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Black hole spectra in holography: Consequences for equilibration of dual gauge theories

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Abstract

For a closed system to equilibrate from a given initial condition there must exist an equilibrium state with the energy equal to the initial one. Equilibrium states of a strongly coupled gauge theory with a gravitational holographic dual are represented by black holes. We study the spectrum of black holes in Pilch–Warner geometry. These black holes are holographically dual to equilibrium states of strongly coupled $SU(N)$ $\mathcal{N}=2^*$ gauge theory plasma on S^3 in the planar limit. We find that there is no energy gap in the black hole spectrum. Thus, there is a priori no obstruction for equilibration of arbitrary low-energy states in the theory via a small black hole gravitational collapse. The latter is contrasted with phenomenological examples of holography with dual four-dimensional CFTs having non-equal central charges in the stress–energy tensor trace anomaly.

1. Introduction and summary

Consider an interacting system in a finite volume. Suppose that the theory is gapless — there are arbitrary low-energy excitations. If a generic state in a theory equilibrates, there cannot be a gap in the spectrum of equilibrium states in the theory. This obvious statement has a profound im-

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plication for strongly coupled gauge theories with an asymptotically AdS gravitational dual [1]. In a holographic dual the equilibrium states are realized by black holes [2]. Thus, if it is possible to prepare an arbitrary low-energy initial configurations in a holographic dual with a gapped spectrum of black holes, such states of the boundary gauge theory will never equilibrate. Correspondingly, the asymptotically AdS dual is guaranteed to be stable against gravitational collapse for sufficiently small amplitude of the perturbations. Examples of this type would violate ergodicity from the field theory perspective.

In this paper we show that while it is possible to realize above scenario in a phenomenological (bottom-up) holographic example — the Einstein–Gauss–Bonnet (EGB) gravity with a negative cosmological constant, it does not occur in a specific model of gauge theory/supergravity correspondence we consider — the holographic duality between $\mathcal{N}=2^*$ $SU(N)$ gauge theory and the gravitational Pilch–Warner (PW) flow [3–5].

From the gauge theory perspective, $SU(N)$ $\mathcal{N}=2^*$ gauge theory is obtained from the parent $\mathcal{N}=4$ SYM by giving a mass to $\mathcal{N}=2$ hypermultiplet in the adjoint representation. In $R^{3,1}$ space–time, the low-energy effective action of the theory can be computed exactly [6]. The theory has quantum Coulomb branch vacua $\mathcal{M}_{\mathcal{C}}$, parameterized by the expectation values of the complex scalar Φ in the $\mathcal{N}=2$ vector multiplet, taking values in the Cartan subalgebra of the gauge group,

$$\Phi = \mathrm{diag}(a_1, a_2, \cdots, a_N)\,, \qquad \sum_i a_i = 0\,, \tag{1.1}$$

resulting in complex dimension of the moduli space

$$\dim_{\mathbb{C}} \mathcal{M}_{\mathcal{C}} \;=\; N-1\,. \tag{1.2}$$

In the large-N limit, and for strong 't Hooft coupling, the holographic duality reduces to the correspondence between the gauge theory and type IIb supergravity. Since supergravities have finite number of light modes, one should not expect to see the full moduli space of vacua in $\mathcal{N}=2$ examples of gauge/gravity correspondence. This is indeed what is happening: the PW flow localizes on a semi-circle distribution of (1.1) with a linear number density [4],

$$\begin{gathered}\mathrm{Im}(a_i) = 0\,, \qquad a_i \in [-a_0, a_0]\,, \qquad a_0^2 = \frac{m^2 g_{YM}^2 N}{4\pi^2}\,, \\ \rho(a) = \frac{8\pi}{m^2 g_{YM}^2}\sqrt{a_0^2 - a^2}\,, \qquad \int_{-a_0}^{a_0} da\; \rho(a) = N\,,\end{gathered} \tag{1.3}$$

where m is the hypermultiplet mass. This holographic localization can be deduced entirely from the field theory perspective [7], using the S^4-supersymmetric localization techniques [8]. To summarize, $\mathcal{N}=2^*$ holography is a well-understood nontrivial example of gauge/gravity correspondence that passes a number of highly nontrivial tests [4,7,9].

We would like to compactify the background space of the $\mathcal{N}=2^*$ strongly coupled gauge theory on S^3 of radius ℓ — in a dual gravitational picture we prescribe the boundary condition for the non-normalizable component of the metric in PW effective action to be that of $R\times S^3$. This is in addition to specifying non-normalizable components (corresponding to m in (1.3)) for the two PW scalars, dual to the mass deformation operators of dimensions $\Delta=2$ and $\Delta=3$ of the gauge theory hypermultiplet mass term. Thus, we produced a holographic example of