Q 35: Quantum Optics: Cavity and Waveguide QED II

Time: Wednesday 14:30–16:30 Location: E001

Q 35.1 Wed 14:30 E001

Observation of superradiant bursts in waveguide QED — Christian Liedl, Felix Tebbenjohanns, •Constanze Bach, Sebastian Pucher, Arno Rauschenbeutel, and Philipp Schneeweiss — Department of Physics, Humboldt-Universität zu Berlin, 10099 Berlin, Germany

Dicke superradiance describes the collective decay dynamics of a fully inverted ensemble of two-level atoms. There, the atoms emit light in the form of a short, intense burst due to a spontaneous synchronization of the atomic dipoles. Typically, to observe this phenomenon, the atoms must be placed in close vicinity of each other. In contrast, here we experimentally observe superradiant burst dynamics with a one-dimensional ensemble of atoms that extends over thousands of optical wavelengths. This is enabled by coupling the atoms to a nanophotonic waveguide, which mediates long-range dipole-dipole interactions between the emitters. The burst occurs above a threshold atom number, and its peak power scales faster with the number of atoms than in the case of standard Dicke superradiance. Moreover, we study the coherence properties of the burst and observe a sharp transition between two regimes: in the first, the phase coherence between the atoms is seeded by the excitation laser. In the second, it is seeded by vacuum fluctuations. Our results shed light on the collective radiative dynamics of spatially extended ensembles of quantum emitters and may turn out useful for generating multi-photon Fock states as a resource for quantum technologies.

Q 35.2 Wed 14:45 E001

Applications of cooperative subwavelength quantum emitter arrays — •Nico Bassler[1,2], Michael Reitz[1], Kai Phillip Schmidt[2], and Claudiu Genes[1,2] — [1]Max Planck Institute for the Science of Light, Erlangen, Germany — [2]Friedrich Alexander University, Erlangen, Germany

Abstract: We describe applications of subwavelength quantum emitter arrays as optical elements and in the context of chiral hybrid cavity design. A single two-dimensional array can act as an optical atom-thick metasurface with a narrow reflectivity window [1]. For normal illumination, the cooperative optical response, stemming from emitter-emitter dipole exchanges, can be augmented via externally tunable magnetic fields to control the state of polarization in transmission [2]. This is particularly interesting for the case of circularly polarized light, where the array can act as a chiral mirror, thus allowing the design of strongly frequency dependent, hybrid [3], chiral cavities. We then consider the application of such chiral cavities to the sensitive detection of chirality in enantiomers.

[1] J. Rui, D. Wei, A. Rubio-Abadal, S. Hollerith, J. Zeiher, D. M. Stamper-Kurn, C. Gross, and I. Bloch, *A subradiant optical mirror formed by a single structured atomic layer,* Nature 583, 369 (2020). [2] N. S. Bassler, M. Reitz, K. P. Schmidt, C. Genes, Linear optical elements based on cooperative subwavelength emitter arrays, arXiv:2209.03204 (2022). [3] O. Cernotik, A. Dantan and C. Genes, Cavity quantum electrodynamics with frequency-dependent reflectors, Phys. Rev. Lett. 122, 243601 (2019).

Q 35.3 Wed 15:00 E001

Waveguide-coupled superconducting nanowire single-photon detectors enhanced by subwavelength grating metamaterials — •Alejandro Sánchez-Postigo, Connor Graham-Scott, and Carsten Schuck — Institute of Physics, University of Münster, Heisenbergstraße 11, 48149 Münster, Germany

Waveguide-coupled superconducting nanowire single-photon detectors (SNSPDs) have developed into one of the most attractive single-photon detector technologies for integrated quantum photonics. Embedding ultra-short, transversally oriented superconducting nanowires within optical cavities have enabled waveguide-coupled SNSPDs with ultra-fast reset times and low timing jitter. However, actual devices exhibit on-chip detection efficiencies (OCDE) as low as 30%, mainly due to scattering loss in the crossing between the waveguide and the slab that supports the nanowire.

Subwavelength grating (SWG) metamaterials are periodic structures that, patterned at a scale that is smaller than the operating wavelength, allow for synthesizing artificial materials with tailored refractive index. In the last years, SWG structures have enabled many silicon photonics devices with unprecedented performance, including waveguides, fiber-chip couplers and filters. These promising metamaterials hold great potential for engineering the integration of SNSPDs with nanophotonic waveguides and tailoring the detector performance.

Here we show our progress on integrating, for the first time, SNSPDs with SWG structures, with the aim of reducing the scattering loss of the former and hence increasing their OCDE.

Q 35.4 Wed 15:15 E001

Inverse design approach to x-ray quantum optics with Mössbauer nuclei in cavities — Oliver Diekmann[1,2], Dominik Lentrodt[1,3], and •Jörg Evers[1] — [1]Max Planck Institute for Nuclear Physics, Heidelberg, Germany — [2]Institute for Theoretical Physics, Vienna University of Technology, Austria — [3]Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, Freiburg, Germany

Nanometer-sized thin-film cavities containing ensembles of Mössbauer nuclei have been demonstrated to be a rich platform for x-ray quantum optics [1]. At low excitation, these systems allow one to implement tunable artificial quantum systems at hard x-ray energies. However, until recently, the inverse problem of determining a cavity structure which realizes a desired level scheme remained unsolved. In this talk, I will introduce the inverse design and develop a comprehensive optimization which allows one to determine optimum cavity systems realizing few-level schemes with desired properties [2,3]. Using this approach, the accessible parameter spaces of artificial multi-level systems can be characterized. Further, I will discuss a number of qualitative insights into x-ray photonic environments for nuclei that will likely impact the design of future x-ray cavities and thereby improve their performance.

[1] R. Röhlsberger and J. Evers, in: Yoshida and Langouche (eds.), Modern Mössbauer Spectroscopy, Springer Vol. 137, p. 105 (2021).
[2] O. Diekmann, D. Lentrodt and J. Evers, Phys. Rev. A 105, 013715 (2022).
[3] O. Diekmann, D. Lentrodt and J. Evers, Phys. Rev. A 106, 053701 (2022).

Q 35.5 Wed 15:30 E001

Spectral dynamics of a strongly coupled system of Yb atoms in a high-finesse cavity — Dmitriy Sholokhov, •Saran Shaju, Ke Li, and Jürgen Eschner — University of Saarland, Saarbrücken, Germany

We trap ^{174}Yb atoms in a MOT using the 182 kHz narrow $^1S_0$ - $^3P_1$ (556 nm) transition, thereby creating a considerably colder and denser atomic cloud as compared to the case of MOT trapping on the dipole-allowed, 28 MHz wide $^1S_0$ - $^1P_1$ line at 399 nm [1]. The cloud resides in a 5 cm long, ∼45 000 finesse optical cavity resonant with the 556 nm transition. We observe strong nonlinear interaction between cavity and atoms which, together with the time-dependent atom number inside the cavity mode, leads to complex dynamics of the system. In this contribution we characterize and analyze time-dependent and spectral properties of the light emitted into cavity and free space.

[1] H. Gothe, D. Sholokhov, A. Breunig, M. Steinel, J. Eschner, Phys. Rev. A 99, 013415 (2019)

Q 35.6 Wed 15:45 E001

Controlling the spontaneous emission of trapped ions for quantum applications — •Giovanni Cerchiari, Yannick Weiser, Lorenz Panzl, and Rainer Blatt — Universität Innsbruck, Technikerstrasse 25/4, A-6020 Innsbruck, Austria

Trapped atomic ions are one of the most prominent platforms for bridging the gap between fundamental quantum physics research and quantum technology applications. In ions, laser excitation is used to encode quantum information into the electronic excited states, which, however, are unstable and can spontaneously relax by photon emission. The spontaneous emission of photon is recognized as one of the key constraints for the long-term storage of information and for the encoding process. In this contribution, I will explain why we believe that spontaneous emission is not a fundamental limit, but rather a phenomenon that may be controlled and suppressed to enhance quantum technology.

Q 35.7 Wed 16:00 E001

Subradiant States in Cavity QED — •Tom Schmit[1], Alexander Baumgärtner[2], Simon Hertlein[2], Carlos Máximo[2], Davide Dreon[2], Tobias Donner[2], and Giovanna Morigi[1] — [1]Theoretische Physik, Universität des Saarlandes, 66123 Saarbrücken, Germany — [2]Institute for Quantum Electronics, Eidgenössische Technische Hochschule Zürich, Otto-Stern-Weg 1, 8093 Zürich, Switzerland

We analyse theoretically self-organization of transversally pumped atoms that strongly couple to two cavity modes in the dispersive regime by means of the quantum master equation of Ref. [1]. We determine the stationary state and discuss the emerging phase diagram as a function of the experimental control parameters. We argue that, when the atomic detuning from the pump is on the blue, the atoms selforganize in patterns that exhibit the characteristics of subradiance. We then analyse the stability of these subradiant states by means of a quantum Euler equation, which we derive from the master equation in an appropriate limit. We compare our predictions with experimental measurements in the corresponding regime and find qualitative and quantitative agreement. ~\\ $[1]$ S. B. J{\"a}ger, T. Schmit, G. Morigi, M. J. Holland, and R. Betzholz, Phys. Rev. Lett. \textbf{129}, 063601 (2022).\\ $[2]$ P. Zupancic, D. Dreon, X. Li, A. Baumgärtner, A. Morals, W. Zheng, N. R. Cooper, T. Esslinger, and T. Donner, Phys. Rev. Lett. \textbf{123}, 233601 (2019).

Q 35.8 Wed 16:15 E001

Waveguide QED with Rydberg superatoms — •Nina Stiesdal[1], Lukas Ahlheit[1], Kevin Kleinbeck[2], Jan Kumlin[3], Anna Spier[1], Jan de Haan[1], Hans-Peter Büchler[2], and Sebastian Hofferberth[1] — [1]IAP, University of Bonn — [2]ITP3, University of Stuttgart — [3]CCQ, Aarhus University

The field of Waveguide QED investigates how light in a single mode propagates through a system of localized quantum emitters. If the coupling between individual photons and emitters is sufficiently strong, the photons can mediate an effective interaction between the emitters, creating a many-body system. The cascaded interaction with saturated emitters can be interpreted as a photon-photon interaction.

We realize effective two-level emitters by exploiting the Rydberg blockade effect. By confining $N\sim10.000$ atoms to a single blockaded volume, the ensemble only supports a single excitation creating a so-called Rydberg superatom. Due to the collective nature of the excitation, the superatom effectively represents a single emitter coupling strongly to single photons. The directional emission of the superatom into the initial probe mode realizes a waveguide-like system in free-space without any actual light-guiding elements.

This talk will discuss how we scale this system from one to few strongly coupled superatoms to study how the propagation of quantized light fields through a small emitter chain results in photon-photon correlations and entanglement between the emitters. We also show how we use controlled dephasing of the collective excitation into collective dark states to subtract exact photon numbers from an incoming pulse.