Q 21: Optomechanics I

Time: Monday 16:15–17:45 Location: K 0.023

Q 21.1 Mon 16:15 K 0.023

Rotating ring resonators and Maxwell's equations in non-inertial frames — •Anton Lebedev — Institut für Theoretische Physik Tübingen, Tübingen

The majority of laws in physics is formally expressed in the form of (partial) differential equations (PDEs). Each differential equation remains incomplete without initial or boundary conditions.

Using Maxwell's equations and rotating planar domains I endeavour to highlight the intimate relationship between PDEs and boundary conditions. The necessity of the general covariant formulation of the laws of electrodynamics when dealing with accelerated motion will be highlighted. This will be used to derive of a Coriolis-Zeeman addendum to the wave equation for rotating ring resonators. All of the above will be done using the examples of isospectral domains and planar ring resonator models. Furthermore the use of the Coriolis-Zeeman term for a geometric classification of planar domains will be discussed.

Q 21.2 Mon 16:30 K 0.023

Quantum State Retrodiction in Gaussian Systems — •Jonas Lammers[1,2] and Klemens Hammerer[1,2] — [1]Institut für Theoretische Physik, Leibniz Universität Hannover — [2]Max-Planck-Institut für Gravitationsphysik (Albert-Einstein-Institut), Hannover

Open quantum systems whose environment is observed evolve according to stochastic master and Schrödinger equations. These predict the system state conditioned on past observations. We address the problem of verification of conditionally prepared states through *retrodiction*, i.e., the estimation of a state lying in the past. We apply the method to Gaussian states in linear systems, and compute the backwards evolution of their first and second moments. In particular, we consider an optomechanical oscillator coupled to a thermal bath.

Q 21.3 Mon 16:45 K 0.023

Designing light-mediated interactions between atoms and a mechanical oscillator — •Thomas Karg[1], Baptiste Gouraud[1], Klemens Hammerer[2], and Philipp Treutlein[1] — [1]Department of Physics, Universität Basel, Klingelbergstrasse 82, 4056 Basel, Switzerland — [2]Institute for Theoretical Physics and Institute for Gravitational Physics (Albert Einstein Institute), Leibniz Universität Hannover, Callinstraße 38, 30167 Hannover, Germany

Hybrid systems in which a mechanical oscillator is coupled to atomic spins are promising for quantum control of mechanical motion, quantum sensing and signal transduction as well as the study of non-classicality in macroscopic objects.

In our experiment we use laser light to couple an atomic ensemble to an optomechanical system. In this context we explore interactions mediated by an optical mode to which both systems couple in a cascaded fashion. This approach is versatile because it allows to couple spatially separated systems in a variety of different schemes making use of light as a quantum resource. Moreover it is of fundamental interest to explore the limits as to whether light can effectively act like a spring, mediating Hamiltonian interaction between distant oscillators.

We will report on both experimental and theoretical work towards the implementation of such a quantum interface between a collective atomic spin and a membrane inside a cryogenic optical cavity. We address the challenges of reaching the quantum regime in this hybrid system and present a unified theory of light-mediated interactions.

Q 21.4 Mon 17:00 K 0.023

Rotational quantum revivals of nanoscale particles — •Birthe Papendell, Benjamin A. Stickler, and Klaus Hornberger — Fakultät für Physik, Universität Duisburg-Essen

Recent progress in the optical manipulation [1-4] of levitated nanoparticles as well as the prospect of ro-translational ground state cooling [5] open the door for quantum experiments with orientational coherences. We present a scheme for the observation of quantum revivals in the rotation state of a nanoparticle in high vacuum. To assess the feasibility of the setup the rotational quantum dynamics nanometer-sized double-walled carbon nanotubes is studied in presence of environmental decoherence.

[1] Kuhn et al., Nano Lett. 15, 5604 (2015)
[2] Hoang et al., Phys. Rev. Lett. 117, 123604 (2016)
[3] Kuhn et al., Optica 4, 356-360 (2017)
[4] Kuhn et al., Nat. Commun. 8, 1670 (2017)
[5] Stickler et al., Phys. Rev. A 94, 033818 (2016)

Q 21.5 Mon 17:15 K 0.023

Long-range optical trapping and binding of microparticles in hollow-core photonic crystal fibre — •Shangran Xie[1], Dmitry Bykov[1], Richard Zeltner[1], Gordon Wong[1], Tijmen Euser[2], and Philip Russell[1] — [1]Max Planck Institute for the Science of Light, Staudtstrasse 2, 91058 Erlangen, Germany — [2]NanoPhotonics Centre, University of Cambridge, Cavendish Laboratory, CB3 0HE Cambridge, UK

Optically levitated micro- and nanoparticles offer a playground for investigating photon-phonon interactions over macroscopic distances. An optically tweezered particle at low gas pressure is isolated from the external environment resulting in very high mechanical Q-factor. Optical binding between arrays of trapped particles adds an additional dimension to the field of "levitated optomechanics", allowing access to the rich collective dynamics. Here we report long-range optical binding of multiple microparticles, mediated by intermodal scattering and interference inside the evacuated core of a hollow-core photonic crystal fibre (HC-PCF). Three polystyrene microparticles are stably bound together with an inter-particle distance of ~40 μm, or 50 times longer than the trapping wavelength. The bound-particle array can be translated over centimetre distances along the fibre. The collective mechanical modes of the bound-particle array could be observed under 6 mbar pressure. The measured inter-particle distance and mechanical eigen-frequencies are supported by an analytical formalism modelling the binding dynamics. HC-PCF offers a unique platform for investigating levitated collective optomechanics in a well-protected environment.

Q 21.6 Mon 17:30 K 0.023

Optomechanically coupled nanospike array on the endface of a fibre — •Zheqi Wang, Shangran Xie, Xin Jiang, and Philip Russell — Max Planck Institute for the Science of Light, Staudtstr. 2, 91058 Erlangen, Germany

Arrays of optically coupled mechanical oscillators are promising for exploring the light-controlled linear and nonlinear dynamics of complex systems. Here we report the fabrication and characterization of an optomechanically coupled glass nanospike array on the endface of a multi-core fibre. The multi-core fiber is made from soft glasses by the stack-and-draw technique, using two types of specially developed germanate glasses with widely different etch rates when subjected to a solution of nitric acid. Through wet-etching at one end of the fiber, an array of free-standing nanospikes can be obtained at the fiber endface. We have fabricated a fiber with a close-packed hexagonal array of seven cores of diameter 1.1 μm, the core centres being spaced 1.5 μm apart. After etching, the cladding material is removed, resulting in seven suspended conical nanospikes of length $\sim$20 μm. The diameter at the very end of the nanospikes is less than 50 nm. The optical mode in each step-index core spreads out adiabatically as it travels towards the tip, resulting in strong coupling between the individual nanospikes and significant optical forces that can be used to drive the mechanical motion of the nanospikes. The strength of the optomechanical interaction is estimated by numerical simulations and confirmed by preliminary experimental results. This unique system offers many new possibilities for exploring the behaviour and applications of optomechanical arrays.