Q 57: Optomechanics II

Time: Thursday 14:30–16:30 Location: P/H1

Q 57.1 Thu 14:30 P/H1

Sympathetic cooling of a membrane oscillator in an hybrid mechanical-atomic system — •A. Faber[1], A. Jöckel[1], T. Kampschulte[1], M. Korppi[1], M. T. Rakher[1], L. Beguin[1], B. Vogell[2], K. Hammerer[3], P. Zoller[2], and P. Treutlein[1] — [1]Universität Basel, Departement Physik — [2]Universität Innsbruck, IQOQI — [3]Universität Hannover, Institut für theoretische Physik

Sympathetic cooling with ultracold atoms and atomic ions enables ultralow temperatures in systems where direct laser or evaporative cooling is not possible. So far, it has only been used to cool other microscopic particles such as atoms of a different species or molecular ions up to the size of proteins. In our experiment we use ultracold atoms to sympathetically cool the fundamental vibration of a Si_3N_4 membrane from room temperature to 650±330 mK [1]. The interactions between the atoms and the membrane are mediated by laser light over a macroscopic distance and are enhanced by an optical cavity around the membrane [2]. This enables effective cooling although the mass of the membrane exceeds that of the atoms by 10^{10}. Our hybrid optomechanical system operates in a regime of large atom-membrane cooperativity and will with further improvements enable a number of exciting experiments on quantum control of mechanical motion.

[1] A. Jöckel *et al.*, Nature Nanotechnology (2014).
[2] B. Vogell *et al.*, Phys. Rev. A 87, 023816 (2013).

Q 57.2 Thu 14:45 P/H1

Optomechnical studies in a nonlinear crystalline whispering gallery mode resonator — •Alexander Otterpohl[1,2], Michael Förtsch[1,2], Vittorio Peano[1], Gerhard Schunk[1,2], Ulrich Vogl[1,2], Florian Sedlmeir[1,2], Dmitry Strekalov[1,2], Harald Schwefel[1,2], Gerd Leuchs[1,2], Florian Marquardt[1,2], and Christoph Marquardt[1,2] — [1]Max Planck Institut für die Physik des Lichts, Günther-Scharowsky-Str. 1, Bau 24, 91058, Erlangen, Deutschland — [2]Institut für Optik, Information und Photonik, Universität Erlangen-Nürnberg, Staudtstraße 7/B2, 91058, Erlangen, Deutschland

Whispering gallery mode resonators (WGMR) have demonstrated to be well suited to couple the optical and the mechanical degrees of freedom. Various experiments have been realized using WGMRs made out of amorphous and crystalline materials and at various sizes, ranging from micrometer to millimeter. Here, we report on the experimental observation of optomechanical interactions in a macroscopic (radius 2mm) crystalline $LiNbO_3$ WGMR. The use of a nonlinear crystal offers the possibility to combine the optomechanics with nonlinear optical processes. To minimize damping of the mechanical modes, we realized a suspended setup design, where the WGMR is only mounted from the top. We observe more than twenty mechanical modes in a frequency range between 5 and 40 MHz with a maximum mechanical quality factor of $Q_{mech} = 3 \times 10^3$. We are currently exploring the optomechanical properties of the WGMR in combination with the generation of parametric light and will report on our latest progress.

Q 57.3 Thu 15:00 P/H1

Light-Mediated Coupling of a Quantum Mechanical Oscillator to the Internal States of a Distant Atomic Ensemble — •Berit Vogell[1], Tobias Kampschulte[2], Matthew T. Rakher[2], Aline Faber[2], Philipp Treutlein[2], Klemens Hammerer[3], and Peter Zoller[1] — [1]Institut für Quantenoptik und Quanteninformation, Universität Innsbruck, Institut für theoretische Physik — [2]Universität Basel, Department Physik — [3]Universität Hannover, Institut für theoretische Physik

Hybrid quantum systems in which a mechanical oscillator is coupled to a well-controlled microscopic quantum system currently attract great interest. Such systems offer new possibilities for cooling, detection and quantum control of vibrations in engineered mechanical structures. Previous theoretical work on coupling nano-mechanical oscillators to atoms has focused on coupling to the *motional* atomic degrees of freedom [1]. Along these lines, a recent experiment demonstrated substantial sympathetic cooling of a mechanical oscillator [2]. In the present work we provide the theoretical framework for coupling of a nanomechanical oscillator to the *internal* states of the atomic ensemble [3]. This allows us to couple the atomic ensemble to mechanical oscillators in a wide frequency range, offers the opportunity for large coupling strengths, and benefits from the sophisticated atomic toolbox.

[1] B. Vogell *et al.*, Phys. Rev. A 87, 023816 (2013)
[2] A. Joeckel *et al.*, Nature Nanotechnology (2014)
[3] B. Vogell *et al.*, in preparation (2014)

Q 57.4 Thu 15:15 P/H1

Optical trapping and control of nanoparticles inside hollow core photonic crystal fibers — •David Grass, Julian Fesel, Nikolai Kiesel, and Markus Aspelmeyer — University of Vienna

Optically levitated nanospheres in ultra-high vacuum are a promising approach to high-Q optomechanical systems. To this end a reproducible and clean loading mechanism for nanoparticles with a diameter on the order of 100nm is required. Here we will present the current status of such a mechanism utilizing hollow core photonic crystal fibers [1]. They allow controlled transport and promise deterministic loading of levitated nanoparticles into an ultra-high vacuum environment.

[1] Russell, P. S. J. (2003). Photonic crystal fibers. Science, 299(5605)

Q 57.5 Thu 15:30 P/H1

A scheme for cavity-based 3D optical trapping and cooling of silica nanospheres — •Uroš Delić[1], Marzieh Bathaee[2], Florian Blaser[1], Nikolai Kiesel[1], Alireza Bahrampour[2], and Markus Aspelmeyer[1] — [1]Vienna Center for Quantum Technology and Science, Faculty of Physics, University of Vienna, A-1090 Vienna, Austria — [2]Department of Physics, Sharif University of Technology Tehran, Iran

Silica nanospheres, optically levitated in a high-finesse cavity, has been proposed as a new optomechanical system which provides exceptional quality factors (10^{11}) when operated in ultra-high vacuum [1]. This would enable cooling of nanosphere center-of-mass (CM) motion close to its ground state and quantum state preparation of a macroscopic object in a room-temperature environment.

Previously, we have demonstrated one-dimensional cavity cooling of CM motion of a trapped nanosphere [2]. Three-dimensional (3D) cooling is a prerequisite to access higher vacuum levels [3] and reach long trapping times [4]. In this talk we propose a scheme for a purely cavity-based 3D trapping and cooling [5]. This promises to stabilize the CM motion at lower pressures and provide cooling of the CM motion in all three dimensions. We will discuss first experimental steps in this direction.

[1] Aspelmeyer, Kippenberg, Marquardt, arXiv:1303.0733 (2013). [2] Kiesel et al., PNAS 110:14180-14185 (2013). [3] Gieseler et al., PRL 109(10):103603 (2012). [4] Koch et al., PRL 105(17): 173003 (2010). [5] Bathaee et al., in preparation

Q 57.6 Thu 15:45 P/H1

pulsed optical measurement of mechanical displacements close to the standard quantum limit — •sungkun hong[1], ralf riedinger[1], alex krause[2], oskar painter[2], and markus aspelmeyer[1] — [1]Vienna Center for Quantum Science and Technology (VCQ), Faculty of Physics, University of Vienna, A-1090 Vienna, Austria — [2]Thomas J. Watson, Sr., Laboratory of Applied Physics, California Institute of Technology (Caltech), Pasadena, CA 91125, USA

Quantum-non-demolition (QND) measurement of massive mechanical objects is an outstanding problem in quantum physics. As a promising route, the optomechanical scheme employing a series of short optical pulses [1,2] has been recently investigated. Here, we present a significant step towards realizing QND detection of mechanical displacements using this method. We employ a micro-fabricated optomechanical crystal and a high-speed homodyne detection setup to demonstrate the displacement measurement with its imprecision close to the mechanical zero-point fluctuation. We discuss further possibilities of the scheme, which include a full state tomography and generation of squeezed mechanical states beyond the standard quantum limit.

[1] M. R. Vanner, I. Pikovski, G. D. Cole, M. S. Kim, C. Brukner, K. Hammerer, G. J. Milburn, and M. Aspelmeyer, Pulsed quantum optomechanics, Proc. Natl. Acad. Sci. U. S. A., vol. 108, no. 39, pp. 16182-7, 2011 [2] M. R. Vanner, J. Hofer, G. D. Cole, and M. Aspelmeyer, Cooling-by-measurement and mechanical state tomography via pulsed optomechanics., Nat. Commun., vol. 4, p. 2295, 2013

Q 57.7 Thu 16:00 P/H1

Entanglement-enhanced quantum control of optomechanical systems — •Sebastian G. Hofer[1,2], Markus Aspelmeyer[1], and Klemens Hammerer[2] — [1]Vienna Center for Quantum Science and Technology (VCQ), Faculty of Physics, University of Vienna, Vienna, Austria — [2]Institute for Theoretical Physics, Institute for Gravitational Physics (Albert Einstein Institute), Leibniz University Hannover, Hannover, Germany

The optomechanical radiation pressure interaction provides the means to create entanglement between a mechanical oscillator and an electromagnetic field. In this talk I show how we can utilize this entanglement within the framework of time-continuous quantum control in order to engineer the quantum state of the mechanical system. Specifically, I analyze how to prepare low-entropy mechanical states by feedback cooling operated in the blue detuned regime, the creation of bipartite mechanical entanglement via time-continuous entanglement swapping, and preparation of a squeezed mechanical state by time-continuous teleportation [1]. Furthermore I discuss how additionally coupling the light field to a qubit can be used to prepare non-classical mechanical quantum states. These protocols extend earlier work [2] analyzing pulsed optomechanical entanglement creation—recently realized experimentally in [3]—and teleportation. They are all feasible in optomechanical systems exhibiting a cooperativity larger than 1.

[1] S.G. Hofer and Klemens Hammerer, arXiv:1411.1337 [quant-ph]
[2] S.G. Hofer et al., Physical Review A 84, 052327 (2011)
[3] T.A. Palomaki et al., Science 342, 710 (2013)

Q 57.8 Thu 16:15 P/H1

Optomechanics in a Michelson-Sagnac Interferometer — •Lisa Kleybolte[1], Andreas Sawadsky[1], and Roman Schnabel[2] — [1]Institut für Gravitationsphysik, Leibniz Universität Hannover — [2]Institut für Laserphysik, Universität Hamburg

The signal-recycled Michelson-Sagnac interferometer with a SiN-membrane as a mechanical oscillator is a manifold topology for the investigation of the optomechanical coupling. Beside the successful demonstration of dissipative coupling, this interferometer topology could reach a broadband radiation pressure noise (RPN) limited displacement sensitivity. Therefor thermal noise and shot noise have to be significantly reduced. Here we present spectra of a Michelson-Sagnac Interferometer operating in a cryogenic environment at 8K. Furthermore we show how the input of squeezed light into the dark port could influence the optomechanical coupling in our system and how it will be used to improve our sensitivity to reach the RPN.