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
Jahrestreffen des Fachverbandes Quantenoptik und Photonik

Mittwoch, 13:30–14:15 in Raum SCH251

- Bericht des Fachverbandsleiters
- Vorstellung des Sektionssprechers
- Verschiedenes
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.

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.

We report on the operation of a closed-cycle dilution refrigerator for 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.
Itively, incoherent noise helps to generate coherent quantum effects.

Quantum Optics and Photonics Division (Q) Monday

10129, Torino, Italy —

1 —

Two-point density correlations of quasicondensates in free ex-

chanical arrays.

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.

Quantum dynamics in optomechanical arrays —

In the context of quantum mechanics, we consider the dynamics of a quantum system in interaction with its environment. This interaction can lead to decoherence and loss of quantum coherence, which is a fundamental issue in quantum technology and applications.

Optomechanically Induced Transparency —

Optomechanically Induced Transparency (OMIT) is a phenomenon that occurs when a mechanical resonator is coupled to a cavity. The OMIT effect can be used to control the transmission of light through the cavity, which can be useful in various applications such as quantum computing and sensing.

Shot noise limited displacement measurement of a high Q micro-

canical oscillator below the peak value of the SQL —

1. The shot noise limit is a fundamental limit on the precision of measurements. Below the shot noise limit, quantum fluctuations become significant and can limit the performance of quantum sensors.

Bose-Einstein condensates in optical micro-potentials —

Bose-Einstein condensates are a state of matter in which a large number of bosons are found in the same quantum state, creating a macroscopic quantum coherence. In optical micro-potentials, these condensates can be confined in one or two dimensions, which allows for precise control and manipulation of the quantum state of the system.

Bogoliubov theory of disordered Bose-Einstein condensates —

Bogoliubov theory is a powerful tool for describing the quantum dynamics of a Bose-Einstein condensate in a disordered potential. This theory allows for the calculation of various properties such as the ground state and low-lying excited states of the system.

Time: Monday 10:30–13:00

Location: HÜL 386
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

Quantum Optics and Photonics Division (Q) Monday

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 sys-
tems, including cold atomic gases and solid-state quasiparticles. How-
ever 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 exper-
imentally 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 tempera-
ture 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.

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, App-
pelstr. 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 su-
persolid, pair superfluid and various Haldane insulator phases for dif-
ferent 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 Schnee-
der and Reinhold Walser — Institut für Angewandte Physik, TU
Darmstadt

The interaction of carbon nanotubes with cold gases has many un-
knowns. In particular, the interaction potentials and loss rates are
under intense investigations (cf Casimir-Polder potential). In this con-
tribution 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 hydrodynam-
is in a perturbative limit (linear response) to calculate the particle
loss rate for certain potential shapes. This model incorporates two ba-
sic 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 Novak1,2, Maximilian Schmidt1,2, Jan Schölle1,2, Denes Saxty1,2, and
Thomas Gaenez1,2 — Institut für Theoretische Physik, Ruprecht-
Karls-Universität Heidelberg, Philosophenweg 16, 69120 Heidelberg —
2ExtreMe Matter Institute EMMI, GSI Helmholtzzentrum für Schwe-
rienenforschung 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 dis-
tinctly 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 ZPI effective action,
are discussed in comparison to the well-known Kolmogorov scaling of
vortical motion. These phenomena of strong turbulence should in prin-
ciple 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 Henkel1, Antonio Negretti2, Stuart P. Cockburn2, and
Nikolaos Proukakis1,3 — Universität Potsdam, Germany —
3Universität Ulm, Germany — 2Newcastle University, U.K.

We analyze a dilute Bose gas in a one-dimensional trap, using a modi-
ﬁed 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 pres-
sure in a trap and of a renormalized two-body interaction in smoothing out
the qc border.

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 Gün-
ther 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 macro-
scopic quantum tunneling. The tunneling rate can be calculated with
the Euclidean action of the bounce trajectory. We search for the nu-
merical 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

Time: Monday 10:30–13:00

Q 3.1 Mon 10:30 BAR Schön
Ultracold and dense samples of ground-state molecules —
• Johann Georg Danel, Manfred Mark, Elmar Haller, Lukas
Reichschläger, and Hannes-Christoph Nägele — Institut für Ex-
perimentalphysik, Universität Innsbruck, Innsbruck, Austria

We produce ultracold and dense samples of rovibrational ground state
(RGS) molecules near quantum degeneracy in the presence of an op-
tical lattice. We first associate Cs2 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 dis-
cuss 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 —
• Arsteenu R. P. Lima1 and Axel Pelster2 — 1Institut für
Theoretische Physik, Freie Universität Berlin, Arnimallee 14, 14195
Berlin, Germany — 2Fachbereich Physik, Universität Duisburg-Essen,

Location: BAR Schön
Quantum Optics and Photonics Division (Q) Monday

Lotharstrasse 1, 47048 Duisburg, Germany
Nowadays, Bose-Einstein condensates with a weak anisotropic and long-range dipole-dipole interaction, such as 85Rb condensates, are considered to be relatively well understood in terms of the Gross-Pitaevskii mean-field theory. However, for highly magnetic atoms, such as dysprosium, or for strongly polar heteronuclear molecules, as for instance 4K18Rb, the dipole approximation to derive the Bogoliubov spectrum becomes 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 — 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 center of the molecule. At the position of the latter the ellipses are approximated by plane waves, and the 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 $E_{\text{kin}} > 0$ 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.


Q 3.4 Mon 11:15 BAR Schön
Optical Manipulation of Large Molecule Beams for Molecule Interference
— PAUL VENN and HENDRICH ÜLBRICH 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 local dipol of the latter with an intensity of approx. 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 RAUSHENBRETEL 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 terylene 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 molecule quantum system.

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


Q 3.6 Mon 11:45 BAR Schön
Low Temperature Studies on Single Molecules interacting with Plasmonic Structures
— BERNHARD GROTZ1, ILJA GERHARDT1,2, PETR SYVUSEV1, FEDOR JELEZKO1, and JÖRG WRAECHTTRUP1,2 — 1Forschungsinstitut für Physik und Forschungszentrum Jülich, 52425 Jülich, Germany — 2Max 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 incorporate the inoccping 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.


Q 3.7 Mon 12:00 BAR Schön
Interlayer superfluidity and scattering in bilayer systems of polar molecules
— ALBERT PILKOVSKY1, MICHAEL KLAWUNN1,2, G. V. SHLYAPNIKOV3, and LUIS SANTOS3 — 1Institut für Theoretische Physik, Leibniz Universität Hannover, Appelstr. 2, 30167 Hannover, Germany — 2INO-CNRS BEC Center and Dipartimento di Fisica, Università di Pavia, 27100 Pavia, Italy — 3Laboratoire 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 BEC-BEC crossover [A. Pilkovskii 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 AGANOGLU1, MIKHAIL LEMESHKO2, BRETLISLAV FRIEDRICH2, ROSARIO GONZALEZ-PÉREZ3, and CHRISTIANE P. KOCH1,4 — Freie Universität Berlin, Institut für Theoretische Physik Fritz-Haber-Institut der Max-Planck-Gesellschaft, Berlin 3Universidad de Granada, Facultad de Ciencias, Spain — 4Universität 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 intermolecular 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 the state of these and bound 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.

Quantum reflection and localization in bound systems — Elias Diessen1 and Jan-Michael Rost2 — 1Max-Planck-Institut für Physik komplexer Systeme — 2Max-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.


A fundamental limit to spin-exchange optical pumping of $^3\text{He}$-nuclei — H.R. Sadeghpour, T.V. Tcherbul, 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 $^3\text{He}$ nuclei by collisions with spin-polarized alkalimetal atoms is established. Using accurate ab initio calculations of molecular interactions and scattering properties, requiring no ad-

Quantum Physics and Quantum Information Theory (Q) — Harald Friedrich, Tim-Oliver Müller, and Harald Friedrich — Physik Department, TU München, Germany

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 $-1/r^a$ (with $a>2$) support at most a finite number of vibrational bound states, and their energies $E_n$ are related to their quantum numbers $n$ via a quantization rule $v_F \sqrt{n} = v F(E_n)$, where $v_F$ is the not-necessarily integer threshold quantum number. At near-threshold energies the quantization function $F(E)$ is predominantly determined by a contribution $F_{\text{all}}(E)$ stemming from the potential’s tail, which is a universal function depending only on the power $a$. Quantum effects are important near the dissociation threshold and $F(E)$ differs significantly from the widely used semiclassical expression derived by LeRoy and Benedek [1]. Explicit analytical expressions for $F_{\text{all}}$ have been presented for the van der Waals interaction between two neutral polarization atoms or molecules ($a=6$) [2] as well as for the dispersion energy occurring in certain diatomic molecular ions ($a=4$) [3] and recently also for the power $a=3$ [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 coupling in the quantum dynamics, including quantum effects near the threshold.


Quantum Physics and Quantum Information Theory (Q) — Harald Friedrich, Tim-Oliver Müller, and Harald Friedrich — Physik Department, TU München, Germany

Universal}s 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 $V(r) = -\hbar^2\alpha^2/2m + \hbar^2\alpha^2/2(2m^*)^2$ with $\alpha > 2$ are strongly related to the location of the bound states just below the dissociation threshold. It has been shown that the noninteger part $\Delta n$ 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, $\tan(\delta_n) = A_n/A_0 \sin(\phi_n - \phi_0)/\cos(\phi_n - \phi_0)$, where $A_n/A_0$ and $\phi_n$ are universal functions of energy, which depend on the potential tail (i.e. $\alpha$) alone and $\phi_0$ contains a single parameter $\Delta n$, accounting for all short range effects. The bound states below threshold are given by the quantization function [3], $F_{\text{all}}(E_n) = n_{\text{th}} - n$, so that the whole energy spectrum around the dissociation threshold is determined by the scattering length.


justable parameters, it is demonstrated that attainable polarization of $^3\text{He}$ 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 $^3\text{He}$. In a complementary calculation, it is suggested that it may be possible to overcome this limit by using atomic silver ($^\text{Ag}$) 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 Hauke**, Tübingen University—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**, 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 cavity, 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**

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**

- **Iraaki Titvinidze**

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 state 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.
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 one 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 and powerful tool to access single atom methods, that may underestimate the atom number in dense samples due to photon reabsorption processes.

Imaging of microwave fields using ultracold atoms — Pascal Böhr1, Max Riedel2, Theodor Hännisch2, and Philipp Teutelken1 — 1Department Physik, Universität Basel, Klingelbergstrasse 82, 4056 Basel, Switzerland — 2Max-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.

Feedback Cooling of a Single Neutral Atom — Christian Sades, Markus Koch, Maximilian Balbach, Hayfran Chirani, Alexander Kuban, Alceoi Orijjountiev, Perfin Pünkse, Karim Muhr, Tatiana 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-fined 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 intensity of a transmitted probe beam. We analyze the flux of the transmitted photons which carries information about the atomic intensity of a transmitted probe beam.

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.


Feedback of a single neutral atom — melting the single atom by this technique to a temperature of about 160 mK. Additionally, we demonstrate cooling orders of magnitude, reaching values of more than 17 seconds with an apparatus which cools an atom to a temperature of about 160 mK. The combined techniques improve our signal-to-noise ratio to spatially separated ensembles each comprising between 10 and 2000 atoms. The combined techniques improve our signal-to-noise ratio to spatially separated ensembles each comprising between 10 and 2000 atoms.

RAP can be observed, an atomchip with three current carrying wires in a time and space dependent treatment of the counting process. The advantage that much less optical access is required.

Improvement of the Mandel formula in the absence of fringes. A maximum-likelihood estimator is then derived for the fundamental photon-shot-noise level and proves beneficial even in the absence of fringes. A maximum-likelihood estimator is then derived for the fundamental photon-shot-noise level and proves beneficial even in the absence of fringes.

Control of refractive index and motion of a single atom by quantum interference — Tobias Kampschulte1, Wolfgang Aitz1, Stefan Brakhan2, Martin Eckstein1,2, Miguel Martinez-Dorantes1, René Reimann1, Artur Widera1,2, and Diansheng Zhang1,2 — Fachbereich Physik der Technischen Universität Bonn, Wegelerstr. 8, 53115 Bonn — 1Max-Born-Institut, Abteilung A2, Max-Born-Str. 2 A, 12489 Berlin — 2Fachbereich Physik der TU Kaiserslautern, Erwin-Schrödinger-Str., 67663 Kaiserslautern

Control of refractive index and motion of a single atom by quantum interference — Tobias Kampschulte1, Wolfgang Aitz1, Stefan Brakhan2, Martin Eckstein1,2, Miguel Martinez-Dorantes1, René Reimann1, Artur Widera1,2, and Diansheng Zhang1,2 — Fachbereich Physik der Technischen Universität Bonn, Wegelerstr. 8, 53115 Bonn — 1Max-Born-Institut, Abteilung A2, Max-Born-Str. 2 A, 12489 Berlin — 2Fachbereich Physik der TU Kaiserslautern, Erwin-Schrödinger-Str., 67663 Kaiserslautern

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Improvement of the Mandel formula in the absence of fringes. A maximum-likelihood estimator is then derived for the fundamental photon-shot-noise level and proves beneficial even in the absence of fringes. A maximum-likelihood estimator is then derived for the fundamental photon-shot-noise level and proves beneficial even in the absence of fringes.
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 new effects 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.

Quantum Information: Concepts and Methods

Q 7: Quantum Information: Concepts and Methods 1

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

Verifying W-entanglement — •EMERSON SADURNI1, WILLIAM CASE2, and WOLFGANG SCHLEICH1 — 1Institut fuer Quantenphysik, Ulm Universitaet, Albert-Einstein Allee 11 89081 Ulm - Germany — 2Department of Physics, Grinnell College, P.O. Box 805, Grinnell, Iowa 50112

Quantum Optics and Photonics Division (Q) Monday

Verifying W-entanglement

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

Electron Laser Science, Universitaet Hamburg
Mask-based Fourier transform holography (FTH) is used to record images of biological objects with 2.2 mm 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 6.8 Mon 12:30 SCH A01
Single-Slit Focusing and its Representations — •EMERSON SADURNI1, WILLIAM CASE2, and WOLFGANG SCHLEICH1 — 1Institut fuer Quantenphysik, Ulm Universitaet, Albert-Einstein Allee 11 89081 Ulm - Germany — 2Department 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 POSTAVARU1,2, ZOLTÁN HARMAN1,2, and CHRISTOPH H. KEITEL1,3 — 1Max Planck Institute for Nuclear Physics, Saupfercheckweg 1, 69117 Heidelberg, Germany — 2ExtreMe Matter Institute EMMI, Plandestrasse 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 electrodynamics 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.

Quantum systems can induce entanglement that significantly exceeds the threshold of the static case. Unlike 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.


Q 7.5 Mon 11:30 SCH A118
Quantification of entanglement and polynomial invariants of homogeneous degree 4 — Christopher Eltschka1, Thierry Bastin2, Andreas Osterloh1, and Jens Siewert2,3,4
1Institut für Theoretische Physik, Universität Regensburg, 93040 Regensburg, Germany
2Institut de Physique Nucléaire, atomique et de Spectroscopie, Université de Liège, 4000 Liège, Belgium — 3Fakultät für Physik, Universität Duisburg-Essen, 47048 Duisburg, Germany — 4Departamento de Química Física, Universidad del País Vasco, 48080 Bilbao, Spain — 5Herbasque, 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 $S(2, C)^{\otimes N}$-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-quotient systems.


Q 7.6 Mon 11:45 SCH A118
Maximizing entanglement with numerically optimized pulse design — Fabian Bohnet-Waldraff1, Florian Minter2, Uwe Sanders3, Steffen Glaeser1, and Andreas Buchleitner1
1Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, Hermann-Herder-Str. 3, 79044 Freiburg — 2Freiburg Institute for Advanced Studies (FRIAS), Albert-Ludwigs-Universität Freiburg, Albertstrasse 19, 79040 Freiburg — 3Department 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 contemporary techniques of quantum control, 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 application we apply this framework to nitrogen vacancy centers in diamond.


Q 7.7 Mon 12:00 SCH A118
On Hybrid Entanglement — Karsten Kreiš1,2 and Peter van Loock1,2
1QI, MPL, Erlangen, Germany — 2Institut für Theoretische Physik 1, 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 entanglement measures such as the logarithmic negativity. [1] E. Shchukin and V. 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 Eltschka1, Oliver Viehmann2, and Jens Siewert2,3,4
1Institut für Theoretische Physik, Universität Regensburg, Regensburg, Germany — 2Physics Department, ASC, and CeNS, Ludwig-Maximilians-Universität, München, Germany — 3Department of Química Física, Universidad del País Vasco - Euskal Herriko Universitatea, Bilbao, Spain — 4Herbasque, 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].


Q 7.9 Mon 12:30 SCH A118
Entanglement verification with realistic measurement devices via squash models — Tobias Moroder1, Öfri Förrath2, Norbert Beaudry3, Marco Piani4, and Norbert Lütkenhaus4
1Institute for Quantum Optics and Quantum Information, Innsbruck, Austria — 2Department of Physics, University of Siegen, Germany — 3Institute for Theoretical Physics, ETH Zurich, Switzerland — 4Institute 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 Ranade1 and Nathan Harshman1,2
1Institut für Quantenphysik, Universität Ulm, 89069 Ulm — 2Department 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.
Quantum Optics and Photonics Division (Q) Monday

Q 8.1 Mon 10:30 SCH A215
Geometric Spin Hall Effect of Light — JAN KORGEL1,2, ANDREJA AIELLO1,2, CHRISTIAN GAEBLER1,2, THOMAS SCHLOTHI1,2, SHIH-YOAO ZHU1,2, and GERD LEUCHT1,2

1MPI für die Physik des Lichtes, Erlangen, Deutschland — 2Institut 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 wave-lengths 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 performed 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, KAMBEJ JAMSHID, ANDREJ Wiatrek and THOMAS SCHNEIDER — Institut für Hochfrequenztechnik, Hochschule für Telekommunikation Leipzig


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 EVERS1, KEVIN XIA1, and SHI-YAO ZHU2 — 1Max-Planck-Institut für Kernphysik, Heidelberg, Germany — 2Computational 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-photonic communication or computation infrastuctures 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 mageto-optical effects, and therefore are scalable and compatible with on-chip opera- tion. The operation is demonstrated 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 — KAMBEJ JAMSHID 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 medium 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. Lin-

ear mapping between the frequency and time domain is obtained if the dispersive media shows pure second order dispersion. FTTC can be used to manipulate the spectrum of a laser pulse by inserting an optical delay line. 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, HADOR HARTWIG und FEDOR MITSCHE — Universität Rostock, Institut für Physik, Universität Rostock, 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].


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


Q 8.6 Mon 11:45 SCH A215
Observation of spontaneous Raman scattering in 220nm Silicon-on-Insulator (SOI) waveguides — SIGURD SCHLADER2, SHAIMAA MAHDI1, SHA WANG1, AHS AL-DAIDI1, BŁĘCIENT A. FRANKI1, VIKTOR LISINETSKI2, STEFAN MEISTER1, and HANS J. EICHLER1 — 1Technische Universität Berlin, Institut für Optik und Atomare Physik, Berlin, Germany — 2Technische 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 wave-lengths 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 90mW at 1441.4nm was obtained with a pump power of 22mW. Also the po- larization 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
2-Scan Characterization of Zwitterionic Chromophores for Optoelectronic Switching — ULRICH SKRZYPCZAK1,2, GRANT V. WILLIAMS2, STEFAN JANSEN2, MANUELA MICLEA1,2, and STEFAN SCHWEIZER1,3 — 1Centre for Innovation Competence Sili-nano®, Martin Luther University of Halle-Wittenberg, Karl-Freiherren-Fritschi-Str. 3, 06120 Halle (Saale) — 2Industrial Research Ltd., P.O. Box 31310, Lower Hutt 5040, New Zealand — 3Fraunhofer Center for Silicon Photovoltaics, Walter-Hübbe-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 response that is several or more orders of magnitude larger. A number of NLO chromophores have recently been synthesized and optimized for a large 2nd order NLO response that is several or more orders of magnitude larger.

The NLO refractive index and the two-photon absorption coefficient were determined by analyzing the results from z-scan measurements. 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 SUCK1,2, STEPHANE COLLIN3, YANNICK DE WILDE1, and GILES TESSIER1 1Institut Langevin, ESPCI ParisTech-CNRS, 10 rue Vauquelin, 75231 Paris, France — 2Fondation Pierre-Gilles de Gennes pour la Recherche, 29 rue d’Ulm, 75005 Paris, France — 3CNRS-LPFN, Rue Vauquelin, 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 driven optical 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 using 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 SOI2 coated 1D-photonic crystal microcavities in ultra-small SOI waveguides — SEBASTIAN KUPJAJI1, BLENT A. FRANKE2, AWS AL-SAADI1, MIROSŁAW SZCZAMBURA1, SHAIMA MAHD1, VI-
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, 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.

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.

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.


Q 10: Quantum Gases: Bosons 2

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 Kühnert, David Alexander Smith, and Jörg Schmiedmayer — Atomphysik, 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.

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.


Q 10.3 Mon 15:00 HÜL 386
Open Bose-Hubbard model: Beyond the mean-field approximation — Georgios Kordas, Dirk Wuttigart, and Sandro Wiemberger — 1 Institut für Theoretische Physik, Universität Heidelberg, Philosophenweg 19, D-69120 Heidelberg, Germany — 2 Max-Planck-Institut für Dynamik und Selbstorganisation, 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 Łakomy1, Reinh Nauth2, and Luis Santos3 — 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 Scholz1,2, Maximilian Schmidt1,2, Boris Nowak1,2, Denes Sexty1,2, and Thomas Gasenzer1,2 — 1 Institut für Theoretische Physik, Ruprecht-Karls-Universität Heidelberg, Philosophenweg 16, 69120 Heidelberg — 2 Exterm Matter Institute EMMI, GSI Helmholtzentrum 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

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 Köpferrmann 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 pho-
tons 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 polarization 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-phonon 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 Schö

**Single atom-photon interfaces with strongly focused optical modes** — Gleb Maslennikov, Syed Abdullah Aljunied, Tianwei Lee, Martin Parsol, Dao Hoang Lan, Kadir Durak, Brenda Cheng, and Christian Kurtsiefer — Centre for Quantum Technologies / Dept. of Physics, National University of Singapore

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. 


Q 11.3 Mon 15:15 BAR Schö

**Entanglement-preserving absorption of single photons by a single atom** — Michael Schug, Jan Huwer, Jovke Ghosh, Nicolas Piro, Marc Almendros, Felix Rohde, Carsten Schuck, Francois Dubin, and Jörgen Eschner — ICFO - Institut de Ciencies Fotòniques, Mediterranean Technology Park, 08860 Castelldefels (Barcelona), Spain

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 absorption 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 Schö

**Entanglement Distribution with an Atom-Cavity System** — Carolin Hahn, Martin Mücke, Jörn 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 entanglement the polarization state of the emitted photon with the Zeeman-state of the atom. After a chosen time $\Delta t$, the atomic state is mapped onto the polarization state 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 $\Delta t = 150\mu s$. 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 Schö

**Entangling two single atoms at remote locations** — Julian Hofmann, Norbert Orthegel, Michael Krug, Florian Henkel, Wenziam Rosenfeld, Markus Weber, and Harald Weinfurter — Department für Physik der LMU, München

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.


Q 12: Quantum Information: Concepts and Methods

Time: Monday 14:30–16:00

Q 12.1 Mon 14:30 SCH A118

**Poincaré sphere representation for classical inseparable states of the electromagnetic field** — Annemarie Holleckner, Andrea Aichel, Christian Gabriel, Christoph Marquardt, and Gerd Leuchs — Max Planck Institute for the Science of Light, G"{u}nter-Scharowsky-Str. 1, 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, Matthias Ohliger, Tobias J. Osborne, and Jens Eisert — University Potsdam, Institut für Physik und Astronomie, Karl-Liebknecht-Straße 24/25, 14476 Potsdam

We show that ground states of frustrated 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-network structure. 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.


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, Christopher Petzschka and Jens Siemons — Physics Department, ASC and CoNIS, Ludwig-Maximilians-Universität, München, Germany

2 Institut für Theoretische Physik, Universität Regensburg, Regensburg, Germany

— Departamento de Química Física, Universidad del País Vasco – Euskal Herriko Unibertsitatea, Bilbao, Spain

— 4Kerbasque, 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 or 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)⊗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.


Q 12.6 Mon 15:45 SCH A118

Driving-enhanced multi-partite entanglement in a qubit network — • Simon Sauerk and Florian Minter and Andreas Buchleitner — 1 Physikalisches Institut, Albert-Ludwigs-Universität, Herrmann-Herder-Str. 3, D-79104 Freiburg, Germany

2 Freiburg Institute for Advanced Studies, Albert-Ludwigs-Universität Freiburg, Albertstr 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 presently available. Furthermore, not much is known 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 multi-partite entanglement therein. To this end, we identify the dressed states of the driven system in the Floquet picture 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

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 auf Laserablation basierende Strukturierung erfolgte mit einem stark auf die Oberfläche einer \( 2 \mu m \)-dicken Tm(2,5at.\%):Y\(_2\)O\(_3\)-Schicht fokussiertem fs-Laser. Mit Pulsenergien von \( 150 \) nJ und Pulsdauern von \( 100 \) fs wurden auf diese Weise Strukturen mit einer Breite von ca. \( 1 \) \( \mu \)m und einer Tiefe von ca. \( 0,4 \) \( \mu \)m geschrieben. Homogene Materialabtrag konnte bei Pulsreihentoleranz von 1 kHz und Verformungsgeschwindigkeiten von bis zu \( 400 \mu m/s \) erzielt werden.

Q 13.2 Mon 14:45 SCH A215

Wellenlängenstabilisierter Tm-Faserlaser bei 1833 nm — • Samir Lamrini, Philipp Koopmann, Karsten Scholle, Michael Schäfer, Jens Thomas, Christian Vogtlander, Stephan Nolte, Peter Fehribach und Martin Hofmann — 1LSA laser products, Katlenburg-Lindau — 2Lehrstuhl für Photonik und Teraerhechnologie, Ruhr-Universität Bochum — 3Institut für Angewandte Physik, Friedrich-Schiller-Universität Jena

Laser, die im Wellenlängenbereich um 2 \( \mu m \) emittieren, sind aufgrund ihrer Eigenschaften vielfältig einsetzbar, z. B. in der Medizin, Mess- oder als Pumpquellen für OPOs im mittleren Infrarotbereich. Viele dieser Anwendungen erfordern neben hohen Ausgangsleistungen, vielseitigeren Einsatz von Technologien oder als Pumpquelle für OPO in den Kern der aktiven Faser geschrieben. Verlustbehaftete Speleistellen bleiben somit erspart. Mit einer Singlemode-Faser (10/125 \( \mu m \), NA = 0,46) wurden im diodengepumpten Betrieb 9,1W Ausgangsleistung bei einer Schwelle von 1W erreicht. Bei maximaler Ausgangsleistung wurden lediglich 215mW in das entgegen gesetzte Richtung emittiert, was vielschichtig für ein solches System ist. Die Gesamtstrahlleistung (optisch-optisch) beträgt 38 \% bei einem dienen Wirkungsgrad von 42 \%. Das Laserspektrum bei 1833 nm hatte eine Halbwertsbreite von 0,5nm.
Q 13.3 Mon 15:00 SCH A215
Thermo-Optical Aberrations of the Gain Medium of an Yb:YAG Thin-Disk Laser — • Julian Pircherhammer, 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 of the pumped 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 Ullmann1, Robert Elsner2, Axel Heuer2, Martin Ostermeier1,2, and Ralf Menzel1 — 1 Universität Potsdam, Institut für Physik und Astronomie, Karl-Liebknecht-Str. 24-25, 14476 Potsdam, Germany — 2 HIL Innovative Berlin Laser GmbH, Am Schlangengraben 16, 13597 Berlin


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


Q 13.5 Mon 15:30 SCH A215
Verlustprozesse in hoch Yb-dotierten oxidischen Lasermaterialien: Untersuchungen zur Photoleitfähigkeit und ihrer Temperaturabhängigkeit — • Ulrike Wolters, Uwe Kelling, Henning Köhn, Susanne Friedrich-Thornton, Klaus Petermann, and Günter Huber — Institut für Lasertechnik, Universität Hamburg


Q 14.1: Ultrakurze Laserpulse: Erzeugung

Q 14.1 Mon 14:30 SCH 251
Ultrakurze 120 μJ Laserpulse durch kohärentes Kombinieren zweier Faserverstärker — • Sven Brinkman, Inke Schäfer, Alexander Klein, Marco Pflüger, Jens Limpert, and Andreas Tünnermann — 1 Institut für Angewandte Physik, Albert-Einstein-Str. 15, 70745 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


Q 14.2 Mon 14:45 SCH 251
Development of a laser-based XUV source on the μJ level — • Wolfgang Helml, Gilad Marcus, Laszlo Veszely, Reinhard Kienberger, and Ferenc Krausz — 1 Max-Planck-Institut für 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 sub-femtosecond 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 (<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, corre-
sponding to $\sim 2.24 \times 10^{-4}$ mJ per pulse. First tests with a multi-
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. Mittenweg1, A. Azima1, J. Boedewadt3, F. Curbis4, H. Delsin-
Hashemi1, M. Drescher1, U. Hippi1, T. Maltezopoulos1,2, V. Muthu-
trüer1, M. Reinders1, J. Roedens-Schulenburg2, J. Rossbach1, T. R.
Tarkeshian1, M. Wieland1, S. Bajt1, S. Duesterer2, J. Feldhaus2, T. Laarmann2, H. Schlarb2, S. Khan1, and R. Ischebeck4
1University of Hamburg — 2DESY, Hamburg — 3DELTA, Dortmund — 4PSI, Villigen, Switzerland
The Free electron LAser in Hamburg (FLASH) is currently operated in
the self-amplified spontaneous emission mode (SAFE), producing
photons in the XUV range. Due to the statistical nature of SAFE
the radiation shows intensity and spectral pulse-to-pulse fluctuations.
Moreover, the electron acceleration process introduces arrival time fluc-
tuations of the electron bunch at the undulator entrance, which leads
to a temporal jitter of the XUV pulses. In order to reduce these fluc-
tuations a seeding scheme for the electron bunch can be used. To this
end, XUV seed pulses also 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 experi-
mentations 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 ESTGU1.

Q 14.4 Mon 15:15 SCH 251
Prepulse suppression in a Multi-10-TW diode-pumped
Yb:Glass laser —
- Christian Köhler1, Ragnar Bödefeld1, Marco Hornek1,2, Alexander Säveret1, Joachim Hein1, and Malte Christoph Kaluza1,2
1Institute of Optics and Quantum Electronics, FSU Jena — 2Helmholtz-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 ($\sim 10^{-5}$) will leak into the subsequent regenerative amplifier cavity.

Q 14.5 Mon 15:30 SCH 251
Compact 7.4 W femtosecond oscillator for white-light gen-
eration and nonlinear microscopy —
- Andy Steinmann, Bernd Metzger, Robin Hegenscheid, and Harald Giesen — 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.
By 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 1.8 µm.

Q 14.6 Mon 15:45 SCH 251
Non-collinear Optical Parametric Chirped-Pulse Amplifica-
tion of ultrashort pulses at 20 kHz —
- Wataru Kobayashi1, Ji-aaa Zheng1, Thomas Haman1, Markus Lührmann2, Johannes A. L’huillier2, Richard Wallenstein2, and Helmut Zacharias1
1Physikalisches Institut, Westfälische Wilhelms-Universität, Wilhelm-Klemm-Str.10, 48149 Münster, Germany — 2TU Kaiserslautern, Fachbereich Physik, Erwin-Schrödinger-Str. 46, 67663 Kaiserslautern, Germany
We present a non-collinear optical parametric chirped-pulse amplifi-
cation (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 7 fs, 2 nJ seed pulses at a repetition rate of 80 MHz. A frequency-doubled mode-locked Nd:YVO4 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 griss 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.

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-adsorbed surface modification methods apply a gaseous absorber at the backside of the processed material. 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 of characterizing 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.


Institut für Optik und Quantenelektronik, Friedrich-Schiller Universität Jena, Max-Wien-Platz 1, 07743 Jena, Germany — Institut für Laser- und Plasmaphysik, Heinrich-Heine Universität Düsseldorf, Universitätsstrasse 1, 40225 Düsseldorf, Germany — Helmholtz-Institut Jena, Helmholtzweg 4, 07743 Jena, Germany

The use of ultra intense laser pulses to excite plasma waves with a relativistically phase velocity is a possible route to develop compact particle accelerators. Quasimonoenergetic x-ray 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 "third generation" synchrotrons.

In this poster we present measured x-ray betatron spectra recorded in Düsseldorf and Jena with maximum emission at several 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.

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


Kinetic description of laser-induced dielectric breakdown of insulators — Nils Brouwer, Oliver Brenk, Helena Krutsch, Dieter H. H. Hoffmann, and Bärbel Rethfeld

Technische Universität Kaiserslautern, Deutschland — 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.

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 membranes [3] is a highly active field of research. The investigation of structural dynamics in graphene after ultrafast 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.

Preparation of free-standing single and few-layer graphene for Ultrafast Electron Diffraction experiments — 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. Semiconductornanocrystals - 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 CdSe (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 signal for a variety of different pulse shapes is measured.

Preparation of free-standing single and few-layer graphene for Ultrafast Electron Diffraction experiments — Christian Spielmann — University of Kassel, Institute for Physics and CINSaT, Heinrich-Plett-Str. 40, D-34132 Kassel, Germany

In this poster we present measured x-ray betatron spectra recorded in Düsseldorf and Jena with maximum emission at several 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.

Spectroscopy and coherent control of colloidal semiconductornanocrystals by phase-shaped femtosecond laser pulses — 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

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using a Non-Collinear Cherenkov-Type Geometry — •ULRICH ARTHUR FROMM, BENJAMIN EWER, MAIK SCHELLER, SANGAM CHATTERJEE, and MARTIN KOCH — Department of Physics and Material Science 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 non-linear 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 χ(2) process which generates strong THz radiation at high laser pump power. A solution is the use of an intensity enhanced pulse of infrared light into THz waves. A simple thin slab of bulk LiNbO3 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 LiNbO3-air interface, a silicon prism is contacted to the crystals surface. Using an additional diffractive grating to tilt the laser's 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 \, \mu\text{V/m} are obtained at pump pulse energies of 450\,\mu\text{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, GUIDO PALMIERI, MARCEL SCHULTZ, KOTARO OBARA
— Max-Planck-Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover

— Laser Zentrum Hannover, Hollerithallee 8, 30419 Hannover


Q 15.11 Mon 16:30 P1
High repetition rate High Harmonic Generation source for coherent XUV microscopy and electron spectroscopy

— JÜRGEN SCHMIDT, CHRISTIAN SPÖHL, MICHAEL HOFFSTETTER, SOO HOON CHEW, ALEXANDER GUGGENMOS, MIHAEL KRAINIC
— 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 X-ray 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 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:sapphire 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 even for indispensable for detector types which barely can handle multi-hit events, e.g. delay-line 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 Pulse in der Elektronenbeschleunigung — •MARIA REUTER, ALEXANDER SÁVERT, AJAY KAWSHIK ARUNACHALAM, MICHAEL SCHNELL, MARIA NICOLAI, CHRISTINA WIDMANN, BÖRN LANDGRAB, OLIVER JÄCKEL, CHRISTIAN SPIELMANN, GERHARD G. PAULUS and MALTE C. KALUZA — Institut für Optik und Quantenelektronik, Jena


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 SÁVERT, MICHAEL SCHNELL, MARIA REUTER, OLIVER JÄCKEL, CHRISTIAN SPIELMANN, GERHARD G. PAULUS and MALTE C. KALUZA — Institut für Optik und Quantenelektronik, Friedrich-Schiller-Universität, Jena


Q 15.14 Mon 16:30 P1
Time Resolved Electron Diffraction of a Charge Density Wave — •EICHERGER MAXIMILIAN, SCHAFFER HANZO, KRUOMA MARINA, BEYER MARKUS, DESSARI JURJAN, MORENA GUSTAVO, SCIANNI GERMAN, MILLER DNYNEV, — Universität Konstanz, Germany

— 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.

Q 15.15 Mon 16:30 P1
Broadband polarization control and preservation for scanning near-field optical microscopy — •CHRISTOPH ZEH, RON SPITTEL, SONJA UNGER, JÖRG OETZ, BERND KÖHLER, JOHANNES KIRCHHOFF, HARTMUT BARTEL, and LUKAS M. ENG

— Fraunhofer Institut für Zerstörungsfreie Prüfverfahren IZFP, Institutsteil Dresden, Maria-Reiche-Str. 2, 01109, Dresden — Institut für Physikalische Technologie, 38108 Braunschweig, Germany — 3Institut für Angewandte Photophysik, Technische Universität Dresden, 01062 Dresden, Deutschland

We employ 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.
To achieve high throughput with apertureless fiber probes for scanning near-field optical microscopy (SNOM) radial polarization, 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 major 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 Floess1, Tobias Grossmann1,2, Mario Hauser1, Saskia Becker1, Torsten Beck3, Timo Mappers2, and Heinz Kalt3 — 1Institut für Angewandte Physik, Karlsruhe Institute of Technology (KIT), 76128 Karlsruhe, Germany — 2Institut für Mikrosystemtechnik, Karlsruhe Institute of Technology (KIT), 76128 Karlsruhe, Germany

We report on simulations of high-Q microcavities using the JCMelement-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 spectral region.

Q 15.17 Mon 16:30 P1
Accurate generation of polarization-shaped femtosecond laser pulses with zeptosecond precision — Jens Köhler, Tim Bayer, Christian Sarpe, Tom Bolze, Matthias Wollenhaupt, and Thomas Baumert — Institut für Physik und CIN-SaT, Heinrich-Plett-Str. 40, D-34312 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 modulations 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-Linking 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.


Q 15.18 Mon 16:30 P1
Adhering and coupling emitter-doped organic crystals to optical nanofibers — David Papencordt, Mario Hauser, Moritz Eyer1, Rolf Mi1, Helmut B1, Michael Dietterich2, Peter Michler3, Fedor Jelezko, and Jörg Wrachtrup1,2 — 1Physikalisches Institut, Universität Stuttgart — 2Institut für Halbleiteroptik und Funktionelle Grenzflächen, Universität Stuttgart

Optical nanofibers have proven to be an extremely 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 [3]. Additional inline spectrometers form such measurements under cryogenic conditions. In particular, it should be possible to realize nanofiber-based spectroscopy 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").


Q 15.19 Mon 16:30 P1
Phase behaviour of electro-optic liquid crystals-oil blends — Kristin Bornhorst, Martin Blass, and Florentia Costache — Fraunhofer Institut für Photonische 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-cya-no-4*-n-alkylphenyle (nCB) with immersion oils. EO effect in blends occurs in their nematic as well as their isotropic phases. We study both phase transitions 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-isotropic transition temperature, TNI, as well as the crystalline-nematic transition temperature, TCG, shift largely toward lower temperatures with increasing oil concentration. For instance, TNI 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 Eyer1, Helmut B1, Merle Becker1, Robert Rossbach2, Daniel Richter1, Michael Dietterich1, Peter Michler2, Fedor Jelezko, and Jörg Wrachtrup1 — 1Physikalisches Institut, Universität Stuttgart — 2Institut 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 photon 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 qubits.

Q 15.21 Mon 16:30 P1
Direct evaluation of the spatio-temporal coherence properties of free electron laser pulses at FLASH — Sebastian Röling1, Michael Wöstant2, Rolf Mit1, Björn S1, Kai Tiedtke1, and Helmut Zacharias1 — 1Westfälische Wilhelms-Universität Münster, Wilhelm Klemm Str. 10, 48149 Münster — 2Helmholtz-Zentrum Berlin für Materialien und Energie, A.-Einstein-Str. 15, 12489 Berlin — 3Deutsches Elektronen-Synchrotron, DESY, Notkestraße 85, 22607 Hamburg

Monday
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 $\lambda^3$ 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 $\Delta x_2$ between the interfering points of the beam. With increasing $\Delta x_2$ 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).

Fabrication and characterization of low-loss waveguides in lithium niobate — Benjamin Wirgand, Andreas Lienhard, Marike Stolzen, Felix Röbisch, Andrea Wolff, Johannes L'Huillier, and Christoph Brücher

University of the Saarlandes, FFL 7.2 Experimentalphysik, Campus E2.6, 66123 Saarbrücken

Photonic-Zentrum Kaiserslautern e.V., Kolumenhofstr. 10, 67663 Kaiserslautern

Nanoo+Bio Center, Erwin-Schrödinger-Str. Geb. 13, 67663 Kaiserslautern

Waveguides in LiNbO$_2$ 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.

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 - Atom Institut, 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 electrodynamics 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-optical 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.

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 - Atom Institut, 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.

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 novel concept that uses a single-fibre interferometer using the up-taper of an OMF as a beam splitter and the up-taper as a beam combiner, 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.

Point-by-point inscription of Bragg gratings in coated standard telecommunication fibers using infrared femtosecond laser pulses — Jörg Burgmeier, Günter Flachenecker, Markus Thiel, and Wolfgang Schade

Institut für Angewandte Physik, Universität Bonn, Wegelerstr. 8, 53115 Bonn, Germany

Writing of fibre Bragg gratings (FBG) in non-photoalignment 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.

Development of low-loss silicon rib waveguides with 4 microns height — Harald Richter, René Eiermann, Mirko Lisker, Lars Ziemann, Katrin Schulz, IHP Frankfurt, Im Technologiepark 25, 63860 Golm

Institut für Angewandte Physik, Universität Bonn, Wegelerstr. 8, 53115 Bonn, Germany

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 the realisation of photonic 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 angle deviations determine the silicon waveguide quality essentially. The present work is focused on the development of a mask for femtosecond laser induced waveguide fabrications on SOI wafers with a layer thickness of 4 microns height. Different hard mask layer stacks for the deep silicon etch process were tested and optimized. Experiments have shown that 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 Thiel¹, Günther Flachenecker², Jörg Burgmeier³, and Wolfgang Schade³
¹Max Planck Institute for Quantum Optics, GmbH, Hans-Kopfermann-Straße 1, 85748 Garching, Germany; ²Institute of Photonics Technology of the TU Clausthal, EnergieCampus, Am Stollen 19, 38640 Goslar; ³Fauhofer 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 significant 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. Jann, 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 — Meirle Becker¹, Daniel Drewery², Helmut Fedder³, Fedor Jelezko¹, Harald Giesen², and Jörg Wrachtrup³
¹Physikalisches Institut, Universität Stuttgart, 70550 Stuttgart; ²Max Planck Institut für Quantenoptik, Garching; ³Physikalisches 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. 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 15.30 Mon 16:30 P1
Phase-preserving amplitude regeneration of quadrature-amplitude-modulated signals — ThoRHa, Georgy Onishchukov², Berhard Schmauss¹
¹Chair for Microwave Engineering, University Erlangen; ²Max Planck Institute for the Science of Light

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 — Berfin Gjonaj¹, Jochen Aulbach², Patrick M. Johnson³, Allard P. Moms², Laurens Kuipers¹, and Ad Lagendijk³
¹FOM Institute for Atomic and Molecular Physics AMOLF, Science Park 113, 1098 XG Amsterdam, The Netherlands; ²Complex Photonic Systems, MESA+ Institute, University of Twente, Post Office Box 217, NL-7500 AE Enschede, The Netherlands; ³Faculty of Physics, University of Amsterdam, 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 Schrieve, Christian Bohley, and Jörg Schilling
Max Planck Institute for the Science of Light

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 porous chains into photonic wires. Here, possible designs of slotted photonic wire microcavities are numerically investigated, which allow intensive light matter interaction in the microcavities, here, consisting 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 Schmölle
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
Lichtstrahlung an einem atomaren Dipol in einem optomechanischen Resonator — Daniel Breyer, Giovanna Morigi and Marc Bienenert
Theoretische Quantenphysik, Universität des Saarlandes, 66041 Saarbrücken


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 Wellenpakets des mechanischen Ozillators viel kleiner ist als die Breite 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. Wir geben einen Ausblick, wie die Manipulation oder die Charakterisierung des Bewegungszustands des mechanischen Ozillators erreicht werden kann.

Q 15.35 Mon 16:30 P1
A table-top demonstration of radiation pressure — Diliek

Kronwald
Effects of ultrastrong light-mechanics coupling

Michael Schmidt, Max Ludwig, and Florian Marquardt
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 15.36 Mon 16:30 P1
Light-induced entanglement between vibrational modes in optomechanical systems with localized vibrational modes

Q 15.37 Mon 16:30 P1
Effects of ultrastrong light-mechanics coupling

Andreas Kronwald, Max Ludwig, and Florian Marquardt
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 Wittke, Christian Wagner, and Anno Rauchsc̈hnke
1 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.

Financial support by the ESF (EURYI Award) and the Volkswagen Foundation (Lichtenberg Professorship) is gratefully acknowledged.

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.

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.


Q 15.40 Mon 16:30 P1
Faserstärker basierter Ersatz für einen Er+-Laser

Benjamin Rein, Tobias Beck, and Thomas Walter
TU Darmstadt, Institut für Angewandte Physik, Laser und Quantenoptik, Schloßgartenstraße 7, D-64289 Darmstadt

It is a smallband intensive and wide abstrinable lasersystem vorgestellt, dass bei einer Wellenlänge von 154,5 nm emittiert und als Ar+-Laser eingesetzt werden kann. Die spektralen Eigenschaften des Lasersystems werden durch die Seedquelle vorgegeben, welche eine optische Leistungsinstabilität, die eine Veränderung der reinen Wellenlänge um 10 ppm pro Watt aufweist. Der Laser ist für die Anwendung in der Medizin interessant.

Q 15.41 Mon 16:30 P1
Diodengepumpte Femtosekunden-Laser geschriebene Kanal-Wellenleiterlasern in Yb:YAG-Kristallen

Thomas Calmano, Jörg Siebenmorgen, Klaus Petermann, and Günter Huber
Universität Hamburg, Institut für Laser-Physik, Hamburg


Q 15.42 Mon 16:30 P1
Er3+-Doped YVO4 Laser Emitting around 1.6µm

Christian Brandt, Francesca Moglia, Klaus Petermann, and Günter Huber
Institut of Laser-Physics, Luruper Chaussee 149, 22761 Hamburg, Germany

Resonantly inband pumped Er3+-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 remote measurements of CO2 using the DIAL (Differential Absorption Lidar) technique an efficient laser is needed to achieve absorption bands of the CO2 molecule at 1579 nm or 1603 nm.

Q 15.43 Mon 16:30 P1
Er3+-Doped YVO4 Laser Emitting around 1.6µm

Resonantly inband pumping an Er(1.1%) YVO4 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
Ein universeller, VCSEL-geseeder ns-Ti:Sa Laser mit (fou-
application. Between these tuning bands the laser also oscillated at
laser wavelength could be tuned from 1578.8 to 1582.3nm and from
oscillated between 1603 and 1608nm. By using a birefringent filter the
Depending on the output coupler transmission the free running laser
Quantum Optics and Photonics Division (Q) Monday
Für die entsprechenden Wellenlängen betrugen 61,5%, 52,1%, 32,0%
bei einer absorbierten Pumpleistung von etwa 1,5W konnten maxi-
tempe und einer Länge von 2,9mm, im sichtbaren Spektralbereich maxima-
der Messungen präsentiert, die eine Aufschlüsselung der Linienbreite
in verschiedene Rauschtypen ermöglichen. Der Einfluss des Stabilisie-
rechts parametrischen Prozesses erzeugt. Die Leistung der Terahertz-
icht, Universität Bonn, Wegelerstr. 8, 53115 Bonn

Random lasing is a phenomenon found in strongly scattering materi-
als that provide sufficient optical gain. Optical 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 behav-
ior can be explained by carrier density fluctuations caused by spatially
overlapping modes.

Aktive Regelung und Kontrolle der Linienbreite eines ECDLS —
— Thorsten Führer und Thomas Walter — TU Darmstadt, In-
stitut für Angewandte Physik, AG Laser und Quantenoptik, Schloss-
gartenstr. 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 Präzisions-
spektroskopie, sind ECDLS daher unverzichtbar. Es wird ein aktives
Stabilisierungsverfahren präsentiert, das neben dem Erreichen großer
modensprunghafter Durchstimmbereiche die Möglichkeit bietet, die
Linienbreite des ECDLS zu minimieren und während des Abstimmens
bei einer fixen Wellenlänge konstant zu halten. Dar-
voraus hinaus lässt sich die Linienbreite innerhalb gewisser Schranken
beim ECDLs als Fehlersignal für einen geschlossenen Regelkreis, der die
Reaktion des Gesamtsystems aufrecht erhält.

Basiert auf der Technik der selbst-heterodynen Detektion wer-
den Messungen präsentiert, die eine Aufschlüsselung der Linienbreite
in verschiedene Rauschtypen ermöglichen. Der Einfluss des Stabilisie-
verfahrens auf den jeweiligen Typus wird diskutiert.

Effect of detuning in Fourier domain mode locked lasers on the performance of optical coherence tomography —
— Lars Kirsten, Julia Walther, Peter Cimalla, Sven Messerschmitt, Mirko Meiners, and Edmund Koch — Dresden University of Technology, Faculty of Medicine Carl Gustav Carus, Clinical Sensing and Moni-
toring, Fetscherstraße 74, 01307 Dresden, Germany
Optical coherence tomography (OCT) is an interferometric imag-
ing 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 pe-
riodically 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 per-
formance 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.


Induzierte spontane Lasertätigkeit in Quecksilber durch
Zweiphotonenanregung —
— Daniel Kolbe, Andreas Koglba-
er, Ruth Steinborn und Jochen Walz — Institut für Physik, Joh-
annes Gutenberg-Universität Mainz und Helmholtz-Institut Mainz,
D-55099 Mainz
Die geringe Anregungswahrscheinlichkeit bei einer Zweiphotonenreso-
nanz stellt eine Herausforderung dar, diesen Prozess als Pumpmecha-
nismus zum Laserbetrieb zu nutzen. Die nötigen Pumpintensitäten
werden meist nur durch gepulste Quellen erreicht. Hier wird von spon-
taner Lasertätigkeit auf dem 7S-S-6S Übergang in Quecksilber mit
kontinuierlichen Pumplasern berichtet. Durch die Wahl der Verstimm-
zung zum intermediären 6P-6P Niveau kann die Zweiphotonenanregung
stärker erhöht werden und die Laserschwellen kann bereits bei wenigen
100 mW Pumpleistung überwunden werden. Durch Veränderung der
Leistungen kann isotopenselektive Lasertätigkeit beobachtet werden.

Dauerstrich optisch parametrischer Oscillator zur Erzeugung
von Terahertzstrahlung und Kombination mit einemPhoto-
mischer zur kohärenten Detektion* —
— Jens Kiesling, Rosita
Sowade, Karsten Busch und Ingo Breuning — Physikalisches Insti-
tut, Universität Bonn, Wegerstr. 8, 53115 Bonn
Wir stellen einen durchstimmbaren optisch parametrischen Oscillator
vor, der auf periodisch gepulstem Lithiumnionobat basiert und kontinu-
ierlicher Terahertzstrahlung um 1,4 THz mittels eines kaskadierten op-
tisch parametrischen Prozesses erzeugt. Die Leistung der Terahertz-
Unequal spacing of attosecond pulse trains from relativistic surface high harmonic generation \cite{1}.

Quantum Optics and Photonics Division (Q) Monday

Universität Jena —
Friedrich-Schiller-Universität Jena —
Helmholtz-Institut Jena

The interaction of an intense ultrafast laser pulse with a solid density plasma leads to the emission of UV 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 and the plasma scale length. We observe a strong influence of the plasma-vacuum boundary and the electrons therein quiver due to the oscillating electric field of the driving laser field. The conversion efficiency for CWE harmonics is of order 0.5 mW at 280 nm, sufficient for efficient photoionization.

Thomson backscattering on laser-accelerated relativistic electron sheets \cite{2}, \cite{3}.

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 40-TW pulse using a 1000-crystal laser arrangement. The emission is temporally dented and is in good agreement with a Particle-In-Cell simulations and the experiment.

Efficiency of surface high harmonic radiation generated with a table-top terawatt laser \cite{4}.

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/cm², 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 17th harmonic, assigned to the CWE mechanism, has a pulse energy of \(\approx 1 - 10\ \mu\text{J}\). Relativistic surface harmonics (ROM) contain 100 nJ and 20 nJ for the 21st and 25th harmonic respectively. The conversion efficiency for CWE harmonics is \(10^{-5}\). The relativistic harmonics have a conversion efficiency of \(10^{-2}\) (21st) to \(10^{-8}\) (25th). A comparison with efficiencies that are obtained using Particle-In-Cell simulations shows good agreement for our experimental parameters.

Gekoppelte Ringresonatoren mit Tapered Amplifier und miniaturisiertem SHG Resonator zur effizienten Frequenzverdopplung auf 488 nm \cite{5}.

Quantum Optics and Photonics Division (Q) Monday

Continuous wave Lyman-\(\alpha\) (121.56 nm) generation by four-wave mixing in mercury \cite{6}.

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-\(\alpha\) 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:Lu₂O₃ disk laser (1015 nm). Additionally FWM in a three color enhancement cavity and a hollow core fiber is investigated.

Frequency-Quadrupled 285nm Diode Laser System for Photoionization of Mg using LBO as a Second Harmonic Generation Crystal \cite{7}.

Trapped Mg ions have shown to be a good candidate for quantum simulations\cite{8}. 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 285 nm single mode laser light via one SHG resonator from a dye laser at 570 nm. However, dye lasers and their optical pumps are expensive and work intensive to maintain and operate. An alternative is frequency quadrupling of a diode laser at 1140 nm, previously realized using periodically poled LiNbO₃ in the first SHG cavity\cite{9}. We report on an all solid state frequency-quadrupling system pumped by a diode laser at 1140 nm, using an LBO crystal for SHG in the first resonator. Despite its low non-linear coefficient of only 0.82 pm/V, we are currently able to achieve 9.5 mW at 570 nm from a pump power of 70 mW and optimize the system for a doubling efficiency of 20% of the first SHG at a pump power of 100 mW. This should provide on the order of 0.5 mW at 280 nm, sufficient for efficient photoionization.\cite{10}

Quantum Optics and Photonics Division (Q) Monday

Q 15.56 Mon 16:30 P1

Intracavity absorption spectroscopy with an Er\textsuperscript{3+}-doped fiber ring laser — •Peter Fjodorow, Lüb Leal, Benjamin Löhrden, 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 establish narrow absorption features. With a novel 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\textsuperscript{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.


Q 15.57 Mon 16:30 P1

Aufbau eines Integrated-Cavity-Output-Spektrometers im mittleren Infrarot — •Lars Czerniwnig, Kathrin Heinrich, Marcus Soeroe und Peter Herbrand — Institut für Lasermedizin, Universitätssklinikum Düsseldorf, Universitätsstr. 1, 40225 Düsseldorf


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 — •Jürgen Walther and Edmund Koch — Clinical Sensing 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 function of the observed structures. With similar parameters, the signal power decrease in Spectral Domain OCT can 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 the relative intensity noise (RIN). This system 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.

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, Hanni H. Mai, Timo Schotzko, Imran Memon, Martin Bartels, and Hartmut Hillmer — Institute of Nanotechnology and Analytics, University of Kassel, 34132 Kassel, Germany

Optical spectroscopy has become one of the most prevalent characterizing approaches 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 and optical quality. The fabrication 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 (λ/Δλ) 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, Sandora Schink, Bashir Kudhair, and Hartmut Hillmer — Institute of Nanotechnology 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 the relative intensity noise (RIN). This system is also applicable in 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 parent 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 near 5 nm to 200 nm. For all absorber materials the ablation threshold was determined, allowing the metal ablation threshold up to 10 J/cm\textsuperscript{2} and the surface was processed with different pulse numbers up to 10 pulses. The treated fused silica was analysed with microscopical (white-light interferometry,
Carrier-envelope phase stabilized 9.3 fs, 0.54 μJ pulses at 1.8 μm — Ding Wang1, Canhu Xu1, Liew Song1, Mu-Long Hua1, Ruxin Li1, and Zhizhan Xu1 — State Key Laboratory of Atomic and Molecular Physics, Shanghai Institute of Optics and Fine Mechanics, Chinese Academy of Sciences, Shanghai 201800, China — Laboratoire d’Optique Appliquée, ENSTA ParisTech, Ecole Polytechnique, CNRS, 91761 Palaiseau Cedex, France

New beamline for applied high harmonics spectroscopy — Jochen Vieker1, Hatem Dachkouli, Martin Michelsworth, Tobias Milde, and Ulfrich Heinzmann — Molecular and Surface Physics, University of Bielefeld

Spectroscopy of high harmonic generation (HHG) on laserfield-aligned molecules using femtosecond light sources 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 system, was recently put into operation. The beam is generated by a 50 Hz Ti:Sa lasersystem (804 nm), producing 50 fs, 15 mJ pulses.

New carrier-envelope phase stabilized 9.3 fs, 0.54 μJ pulses at 1.8 μm with well-defined etching depth up to 500 nm with well-defined etching regions can be achieved. 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].

Precision measurement of carrier-envelope phase dependent ATI spectra for Xenon, Argon, and Neon. This data was obtained using a high-resolution spectrometer (COLTIRMS) measurement of ultra-short laser-induced nonsequential 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 utilizing in a wide variety of CEP sensitive measurements. Here we find that the yield of Ar²⁺ in 4 fs laser fields at 750 nm and an intensity of 1.6 × 10¹⁴ W/cm² shows a strong CEP dependence which compares with recent theoretical predictions employing quantitative rescattering (QRS) theory. Additionally, the Ar²⁺ momentum, along the laser polarization axis, is strongly influenced by the CEP.

New kind of single-shot pulse length measurement of intense few-cycle laser pulses — T. Rathje1, A. M. Sayler1, W. Müller2, C. Köhler3, K. Rühle4, G. G. Paulus1, and M. Kling5, 6 — Institut für Optik und Quantenelektronik and Helmholtz Institut Jena, Max-Wien-Platz 1, 07743 Jena, Germany — 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 extreme-ultraviolet (XUV) pulses. Since these experiments are sensitive to the electric field of the laser light, the characterization of the wavefront is critical for the understanding of these effects. We present a new technique to determine the pulse length by using a stereoscopic 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. We utilize the 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 wavefront 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).

Precision measurement of carrier-envelope phase dependent ATI spectra for the noble gases using phase-tagging technique — Dominik Hoff1, Stefan Fasold1, Tim Rathje1, Walter Müller1, Klaus Rühle2, A. M. Sayler2, and G. G. Paulus2 — Institut für Optik und Quantenelektronik and Helmholtz Institut Jena, Max-Wien-Platz 1, 07743 Jena, Germany, and Max-Planck-Institut für Quantenoptik, Garching 85748, Germany, and Kansas State University, Manhattan, KS 66506, USA and Max-Planck-Institut für Kernphysik, Heidelberg, 69117, Germany, and University of Virginia, Charlottesville, VA 22904, USA

Single-shot carrier envelope phase tagged nonsequential double ionization of argon in intense 4-fs laser fields — A. M. Sayler1, T. Rathje1, W. Müller2, K. Rühle3, G. G. Paulus2, Nora G. Johnson2,3,4, O. Herrwerth2, A. Wirth2, S. De1, I. Ben-Itzhak5, G. Liez6, B. Bergues2, A. Senftleben7, C. D. Schröter8, R. Moshammer2, J. Ullrich2, K. J. Betsch2, R. V. Sayler1, J. Baumert1, and Do. K. Kim2 — Institute für Optik und Quantenelektronik and Helmholtz Institut Jena, Max-Wien-Platz 1, 07743 Jena, Germany, 2Max-Planck-Institut für Quantenoptik, Garching 85748, Germany, 3Kansas State University, Manhattan, KS 66506, USA, 4Max-Plank-Institut für Kernphysik, Heidelberg, 69117, Germany, 5University of Virginia, Charlottesville, VA 22904, USA

Single-shot carrier envelope phase (CEP) tagging has been utilized in a target in the realization of ion momentum spectroscopy (COLTIRMS) measurements of ultrashort laser-induced nonsequential double ionization (NSDI) of argon. This novel technique facilitates a unprecedented level of stability, longevity, and precision in the determination of CEP dependence and, in general, shows great promise for utilizing in a wide variety of CEP sensitive measurements. Here we find that the yield of Ar²⁺ in 4 fs laser fields at 750 nm and an intensity of 1.6 × 10¹⁴ W/cm² shows a strong CEP dependence which compares with recent theoretical predictions employing quantitative rescattering (QRS) theory. Additionally, the Ar²⁺ momentum, along the laser polarization axis, is strongly influenced by the CEP.

We present results on measurements and simulations of collinear wavefronts of both the laser light and the ATI light. We demonstrate how to use the electron time-of-flight signals to determine the asymmetry of the electric field of the laser light. We also show how to use this technique to determine the pulse length and provide a proof-of-concept experiment for a new interferometer needed for their characterization [1].

We present results on measurements and simulations of collinear wavefronts of both the laser light and the ATI light. We demonstrate how to use the electron time-of-flight signals to determine the asymmetry of the electric field of the laser light. We also show how to use this technique to determine the pulse length and provide a proof-of-concept experiment for a new interferometer needed for their characterization [1].
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 SCHULTZER1,2, STEFAN RAUSCH1,2 und UWE MORGNER1 — 1Institut für Quantenoptik, Leibniz Universität Hannover, Hannover, Germany — 2QUEST: Centre for Quantum Engineering and Space-Time Research, Hannover, Germany


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 Pris men 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 PFEPFER — 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 4f-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 LEITNER1, ALEXANDER FIRSOV1, ALEXEI BERSO2, and PHILIPPE WESSERT2 — 1Institute of Methods and Instrumentation for Synchrotron Radiation Research, Helmholtz-Zentrum Berlin — 2Institute 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 HZIR/BESSY II we characterized the properties of off-axis reflection zone plates (RZP) for simultaneously monochromatizing and focusing a femtosecond VUV photon source. Our setup generated kHz 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 plate 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 can have a higher efficiency and a 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 HANSENG1,2**, ANDREAS DREICHEN1,2, GEORGI MALESHKOV3, and GEORGER GEORG PAULS4,5,6,7 — 1Institut für Optik und Quantenelektronik, Friedrich-Schiller-Universität Jena, Max-Wien-Platz 1, 07743 Jena, Germany — 2Helmholtz-Institut Jena, Helmholtzweg 4, 07743 Jena, Germany — 3Department of Quantum Electronics, Sofia University, 5 James Bouchar 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 θ, 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 — **SASCHA GERGELY**, TOBIAS GOERZ1, MATEusz IBEK1, DOMINIK FLOESS1, TORSTEN BECK1, TIMO MAPPES2, and HEINZ KALT1 — 1Institut für Angewandte Physik, Karlsruhe Institute of Technology (KIT), 76128 Karlsruhe, Germany — 2Institut für Mikrostrukturtechnik, Karlsruhe Institute of Technology (KIT), 76128 Karlsruhe, Germany

We report on utilizing high-Q polymeric conic 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 possesses cavity Q factors above two million in the 1300 nm wavelength range. 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 concentra
tion, 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 DORNBUCH1, FLORIAN BACH2, MARTo HNWeIASS1, JÖRG PFEPPEL1, TORSTEN BECK1, CHRISTIAN KÖNS1, and HEINZ KALT1 — 1Institute of Applied Physics, Karlsruhe Institute of Technology (KIT), Karlsruhe, Germany — 2Institute 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 model 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 OTTERBACH1**, ALEXEY V. GORSKOV2, EUGEN DEMLER1, MICHAEL FLEISCHHAUER1, and MIRH AID D. LUKIN3 — 1Fachbereich Physik & Forschungszentrum OPTIMAS, TU Kaiserslautern — 2Physics Department, California Institute of Technology, Pasadena, CA, USA — 3Physics 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 the sense that the relative phase is exactly independent of any fine-tuning 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.


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, Germany

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-Schrodinger equation with an intense field, i.e., by introducing a transverse, strongly focused field component 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.


Q 15.77 Mon 16:30 P1 Robustness of trapping states in microwave cavity QED — CHRISTIAN ARENZ and GIOVANNA MORICI — 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 velocity conditions of preparing these states for experimentally accessible parameters [2,3].


Q 15.78 Mon 16:30 P1 An optical cavity with a strongly focused mode — KADEM DURAK, SYED ABDULLAH ALUNID, BRENDI CHING, GLEB MASLENIKOV, 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 lack spatial confinement and field enhancement can be accomplished by placing the atoms in focused cavity modes [1]. We investigate an anachronic cavity lens configuration [2], which provides strong coupling with a moderate finesse cavity and allows for efficient matching to Gaussian modes outside the cavity [3]. We report on our progress for mode characterization and alignment of such a nearly-ideal nano-lens.


Q 15.79 Mon 16:30 P1 Theoretical aspects of the QFEL — RAINER ENDRIECH, ENNO GEHRING, MATTHIAS KNOHL, PAUL PREIS, ROLAND SAUERBREY, and WOLFGANG P. SCHLEGEL — Institute for Quantum Physics, Universität Ulm, 89069 Ulm, Germany — Forschungszentrum Dresden-Rossendorf, 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 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 of 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. HATSAGORTSIVAN, 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.


Q 15.81 Mon 16:30 P1 Plasmon-mediated interaction and level shifts of atoms: a Green’s function approach — DAVID DZOTIKA and MICHAEL FLEISCHHAUSER — TU Kaiserslautern, Kaiserslautern, Germany — Quantum Systems 1RMIKKF, 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 antisymmetric Dicke states. Besides the modification of decay rates, dipole-dipole shifts of states 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.
realize those solutions in an experiment by time-continuously monitoring the environment (e.g. by homodyne 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, JÖRGEN 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 oscillator coupled to an ohmic bath. Performing optimal control on this system, allows us to construct a translation with a single thermal reservoir and without involving internal degrees of freedom [2].


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 change 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 KOLHLAUS, THOMAS VON MBERG, SIMON BENNÖ, ANDREA BERTOLDI, PHILIPPE BOUER, ARNAUD LANDRAGIS, and ALAIN ASPECT — Laboratoire Charles-Fabry de l’Institut d’Optique, CNRS and Univ. Paris-Sud, Campus Polytechnique, RD 128, F-91127 Palaiseau, FRANCE — 2LNE-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-Ludwig-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 analysed, 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.


Q 15.87 Mon 16:30 P1 Photonsynthesis 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 THAKUR1,2 and JAMAL BERKADAN1,2 — Max Planck Institute of Microstructure Physics, Weinberg 2, 06120 Halle (Saale), Germany

— 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 w 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 w 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 CASABONE1, ANDREAS STUTZ1, BIRGIT BRANDSTÄTTTER1, DIANA HABICHER1, JOHANNES GHEZZI1, ANDREW MCCULUNG1, TRACY NORTHUP1, and RAINER BLATT1,2,3 — 1Institut für Experimentalphysik, Universität Innsbruck, technikerstraße 25/4, 6020 Innsbruck, Austria — 2Institut für Quantenoptik und Quanteninformation der Österreichischen Akademie der Wissenschaften, Otto-Hititmaier-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 40Ca+ 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 4F<sub>3/2</sub> ↔ 3D<sub>5/2</sub> transition; we now generate single photons on the 4F<sub>5/2</sub> ↔ 3D<sub>5/2</sub> transition. All Zeeman states are resolved in agreement with theoretical simulations. A laser on the narrow 4S<sub>1/2</sub> ↔ 3D<sub>5/2</sub> 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. HATASORGYAN, and CHRISTOPH H. KITTEL — 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
Tapered Optical Fibers can be analyzed in situ, providing insight into the internal photo-physical distribution of the dipole transition moments in the layered system. Radiation characteristics, we elaborate specifically how the orientation of OLEDs (i.e. in electrical operation) and corresponding optical internal luminescence quantum efficiency can be determined in situ. Studies in recent years have shown that the latter attributes (which are well known as the key parameter to improve OLED efficiency in order to further enhance the single photon collection efficiency) are spent to develop OLEDs towards competitive sources for general lighting applications. In this context, the light outcoupling problem is 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 different parts of the complex plane inherit the properties of the different representations of the zeta function. To understand their behavior we investigate the Wigner functions of these so-called zeta states.

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 different parts of the complex plane inherit the properties of the different representations of the zeta function. To understand their behavior we investigate the Wigner functions of these so-called zeta states.

Q 16.1 Tue 10:30 HSZ 02
Optical Processes in OLEDs: Molecular Photonics — Michael Flümmich, 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. So far 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) 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, Julian Hermelbrach, Markus Weber, Wenjamin Rosenfeld, Rainer Jacob, Johannes Ghetta, Andrew McClung, Tracy Northup, and Rainer Blatt — 1Institut für Experimentalphysik, 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 16.3 Tue 11:15 HSZ 02
Fiber-integrated diamond-based single photon source — Tim Schröder, Andreas Wolfgang Schell, Günter Kewes, Thomas A. 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.
Quantum Optics and Photonics Division (Q)

A spintronic circularly-polarized single-photon source

— Andreas Merz, Pablo Asshoff, Robin Schwerdt, Heinz Kalt, and Michael Hettemich — 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 $B = 6T$, a pronounced spin-polarization of $\approx 65\%$ is achieved, while at $B = 2T$, it even approaches 95%. Autocorrelation measurements in pulsed operation mode prove the light emitted being non-classical.

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 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 analysing the statistics of the emitted photons using the Hanbury Brown and Twiss approach.


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 excitation 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 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.

Q 17.1 Tue 10:30 BAR Schön
Exploring Many-Body Interaction in a Strongly Interacting 6Li-40K Fermi-Fermi Mixture — Christoph Koester, Marc Anderegg, Sven Heidrich, Christian-Sidorenko, Florian Schreck, and Rudolf Grimm;
1Institut für Quantenoptik und Quanteninformation, Österreichische Akademie der Wissenschaften, Innsbruck, Austria — 2Institut für Experimentalkernphysik und Zentrum für Quantenphysik, Universität Innsbruck, Innsbruck, Austria — 3Swinburne University of Technology, Melbourne, Australia
We have realized the first strongly interacting 6Li-40K 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.

Q 17.2 Tue 10:45 BAR Schön
Deterministic preparation and control of a few-fermion system — Gerhard Zürn1,2, Thomas Lompe1,2, Theo Ottsten1,2, Martin Ries1,2, Friedhelm Seiwane3,2,3, Andre Wenzl1,2, and Selim Jochim1,2,3; 1Physikalisches Institut, Universität Heidelberg — 2MPI für Kernphysik, Heidelberg — 3ExtreMe 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 ~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 Stadler1, Torben Müller1, Bruno Zimmermann1, Jakob Meineke1, Jean-Philippe Brantut1, Henrik Moritz1, and Tilman Esslinger1; 1Institut für Quantenelektronik, ETH Zürich, Schweiz — 2Institut für Laser-Physik, Universität Potsdam, 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 realizations 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 Zollner1, Georg Müller2, and Christopher J. Pethick; 1Niels Bohr Institute, Copenhagen, Denmark — 2Aarhus University, Aarhus, Denmark
We study an impurity atom in a two-dimensional (2D) Fermi gas using variational wave functions for (i) an impurity defined 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 distortion 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; 1Fachbereich 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 Stellmer1,2, Meng Khoon Tev1, Mark Parigger1,2, Rudolf Grimm1,2, and Florian Schreck1; 1Institut für Quantenoptik und Quanteninformation, 6020 Innsbruck, Austria — 2Institut 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 87Sr atoms is spin-polarized and sympathetically cooled by interspecies collisions with the bosonic 84Sr isotope. At the end of evaporation, 2 x 10^7 84Sr atoms at a degeneracy of T/TF = 0.30(5) coexist with a BEC of 84Sr. Fermions with two valence electrons have a rich electronic structure, which comprises metastable states, narrow intercombination lines, and a nuclear spin manifold. The fermions can be used for quantum simulation. In the Bose-Einstein condensate, the fermions form a lattice which is the next step towards the realization of such systems. Furthermore, we report on BEC of 86Sr with an unusually large scattering length of ~800a₀.

Q 17.7 Tue 12:00 BAR Schön
Radio-Frequency Association of Efimov Trimmers — Thomas Lompe1,2, Theo Ottsten1,2,3, Friedhelm Seiwane3,2,3, Andreas Wenzl1,2, Gerhard Zürn1,2, and Selim Jochim1,2,3; 1Physikalisches Institut, Ruprecht-Karls-Universität Heidelberg, Germany — 2Max-Planck-Institut für Kernphysik, Saupfercheckweg 1, 69117 Heidelberg, Germany — 3ExtreMe 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.
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.

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.

**Loschmidt Echo of a Trapped Fermi Gas**

**Far-From-Equilibrium Dynamics of Ultracold Fermi Gases**

Q 18.1 Tue 10:30 BAR 106

**Jordanian resonances of harmonically trapped atoms**

*Philipp-Immanuel Schneider, Yuliya 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 excited bands and band gaps of an optical lattice.


**Single Cs Atoms Interacting with an Ultracold Rb Gas**

*Philipp-Immanuel Schneider, Yuliya V. Vanne, and Alejandro Saenz — AG Moderne Optik, Humboldt-Universität zu Berlin, Newtonstrasse 15, 12489 Berlin

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 collisions 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.
Probing an ultracold atomic crystal with matter waves — Bryce Gadway, Daniel Peirot, 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.

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.

Injection locking of a trapped-ion phonon laser — Ian Herrmann, Vahala, 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 condensate arising from the external trapping potential.

Injection locking of a trapped-ion phonon laser: the detection of ultraweak forces — Sebastian Knünz, Reitter, and Martin Plenio — Institut für Theoretische Physik, Albert-Einstein Allee 11, Universität Ulm, D-89069 Ulm

Due to the enormous sensitivity, the detection of weak forces has become possible in modern precision measurements. An example is the detection of the nuclear spin of a single atom or molecule.

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.

Quantum Optics and Photonics Division (Q) Tuesday

Q 18.6 Tue 11:45 BAR 106

Injection locking of a trapped-ion phonon laser: the detection of ultraweak forces — 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.

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 is applicable to such distinct physical systems as laser beams propagating in disordered photonic crystals or Bose-Einstein condensates expanding in a disordered environment.

Q 19.1 Tue 10:30 HÜL 386

Interacting ultracold bosons in optical lattices: Scattering and decoherence — Hannah Venzi1, Stefan Hunn1, Scott Sanders3, Tobias Zech1, Lewin Stein1,2, Florian Mintert3, Moritz Hiller1, and Andreas Buchleitner2 — 1Physikalisches Institut, Universität Heidelberg, Philosophenweg 16, 69120 Heidelberg, Germany, 2Physikalisches Institut, Universität Heidelberg, Philosophenweg 16, 69120 Heidelberg, Germany, 3Theorie der Stark-Resonanz, Universität Heidelberg, Philosophenweg 16, 69120 Heidelberg, Germany

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 is applicable to such distinct physical systems as laser beams propagating in disordered photonic crystals or Bose-Einstein condensates expanding in a disordered environment.

Q 19.2 Tue 11:00 HÜL 386

Modulation of polaron condensates with acoustic periodic potentials — Edgar Cerda1, Dmitriy Krizhanovskii2, Klaus Biermann2, Michiel Wouters3, Rudolph Hey1, Paulo Santos1, and Maurice Skolnick2 — 1Paul-Drude-Institut Berlin, Hausvogteiplatz 5-7, 10117 Berlin, Germany, 2University of Sheffield, Sheffield S3 7RF, United Kingdom, 3Ecole 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 limit 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 micropcavity. 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 many-body problem is investigated by means of analytical and numerical approaches and it displays unconventional uncompressible phases, Bose glass and quasi-condensate.

Q 19.4 Tue 11:30 HÜL 386

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 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 Scherer1, Bernd Lücke2, Jan Peise3, Jens Krüwer2, Oliver Topic1, Frank Deuretzbacher2, Wolfgang Ertmer2, Luis Santos2, Jan Arek2, and Carsten Klempf1 — 1Institut für Quantenoptik, Leibniz Universität Hannover; 2Institut für Theoretische Physik, Leibniz Universität Hannover; 3QuANTOP, 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 104 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 non-classical 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 Trichmann, 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.


Q 19.7 Tue 12:15 HÜL 386
Comparison of stochastic techniques for finite temperature Bose gases — Stuart Cockburn1, Antonio Negretti2, Nikolaos Proukakis, and Carsten Henkel3 — 1School of Mathematics and Statistics, University of Newcastle upon Tyne, Newcastle upon Tyne, NE1 7RU, United Kingdom; 2Institut für Quanteninformationssverarbeitung, Universität Ulm, Albert- Einstein-Allee 11, 89069 Ulm, Germany; 3Institut 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 Schulle1, Nacreur Gaaloul1, Holger Ahlers1, Sebastian Bose2, Felix Kösel1, Vyacheslav Lebedev1, Wolfgang Ertmer1, Luis Santos2, and Ernst Rasel1 — 1Institut für Quantenoptik, LU Hannover; 2Institut 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 20.1 Tue 10:30 SCH A118

Experimental investigation of the uncertainty principle using entangled photons — •ROBERT LEITZER, THOMAS DAMEL, ROGER COLBECK, KENT FISHER, and KEVIN RESCH — 1Institute for Quantum Computing, University of Waterloo, Waterloo, N2L 3G1, ON, Canada — 2Perimeter 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 of two measurements that are 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 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, MATTHIAS OHLLGER, DAVID GROSS, and JENS EISERER — 1Universität Potsdam, Institut für Physik und Astronomie (Haus 28) Karl-Liebknecht-Straße 24/25 14476 Potsdam, Germany — 2ETH Zürich, Theoretische Physik, Wolfgang-Pauli-Straße 27, 8093 Zürich, Switzerland

Recent 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 multipartite 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 be evaluated when only some observables are measured. Furthermore, it results in a computable entanglement monotone for genuine multipartite 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 robustness approaches unity exponentially fast with an increasing number of qubits.

Q 20.3 Tue 11:00 SCH A118

Taming multiparticle entanglement — •BASTIAN JUNDTITSCH, TOBIAS MORODER, and OTFRIED GÖHNE — 1Institut für Quantenoptik und Quanteninformation, Österreichische Akademie der Wissenschaften, Technikerstraße 21a, A-6020 Innsbruck, Austria — 2Fachbereich 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 multipartite 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 be evaluated when only some observables are measured. Furthermore, it results in a computable entanglement monotone for genuine multipartite 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 robustness approaches unity exponentially fast with an increasing number of qubits.

Q 20.4 Tue 11:15 SCH A118

Measuring entanglement in condensed matter systems — •MARCUS CRAMER, MARTIN PLESMO, and HARALD WUNDERLICH — 1Institut für Theoretische Physik, Universität Ulm, Germany — 2QUOLS, 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


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, ARNAU RIERA, and JOSÉ IGNACIO LATORRE — 1Theoretical Physics, The University of the Basque Country, E-48080 Bilbao, Spain — 2Institute of Physics and Astronomy, University of Potsdam, D-14476 Potsdam, Germany — 3Department d’Estructura i Constituents de la Matèria, 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 NOVOTNÝ, GERMAN ALBER, and IGOR JEX — 1Institut für Angewandte Physik, Technische Universität Darmstadt, D-64289 Darmstadt, Germany — 2Department of Physics, FNSPE CTU in Prague, Czech Republic

The asymptotic decoherence originating from iteratively applied random unitary coupling 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

• Geza Toth1,2,5, Witlef Winczorek3,4, David Gross6, Roland Krischek1,2, Christian Schwemmer1,4, and Harald Weinfurter1,2 — 1Theoretical Physics, The University of the Basque Country, E-48080 Bilbao, Spain — 2IKERBASQUE, Basque Foundation for Science, E-48011 Bilbao, Spain — 3Research Institute for Solid State Physics and Optics, H-1325 Budapest, Hungary — 4Max-Planck-Institut für Quantenoptik, D-85748 Garching, Germany — 5Fakultät für Physik, Ludwig-Maximilians-Universität, D-80799 Garching, Germany — 6Institute 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 of the state in many, relevant cases. This 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 Schwemmer1,2, Geza Toth1,2,5, Witlef Winczorek3,4, David Gross6, Roland Krischek1,2, and Harald Weinfurter1,2 — 1Max-Planck-Institut für Quantenoptik, D-85748 Garching — 2Fakultät für Physik, Ludwig-Maximilians-Universität, D-80797 München — 3Department of Theoretical Physics, The University of the Basque Country, E-48080 Bilbao — 4IKERBASQUE, Basque Foundation for Science, E-48011 Bilbao — 5Research Institute for Solid State Physics and Optics, Hungarian Academy of Sciences, H-1325 Budapest — 6Faculty of Physics, University of Vienna, A-1090 Vienna — 7Institute 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 Töth 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] Töth et al., Phys. Rev. Lett., in press; talk by Töth

References


Q 21.1 Laserentwicklung: Festkörperraser 2

Time: Tuesday 10:30 - 12:45

Q 21.1 Tue 10:30 SCH A215
Diodengepumpter Laserbetrieb von Tm:Sc2O3 bei 2116 nm

— Philipp Koopmann1,2, Samir Lasraini2, Karsten Scholle2, Peter Fuhrberg2, Klaus Petermann3, and Günter Huber1 — 1Institut für Laser-Physik, Universität Hamburg, Germany — 2LISA laser products, Katlenburg-Lindau, Germany

Q 21.3 Tue 11:00 SCH A215
46 W regenerative amplifier based on Nd:YVO₄ seeded by a gain switched diode laser
• Florian Hartik, Markus Lührmann, Christian Treuhald, Thorsten Uhl, Ralph Knapp, Achim Nestler, Andreas Klein, Götz Eberhard, Johannes L’huillier, Photikon-Zentrum Kaiserslautern e.V., 67663 Kaiserslautern, Germany 2Lumera Laser GmbH, 67663 Kaiserslautern, Germany ˘ 3Ferdinand-Braun-Institut, Leibniz-Institut für Höchstfrequenztechnik, 12489 Berlin, Germany
We report on a Nd:YVO₄ 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 M⁴-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.

Q 21.4 Tue 11:15 SCH A215
Yb:LiYF₄ as Scheibenlasermaterial — Kolja Biehl, Susanne T. Friedrich-Thorton, Christian Klänkel, Daniela Parisio, Klaus Petermann, Mauro Tonelli, Günter Huber
1Institut für Laser-Physik, Universität Hamburg, Deutschland 2NIST-Nanoscience Institute-CNRS, Dipartimento di Fisica, Pisa, Italien

Q 21.5 Tue 11:30 SCH A215
Joule-level, room-temperature Yb:YAG and Yb:CaF₂ lasers — Markus Lober, Matthias Siebold, Franziska Kroll, Fabian Röser, Jörg Körner, Joachim Hein, Ulrich Schramm, Roland Sauerbrey
1Helmholtz-Centre Dresden Rossendorf, Bautzner Landstr. 400, 01328 Dresden, Germany ˘ 2Institute for Optics and Quantum Electronics, Max-Vien-Plata 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 (Petawatt, Energy Efficient Laser for Optical Plasma Experiments) with a pulse duration of 200 fs and a pulse energy of 270 µJ was demonstrated. The laser presents gain and efficiency measurements of a joule-level active mirror amplifier for the investigation 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 a Ytterbium-doped amplifier using either Yb:YAG or Yb:CaF₂. 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 Pr⁴⁺:LiYF₄-Laser — Sebastian Möller, Nils-Owe Hansen, Ortwin Hellmig and Günter Huber — Universität Hamburg, Institut für Laserphysik

In diesem Lasersystem diente ein Fabry-Perot-Etalon als Auskopplerspigel. Das Etalon wird aus einem Spiegelpaar mit variablen Luftspalt gehäuft. Die Änderung dieses Luftspaltes mittels eines Piezoaktors ermöglicht eine schnelle Variation des Auskoppelpulses für die beiden Laserwellenlängen.

Zusätzlich wurden Untersuchungen zur Erzeugung gewinngeschalteter Laserpulse mittels Modulation der Pumpleistung durchgeführt. Dabei konnte gemessen werden, dass mit einem Laserdiode-Pumpenwellenlänge von 308 nm Pulseenergie und einer Pulspitzenleistung von 2,1 W bei 640 nm bzw. 670 ns Pulsdauer und 1,4 W Puls spitzenleistung bei 532 nm erzeugt werden. In Kombination mit der schnellen Variation des Auskoppelpulses lieferte das System gewinngeschaltete Laserpulse mit einer Repe titionsrate 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 and Thomas Walther — TU Darmstadt, Institut für Angewandte Physik, Laser und Quantenoptik, Schloßgartenstraße 7, D-64289 Darmstadt
Wir stellen eine Laserquelle bei 1092 nm vor, die spektral bis 26 GHz modensprungfrei abgestimmt werden kann. Die Scanfrequenz beträgt dabei bis zu 100 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 frequenzverdopplt. 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 Brez- kowiak, Thomas Dirhl, Andreas Koglbaurer, Daniel Kolbe, Matthias Sattler, Ruth Steinborn, Jochen Walz — Ferdinand-Braun-Institut, Leibniz-Institut für Physik, Johannes Gutenberg-Universität Mainz, Helmholtz-Institut Mainz, D-55099 Mainz

Q 21.9 Tue 12:30 SCH A215
Kompakte Dauerstrichlaser mit hohen Effizienzen im ultra violetten Spektralbereich — Philip Metz, Teoman Gün and Günter Huber — Universität Hamburg, Institut für Laser-Physik
Die meisten Systeme zur Erzeugung kohärenter ultravioletter (UV) Dauerstrich-Strahlung basieren auf einer zweifachen Frequenzver-

Q 22: Ultrakurze Laserpulse: Anwendungen 1

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

Erzeugung Harmonischer Strahlung mit Goldnanoboden — Nils Pfullmann, Carsten Clever, Christian Waltermann, Milutin Kovacevic, Tobias Hanke, Rudolf Bratschitsch, Alfred Leitenstorfer und Uwe Morgner — 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


Generation und charakterisierung von femtosekunden-laser induzierten nanostruktur auf thin gold films — Conny Axtel Hulverscheidt, Martin Reininghaus und Dirk Wortmann — RWTH Aachen University, Lehrstuhl für Lasertechnik, Steinbachstr. 15, D-52074 Aachen

Femtosekund (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 and 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 plasma generation 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.

Zeptosecond precision pulse shaping — Jens Köhler, Matthias Wollenhaupt, Tim Bayer, Christian Sarpe, and Thomas Baumert — Universität Kassel, Institut für Physik und Zentrum für Interdisziplinäre Nanoscientificis Science and Technology (CINaS), Heinrich-Pllett-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 20% precision of 300 fs ± 0.3 fs 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.

Parametervariation femtosekunden-geschriebener Wellenleiter in YAG-Kristallen — Anna-Greta Paschke, Thomas Calman, Moritz Emons, Martin Reininghaus, Klaus Petermann and Günter Huber — Universität Hamburg, Institut für Laser-Physik, Hamburg


\[ \Delta n \approx \frac{356}{34132} \approx 0.01 \]

Dies führt dann aufgrund des optischen Effekts zu einer lokalen Erhöhung des Brechungsindex um \( \Delta n \approx \frac{356}{34132} \approx 0.01 \). 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.

Q 22.4 Tuesday 11:15 SCH A01

Superresolved femtosecond nanosurgery of cells — Matthias Pospiech, Moritz Emmons, Kai Kütemeier, Alexander Heisterkamp and Uwe Morgner — 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 Tuesday 11:45 SCH A01

Combining fs-pulse tailoring and self-phase modulation for nonlinear microscopy — Tillmann Kalas, Jens Köhler, Christian Sarpe-Tudoran, Matthias Wollenhaupt, and Thomas 2


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 be-

Entanglement dynamics of multi-qubit states in single-

Quantum Optics and Photonics Division (Q)

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.

We present the generation of characteristic Ka 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 10^18 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.

Ultra-broadband third-harmonic generation in fs-

filamentation — •FABIAN GAUSSMANN, DIRK HEMMERS, and GEORG PRETZLER — Institut für Laser- und Plasmaphysik, Heinrich-Heine-Universität Düsseldorf

We have shown that 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.

Application of the multiple rate equation — •OLIVER BRENNER, NILS BROUWER, and BÂRBELE 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 Boltzmann’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.

Monochromatizing a Femtosecond High-Order Harmonic VUV Photon Source with Reflective Off-Axis Zone Plates — •MATTHEUS IRK, TORSTEN LIEPTNER, ALEXANDER FIRSOV, ALLEXI ERKO, and PHILIPPE WERNERT — 1Institute for Methods and Instrumentation for Synchrotron Radiation Research, Helmholtz-Zentrum Berlin — 2Institute 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 low 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/BESSY II 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 plate substrate. Each as 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 diffraction limit i.e. focal point and spectrum was recorded on an x-ray CCD camera and spectral resolution and focal characteristics were determined.

Q 23.2: Poster 2: Intersectional Session

Time: Tuesday 18:00–21:00

Entanglement dynamics of multi-qubit states in single- and many-sided noisy channels — •MICHAEL SIOMAU and STEPHAN FRITZSCHE — 1Max-Planck-Institut für Kernphysik, Postfach 103980, D-69029 Heidelberg, Germany — 2Physikalisches Institut, Heidelberg Universität, D-69120 Heidelberg, Germany — 3Department of Physical Sciences, P.O.Box 3000, FIN-90014 University of Oulu, Finland — 4GSI 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 \( \sigma_x \), \( \sigma_y \), and \( \sigma_z \). 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 entan-
Cyclic Mutually Unbiased Bases and the Fibonacci Sequence

– Ulrich Seyfarth 1, Kedar Ranadive 2, and Gernot Alber 3

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 contract 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.

References:

Designing Ideal Hamiltonian Qubit Dynamics by Dynamical Recoupling

– Holger Friedych 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:

Local Entropy Flow in Qubit Networks Under Random Controlled Unitary Transformations

– Jakob Novotny 1, 2, Gernot Alber 2, and Igor Jex 3

1 Institut für Quanteninformationsverarbeitung, Universität Ulm — 2 Institut für Theoretische Physik, Universität Ulm

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 behavior of the entropy 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:

Noise Spectrum Analysis at the NV center in diamond

– Konstantin Schukraft, Florian Reimp, Fedor Jelezko, and Jörg Wrachtrup

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

References:
computers.

Illustrating the Geometry of Quantum Channels — Corey O’Meara, Gunther Dür, and Thomas Schulte-Herbrüggen

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.

Quantum information transfer with trapped-ion antennae — Regina Lechner, Maximilian Harlander, Michael Brownnutt, Rainer Blatt, and Wolfgang Hänsel

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.

Quantum Key Distribution on Hanover Campus — Vitus Hänsch, Tobias Ebler, Jörg Dür, Torsten Franz, Roman Schnabel, and Reinhard Werner

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 telecommunications 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.

Efficient entanglement purification protocol using chains of atoms and optical cavities — Denis Gonta and Peter van Loock

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 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.

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Q 23.18 Tue 18:00 P1 Quantum key distribution on Hanover Campus: Theory — Jörg Dühme1, Torsten Franz2, Reinhard F. Werner1, Vitus Händchen2, Tobias Eberle3, and Roman Schnabel1 — 1Leibniz Universität Hannover, Institut für Theoretische Physik, AG Quanteninformation — 2Albert Einstein Institut, Quantum Interferometry. We report on the implementation of an entanglement-based quantum cryptography 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 23.20 Tue 18:00 P1 Fabrication and characterisation of tailored waveguide PDC sources in RPE:PPLN for quantum communication — Stephan Krapick1, Hubertus Suche, Harald Herrmann, Raimund Ricken, Victor Quiring, Christine Silberhorn, and Wolfgang Sohler1 — 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-phase-matching is employed to enable photon pair generation. In the fabrication process of the waveguides, the so-called 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 352 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 Hein1,2,3, Chris Erven1, Raymond Laflamme1,4, Gregor Weihs3,5, and Thomas Jennewein3,4 — 1Max Planck Institute for the Science of Light, Erlangen, Germany — 2Institute of Optics, Information and Photonics, University of Erlangen-Nurenberg, Erlangen, Germany — 3Institute of Quantum Computing, University of Waterloo, Waterloo, ON, Canada — 4Perimeter Institute, Waterloo, Canada — 5Institute 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 transmission 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 ratios 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 Khan1,2, Christoph Wittmann1,2, Nitin Jain1,2, Josef Fürst1,2, Nathan Killoran3, Norbert Lütkenhaus3, Christoph Marquardt1,2, and Gerd Leuchs1,2,3 — 1Max-Planck-Institut für die Physik des Lichts, Günther-Schawlow-Str. 1, 91058 Erlangen — 2Institut für Optik, Information und Photonik, Universität Erlangen-Nürnberg, Staudtstraße 7/B2, 91058 Erlangen — 3Institute 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 Daschner1, Harald Kübler1, Bernhard Huber1, Thomas Baluktschan1, Andrea Kölle2, James P. Shaffer2, Robert Liptay3, and Tilman Pfau1 — 1Physikalisches Institut, Universität Stuttgart, Germany — 2Homer 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, 1590 (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 Latka1, 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-
experiments 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].

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 in our 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 to the original state. The fidelity of the retrieved state with respect to the classical limit of 0.5, showing the memory’s suitability as building blocks of a quantum repeater for long-distance quantum communication.

Non-linear optics using single-atom cavity Electromagnetically Induced Transparency — Els Diguido, José Villas-Boas, Stephan Ritter, and Gerhard Rempe — Max-Planck-Institute of Quantum Optics, Hans-Kopfermann-Str. 1, 85748 Garching

A fundamental challenge for quantum optics is the realization of non-linear 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 systems and setup 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.

Spin-Spin interaction in impurity doped ion crystal — Peter Ivanov, Amado Baustista-Salvador, Jens Welzel, Niels Kurz, Frank Zieske, Max Hettrich, Ullrich Poschinger, and Ferdi-nand 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 $^{40}\text{Ca}^+$ 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 in conventional strength of the magnetic field makes spin interactions important 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.
interplay with different Zeeman substates are investigated and future $\mu$ with their sub-natural linewidth are best suited to drive transitions long-wavelength radiation. Therefore stimulated Raman transitions in our atom-cavity system as the cavity assembly largely shields the subspaces. Efficient state transfer by microwave radiation is prohibited work. Coherent manipulation of the atomic state allows single qubit date for the distribution of quantum information over a quantum net-

Single atoms trapped in a high-finesse optical cavity are an ideal candi-
dation via vacuum stimulated Raman transitions (vSTIRAP) between systems can be used for efficient and controlled single photon produc-
tion 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 inter-
mediate 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 Upphoff, Christian Nölleke, Andreas Reiserer, Holger Specht, Eden Figueroa, Stephan Ritter, and Gerhard Rempe — Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Str. 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 net-
work. 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 $\pi$-pulses in 1 $\mu$s, 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 and 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 "heller" *"dunkel"klassifiziert, so dass die Güte dieser Zustandsdiskriminierung fundamental durch Schrottrauschen und Hintergrundlilicht limitiert ist[1]. Wir benutzen eine EMCCD-Kamera, um mithilfe der Ortsauflösung festzustellen, inwie-
weit es möglich ist die optimale Güte der Diskriminierung zu erreichen [2]. Es werden Fluoreszenznennungen an einem $^{40}$Ca$^+$ Ion benutzt, um den Ausleseprozess präzise zu modellieren. Auf dieser Basis wer-
den verschiedene Zustandsklassifikationsalgorithmen in Simulationen verglichen.


Q 23.34 Tue 18:00 P1
Interfacing ions with Nanofibres — Benjamin Ames, Michael Brownnutt, Jan Petersen, Arno Rauchenschuetz, and Rainer Blatt — Max-Planck-Institut für Quantenphysik, Uni. Innsbruck, Technikerstr. 25, 6020 Innsbruck, Austria — 2Institut für Experimentalphysik, Uni. Innsbruck, Technikerstr. 25, 6020 Innsbruck, Austria — 3Institut für Quantenoptik und Quanteninformation, Österreichische Akademie der Wissenschaften, 6020 Innsbruck, Austria

Given the advances made in trapped-ion quantum information pro-
cessing, 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 techni-
cal and physical challenges, particularly with regard to positional sta-
bility, and ion heating close to nanostructures. We describe an ion-
trap/nanofibre system used to investigate single photon 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 phasen-
kohärenter Frequenzumschaltung — T.F. Glöger, M. Joh-
nings, A. Kirchmova, Chr. Plitz, B. Scharfenberger, A. Varon

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 Hyperfeinzustän-
den $|S_{1/2}, F=0\rangle\rightarrow|S_{1/2}, F=1\rangle$ des $^{171}$Yb$^+$ Ion realisiert. Zur di-
ase Phase amplitude dämpfung wird ein Mikrowellensignal einer Frequenz von etwa 12.6 GHz benötigt. Durch einen Magnetfeldgra-
dienten entlang der Fallnachse werden Qubits in den zeevaraufge-
spaltenen Übergängen ($F=0\rangle \rightarrow \langle F=1, m_F=\pm 1\rangle$) ein einzelm im Fre-
zenraum adressierbar. Zur Quantenzustandsmanipulation mehrerer Ionen ist es notwendig, die Frequenz des elektromagnetischen Feldes phasenkohärenten schalten zu können.

Wir erzeugen das benötigte Mikrowellensignal durch Mischen ei-
nes schmalbandigen Signals mit 12.568 GHz mit den Signalen zwei-
er phasenkohärenten schaltbaren Signalgeneratoren mit Frequenzen von 1-150 MHz in IQ-Konfiguration. Dies ermöglicht einen Adressierungs-
raum der Qubits von 300 MHz.

Der experimentelle Aufbau wird vorgestellt und hinsichtlich Fre-
quenzstabilität, Amplitudennennung und Phasenrauschen charakte-
risiert. Darüber hinaus werden die Adressierung und Manipulation mehrerer $^{171}$Yb$^+$ Ionen in einer linearen Paul-Falle mit Magnetfeld-
gradient demonstriert.

Q 23.36 Tue 18:00 P1
Direct Characterization of Quantum Dynamics in a system of $^{40}$Ca$^+$ - ions — Daniel Nickl, Julio T. Barreiro, Philipp Schindler, Thomas Monz, Michael Chwalla, Stefan Quint, Markus Henning, and Rainer Blatt — Institut für Experimentalphysik, Universität Innsbruck, Technikerstr. 25, 6020 Innsbruck, Austria — 2Institut für Quantenoptik und Quanteninfor-

mation, Österreichische Akademie der Wissenschaften, Technikerstr. 21A, 6020 Innsbruck, Austria

Quantum process tomography (QPT) is an essential tool for charac-
terizing 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 char-
terization 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 ex-
perimental realization of DCQD is reported in a system of $^{40}$Ca$^+$ ions confined in a linear Paul trap. The unitary processes $\sigma_X, \sigma_Y, \sigma_Z$ as well as the entanglement of a single ion with an auxiliary qubit are characterized by 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. The system’s spontaneous decay time ($T_1$) and dephasing time ($T_2$) are quantitatively analysed with a single experimental setting.


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 is 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 qubits by more than a factor of magnitude, beyond 100 μs. Further optimization strategies will be discussed.


Q 23.38 Tue 18:00 P1

Efficient single-mode fiber coupling of photons from a single ion — ●Christoph Kurz, Jan Huwer, Michael Schug, José Brito, Philipp Müller, Joyce Ghosh, and Jürgen Eschner — 1Universität des Saarlandes, Experimentalphysik, Campus E2.6, 66123 Saarbrücken — 2Institut de Ciències Fotòniques, Mediterranean Technology Park, 08860 Castelldefels (Barcelona)

We operate two independent linear Paul traps with single 40Ca+ ions, which provides a highly modular setup for implementing quantum information processing and communication schemes [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 optimizing the fiber coupling and making use of constructive interference of light from the ion and its mirror image [2].


Q 23.39 Tue 18:00 P1

Fast and stable laser pulses using EOM for quantum information — ●Stephan Quan, Daniel Nigg, Markus Hennrich, and Rainer Blatt — Institut für Experimen
talphysik, Universität Innsbruck, Technikerstr. 25, 6020 Innsbruck, Austria — 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 98%. 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 is 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 provide 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.


Q 23.41 Tue 18:00 P1

Entanglement between two remotely trapped atoms — ●N. Ortner, J. Hofmann, M. Kruiz, L. Henretin, W. Rosenfelder, M. Wehner, and H. Weinfurter — 1Fakultät für Physik der LMU München, Schellingstr. 4/III, 80799 München — 2Max-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 experiments 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].


Q 23.42 Tue 18:00 P1

Towards quantum simulations in a two-dimensional lattice of ions — ●Christian Schneider, Johannes Stroehle, Martin Endrleln, Thomas Huber, Stephan Dusewel, 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 (Unai 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 \(40 \mu\)m and a height above the surface of \(40 \mu\)m, which could already allow to achieve a sufficient coupling strength between the ions for first quantum simulation experiments in two dimensions.


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 Christoph 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

Optical Trapping of an Ion - Results and Perspectives — ●Thomas Huber, Martin Endrleln, Christian Schneider, Stephan Dusewel, 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 com-
plex 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. In 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 Horner1, Helmut Fedder2, Michael Kläs1, Joachim Markham2, Markus Sondermann2, and Gerold Leuchs1,2

1Institut für Optik, Information und Photonik (IOIP), Universität Erlangen-Nürnberg, Staudstr. 7/B2, 91058 Erlangen
2Max-Planck-Institut für die Physik des Lichts (MPL), Günther-Scharowsky-Str. 1/Bau 24, 91058 Erlangen

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 (99.9%) 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 we present an overview of the current understanding of the contributing factors to the spin decoherence is presented.

Q 23.46 Tue 18:00 P1
Trapping of ions in a deep parabolic mirror

•Robert Maiwald1,2, Andrea Golla1,2, Benoît Chalopin2, Martin Fischer1,2, Alessandro S. Villar2, Markus Sondermann1,2, and Gerold Leuchs1,2

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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, 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 enabling efficient spin 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 occur with a natural abundance of 1.1%. Here we present our current 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. Complementarily, we study the decopling 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 23.48 Tue 18:00 P1
Generation of a light mode that couples efficiently to a dipole transition

•Andrea Golla1,2, Benoît Chalopin2, Robert Maiwald1,2, Irina Harder1, Markus Sondermann1,2, and Gerold Leuchs1,2

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2Max-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 optimizing 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 Fedder1, Jan Horner1, Michael Kläs1, Florian Dolde3, Junich Isoya3, Matthew Markham2, Daniel Twitchen2, Fedor Jelezko1, and Jörg Wrachtrup1

1Universität Stuttgart, 70550 Stuttgart, Germany — 2Element Six Ltd, Ascot, UK — 3Graduate School of Library, Information and Media Studies, University of Tsukuba, 1-2 Kauga, Tsukuba, Ibaraki 305-8550, Japan

The Nitrogen-Vacancy (NV) center in diamond is a 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 occur with a natural abundance of 1.1%. Here we present our current 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. Complementarily, 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 Singer1, Ulrich G. Poschinger1, Michael Murphy2, Frank Ziesel1, Tommaso Callarco2, and Ferdinand Schmidt-Kaler1

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We present powerful numerical tools for the optimization of the external control of the motional and internal states of trapped neutral atomic ions, and for the case of trapped laser-cooled ions in a segmented ion-trap. 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 numerical methods presented can also be used to gain an intuitive under standing of quantum experiments with trapped ions by performing virtual simulated experiments on a personal computer [2].

Ultra-bright and compact fibre coupled single photon source based on a defect centre in diamond using a solid immersion lens — FRIEDMANN GAÊDER, TIM SCHROEDER, and OLIVER BENSON — AG Nano Optics, Institut für Physik, Humboldt Universität zu Berlin, Newtonstraße 15, 12489 Berlin

Quantum interference and non-locality of independent photons from disparate sources — RALPH WIGGNER, JOACHIM VON ZANTHIER, and GRISH AGARWAL — Institut für Optik, Information und Photonik, Universität Erlangen-Nürnberg, Erlangen, Germany — 2Department of Physics, Oklahoma State University, Stillwater, OK, USA

Interaction of two-level atoms with circularly polarized light — ARMEN HAYKAPETYAN and STEPHAN FRITZSCHE — 1Max-Planck-Institut für Kernphysik, Postfach 103980, D-69029 Heidelberg, Germany — 2Department of Physics, P.O. Box 3000, Finn-90014 University of Oulu, Finland — 3GSII Heimholtzentrum für Schwerionenforschung, D-64291 Darmstadt, Germany

How well can photons change their colour - about the efficiency of single photon frequency down-conversion — SUSANNE BLUM, GEORGINA OLIVARES-REINERI, CARLO OVVATTAN, SEBASTIAN ZASKE, CHRISTOPH BECHER, and GIOVANNA MORETTI — 1Universität des Saarlandes, Germany — 2Universidad de Concepción, Chile — 3Universitat Autónoma de Barcelona, Spain

Towards coupling of a single N-V center in diamond to a fiber based micro-cavity — ROLAND ALBRECHT, CHRISTIAN DEUTSCH, JAKOB REICHDEL, TIM SCHROEDER, RICO HENZE, OLIVER BENSON, and CHRISTOPH BECHER — Fachrichtung 7.2, (Experimentalphysik), Universität des Saarlandes, Campus E2.6, 66123 Saarbrücken — 2Laboratoire Kastler Brossel, ENS/UPMC-Paris 6/CNRS, 24 rue Lhomond, 75005 Paris, France — 3Institut 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 successful 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 depositing the dielectric mirror. This approach allows one to scan 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.


Probing the Wigner function of pulsed single photons point-by-point — KAI HANG LAIHO, GEORGE BERG ANDRICICH, CASSEMINO, DAVID GROSS, and CHRISTINE SILBERHORST — 1Scientific Light, Erlangen, Germany — 2Institute 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 phase-averaged value of the photon density 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 spec-

Quantum Optics and Photonics Division (Q) Tuesday
An optimized 1560nm polarization squeezer for quantum information protocols — Christian Gabriel, Joel F. Corney, Christoph Markwardt, and Gerd Leuchs — 1Max Planck Institute for the Science of Light, Günther-Scharowsky-Strasse 1, D-91058 Erlangen, Germany — 2Institute for Optics, Information and Photonics, University Erlangen-Nuremberg, Staudtstrasse 7/B2, D-91058 Erlangen, Germany — 3ARC 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 free-space link.

Einfluss der Photonenstatistik auf die Kalibrierung von Einzelphotonendetektoren — Waldermar Schmunk, Silke Peters, Mark Rodenberger, Helmut Hofer and 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 Lichtes beeinflusst wird. Denn im Gegensatz zu analogen registrieren digitale Detektoren das gleichzeitige Eintreffen mehrerer Photon als ein Einphoton-Ereignis, was zu Fehleinschätzungen der gemessenen Detektionsseffizienzen 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 Detektionsseffizienz von SPADs. Eine Lampe, ein Laser sowie eine Einzelphotonquelle \( g^2(0) = 0.15 \) erzeugen die benötigte Strahlung. Übereinstimmend mit den Vorhersagen einer Modellierung zeigt sich, dass sich die mit Laser und Lampe gemessenen relativen Detektionsseffizienzen von 0,165 ± 0,002 sowie 0,162 ± 0,001 signifikant von denen der nicht-klassischen Einzelphotonquelle von 0,122 ± 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.

Correlation measurements on optical fields from a Whispering Gallery Mode Optical Parametric Oscillator — Gerhard Schunk, Josef Först, Dmitri Strekalov, Michael Förtsch, Ulrik L. Anderson, Andrea Aiello, Christoph Markwardt, and Gerd Leuchs — 1Max Planck Institute for the Science of Light, Institute for Optics, Information and Photonics, University Erlangen-Nuremberg, Erlangen, Germany — 2Institut für Quantenphysik, Universität Ulm, D-89069 Ulm, Germany — 3Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California, USA — 4Department 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**


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. 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.

**Q 24.2** Wed 10:45 HSZ 02 A multiband ground-state superfluid — Parvis Soltanpanah, Julian Struck, Dirk-Sören Lüthmann, Andreas Bick, JWekke Plenio, Rodolphe Le Tarant, Patrick Wendin, 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 well described by a single quasi-momentum state in the lower 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 multiband superfluid ground state 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, Valentin Murg, Mari-Carmen Barula, Juan Ignacio Cirac, Ulrich Schneider, and Immanuel Bloch — 1Max Planck Institute of Quantum Optics, Hans-Kopfermann-Strasse 1, 85748 Garching, Germany — 2University of Vienna, Faculty of Physics, Boltzmanngasse 5, 1090 Vienna, Austria — 3Ludwig-Maximilians-University Munich, Faculty of Physics, Schellingstrasse 4, 80799 Munich, Germany

Quantum Optics and Photonics Division (Q) Wednesday
Ultrasound 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 approximation.

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**, Fernando M. Cucchietti, Norbert Schuch, Tobias Donner, and Tilman Esslinger

Complete devil’s staircase and crystal-superfluid transitions in the initial state and the importance of a harmonic trap. resulting time scales for the adiabatic evolution, the effect of defects in the initial state and the importance of a harmonic trap.

**Q 24.5** Wed 11:30 HSZ 02

Towards Plaquettes in Optical Superlattice — **Marcos Ataíl2, Monika Aidersburger1, Matteo Nascimbene2, Stefano Trotzky1, and Immanuel Bloch1**

**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 Krieglesteiner, Andreas Klunger, and Hans-Christoph Nägerl

**Q 24.7** Wed 12:00 HSZ 02

Scanning electron microscopy of ultracold atoms — **Peter Würtz**, Andreas Vogler, Anne 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 100 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 Olschläger, Christina Staarmann, Parsi 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.


**Q 24.9** Wed 12:30 HSZ 02

The Dicke quantum phase transition in an optical cavity QED system — **Ralph Moeller**, Christian Baumann, Hendrik Brennecke, Tobias Donner, Christine Gueblin, and Tilman Esslinger — Institute for Quantum Electronics, ETH Zurich, 8093 Zurich, Switzerland — 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, Lotharstrasse 1, D-47057 Duisburg, Germany

We study the Bose–Hubbard–Model in terms of reduced density matrices of one ($ρ_1$), two ($ρ_{12}$) and more lattice sites. By complete induction, we prove a hierarchy of correlations such as

$$g_3(\gamma) = \frac{g_2(\gamma)}{g_1(\gamma)}$$

where $g_1$, $g_2$, and $g_3$ denote the one-, two- and three-body correlation function respectively.
Matter wave interferometry: Molecular mass, complex properties of this optical dipole trap allow for fast and efficient laser cooling. 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**


GAIN (Gravitmetric 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, Stefan Gerlich, Jens Tüxen, Stefan Nimmrichter, Marcel Mayor, and Markus Arndt — University of Vienna, Quantum Nanophysics, Austria — 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:**


This facilitates a controlled analytical description of many-body quantum dynamics away from equilibrium.

We apply this approach to some physical example scenarios.

**Q 25.4 Wed 11:15 BAR Schön**

**Chip-based Bragg interferometry with Bose-Einstein condensates in microgravity**

- Markus Kruitziker, Achim Peters, and the QUANTUS Team — Institute für Physik, HU Berlin — Institut für Quantenoptik, LU Hannover — Institut für Laserphysik, Uni Hamburg — ZARM, Uni Bremen — Institut für Quantenphysik, Uni Ulm — MPQ, München — Institut für angewandte Physik, TU Darmstadt — Midlands Ultracold Atom Research Centre, University of Birmingham, UK — 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 observing 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 Uibrecht — 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 Beauplis, Bruno Pelle, Sophie Félisson, Xiaolong Wang, Marie-Christine Angonin, Peter Wolf, and Franck Perera Dos Santos — NLE-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 performed in the vicinity of the retro-reflective lattice mirror’s surface.

In the experiment Forca-G, such an interferometer is realized with 87Rb 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 Schöñ

A dual species matter-wave interferometer in microgravity — ●Jan Rudolph1, Ernst Maria Rasel1, and the QUANTUS Team2,3,4,5,6,7,8,9,10 1Institut für Quantenoptik, TU Hannover — 2Institut für Quantenoptik, Universität Hannover — 3Institut für Laser-Physik, Universität Hamburg — 4Institut für Quantenphysik, Universität Ulm — 5Institut für angewandte Physik, TU Darmstadt — 6MUARC, University of Birmingham — 7FBH, Berlin — 8MPQ, 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 87Rb and 40K 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 realize 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 50 WM 11311.328

Q 25.8 Wed 12:15 BAR Schöñ

Simple description of atom interferometry with Bose-Einstein condensates — ●André Wenzlawski1, Klaus Sengstock1, and the QUANTUS Team2,3,4,5,6,7,8,9,10 1Institut für Laser-Physik, Universität Hamburg — 2Institut für Quantenoptik, Universität Ulm — 3Institut für Quantenphysik, Universität Hannover — 4ZARM, Universität Bremen — 5Institut für Quantenphysik, Universität Ulm — 6Institut für angewandte Physik, TU Darmstadt — 7Midlands Ultracold Atom Research Centre, University of Birmingham, UK — 8FBH, Berlin — 9MPQ, 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 and introduce a Hamilton formalism for the new dynamical variables, and point out the connection to the constants of motion of the Gross-Pitaevskii equation.

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.

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 $^{87}\text{Rb}$ 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 Neuner, 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 observation of single photon [1]. However, especially 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 $^{87}\text{Rb}$ 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].


Q 26.3 Wed 11:15 HÜL 386 Charge states of the nitrogen-vacancy center in diamond unraveled by single shot NMR — •Gerard Waldherr, Johannes Beck, Matthias Steiner, Philipp Neumann, Fedor Jelezko, and Jörg Wrachtrup — 3. Physikalisches Institut, Universität Stuttgart, 70550 Stuttgart, Deutschland

Nitrogen-vacancy (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 non-demolition 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 Said1, Johannes Beck2, Gerald Waldherr3, •Philipp Neumann4, Fedor Jelezko2, Jason Twamley1, and Jörg Wrachtrup3 — 1Macquarie University Sydney, Australia — 2Universität 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 sequences 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 entangled qubits. We present an experimental demonstration of our concept 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 kaler Ionen als Quantenregister — •Michael Johanning1, Kunling Wang2, Mang Feng2 und Christoph Wunderlich1 — 1Fachbereich Physik, Universität Siegen, 57068 Siegen — 2State Key Laboratory of Magnetic Resonance and Atomic and Molecular Physics, Wuhan Institute of Physics and Mathematics, Chinese Academy of Sciences, Wuhan 430071, China

We schlagen einen neuen Implementierungsansatz zur Quanteninformationsverarbeitung vor, bei dem Quanten in Kern- und Elektronenspins einer kalten gespeicherten Ionenkette kodiert sind. Im Paschen-Back-Regime lassen sich in der Hochfeldnäherung die Kernspins gut vom dephaserenden 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. Baumgart1, N. Timoney1, A. Retzker2, A.F. Varón3, M. Johanning1, M. Pleno2, and C. Wunderlich1 — 1Fachbereich Physik, Universität Siegen, 57068 Siegen — 2Institute 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 that coherence times and exchange of information between 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 2 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 Köbler, Michael Schlagmüller, Renate Daschner, Albin Urbay, Robert Löw, and Tilman Pfau — 1Physikalisches 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 Górecki, Tommaso Calarco, and Christiane P. Koch, 1 Institut für Theoretische Physik, Freie Universität Berlin, Germany — 2Fakultät für Quanteninformationsverarbeitung, Universität Ulm, Germany — 3Institut 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 optimal the pulse. 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 27.4 Wed 11:30 BAR 106

Overview of laser cooling of relativistic C$^+$ ion beams at ESR — Michael Busßmann, Franziska Kroll, Markus Löser, Matthias Schäffer, Ulrich Schramm, Wei-Qiang Wen, Daniel F.A. Winters, Tobias Beck, Benjamin Reindl, Thomas Walther, Gerhard Burkhardt, Fried Nöstlinger, Thomas Kühl, Christian Novotny, Christoph Kozhuharov, Christoph Gerpich, Markus Steck, Christina Dimopoulou, Fritz Nolden, Xinwen Ma, and Thomas Stöhrer

We present an overview of the setup for all-optical cooling and beam diagnostics for relativistic C$^+$ ions 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 — Mattea Jona - Larino, Lüs Santos, Stefan Mueller, Juliette Bily, Emanuel Hess, Holger Kadau, Philipp Weinfurther, David Peter, and Tilman Pfau

1ITP, Institut für Theoretische Physik, Leibniz Universität Hanover — 25Physikalisches Institut, Universität Stuttgart

We consider a system of ultracold dipolar bosons in the vicinity of the Mott-insulator–superfluid phase transition. Making use of the Gutzwiller ansatz we have found antisymetric 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.
We assume all dipoles to be aligned along the lattice direction. We in-
vestigate the stability of the system as a function of the lattice strength
and we highlight the role played by the long range dipole-dipole inter-
action. 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 (52Cr) con-
densate, finding the experimental evidence of the dipole-long
range character.

Q 27.6 Wed 12:00 BAR 106
Stability of a Dipolar Quantum Gas in a 1D Optical Lattice — Ṣtefan Müller1,2, Juliette Billy3, Emanuel Heni3, Hol-
gar Kadau1, Philipp Weimann1, David Peter1, Mattia Jona Lasinio4, Luís Santos5 and Tilman Pfau1 — 5. Physikalisches
Institut, Universität Stuttgart — 2Cluster of Excellence QUEST, In-
istitut 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 1 10 to 200 Bohr radii.
Theoretical studies support significant intersite coupling via the long
range dipole-dipole interactions.


Q 27.7 Wed 12:15 BAR 106
Controlled Charge Transport in lattice confined Alkaline-
Earth Gases — Rick Muckeheier1, Alexander Esfeld2, Igor
Lesanovsky2, and Thomas Pohl1 — 1Max Planck Institute for the
Physics of Complex Systems, Dresden, Germany — 2School 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 com-
posed 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 opportuni-
ties 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 Nick-
las, 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 pla-
ids. Here we report on a method for controlling the effective inter-
actions that govern the miscibility of the system by dressing the two
components with a linear coupling field. We experimentally investi-
gate 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 pa-
rameter 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

Q 28.1 Wed 10:30 SCH A01
Faked-state attacks on commercial quantum key distri-
bution — Nytt Jahn1,2, Lars Lydersen1,2, Christoph-
Per Wittmann1,2, Carlos Wiersch3, Dominique Elser1,2, Christoph
Marquardt1,2, Vadim Makarov1,4, Johannes Skaar1,4, and Gerd Luech2,1,2 — 1Max Planck Institute for the
Science of Light, Guenther-Scharowsky-Str. 1, Bau 24, 91058, Er-
langen, Germany — 2Institut fuer Optik, Information und Photonik,
University of Erlangen-Nuremberg, Staudtstrasse 7/B2, 91058, Erlan-
gen, Germany — 3Department of Electronics and Telecommunications,
Norwegian University of Science and Technology, NO-7491 Trondheim,
Norway — 4University Graduate Center, NO-2027 Kjeller, Norway —
5Departamento de Física, 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 dis-
tribution 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 LiNbO3 ridge
waveguide and yield converted photons at 1557 nm. An internal con-
version efficiency exceeding 80% is achieved. Together with a high
conversion efficiency of 95% into the waveguide at 738 nm this leads to
saturation 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.
M. Schreck, and C. Becker, “Single photon emission from silicon-

Q 28.3 Wed 11:00 SCH A01
Daylight Free Space Quantum Communication using Con-
tinuous Polarization Variables — Christian Pruninger1,2,
Bettina Hein1,2, Christoph Wittmann1,2, Christoph
Marquardt1,2, and Gerd Luech2,1,2 — 1Max-Planck-Institut für
die Physik des Lichts, Günther-Scharowsky-Str. 1 / Bau 24, 91058
Erlangen, Deutschland — 2Institut für Optik, Information und Pho-
tonik, 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 spa-
tial 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 pat-
terns. This allows for investigation of the influences of the turbulent
atmosphere on our quantum states. A main drawback when work-
ing with an atmospheric channel is spatial beam jitter. We studied
these kind of effects in detail and will present methods to reduce their

Q 28.4 Wed 11:20 SCH A01
Remote Controlled Charge Transport in lattice confined
Alkaline-Earth Gases — Stefan Reimann1,2, Volker Wicht7,
Christoph Marquardt1,2, and Gerhard Lossch1,2 — 1Max Planck
Institut für Biophysik, Jena, Germany — 2Department of Physics,
University of Jena, Germany

We present a new method to control charge transport in lattice
confined alkaline-earth gases. A strong pump beam at 1404 nm is used
to prepare a state of a single SiV ion in a certain hyperfine state.
Simultaneously, the state of a remote ion is controlled by this pump
beam. The resulting probability to find the remote ion in a certain
hyperfine state is measured. This allows for remote preparation of
this kind of effects in detail and will present methods to reduce their

Q 28.5 Wed 11:40 SCH A01
Single photon interference on a lithium niobate photonic
chip — Piotr Kundzicz1,2, Matthias Weymann3, Alexander
dEckardt1,2, and Tilman Pfau1 — 1Max Planck Institute
for the Physics of Complex Systems, Dresden, Germany — 2Department
of Physics, Technical University of Berlin, Germany

We explore the use of a photonic chip to perform a single photon
interference experiment using a lithium niobate crystal. The non-linearity
of the crystal allows for efficient nonlinear mixing of two single
photon states. This enables for quantum communication applications
such as quantum key distribution or quantum computing. In this work
we use this property to perform a single photon interference experi-
ment. We prepare a single photon in a specific spatial mode of a
lithium niobate photonic crystal and measure the probability of find-
ing it in the same or a different spatial mode after passing the chip.

Q 28.6 Wed 12:00 SCH A01
Optical Current Feedback for Remote Control of
Lattice Confined Polarization Variables — Christian
Pruninger1,2, Bettina Hein1,2, and Christoph Wittmann1,2 —
1Max-Planck-Institut für die Physik des Lichts, Günther-
Scharowsky-Str. 1 / Bau 24, 91058 Erlangen, Deutschland — 2Institut
für Optik, Information und Photonik, Universität Erlangen-Nürnberg,
Staudtstrasse 7 / B2, 91058 Erlangen, Deutschland

We present a novel method for remote control of quantum states
in a lattice confined alkaline-earth gases. The method allows for
remote preparation of quantum states in the lattice, providing a
new class of quantum gate operations. The method is based on
the physical process of resonant two-photon absorption in a
lithium niobate crystal. The non-linearity of the crystal allows
for efficient nonlinear mixing of two single photon states. This
enables for quantum communication applications such as quantum
key distribution or quantum computing. In this work we use this
property to realize a remote control of a quantum state in a
lattice confined alkaline-earth gas.
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 processing. Specifically, we consider algorithms that are important for scalable quantum information processing, such as those that allow for the efficient distribution of quantum states.

The excitation of a two-level atom by a propagating light pulse plays 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 $P_r(t)$ 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 $P_r(t)$ 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.

References:

Lenses as an Atom-Photon Interface: A Simple Model — Colin Teo$^1$ and Valerio Scarani$^1,2$ — 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 $P_r(t)$ 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 $P_r(t)$ 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.

References:

Experimental optimum unambiguous discrimination of two mixed single-photon states — Gesine Steudel$^1$, Sebastian Krauer$^1$, Ulrike Herzog$^1$, Erik Stock$^2$, Dieter Birnbacher$^2$, and Oliver Benson$^1$ — Humboldt-Universität Berlin, AG Nanophoton, Newtonstr. 15, 12489 Berlin — 2Technische Universität Berlin, Institut für Festkörperphysik, Hardenbergr. 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].

References:
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

Superkontinuumerzeugung mit Rückkopplung — ©Michael Kurs, Nicoletta Brauckmann, Sven Dohner, Maximilian Brinckmann, Till Waldbaum, Petra Gross und Carsten Fallnich — Institut für Angewandte Physik, Westfälische Wilhelms-Universität Münster, Corrensstr. 2, 48149 Münster


Q 29.3 Wed 11:00 SCH 251

A Widely tunable XUV frequency comb source — ©Dominik Z. Kandula¹, Tjeerd J. Pinkert¹, Christoph Gohe³, Itai Barmess¹, Jonas Morgenweg³, Wim Usachis¹, and Kielo S.E. Eikema¹

1 LaserLaB Amsterdam, Institute for Lasers Life and Biophotonics, Vrije Universiteit, De Boelelaan 1081, 1081HV Amsterdam, Netherlands — Max Born Institute, Max-Born-Str. 2A, 12489 Berlin, Germany — 3 Ludwig-Maximilians-Universität, Schellingstrasse 4, 80333 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 70nm 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 Oscillator hoher mittlerer Leistung mit Femtosekunden-Pulsen und schnell durchstimmbarem Spektrum — ©Tino Lang¹, Michael Jackstadt¹, János Hebling¹, Peter Seith¹, Wim Usachis¹, Dominik Z. Kandula¹, and Christoph Gohe³

1 LaserLaB Amsterdam, Institute for Lasers Life and Biophotonics, Vrije Universiteit, De Boelelaan 1081, 1081HV Amsterdam, Netherlands — Max Born Institute, Max-Born-Str. 2A, 12489 Berlin, Germany — 3 Ludwig-Maximilians-Universität, Schellingstrasse 4, 80333 München, Germany

We present a novel optical parametric oscillator (OPO), which is based on cascaded parametric processes in MgO doped periodically poled congruent lithium niobate. The OPO signal and a second harmonic of the OPO signal have been achieved. The second harmonic is generated in a 1mm long MgO-doped periodically poled congruent lithium niobate crystal, which is placed inside a second harmonic crystal, which is placed inside a second harmonic crystal. The frequency of the second harmonic is chosen to be 1500 nm, which is close to the wavelength of the signal. The OPO signal is then amplified to several mJ per pulse in a noncollinear optical parametric chirped pulse amplifier. The amplified signal is then used to generate a frequency comb in the extreme ultraviolet (XUV) spectral range. The frequency comb is then used to measure the energy of helium, neon and argon with visibilities of up to 62%, at wavelengths from 51.5 nm to 83.5 nm. Using the 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.
than 600 fs. In particular, we achieved up to 1.5 W using 60 % output power coupling rate. A peak in conversion efficiency could be observed at approximately 3 to 5 times threshold power pump. 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.


Broad area (BA) lasers are the most efficient light sources available, but suffer from poor beam quality due to the lack of transversal 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 Würth, Adam Bauer, Sven Hofling, Martin Kapp, Lukas Worschecht, and Alfred Forchel — Technische Physik, Universität 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. Steepwise 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

Q 30.1 Wed 10:30 SCH A118 Sensing with coupled microcavity systems — Sandra Isabell 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.


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 microparticle 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 Nondiffraction Beams — Falko Diebel, Patrick Rose, Martin Boguslawski, Julian Becker, and Cornelius 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. Beams 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 characterized 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.
Spatial analysis of optically induced photonic lattices — 

Sybille Niemeyer, Patrick Rose, Martin Boguslawski, and Cornelia Denz — Institut für Angewandte Physik und Center for Nonlinear Science (CeNoS), Westfälische Wilhelms-Universität Münster, 48149 Münster, Germany

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 refractive index structure, which will certainly lead to a better understanding of many sophisticated effects in photonic lattices. 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 properties 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.

Linear and Nonlinear Measurements on Silicon-Organic Hybrid Waveguide Structures — Peter W. Noite, Clemens Schreiber, and Jörg Schilling — Centre for Innovation Competence SiLi-nano, Martin-Luther-Universität 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 properties 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 31: Quantum Gases: Opt. Lattice 2

Time: Wednesday 14:30-16:00

Q 31.1 Wed 14:30 HSZ 02

Probing nearest-neighbor correlations of ultracold fermions in an optical lattice — THOMAS UEHLINGER, DANIEL GREIF, LETICIA TARRELL, ROBERT JØRDENS, GREGOR JOTZU, and TILMANN 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 \textit{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 LÜH-MANN, 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 density 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. GORELIK¹, IRAKLI TITVINIDZE², WALTER HOFFSTETTER², MICHAEL SNOEK³, and NILS BLÜMER¹ — ¹Institute of Physics, Johannes Gutenberg University, Mainz, Germany — ²Institute for Theoretical Physics, Johann Wolfgang Goethe University, Frankfurt, Germany — ³Institute 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.


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.


Q 31.5 Wed 15:30 HSZ 02

Probing Quantum Density Fluctuations of Ultracold Atoms with Matter Wave Optics — SCOTT SANDERES, FLO-RIAN 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 these ideas, 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.
Quantum computation and simulation using dissipation

Daniel Nigg

Quantum information processing with trapped ions at NIST

Most current schemes for Quantum Information Processing (QIP) with 1, 30167 Hannover and PTB, Bundesallee 100, 38116 Braunschweig USA—Present address: QUEST, Universität Hannover, Welfengarten 1, 30167 Hannover and PTB, Bundesallee 100, 38116 Braunschweig.

Secondly, we employ a single ion to measure a magnetic field gradient, and sideband cooling. The magnetic field gradient not only allows to address the ions independently [1] but also accounts for an effective spin-spin coupling [3]. 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 potential of hundreds of 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.


Q 32.4 Wed 15:15 HÜL 386

Optical Ion Trapping - Cooling and Perspectives

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-Str. 25, 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 potential of hundreds of 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.


Q 32.6 Wed 15:45 HÜL 386

Towards quantum simulations in a two-dimensional lattice of ions — Johannes Stroehle, Christian Schneider, Martin Endler, Thomas Huber, Stephan Duewel, and Tobias Schaeetz — 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.

[2] H. Schmitz et al., PRL 103, 090504 (2009) and
P. Zähringer et al., PRL 104, 100503 (2010)

Q 32.7 Wed 16:00 HÜL 386
2D Arrays of RF-Addressable Ion Traps — Michael Brownutt, Rainer Blatt — Institut für Experimentalmathematik, Innsbruck, Österreich — 2Institut 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 seg-
mented 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 dimen-
sion 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

Q 33.1 Wed 14:30 SCH A118
Quantum key distribution with finite resources: Coherent vs. Collective attacks — Markus Mertz, Silvère Abruzzo, Sylvia Bratzik, Hermann Kampermann, and Dagmar Bruss — Institut für Theoretische Physik III, Heinrich-Heine-Universität Düsseldorff

Q 33.2 Wed 14:45 SCH A118
Probabilistic Phase-Covariant Cloning of Coherent States — Christoffer Wittmann, Peter Marek, Radim Filip, Mario A. Usuga, Christoph Marquardt, Ulrik L. Andersen, and Gerda Leuchs — 1Max-Planck-Institut für die Physik des Lichtes, Günther-Scharowsky-Str. 1 / Ban 24, 91058 Erlangen, Germany — 2Department of Physics, Technical University of Denmark, Building 309, 2800 Lyngby, Denmark — 3Institute for Quantum Optics and Photonics, University Erlangen-Nuremberg, Staudtstr. 7/B2, 91058 Erlangen, Germany — 4Department of Optics, Palacky 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 pro-
tocols. 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 pho-
ton 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].

Marquardt, G. Leuchs and U.L. Andersen, Nat. Phys. 6, 767 (2010).

Q 33.3 Wed 15:00 SCH A118
Squashing model and applications to quantum key distribution
protocols — Oleg Gittsovich, Vanar Narasimhamurthy, Ruben Andrei Romero Alvaraes, Norman Beaudry, Tobias Moroder, and Norbert Lütkenhaus — 1Institute for Quantum Computing & Department of Physics and Astronomy, University of Waterloo, 200 University Avenue West, N2L 3G1 Waterloo, Ontario, Canada — 2Quantum Information Theory Group, Institute of Theoretical Physics I, University Erlangen-Nuremberg, Staudtstrasse 7/B2, 91058 Erlangen, Germany — 3Max Planck Institute for the Science of Light, Günther-Scharowsky-Straße 1/24, 91058 Erlangen, Germany — 4Department of Physics, University of Toronto, Toronto, Ontario, M5S 3G4, Canada — 5Institute for Theoretical Physics, ETH Zurich, Switzerland

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 quan-
tum 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 informa-
tion technology.

The new method is systematically compared to the standard “model
cbased” 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 and Peter van Loock — 1Optical Quantum Information Theory Group, Max Planck Institute for the Science of Light, Erlangen, Germany — 2Institute 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 lab-
atory. 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 to-
wards 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], also as a countermeasure to stochastic,
non-Gaussian error models [4].


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 $10^{-4}$ to $10^{-5}$ 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.


Q 34: Cold Molecules II

Time: Wednesday 14:30–16:00

Q 34.1 Wed 14:30 BAR Schön
A Molecular Synchrotron — F. Filsinger1, D. Lee2, T. Hoffmann2, S. Bratzik1, T. Schröder1, T. Förster3, and M. B. Plenio4
1-4Fritz-Haber-Institut der MPG, Berlin — 5Max-Planck-Institut für Quantenoptik, Garching — 6D-22607 Hamburg

We present a major step forward in the field of molecular beams, the molecular synchrotron [1]. This device allows us to load molecules into a molecular synchrotron, which is bent in an elliptical shape, allowing to focus the molecules using static electric fields and a repulsive potential for polar molecules in low field regions [2]. The synchrotron consists 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 epimorize the level of control that can now be achieved over molecular beams and brings a low-energy molecular collider within close reach.


Q 34.2 Wed 14:45 BAR Schön
Millimeter wave control over neutral molecules in a Stark decelerator — M. Abe2, F. Santambrogio3, A. Meek2, and G. Meijer3
1Fritz-Haber-Institut der MPG, Berlin — 2Center for Free-Electron Laser Science, DESY, Hamburg — 3Universität Hamburg

We have recently demonstrated a microwave lens for polar molecules [1,2]. 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 (C6H5CN), a prototypical large polar molecule. The transmission and the m/$\mu$-selector 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.


Q 34.3 Wed 15:00 BAR Schön
Focusing metastable CO molecules with an elliptical electrostatic mirror — A. Meek1, F. Santambrogio2, A. Meek2, G. Meijer3
1Fritz-Haber-Institut der MPG, Berlin — 2Center for Free-Electron Laser Science, DESY, Hamburg — 3Universität Hamburg

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 regions. 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 — J. Hüfner1,2,3, M. Reetz1,2, G. Röhrich1,2,3, and W. Sibbett4
1Fritz-Haber-Institut der MPG, Berlin — 2Center for Free-Electron Laser Science, DESY, Hamburg — 3Universität Hamburg — 4Department of Physics, University of York

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 3P2 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/$\mu$-selector — S. Putzke, F. Filsinger, M. Röhrich, R. König, R. Renner, and C. Schaffner
1Fritz-Haber-Institut der MPG, Berlin — 2Center for Free-Electron Laser Science, DESY, Hamburg — 3Universität 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 sufficiently different Stark effect, can be filtered selectively. This method has been successfully used for the conformer selection of 3-aminophenol in a m/$\mu$-selector [2]. The resolution can be improved by changing the duty-cycle of the half-periods in the switching cycle [3].

Here we present recent results obtained with a new setup second generation AG guide. We investigate the transmission of individual rotational quantum states of benzene (C6H6N), a prototypical large polar molecule. The transmission and the m/$\mu$-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 benzene.


Q 34.6 Wed 15:45 BAR Schön
Microwave lens: Focusing properties and potential losses — S. Merz, C. Brieger1, A. J. A. Meek2, and G. Meijer3
1Fritz-Haber-Institut der MPG, Berlin — 2Center for Free-Electron Laser Science, DESY, Hamburg — 3Universität 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. 


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**Q 35.4 Wed 15:15 SCH A01**

Visualisierung des Elektronen-Beschleunigungsprozesses bei der Laser-Wakefield-Beschleunigung

**Marina Nicolai**

Hans-Peter Schilvenicht 1

P. M. D. Mangles 2

Alexander G. R. Thomas 3

A. Moradi 4

Zulfiqar Na’imuddin 2

Karl M. Kruschelnick 5

Alexander Sävert 5

Malte C. Kauza 3

1 Institut für Optik und Quantenelektronik, 07743 Jena — 2 Imperial College London — 3 UCLA Los Angeles


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 Plasamawelle umgeben. Wenn ein linear polarisierter Probepuls einen Bereich im Plasma mit starken Magnetfeldern durchfährt, 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 unter sucht werden.

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**Q 35.5 Wed 15:30 SCH A01**

Photonische Struktur-basierte Beschleunigung von nicht-relativistischen Elektronen

**John Breuer** und **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.


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**Q 35.6 Wed 15:45 SCH A01**

*Time-resolved amplified spontaneous emission in quantum dots — Jördi Gomis-Bresco 1, Sabine Dommers-Völkel 2, Oliver Schöpf 1, Oyvind Kaptan 2, Olga Dyatlova 3, Dieter Bimberr 2, and Ulrike Woggon 4 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
Q 36: Laseranwendungen und Photonik 1

**Location:** SCH 251

**Time:** Wednesday 14:30–16:00

**Q 36.1 Wed 14:30 SCH 251**

**Ein Dreifarben-Überhöhungsresonator zur Erzeugung von Lyman-α-Strahlung**

- Anna Beczkowiak, Daniel Kolbe, Andreas Koglbauer, Ruth Steinborn, Andreas Müller, Thomas Diehl, Matthias Stappel, Matthias Sattler und Jochen Walz
- Institut für Physik, Johannes-Gutenberg-Universität Mainz, 55099 Mainz und Helmholtz-Institut Mainz, 55099 Mainz


**Q 36.2 Wed 14:45 SCH 251**

**Optical mode structure of a harmonically mode-locked Yb femtosecond fiber laser**

- Simon Herr1,2, Til Steinmetz1,2, Tobias Wilken1, Martin Engelbrecht1, Theodor W. Hänisch1, Thomas Udem1, and Ronald Holzwarth1,2
- Max-Planck-Institute for Quantum Optics, Hans-Kopfermann-Str. 1, 85748 Garching, Germany
- 1Menlo 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 spectographs. 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 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**

**Stimuliertes Raman-Streuung und Raman-Laser mit Silizium bei tiefen Temperaturen**

- Oliver Lux, Hans Rhee, Stefan Meister, Hans H. Drässing, Eckehard Avron, and Andreas Steffen
- Institut für Optik und Atome, TU Berlin, Straße des 17. Juni 135, 10623 Berlin


**Q 36.4 Wed 15:15 SCH 251**

**Durchstimmbar optisch parametrische Oscillation in Flüssigkeit**

- Thomas Beckmann, Heiko Linnenbank, Karsten Buse, and Ingo Breuning
- Physikalisches Institut, Universität Bonn, Wegelerstr. 8, 53115 Bonn

Optisch parametrische Ozillatoren sind weit durchstimmbare Quellen kohärenter Lichts. Durch Quasiphasenanpassung lässt sich der Prozess auf beliebige Wellenlängenbereiche ausdehnen. Um das Konzept auf einen Fü lsträngleresonator zu übertragen und dessen wellenlängenunabhängige Intensitätsüberhöhung zu nutzen, sind radial gepolte Strukturen notwendig, da sich hier das Licht auf einer Kugelbahn bewegt.

Ein Fü lsträngleresonator mit radialer Domänenstruktur zur Quasiphasenanpassung optisch parametrischer Ozillationen mit 1040 nm Pumppwellenlänge wird realisiert. Der Ozillator 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 Müller, Matthias Sattler, Matthias Stappel, Ruth Steinborn, and Jochen Walz
- Institut für Physik, Johannes Gutenberg-Universität 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 vacuo.

It has already been successfully demonstrated by sum-frequency-generation in mercury-vapor, which gives an output power of 0.4 W [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.


**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 Lasermedin, Universitätssklinikum Düsseldorf, Universitätstr. 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...
Q 37: Cold Molecules III

Time: Wednesday 16:30–18:15

Q 37.1 Wed 16:30 BAR Schön
Visible vibrational spectroscopy of cold \( \text{H}_2^+ \) 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

\( \text{H}_2^+ \) 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 \( \text{H}_2^+ \) 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 \((B_2^+)=4.77 \times 10^3 \text{ cm}^{-1}\) 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 \( \text{H}_2^+ \) vibrational ground state, to, recently, final levels up to 16600 \( \text{cm}^{-1} \), 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 \( \text{Rb}_2 \) triplet molecules — Christoph Strauss, Tetsu Takekoshi, Florian Lang, Klaus Winkler, Rudolf Grimm, Marius Lysebro, Leif Vestergaard, Ebbehard Thiemann, and Johannes Hecker Denschlag — 1Universität Ulm, Institut für Quantenmaterie, Albert-Einstein-Allee 45, D-89081 Ulm, Germany — 2Institut für Experimentalphysik und Zentrum für Quantenphysik, Universität Innsbruck, A-6020 Innsbruck, Austria — 3Institut für Quantenoptik und Quanteninformation der Österreichischen Akademie der Wissenschaften, A-6020 Innsbruck, Austria — 4Department of Physics, University of Oslo, 0316 Oslo, Norway — 5Gottfried 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 \( \text{Rb}_2 \). We present a complete analysis of the triplet ground state \( \Delta \Sigma \Sigma \Sigma \) and the first excited triplet state \((1)\Sigma \Sigma \Sigma \) of Rubidium 87 discussing its vibrational, rotational, hyperfine and Zeeman structure. We perform laser spectroscopy on ultracold Feshbach molecules to obtain a trap condition 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 \( \Delta \Sigma \Sigma \Sigma \) and the \( \chi \Delta \Sigma \Sigma \Sigma \) 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

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 low range electron-neutral interactions. One of the best studied molecular anions is \( \text{OH}^- \). 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.


Q 37.4 Wed 17:15 BAR Schön
Interaction of cold atoms with molecular ions — Anna Göritz, Johannes Deiglmayr, Thorsten Best, Rico Otto, Matthias Weidemüller, and Roland Wester — 1Physikalisches Institut, Universität Freiburg, Germany — 2Physikalisches Institut, Universität Innsbruck, Austria — 3Physikalisches Institut, Universität 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 highly 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 \( \text{Rb} \) 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 \( \text{OH}^-+\text{Rb} \rightarrow \text{OH}^-+\text{Rb}+\text{E}_{\text{kink}} \), 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 Schmidt 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 \( \text{H}_2 \) at low temperatures — Stephanie Eisenbach, Rico Otto, Alexander von Zastrow, Thorsten Best, and Roland Wester — 1Physikalisches Institut, Universität Freiburg, Hermann-Herder-Str. 3, 79104 Freiburg — 2Institut 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. \( \text{F}+\text{H}_2 \). Another example may be the isotope exchange reaction \( \text{D}^-+\text{H}_2 \rightarrow \text{H}^-+\text{HD} \), with a reaction barrier height of 330 meV. This reaction can proceed over the barrier at high kinetic energies of the reactants [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−D2 is derived.


Q 37.6 Wed 17:45 BAR Schön
Reactive Scattering with cold Molecules out of a RF Multi-polar Ion Trap — Jonathan Bron1, Rico Ott1, Sebastian Trippel1, Martin Steiß2, Thorsten Best2, and Roland Waster2
— 1Physikalisches Institut, Universität Freiburg, Hermann-Herder-Str. 3. 79104 Freiburg — 2Institut f. Ionenphysik ang und Gewandeh 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 multipolar 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 CH3 for relative 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. Engler, Manuel Mihelen, Christian Sommer, Josef Bayrl, 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 divided 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.


Q 38: Ultra-cold atoms, ions and BEC IV

Time: Wednesday 16:30–18:00

Q 38.1 Wed 16:30 BAR 205
Quantum dynamics of strongly interacting bosonic mixture. — Budhaditya Chatterjee1, Ioannis Bouzios2, and Peter Schmelcher2
— 1Physikalisches Institut, Universität Heidelberg, Philosophenweg 12, 69120 Heidelberg, Germany — 2Zentrum 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 intra-species repulsion elongates the tunneling period for small inter-species correlations.

Q 38.2 Wed 16:45 BAR 205
Atomic homodyne detection of two mode squeezed states — Helmut Strobel, Christian Gross, Eike Nicklas, Tilman Zielold, Jiri Tomkovic, and Markus K. Oberthaler — Kirchhoff Institut 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, 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 23Na and 6Li. 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.


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 available 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 Zenischi1, Martin Berninger2, Bo Huang1,2, Stephan Bessler1, Hans-Christian Nöckel1, Francesca Ferlaino1, and Rudolf Grimm1,2 — 1Institut für Experimentalphysik, Universität Innsbruck, 6020 Innsbruck, Austria — 2Institut 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 well-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

Q 38.6 Wed 17:45 BAR 205
Structural Defects in Ion Chains by Quenching the External Potential: The Inhomogeneous Kibble-Zurek Mechanism —
GIOVANNA MORGIO, ADOLFO DEL CAMPO1, GABRIELE DI CHIARA3, MARTIN PLENIO1, and ALEX RETZKE2 — 1Universitaet Ulm, Ulm, Germany — 2Universität des Saarlandes, Saarbrücken, Germany — 3Universitat 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

Q 39.1 Wed 16:30 TOE 317
Direct mid-infrared femtosecond pulse shaping with a calomel acusto-optic programmable dispersive filter — PATRICK NUEBENBERGER1,2, RAZAN MAHDI1, JIEREN LI1, ADAM HARTMANN1, and TAIKAI RUI2 — 1Laboratoire d’Optique et Bio-sciences, Ecole Polytechnique, CNRS UMR 7645, INSERM U696, 91128 Palaiseau, France — 2Laboratoire de Physique des Milieux Complexes, Université Paris-Sud, Bât. 503, 91401 Orsay, France

Direct mid-infrared femtosecond pulses are 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 — REINE COTTARD, CHRISTIAN GRAU, ERIK T. NIBERG, 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, allows 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 temporal separation or alternately chirped pulses. We fully characterize the amplitude and phase of these shaped 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 — STEPHAN RUETZL1, ANJA KRISCHKE1, TOBIAS BRINNEN1, and DAVID J. TANNOR2 — 1Institut für Physikalische und Theoretische Chemie, Universität Würzburg, Am Hubland, 97074 Würzburg — 2Department 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 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 Electronic Dynamics in K2 — TIM BAYER, HENDRIKE BRAUN, CRISTIAN SARPE, MATTHIAS WOLLENHaupt, and THOMAS BAUMERT — University of Kassel, Institute of Physics and CINaSIt, D-34132 Kassel, Germany

The strong-field control mechanism SPODS (Selective Population of Dressed States) has been demonstrated on atoms using variously shaped femtosecond laser pulses [1,2,3]. The possibility of SPODS to the coherent control of molecules and chemical reactions was pointed out by wave packet calculations on K2 [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 nuclear 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.


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 VIJVER-RIEDER — 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 dimension of the control IR-pulse.


Q 39.6 Wed 17:45 TOE 317 Efficient and robust strong-field control of population transfer 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 CINaSät, 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 combinatorially.

Q 40.0 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 Salger¹, Sebastian Kling², Sergey Denisov², Alexey Ponomarev², Peter Hänggi², and Martin Weitz¹ — ¹Institut für Angewandte Physik, Wegelerstraße 8, 53115 Bonn — ²Institut für Physik, Universitätsstrasße 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 paradoxical situation, when the motion of a particle is always in opposite 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.


Q 40.2 Wed 16:45 HSZ 02 Direct observation of quasi-local relaxation with strongly correlated bosons in an optical lattice — Stefan Trotzky¹,²,³, Yau-Ao Chien¹,²,³, Andreas Fleisch¹, Ian P. McCulloch⁵, Ulrich Schollwöck⁶, Jens Eisert⁶, and Immanuel Bloch¹,²,³ — ¹Ludwig-Maximilians Universität München — ²MPI für Quantenoptik, Garching — ³Johannes-Gutenber Universität Mainz — ⁴Forschungszentrum Jülich — ⁵University of Queensland — ⁶Institute for Advanced Study, Princeton University.

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 Luschi¹, Benjamin Diebler⁴, Luca Tanzi⁵, Chiara D’Errico¹, Giacomo Roati¹, Matteo Zaccanti¹,², Michele Modugno¹,³, Massimo Inguscio¹, and Giovanni Modugno¹ — ¹LENS and Università di Firenze, and CNR-INO, Italy — ²Institut für Quantenoptik und Quanteninformation, Innsbruck, Austria — ³IKERBASQUE, 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 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 $\sigma$ 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 temperature.

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 Universität Freiburg, Hermann-Heerder-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.


Q 40.5 Wed 17:30 HSZ 02

Interaction-based reduction of weak localization in coherent transport of Bose Einstein Condensates — Jörg Michel, Timo Hartmann, Juan Diego Urbina, Cyril Petitetian, Thomas Wellens, Peter Schlagheck, and Klaus Richter

— 1Institut für Theoretische Physik, University of Regensburg, Germany
2SPSMS-INAC-CEA, Grenoble, France — 3Physics Department, University of Fribourg, Switzerland — 4Physics 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

Andersen orthogonality catastrophe in ultracold quantum gases — Daniel Kotkin, Martina Hentschel, and Walter Strunz

— 1Max-Planck-Institut für Physik komplexer Systeme, Nöthnitzer Straße 83, 01187 Dresden — 2Institut 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-temporally modulated 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

Q 41.1 Wed 16:30 HÜL 386

Frequency standard based on the octupole transition in \(^{171}\text{Yb}^+\) — Nils Huntzemann, Maxim Orkhapkin, Burkhard Lippich, Stefan Weyers, Christian Tamm, and Eckhard 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 \(2S_{1/2}(F = 0) \rightarrow 2P_{3/2}(F = 3)\) of a single trapped laser-cooled \(^{171}\text{Yb}^+\) ion at 467 nm.

In comparison with a previously realized optical frequency standard in \(^{171}\text{Yb}^+\) [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 \(\alpha\).

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 \(^{87}\text{Sr}\) — Stephan Falke, Thomas Middelmann, Fritz Rheinle, Uwe Stern, and Christian Lisdat

— Physikalisch-Technische Bundesanstalt (PTB), Bundesallee 100, 38116 Braunschweig, Germany

We present an absolute frequency measurement of the Sa \(^{2}1\,S_0 \rightarrow 5\,S_{0} + 3\,F_{3/2}\) transition of \(^{87}\text{Sr}\) 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 determined 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 \(3 \times 10^{-15}\) 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. Wubbena, Jan Freibe, Matthias Riedmann, Hrishikesh Kelkar, Steffen Röhmann, Dominika Fim, Klaus H. Zippel, Wolfgang Etter, 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 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 \(^{3}S_{0} - ^{3}P_{1}\) using a Ramsey-Bordé interferometer geometry.

We trap the bosonic isotopic \(^{24}\text{Mg}\) 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 \(\mu\)K 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-
Quantum Optics and Photonics Division (Q) Wednesday


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 radius charge. 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 (ΔF = 1, Δm_F = ±1) transitions as a diagnostic tool for atomic fountain clocks — Nils Nemitz, Vladislav Gerginov, Stefan Wevers, and Robert Wynands — Physikalisch-Technische Bundesanstalt, Braunschweig

Atomic cesium fountain clocks provide the most accurate realization of the SI second by making use of the |F = 3, m_F = 0⟩ to |F = 4, m_F = 0⟩ 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 Δm = ±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 — Oscar-Andrey Herrera-Sancho, Maxim Okhapkin, Kai Zimmermann, Alexey Taichenachenkov, Valeriy Yudin, Christian Tammi, and ErkkaRaid Pelg — Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig, Germany — Institute of Laser Physics, Siberian Branch of RAS, Novosibirsk 630090, Russia

In our experiment more than 10^5 232Th^+ 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 609.9 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 TiSa 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 232Th are in progress.

Q 42: Laserentwicklung: Festkörperlaser 3

Time: Wednesday 16:30-17:45

Q 42.1 Wed 16:30 SCH 251 Optische Verstärkung in Er^{3+}:Y_{2}O_{3}:Rippenwellenleitern — Jonathan Thielmann, Sebastian Heinrich, Klaus Petermann, and Günter Hüber — Institut für Laserphysik, Universität Hamburg

The dipole polarizability of Er^{3+}:Y_{2}O_{3} is high in the near infrared. This makes Er^{3+}:Y_{2}O_{3} an interesting candidate for optical amplifiers. The use of planar waveguides as well as fiber-like waveguides such as etched capillary fibers and extended cavity diode lasers is planned.

Q 42.2 Wed 16:45 SCH 251 Erzeugung von 7 \mu J Pulselnergie mit einem Zwei-Kristall Yb:KYW-Oszillator mit Cavity-Dumping — Guido Palmer, Moritz Emmons, Marcel Schultz, and Uwe Morgen — Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover — 2 Laser Zentrum Hannover, Hollerithalle 6, 30419 Hannover


Q 42.3 Wed 17:00 SCH 251 Development of an all semiconductor laser system for ultrashort pulse generation — Jan C. Balzer, Thorsten Schulte, Andreas Klenke, Götz Eberle, Günter Tränkle, and Martin R. Hoffmann — 1 Chair for Photonics and Terahertz Technology, Building ID 0/327, 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 diode laser system based on a Yb:YVO_{4} rod-type-Faser is in operation.

Um dies zu realisieren, wurde ein Multiwellenlängenlaser aufgebaut. Die inkoherente 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 4 „Emittern“ wurde mit SBC eine Ausgangsleistung von \( \approx 400 \text{ mW} \) und eine spektrale Bandbreite von \( \pm 25 \text{ nm} \) realisiert. Der Einfluss der Bandbreite auf den Specklekontrast wurde bei verschiedenen Betriebsparametern untersucht.

Q 42.5 Wed 17:30 SCH 251 UV-Strahlquelle mittels Frequenzverfachung eines Faser verstärkers

Q 43: Laseranwendungen und Photonik 2

Time: Wednesday 16:30–17:30


Technische Universität Berlin, Institut für Optik und Atomare Physik, Berlin, Germany — Technische Hochschule Wildau, Institut für Plasma- und Lasertechnik, Wildau, Germany

1D-photonic crystal halflm Fabry–Pr{\text{e}}rot 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 half-Ke diameter, cavity length, and mirror reflectivity was produced and investigated. Q-factors of up to 1500 could be observed around 1550 nm wavelength with an insertion loss of 3 \text{ dB}. The results will be discussed and compared and simulated.

Q 43.2 Wed 16:45 SCH A118 Single optical microfibre interferometer — • Konstantin Karapetian, Wolfgang Alt, Fabian Bruse, and Dietmar Meschede — Instituto 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 combiner, 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

Q 43.4 Wed 17:15 SCH A118 Tunable thin film Fabry–Pr{\text{e}}rot filters directly coated on the end-faces of optical fibers — • David Schweda, D., Stefan Meister, S., Marcus Dzieziska, R., Ronny Juhr, R., Stefan Prokr, S., Manfred Eich, M. and Hans J. Eichler, H. — Technische Universität Hannover, Institut für Optik und Atomare Physik, Hannover, Germany

Thin film Fabry–Pr{\text{e}}rot 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–Pr{\text{e}}rot 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 1550 nm.
Quantum Optics and Photonics Division (Q)

Thursday

Q 44.4 Thu 11:30 HSZ 02
Realization of photonic crystal microcavities in single crystal diamond — •Janine Riedrich-Möller1, Laura Kipfstuhl2, Christian Hepp3, Martin Fischer2, Stephan Gsell2, Matthias Schreck2, and Christoph Becher2 — 1Universität des Saarlandes, Fachrichtung 7.2 (Experimentalphysik), Campus E2.6, 66123 Saarbrücken — 2Universität 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 high-efficient emitters and control of spontaneous emission. Such photonic crystal microcavities offer the possibility to fabricate single color centers with extraordinary properties by coupling color centers to micro-cavities e.g. fiber-based or photonic crystal cavities.


Q 44.3 Thu 11:15 HSZ 02

Q 44.6 Thu 12:00 HSZ 02
Deterministic Coupling of Individual Quantum Systems to Photonic Crystal Structures — •Janie Wouters3, •Andreas W. Schell1, Günter Kwei1, Nils Nöske2, Max Schoenges2, Bernd Löchel1, Michael Barth1, and Oliver Benson2 — 1Nano-Optics, Institute of Physics, Humboldt-Universität zu Berlin, Newtonstr. 15, 12489 Berlin — 2Operator Centre Microtechnology, Helmholtz-Centre for Materials and Energy, Albert-Einstein-Straße 15, 12489 Berlin

The controlled and scalable coupling of single quantum emitters to resolve the photon number. Additional measurements were performed by on/off-statistics using avalanche photodetection assisted by a maximum likelihood estimation. From a photon 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 44.2 Thu 11:00 HSZ 02
Quantum Light from a Whispering Gallery Resonator — •Josef Först1, Dmitry Strekalov2, Dominique Elsen1, Ulrik L. Andersen1,3,4, Andrea Aibello1, Christoph Marquardt1, and Gerhard Leuchs5 — 1Max Planck Institute for the Science of Light, Nuremberg, Germany — 2Jet Propulsion Laboratory, California Institute of Technology, Pasadena, USA — 3Department of Physics, Technical University of Denmark, Kgs. Lyngby, Denmark

Optical subharmonic generation, also referred to as parametric downconversion (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 non-linear 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 Nio- bate, we were able to show extremely efficient PDC in our WGM OPO. As the signal and idler photon pair are emitted on anti-symmetric modes 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.


Q 44.1 Thu 10:30 HSZ 02
Solid state single photon sources based on color centers in diamond — •Elke Neel1, David Stemme2, Christian Hepp3, Janine Riedrich-Möller1, Roland Albrecht1, Jan Meijer4, Martin Fischer3, Stefan Gsell3, Matthias Schreck3, and Christoph Becher2 — 1Universität des Saarlandes, FR 7.2 Experimentalphysik, D-66123 Saarbrücken — 2RUBION, Ruhr-Universität Bochum, D-44780 Bochum — 3Universität 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 perform detailed spectroscopy investigating level structures, polarization and the influence of spectral diffusion. We use this information to fabricate strongly coupled quantum systems by coupling color centers to micro-cavities e.g. fiber-based or photonic crystal cavities.


Q 44.5 Thu 11:05 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 high-Q resonant cavity (Q≈24000), leading to a coupling strength of $g \approx 150 \mu$eV. 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 classically linking 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 strongly-coupled system are analysed in a standard Hanbury-Brown-Twiss correlation setup. Due to the fast decay dynamics of the quantum dot we additio
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 — •Center Kowes, Andreas Schell, Thomas Aschele, and Oliver Benson — Humboldt-Universität zu Berlin, Institut für Physik, Nanoptik 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 nanooantenna. The NV centres were systematically rearranged through AFM nanomanipulation around the nanooantenna, 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, Markus Raupach, Christian Schneider, Martin Furst, Sebastian Nauerth, Matthias Lehmkühler, Henning Weier, Stephan Reitzenstein, Sven Höfling, Martin Kamp, Harald Weinfurter, and Alfred Forchel — Technische Physik und Wilhelm Conrad Röntgen Research Center for Complex Material Systems, Universität Würzburg, Am Hubland, 97074 Würzburg, Germany — 2Fakultät für Physik, Ludwig-Maximilians-Universität, 80799 Munich, Germany — 3qutools GmbH, 80529 Munich, Germany — 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 $\varphi(2,0)$-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 $10^{-5}$.


Q 45: Precision Measurement and Metrology 2

Time: Thursday 10:30–13:00

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 0.001 Hz und 1 Hz messen. Wichtige Teile der Laserinterferometrie

Q 45.2 Thu 11:00 HÜL 386 Realistic Test of a Transportable 1 Hz-Linewidth Laser — •Stephan Vogt, Christian Lisdam, Thomas Legiero, Sebastian Härnes, Uwe Sterr, Ingo Ernsting, Alexander Nesvros, and Stephan Schiller — 1Physikalisch-Technische Bundesanstalt (PTB), Bundesallee 100, 38116 Braunschweig, Germany — 2Institut 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 best microwave clocks. So far these clocks have been only available in

Q 45.3 Thu 11:15 HÜL 386 Development of a cryogenic sub-Hz laser system for optical clocks — •Christian Hagemann, Thomas Kessler, Thomas Legiero, Uwe Sterr, Fritz Riehle, Michael J. Martin, and Jun Ye — 1Physikalisch-Technische Bundesanstalt (PTB) and Centre for Quantum Engineering and Space-Time Research (QUEST), Bundesallee 100, 38116 Braunschweig, Germany — 2JILA, 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 system 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 $10^{-15}$ ($1 \sigma$) 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*, Bernhard Grotz*, Gopalakrishnan Balasubramanian†, Julia Tisel*, Eike Oliver Schäpers-Noltel‡, Markus Ternes*, Florian Rempe*, Klaus Kern*, Fedor Jelezko*, and Jörg Wrachtrup†

1 Universität Stuttgart, 2 Physikalisches Institut, 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 $1 \text{kHz}$ wide and accessible to 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 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


1 Max-Planck-Institut für Gravitationsphysik, 2 Max-Planck-Institut für biophysikalische Chemie, 3 Leibniz Universität Hannover, 4 Waseda University, 5 California Institute of Technology, 6 University of Glasgow, 7 Gi2 8QQ, UK

The AEL 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 $10^{-14}$ Hz/$\sqrt{\text{Hz}}$ at $20 \text{Hz}$ dropping to below $10^{-15}$ Hz/$\sqrt{\text{Hz}}$ at $1 \text{kHz}$. For this purpose we have designed a $\sim 20 \text{Hz}$ round-trip optical cavity with each mirror individually suspended from a triple cascaded pendulum system. 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*, Tiilo Steinmetz†, Rafael Probst†, Ronald Holzwarth‡, Theodor W. Hänsch†, and Thomas Udem†

1 Max-Planck-Institut für Quantenoptik, 2 Garching, 3 Menlosystems GmbH, Martinsried

High precision spectroscopy in astronomy is at present limited by the available calibration sources. Frequency combs 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 (FCPs) to have a mode spacing of $> 10 \text{GHz}$. After frequency doubling the comb, $\sim 6 \text{nm}$ 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.

Q 45.7 Thu 12:15 HÜL 386

High-präzise Frequenzmetrologie über Glasfasernetzwerke — *Katharina Friedebühl*, Ronald Holzwarth, Thomas Udem, Theodor W. Hänsch, Osama Tekra, Gesine Gösche und Harald Schnatz†

1 Max-Planck-Institut für Quantenoptik, Garching — 2 Physikalisch-Technische Bundesanstalt, Braunschweig


Q 45.8 Thu 12:30 HÜL 386

**Status of the development of LISA Pathfinder** — *Jens Reich, Antonio Francisco García Maren*, Heather Audley*, Gerhard Heinzel* und Karsten Danzmann*

1 Max-Planck-Institut für 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 microwrnothn 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 Legiero*, Thomas Kessler*, Christian Hagemeier, Gesine Gösche, and Harald Schnatz† — Physikalisches-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 metrology, 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 cavity and the electronics package fits into a 19-inch rack system with a base of 60 x 60 cm$^2$ and a height of 1.50 m. Its short term stability of a few times $10^{-15}$ allows a variety of applications where a mobile highly stable reference frequency is required.

Supersolid Phase of Cold Fermionic Polar Molecules in 2D Optical Lattices — •LIANG HE and WALTERS 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 40K87Rb [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.


Fermi-Hubbard physics with ultracold fermions in optical lattices — •DANIEL GREIF, LETICIA TARHUELL, THOMAS UEHLINGER, GREGOR JOZUTZI, and TILMAN ESBLINGER — 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 remain 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.

Generalized Hartree-Fock Theory for Interacting Fermions in Lattices: Numerical Methods — •CHRISTINA KRAUS and IGNACIO CISAC — 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 at finite temperature, and out of equilibrium. Specifically, we show how to determine the theory for fermionic systems in lattices, both in thermal equilibrium and out of equilibrium. We present numerical methods to solve the Generalized Hartree-Fock theory for interacting fermions in lattices, both in thermal equilibrium and out of equilibrium. We report on recent progress of creation and characterization of low entropy states in the lattice.

Quantum-noise quenching in quantum tweezers — •STEFANO ZIPPOLI1,2,3, BERND MOHRING1, ERIC LUTZ5, GIOVANNA MORIGI1,2, and WOLFGANG SCHLEICHER4 — 1Département de Physique, Université Autonoma de Barcelona, E-08193 Bellaterra, Spain — 2Theoretische Physik, Universität des Saarlandes, D-66041 Saarbrücken, Germany — 3Fachbereich Physik und research center OPTIMAS, Technische Universität Kaiserslautern, D-67663 Kaiserslautern, Germany — 4Institut für Quantenphysik, Universität Ulm, D-89081 Ulm, Germany — 5Department of Physics, University of Augsburg, D-86135 Augsburg, Germany

The efficiency of extracting single atoms or molecules from an ultra-cold bosonic reservoir is theoretically investigated for a protocol based on lasers, coupling the hyperfine state in which the atoms form a condensed state 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 tweezers traps for neutral atoms.

Definite angular momentum and fragmentation in 3D attractive BECs — •MARIOS C. TSATSOS1, ALXÈRE I. SYRKESTO2, OFIR E. ALON1,2, and LORENZ S. CEDERHAUS3 — 1Theoretische Chemie, Physikalisch-Chemisches Institut, Universität Heidelberg, Im Neuenheimer Feld 229, D-69120 Heidelberg, Germany — 2Department 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 do not exceed some critical values. Otherwise the system collapses. The Gross-Pitaevskii (GP) theory predicts the maximum (critical) number of bosons Nc GP that, for a given λ, 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 Nc GP .

Continuous Loading of a Conservative Trap from an Atomic Fountain — •MAX FALKENAU1, VALENTIN VOLCHKOV1, JAHN RÜHRIG1, AXEL GRIESMÄRKE1,2, and TILMAN PPAU1,3,4,5 — 1Physikalisches Institut, Universität Stuttgart, Germany — 2Niels-Bohr Institute, Copenhagen, Denmark

We present results on the fast accumulation of 52Cr 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 2·107 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.

Novel magnetic trap design for ultra-cold metastable helium atoms with large optical access — •FRANZ SIEVERS, JULIETTE SIMONET, SANJUKTA ROY, JÉRÔME BEUGNON, MICHELLE LEDUC, and CLAUDE COHEN-TANNoudji — Laboratoire Kastler Brossel, École Normale Supérieure, 24 rue Lhomond, 75231 Paris, France

We present the design of a modified Cleverleaf-type Ioffe-Pritchard trap for Bose-Einstein condensation of ultra-cold atoms, compatible with sit in 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 on the trap design, as well as the electrical 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.

Gauge fields for ultra-cold Ytterbium atoms — •SEBASTIAN KRINNER1,2, FABRICE GERBIÈRE1, JÉRÔME BEUGNON1, and JEAN DALIBARD1 — 1Laboratoire Kastler Brossel, 24 rue Lhomond, 75005 Paris, France — 2Institute for Quantum Electronics, ETH Zürich, Hönggerberg, CH-8093 Zürich, Switzerland

Cold atoms in optical lattices can serve as model systems for condensed...
Radiofrequency spectroscopy of a strongly interacting two-lasers.

1.2W corresponds to 80% efficiency and suggests an alternative to dye via the technique of second-harmonic generation. As a showcase I will intercombination line at 556nm. Both laser wavelengths are produced at 399nm and subsequent magneto-optical trapping using the green square lattice.

Quantum Optics and Photonics Division (Q) Thursday jamin P. Lanyon

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

Digital quantum simulation with trapped ions — BENJAMIN P. LANYON1,2, CORNELIUS HEMPEL1,2, MARKUS MÜLLER1,3, FLORIAN ZÄHRINGER1,2, MARKUS RAMBACH2, RENÉ GERRITSMAN1, PHILIPP SCHINDLER2, DANIEL NIGG2, JULIO T. BARREIRO2, MARKUS HENNRIKUS2, RAFFAEL BLATT1,2, and CHRISTIAN F. ROOS1 — Institut für Quantenoptik und Quanteninformation, Österreichische Akademie der Wissenschaften, Technikerstr. 21a, 6020 Innsbruck, Austria — 2Institut für Experimentalphysik, Universität Innsbruck, Technikerstr. 25, 6020 Innsbruck, Austria — 3Institut für Theoretische Physik, Universität Innsbruck, Technikerstr. 25, 6020 Innsbruck, Austria

A universal quantum simulator is a 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 calculable 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).

Quantum memories based on engineered dissipation — FERNANDO PASTAWSKI, LUCA 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.

Deterministic entanglement of ions in separate traps — MAXIMILIAN HARLANDER1, REGINA LECHNER1, MICHAEL BROWNNUDD1, WOLFGANG HÄNSEL1,2, and RAFFAEL BLATT1,2 — 1Institut für Experimentalphysik, Universität Innsbruck — 2Institut für Quantenoptik 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 Zoller 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 necessary 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 μm. This enables possible schemes to provide entangling gates between two trapping zones, using a Mølmer-Sørensen type interaction.

Coherent Photon Conversion enabling Nonlinear Optical Quantum Computing — NATHAN K. LANGFORD1,2, SVEN RAMOELO1,2, ROBERT PREVEDEL1,2, WILLIAM J. MUNRO1,2, GERARD J. MILBURN1, and ANTON ZEILINGER1,2 — 1University of Vienna, Austria — 2IQOQI Vienna, ÖAW, Austria — 3NTT Laboratories, Japan — 4University of Queensland, Australia

Photonics 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 scalable 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 χ(3) interaction inducing an effective χ(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 undergoing 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.

Scalable Architecture for a Room Temperature Solid-State Quantum Computer — J. MILBURN1, R. DEVONSHIRE1, R. BLATT1,2, and S. LLOYD3 — 1Max-Planck-Institut für Quantenoptik Hans-Kopfermann-Str. 1 D-85748 Garching, Germany — 2Department of Physics, University of Innsbruck, Technikerstr. 25, 6020 Innsbruck, Austria — 3University of Queensland, Australia

Large coordination number expansion for a lattice Bose gas — PATRICK NAVÉZ1, RALF SCHÜTZHOILD2, and KONSTANTIN KRUTITSKY1 — 1Institut für Theoretische Physik, TU Dresden, D-01062 Dresden, Germany — 2Fakultät 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 1/2 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 Guttrailer mean field approach which 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.
Quantum Optics and Photonics Division (Q) Thursday

Q 47.6 Thu 11:45 BAR Schön
Controlling qubit arrays with XW Hamiltonians by acting on a single qubit — Vladimir M. Stojanovic1, Rahul Heule3, Christoph Bruder1, and Daniel Burgarth1
1Department of Physics, University of Basel, Switzerland — 2Institute 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-class qubit arrays.

Q 47.7 Thu 12:00 BAR Schön
Continuous-variable quantum logic gate decompositions — Seckin Sepl 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.

Q 47.8 Thu 12:15 BAR Schön
Holonomic quantum computing using symmetry-protected topological order — Joseph M. Renes1, Akimasa Miyake2, Gavin K. Brennen3, and Stephen D. Bartlett4 — 1TU Darmstadt, Darmstadt, Germany — 2Perimeter Institute, Waterloo, Canada — 3Macquarie University, Sydney, Australia — 4University 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 de-generated 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 would be feasible to 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 computer, 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

Q 48.1 Thu 10:30 SCH 251
Charge exchange reactions between a single 138Ba+ ion and an ultracold sample of neutral 87Rb atoms — Anne Härter, Arjoun Krickow, Stefan Schmid, Wolfgang Schnitzler, and Johannes Hecker Denschlag — Universität Ulm, Institut für Quantenoptik und Quanteninformation, Albertstr. 13/15, 89069 Ulm, Germany
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 138Ba+ ion with an optically confined atomic sample of 87Rb 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 Ba+ + Rb → Ba + 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].

Q 48.2 Thu 10:45 SCH 251
Dipolar Bose-Einstein Condensates with Weak Disorder — Christian Krumnow1 and Axel Pelster2 — 1Institut für Theoretische Physik, Freie Universität Berlin, Arnimallee 14, 14195 Berlin, Germany — 2Fachbereich 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 tem-
perature. For a small dipolar interaction the superfluid depletion for a motion parallel or perpendicular to the dipoles is larger than the condensate depletion due to the interaction 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].


Q 48.3 Thu 11:00 SCH 251

Nonlocal quantum superposition states via scattering of a bright quantum matter wave soliton

[Bettina Gert-Jerken 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.


Q 48.4 Thu 11:15 SCH 254

Homogeneous Bose-Einstein Condensate with Weak Disorder

[Vladimir Lukovic1, Anton Balaz1, and Axel Pelster2 — 1Scientific Computing Laboratory, Institute of Physics Belgrade, University of Belgrade, Pregrevica 118, 11080 Belgrade, Serbia — 2Fachbereich 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.


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, Germany]

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, Germany]

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, Germany]

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

Q 49.1 Thu 10:30 SCH A215

Interferometrically readout micro tuning forks applied in photoacoustic spectroscopy

[Michael Köhring1, Martin Angelmark2, and Wolfgang Schade2 — 1Fraunhofer Heinrich Hertz Institute, Am Stollen 19, 38640 Goslar — 2Clausthal University of Technology, Institut für Energieforschung und Physikalische Technologie, 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,
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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 PENZKOGER — Fakultät für Physik, Universität Regensburg, Universitätstrasse 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 (LF+ ≈ 0.8 eV, pKa ≈ 0.8) via neutral (LF0) to anionic (LF−) at high pH (pKa ≈ 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+ is nearly non-fluorescent (\( \phi_F = 5 \times 10^{-5} \)).

In the ground state a pH dependent thermodynamic equilibrium of cationic, neutral and anionic lumiflavin exists by reaction with H2O, H3O+ 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 intramolecular photo-induced proton transfer from H2O+ to LFH+. At high pH no photo-induced intermolecular proton transfer takes place.

Q 49.3 Thu 11:00 SCH A215 Laser Raman Spectroskopie an Tritium für KATRIN — SEBASTIAN FISCHER — für die KATRIN Kollaboration, Karlsruher Institut für Technologie, ITEP - Tritiumlabor, Karlsruhe, Deutschland

Das Karlsruher TRITium Neutrin-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 Triticumquelle und ein elektrostatisches Spektrometer.

Zum Erreichen der Sensitivität von 0,2 eV c−2 (90% CL) ist es erforderlich, die Tritiumkonzentration im Gedeck technischübersprüht von 10 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 Swansea (Wales) entwickelt wurde. Für Wasserstoff-Isotopologe (T2, HT, DT, H2, D2, HD) wird innerhalb von 100 s Meszeit die erforderliche Präzision von 0,1 % und eine Nachweisgröße (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 BMWF unter Förderkennzeichen 05A08VK2 und von der DFG im Sonderforschungsbereich SFB/Transregio 27 „Neutrinos and Beyond“


Q 49.4 Thu 11:15 SCH A215 Direction-selective optical limiting in bi-layer glass-metal nanocomposites — SABITHA MOHAN and GERHARD SEIFERT — Physik Institute, Martin-Luther-Universität Halle-Wittenberg, von-Danneelmann-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 \( \lambda = 800 \text{nm} \), pulse duration \( \tau = 80 \text{fs} \), repetition rate 1kHz) as excitation source. This wavelength is suited for two-photon absorption by the Ag nanoparticle’s surface Plasma 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 was excited 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, where the modelled intensity induced nonlinear absorption of 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 BOTTGER1, ULRIKE WILKER1, MARTIN ANGELMAIER2, and WOLFGANG SCHADE1,2 — 1Clausthal University of Technology, Energie- Forschungszentrum Niedersachsen, EnergieCampus, Am Stollen 19, 38640 Goslar — 2Fraunhofer 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 and 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 demands 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 light power 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 CZEWINSKI, KATHRIN HEINRICH, MARCUS SOWA and PETER HERING — Institut für Lasermedizin, Universitätsklinikum Düsseldorf, Universitätsstr. 1, 40225 Düsseldorf

Die Cavity-Leak-Out-Spektroskopie (COALS) ist eine ausgezeichnete Methode für die isotopenselektive Analyse von Spurengasen. COALS ist eine Weiterentwicklung der Absorptionspektroskopie, wobei mit Hilfe eines optischen Resonators die Wechselwirkungstrecke zwischen Laserlicht und absorbierendem Medium verlängert wird, um die Nachweisgrenze zu verbessern. Bei der Messung 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 51s - ohne auf 109s - mit Temperaturstabilisierung erreicht. Die minimale rauschäquivalente Absorption konnte von 1,61·10−10 cm−1 auf 1,03·10−10 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 KWER, CHRISTINA BOGAN, TORAS MEIER, JAN PÖLD, BENNO WILKEL und KARSTEN DANZMANN — Albert-Einstein-Institut Hannover

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% TEM00 Mode, relativen Leistungsdfluktuationen von $10^{-4}$ Hz$^{-1/2}$, relativen Strahlagefluktuationen von $10^{-5}$ Hz$^{-1/2}$ und Frequenzfluktuationen im Bereich $10$ Hz$^{-1/2}$. Eine Charakterisierung dieses Lasersystems sowie weiterführende Laserstabilisierungs- und Hochleistungs-Frequenzverdopplungsperimente 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 Hewittson, Gerhard Heinzel, and Karsten Danzmann - Max-Planck Institut für Gravitationsphysik (Albert-Einstein Institut) Hannover und QUEST, Leibniz Universität Hannover, Callinstraße 36, 30167 Hannover

LISA Pathfinder ist die technologie demonstration space mission für 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 photometer 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, Timmy James, Richard Lewis, Helmut Telle - für die KATRIN Kollaboration, Karlsruher Institut für Technologie, ITEP - Tritiumlabor, Karlsruhe, Deutschland - 2University of Swansea, Wales, UK

Ramanspektroskopie eignet sich als Methode zur Inline-Bestimmung der Tritiumreinheit in Gasen aus Wasserstoffisotopologen ($T_2$, $D_2$, $H_2$, $HD$, $H_2O$) in Anwendungen am Brennstoffkraftstoffkreislauf eines Fusionsreaktors (wie ITER) oder in Tritium-Neutronmassenexperimenten (wie KATRIN). Auf Grund des starken Isotopieeffekts der Wasserstoffisotopologen sind die reinen Vibrationsanregungen deutlich von einander getrennt und eignen sich somit zur quantitativen Analyse von Gasmischungen.


Gefördert vom MBF unter Förderkennzeichen 05A08VK2 und von der DFG im SFB/Transregio 27 "Neutinos and Beyond".

Q 49.10 Thu 12:45 SCH A215
Aufbau einer Anlage zur Herstellung von optischen Faserkomponenten mittels eines CO2-Laser
- Felix Wichmann, Thomas Theeg, Hendrik Gerber, Katharina Hausmann, Hakon Sayin, Lars Richter, Jörg Neumann, Dietmar Kracht

Laser Zentrum Hannover e.V., Hollerithallee 8, 30419 Hannover, 4Centre for Quantum Engineering and Space-Time Research (QUEST), Wellegarten 1, 30167 Hannover

In faserbasierten Lasersystemen werden hohe optische Leistungen innerhalb kleiner Faserkerndurchmesser geführt. Die dabei auftretenden Intensitäten können zur Zerstörung der Endfläche oder der gesamten Faser führen. Mit Hilfe angespitzter 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.


Q 50: Quantum Effects: Entanglement and Decoherence

Time: Thursday 10:30–13:00

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, Hans J. Briegel, Sanjay Reddy Popescu, Hendrik Briegel - 1Institut für Theoretische Physik, Universität Innsbruck, Austria - 2Institut für Quantenoptik und Quanteninformation, Österreichische Akademie der Wissenschaften, Innsbruck, Austria - 3H. Wills Physics Laboratory, University of Bristol, U.K. - 4Hewlett-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 coherence 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, Alexander Wolf, Gabriel De Chiara, Eric Lutz, and Giovanna Morici - 1Theoretische Physik, Universität des Saarlandes, D-66041 Saarbrücken, Germany - 2Institut für Quantenphysik, Universität Ulm, D-89089 Ulm, Germany - 3Grup de Física Teòrica, Departament de Física, Universitat Autònoma de Barcelona, E-08193 Bellaterra, Spain - 4Department of Physics, University of Augsburg, D-86135 Augsburg, Germany - 5Grup d’Optica, 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.


Q 50.3 Thu 11:00 SCH A01
Effects of retardation on sudden death and revival of entanglement
- Qurat ul-ain, Zbigniew Ficek, and Jörg Evers

- 1Max-Planck-Institut für Kernphysik, Heidelberg, Germany - 2The 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 identify 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.


Q 50.4 Thu 11:15 SCH A01
Unconditional Preparation of Bound Entanglement — •AKI SAMBLOWSKI, JAMES DIGUGLIELMO, BORIS HAGE, CARLOS PINEDA, JENS EISERT, and ROMAN SCHNABEL — Institut für Quantenoptik und Quanteninformation, Innsbruck, Austria

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.

The possibility of unconditional preparation of a bound entangled state of light 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.

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.


Q 50.7 Thu 12:00 SCH A01
Environment-assisted entanglement in a Penning trap — •MICHAEL GENKIN and ALEXANDER EISEFELD — 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 the observation of entanglement at higher temperatures; In this context, we also briefly address the interplay with decoherence which is known to grow with increasing temperature.
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.


**Q 51: Ultracold Atoms: Trapping and Cooling 1**

**Location:** SCH A118

**Morgan — 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 51.6 Thu 15:45 SCH A118**


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].


**Trapping ions with lasers — Cecilia Cormick und Giovanna Morigi**

We present the measurement of the AC-Stark shift of the field for the Bose enhancement [1].

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Trapping ions with lasers around two-photon resonance [2].

Quantum Optics and Photonics Division (Q) Thursday

We consider a single, harmonically trapped atom in an optical dipole trap — Tobias Weber, Frank Markert, Peter Würtz, Andreas Koglbauer, Tatjana Gerick, Andreas Vogl, und Hierwig Ott 1 Fachbereich Physik, Universität Kaiserslautern — 2 Institut für Physik, Universität Mainz

Therefore, we demonstrate that the off resonant measurements are non-destructive with respect to the number of trapped atoms. Finally, we present first results on Butler-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 quantum 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.

We present the measurement of the AC-Stark shift of the 1D$_{25s}$ Rydberg state of rubidium 87 in an optical dipole trap formed by a focused 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.

AC-Stark shift and photoionization of Rydberg atoms in an optical dipole trap — Tobias Weber, Frank Markert, Peter Würtz, Andreas Koglbauer, Tatjana Gerick, Andreas Vogl, und Hierwig Ott

EIT cooling of an atom in optical resonators — Marc Bienert und Giovanna Morigi — Theoretische Quantenphysik, Universität des Saarlandes, 66041 Saarbrücken, Germany

We consider a single, harmonically trapped atom in an optical dipole trap — Tobias Weber, Frank Markert, Peter Würtz, Andreas Koglbauer, Tatjana Gerick, Andreas Vogl, und Hierwig Ott. 2 Fachbereich Physik, Universität Kaiserslautern — 2 Institut für Physik, Universität Mainz

We present the measurement of the AC-Stark shift of the 1D$_{25s}$ Rydberg state of rubidium 87 in an optical dipole trap formed by a focused 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.

EIT cooling of an atom in optical resonators — Marc Bienert und Giovanna Morigi

**References**

Q 52.1 Thu 14:30 HÜL 386

**Fluorescent Nanodiamonds for Fluorescence Resonance Energy Transfer Imaging and Magnetometry**

M. C. Tessler, A. Gopalakrishnan, B. Balasubramanian, J. P. Boudoü, P. Curmi, R. Reuter, B. Naydenov, A. Lämmlé, F. Jelezko, and J. Wrachtrup

**Abstract:**

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 inside 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 donor) and quencher molecules of fluorescent dyes (FRET acceptor) have been done [3].


Q 52.2 Thu 14:45 HÜL 386

**Readout of satellite-satellite interferometer with 200km arms and nm precision**

O. Gerberding, B. Sheard, I. Bykov, J. Kullmann, G. Heinzel, and K. Danzmann

**Abstract:**

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 40 MHz, 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**

S. Kroeker, F. Brückner, E. Kley, and A. Tennermann

**Abstract:**

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 reflectivities close to unity 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**

M. Wimmer, M. Britzger, D. Friedrich, B. Hemm, K. Danzmann, and R. Schnabel

**Abstract:**

Michelson interferometer with Fabry-Perot cavities in the arms. The end mirrors will be made of K9/HG-BioPerot 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 100 Hz. The layout, status, and progress of the AEI 10 m prototype will be given in this talk.

Q 52.5 Thu 15:30 HÜL 386

**The AEI 10m Prototype Interferometer**

T. Westphal

**Abstract:**

A 10 m 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 100 g test masses.

For the pre-isolation of the experimental setup three seismically isolated optical tables inside a large (ca. 100 m³) 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 35 W Nd:YAG laser. The main instrument is a 10 m Michelson interferometer with Fabry-Perot cavities in the arms. The end mirrors will be made of K9/HG-BioPerot 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 100 Hz. The layout, status, and progress of the AEI 10 m 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**


**Abstract:**

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 in the LISA Pathfinder. This contribution presents an overview 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 LTPDA data analysis (LTPDA) toolbox.
Experimental Qudit Entanglement

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

Quantum Optics and Photonics Division (Q) Thursday

We make use of a scalable scheme using unbalanced interferometers 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 qutrits 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.


Testing spectral modes in parametric downconversion — Malte Avenhaus1, Andreas Christ2, Katiúscia N. Cassemiro3, and Christine Silberhorn1,2

Max-Planck-Institute für Quantenoptik, Hans-Kopfermann-Str. 1, D-85748 Garching, Germany — 2Ludwig-Maximilians-Universität, Schellingstr. 4, D-80797 München, Germany — 3Institut Fizyki Teoretycznej i Astrofizyki, Uniwersytet Gdański, PL-80-952 Gdańsk, 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. Parametric downconversion has found wide application in quantum optics. Great effort has recently been attributed to generate states with quantum correlations that are necessary but not sufficient to achieve measurement 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.

Testing spectral modes in parametric downconversion — Malte Avenhaus1, Andreas Christ2, Katiúscia N. Cassemiro3, and Christine Silberhorn1,2

Max-Planck-Institute für Quantenoptik, Hans-Kopfermann-Str. 1, D-85748 Garching, Germany — 2Ludwig-Maximilians-Universität, Schellingstr. 4, D-80797 München, Germany — 3Institut Fizyki Teoretycznej i Astrofizyki, Uniwersytet Gdański, PL-80-952 Gdańsk, Poland

Near-unity collection efficiency of single photons using a planar dielectric antenna — K Wanggaard, 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 broadband 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. Nature 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.

Towards experiments with atoms in coupled cavity arrays — Guillaume Lepert1, Michael Trupke2, Michael Hartmann3, Martin Plenio4, and Ed Hinds5 — 1Centre for Cold Matter, Imperial College, Prince Consort Road, London SW7 2BW, United Kingdom — 2Technische Universität Wien - Atominstitut, Stadionallee 2, 1020 Wien, Austria — 3Technische Universität München, Physik Department, James-Franck-Strasse, 85748 Garching, Germany — 4Universität 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 realizations, 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 miniaturized atoms. This device is a step towards the miniaturization of 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.

Spectroscopy of a single molecule with a stream of lifetime-limited single photons — Yves Reuz, Samuel Walt, Gerit 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.
Quantum Optics and Photonics Division (Q) Thursday

Q 54.1 Thu 14:30 SCH A01
Observation of squeezed light with one atom

ALEXEI OURJOVTTJ, ALEXANDER KURANEK, MARKUS KOCH, CHRISTIAN SAMES, PEPPJN 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 vapors, 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 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 CHIHANI, ALEXANDER KURANEK, 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 realabsorption 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 RÖHLISBERGER1, KAI SCHLAGE1, BALARAM SAHOO1, SEBASTIEN COUET2, and RUDOLF RÜFFER3 — DESY, Notkestr. 85, 22607 Hamburg — KU Leuven, Celestijnenlaan 200D, 3001 Leuven, Belgium — 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 of the transition energy is expected to be difficult to observe due to the number graphs required for calculating the T-matrix.

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 54.4 Thu 15:15 SCH A01
Temperature invariance of Casimir-Polder potentials

STEFAN YOSHI BUHMANN1, SIEMEN ANNOV ELLINGSEN2, and STEFAN SCHIELE1,2 — Quantum Optics and Laser Science, Blackett Laboratory, Imperial College London, Prince Consort Road, London SW7 2AZ, United Kingdom — 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].


Q 54.5 Thu 15:30 SCH A01
Theory of the QFEL — PAUL PREISS1,2, MATTHIAS KNOLL3, ROLAND SAUERBREV3, and WOLFGANG P. SCHLEGCH2 — Forschungszentrum Dresden-Rossendorf, 01314 Dresden, Germany — 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 theoreatical 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 Rosendorf 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 HAASE, JUERGEN SCHIFFERLE, 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].

condensates with time-dependent atom-atom interactions

Stability and decay of Bloch oscillations in Bose-Einstein


perspectives for state-of-the-art experiments with ultracold bosons.

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We compare the interband dynamics for the single particle limit and

Hubbard Hamiltonian for a one-dimensional tilted optical lattice [2].

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onantly enhanced tunnelling (RET) and Bloch oscillations. Regular

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, res-

quently enhanced tunnelling (RET) and Bloch oscillations [1].

In particular we show that

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 study the dynamics of two interacting bosons in one-dimensional

of the single particle limit and

for the fully interacting system, by computing the average occupation

of the upper band. The spectral properties (avoided crossings) pro-

vide 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 per-

spectives for state-of-the-art experiments with ultracold bosons.


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 Gauß**¹, Elena Díaz², Cord A. Müller³, Rodri- go Lima⁴, and Francisco Domínguez-Adame⁵ — ¹GISC, Departamento de Física de Materiales, Universidad Complutense, E-28040 Madrid, Spain — ²Institute for Materials Science, Technische Universität Dresden, D-01062 Dresden, Germany — ³Centro de Investigación en Quanti- tum Technologies, National University of Singapore, Singapore 117543, Singapore — ⁴Instituto de Física, Universidad 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].


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 theo-

rem, provided the single-band approximation remains viable. However,

interband transitions induced by strong time-periodic forces, which lie

outside the scope of this old approach, offer most interesting perspec-

tives 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 — **Tim Hartmann**¹, Juan Diego Urbina², Klaus Richter³, and Peter Schlagheck² — ¹Institute for Theoretical Physics, University of Regensburg, D-93040 Regensburg, Germany — ²Département 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 poten-

tials [2] makes it now interesting and feasible to study coherent trans-

port of Bose-Einstein condensates through various mesoscopic struc-

tures. 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 analogo-

us scenario of weak localisation in ballistic billiard geometries which exhibit chaotic classical dynamics. To this end we numerically in-

vestigate the quasi-stationary propagation of a condensate through such structures within the mean-field approximation. The transmis-

sion 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.


Q 55.5 Thu 15:30 BAR Schön

Decomposition of localization in a nonlinear generalization of the quantum kicked rotor — **Goran Gligorčić**, **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 understand how this nonlinearity affects the kicked rotor model. Particularly, we aim to understand the influence of nonlinearity on dynamical localiza-

tion; 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 subdiffu-

sion law in this regime and test its universality.


Q 55.6 Thu 15:45 BAR Schön

Localization of two interacting bosons in a random potential — **Dmitry Kriemar**, **Ramaz Khomeriki**, and **Sergei Flach** — ¹Max Planck Institute for the Physics of Complex Systems, 01189 Dresden, Germany — ²Institute for Theoretical Physics, University of Tübingen, 72076 Tübingen — ³Physics Department, Tbilisi State University

We study the dynamics of two interacting bosons in one-dimensional random lattices using the Bose-Hubbard model. In the absence of in-

teraction 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 $\xi$ in comparison to the single particle localization length $\xi_1$ 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].

Q 56: Ultrakurze Laserpulse: Anwendungen 3

Time: Thursday 14:30–15:45
Location: SCH A215

Role of Ferroelectric Domain Distribution and Shape in Cerenkov Second Harmonic Generation — Philipp Roedig, Mousa Ayoub, Jorg 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 multidomain 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.

Hystereoseffekte in einem Rückkoppelungssystem zur Superkontinuumszerzeugung — John Weitze, Nicoletta Brauckmann, Michael Kues, Petra Gross and Carsten Fallnich — Institut für Angewandte Physik, Westfälische Wilhelms-Universität, Münster, Deutschland

Beider Erzeugung von Superkontinua wird schmalbandiges Licht durch das Zusammenwirken von Dispersion mit nichtlinearen Prozessen wie beispielsweise Selbstphasenmodulation, Vier-Wellen-Mischung und Raman-Streuung spektral verbreitet.

In unserem experimentellen Aufbau werden Superkontinua durch Einkopplung von Femtosekunden-Laserimpulsen aus einem Titan:Saphir-Laser in eine mikrostrukturierte Glasfaser innerhalb eines Ringsenors 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 Periodenverflachung und Grenzyklen bis hin zu chaotischem Verhalten. Die Einstellung dieser Dynamiken hängt stark von der Phase der Überlagerung ab, die über die Länge des Ringsenors 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 Hystereoseffekte auftreten.

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 determina-

tion 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 $10^{19}$ 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 multi photon Compton scattering off the strong few-cycle laser pulse [2].

Weak localisation with short loops — Malte C. Tichy, Markus Tirschch, Florian Mintert, and Andreas Buchleitner

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Institute for Quantum Optics and Quantum Information - Austrian Academy of Sciences - Technikerstr. 21A - A-6020 Innsbruck, Austria —

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 multipole 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.


Nonlinear BEC Dynamics induced by Harmonic Modulation of Atomic $s$-wave Scattering Length — Ivana Vidanovic, Antun Balaz, Hamed Al-Jibbouri, and Axel Pelster

Scientific Computing Laboratory, Institute of Physics Belgrade, University of Belgrade, Pregrjevac 118, 11080 Belgrade, Serbia —

Institut f"{u}r Theoretische Physik, Freie Universität Berlin, Arnimallee 14, 14195 Berlin, Germany —

Fachbereich Physik, Universität Duisburg-Essen, Lothystrasse 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.


Exact Lieb-Linger Dynamics — Jan Zill, Matthias Kronenwett, and Thomas Gasenzer

Institut für Theoretische Physik, Ruprecht-Karls-Universität Heidelberg, Philosophenweg 16, 69120 Heidelberg —

ExtreMe Matter Institute EMMI, GSI Helmholtz-Zentrum 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 approximate analytical and numerical methods in quantum field theory.

Dipole potentials for guided atom-optics — T. Birkl, J. Küber, M. 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 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 waveguide.

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
Scalng laws of turbulent ultracold bosons — •Boris Nowak1,2, Maximilian Schmidt1,2, Jan Scholze1,2, Denes Sexty1,2, and Thomas Gasenzer1,2 — 1Institut für Theoretische Physik, Ruhr-Universität Bochum, Universitätsstraße 150, 44801 Bochum, Germany, and 2Max-Planck-Institut für Physik, Föhringer Ring 6, 80805 München, Germany

Critical dynamics of ultracold bosons in one dimension — •Maximilian Schmidt1,2, Jan Scholze1,2, Boris Nowak1,2, Denes Sexty1,2, and Thomas Gasenzer1,2 — 1Institut für Theoretische Physik, Ruhr-Universität Bochum, Universitätsstraße 150, 44801 Bochum, Germany, and 2Max-Planck-Institut für Physik, Föhringer Ring 6, 80805 München, Germany

A simple four-mode Bose-Hubbard model with intrinsic time-scale separation 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 phononics 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 40Ca — •Oliver Apel1, Stefan Kahl1, Manuel Selg2, Christian Krafft1, Fritz Riehle1, and Uwe Sterr2 — 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 up to 3S1/2-3P1 asymptotes. By using experimentally coupling the 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 3P0 and 3P1 states and study the coherence loss. The excitation to the long-lived 3P0 state demands for an ultranarrow laser, which is not yet available.

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-Selz1, Gal Aviv1, Simon Goodall2, Lucia Hackermüller1, Thomas Fernholz1, and Peter Krüger2 — 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 — •Lucas Gilz1 and James Aänglin2 — 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. Whereas 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 Federsel1, Michael Gehring1, Philip Schneeweiss1, Gabriela Visanescu1, Dieter Kern2, Andreas Günter1, and Jörges Fortagh1 — 1Physikalisches Institut der Universität Tübingen Auf der Morgenstelle 14 D-72076 Tübingen, Germany

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 densates with a single carbon nanotube and recording the atom loss.

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 different 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 1D. This crossover corresponds to the strongly correlated counterpart of the BCS-BEC crossover, which for our lattice model occurs in the weakly coupled regime.

A new setup for the study of strongly correlated low-dimensional systems — Florian Wittkötter, Wolfram Weimer, Kai Morgener, Niels Strohmaier, and Henning Mortz — 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.

Approaching a three-component Fermi gas in an optical lattice — Martin Rink, Andre Wenz, Philipp Simon, Thomas Lompe, Friedhelm Seiwane, Andreas Zeh, and Selim Jochim — Physikalisches Institut, Universität Heidelberg — Max-Plank-Institut für Kernphysik We report on our progress towards the realisation 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.

Bosons and fermions in three-dimensional optical lattices: Multi-band and nonlinear hopping corrections — Alexander Merling 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.

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.

Perspectives of Few Body Physics in an Ultracold Mixture of $^6$Li and $^{13}$Cs — Romain Müller, Marc Repp, Rico Pires, Juris Ulmanns, 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 $^{13}$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) between $^{133}$Cs and $^6$Li are necessary. Additionally, the extremely large mass-difference of Li and Cs results in the smallest est scaling factor of all alkali combinations for the appearance of universal Efimov states. Recently, several proposals showed that preparing interspecies interactions via magnetic field (i.e. knowledge of Feshbach resonances) between $^{133}$Cs and $^6$Li. A precise control over the scattering length enables the observation of a large series of this trimer states.

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. We discuss the experimental approach used to study Efimov physics and the few body effects in this mixture.

2. K. Helfrich et al., PRA 81, 042715 (2010)
3. T. G. T. Tiecke et al., PRA 82, 042712 (2010)
implement quantum simulators of gauge fields including the general class of non-abelian (non-commutative) gauges, so far never observed for atoms.

Towards Bose-Fermi mixtures in disordered optical lattices — Mathias Baumert, Nadine Meyer, Michael Holyznki, Marisa Peruza Ortiz, Kai Bongs and Jochen Kronjäger — University of Birmingham, School of Physics & Astronomy, Birmingham, United Kingdom — 1Universität Hamburg, Institut für Laserphysik, Hamburg, Germany

We are presenting progress towards a new setup for a $^{85}$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 gluing 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. Penzhorn 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.

Spontaneous Breaking of Spatial and Spin Symmetry in Spinor Condensates — Manuel Scherrer, Bernd Lücke, Jan Frisse, Gábor Gébehyvesz, Oliver Topci, Frank Deuretzbacher, Wolfgang Ertmer, Luis Santos and Carsten Klempt — 1Institut für Quantenoptik, Leibniz Universität Hannover, 30167 Hannover, Germany — 2Institut für Theoretische Physik, Leibniz Universität Hannover, 30167 Hannover, Germany — 3QUANTOP, Department of Physics and Astronomy, Universität of Aarhus, 8000 Aarhus 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.

An atomic parametric amplifier for the production of non-classical states — Manuel Scherrer, Bernd Lücke, Jens Kruse, Jan Frisse, Oliver Topci, Frank Deuretzbacher, Wolfgang Ertmer, Jan Arlt, Luis Santos and Carsten Klempt — 1Institut für Quantenoptik, Leibniz Universität Hannover, 30167 Hannover, Germany — 2Institut für Theoretische Physik, Leibniz Universität Hannover, 30167 Hannover, Germany — 3QUANTOP, Department of Physics and Astronomy, Universität 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 spatially separated by a 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.
pendent Zeeman shift between 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 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.

Quantum Optics and Photonics Division (Q) Thursday

Q 57.30 Thu 16:30 P1

Non-equilibrium dynamics in a Kondo lattice of ultracold fermionic alkaline-earth-metal atoms — SIBERIUS BOCK1,2, MATTHIAS KRONENWETT1,2, MICHAEL FOSS-FRIG3, ANA MARIA REV3, and THOMAS GASENZER1,2 — Institut für theorische Physik, Philosophenweg 16, 69120 Heidelberg — 3ExtreMe Matter Insti-

tute EMMI, GSI Helmholtzzentrum für Schwerionenforschung GmbH, Planckstr. 1, 64291 Darmstadt — JLLA, 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 correlation functions. This is a consequence the tunneling process becomes explicitly occupation-weighted distribution of frequencies appearing in the local density of states.

Q 57.31 Thu 16:30 P1

Repulsiv gebundene Teilchenpaare aus Bosonen und Fermionen im optischen Gitter — EVA KATHARINA RAPPEL, 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 Spins-1/2 XXZ Modell äquivalent sind, ist es dann der Fall, dass die effektive Wechselwirkung möglich, sämtliche Phasen, die das XXZ Modell aufweist, auch bei den Teilchenpaaren zu beobachten. Im eindimensionalen Fall berechnen wir dazu Teilchenzahlverteilungen und Korrelationen der Paare im harmonischen Faltenpotential und im Kastenpotential mit Hilfe der Time Evolving Block Decimation (TEBD) Methode. Da das Phasendiagramm des Spins-1/2 XXZ Modells in 1d analytisch exakt bekannt ist, erhebt es uns eine vollständige und exakte Klassifizierung und Interpretation der Teilchenzahlverteilungen in 1d.

Q 57.32 Thu 16:30 P1

Quantum dynamics in the bosonic Josephson junction — MORITZ HILLER1, MAYA CHUCHEN2, KATHARINA SMITH-MANNSSCHOTT3,4, TSAMPIKOS KOTTSOS3, AMICAY VARD5,6, and DORON COHEN2 — 1Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, Hermann-Herder-Str. 3, 79104 Freiburg — 2Department of Physics, Ben-Gurion University of the Negev, P.O.B. 653, Beer-Sheva 84105, Israel — 3Department of Physics, Wel-

leyan University, Middletown, Connecticut 06459, USA — 4MPI für Dynamik und Selbstorganisation, Bunsenstraße 10, 37073 Göt-
tingen — 5Department of Chemistry, Ben-Gurion University of the Negev, P.O.B. 653, Beer-Sheva 84105, Israel — 6ITAMP, 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 ini- 

tially incoherent condensates, we find a universal value for the buildup of coherence in the Josephson regime. In addition, we contrast two seemingly similar on-separatorix coherent preparations, finding striking differences in their convergence to classicality as the number of particles increases.


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 OLSCHLÄGER, JULIAN STRUCK, CHRISTINA STAARMANN, PAVLIS SOLTAN-PANAH, RODOLPH LE TARGAT, PATRICK WINDPASSINGER, and KLAA S 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.


Q 57.35 Thu 16:30 P1

Local mean field in optical lattices — ADRIAN NIEDEERLE 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 describes 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.


Q 57.36 Thu 16:30 P1

Effective occupation-dependent tunneling in optical lattices — MARIA LANGRECKER, OLE JORGENSEN, DIRK-Sören LÜHMANN, and KLAA S 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
Quantum Optics and Photonics Division (Q) Thursday

Quantum Many-Body Systems on the Single-Atom Level —


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.

Using a high resolution objective we observed fluorescence images of bosonic Mott insulators in the atomic limit. We reconstructed the amplitude and phase of the density fluctuations on the lattice from fluorescence images to obtain the local excitations with high fidelity. A comparison of the radial density distributions with theory provides a precise in situ measurement of the phase of the system. Our experimental sensitivity is promising for the direct manipulation of all relevant parameters.

We report on experiments with a two-component ultracold Fermi gas of Rb and fermionic 40K atoms in a blue detuned optical lattice. Previous experiments regarding equilibirum 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 57.37 Thu 16:30 P1

Detection of the Amplitude Mode in a Strongly Interacting Superfluid by Bragg Spectroscopy — Sören Götzke, 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 with momentum-resolved Bragg spectroscopy, Nature Physics advance online publication, 29.11.2009 (DOI: 10.1038/nphys1476)


Q 57.38 Thu 16:30 P1

Probing ultracold fermions in optical lattices — Jasper Simon Krauser, Sören Götzke, 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 87Rb and 40K 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.


Q 57.39 Thu 16:30 P1

Quantum Many-Body Systems on the Single-Atom Level —


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.

Using a high resolution objective we observed fluorescence images of bosonic Mott insulators in the atomic limit. We reconstructed the amplitude and phase of the density fluctuations on the lattice from fluorescence images to obtain the local excitations with high fidelity. A comparison of the radial density 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.


Q 57.40 Thu 16:30 P1


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 Rb and 40K atoms in a blue detuned optical 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 optical 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


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 87Rb.

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.


Q 57.42 Thu 16:30 P1


Bose-Fermi mixtures provide an accessible way to study many-body physics due to the combination of two 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-Fermi 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

Q 57.44 Thu 16:30 P1
Experiments with ultracold atoms in optical superlattices

Q 57.45 Thu 16:30 P1
Non-Equilibrium Phase Transition of Ultracold Bosons in an Optical Lattice Coupled to a BEC Reservoir

Q 57.46 Thu 16:30 P1
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.


Q 57.47 Thu 16:30 P1
Relativistic Description of Bose-Einstein Condensates

Q 57.48 Thu 16:30 P1
Semiclassical dynamics of self-organization of atoms in optical cavities

Q 57.49 Thu 16:30 P1
Ring structures in linear multipole ion traps

Q 57.50 Thu 16:30 P1
Quest for anisotropic solitons in dipolar Bose-Einstein condensates

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.


Experiments with laser-cooled atoms trapped in the evanescent field surrounding an optical nanofiber — D. Reitze, R. Mitsch, M. Müller, S. T. Dawkins, and A. Rauschenbeutel.

Quantum Optics and Photonics Division (Q) Thursday 16:30 P1

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 surrounding 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 vacuum Rabi oscillations, yielding a high optical density of up to 39 \( \tau \) 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 — R. Reimann, W. Alt, S. Brakhane, M. Eckete, T. Kampschulte, M. Martinez-Dorantes, A. Wiedlocha, and D. Meschede.

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].


Q 57.52 Thu 16:30 P1 Phase space compression with an accelerated diode and mirror potential — S. Schmitt, J. Gonzalez-Mugica, and A. Ruschhaupt.

We propose a scheme to cool atoms by collision with an accelerated potential. To achieve phase space compression we combine this with an irreversible diode 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 — B. Höltermeier, C. Hofmann, S. Götz, E. Busche, and M. Weidmüller.

We present a compact modular source for ultracold rubidium atoms based on the 2D-MOT design first demonstrated in [1]. Aimed 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 UVH 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.


Q 57.54 Thu 16:30 P1 Vibrational ground state cooling of a neutral atom in a tightly focused optical dipole trap — S. Aurelio A. Aljundi, J. Wang Lee, M. Parnsold, B. Ching, G. Maslennikov, and C. Kusterfieb.

Recent experiments have shown that an efficient interaction between a single trapped atom and light can be established by concentrating light fields in 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 ~ 1 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 \( ^{87} \text{Rb} \) atom to the ground state of the trap.

We have cooled the atom along the transverse trap axis (trap frequency \( \nu_r = 55 \text{kHz} \)), to a mean vibrational state \( n_r = 0.55 \) and investigate the impact on atom-light interfaces.


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 in ultracold gases. By loading these Fermi-Bose 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 \( ^{87} \text{Rb} \) and \( ^{40} \text{K} \). 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.


Q 57.56 Thu 16:30 P1 Trap loss in a double species MOT of Yb and Rb — M. Madalinski, C. Brun, F. Münchow, and A. Görlitz.

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 separately \( ^{171} \text{Yb} \) and \( ^{85} \text{Rb} \) atoms but we observe a strong loss of Yb in the combined MOT. The Yb MOT uses a Feshbach resonance at 55.8 mK. 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
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 accurate measurement of the average atom number. With these tools we for the first time perform measurements of 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 — 

MICHELE MARTINEZ-DORANTES, WOLFGANG Aitz, STEFAN BRAHANE, TOBIAS KAMPSCHEU, RENÉ REIMANN, ARTUR WIDERA, and DIETER MIESCHE —

Institut für Angewandte Physik der Universität Bonn, Wegelerstr. 8, 53115 Bonn, Germany

We present our latest results of loading and transporting atoms in an optical cavity. For the preparation and stabilization of atomic states will be shown. First experimental results of an extension to a feedback loop for the preparation and stabilization of atomic states will be shown.

Q 57.62 Thu 16:30 P1

Single-atom-resolved spin manipulation in a Mott insulator — 


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 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

Hochstabilierter Frequenzstabilitätstransfer — 

DAVE BRAUNS, MATTHIAS WOLKE, JULIAN KLINNER and ANDREAS HEMMERICH —

Universität Hamburg, Hamburg, Deutschland

Many-body effects in Rydberg gases — Martin Gattner, Jörg Evers, and Thomas Gamnenz — MPI für Kernphysik, Heidelberg — Institut für theoretische Physik, Heidelberg

The early theoretical treatement of ensembles of Rydberg atoms focused 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.


Mean-field models for correlated Rydberg gases — Kilian Heg 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.

Towards experiments with ultracold Rydberg gases at high atomic densities — Aline Faber, Hannes Busche, Christoph Hofmann, Georg Günter, Hanna Schmemp, Martin de Saint-Vincent, Shannon Whittle and 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. Combing large optical access with a high level of electric field control.


Laser cooling of dense atomic gases by collisional redistribution of radiation — Simon Haselmann, Anne Sasse, 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 redistribu-
tion 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.
Inelastic scattering of a probe particle on a Bose-Einstein condensate — STEFAN HUNN, MORITZ HILLER, TASMPIKOS KOTTOSS, DORON COHEN, AND ANDREAS BUCHELEITNER. — 1Albert-Ludwigs-Universität Freiburg, Hermann-Herder-Str. 4, 79104 Freiburg – 2Department of Physics, Wesleyan University, CT, USA – 3Department 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.

Quantum Optics and Photonics Division (Q) Thursday

P 1

Inelastic scattering of a probe particle on a Bose-Einstein condensate — STEFAN HUNN, MORITZ HILLER, TASMPIKOS KOTTOSS, DORON COHEN, AND ANDREAS BUCHELEITNER. — 1Albert-Ludwigs-Universität Freiburg, Hermann-Herder-Str. 4, 79104 Freiburg – 2Department of Physics, Wesleyan University, CT, USA – 3Department 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.

P 77.74 Thu 16:30 P1

Spectroscopic determination of YbRb ground state interaction potentials — FRANK MUNCHOW, CRISTIAN BRUM, 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 demonstrated the observation 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 vibronic structure of the electronic ground state. This will be done by so-called Allen-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.


P 77.75 Thu 16:30 P1


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 allow to confine polar molecules by an optical lattice along one axis 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.

P 77.76 Thu 16:30 P1

Berry phase in atom optics — POLINA V. MIRONOVA, MAXIM A. EFREMOV, AND WOLFGANG P. SCHLEICH. — 1Institut für Quantenphysik, Universität Ulm, D-89069 Ulm – 2Institut für Angewandte Physik, Technische Universität Darmstadt, D-64289 Darmstadt – 3LPTMS, 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 protocol where one can 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 one dimension of the 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.

P 77.77 Thu 16:30 P1

Towards a miniaturized frequency comb system for atom optics in microgravity — HANNES DUNCKER, ANDRE WENZLAWSKI, A. JONES RAPIPOOR, PATRICK WINDPASSINGER, KLAUS SENGSTOCK, AND THE LASUS TEAM. — 1Institut für Laser-Physik, Universität Hamburg, Luruper Chaussee 149, 22761 Hamburg — 2Institut für Quantenoptik, Leibniz Universität Hannover.
Quantum Optics and Photonics Division (Q)

Thursday

Welfengarten 1, 30167 Hannover — Institut für Physik, Humboldt Universität zu Berlin, Newtonstr. 15, 12489 Berlin — Ferdinand-Braun-Institut, Leibniz-Institut für Höchstfrequententechnik, Gustav-Kirchhoff-Str. 4, 12489 Berlin

Atom optics under microgravity plays stringent requirements on the deployed laser systems in terms of reliability, robustness, weight, volume and power consumption. Within this project, new microbench 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 glasscascaded 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 is required in a form factor suitable for microgravity platforms 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 0988.

Q 57.78 Thu 16:30 P1

Advanced laser system for atom interferometry — Christoph Greenschick1, Max Schiemangk2, Achim Peter3, and the QUANTUS TEAM1,2,3,4,5,6,7,8,9

1Institut für Physik, Universität Bremen — 2Institut für Quantenoptik, LU Hannover — 3Institut für Laserphysik, Universität Hamburg — 4ZARM, Universität Bremen — 5Institut für Physik, HU Berlin — 6Institut für Physik, Universität Hamburg — 7Midlands Ultracold Atom Research Centre, University of Birmingham, UK — 8FBH, Berlin

In preparation for future quantum gas experiments in space, preliminary experiments are currently being performed at the ZARM drop tower in Bremen with the goal to study the effects of microgravity on matter-wave interference using rubidium and potassium together with the electronics for the optical switching and frequency shifting. A version of this microbench is used for the instrument to unfold its full potential for ultra-high sensitivity. The poster presents key components of a compact and robust laser system, which is planned for the near future.

The poster presents components of a compact and robust laser system, which is planned for the near future. The poster presents key components of a compact and robust laser system, which is planned for the near future. The poster presents key components of a compact and robust laser system, which is planned for the near future.

Q 57.79 Thu 16:30 P1

Interferometry with Bose-Einstein condensates in microgravity — Holger Ahlers1, Nacer Gaaloul2, Stephan Seidel3, Waldemar Herr2, Jan Rudolph1, Christina Rodel2, Dennis Becker1, Manuel Popp1, Thijs Wendrich1, Wolfgang Ertmer2, Ernst Maria Rasel1, and the QUANTUS TEAM3,4,5,6,7,8,9

1Institut für Physik, Humboldt Universität Berlin — 2Institut für Quantenoptik, LU Hannover — 3Institut für Laserphysik, Universität Hamburg — 4ZARM, Universität Bremen — 5Institut für Physik, HU Berlin — 6Institut für Laserphysik, Universität Hamburg — 7Institut für angewandte Physik, TU Darmstadt — 8Midlands Ultracold Atom Research Centre, University of Birmingham, UK — 9FBH, Berlin

The performance of high precision atom interferometers is often limited by vibrations of optical components introducing Raman phase shifts. Two microgravities, an active 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 57.80 Thu 16:30 P1

A dual species matter-wave interferometer in microgravity — Dennis Becker1, Waldemar Herr2, Jan Rudolph1, Manuel Popp1, Christina Rodel2, Thijs Wendrich1, Holger Ahlers3, Stephan Seidel3, Nacer Gaaloul2, Wolfgang Ertmer2, Ernst Maria Rasel1, and the QUANTUS TEAM3,4,5,6,7,8,9

1Institut für Quantenoptik, LU Hannover — 2ZARM, Universität Bremen — 3Institut für Physik, HU Berlin — 4Institut für Laserphysik, Universität Hamburg — 5Institut für Quantenphysik, University of Birmingham, UK — 6Institut für angewandte Physik, TU Darmstadt — 7MUARC, University of Birmingham, UK — 8FBH, Berlin — 9MPQ, 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 87Rb and 40K 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 — Thuis 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 especially 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 50WM9039.

Q 57.82 Thu 16:30 P1

Active low frequency vibration isolation for high precision atom interferometer — Christian Freier — Humboldt Universität Berlin

The performance of high precision atom interferometers is often limited by vibrations of optical components introducing Raman phase shifts. The project has built a compact and high-resolution microgravity 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 Gravitationsphysik (Albert Einstein-Institut), Institut für Gravitationsphysik, Leibniz Universität Hannover and 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 ~ 10^-19 m/√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
Optical simulations for inter-satellite interferometry

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. 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 sensitivity 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 Gravitationsphysik und Institut für Gravitationsphysik der 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 properties of the system and to optimize 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. 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 57.85 Thu 16:30 P1
Optical simulations for inter-satellite interferometry — ●CHRISTOPH MAHRDT, EVGuenIA GRANOVA, BENJAMIN SHEARD, GUDRUN WANNER, GERHARD HEINZEL und KARSTEN DANZMANN — Max-Planck-Institut für Gravitationsphysik (Albert-Einstein-Institut), Hannover und QUEST, Leibniz Universität 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 Dübendorf (Switzerland)キャンペーン 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 Dübendorf (Switzerland)キャンペーン 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 Dübendorf (Switzerland)キャンペーン D-30167 Hannover.

Q 57.87 Thu 16:30 P1
The LISA optical bench — ●JOHANNA BOGENSTahl, GERHARD HEINZEL, MICHAEL TRÖBES, CHRISTIAN DIEKMANN, ROLAND FLEDDERMANN, GUDRUN WANNER, EVGENIE GRANOVA, MARINA DRHNE, und KARSTEN DANZMANN — Max Planck Institute for Gravitational Physics (Albert Einstein Institute) Callinstr. 38 D-30167 Hannover

With our recent frequency measurement of the $3_{\text{S}}$ to $3_{\text{P}}$ transition of $^{87}$Sr we reached a level of precision that opens the demand for investigations of the blackbody radiation shift in the near infrared, of the ambient housing at 300 K causes a shift of 5 x $10^{-15}$ and the correction leaves an uncertainty of 1.6 x $10^{-16}$ 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 57.88 Thu 16:30 P1
Avoiding blackbody radiation shifts, density shifts, and fiber-induced laser degradation in an optical lattice clock — ●THOMAS MIDDLEMANN, STEPHAN FALKE, STEFAN VOGT, FRITZ RIEHLE, UWE STERR, und CHRISTIAN LIEBAST — Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig

Quantenrausch-limitierte Laser-Amplitudendetektion von Hochleistungslasern — ●PATRICK KWEE, BENNO WILKKE und KARSTEN DANZMANN — Albert-Einstein-Institut Hannover


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 einfachen Photodiode kann detektiert werden. Erste Messungen an einem 1064 nm Nd:YAG Laser bei Frequenzen zwischen 10...100 MHz wurden vorgestellt.

Q 57.89 Thu 16:30 P1
Towards a Portable Aluminum Optical Clock — ●JANNEs B. WÜBBENA, SANA AMARI, OLAF MANDEL, IVAN V. SHERSTOV, und PIET O. SCHMIDT — QUEST Inst. for Exp. Quantum Metrology, PTB Braunschweig und 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 x $10^{-17}$.
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 $^1S_0 \rightarrow ^3P_0$ 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 $^4$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-shielding detection is available. [1] C.W. Chou et al., Phys. Rev. Lett. 104, 070802 (2010)

A Single Laser System for Ground State Cooling of $^{25}$Mg$^+$ — FLORIAN GEBERT, BÖRGE HEMMELRING, 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 created a 5 level manifold for the $^{25}$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 $^{25}$Mg$^+$, Ti$^+$ and Fe$^+$ for the comparison with quasar absorption spectra to study possible time variation of the fine structure constant $\alpha$. 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.


Stromion in an Optical Lattice as a Mobile Frequency Reference — OLE KOCK, STEVEN JOHNSON, YESHIAL SINGH, and KAI BECHER — 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$^{-15}$ [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 the singlet state to the 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 terrestrial applications. The narrow linewidth of the hyperfine components ($\approx$ 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 a01 component of the R(563)2-0 transition of $^{127}$I$^+$. 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 by the German Space Agency DLR with funds provided by the Federal Ministry of Economics and Technology (BMWi) under grant number DLR 50OQ0601.

A mobile atom interferometer for high precision measurement of local gravity — VLADIMIR SCHOLZIK, MALTE SCHMIDT, ALEXANDER SEMBERGER, MATTHIAS HAUTH, CHRISTIAN FREHRE, and ACHIM PETERS — Institut für Physik, Hu Berlin, Germany

GAIN (Gravitmic 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 $10^{15}$, i.e. one part in 8 million, we expect to offer a new 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.

Paving the way to coherent modern control of quantum optical systems — TEMO LENKER, DIRK SCHÜTTE, MAXIMILIAN WIMMER, and MICHELLE HURS — Albert-Einstein-Institut Hannover, Max-Planck-Institut für Gravitationsphysik und Centre for Quantum Engineering and Space-Time Research (QUEST), Leibniz Universität Hannover, Welzengarten 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 atomic fountain, to exemplify the latter we will show preliminary work of treating recycling techniques in interferometric gravitational wave detectors as a coherent control problem.

Stabilization of the Advanced LIGO laser — CHRISTINA BOGAN, JAN-HENDRIK FOEH, PATRICK KWEE, BENNO WILKE, 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 stabilisation scheme is crucial. In order to achieve a TEM00 mode content of more than 98.8% a bow-tie shaped cavity is used as a mode-cleaner which also suppresses beam pointing and power noise at radio frequencies. The laser frequency is stabilized to a high finesse reference 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 linewidth of the hyperfine components (less than 1000 Hz) 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 a01 component of the R(563)2-0 transition of $^{127}$I$^+$. 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.
cavity. A nested control loop prestabilizes the laser system’s power to a relative power noise of $2 \times 10^{-8}$ (Hz)$^{-1/2}$ and provides an additional input to achieve a relative power noise of $2 \times 10^{-9}$ (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 GŁOWSKI, CHRISTIAN SCHUBERT, GUNNAR TACKMANN, WOLFGANG ETTMER, 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 Rb-87 atoms to precisely measure rotations. The sensitivity of the sensor therefore reaches a resolution of few $10^{-9}$ 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 photons 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 Kammergenerator unter Scherereolosigkeit (FOKUS)** — THOMAS WILKEN, MATTHIAS LEZIS, MARC FISCHER, THEODOR W. HÄNSCH, and RONALD ZHOLWARTZ — Max-Planck-Institut für Quantenoptik, Garching – Menlosystems GmbH, Martinsried

In der letzten Zeit 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 einzusetzen zu können, ist es notwendig, Frequenzkämme soweit zu entwickeln, dass sie sowohl einen Raketenstart als auch die Bedingungen unter Schereolosigkeit außerhalb unserer Atmosphäre aushalten. Dazu sind im Rahmen des PRIMUS-Projekts im letzten Jahr schon erste Experimente am Fallturm des ZARM in Bremen erfolgreich durchgeführt worden.

Das FOKUS-Projekt zielt nun auf die Konstruktion eines satellitenbaugründigen Frequenzkamms. Dazu sind Verbesserungen in der Stabilität des Ozillators und des f-2f Interferometers notwendig und die Strahlungshärt der verwendeten Komponenten muss untersucht werden. Erste Ergebnisse werden hier präsentiert.

Q 57.99 Thu 16:30 P1

**Fokusexperimente in Anwesenheit von 18-2S Transition in atomic hydrogen** — CHRISTIAN G. PARTHEY, ARTHUR MATVEEV, JANIS ALINS, AXEL BEYER, NIKOLAI KOLACHEVSKY, RANZDOLF POHL, THOMAS UDEM, and THOMAS W. HÄNSCH — Max-Planck-Institut für Quantenoptik, Garching – Ludwig-Maximilians-Universität, 80799 München

Precision spectroscopy of the 18-2S 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 boosts of violations. Here we report on a new measurement of the 1S-2S transition pushing the uncertainty to the $10^{-12}$ level. We describe the studied systematic effects in detail.

Q 57.100 Thu 16:30 P1

**Stable fibre interferometers for ground-based interferometers performing in the pico-meter stability level** — LINA-ELLEN WITTRAU, JUNNA BOGENSENHOLM, GERHARD HEINDEL, and KARSTEN DANZMANN — Max-Planck-Institut für Gravitational Physics (Albert-Einstein-Institute) Hannover and QUEST, Leibniz Universität 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 pico-meter 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 Göteborg.

It has been shown that this improvement of the fiber injectors is not only required for space-borne but also for ground-based interferometers performing at the pico-meter 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 DÖRINGHOFF, MORITZ NAGEL, EVGENY V. KOVALCHUK, and ACHIM PETERS — Humboldt-Universität zu Berlin, Institut für Physik, Alte Optische Metrologie, Nussallee 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 Hz/$\sqrt{\text{Hz}}$ 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 QO 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, URBICH VREDE, DANIEL TAUKES, MAIC ZASER, NACHSLEV LIEBEDEV, ERNST RASEL, and WOLFGANG ETTMER — 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 potasium 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 suppressing most of the classical noise sources 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.

Q 57.103 Thu 16:30 P1

**High Sensitivity Magnetic Sensing by Ensemble Measurements on Densely Packed Defect Centers in Bulk Diamond** — THOMAS WOLF, MRHE BECKER, Gopalakrishnan BALASUBRAMANIAN, FEDOR JELZEKOV, and JORGG WRAHTRUP — 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, fluorescence and high resolution optical microscopy and magnetometry. Recent 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 $3\sigma T/Hz^{1/2}$ has been shown) scales with the square root of the number of NV-centers probed. Ensemble measurements give the opportunity for high sensitivity magnetic sensing with a projected sensitivity in the range of $\mathcal{F}/Hz^{1/2}$ while keeping the dimensions of the sensor small.


A fiber-based femtosecond frequency comb for precision measurements in microgravity — Andreas Rieß, Claus Lämmerzahl, and Sven Hermann — 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 precise measurement of the 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.

A compact Yb optical lattice clock — Charbel Abou Jaoudeh, Gregor Mura, Tobias Franzen, Taner Esat, Cristian Bruni, and Axel Görlitz — Institut für Experimentalphysik, Universität - str. 1, 40225 Düsseldorf

Optical clocks using neutral atoms hold the promise to eventually reach an accuracy at a level of $10^{-16}$. 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 magneto-optical trap (MOT) with more than $2 \times 10^5$ MOT atoms. Subsequent optical cooling to $20 \%$ from the bosonic $^{171}$Yb and fermionic $^{171}$Yb MOT into the second stage MOT operating on the narrow $^6S_0 \rightarrow ^6P_1$ transition at 556 nm and further cooling of the atoms to temperatures of $20 \mu K$ has also been achieved. The next step will be to load the atoms into a 1D optical lattice at the magic wavelength of 739 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 $\mu$m and a potential depth of 300 $\mu K$ if 300 mW of radiation from a tapered diode laser are coupled into the resonator.


Lorentz Invariance is a fundamental component of General Relativity and 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 $10^{-17}$ to $10^{-18}$ regime, corresponding to the detection of 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.

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.

LISA 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.

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Q 58.1 Fri 10:30 HSZ 02
CPT and EIT - Dark state resonances in interacting systems — Hanna Schimpf1, Georg Günter1, Christoph S. Hofmann1, Thomas Amthor1, Matthias Weidentuli1, Jonathan D. Pritchard2, Daniel Maxwell2, Alex Gauguet2, Kevin J. Weatherill2, Matthew P. A. Jones2, Charles S. Adams2, Sevilay Sevincli3, Cenap Arz3, and Thomas Pohl1 — 1Physikalisches Institut, Universität Heidelberg, Philosophenweg 12, 69120 Heidelberg — 2Department of Physics, Durham University, Rochester Building, South Road, Durham DH1 3LE, United Kingdom — 3Max-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.


Q 58.2 Fri 10:45 HSZ 02
Enhanced Optical Nonlinearities with Cold Rydberg Gases — Sevilay Sevincli1, Cenap Arz2, and Thomas Pohl1 — 1Max Planck Institute for the Physics of Complex Systems, Nöthnitzer Strasse 38, 01187 Dresden, Germany — 2School 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 microwave 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 Ris1 and Giovanna Morrigi2,3 — 1NEST, Scuola Normale Superiore & Istituto di Nanoscienze - CNR, Piazza dei Cavalieri 7, I-56126 Pisa, Italy — 2Departamento de Física, Universitat Autònoma de Barcelona, E-08193 Bellaterra, Spain — 3Theoretische Physik, Universität, at des Saarlandes, D-66041 Saarbrücken, 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 mean value. The measurement is performed in the light scattered into one 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.


Q 58.4 Fri 11:15 HSZ 02
A Double-Species 2D+MOT for Potassium and Rubidium — Lucia Duca1, Tracy Li1, Martin Boll1, Jens Philipp Ronzheimer1, Ulrich Schneider1, and Immanuel Bloch1,2 — 1Fakultät für Physik, Ludwig-Maximilians-Universität, 80799 München — 2Max-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 \( T < \frac{\hbar \nu_0}{2k_B} \). 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 \(^{40}\text{K}\) and \(^{87}\text{Rb}\) 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

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 successful 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 the guide. When combined with beam splitting devices this will enable experiments like guided electron interferometry or the controlled interaction of confined electrons.


Q 58.6 Fri 11:45 HSZ 02
Ultracold atoms in disordered quantum potential — H. van Harlingen1,2, Wolfgang Niedenzu3, Helmut Ritsch3, and Giovanna Morrigi1,2,3 — 1Grup d’Optica, Departament de Física, Universitat Autònoma de Barcelona, E-08193 Bellaterra, Barcelona, Spain — 2Theoretische Physik, Universität des Saarlandes, D-66041 Saarbrücken, Germany — 3Institut 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 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.
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 HS 02

Laserkühlung von dichten atomaren Alkali-Edelgas-Mischungen durch kollisionsinduzierte Fluoreszenzverteilung — •ANNE SASS, ULRICH VOGEL, SIMON HASSELLMANN und MARTIN WEITZ — Institut für Angewandte Physik der Universität Bonn, Wegelerstraße 8, D-53115 Bonn


Q 58.8 Fri 12:15 HS 02

A hexapole-compensated magneto-optical trap on a mesoscopic atom chip — •STEFFEN JÖLLENBORG, JAN MAHNKE, RICHARD RANDOLL, MANUELA HANKE, ILKA GEBEL, WOLFGANG ERTMEN, JAN ARLT, und CARSTEN KLEMP — 1Institut für Quantenoptik, Leibniz Universität Hannover — 2Department of Physics and Astronomy, Aarhus University

Wir realisiert einen magneto-optical trap (MOT) auf einer mesoskopischen Halbleiterebene, die als Startpunkt für Experimente zum Transport von Atomen in einem Magnetischer Transportstrahls verwendet werden kann. Der trap nutzt die Spurweitung der Atome im elektrischen und magnetischen Feld, um eine Kühleffizienz der Atome zu erreichen.

Q 59: Quantum Effects: Interference and Correlations

Time: Friday 10:30–12:45

Q 59.1 Fri 10:30 SCH A01

Measuring Quantum Superpositions of Different Structures of Ion Coulomb Crystals — •JENS DOMAGG I BALTRUSCHI, GABRIELLE DEL HUAN ALCAZAR, TOMASO CALARCO, und ERIC HONNA MORIGI — 1Theoretische Quantenphysik, Universität des Saarlandes, Germany — 2Grup d’Òptica, Universitat Autònoma de Barcelona, Spain — 3Fisica Teorica: Informacio i Fenomen Quancits, Universitat Autònoma de Barcelona, Spain — 4Institut für Quanteninforma- tionsverarbeitung, 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 correlates to 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 und SANDRO WIDMÜBER —

Institut für Theoretische 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 in the quantum accelerator modes observed by Oberthaler et al. [1]. We will first remind the pseudo-classical formalism introduced by Fishman et al. [2]. 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.


Q 59.3 Fri 11:00 SCH A01

Probing motional squeezing with correlation functions.

— •ANDREAS CHRIST, KAISA LARIO, ANDREAS ECKSTEIN, KATŽIÚC NIA N. CASSEMIRO, und CHRISTINE SILBERHORN — 1Applied Physics, University of Paderborn, Warburger Straße 100, 33098 Paderborn, Germany — 2Max Planck Institute for the Science of Light, Günther-Scharowsky Straße 1/Building 24, 91058 Erlangen, Germany

Broadband motional squeezers constitute a powerful quantum resource with promising potential for different applications in quantum information technologies such as information coding in quantum com-
munication 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 of 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 of squeezed states. Moreover, the measurements are loss-independent due to the structure of the normalized correlation function measurements.

Q 59.4 Fri 11:15 SCH A01
Decoherence effects in quantum walks: From ballistic spread to localization — Andreas Schreiber1, Katúška N. Căsăsmir1, Václav Potocký2, Aurél Gábris3, Igor Jex4, and Christine Silberhorn1

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 Gnirrist 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 Sadurní and Wolfgang Schleich — Institut füer Quantenphysik, Uni Ulm, Universitäet, 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 MAYER1, Malte C. Tuchy1, Florian MINTER2, and Andreas Buchleitner3 — 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 statistics from pure many-particle interference effects.


Quantum Optics and Photonics Division (Q) Friday
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 in-separability.


Q 60.2 Fri 10:45 SCH 254

Entangling photons via the quantum Zeno effect — Ralf Schützhold, Andreas Oestrehoh, and Nikolai 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 254

Four-Photon Distinguishability Transition — Malte C. Tichy¹, Hyang-Tag Lim², Young-Sik Ra², Florian Miertz¹,³, Yooh-Oo Kim², and Andreas Buchleitner¹ — Physikalisches Institut - Universität Freiburg - Hermann-Herder-Str. 3 · D-79104 Freiburg — ¹Department of Physics - Pohang University of Science and Technology (POSTECH) - Pohang, 790-784, Korea — ²Physik-Institut 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.

Q 60.4 Fri 11:15 SCH 254

Einstein-Podolsky-Rosen Correlations from a Vacuum-Class Two-Mode Squeezed State — Tobias Eberele1,²,³, Vi- tus Händchen1, Jong Duhm²,³, Torsten Franzi²,3, Reinhard Wernik3, and Roman Schnabel3 — 1Max-Planck-Institut für Gravitationsphysik (Albert-Einstein-Institut) and Institut für Gravitationsphysik der Leibniz Universität Hannover, Callinstraße 38, 30167 Hannover, Germany — 2Institut für Theoretische Physik der Leibniz Universität Hannover, Appelstrasse 2, 30167 Hannover — 3Centre for Quantum Engineering and Space-Time Research - QUEST, Leibniz Universität Hannover, Wellengarten 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 254

Operator ordering and causality — Lev Plimak¹, Wolfgang Schleich², and Stig Stenholm³,⁴ — ¹Abteilung Quantenphysik, Universität Ulm, D-89069 Ulm, Germany — ²Physics Department, Royal Institute of Technology, KTH, Stockholm, Sweden — ³Laboratory 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.

Q 60.6 Fri 11:45 SCH 254

Entangled photons in a disordered waveguide — Frank Schlawin, Nicolas Cherрюet, and Andreas Buchleitner — Institut de physique, 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 254

Probability amplitudes of two-levels atoms beyond the dipole approximation — Armen Hayrapetyan and Stephan Fritzsche²,³ — ²Max-Planck-Institut für Kernphysik, Postfach 103980, D-69020 Heidelberg, Germany — ³Department of Physics, P.O. Box 3000, Fin-90014 University of Oulu, Finland — ⁴GSI 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

Q 61.1 Fri 10:30 SCH A118

Phase-dependent wave-particle duality and delayed choice of the which-way detector observable — Ulke 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 $\psi < 1$, the new observable enables us to extract full WWI which seems to contradict the inequality $D^2 + V^2 \leq 1$ 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 $D^2 + V^2 \leq 1$ may be violated by adeptly choosing the observable which is to be measured after the particle has been detected [4].

Q 61.2 Fri 10:45 SCH A118

Quantum Optics and Photonics Division (Q) Friday

Shor’s algorithm and the factorization with Gauss sums —
Sabine Wolk 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 finds periods.

On the other side, there exist functions other than $a^N \bmod N$ 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 $a^N \bmod N$ 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 —
Sonke 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 Seyfarth1, Kedar Ranada2, and Grégoire Alanier1 —
1Institut für Angewandte Physik, Technische Universität Darmstadt, 64289 Darmstadt, Germany — 2Institut 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 calculations. 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.


Q 61.5 Fri 11:30 SCH A118
Optimal molecular networks for exciton 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 Kleinmann1, Otfried Gühne1, José Portillo2, Jan-Ake Larsson3, and Adán Cabello4 —
1Fachbereich Physik, Universität Siegen, D-57068 Siegen, Germany — 2Departamento de Matemática Aplicada I, Universidad de Sevilla, E-41012 Sevilla, Spain — 3Institut für Systemtechnik och Matematiska Institutionen, Linköpings Universität, SE-581 83 Linköping, Sweden — 4Departamento 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 Ziere — Institut für Theoretische Physik, Universität Hannover

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 each other. 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 Gutschow — 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
Differentail Magnetometry with Multipartite Singlets —
Nigo Urizar-Lanz1 and Géra Tóth2,3,4 —

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.

We propose Lie-algebraic methods to simulate unitary dynamics of
Laserelemententwicklung für CARS Mikroskopie — •Petra Gross, Carsten Clerff, Lisa Kleinhenz, Peter Kühntopp, Stefan Dörner, Jan Brockhaus und Carsten Fallnich — Institute für Angewandte Physik, Westfälische Wilhelms-Universität, Correnstr. 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 Flexibilität, die dafür benötigten komplexen Laserquellen verhindern jedoch bisher eine breite Verwendung.


High-speed optical coherence tomography using a Fourier do- main mode locked laser — •Lars Kirsten, Julia Walther, Per- ter Cimalla, Sven Messerschmitt, Mirko Mehner, and Edmund Koch — Dresden University of Technology, Faculty of Medicine Carl Gustav Carus, Clinical Sensing and Monitoring, Fetscherstraße 74, 01307 Dresden, Germany

Optical coherence tomography (OCT) is a non-invasive 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.


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 air peaks of a scanned optical resonator was developed. Due to the high frequency of intra-cavity material or the mirror coatings, the transmitted as well as the reflected air peaks show a hysteresis depending on the scan direction. A time domain simulation based on is used to fit the measurement data. Using these methods we measured the absorption of high reflective mirror coatings and a PPKT substrate. To prove the quantitative result of the measurements we compared our results of measurements with a calorimetric method and values known from literature respectively.

Hochstables Multiwellenlängensystem für die 3D- Oberflächenmesstechnik — •Axel Heuer, Daniilo Skoczowsky, Andre Hamdorf, Christof Zink and Ralf Menzel — Universität Potsdam, Institut für Physik und Astronomie, Photomik, Karl-Liebknecht-Str. 24-25, Haus 28, 14476 Potsdam


Es wird ein Lasersystem mit frequenzstabilisierten roten Laserdioden vorgestellt, welches die reproduzierbare Umschaltung zwis- chen 6 verschiedenen Wellenlängen erlaubt. Die Schaltzeiten liegen bei ca. 2 ms und die Wellenlängenstabilität ist besser 1 ppm.

CO-Bestimmung aus Blutproben — •Philippe Seidel, Marcus Sowa und Peter Hering — Institut für Lasermedizin, Universitäts- klinikum Düsseldorf, Universitätsstr. 1, 40225 Düsseldorf

Laser Pulses
Generation and Dispersion Management of Femtosecond Lasers, seem to yield very promising results.

It is vital to precisely know the dispersive behavior of each element, which can quickly be calculated and put into operation. For this purpose, it is possible to interactively design a pulse compressor.

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 glass capillary tube filled with a nonlinear medium.

Ein Brillouin-LIDAR zur Messung von Temperaturprofilen des Ozeans: Fortschritte am ESFADOF-Detektor zum praktischen Einsatz — Andreas Rudolf, Alexander Popescu und Thomas Walthier — Institut für Angewandte Physik, AG Laser und Quantenoptik, Technische Universität Darmstadt, Schloßgartenstr. 7, 64289 Darmstadt

Die Kenntnis des lokalen Wärmegleichgewichts der Weltraum ist für die Sedimentation von Bedeutung, insbesondere für die Ermittlung der Bodentemperatur. Die Temperaturmessung kann durch den Einsatz von Wärmeprobeinrichtungen erfolgen, die auf der Basis von Brillouin-Streuung basieren. Es wird ein ESFADOF-Detektor vorgestellt, der die experimentelle Eindringtiefe der Brillouin-Streuung auf 0.5 mm erhöht und eine Temperaturauflösung von 0.1 °C ermöglicht.

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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 being processed by focusing ultra short pulse 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-laser system (BMI America, 1045nm) on fused silica and borosilicate glass are investigated. Modulation 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 occurring heat accumulation and the laser induced lens during processing. The spectral analysis of emitted radiation provides further information about the electronic absorption processes such as the formation of colour centres, non-bridging oxygen-vacancies and peak temperatures.

Q 63.8 Fri 12:15 SCH A215 Strong-field above-threshold photoemission from sharp metal tips — Michael Kräger, Markus Schenk, 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 $10^{13}$ W/cm² we observe a suppression of the lowest-order peak as well as a shift of the spectral features towards lower energies. This shift scales linearly with intensity with a slope of $-1$ eV/$(10^{12}$ W/cm²). 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] 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 Kräger, 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.