Multiparameter quantum-enhanced phase sensing with squeezed light

Giorgio Minati[1], Enrico Urbani[1], Nicolò Spagnolo[1], Valeria Cimini[1], and Fabio Sciarrino[1]

1. *Sapienza University of Rome, Department of Physics, Piazzale Aldo Moro 5, 00185 Rome, Italy*

Abstract: We demonstrate a multiparameter adaptive phase-estimation protocol with squeezed light that jointly infers phase and nuisance parameters in real time, achieving unconditional sub-shot-noise sensitivity without relying on pre-calibration of the employed probe.

Squeezed states of light are a key resource in quantum metrology, particularly for phase estimation, while remaining compatible with compact, room-temperature interferometers. Exploiting squeezing is therefore essential not only for fundamental physics, but also for emerging technologies such as next-generation interferometry, imaging and distributed sensing. In practice, however, quantum-enhanced precision can only be achieved if the measurement projection is properly optimized, making adaptive strategies essential [1].

Current adaptive strategies suffer from two major drawbacks, on one hand they operate over at most half the phase range and on the other they depend heavily on pre-calibration of the probe parameters thus compromising the true unconditional quantum advantage of the previously developed protocols [2]. Our approach overcomes both these limitations simultaneously by jointly inferring the nuisance parameters together with the phase, using that information in real time to set the optimal measurement projection [3].

Our multiparameter adaptive protocol achieves phase estimation precisions below the shot-noise limit across the full interval $[0,\pi)$, thereby demonstrating unconditional quantum enhancement in phase sensitivity without the necessity of pre-calibrating any parameter of the setup. This protocol therefore allows phase estimation precision close to the Quantum Cramér-Rao Bound, while remaining resilient to probe fluctuations, providing a framework particularly well suited to practical applications.

We experimentally demonstrate this multiparameter adaptive protocol using homodyne detection with an FPGA-based feedback adaptively updating the local oscillator phase in real time as data are acquired. The scheme achieves unconditional sub-shot-noise sensitivity across the full phase range and for different squeezing levels. Our results establish a practical pathway to self-calibrating quantum sensors based on squeezed light, as it introduces an adaptive phase estimation protocol that automatically counteracts probe and system fluctuations, applied in a relevant framework using squeezed light that can be used in different applications. This represents a step towards practical implementation scenarios in which often a precise control of the experimental conditions and probe parameters is often not feasible.

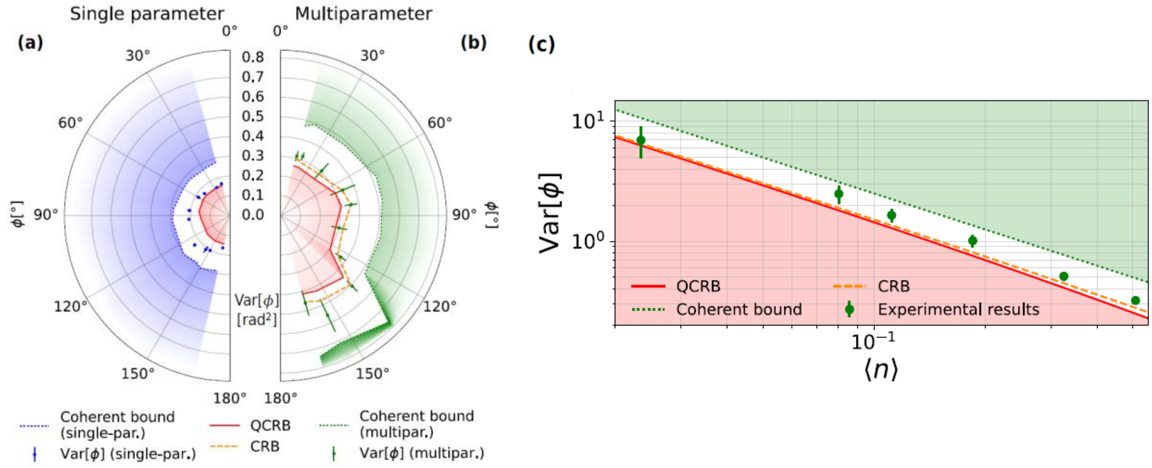

Fig. 1 Experimental variances of the adaptive phase estimation (radial axis) as a function of the phase ϕ (angular axis), spanning. Results are obtained with the single- [panel (a)] and multiparameter [panel (b)] adaptive protocols are reported as green and blue dots, respectively. (c) Scaling of phase estimation variance for different squeezing strength.

Example References

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