Q 60: Quantum Effects (Cavity QED)

Time: Friday 11:00–13:00 Location: f442

Q 60.1 Fri 11:00 f442

Ab initio few-mode theory — •Dominik Lentrodt and Jörg Evers — Max-Planck-Institut für Kernphysik, Heidelberg, Germany

Few-mode models, such as the Jaynes-Cummings model and its many generalizations, have been an indispensable tool in studying the quantum dynamics of light-matter interactions. In particular in cavity and circuit QED these models have been tremendously successful and have been employed in combination with the famous input-output formalism to compute, for example, scattering observables. Recently, however, extreme regimes, such as the overlapping modes and ultra-strong coupling regime, have become accessible in various experimental platforms. In these regimes the applicability of input-output models has been debated. In this talk, we will present an ab-initio method to construct few-mode Hamiltonians that apply even in such extreme regimes [1]. Our theory extends the validity range of Jaynes-Cummings type models without abandoning their conceptual and computational simplicity. In a nutshell, our scheme provides a way to extract relevant degrees of freedom from a structured environment in an open quantum system, allowing to construct a non-perturbative expansion in the mode number. We will outline implications for a broad range of platforms, including quantum optics with non-Hermitian degeneracies [2], multi-mode strong coupling [3], and quantum scattering theory in general [4]. [1] Lentrodt & Evers (2018) arXiv:1812.08556, [2] Özdemir et. al. *Nat. Mat.* **18** 783 (2019), [3] Krimer et. al. *Phys. Rev. A* **89** 033820 (2014), [4] Rotter & Gigan *Rev. Mod. Phys.* **89** 015005 (2017)

Q 60.2 Fri 11:15 f442

Multi-atom scaling of light-matter interactions in a fiber-coupled cavity — •Fabian Spallek and Stefan Yoshi Buhmann — Physikalisches Institut, Freiburg i.Br., Germany

The coupling of tightly controlled single resonant photons and transitions in neutral atoms in open fiber cavities allows for strongly coupled, highly coherent collective light-matter interaction rates. They could provide a high cooperativity, high-bandwidth, fiber-coupled channel for photonic interfaces such as quantum memories and single-photon sources [1]. We use methods from macroscopic Quantum Electrodynamic (QED) and Cavity-QED to investigate how the light-atom interactions depend on the positioning of the atoms with respect to the mode, which can be controlled by an optical dipole trap [2][3]. In this way, we can predict the collective Rabi frequency and the quantitative scaling of the observed Purcell enhancement for a given collection of trapped atoms. Similarities of these collective effects to superradiance in other settings are discussed.

[1] J. Gallego, W. Alt, T. Macha, M. Martinez-Dorantes, D. Pandey, and D. Meschede, *Strong Purcell Effect on a Neutral Atom Trapped in an Open Fiber Cavity*, Phys. Rev. Lett. 121, 173603, (2018)
[2] S. Esfandiarpour, H. Safari, R. Bennett, and S. Y. Buhmann, *Cavity-QED Interactions of Two Correlated Atoms*, J. Phys. B: At. Mol. Opt. Phys. 51, 094004, (2018)
[3] S. Esfandiarpour, H. Safari, and S.Y . Buhmann, *Cavity-QED Interactions of Several Atoms*, J. Phys. B: At. Mol. Opt. Phys. 52, 085503, (2019)

Q 60.3 Fri 11:30 f442

The coupling of free-electrons with whispering-gallery modes — •Ofer Kfir[1], Hugo Lourenço-Martins[1], Gero Storeck[1], Murat Sivis[1], Tyler Harvey[1], Tobias Kippenberg[2], Armin Feist[1], and Claus Ropers[1] — [1]University of Göttingen, Göttingen, Germany — [2]EPFL, Lausanne, Switzerland

Electron microscopes are a ubiquitous tool for nanoscopic characterization, providing for resolutions down to the atomic scale. In recent years, classical light fields are being employed for quantum-state manipulations of electron beams, enabling acceleration (1), attosecond electron pulses (2) and light-induced phase retarders (3). However, the typically weak coupling between electrons and photons requires strong fields to produce meaningful effects. Here we show theoretically and experimentally that whispering-gallery modes (WGM) in microresonators can push electron-photon interactions towards the strong coupling regime. Our experiment (4) shows that WGMs have an enhanced interaction with electrons, manifested in hundreds of electron-energy sidebands. We discuss a roadmap to approach a measureable entanglement between cavity-photons and free-electrons (5), and predict the properties of such a state. In the future, complex optical states may be imprinted on electron beams, providing for optical spectroscopy with spatial resolution at the atomic scale.

1. E. A. Peralta, et al., Nature. 503, 91 (2013). 2. K. E. Priebe, et al., Nat. Phot. 11, 793 (2017). 3. O. Schwartz, et al., Nat. Meth. 16, 1016 (2019). 4. O. Kfir, et al., arXiv:1910.09540 (2019). 5. O. Kfir, Phys. Rev. Lett. 123, 103602 (2019),

Q 60.4 Fri 11:45 f442

Monolithic Fiber Fabry-Perot Cavities with improved mode matching. — •Madhavakkannan Saravanan, Carlos Saavedra Salazar, Deepak Pandey, Hannes Pfeifer, Wolfgang Alt, and Dieter Meschede — Institute of Applied Physics, University of Bonn, Germany

Fiber Fabry-Perot cavities (FFPCs) are an established tool to optically interface atomic, molecular or solid-state systems. However, the stability and, in the case of long cavities, the mode matching of the guided fiber mode to the FFPCs remain challenging.

To overcome these limitations we use a monolithic FFPC design that combines high passive stability with tunability across a free spectral range. Improving the mode matching to a guided fiber mode can be accomplished using stacks of different fiber types such as single-mode, multi-mode and graded-index fibers [1]. We show how the fabrication of these assemblies using splicing of fibers with different material characteristics as well as cleaving with micrometer precision can be accomplished. The quality of fabricated assemblies is assessed by microscope-imaging of the out-coupled fiber mode.

The combination of these techniques has the potential to extend the range of applications for FFPCs to e.g. frequency filters, cavity ring-down spectroscopy or cavity-QED with ions.

[1] Gulati et al., Sci Rep 7, 5556, (2017).

Q 60.5 Fri 12:00 f442

Benchmarking the coupling of single photon emitters to optical resonators — •Gregor Bayer[1], Stefan Häussler[1,2], Igor Aharonovich[3], David Hunger[4], and Alexander Kubanek[1,2] — [1]Institut für Quantenoptik, Universität Ulm — [2]Center for Integrated Quantum Science and Technology — [3]School of Mathematical and Physical Sciences, University of Technology Sydney — [4]Physikalisches Institut, Karlsruher Institut für Technologie

Solid-state based quantum emitters offer a promising platform for various quantum technology applications like quantum repeaters. We present a light matter interface based on a high quality microcavity and compare single photon emitting defects in tailored host matrices with the focus on overcoming the remaining challenges for a scalable use in form of a low rate of coherent photons, poor extraction efficiency out of the host material and low quantum yield. We investigate the system's scattering losses to estimate the possible Purcell enhancement in high Q resonators.

Q 60.6 Fri 12:15 f442

Single-Photon Switching: A Single Molecule Strongly Coupled to a Microcavity — •André Pscherer, Manuel Meierhofer, Daqing Wang, Hrishikesh Kelkar, Diego Martín-Cano, Stephan Götzinger, and Vahid Sandoghdar — Max-Planck-Institut für die Physik des Lichts, Erlangen, Germany

Nonlinear light-matter interactions usually involve macroscopic materials and high intensities, often involving pulsed lasers. Considering the intrinsic optical nonlinearity of atoms and molecules, however, one can imagine performing operations such as switching by using single quantum emitters and single photons. We show that single organic molecules embedded in a solid nanoscopic matrix can indeed provide access to this realm when coupled to a Fabry-Pérot cavity with a very small mode volume. We demonstrate vacuum Rabi oscillations, single-photon switching and four-wave mixing at the level of single photons in the strong coupling regime [1].

[1] A. Pscherer, *et al.*, *in preparation.*

Q 60.7 Fri 12:30 f442

Continuous Quantum Light from a Dark Atom: Theory — •Bo Wang[1], Christopher Ianzano[1], Nicolas Tolazzi[1], Celso Villas-Boas[2], and Gerhard Rempe[1] — [1]Max Planck Institute for

Quantum Optics — [2]Universidade Federal de Sao Carlo

Single photons can be generated from a single atom strongly coupled to an optical cavity via a stimulated Raman adiabatic passage between two atomic ground states [1]. During the generation of the photon, the atom stays within the dark state of electromagnetically induced transparency(EIT) avoiding spontaneous decay from the excited state. In contrast to this well-known scenario, here we present the theoretical result to generate quantum light continuously from an atom in the dark state. A coherent coupling is added between the atomic ground states to allow the coherent generation of multiple photons. This would usually result in the destruction of the dark state and the reappearance of spontaneous decay. However, the dark states of the strongly coupled cavity EIT result from the interference between two atomic ground states entangled with different photonic states [2]. Such dark states are preserved from the local coupling that is applied only within the atomic Hilbert space. Additionally, the nonlinearity of the system allows us to control the quantum fluctuations of the generated light via a quantum Zeno effect.

[1]Kuhn, A et al., Phys. Rev. Lett. 89(6), 067901 (2002).
[2]Souza, J.A. et al., Phys. Rev. Lett. 111, 113602 (2013).

Q 60.8 Fri 12:45 f442

Continuous Quantum Light from a Dark Atom: Experiment

— •Christopher Ianzano[1], Nicolas Tolazzi[1], Bo Wang[1], Celso Villas-Boas[2], and Gerhard Rempe[1] — [1]Max Planck Institute for Quantum Optics — [2]Universidade Federal de Sao Carlo

Cavity QED has been shown to be a powerful tool in atomic physics and quantum optics experiments. In a conventional lambda-type cavity EIT system, a ladder of dark states that are harmonic in intracavity photon number is generated. By Closing the lambda system with a field (or in our case a Raman pair) that directly couples the two ground states, transitions are driven between these dark states. We demonstrate experimentally a four-wave-mixing scheme where the field emitted from the cavity shifts frequency as the sum-difference frequency of the three input fields. Additionally, the output photon statistics are analyzed as a function of input field strengths, and a Zeno-blockade effect is observed. For weak driving, the system is constrained very well to the ground state and the first dark state, but as the driving strength is increased, the blockade is lifted and higher photon number dark states are accessed. Additionally, because the transitions driven are all dark states, the atomic excited state is not populated. In the high-driving limit, we show a field that is increasingly coherent without significantly increasing the average photon number, allowing us to tune the output photon statistics without changing the intracavity field.