptik, Hans-Kopfermann-Str. 1, D-85748 Garching

Investigations of ultracold quantum gases in optical lattices have so far been mostly restricted to access global information of the system. Here we present a detection technique that enables us to measure the local distribution of the particles on a single-site and single-atom level[1].

Using a high resolution objective we observed fluorescence images of bosonic Mott insulators in the atomic limit. We reconstructed the atom distribution on the lattice from our images and identified individual excitations with high fidelity. A comparison of the radial density and variance distributions with theory provides a precise in situ temperature and entropy measurement from single images.

Furthermore we will present progress towards in-situ thermometry and the direct measurement of correlations across the superfluid-to-Mott-insulator transition.

[1] J. Sherson et al., Nature 467, 68 (2010).

Q 57.38 Thu 16:30 P1

Detection of the Amplitude Mode in a Strongly Interacting Superfluid by Bragg Spectroscopy — •Sören Götze, Jannes Heinze, Jasper Simon Krauser, Bastian Hundt, Nick Fläschner, Christoph Becker, and Klaus Sengstock — Institut für Laser-Physik, Universität Hamburg

By the creation of ultracold quantum gases in optical lattices, superfluidity can be studied over a wide range of tunable parameters, including the regime of strong correlations. However, for an in-depth understanding of the system's excitational structure, especially in the strongly correlated regime, new methods of detection and analysis are required [1]. We report on the first dedicated investigation of the recently proposed amplitude mode using Bragg spectroscopy on a strongly interacting BEC in a 3D optical lattice. We compare our data with a spatially resolved, time-dependent dynamic Gutzwiller calculation and thereby clearly identify the underlying mode structure, including systematic shifts of the resonances, e.g. due to the backaction of the Bragg beams and beyond linear response effects [2].

[1] P. T. Ernst et al., Probing superfluids in optical lattices by momentum-resolved Bragg spectroscopy, Nature Physics advance online publication, 29.11.2009 (DOI: 10.1038/nphys1476)

[2] U. Bissbort et al., Detecting the Amplitude Mode of Strongly Interacting Lattice Bosons by Bragg Scattering, arXiv:1010.2205

Q 57.39 Thu 16:30 P1

Probing ultracold fermions in optical lattices — •Jasper Simon Krauser, Sören Götze, Jannes Heinze, Bastian Hundt, Nick Fläschner, Dirk-Sören Lühmann, Christoph Becker, and Klaus Sengstock — Institut für Laserphysik, Universität Hamburg

Quantum gases in optical lattices offer a wide range of applications for quantum simulation due to fully tunable lattice and atomic interaction parameters. In our setup we sympathetically cool ^{87}Rb and ^{40}K and load this mixture into an optical lattice superimposed with a magic dipole trap. In this poster, we discuss experimental aspects and recent results of our Bose-Fermi mixture project. In detail, we report on high resolution spectroscopy of ultracold fermions in optical lattices with full momentum resolution. We can accurately extract the band structure and filling information allowing for the determination of the phase of the system. Our experimental sensitivity is promising for the extension of these studies to observe interaction shifts due to the presence of bosonic atoms [1,2] as well as changes in the density of states for interacting fermionic gases.

[1] Lühmann et al., PRL 101, 050402 (2008)

[2] Best et al., PRL 102, 030408 (2009)

Q 57.40 Thu 16:30 P1

Interacting Fermions in Optical Lattices - Exploring the Fermi-Hubbard Hamiltonian — •Jens Philipp Ronzheimer[1], Lucia Hackermüller[2], Simon Braun[1], Michael Schreiber[1], Tim Rom[1], Sebastian Will[1], Thorsten Best[3], Ulrich Schneider[1], and Immanuel Bloch[1] — [1]LMU München & MPQ Garching — [2]U Nottingham — [3]ALU Freiburg

Fermions in optical lattices can constitute an ideal and defect-free implementation of the Fermi-Hubbard Hamiltonian. While being more accessible to measurements than condensed matter systems, they allow at the same time for the direct manipulation of all relevant parameters.

We report on experiments with a two-component ultracold Fermi gas of ^{40}K atoms in a blue detuned lattice. Previous experiments regarding equilibrium states of the Fermi-Hubbard Hamiltonian as well as results on the dynamics of out-of-equilibrium states in the homogeneous Hubbard model are presented.

The experimental setup allows for a variety of experiments with Bose-Fermi and Fermi-Fermi mixtures in optical lattices in 1,2 and 3 dimensions. Employing a red detuned Dipole trap and a blue detuned lattice at tunable wavelength, we are able to adjust every parameter of the respective Hamiltonians individually. The experimental setup has been rebuilt after moving to the LMU in Munich and we present the improved parameters as well as an analysis of current challenges and ways to overcome them.

Q 57.41 Thu 16:30 P1

Novel Preparation Schemes for Hexagonal Lattices — •Christina Staarmann, Parvis Soltan-Panahi, Julian Struck, Christoph Ölschläger, Dirk-Sören Lühmann, Rodolphe Le Targat, Patrick Windpassinger, and Klaus Sengstock — Institut für Laser-Physik, Universität Hamburg, Luruper Chaussee 149, 22761 Hamburg, Germany

We have recently realized a spin-dependent hexagonal lattice, which imposes an intrinsic magnetic ordering on the atoms [1]. In this way, it is possible to uniquely study interaction effects between different spin-states leading to novel quantum phases such as the realization of an interaction induced mixing of the s- and p-band states in the superfluid regime. Another interesting aspect of the hexagonal lattice geometry is its linear – Dirac-particle like – dispersion relation at the vicinity of the so-called Dirac cones which can even be explored in case of an ultracold cloud of bosonic atoms, such as ^{87}Rb.

Here, we present a novel experimental preparation scheme, which allows for an in-situ manipulation of the spin-dependent potential. This is achieved by a controlled change of the magnetic quantization axis of the system. In this way it is also possible to continuously tune the band-gap at the Dirac cone, offering an important prerequisite to study Dirac-like physics with ultracold atoms.

[1] Multi-Component Quantum Gases in Spin-Dependent Hexagonal Lattices: P. Soltan-Panahi, J. Struck, P. Hauke, A. Bick, W. Plenkers, G. Meineke, C. Becker, P. Windpassinger, M. Lewenstein, K. Sengstock, Preprint: arXiv:1005.1276 (2010)

Q 57.42 Thu 16:30 P1

Interacting Bose-Fermi Mixtures in Optical Lattices — •Simon Braun[1], Sebastian Will[1], Thorsten Best[2], Philipp Ronzheimer[1], Michael Schreiber[1], Tim Rom[1], Ulrich Schneider[1], Dirk-Sören Lühmann[3], and Immanuel Bloch[1] — [1]Ludwig-Maximilians-Universität München — [2]Albert-Ludwigs Universität Freiburg — [3]Universität Hamburg

Mixtures of ultracold quantum gases in optical lattices form novel quantum many-body systems, whose properties are governed by an intriguing interplay of quantum statistics, inter- and intraspecies interactions, as well as the relative atom numbers of the constituents.

In our setup, we cool bosonic ^{87}Rb and fermionic ^{40}K to simultaneous quantum degeneracy. We realize a Bose-Fermi Hubbard model by loading the atoms into the combined potential of a blue-detuned three-dimensional optical lattice and a red-detuned dipole trap. Interspecies interactions are controlled using Feshbach resonances and Raman transitions between different Zeeman sublevels.

Our investigations of the many-body properties of an attractively interacting Bose-Fermi mixture revealed a marked shift in the superfluid to Mott insulator transition due to selftrapping. By studying the quantum collapse and revival dynamics of the bosonic component in the 3D optical lattice, we were able to measure the Bose-Bose and Bose-Fermi interaction energies with high precision and revealed a modification of Bose-Bose interactions induced by an interacting fermion.

Finally, we present improvements to the experimental apparatus implemented after relocation to Munich.

Q 57.43 Thu 16:30 P1

The Dicke quantum phase transition in an optical cavity QED system — •Rafael Mottl[1], Kristian Baumann[1], Ferdinand Brennecke[1], Tobias Donner[1], Christine Guerlin[2], and Tilman Esslinger[1] — [1]Institute for Quantum Electronics, ETH Zurich, 8093 Zurich, Switzerland — [2]Thales Research and Technology, 91767 Palaiseau Cedex, France

The Dicke model describes the collective interaction between an ensemble of two-level atoms and a single electromagnetic field mode, and remains a fundamental theme in quantum optics. In the thermodynamic limit this system was predicted to undergo a quantum phase transition from a normal to a superradiant phase. We have achieved its first experimental realization in an open system in which a Bose-Einstein condensate is loaded into an optical high-finesse cavity. The superfluid atoms collectively couple a far-detuned pump field to the empty cavity mode. Above a critical pump power the atoms self-organize into an emergent checkerboard pattern which shows supersolid character. The boundary of this novel phase was mapped out and coincides with its theoretical description by the Dicke model. Investigating the excitation spectrum below threshold by Bragg spectroscopy, we could identify a vanishing energy gap when approaching the critical point - a precursor of the quantum phase transition.

Q 57.44 Thu 16:30 P1

Experiments with ultracold atoms in optical superlattices — •Monika Aidelsburger[1], Marcos Atala[1,2], Yu-Ao Chen[1,2], Sylvain Nascimbène[1,2], Stefan Trotzky[1], and Immanuel Bloch[1,2] — [1]Fakultät für Physik Ludwig-Maximilians-Universität, 80799 München, Deutschland — [2]Max-Planck-Institut für Quantenoptik, 85748 Garching, Deutschland

Optical lattices became an essential tool for simulating condensed matter physics with ultracold atoms. By adding a standing wave with twice the periodicity to one of the three axis of a simple cubic lattice we can create a three-dimensional array of isolated double wells. We would like to present our recent experiments done in this configuration and discuss the extension of the current system to a two-dimensional superlattice. This will enable us to investigate minimum forms of topologically ordered quantum states in isolated plaquettes, such as Resonating Valence Bond states and to study ring exchange interactions, the basic ingredient of lattice gauge theories.

Q 57.45 Thu 16:30 P1

Non-Equilibrium Phase Transition of Ultracold Bosons in an Optical Lattice Coupled to a BEC Reservoir — •Mathias Hayn[1] and Axel Pelster[2] — [1]Institut für Theoretische Physik, Freie Universität Berlin, Arnimallee 14, 14195 Berlin, Germany — [2]Fachbereich Physik, Universität Duisburg-Essen, Lotharstrasse 1, 47048 Duisburg, Germany

Recently, a promising quantum optical realization for a driven-dissipative many-body system of bosons in a lattice was proposed [1], in which the competition of unitary Hamiltonian and dissipative Liouvillian dynamics leads to a non-equilibrium phase transition [2]. At first, we give a detailed derivation of this model, based on microscopic Hamiltonians for both bosons in an optical lattice and for a bath in form of a weakly interacting Bose gas. We obtain the result that the dynamics of the bosons in the optical lattice can be described by a master equation in Linblad form, with the dissipative coupling being non-zero only in one dimension. Afterwards, we convert the master equation into a hierarchy of moment equations, which is approximately solved. In the limit of small particle densities we are able to determine, in accordance with the findings of Ref. [2], the order parameter as well as the critical interaction strength, which characterise the onset of a non-equilibrium phase transition from a thermal to a superfluid state.
[1] S. Diehl, A. Micheli, A. Kantian, B. Kraus, H.P. Büchler, and P. Zoller, Nature Phys. **4**, 878 (2008).
[2] S. Diehl, A. Tomadin, A. Micheli, R. Fazio, and P. Zoller, Phys. Rev. Lett. **105**, 015702 (2010).

Q 57.46 Thu 16:30 P1

Quest for anisotropic solitons in dipolar Bose-Einstein condensates — •Patrick Köberle, Rüdiger Eichler, Jörg Main, and Günter Wunner — 1. Institut für Theoretische Physik, Uni Stuttgart

Quasi-two-dimensional bright solitons have been predicted to exist in dipolar Bose-Einstein condensates [1]. Yet, an experimental proof is still lacking. We first present calculations to mark the stability regions for experimentally relevant parameters. We then show the results of simulations of a planned experiment. They demonstrate how solitons can be created dynamically and reveal that this is still possible if some noise is added to the scattering length. This is of special importance because noise is always present in the experiment and could potentially destroy the soliton.
I. Tikhonenkov, B. A. Malomed, and A. Vardi, Phys. Rev. Lett. **100**, 090406 (2008)

Q 57.47 Thu 16:30 P1

General Relativistic Description of Bose-Einstein Condensates — •Oliver Gabel and Reinhold Walser — Institut für Angewandte Physik, Technische Universität Darmstadt, Hochschulstr. 4a, 64289 Darmstadt

Releasing Bose-Einstein condensates from traps is the standard way to observe the state of the system by *time-of-flight* measurements. This free fall is usually limited by the size of the vacuum chamber and is too short to study gravitational physics questions. With the realization of the QUANTUS experiment [1], it has become possible to perform free-fall experiments over large distances of 100 m and long times of 5–10 seconds. After detailed modeling of the Newtonian evolution of the release [2], it becomes relevant to quantify the expected relativistic corrections.

In this contribution, we present first results on the way towards a general relativistic description of free-falling and Earth-bound Bose-Einstein condensates.
[1] T. van Zoest et. Al., *Bose-Einstein Condensation in Microgravity*, Science, **328**, 1540 (2010).
[2] 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 57.48 Thu 16:30 P1

Semiclassical dynamics of self-organization of atoms in optical cavities — •Stefan Schütz[1], Hessam Habibian[2], and Giovanna Morigi[1] — [1]Theoretische Physik, Universität des Saarlandes, D-66041 Saarbrücken, Germany — [2]Departament de Física, Universitat Autònoma de Barcelona, E-08193 Bellaterra, 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. The analysis is based on a model, in which the coupled cavity field and atomic dynamics are evaluated by numerically solving the Heisenberg-Langevin equation in the semiclassical limit, namely, when the number of cavity photons is much larger than unity and the atomic momentum is much larger than the photon recoil [1]. Noise sources are here diffusion due to spontaneous decay and photon losses via the resonator. We study the onset of selforganization, focussing in particular on the patterns obtained, when the atoms belong to different species.
[1] P. Domokos *et al.*, J. Phys. B: At. Mol. Opt. Phys. **34** 187-198 (2001)

Q 57.49 Thu 16:30 P1

Ring structures in linear multipole ion traps — •Florian Cartarius, Cecilia Cormick, and Giovanna Morigi — Theoretische Physik, Universität des Saarlandes, 66041 Saarbrücken, Germany

Doppler cooled ions in linear radiofrequency multipole traps [1] can organize in ordered structures. The equilibrium positions of the ions result from the balance between the mutual Coulomb repulsion and the external trapping potential. If the confinement along the axial direction of the trap is much tighter than along the transverse directions, the ions can form ring-shaped structures. In this work, we theoretically analyse the equilibrium configurations of dozens of ions in anisotropic traps for different orders of the multipolar potential. In particular, we identify parameter regimes where the one-ring arrangement is stable, and study the collective motional modes.

[1] D. Douglas, A. Frank, and D. Mao, Mass Spectrom. Rev. 24, 1-29 (2005)

Q 57.50 Thu 16:30 P1

Experiments with laser-cooled atoms trapped in the evanescent field surrounding an optical nanofiber — •Daniel Reitz[1], Rudolf Mitsch[1], Melanie Müller[1], Samuel T. Dawkins[2], and Arno Rauschenbeutel[1] — [1]Technische Universität Wien - Atominstitut, Stadionallee 2, A-1020 Wien — [2]Johannes Gutenberg-Universität Mainz, AG QUANTUM, 55099 Mainz, Germany

We present recent results of experiments with Cs-atoms in our nanofiber-based optical dipole trap. The atoms are trapped in a 1d optical lattice formed by a two color-evanescent field sourrounding the optical nanofiber. Atoms inside the trap are detected by measuring the transmission of a weak probe beam, launched through the fiber. At resonance, each atom absorbs about one percent of the probe via evanescent field coupling, yielding a high optical density of up to 39 for about 2000 trapped atoms. Adding a second light field in the fiber allows us to coherently prepare the atomic ensemble. First results of measurements of the Autler Townes Effect as well as first observations of electromagnetically induced transparency are presented. Finally, in the dispersive regime, the interaction-induced phase shift experienced by the probe is measured, providing us with additional information. We show that by using this method, the lifetime of the atoms in our trap can be measured non-destructively. Our work opens the route towards the realization of hybrid quantum systems that combine atoms with, e.g., solid state quantum devices and towards non-linear optics applications. Financial support by the Volkswagen Foundation, the ESF and the FWF (CoQuS) is gratefully acknowledged.

Q 57.51 Thu 16:30 P1

Control of refractive index and motion of a single atom by quantum interference — •René Reimann[1], Wolfgang Alt[1], Stefan Brakhane[1], Martin Eckstein[1,2], Tobias Kampschulte[1], Miguel Martinez-Dorantes[1], Artur Widera[1,3], and Dieter Meschede[1] — [1]Institut für Angewandte Physik der Universität Bonn, Wegelerstr. 8, 53115 Bonn — [2]Max-Born-Institut, Abteilung A2, Max-Born-Str. 2 A, 12489 Berlin — [3]Fachbereich Physik der TU Kaiserslautern, Erwin-Schrödinger-Str., 67663 Kaiserslautern

The properties of an optically probed atomic medium can be changed dramatically by coherent interaction with a near-resonant control light field. We will present our experimental results on the elementary case of electromagnetically induced transparency (EIT) with a single neutral atom inside an optical cavity probed by a weak field [1]. We have observed modification of the dispersive and absorptive properties of a single atom by changing the frequency of the control light field in the off-resonant regime.

In this regime, the creation of a transparency window close to a narrow absorption peak can give rise to a sub-Doppler cooling mechanism. We have observed strong cooling and heating effects in the vicinity of the two-photon resonance. The cooling increases the storage time of our atoms twenty-fold to about 16 seconds. Recent investigations of this effect outside the cavity using microwave sideband spectroscopy have revealed that a large fraction of atoms is cooled to the axial ground state of the trap.

[1] T. Kampschulte *et al.*, Phys. Rev. Lett. **105**, 153603 (2010)

Q 57.52 Thu 16:30 P1

Phase space compression with an accelerated diode and mirror potential — •Sönke Schmidt[1], J. Gonzalo Muga[2], and Andreas Ruschhaupt[1] — [1]Institut für Theoretische Physik, LU Hannover, Germany — [2]Departamento de Química Física, UPV-EHU, Bilbao, Spain

We propose a scheme to cool atoms by collision with an accelerated potential. To achieve phase space compression we combine this with an irreversible diodic device. An incoming beam of atoms can pass this diode only in one direction and thus becomes trapped between the diode and the potential. Furthermore it gets slowed due to subsequent collisions with both the moving potential and the diode. We show both analytical and numerical results and compare it to other schemes.

Q 57.53 Thu 16:30 P1

A compact modular 2D-MOT setup — Bastian Höltkemeier, Christoph Hofmann, Simone Götz, •Hannes Busche, and Matthias Weidemüller — Physikalisches Institut, Universität Heidelberg, Philosophenweg 12, 69120 Heidelberg

We present a compact modular source for ultracold rubidium atoms based on the 2D-MOT design first demonstrated in [1]. Aiming for maximal compactness and minimal weight of the setup, a specially designed optics module generates three adjacent cigarshaped cooling regions that allow for two-dimensional atom cooling. By means of two imbalanced counterpropagating pushing beams, a so-called 2D$^+$-configuration is realized. Inspired by [2], the optics module also features a set of permanent bar magnets to generate a two-dimensional magnetic quadrupole field. Using positioning pins, the optics module can easily be attached to or removed from the UHV glass cell. This allows external alignment and facilitates the assembly of the 2D-MOT. So far, two modules are implemented in our Rydberg experiment and our transportable MOTRIMS experiment. In general, the design could be adapted to other alkali atoms, except lithium.

[1] K. Dieckmann et al., Phys. Rev. A 58, 3891 (1998)
[2] T. G. Tiecke et al., Phys. Rev. A 80, 013409 (2009)

Q 57.54 Thu 16:30 P1

Vibrational ground state cooling of a neutral atom in a tightly focused optical dipole trap. — •Syed Abdullah Aljunid[1], JianWei Lee[1], Martin Paesold[2], Brenda Chng[1], Gleb Maslennikov[1], and Christian Kurtsiefer[1] — [1]Centre for Quantum Technologies / Dept. of Physics, National University of Singapore — [2]ETH, Zurich

Recent experiments have shown that an efficient interaction between a single trapped atom and light can be established by concentrating light field at the location of the atom by focusing [1-3]. However, to fully exploit the benefits of strong focusing one has to pinpoint the atom at the maximum of the field strength. The position uncertainty due to residual kinetic energy of the atom in the dipole trap (depth $\sim 1\,\mathrm{mK}$) after molasses cooling is significant (few 100 nm) already for moderate focusing strength [2]. To address this problem we implement a Raman Sideband cooling technique, similar to the one commonly used in ion traps [4], to cool a single ^{87}Rb atom to the ground state of the trap. We have cooled the atom along the transverse trap axis (trap frequency $\nu_\tau = 55\,\mathrm{kHz}$), to a mean vibratonal state $\bar{n}_\tau = 0.55$ and investigate the impact on atom-light interfaces.

[1] M. K. Tey, et al., Nature Physics **4** 924 (2008)
[2] M. K. Tey et. al., New J. Phys. **11**, 043011 (2009)
[3] S.A. Aljunid et al., Phys. Rev. Lett. **103**, 153601 (2009)
[4] C. Monroe et al., Phys. Rev. Lett. **75**, 4011 (1995)

Q 57.55 Thu 16:30 P1

A New Setup for Probing Bose-Fermi Mixtures in Optical Lattices — •Tracy Li[1], Lucia Duca[1], Martin Boll[1], Jens Phillip Ronzheimer[1], Ulrich Schneider[1], and Immanuel Bloch[1,2] — [1]Fakultät für Physik, Ludwig-Maximilians-Universität, 80799 München, Germany — [2]Max-Planck-Institut für Quantenoptik, 85748 Garching, Germany

Degenerate Bose-Fermi mixtures consist of different atomic species with different quantum-statistics. The interactions between these particles can give rise to a rich variety of effects such as novel quantum phases or polaron physics. In particular, by trapping Bose-Fermi mixtures in optical lattices, we can create a controlled and versatile model system for probing condensed-matter phenomena.

In the experiment, the atoms will be lasercooled using a combination of a 2D+ [1] and 3D magneto-optical traps (MOTs). We present and characterize a new design for a 2D+MOT of ^{87}Rb and ^{40}K. The 2D+MOT generates a collimated, continuous beam of atoms for more efficient loading into the two-species 3D MOT. After the MOTs, the mixture is magnetically transported into a glass cell, where sympathetic and evaporative cooling to simultaneous quantum degeneracy occur first in a plugged quadrupole trap and then in a crossed dipole trap. We present the current status of this experiment.

[1] Dieckmann et.al., PRA 58, 3891 (1998).

Q 57.56 Thu 16:30 P1

Trap loss in a double species MOT of Yb and Rb — •Maximilian Madalinski, Cristian Bruni, Frank Münchow, and Axel Görlitz — Institut für Experimentalphysik, HHU Düsseldorf, 40225 Düsseldorf

Ultracold mixtures of two atomic species are an excellent environment to study their interspecies collisions, to produce exotic heteronuclear molecules or to study double species quantum gases. In our experiment we are able to trap seperately 10^9 Rb and 10^7 Yb atoms but we observe a strong loss of Yb in the combined MOT. The Yb MOT uses the $^1S_0$ to $^3P_1$ intercombination transition at 555.8 nm. The production of excited molecules was already achieved in this configuration. Here we present a method of determining the trap loss coefficients of Yb through Rb in our combined trap. Since Yb has trapable bosonic and fermionic isotopes collisions in every combination can be explored.

Q 57.57 Thu 16:30 P1

Segmentierte Oberflächenfalle mit integriertem Magnetfeldgradienten — •Peter Kunert und Christof Wunderlich — Fachbereich Physik, Universität Siegen, 57068 Siegen, Deutschland

Ein erfolgversprechender Ansatz, um Ionenfallen auf kleine Dimensionen zu skalieren und somit zu Arrays erweiterbar zu machen, liegt in der Entwicklung von Oberflächenfallen. Bei diesen Fallen wird durch geschicktes Anlegen von Radiofrequenz- und DC-Spannungen an planaren Elektroden eine Potentialtiefe der Größenordung 0,1 eV zum Einfangen von Ionen erzeugt. Mittels segmentierten DC-Elektroden können die eingefangenen Ionen in der Falle transportiert werden. Dank bekannter Herstellungsmethoden aus der Mikrosystemtechnik (Lithographie, Galvanik) ist die Produktion dieser Fallen zeit- und kostengünstig. Darüberhinaus lassen sich auf den Fallenchips sowohl Leiterbahnen zur Erzeugung von Magnetfeldgradienten am Ort der Ionen als auch Mikrowellenleiter integrieren.

Die Simulationen verschiedener Fallengeometrien werden vorgestellt und analysiert. Verschiedene Ansätze zur Realisierung von Magnetfeldgradienten am Ort der Teilchen werden diskutiert. Die Herstellung eines Fallenchips wird erläutert. Der Aufbau des Experimentes wird präsentiert.

Q 57.58 Thu 16:30 P1

Microwave guiding of electrons in a planar Paul trap — •Roman Fröhlich, Johannes Hoffrogge, Jakob Hammer, and Peter Hommelhoff — Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Straße 1, 85748 Garching bei München

We present an experiment demonstrating the guiding of electrons in a linear Paul trap [1]. The trapping potential is generated by a microstructured planar electrode geometry. The trap is driven at frequencies of around 1 GHz, leading to trap frequencies of about 150 MHz. In comparison to the confinement of ions much higher driving frequencies are necessary because of the higher charge to mass ratio of electrons. We show that guiding works over a range of electron energies from 1eV to 5eV and characterize the effect of substrate charging on the guiding properties. We also investigated the effect of trap stability and depth over a wide range of driving frequencies and voltages. Furthermore we present second generation substrates with high aspect ratio and more complex trap electrode structures, fabricated by thick film lithography. This includes beam splitters and electrically long structures. These devices together with coherent electron emitters like single atom tips may enable applications such as guided electron interferometry.

[1] J. Hoffrogge, R. Fröhlich and P. Hommelhoff - submitted (2010)

Q 57.59 Thu 16:30 P1

Towards sequential BEC production with high repetition rates on a mesoscopic wire structure — Stefan Jöllenbeck[1], •Jan Mahnke[1], Richard Randoll[1], Manuela Hanke[1], Ilka Geisel[1], Wolfgang Ertmer[1], Jan Arlt[2], and Carsten Klempt[1] — [1]Institut für Quantenoptik, Leibniz Universität Hannover — [2]Department of Physics and Astronomy, Aarhus University

The sensitivity of atom interferometers could be increased by using quantum degenerate input states. To gain the advantage of a higher resolution would require a source providing sufficiently large ensembles as well as high repetition rates. While conventional BEC experiments do not reach the required repetition rates, microscopic atom chips may enhance cooling rates. However, atom chips typically capture significantly smaller ensembles. Our aim is to combine the advantages of both types of experiments by using a mesoscopic wire structure to provide the magnetic fields for magneto-optical and magnetic trapping.

Fast sequential BEC production will be achieved by consecutive loading of magneto-optical traps. The captured atoms are subsequently transferred to a shielded vacuum region on a magnetic conveyor belt. By parallel evaporation of several clouds during the transport, high BEC repetition rates of more than 2 Hz will be achievable.

We present our latest results of loading and transporting atoms in our magnetic conveyor belt.

Q 57.60 Thu 16:30 P1

Manipulation of small atom clouds in a microscopic dipole trap — •Andreas Fuhrmanek, Ronan Bourgain, Yvan Sortais, Philippe Grangier, and Antoine Browaeys — Institut d'Optique, RD 128 Campus Polytechnique, 91127 Palaiseau Cedex, France

Recent years have seen a growing interest in the study of small, but dense cold atomic ensembles. Here we present our progress on the manipulation of cold atomic clouds in a regime where they contain only a few tens of atoms. In our case we use 87Rb atoms, trapped in a microscopic optical dipole trap, to study this mesoscopic regime. We use a single atom to measure the resolution of our imaging system. This method provides a calibration of our detection scheme which is useful to understand the regime where many atoms are trapped. We also implement an atom counting method that is capable of reconstructing the atom number distribution inside the dipole trap and allows a acurate measurement of the average atom number. With these techniques in hand we perform measurements on the dipole trap losses in the presence of near resonant light. The results help to understand the mechanisms of subpoissonian dipole trap loading and should be useful for the realisation of a BEC with a few atoms only.

Q 57.61 Thu 16:30 P1

Feedback control of the hyperfine ground states of neutral atoms in an optical cavity — •Miguel Martinez-Dorantes[1], Wolfgang Alt[1], Stefan Brakhane[1], Tobias Kampschulte[1], René Reimann[1], Artur Widera[1,2], and Dieter Meschede[1] — [1]Institut für Angewandte Physik der Universität Bonn, Wegelerstr. 8, 53115 Bonn — [2]Fachbereich Physik der TU Kaiserslautern, Erwin-Schrödinger-Str., 67663 Kaiserslautern

Detection and manipulation of atomic spin states is essential for many experimental realizations of quantum gates. Feedback schemes to stabilize the states and their superpositions can counteract perturbations caused by the environment.

In our experiment we deduce the atomic spin state of one or two Caesium atoms by measuring the transmission of a probe laser through a high-finesse cavity. Depending on the number of atoms in the hyperfine state that strongly couples to the cavity, the resonance of the cavity is shifted and the probe laser transmission is decreased. We employ a Bayesian update formalism to obtain time-dependent probabilities for the atomic states of one and two atoms [1].

We will present an experimental implementation using a digital signal processor which allows us to determine the atomic spin state in real-time. First experimental results of an extension to a feedback loop for the preparation and stabilization of atomic states will be shown.

[1] S. Reick, K. Mølmer *et al.*, J. Opt. Soc. Am. B **27**, A152 (2010)

Q 57.62 Thu 16:30 P1

Single-atom-resolved spin manipulation in a Mott insulator — •T. Fukuhara, C. Weitenberg, M. Endres, J. F. Sherson, M. Cheneau, P. Schauss, I. Bloch, and S. Kuhr — Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Str. 1, D-85748 Garching

Ultracold atoms have attracted a lot of interest due to the excellent controllability of parameters. Extending this control down to single lattice sites is a long-standing quest in the field. Here we report on single-site-resolved spin manipulation in an atomic Mott insulator. A combination of a differential light shift caused by a tightly focused laser beam and a microwave sweep allowed us to flip the spin of selected atoms and to create arbitrary two-dimensional spin patterns starting from a Mott insulator with unity filling. To investigate the effect of our scheme on the motional state of the atoms, we directly observed the coherent tunneling dynamics of single atoms after addressing and found that most of the atoms remained in the motional ground state. Our technique opens new perspectives in a wide range of novel applications from quantum dynamics of spin impurities, entropy transport, implementation of novel cooling schemes, and engineering of quantum many-body phases to quantum information processing.

Q 57.63 Thu 16:30 P1

Hochstabiler Frequenzstabilitätstransfer — •Dave Brauns, Matthias Wolke, Julian Klinner und Andreas Hemmerich — Universität Hamburg, Hamburg, Deutschland

Im Rahmen von Experimenten der Optomechanik mit einem Bose-Einstein-Kondensat in einer Mode eines Hochfinesse-Resonators ist ein hochstabiler Frequenzstabilitätstransfer nötig. Hierzu werden mittels Pound-Drever-Hall-Regelung zwei Laser mit einer Wellenlängendifferenz von mehreren 10 Nanometern auf einen Resonator mit einer Linienbreite von nur 4 kHz stabilisiert. Im nächsten Schritt werden die beiden Laser mit festem Frequenzabstand synchron mittels einer AOM-Regelung auf den Experimentresonator (Linienbreite ca. 20kHz) frequenzstabilisiert. Durch diese Regelungskette wird ein schmalbandiger Experimentierlaser bei einer nahezu beliebigen Frequenz relativ zur Resonatorresonanz zur Verfügung gestellt.

Q 57.64 Thu 16:30 P1

Many-body effects in Rydberg gases — •Martin Gärttner[1], Jörg Evers[1], and Thomas Gasenzer[2] — [1]MPI für Kernphysik, Heidelberg — [2]Institut für theoretische Physik, Heidelberg

The early theoretical treatmet of ensembles of Rydberg atoms fucused on mean field models, which explain the observed Rydberg blockade well, but disregard all quantum many-body features of the system. It has been shown recently [1,2,3] that these microscopic many-body features are important, especially at high atom densities.

We investigate the dynamics of cold interacting Rydberg gases taking into account the full many body Hamiltonian. For small atom numbers we perform fully coherent exact many body simulations. The parameter space is explored for certain toy models with a focus on higher order correlations. More realistic situations with larger atom numbers and decoherence effects are treated by Monte Carlo sampling. Here we make use of the assumption of the Rydberg blockade to reduce the number of basis states of our otherwise tremendously large Hilbert space.

[1] T. Pohl and P. R. Bermann, Phys. Rev. Lett. 102, 013004 (2009)
[2] B. Sun and F. Robicheaux, Phys. Rev. A 78, 040701 (2008)
[3] H. Schempp *et al.*, Phys. Rev. Lett. 104, 173602 (2010)

Q 57.65 Thu 16:30 P1

Mean-field models for correlated Rydberg gases — •Kilian Heeg and Jörg Evers — Max-Planck-Institut für Kernphysik, Heidelberg, Germany

Mean field models are discussed for the description of clouds of Rydberg atoms. We are in particular interested in situations in which n-body correlations with n>2 are of importance, such as in recent experiments on coherent population trapping in Rydberg atoms. We compare different approaches with each other, with experimental data, and with more demanding numerical models, with the aim of estimating the validity range.

Q 57.66 Thu 16:30 P1

Towards experiments with ultracold Rydberg gases at high atomic densities — •Aline Faber, Hannes Busche, Christoph Hofmann, Georg Günter, Hanna Schempp, Martin de Saint-Vincent, Shannon Whitlock und Matthias Weidemüller — Physikalisches Institut, Universität Heidelberg, Philosophenweg 12, 69120 Heidelberg

Rydberg atoms have gained much interest in recent years due to the remarkable fact that their properties like the dipole-dipole interaction or the lifetime can readily be tuned over several orders of magnitude [1]. Latest developments are aiming for effects occurring in ultracold and very dense atomic samples, like Ryberg-ground state molecule formation [2] or dynamical crystallization [3].

We report on the status of our new Rydberg apparatus. The setup combines large optical access with a high level of electric field control. A compact 2D-MOT serves as a high flux source of cold atoms. Combined with all-optical Bose-Einstein condensation in an optical trap at 1064nm the new apparatus will allow for duty cycles of several seconds. The large optical access makes the setup versatile and will allow us to perform Rydberg excitation in very dense atomic samples as well as in optical lattices.

[1] Saffman et al., Rev.Mod.Phys. 82, 2313 (2010)
[2] Bendkowsky et al., Nature 458, 1005 (2009)
[3] Pohl et al., Phys.Rev.Lett. 104, 043002 (2010)

Q 57.67 Thu 16:30 P1

An electron microscope for the detection and manipulation of Rydberg atoms — •Tobias Weber, Torsten Manthey, Julia Grün, Thomas Niederprüm, Vera Guarrera, Giovanni Barontini, and Herwig Ott — Fachbereich Physik, Universität Kaiserslautern

The strong dipole-dipole interaction between Rydberg atoms leads to a huge number of exotic and interesting phenomena (e.g. plasma formation or dipole blockade) that can be studied in the realm of ultracold quantum gases, especially when optical lattices are present. In this poster, we will present a new apparatus for the production, the manipulation and the detection of ultracold Rydberg atoms in optical lattices. The main feature of this apparatus is the presence of a scanning electron microscope inside the vacuum chamber that will allow us the manipulation and the detection of single Rydberg atoms in each lattice site.

Q 57.68 Thu 16:30 P1

A new cavity QED apparatus at work — •Haytham Chibani, Markus Koch, Christian Sames, Maximilian Balbach, Alexander Kubanek, Alexei Ourjoumstev, Pepijn Pinkse, Karim Murr, Tatjana Wilk, and Gerhard Rempe — Max Planck-Institut für Quantenoptik, Hans-Kopfermann-Str. 1, 85748 Garching, Germany

Manipulating the dynamical processes of individual quantum systems quantum by quantum, is one of the most important goals in modern physics. Our quantum system consists of a single atom strongly coupled to a single mode of an optical resonator. We developed a new setup [1] which features an asymmetric cavity with one of the mirrors having a higher transmission. The resulting higher information rate allows an efficient implementation of a real-time feedback scheme which cools the motion of a single atom trapped inside the resonator and, hence, also increases its storage time. The longer storage time in conjunction with the enhanced transmission increases the effective duty cycle of the experiment by almost 3 orders of magnitude compared to our previous work [2]. This paves the way to measure higher order intensity correlations of the transmitted probe light. As a first step towards this goal, we measured the time-dependent three-photon correlation function of the probe light while single atoms were passing through the cavity mode. These measurements provide unique information on the system dynamics, in particular on the doubly excited dressed states.

[1] M. Koch et al., Phys. Rev. Lett. 105, 173003 (2010)
[2] A. Kubanek et al., Nature 462, 898-901 (2009)

Q 57.69 Thu 16:30 P1

Fallendesignstudien für eine deterministische hochauflösende Einzelionenquelle — •Georg Jacob, Stefan Ulm, Andreas Kehlberger, Stefan Weidlich, Ferdinand Schmidt-Kaler und Kilian Singer — Johannes Gutenberg-Universität, Institut für Physik, 55128 Mainz, Deutschland

In den von uns bisher durchgeführten Experimenten wurde eine deterministische Einzelionenquelle auf Basis einer segmentierten Paulfalle realisiert [1]. Auch wurde bereits die Fokusierbarkeit eines mit diesem System erzeugten Ionenstrahls gezeigt [2]. Um die theoretischen Vorhersagen bezüglich der räumlichen Auflösung zu bestätigen ist es unerlässlich die Ionen vor dem Extrahieren in den Grundzustand der Bewegung zu kühlen [3]. Da dies hohe Fallenfrequenzen erfordert und es gleichzeitig notwendig ist die Ionenkristalle in der Falle zu trennen und zu transportieren [4], wurde ein mikrostrukturierter Aufbau gewählt. Des Weiteren wurde die Fallengeometrie mittels numerischer Verfahren [5] hinsichtlich den Anforderungen an die Emittanz und der Geschwindigkeitsverteilung des Ionenstrahls optimiert.

[1] W. Schnitzler et al., Phys. Rev. Lett. **102**, 070501 (2009)
[2] W. Schnitzler et al., NJP **12**, 065023 (2010)
[3] R. Fickler et al., J. Mod. Optics **56**, 2061 (2009)
[4] J. Eble et al., JOSA B **27**, A99 (2010)
[5] K.Singer et al., RMP **82**, 2609 (2010)

Q 57.70 Thu 16:30 P1

Laser cooling of dense atomic gases by collisional redistribution of radiation — •Simon Hasselmann, Anne Sass, Ulrich Vogl, and Martin Weitz — Institut für Angewandte Physik der Universität Bonn, Wegelerstr. 8, 53115 Bonn

We report on a laser cooling mechanism based on collisional redistribution of fluorescence in high pressure gas mixtures of alkali- and noble gas atoms. During atomic collisions in such a strongly pressure broadened system, far red detuned radiation can be absorbed and afterwards be reemitted closer to the unperturbed resonance. During each excitation cycle, kinetic energy of the order of the thermal energy kT is extracted from the sample. In our experiments we use alkali atoms in argon buffer gas at a pressure of several hundred bar and we observe temperature changes up to 527 K within a tenth of a second from an initial temperature of 680 K. The cooling power of this method is four to five orders of magnitude larger than in the Doppler cooling of dilute atomic gases.

Further prospects of the method include the rapid laser cooling of dense gases beyond the critical point of the gas, where investigations of supercooled fluids become viable. We are also planning to explore the cooling of molecular gases with redistribution laser cooling.

Q 57.71 Thu 16:30 P1

Inelastic scattering of a probe particle on a Bose-Einstein condensate — •Stefan Hunn[1], Moritz Hiller[1], Tsampikos Kottos[2], Doron Cohen[3], and Andreas Buchleitner[1] — [1]Albert-Ludwigs-Universität Freiburg, Hermann-Herder-Str. 3, 79104 Freiburg — [2]Department of Physics, Wesleyan University, CT, USA — [3]Department of Physics, Ben-Gurion University, Beer-Sheva, Israel

We devise a microscopic scattering approach to probe the excitation spectrum of a Bose-Einstein condensate: A probe particle with momentum k moves in a waveguide which is placed in the proximity of a BEC confined by an optical lattice. When the particle approaches the condensate, it exchanges energy with the latter. We investigate the statistical properties of the resulting inelastic scattering process. In the parameter regime where the inter-atomic interactions induce chaotic spectral statistics, the inelastic cross section exhibits universal Ericson fluctuations. On the other hand, we show how a mixed regular/chaotic phase space of the underlying mean-field dynamics is reflected in the sparsity of the scattering matrix.

Q 57.72 Thu 16:30 P1

Optical vortices of slow light using tripod scheme — •Algirdas Mekys, Julius Ruseckas, and Gediminas Juzeliunas — Institute of Theoretical Physics and Astronomy, Vilnius University, A. Goštauto 12, LT-01108 Vilnius, Lithuania

We consider propagation, storing and retrieval of slow light in a resonant atomic medium of cold atoms illuminated by two control laser beams of larger intensity [1,2]. The probe and two control beams act on atoms in a tripod configuration of the light-matter coupling. The first control beam is allowed to have an orbital angular momentum. Application of the second vortex-free control laser ensures the lossless (adiabatic) propagation of the probe beam at the vortex core where the intensity of the first control laser goes to zero. Storing and release of the probe beam is accomplished by switching off and on the control laser beams leading to the transfer of the optical vortex from the first control beam to the regenerated probe field. A part of the stored probe beam remains frozen in the medium in the form of atomic spin excitations, a number of which increases with increasing the intensity of the second control laser. We analyze such losses in the regenerated probe beam and provide conditions for the optical vortex of the control beam to be transferred efficiently to the restored probe beam.

[1] A. Raczynski, J. Zaremba, and S. Zielinska-Kaniasty, Phys. Rev. A, **75**, 013810 (2007).

[2] J. Ruseckas, A. Mekys, and G. Juzeliunas, Opt. Spektrosc. **108**, 438 (2010).

Q 57.73 Thu 16:30 P1

Towards a two-species mixed gas of ^{6}Li and ^{133}Cs atoms and LiCs molecules at high phase-space densities — •Stefan Schmidt[1], Marc Repp[1], Johannes Deiglmayr[2], Rico Pires[1], Juris Ulmanis[1], Romain Müller[1], Kristina Meyer[1], Roland Wester[3], and Matthias Weidemüller[1] — [1]Physikalisches Institut, Ruprecht-Karls-Universität Heidelberg — [2]Physikalisches Institut, Albert-Ludwigs-Universität Freiburg — [3]Institut für Ionenphysik und Angewandte Physik, Leopold-Franzens-Universität Innsbruck

The LiCs dimer is a particularly promising candidate for observing dipolar effects, as it possesses the largest dipole moment of 5.5 Debye of all alkali dimers [1]. We have studied the formation of LiCs molecules via photoassociation [2] at MOT temperatures. The population dynamics of ro-vibrational states in a trapped sample of ultracold LiCs molecules via black-body driven transitions or spontaneous decay was further investigated [3].

This poster will present the current status of a redesign of our experimental apparatus. A double-species Zeeman slower will allow to consecutive decelerate Cs and Li atoms. Further cooling steps, like Raman sideband cooling of Cs atoms and forced evaporative cooling in independent dipole traps, will bring the species to quantum degeneracy. After bringing the two gases together, molecules are to be formed via Feshbach resonances followed by a STIRAP step.

[1] J. Deiglmayr *et al.*, Phys. Rev. A 82, 032503 (2010)

[2] J. Deiglmayr *et al.*, Phys. Rev. Lett. 101, 133004 (2008)

[3] J. Deiglmayr *et al.*, in preparation

Q 57.74 Thu 16:30 P1

Spectroscopic determination of YbRb ground state potentials — Frank Münchow, •Cristian Bruni, 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. In our experiment, the ultimate goal is the production of ultracold YbRb molecules in the electronic and rovibrational ground state. The special property of these molecules is that they possess a magnetic as well as an electric dipole moment. As a first step, we have already observed the production of weakly bound and vibrationally highly excited molecules via photoassociation in a combined magneto-optical trap close to the Rb D1-line at 795 nm [1].The next step which is currently under investigation is the spectroscopic determination of the vibrational structure of the electronic ground state. This will be done by so-called Autler-Townes spectroscopy where a second laser is used to probe transitions between the ground and excited molecular state. The knowledge of the molecular binding energies and thus the potential curves will be crucial on the way to the formation of ground state molecules either by STIRAP or using Feshbach resonances.

[1] N. Nemitz, F. Baumer, F. Münchow and A. Görlitz, Phys. Rev. A 79, 061403(R) (2009)

Q 57.75 Thu 16:30 P1

Two dimensional arrays of ultra cold polar molecules: possible structural transitions — •Sofia Kantorovich[1,2], Rudolf Weeber[2], Christian Holm[2], and Hans Peter Buechler[3] — [1]Ural State University, Lenin av. 51, Ekaterinburg, 620000, Russia — [2]ICP, Universitaet Stuttgart, Pfaffenwaldring 27, 70569, Stuttgart, Deutschland — [3]ITP III, Universitaet Stuttgart, Pfaffenwaldring 57, 70550, Stuttgart, Deutschland

Polar molecules have attracted a lot of interest due to their large electric dipole moment, which in combination with external electric fields gives rise to strong dipole-dipole interactions. Recent experimental advances allowed to confine polar molecules by an optical lattice along one axes so, that a set of parallel layers is built. Each dipole moment points along the same axis, therefore, the structure within the layer is dominated by the repulsion, and the interaction between layers is mainly attractive. Here we focus on the classical regime, where the dipole-dipole interaction dominates over the kinetic contribution, and study the ground state of the array of strings of ultra cold polar molecules as a function of the ratio between intermolecular distance within one string and the separation of the strings, and showed that at a certain range one observes a structural transition from the simple square lattice to a 2D hexagonal one. Hence, by changing this ratio one can control ground state configurations, opening new possibilities for an experimental control of the ultra cold polar molecules' arrays. Quantum fluctuations can be implemented in this approach via perturbation theory.

Q 57.76 Thu 16:30 P1

Berry phase in atom optics — •Polina V. Mironova[1,2], Maxim A. Efremov[3], and Wolfgang P. Schleich[1] — [1]Institut für Quantenphysik, Universität Ulm, D-89069 Ulm — [2]Institut für Angewandte Physik, Technische Universität Darmstadt, D-64289 Darmstadt — [3]LPTMS, Université Paris-Sud, 15 rue Georges Clémenceau, F-91405 Orsay cedex

We consider the scattering of a two-level atom from a near-resonant standing light wave. Within the Raman-Nath approximation on the atomic center-of-mass motion, adiabatic turn-on and -off of the interaction together with the rotating wave approximation we obtain a condition for the cancelation of the dynamical phase and show that the scattering picture is determined only by the Berry phase dependent on the internal and external atomic degrees of freedom. Moreover, we propose a novel possibility to observe the Berry phase based on the atomic lens construction. This application of the Berry phase might be useful in the lithography with cold atoms.

We enlarge our analysis of the Berry phase in atom optics by considering the case of atomic scattering by the traveling wave, where we take the kinetic energy operator into account. Here we present the exact solution in the case of the inverse-cosh envelope of the electromagnetic field, and show that it is the same as the result derived within the Berry's approach.

Q 57.77 Thu 16:30 P1

Towards a miniaturized frequency comb system for atom optics in microgravity — •Hannes Duncker[1], André Wenzlawski[1], A. Jones Rafipoor[1], Patrick Windpassinger[1], Klaus Sengstock[1], and the Lasus Team[1,2,3,4] — [1]Institut für Laser-Physik, Universität Hamburg, Luruper Chaussee 149, 22761 Hamburg — [2]Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover — [3]Institut für Physik, Humboldt Universität zu Berlin, Newtonstr. 15, 12489 Berlin — [4]Ferdinand-Braun-Institut, Leibniz-Institut für Höchstfrequenztechnik, Gustav-Kirchhoff-Str. 4, 12489 Berlin

Atom optics under microgravity places stringent requirements on the deployed laser systems in terms of reliability, robustness, weight, volume and power consumption. Within this project, new technologies are developed which meet these demands to support experiments performed within the QUANTUS project at the drop tower in Bremen and make future sounding rocket missions feasible. For the latter, a compact glassceramic based splitting module is developed to allow for reliable switching and modulation of laser light for the generation and manipulation of ultracold Rubidium. Furthermore, a frequency comb system in a form factor suitable for microgravity platforms is currently in its design phase. Such a system paves the way for tests of the universality of free fall using a dual species atom interferometer.

The 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 50WM 0938.

Q 57.78 Thu 16:30 P1

Advanced laser system for atom interferometry — •Christoph Grzeschik[1], Max Schiemangk[1], Achim Peters[1], and the QUANTUS Team[1,2,3,4,5,6,7,8,9] — [1]Institut für Physik, HU Berlin — [2]Institut für Quantenoptik, LU Hannover — [3]Institut für Laserphysik, Uni Hamburg — [4]ZARM, Uni Bremen — [5]Institut für Quantenphysik, Uni Ulm — [6]MPQ, München — [7]Institut für angewandte Physik, TU Darmstadt — [8]Midlands Ultracold Atom Research Centre, University of Birmingham, UK — [9]FBH, Berlin

In preparation for future quantum gas experiments in space, preliminary experiments are currently performed at the ZARM drop tower in Bremen and a sounding rocket mission is planned for the near future.

The poster presents key components of a compact and robust laser systems, e.g. a Raman laser system and a hybrid integrated master oscillator power amplifier (MOPA). To provide an intrinsic phase stability the Raman laser system is based on injection locking of modulated light. Capture range measurements and the suppression of parasitric frequencies have been investigated with different types of injected diodes. The MOPA, whose components are integrated on a 10×50 mm^2 microbench, allows for outputpower in the Watt range, while preserving the spectral characterisics of the DFB laser diode, which has an intrinsic linewidth of approx. 100 kHz at operation conditions.

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.

Q 57.79 Thu 16:30 P1

Interferometry with Bose-Einstein condensates in microgravity — •Holger Ahlers[1], Naceur Gaaloul[1], Stephan Seidel[1], Waldemar Herr[1], Jan Rudolph[1], Christina Rode[1], Dennis Becker[1], Manuel Popp[1], Thijs Wendrich[1], Wolfgang Ertmer[1], Ernst Maria Rasel[1], and the QUANTUS Team[2,3,4,5,6,7,8,9] — [1]Institut für Quantenoptik, LU Hannover — [2]Institut für Quantenphysik, Universität Ulm — [3]ZARM, Universität Bremen — [4]Institut für Physik, HU Berlin — [5]Institut für Laser-Physik, Universität Hamburg — [6]Institut für angewandte Physik, TU Darmstadt — [7]Midlands Ultracold Atom Research Centre, University of Birmingham, UK — [8]FBH, Berlin — [9]MPQ, Garching

Matter-wave sensors are considered as one of the most promising fields to progress in metrology and fundamental tests. In this poster, we report about the development of a miniaturized and robust experiment using ultra cold atoms in a free fall environment as a test-bed for matter-wave interferometry on long timescales. More than 200 experiments were successfully performed in microgravity and a BEC was observed after free expansions of up to 1s [1]. The implementation of an atom interferometer operating with a Bose-Einstein Condensate was recently demonstrated and several experiments carried out.

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 1131.

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

Q 57.80 Thu 16:30 P1

A dual species matter-wave interferometer in microgravity — •Dennis Becker[1], Waldemar Herr[1], Jan Rudolph[1], Manuel Popp[1], Christina Rode[1], Thijs Wendrich[1], Holger Ahlers[1], Stephan Seidel[1], Naceur Gaaloul[1], Wolfgang Ertmer[1], Ernst Maria Rasel[1], and the QUANTUS Team[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, UK — [8]FBH, Berlin — [9]MPQ, Garching

The aim of QUANTUS-II is to test the weak equivalence principle in the quantum domain using matter-wave interferometry. To this end, a degenerated Bose-Fermi mixture of ^{87}Rb and ^{40}K will be created in microgravity to take advantage of an extended time of free evolution. Our compact atom chip based setup can employ the catapult mode of the drop tower in Bremen, which provides up to 9 seconds of microgravity. The poster shows the setup, the up to date progress and future prospects of this ambitious and technically challenging project. 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 1131.

Q 57.81 Thu 16:30 P1

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 that contain everything for the experiment like vacuum, lasers, optics, and the electronics. The LASUS project develops diode lasers, optical modules and electronics for such experiments, and specifically for the QUANTUS microgravity experiments. The focus of this contribution is on how to make all of the electronics to control the entire laser system for capturing and manipulating rubidium and potassium together with the electronics for the optical switching and frequency shifting, fit in a volume of a few liters. This will be achieved by a computer controlled modular setup using custom build high density circuit boards with mainly SMD components and by having all settings remote controlled via the onboard computer. Another key component in the miniaturization is the FPGA-based frequency controller which integrates several conventional PID controllers and modulation and demodulation devices for several laser systems in a single compact device. 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 50WM0939.

Q 57.82 Thu 16:30 P1

Active low frequency vibration isolation for high precision atom interferometry — •Christian Freier — Humboldt Universität Berlin

The performance of high precision atom interferometers is often limited by vibrations of optical components introducing Raman phase noise. We have built and characterized an active low frequency vibration isolation platform which isolates one key component of our atom interferometer from environmental vibrations and allows us to perform high precision gravity measurements.

The platform combines a 0.5 Hz commercial spring-based passive vibration isolator with a custom built feedback loop. The active feedback system measures residual vibrations on the platform using a commercial weak-motion seismometer. This acceleration signal is fed back into voice coil actuators which exert a force on the floating isolator in order to cancel out the residual vibrations.

Using this method the resonance frequency of the isolator has been lowered to 0.03 Hz, which enables high performance low-frequency vibration isolation in a small portable package.

Q 57.83 Thu 16:30 P1

Length sensing and control of the AEI 10 m Prototype sub-SQL interferometer — •Christian Gräf for the AEI 10m Prototype Team — Max-Planck-Institut für Gravitationphysik (Albert-Einstein- Institut), Institut für Gravitationsphysik, Leibniz Universität Hannover und QUEST

The AEI 10 m Prototype sub-SQL interferometer, which is currently being set up at the AEI in Hannover, Germany, aims at beating the Standard Quantum Limit (SQL) at Fourier frequencies of ~ 100 Hz, reaching for a displacement sensitivity of $\sim 10^{-19}\,\mathrm{m}/\sqrt{\mathrm{Hz}}$. Reducing the impact of fluctuations on the lengths in the optical setup is crucial for the instrument to unfold its full potential for ultra-high sensitiv-

ity measurements of the differential mode of its interferometer arms. Electronic feedback control has proven an essential tool to fulfill this requirement by actively feeding back length error signals, obtained by phase modulation/demodulation techniques, to the suspended optics of the interferometer. A high-performance real time digital control system is employed to hold the multitude of length degrees-of-freedom tightly at predefined operating points. Due to the high complexity of the underlying optical system, simulations play a key role in the design of the signal extraction and control scheme.
In this talk an overview of selected aspects of the longitudinal sensing and control system design for the AEI 10 m Prototype sub-SQL interferometer is given.

Q 57.84 Thu 16:30 P1

Optische Tests an einem Dreifachspiegel für eine schnelle GRACE (Gravity Recovery and Climate Experiment) Nachfolgemission — •Gunnar Stede, Benjamin Sheard, Gerhard Heinzel und Karsten Danzmann — Albert-Einstein-Institut Hannover, Max-Planck-Institut für Gravitationspyhsik und Institut für Gravitationsphysik der Universität Hannover

GRACE ist eine Satellitenmission zur Vermessung des Erdschwerefeldes, basierend auf Abstandsmessungen, zweier 200km zueinander entfernten Satelliten, im Submikrometerbereich. In einer schnellen GRACE Nachfolgemission kann das vorhandene Mikrowelleninterferometer durch ein Laserinterferometer ergänzt werden um die Auflösung zu erhöhen. Da die optische Achse zwischen den beiden Masseschwerpunkten durch das Mikrowelleninterferometer versperrt ist, muss der Laserstrahl um dieses herum geführt werden. Damit die gemessene optische Weglänge auch im Falle einer Fehlausrichtung der Satelliten konstant bleibt, wird ein sogenannter Dreifachspiegel benutzt, dessen optische Weglänge unabhängig von seiner Orientierung ist. Hier stellen wir Testmethoden des Dreifachspiegels und erste Ergebnisse vor.

Q 57.85 Thu 16:30 P1

Optical simulations for inter-satellite interferometry — •Christoph Mahrdt, Evgenia Granova, Benjamin Sheard, Gudrun Wanner, Gerhard Heinzel, and Karsten Danzmann — Max-Planck-Institut für Gravitations Physik (Albert-Einstein-Insitut) , Hannover und QUEST, Leibniz Universität Hannover

High precision metrology based on laser interferometry between satellites is currently under development for fundamental physics missions such as LISA or earth observation missions like a GRACE follow-on. These missions will measure the relative distance between two satellites with an unprecedented accuracy. The development of optical systems for these missions is highly demanding, since issues such as stray light, wavefront errors, beam pointing and optical pathlength stability have to be taken care of. Careful analysis of the optical setups need to be done and not all properties of an inter-satellite interferometer can be tested on ground. Therefore, optical simulations are needed to find possible error sources, optimise the setups and to find requirements on the placement and alignment of optical components. A software toolkit currently under development combines raytracing with Gaussian beam propagation for calculation of optical pathlength, the beam axes and interferometer signals, including phase and differential wavefront sensing. To trace non-Gaussian beams through interferometers, decomposition into Hermite-Gauss modes is implemented and under verification. Another part under development is the implementation of general astigmatism for Gaussian beams. This talk will give an overview of the simulation software, its status and applications.

Q 57.86 Thu 16:30 P1

Pre-experiments for the LISA optical bench — •Christian Diekmann, Johanna Bogenstahl, Marina Dehne, Roland Fleddermann, Evgenia Granova, Gudrun Wanner, Michael Troebs, Gerhard Heinzel, and Karsten Danzmann — Max-Planck Institute for Gravitational Physics (Albert Einstein Institut), Hannover and QUEST, Leibniz University Hannover

The space-based gravitational wave detector Laser Interferometer Space Antenna (LISA) will detect gravitational waves in the frequency range between 0.03 mHz and 1 Hz. This will be done by measuring distance changes between free-flying testmasses. The key elements for these measurements are the so-called optical benches. A prototype of these benches is currently being built for the European Space Agency (ESA). For this purpose, several pre-experiments like the backlink fiber experiment had to be performed. This and other experiments will be discussed in the presentation.

Q 57.87 Thu 16:30 P1

The LISA optical bench — •Johanna Bogenstahl, Gerhard Heinzel, Michael Troebs, Christian Diekmann, Roland Fleddermann, Gudrun Wanner, Evgenia Granova, Marina Dehne, and Karsten Danzmann — Max Planck Institute for Gravitational Physics (Albert Einstein Institute) Callinstr. 38 D-30167 Hannover

The space-based gravitational wave detector Laser Interferometer Space Antenna (LISA) shall detect gravitational waves by measuring distance changes between its three satellites using interferometers. Currently, the first prototype of the so-called optical bench, that contains the interferometric setups for the lengths measurements of LISA, is being built for the European Space Agency (ESA). This optical bench will be tested at the Albert Einstein Institute and its functionality and sensitivity will be characterised. For this purpose, special tools and pre-experiments are necessary that will be discussed in the presentation.

Q 57.88 Thu 16:30 P1

Avoiding blackbody radiation shifts, density shifts, and fiber-induced laser degradation in an optical lattice clock — •Thomas Middelmann, Stephan Falke, Stefan Vogt, Fritz Riehle, Uwe Sterr, and Christian Lisdat — Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig

With our recent frequency measurement of the $^1S_0 - {}^3P_0$ transition of ^{87}Sr we reached a level of precision that opens the demand for investigations of the blackbody radiation shift. The blackbody radiation of the ambient housing at 300 K causes a shift of 5×10^{-15} and the correction leaves an uncertainty of 1.6×10^{-16} due to uncertainty of the temperature sensitivity coefficient and incomplete characterization of the environmental temperature. We will present the status of our experiments aiming at measuring the coefficient and to work at 77 K.

In current optical lattice clock experiments inhomogeneous excitation makes fermions distinguishable and thus collision shifts are observed. An imperfect alignment or wave front distortion of the clock laser beam causes motional state-dependent Rabi frequencies leading to motional state-dependent superposition states. The atoms lose their initial indistinguishability and are subject to s-wave collisions. By controlling the inhomogeneity of the excitation we investigate this effect.

Moreover, a fiber length stabilization was applied for the spectroscopy pulse to ensure that no significant frequency chirps occur during the 90 ms spectroscopy pulse. The work is supported by the Centre for Quantum Engineering and Space-Time Research (QUEST), ESA, DLR, and the ERA-NET Plus Programme.

Q 57.89 Thu 16:30 P1

Quantenrausch-limitierte Laser-Amplitudendetektion von Hochleistungslasern — •Patrick Kwee, Benno Willke und Karsten Danzmann — Albert-Einstein-Institut Hannover

Viele Präzisionsmessungen verwenden Modulationstechniken bei Radiofrequenzen ab 10 MHz, um störende Rauschquellen bei niedrigen Frequenzen zu vermeiden. Diese Techniken setzen allerdings eine empfindliche Detektion der Laser-Amplitude in diesem Frequenzbereich voraus. Das fundamentale Limit ist das Quantenrauschen, das von der detektierten Laserleistung abhängt, wobei eine höhere Leistung die Empfindlichkeit verbessert.

Die heute verwendeten Photodioden sind hier üblicherweise bei einer Leistung von ca. 10. . . 100 mW durch die Zerstörschwelle der Photodiode und durch den dynamischen Bereich der Ausleseelektronik limitiert. Dies steht im Kontrast zu den verfügbaren Laserleistungen von bis zu ca. 100 W im Bereich der Präzisionsmessungen.

Ein Experiment wird vorgestellt, dass die *Optical AC Coupling* Technik verwendet, um eine quantenrausch-limitierte Amplitudendetektion von 10. . . 100 W Laserstrahlen zu erlauben. Dabei wird ein optischer Resonator verwendet, um die Empfindlichkeit einer Photodiode zu erhöhen. Eine etwa tausendfach höhere Leistung im Gegensatz zu einer einfach Photodiode kann detektiert werden. Erste Messungen an einem 1064 nm Nd:YAG Laser bei Frequenzen zwischen 10. . . 100 MHz werden vorgestellt.

Q 57.90 Thu 16:30 P1

Towards a Portable Aluminum Optical Clock — •Jannes B. Wübbena, Sana Amairi, Olaf Mandel, Ivan V. Sherstov, and Piet O. Schmidt — QUEST Inst. for Exp. Quantum Metrology, PTB Braunschweig and Leibniz Univ. of Hannover, Germany

Optical Aluminum ion clocks were the first and until now the only clocks to achieve a fractional frequency inaccuracy lower than 1×10^{-17}

[1]. This accuracy enables many applications, varying from frequency metrology to relativistic geodesy. Here we report on the status of a movable Aluminum ion clock that will allow transport to other sites for high accuracy frequency comparisons.

The 267 nm $^1S_0 \leftrightarrow {}^3P_0$ transition in $^{27}Al^+$ is a superior candidate for frequency standards because it has a very narrow line width (8 mHz), no electric quadrupole shift and the lowest known blackbody radiation shift among all atomic species currently considered for clocks. Limitations arising from the lack of an accessible cooling and state detection transition in Aluminum will be overcome by trapping the $^{27}Al^+$ together with a $^{40}Ca^+$ ion. This "logic ion" is Doppler cooled and will sympathetically cool the Aluminum. Techniques developed for quantum information processing will be used to transfer the atomic state of the Al^+ to the Ca^+ where high efficiency electron-shelving detection is available.

[1] C.W. Chou *et al.*, Phys. Rev. Lett. 104, 070802 (2010)

Q 57.91 Thu 16:30 P1

A Single Laser System for Ground State Cooling of $^{25}Mg^+$ — •Florian Gebert, Börge Hemmerling, Yong Wan, Ivan V. Sherstov, and Piet O. Schmidt — QUEST Inst. for Exp. Quantum Metrology, PTB Braunschweig and Leibniz Univ. of Hannover, Germany

We present a single solid-state laser system to cool, coherently manipulate and detect $^{25}Mg^+$ ions confined in a linear Paul trap. Coherent manipulation is accomplished by coupling two hyperfine ground state levels using a pair of far-detuned Raman laser beams. Resonant light for Doppler cooling and detection is derived from the same laser source using the sidebands of an electro-optic modulator. With this setup we cooled the axial vibrational mode of a single $^{25}Mg^+$ ion to the ground state using resolved sideband cooling. Its performance is studied by the time evolution of the Raman-stimulated sideband transitions. Our Setup is a major simplification over existing state-of-the-art systems, typically involving up to three separate laser sources. With this setup we will perform direct frequency comb spectroscopy using quantum logic to determine important transitions of Ca^+, Ti^+ and Fe^+ for the comparison with quasar absorption spectra to study possible time variation of the fine structure constant α. In our experiment the quantum logic scheme [2] will be used for cooling and state detection. Another application of our setup will be the cooling of molecular ions to their internal ground state.

[1] B. Hemmerling *et al.*, arXiv:1010.5664v1 [quant-ph]
[2] P. O. Schmidt *et al.*, Science 309, 749-752 (2005)

Q 57.92 Thu 16:30 P1

Strontium in an Optical Lattice as a Mobile Frequency Reference — •Ole Kock, Steven Johnson, Yeshpal Singh, and Kai Bongs — School of Physics and Astronomy, University of Birmingham, United Kingdom

The higher frequencies (10^{15} Hz) of the atomic transitions enable a greater accuracy than the current microwave frequency (10^{10} Hz) standard. Optical clocks have now achieved a performance significantly beyond that of the best microwave clocks, at a fractional frequency uncertainty of $8.6 * 10^{-18}$ [Chou]. With the rapidly improving performance of optical clocks, in the future, most applications requiring the highest accuracy will require optical clocks. We are setting up an experiment aimed at a mobile frequency standard based on strontium (Sr) in a blue detuned optical lattice. Sr is an alkaline-earth element and has two electrons in its outer shell, which give rise to a singlet state (ground state) and a triplet state. The dipole transitions from a singlet state to a triplet state are forbidden, which results in a long meta-stable lifetimes and as narrow line widths as one mHz. The unprecedented accuracy in time promises new applications like relativistic geodesy for exploration of oil and minerals, fundamental tests of general relativity and synchronization for long base line astronomical interferometry. It is worth mentioning that very recently, space has also opened up as a new venue for precision measurements based on cold atoms. An up to date progress on a compact and robust frequency standard experiment will be presented. 1) C.W. Chou, D. B. Hume, J. C. J. Koelemeij, D. J. Wineland, and T. Rosenband, PRL 104, 070802 (2010).

Q 57.93 Thu 16:30 P1

High performance iodine frequency reference aiming at a stability of 1×10^{-15} — •Klaus Döringshoff, Katharina Möhle, Moritz Nagel, Evgeny V. Kofvalchuk, and Achim Peters — Humboldt-Universität zu Berlin, Institut für Physik, AG Optische Metrologie, Newtonstr. 15, 12489 Berlin

Future space missions, including the Laser Interferometer Space Antenna (LISA), rely on laser systems with high frequency stability over long time scales. Hyperfine-resolved optical transitions in molecular iodine (I_2) could provide stable references for space missions, but also for terrestrial applications. The narrow linwidth of the hyperfine components (≈ 300 kHz) at 532 nm and strong absorption coefficient in combination with intrinsically stable frequency doubled Nd:YAG lasers allow for the realization of highly frequency stable, reliable and practical secondary frequency standards. Here we present our iodine frequency reference for the validation of tunable optical frequency references for the spaceborne gravitational wave detector LISA. For absolute frequency stabilization the frequency doubled output of a 1064 nm Nd:YAG laser is stabilized to the a_{10} component of the R(56)32-0 transition of $^{127}I_2$. Using a 80 cm iodine cell and the MTS technique a frequency stability of 1×10^{-14} at 1 s and 5×10^{-15} at 100 s integration time is achieved. We present our efforts aiming at a frequency stability of 1×10^{-15} at averaging times of 1000 s.

This work is supported the German Space Agency DLR with funds provided by the Federal Ministry of Economics and Technology (BMWi) under grant number DLR 50OQ0601.

Q 57.94 Thu 16:30 P1

A mobile atom interferometer for high precision measurement of local gravity — •Vladimir Schkolnik, Malte Schmidt, Alexander Senger, Matthias Hauth, Christian Freier, and Achim Peters — Institut für Physik, HU Berlin, Germany

GAIN (Gravimetric Atom Interferometer) is a mobile gravimeter, which is based on interfering ensembles of laser cooled ^{87}Rb atoms in an atomic fountain configuration. With a targeted accuracy of a few parts in 10^{10} for the measurement of local gravity, g, this instrument will offer about an order of magnitude improvement in performance over the best currently available absolute gravimeters.

This poster will outline the working principle of our mobile gravimeter and describe its subsystems in detail. Furthermore we present first measurements after the move into our new building and discuss plans for future improvements.

Q 57.95 Thu 16:30 P1

Paving the way to coherent modern control of quantum optical systems — Timo Denker, Dirk Schütte, Maximilian Wimmer, and •Michèle Heurs — Albert-Einstein-Institut Hannover, Max-Planck-Institut für Gravitationsphysik und Centre for Quantum Engineering and Space-Time Research (QUEST), Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover, Germany

Modern control techniques offer highly attractive possibilities when applied to stabilisation tasks in quantum optics and interferometric gravitational wave detection. The approach is inherently multivariable and incorporates a concept of optimality. Moreover, the feasibility of the stabilisation task is known a priori. The highly systematic approach to control yields a thorough understanding of the underlying physics of the system under consideration.

Coherent control on the other hand is a technique of stabilisation that doesn't measure the variable of interest, thereby offering tantalising possibilities for QND type schemes. Recent implementations include the work by Mabuchi et al..

We present our roadmap to achieve a merging of modern and coherent control in the future, and propose experiments to finally reach this goal. We will show recent, current and future quantum optical applications for modern control techniques and coherent control. As an example of modern control in quantum optics we present the frequency stabilisation of an optical cavity, to exemplify the latter we will show preliminary work of treating recycling techniques in interferometric gravitational wave detectors as a coherent control problem.

Q 57.96 Thu 16:30 P1

Stabilization of the Advanced LIGO laser — •Christina Bogan, Jan-Hendrik Pöld, Patrick Kwee, Benno Willke, and Karsten Danzmann — Albert-Einstein-Institut Hannover

Most high precision measurements require a very stable and robust light source. The gravitational wave detector Advanced LIGO has very strict requirements according to the frequency and power stability as well as to the spatial beam profile of the injected continuous wave 200W Nd:YAG laser. Therefore a combined active and passive stabilization scheme is essential. In order to achieve a TEM00 mode content of more than 98.8% a bow-tie shaped cavity is used as a modecleaner which also supresses beam pointing and power noise at radio frequencies. The laser frequency is stabilized to a high finesse reference cavity. A nested control loop prestabilizes the laser system's power to a relative power noise of $2 * 10^{-8}(\mathrm{Hz})^{-1/2}$ and provides an additional input to achieve a relative power noise of $2 * 10^{-9}(\mathrm{Hz})^{-1/2}$ at the interferometer input.

The concepts and results of the stabilization of the Advanced LIGO laser are presented.

Q 57.97 Thu 16:30 P1

Cold Atom Sagnac Interferometer — •Sven Abend, Peter Berg, Michael Gilowski, Christian Schubert, Gunnar Tackmann, Wolfgang Ertmer, and Ernst M. Rasel — Institut für Quantenoptik, Leibniz Universität Hannover

The project CASI (Cold Atom Sagnac Interferometer) realizes an atomic gyroscope based on matter-wave interferometry with cold Rubidium-87 atoms to precisely measure rotations. The sensitivity of the sensor therefore reaches a resolution of few 10^{-7} rad/s. Besides the reduction of the dominant noise sources, the modification of the conventional Raman beam splitting process to large momentum transfer beam splitter is an approach to increase the sensitivity by enlarging the enclosed interferometric area. The transfer of many photon momenta onto the atomic ensemble is realized via a rapid adiabatic passage in an accelerated optical lattice of two counter propagating light fields. In this poster the first results of the application of large momentum beam splitters in the atomic gyroscope are presented. Furthermore, we report on the present status of the apparatus including the analysis of systematic effects, which lead to the current limitation of the sensor. Finally, future improvements based on the provided analysis of the sensor will be discussed. This work is supported by the DFG, QUEST, and IQS.

Q 57.98 Thu 16:30 P1

Faserlaserbasierter Optischer Kammgenerator unter Schwerelosigkeit (FOKUS) — •Tobias Wilken[1], Matthias Lezius[1], Marc Fischer[2], Theodor W. Hänsch[1] und Ronald Holzwarth[1,2] — [1]Max-Planck-Institut für Quantenoptik, Garching — [2]Menlosystems GmbH, Martinsried

In den letzten Jahren hat sich die Entwicklung des Frequenzkamms als Schlüsseltechnologie der Quantenoptik herausgestellt, ohne die in vielen Bereichen eine ausreichende Kontrolle über das Lichtfeld nicht möglich wäre. Insbesondere bei der Präzisionsspektroskopie oder Frequenzstabilisierung von Lasern ist ein Frequenzkamm heutzutage unverzichtbar geworden.

Um optische Atomuhren oder Atominterferometer auf Satellitenmissionen einsetzen zu können, ist es notwendig, Frequenzkämme soweit zu entwickeln, dass sie sowohl einen Raketenstart als auch die Bedingungen unter Schwerelosigkeit außerhalb unserer Atmosphäre aushalten. Dazu sind im Rahmen des PRIMUS-Projekts im letzen Jahr schon erste Experimente am Fallturm des ZARM in Bremen erfolgreich durchgeführt worden.

Das FOKUS-Projekt zielt nun auf die Konstruktion eines satellitentauglichen Frequenzkamms. Dazu sind Verbesserungen in der Stabilität des Oszillators und des f-$2f$ Interferometers notwendig und die Strahlungshärte der verwendeten Komponenten muss untersucht werden. Erste Ergebnisse werden hier präsentiert.

Q 57.99 Thu 16:30 P1

Systematic frequency shifts in precision spectroscopy of the 1S-2S transition in atomic hydrogen — Christian G. Parthey[1], Arthur Matveev[1], Janis Alnis[1], •Axel Beyer[1], Nikolai Kolachevsky[1], Randolf Pohl[1], Thomas Udem[1], and Theodor W. Hänsch[1,2] — [1]Max-Planck-Institut für Quantenoptik, 85748 Garching — [2]Ludwig-Maximilians-Universität, 80799 München

Precision spectroscopy of the 1S-2S transition in atomic hydrogen has been used to test quantum electro dynamics (QED), determine the Rydberg constant and the proton charge radius. It can also be used to set limits on possible Lorentz-boost invariance violations. Here we report on a new measurement of the 1S-2S transition pushing the uncertainty to the 10^{-15} level. We describe the studied systematic effects in detail.

Q 57.100 Thu 16:30 P1

Stable fibre injectors for ground-based interferometers performing in the picometer stability level — •Lina-Ellen Wittrock, Johanna Bogenstahl, Gerhard Heinzel, and Karsten Danzmann — Max-Planck Institute for Gravitational Physics (Albert-Einstein Institute) Hannover and QUEST, Leibniz University Hannover, Germany

Laser Interferometer often require fiber injectors because the laser is not located directly on the optical bench. Conventional injectors are extremely sensitive in terms of mechanical and thermal stress, which causes problems for interferometric measurements at the picometer stability level. Therefore, their application is not suitable for laser interferometers like the planned space missions LISA (Laser Interferometer Space Antenna) and LISA Pathfinder (LPF). Customized ultra-stable injectors were already developed for implementation on the optical bench of LPF Technology Package at the Institute for Gravitational Research, University of Glasgow.

It has been shown that this improvement of the fiber injectors is not only required for space-bourne but also for ground-based interferometers performing at the picometer stability level. This will be essential for pre-experiments for LISA. The design, construction and implementation of customized ultra-stable fiber injectors for our ground-based experiments will be presented.

Q 57.101 Thu 16:30 P1

Tunable high finesse cavities incorporating a piezoelectric actuator — •Katharina Möhle, Klaus Döringshoff, Moritz Nagel, Evgeny V. Kovalchuk, and Achim Peters — Humboldt-Universität zu Berlin, Institut für Physik, AG Optische Metrologie, Newtonstr. 15, 12489 Berlin

The spaceborne gravitational wave detector LISA (Laser Interferometer Space Antenna) aims to measure gravitational waves with a strain $< 10^{-21}$, which demands an extraordinary frequency stability of the same order of magnitude. Therefore, a three-stage frequency stabilization scheme is proposed, which requires a tunable prestabilization in order to accommodate slow Doppler-shifts caused by yearly variation of the triangular satellite configuration.

For this purpose we investigated the performance of a tunable high finesse optical cavity incorporating a piezoelectric actuator. Our beat measurements reveal a laser frequency noise below 20 $\mathrm{Hz}/\sqrt{\mathrm{Hz}}$ at Fourier frequencies higher than 10 mHz while the cavity can be continuously tuned over more than one free spectral range with a bandwidth of 5 kHz. Thus, our setup fulfills the requirements for a tunable prestabilization for LISA.

Furthermore, we will compare different piezo materials and discuss diverse piezo tunable cavity designs, which account for the requirements given by a space mission.

This work is supported by the German Space Agency DLR with funds provided by the Federal Ministry of Economics and Technology (BMWi) under grant number DLR 50 OQ 0601.

Q 57.102 Thu 16:30 P1

Testing the universality of free fall with a two species atomic gravimeter — •Jonas Hartwig, Dennis Schlippert Schlippert, Ulrich Velte, Daniel Tiarks, Maic Zaiser, Vyacheslav Lebedev, Ernst Rasel, and Wolfgang Ertmer — Institut für Quantenoptik, Hannover

The universality of free fall (UFF) is one of the fundamental postulates of general relativity. It is well measured with macroscopic test masses in experiments like lunar laser ranging and torsion balance. An alternate approach employs atom interferometers which allow for a high precision measurement of forces utilising the quantum nature of matter. A comparison between two atomic isotopes was already demonstrated but only as a proof of principle experiment with limited accuracy.

In the CAPRICE Experiment we are comparing the free fall of potassium and rubidium atoms with a differential atomic gravimeter. This will lead to a precision test of the UFF with two quantum objects We use a 2D/3D MOT system together with an optical dipole trap for trapping and cooling the atomic ensembles. The light fields for the manipulation of both species use the same optical system, thus supressing most of the classical noise sources usually limiting measurement precision in a single species gravimeter.

We will present our first results with the single species rubidium gravimeter and show the progress of the system update to trap and manipulate potassium atoms. We also show our progress in working with an optical dipole trap of 1960 nm wavelength.

Q 57.103 Thu 16:30 P1

High Sensitivity Magnetic Sensing by Ensemble Measurements on Densely Packed Defect Centers in Bulk Diamond — •Thomas Wolf, Merle Becker, Gopalakrishnan Balasubramanian, Fedor Jelezko, and Jörg Wrachtrup — 3rd Physics Institute and Research Center SCOPE, University of Stuttgart

Single, fluorescent defect centers in diamond namely the NV-center have led to numerous scientific contributions in the past in apparently very different areas of application, e.g. quantum computing and spintronics[1], fluorescence and high resolution optical microscopy[2] and magnetometry.

In this work approaches towards high sensitivity magnetometry are presented using ensemble measurements on densely packed NV-centers in bulk diamond at room temperature. Using EPR and optical techniques, the spin states of the NV-centers can be changed and read out. The sensitivity towards external magnetic fields of these measurements (for a single NV-center $3nT/Hz^{\frac{1}{2}}$ has been shown) scales with the square root of the number of NV-centers probed[3]. Ensemble measurements give the opportunity for high sensitivity magnetic sensing with a projected sensitivity in the range of $fT/Hz^{\frac{1}{2}}$ while keeping the dimensions of the sensor small.

[1] P. Neumann et al., Science 320, 5881, 1326-1329 (2008)
[2] G. Balasubramanian et al., Nature 455, 648-651 (2008)
[3] J. Taylor et al., Nature Physics, 4, 810-816 (2008)

Q 57.104 Thu 16:30 P1

A fiber-based femtosecond frequency comb for precision measurements in microgravity — •Andreas Resch, Claus Lämmerzahl, and Sven Herrmann — ZARM Universität Bremen, Am Fallturm, 28359 Bremen

We use a compact fiber-based femtosecond frequency comb in the microgravity environment of the Bremen drop tower at ZARM to explore possible applications in precision experiments, both earthbound and space-based. To this end we have acquired a frequency comb that was designed specifically for the use in a drop tower experiment. The prospective application of this frequency comb is in an experiment that tests the universality of free fall from a differential measurement of a dual species atom interferometer. Due to the extended time of free fall available in the microgravity environment of the drop tower, and ultimately on board the International Space Station, the sensitivity of such an atom interferometer will be significantly enhanced as compared to earthbound laboratory experiments. In order to do a precision measurement of the differential phase of the atom interferometers we will use the frequency comb in two ways: First to lock the lasers at 780 nm and 767 nm to the comb's lines, secondly to generate a microwave signal, from which the Raman splitting frequencies can be derived. In order to generate the low-noise microwave signal, the frequency comb will be stabilized to an optical high-finesse cavity. We acknowledge support by the German Space Agency DLR with funds provided by the Federal Ministry of Economics and Technology (BMWi) under grant number DLR 50 WM 0842.

Q 57.105 Thu 16:30 P1

Towards an optical lattice-based magnesium frequency standard — •Klaus Zipfel, Matthias Riedmann, Jan Friebe, Hrishikesh Kelkar, Temmo Wübbena, Andre Kulosa, Andre Pape, Dominika Fim, Wolfgang Ertmer, and Ernst Maria Rasel — Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover

Optical atomic clocks have large potential regarding accuracy and stability compared to the best microwave clocks. Alkaline-earth magnesium (Mg) is an interesting candidate for a future neutral atom optical clock because of its low sensitivity to blackbody radiation, which is currently limiting the accuracy of state-of-the-art Sr lattice clocks.

At the magic wavelength of Mg, which has been predicted to be at 463 nm, the differential AC-Stark shift of the strictly forbidden $^1S_0 \rightarrow {}^3P_0$ clock transition cancels out. Furthermore, the tight confinement of the atoms in the lattice will enable us to reach the Lamb-Dicke regime, allowing first order Doppler-free spectroscopy.

As a precursor, we loaded Mg atoms in an optical dipole trap at 1064 nm. Using a continuous loading scheme, we reach up to 10^5 atoms at an average temperature of 100 μK. Currently, we investigate to create an optical lattice inside an optical resonator to enhance the trap depth and the loading of this lattice.

Q 57.106 Thu 16:30 P1

LISA Backlinkfiber - Return loss of a polarization maintaining single-mode optical fiber — •Jan Rybizki, Roland Fleddermann, Michael Tröbs, Gerhard Heinzel, and Karsten Danzmann — Max-Planck Institute for Gravitational Physics (Albert-Einstein-Institute) Hannover and QUEST, Leibniz University Hannover

The Laser Interferometer Space Antenna (LISA) mission by ESA and NASA for the detection of gravitational waves in the frequency range from 0.1 mHz to 1 Hz requires optical fibers for the intrasatellite transfer of light between the optical benches.

The so called Backlinkfiber introduces new noise mostly by its own backreflection (return loss) which effectively looks like a non-reciprocal phase shift and thus enters the final science measurement.

A setup to quantify these reflections for different fibers and the results with implications on possible solutions to minimize the noise will be presented.

Q 57.107 Thu 16:30 P1

Towards an Ultra-Stable Optical Sapphire Cavity System for Testing Lorentz Invariance — •Moritz Nagel, Katharina Möhle, Klaus Döringshoff, Evgeny V. Kovalchuk, and Achim Peters — Humboldt-Universität zu Berlin, Institut für Physik, AG Optische Metrologie, Newtonstr. 15, 12489 Berlin

We present a design for an ultra-stable cryogenically cooled sapphire optical cavity system, with a fractional frequency stability better than 10^{-16} at one second integration. This so far unrealized stability in optical resonator systems could be used to enhance a broad range of experimental and technical applications, e.g. high-precision spectroscopy or deep-space communication.

We plan to use the ultra-stable cavities to perform the best laboratory-based test of Lorentz invariance. The cavities will be arranged in a Michelson-Morley configuration and continuously rotated for more than one year using a custom-made high-precision low noise turntable system. The sensitivity of this setup to violations of Lorentz invariance should be in the 10^{-19} to 10^{-20} regime, corresponding to more than a 100-fold improvement in the precision of modern Michelson-Morley type experiments. Furthermore, ultra-stable cryogenic microwave whispering gallery resonators will be added to the experiment in collaboration with the University of Western Australia. With this co-rotating microwave and optical resonator setup we will for the first time be able to search for new types of Lorentz violating signals.

Q 57.108 Thu 16:30 P1

A compact Yb optical lattice clock — •Charbel Abou Jaoudeh, Gregor Mura, Tobias Franzen, Taner Esat, Cristian Bruni, and Axel Görlitz — Institut für Experimentalphysik, Universitätstr. 1, 40225 Düsseldorf

Optical clocks using neutral atoms hold the promise to eventually reach an inaccuracy at a level of 10^{-18}. Here we report on the development of a transportable source of ultracold Yb atoms for an optical lattice clock. All laser systems in the compact apparatus are diode-based. We have already implemented the first cooling stage using blue laser diodes at 399 nm and realized a magnetooptical trap (MOT) with more than 10^7 atoms. Successful transfer of 20 % from the bosonic ^{174}Yb and fermionic ^{171}Yb MOT into the second stage MOT operating on the narrow $6^1S_0 \rightarrow 6^3P_1$ transition at 556 nm and further cooling of the atoms to temperatures of 20 μK has also been achieved. The next step will be to load the atoms into a 1D optical lattice at the magic wavelength of 759 nm which is formed in a resonator inside the vacuum chamber. The special design of the lattice setup allows for a large-volume optical lattice with a diameter of 155 μm and a potential depth of 300 μK if 300 mW of radiation from a tapered diode laser are coupled into the resonator.

Q 57.109 Thu 16:30 P1

A Modern Michelson-Morley Experiment Using Cryogenic Sapphire Microwave Oscillators — •Stephen Parker[1], Paul Stanwix[1], Michael Tobar[1], John Hartnett[1], Eugene Ivanov[1], Moritz Nagel[2], and Achim Peters[2] — [1]School of Physics, The University Of Western Australia, Crawley 6009, Western Australia, Australia — [2]Humboldt-Universität zu Berlin, Institut für Physik, AG Optische Metrologie, Newtonstr. 15, 12489 Berlin

Lorentz Invariance is a fundamental component of General Relativity and the Standard Model of Particle Physics.We describe the details of our latest Michelson-Morley experiment that has recently been set up at Humboldt University in Berlin. The experiment compares the resonant frequencies of two orthogonally aligned cryogenic sapphire microwave oscillators that are actively rotated in the laboratory. A standing wave whispering gallery mode is excited in the cryogenic sapphire oscillators which resonates at 13 GHz. They exhibit a frequency stability on the order of 10^{-16} for integration times from 10 - 40 seconds (approximately the period of active rotation). This low stability increases the sensitivity of the experiment to violations of Lorentz Invariance which we express as bounds on coefficients from the Standard Model Extension. The experiment will be run for a full year ending in December 2011, after which it will be combined with a set of optical sapphire resonators for a joint experiment with the optical metrology group at Humboldt University.

Q 58: Ultracold Atoms: Trapping and Cooling 2

Time: Friday 10:30–13:00 Location: HSZ 02

Q 58.1 Fri 10:30 HSZ 02

CPT and EIT - Dark state resonances in interacting systems — •Hanna Schempp[1], Georg Günter[1], Christoph S. Hofmann[1], Thomas Amthor[1], Matthias Weidemüller[1], Jonathan D. Pritchard[2], Daniel Maxwell[2], Alex Gauguet[2], Kevin J. Weatherill[2], Matthew P.A. Jones[2], Charles S. Adams[2], Sevilay Sevinçli[3], Cenap Ates[3], and Thomas Pohl[3] — [1]Physikalisches Institut, Universität Heidelberg, Philosophenweg 12, 69120 Heidelberg — [2]Department of Physics, Durham University, Rochester Building, South Road, Durham DH1 3LE, United Kingdom — [3]Max-Planck-Institut für Physik Komplexer Systeme, Nöthnitzer Str. 38, 01187 Dresden

Coherent Population Trapping (CPT) and the related phenomenon of Electromagnetically Induced Transparency (EIT) are paradigms for quantum interference effects. EIT involving a Rydberg state has recently been studied experimentally [1] and has also attracted much interest in the context of quantum information processing [2]. In this work we compare experiments on CPT [3] and EIT [4] in Rydberg gases with controlled interparticle interactions. We present many-body calculations which take the resulting interparticle correlations into account.

[1] A. K. Mohapatra et al., PRL 98 113003 (2007)
[2] M. Müller et al., PRL 102 170502 (2009)
[3] H. Schempp et al., PRL 104 173602 (2010)
[4] J.D. Pritchard et al., PRL 105 193603 (2010)

Q 58.2 Fri 10:45 HSZ 02

Enhanced Optical Nonlinearities with Cold Rydberg Gases — •Sevilay Sevinçli[1], Cenap Ates[2], and Thomas Pohl[1] — [1]Max Planck Institute for the Physics of Complex Systems, Nöthnitzer Strasse 38, 01187 Dresden, Germany — [2]School of Physics and Astronomy, University of Nottingham, Nottingham, NG7 2RD, United Kingdom

Owing to the high sensitivity of Rydberg atoms to external fields and to interactions among themselves, ultracold Rydberg gases provide an ideal system for nonlinear optics. Here, we present a quantum and a classical many-body approach to describe interaction effects on the propagation of classical light pulse in an Rydberg-EIT medium. The nonlinear susceptibility shows perfect match between the two methods and is shown to exhibit a universal scaling behavior.

We further propose a microvawe dressing scheme, that allows to modify the interactions between Rydberg atoms, and thereby control the optical properties of the gas. In particular, this allows to greatly enhance genuine three-body interactions, giving rise to large fifth-order nonlinearities. Finally, we present an analytical derivation of the optical susceptibility, providing an intuitive picture for these effects.

Q 58.3 Fri 11:00 HSZ 02

Homodyne Detection of Matter Wave — •Stefan Rist[1] and Giovanna Morigi[2,3] — [1]NEST, Scuola Normale Superiore & Istituto di Nanoscienze - CNR, Piazza dei Cavalieri 7, I-56126 Pisa, Italy — [2]Departament de F\'isica, Universitat Aut\'onoma de Barcelona, E-08193 Bellaterra, Spain — [3]Theoretische Physik, Universit\"at des Saarlandes, D-66041 Saarbr\"ucken, Germany

We present a scheme which allows one for measuring the mean value of the atomic field operator of an ultracold bosonic gas. The scheme we consider is an extension of the experimental setups in [1,2] where atoms were outcoupled of two Bose-Einstein condensates by means of Bragg-scattering. Our scheme is the matter-wave analogon of homodyne detection in optics, where a quantum field is superposed at a beam splitter to a local oscillator. In our case the local oscillator is a Bose-Einstein condensate, from which atoms are outcoupled by means of two Raman lasers, and superimposed with the atoms outcoupled from the atomic system to determine.

The measurement is performed in the light scattered into one of of the Raman beams which is shown to be proportional to the mean value of the field operator of the atomic system. We provide two examples, such as the measurement of the temperature of a Bose-Einstein condensate and of the superfluid fraction in an optical lattice.

[1] M. Saba et al. Science 307, 1945 (2005).
[2] Y.~Shin et al. Phys. Rev. Lett. 95, 170402 (2005).

Q 58.4 Fri 11:15 HSZ 02

A Double-Species 2D+MOT for Potassium and Rubidium — •Lucia Duca[1], Tracy Li[1], Martin Boll[1], Jens Philipp Ronzheimer[1], Ulrich Schneider[1], and Immanuel Bloch[1,2] — [1]Fakultät für Physik, Ludwig-Maximilians-Universität, 80799 München — [2]Max-Planck-Institut für Quantenoptik, 85748 Garching

In recent years there has been a growing interest in the realization of low entropy phases of the Fermi-Hubbard model using ultracold fermions in optical lattices. One of the requirements for achieving e.g. anti-ferromagnetic order is to reduce the initial temperature below $T/T_F<0.065$ [1]. This requires a careful elimination of all heating sources and an optimization of all cooling steps.

Within a new experimental setup that is currently under construction, we use a double-species 2D+MOT [2] for ^{40}K and ^{87}Rb as an atomic source of slow atoms. Compared to the use of dispensers, this pre-cooling stage allows us to operate the 3D MOT at pressures below 10^{-10} mbar while simultaneously speeding up the experimental cycle and increasing the number of trapped K atoms that will be available for evaporative cooling. We present our 2D+MOT setup and our first experimental results.

[1] Fuchs et.al., arXiv: 1009.2759v1
[2] Dieckmann et.al., PRA 58, 3891 (1998).

Q 58.5 Fri 11:30 HSZ 02

Microwave guiding of electrons in a planar quadrupole guide — •Johannes Hoffrogge, Roman Fröhlich, Jakob Hammer, and Peter Hommelhoff — Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Straße 1, 85748 Garching bei München

We present the transverse confinement and guiding of electrons in a linear AC quadrupole guide operated at microwave frequencies. The guiding potential is generated by the electrode pattern of a microfabricated planar Paul trap. This facilitates the combination with microwave transmission lines patterned on the same substrate to achieve the high driving frequencies necessary for stable electron confinement. In a proof-of principle experiment [1] we demonstrate successfull guiding in an electrically short device by conducting laterally confined electrons along a curved trajectory. The guide is operated at 1 GHz driving frequency and generates a two dimensional potential with 150 MHz trapping frequency 500 μm away from the surface. We also characterize the guiding behaviour of this device in terms of trap depth and stability and compare it to numerical particle tracking simulations. The precise control over the electrons and the possibility to easily scale the trapping potential to more complicated structures opens a wide range of applications. With a single atom tip as electron source, it might become feasible to directly inject electrons into the transverse ground state of motion of the guide. When combined with beam splitting devices this will enable experiments like guided electron interferometry or the controlled interaction of confined electrons.

[1] J. Hoffrogge, R. Frohlich and P. Hommelhoff - submitted (2010)

Q 58.6 Fri 11:45 HSZ 02

Ultracold atoms in disordered quantum potential — •Hessam Habibian[1,2], Wolfgang Niedenzu[3], Helmut Ritsch[3], and Giovanna Morigi[1,2] — [1]Grup d'Optica, Departament de Física, Universitat Autònoma de Barcelona, E-08193 Bellaterra, Barcelona, Spain — [2]Theoretische Physik, Universität des Saarlandes, D-66041 Saarbrücken, Germany — [3]Institut für Theoretische Physik, Universität Innsbruck, A-6020 Innsbruck, Austria

We study the self-organized atomic patterns which emerge by mechanical effect of light in an optical resonator when the atoms are driven by a laser. The laser wave vector is at a tilted angle from the axis of the cavity such that the light scattered by each atom has a (pseudo-)random phase. Depending on the intensity of the laser and the angle with the cavity axis, the atomic crystal may exhibit defects. We study the quantum ground state of the system in this configuration.

Q 58.7 Fri 12:00 HSZ 02

Laserkühlung von dichten atomaren Alkali-Edelgas-Mischungen durch kollisionsinduzierte Fluoreszenzredistribution — •Anne Sass, Ulrich Vogl, Simon Hasselmann und Martin Weitz — Institut für Angewandte Physik der Universität Bonn, Wegelerstraße 8, D-53115 Bonn

Der Grundgedanke, Materie mit Licht zu kühlen, wurde erstmals 1929 von Peter Pringsheim vorgestellt. Seither haben sich Doppler-Kühlung dünner atomarer Gase und zuletzt Anti-Stokes-Kühlung von Festkörpern als sehr erfolgreiche Anwendungen dieses Konzeptes herausgestellt. Das hier vorgestellte Verfahren der stoßinduzierten Redistributionskühlung stellt einen neuartigen Laserkühlmechanismus basierend auf atomaren Zwei-Niveau-Systemen dar. Wir berichten über Experimente zur Kühlung von Alkali-Edelgas-Mischungen in einer Hochdrucksichtzelle bei einigen hundert bar Druck. Kollisionen im dichten Gas ermöglichen die Absorption eines rot verstimmt eingestrahlten Laserstrahls, der spontane Zerfall erfolgt nah an der ungestörten Resonanz. Die so pro Kühlzyklus aus dem atomaren Ensemble extrahierte Energie liegt in der Größenordnung der thermischen Energie kT; die Dichte des gekühlten Gases ist um mehr als zehn Größenordnungen höher als die typischen Werte in Experimenten zur Doppler-Kühlung. Aktuell erreichen wir in unseren Experimenten relative Temperaturänderungen um 120 K und 527 K für unterschiedliche Alkaliatomspezies. Zukünftig gilt es, das Kühlprinzip auch auf molekulare Gase anzuwenden und die technische Anwendbarkeit des Verfahrens, etwa für Kryokühler, zu überprüfen.

Q 58.8 Fri 12:15 HSZ 02

A hexapole-compensated magneto-optical trap on a mesoscopic atom chip — •Stefan Jöllenbeck[1], Jan Mahnke[1], Richard Randoll[1], Manuela Hanke[1], Ilka Geisel[1], Wolfgang Ertmer[1], Jan Arlt[2], and Carsten Klempt[1] — [1]Institut für Quantenoptik, Leibniz Universität Hannover — [2]Department of Physics and Astronomy, Aarhus University

We realized a magneto-optical trap (MOT) on a mesoscopic chip structure which will be used as a starting point for experiments to trap and transport atoms in a magnetic conveyor belt.

Our MOT setup consists of nine millimeter-scale wires which generate a quadrupole field with minimized distortions. The wires are placed outside of our vacuum system above a steel foil which forms one wall of our vacuum chamber. A gold coating on the vacuum side of this foil allows for the standard mirror MOT configuration. Together with a pre-cooled beam from a 2D$^+$-MOT, we achieve an initial loading rate of 8.4×10^{10} atoms/s and a final number of 8.7×10^9 captured atoms within 300 ms.

Since the MOT can be operated by only local magnetic fields, the wire structure will support a serialized production of Bose-Einstein condensates in the magnetic conveyor belt.

Q 58.9 Fri 12:30 HSZ 02

Reconstructing the Wigner function of an atomic ensemble — •Roman Schmied and Philipp Treutlein — Departement Physik, Universität Basel, Schweiz

At the core of quantum information technology lies the deterministic and robust generation of entanglement. The accurate measurement of this entanglement is central for advancing the techniques for entanglement generation. For this we have developed a novel method which allows us to reconstruct the Wigner function of the total pseudospin of a large ensemble of ultracold atoms from tomographic data. We illustrate the method with experimental data from a spin-squeezed cloud of ^{87}Rb atoms.

Q 58.10 Fri 12:45 HSZ 02

Optimized magnetic lattices for ultracold atomic ensembles — •Roman Schmied[1], Dietrich Leibfried[2], Robert Spreeuw[3], and Shannon Whitlock[4] — [1]Departement Physik, Universität Basel, Schweiz — [2]National Institute of Standards and Technology, Boulder, CO, USA — [3]Van der Waals–Zeeman Instituut, Universiteit van Amsterdam, The Netherlands — [4]Physikalisches Institut, Universität Heidelberg

Atom chips provide a versatile and reliable laboratory for quantum-mechanical experiments with ultracold atoms. The next generation of atom chips calls for a dramatic increase in the complexity of the spatially structured electromagnetic fields required for trapping and manipulating these atoms. We introduce a general method* for designing tailored lattices of magnetic microtraps for ultracold atoms on the basis of patterned permanently magnetized films. A fast numerical algorithm is used to automatically generate patterns that provide optimal atom confinement while respecting the desired lattice topology and trap parameters. This will allow atom-chip based quantum technology to be extended to arrays of microtraps with state-dependent potentials, opening the way to constructing quantum processors and quantum simulators through interacting ultracold atoms.

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* R. Schmied *et al.*, New J. Phys. **12**, 103029 (2010)

Q 59: Quantum Effects: Interference and Correlations

Time: Friday 10:30–12:45 Location: SCH A01

Q 59.1 Fri 10:30 SCH A01

Measuring Quantum Superpositions of Different Structures of Ion Coulomb Crystals — •Jens Domagoj Baltrusch[1,2], Gabriele De Chiara[2,3], Tommaso Calarco[4], and Giovanna Morigi[1,2] — [1]Theoretische Quantenphysik, Universität des Saarlandes, Germany — [2]Grup d'Òptica, Universitat Autònoma de Barcelona, Spain — [3]Física Teòrica: Informació i Fenòmens Quàntics, Universitat Autònoma de Barcelona, Spain — [4]Institut für Quanteninformationsverarbeitung, Universität Ulm, Germany

We study the creation of quantum superposition states of different structural configurations in small ion Coulomb crystals by utilizing state-dependent potentials. In particular, we focus on the creation of a superposition between an ion crystal in the zigzag stable state and in the linear quantum ground state. The structural properties can be measured with the help of Ramsey interferometry [De Chiara et al. PRA 78, 043414 (2008)], whereby the visibility as a function of the time between the Ramsey pulses carries information about the autocorrelation function of the crystal. We present calculations of the visibility signal for different possible preparation methods, and discuss their experimental feasibility.

Q 59.2 Fri 10:45 SCH A01

Fidelity at quantum resonance for kicked atoms in a gravitational field — •Remy Dubertrand and Sandro Wimberger — Institut for Theoretical Physik, Heidelberg, Germany

We are interested in a generalisation of the kicked rotor system when a constant field term is added, modeling gravity in experiments. Such a difference has already shown significantly new consequences, especially the quantum accelerator modes observed by Oberthaler et al. [1]. We will first remind the pseudo-classical formalism introduced by Fishman et al. [2]. Then the fidelity of quantum kicked rotors at a quantum resonance will be derived. Lastly the experimental state of the art and our theoretical perspectives based on the mentioned pseudo-classical method along the lines of [3] will be shortly described.

[1] M. K. Oberthaler et al., Phys. Rev. Lett. 83, 4447 (1999)
[2] S. Fishman et al., J. Stat. Phys. 110, 911 (2003)
[3] M. Abb et al., Phys. Rev. E 80, 035206(R) (2009)

Q 59.3 Fri 11:00 SCH A01

Probing multimode squeezing with correlation functions. — •Andreas Christ[1,2], Kaisa Laiho[2], Andreas Eckstein[2], Katiúscia N. Cassemiro[2], and Christine Silberhorn[1,2] — [1]Applied Physics, University of Paderborn, Warburger Straße 100, 33098 Paderborn, Germany — [2]Max Planck Institute for the Science of Light, Günther-Scharowsky Straße 1/Building 24, 91058 Erlangen, Germany

Broadband multimode squeezers constitute a powerful quantum resource with promising potential for different applications in quantum information technologies such as information coding in quantum communication networks or quantum simulations in higher dimensional systems. However, the characterization of a large array of squeezers that coexist in a single spatial mode is challenging. In this talk we tackle this problem and present a straightforward method to determine the number of squeezers and their respective squeezing strengths by using simple, broadband multimode correlation function measurements. These measurements employ the large detection windows of state of the art avalanche photodiodes to simultaneously probe the full Hilbert space of the generated state, which enables us to benchmark the squeezed states. Moreover, the measurements are loss-independent due to the structure of the normalized correlation function measurements. This is a significant advantage, since detectors with low efficiencies are sufficient. Our approach is less costly than full state tomography methods relying on multimode homodyne detection which builds on much more demanding measurement and analysis tools and appear to be impractical for larger Hilbert spaces.

Q 59.4 Fri 11:15 SCH A01

Decoherence effects in quantum walks: From ballistic spread to localization — •Andreas Schreiber[1], Katiúscia N. Cassemiro[1], Václav Potocek[2], Aurél Gábris[2], Igor Jex[2], and Christine Silberhorn[1,3] — [1]MPI for the Science of Light, IQO Group, Erlangen, Germany. — [2]Department of Physics, FNSPE, Czech Technical University in Prague, Praha, Czech Republic. — [3]University of Paderborn, Applied Physics, Paderborn, Germany.

Quantum walks describe the evolution of quantum particles in a discretized environment. This universal model serves not only as an explanation for coherent procedures in nature, like the energy transport in photosynthesis, but also offers a foundation for a new type of quantum computing. In both scenarios it is crucial to investigate the impact of decoherence on the system.

Here we present an all optical implementation of an one-dimensional quantum walk with a controllable source of decoherence. We demonstrate a fully coherent spread of a photon's wavepacket in a quantum walk of up to 28 steps. Furthermore, we generated three classes of decoherence, changing the evolution to a fast ballistic quantum walk, a diffusive classical walk and the first Anderson localization in a discrete quantum walk architecture.

Q 59.5 Fri 11:30 SCH A01

Separability criterion for modular variables — •Clemens Gneiting and Klaus Hornberger — Max Planck Institute for the Physics of Complex Systems, Noethnitzer Str. 38, 01187 Dresden

In the spirit of Young-type interference experiments in the single-particle case, one can establish bipartite entanglement in the motion of material particles by nonlocal spatial interference patterns. I introduce a natural class of non-Gaussian states which yield such nonlocal interference patterns under position measurements and violate a suitable separability criterion. The latter is formulated in terms of modular variables, a concept adapted to interference phenomena and thus capable to capture the expressed correlations.

Q 59.6 Fri 11:45 SCH A01

Trapping particles in bent waveguides — •Emerson Sadurni and Wolfgang Schleich — Institut fuer Quantenphysik, Ulm Universitaet, Albert-Einstein Allee 11 89081 Ulm - Germany

Is it possible to trap a quantum particle in an open geometry? In this work we deal with the boundary value problem of the stationary Schroedinger (or Helmholtz) equation within a waveguide with straight segments which form a sharp angle. We show that the presence of bound states, which has no counterpart in a ray-tracing picture, originates from the diffracting boundary alone. Conformal mapping proves to be useful in the derivation of analytic results. An analogy with a problem involving rigid molecules is established.

Q 59.7 Fri 12:00 SCH A01

Many-particle Quantum Walks — •Klaus Mayer[1], Malte C. Tichy[1], Florian Mintert[1,2], Thomas Konrad[3], and Andreas Buchleitner[1] — [1]Albert-Ludwigs-Universität Freiburg, Hermann-Herder-Strasse 3, 79104 Freiburg, Germany — [2]Freiburg Institute for Advanced Studies, Albert-Ludwigs-Universität Freiburg, Albertstrasse 19, 79104 Freiburg, Germany — [3]School of Physics, University of KwaZulu-Natal, Private Bag 54001, Durban 4000, South Africa

We study quantum walks of many non-interacting particles in a beam splitter array, as a paradigmatic testbed for the competition between single-particle and many-particle interference [1].

We derive a general expression for multi-mode particle number correlation functions, valid for initially entangled or non-entangled fermions and bosons, and infer pronounced signatures of many-particle interferences in the multi-mode counting statistics. The latter permits the differentiation of mere quantum statistical from pure many-particle interference effects.

[1] K. Mayer et al., arXiv: 1009.5241 (2010)

Q 59.8 Fri 12:15 SCH A01

Single photon sources: the disastrous second photon — •Karl Otto Greulich — Fritz Lipmann Institute Beutenbergstr.11 D 07745 Jena

Double - and triple - slit experiments for confirming wave particle properties of light, or experiments on entanglement for proving non - locality strictly require single photons or single photon pairs. Often multiatom light sources such as pump lasers are involved and it is assumed that the attenuation is sufficient to safely work in the single photon limit. A few pulses containing a second photon cannot be definitely excluded, but this is often thought to be acceptable. Detailed numerical evaluation quantifies the risk that contaminating second photons may invalidate interpretations of, at least, non - locality experiments - and perhaps also single photon double slit experiments.

1 K.O. Greulich Single molecule experiments challenge the strict wave particle dualism of light 2010 Int J Mol Sci, 11, 304 - 311

2 K.O. Greulich Another loophole for Bell inequalities 2009 Proc. SPIE 2009 7421 2301-2307

3 http://www.fli-leibniz.de/www_kog/ Then click the symbol for Physics

Q 59.9 Fri 12:30 SCH A01

Entanglement measures and interference contrast — •Federico Levi and Florian Mintert — Freiburg Institute for Advanced Studies (FRIAS), Albert-Ludwigs-Universität Freiburg, Albertstr. 19, 79104 Freiburg.

Both entanglement and interference are phenomena that display the difference between a quantum system and its classical counterpart. They both originate from the quantum superposition principle, and they have been related to each other qualitatively e.g. in interference of photon pairs [1]. However, a clear, conceptual or quantitative connection between these two features of quantum mechanics has yet to be established, and quantifications of either of these features appear rather differently; the fringe contrast provides a clear experimental quantification of interference, whereas entanglement measures are typically rather abstract and do not offer any physical insight into the nature of entanglement.

With the goal to shed some light on the relationship between entanglement and quantum interference, we aim to construct entanglement measures in terms of the fringe contrast.

[1] M.A.Horne, A.Shimony, A.Zeilinger, Phys. Rev. Lett. **62**, 2209 (1989).

Q 60: Quantum Information: Photons and Nonclassical Light 2

Time: Friday 10:30–12:15 Location: SCH 251

Q 60.1 Fri 10:30 SCH 251

Two Color Entanglement — •Christina E. Laukötter[1], Aiko Samblowski[1], Nicolai Grosse[2], Ping Koy Lam[2], and Roman Schnabel[1] — [1]Institut für Gravitationsphysik, QUEST, Leibniz Universität Hannover and Max-Planck-Institut für Gravitationsphysik (Albert-Einstein-Institut), Callinstr. 38, 30167 Hannover, Germany — [2]Department of Quantum Science, Research School of Physics & Engineering, The Australian National University, Australian Capital Territory 0200, Australia

We report on the experimental generation of entangled states of light between the wavelengths 810 and 1550 nm in the continuous variable regime [1]. The fields were produced by a type I optical parametric oscillator operating above threshold. Balanced homodyne detection was used to detect the non-classical noise properties, while filter cavities provided the local oscillators by separating carrier fields from the entangled sidebands. We were able to obtain a conditional variance based measure of I = 0.82, where values below unity demonstrate inseparability.

[1] A. Samblowski, C. E. Laukötter, N. Grosse, P. K. Lahm, R. Schnabel "Two Color Entanglement" arXiv:1011.5766v1 (2010)

Q 60.2 Fri 10:45 SCH 251

Entangling photons via the quantum Zeno effect — Ralf Schützhold, Andreas Osterloh, and •Nicolai ten Brinke — Fakultät für Physik, Universität Duisburg-Essen, Lotharstraße 1, D-47057 Duisburg, Germany

We present an approach for entangling photons using the quantum Zeno effect and strong two-photon absorption. The quantum Zeno effect describes the suppression of the time evolution of a quantum state by frequent measurements. This effect can be employed for entanglement generation, e.g., to implement a quantum-CNOT gate in a linear optics approach to quantum computing. In contrast to previous proposals, our approach might also work in free space, i.e., without resonators or cavities.

Q 60.3 Fri 11:00 SCH 251

Four-Photon Distinguishability Transition — •Malte C. Tichy[1], Hyang-Tag Lim[2], Young-Sik Ra[2], Florian Mintert[1,3], Yoon-Ho Kim[2], and Andreas Buchleitner[1] — [1]Physikalisches Institut - Universität Freiburg - Hermann-Herder-Str. 3 - D-79104 Freiburg — [2]Department of Physics - Pohang University of Science and Technology (POSTECH) - Pohang, 790-784, Korea — [3]Freiburg Institute for Advanced Studies (FRIAS) - Universität Freiburg - Albertstr. 19 - D-79104 Freiburg

The propagation of photons through a four-port beam-splitter is considered theoretically and experimentally with photon quadruplets created by spontaneous parametric down-conversion [1]. All event probabilities turn out to be sensitively dependent on the mutual indistinguishability of the photons. We find that the rate of individual output events – which may be either enhanced or suppressed with respect to the case of distinguishable particles – depends non-monotonically on the degree of distinguishability, and explain this behavior in terms of an intricate interplay between constructive and destructive many-particle interferences. These effects constitute qualitatively new features with respect to the well-known two-photon Hong-Ou-Mandel effect.

[1] M.C. Tichy et al., arXiv:1009.4998

Q 60.4 Fri 11:15 SCH 251

Einstein-Podolsky-Rosen Correlations from a Vacuum-Class Two-Mode Squeezed State — •Tobias Eberle[1,3], Vitus Händchen[1], Jörg Duhme[2,3], Torsten Franz[2], Reinhard Werner[2], and Roman Schnabel[1] — [1]Max-Planck-Institut für Gravitationsphysik (Albert-Einstein-Institut) and Institut für Gravitationsphysik der Leibniz Universität Hannover, Callinstraße 38, 30167 Hannover, Germany — [2]Institut für Theoretische Physik der Leibniz Universität Hannover, Appelstraße 2, 30167 Hannnover — [3]Centre for Quantum Engineering and Space-Time Research - QUEST, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover, Germany

In this talk we present the experimental and theoretical analysis of vacuum-class two-mode squeezed states, i.e. of bi-partite continuous variable entangled states generated by mixing a squeezed mode with a vacuum mode at a 50:50 beam splitter. We observed one of the strongest Einstein-Podolsky-Rosen (EPR) correlations in the continuous variable regime. Theoretically we found that arbitrarily strong EPR correlations are possible with this scheme only depending on the optical loss and the input squeezing.

Q 60.5 Fri 11:30 SCH 251

Operator ordering and causality — •Lev Plimak[1], Wolfgang Schleich[1], and Stig Stenholm[1,2,3] — [1]Abteilung Quantenphysik, Universitaet Ulm, D-89069 Ulm, Germany — [2]Physics Department, Royal Institute of Technology, KTH, Stockholm, Sweden — [3]Laboratory of Computational Engineering, HUT, Espoo, Finland

We show that a causality violation emerges if the conventional definition of the time-normal operator ordering [1] is taken outside the rotating wave approximation. It disappears were the amended definition [2] used. Relativistic causality is demonstrated for a time-normal product of two operators under the most general assumptions about quantum dynamics.

[1] P.L.Kelly and W.H.Kleiner, Phys.Rev. 136, A316 (1964).
[2] Lev Plimak and Stig Stenholm, Annals of Physics, 323, 1989 (2008).

Q 60.6 Fri 11:45 SCH 251

Entangled photons in a disordered waveguide — •Frank Schlawin, Nicolas Cherroret, and Andreas Buchleitner — Institute of phyiscs, Albert-Ludwigs University of Freiburg, Hermann-Herder-Str. 3, 79104 Freiburg, Germany

In this talk, we will consider the propagation of non-classical light through a quasi one-dimensional, disordered waveguide. We will investigate the interplay between the classical noise originating from the disorder, and the quantum properties of the radiation. In particular, we will show that strongly non-classical features of the light, such as entanglement, may have a tremendous impact on the statistical distribution of the coincidence rate measured in transmission (the "two-photon speckle").

Q 60.7 Fri 12:00 SCH 251

Probability amplitudes of two-levels atoms beyond the dipole approximation — •Armen Hayrapetyan[1] and Stephan Fritzsche[2,3] — [1]Max-Planck-Institut für Kernphysik, Postfach 103980, D-69029 Heidelberg, Germany — [2]Department of Physics, P.O. Box 3000, Fin-90014 University of Oulu, Finland — [3]GSI Helmholtzzentrum für Schwerionenforschung, D-64291 Darmstadt, Germany

The interaction of a two-level atom with linearly polarized light is considered beyond the typical dipole approximation. Using an invariant approach for the Schrödinger equation, we derived expressions for the probability amplitudes that depend on both, the space and time coordinates of the varying light field. In this talk, analytical solutions for these amplitudes are presented and discussed in terms of the phase of the radiation field. These solutions are applicable for wavelengths larger or comparable to the size of the atoms. The population inversion is discussed in terms of the phase of the radiation.

Q 61: Quantum Information: Concepts and Methods 4

Time: Friday 10:30–13:00 Location: SCH A118

Q 61.1 Fri 10:30 SCH A118

Phase-dependent wave-particle duality and delayed choice of the which-way detector observable — •Uwe Schilling and Joachim von Zanthier — Institut für Optik, Information und Photonik and Erlangen Graduate School in Advanced Optical Technologies (SAOT), Universität Erlangen-Nürnberg, 91058 Erlangen, Germany

It is well-known that when probing wave-particle duality in a two-way interferometer with a which-way detector, the amount of which-way information (WWI) depends on the observable which one reads out from the which-way detector. One may for example extract all WWI principally available [1] or, contrariwise, realize a quantum eraser [2] which erases all WWI. We introduce a still different observable which allows to either fully reveal or partially erase the WWI, depending on the phase shift in the interferometer [3]. In particular, for particles arriving in the minima of an interference pattern with $\mathcal{V} < 1$, the new observable enables us to extract full WWI which seems to contradict the inequality $\mathcal{D}^2 + \mathcal{V}^2 \leq 1$ introduced in Ref. [1]. We resolve this ostensible contradiction for the case that only the new observable is measured [3]. However, we also show that $\mathcal{D}^2 + \mathcal{V}^2 \leq 1$ may be violated by adeptly choosing the observable which is to be measured after the particle has been detected [4].

[1] B.-G. Englert, Phys. Rev. Lett. **77**, 2154 (1996)
[2] M. O. Scully and K. Drühl, Phys. Rev. A **25**, 2208 (1982)
[3] U. Schilling and J. von Zanthier, to be published
[4] U. Schilling and J. von Zanthier, quant-ph/1006.2037 (2010)

Q 61.2 Fri 10:45 SCH A118

Shor's algorithm and the factorization with Gauss sums — •Sabine Wölk and Wolfgang Schleich — Institut für Quantenphysik, Universität Ulm, D-89069 Ulm, Germany

Shor's algorithm is one of the famous algorithms which scales polynomial whereas analog computers need exponential time to solve the same problem. However, Shor's algorithm does not factor numbers, it just find periods.

On the other side, there exist functions other than $a^\ell \bmod N$ used in Shor's algorithm whose period also contains information about the factors of N. One of these functions is the standard Gauss sum.

In our talk, we will discuss the problems and improvements which emerge when we replace in Shor's algorithm the function $a^\ell \bmod N$ by the standard Gauss sum. Furthermore, we show that the periodicity must not occur in the states itself, but can also appear in the probability amplitudes.

Q 61.3 Fri 11:00 SCH A118

Uncertainty relations and the graph state formalism — •Sönke Niekamp, Matthias Kleinmann, and Otfried Gühne — Fachbereich Physik, Universität Siegen, Walter-Flex-Straße 3, 57068 Siegen

Uncertainty relations not only describe a fundamental concept of quantum mechanics, but also have found application in quantum cryptography and entanglement detection. Entropic uncertainty relations have turned out to be particularly useful. Central questions here are the characterization of observables yielding strong uncertainty relations and the extension to the case of more than two observables. We demonstrate how the stabilizer or graph state formalism can be applied to these problems. For an arbitrary number of qubits we construct measurement bases for which the Maassen-Uffink entropic uncertainty relation is tight. We compare the relative strengths of variance-based and various entropic uncertainty relations for dichotomic anticommuting observables and discuss the generalization to other classes of observables.

Q 61.4 Fri 11:15 SCH A118

A Simple Construction of Cyclic Mutually Unbiased Bases — •Ulrich Seyfarth[1], Kedar Ranade[2], and Gernot Alber[1] — [1]Institut für Angewandte Physik, Technische Universität Darmstadt, 64289 Darmstadt, Germany — [2]Institut für Quantenphysik, Universität Ulm, Albert-Einstein-Allee 11, 89069 Ulm, Germany

Many applications of complete sets of mutually unbiased bases (MUBs) in the field of quantum information theory are known. In particular, in the context of quantum cryptography they yield generalizations of the six-state protocol for qubits. Recently it was shown that in even prime-power dimensions such MUBs can be generated by a single unitary operator [1,2] so that they are 'cyclic'. In this contribution we present a method for constructing cyclic MUBs in higher dimensions recursively. This method enables one to construct generators of complete sets of cyclic MUBs for very high dimensions without elaborate numerical calculation. These results may be relevant for high-dimensional generalizations of the quantum cryptographic six-state protocol as well as possible applications in quantum state discrimination.

[1] H. F. Chau, IEEE Trans. Inf. Theory 49, 457 (2003)
[2] R. Gow, arXiv:math/0703333v2 (2007)

Q 61.5 Fri 11:30 SCH A118

Optimal molecular networks for excitonic energy transport — •Torsten Scholak, Thomas Wellens, and Andreas Buchleitner — Physikalisches Institut, Universität Freiburg, Hermann-Herder-Str. 3, D-79104 Freiburg, Germany

Our study of coherent excitation transfer in finitely sized disordered molecular networks reveals certain optimal conformations that feature fast and perfectly efficient transport of energy—solely by means of constructive quantum interference. The properties and mechanics of these remarkable conformations are the subject of this talk. Our insights may help to better understand the efficient energy transfer in photosynthetic light-harvesting complexes.

Q 61.6 Fri 11:45 SCH A118

Classical simulation of dynamical quantum systems — •Robert Zeier — Technische Universität München, Department Chemie, Lichtenbergstr. 4, 85747 Garching

We propose Lie-algebraic methods to simulate unitary dynamics of closed quantum systems using classical computers. A wide range of approaches represent mixed quantum states and unitary transformations by explicit matrices which are assumed to be sparse. In contrast, we rely on direct computations in structure-constant Lie algebras where Lie-algebra elements are given as sparse vectors and the commutator is efficiently implemented while accounting for sparsity. Building on this representation, we present a method to compute the time evolution which avoids direct matrix exponentiation. We discuss the efficiency of our methods.

Q 61.7 Fri 12:00 SCH A118

How contextual is quantum mechanics? — •Matthias Kleinmann[1], Otfried Gühne[1], José Portillo[2], Jan-Åke Larsson[3], and Adán Cabello[4] — [1]Fachbereich Physik, Universität Siegen, D-57068 Siegen, Germany — [2]Departamento de Mathemática Aplicada I, Universidad de Sevilla, E-41012 Sevilla, Spain — [3]Institutionen för Systemteknik och Matematiska Institutionen, Linköpings Universitet, SE-581 83 Linköping, Sweden — [4]Departamento de Física Aplicada II, Universidad de Sevilla, E-41012 Sevilla, Spain

The Kochen-Specker theorem proves that any classical model of quantum mechanics necessarily is contextual, i.e., the value of an observable depends on which other, compatible observable is measured simultaneously. We investigate classical models that simulate quantum contextuality for sequential measurements. Such models can be described by means of finite automata and we quantify the number of different states an automaton obtains during a measurement sequence as being the memory need of the automaton. We analyze this memory need for different scenarios and show that the simulation of a two-qubit system can require more than two bits of classical memory.

Q 61.8 Fri 12:15 SCH A118

Quantum Simulation by Example: Exploiting Symmetry Principles of Quantum Systems Theory — •Thomas Schulte-Herbrüggen and Robert Zeier — Dept. Chem., TU-Munich, Germany

We present a plethora of examples showing under which conditions spin systems, fermionic systems, and bosonic systems with pair or higher many-body interactions can mutually simulate eachother.

These illustrations are part of a unified framework of quantum systems theory, where symmetry principles translate into simple algorithms deciding engineering problems of controllability, observability, and the design of universal quantum hardware.

Q 61.9 Fri 12:30 SCH A118

Performance of quantum convolutional and block error-correcting codes — •Johannes Gütschow — Institut für Theoretische Physik, Universität Hannover

Quantum convolutional error-correcting codes are often said to have the potential to outperform block codes in terms of code rate and decoding complexity. In this talk we will compare the performance of convolutional codes and block codes under constraints on the size of the encoding and decoding operations (the block length). We will analyze the relation between code rate, the correctable error rate and the block length.

We will first derive a Hamming type bound on the number of correctable errors per block for convolutional codes. Using this bound in different settings we will compare the theoretical performance of convolutional codes to that of block codes and finally give examples for convolutional codes in these settings.

Q 61.10 Fri 12:45 SCH A118

Differencial Magnetometry with Multipartite Singlets — •Iñigo Urizar-Lanz[1] and Géza Tóth[1,2,3] — [1]Theoretical Physics, The University of the Basque Country, E-48080 Bilbao, Spain — [2]IKERBASQUE, Basque Foundation for Science, E-48011 Bilbao, Spain — [3]Research Institute for Solid State Physics and Optics, H-1525 Budapest, Hungary

We present a method for measuring the gradient of a magnetic field using a multi-qubit singlet state taking advantage of the fact that the singlet state is insensitive to homogenous fields. By measuring the time dependence of the variance of the collective angular momentum operators, we obtain the gradient of the magnetic field. We present realistic calculations for singlet states realized in a spin chain or with cold atomic ensembles.

Q 62: Laseranwendungen: Lebenswiss. und Umweltphys.

Time: Friday 10:30–13:00 Location: HÜL 386

Q 62.1 Fri 10:30 HÜL 386

Laserquellenentwicklung für CARS Mikroskopie — •Petra Gross, Carsten Cleff, Lisa Kleinschmidt, Jörn Epping, Sven Dobner, Jan Brockhaus und Carsten Fallnich — Institut für Angewandte Physik, Westfälische Wilhelms-Universität, Corrensstr. 2. 48149 Münster

Kohärente Anti-Stokes Raman Streuung (CARS) kann als chemisch selektiver Kontrastmechanismus für nichtlineare Mikroskopie genutzt werden. Die Einsatzmöglichkeiten der CARS Mikroskopie sind insbesondere in den Lebenswissenschaften von potenziell hoher Bedeutung, die dafür benötigten komplexen Laserquellen verhindern jedoch bisher eine breite Verwendung.

Wir berichten in diesem Beitrag über unsere Arbeiten zur der Strahlquellenentwicklung, über Anwendungsmöglichkeiten der CARS Mikroskopie, sowie über unsere Untersuchungen zur räumlichen und spektralen Auflösungsverbesserung. Zum Beispiel stellen wir eine neuartige Strahlquelle vor, die auf einem Femtosekunden Titan-Saphirlaser und auf Superkontinuumserzeugung in einer mikrostrukturierten Glasfaser beruht. Diese Strahlquelle ist besonders kostengünstig und kompakt, was in der Zukunft den Einsatz der CARS Mikroskopie im praktischen Laboralltag erleichtern könnte. Des weiteren diskutieren wir das spektrale Auflösungsvermögen von Femtosekundenstrahlquellen, das z.B. durch gezieltes Strecken der Impulse entscheidend verbessert werden kann.

Q 62.2 Fri 11:00 HÜL 386

High-speed optical coherence tomography using a Fourier domain mode locked laser — •Lars Kirsten, Julia Walther, Peter Cimalla, Sven Meissner, Mirko Mehner, and Edmund Koch — Dresden University of Technology, Faculty of Medicine Carl Gustav Carus, Clinical Sensoring and Monitoring, Fetscherstraße 74, 01307 Dresden, Germany

Optical coherence tomography (OCT) is a noninvasive imaging modality [1] generally used in medical diagnostics for 2D and 3D visualization of tissue with a spatial resolution of a few micrometers. Broadband light sources at the spectral range of 700 nm to 1500 nm are used because of low scattering and absorption in tissue resulting in a large penetration depth of typically 1 mm. The superposition of backscattered light from the sample and reference light in the interferometer generates the interference spectrum which is detected spectrally resolved in Fourier domain OCT. Multiple OCT applications suffer from motion artifacts and demand short image acquisition times especially under in vivo conditions. For achieving fast image acquisition, the principle of Fourier domain mode locking (FDML) is a suitable approach [2]. The presented FDML laser provides wavelength sweeps centered at 1300 nm and repetition rates of 50 kHz and 123 kHz, respectively. The functionality of OCT imaging is demonstrated in different biomedical applications.

[1] D. Huang et al. Science 254, 1178-1181 (1991)
[2] R. Huber et al. Optics Express 14, 3225-3237 (2006)

Q 62.3 Fri 11:15 HÜL 386

Absorption measurements via self-phase modulation of light — •Jessica Steinlechner, Stefan Ast, Nico Lastzka, Sebastian Steinlechner, and Roman Schnabel — Albert Einstein Institut, MPI für Gravitationsphysik, QUEST, Leibniz Universität Hannover

The precise measurement of small optical absorptions in dielectric coatings and nonlinear materials is a challenging task. Within the SFB TR7 an absorption measurement scheme based on the shape of the airy peaks of a scanned optical resonator was developed. Due to the heating of the intra-cavity material or the mirror coatings, the transmitted as well as the reflected airy peaks show a hysteresis depending on the scan direction. A time domain simulation based on is used to fit the measurement data. Using these method we measured the absorption of high reflective mirror coatings and a PPKTP substrate. To prove the quantitative result of the measurements we compared our results to measurements with a calorimetric method and values known from literature respectively.

Q 62.4 Fri 11:30 HÜL 386

Hochstabiles Multiwellenlängenlasersystem für die 3D-Oberflächenmesstechnik — •Axel Heuer, Danilo Skoczowsky, Andre Hamdorf, Christof Zink und Ralf Menzel — Universität Potsdam, Institut für Physik und Astronomie, Photonik, Karl-Liebknecht-Str. 24-25, Haus 28, 14476 Potsdam

Für die hochpräzise 3D-Oberflächenvermessung von Bauteilen im Produktionsprozess bedarf es eines Messsystems, das robust und schnell ist, damit es für die Inline-Kontrolle eingesetzt werden kann. Möglich wird dies durch den Einsatz von Multi-Lambda-Digital-Holographie (MLHD). Durch den Einsatz mehrerer kohärenter Lichtquellen verschiedener Wellenlänge, die nicht kohärent miteinander überlagert werden, ergeben sich verschiedene virtuelle synthetische Wellenlängen. Realisiert wird dieses durch den Aufbau einer Mehrwellenlängenlichtquelle. Eine synthetische Welle entsteht hier durch die virtuelle Überlagerung von zwei gegeneinander um nur wenige pm bis nm verstimmter Wellen. Mit diesem Verfahren kann aufgrund unterschiedlicher Messwellenlängen (Laser- bzw. synthetische Wellenlängen) ein breiter Messbereich von sub-um bis in den m-Bereich erschlossen werden. Auflösung und Reproduzierbarkeit des Messsystems sind dabei vom Abstand der verwendeten Einzelwellenlängen und deren spektraler Stabilität abhängig. Auswahl und präzise Stabilisierung der Lichtquellen sind wichtige Arbeitsziele. Es wird ein Lasersystem mit frequenzstabilisierten roten Laserdioden vorgestellt, welches die reproduzierbare Umschaltung zwischen 6 verschiedenen Wellenlängen erlaubt. Die Schaltzeiten liegen bei ca. 2 ms und die Wellenlängenstabilität ist besser 1 pm.

Q 62.5 Fri 11:45 HÜL 386

Hochempfindlicher Nachweis von Zwei-Photonen-Fluoreszenz (TPF) mit weniger als 100 μW cw-Anregungsleistung mittels eines Diodenlasers — •Henning Kurzke, Michael Seefeldt, Axel Heuer und Ralf Menzel — Universität Potsdam, Institut für Physik und Astronomie, Photonik, Karl-Liebknecht-Str. 24-25, Haus 28, 14476 Potsdam

Die Fluoreszenzanregung durch die gleichzeitige Absorption zweier Photonen der halben Anregungsenergie zeichnet sich durch eine quadratische Abhängigkeit der Fluoreszenzrate von der Anregungsintensität aus. Das so realisierte kleinere Wechselwirkungsvolumen erlaubt eine höhere räumliche Auflösung gegenüber der Ein-Photonen-Absorption. Gleichzeitig erlauben größere Wellenlängen häufig höhere Eindringtiefen. Dies macht die TPF interessant für biologische und medizinische Anwendungen. Allerdings ist der Zwei-Photonen-Absorptions-Wirkungsquerschnitt sehr klein, so dass die dafür benötigten hohen Anregungsintensitäten meist mit Kurzpulssystemen realisiert werden. Diese sind komplex und kostenintensiv. Wir präsentieren Ergebnisse zur TPF mit einem kommerziellen cw-Dioden-Laser. Bei einer Anregungswellenlänge von 976 nm wurden klassische Laserfarbstoffe untersucht. Der vorgestellte Aufbau erlaubt den hochempfindlichen Nachweis der TPF mit cw-Anregungsleistungen kleiner als 100 μW. Durch die geringen Intensitäten können Probleme (z.B. andere nichtlineare optische Effekte) minimiert werden.

Q 62.6 Fri 12:00 HÜL 386

^{13}CO-Bestimmung aus Blutproben — •Philipp Seidel, Marcus Sowa und Peter Hering — Institut für Lasermedizin, Universitätsklinikum Düsseldorf, Universitätsstr. 1, 40225 Düsseldorf

Es wird ein Verfahren zur Kohlenmonoxidbestimmung (CO) im Blut präsentiert, welches zur Selbstkontrolle der Bestimmung der Hämoglobingesamtmasse (tHb) durch eine CO-Atemanalyse dient; eine Methode, die in unserem Institut entwickelt wird. Ein Vorteil dieser Vorgehensweise auf Basis der Cavity-Leak-Out-Spektroskopie (CALOS) im mittleren Infrarot-Bereich (ca. 5μm), liegt in der Durchführbarkeit isotopologenselektiver Messungen. Kommerziell erhältliche Blutanalysegeräte, wie sie beispielsweise in Krankenhauslaboren zu finden sind, besitzen diese Eigenschaft nicht. Durch die Verwendung des nichtradioaktiven Isotopologs ^{13}CO, welches lediglich zu 1,1% in der natürlichen Zusammensetzung von Kohlenmonoxid vorkommt, sind nur geringe Mengen für den Vorgang der tHb-Bestimmung nötig. Das in dem Vortrag vorgestellte Prinzip beruht darauf, dass das in Form von Carboxyhämoglobin (COHb) gebundene CO freigesetzt wird. Die COHb-Konzentration wird dann durch das Volumen des freigesetzten CO berechnet, welches durch eine CALOS-Messung quantifiziert wird. Eine Optimierung der Reaktion hinsichtlich der Temperatur und des Aufbaus ist Bestandteil der laufenden Arbeiten. Im Rahmen des Vortrags sollen das System und erste Ergebnisse präsentiert werden.

Q 62.7 Fri 12:15 HÜL 386

Untersuchung der Lebensdauer von Antireflexionsschichten unter Tritiumatmosphäre für KATRIN — •Kerstin Schönung — für die KATRIN Kollaboration, Karlsruher Institut für Technologie, IEKP, Karlsruhe, Deutschland

Das KArlsruher TRItium Neutrino-Experiment KATRIN wird eine modellunabhängige Bestimmung der Neutrinomasse leisten. Hierfür wird das Energiespektrum der Betaelektronen einer fensterlosen molekularen gasförmigen Tritiumquelle an seinem kinematischen Endpunkt von 18,6 keV mit einem hochauflösenden, elektrostatischen Filter untersucht. Um die gewünschte Sensitivität von 0,2 eV/c^2 (90 % CL) zu erreichen, ist es notwendig den Tritiumgehalt des Gases mit Hilfe eines Laser-Raman-System mit einer Präzision von 0,1 % zu bestimmen. Dazu wird vor der Einspeisung in die Tritiumquelle das gesamte Gasgemisch durch eine Probenzelle des Raman-Systems gepumpt.

Nach einem dreimonatigen Testbetrieb mit Tritium mit 185 mbar Partialdruck wurde eine Beschädigung der Antireflexionsschicht der optischen Fenster der Probenzelle festgestellt. Diese scheint auf den hohen Partialdruck von Tritium zurückführbar zu sein, da keine Beschädigung bei Gasmischungen mit 13 mbar Partialdruck Tritium beobachtet werden konnte. Die aufgetretenen Mängel verhindern das Erreichen der geforderten Präzision der Ramanspektroskopie.

Dieser Vortrag behandelt mögliche Ursachen der Beschädigung. Außerdem wird ein Testexperiment vorgestellt, mit dem eine tritiumtaugliche Beschichtung gefunden werden soll. Es werden die verwendeten Messmethoden und der derzeitige Stand des Experiments präsentiert.

Q 62.8 Fri 12:30 HÜL 386

Ein Brillouin-LIDAR zur Messung von Temperaturprofilen des Ozeans: Optimierung des ESFADOF-Pumpprozesses — •Vincenzo Talluto, Andreas Rudolf und Thomas Walther — Institut für Angewandte Physik, AG Laser und Quantenoptik, Technische Universität Darmstadt, Schlossgartenstr. 7, 64289 Darmstadt

Faraday **A**nomalous **D**ispersion **O**ptical **F**ilter (FADOF) sind besonders schmalbandige, atomare Kantenfilter. Sie sind in der Lage, minimale Frequenzverschiebungen des Eingangssignals in große Intensitätsänderungen des Ausgangssignals zu überführen. Erreichbar sind Transmissionsänderungen von nahezu 100% innerhalb einer Frequenzverschiebung von einem GHz und kleiner.

Ein **E**xcited **S**tate FADOF (ESFADOF) soll als Detektor des von uns entwickelten Brillouin-LIDAR eingesetzt werden. Das System ist für den Einsatz an Bord eines Helikopters gedacht und wird die berührungslose Messung von Temperaturprofilen des Ozeans ermöglichen.

Hierzu muss der ESFADOF Frequenzverschiebungen der temperaturabhängigen Brillouin-Streuung von ±7-8 GHz auflösen. Um den Filter in der Nähe des Absorptionsminimums von Wasser zu betreiben, wird ein atomarer Übergang bei 543 nm zwischen zwei angeregten Zuständen in Rubidium genutzt. Das Rubidium muss daher bei 780 nm optisch gepumpt werden. Wir zeigen, dass es durch geeignete Optimierung dieses Pumpprozesses möglich ist, die Filtercharakteristik maßgeblich und gezielt zu gestalten. Insbesonders lassen sich die Transmissionskanten mit hoher Genauigkeit symmetrisieren.

Q 62.9 Fri 12:45 HÜL 386

Ein Brillouin-LIDAR zur Messung von Temperaturprofilen des Ozeans: Fortschritte am ESFADOF-Detektor zum praktischen Einsatz — •Andreas Rudolf, Alexandru Popescu und Thomas Walther — Institut für Angewandte Physik, AG Laser und Quantenoptik, Technische Universität Darmstadt, Schlossgartenstr. 7, 64289 Darmstadt

Die Kenntnis des lokalen Wärmegehalts der Weltmeere ist für die marine Forschung von hohem Interesse. Um ihn zu messen, ist eine tiefenaufgelöste Bestimmung der Wassertemperatur notwendig. Als berührungsloses Verfahren bietet sich die lasergestützte Messung an Bord eines Helikopters an. Hierzu entwickeln wir ein flugtaugliches Brillouin-LIDAR, welches die Brillouin-Streuung als Temperaturindikator nutzt.

Die gepulste Strahlquelle wird durch einen frequenzverdoppelten, Yb-dotierten Faserverstärker realisiert. Der Detektor ist ein spektral hochauflösender Kantenfilter und wird als **E**xcited **S**tate **F**araday **A**nomalous **D**ispersion **O**ptical **F**ilter (ESFADOF) bezeichnet. Herzstück des ESFADOF ist eine optisch gepumpte Rubidium-Gaszelle, die von einem konstanten Magnetfeld durchdrungen wird.

Der limitierende Faktor lag bislang in der Stärke, Ausdehnung und Homogenität des Magnetfelds. Mit einer neu entwickelten Anordnung von Permanentmagneten auf Basis eines Halbach-Arrays wird diese Einschränkung nun überwunden. Das System erzeugt auf einer Länge von 50 mm ein homogenes Feld mit einer Stärke von 0,6 T. Die Filtercharakteristik verbessert sich hierdurch entscheidend. Im Vortrag werden die neuesten Ergebnisse des Gesamtprojekts präsentiert.

Q 63: Ultrakurze Laserpulse: Erzeugung und Anwendungen 2

Time: Friday 10:30–12:45 Location: SCH A215

Q 63.1 Fri 10:30 SCH A215

Generation and Dispersion Management of Femtosecond Laser Pulses — •Andreas Fischer, Konstantin Simeonidis, Alexander Sperl, and Joachim Ullrich — Max-Planck-Institut für Kernphysik

To create few-cycle laser pulses, special techniques have to be employed. One possibility is the spectral broadening of a light pulse by self-phase-modulation (SPM) in a glas capillary tube filled with a noble gas. The dispersion, caused by optical elements, has severe impact on the temporal shape of a few-cycle laser pulse and leads to temporal broadening. Dispersion control is therefore indispensable in such a laser system.

This talk delineates an effective method of simulating the effects of dispersion caused by an optical path, affecting the laser pulse. Using this simulation it is possible to interactively design a pulse compressor, which can quickly be calculated and put into operation. For this method it is vital to precisely know the dispersive behavior of each element. A dispersion measurement instrument has been developed and successfully comissioned. First applications of the simulation, namely the interactive design of a pulse compressor consisting of dispersive mirrors, seem to yield very promising results.

Q 63.2 Fri 10:45 SCH A215

Justagefreie ps-Faserlaserquelle auf Basis von Vierwellenmischung für kohärente Raman-Mikroskopie — •Mario Chemnitz[1], Martin Baumgartl[1], Cesar Jauregui Misas[1], Jens Limpert[1] und Andreas Tünnermann[1,2] — [1]Institut für Angewandte Physik, Albert-Einstein-Strasse 15, 07745 Jena — [2]Fraunhofer-Institut für Angewandte Optik und Feinmechanik, Albert-Einstein-Str. 7, 07745 Jena

Kohärente Raman-Mikrospektroskopie wurde als leistungsfähiges Verfahren für die markerfreie Mikroskopie in zahlreichen Arbeiten demonstriert. Der breite Einsatz dieses Verfahrens für Anwendungen wie z.B. der Tumorerkennung im klinischen Bereich wird aktuell durch die hohe Komplexität der benötigten synchronisierten Zweifarben-Kurzpulslaserquelle verhindert. Wir stellen ein kompaktes justagefreies Faserlaserkonzept vor, basierend auf entarteter Vierwellenmischung (FWM) in Photonischen Kristallfasern (PCF). Der parametrische Prozess wird mittels Ytterbium-basiertem Pikosekunden-Faserlaser gepumpt. Per FWM werden ps-Pulse bei Signal- und Idler-Wellenlängen in einem durchstimmbaren Abstand um 2850cm^{-1} erzeugt, welche zur Anregung der CH-Streckschwingung in Lipiden genutzt werden kann. Designparameter der PCF wurden mit Hilfe numerischer Simulationen für die benötigten Wellenlängen optimiert. Der Ansatz liefert ein vollständig faserintegriertes und damit justage- und wartungsfreies Lasersystem, welches optimal für den Einsatz in der klinischen Analytik geeignet ist.

Q 63.3 Fri 11:00 SCH A215

Hochrepetierendes, CEP-stabilisiertes OPCPA-System mit μJ-Pulsenergien und Pulsdauern von weniger als 6 fs — •Marcel Schultze[1], Thomas Binhammer[2], Moritz Emons[1], Tino Lang[1] und Uwe Morgner[1] — [1]Institut für Quantenoptik, Leibniz Universität Hannover, Deutschland — [2]VENTEON Laser Technologies GmbH, Garbsen, Deutschland

Wir präsentieren ein zweistufiges parametrisches Verstärkersystem, das bei hohen Wiederholraten von 100 bis 500 kHz Pulse mit mehr als 3 μJ generiert. Die Pulse selber besitzen dabei eine Pulsdauer von weniger als 2 optische Zyklen. Realsiert wird dies über einen breitbandigen Titan:Saphir-Oszillator, welcher sowohl die Seedpulse für den parametrischen Verstärker als auch für den Pumpverstärker bereitstellt. Die Pumpstrahlung wird dabei direkt in einem regenerativen Yb:YAG Scheibenverstärker mit anschliessender Frequenzverdopplung generiert. Die eigentliche parametrische Verstärkung wird in einem zweistufigen Aufbau in zwei BBO-Kristallen realisiert. Das verstärkte Spektrum reicht dabei von ca. 680 bis 1000 nm und unterstützt Pulsdauern von ca. 5.2 fs. Die anschliessende Komprimierung der Pulse geschieht mit Hilfe von gechirpten Spiegeln. Zusammenfassend können somit komprimierte Pulsdauern von 5.7 fs mit Pulsenergien grösser 3 μJ und resultierenden Pulsspitzenleistungen von mehr als 250 MW erzeugt werden. Zusätzlich ist die Träger-Einhüllenden Phase (CEP) des Ti:Sa-Oszillators stabilisiert und eine stabile Phase nach dem Verstärker verifiziert worden.

Q 63.4 Fri 11:15 SCH A215

Modengekoppelter Faserlaser mit über 1 Watt mittlerer Leistung und fourierlimitierten Pulsdauern von unter 60 fs — •Jan Matyschok[1], Oliver Prochnow[2], Thomas Binhammer[2], Stefan Rausch[1], Katharina Hausmann[3], Hakan Sayinc[3], Dietmar Kracht[3] und Uwe Morgner[1,3,4] — [1]Institut für Quantenoptik, Leibniz Universität Hannover, 30167 Hannover, Germany — [2]Venteon Laser Technologies GmbH, 30827 Garbsen, Germany — [3]Laser Zentrum Hannover e.V., 30419 Hannover, Germany — [4]Centre for Quantum Engineering and Space-Time Research (Quest), 30167 Hannover, Germany

Ultrakurzpuls-Ytterbium-Faseroszillatoren erreichen durch neue Konzepte immer höhere mittlere Leistungen. Dies ist unter anderem durch die Verwendung von leistungsstärkeren Pumpdioden und Doppelkern-Fasern ermöglicht worden. Durch den Verzicht auf eine Dispersionskompensation und die dadurch resultierende hohe Gesamtdispersion im Resonator wird es grundsätzlich schwieriger, ultrakurze Pulse bei gleichzeitig hoher mittlerer Leistung zu erzeugen. In dem realisierten Laser ist es dennoch gelungen sehr hohe Bandbreiten von über 60 nm (-20 dB) zu erzeugen. Dies entspricht einer fourierlimitierten Pulsdauer von unter 60 fs. Der Oszillator wurde über das Prinzip der nichtlinearen Polarisationsdrehung modengekoppelt. Eine zusätzliche Amplitudenmodulation durch ein doppelbrechendes Filter stabilisierte dabei die Modenkopplung im breitbandigen Betrieb. Durch die zur Verfügung stehende Pumpleistung war die Ausgangsleistung des Lasers auf 1,1 W limitiert.

Q 63.5 Fri 11:30 SCH A215

Lasersysteme für die Quelle polarisierter Elektronen am Darmstädter S-DALINAC — •Antje Weber, Joachim Enders, Martin Espig, Janina Lindemann, Markus Roth, Fabian Schneider, Markus Wagner und Benjamin Zwicker — Institut für Kernphysik, Darmstadt, Deutschland

Der Darmstädter supraleitende Elektronen-Linearbeschleuniger S-DALINAC ist im Jahr 2010 um eine neue Quelle polarisierter Elektronen erweitert worden. Die polarisierten Elektronen werden durch Beschuss einer Strained-superlattice-GaAs-Photokathode mit zirkular polarisiertem Laserlicht erzeugt. An der Darmstädter Quelle werden dazu zwei Lasersysteme verwendet, ein Diodenlaser und ein modengekoppelter Titan-Saphir-Laser. Zur Wartung und Weiterentwicklung der Lasersysteme sind diese in einem ca. 40 m von der Kathode entfernten Raum untergebracht. Wir berichten über Anforderungen, Diagnose und Zuverlässigkeit dieser Lasersysteme sowie über den Transport des Laserstrahls zur Kathode und die benötigte Stabilisierung im Orts- und Zeitraum.

Gefördert durch die DFG im Rahmen des SFB 634.

Q 63.6 Fri 11:45 SCH A215

Kompression ultrakurzer Laserpulse eines Faserverstärkersystems mit edelgasgefüllten Hohlfasern bei hohen Durchschnittsleistungen — •Henning Carstens[1], Steffen Hädrich[1,2], Jan Rothhardt[1,2], Jens Limpert[1,2] und Andreas Tünnermann[1,2,3] — [1]FSU Jena, IAP, Albert-Einstein-Straße 15, D-07745 Jena — [2]Helmholtz Institut Jena, Max-Wien-Platz 1, D-07743 Jena — [3]Fraunhofer IOF, Albert-Einstein-Str. 7, D-07745 Jena

Edelgas gefüllte Hohlfasern werden genutzt, um Laserpulse eines 1 mJ, 480 fs, 50 kHz Faserverstärkersystems zu komprimieren. Nach der Kompression wurde eine Pulsdauer von 35 fs bei einer Pulsenergie von 380 μJ gemessen, was einer Pulsspitzenleistung von 5.7 GW entspricht. Nach unserem Wissen ist dies die höchste Durchschnittsleistung (19 W), welche bisher aus einer Hohlfaserkompression extrahiert werden konnte. Die erste Stufe besteht aus einer 53 cm langen mit Xenon gefüllten Faser, die zweite aus einer 20 cm langen mit Argon gefüllten Faser, wobei beide Fasern einen Innendurchmesser von 200 μm haben. Die Laserpulse erfahren im Edelgas aufgrund der Selbstphasenmodulation eine beträchtliche spektrale Verbreiterung. Im Zentrum besitzen die Pulse dadurch einen nahezu linearen Chirp. Entfernt man diesen, z.B. mit GTI Spiegeln, verkürzen sich die Pulse aufgrund der vergrößerten spektralen Bandbreite. Mit breitbandigeren Spiegeln und einem Druckgradienten in der Faser werden in Zukunft kürzere Pulse bei erhöhter Stabilität möglich sein, was zu noch höheren Spitzenleistungen führt. Damit sollte mit diesem System die Erzeugung hoher Harmonischer bei herausragenden Durchschnittsleistungen möglich sein.

Q 63.7 Fri 12:00 SCH A215

Laser Induced Lensing During In-Volume Modification of Glass With Fs-Laser Radiation — •Anna Schiffer, Martin Hermans, and Jens Gottmann — Lehrstuhl für Lasertechnik, RWTH Aachen, Steinbachstr. 15, 52074 Aachen

The manufacturing of transparent microcomponents and integrated optical systems is an important development for future technologies. Glass-microcomponents and waveguides are processed by focusing ultra short pulsed laser radiation into glass using microscope objectives and translation stages. Fs-Laser radiation is absorbed by multi-photon processes within the focal volume. Optical and chemical properties of the material change, thus showing waveguiding characteristics and a change in etchability. Effects of a fs-fiber laser system (IMRA America, 1045nm) on fused silica and borosilicate glass are investigated. Modification characteristics are changed by variation of repetition rate, pulse energy, focusing numerical aperture and writing speed.

The aforementioned modification process of glass is not fully understood. In order to develop an applicable process for industrial use further investigation is needed. In-situ analysis by interference microscopy and emission spectroscopy offers the possibility of establishing a correlation between the observed experimental data and resulting modification. Interference microscopy provides information on occuring heat accumulation and the laser induced lens during processing. The spectral analysis of emitted radiation provides further information about the electronic absorbtion processes, such as the formation of colour centres, non-bridging oxygen-vacancies and peak temperature.

Q 63.8 Fri 12:15 SCH A215

Strong-field above-threshold photoemission from sharp metal tips — •Michael Krüger, Markus Schenk, and Peter Hommelhoff — Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Str. 1, 85748 Garching bei München

We focus low-power few-cycle laser oscillator pulses on sharp tungsten tips and measure the energy of the emitted electrons. We observe above-threshold photoemission with a photon order of up to nine. At intensities exceeding 10^{11} W/cm^2 we observe a suppression of the lowest-order peak as well as a shift of the spectral features towards lower energies [1]. This shift scales linearly with intensity with a slope of $-1\,\mathrm{eV}/(10^{12}\,\mathrm{W/cm^2})$. We conclude that these phenomena owe to an AC Stark shift of the continuum states and thus are strong-field effects. A comparison of the measured shift with the shift expected from laser and focal spot parameters reveals that the laser electric field at the tip's apex is enhanced by a factor of about 4. This enhancement enables us to enter the strong-field regime with low-power oscillator pulses only. Furthermore, we observe a plateau and a cut-off in the high-energy part of the spectra. This is an evidence that electrons recollide with the tip, implying that high-harmonic radiation can be expected to be generated at the tip. Also coherent control of photoemission should be feasible since strong carrier-envelope phase effects have been observed with this system [2].

[1] M. Schenk, M. Krüger, P. Hommelhoff, accepted for publication in Physical Review Letters (2010)

[2] see contribution of M. Schenk et al. at this conference

Q 63.9 Fri 12:30 SCH A215

Tip-based electron source for femtosecond electron diffraction — •Jan-Paul Stein, Markus Schenk, Michael Krüger, Peter Baum, and Peter Hommelhoff — Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Straße 1, 85748 Garching bei München

In today's femtosecond electron diffraction and microscopy experiments, femtosecond UV pulses are employed to trigger photoemission of electrons from a flat metallic surface cathode. Subsequently, the electrons undergo acceleration in a constant electric field. Due to the limited maximum applicable electric field of roughly 10 MV/m even single electron pulses cannot get shorter than 100 fs at the target [1]. The aim of this study is to replace the flat cathode by a sharp metal tip [2] with a radius of curvature on the order of a few hundred nanometers. Due to the tip geometry the electric field at the apex is strongly enhanced and reaches values of GV/m. Hence electrons experience a strong acceleration right after emission. Electrons leaving the tip with different initial kinetic energies therefore develop a significantly lower timing jitter during their propagation, translating into shorter pulse durations than in conventional setups. Furthermore, the electron beam emittance decreases drastically. We will present results of a detailed analytic and numerical analysis of different setup parameters and discuss the current experimental status.

[1] M. Aidelsburger, F. O. Kirchner et al., PNAS 107 19714 (2010)
[2] P. Hommelhoff, C. Kealhofer et al., Phys. Rev. Lett. 96 077401 (2006)