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ORIGINAL ARTICLE

Hawking radiation of Kerr-Newman black hole in different tortoise coordinate transformations

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Abstract Hawking radiation effect of Maxwell's electromagnetic fields in the Kerr-Newman black hole space-time is investigated using two different tortoise coordinate transformations. It has been shown that the new tortoise coordinate transformation produces constant term ξ in the expression of surface gravity and Hawking temperature. If ξ is set to zero, the surface gravity and Hawking temperature will be equal to those obtained from the old tortoise coordinate transformation. This indicates that new transformation is more reliable and accurate. The black body radiant spectrum of photon displays a new spin-rotation coupling effect.

Keywords Kerr-Newman solution · Hawking radiation · New tortoise coordinate transformation

1 Introduction

Hawking proposed thermal radiation of black hole using the techniques of quantum field theory in curve space-time (Hawking 1974, 1975). Subsequently, Bekenstein (1973, 1974) and Bardeen et al. (1973) built the black hole thermodynamics successfully. Damour and Ruffini (1976) and Sannan (1988) proposed a new method to study the Hawking radiation of non-stationary black hole. In this method, the radial part of Klein-Gordon scalar field, Dirac and Maxwell's electromagnetic field equations can be transformed into standard form of wave equation near the event horizon. Separating the wave equation, the ingoing wave and outgoing wave equations can be derived. Extending the outgoing wave equation through the lower half of the complex plane, the thermal emission spectra can be obtained. Zhao et al. (1981, 1994) extended the Damour-Ruffini-Sannan method to study Hawking radiation effect of a non-stationary black hole space-time by introducing common tortoise coordinate transformation. The position of event horizon r_h and surface gravity κ_h are directly introduced at the tortoise coordinate transformation and assumed them to be unknown quantities.

According to Wu and Cai (2001, 2002) and Ibohal and Ibungochouba (2011), the tortoise coordinate transformation can be defined as

$$
\begin{aligned}
&r_* = r + \frac{1}{2\kappa(u_0,\theta_0)} \ln\bigl[r - r_h(u,\theta)\bigr],\\
&u_* = u - u_0, \qquad \theta_* = \theta - \theta_0,
\end{aligned}
\tag{1}
$$

where $r_h = r_h(u,\theta)$ are the location of the horizon and κ is the adjustable parameters to be determined. All parameters u_0 and θ_0 are constant under the tortoise coordinate transformation and assumed to be initial state of the hole. The transformation (1) does not satisfy the dimensional rule. Recently, Zhao et al. (1981) and Yang et al. (2009) introduced a new tortoise coordinate transformation as

$$
\begin{aligned}
&r_* = r + \frac{1}{2\kappa(u_0,\theta_0)} \ln\left[\frac{r - r_h(u,\theta)}{r_h(u,\theta)}\right],\\
&u_* = u - u_0, \qquad \theta_* = \theta - \theta_0.
\end{aligned}
\tag{2}
$$

In this paper, we used the new generalized tortoise coordinate transformation (2) to restudy the Hawking radiation effect of Maxwell's electromagnetic field in a non-stationary Kerr-Newman black hole. It is interesting to mention that Hawking radiation spectra remains as black body, although the extra constant term ξ is induced in the relevant Hawking temperature and surface gravity. We derive the spin rotation coupling effect between the spin of the particles and angular momentum of the non-stationary Kerr-Newman black hole.

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