Mechanical resonators with weak coupling to any thermal reservoir preserve their motional (quantum) state unless perturbed by external forces. Such ‘coherent’ mechanical devices are thus excellent probes for small forces. This includes, in particular, forces induced by electromagnetic quantum fluctuations, the domain of quantum optomechanics.

We have recently introduced a new approach to define mechanical resonator modes, which simultaneously provides spatial confinement, full isolation from the substrate, and $\sim 10^5$-fold dilution of the resonator material’s intrinsic dissipation. At moderate cryogenic temperature (4 K), coherence times approach those of trapped ions, and force sensitivity reaches into the state-of-the-art $\alpha N/Hz^{1/2}$-domain.

In our experiments, we subject these resonators to laser light in a membrane-in-the-middle arrangement, realizing quantum cooperativities exceeding 50. This allows us to cool the resonators close to their quantum ground state, and work in the regime where the optical force’s quantum fluctuations dramatically exceed all thermal force noise. We will discuss the arising opportunities to study multimode quantum optomechanics, entanglement generation, quantum measurement backaction evasion, and hybrid systems involving spin ensembles or microwave modes. We show how adaptations of such devices could renew scanning force microscopy, in particular magnetic resonance force microscopy, departing from the common the-tip-is-the-sensor paradigm.


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