Q 61: Quantum Optics (Miscellaneous)

Time: Thursday 16:30–18:30 Location: P

Q 61.1 Thu 16:30 P

Generating multi-photon graph states in the telecom wavelength regime using sagnac single-photon sources — •Nico Hauser, Simone d'Aurelio, Matthias Bayerbach, Shreya Kumar, and Stefanie Barz — Institute for Functional Matter and Quantum Technologies and IQST, University of Stuttgart, 70569 Stuttgart, Germany

Graph states with multiple qubits are important resources for quantum computation and quantum communication. In particular, multipartite communication protocols between three and more parties can benefit from maximally entangled N-qubit states. Examples are quantum secret sharing protocols, quantum conference key agreement and secure quantum e-voting - all of which require a reliable generation of entangled N-qubit states. Therefore, the experimental generation of such states is of great importance, in particular, in the telecom wavelength regime in order to use existing and well established fiber networks. In this work, we investigate the generation of multipartite entangled states using single photon sources based on spontaneous parametric down-conversion in ppKTP-crystals. The sources are operated in a sagnac interferometer type scheme that allows generating two-photon Bell states. Fusing multiple of those states at beam splitters then creates multipartite entangled states. These can then serve as the basis for implementing multipartite communication protocols.

Q 61.2 Thu 16:30 P

Tracking Rydberg state dynamics to study the effect of long-range dipole-dipole interactions on Superradiance — •Elmer Suarez, Philip Wolf, Patrizia Weiss, and Sebastian Slama — Center for Quantum Science and Physikalisches Institut, Eberhard-Karls Universität Tübingen, Auf der Morgenstelle 14, 72076 Tübingen, Germany

We report on the real-time detection of internal-state dynamics of cold Rubidium atoms being excited to the $30D_{5/2}$ Rydberg state via two-photon excitation. The atoms are overlapped with the mode of an optical cavity and excited by two laser beams transverse to the cavity axis. The excitation changes the collective atom-cavity coupling, which we detect by measuring the cavity transmission. We observe not only the excitation dynamics, but also the transfer of population from the Rydberg state to other neighbouring states due to black-body radiation, and the decay back to the ground state. Moreover, we find a superradiant enhancement of this decay and a density-dependent mitigation of superradiance which we attribute to dipole-dipole interactions between atoms in neighbouring Rydberg states. The findings contribute to resolve a recent controversy on the role of BBR-induced superradiance in cold atomic gases.

Q 61.3 Thu 16:30 P

Waveguide QED with Rydberg superatoms — •Lukas Ahlheit[1], Nina Stiesdal[1], Hannes Busche[1], Kevin Kleinbeck[2], Jan Kumlin[2], Hans-Peter Büchler[2], and Sebastian Hofferberth[1] — [1]Institute for Applied Physics, University of Bonn — [2]Institute for Theoretical Physics III, University of Stuttgart

A Rydberg superatom is a model 2-level system formed by thousands of atoms sharing a single excitation to a Rydberg state. Only a single excitation is allowed in the system due to the Rydberg blokade, and due to the collectivity of the excitation, the system couples strongly to a driving coherent field of few photons, and features directionality defined by this driving mode.

On this poster we discuss how we experimentally implement a 1D chain of Ryderg superatoms, and how we use this system to study the dynamics of emitter-light-couplings. In particular, the directed emission of the superatoms makes our free-space chain of superatoms very similar to a chain of emitters coupled to a 1D optical waveguide. This has recently allowed us to realize a multi-photon subtractor, which we present here. We have also studied the collective internal dynamics of many-atom-systems with a single, shared excitation. We discuss how these internal dynamics can be included in a 1D waveguide model.

Q 61.4 Thu 16:30 P

Nanophotonic fiber-coupled silicon carbide quantum interface — •Lukas Niechziol, Raphael Nold, Marcel Krumrein, Jonathan Körber, Izel Gediz, Jonas Zatsch, Florian Kaiser, and Jörg Wrachtrup — 3rd Institute of Physics, University of Stuttgart, 70569 Stuttgart, Germany

In the field of quantum sensing, quantum cryptography and quantum computing silicon vacancy centers in silicon carbide have recently quickened the interest of many research groups, due to its availability, spin configuration, integratabilty and more. Until now most publications focus on color centers in bulk material. This results in collecting efficiencies between 0.1% and 1%. In our experiment we will use waveguides with photonic crystal cavities to enhance the photon flux of the color centers. These photons will travel to a taper of the waveguide to be transferred to a tapered fiber. We used FTDT simulations to find optimal parameters for single-mode waveguide geometries as well as for the fiber. The simulation showed that the waveguides we plan to use achieve a transmission of a color center (dipole) of 42.4% into the desired TE fundamental mode of the waveguides. Additionally a transmission efficiency over the quantum interface of about 99.0% resulting in a total collecting efficiency of 41.9% of the light of a color center into a fiber. Our goal is to translate the results of our simulations towards highly efficient quantum interface including a photonic crystal cavity with a deposited color center.

Q 61.5 Thu 16:30 P

Generation of GHZ-states using Symmetric Bell Multiport Beam Splitters — •Daniel Bhatti and Stefanie Barz — Institute for Functional Matter and Quantum Technologies & IQST, University of Stuttgart, Germany

Symmetric Bell multiport beam splitters, with N input and output modes, have been found useful for investigating the indistinguishability of multiple photons [1,2] and also for generating post-selected, highly entangled multi-photon states [3]. Interestingly, when employing polarization encoding varying the indistinguishability of the N independent input photons leads to different classes of entangled states [4]. In the case of N=3 and N=4 the generation of polarization encoded W-states and GHZ-states has been analyzed theoretically and in the case of W-states it has even been generalized to arbitrary N [5]. Choosing a particular set of polarization states for the N independent partially distinguishable input photons we, here, present a generalization for the generation of polarization encoded GHZ-states. This leads to different results for even and odd numbers of photons.

[1] A. J. Menssen, et al., PRL 118, 153603 (2017).
[2] A. E. Jones, et al., PRL 125, 123603 (2020).
[3] S. Paesani, et al., PRL 126, 230504 (2021).
[4] Y. L. Lim and A. Beige, Phys. Rev. A 71, 062311 (2005).

Q 61.6 Thu 16:30 P

Towards realizing an optical Racetrack memory — •Parvez Islam and Patrick Windpassinger — Institut für Physik, JGU, Mainz

Long distance quantum communications require the storage and on demand retrieval of the quantum qubits. Quantum memories with light stored in cold atomic ensembles is an established light storage platform towards scalable quantum networks. Controlled transport and manipulation of the stored light gives further control and opens new opportunities in quantum communication. Additionally, multiple storage sites or spatially separated hubs of storage sites can help realize novel devices like optical racetrack memories and quantum repeaters. We present our ongoing work on realizing an optical racetrack memory. An optical racetrack memory, in principle, consists of a multisegmented array of atomic ensembles which are individually addressable with a perpendicular Write/Read head. Light storage is achieved using EIT and transport by an optical conveyor belt as demonstrated in our previous work [1]. With individually addressable multiple storage sites which can be shifted spatially after storage and subsequently retrieved on demand, this work will serve as a proof of principle for realizing an optical racetrack memory. Furthermore, we plan to investigate the splitting and merging of stored polaritons. The stored light pulses are mapped into a collective excitation of the storage medium, forming strongly coupled light-matter quasiparticles called Dark state polaritons. Controlled splitting/merging of stored polaritons will provide more insight on light-matter interactions. [1] W.Li et al., Phys. Rev. Lett. 125, 150501

Q 61.7 Thu 16:30 P

Construction of a new type of room-temperature single-photon source based on two-photon interferences — •Lucas Pache, Martin Cordier, Francisco Crespo, Charlotta Gurr, Max Schemmer, Philipp Schneeweiss, Jürgen Volz, and Arno Rauschenbeutel — Department of Physics, Humboldt-Universität zu Berlin, 10099 Berlin, Germany

Single-photon sources are a key component for future quantum technologies. Here, we report on the progress in implementing a new type of single-photon source. This source relies on a two-photon interference effect which has been recently demonstrated in a proof-of-principle experiment with cold atoms [1]. The mechanism relies on engineering destructive two-photon interference, in order to transform a coherent laser field into a stream of single photons [2]. The physical origin of this effect is the collectively enhanced non-linear response of many weakly coupled atoms. Now, we transfer this concept to a vapor cell experiment with ^{85}Rb atoms and circumvent Doppler broadening by a two-color excitation scheme. This allows to generate indistinguishable single photons from a compact room-temperature source. The scheme can be readily adapted to the telecom range (1529nm).

[1] Prasad, et. al, Nature Phot. (2020).
[2] European patent pending (PCT/EP2019/075386).

Q 61.8 Thu 16:30 P

Superradiance and multilevel interference in an atomic chain — •Aleksei Konovalov and Giovanna Morigi — Universität des Saarlandes

We analyse the properties of the light coherently scattered by a chain of atomic dipoles. We develop a model of coherent dipoles which accounts for the effect of vacuum-induced interference in a multilevel structure [1] and analyse its effect of the coherently scattered light for a chain of Na 23 and a chain of Rb 87 atoms.

[1] Aleksei Konovalov and Giovanna Morigi Phys. Rev. A 102, 013724 (2020)

Q 61.9 Thu 16:30 P

Machine learning Lindblad dynamics — •Francesco Carnazza[1], Federico Carollo[1], Sabine Andergassen[1], Dominik Zietlow[2], Georg Martius[2], and Igor Lesanovsky[1] — [1]Institut für Theoretische Physik and Center for Quantum Science, Universität Tübingen, Auf der Morgenstelle 14, 72076 Tübingen, Germany — [2]Max Planck Institute for Intelligent Systems, Max-Planck-Ring 4, 72076 Tübingen, Germany

Even if full knowledge of the wave-function of a quantum system is unattainable, important information can still be retrieved by observing local degrees of freedom. Typically, it is possible to single out and measure just a subsystem, while regarding the rest as a bath. In the simplest case, the evolution of the reduced quantum state obtained by tracing out the environment is governed by a Markovian, i.e. time independent, quantum master equation, also known as Lindblad master equation. Here we investigate if it is possible to train a fully interpretable neural network which learns the parameters of a Lindblad generator [1]. We test this idea in a class of spin models, and investigate in which certain situations the network can indeed provide good predictions.

[1] P. Mazza *et al*. Phys. Rev. Research **3**, 023084 (2021)

Q 61.10 Thu 16:30 P

Collective phenomena in a system of two interacting qubits — •Robin Rüdiger Krill, Tom Schmit, and Giovanna Morigi — Theoretische Physik, Universität des Saarlandes, 66123 Saarbrücken, Germany

Collective phenomena play a fundamental role in classical physics as well as quantum physics. A prominent classical collective phenomenon is synchronization, where the constituents of an interacting many-body system move in unison. Recently, efforts were made to extend the notion of synchronization to quantum systems [1]. Drawing from a recent work [2], we analyse the relation between superradiance [3], subradiance, and synchronization, focussing in particular on the timescale characterizing the onset of these phenomena.

[1] R. H. Dicke, Phys. Rev. **93**, 99 (1954).
[2] F. Galve, G. L. Giorgi, and R. Zambrini, Quantum Science and Technology. Springer, Cham. pp. 393-420 (2017).
[3] B. Bellomo, G. L. Giorgi, G. M. Palma, and R. Zambrini, Phys. Rev. A **95**, 043807 (2017).

Q 61.11 Thu 16:30 P

Quantum fluctuations and correlations in open quantum Dicke models — •Mario Boneberg, Igor Lesanovsky, and Federico Carollo — Institut für Theoretische Physik, Universität Tübingen, Auf der Morgenstelle 14, 72076 Tübingen, Germany

In the vicinity of ground-state phase transitions quantum correlations can display non-analytic behavior and critical scaling. This signature of emergent collective effects has been widely investigated within a broad range of equilibrium settings. However, under nonequilibrium conditions, as found in open quantum many-body systems, characterizing quantum correlations near phase transitions is challenging. Moreover, the impact of local and collective dissipative processes on quantum correlations is not broadly understood. This is, however, indispensable for the exploitation of quantum effects in technological applications, such as sensing and metrology. We consider as a paradigmatic setting the superradiant phase transition of the open quantum Dicke model and characterize quantum and classical correlations across the phase diagram [1]. We develop an approach to quantum fluctuations which allows us to show that local dissipation, which cannot be treated within the commonly employed Holstein-Primakoff approximation, rather unexpectedly leads to an enhancement of collective quantum correlations, and to the emergence of a nonequilibrium superradiant phase in which the bosonic and spin degrees of freedom of the Dicke model are entangled.

[1] M. Boneberg, I. Lesanovsky, and F. Carollo, arXiv:2110.13191 (2021).

Q 61.12 Thu 16:30 P

Coherent spectroscopy of Europium-doped materials — •Christina Ioannou[1], Jannis Hessenauer[1], Evgenij Vasilenko[1], Phillipe Goldener[2], Diana Serrano[2], Mario Ruben[1], Senthil Kuppusamy[1], and David Hunger[1] — [1]Karlsruhe Institute of Technology — [2]Institut de Recherche de Chimie Paris

Solid state crystals doped with rare earth ions (REI) such as Europium have been demonstrated to be excellent candidates for optically addressable spin qubits. The coherence properties of REI within the partially filled 4f shell are exceptional due to their immunity against fluctuations of their environment as a result of the shielding effect of the outer filled electronic shells. Still, the host material affects the properties of the ions, such as the optical and spin coherence time. We use ensemble spectroscopy techniques such as spectral hole burning and photon echo techniques to investigate the optical coherence time of Europium in promising host materials. These techniques allow the measurement of the homogeneous linewidth of particular ion classes in spite of the significant inhomogeneous broadening of the ensemble. The host materials that we investigate are Y2SO3 nanocrystals and specifically designed molecular complexes [1]. Furthermore, we demonstrate our newly developed fiber based setup used for these measurements. This setup is compact and only needs very small amounts of sample. It is easily installed inside a cryostat, without the need of free-space optical access, while still maintaining good collection efficiency.

[1] Serrano et al., arXiv:2105.07081, in print at Nature

Q 61.13 Thu 16:30 P

A Novel Setup for Coupling Diamond Color Centers to Open Fiber-based Microcavities — •Yanik Herrmann[1,2], Julius Fischer[1,2], Laurens Feije[1,2], Matthew Weaver[1,2], Maximilian Ruf[1,2], Julia Brevoord[1,2], Matteo Pasini[1,2], and Ronald Hanson[1,2] — [1]QuTech, Delft University of Technology, P.O. Box 5046,2600 GA Delft, Netherlands — [2]Kavli Institute of Nanoscience, Delft University of Technology, P.O. Box 5046,2600 GA Delft, Netherlands

Quantum networks [1,2] are promising both for applications like secure communication and for basic science tests of quantum mechanics at a large scale. The Nitrogen-Vacancy (NV) center in diamond is an excellent node candidate, because of its long spin coherence and accessible local qubit registers, but it has limited collectible coherent photon emission. Integration into an optical cavity can boost collection via the Purcell effect [3], but the sensitivity of open cavities to vibrations from the environment has so far been a major roadblock for developing the system further into a quantum network node, capable of entanglement generation [4]. Here we present a new low temperature setup, which is in particular designed to provide a low vibration level while maintaining high flexibility over the cavity and fiber control. [1] S. Wehner et al., Science 362, 6412 (2018), [2] M. Pompili et al., Science 372, 6539 (2021), [3] E. Janitz et al., Optica 7, 1232-1252 (2020), [4] M. Ruf et

al., Phys. Rev. Applied 15, 024049 (2021),

Q 61.14 Thu 16:30 P

Light-induced correlations in cold dysprosium atoms — •Marvin Proske[1], Ishan Varma[1], Niels Petersen[1,2], Nico Bassler[4], Claudiu Genes[3,4], Kai Phillip Schmidt[4], and Patrick Windpassinger[1,2] — [1]QUANTUM, Institut für Physik, JGU Mainz — [2]Graduate School Materials Science in Mainz — [3]Max Planck Institute for the Science of Light, Erlangen — [4]Department of Physics, FAU Erlangen-Nuremberg

With the evergrowing interest in quantum cooperativity, comes an ongoing effort to study light-induced correlations in atomic media. In these typically extreme dense regimes, with atomic distances below the scattering lights wavelength, a direct matter-matter coupling is introduced by electric and magnetic interactions. We intend to study light-matter interactions in dense dipolar media with large magnetic moments to explore the impact of magnetic dipole-dipole interactions onto the cooperative response of the sample. With the largest groundstate magnetic moment in the periodic table (10 Bohr-magneton), dysprosium is the perfect choice for these experiments.

This poster reports on our recent work to generate dense ultracold dysprosium clouds utilizing a microscopic optical dipole trap. Further, we give a perspective on future adaptations of this technique with a self-built science cell, that serves as a highly accessible platform to manipulate the atomic cloud. The small dimensions of the cell allow for extremely tight optical dipole trapping and precise magnetic field control at the position of the atoms.

Q 61.15 Thu 16:30 P

Master equation for ultracold atoms in an optical cavity — •Tom Schmit[1], Carlos Máximo[2], Tobias Donner[2], and Giovanna Morigi[1] — [1]Theoretical Physics, Department of Physics, Saarland University, 66123 Saarbrücken, Germany — [2]Institute for Quantum Electronics, Eidgenössische Technische Hochschule Zürich, Otto-Stern-Weg 1, 8093 Zürich, Switzerland

The recent progress in the control of ultracold quantum gases in optical cavities enabled the realization of quantum simulators to study collective phenomena, such as self-organization. The theoretical description of these systems, however, still poses a big challenge due to the exponential scaling of the Hilbert space in the number of particles, making the full solution of the system's dynamical equations inaccessible, both analytically and numerically. Suitable approximations, most prominently adiabatic and mean-field approximations, are typically the way to tackle this problem, effectively reducing the dimension of the Hilbert space. In this work, we employ projector based techniques [1,2] to derive a description of self-organization of ultracold atoms in an optical cavity including first-order mean-field corrections. The effect of these corrections is then analyzed by comparing to the mean-field model, i.e., the lowest-order approximation.

[1] C. R. Willis and R. H. Picard, Phys. Rev. A **9**, 3 (1974).
[2] P. Degenfeld-Schonburg and M. J. Hartmann, Phys. Rev. B **89**, 245108 (2014).

Q 61.16 Thu 16:30 P

Design and fabrication of metalenses — •Shan Song[1] and Andreas Schell[2] — [1]Institut für Festkörperphysik, Leibniz Universität Hannover, Hannover, Deutschland — [2]Institut für Festkörperphysik, Leibniz Universität Hannover, Hannover, Deutschland

Recently, researchers have shown an increased interest in tailoring light by metasurfaces. A metasurface is a two-dimensional ultra-thin layer, artificially fabricated by planar structures on a sub-wavelength scale. By interaction with the planar structure, the transmitted light can be phase-shifted. Compared to conventional optical elements, metasurfaces are capable to manipulate the light wavefront accurately by specific nanostructures and they can be fabricated using microfabrication processes. The imaging of quantum emitters by metalenses in optical quantum technologies is the focus of interest. We are designing and fabricating a high numerical aperture metasurface lens, which is composed of polysilicon nanodiscs on a quartz glass substrate. By variation of discs diameter and periodicity, the full 2π phase shift and the high numerical aperture are achieved. It consists of multiple steps in the fabrication process, mainly including the deposition of a thin polysilicon layer by low-pressure chemical vapor deposition, the pattern determination by application of hydrogen silsesquioxane negative resist in electron beam lithography and the pattern transfer on polysilicon layer by reactive ion etching. After the fabrication of nanostructures, the structures will be covered with a polydimethylsiloxane layer, which ensures a homogeneous environment of light propagation.

Q 61.17 Thu 16:30 P

Squeezing and Correlations in an Atom Chain — •Kasper Kusmierek[1], Sahand Mahmoodian[2], and Klemens Hammerer[1] — [1]Institute for Theoretical Physics and Institute for Gravitational Physics (Albert-Einstein-Institute), Leibniz University Hannover, Germany — [2]ARC Future Fellow, University of Sydney, Australia

We study squeezing and correlations in an atomic array weakly coupled to a waveguide at large optical depth. The atoms are treated as two level atoms with a ground and excited state. The waveguide supports just modes traveling in one direction such that the whole system constitutes a cascaded system. Properties of light, like squeezing, can be derived via correlations of atoms. Since the degrees of freedom scale exponentially with the number of atoms, at large optical depth the system can not be solved exactly. We use the cumulant expansion method to cut correlations at arbitrary order and compare the resulting properties of the light field at different truncation orders.

Q 61.18 Thu 16:30 P

Implementation of a sub 10ps RMS jitter TDC in Xilinx 7-series FPGAs — •Verena Leopold[1], Yury Prokazov[2], Evgeny Turbin[2], Stefan Richter[1], and Joachim von Zanthier[1] — [1]FAU, Erlangen, Germany — [2]Photonscore, Magdeburg, Germany

For many experiments in quantum optics, it is crucial to detect photon arrival times from (multiple) detectors. Usually a TDC (Time-to-Digital-Converter) is used for recording of this time stream. However for low-contrast, long-running measurements, available TDCs show disadvantages. The main challenges are high quality analog inputs and non-linearities on short ps-timescales. We successfully implemented a TDL (Tapped-Delay-Line) TDC inside an FPGA. Communication with the CPU is established by PCIe. Using Xilinx 7-series silicon, a RMS jitter of (3.24 ± 0.03) ps was obtained with non-linearities in the regime of 0.32%.