Q 48: Quantum Effects II

Time: Thursday 10:30–12:30 Location: Q-H13

Q 48.1 Thu 10:30 Q-H13

Atomic Dynamics in Strongly Coupled Multimode Cavities under Continuous Measurement — Valentin Link[1], •Kai Müller[1], Rosaria G. Lena[2], Kimmo Luoma[3], François Damanet[4], Walter T. Strunz[1], and Andrew J. Daley[2] — [1]Institut für Theoretische Physik, TU Dresden, Dresden, Germany — [2]Department of Physics and SUPA, University of Strathclyde, Glasgow, United Kingdom — [3]Department of Physics and Astronomy, University of Turku, Turun Yliopisto, Finland — [4]Department of Physics and CESAM, University of Liège, Liège, Belgium

Atoms in multimode cavity QED systems provide an exciting platform to study many-body phenomena in regimes where the atoms are strongly coupled amongst themselves and with the cavity. An important challenge in this, and other related non-Markovian open quantum systems is to understand what information we gain about the atoms from continuous measurement of the output light, as most of the existing theoretical frameworks are restricted to either few cavity modes or weak atom-cavity coupling. In this work, we address this problem, describing the reduced atomic state via a hierarchy of equations of motion, which provide an exact conditioned reduced description under monitoring. We utilise this formalism to study how different monitoring for modes of a multimode cavity affects our knowledge about an atomic state, and to improve spin squeezing via measurement and feedback in a strong coupling regime. Our work opens opportunities to understand continuous monitoring of non-Markovian open quantum systems, both on a practical and fundamental level.

Q 48.2 Thu 10:45 Q-H13

***Ab initio* cavity QED - modifying chemistry with strong light-matter interaction** — •Christian Schäfer[1,2], Enrico Ronca[3], Johannes Flick[4,5], Prineha Narang[5], and Angel Rubio[2,4] — [1]Department of Microtechnology and Nanoscience, MC2, Chalmers University of Technology, 412 96 Göteborg, Sweden — [2]Max Planck Institute for the Structure and Dynamics of Matter, Hamburg, Germany — [3]Istituto per i Processi Chimico Fisici del CNR (IPCF-CNR), Via G. Moruzzi, 1, 56124, Pisa, Italy — [4]Center for Computational Quantum Physics (CCQ), The Flatiron Institute, 162 Fifth Avenue, New York NY 10010, USA — [5]John A. Paulson School of Engineering and Applied Sciences, Harvard University, Cambridge, Massachusetts 02138, USA

The alchemical dream of altering a given material on demand into something desirable is at the very heart of chemistry. Optical-Cavity environments provide a novel handle to non-intrusively control materials and chemistry. The self-consistent interaction between complex electromagnetic environments and realistic materials gave birth to a new discipline, sometimes referred to as '*ab initio* QED', on the interface of condensed matter, chemistry and quantum optics.

I will provide a brief introduction into this newly emerged field and illustrate its application that gives rise to the control of chemical reactions [1] and intermolecular interactions.

[1] Schäfer, C., Flick, J., Ronca, E., Narang, P., and Rubio, A., arXiv:2104.12429 (2021).

Q 48.3 Thu 11:00 Q-H13

Nitrogen vacancy centers in diamond membranes coupled to an optical microcavity — •Maximilian Pallmann[1], Kerim Köster[1], Jonathan Körber[3], Julia Heupel[2], Rainer Stöhr[3], Timon Eichhorn[1], Larissa Kohler[1], Cyril Popov[2], and David Hunger[1] — [1]Karlsruher Institut für Technologie — [2]Universität Kassel — [3]Universität Stuttgart

Color centers in diamond centers are very promising candidates for applications in quantum communication and metrology. The nitrogen vacancy center (NV) stands out due to its exceptional spin coherence properties. On the other hand, it suffers from rather bad optical properties due to significant phonon coupling, and only 3% of the emitted light belongs to the Zero phonon line (ZPL). This can be overcome by coupling the emitters to optical cavities, making use of the Purcell effect.

In our experiment, we integrate a diamond membrane to an open access fiber-based Fabry-Perot microcavity [1] to attain emission enhancement into a single well-collectable mode as well as spectral filtering. We investigate the influence of the diamond membrane on the optical properties of the cavity.

Furthermore, we present Purcell-enhanced ensemble-fluorescence of shallow-implanted NV centers and observe cavity-induced collective effects that lead to a bunching behavior in the emission.

[1] Heupel,Pallmann,Körber.Micromachines 2020, 11, 1080;

Q 48.4 Thu 11:15 Q-H13

Nonequilibrium quantum state preparation with Floquet systems in engineered baths — •Francesco Petiziol and André Eckardt — Technische Universität Berlin, Institut für Theoretische Physik, Hardenbergstr. 36, 10623 Berlin, Germany

I will discuss how interesting nonequilibrium quantum states can be prepared and stabilized by combining time-periodic driving with engineered quantum baths, as they are realizable in circuit QED systems. Considering arrays of periodically driven artificial atoms individually coupled to leaky cavities, I will first show that, while the periodic driving allows to engineer desired effective system properties, the cavities can be exploited to cool the systems to their effective ground states. I will illustrate how this mechanism can be used for the robust preparation of states with non-trivial properties. Concretely, I will discuss the preparation of Aharonov-Bohm cages, in which quantum interference constrains the dynamics in small subsystems, and chiral ground state currents.

Q 48.5 Thu 11:30 Q-H13

Inverse design approach to x-ray cavity quantum optics with Mössbauer nuclei — Oliver Diekmann, Dominik Lentrodt, and •Jörg Evers — Max Planck Institute for Nuclear Physics, Heidelberg

Nanometer-sized thin-film cavities containing ensembles of Mössbauer nuclei have been demonstrated to be a rich platform for x-ray quantum optics. At low excitation, these systems can be described by effective few-level schemes, thereby providing tunable artificial quantum systems at hard x-ray energies. With the recent advent of an ab-initio theory [1,2], a numerically efficient description of these systems is now possible. On this basis, we introduce the inverse design and develop a comprehensive optimization which allows one to determine optimum cavity systems realizing few-level schemes with desired properties [3]. Using this approach, we characterize the accessible parameter spaces of artificial two- and three-level systems and determine optimum cavity designs for several applications. Further, we discover 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] D. Lentrodt and J. Evers, Phys. Rev. X **10**, 011008 (2020).
[1] D. Lentrodt *et al.*, Phys. Rev. Research **2**, 023396 (2020).
[2] O. Diekmann *et al.*, arXiv:2108.01960 [quant-ph].

Q 48.6 Thu 11:45 Q-H13

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

We investigate the possibility of MOT trapping of ^{174}Yb atoms using the 182 kHz narrow $^1S_0$ - $^3P_1$ (556 nm) transition, in order to generate lasing on the $^1S_0$ - $^3P_0$ clock transition (578 nm) using the virtual-state lasing mechanism described in [1]. While trapping with 556 nm light, the atomic cloud is considerably colder and denser as compared to the case of MOT trapping on the 28 MHz wide $^1S_0$ - $^1P_1$ line at 399 nm, which was used in [1]. We observe strong interaction between cavity and atoms in the scattering of frequency-shifted trap light into the cavity. The interaction, including the time-dependent atom number inside the cavity mode, leads to complex dynamics of the quantum system, which we characterize and analyze in this contribution.

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

Q 48.7 Thu 12:00 Q-H13

Quantum State Preparation in a Micromaser — Andreas Jan Christoph Woitzik[1,2], Edoardo Carnio[1,2], and •Andreas Buchleitner[1,2] — [1]Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, Hermann-Herder-Straße 3, D-79104, Freiburg im Breisgau, Germany} — [2]EUCOR Centre for Quantum Science and Quantum Computing, Albert-Ludwigs-Universität Freiburg, Hermann-Herder-Straße 3, D-79104, Freiburg im Breisgau, Germany

Quantum algorithms process information encoded into quantum states via an appropriate unitary transformation. Their purpose is to deliver a sought-after target state that represents the solution of a predefined computational problem. From a physical perspective, this process can be interpreted as a quantum state control problem where a given target state is to be prepared through an optimally tailored unitary transformation. In this talk we adopt the one-atom (or micro-) maser as a model to study the transfer of quantum information in state space. We consider a string of atoms that interact sequentially with a cavity mode, to understand the relation between the cavity's convergence towards a given target state and the entanglement content of the injected atomic string.

Q 48.8 Thu 12:15 Q-H13

Coupling a single trapped atom to a whispering-gallery-mode microresonator — •Xinxin Hu[2], Elisa Will[1], Luke Masters[2], Arno Rauschenbeutel[2], Michael Scheucher[1], and Jürgen Volz[2] — [1]Vienna Center for Quantum Science and Technology, Technische Universität Wien, 1020 Vienna, Austria — [2]Department of Physics, Humboldt Universität zu Berlin, 10099 Berlin, Germany

We demonstrate trapping of a single ^{85}Rb atom at a distance of 200 nm from the surface of a whispering-gallery-mode bottle microresonator. The atom is trapped in an optical potential, which is created by retroreflecting a red-detuned focused laser beam from the resonator surface. We counteract the trap-induced light shift of the atomic transition frequency by superposing a second laser beam with suitably chosen power and detuning. This allows us to observe a vacuum Rabi-splitting in the excitation spectrum of the coupled atom-resonator system. This first demonstration of stable and controlled interaction of a single atom with a whispering-gallery-mode in the strong coupling regime opens up the route towards the implementation of quantum protocols and applications that harvest the chiral atom-light coupling present in this class of resonators.