Q 29: Optomechanics I

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

Invited Talk Q 29.1 Wed 10:30 Q-H13

Quantum rotations of levitated nanoparticles — •Benjamin A. Stickler — Faculty of Physics, University of Duisburg-Essen, Germany

The non-linearity and anharmonicity of rigid body rotations gives rise to pronounced quantum interference effects with no analogue in the body's centre-of-mass motion [1]. This talk will briefly review two such effects, orientational quantum revivals [2] and the quantum tennis racket effect [3], and discuss how elliptic coherent scattering cooling [4] opens the door to rotational quantum experiments with nanoscale particles and rotational tests of collapse models.

[1] Stickler, Hornberger, and Kim, Nat. Rev. Phys. 3, 589 (2021).
[2] Stickler, Papendell, Kuhn, Millen, Arndt, and Hornberger, New J. Phys. 20, 122001 (2018).
[3] Ma, Khosla, Stickler, and Kim, Phys. Rev. Lett. 125, 053604 (2020).
[4] Schäfer, Rudolph, Hornberger, and Stickler, Phys. Rev. Lett. 126, 163603 (2021).

Q 29.2 Wed 11:00 Q-H13

Ultrastrong Coupling in an Optomechanical System — •Kahan Dare[1,2], Jannek Hansen[1,2], Aisling Johnson[1,2], Uros Delic[1,2], and Markus Aspelmeyer[1,2] — [1]Vienna Center for Quantum Science and Technology,Faculty of Physics, University of Vienna, Vienna, Austria — [2]Institute for Quantum Optics and Quantum Information, Austrian Academy of Sciences, Vienna, Austria

The ultrastrong coupling regime, where the coherent coupling rate approaches the transition energy of the system, is a rarely studied area of physics despite its vast array of novel physics such as two-mode squeezing, the dynamical Casimir effect and non-gaussian ground states. Only a handful of experiments have been recently developed to probe this regime due to the large technologically challenges associated with engineering such a system.

Here, we implement a simple scheme for reaching the ultrastrong coupling regime in an optomechanical system which can be dynamically tuned to implement a wide range of quantum control protocols. We achieve this by coupling a levitated nanoparticle to an optical cavity through coherent scattering. Together with the ability to cool the system to its motional ground state, this result opens up quantum experiments in the USC regime to simple table-top systems. Lastly, we outline how to extend this to the deep strong coupling regime and its potential for future applications.

Q 29.3 Wed 11:15 Q-H13

Non-classical mechanical states guided in a phononic waveguide — •Amirparsa Zivari, Robert Stockill, Niccolo Fiaschi, and Simon Groeblacher — Delft University of Technology, Delft, Netherlands

Quantum optics – the creation, manipulation and detection of non-classical states of light – is a fundamental cornerstone of modern physics, with many applications in basic and applied science. Achieving the same level of control over phonons, the quanta of vibrations, could have a similar impact, in particular on the fields of quantum sensing and quantum information processing. Here we demonstrate the first step towards this level of control and realize a single-mode waveguide for individual phonons in a suspended silicon micro-structure. We use a cavity-waveguide architecture, where the cavity is used as a source and detector for the mechanical excitations, while the waveguide has a free standing end in order to reflect the phonons. This enables us to observe multiple round-trips of the phonons between the source and the reflector. The long mechanical lifetime of almost 100us demonstrates the possibility of nearly lossless transmission of single phonons over, in principle, tens of centimeters. Our experiment represents the first demonstration of full on-chip control over traveling single phonons strongly confined in the directions transverse to the propagation axis and paves the way to a time-encoded multimode quantum memory at telecom wavelength and advanced quantum acoustics experiments.

Q 29.4 Wed 11:30 Q-H13

Cavity optomechanics with polymer drum resonators in fiber Fabry-Perot cavities — •Lukas Tenbrake[1], Alexander Fassbender[2], Sebastian Hofferberth[1], Stefan Linden[2], and Hannes Pfeifer[1] — [1]Institute of Applied Physics, University of Bonn, Germany — [2]Institute of Physics, University of Bonn, Germany

Cavity optomechanical experiments in micro- and nanophotonic systems have demonstrated record optomechanical coupling strenghts, but require elaborate techniques for interfacing. Their scaling towards larger systems including many mechanical and optical resonators is limited. Here, we demonstrate a directly fiber-coupled tunable and highly flexibile platform for cavity optomechanics based on polymer structures in fiber Fabry-Perot cavities (FFPCs). The polymer structures are fabricated using 3D direct laser writing. They form drum resonators with frequencies in the MHz regime. Vacuum coupling strengths exceeding 20 kHz to micron sized FFPC modes are observed. The extreme flexibility of the laser writing process allows for a direct integration of the mechanical resonator on fiber mirrors, but also for larger scale structures on macroscopic substrates. Moreover, the tolerance of FFPCs to optical power allows the observation of strong optomechanical spring effects. The ease of interfacing, the favorable scaling capabilities and the possible integration with other systems like electrodes makes it a promising platform for current challenges in cavity optomechanics.

Q 29.5 Wed 11:45 Q-H13

Synchronization of two levitated nanoparticles via direct dipole-dipole coupling — •Manuel Reisenbauer[1], Livia Egyid[1], Anton Zasedatelev[1,2], Iurie Coroli[1,2], Benjamin A. Stickler[3], Henning Rudolph[3], Markus Aspelmeyer[1,2], and Uros Delic[1,2] — [1]University of Vienna, A-1090 Vienna, Austria — [2]IQOQI, Austrian Academy of Sciences, A-1090 Vienna, Austria — [3]University of Duisburg-Essen, 47048 Duisburg, Germany

Synchronization is the phenomenon of multiple oscillators moving in unison despite their intrinsic frequencies being non-degenerate. This not only locks their frequencies/phases together, but the system also experiences lower phase noise, promising increased sensing performance over a single oscillator.

Systems up to date show only dynamics of frequencies of the coupled oscillators, neglecting phase dynamics completely. Also, separate readout of the individual oscillator position is impossible in many integrated systems, restricting the analysis to collective signatures only.

We present an experiment with two nanoparticles levitated in parallel optical tweezers, employing a direct optical dipole-dipole coupling to synchronize their motion. We present conclusive signatures of synchronization and show the transition from individual oscillators to a synchronized state. Our work shows possible applications to sensing and metrology employing the reduction of phase noise below the thermomechanical limit of each individual oscillator. Finally, we discuss the scalability of our system to large arrays of trapped particles and its operation in the quantum regime.

Q 29.6 Wed 12:00 Q-H13

Efficient optomechanical mode-shape mapping of micromechanical devices — David Hoch[1,2,3], Timo Sommer[1,2], Kevin-Jeremy Haas[1], Leopold Moller[1], Julius Röwe[1], and •Menno Poot[1,2,3] — [1]Department of Physics, Technical University of Munich, Garching, Germany — [2]Munich Center for Quantum Science and Technology (MCQST), Munich, Germany — [3]Institute for Advanced Study, Technical of University Munich, Garching, Germany

The rapidly growing interest in (quantum) optomechanics calls for an efficient method to map eigenmode shapes. One - very time-consuming - way to do this is to measure the driven response for every mode at different locations on the resonator. A faster approach is to drive each mode at a single frequency and record their amplitudes, but drift of the resonance frequency makes this impractical for high-Q resonators. Here, we present an efficient way of simultaneously mapping up to 6 eigenmodes. Our method is robust against drift by employing an improved phase-lock loop (PLL) that can also lock to regions with different signs of the mode shape. We demonstrate the capabilities of our technique on a square Si3N4 membrane in vacuum. The membrane is excited with a piezoelectric element and modes between 1 and 21.6 MHz are mapped accurately. Proof-of-principle measurements already shine new light on e.g. mode splitting, clamping losses, and superposition of degenerate modes. Currently ongoing experiments on crosstalk compensation and on non-flat resonators are also discussed.

Q 29.7 Wed 12:15 Q-H13

Levitodynamics in free fall — •Christian Vogt, Govindarajan Prakash, Vincent Hock, Marian Woltmann, Sven Herrmann, and Claus Lämmerzahl — Universität Bremen, ZARM (Zentrum für angewandte Raumfahrttechnologie und Mikrogravitation

Physicists have not yet been able to unite two of the most successful theories of our time, quantum theory and relativity. One way to test the interplay between these two theories is to observe interferometers with ever heavier particles. A promising candidate for observing interferometers with "large" masses are motion-cooled silica nanoparticles. These can be optically trapped in vacuum, and due to the appropriate insulation, ground-state cooled even in an environment at room temperature.
In near-field interferometers, the required free evolution time of the particles is described by the Talbot time, which scales with mass. In the NaiS project, we will extend this time from hundreds of milliseconds to several seconds by transferring the techniques of levitated optomechanics to the weightlessness environment of the 146 m high drop tower in Bremen.
This talk will focus on the experimental setup suitable for drop tower operation and how to solve the problem of low repetition rates in weightlessness.