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A hybrid system of a membrane oscillator coupled to ultracold atoms

The control over micro- and nanomechanical oscillators has recently made impressive progress [1]. First experiments demonstrated ground-state cooling and single-phonon control of high-frequency oscillators using cryogenic cooling and techniques of cavity optomechanics [2]. 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 [3]. Ultracold atoms are an attractive choice for such hybrid systems: Mechanical structures 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 [4].
Here we use trapped ultracold atoms to sympathetically cool the fundamental vibrational mode of a Si_3N_4 membrane [5]. 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 [6]. Our scheme could provide ground-state cooling and quantum control of low-frequency oscillators such as levitated nanoparticles [7], in a regime where purely optomechanical techniques cannot reach the ground state.
Finally, I will present a scheme where an optomechanical system is coupled to internal states of ultracold atoms [8]. 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.

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