MAR13-2012-020455

Abstract for an Invited Paper
for the MAR13 Meeting of
the American Physical Society

Approaching the Quantum Limits of Displacement Detection

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While high quality factor mechanical resonators (such as cantilevers and membranes) are routinely used as exquisite sensors, only recently are these engineered devices encountering the fundamental limits and opportunities afforded by quantum mechanics. The standard quantum limit of displacement detection requires a balance between the measurement imprecision and momentum imparted on the object of interest. One promising measurement scheme for achieving, and possibly surpassing, these quantum limits of measurement is that of cavity optomechanics—an architecture in which a mechanical resonator modulates the frequency of a high frequency electromagnetic resonance. Ideally, the quantized nature of the measurement photons will impart backaction in the form of radiation pressure shot noise, but observation of this quantum effect in macroscopic mechanical resonators has proven experimental difficult due to the relatively weak forces of the light. We realize a microwave cavity "opto" -mechanical system by incorporating a freely-suspended membrane in a superconducting microwave resonant circuit, which simultaneously exhibits high quality factor electrical and mechanical modes [1]. The relatively large electomechanical coupling has led to experimental observation of the strong coupling regime [1] as well as sideband cooling of the mechanical mode to its quantum ground state [2]. I will present recent experiments of similar circuits in which the displacement sensitivity goes beyond that at the standard quantum limit by several orders of magnitude. These measurements also clearly show the fundamental trade-off between measurement imprecision and backaction. We observe the radiation pressure shot noise of the microwave photons and show that it can completely overwhelm the classical, thermal motion of the membrane. [1] Teufel et al., Nature 471, 204-208 (2011).

[1] Teufel et al., Nature 475, 359-363 (2011).