Q 24: Quantum Effects

Time: Tuesday 16:30–18:30 Location: P

Q 24.1 Tue 16:30 P

Towards Lasing Without Inversion in Mercury Vapor at 253.7 nm — •Daniel Preissler and Thomas Walther — TU Darmstadt, Institute for Applied Physics, Laser and Quantum Optics, Schlossgartenstr. 7, D-64289 Darmstadt

UV and VUV laser sources have a broad application range in industry and commercial use as well as in research. The development of conventional direct laser sources in the regime of small wavelengths has reached a limit, since the pump energy to obtain population inversion scales at least with the fourth power of the desired laser frequency. But if the coherent (re-)absorption of photons at the laser frequency could be suppressed, a small population of the upper laser level would be sufficient to create amplification and/or lasing. This idea is called Lasing Without Inversion (LWI) and can be achieved by use of atomic coherence effects similar to EIT and CPT.

An experimental setup of an amplification without inversion (AWI) scheme is realized in atomic mercury vapor [1]. Because of its four-level system, allowing for a Doppler free three-photon-coherence, UV LWI at 253.7 nm can be generated by two laser systems at 435.8 nm and 546.1 nm as driving fields. Through extensive simulations [2] critical parameters of the laser systems involved, in particular their powers and linewidths, were identified. In this contribution the results of those simulations as well as the overall state of the experiment will be presented.

[1] Rein et al. (2021) arXiv:2111.03023

[2] Sturm et al. (2014) doi.org/10.1364/josab.31.001964

Q 24.2 Tue 16:30 P

Stabilization schemes for a Laser System at 546.1nm used in a Lasing without Inversion experiment in Mercury — •Noah Eizenhöfer, Daniel Preissler, and Thomas Walther — TU Darmstadt, Institut für Angewandte Physik, AG Laser und Quantenoptik, Schlossgartenstr. 7, D-64289 Darmstadt

Lasing without Inversion (LWI) is an alternative concept to generate radiation in the (V)UV regime. It is based on coherent effects leading to a suppression of the absorption on the lasing transition. This overcomes the problem of conventional lasers in the UV regime since their necessary pump power scales with f^4. A LWI experiment can be realized in Mercury with possible resulting wavelengths at 185 nm and 253.7 nm. (1)

One of the most important requirements for achieving LWI in mercury is the use of two driving lasers at 435.8 nm and 546.1 nm with very narrow bandwidths. The current status of the coupling laser at 546.1 nm is presented. The system is based on the generation of the second harmonic of the radiation from an ECDL. The feasibility of different schemes for the stabilization of the system to the corresponding atomic transition, e.g. Polarization Spectroscopy and Modulation Transfer Spectroscopy, is evaluated.

(1) Fry et al.: "Four-level atomic coherence and cw VUV lasers". Optics Communications 179 (2000), 499-504

Q 24.3 Tue 16:30 P

Towards cavity-enhanced single ion spectroscopy of Yb^{3+}: Y_2O_3 — •Jannis Hessenauer[1], Diana Serrano[2], Philippe Goldner[2], and David Hunger[1] — [1]Karlsruher Institut für Technologie, Physikalisches Institut, Karlsruhe, Germany — [2]Université PSL, Chimie ParisTech, CNRS, Paris, France

Rare-earth ions are promising candidates for optically addressable spin qubits, owing to their long optical and spin coherence times in the solid state. Yb^{3+} is of special interest amongst the rare earth ions due to its simple energy level scheme, strong transition oscillator strength and excellent coherence even at low magnetic fields [1]. An efficient spin-photon interface for quantum information technology requires the coupling of single ions to a high finesse cavity to enhance the transitions via the Purcell effect.

To that goal, we integrate nanocrystals into a fiber-based Fabry-Pérot microcavity by spincoating them on a planar mirror [2]. We characterize the nanocrystal distribution on a mirror via confocal microscopy and scanning cavity microscopy. We observe that long optical lifetimes and spectral features are preserved in nanocrystals. Finally, we present first results of cavity enhanced spectroscopy of Yb^{3+}: Y_2O_3 at room temperature.

[1] Kindem, Jonathan M., et al. "Control and single-shot readout of an ion embedded in a nanophotonic cavity." Nature 580.7802 (2020): 201-204.

[2] Casabone, Bernardo, et al. "Cavity-enhanced spectroscopy of a few-ion ensemble in Eu3+: Y2O3." NJP 20.9 (2018): 095006.

Q 24.4 Tue 16:30 P

Integrating a fiber cavity along the axis of a linear ion trap — •Viktor Messerer[1], Markus Teller[1], Klemens Schüppert[1], Roberts Berkis[1], Pritom Paul[1], Dario A. Fioretto[1], Maria Galli[1], Yueyang Zou[1], Jakob Reichel[2], and Tracy E. Northup[1] — [1]Institut für Experimentalphysik, Universität Innsbruck, Technikerstraße 25, 6020 Innsbruck, Austria — [2]Laboratoire Kastler Brossel, ENS-Université PSL, CNRS, Sorbonne Université, Collège de France, 24 rue Lhomond, 75005 Paris, France

Quantum networks allow for distributed quantum computation, inherently secure communication as well as enhanced quantum sensing. The nodes of a quantum network consist of multiple controllable stationary qubits and an interface to traveling qubits to interconnect distant network nodes. Trapped ions, coupled to an optical resonator mode allows for an efficient and deterministic ion-photon interface.

Recent experiments with a single trapped ion coupled to a fiber-based optical resonator have demonstrated a coherent coupling rate exceeding the atomic spontaneous-emission rate. This coherent ion-photon interaction is expected to enhance the fidelity and efficiency of quantum communication protocols.

We designed and constructed a system for strong coupling of multiple ions to a fiber cavity. The fiber mirrors are integrated along the axis of a linear Paul trap. Ions can be positioned along this axis without introducing excess micromotion. We will present the apparatus, measurements of the ion trap heating rate and micromotion, as well as first experimental results of coupling an ion to the cavity.

Q 24.5 Tue 16:30 P

Boundary Layer Model for the Reflectivity of a Metal and the Casimir Force — Mandy Hannemann and •Carsten Henkel — Universität Potsdam, Institut für Physik und Astronomie

The scattering of electromagnetic waves at a surface is a basic process in sensing and spectroscopy. It also determines dispersion forces of the van der Waals and Casimir(-Polder) type [1]. We revisit the reflectivity of a metallic surface combing a hydrodynamic model for conduction electrons with a boundary-layer theory [2]. Models based on a “no-slip” boundary condition involve a new length and time scale that characterises the near-surface response [3]. These parameters provide a framework that pushes theoretical calculations of the Casimir pressure between two planar surfaces closer to experimentally observed values. We compare the results to a recent proposal involving non-local dielectric functions [4].

[1] G. Bimonte and E. Santamato, “General theory of electromagnetic fluctuations near a homogeneous surface in terms of its reflection amplitudes,” Phys. Rev. A **76** (2007) 013810.

[2] D. Bedeaux and J. Vlieger, “Optical Properties of Surfaces” (World Scientific 2004).

[3] M. Hannemann, G. Wegner, and C. Henkel, “No-Slip Boundary Conditions for Electron Hydrodynamics and the Thermal Casimir Pressure,” Universe **7** (2021) 108

[4] G. L. Klimchitskaya and V. M. Mostepanenko, “An alternative response to the off-shell quantum fluctuations: A step forward in resolution of the Casimir puzzle,” Eur. Phys. J. **C** 80 (2020) 900.

Q 24.6 Tue 16:30 P

Cavity-enhanced spectroscopy of molecular quantum emitters — •Evgenij Vasilenko, Weizhe Li, Senthil Kuppusamy, Mario Ruben, and David Hunger — Institute for Quantum Materials and Technologies, Kalrsruhe Institute of Technology (KIT)

Rare earth ions in solid-state hosts are a promising candidate for optically addressable spin qubits, owing to their excellent optical and spin coherence times. Recently, also rare earth ion-based molecular complexes have shown excellent optical coherence properties [1]. Due to the long optical lifetime of the optical transition $^5D_0$-$^7F_0$, an efficient spin-photon interface for quantum information processing requires the coupling of single ions to a microcavity.Open-access Fabry-Pérot fiber cavities have been demonstrated to achieve high quality factors and low mode volumes, while simultaneously offering large tunability and efficient collection of the cavity mode [2]. Since the used molecular quantum emitters require a cryogenic environment, the demands on mechanical stability of the cavity setup have a high priority. To tackle these challenges, we report on the development of a monolithic type of cavity assembly, sacrificing some lateral scanning ability for the purpose of significantly increasing the passive stability. We integrate molecules into the cavity in the form of a crystalline thin film on a macroscopic mirror and identify a sub-nanometer local surface roughness, sufficient to avoid excessive scattering loss. We report on first studies of cavity-enhanced emission spectroscopy.

[1] Serrano et al., to appear in Nature, arXiv:2105.07081
[2] Hunger et al., New J. Phys 12, 065038 (2010)

Q 24.7 Tue 16:30 P

Light-matter interaction at the transition from single-mode to multimode cavity QED — •Daniel Lechner, Riccardo Pennetta, Martin Blaha, Philipp Schneeweiss, Jürgen Volz, and Arno Rauschenbeutel — Humboldt Universität zu Berlin, Institut für Physik, Newtonstr. 15, 12489 Berlin, Germany

Cavity QED is conventionally described by the Tavis-Cummings model, where quantum emitters strongly couple to a single-mode cavity. This description implicitly assumes that the cavity roundtrip time, t_{rt}, is by far the smallest timescale of the system and, in particular, much smaller than the lifetime, τ, of the quantum emitters. Here, we present an experiment in which this condition is progressively not fulfilled. The setup consists of a fiber ring-resonator with variable length, coupled to cold cesium atoms via an optical nanofiber. Consequently, we can explore the transition from a regime close to single-mode cavity QED to multimode cavity QED with resonator lengths of 5.8 m ($t_{rt} \approx \tau$) and 45.5 m ($t_{rt} \gg \tau$). We record the response of the atom–cavity system after the sudden switch-on of resonant laser light. For the 5.8-m resonator, on top of the conventional Rabi oscillations, we observe the appearance of sharp features at multiples of the roundtrip time. For the 45.5-m long cavity, due to coupling to many resonator modes, the Rabi oscillations disappear and only the response of the atomic ensemble after each individual roundtrip remains. Our observations shed light on the interplay between the single-pass collective response of the atoms to the propagating cavity field and the ensemble–cavity dynamics.

Q 24.8 Tue 16:30 P

Time-Dependent Photon Counting Statistics Emitted from a Chiral Atom Chain — •Tom von Scheven, Igor Lesanovsky, and Beatriz Olmos — Institut für Theoretische Physik, Universität Tübingen, Auf der Morgenstelle 14, 72076 Tübingen, Germany

We study the steady state of a laser-driven chain of two-level atoms coupled to a chiral waveguide [1]. Depending on the distance between the atoms and the laser detuning this state may be either a dark state or a mixture of a dark and a bright state. Here, we investigate the dynamical evolution of this system towards stationarity.

To do so, we introduce an imaginary counting field to the master equation that governs the dynamics of the system under consideration. This gives us access to the dynamics of not only the average photon count rate but rather the full counting statistics of the photon emission into the waveguide.

We show that, even though two systems may converge to different stationary states, their probability distributions evolve in an almost indistinguishable way for very long times.

Our results demonstrate the potential of the use of imaginary counting fields for the unravelling of the dynamics of quantum optical many-body systems.

[1] G. Buonaiuto *et al.*, New J. Phys. **21**, 113021 (2019)

Q 24.9 Tue 16:30 P

Revising cavity QED: Towards an accurate description of light-matter coupling — •Martin Blaha, Aisling Johnson, Arno Rauschenbeutel, and Jürgen Volz — HU Berlin, 12489 Berlin, Germany

The Jaynes-Cummings (JC) and Tavis-Cummings (TC) models are the standard descriptions of light-matter interaction between one or many emitters and a cavity field. In our work, we identify limits to these models, showing that they give inaccurate predictions if the emitter modifies the cavity field already significantly after a single roundtrip. This results in inaccurate predictions for the intra-cavity field, especially when investigating the case of coupling a large number of emitters to the cavity field [1].

To this end, we developed an alternative Hamiltonian by combining a waveguide approach with cavity QED, where we investigate the cascaded interaction between a propagating cavity field and each individual coupled emitter. This allows us to identify boundaries of validity of the JC and TC model. More importantly, solving our model we obtain predictions that substantially deviate from the predictions obtained from the JC and TC model, such as asymmetric vacuum-Rabi splitting, relevant for single emitters with almost perfect coupling to the cavity mode or the emergence of new resonances in the reflection spectra of resonators containing large ensembles of emitters [2].

[1] arXiv:2107.04583 (2021) [2] PRL 123 (24), 243602 (2019)

Q 24.10 Tue 16:30 P

Circular Bragg gratings for Integrated Enhancement of Quantum Emitters — •Dario Mekle, Jonas Grammel, and David Hunger — Physikalisches Institut, Karlsruher Institut für Technologie

Surface-emitting Circular Bragg gratings, forming center-disk cavities, are already successfully employed for distributed feedback lasers and quantum emitter applications based on nitrogen vacancy centers or semiconductor quantum dots. We aim to transfer this approach to achieve a better collection efficiency of rare earth ion based emitters in the form of nanocrystals or molecules. On the one hand, the collection efficiency is improved by the cavity induced Purcell enhancement and, on the other hand, by the better overlap between the far field emission pattern of the dipole emitter and the guided modes of the optical fiber being coupled into. A finite element analysis is used to perform geometric parameter optimizations of two cavity designs based on PMMA (or similar polymers) and air, where the inner resonator disk, which also contains the emitter, is once made of PMMA and the other time inverted with an air center.

The results obtained so far are very promising. In particular, it was possible to simulate a cavity geometry that leads to a Purcell factor of more than 140, which is significantly higher than previously published results.

Q 24.11 Tue 16:30 P

Sub- and superradiant modes in coupled ring-lattices — •Marcel Cech, Beatriz Olmos, and Igor Lesanovsky — Institut für Theoretische Physik, Universität Tübingen, Auf der Morgenstelle 14, 72076 Tübingen, Germany

A hallmark of an open quantum system is its dissipative character, which means that the system loses energy and coherence due to the coupling with its environment. In a many-body system, however, collective effects - such as sub-radiance - allow to suppress excitation and energy loss [1]. We demonstrate this effect in a system of interacting four-level atoms that are coupled to the radiation field. In particular, we focus on ring-shaped lattices which we combine to create metastructures in the three dimensional space. We consider the properties of these subradient states as a function of the number of rings and their mutual coupling strength. Our analysis shows that for lattice spacings on the order of the wavelength of the atomic transition a subspace of subradiant states emerges, which can be utilized to create lossless excitation transport.

[1] J. A. Needham *et al.*, New. J. Phys. **21** 073061 (2019)

Q 24.12 Tue 16:30 P

Collective decay in a dissipative Rydberg-gas — •Chris Nill, Federico Carollo, and Igor Lesanovsky — Institut für Theoretische Physik, Universität Tübingen, Auf der Morgenstelle 14, 72076 Tübingen, Germany

We analyse the dynamics and the steady state of a driven open quantum spin system, which models the dynamics of a strongly interacting gas of Rydberg atoms, weakly coupled to a Markovian bath.
A common approach to describe the dissipation of such systems is to choose single-site dissipation, such as spin decay or dephasing [1]. However, the strong interaction among Rydberg atoms is expected to give rise to dissipative processes with an additional dependency on neighbouring excited atoms.
We simulate the excitation dynamics within both approaches and highlight their differences. To this end we utilise exact diagonalisation, quantum jump Monte-Carlo simulations and mean-field calculations. We identify parameter regimes in which the difference between single-site and interaction-dependent dissipation becomes most pronounced and might be tested experimentally.

[1] C. Ates *et al.*, Phys. Rev. A **85**, 043620 (2012)

Q 24.13 Tue 16:30 P

Superdecoherence of spin states — •Jérôme Denis and John Martin — Institut de Physique Nucléaire, Atomique et de Spectroscopie, CESAM, University of Liège, B-4000 Liège, Belgium

We present a detailed study of the depolarization dynamics of an individual spin with an arbitrary spin quantum number j, or, equivalently, of a system of $N = 2j$ constituent spin-1/2 initially in a symmetric state undergoing collective depolarization. In particular, we identify the most superdecoherent states. In the case of isotropic depolarization, we show that a class of maximally entangled pure states distinct from GHZ and W states, a.k.a. spin anticoherent states [1,2], display the highest decoherence rate for any number of spins. Moreover, we find that these states become absolutely separable after a time which does not depend on the number of spins. We also prove that entanglement is a necessary and sufficient condition, both for pure and mixed states, for superdecoherence to take place [3]. Finally, for anisotropic depolarization, we identify not only the states with the highest initial decoherence rate, but also the states that lose their purity most rapidly over any finite time for a few spins. [1] J. Zimba, Electron. J. Theor. Phys. 3, 143 (2006). [2] D. Baguette, T. Bastin, and J. Martin, Phys. Rev. A 90, 032314 (2014) [3] G. M. Palma, K.-A. Suominen, and A. K. Ekert, Proc. R. Soc. London, Ser. A 452, 567 (1996).

Q 24.14 Tue 16:30 P

Out-of-Time-Order Correlators in a power-law interacting Heisenberg spin chain with random positions — •Maximilian Klaus Müllenbach[1], Adrian Braemer[1], Sebastian Geier[1], Clément Hainaut[2], Martin Gärttner[1,3,4], Matthias Weidemüller[1], and Gerhard Zürn[1] — [1]Physikalisches Institut, Universität Heidelberg, Im Neuenheimer Feld 226, 69120 Heidelberg, Germany — [2]Université de Lille, CNRS, UMR 8523, laboratoire de Physique des Lasers, Atomes et Molécules, Lille, France — [3]Kirchhoff-Institut für Physik, Universität Heidelberg, Im Neuenheimer Feld 227, 69120 Heidelberg, Germany — [4]Institut für Theoretische Physik, Universität Heidelberg, Philosophenweg 16, 69120 Heidelberg, Germany

We use out-of-time-order correlators (OTOCs) to study the propagation of information in disordered isolated quantum systems. Specifically we study operator spreading in a 1D random-position XXZ model with power-law interactions as a function of disorder strength using numerically exact techniques. OTOCs, i.e the squared commutators, of a local Pauli operator and time-evolved originally distant Pauli operators are known to show "light cone"-like behaviour. We characterize these emerging "light cone" structures across the localization to delocalization phase transition. Furthermore we present an experimental scheme based on Floquet Hamiltonian Engineering to perform necessary echo protocols in an interacting system of Rydberg atoms and techniques to extract OTOCs experimentally from quadratic order response functions.

Q 24.15 Tue 16:30 P

Quantum scattering off a diffusive domain — •Nils Krause, Benjamin Stickler, and Klaus Hornberger — University of Duisburg-Essen, Faculty of Physics, 47048 Duisburg, Germany

We investigate the quantum scattering of massive particles in presence of spatially confined momentum diffusion. An analytical method is presented to determine the classical S-matrix, mapping incoming onto outgoing phase space distributions. We compare the results with numerical simulations and discuss how this framework can be extended to describe quantum scattering.

Q 24.16 Tue 16:30 P

Network dynamics in the presence of stochastic fluctuations — •Frederic Folz[1], Kurt Mehlhorn[2], and Giovanna Morigi[1] — [1]Theoretische Physik, Universität des Saarlandes, 66123 Saarbrücken, Germany — [2]Algorithms and Complexity Group, Max-Planck-Institut für Informatik, Saarland Informatics Campus, 66123 Saarbrücken, Germany

We analyse dynamics of a classical network. The dynamics is governed by a mathematical model inspired by the food search of the slime mold Physarum polycephalum - a primitive organism that has demonstrated its ability to solve shortest path problems and to design efficient transport systems. We characterize the networks dynamics by applying measures for their robustness, transport efficiency and costs. We then add noise in the form of Langevin forces and study its effects on the network dynamics. We show that noise can favour the formation of certain network topologies yielding specifically high performance. We identify an optimal noise level to achieve the best balance between robustness, transport efficiency and costs.