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ORIGINAL ARTICLE

Vaidya black hole in non-stationary de Sitter space: Hawking's temperature

Ngangbam Ishwarchandra · K. Yugindro Singh

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Abstract In this paper we present a class of non-stationary solutions of Einstein's field equations describing embedded Vaidya-de Sitter black holes with a cosmological variable function $\Lambda(u)$. The Vaidya-de Sitter black hole is interpreted as the radiating Vaidya black hole is embedded into the non-stationary de Sitter space with variable $\Lambda(u)$. The energy-momentum tensor of the Vaidya-de Sitter black hole is expressed as the sum of the energy-momentum tensors of the Vaidya null fluid and that of the non-stationary de Sitter field, and satisfies the energy conservation law. We study the energy conditions (like weak, strong and dominant conditions) for the energy-momentum tensor. We find the violation of the strong energy condition due to the negative pressure and leading to a repulsive gravitational force of the matter field associated with $\Lambda(u)$ in the space-time. We also find that the time-like vector field for an observer in the Vaidya-de Sitter space is expanding, accelerating, shearing and non-rotating. It is also found that the space-time geometry of non-stationary Vaidya-de Sitter solution with variable $\Lambda(u)$ is Petrov type D in the classification of space-times. We also find the Vaidya-de Sitter black hole radiating with a thermal temperature proportional to the surface gravity and entropy also proportional to the area of the cosmological black hole horizon.

N. Ishwarchandra (✉) · K.Y. Singh
Department of Physics, Manipur University, Imphal 795003, Manipur, India
e-mail: ngishwarchandra@manipuruniv.ac.in

N. Ishwarchandra
e-mail: ngishwarchandra@gmail.com

K.Y. Singh
e-mail: yugindro361@gmail.com

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1 Introduction

In general relativity the Schwarzschild solution is regarded as a black hole in an asymptotically flat space. The Schwarzschild-de Sitter solution is interpreted as a black hole in an asymptotically de Sitter space with non-zero cosmological constant Λ (Gibbons and Hawking 1977). The Schwarzschild-de Sitter solution is also considered as an embedded black hole that the Schwarzschild solution is embedded into the de Sitter space with cosmological constant Λ to produce the Schwarzschild-de Sitter black hole (Cai et al. 1998). The Vaidya solution having a variable mass $m(u)$ with retarded time u is a non-stationary generalization of Schwarzschild black hole of constant mass m (Vaidya 1999). Mallett (1985) has introduced Vaidya-de Sitter solution with constant Λ by making the Schwarzschild mass m variable with respect to the retarded time u as $m(u)$ and studied the nature of the Vaidya-de Sitter space-time (Mallett 1986).

Here the idea of this paper is to propose an exact solution of Einstein's field equations describing Vaidya black hole embedded into the non-stationary de Sitter space to obtain Vaidya-de Sitter black hole with variable $\Lambda(u)$. This Vaidya-de Sitter solution with variable $\Lambda(u)$ will have the limit $m(u) = \pm(1/3)\Lambda(u)^{(-1/2)}$ of the Vaidya mass $m(u)$ in the extreme black hole case $9\Lambda(u)m^2(u) = 1$, which could not explain with the constant Λ in Mallett (1985). This situation can be seen in the next section of this paper.

It is well known that the original de Sitter cosmological model is *conformally* flat $C_{abcd} = 0$ space-time with *constant curvature* $R_{abcd} = (\Lambda/3)(g_{ac}g_{bd} - g_{ad}g_{bc})$ (Hawking