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Gaussian interferometric power and Black box estimation of Unruh temperature

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ABSTRACT

We present a black box estimation paradigm of Unruh temperature in a relativistic bosonic continuous-variable setting. It is shown that the guaranteed precision for the estimation of Unruh temperature can be evaluated by the Gaussian interferometric power for a given probe state. We demonstrate that the amount of interferometric power is always beyond the entanglement type quantum correlations in a relativistic setting. It is found that due to the fact that Unruh radiation acts as a thermal bath on the probe system, it destroys available resources of the probe system and reduces the guaranteed precision of the estimation of Unruh temperature. We also find that the thermal noise induced by Unruh effect will generate interferometric power between accelerated Bob and his auxiliary partner anti-Bob, while it *does not* generate any correlation between inertial Alice and anti-Bob.

1. Introduction

Quantum metrology studies how to exploit quantum mechanics to enhance the precision in estimating unobservable physical quantities [1]. Quantum correlations, such as entanglement and

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discord-type quantum correlations [2–4], are responsible for this enhancement. That is, probe systems prepared in squeezed or entangled states can bring in a gain in precision for the estimation of parameters compared to that of separable probes [1–4]. However, quantum correlations in the form of entanglement have been proven neither necessary nor sufficient for quantum-enhanced metrology [5,6] because one can achieve supra-classical enhancement of precision even without using entanglement. Recently, Girolami et al. established a general quantitative equivalence between interferometric power of a bipartite state and the guaranteed precision for the estimation of a parameter embedded in a unitary dynamics applied to one subsystem [7]. Later, G. Adesso extended the study of interferometric power to a setting with continuous-variable probes and obtained a closed formula of interferometric power for two-mode Gaussian states [8]. C. Sabín and G. Adesso discussed how the dynamical Casimir effect, which consists in the generation of photons out of the vacuum of a quantum field with moving boundary conditions, influences the interferometric power of two-mode Gaussian states [9].

On the other hand, the Unruh effect [10,11] is an important prediction in quantum field theory. The Unruh effect describes the fact that a uniformly accelerated atom in Minkowski vacuum observes the field as a thermal bath since the field quantization associated with inertial and accelerated observers are inequivalent [10,11]. It has been found that the temperature T of the Unruh thermal bath directly depends on the observer's proper acceleration a. Such a prediction is regraded as an important support to the compromise of relativity theory and quantum mechanics. However, despite its significant role in modern physics, the experimental detection of the Unruh effect is exceedingly difficult because the Unruh temperature is smaller than 1 Kelvin even for accelerations up to 10^{21} m/s^2 [11]. Recently, metrological techniques have been applied to improve the estimation of Unruh effect [12–16]. M. Aspachs et al. studied the optimal estimation of a relativistic setting [17,18] by using Gaussian probes in a continuous-variable setting. These results are of great interest for the desktop observation of the Unruh effect and space-based quantum information processing tasks.

In this paper we present a black box paradigm [7] for the estimation of Unruh temperature in a bosonic continuous-variable setting. We assume that an accelerated observer Bob, assisted by a static observer Alice, aims to determine the Unruh temperature introduced by a "black box" process as precisely as possible. Alice and Bob prepare n copies of the scalar field in two-mode squeezed state with squeezing parameter s [19] as probe states for the estimation. The black box is implemented by the transformation of bosonic modes from the perspective of the accelerated observer. Alice and Bob publicly know Bob's state is transformed due to Bob's accelerated motion, while the local dynamics choice of the black box, which depends on Bob's acceleration and therefore relates to Unruh temperature of the thermal bath, is unknown in priori. After the transformations, Alice and Bob perform some joint measurements on the transformed state to get an estimation for the Unruh temperature T. We calculate the interferometric power for the transformed state, which is mathematically defined by the minimum quantum Fisher information during a quantum parameter estimation process, minimizing over all possible local dynamics which encodes the estimated parameter T [8,20]. We find that some interferometric power is destroyed by the thermal noise of Unruh effect and the rest part is redistributed. We also find that the thermal noise induced by Unruh effect will generate interferometric power between accelerated Bob and his auxiliary partner anti-Bob.

This paper is organized as follows: In Section 2 we introduce definition and measure of interferometric power in a bosonic continuous-variable setting. In Section 3 we discuss the effect of Unruh thermal noise on the two-mode Gaussian state. In Section 4 we discuss how the interferometric power and the guaranteed precision for the estimation of Unruh temperature are influenced by the thermal noise induced by the Unruh radiation. In Section 5 we conclude with a summary of the results.

2. Gaussian interferometric power: definition and measurement

We consider the probe state σ_{AB} which is a Gaussian state comprised of two modes A and B, respectively described by the annihilation operators $\hat{a}$ and $\hat{b}$. The corresponding position and momentum operators for each mode are defined as $\hat{q}_A = (\hat{a} + \hat{a}^\dagger)/\sqrt{2}$ and $\hat{p}_A = (\hat{a} - \hat{a}^\dagger)/i\sqrt{2}$ and similarly for mode B, where we construct the operators in natural units $\hbar = 1$. Then one