

Observation of Radiation Pressure Shot Noise on a Macroscopic Object

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Reversible and efficient conversion between microwave and optical light

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The field of optomechanics has undergone a revolution in recent years with the successful harnessing of tiny radiation pressure forces to cool and control the motion of a variety of mechanical oscillators ranging in mass from kilograms to picograms [1,2]. That electromagnetic radiation exerts a force on material bodies was understood by Maxwell when he developed classical electrodynamics. It was Einstein who first recognized that radiation pressure must fluctuate randomly due to the shot noise of photons as ‘particles of light’ impinging on material objects. Remarkably, Einstein arrived at this conclusion very early, well before the development of quantum electrodynamics, using deep arguments about the thermal equilibration of the motion of a mirror bathed in black-body radiation [3].

Radiation pressure produces exceedingly weak forces and the quantum fluctuations of those forces are weaker still. Nevertheless Purdy et al. recently succeeded in observing the effects of radiation pressure shot noise in randomly exciting the mechanical motion of a macroscopic optical element [4]. This tour-de-force result has been a long-standing goal of the optomechanics community.

A second long-standing goal has been to develop a hybrid device which converts quantum states of microwave fields to the corresponding quantum states of optical fields and vice-versa. Optical frequencies (in this case 282 THz) are about five orders of magnitude higher than ~ 7 gigahertz microwave frequencies. This means that, despite being fundamentally the same types of objects, optical photons have a 10^5 times more energy than microwave photons and the two require rather different technologies to control them.

Andrews et al. have recently overcome the technological challenges associated with this and demonstrated reversible and efficient quantum information transfer across this huge difference in frequency scales. This is an important milestone because it will enable coherent connection between the remarkable progress in quantum information processing at microwave frequencies using superconducting qubits ('circuit QED') and optical fiber technology which permits transmission of quantum information over very large distances.

The quantum conversion is achieved by means of an ultra-thin membrane as a drumhead whose vibrations simultaneously parametrically modulate the frequency of both a microwave resonator and an optical resonator. By application of appropriate drives to each resonator one can engineer an effective Hamiltonian which converts microwave photons to optical photons and vice versa. Andrews et al. carry out a thorough set of tests and calibrations to show that they achieve a conversion efficiency of approximately 10%. Hopefully future experiments building on this result will be able to further increase the efficiency and also operate at refrigerator temperatures of 40 mK rather than 4K to reduce the deleterious effects of the thermal 'phonon' population of the drumhead degree of freedom. A huge technical challenge (on which Andrews et al. have already made substantial progress) is to keep the membrane cold while maintaining significant circulating power in the optical resonator.

References:

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