Quantum Optical Sensing: Single Mode, Multi-Mode, and Continuous Time

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High-sensitivity photodetection systems have long been limited by noises of quantum-mechanical origin. Thus, in both optical communications and optics-based precision measurements it is necessary to optimize over quantum resources — both states and measurements — in order to delineate the ultimate performance limits of such systems. The particular case of phase-based precision measurements has received great attention in this regard. Theory has shown that squeezed-state or N00N-state interferometers can provide Heisenberg-limited root-mean-square (rms) phase-estimation errors of ~ 1/N where N is the measurement's average photon number, whereas a conventional (coherent-state) interferometer's rms error is at the standard quantum limit (SQL) of $\sim 1/N^{1/2}$. The 1/N limit also emerges from more abstract studies, which focus on optical phase measurement as the dual to photon-number measurement. Indeed, going beyond the optical setting to quantum measurements more generally, recent work indicates that ~1/N precision, where N is the number of measurement interactions, may be the ultimate quantum limit. We will contrast single-mode, multi-mode, and continuous-time paradigms for optics-based precision measurement, and use the latter to suggest that 1/N precision may not be the ultimate quantum limit.