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Hawking evaporation time scale of topological black holes in anti-de Sitter spacetime

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Abstract

It was recently pointed out that if an absorbing boundary condition is imposed at infinity, an asymptotically anti-de Sitter Schwarzschild black hole with a spherical horizon takes only a finite amount of time to evaporate away even if its initial mass is arbitrarily large. We show that this is a rather generic property in AdS spacetimes: regardless of their horizon topologies, neutral AdS black holes in general relativity take about the same amount of time to evaporate down to the same size of order L, the AdS length scale. Our discussion focuses on the case in which the black hole has toral event horizon. A brief comment is made on the hyperbolic case, i.e. for black holes with negatively curved horizons.

1. Finite upper bound for Hawking radiation time

Anti-de Sitter (AdS) spacetime plays an important role in theoretical physics [1], especially in the holographic duality between AdS spacetime and conformal field theory (CFT) [2]. As is well known, AdS spacetime is not globally hyperbolic, and one needs to impose some boundary conditions at infinity. If the usual reflective boundary condition is chosen, a light ray from an arbitrary "center" in the bulk can reach the boundary and be reflected back in a finite proper

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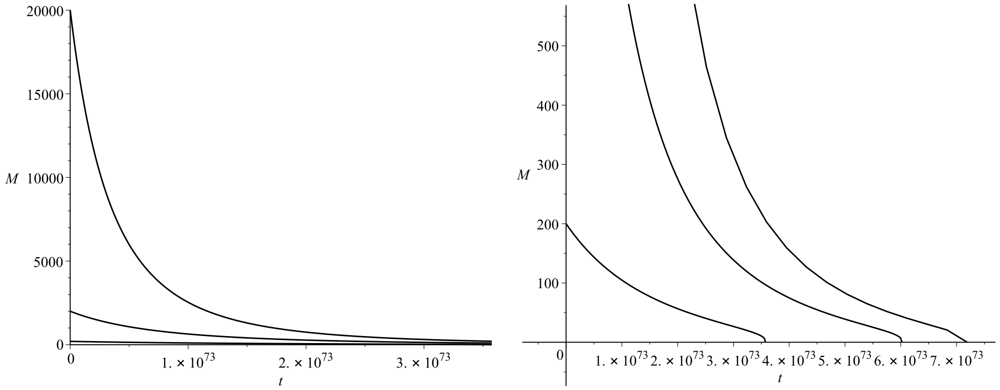

Fig. 1. **Left:** The evolution of some AdS-Schwarzschild black holes with an absorbing boundary condition imposed at infinity. In this example, we set the numerical value $L = 100$, and the initial masses of the black holes are 200, 2000, and 20 000, respectively. **Right:** A closer look toward the end of the evaporation, from which we see that these black holes reach the zero mass limit at about the same time of order $L^3/\hbar$, within an order of magnitude or so. The evolution should only be trusted quantitatively upto $M \sim L$ beyond which the geometric optics approximation is no longer valid. The following comments are true also for the other figures that show mass evolution of the various black holes in this work: since we have neglected the greybody factors, the lifetime is expected to be off by a few magnitudes anyway. Note also that in the units in which length is in centimeters, and $G = 1 = c$, $\hbar = \hbar G/c^3 \approx 3 \times 10^{-66}$ cm^2.

time of an observer sitting at said "center". A large[1] black hole in the bulk therefore tends not to evaporate, but instead achieve thermal equilibrium with its own Hawking radiation that gets reflected back from infinity.

However, one could choose an absorbing boundary condition instead, say by coupling the boundary field theory with an auxiliary system ("AUX"), such as another CFT. (In quantum field theory, boundary conditions are also required for quantization in a non-globally hyperbolic manifold. See [3] for a discussion of "transparent" vs. "reflective" boundary conditions and the various quantization schemes in AdS spacetime. The boundary condition also affects whether a given asymptotically AdS spacetime is stable under small perturbation [4,5].) With such a "CFT-AUX" system at work, even large AdS black holes can evaporate [6–9]. Dynamical and non-equilibrium scenarios are of great interest in holography [10], especially in the applications to material systems like condensed matter and quark gluon plasma. The understanding of the behaviors of evaporating large black holes is a crucial step toward this goal.

In a recent work by Don Page [11], it was shown that an asymptotically anti-de Sitter black hole with a standard spherical horizon of S^2 topology equipped with the canonical round metric (hereinafter, "AdS-Schwarzschild black hole") takes a time proportional to L^3 to evaporate away. Some numerical examples are provided in Fig. 1. These plots assume the mass loss of the black holes follow the geometric optics approximation, which of course is only true for large mass regime $M \gg L$. In other words, the evolution of the masses beyond $M \sim L$ should not be trusted quantitatively in the plots, though it is still *qualitatively* correct. As explained in [11], the evolution from $M \sim L$ down to $M = 0$ should take a time of around $t \sim L$.

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[1] "Large" means the size of the black hole is larger than the AdS length scale L.