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ORIGINAL ARTICLE

Fading Hawking radiation

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Abstract In this study, we explore a particular type Hawking radiation which ends with zero temperature and entropy. The appropriate black holes for this purpose are the linear dilaton black holes. In addition to the black hole choice, a recent formalism in which the Parikh-Wilczek's tunneling formalism amalgamated with quantum corrections to all orders in $\hbar$ is considered. The adjustment of the coefficients of the quantum corrections plays a crucial role on this particular Hawking radiation. The obtained tunneling rate indicates that the radiation is not pure thermal anymore, and hence correlations of outgoing quanta are capable of carrying away information encoded within them. Finally, we show in detail that when the linear dilaton black hole completely evaporates through such a particular radiation, entropy of the radiation becomes identical with the entropy of the black hole, which corresponds to "no information loss".

Keywords Hawking radiation · Information paradox · Linear dilaton black hole · Tunneling formalism · Quantum corrections

1 Introduction

Stephen Hawking (1974, 1975, 1976) and Bekenstein (1973) showed in their seminal works that a black hole (BH) should slowly radiate away energy with its characteristic temperature and entropy. But the semi-classical picture of the Hawking radiation has a thermal nature, which poses a fundamental physical problem. Because, when the material entering the BH is a pure quantum state, the transformation of that state into the mixed state of Hawking radiation would destroy information about the original quantum state. However, this violates quantum mechanical unitarity and presents a physical paradox—so called the information loss paradox. For review of the topic and references on the BH information loss problem the reader may refer to Preskill (1992), Page (1994), Russo (2005).

There are various ideas about how the paradox could be solved. Among them, may be the most elegant and comprehensible one is the Parikh and Wilczek (PW)'s quantum tunneling formalism (Parikh and Wilczek 2000). Their tunneling formalism is based on the null geodesics together with the WKB method. They showed explicitly how the inclusion of back-reaction effects, which guarantees the conservation of energy during a particle tunneling the horizon, yields a non-thermal correction to the BH radiation spectrum. For a recent review of "tunneling methods and Hawking radiation" one may consult (Vanzo et al. 2011). On the other hand, the form of their non-thermal correction had a shortcoming since they did not consider the Planck-scale ($\hbar$) quantum corrections, which elicit correlations between quanta emitted with different energies. The first attempt to fix this shortcoming came from Arzano et al. (2005), who proposed a modified version of the tunneling picture in which a leading order Planck-scale quantum correction was introduced. In addition to this, Banerjee and Majhi (2008) have recently provided a general framework for studying quantum corrections to all orders in $\hbar$ to the entropy of a BH. When the effects of the quantum corrections are neglected, one recovers the PW's results of the BH (Parikh and Wilczek 2000). Although there are supportive studies, see for instance Majhi (2009), Banerjee and Modak (2009), Zhu et al. (2009), Akbar and Saifullah (2010), Mirza and Sherkat-

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