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A hybrid system of a membrane oscillator coupled to ultracold atoms

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The control over micro- and nanomechanical oscillators has recently made impressive progress. First experiments demonstrated ground-state cooling and single-phonon control of high-frequency oscillators using cryogenic cooling and techniques of cavity optomechanics. Coupling engineered mechanical structures to microscopic quantum system with good coherence properties offers new possibilities for quantum control of mechanical vibrations, precision sensing and quantum-level signal transduction. Ultracold atoms are an attractive choice for such hybrid systems: Mechanical can either be coupled to the motional state of trapped atoms, which can routinely be ground-state cooled, or to the internal states, for which a toolbox of coherent manipulation and detection exists. Furthermore, atomic collective states with non-classical properties can be exploited to infer the mechanical motion with reduced quantum noise. Here we use trapped ultracold atoms to sympathetically cool the fundamental vibrational mode of a Si_3N_4 membrane [1]. The coupling of membrane and atomic motion is mediated by laser light over a macroscopic distance and enhanced by an optical cavity around the membrane. The observed cooling of the membrane from room temperature to 650 ± 230 mK shows that our hybrid mechanical-atomic system operates at a large cooperativity. Our scheme could provide ground-state cooling and quantum control of low-frequency oscillators such as levitated nanoparticles, in a regime where purely optomechanical techniques cannot reach the ground state. Furthermore, we will present a scheme where an optomechanical system is coupled to internal states of ultracold atoms [2]. The mechanical motion is translated into a polarization rotation which drives Raman transitions between atomic ground states. Compared to the motional-state coupling, the new scheme enables to couple atoms to high-frequency structures such as optomechanical crystals.

[1] A. Jöckel, A. Faber, T. Kampschulte, M. Korppi, M. T. Rakher, and P. Treutlein, Nature Nanotech. 10, 55-59 (2015).
[2] B. Vogell, T. Kampschulte, M. T. Rakher, A. Faber, P. Treutlein, K. Hammerer, and P. Zoller, arXiv:1412.5095 (2014).