Creating quantum states of mechanical motion via pulsed optomechanics

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Abstract. Cavity quantum optomechanics utilizes the radiation-pressure interaction between light and a moveable mechanical object inside a cavity for applied and fundamental physics. When combined with the tools of quantum optics, optomechanics provides a route for engineering non-classical states of motion in a more macroscopic regime. We explore the pulsed regime of cavity quantum optomechanics, which utilizes pulses of light much shorter than a mechanical period, for mechanical quantum state engineering applications. In particular, we propose protocols for preparing mechanical superposition states [1] and entanglement between two massive oscillators [2].
Keywords: cavity optomechanics, entanglement, measurement, nonclassicality

Growing cat states [1]: Consider a short pulse of light incident upon an optomechanical cavity. During the interaction, the light accumulates a phase shift that depends upon position of the oscillator, while the mechanics experiences a momentum kick proportional to the photon number. Utilizing this nonlinear interaction, we consider optical interferometry techniques on the output field together with photon counting for preparation of mechanical superposition states. In this setting the separation of the superposition is set by the coupling strength.

To engineer more macroscopic quantum states for a given coupling strength, we propose a multistep scheme, where each step of the protocol grows the mechanical superposition state towards a well-separated Schrödinger cat state. Further, we study the nonclassicality of these states as a function of the step number, as well as the loss and decoherence between steps.

Entanglement in a flash [2]: These pulsed techniques also provide a rich platform for bipartite quantum state generation. To this end, we propose schemes to generate and verify both optical-mechanical and mechanical-mechanical entanglement outside of the resolved-sideband regime of optomechanics. In particular, we introduce schemes based on optical interferometry and sequential optomechanical interactions. Our protocols utilize a pulsed mechanical precooling stage to increase the amount of entanglement generated and we also study how optical squeezing can provide resilience to the open system dynamics between the pulsed interactions. The pulsed nature of our protocols allows for direct access to the non-classical correlations in the time domain, with applications ranging from quantum metrology to tests of quantum decoherence. With improvements to the optical detection efficiency, our protocols can be realized with present day experiments.

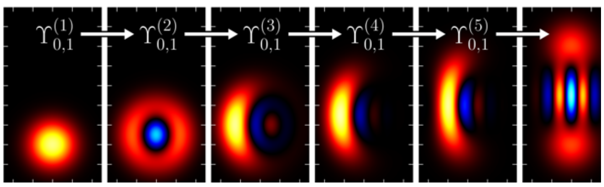

Figure 1: Growing mechanical cats with a multistep protocol.

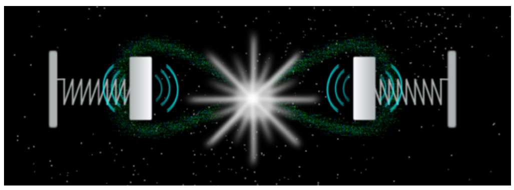

Figure 2: Entangling massive objects with a flash of light.

References

[1] Jack Clarke and Michael R Vanner, Quantum Sci. Technol. **4**, 014003 (2019)
[2] Jack Clarke *et al.*, New J. Phys. **22**, 063001 (2020)