Q 62: Optomechanics

Time: Friday 10:30–12:45 Location: S SR 111 Maschb.

Group Report Q 62.1 Fri 10:30 S SR 111 Maschb.
Experiments with levitated optomechanics — •Hendrik Ulbricht — Department of Physics and Astronomy, University of Southampton, SO17 1BJ, Southampton, UK

We will report on our experiments with levitated optomechanical systems relevant for both sensing applications and the study of fundamental physics. Such experiments include optical parametric feedback cooling towards the quantum mechanical ground state, generation of squeezed motional states of thermal ensembles, rotation and precession motion, measurement of surface forces and the implementation of real-time Kalman filters to manipulate the motion of trapped nanoparticles in vacuum.

Q 62.2 Fri 11:00 S SR 111 Maschb.
Levitation of nanodiamonds containing single emitters in a Paul trap — •Andreas W. Schell[1,2], Gerard P. Conangla[2], Raul Rica[2], and Romain Quidant[2] — [1]Quantum Optical Technology Group, CEITEC, Brno, Czech Republic — [2]ICFO, Barcelona, Spain

Here, we present a method for levitating nanodiamond crystals containing single nitrogen vacancy centers for use in levitation optomechanics. Levitation optomechanics exploits the unique mechanical properties of trapped micro and nano-objects in vacuum and has the potential to push forward the limits of experimental physics leading to a better understanding of quantum decoherence and novel ultrasensitive sensing schemes. While optical levitation of nanodiamonds in vacuum results in thermal damage, it has been shown that a single charged submicron particle can be stabilized in a quadrupole ion trap allowing for the observation of NV fluorescence [1]. Here, we will demonstrate trapping in vacuum and center-of-mass feedback cooling of a nanodiamond holding a single NV center in a three-dimensional Paul trap [2]. The achieved motion control enables us to optically interrogate and characterize the single NV response. The platform developed here consisting of a three-dimensional Paul trap with high numerical aperture optical access and the possibility to perform feedback cooling in vacuum.

[1] Kuhlicke, A., Schell, A. W., Zoll, J., & Benson, O. Applied Physics Letters, 105(7), 073101 (2014). [2] Planes, G., Schell A., W., Rica, R., Quidant, R., Nano Letters 18, 3956-3961

Q 62.3 Fri 11:15 S SR 111 Maschb.
Levitated electromechanics with charged nanoparticles — •Lukas Martinetz, Klaus Hornberger, and Benjamin A. Stickler — Fakultät für Physik, Universität Duisburg-Essen

Levitating a charged nanoscale particle between two capacitor plates, which are integrated into an electric circuit, provides a promising route to supplement techniques from levitated optomechanics. The ro-translational motion of a charged particle induces a current in the circuit, which can be used to detect, manipulate, and cool the particle motion [1-2]. We show that coupling the nanoparticle to a series or parallel RLC circuit can be used to realize resistive quantum cooling, even in the presence of circuit-induced heating due to Johnson-Nyquist noise. The resulting quantum master equation demonstrates how the quantum state of the nanoparticle can be manipulated with scalable electric circuitry, opening the door for levitated quantum electromechanics.

[1] J. Millen et al., Levitated electromechanics: all-electrical cooling of charged nano- and micro-particles, arXiv:1802.05928v2 (2018)

[2] L. S. Brown et al., Geonium theory: Physics of a single electron or ion in a Penning trap, Rev. Mod. Phys. 58, 233 (1986)

Q 62.4 Fri 11:30 S SR 111 Maschb.
Towards coherent dynamics in an atomic-mechanical quantum hybrid experiment — •Tobias Wagner[1], Jakob Butlewski[1], Philipp Rohse[1], Clara Schellong[1], Hai Zhong[2], Alexander Schwarz[2], Roland Wiesendanger[2], Klaus Sengstock[1], and Christoph Becker[1] — [1]ZOQ-Center for Optical Quantum Technologies, Luruper Chaussee 149, 22761 Hamburg — [2]Institute of Applied Physics, University of Hamburg, Jungiusstraße 9-11, 20355 Hamburg

Quantum hybrid systems have recently attracted considerable interest due to their prospects of combining the benefits of several very different quantum systems. Technological applications range from quantum computation and quantum communication to quantum enhanced sensing. We have realized a specific quantum hybrid experiment to optically couple ultracold atoms to a cryogenically cooled membrane oscillator inside a fiber Fabry-Perot cavity. In our first experiments we have characterized in detail the coupling of the mechanical oscillator to the atoms by means of dissipative sympathetic cooling. Here, we present work towards coherent dynamics in the quantum hybrid system. Specifically, we improved our optomechanical system with an ultra-high-Q mechanical oscillator to allow ground-state cooling by means of active feedback control. For state preparation on the atomic side we perform microsecond pulsed lattice loading for non-adiabatic transfer of a Bose-Einstein condensate into the ground-state of our optical coupling lattice beam. This work is supported by the DFG via grants of Wi1277/29-1, BE 4793/2-1, SE 717/9-1 and by the CUI.

Q 62.5 Fri 11:45 S SR 111 Maschb.
Quantum-optical tests of Planck-scale physics — •Shreya Prasanna Kumar and Martin Plenio — Institute of Theoretical Physics and Center for Integrated Quantum Science and Technology (IQST), Albert-Einstein-Allee 11, Universität Ulm, 89069 Ulm, Germany

Recently it was proposed to use cavity-optomechanical systems to test for quantum gravity corrections to quantum canonical commutation relations [Nat. Phys. 8, 393-397 (2012)]. Improving the achievable precision of such devices represents a major challenge that we address with our present work. More specifically, we develop sophisticated paths in phase-space of such optomechanical system to obtain significantly improved accuracy and precision under contributions from higher-order corrections to the optomechanical Hamiltonian. An accurate estimate of the required number of experimental runs is presented based on a rigorous error analysis that accounts for mean photon number uncertainty, which can arise from classical fluctuations or from quantum shot noise in measurement. Furthermore, we propose a method to increase precision by using squeezed states of light. Finally, we demonstrate the robustness of our scheme to experimental imperfection, thereby improving the prospects of carrying out tests of quantum gravity with near-future optomechanical technology.

Q 62.6 Fri 12:00 S SR 111 Maschb.
Quantum noise limited microwave to optics conversion — •Moritz Forsch[1], Robert Stockill[1], Andreas Wallucks[1], Igor Marinković[1], Claus Gärtner[1,2], Richard Norte[1], Frank van Otten[3], Andrea Fiore[3], Kartik Srinivasan[4], and Simon Gröblacher[1] — [1]Delft University of Technology, Delft, The Netherlands — [2]University of Vienna, Vienna, Austria — [3]Eindhoven University of Technology, Eindhoven, The Netherlands — [4]National Institute of Standards and Technology, Gaithersburg, USA

Conversion between microwave and telecom signals is of great interest for both classical and future quantum telecommunication. In the quantum regime, it allows for the transport of quantum signals over long distances which would otherwise be impossible in the microwave regime. For quantum applications, it is necessary to keep the amount of added classical noise during this conversion process to a minimum. Here, we demonstrate mechanically mediated conversion with less than a single phonon of thermal noise added. We achieve this using a hybrid electro-opto-mechanical system which couples surface acoustic waves driven by a resonant microwave signal to an optomechanical crystal with a mechanical mode at 2.7 GHz. By cooling the mechanical mode at the core of this transduction process into the quantum ground state, we reduce the added thermal noise to less than one phonon. Furthermore, we show that the coherence of the input state is preserved throughout the entire transduction process, even for very weak coherent input states corresponding to only one coherent phonon in the resonator.

Q 62.7 Fri 12:15 S SR 111 Maschb.
Tuning the Order of the Nonequilibrium Quantum Phase Transition in a HybridAtom-Optomechanical System — •Niklas Mann[1], Axel Pelster[2], and Michael Thorwart[1] — [1]I. Institut für Theoretische Physik, Universität Hamburg, Jungiusstraße 9, 20355 Hamburg, Germany — [2]Physics Department and Research Center OPTIMAS, Technische Universität Kaiserslautern,

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A quantum many-body hybrid system is considered formed by a nanomembrane, which interacts optomechanically with light in a pumped cavity, and an ultracold atom gas in the optical lattice of the out-coupled light. An effective atom-membrane coupling can be realized in two different ways: first, the membrane is coupled to the motion of the atoms in the lattice[1] and, second, the motion of the membrane is coupled to transitions between two internal atomic states[2]. By tuning the applied laser intensity, the optomechanical coupling of the membrane motion to the atomic motional or internal states can be tuned and a nonequilibrium quantum phase transition occurs above a critical intensity. Focussing on the latter case, the nonequilibrium quantum phase transition is characterized by a sizeable occupation of the energetically higher internal states and a displaced membrane. In contrast to the motional coupling scheme, its order can be changed by tuning the transition frequency.

[1] N. Mann, M. Reza Bakhtiari, A. Pelster, M. Thorwart, Phys. Rev. Lett. **120**, 063605 (2018)

[2] N. Mann, A. Pelster, M. Thorwart, submitted (arXiv:1810.12846)

Q 62.8 Fri 12:30 S SR 111 Maschb.

Self-organization and optomechanics: connection with the HMF — •Francesco Rosati[1], Mathias Weisen[2], Giovanna Morigi[1], and Gian-Luca Oppo[2] — [1]Universität des Saarlandes — [2]University of Strathclyde

A striking feature of quantum optics is the possibility of realizing long-range interacting systems with a high degree of control and tunability. In particular, we investigate here a one-dimensional cloud of cold atoms homogeneously pumped by a far-detuned laser and retroreflected by a single planar mirror. This system is known to display the formation of self-organized structures in the light intensity and the atomic density due to opto-mechanical instabilities. The aim of this work is to look for connections between the occurring of self-organization, synchronization and phase transitions in our system via a mapping to the Hamiltonian Mean-Field model.