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Spectroscopy of a canonically quantized horizon

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Abstract

Deviations from Hawking's thermal black hole spectrum, observable for macroscopic black holes, are derived from a model of a quantum horizon in loop quantum gravity. These arise from additional area eigenstates present in quantum surfaces excluded by the classical isolated horizon boundary conditions. The complete spectrum of area unexpectedly exhibits evenly spaced symmetry. This leads to an enhancement of some spectral lines on top of the thermal spectrum. This can imprint characteristic features into the spectra of black hole systems. It most notably gives the signature of quantum gravity observability in radiation from primordial black holes, and makes it possible to test loop quantum gravity with black holes well above Planck scale.

1. Introduction

Most astrophysicists agree that black holes exist and radiate. So far three types of black hole radiations have been investigated: (i) the Hawking radiation, (ii) the gravitational radiation, and (iii) the X-ray emission from the infalling materials into a black hole. In this note, the quantum geometry of the horizon is, under certain assumption, shown to imply revision of the first type of black hole radiation.

The Hawking radiation is known semi-classically to be continuous. However, the Hawking quanta of energy are not able to hover at a fixed distance from the horizon since the geometry of the horizon has to fluctuate, once quantum gravitational effects are included. Thus, one suspects a modification of the radiation when quantum geometrical effects are properly taken into account. Any transition between two horizon area states can affect the radiation pattern of the black hole.

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The quantum fluctuations of horizon may either modify, alter or even obviate the semiclassical spectrum, [1,2].

Bekenstein and Mukhanov in [3] studied a simple model of the quantum gravity of the horizon in which area is equally spaced. They found no continuous thermal spectrum but instead black holes radiate into discrete frequencies. The natural width of the spectrum lines turns out to be smaller than the energy gap between two consecutive lines. Thus, their simple model predicts a falsifiable discrete pattern of *equidistant* lines which are unblended. This result is not completely in contradiction with Hawking prediction of an effectively continuous thermal spectrum of black hole using semiclassical method, since the discrete line intensities are enveloped in Hawking radiation intensity pattern.

More recently, it has been possible to study the quantum geometry of horizons using precise method in loop quantum gravity. In this non-perturbative canonical approach, the quantum geometry is determined by geometrical observable operators. Canonical quantization of geometry supports the discreteness of quantum area.[1] This theory does not reproduce equally spaced area, instead the quanta become denser in larger values, [6,7]. Having defined a black hole horizon as an internal *boundary* of space [8], only a subset of area eigenvalues contribute to identifying the horizon area. In fact, this subset contains the area associated to the edges puncturing the boundary. This subset is not evenly spaced and it turns out that the area fluctuations of such a horizon do not imprint quantum gravitational characteristics on black hole radiation, [9].

Nonetheless, restricting the quanta of horizon area to the subset of punctures is based on a non-trivial gauge-fixing of the horizon degrees of freedom. This is sufficient for the purpose of black hole entropy calculation since it results to the residence of a finite number of degrees of freedom on the horizon, independently from the bulk. Such a quantization, while is too restrictive, leaves some physical ambiguities. For instance, in classical general relativity spacetime metric field does not *end* at a black hole horizon, instead it extends through the black hole. In fact, a quantum black hole in a space manifold, instead of being the reason for termination of quantum space, partitions it into three subgraphs: (1) the partition that reside outside of horizon, Γ_{ext}, (2) the partition that reside inside of the horizon, Γ_{int}, and (3) the partition that lies on the horizon 2-surface, Γ_{s}. On the horizon surface some vertices and completely tangential edges reside. The spin network states associated to a partition that consists of the vertices lying on the horizon are called *horizon spin network states*. These states determine the whole quantum geometry of the underlying horizon, Fig. 1. Under some simplifications, the spin network state associated to a spherical symmetric structure has been worked out in [12]. The quanta of such a horizon area is chosen from the complete spectrum. It reproduces the Bekenstein–Hawking entropy [10]. Moreover, in this note it is shown that such a black hole exhibits unexpectedly a macroscopic effect in the black hole radiation.

The aim of this note is two fold:

1. Firstly, in Part (8) an unexpected symmetry, the so-called "ladder symmetry", in the complete spectrum of area is descried. In fact, this spectrum can be decomposed into a several *evenly* spaced sets, each with individual gap between levels. This leads to a reduced formula of area

[1] A summary of emergent aspects of non-stringy quantum gravity theories can be found in [4,5], and the references therein.