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Two-dimensional black holes in a higher derivative gravity and matrix model

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Abstract

We construct perturbatively a class of charged black hole solutions in type 0A string theory with higher derivative terms. They have extremal limit, where the solution interpolates smoothly between near horizon AdS_2 geometry and the asymptotic linear dilaton geometry. We compute the free energy and the entropy of those solutions using various methods. In particular, we show that there is no correction in the leading term of the free energy in the large charge limit. This supports the duality of the type 0A strings on the extremal black hole and the 0A matrix model in which the tree level free energy is exact without any α' corrections in the leading order.

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1. Introduction

Black holes are interesting objects in gravity and string theory, which may be awaiting the complete understanding on the quantum nature of gravity. Since black holes have a large curvature value region near the singularity, the non-perturbative formulation of gravity theory or its non-perturbative stringy generalization may be needed to understand the full quantum nature of black holes. Though full non-perturbative descriptions of M/string theories are not avail-

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able yet, there are several interesting toy string models whose non-perturbative descriptions are known. One such class of toy models is the one of matrix models which correspond to the non-perturbative formulation of noncritical string theories. Specifically, various two-dimensional string theories on the flat background can be reformulated in terms of matrix models. In some cases, the dual matrix models are believed to be a complete non-perturbative formulation of the corresponding noncritical string theories. Then, one may naturally ask whether there are black hole solutions in a noncritical string theory, and if there are, how they can be incorporated and understood in the context of dual matrix model.

It was proposed in [1] that the type 0A matrix model with $\mu = 0$ and non-zero RR fluxes $q_+ = q_- = q$ is dual to 0A string theory on the extremal black hole [2]. Later on, the type 0A matrix model was generalized [3] to incorporate two kinds of RR fluxes and found that it depends only on the combined flux[1] $Q = q_+ + q_-$. Since the generalized matrix model is the same as the matrix model with just one kind of RR flux and there is no evidence for the existence of black holes in the type 0A matrix model side, it was argued that the matrix model is not related to the 0A strings on black holes [3]. Furthermore, the curvature radius of the black hole solution is the order of string length scale, independent of charge, and therefore the low energy gravity cannot be trusted and it is not clear whether the black hole exists at all. Nevertheless, there are some pursuits of matching between the matrix model and type 0A strings on black holes or *AdS* space [4–6] with partial success.

In this paper we will try to extend these efforts by including lowest order α' corrections in the low energy effective gravity for type 0A string theory. As we mentioned, the curvature radius of the black hole is the order of string length scale, and therefore higher derivative terms should be taken into account. One of the motivation of this work is to determine how the behavior of the black hole geometry is modified under the higher derivative correction.

We find the perturbative evidence of the existence of charged black holes even with the higher derivative terms in the type 0A string theory, which interpolate smoothly between the near horizon geometry and the asymptotic geometry. In the case of the extremal black hole, the near horizon geometry is AdS_2, as usual. This is in contrast to the four-dimensional cases where it is not easy to find the interpolating solutions. We compute the exact entropy of this extremal black hole using Sen's formalism and find the condition on the coefficient a of the higher derivative term in order to have the extremal black hole solution. We also compute the free energy of the non-extremal black holes using Euclidean action approach and Wald's Noether charge method. In the extremal limit, the leading term, in the large charge limit, of the free energy turns out to be unaffected under the α'-correction. This agrees with the result from the matrix model, which supports the duality of those two models.

The organization of the paper is as follows. In Section 2, we briefly review some relevant aspects on the type 0A string theory and its dual 0A matrix model. We also review the black hole solutions in type 0A string theory. In Section 3, we construct charged black hole solutions in the presence of higher derivative terms in the metric. We construct solutions, perturbatively in the coefficient a, and find the black hole geometries which interpolate near horizon region and asymptotic region, which is linear dilaton geometry. In Section 4, we compute the free energy and the entropy of the charged black hole solutions, for both extremal and non-extremal cases using various approaches. The computation supports the duality between the 0A matrix

[1] There is an additional term which depends on the difference between RR fluxes, but it was irrelevant to arguments for black holes [3].