Nonthermal acceleration radiation of atoms near a black hole in presence of dark energy

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We investigate how dark energy affects atom-field interaction. To this end, we consider acceleration radiation of a freely falling atom close to a Schwarzschild black hole (BH) in the presence of dark energy characterized by a positive cosmological constant Λ. The resulting spacetime is endowed with a BH and a cosmological (or de Sitter) horizon. Our consideration is a *nonextremal* $(1+1)$-dimensional geometry with horizons far apart, giving rise to a flat Minkowski-like region in between the two horizons. Assuming a scalar (spin-0) field in a Boulware-like vacuum state, and by using a basic quantum optics approach, we numerically achieve excitation probabilities for the atom to detect a photon as it falls toward the BH horizon. It turns out that the nature of the emitted radiation deeply drives its origin from the magnitude of Λ. In particular, radiation emission is enhanced due to dilation of the BH horizon by dark energy. Also, we report an oscillatory nonthermal spectrum in the presence of Λ, and these oscillations, in a varying degree, also depend on BH mass and atomic excitation frequency. We conjecture that such a hoedown may be a natural consequence of a constrained motion due to the bifurcate Killing horizon of the given spacetime. The situation is akin to the Parikh-Wilzcek tunneling approach to Hawking radiation where the presence of extra contributions to the Boltzmann factor deforms the thermality of flux. It apparently hints at field satisfying a modified energy-momentum dispersion relation within classical regime of general relativity arising as an effective low energy consequence of an underlying quantum gravity theory. Our findings may signal new ways of conceiving the subtleties surrounding the physics of dark energy.

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I. INTRODUCTION

Quantum vacuum, unlike its classical counterpart, is full of surreal activities and its structure is modified in presence of external influences [1]. Parker's [2] realization of cosmological particle creation as a result of expansion of Universe and Hawking's [3] astonishing discovery that black holes (BHs) emit radiation, both fundamentally stem from the behavior of vacuum in presence of gravitational fields. Similar physics is manifested in Unruh effect [4], the flat spacetime analog of Hawking radiation, which posits that a detector accelerating uniformly in Minkowski vacuum thermalizes with a temperature proportional to its proper acceleration [5], and stands as an important signpost for a *not-yet* accomplished full theory of quantum gravity [6]. These phenomena bear close correspondence to the observation by Moore [7] and others [8–11] that moving boundaries (mirrors) create particles out of vacuum in Minkowski spacetime in the well-known process of *dynamical Casimir effect* (DCE), first observed in superconducting circuits few years ago [12]. These huge endeavors have led to a remarkable realization about the correspondence between moving mirrors and black holes [13–15]. This is a major paradigm in the theory of quantum fields on curved geometries [16], a blend of quantum field theory, general relativity and thermodynamics. It has been highly successful in explaining the large scale structure formation and origin of cosmic background radiation (CMB) anisotropies in the earliest epochs of our Universe [2]. These ideas have also been instrumental in paving way for the rapidly developing field of relativistic quantum information, where the acceleration has been shown to have significant bearing on quantum informational and communication processes [17].

Though the problem of accelerated mirrors and the particle creation has been pursued for a long time shortly

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