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Dark information of black hole radiation raised by dark energy

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Abstract

The "lost" information of black hole through the Hawking radiation was discovered being stored in the correlation among the non-thermally radiated particles (Parikh and Wilczek, 2000 [31], Zhang et al., 2009 [16]). This correlation information, which has not yet been proved locally observable in principle, is named by dark information. In this paper, we systematically study the influences of dark energy on black hole radiation, especially on the dark information. Calculating the radiation spectrum in the existence of dark energy by the approach of canonical typicality, which is reconfirmed by the quantum tunneling method, we find that the dark energy will effectively lower the Hawking temperature, and thus makes the black hole has longer life time. It is also discovered that the non-thermal effect of the black hole radiation is enhanced by dark energy so that the dark information of the radiation is increased. Our observation shows that, besides the mechanical effect (e.g., gravitational lensing effect), the dark energy rises the stored dark information, which could be probed by a non-local coincidence measurement similar to the coincidence counting of the Hanbury–Brown–Twiss experiment in quantum optics.

1. Introduction

Dark energy and dark matter are mysterious to compose our universe together with various material particles [1,2], which can form the generic black holes in some circumstance. While dark

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Table 1
Correction of dark energy on Black hole radiation.

	Without dark energy	With dark energy
Hawking temperature T_H	$(8\pi M)^{-1}$	$(8\pi M)^{-1}\left(1 - 16M^2\Lambda/3\right)$
Black hole life time t	$5120\pi M^3$	$5120\pi M^3\left(1 + 56M^2\Lambda/5\right)$
Dark information I	$8\pi E_a E_b$	$8\pi E_a E_b\left(1 + 16M^2\Lambda\right)$

matter are now widely thought to be some form of massive exotic particles, such as primordial black hole formed within the first several second of our universe [3], it seems that black holes have nothing to do with dark energy because dark energy is not affected by gravity, no matter what size the black hole is and no matter where the dark energy locates around the horizon of the black hole (see Table 1). However, dark energy can causes some "opposite gravity effect" so that the universe will expand faster and faster, thus it makes everything in the universe become more distant so that the gravitational lensing effect can be revised by dark energy [4]. In other hand, dark energy can push the black hole horizon away from its center in increase the horizon area (entropy) and thus and in turn it can exert significant influences on both the black hole radiation and the corresponding information loss. In this paper we will investigate these influences based on statistical mechanics about entropy.

It is well known that, dark energy composes 69% of our universe while the dark matter and ordinary matter constitute the remaining 31% [1]. Many theories about dark energy have been proposed [5,6], including a constant energy density filled in space, or some scalar fields named quintessence [7]. However, dark energy is still a hypothesis used to explain the accelerating expansion of the universe [8], and a convincing theory for dark energy is lacked yet. Recently, LIGO and Virgo have made a breakthrough to detect gravitational waves [9], the provided experimental data showed new possible evidence for dark energy [10–13]. Besides the recently discovered gravitational lensing effect [4] and the estimated proportion, more detailed properties of the dark energy and its influence on other objects, such as thermodynamic influences, have not yet been comprehensively understood and studied, both in theory and experiment.

In view of the expanding of the universe, as a result of the repulsion effect provided by dark energy, the celestial bodies in the universe will be stretched by the expansion of the space, thus, their geometry are changed. Let us now pay our attention to the influences of dark energy on black hole. As a kind of celestial body, one of its geometric features, the surface area, will be affected by the dark energy. It follows from the black hole thermodynamics that the surface area of a black hole, namely the horizon area, corresponds to the Bekenstein–Hawking (B–H) entropy of black hole [14]. In addition, as we have shown, the Hawking radiation spectrum can be straightforwardly derived form the explicit expression of the B–H entropy with mass, charge and angular momentum as three hair variables [15]. Therefore, the dark energy may influence the black hole radiation spectrum. As a result, the change of the radiation spectrum of the black hole will effect on various properties of the black hole and its radiation, such as the temperature of the radiation field, namely the Hawking temperature, the life time of the black hole and so on.

Considering the non-thermal effect of the black hole radiation, Zhang et al. [16] found that there exists information correlation among the radiated particles from the black hole. The two or more particle correlation can be regarded as a kind of hidden information of the black hole because once it were ignored, the paradox of black hole information loss would appear. In other words, the information we used to believe being lost in the Hawing radiation process is actually

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