Multicopy metrology with many-particle quantum states

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The main goal of quantum metrology is to estimate the unknown phase shift Θ in an interferometer with the smallest possible uncertainty. Using separable quantum states, one can have the precision of $(\Delta\Theta)^2{\sim}1/N$, at best, where N is the number of particles. This can only be overcome with the help of entangled states, in which case, the so-called Heisenberg scaling $(\Delta\Theta)^2{\sim}1/N^2$ can be achieved, which, for our case, represents the maximal metrological usefulness [1].

We say that a quantum state is useful for metrology if it can outperform the precision limit for separable states for phase estimation. It is remarkable, that, entanglement is required for metrological usefulness, however, there are entangled states that are not useful for metrology.

In Ref. [2], we consider the idea of activating the metrological usefulness by taking several copies of bi- and multi-partite quantum states. In doing so, we identify a large class of states that can become maximally useful in the limit of infinite number of copies in such a way that the Heisenberg scaling is attained exponentially fast in the number of copies.

We show that, on the other hand, pure entangled states with even a small amount of white noise do not become maximally useful even in the limit of infinite number of copies. Moreover, we also provide numerical evidence that for some of these states, adding further copies cannot increase their metrological usefulness.

Finally, we also show that the non-useful multi-qubit entangled states presented in [3] can be made useful if we embed the qubits locally in qutrits.

Our scheme for activation can be relevant for Noisy Intermediate-Scale Quantum (NISQ) technology as we also consider the case of moderate number of copies [4].

References

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