Q 42: Poster: Quantum Optics and Photonics III

Time: Wednesday 16:30–19:00 Location: Empore Lichthof

Q 42.1 Wed 16:30 Empore Lichthof

Synchronization of Two Ensembles of Atoms via Quantum and Classical Channels — •Alexander Roth and Klemens Hammerer — Institute for Theoretical Physics, Leibniz University Hannover

We show synchronization in a system of two cascaded superradiant frequency detuned lasers and point out the differences to two superradiant ensembles of atoms in one cavity [1]. Furthermore we show that this synchronization does not rely on the quantum coupling between both lasers, but can be simulated using a classical channel. Additionally we show that the synchronization of two superradiant ensembles of atoms coupling to the same cavity mode can also be simulated using a classical coupling channel.

[1] PRL 113.15 (Oct. 6, 2014) M. Xu, D. Tieri, E. Fine, J. K. Thompson, and M. Holland. "Synchronization of Two Ensembles of Atoms".

Q 42.2 Wed 16:30 Empore Lichthof

Quantum-phase synchronization — •Lukas Fiderer[1], Marek Kus[2], and Daniel Braun[1] — [1]Eberhard-Karls-Universität Tübingen, 72076 Tübingen, Germany — [2]Center for Theoretical Physics of the Polish Academy of Sciences, 02-068 Warsaw, Poland

We study mechanisms that allow one to synchronize the quantum phase of two qubits relative to a fixed basis. Starting from one qubit in a fixed reference state and the other in an unknown state, we find that contrary to the impossibility of perfect quantum cloning, the quantum-phase can be synchronized perfectly through a joined unitary operation. When both qubits are initially in a pure unknown state, perfect quantum-phase synchronization through unitary operations becomes impossible. In this situation we determine the optimal average quantum-phase synchronization fidelity, the distribution of relative phases and fidelities, and identify quantum circuits that enable this optimal fidelity. A subset of these optimal quantum circuits achieves perfect quantum-phase synchronization for a class of unknown initial states restricted to the equatorial plane of the Bloch sphere.

Q 42.3 Wed 16:30 Empore Lichthof

Retrieving two-dimensional source geometries via spatial frequency filtering using higher order spatial photon correlations — •Felix Waldmann[1], Anton Classen[1,2], Raimund Schneider[1,2], Thomas Mehringer[1,2], and Joachim von Zanthier[1,2] — [1]Institut für Optik, Information und Photonik, Universität Erlangen-Nürnberg, 91058 Erlangen — [2]Erlangen Graduate School in Advanced Optical Technologies (SAOT), Universität Erlangen-Nürnberg, 91052 Erlangen

Measurements of higher order photon correlations are becoming increasingly attractive due to numerous applications in the field of imaging [1,2]. Recently we demonstrated a detection scheme, which resolves regular 1D source geometries of N independent classical emitters with thermal statistics at sub-Abbe resolution by making use of spatial photon correlations of order $m = N$ [2]. Here we present a generalization of this scheme relying on a sequential measurement of spatial photon correlations of different orders to reconstruct 2D source geometries. By choosing specific detector positions the scheme isolates - depending on the correlation order m - sequentially all spatial frequencies of the setup, which we call spatial frequency filtering. Using the gathered information allows to retrieve the 2D source geometry. In the experiment the independent thermal sources are realized by pinholes drilled in an opaque mask and illuminated with laser light scattered from a rotating ground glass disk.

[1] J. H. Shapiro, R. W. Boyd, Quantum. Inf. Process. 4, 949 (2012)
[2] S. Oppel et al., Phys. Rev. Lett. 109, 233603 (2012)

Q 42.4 Wed 16:30 Empore Lichthof

Anticoherence of spin states with point-group symmetries — •Dorian Baguette[1], François Damanet[1], Olivier Giraud[2], and John Martin[1] — [1]Institut de Physique Nucléaire, Atomique et de Spectroscopie, Université de Liège, 4000 Liège, Belgium — [2]LPTMS, CNRS, Univ. Paris-Sud, Université Paris-Saclay, 91405 Orsay, France

We investigate multiqubit permutation-symmetric states with maximal entropy of entanglement. Such states can be viewed as particular spin states, namely anticoherent spin states. Using the Majorana representation of spin states in terms of points on the unit sphere, we analyze the consequences of a point-group symmetry in their arrangement on the quantum properties of the corresponding state [1]. We focus on the identification of anticoherent states (for which all reduced density matrices in the symmetric subspace are maximally mixed) associated with point-group-symmetric sets of points. We provide three different characterizations of anticoherence and establish a link between point symmetries, anticoherence, and classes of states equivalent through stochastic local operations with classical communication. We then investigate in detail the case of small numbers of qubits and construct infinite families of anticoherent states with point-group symmetry of their Majorana points, showing that anticoherent states do exist to arbitrary order.

[1] D. Baguette *et al.*, Phys. Rev. A **92**, 052333 (2015).

Q 42.5 Wed 16:30 Empore Lichthof

Loading Scheme for Surface Traps With Beryllium Ions — •Johannes Mielke[1], Henning Hahn[1], Timko Dubielzig[1], Martina Wahnschaffe[1,2], and Christian Ospelkaus[1,2] — [1]Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover, Germany — [2]PTB, Bundesallee 100, 38116 Braunschweig, Germany

Surface electron ion traps are promising systems for scalable quantum information processing. In one of the present projects in our group, we are developing advanced trap designs with integrated microwave conductors providing the near field configuration to drive $^9Be^+$ hyperfine qubit transitions [1]. A scheme for efficient loading of surface traps with beryllium ions is presented. We use a nanosecond pulsed laser for ablation of neutral atoms from a beryllium wire and a laser system for subsequent two-photon ionization. The ionization laser is based on an infrared diode laser, which is frequency quadrupled by two cavity-enhanced frequency doubling stages, similar to [2]. Furthermore we discuss a spectroscopy scheme using a Beryllium-vapor lamp for locking the ionisation laser to the neutral beryllium $2p^1S_0 \rightarrow 2s^1P_1$ transition.

[1] M. Carsjens et al., Appl. Phys. B, 114: 243-250 (2014)
[2] H.-Y. Lo et al., Appl. Phys. B, 114: 17-25 (2014).

Q 42.6 Wed 16:30 Empore Lichthof

Superconducting Atom Chips — Christoph Hufnagel[2], Deshui Yu[2], Chee Howe Ew[2], Chin Chean Lim[2], Alessandro Landra[2], and •Rainer Dumke[1,2] — [1]Division of Physics & Applied Physics, School of Physical & Mathematical Sciences, Nanyang Technological University, Singapore — [2]Centre for Quantum Technologies, National University of Singapore, Singapore

Superconducting and Cryogenic Atom Chips

Recently superconducting atom chips have generated a lot of interest due to their attractive properties, such as the Meissner effect for type-I superconductors and vortices for type-II superconductors. Thermal and technical noise in proximity to superconducting surfaces have been shown both theoretically and experimentally to be significantly reduced compared to conventional atom chips. Superconducting atom chips have the potential to coherently interface atomic and molecular quantum systems with quantum solid state devices. I will present recent developments in our superconducting atom chip experiment.

Q 42.7 Wed 16:30 Empore Lichthof

Measurement of ion heating rate in a planar ion trap at variable distance to the trap surface — •Ivan Boldin and Christof Wunderlich — University of Siegen, Germany

Electric field noise in the vicinity of metal surfaces is an important issue in various fields of experimental physics. In experiments with cold trapped ions such noise results in heating of the ions' motional degrees of freedom. In realizations of quantum information processing based on trapped ions this heating can become a major source of decoherence. Since this effect scales as $1/d^4$ (with the ion-electrode separation d), it is particularly prominent for planar electrode ion traps where this separation can be as small as tens of micrometers.

This electric field noise-induced heating has been studied in many experimental and theoretical works over the last years [1 - 3]. However, to our knowledge there has been no direct experimental measurement of the heating rate of ions above a single planar electrode ion trap as a function of the ion-surface separation. Here, we present the result of such measurements. Our trap is made of gold electroplated on sapphire [4]. The ion-surface distance can be varied in the range of 45 - 155 μm. We measure the heating rate by the recooling method that is, measuring the photon scattering rate as a function of time after allowing the ion to heat up for a certain time.

1) L. Deslauriers et al., PRL 97, 103007 (2006);
2) M. Brownnutt et al., arXiv:1409.6572 (2014);
3) I. Talukdar et al., arXiv:1511.0062 (2015);
4) P.J. Kunert et al., Appl. Phys. B 114, 27-36 (2014).

Q 42.8 Wed 16:30 Empore Lichthof

Cryogenic surface-electrode ion trap apparatus — •Timko Dubielzig[1], Sebastian Grondkowski[1], Martina Wahnschaffe[1,2], and Christian Ospelkaus[1,2] — [1]Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover, Germany — [2]PTB, Bundesallee 100, 38116 Braunschweig, Germany

We describe the infrastructure necessary to operate a surface-electrode ion trap with integrated microwave conductors for near-field quantum control of ^{9}Be$^+$ in a cryogenic environment. These traps are promising systems for analog quantum simulators and for quantum logic applications. Our group developed a trap with an integrated meander-like microwave guide for driving motional sidebands on a ^{9}Be$^+$ ion [1]. To suppress electrical field noise, acting on the ion and originating from thermal effects [2], the trap will be operated in a cryogenic vacuum chamber. We will discuss the vibration isolated closed cycle cryostat and the design of the vacuum chamber with all electrical supplies necessary to apply two different microwave currents, DC- and RF-voltages. We will also discuss magnetic-field coils producing an ultra-stable magnetic field at 22.3 mT and the resulting field-independent hyperfine qubit. Furthermore we will present the cryogenic, high aperture and fully acromatic imaging system. We report on recent progress in operation of the apparatus.

[1] Applied Physics B - 10.1007/s00340-013-5689-6 (2013)
[2] J. Chiaverini and J. M. Sage, PRA 89, 012318 (2014)

Q 42.9 Wed 16:30 Empore Lichthof

Towards multi-qubit near-field microwave quantum logic in a multi-layer surface-electrode trap — •Henning Hahn[1,2], Giorgio Zarantonello[1,2], Martina Wahnschaffe[1,2], Matthias Kohnen[1,2], Amado Bautista-Salvador[1,2], and Christian Ospelkaus[1,2] — [1]Leibniz Universität Hannover, Germany. — [2]Physikalisch-Technische Bundesanstalt, Braunschweig Germany.

In quantum information processing with trapped ions, tightly focused laser beams are typically used for coupling internal states and motional states of individual ions as required for multi-qubit entangling gates. However, scaling laser-based techniques for multi-qubit gates remains challenging. In an alternative approach, the desired state coupling is achieved by oscillating microwave near-field gradients created by currents in conductors embedded in a planar ion trap. In an adaption of the first demonstration setup [1], the number of microwave electrodes was reduced to a single meander-like conductor to suppress previously limiting relative phase and current fluctuations by design [2].

Here we discuss the integration of a meander-like conductor into a multi-layer ion trap and address the fabrication process involved. Since residual magnetic fields are reduced, less excitation on off-resonant carrier transitions is expected and thus, gate fidelities can be improved. Moreover, we show a vacuum setup with built-in Ar$^+$ bombardment for reducing motional heating rates by *in-situ* electrode cleaning [3].

[1] C. Ospelkaus *et al.*, Nature, **476**, 181 (2011)
[2] M. Carsjens *et al.*, Appl. Phys. B **114**, 243 (2014)
[3] D. A. Hite *et al.*, Phys. Rev. Lett. **109**, 103001 (2012)

Q 42.10 Wed 16:30 Empore Lichthof

Randomized Benchmarking on Ground State Qubits — •Michael Meth[1], Philipp Schindler[1], Martin van Mourik[1], Matthias Brandl[1], Anton Nolf[1], Thomas Monz[1], and Rainer Blatt[1,2] — [1]Institut für Experimentalphysik, Universität Innsbruck, Technikerstrasse 25, 6020 Innsbruck, Austria — [2]Institut für Quantenoptik und Quanteninformation, Akademie der Wissenschaften, Technikerstrasse 21a, 6020 Innsbruck, Austria

Quantum information processing using optical transitions in ions has been successful for many experiments. Alternatively, quantum information can also be encoded in ground states and processed by lasers driving Raman transitions. This leads to longer coherence times as laser frequency fluctuations have no effect. Here, we report on single qubit operations on ground state qubits in ^{40}Ca$^+$. We characterize the performance of single qubit operations using randomized benchmarking. In order to produce the required number of gates, a new FPGA based control system had to be implemented to allow for longer sequences.

Q 42.11 Wed 16:30 Empore Lichthof

Generating N00N-like (macroscopic) quantum states — •Falk Töppel[1,2], Maria V. Chekhova[1,2], and Gerd Leuchs[1,2] — [1]Max Planck Institute for the Science of Light, Günther-Scharowsky-Straße 1/Bldg. 24, 91058 Erlangen, Germany — [2]Institute for Optics, Information and Photonics, Universität Erlangen-Nürnberg, Staudtstraße 7/B2, 91058 Erlangen, Germany

We demonstrate the potential of a recently proposed protocol for conditional state preparation to generate new and interesting two-mode (macroscopic) quantum states. Our protocol allows one to manipulate the photon number distribution of a two-mode (macroscopic) quantum states of light such that contributions with similar photon numbers in both modes are suppressed. The key feature of the protocol is that quantum entanglement shared between the two modes is preserved.

Let us consider the superposition of a coherent state and a squeezed vacuum state at a 50/50 beam splitter. This quantum state is known to resemble a N00N state with fidelity $> 90\%$ when post-selecting on a certain total photon number, although its photon number distribution is very different from the one of a N00N state. We can enhance the N00N-like contributions of the considered state with the above mentioned protocol. The filtered state exhibits super-resolution when post-selecting on a fixed total number of photons, just as it is known for the considered input state. This indicates that superposition terms are not destroyed by the protocol. We examine entanglement properties of the new quantum state and study its potential to violate Bell's inequality.

Q 42.12 Wed 16:30 Empore Lichthof

Using Schrödinger cat states of Rydberg atoms to measure electric fields — •Eva-Katharina Dietsche, Adrien Facon, Dorian Grosso, Serge Haroche, Jean-Michel Raimond, Michel Brune, and Sebastien Gleyzes — Laboratoire Kastler Brossel, College de France, ENS-PSL, UPMC-Sorbonne Universite, CNRS, 11 Place Marcelin Berthelot 75005 Paris, France

We present a quantum-enabled measurement of the electric field using Rydberg atoms. We prepare the atom in a quantum superposition of two circular states with principle quantum number n=50 and n=51. Using a radiofrequency field resonant with the Stark transition in the n=50 manifold we transfer the n=50 part of the wave function from its horizontal circular orbit to a tilted elliptical trajectory. This creates a Schrödinger cat superposition of two states with very different polarizabilities whose relative phase is highly sensitive to variations in the amplitude of the electric field. Detecting this phase change using Ramsey interferometry allows us to measure the electric field with a precision below the standard quantum limit (SQL). This single-atom-electrometer allows us to measure weak field variations in the order of 1mV/cm in a few tens of nanoseconds, paving the way to non-invasive space- and time-resolved field measurements.

Q 42.13 Wed 16:30 Empore Lichthof

Entanglement of Indistinguishable Particles and its Quantification — •Florian Sokoli and Burkhard Kümmerer — Fachbereich Mathematik, TU Darmstadt

In this contribution we propose measures of entanglement for indistinguishable particles which are based on generalized norms. These measures are capable of quantifying entanglement of indistinguishable particles in the most general scenario of arbitrary multipartite (mixed) quantum states in any dimension. In particular, we obtain a necessary and sufficient separability criterion for this case. We demonstrate that these measures are related to corresponding measures of entanglement for distinguishable particles by a state-independent factor of $k!$ where k is the number of particles.

Ref.: F. Sokoli, B. Kümmerer: arXiv:1507.04615v1

Q 42.14 Wed 16:30 Empore Lichthof

Maximally entangled vs. separable: An approach to the characterization of random unitary channels — •Daniel Bruns, Jan Sperling, and Stefan Scheel — Insitut für Physik, Rostock

Modern applications in quantum computation and quantum communication necessitate the characterization of quantum states and quantum channels. In practice, this means that one has to determine the quantum performance of a physical system in terms of measurable quantities. Witnesses, if properly constructed, succeed in doing this task. We derive a method that is capable to construct witnesses for the characterization of channels, whose dynamics can be formulated solely in terms of a statistical mixture of unitary evolutions. Those *random unitary channels* were studied in [1] as giving evidence for classical error mechanisms occurring in the preparation and processing of quantum states.

It has been shown that random unitary channels are equivalent to bipartite quantum states decomposable into a convex combination of maximally entangled states. Conversely, a separable state is defined as a mixture of product states. Based on our treatment we are able to witness these opposing attributes at once and, furthermore, get an insight into the different geometric structures.

[1] K.M.R. Audenaert and S. Scheel. New J. Phys. 10, 023011 (2008)

Q 42.15 Wed 16:30 Empore Lichthof

Gaussian Quantum Steering of Two Bosonic Modes in a Thermal Environment — •Tatiana Mihaescu[1,2] and Aurelian Isar[2] — [1]Institute of Theoretical Physics, Heinrich Heine University of Duesseldorf, Germany — [2]Department of Theoretical Physics, National Institute of Physics and Nuclear Engineering, Bucharest-Magurele, Romania

Einstein-Podolsky-Rosen steerability of quantum states is a property that is different from entanglement and Bell nonlocality. We describe the time evolution of a recently introduced measure that quantifies steerability for arbitrary bipartite Gaussian states [1] in a system consisting of two bosonic modes embedded in a common thermal environment.

We work in the framework of the theory of open systems. If the initial state of the subsystem is taken of Gaussian form, then the evolution under completely positive quantum dynamical semigroups assures the preservation in time of the Gaussian form of the state [2].

We study Gaussian quantum steering in terms of the covariance matrix under the influence of noise and dissipation and find that the thermal noise introduced by the environment destroys the steerability between the two parts [3].

We make a comparison with other quantum correlations for the same system, and show that, unlike Gaussian quantum discord, which is decreasing asymptotically in time, the Gaussian quantum steerability suffers a sudden death behaviour, like quantum entanglement.

Q 42.16 Wed 16:30 Empore Lichthof

Joint measurability and Channel Steering — •Fabiano Lever — University of Siegen, Sigen, Germany

The task of quantum steering refers to the idea of one party, (Alice) remotely affecting another party (Bob) state by performing local measurements on her half of a bipartite state. While entanglement between the two parties is a fundamental ingredient for the task, alone it is not sufficient. Steering requires stronger correlations than just entanglement. Moreover, it has recently been shown that in order to prove steering, Alice has to use incompatible measurements on her subsystem. This fact points us to the idea that incompatibility is necessary to perform measurament based quantum tasks.

Our work focuses on the application of this idea to the steering of broadcast quantum channels (i.e. channles with more that one output), modeling scenarios in which some of the information leaks to the environment. In particular, we show that there is a one to one mapping between the steerability of quantum channels and the joint measurability problem for a set of POVMs.

Q 42.17 Wed 16:30 Empore Lichthof

Compatibility and Noncontextuality for Imperfect Measurements — •Jannik Hoffmann, Costantino Budroni, and Otfried Gühne — Naturwissenschaftlich-Technische Fakultät, Universität Siegen, Walter-Flex-Str. 3, 57068 Siegen, Germany

The notion of contextuality refers to impossibility of a classical description for each observable, which is independent of the measurement context, i.e., the set of compatible measurements done with it. Initially defined for commuting projective measurements [1,2], there have been different attempts to extend the notion of contextuality to deal with imperfect measurements and experimental errors. Here, we will focus on the error parameters introduced by Gühne et al. [3] and Kujala et al. [4] and investigate the questions of which errors can be detected and what is the relation with the original notion of noncontextuality. In particular, we discuss the case of sequential projective measurements, with and without noise, and more general measurements described by positive operator valued measures (POVMs) and instruments.

References

[1] S. Kochen and E. P. Specker, J. Math. Mech. 17, 59 (1967).
[2] A. A. Klyachko, M. A. Can, S. Binicioglu, and A. S. Shumovsky, Phys. Rev. Lett. 101, 020403 (2008).
[3] O. Gühne, M. Kleinmann, A. Cabello, J.-Å. Larsson, G. Kirchmair, F. Zähringer, R. Gerritsma, C.F. Roos, Phys. Rev. A 81, 022121 (2010).
[4] J. V. Kujala, E. N. Dzhafarov, J.-Å. Larsson Phys. Rev. Lett. 115, 150401 (2015).

Q 42.18 Wed 16:30 Empore Lichthof

Witnessing genuine multilevel entanglement — •Tristan Kraft, Christina Ritz, and Otfried Gühne — Department Physik, Universität Siegen, Germany

Entanglement is arguably one of the most intriguing phenomena in physics and is believed to be a fundamental resource for quantum communication and quantum information. In recent years due to the hard work of many experimentalists the preparation of entangled systems with dimensions larger than two became feasible. Therefore it is necessary to have strong entanglement criteria to detect genuine multilevel entanglement in higher dimensional systems.

Here we present entanglement criteria based on qudit graph states which are generalizations of the well known qubit graph states. We also discuss the fact that in some cases the certification of genuine multilevel entanglement does not imply the ability to coherently manipulate a qudit system in its entirety.

Q 42.19 Wed 16:30 Empore Lichthof

Logic operations with polarization-encoded x-rays processed by nuclear transitions — •Jonas Gunst, Christoph H. Keitel, and Adriana Pálffy — Max-Planck-Institut für Kernphysik, Heidelberg

Since the computational demands are expected to become increasingly complex over time, a basic goal of information science is to build storage and processing devices in their most compact form. In the case of photonic circuits, the size is fundamentally limited by the diffraction limit of the used photons ($\sim 1\mu$m for optical photons) which could be drastically reduced by going to shorter wavelengths like for instance x-rays. However, using polarization-encoded x-rays as information carriers requires control schemes performed on the single-photon level.

Here, we investigate theoretically how to manipulate the x-ray polarization by employing the resonant interaction with low-lying nuclear transitions ($\sim$ keV). In the course of nuclear forward scattering on ensembles of Mössbauer ^{57}Fe nuclei, the collective response becomes sensitive to the incoming polarization state under the impact of an external magnetic field [1]. We show that it is possible to perform logical operations on polarization-encoded x-rays by applying a rotation of the magnetic field temporally synchronized with the nuclear excitation [2]. This x-ray processing scheme can be tested and quantified experimentally at present synchrotron radiation facilities.

[1] Yu. V. Shvyd'ko *et al.*, Phys. Rev. Lett. **77**, 3232 (1999).
[2] J. Gunst *et al.*, arXiv:1506.00517 (2015).

Q 42.20 Wed 16:30 Empore Lichthof

Räumlich getrennte Bellzustände in einer segmentierten Paulfalle — •Thomas Ruster, Henning Kaufmann, Christian Schmiegelow, Jonas Schulz, Ferdinand Schmidt-Kaler und Ulrich Poschinger — QUANTUM, Institut für Physik, Universität Mainz, Staudingerweg 7, 55128 Mainz, Germany

Bellzustände sind die Grundlage für vielfältige Anwendungen, z.B. für Quantenrepeater [1], Hochpräzisionsmessungen [2], oder zur Erzeugung dekohärenzfreier Quantenbits [3]. In segmentierten Paulfallen lassen sich Bellzustände nicht nur erzeugen, sondern auch über makroskopische Distanzen voneinander trennen. Das ermöglicht die Skalierung von Experimenten auf eine höhere Anzahl an Ionen und die präzise Vermessung von inhomogenen Magnetfeldern.

Zur Realisierung skalierbarer Experimente kombinieren wir Laser-Ion-Wechselwirkungen mit dem Transport von Ionen innerhalb der Falle und dem Trennen bzw. Zusammenfügen von Ionenkristallen [4,5].

Wir zeigen, dass die Kohärenzzeit von Bellzuständen unverändert bleibt, selbst wenn deren konstituierenden Ionen auf makroskopische Distanzen bis zu 5.5mm voneinander getrennt werden.

[1] H. J. Kimble, Nature **453**, 1023-1030 (2008)
[2] V. Giovannetti et al., Phys. Rev. Lett. **96**, 010401 (2006)
[3] H. Häffner et al., Appl. Phys. B **81**, 151 (2005)
[4] R. Bowler et al., Phys. Rev. Lett. **109**, 080502 (2012)

[5] T. Ruster et al., Phys. Rev. A **90**, 033410 (2014)

Q 42.21 Wed 16:30 Empore Lichthof

Increasing the information content of single photons — •Tristan Tentrup, Thommas Hummel, Allard Mosk, and Pepijn Pinkse — MESA+ Institute for Nanotechnology, Universiteit Twente

A common way to encode information in single photons is the use of polarization, which allows a maximum of 1 bit per photon. Encoding in a higher dimensional Hilbert space allows to transfer more information per photon. Examples of encoding methods are time binning and the use of orbital angular momentum states. We use a spatial light modulator (SLM) to control the spatial position of single photons generated by a spontaneous parametric down-conversion source. Exploiting modern two-dimensional photon counting imaging systems, we detect their (x,y) positions and discuss the limit on information density. A possible application of this work is Quantum Key Distribution (QKD), where an increase in information per photon not only increases the possible key generation rate but also the security of the protocol.

Q 42.22 Wed 16:30 Empore Lichthof

Proposal for a telecom quantum repeater with single atoms in optical cavities — •Manuel Brekenfeld, Manuel Uphoff, Dominik Niemietz, Stephan Ritter, and Gerhard Rempe — Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Str. 1, 85748 Garching, Germany

Quantum repeaters hold the promise to enable long-distance quantum communication via entanglement generation over arbitrary distances. Single atoms in optical cavities have been shown to be ideally suited for the experimental realization of many tasks in quantum communication [1]. To utilize these systems for a quantum repeater, it would be desirable to operate them at telecom wavelengths. We propose to use a cascaded scheme employing transitions at telecom wavelengths between excited states of alkali atoms for entanglement generation between a single photon at telecom wavelength and a single atom at the crossing point of two cavity modes [2]. A cavity-assisted quantum gate can be used for entanglement swapping. We estimate the performance of these systems using numerical simulations based on experimental parameters obtained for CO_2 laser-machined fiber cavities in our laboratory. Finally, we show that a quantum repeater employing the aforementioned scheme and current technology could outperform corresponding schemes based on direct transmission.

[1] Ritter *et al.*, Nature **484**, 195 (2012)
[2] Uphoff *et al.*, arXiv:1507.07849 (2015)

Q 42.23 Wed 16:30 Empore Lichthof

A cavity mediated photon-photon gate — •Stephan Welte, Bastian Hacker, Stephan Ritter, and Gerhard Rempe — Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Str. 1, 85748 Garching

Photons are promising candidates for applications in quantum information processing and quantum communication. However, the direct interaction between two photons is negligible in free space, which is a drawback when it comes to the implementation of quantum logic gates between them. A solution to this problem was proposed by Duan and Kimble [1]. A strongly coupled atom in an optical cavity can mediate an effective interaction between two photons. Recently, we experimentally realized a quantum gate between an intracavity atom and a photon which is reflected off the cavity [2]. This atom-photon gate can be a building block of the aforementioned gate protocol for two photons. We will discuss the prospects and challenges for implementing the Duan-Kimble proposal in our setup and report on the current status of the experiment.

[1] L.-M. Duan, H. J. Kimble, Phys. Rev. Lett. 92, 127902 (2004)
[2] A. Reiserer, N. Kalb, G. Rempe and S. Ritter, Nature 508, 237 (2014)

Q 42.24 Wed 16:30 Empore Lichthof

Entanglement Dynamics in Superconducting Phase Qudits under Pythagorean Control — •Daniel Basilewitsch[1], Nadav Katz[2], and Christiane Koch[1] — [1]Institute of Physics, University of Kassel, Kassel, Germany — [2]Racah Institute of Physics, The Hebrew University of Jerusalem, Jerusalem, Kassel

Pythagorean control of a superconducting phase qudit has recently been demonstrated in first experiments. The concept of Pythagorean control generalizes population inversion in a two level system, which is solved by Rabi oscillations, to four levels. We analyze the observed state dynamics of the qudit and determine the available quantum gates when interpreting the four-level qudit as two coupled qubits. In the strong field regime, the state dynamics differs from that expected with Pythagorean control due to the presence of additional levels and the finite anharmonicity of the qudit ladder. Moreover, Pythagorean control is compromised by the coupling of the qudit to its environment, causing decoherence. We use optimal control theory (OCT) to adapt the analytical controls to the presence of additional levels and decoherence, to counter the effects of finite anharmonicity and to improve gate fidelities and times.

Q 42.25 Wed 16:30 Empore Lichthof

Optimal absorption of a photon by a quantum node — Susanne Blum[1,2], •Tom Schmit[1], Daniel Reich[3,4], Tommaso Calarco[5], Christiane Koch[3], and Giovanna Morigi[1] — [1]Universität des Saarlandes, Saarbrücken, Germany — [2]Theodor-Heuss-Gymnasium, Esslingen, Germany — [3]Universität Kassel, Kassel, Germany — [4]Universität Aarhus, Aarhus, Denmark — [5]Universität Ulm, Ulm, Germany

We discuss protocols for achieving perfect absorption of a photon by a single trapped atom, or solid-state emitter, in a high-finesse cavity. Specifically, we compare the efficiency of protocols based on adiabatic transfer with the one of protocols based on optimal control theory. We focus on the setup of [Reiser et al., Nature 508, 237 (2014)]. Our ultimate goal is to identify the conditions on external fields driving the atom, which are required for absorbing a photon of *arbitrary* spectral form. We discuss the efficiency of the protocols for a certain class of photonic wave forms. This analysis contributes to the development of a toolbox for quantum networks using hybrid platforms.

Q 42.26 Wed 16:30 Empore Lichthof

Analyse einiger Quantenrepeaterprotokolle am konkreten Aufbau einer existierenden Ionenfalle — •Andreas Pfister, Marcel Salz, Max Hettrich, Ulrich Poschinger und Ferdinand Schmidt-Kaler — QUANTUM, Institut für Physik, Johannes-Gutenberg-Universität Mainz

Anhand eines existierenden Aufbaus werden mehrere Protokolle zur Verteilung von Verschränkung in Quantenrepeatern verglichen [1]. Der Aufbau basiert auf einer mikrostrukturierten, segmentierten linearen Paulfalle für $^{40}Ca^+$, in der ein faserbasierter Mikroresonator als Licht-Ionen-Schnittstelle fungiert, dessen kleines Modenvolumen eine hohe Kopplungsrate von $g_c = 2\pi \times 20$ MHz ermöglicht, trotz relativ hoher Verluste von $\kappa = 2\pi \times 36.6$ MHz. Ionen können in der Falle in den Resonator hinein- und heraus bewegt werden, so dass mehrere Qubits über einen I/O Port kommunizieren können.

Es wurden ein Protokoll basierend auf Verteilung verschränkter Photonen untersucht [2], eine Variation des DLCZ-Algorithmus [3] und ein hybrides Protokoll [4]. Die Abschätzung für die Verschränkungsverteilung ergibt Raten von ca. 30 s^{-1} für nichtlokale Bellzustände mit Fidelities größer 0.9. Es werden die Parameter identifiziert, die die Rate am stärksten begrenzen. Raten von einigen hundert Verschränkungen pro Sekunde scheinen mit aktueller Technologie erreichbar.

[1] A. Pfister et al., arXiv:1508.05272 (2015)
[2] N. Sangouard et al. , *New J. Phys.*, 15(8):085004, 2013.
[3] L.-M. Duan et al, *Nature*, 414:413–418 (2001).
[4] P. van Loock et al., *Phys. Rev. Lett.*, 96:240501 (2006).

Q 42.27 Wed 16:30 Empore Lichthof

A Fast Multichannel Signal Generator for Segmented Ion Traps — •Vidyut Kaushal, Heinz Lenk, Kilian Singer, Ferdinand Schmidt-Kaler, and Ulrich Poschinger — QUANTUM, Institut für Physik, Universität Mainz, Staudingerweg 7, 55128 Mainz, Germany

Modern segmented ion traps require hardware for individual real-time control of the segment voltages, with stringent requirements on signal integrity and sampling rate. We present the functional design of a fast multichannel, arbitary waveform generator, which supports up to 80 independent analog output channels. The device reaches a maximum analog update rate of 3.9 million samples/s for all channels simultaneously. Additionally, the delay between consecutive samples can be controlled in steps of 20 ns, resolving typical trap oscillation periods - a crucial feature for the control of fast shuttling operations [1,2]. The output voltage range of ± 40 V allows for tight confinement of trapped ions and compensation of signal distortion.

We describe the architecture of the device in detail and present a thorough characterization of the relevant signal characteristics, such as slew rate, long-time stability, nonlinearities, glitch impulse areas and output noise. We also discuss future extensions towards a complete real-time control system including feedback capbilities.

[1] A. Walther et al., PRL 109, 080501 (2012)
[2] T. Ruster et al., PRA 90, 033410 (2014)

Q 42.28 Wed 16:30 Empore Lichthof

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

Ion traps are a promising tool for quantum simulators and quantum computers [1]. Microfabricated surface traps offer the possibility to miniaturize ion traps, which is a possible route towards a scalable quantum computer. However, the proximity of the ions to the surface of the trap leads to motional heating, the origin of which is not well understood [2].

To investigate different sources of motional heating, we operate a surface ion trap made of YBCO, a high-temperature superconducting material. The trap is designed in such a way that Johnson noise should be the dominant source of motional heating above the critical temperature $T_c \approx 85$ K, whereas below T_c it should be negligible compared to other noise sources. Using a local heating element, we adjust the temperature of the trap chip and observe the superconducting transition by measuring the Q factor of the RF resonant circuit or the resistance of on-chip structures. Probing the motional heating of a trapped ion, we expect to observe pronounced changes in the characteristics of the electric field noise in a small temperature range around T_c.

[1] R. Blatt, C.F. Roos, Nature Phys. 8, 277 (2012)
[2] M. Brownnutt, M. Kumph, P. Rabl, and R. Blatt, arXiv:1409.6572 (2014)

Q 42.29 Wed 16:30 Empore Lichthof

Scaling down cryogenic surface ion traps for quantum information processing — •Kirill Lakhmanskiy[1], Philip Holz[1], Stefan Partel[2], Stephan Kasemann[2], Volha Matylitskaya[2], Johannes Edlinger[2], Yves Colombe[1], and Rainer Blatt[1,3] — [1]Institute for Experimental Physics, University of Innsbruck, Austria — [2]Fachhochschule Vorarlberg, Dornbirn, Austria — [3]Institute for Quantum Optics and Quantum Information, Innsbruck, Austria

Ion traps are a promising platform for quantum information processing. We report on our recent experimental results with microfabricated surface ion traps in cryogenic environment using two different trapping architectures. In the first project we use linear surface ion traps based on intrinsic silicon. These traps were fabricated using a deep reactive-ion etching process followed by silicon oxidation and metal deposition. We were able to show very low motional heating rates at an ion-electrode separation of 230 μm [1]. Our current goal is to scale down the traps while keeping the heating rate sufficiently low to perform high-fidelity quantum operations. The aim of the second project is to realize a 2D array of individual point traps for quantum simulation. We use a microfabricated 4×4 ion trap array with an ion-ion separation of 100 μm. This distance may be reduced while operating the trap using switchable RF electronics [2], to a point where coherent operations mediated by the Coulomb interaction become possible.

[1] M. Niedermayr et al., New J. Phys. 16, 113068 (2014)
[2] M. Kumph, P. Holz, K. Langer, M. Niedermayr, M. Brownnutt, and R. Blatt, arXiv:1402.0791

Q 42.30 Wed 16:30 Empore Lichthof

Optimizing a quantum computer with randomized benchmarking — •Roman Stricker, Alexander Erhard, Daniel Nigg, Esteban Martinez, Philipp Schindler, Thomas Monz, and Rainer Blatt — Institute for Experimental Physics, University of Innsbruck, Austria

The realization of a quantum computer has become a major research field over the last decade. For a successfull implementation, error-sources need to be kept as small as possible. One promising way of characterizing these errors is by means of randomized benchmarking. We report on an experiment characterizing Clifford operations. The experiment is performed on a $^{40}Ca^+$ ion-trap quantum computer. The goal was to implement randomly chosen sets of single-qubit gates with arbitrary lengths, where each specific set is chosen to be a self-inverting sequence. Measuring the difference between the experimental outcome and the ideal transformation leads to an estimation of the fidelity of a certain set. To obtain the fidelity of a single gate, we analyze the result of different random sequences. We use this as a tool to improve our experimental setup, such as stabilizing the lasers intensity or reducing fiber noise. We found a single-qubit fidelity of above 99%.

Q 42.31 Wed 16:30 Empore Lichthof

Entangling two single trapped atoms over a distance of 400 m — •Robert Garthoff[1], Daniel Burchardt[1], Norbert Ortegel[1], Kai Redeker[1], Wenjamin Rosenfeld[1], and Harald Weinfurter[1,2] — [1]Ludwig-Maximilians-Universität, München — [2]Max-Planck-Institut für Quantenoptik, Garching

Long distance between entangled quantum systems is essential for quantum repeaters as well as for conclusive tests of Bell's inequality, which itself is a central part in novel applications as device-independent quantum key distribution and certified generation of quantum random numbers.

We present an experimental realization employing heralded entanglement between two single Rb-87 atoms over a distance of 400 meter. To achieve a high degree of entanglement precise control of external parameters is required. In addition to the long distance requiring long coherence times, we implemented an fast and efficient atomic state readout with an overall duration of the state measurement below 1μs. In order to obtain a high number of events a longtime stability of the experimental setup presents an additional challenge. Together these ingredients form the basis for robust generation of entanglement and space-like separated measurements on the widely separated atoms as necessary for a conclusive test of Bell's inequality. Moreover this system represents a basic quantum repeater link and may become a testing platform for device-independent quantum key distribution.

Q 42.32 Wed 16:30 Empore Lichthof

Quantum Key Distribution from a mobile phone — Gwenaelle Mélen[1], Tobias Vogl[1], Markus Rau[1], •Silvan Streit[1,2], Peter Freiwang[1], Giacomo Corrielli[3,4], Andrea Crespi[3,4], Roberto Osellame[3,4], and Harald Weinfurter[1,5] — [1]Faculty of Physics, Ludwig-Maximilians-Universität, 80799 München, Germany — [2]Department of Electrical and Computer Engineering, Technische Universität München, 80333 München, Germany — [3]Istituto di Fotonica e Nanotecnologie, Consiglio Nazionale delle Ricerche (IFN-CNR), 20133 Milano, Italy — [4]Dipartimento di Fisica, Politecnico di Milano, 20133 Milano, Italy — [5]Max-Planck-Institut für Quantenoptik, 85748 Garching bei München, Germany

We present an integrated optics module enabling Quantum Key Distribution from a small and mobile sender device. The new optics platform ($35\times20\times8$ mm) uses a VCSEL array, micro-optical elements and laser written waveguides to generate NIR faint polarised laser pulses with 100 MHz repetition rate. Fully automated beam tracking and live basis-alignment on Bob's side ensure user-friendly operation with a secret key rate over 100 kHz. Using BB84-like protocols, Alice's low-cost mobile device can exchange secure key and information everywhere within a trusted node network.

Q 42.33 Wed 16:30 Empore Lichthof

A Fabry-Perot Microcavity for diamond based (NV) quantum information and communication processing — •Roland Nagy[1], Sen Yang[1], Helmut Fedder[1], Durga Dasari[1,2], and Jörg Wrachtrup[1,2] — [1]3rd Institute of Physics and Research Center SCOPE, University of Stuttgart, Pfaffenwaldring 57, 70569 Stuttgart, Germany — [2]Max Planck Institute for Solid State Research, Stuttgart

A high fidelity coupling of solid-state spins to microcavities opens up new prospectives for the field of quantum communications and quantum information processing. With applications towards photon memories, and entangled photon generation they could become key elements in quantum networks transporting quantum states and entanglement over long distances.

In this poster I will present a scheme to couple the electronic states of a Nitrogen Vacancy (NV) center in a thin diamond membrane to a Fabry-Perot cavity [1]. In the presence of a long-lived nuclear spin I will show how this system could become a robust hybrid device to store and entangle photons [2].

[1]. Erika Janitz et al. Phys. Rev. A 92, 043844
[2]. D. D. Bhaktavatsala Rao et al. Phys. Rev. B 92, 081301(2015)(R)

Q 42.34 Wed 16:30 Empore Lichthof

Pulse-controlled quantum gate sequences on a strongly coupled qubit chain — •Holger Frydrych[1], Michael Marthaler[2], and Gernot Alber[1] — [1]Technische Universität Darmstadt, Germany — [2]Karlsruher Institut für Technologie, Germany

We propose a selective dynamical decoupling scheme on a chain of permanently coupled qubits with XX type interactions, which is capable of dynamically suppressing any coupling in the chain by applying sequences of local pulses to the individual qubits. We demonstrate that high-fidelity single- and two-qubit gates can be achieved by this procedure and that sequences of gates can be implemented by this pulse control alone. We discuss the applicability and physical limitations of our model specifically for strongly coupled superconducting flux qubits. Since dynamically modifying the couplings between flux qubits is challenging, they are a natural candidate for our approach.

Q 42.35 Wed 16:30 Empore Lichthof

Estimating necessary detector efficiencies for a Bell test using semidefinite programming — •Alexander Sauer, Nils Trautmann, and Gernot Alber — Institut für Angewandte Physik, Technische Universität Darmstadt

Loophole free violation of Bell inequalities is crucial for fundamental tests of quantum nonlocality. It is also important for future applications, such as device-independent quantum cryptography. Based on a detector model which includes detector inefficiencies and dark counts, we estimate the minimal requirements on detectors for performing a loophole free Bell test. Thereby, we also search for Bell inequalities which are robust against imperfect detectors in a bipartite setup. Our numerical investigation is based on semidefinite programming for characterizing possible quantum correlations[1]. We also examine critical detector efficiencies for a specific energy-time entanglement-based Bell experiment[2] designed to overcome limitations of Franson-type interferometers[3].

[1] M. Navascues, S. Pironio, and A. Acín, 2008, New J. Phys. 10, 073013. [2] A. Cabello, A. Rossi, G. Vallone, F. De Martini, and P. Mataloni, 2009, Phys. Rev. Lett. 102, 040401. [3] J.D. Franson, 1989, Phys. Rev. Lett. 62, 2205.

Q 42.36 Wed 16:30 Empore Lichthof

Entanglement purification of distant atomic Qubits with ancillary multiphoton states — •Ludwig Kunz, József Zsolt Bernád, Mauricio Torres, and Gernot Alber — Institut für Angewandte Physik, Technische Universität Darmstadt, 64289 Darmstadt, Germany

We propose a scheme for conducting entanglement purification on distant two-level atoms. The atomic qubits are sent through a cavity one after the other and interact with a single mode of the radiation field inside the cavity. The atoms are post-selected by measuring the cavity field with the help of a balanced homodyne detection. It is demonstrated that the resulting quantum operation is a convenient basic building block for an entanglement purification protocol.

Q 42.37 Wed 16:30 Empore Lichthof

Two-photon interference with a non-degenerate photon-pair source — Gerhard Schunk, •Golnoush Shafiee, Ulrich Vogl, Dmitry Strekalov, Alexander Otterpohl, Navid Soltani, Florian Sedlmeir, Harald G. L. Schwefel, Gerd Leuchs, and Christoph Marquardt — Max Planck Institute for the Science of Light, Institute for Optics, Information and Photonics, University Erlangen-Nuremberg, Erlangen, Germany

Single photons and photon pairs are an important resource for quantum information processing. Our compact source of photon pairs [1] and squeezed light [2] is based on spontaneous parametric down conversion (SPDC) in a triply resonant whispering-gallery resonator (WGR) made of lithium niobate. Single-mode operation of this source has been shown. We recently demonstrated the tuning of our SPDC source to different narrowband atomic transitions in the near-infrared, which makes our source compatible with a wide range of atomic quantum memories [3].

We currently investigate SPDC in counter-propagating modes in one WGR, which can be viewed as two identical photon-pair sources. Here we study entanglement creation via the interference of two heralded signal photons. This system opens up novel possibilities to realize proposed quantum repeater schemes.

[1] M. Förtsch et al., Nat. Commun. 4, 1818 (2013). [2] J. U. Fürst et al., Phys. Rev. Lett. 106, 113901(2011). [3] G. Schunk et al., Optica 2, 773-778 (2015).

Q 42.38 Wed 16:30 Empore Lichthof

Entangling the whole by beam splitting one part — •Christian Peuntinger[1,2], Callum Croal[3], Vanessa Chille[1,2], Christoph Marquardt[1,2], Gerd Leuchs[1,2], Natalia Korolkova[3], and Ladislav Mišta Jr.[4] — [1]Max Planck Institute for the Science of Light, Guenther-Scharowsky-Str. 1/Bldg. 24, D-91058 Erlangen, Germany — [2]Institute of Optics, Information and Photonics, University of Erlangen-Nuremberg, Staudtstr. 7/B2, D-91058 Erlangen, Germany — [3]School of Physics and Astronomy, University of St.Andrews, North Haugh, St. Andrews, Fife, KY16 9SS, Scotland — [4]Department of Optics, Palacký University, 17.listopadu 12, 771 46 Olomouc, Czech Republic

A beamsplitter is a widely used optical element to create continuous variable entanglement. In the case of Gaussian states, the input modes need to exhibit squeezing for this purpose. We experimentally demonstrate the creation of entanglement by mixing two modes, which do not possess the required squeezing themselves [1]. This is possible if the modes are correlated to a third mode, which can be separable. The three mode states we are utilizing are the prerequisite of the distribution of entanglement [2,3] and the sharing of entanglement [4] by means of a separable mode. The creation of entanglement using a seemingly unsuitable two mode state highlights the role of global correlations.

[1] Callum Croal et al., Phys. Rev. Lett. **115**, 190501 (2015).
[2] L. Mišta, Jr. and N. Korolkova, Phys. Rev. A **77**, 050302(R) (2008).
[3] L. Mišta, Jr. and N. Korolkova, Phys. Rev. A **80**, 032310 (2009).
[4] L. Mišta, Jr., Phys. Rev. A **87**, 062326 (2013).

Q 42.39 Wed 16:30 Empore Lichthof

Towards squeezing distillation for free-space links — •Andreas Thurn, Kevin Günthner, Christian Peuntinger, Dominique Elser, Christoph Marquardt, and Gerd Leuchs — Max Planck Institute for the Science of Light (MPL), Erlangen, Germany and Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU)

Squeezed states of light are an important resource for continuous variable quantum information protocols. Such states are fragile and degraded during transmission due to unavoidable coupling to the environment leading to excess noise and loss. Squeezing distillation is a way to overcome this degradation of squeezed states and has already been successfully implemented in a laboratory environment [1]. We want to go beyond laboratory experiments and investigate the potential of squeezing distillation in the case of natural noise stemming from a free-space link. This link is a realistic intra city free-space channel of 1.6km length being subject to atmospheric turbulences [2].

[1] J. Heersink *et al.*, Phys. Rev. Lett. **96**, 253601 (2006).
[2] C. Peuntinger *et al.*, Phys. Rev. Lett. **113**, 060502 (2014).

Q 42.40 Wed 16:30 Empore Lichthof

Quantum Receivers for Coherent Communication — •Sourav Chatterjee[1,2], Christian R. Müller[1,2], Gerd Leuchs[1,2], and Christoph Marquardt[1,2] — [1]Max Planck Institute for the Science of Light, Erlangen, Germany — [2]Department of Physics, University of Erlangen-Nuremberg (FAU), Germany

The impossibility of perfectly discriminating non-orthogonal states is vital for quantum key-distribution. In classical communication, however, it imposes strict constraints on channel capacity. Conventional receiver architectures for coherent state alphabets are approaching their sensitivity limit -the standard quantum limit (SQL). Quantum mechanics allows for a much lower error bound compared to SQL, the Helstrom bound. This imposes a need for innovations on receiver technologies. Optimal and near-optimal strategies have been proposed and experimentally demonstrated for binary phase-shift keying (BPSK) [1]. For quadrature phase-shift keying (QPSK), a hybrid receiver, based on a combination of homodyne and single photon detection, was demonstrated to outperform the SQL for any signal power [2]. Moreover, a near-optimal, feedback supplemented strategy with photon number resolution technology was proposed in our group [3], and research is in progress to realize this receiver experimentally. We review the recent progress on quantum receivers and compare different strategies on performance and robustness against technical imperfections.

[1] C. Wittmann et al., Phys. Rev. Lett. 101, 210501 (2008) [2] C. R. Müller et al., New J. Phys. 14, 083009 (2012) [3] C. R. Müller et al., New J. Phys. 17, 032003 (2015)

Q 42.41 Wed 16:30 Empore Lichthof

Free-space quantum key distribution at a wavelength of 10.6 μm using continuous variables — •Kevin Jaksch[1,2], Imran Khan[1,2], Tobias Frank[1,2], Jonas Geyer-Ramsteck[1,2], Christian Peuntinger[1,2], Birgit Stiller[1,2,3], Ulrich Vogl[1,2], Dominique Elser[1,2], Christoph Marquardt[1,2], and Gerd Leuchs[1,2,4] — [1]Max Planck Institute for the Science of Light Erlangen, Germany — [2]Institute of Optics, Information and Photonics, University of Erlangen-Nuremberg, Germany — [3]Centre for Ultrahigh bandwidth Devices for Optical Systems (CUDOS), School of Physics, University of Sydney, NSW 2006, Australia — [4]Department of Physics, University of Ottawa, 25 Templeton, Ottawa, ON, Canada

A beam of light, transmitted through the atmosphere, is scattered by atmospheric particles. If the wavelength is much larger than the particle size, these losses are significantly reduced. We propose a novel free-space quantum key distribution (QKD) system operating at a wavelength of 10.6 μm (which is much larger than the size of a water droplet under hazy conditions) in the continuous-variable domain. We plan to use the polarization degree of freedom to encode quantum states and continuous-variable Stokes detection as a measurement scheme. This measurement benefits from a higher detection efficiency than direct detection and acts as a narrowband filter against backround noise sources. We study the feasibility of this wavelength for atmospheric quantum communication, considering beam propagation effects and the performance of the available technology. Note, that there are no single-photon detectors available at this wavelength.

Q 42.42 Wed 16:30 Empore Lichthof

Suppression of Rabi oscillations in hybrid optomechanical systems — •Timo Holz[1,2], Ralf Betzholz[2], and Marc Bienert[2] — [1]Heinrich-Heine-Universität, Düsseldorf, Germany — [2]Universität des Saarlandes, Saarbrücken, Germany

In a hybrid optomechanical setup consisting of a two-level atom in a cavity with a pendular end mirror, the interplay between the light field's radiation pressure on the mirror and the dipole interaction with the atom can lead to an effect, which manifests itself in the suppression of Rabi oscillations of the atomic population. This effect is present when the system is in the so-called single-photon strong-coupling regime. We consider this nonlinear effect in different parameter regimes, both numerically and analytically and study the quantum dynamics in the Wigner phase space. We conclude by discussing the dissipative dynamics of the hybrid optomechanical system.

Phys.Rev.A 92, 043822 (2015)

Q 42.43 Wed 16:30 Empore Lichthof

Coupling cold atoms to a cryogenically cooled optomechanical device — •Tobias Wagner[1], Christina Staarmann[1], Philipp Christoph[1], Ortwin Hellmig[1], Andreas Bick[1], Klaus Sengstock[1], Hai Zhong[2], Alexander Schwarz[2], and Roland Wiesendanger[2] — [1]Center for Optical Quantum Technologies, Hamburg, Germany — [2]Insitute for Applied Physics, Hamburg, Germany

We present work towards a new hybrid quantum system consisting of a sample of cold atoms coupled to a cryogenically precooled mechanical oscillator. Our ultimate goal is the investigation of two very different macroscopically large quantum systems coherently coupled to each other. For this purpose we have set up a Rubidium-BEC apparatus coupled to a SiN membrane placed inside a fiber Fabry Perot cavity via an optical lattice. This membrane in the middle system is cooled to below 500mK in a dilution refrigerator. We present details on the coupling laser system including a Pound Drever Hall lock of the fiber Fabry Perot cavity, a highly sensitive homodyne detection setup for the membrane motion and a coupling lattice. In order to tune the parameters of the coupling lattice the frequency of the coupling laser is locked to atomic resonance with an adjustable offset via a transfer lock. The homodyne detection is able to detect thermal membrane motion at cryogenic temperatures and we present first results regarding further feedback cooling of the membrane.

This work is supported by the DFG grants no. BE 4793/2-1 and SE 717/9-1.

Q 42.44 Wed 16:30 Empore Lichthof

Hybrid optomechanics with cold atoms and a nanomechanical membrane — Thomas Karg, •Andreas Jöckel, Aline Faber, Tobias Kampschulte, Lucas Béguin, and Philipp Treutlein — Departement Physik, Universität Basel, Schweiz

Hybrid systems in which a mechanical degree of freedom is coupled to a microscopic quantum system promise control and detection of mechanical motion at the quantum level. This will open up possibilities for precision sensing, quantum signal transduction and fundamental tests of quantum mechanics. In our experiment we study the interaction of a cold atomic ensemble with a silicon nitride membrane inside an optical cavity. Long-distance coupling between the two is established by an optical standing wave that is reflected from the cavity. Recently this mechanism has been exploited to sympathetically cool the membrane's fundamental vibrational mode from room temperature to below 1 Kelvin [1].
Here we will report on the status of a new experimental setup. We are implementing a new cryogenic optomechanical system with larger optomechanical cooperativity and an atomic ensemble with large optical depth in a far-detuned dipole trap. With these improvements we plan to couple the membrane oscillator to collective spin excitations of the atomic ensemble [2], allowing us to achieve strong coupling between the two systems.

[1] Jöckel et al., Nature Nanotechnology 10, 55-59 (2015).
[2] Vogell et al., New Journal of Physics 17, 043044 (2015).

Q 42.45 Wed 16:30 Empore Lichthof

Optomechanical damping of nanomembranes in ring cavities — Simon Schuster, •Sebastian Slama, Arzu Yilmaz und Claus Zimmermann — Eberhard-Karls Universität Tübingen, Phys. Institut, Auf der Morgenstelle 14, 72076 Tübingen

We report on the observation of the optomechnical damping of an oscillating silicon nitride nanomembrane inside an optical ring cavity. The underlying damping mechanism is different from the typical situation achieved in linear cavities, where the cavity resonance frequency depends on the membrane position. This is not the case in a ring cavity, where the damping is solely caused by the fact that the electric fields in the cavity follow the membrane motion not instantaneously, but with the timescale of the cavity decay time. We quantify the different contributions of radiation pressure force, dipole force and bolometric forces, including the action of a second reflector in the cavity. In our setup this second reflector describes back-reflection from imperfections at the mirror surfaces. However, it may also represent a second membrane in the cavity, which makes this system a future playground for studying sychronization effects.

Q 42.46 Wed 16:30 Empore Lichthof

Towards and beyond squeezed vacuum states in a nonlinear crystalline whispering gallery mode resonator — •Alexander Otterpohl[1,2], Gerhard Schunk[1,2], Ulrich Vogl[1,2], Florian Sedlmeir[1,2], Golnoush Shafiee[1,2], Dmitry Strekalov[1,2], Tobias Gehring[3], Harald G. L. Schwefel[4], Ulrik L. Andersen[3], Gerd Leuchs[1,2], and Christoph Marquardt[1,2] — [1]Max Planck Institute for the Science of Light, Guenther-Scharowsky-Str. 1 Bldg. 24, 91058 Erlangen, Germany — [2]Institute of Optics, Information and Photonics, University of Erlangen-Nuremberg, Staudtstr. 7 B2, 91058 Erlangen, Germany — [3]Department of Physics, Technical University of Denmark, Fysikvej, 2800 Kgs. Lyngby, Denmark — [4]Department of Physics, University of Otago, 730 Cumberland Street, 9016 Dunedin, New Zealand

Macroscopic crystalline whispering gallery mode resonators (WGMR) made out of $LiNbO_3$ are a versatile source of non-classical light generated via optical parametric down-conversion [1]. In particular, we have demonstrated squeezing of a single parametric beam as well as twin-beam squeezing at above threshold operation. Here, we present the prospects for generating squeezed vacuum states in WGMRs, which requires degenerate operation below threshold. Furthermore, the pathway to degeneracy allows us to produce frequency combs and facilitates more elaborate proposals such as enhanced optomechanical position detection via intra-cavity squeezing [2].

[1] J. U. Fürst et al., Phys. Rev. Lett. **106**, 113901(2011).
[2] V. Peano et al., arXiv:1502.06423v1 (2015), accept. on PRL

Q 42.47 Wed 16:30 Empore Lichthof

Optical ablation of gold bowtie nanoantenna — •Liping Shi — Welfengarten1

We experimentally demonstrate the optical ablation of gold bowtie nanoantenna under the irradiation of laser pulses output from Ti: Sapphire femtosecond oscillator. The temporal behavior of third harmonic enhancement factor from bowtie antennas is introduced to determine durability of nanostructure. We observed two different channels of optical ablation from gold bowtie nanoantenna: thermal effects induced melting and near-field enhancement induced ion ejection. It is shown that by employing thicker nanoantenna can significantly increase the thermal damage fluence threshold, but the optical ablation originated from field emission is inevitable in vacuum. However, our experiments show that if the nanoantenna are exposed in air, this field emission can be dramatically suppressed, which might be attributed to the adsorption of gas molecules at sharp features of field-enhancing structures. We also numerically employed the two-temperature model to estimate the free electrons as well as gold lattice temperature, and solved the one-dimensional heat diffusion equation to simulate the spatial and temporal distribution of temperature in substrate sapphire.

Q 42.48 Wed 16:30 Empore Lichthof

3D Pointillism Microscopy setup with two objectives — •Nora Schmidt[1], Jana Hüve[1,2], and Jürgen Klingauf[1,2] — [1]Institute of Medical Physics and Biophysics, Robert-Koch-Straße 31, and CeN-Tech, Heisenbergstraße 11, 48149 Münster — [2]Authors contributed equally to this work

We have custom-built a setup for localisation microscopy techniques like PALM or STORM with two objectives. This enables us to collect two times more photons from each fluorescent molecule and therefore to increase the resolution accuracy by a factor of $\sqrt{2}$ [1]. Optional three-dimensional imaging is possible by inserting additional cylindrical lenses into the beam path.

We have characterised the localisation accuracy of this setup and found that using a second objective clearly improves our results. For 6600 photons we have obtained a localisation accuracy of 4 nm in the lateral plane and of 9 nm along the axial direction.

To further test the performance of our setup, we have imaged well-known biological structures of sub-resolution size, and have obtained results which match well with previously reported observations.

To further improve the localisation accuracy along the optical axis, we plan to use interferometric detection of the fluorescence light [2] as a second detection option. With this technique, we expect to improve the axial localisation accuracy to values similar to or even better than the localisation accuracy in the lateral plane.

[1]: K. Xu et al. *Nat. Methods*, **9**, 185 (2012)

[2]: G. Shtengel et al. *Proc. Natl. Acad. Sci. U.S.A.*, **106**, 3125 (2009)

Q 42.49 Wed 16:30 Empore Lichthof

Cold atom-semiconductor hybrid quantum system — •Janik Wolters[1], Lucas Béguin[1], Fei Ding[2], Aline Faber[1], Jan-Philipp Jahn[1], Andreas Jöckel[1], Andreas Kuhlmann[1], Mathieu Munsch[1], Armando Rastelli[3], Nicolas Sangouard[1], Oliver G. Schmidt[2], Philipp Treutlein[1], and Richard J. Warburton[1] — [1]Universität Basel, Departement Physik, CH-4056 Basel — [2]IFW Dresden, Germany — [3]Johannes-Kepler University Linz, Austria

Semiconductor quantum dots are excellent single-photon sources, providing triggered single-photon emission at a high rate and with high spectral purity. Independently, atomic ensembles have emerged as one of the best quantum memories for single photons, providing high efficiency storage and long memory lifetimes. In this project, we combine these two disparate physical systems to exploit the best features from both worlds. On the one hand, we have characterized a new type of self-assembled GaAs/AlGaAs quantum dots that emit narrow-band single-photons ($\Delta\nu \sim 1$ GHz) at Rb wavelengths. Fine tuning of the photon frequency is achieved via strain. This allows performing spectroscopy of the Rb D2-line at the single-photon level, proving the addressability the different hyperfine transitions [1]. On the other hand, detailed theory of an EIT-based memory scheme in a dense ultracold ensemble of ^{87}Rb atoms (OD $\sim$ 1000) was developed [2]. In the long term, such a memory will form the basis for experiments on hybrid entanglement and quantum networks.

[1] J.-P. Jahn et al., arXiv:1508.06461 (2015).

[2] M. T. Rakher et al., *Phys. Rev. A* **88** 053834 (2013).

Q 42.50 Wed 16:30 Empore Lichthof

Interfacing single molecules with optical nanofibers — •Hardy Schauffert, Sarah Skoff, David Papencordt, and Arno Rauschenbeutel — Technische Universität Wien, Atominstitut, Stadionallee 2 , 1020 Wien

In recent years, tapered optical fibers with nanowaist have gained a lot of attention as versatile platforms for strong light-matter interaction due to their small effective mode volume. The sub-wavelength diameter of the waist results in a crucial amount of light propagating outside of the fiber as a high intensity evanescent wave. An emitter brought close to the surface of the nanofiber can then have a big effect on the guided light field. Possible emitters are single organic molecule embedded in a crystal matrix such as terrylene in p-terphenyl. These molecules exhibit a naturally strong Zero-phonon-line, which can be as narrow as tens of MHz at cryogenic temperature and are very photostable. This together with optical nanofiber makes them promising candidates as building blocks for fiber integrated quantum networks. We will show first results on single molecule spectroscopy using optical nanofibers and give an outlook of the rich variety of experiments that can be done with such a platform.

Q 42.51 Wed 16:30 Empore Lichthof

Towards efficient solid-state based light-matter interfaces based on dielectric slot waveguides — •Martin Zeitlmair[1], Lars Liebermeister[1], Peter Fischer[1], Lukas Worthmann[1], Markus Weber[3], and Harald Weinfurter[1,2] — [1]Ludwig-Maximilians-Universität, München — [2]Max-Planck-Institut für Quantenoptik, Garching — [3]Max-Planck-Institut für die Physik des Lichts, Erlangen

Efficient light-matter interfaces are a crucial prerequisite for future applications in applied quantum information science and ultra-sensitive phase, absorption, and fluorescence spectroscopy. Such light-matter interfaces require two key components: a non-classical light source and a waveguiding structure to control the propagation of photons. Here, we present progress towards a novel on-chip interface operating over a broad spectral range in the visible spectrum, which is based on diamond defect centers and tailored dielectric slot waveguides.

The proposed scheme uses defect centers hosted in a nanodiamond as a stable nonclassical light source. With the help of an AFM-based pick-and-place technique, the nanodiamond will be positioned inside the slotted region of a fabricated Ta_2O_5 waveguide. By optimizing the slot waveguide geometry with the additional requirement of allowing access for the AFM-tip, coupling efficiencies over 60% for the whole spectrum of the NV-center are expected with slot widths of 40nm.

Q 42.52 Wed 16:30 Empore Lichthof

Investigating Single Quantum Emitters in Nanodiamonds for Quantum Optics — •Dominik Zepp, Alexander Landowski, Michael Renner, Georg von Freymann, and Artur Widera — TU Kaiserslautern

We study color centers in nanodiamonds for applications as single photon emitter in quantum optics. We use a custom-built microscope setup which is capable of simultaneously imaging the spatial distribution of particles on the sample and measuring the spectrum of one diffraction limited spot. This allows us to investigate blinking behavior, photostability and spectral dynamics of an ensemble of fluorescing nanodiamonds when illuminated by various wavelengths ranging from white LED, 780nm, and 532nm. We will report on the current status to control such emitters and their emitted photons for micro-sized quantum optical experiments.

Q 42.53 Wed 16:30 Empore Lichthof

SiV Centres in Microcavities - an Efficient Single Photon Source at Room Temperature — •Julia Benedikter[1,2], Elke Neu[3], Roland Albrecht[3], Christoph Becher[3], Theodor W Hänsch[1,2], and David Hunger[1,2] — [1]Ludwig-Maximilians-Universität München, Germany — [2]Max-Planck-Institut für Quantenoptik, Garching, Germany — [3]Universität des Saarlandes, Saarbrücken, Germany

Single photon sources are an integral part of various quantum information applications. Solid state emitters offer on-demand single photon emission without the need for very involved set-ups. The emission properties, especially the very narrow single phonon line, and stability of the silicon vacancy centre in diamond make it a promising candidate for a single photon source at room temperature. We use fibre-based microcavities [1, 2] to Purcell-enhance and efficiently collect the emission of single SiV centres in nanodiamonds. We operate in the bad emitter regime, where a cavity with a mode volume of a few cubic wavelengths can achieve high effective Purcell factors up to about 20. We report on measurements on narrow-line bright single SiV centres in free space and in an ultra-small mode volume cavity and compare rates and time constants. Furthermore, we will discuss an empirical model for shelving and deshelving processes.

[1] Hunger et al., NJP 12, 065038 (2010)

[2] Hunger et al., AIP Advances 2, 012119 (2012)

Q 42.54 Wed 16:30 Empore Lichthof

Spectral diffusion of Silicon-Vacancy centers in Nanodiamonds — •O. Wang[1], L. Rogers[1], A. Kurtz[1], D. Rudnicki[2], U. Jantzen[1], V.A. Davydov[3], V.N. Agafonov[4], A. Kubanek[1], and F. jelezko[1] — [1]Institute of Quantum Optics, Ulm, Germany — [2]Institute of Physics, Jagiellonian University, Krakow, Poland — [3]Institute for High Pressure Physics, Russian Academy of Science, Moscow, Russia — [4]Greman, Universit F. Rabelais, Tours, France

With appealing properties, weak side band and mostly polarized fluorescence, silicon vacancy centers (SiVs) in diamonds have become an attractive and promising system for the realization of bright, narrow bandwidth, single-photon sources. In bulk diamond at cryogenic temperatures the SiV ZPL has been observed with a linewidth limited only by fluorescence lifetime, and the transitions were spectrally stable over hours.Unfortunately the spin coherence time was found to be severely limited by phonon processes in the ground state, which may be quenched in small nanodiamonds (NDs).

However, SiV centres in NDs are found to exhibit an intermittency in their luminescence, which is known as *blinking", and also significant spectral diffusion. We have investigated the fluorescence of SiV in small NDs produced using a novel High Pressure and High Temperature synthesis. These have exhibited ZPL linewidths five times narrower than any other reported SiV in NDs. We have measured spectral diffusion as a function of excitation laser intensity, and found it to be suppressed with lower laser power. This suggests the mechanism may arise from photo-chemistry on the ND surface.

Q 42.55 Wed 16:30 Empore Lichthof

Towards efficient readout of electron spin state in Silicon Vacancy centers in diamond — •Aroosa Ijaz, Petr Siyushev, Lachlan Rogers, and Fedor Jelezko — Institute for Quantum Optics, Universitat Ulm, Germany

Efficient qubit systems are being actively researched globally. A qubit needs to have an efficient photon interface, long coherence times, stability and easy control. Some active systems of research include trapped ions, quantum dots and color centers in solids. Currently, the most prominent color center for quantum information is Nitrogen Vacancy (NV) center in diamond. The stiff lattice of diamond protects the coherent properties of the center's spin.

The spin-photon interface for NV centers is, however, poor. Silicon Vacancy (SiV) center has recently emerged as a competitor to the NV center due to its uniquely attractive optical properties. Compared to NV centers, it provides a feasible interface between stationary and flying qubits. This center has also been shown to emit indistinguishable photons which will pave the way towards scalable quantum networks.

We use the extinction of light by single defects in bulk diamond to obtain high contrast resonant detection as compared to the usual off-resonant measurements over the phonon side band. This technique improves electron spin state readout when the defect is addressed resonantly and allows for single-shot optical readout of electron spin.

Q 42.56 Wed 16:30 Empore Lichthof

Narrowband, room-temperature single photon emitters based on silicon- vacancy centers in diamond nanocrystals produced by a wet-milling process — •Sarah Lindner[1], Alexander Bommer[1], Andreas Muzha[2], Anke Krueger[2], Laia Gines[3], Oliver Williams[3], and Christoph Becher[1] — [1]Fachrichtung 7.2 (Experimentalphysik), Universität des Saarlandes, Campus E2.6, 66123 Saarbrücken — [2]Institut für Organische Chemie, Universität Würzburg, Am Hubland, 97074 Würzburg — [3]School of Engineering, Cardiff University, Newport Road, Cardiff CF24 3AA

Single-photon sources with well-defined spectral properties are of special interest to quantum technologies. Silicon vacancy (SiV) color centers in diamond nanocrystals are especially promising single photon sources due to their narrow emission bandwidth and high emission rate at room temperature [1]. To even further enhance these properties, SiV centers can be coupled to optical systems, which require nanodiamonds of sizes $<$ 100 nm and low strain, to preserve the advantageous optical properties of the SiV center. Here we report on SiV centers in nanodiamonds which are produced by milling down a polycrystalline diamond film [2] containing SiV centers exploiting a wet-milling process [3]. Different center wavelengths of the zero-phonon-lines and varying linewidths among SiV centers in distinct nanodiamonds are observed. As some of the nanodiamonds contain single SiV centers they are favorable candidates for the integration into photonic systems.

[1] E. Neu et al., NJP 13, 25012 (2011), [2] O. A. Williams et. al., PSS A 203, 3375 (2006), [3] S. Heyer et. al., ACS Nano 8, 5757 (2014)

Q 42.57 Wed 16:30 Empore Lichthof

Coupling of color centers in nanodiamonds to open access micro-cavities — •Marcel Schmidt[1], A. Bommer[1], S. Lindner[1], L. Gines[2], O. Williams[2], A. Muzha[3], A. Krueger[3], and C. Becher[1] — [1]Fachrichtung 7.2 (Experimentalphysik), Universität des Saarlandes, Campus E2.6, 66123 Saarbrücken — [2]School of Engineering, Cardiff Universtiy, Newport Road, Cardiff CF24 3AA, Wales — [3]Institut für Organische Chemie, Universität Würzburg, Am Hubland, 97074 Würzburg

Since its first demonstration as qubit in quantum information applications, the nitrogen vacancy (NV) centre gained much attention as promising candidate for remote entanglement schemes [1] and quantum sensing [2]. A way to improve its suitability is the coupling of single NV centres to open access micro-cavities which increases the photon rate per frequency interval [3]. A theoretical model predicts a transition into a Purcell-enhanced regime at cryogenic temperatures, when the narrow zero phonon line (ZPL) of the NV centre is coupled to a fundamental mode of the cavity. We here report our progress towards cryogenic cavity coupling of NV centres. In recent years, another color centre, the silicon vacancy (SiV) centre has been established as bright single photon source [4]. Due to its narrow ZPL linewidth at room temperature and its short lifetime of the excited state, coupling this color centre to a micro-cavity can provide a high speed, high efficiency single photon source at room temperature. [1] B. Hensen, Nature 526, 682-686 (2015) [2] L. Rondin, Rep. Prog. Phys. 77 (2014) [3] R. Albrecht, PRL 110, 243602 (2013) [4] E. Neu, NJP 13, 025012 (2011)

Q 42.58 Wed 16:30 Empore Lichthof

Color centers in diamond as nanoscale quantum sensors — •Richard Nelz, Amandeep Kaur, Ettore Bernardi, Selda Sonusen, and Elke Neu — Universität des Saarlandes, FR 7.2 Experimentalphysik, Campus E2.6, 66123 Saarbrücken

Single nitrogen vacancy (NV) color centers in diamond are highly suitable as nanoscale quantum sensors for e.g. optical near fields and magnetic fields; the later due to their coherent, optically addressable electronic spin-states [1]. As a result of the high refractive index of diamond it is intrinsically challenging to efficiently extract the fluorescence of the NV center. Optical read-out of the NV sensor requires efficiently collecting the center's fluorescence which we achive using dedicated diamond nanostructures: We integrate NV centers into nanopillars that function as tips for scanning probe microscopy and waveguides for light. We present optimized approaches towards the fabrication of all diamond scanning probe devices and their applications.

[1] Rondin et al., Rep. Prog. Phys. **77** 056503 (2014)

Q 42.59 Wed 16:30 Empore Lichthof

A microfluidic high-finesse open acces cavity — •Matthias Mader[1,2], Theodor W. Hänsch[1,2], and David Hunger[2,1] — [1]Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Straße 1, 85748 Garching — [2]Ludwig-Maximilians-Universität München, Schellingstraße 4, 80799 München

Optical characterisation of individual nanosystems provides a wealth of information. However, it is very challenging to observe quantitative spectroscopy signals beyond fluorescence from a single nanoparticle.

Here we present first steps towards a novel method for extinction and dispersion spectroscopy on single nanosystems in an aqueous environment to investigate single biological and chemical nano systems.

Combining an open access high-finesse Fabry-Perot resonator [1] with a microfluidic cell allows ultra-sensitive spectroscopy of individual nano systems under well-controlled conditions. In addition to dispersive detection of the nano object by detecting a shift in the resonance frequency, absorption measurements are possible by observing the transmitted light [2]. Using the cavity mode which is fully accessible for the particle as an optical trap, our approach opens the possibility to store a particle without binding to a surface and to investigate e.g. reaction dynamics on a single particle level.

[1] D. Hunger, T. Steinmetz, Y. Colombe, C. Deutsch, T. W. Hänsch, J. Reichel, New J. Phys. 12, 065038 (2010).

[2] M. Mader, J. Reichel, T. W. Hänsch, D. Hunger, Nature Commns. 6 7249 (2015)

Q 42.60 Wed 16:30 Empore Lichthof

Rotational diffusion of nanorods studied by interferometric scattering detection (iSCAT) — Jens Ehrig, •Mahdi Mazaheri, and Vahid Sandoghdar — Max Planck Institute for the Science of Light, Erlangen, Germany

We use interferometric scattering detection microscopy (iSCAT) to study the rotational diffusion of gold nanorods (GNR) linked to an artificial bilayer lipid membrane on a glass substrate. The technique relies on the interference between light scattered from the GNR and the reference beam reflected from the glass-water interface. Streptavidin-conjugated gold nanorods of length 63 nm and diameter of 25 nm were attached to headgroup-biotinylated DOPE lipids in DOPC supported lipid bilayers. By illuminating the sample with polarized laser light and polarization separation in the detection path, the fast tracking of rotational diffusion of the GNR becomes possible. Specifically, we can calculate the angle of the rod in each video frame, i.e., within a few microseconds. Using this approach one can simultaneously study the rotational and lateral diffusion of very small membrane inclusions and from that infer information on the physical properties and local dynamic behavior of the membrane such as local viscosity, short range diffusion, and compositional heterogeneity.

Q 42.61 Wed 16:30 Empore Lichthof

Nonlocal continuity and invariant currents in locally symmetric photonic crystals — •Christian Morfonios[1], Panayotis Kalozoumis[2], Fotios Diakonos[2], and Peter Schmelcher[1,3] — [1]Centre for Optical Quantum Technologies, Hamburg University, Germany — [2]Physics Department, Athens University, Greece — [3]Centre for Ultrafast Imaging, Hamburg, Germany

Within a nonlocal discrete continuity formalism, we demonstrate the spatial invariance of stationary state currents in one-dimensional domains with inversion-(time-) or translation-(time-) symmetric sub-Hamiltonians. Cases of complete, overlapping, and gapped domainwise symmetry in model setups of effective Schrödinger photonic waveguide crystals are shown, including systems with balanced gain and loss. The invariants enable a mapping between the wave amplitudes of symmetry-related sites, generalizing the Bloch and parity theorems to local translation and inversion symmetry. In scattering systems, simultaneously vanishing inversion-symmetry invariants signify completely transmitting states with correspondingly symmetric density. In periodically driven setups, the invariants are retained for period-averaged quasi-energy eigenstates. Encoding local potential and coupling symmetries into arbitrary stationary states, the theory of symmetry-induced continuity and local invariants may contribute to the understanding of wave structure and response in systems with localized spatial regularities.

Q 42.62 Wed 16:30 Empore Lichthof

Optical helicity and duality symmetry in matter — •Koen van Kruining and Jörg Götte — Max Planck Institut für Physik komplexer Systeme. Nöthnitzer straße 38; 01187 Dresden

In vacuum, electric and magnetic fields can be interchanged without changing the form of Maxwells equations. This is the electric-magnetic duality symmetry and its associated conserved quantity is optical helicity. When light traverses a medium, this symmetry is typically broken. We investigate under what conditions electric-magnetic duality is conserved even for light traversing the most general linear medium and derive a generalised expression for the optical helicity. With the aid of some simple examples we illustrate the consequences of helicity conservation in a medium.

Q 42.63 Wed 16:30 Empore Lichthof

Modelling and fabrication of Rb:KTP waveguides — •Matteo Santandrea, Christof Eigner, Laura Padberg, Helge Rütz, and Christine Silberhorn — Universität Paderborn, Integrierte Quantenoptik, Warburger Str. 100, D-33098 Paderborn

In the future, quantum networks will almost certainly require interfaces between different physical systems, such as atoms and low loss fibers. These interfaces will require low loss, high efficiency and low noise frequency conversion. Optical waveguides in nonlinear materials are ideal candidates for this task due to their inherent phase stability, high nonlinearity, flexibility, small footprint and modularity.

We are developing a quantum interface to convert photons at 397 nm, correspondent to the $^{40}Ca^{+}$ transition, to photons in the telecom C-band, around 1550 nm. In order to bridge this huge energy gap, we exploit the process of sum frequency generation (SFG) in periodically-poled, rubidium-exchanged potassium titanyl phosphate (Rb:KTP) waveguides. Rb:KTP waveguides are ideal candidates for SFG due to their unique combination of high nonlinear coefficients, a wide transmission window extending from infrared to ultraviolet, high photorefractive damage resistance and the possibility to achieve poling periods in the μm range.

Here, we show our technique for the production of those waveguides, discuss a model for the refractive index distribution in our waveguides and present some methods for assessing discrepancies between the model and our waveguides.

Q 42.64 Wed 16:30 Empore Lichthof

Duty cycle optimized periodically poled Rb:KTP waveguides — •Laura Padberg, Christof Eigner, Matteo Santandrea, Helge Rütz, and Christine Silberhorn — Universität Paderborn, Integrierte Quantenoptik, Warburger Str. 100, D-33098 Paderborn

Periodically poled potassium titanyle phosphate (KTP) waveguides are very attractive for non-linear processes in integrated quantum optics. Especially the high optical damage threshold makes it interesting for operating in the visible.

Rubidium-potassium-ion exchange is a practical approach for waveguide fabrication in KTP. However, the doping dependent ionic conductivity of Rb:KTP makes periodic poling a challenging task.

We show our approach for the technologically-challenging periodic poling process, where we utilize an optical monitoring technique. This allows us to monitor the domain-growth inside the waveguide and obtain a reliable 50/50 duty cycle. Successful periodic poling is verified by selective surface etching as well as non-linear optical characterization measurement. With these characterization methods we compare two different poling periods which are attractive for quantum optical applications.