Q 48: Optomechanics II

Time: Thursday 11:00–13:00 Location: E214

Invited Talk Q 48.1 Thu 11:00 E214

Using optomechanical systems to test gravitational theory – possibilities and limitations — •Dennis Rätzel — ZARM, University of Bremen, 28359 Bremen, Germany — Institut für Physik, Humboldt-Universität zu Berlin, 12489 Berlin, Germany

More than 100 years after the first development of a relativistic theory of gravity, there is an ever-increasing amount of predicted, yet untested, phenomena and unsolved scientific puzzles revolving around gravity. There are many proposals to apply quantum sensors to test for such phenomena or experimentally resolve some of the puzzles. In this talk, I will present my perspective on three proposals based on optomechanical systems: measurement of the gravitational field of light and relativistic particle beams, obtaining bounds on Chameleon-field dark energy models, and testing for quantum properties of the gravitational field. I will give a short introduction to the models involved and discuss fundamental constraints.

Q 48.2 Thu 11:30 E214

Force-Gradient Sensing and Entanglement via Feedback Cooling of Interacting Nanoparticles — •Henning Rudolph[1], Uros Delic[2], Markus Aspelmeyer[2,3], Klaus Hornberger[1], and Benjamin Stickler[1] — [1]University of Duisburg-Essen, Duisburg, Germany — [2]University of Vienna, Vienna, Austria — [3]Institute for Quantum Optics and Quantum Information (IQOQI) Vienna, Vienna, Austria

The motion of levitated nanoparticles has recently been cooled into the quantum groundstate by electric feedback [1,2]. In this talk, we show theoretically that feedback-cooling of two levitated, interacting nanoparticles enables differential sensing of forces and the observation of stationary entanglement [3]. The feedback drives the particles into a stationary, non-thermal state which is susceptible to inhomogeneous force fields. We predict that force-gradient sensing at the zepto-Newton per micron range is feasible and that entanglement due to the interaction between charged particles is possible if the detection efficiency of the feedback loop exceeds the ratio of the mechanical normal mode frequencies.

[1] Magrini et al. "Real-time optimal quantum control of mechanical motion at room temperature." Nature (2021)

[2] Tebbenjohanns et al. "Quantum control of a nanoparticle optically levitated in cryogenic free space." Nature (2021)

[3] Rudolph et al. "Force-Gradient Sensing and Entanglement via Feedback Cooling of Interacting Nanoparticles." Physical Review Letters (2022)

Q 48.3 Thu 11:45 E214

A hybrid optomechanical system of an optically levitated nanoparticle and an optical microcavity in a resolved sideband regime — •Zijie Sheng[1,2], Seyed Khalil Alavi[1,2], Harald Giessen[3], Haneul Lee[4], Hansuek Lee[4], and Sungkun Hong[1,2] — [1]Institute for Functional Matter and Quantum Technologies, Universität Stuttgart, 70569 Stuttgart, DE — [2]Center for Integrated Quantum Science and Technology, Universität Stuttgart, 70569 Stuttgart, DE — [3]4th Physics Institute, Universität Stuttgart, 70569 Stuttgart, DE — [4]Department of Physics, Korea Advanced Institute of Science and Technology, Daejeon, 34141, Korea

An optically levitated dielectric nanoparticle coupled to an optical cavity has recently emerged as an optomechanical system with unique features that allow for quantum experiments at room temperature. The field has shown rapid progress in the past few years, including cooling of the particle's motion down to the ground state, achieved with a conventional Fabry-Pérot optical cavity in a resolved sideband regime. We present a new type of optomechanical system comprising a nanoparticle in an optical tweezer and a monolithic optical microcavity in a resolved sideband regime. We use a silica microtoroid as an optical cavity with a Q factor of up to 10^8. The optomechanical coupling is realized through the evanescent field when the particle is near the microtoroid. At a few hundred nanometers from the surface, the coupling of up to tens of kHz can be achieved, five orders of magnitude larger than the previous work with a bulk optical cavity. We discuss our progress toward attaining strong quantum cooperativity.

Q 48.4 Thu 12:00 E214

Phase locking of two levitated nanoparticles via non-reciprocal dipole-dipole coupling — •Manuel Reisenbauer[1], Livia Egyed[1], Murad Abuzarli[1], Anton Zasedatelev[1,2], Henning Rudolph[3], Klaus Hornberger[3], Aspelmeyer Markus[1,2], Benjamin A. Stickler[3], and Uros Delic[1,2] — [1]University of Vienna, A-1090 Vienna, Austria — [2]Austrian Academy of Sciences, A-1090 Vienna — [3]University of Duisburg-Essen, 47048 Duisburg, Germany

Arrays of optically levitated dielectric particles are a novel platform for exploring collective optomechanical dynamics. Recently, strong tunable dipole-dipole and electrostatic interaction have been demonstrated between several levitated particles.

We built an experiment based on an optical trap array of silica nanoparticles. Our platform enables independent control of particle dynamics and non-reciprocal dipole-dipole interactions together with a readout for individual particle motions. We employ a fully non-reciprocal coupling to drive the particles motion into self-sustained oscillations. We observe a phase transition into a collectively synchronized state of motion which we characterize via phase locking.

Our work has possible applications for sensing and metrology employing the reduction of phase noise below the thermomechanical limit of each individual oscillator. Finally, we will discuss the scalability of our system to large arrays of trapped particles.

Q 48.5 Thu 12:15 E214

Superconducting Quantum Magnetomechanics — •Christian M.F. Schneider[1,2,6,7], David Zöpfl[1,2], Mathieu L. Juan[3], Nicolas Diaz-Naufal[4], Lukas F. Deeg[1,2], Aleksei Sharafiev[1,2], Anja Metelmann[4,5], and Gerhard Kirchmair[1,2] — [1]Institute for Quantum Optics and Quantum Information, Austrian Academy of Sciences, 6020 Innsbruck, Austria — [2]Institute for Experimental Physics, University of Innsbruck, 6020 Innsbruck, Austria — [3]Institut Quantique and Département de Physique, Université de Sherbrooke, Sherbrooke, Québec, J1K 2R1, Canada — [4]Dahlem Center for Complex Quantum Systems and Fachbereich Physik, Freie Universität Berlin, 14195 Berlin, Germany — [5]Institute for Theory of Condensed Matter, Karlsruhe Institute of Technology, 76131 Karlsruhe, Germany — [6]Technical University of Munich, Physics Department, 85747 Garching, Germany — [7]Walther-Meißner-Institut, Bayerische Akademie der Wissenschaften, 85748 Garching, Germany

Quantum control of massive mechanical resonators has come within reach in recent years. In this talk, I describe an experimental setup in which we couple magnetic cantilevers to a superconducting microwave resonator or a transmon. When cooled down to mK temperatures, we achieve high and tunable coupling strengths, and could demonstrate control over the mechanical system in form of feedback cooling to around 10 phonons. The intrinsic nonlinearity of the microwave circuit gives rise to a more power efficient cooling performance. For the ultimate goal of quantum control, we couple a transmon directly to the cantilever and show some first characterization measurements.

Q 48.6 Thu 12:30 E214

Nonclassical photon statistics in two-tone continuously driven optomechanics — •Kjetil Borkje[1], Francesco Massel[1], and Jack Harris[2,3] — [1]Department of Science and Industry Systems, University of South-Eastern Norway, PO Box 235, NO-3603 Kongsberg, Norway — [2]Department of Physics, Yale University, 217 Prospect Street, New Haven, Connecticut 06520, USA — [3]Department of Applied Physics, Yale University, 15 Prospect Street, New Haven, Connecticut 06520, USA

We present a study of a standard optomechanical system where the cavity mode is continuously driven at two different frequencies, and where sideband photons are detected by single photon detectors after frequency filtering the output from the cavity mode around its resonance frequency. We first derive the normalized second order coherence associated with the detected photons, and show that it contains signatures of the quantum nature of the mechanical mode which would be absent with only single-tone driving. To identify model-independent nonclassical features, we derive two inequalities for the sideband photon statistics that should be valid in any classical model of the system. We show that these inequalities are violated in the proposed setup. This is provided that the average phonon occupation number of the mechanical mode is sufficiently small, which in principle can be achieved through sideband cooling intrinsic to the setup. The proposed setup thus employs a mechanical oscillator in order to generate a steady-state source of nonclassical radiation.

[1] Børkje et al., Physical Review A, 104, 063507 (2021)

Q 48.7 Thu 12:45 E214

Dissipative cavity optomechanics with a suspended frequency-dependent mirror — Sushanth Kini Manjeshwar[1], Anastasiia Ciers[1], •Juliette Monsel[1], Cindy Peralle[2], Shu Min Wang[1], Philippe Tassin[2], and Witlef Wieczorek[1] — [1]Department of Microtechnology and Nanoscience, Chalmers University of Technology, SE-412 96 Göteborg, Sweden — [2]Department of Physics, Chalmers University of Technology, SE-412 96 Göteborg, Sweden

Cavity optomechanics with a strongly frequency-dependent mirror, such as a photonic crystal mirror, offers novel capabilities in manipulating mechanical motion, such as the implementation of efficient cooling. Here, we build an input-output-based description of such an optomechanical system, generalizing Ref. [1] by including in our model a dissipative optomechanical coupling arising from the change in the loss rate of the cavity due to the mechanical motion. We then analyze the optomechanical properties of the system, in particular the mechanical frequency shift and optomechanical cooling. Finally, we show how our model matches our experimental measurements of a chip-based microcavity. Our setup consists of a suspended photonic crystal mirror [2] and a distributed Bragg reflector mirror, forming a free-space, Fabry-Pérot-type optomechanical microcavity with a length less than the optical wavelength and approaching the ultra-strong coupling regime.

[1] O. Černotík, A. Dantan, C. Genes, Phys. Rev. Lett. 122, 243601 (2019)

[2] S. Kini Manjeshwar, et al., Appl. Phys. Lett. 116, 264001 (2020)