Q 18: Quantum Effects: Cavity QED I

Time: Tuesday 11:00–12:45 Location: P 4

Q 18.1 Tue 11:00 P 4

Real-time generation of predefined atomic patterns inside a cavity — •Eduardo Urunuela, Wolfgang Alt, Jose Gallego, Michael Kubista, Tobias Macha, Miguel Martinez-Dorantes, Deepak Pandey, Lothar Ratschbacher, and Dieter Meschede — Institut für Angewandte Physik der Universität Bonn, Wegelerstr. 8, 53115 Bonn

Cavity QED systems are promising candidates for the implementation of Quantum Information protocols. Some of these systems rely on the coherent coupling of single or multiple atoms with an optical field inside a resonator. It is essential to obtain precise control on the number of atoms and their relative position inside the cavity, for instance for specific entanglement generation protocols [1].

In this work, we present an experimental technique to create predefined patterns of a few atoms inside a fiber Fabry-Perot resonator, in real-time. First, several ^{87}Rb atoms are trapped in a 3D optical lattice inside the fiber cavity. Then, using an EMCCD camera, a fluorescence image of the atoms is acquired in situ, and next the atoms in undesired lattice sites are removed using a focused push-out beam, directed by a 2D acousto-optic deflector.

[1] M. J. Kastoryano et al. PRL. 106, 090502 (2011)

Q 18.2 Tue 11:15 P 4

Signatures of Raman-lasing in a side-pumped Ytterbium atom-cavity system — •Hannes Gothe, Anna Breunig, Martin Steinel, and Jürgen Eschner — Universität des Saarlandes, Saarbrücken

A few million Ytterbium atoms are magneto-optically trapped inside a 5 cm long high-finesse cavity using the dipole-allowed $^1S_0 \leftrightarrow {}^1P_1$ line at 399 nm (29 MHz linewidth). The atoms are side-pumped with 556 nm-light (i.e. laser-excited under 90° to the cavity axis) near the $^1S_0 \leftrightarrow {}^3P_1$ intercombination line (182 kHz linewidth), and the scattering into the cavity modes is observed at the output mirrors. Cavity emission is found above a threshold pump intensity and atom number; moreover, the emitted photons show a flat $g^{(2)}$ correlation function. Both observations indicate a lasing process. The conditions and properties of this emission are studied in detail. We will discuss a four-photon Raman process including pump and trap light as the suspected underlying mechanism.

Q 18.3 Tue 11:30 P 4

Hyperradiance from two atoms coupled to a single-mode cavity — •Marc-Oliver Pleinert[1,2,3], Joachim von Zanthier[1,3], and Girish S. Agarwal[2,4] — [1]Institut für Optik, Information und Photonik, Universität Erlangen-Nürnberg, 91058 Erlangen, Germany — [2]Department of Physics, Oklahoma State University, Stillwater, Oklahoma 74078, USA — [3]Erlangen Graduate School in Advanced Optical Technologies (SAOT), Universität Erlangen-Nürnberg, 91052 Erlangen, Germany — [4]Institute for Quantum Science and Engineering and Department of Biological and Agricultural Engineering, Texas A&M University, College Station, Texas 77843, USA

We investigate the radiative characteristics of a system consisting of two coherently driven atoms coupled to a single-mode cavity, an ideal setup to study aspects of collective behavior over a wide range of coupling parameters. We show that this fundamental setup can distinctly exceed the free-space superradiant behavior, what we call hyperradiance. The phenomenon is accompanied by strong quantum fluctuations and thus cannot be described by a (semi-)classical treatment. Surprisingly, hyperradiance arises for atoms radiating out-of-phase, an alleged non-ideal condition, where one expects subradiance. We are able to explain the onset of hyperradiance in a transparent way by a photon cascade taking place among manifolds of Dicke states with different photon numbers under particular out-of-phase coupling conditions.

Q 18.4 Tue 11:45 P 4

Two-Photon Blockade in an Atom-Driven Cavity QED System — •Karl Nicolas Tolazzi, Christoph Hamsen, Tatjana Wilk, and Gerhard Rempe — Max Planck Institute of Quantum Optics, Hans-Kopfermann-Straße 1, 85748 Garching

N-photon blockade is a dynamical quantum-nonlinear effect in which the absorption of N photons blocks the absorption of N+1 or more photons. This effect occurs in driven systems with an anharmonic ladder of energy eigenstates, e.g. a single atom strongly coupled to a high finesse optical resonator. While single-photon blockade has been demonstrated in such a system before [1], we here report on the first observation of two-photon blockade [2]. As a signature, we show a three-photon antibunching with simultaneous two-photon bunching observed in the light emitted from the cavity. The effect occurs for atom driving, not cavity driving. This can be understood intuitively: while a two-level atom can only add excitations to the system one-by-one, the cavity is not restricted in excitation number. The latter leads to bosonic enhancement which causes the transition strengths between the dressed states to increase with the number of excitations in the system while they remain constant for atom driving. We consider these results as a significant step towards multi-photon quantum nonlinear optics.

[1] Birnbaum et al., Nature 436,87 (2016)
[2] Hamsen et al., arXiv 1608.01571 (2016)

Q 18.5 Tue 12:00 P 4

Coupling a trapped ion to a fiber cavity — •Florian R. Ong[1], Klemens Schüppert[1], Pierre Jobez[1], Dario A. Fioretto[1], Konstantin Friebe[1], Moonjoo Lee[1], Markus Teller[1], Florian Kranzl[1], Konstantin Ott[2], Sebastian Garcia[2], Jakob Reichel[2], Rainer Blatt[1,3], and Tracy E. Northup[1] — [1]Universität Innsbruck, Institut für Experimentalphysik, Technikerstrasse 25, A-6020 Innsbruck, Austria — [2]Laboratoire Kastler Brossel, ENS/UPMC-Paris 6/CNRS, F-75005 Paris, France — [3]Institut für Quantenoptik und Quanteninformation der Österreichischen Akademie der Wissenschaften, A-6020 Innsbruck, Austria

A single atom coupled to an optical cavity can be used as a coherent quantum interface between stationary and flying qubits in a quantum network. Using fiber-based cavities, we expect to reach the strong coupling regime of cavity QED with a single trapped ion. Operating in this regime would enable protocols for quantum communication over long distances to be carried out with enhanced fidelity and efficiency. We will report on our current efforts to couple a calcium ion stored in a linear Paul trap to a fiber cavity. In our setup the cavity is formed between a photonic crystal fiber and a multimode fiber. Both fibers are mounted on separate nanopositioners, enabling us to tune the cavity length and optimize its alignment in vacuum. By developing procedures to control the charges trapped on the fibers' dielectric surfaces, we were able to couple an ion to cavities with lengths of about 500 μm and with finesses in excess of 30,000.

Q 18.6 Tue 12:15 P 4

Coupling ultracold atoms to a superconducting coplanar waveguide resonator — •Helge Hattermann, Li Yuan Ley, Daniel Bothner, Benedikt Ferdinand, Conny Glaser, Lörinc Sárkány, Reinhold Kleiner, Dieter Koelle, and József Fortágh — CQ Center for Collective Quantum Phenomena and their Applications, Physikalisches Institut, Eberhard Karls Universität Tübingen, Auf der Morgenstelle 14, D-72076 Tübingen, Germany

Hybrid quantum systems of superconductors and ultracold atoms have been proposed as a promising candidate for quantum information processing. In such a hybrid system, information is processed by superconducting circuits and stored in an ensemble of trapped atoms, using a superconducting coplanar waveguide resonator as interface between the different quantum systems. Long coherence times of hyperfine superposition states of trapped atoms have already been demonstrated [1], making atoms attractive as a possible quantum memory.

Here, we report on the measurement of the coupling between magnetically trapped ultracold ^{87}Rb atoms and a driven coplanar waveguide resonator which is near-resonant to the atomic hyperfine transition. The field in the cavity is characterized by measuring the frequency shift of the atomic clock states dressed by the cavity field. The determination of this dressing shift for different driving frequencies reveals the lorentzian lineshape of the cavity, in agreement with transmission measurements. This coupling is the first step towards the implementation of an atomic quantum memory for superconducting circuits.

[1] S. Bernon et al., Nat. Commun. 4, 2380 (2013)

Q 18.7 Tue 12:30 P 4

Quantum optical circulator controlled by a single chirally coupled atom — Michael Scheucher, Adèle Hilico, •Elisa Will, Jürgen Volz, and Arno Rauschenbeutel — Vienna Center for Quantum Science and Technology, Atominstitut, TU Wien, Austria

Integrated optical circuits for information processing promise to outperform their electronic counterparts in terms of bandwidth and energy consumption. However, such circuits require components that control the flow of light. Here, a particular important class are nonreciprocal devices. Recently, we realized a quantum optical circulator. For this purpose, we strongly couple a ^{85}Rb atom to a whispering-gallery-mode resonator - a so-called bottle microresonator [1] - in which photons exhibit a chiral nature: their polarization is inherently linked to their propagation direction [2]. Interfaced by two optical nanofibers, the system forms a 4-port device. The fact that the atom exhibits polarization-dependent transition strengths leads to a direction-dependent atom-photon interaction. As a consequence, we observe a nonreciprocal behaviour, where photons are directed from one fiber-port to the next [3]. We show that the internal quantum state of the atom controls the operation direction of the circulator [3]. This working principle is compatible with preparing the circulator in a coherent superposition of its operational states. It thus may become a key element for routing and processing quantum information in scalable integrated optical circuits.

[1] C. Junge et al., Phys. Rev. Lett. 110, 213604 (2013)
[2] P. Lodahl et al., arXiv:1608.00446v1
[3] M. Scheucher et al., arXiv:1609.02492v1