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Title: Microwave Cavity Optomechanics in the Strong Coupling Regime

Abstract:

In the longstanding endeavor to access the quantum nature of macroscopic mechanical motion, the experimental challenge is not only that of state preparation, but also one of measurement. The flourishing field of cavity optomechanics, in which an electromagnetic resonance couples parametrically to a mechanical oscillator, addresses both of these challenges—providing a nearly ideal architecture for both manipulation and detection of mechanical motion at the quantum level. In this talk, I present experiments in which the motion of a high-Q, micromechanical membrane couples to a superconducting microwave resonator. When the circuit is excited with a coherent microwave tone near the cavity resonance, the displacement of the oscillator becomes encoded as modulation of this tone. The microwaves, in turn, also impart forces back on the oscillator which enforce the Heisenberg limits on measurement, and can also be exploited to either cool or amplify the motion. The unprecedented optomechanical coupling strength allows this circuit to enter the strong coupling regime, where the normal modes of the system are now hybrids of the original radiofrequency mechanical and the microwave electrical resonances. The normal mode splitting is verified by direct pump-probe spectroscopy of hybridized cavity resonance and shows excellent agreement with the theoretical predictions. As all of these experiments take place in a cryostat at a temperature below 40 mK, this system operates in the quantum enabled regime where the thermal decoherence rate is small enough that the strong coupling will not preclude ground state cooling. By measuring the noise spectrum of this optomechanical system with a nearly quantum-limited microwave amplifier, the residual thermal motion of the oscillator is easily resolvable above the measurement imprecision. These experiments show the exquisite measurement sensitivity of the system, with displacement and force sensitivities approaching the Heisenberg limit. The final part of this talk will quantify the thermal motion of the oscillator as it is cooled with radiation-pressure forces to below its quantum zero-point motion and enters the strong coupling regime.