Q 1: Micro Mechanical Oscillator 1

Time: Monday 10:30–13:00 Location: HSZ 02

Q 1.1 Mon 10:30 HSZ 02

Listening to the Quantum Drum: Mechanics in its Ground State — •Tobias Donner[1,2], John Teufel[3], Ray Simmonds[3], and Konrad Lehnert[2] — [1]Institute for Quantum Electronics, ETH Zurich, CH-8093 Zurich, Switzerland — [2]JILA, University of Colorado and National Institute of Standards and Technology, Boulder, CO 80309, USA — [3]National Institute of Standards and Technology, Boulder, CO 80305, USA

A mechanical resonator is a physicist's most tangible example of a harmonic oscillator. If cooled to sufficiently low temperatures a mechanical oscillator is expected to behave differently to our classical perception of reality. Examples include entanglement and superposition states where a macroscopic, human made object can be in two places at once. Observing the quantum behavior of a mechanical oscillator is challenging because it is difficult both to prepare the oscillator in a pure quantum state of motion and to detect those states. I will present experiments in which we couple the motion of a micro-fabricated oscillator to the microwave field in a superconducting high-Q resonant circuit. The displacement of the oscillator imprints a phase modulation on the microwave field which we detect with a nearly shot-noise limited interferometer. We employ the radiation pressure force of the microwave photons to cool the mechanical oscillator to its motional ground state.

Q 1.2 Mon 10:45 HSZ 02

Optomechanical Coupling of Ultracold Atoms and a Membrane Oscillator — •Maria Korppi[1,2,3], Andreas Jöckel[1], Stephan Camerer[2,3], David Hunger[2,3], Theodor W. Hänsch[2,3], and Philipp Treutlein[1,2,3] — [1]Universität Basel, Switzerland — [2]Ludwig-Maximilians-Universität, München, Germany — [3]Max-Planck-Institut für Quantenoptik, Garching, Germany

We report the recent results of our experiment, where we couple a single mode of a high-Q membrane-oscillator to the motion of laser-cooled atoms in an optical lattice. The optical lattice is formed by retroreflection of a laserbeam from the membrane surface. The coupling is mediated by power modulation of the lattice beam due to the vibrations of the atoms in the lattice. If the trap frequency of the atoms in the lattice is matched to the eigenfrequency of the membrane, we observe resonant energy transfer between the two systems.

In the long term, such coupling mechanism could be exploited to develop hybrid quantum systems between atoms and solid-state devices. As another intriguing perspective, a new generation of optical lattice experiment is in sight, where the mirrors creating the laser standing waves are micromechanical oscillators interacting with the atoms on a quantum level.

Q 1.3 Mon 11:00 HSZ 02

Tuning the quality factor of a miromechanical membrane oscillator — •Andreas Jöckel[1], Maria Korppi[1,2,3], Stephan Camerer[2,3], Matthias Mader[2], David Hunger[2,3], Theodor W. Hänsch[2,3], and Philipp Treutlein[1,2,3] — [1]Departement Physik, Universität Basel, Switzerland — [2]Ludwig-Maximilians-Universität, München, Germany — [3]Max-Planck-Institut für Quantenoptik, Garching, Germany

We report on the characterization and tuning of the mechanical modes of high-Q SiN-membrane oscillators. Such membranes are used in many optomechanical experiments and have Q-factors up to 10^7 with frequencies in the hundreds of kHz regime and masses of a few ng, resulting in rather large ground state and thermal amplitudes.

We show that the membrane eigenfrequencies can be tuned by locally heating the membranes with laser light, resulting in a release of intrinsic stress. The frequencies of several modes were measured with a Michelson interferometer. We observe that the Q-factor changes dramatically while tuning and reveals resonances in the mechanical dissipation, which allows us to tune the Q-factor over two orders of magnitude. With this technique we achieve an improvement over the bare membrane Q-factor.

Another way of improving the properties of these membranes lies in structuring them with a focused ion beam (FIB) in order to reduce their mass, or applying mirrors to increase the reflectivity.

Q 1.4 Mon 11:15 HSZ 02

A closed-cycle dilution refrigerator with free-space and fiber optical access for quantum optomechanics experiments at 20mK — •Witlef Wieczorek[1], Simon Gröblacher[1], Matthias Bühler[2], Peter Christ[2], Jens Höhne[2], Doreen Wernicke[2,3], and Markus Aspelmeyer[1] — [1]University of Vienna, Faculty of Physics, A-1090 Vienna, Austria — [2]VeriCold Technologies GmbH, Bahnhofstr. 21, D-85737 Ismaning, Germany — [3]Entropy GmbH, Gmundner Str. 37a, D-81379 Munich, Germany

We report on the operation of a closed-cycle dilution refrigerator for quantum optomechanics experiments at 20mK. The sample chamber of the dilution fridge is optically accessible both via optical windows as well as optical fibers, allowing us to perform a variety of optical experiments at low temperatures. It is designed to vibrationally isolate the sample chamber allowing for stable operation of a high-finesse optical cavity. This enables us to perform cavity-optomechanics experiments at ultra-low temperatures.

Q 1.5 Mon 11:30 HSZ 02

Optomechanical cooling close to the ground state — •Rémi Rivière[1], Stefan Weis[1,2], Samuel Deléglise[1,2], Emanuel Gavartin[2], Olivier Arcizet[3], Albert Schliesser[1,2], and Tobias Kippenberg[1,2] — [1]Max-Planck-Institut für Quantenoptik, 85748 Garching, Germany — [2]Ecole Polytechnique Fédérale de Lausanne (EPFL), 1015 Lausanne, Switzerland — [3]Institut Néel, 38042 Grenoble, France

Optomechanical cooling of a mechanical oscillator mediated by the radiation pressure of the light enables preparing a macroscopic system in its quantum ground state. In our experiment, the vehicle used is a silica microtoroid resonator, hosting both optical and mechanical degrees of freedom within the same device. Combining both cryogenic and optomechanical cooling, we demonstrate an occupancy as low as 9±1 phonons, for which limitations to further phonon occupation reduction are only technical. The forthcoming ground state will then enable the study of quantum effects in a macro-object.

Q 1.6 Mon 11:45 HSZ 02

Cavity optomechanics with nonlinear mechanical resonators in the quantum regime — •Simon Rips, Martin Kiffner, Ignacio Wilson-Rae, and Michael Hartmann — Technische Universität München, Germany

The coupling of light and a mechanical resonator within an optomechanical setup can have significant effects on both the light field inside the cavity and the motion of the mechanical resonator. A prominent example is the cavity assisted side-band cooling of the mechanical motion, leading to low phonon occupation and thereby inducing the quantum regime.

Here, we consider the physics of a nonlinear mechanical resonator, coupled to different cavity modes that are each driven by a detuned laser. We show that the mechanical nonlinearity can be used to prepare a *nonclassical steady state* of mechanical motion. The nonclassicality criterion we use is the appearance of a negative Wigner function.

The open coupled quantum system is treated analytically with the projection operator technique. By tracing out the cavity modes, a master equation for the mechanical motion is derived. The structure of that master equation allows to understand the underlying physics and thereby to identify parameters (especially for detuning) that will produce the nonclassical steady state. The results are verified in a numerical treatment of the full coupled optomechanical system.

Q 1.7 Mon 12:00 HSZ 02

Stochastically activated opto-mechanical coupling — •Andrea Mari and Jens Eisert — Institute of Physics and Astronomy, University of Potsdam, 14476 Potsdam, Germany

We study the effect of stochastic noise on the standard opto-mechanical setup: an optical cavity with a vibrating mirror. We show how to engineer an effective bath for the mechanical resonator by using only incoherent thermal light. Thanks to the non-linear interaction Hamiltonian, optical stochastic noise can activate the coupling between a mechanical mode of the mirror and an optical mode of the cavity. This interaction can generate several non-trivial effects, e.g. the counter-intuitive process of cooling with thermal noise. This is another instance - different from stochastic resonance - where somewhat counterintuitively, incoherent noise helps to generate coherent quantum effects.

Q 1.8 Mon 12:15 HSZ 02

Optomechanically Induced Transparency — •Stefan Weis[1,2], Rémi Rivière[2], Samuel Deléglise[1,2], Emanuel Gavartin[1], Olivier Arcizet[3], Albert Schliesser[1,2], and Tobias Kippenberg[1,2] — [1]Ecole Polytechnique Fédérale de Lausanne (EPFL), 1015 Lausanne, Switzerland — [2]Max-Planck-Institut für Quantenoptik, 85748 Garching, Germany — [3]Institut Néel, 38042 Grenoble, France

Electromagnetically induced transparency is a quantum interference effect observed in atoms and molecules, in which the optical response of an atomic medium is controlled by an electromagnetic field. We demonstrate a form of induced transparency enabled by radiation-pressure coupling of an optical and a mechanical mode. A control optical beam tuned to a sideband transition of a micro-optomechanical system leads to destructive interference for the excitation of an intracavity probe field, inducing a tunable transparency window for the probe beam. Optomechanically induced transparency may be used for slowing and on-chip storage of light pulses via microfabricated optomechanical arrays.

Q 1.9 Mon 12:30 HSZ 02

Quantum dynamics in optomechanical arrays — •Florian Marquardt[1,2], Max Ludwig[1], Georg Heinrich[1], Andreas Kronwald[1], Michael Schmidt[1], Jiang Qian[3], and Björn Kubala[1] — [1]Institut für Theoretische Physik, Universität Erlangen-Nürnberg — [2]Max-Planck Institut für die Physik des Lichts — [3]Arnold Sommerfeld Center, Center for NanoScience, Department Physik, LMU München

Optomechanical arrays consist of a number of localized vibrational and optical modes coupled to each other via radiation forces. First versions of such structures have been realized recently based on photonic crystal designs. Future setups are projected to enter the quantum regime. We present our theoretical analysis of the linear and nonlinear quantum dynamics of interacting photons and phonons in such arrays.

Q 1.10 Mon 12:45 HSZ 02

Shot noise limited displacement measurement of a high Q micromechanical oscillator below the peak value of the SQL — •Henning Kaufer, Daniel Friedrich, Andreas Sawadsky, Tobias Westphal, Kazuhiro Yamamoto, and Roman Schnabel — Albert-Einstein-Institut, MPI für Gravitationsphysik, QUEST, Leibniz Universität Hannover

The standard quantum limit (SQL) is a classical limit for measurement precision of a test mass position. Using a SiN membrane with a Q-factor of 10^6 and a mass of 100 ng we achieved a displacement sensitivity of $3 \cdot 10^{-16}$ m/$\sqrt{\text{Hz}}$ in a Michelson-Sagnac interferometer and thereby beat the peak value of the SQL at resonance. The interferometer topology allows implementation of advanced interferometer techniques such as power- or signal recycling. The latter can enhance the displacement sensitivity by a factor of 10 in the first step and reveal thermal noise of the oscillator over a broad frequency range.