DY 21: Focus Session: Nanomechanical Systems for Classical and Quantum Sensing I (joint session TT/DY/HL/QI)

Nanomechanical and cavity-optomechanical systems have been recently established as a controllable and configurable platform that can be engineered to tackle outstanding sensing challenges both in the classical and in the quantum regime. With this focus session, experts from different but synergetically overlapping fields of nanomechanical sensing pursuing classical, non-linear and quantum approaches are brought together. The session shall provide an overview over the recent exciting developments of the techniques explored in micro- and nanomechanical systems and sensing concepts exploring quantum measurement schemes.
This joint session will be continued Wednesday afternoon (TT53) and Thursday morning (TT70). Organized by Eva Weig, Hubert Krenner, and Hans Hübl.

Time: Tuesday 11:45–13:00 Location: H 3007

DY 21.1 Tue 11:45 H 3007

Josephson Optomechanics — •Surangana Sengupta[1], Bjoern Kubala[1,2], Joachim Ankerhold[1], and Ciprian Padurariu[1] — [1]ICQ and IQST, Ulm University, Germany — [2]DLR-QT, German Aerospace Center, Ulm, Germany

In recent years, optomechanical cooling using microwave radiation has been realized in various superconducting circuits with a microwave cavity comprising a mechanical element. Circuits provide an opportunity to engineer nonlinear cavities, by using Josephson junctions, thereby generating quantum states of light for optomechanics experiments.
Here, we will theoretically describe an optomechanical setup where the cavity is realized by an LC circuit driven by a dc-biased Josephson junction. By engineering the nonlinearity, such a cavity becomes an effective N-level system, with $N = 2, 3, ...$, where the access to Fock states N and above is blocked. Consequently, the cavity emission spectrum shows Mollow-type side peaks, analogous to an optical cavity interacting with an atom. We show that at these Mollow side peaks, the system exhibits a new, nonlinear type of optomechanical cooling. We calculate the cooling rate using the spectral density of noise due to the radiation pressure [1] and highlight how its unusual features compared to conventional optomechanics, can be explained in a dressed state picture.

[1] F. Marquardt *et.al.*, Phys. Rev. Lett. **99** (2007) 093902

DY 21.2 Tue 12:00 H 3007

Logarithmic susceptibility of a quantum parametrically modulated oscillator — •Daniel Boness[1], Wolfgang Belzig[1], and Mark Dykman[2] — [1]Department of Physics, University of Konstanz, 78457 Konstanz, Germany — [2]Department of Physics and Astronomy, Michigan State University, East Lansing, Michigan 48824, USA

A weakly damped nonlinear oscillator modulated close to twice its eigenfrequency has two stable states, which have the same vibration amplitudes but opposite phases. The states are equally populated due to classical or quantum fluctuations.

An extra force at half the modulation frequency lifts the symmetry of the states. Even a weak force can result in a significant change of the populations, as it beats against the intensity of quantum and classical fluctuations. We develop an approach that allows us to find this population change.

We also study the effect of the extra force with frequency slightly detuned away from half the modulation frequency. For a detuning that is small compared to the switching rate the force leads to the imbalance of populations that is modulated at the frequency of the detuning. For larger detuning, the adiabatic picture breaks down and the wells are again equally populated. However, the rates of switching between the wells is exponentially increased. We calculate the change of the logarithm of the switching rate, termed logarithmic susceptibility, using the real-time instanton method. The results are relevant for controlling parametric oscillators and their application in quantum information systems.

DY 21.3 Tue 12:15 H 3007

Cavity optomechanics with carbon nanotube quantum dots — •Akong N. Loh, Furkan Özyigit, Fabian Stadler, Niklas Hüttner, and Andreas K. Hüttel — Institute for Experimental and Applied Physics, University of Regensburg, 93040 Regensburg, Germany

Carbon nanotubes (CNTs) are the smallest and lightest nanomechanical beam resonators. When suspended transversally between two electrodes (Ti/Au for example) and then gated, they can act as mechanical beam resonators with large quality factors and also as quantum dots. The motion of a CNT is coupled to other degrees of freedom, such as photons, spins, and electrons. The optomechanical coupling of a single wall carbon nanotube nanomechanical resonator to a microwave cavity has been realized and quantified through optomechanically induced transparency measurements [1]. The quantum dot properties of the CNT were exploited (specifically the nonlinearity of the coulomb blockade) to significantly enhance the coupling strength [1,2]. Current work is directed towards achieving even stronger coupling and possibly groundstate cooling of the nanomechanical resonator through anti-Stokes processes. This requires significant improvement of the microwave cavity, CNT growth and transfer. All measurements are done at ~10 mK in a dilution refrigerator.

[1] S. Blien *et al.*, Nat. Comm. **11** (2020) 1636
[2] N. Hüttner et al., Phys. Rev. Applied, in press (2023), arXiv:2304.02748

DY 21.4 Tue 12:30 H 3007

Signatures of Josephson force in a vibrating carbon nanotube junction — •Andreas K. Hüttel[1,2], Jukka-Pekka Kaikkonen[2], Keijo Korhonen[2], and Pertti Hakonen[2] — [1]Institute for Experimental and Applied Physics, Universität Regensburg, Regensburg, Germany — [2]Low Temperature Laboratory, Dept. of Applied Physics, Aalto University, Espoo, Finland

A carbon nanotube suspended between superconducting electrodes acts simultaneously as nanomechanical resonator and as a Josephson junction. Its energy-dependent density of states and with that displacement-dependent critical current further adds to the complexity of the system, as does both mechanical and electronic nonlinearity. Measurements on such a system display complex behaviour of the vibrational resonance with respect to junction biasing. Strikingly, the resonance frequency appears to decrease in a distinct parameter region where the biasing is similar in size to the junction switching current.

Using highly parallelized Julia code, we numerically solve the coupled differential equation system of the driven (via an ac gate voltage and ac current or voltage bias) system for realistic device parameters and characterize the evolving steady state. Specific attention is given to the impact of the Josephson junction behaviour on the mechanical resonance frequency and the vibration amplitude, and on the ac signal simultaneously acting on gate and bias.

DY 21.5 Tue 12:45 H 3007

Optimization of Flux-Tunable Microwave Resonators for Strong Single-Photon Optomechanics in Nano-Electromechanical Systems — •Korbinian Rubenbauer[1,2], Thomas Luschmann[1,2], Kedar Honasoge[1,2], Achim Marx[1,2], Kirill G. Fedorov[1,2,3], Rudolf Gross[1,2,3], and Hans Huebl[1,2,3] — [1]Walther-Meißner-Institut, Bayerische Akademie der Wissenschaften, Garching, Germany — [2]School of Natural Sciences, Technical University of Munich, Garching, Germany — [3]Munich Center for Quantum Science and Technologies, Munich, Germany

Quantum sensing leverages quantum properties to enhance the precision of sensing applications. One promising implementation for the detection of forces or accelerations are optomechanical systems which encode the displacement of a low-frequency mechanical element onto the properties of a high-frequency optical or electromagnetic resonator. We present a flux-tunable superconducting quantum circuit with an integrated superconducting quantum interference device (SQUID), where the mechanical element is embedded in the SQUID structure. This implements a magnetic field and flux tunable optomechanical interaction with the prospect of reaching the strong single-photon coupling regime. We discuss the design concept of the device and detail its optimization. We corroborate the conceptual improvements with experimental data demonstrating the performance improvements of the microwave resonator, the optomechanical coupling and the mechanical element.