Measuring and manipulating noise in optomechanical systems

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Over the last decade, research in the field of cavity optomechanics has developed extraordinarily sensitive and low loss devices as well as clever measurement techniques to probe macroscopic mechanical systems in the quantum regime. If one observes carefully, the noise in optically detected mechanical resonators can reveal a remarkable tale of the fundamental quantum mechanics of measurement embodied by Heisenberg’s microscope type physics. In this talk we will discuss how to use the scale of the inherent optical-force-driven quantum measurement backaction to directly calibrate measurements of the motion of a nano-optomechanical system. Even in the regime where quantum backaction effects are relative small compared to other noise (e.g. ambient conditions – room temperature and atmospheric pressure operation, and low probing laser power), we measure quantum-backaction-induced correlations on probe light, providing a noise scale related to the mechanical zero-point motion. This scale is then used to calibrate the measured level of Brownian motion of the mechanical resonator, creating a quantum-noise-calibrated absolute thermometer [1]. We are working toward making a metrologically useful version of this compact optomechanical temperature standard.

It is also interesting to keep track of the origin of the thermal noise driving the mechanical resonator. We are developing a nanomechanical thermometry technique that is an acoustic analog of IR blackbody radiation thermometry (Fig.1). We have engineered a silicon nitride membrane mechanical resonator where the dominant source of dissipation is radiation of acoustic energy into its supporting substrate, which is then absorbed by a mechanically lossy ‘acoustic blackbody’ deposited onto the substrate. We show that the Brownian motion of the membrane mode is governed by the temperature of the acoustic blackbody, via exchange of blackbody acoustic radiation through the low loss substrate, and not the material temperature of the membrane. This architecture of dissipation engineering, where a single nanomechanical degree of freedom is intentionally coupled to a well-defined macroscopic bath should improve many of the systematic uncertainties in our primary, quantum-calibrated thermometry, especially self-heating due to absorbed probe light and unknowns in the nature of nanoscale baths.


Fig. 1. Acoustic blackbody radiation thermometry. (a) Simulations of the acoustic radiation patterns into a silicon substrate of two modes of a Si$_3$N$_4$ membrane drumhead resonator. (b) Brownian motion temperature of the modes when the blackbody is heated, showing strong coupling of the (1,10) mode to the acoustic blackbody.

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