High-Precision Multiparameter Estimation of Mechanical Force by Quantum Optomechanics

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We have addressed a long-standing conceptual inconsistency in estimating a weak mechanical force probed by a mechanical oscillator. All current methods approximate small linearized forces by a displacement in position and momentum. However, a linearized force corresponds to a general Gaussian quantum mechanical process affecting the oscillator, including both displacement and squeezing of position and momentum. Ignoring these squeezing effects makes the estimation incomplete and imprecise. Moreover, by doing so, one can underestimate new mechanical effects and their applications. Taking squeezing into account turns the estimation immediately into a challenging multiparameter estimation problem. We have successfully solved this problem and demonstrated that the weak mechanical force could be indeed entirely characterized while keeping errors small.

On the other hand, the fast estimation of a linearized mechanical force requires the system to be in the short-pulsed regime (stroboscopic). In this regime, the limited interaction of mechanical oscillators with light makes the optical readout of the oscillator inefficient. This restriction makes the multiparameter estimation procedure even more complicated. To solve this issue, we propose a scheme that keeps errors small despite the inefficiency of the optical readout and is also robust against the loss and noise involved in the mechanical process. For the first time, such a scheme can detect purely mechanical squeezing induced by the probed mechanical environment. We checked its feasibility for state-of-the-art experimental setups considering as well experiments currently under development.

References

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