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Nuclear Physics B 913 (2016) 834–851

NUCLEAR PHYSICS B

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Thermodynamics of a sufficient small singly spinning Kerr-AdS black hole

Behnam Pourhassan [a,*], Mir Faizal [b,c]

[a] *School of Physics, Damghan University, Damghan, Iran*
[b] *Irving K. Barber School of Arts and Sciences, University of British Columbia – Okanagan, Kelowna, BC V1V 1V7, Canada*
[c] *Department of Physics and Astronomy, University of Lethbridge, Lethbridge, AB T1K 3M4, Canada*

Received 19 August 2016; received in revised form 17 October 2016; accepted 19 October 2016

Available online 25 October 2016

Editor: Hubert Saleur

Abstract

In this paper, we will analyze the thermodynamics of a small singly spinning Kerr-AdS black hole. As the black hole will be sufficient small, its temperature will be large and so we can not neglect the effects of thermal fluctuations. We will demonstrate that these thermal fluctuations correct the entropy of singly spinning Kerr-AdS black hole by a logarithmic correction term. We will analyze the implications of the logarithmic correction on other thermodynamic properties of this black hole, and analyze the stability of such a black hole. We will observe that this form of correction becomes important when the size of the black hole is sufficient small. We will also analyze the effect of these thermal fluctuations on the critical phenomena for such a black hole.

1. Introduction

Black holes are maximum entropy objects, and so a black hole has more entropy than any other object with the same volume [1–5]. It is important to associate a maximum entropy with a black

* Corresponding author.
E-mail addresses: b.pourhassan@du.ac.ir (B. Pourhassan), mirfaizalmir@gmail.com (M. Faizal).

http://dx.doi.org/10.1016/j.nuclphysb.2016.10.013

hole as finite entropy objects can cross the horizon of a black hole. This would spontaneously reduce the entropy of the universe, and thus the second law of thermodynamics can get violated if a maximum entropy is not associated with a black hole. This maximum entropy associated with a black hole scales with the area of the horizon. In fact, the entropy of the black hole can be expressed in terms of the area of the horizon as $s = A/4$. The observation that the maximum entropy of a region of space scales with its area has motivated the holographic principle [6,7]. This principle states that the number of degrees of freedom in any region of space is equal to the number of degrees of freedom on the boundary of that region.

The holographic principle has found various applications in many different areas of physics. However, it is expected that the holographic principle will get modified near Planck scale [8,9]. This is because the area–entropy law of black holes gets modified due to the quantum gravitational effects. In fact, almost all approaches to quantum gravity predict the same functional form for these quantum corrections to the area–entropy relation i.e., the area–entropy law gets corrected by a logarithmic correction term. However, the coefficient of this logarithmic correction term depends on the specific approach chosen, and is different for different approaches to quantum gravity. Such logarithmic correction term has been obtained using the non-perturbative quantum general relativity [10]. This was done by using the relation between the density of states of a black hole and the conformal blocks of a well defined conformal field theory. The Cardy formula has been used for obtaining such corrections terms to the area–entropy relation [11]. The correction for a BTZ black hole has been calculated, and it has been demonstrated that these are logarithmic corrections [11].

The effect of matter fields surrounding a black hole has been studied [12–14]. This analysis has also been used to obtain corrections to the area–entropy relation, and it was observed that this correction term is logarithmic. The string theoretical corrections to the entropy of a black hole have been calculated, and it has been found that the entropy of a black hole gets corrected by logarithmic term generated from string theoretical effects [15–18]. The logarithmic correction to the entropy of a dilatonic black hole has been obtained [19]. The partition function of a black hole has been used to obtain the logarithmic correction to the area–entropy law of a black hole [20]. The corrections obtained using the generalized uncertainty principle are also logarithmic [21,22]. The thermodynamics and statistics of Gödel black hole with logarithmic correction has been studied [23]. Furthermore, $P - V$ criticality of dyonic charged AdS black hole with a logarithmic correction has been also been analyzed [24].

It may be noted that in the Jacobson formalism, the Einstein's equation can be derived from the first law of thermodynamics [25,26]. In this formalism, it is required that the Clausius relation holds for all the local Rindler causal horizons through each space–time point, and this gives rise to the Einstein's equation. As there exists a relation between the geometry and thermodynamics of a black hole, we expect that thermal fluctuations in the thermodynamics will give rise to the quantum fluctuations in the metric. In fact, it has been demonstrated that the entropy of the black hole gets corrected by logarithmic terms due to these thermal fluctuations [27,28]. As such corrections are expected to occur from most approaches to quantum gravity, we will study the effect of such term on our system. Furthermore, as the coefficient of such terms depends on the approach to the quantum gravity, we will not fix the coefficient of such correction term, and hence see the effect of such correction term on the system, which would be generated from different approaches to quantum gravity.

Already, the effect of thermal fluctuations on the thermodynamics quantities of an AdS charged black hole has been analyzed [29]. It was demonstrated that the thermal fluctuations decrease the certain thermodynamics potentials associated with the system, for example, the free