Sympathetic cooling and self-oscillations in a hybrid atom-membrane system

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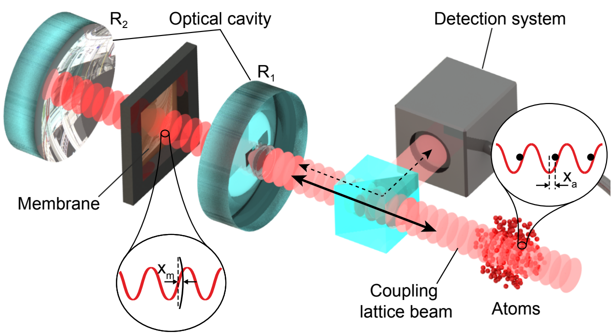
Hybrid systems combining mechanical oscillators and ultracold atoms provide novel opportunities for cooling, detection and quantum control of mechanical motion with applications in precision sensing, quantum-level signal transduction and fundamental tests of quantum mechanics



Hybrid atom-membrane system.

Here we present our hybrid atom-membrane experiment, in which the vibrations of a Si_3N_4 membrane in an optical cavity are coupled to the motion of laser-cooled atoms in an optical lattice. The interactions are mediated by the lattice light over a macroscopic distance and enhanced by the cavity.

Via the coupling to the cold atoms, the fundamental vibrational mode of the membrane at $2\pi \times 274\,\mathrm{kHz}$ is cooled sympathetically from room temperature to $650 \pm 330\,\mathrm{mK}$ [1], even though the mass of the mechanical oscillator exceeds that of the atomic ensemble by a factor 10^{10}. In other systems, sympathetic cooling of molecules with cold atoms or ions has been limited to mass ratios of up to 90. Previous theoretical work has shown that our coupling mechanism is able to cool the membrane vibration into the ground state and to perform coherent state transfers between atomic and membrane motion [2].

Under certain experimental conditions, the atom-membrane system shows self-oscillations, which arise from an effective delay in the backaction of the atoms onto the light. This retardation drives the system into limit-cycle oscillations if the coupling is large.

1. Jöckel *et al.*, *Sympathetic cooling of a membrane oscillator in a hybrid mechanical-atomic system*, Nature Nanotechnology 10, 55-59, 2015
2. Vogell *et al.*, *Cavity-enhanced long-distance coupling of an atomic ensemble to a micromechanical membrane*, PRA 87, 023816, 2013