DY 12: Focus Session: Nonlinear Dynamics of Nanomechanic Oscillators

Time: Monday 15:30–17:45 Location: H20

Invited Talk DY 12.1 Mon 15:30 H20

A phononic frequency comb from a single resonantly driven nanomechanical mode — •Eva Weig — Department of Electrical and Computer Engineering, Technical University of Munich

Doubly-clamped nanostring resonators excel as high Q nanomechanical systems enabling room temperature quality factors of several 100,000 in the 10 MHz eigenfrequency range. Dielectric transduction via electrically induced gradient fields provides an integrated control scheme while retaining the large mechanical quality factor. Dielectrically controlled nanostrings are an ideal testbed to explore a variety of dynamical phenomena ranging from multimode coupling to coherent control. Here I will focus on the nonlinear dynamics of a single, resonantly driven mode. The broken time reversal symmetry gives rise to the squeezing of the string's fluctuations. As a result of the high mechanical Q factor, the squeezing ratio is directly accessible from a spectral measurement. It is encoded in the intensities of the two spectral peaks arising from the slow dynamics of the system in the rotating frame. For stronger driving, an onset of self-sustained oscillation is observed which leads to the generation of a nanomechanical frequency comb. The effect is a consequence of a resonantly induced negative effective friction force induced by the drive. This is the first observation of a frequency comb arising solely from a single mode and a single, resonant drive tone.

DY 12.2 Mon 16:00 H20

Fluctuations and strong nonlinear effects in nanomechanical resonators — •Fan Yang[1], Mengqi Fu[1], Yuxuan Jiang[2], and Elke Scheer[1] — [1]University of Konstanz, Konstanz, Germany — [2]Anhui University, Hefei, China

Membrane resonators are ideal model systems to investigate nonlinear dynamics. Membrane resonators operated in the nonlinear regime, far beyond the Duffing regime exhibit unusual dynamic behavior, including localized overtones of spatial modulation [1], parametric flexural mode coupling, and persistent response [2]. Our research focusing on revealing the microscopic origins, their characterization, local control, exploring the universality and fluctuations [3] of the nonlinear state.

[1] Yang, Fan, et al. "Spatial modulation of nonlinear flexural vibrations of membrane resonators." Physical review letters 122.15 (2019): 154301.

[2]Yang, Fan, et al. "Persistent Response in an Ultrastrongly Driven Mechanical Membrane Resonator." Physical Review Letters 127.1 (2021): 014304.

[3]Yang, Fan, et al. "Mechanically Modulated Sideband and Squeezing Effects of Membrane Resonators" Physical Review Letters 127 (18), 184301.

DY 12.3 Mon 16:15 H20

Tuning nonlinear damping in graphene nanoresonators by parametric-direct internal resonance — •Ata Keşkekler[1], Oriel Shohani[2], Martin Lee[1], Herre van der Zant[1], Peter Steeneken[1], and Farbod Alijani[1] — [1]TU Delft, Delft, The Netherlands — [2]Ben-Gurion University of Negev, Beersheba, Israel

Micro/Nano-mechanical systems are utilized in many technologies and often have been used for their sensing capabilities. An ideal framework for sensitive nanomechanical devices is 2-D materials, and especially graphene, due to its exceptional mechanical, electrical and thermal properties. By their atomically thin nature, these systems are fundamentally nonlinear. In addition to their geometric nonlinearities, graphene membranes have shown nonlinear energy decay mechanisms. Nonlinear damping in these devices is a fundamental limitation to their sensing capabilities yet its full understanding is an open question. Among different dissipation mechanisms, an important factor that is hypothesized to affect damping properties of graphene nanodrums is the intermodal couplings. In this work, we study the nonlinear dynamics of a nanomechanical graphene resonator near its internal resonance condition to amplify the intermodal effects and uncover the physics between nonlinear damping and mode coupling. We observe a massive increase in damping in the vicinity of internal resonance that is followed by a bifurcation causing a dramatic increase of amplitude and resonance frequency. Our study opens up a route towards utilizing modal interactions and parametric resonance to realize resonators with engineered nonlinear dissipation over wide frequency range.

Invited Talk DY 12.4 Mon 16:30 H20

From period-doubling bifurcations to time crystals and coherent Ising machines — •Oded Zilberberg[1,2], Toni L. Heugel[2], Jan Košata[2], Javier del Pino[2], R. Chitra[2], and Alexander Eichler[2] — [1]Department of Physics, University of Konstanz, 78464 Konstanz, Germany — [2]Department of Physics, ETH Zürich, CH-8093 Zürich, Switzerland

Networks of coupled parametric resonators (parametrons) hold promise for parallel computing architectures. These are classical systems with period-doubling bifurcations, where the logic information is stored in oscillation modes of the system. Such networks similarly realize the physics of so-called discrete time crystals (DTCs). The latter are a many-body state of matter whose dynamics are slower than the forces acting on it. I will report on our theoretical and experimental work on parametron networks, their relation to DTCs and their potential application for the realization of coherent Ising machines.

DY 12.5 Mon 17:00 H20

Sideband and noise squeezing effects in nonlinear mechanical membrane resonators — •Mengqi Fu[1], Fan Yang[1], Yuxuan Jiang[2], and Elke Scheer[1] — [1]Fachbereich Physik, Universität Konstanz, 78457 Konstanz, Germany — [2]Anhui University, Hefei, China

The nonlinearity of a mechanical system has been shown to squeeze the noise by redistributing it in two conjugates of the observables under certain conditions and therefore provides a way to break the sensing limit of mechanical systems. In this work, we develop a novel method to characterize the noise squeezing of a nonlinear mechanical system by the frequency response of the low-frequency modulation based on a suspended silicon nitride (Si-N) membrane ($\sim$ 500 nm thickness) structure [1]. We first demonstrate an antiresonance effect between the "quasi modes" of the nonlinear mechanical system in the sideband spectra through low-frequency two-tone probing measurements. Then a direct connection between the antiresonance frequency and the noise squeezing factor of the system can be established to characterize the noise squeezing factor in a simple and robust method.

[1] F. Yang et at., Phys. Rev. Lett., 127, 184301 (2021).

Invited Talk DY 12.6 Mon 17:15 H20

2D membranes in motion — •Herre van der Zant — Kavli Institute of Nanoscience, Department of Quantum Nanoscience, Delft University of Technology, The Netherlands

Atomically thin membranes are ideal building blocks for nanoelectromechanical systems (NEMS) because of their unique mechanical properties and their low mass. We make membranes by transferring atomically thin layers on top of silicon oxide substrates that are prepatterned with circular or rectangular holes. The suspended membranes are characterized by a laser interferometer set-up that gives access to information on the dynamics in the frequency- and time-domain. The setup is equipped with a moveable x-y stage so that the membrane motion can be visualized; the nonlinear response of the motion is used to extract the mechanical parameters including the Young's modulus. Recently, it has become clear that nanomechanics can also probe thermodynamic properties such as thermal conductivity, specific heat, and thermal expansion [Dynamics of 2D material membranes, 2D Materials 8 (2021) 042001]. Specifically, phase transitions are typically accompanied by abrupt changes in the specific heat, resulting in accompanying changes in the strain of the material which are measured via mechanical resonances. In this way, we have detected the Néel temperature of antiferromagnetic $FePS_3$ membranes, their magnetic anisotropy and studied the nonlinear coupling between magnetic and elastic properties.