Analytic topological Dyonic Hairy black hole and thermodynamics

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Abstract

- We solve coupled Einstein-Maxwell-Scalar gravity system to obtain a new family of dyonic-charged-hairy black hole solutions that possess both electric and magnetic charge with planar, spherical and hyperbolic horizon topologies in asymptotic AdS space.
- We investigate the thermodynamics of this system and find drastic changes in its thermodynamical structure in the presence of a scalar field.
- We favour these black holes for their stable nature at low temperatures in the case of the planar and hyperbolic horizon.
- The thermodynamic phase diagram of the spherical hairy dyonic black hole at constant potential resembles to that of a Van der Waals fluid.

Introduction

- Black holes possess energy, temperature and entropy.
- Depending upon asymptotic space, black holes are stable as well as unstable under thermodynamical fluctuation.
- Black holes can undergo phase transition.
- Black holes in GR follow the famous no-hair theorem charge and angular momentum.
- We construct counter-example of no-hair theorem in asymptotically AdS spaces by considering Einstein-Maxwell-Scalar gravity system and thermodynamics.

Model

Dyonic Hairy black hole solution

Einstein-Maxwell Scalar action,

$$S_{EMS} = \frac{1}{16\pi G_4}\int_M d^4x\sqrt{-g}\left[R - \frac{f(\phi)}{4}F_{\mu\nu}F^{\mu\nu} - \frac{1}{2}\partial_\mu\phi\partial^\mu\phi - V(\phi)\right] \quad (1)$$

We consider the following Ansätze

$$ds^2 = \frac{L^2}{z^2}\left[-g(z)dt^2 + \frac{e^{2A(z)}}{g(z)}dz^2 + d\Omega^2_{\kappa,2}\right],$$
$$\phi = \phi(z),$$
$$A_\mu = A_t(z)\delta^t{}_\mu + q_M\chi \quad (2)$$

We take the scale function $A(z) = -Log(1+az)$ and the coupling function $f(z) = 1$ and by using the above 1 we get,

$$\phi(z) = \int dz\, 2\sqrt{\frac{-A'(z)}{z}}, \quad (3)$$

$$V(z) = \frac{z^2e^{-2A(z)}A'(z)g'(z)}{2L^2} - \frac{2ze^{-2A(z)}g(z)A'(z)}{L^2} - \frac{z^2e^{-2A(z)}g''(z)}{2L^2} + \frac{3ze^{-2A(z)}g'(z)}{L^2} - \frac{6e^{-2A(z)}g(z)}{L^2} + \kappa\frac{z^2}{L^2} \quad (4)$$

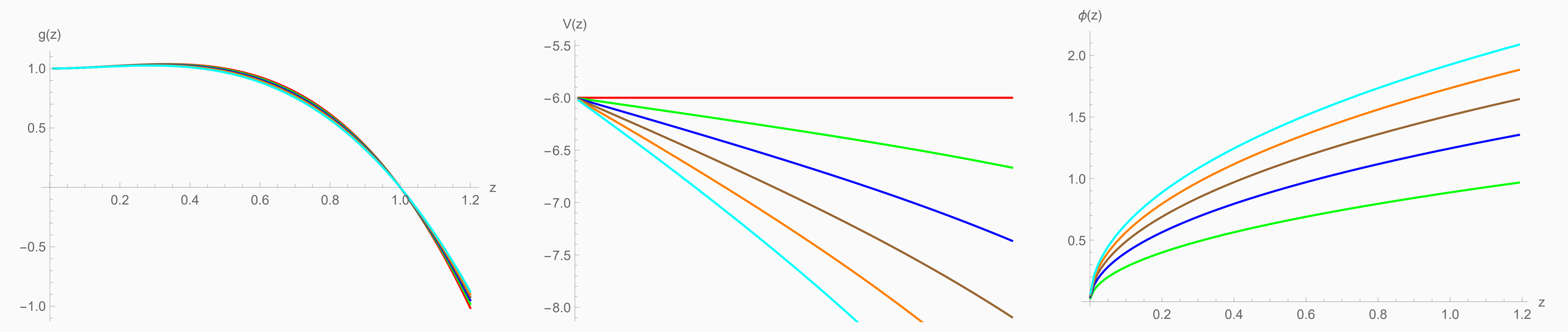

Fig. 1 : Behaviour of $g(z)$, $V(z)$ and $\phi(z)$ for various values of hairy parameter a. Here $z_h = 1$, $\mu_e = 1$, $\kappa = 0$ and $q_M = 1$ are used. Red, green, blue, brown, orange and cyan curves correspond to $a = 0$, 0.05, 0.10, 0.15, 0.20 and 0.25 respectively.

Thermodynamics in Planar Case : $\kappa = 0$

The expression for temperature and entropy

$$S_{BH} = \frac{L^2\Omega_{2,\kappa}}{4G_4 z_h^2}, T = \frac{-g'(z_h)e^{-A(z_h)}}{4\pi} \quad (5)$$

We have considered the AdS length scale $L = 1$.
where $\Omega_{2,\kappa}$ is the unit volume of the boundary space constant hypersurface.

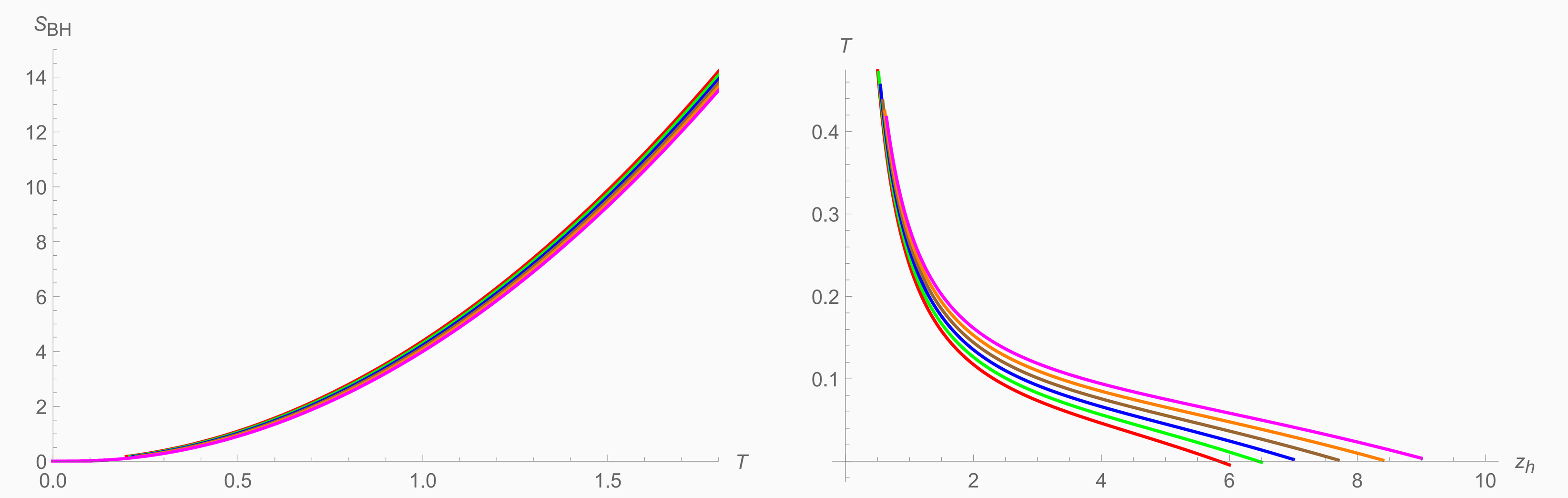

Fig.2 : Hawking temperature T as a function of horizon radius z_h for various values of a. The $S_{BH} - T$ plane for various values of a. Here $\mu_e = 0.1, q_M = 0.1$ are used.

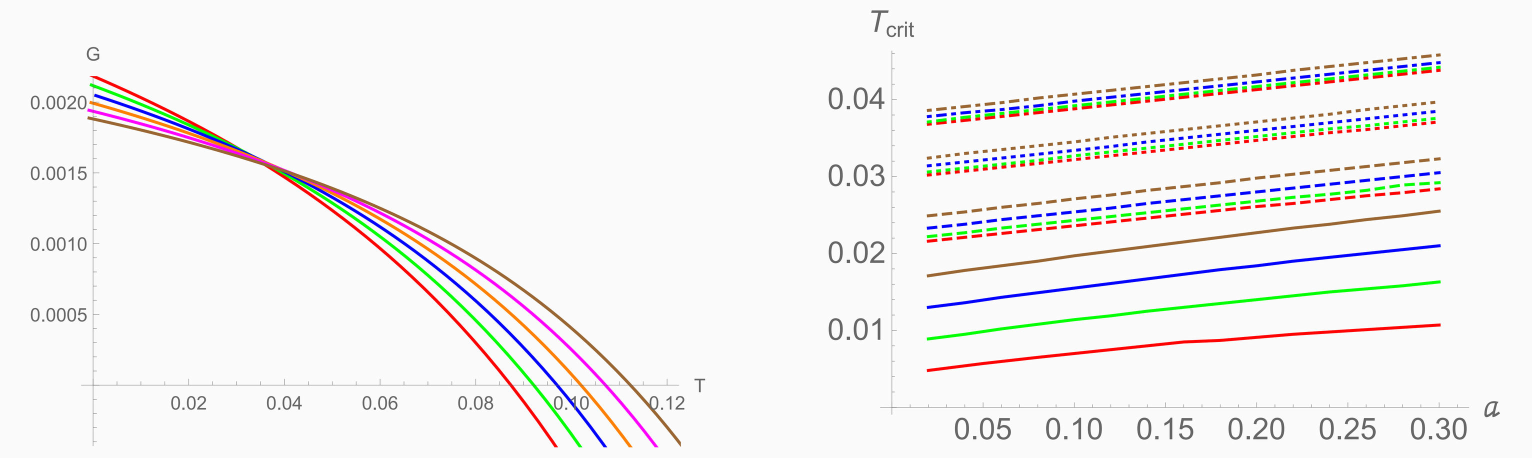

Fig.3 : Gibbs free energy G as a function of Hawking temperature for various values of a with $\mu_e = 0$ and $q_M = 0.3$ and the variation of T_{crit} as function of a with $\mu_e = 0$. Red, green blue, brown and orange curves correspond to $q_M = 0.1, 0.2, 0.3, 0.4$ ans 0.5 respectively.

Thermodynamics in spherical Case: $\kappa = 1$

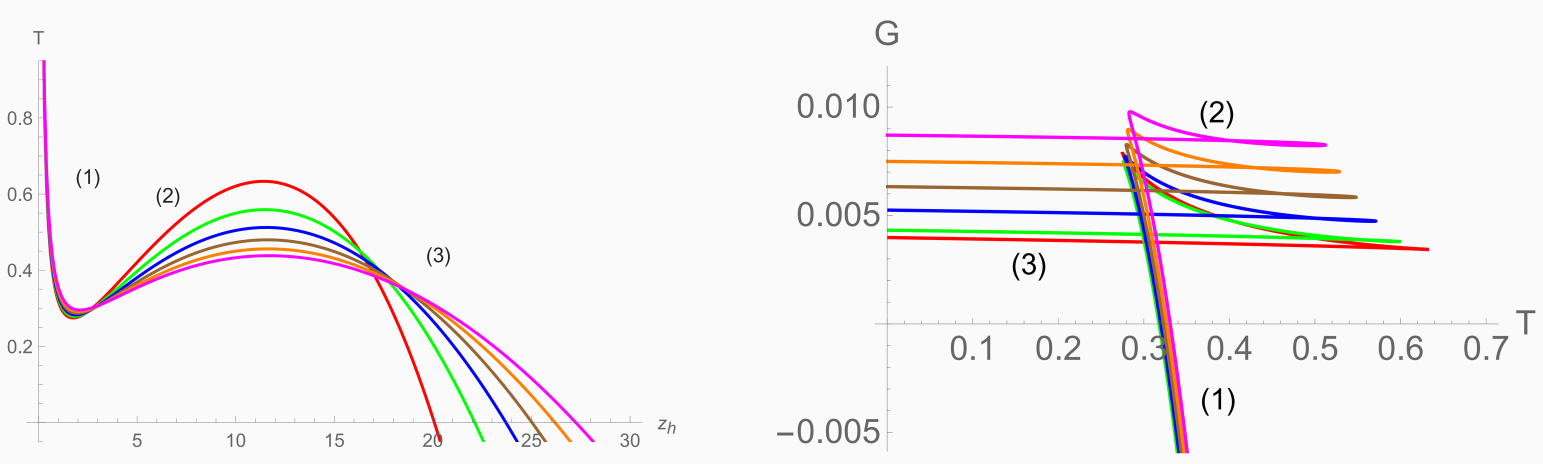

Fig.4 : Hawking temperature T as a function of horizon radius z_h and Gibbs free energy ΔG as a function of Hawking temperature T for various values of a with $\mu_e = 0$ and $q_M = 0.1$.

Fig.5 : Hawking temperature T as a function of horizon radius z_h and Gibbs free energy ΔG as a function of Hawking temperature T for various values of a with $\mu_e = 0.3$ and $q_M = 0$.

Conclusion

- The specific heat is always positive for the planar and hyperbolic cases, thereby establishing these hairy black holes local stability.
- Then from free energy analysis, we get these hairy black holes are thermodynamically preferred at lower temperatures.
- In spherical case, the Hawking-page phase transition as well as the small/large black hole phase transition takes place in the grand canonical ensemble.

Acknowledgment

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Reference

1. Edward Witten. Anti De Sitter Space And Holography. 1998
2. Takashi Torii, Kengo Maeda, and Makoto Narita. No scalar hair conjecture in asymptotic de Sitter space-time. Phys. Rev. D, 59:064027, 1999.
3. Supragyan Priyadarshinee, Subhash Mahapatra, and Indrani Banerjee. Ana- lytic topological hairy dyonic black holes and thermodynamics, 2021.

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