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ORIGINAL ARTICLE

Einstein-scalar-Yang-Mills black holes: a thermodynamical approach

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Abstract We try to find out the nature of different thermodynamical parameters for a black hole solution drawn for a special case in Einstein-Scalar-Yang-Mills gravity. Whether a phase transition occurs for the solution or not is a matter of interest. The nature of the phase transition is tried to understand. Ruppeiner metric and the corresponding Ricci scalar is constructed. It is noticed that the metric is not of positive Ricci for all the parametric values and there exist(s) point(s) in thermodynamic space where the Ricci scalar becomes zero.

Keywords Thermodynamics · Black hole · Yang Mills term · Geometrothermodynamics · Ricci scalar

1 Introduction

In Einstein-Maxwell theory, considering the anti-de Sitter(AdS) asymptotics, study of minimally coupled scalar field is a popular topic now a days (Cadoni et al. 2011). A potential term $V(\phi)$ is added up with the existing common use of kinetic Lagrangian term in this model. Interpretation of such terms are been done as a cosmological term. The potential $V(\phi)$ can be determined from the dynamical equations. It is assumed to be of logarithmic form. Another beautiful behaviour of the model is that it admits asymptotic Lifchitz Black Holes (BHs hereafter) which is of utmost importance as far as Hawking radiation is concerned.

A pure magnetic field added ansatz can be found in Mazharimousavi and Halilsoy (2007, 2008), which is famous as Wu-Yang ansatz and which is efficient enough to be generalised to all higher dimensions. This was done by adding the Yang-Mills term in spite of consideration of Maxwell's field. Mazharimousavi et al. (2013) had proposed a model Einstein-Scalar-Yang-Mills system containing an indispensable potential function $V(\phi)$ as the function of the scalar field. To define scalar filed ansatz, Cadoni et al.'s (2011) method was followed and a logarithmic form was chosen. In this case the superconductivity analogue was not considered which retains the scalar field to be a real one choosing $-g_{tt}=g^{rr}$, coefficient of unit angular line element $d\Omega_d^2$ to be an arbitrary function $R^2(r)$ is was established that $d+1$ dimensional Domail-Wall Universe and explained the conditions under which the FRW universe has double bounces.

Keeping the unit as $16\pi G=c=1$ the $d+2$ dimensional Einstein Yang Mills gravity coupled minimally to a scalar field ϕ is given by Mazharimousavi et al. (2012) as

$$S=\int d^{d+2}x\sqrt{-g}\big[\mathcal{R}-2(\partial\phi)^2-\mathcal{F}-V(\phi)\big], \tag{1}$$

where $\mathcal{R}$ is the Ricci scalar, $\mathcal{F}$ is $trace(F^{(a)}_{\mu\nu}F^{(a)\mu\nu})$ and $V(\phi)$ is an arbitrary function of the scalar field ϕ.

Mazharimousavi et al. (2012) have considered the scalar field as $\phi=\alpha\ln(\frac{r}{r_0})$ with r_0 and α constants and solved the system. With a particular type of choice the BH solution becomes (for detailed calculation see the work of Mazharimousavi et al. 2012).

$$ds^2=-\left(-\frac{8r\ln r}{3}-16Q^2+\frac{8M}{3r^{\frac{1}{2}}}\right)dt^2 + \frac{dr^2}{(-\frac{8r\ln r}{3}-16Q^2+\frac{8M}{3r^{\frac{1}{2}}})}+rd\Omega_3^2. \tag{2}$$

The laws of BH mechanics make after common laws of thermodynamics closely (Bekenstein 1973, 1974; Bardeen et al.

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