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Schwarzschild fuzzball and explicitly unitary Hawking radiation

Ding-fang Zeng

Institute of Theoretical Physics, Beijing University of Technology, Beijing 100124, China

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Abstract

We provide a fuzzball picture for Schwarzschild black holes, in which matters and energy consisting the hole are not positioned on the central point exclusively but oscillate around there in a serial of eigen-modes, each of which features a special level of binding degrees and are quantum mechanically possible to be measured outside the horizon. By listing these modes explicitly for holes as large as $6M_{\rm pl}$, we find that their number increases exponentially with the area. Basing on these results, we construct a simple but explicitly unitary formulation of Hawking radiations.

The horizon and central singularity are two key ingredients of general relativistic black holes, either from observational [1] or pure theoretical [2] aspects. They are also birth-lands of many radical proposition and exciting progresses in quantum gravitation researches, typically the information missing puzzle [3–6] and the Anti-de Sitter/Conformal Field Theory correspondence [7] or more generally the gauge/gravity duality (AdS/CFT here after). Although initiative researchers such as L. Susskind, basing on general ideas of gauge/gravity duality and special picture of string theories [8–20], claims that the war between him and S. Hawking has finished already [21], new ideas on the information missing puzzle's reformulation and resolution continue to appear endlessly, ranging from the famous AMPS observation of firewall paradoxes [22,23] and the ER=EPR proposition [24], to various nonlocal/entanglement [25–35] revision believed being

E-mail address: dfzeng@bjut.edu.cn.

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ignored in Hawking's original calculation, and to totally new mechanisms for black holes to save information [36], although challenged by [37,38].

Basic ideas The general idea of gauge/gravity duality that microstates of black holes could be explained in terms of lower dimensional gauge field theories brings us misunderstandings that, the information of black holes is stored locally in their near horizon region. However, even in the most well understood fuzzball picture of string theories [11–20], S. D. Mathur et al. tell us that for a large class of asymptotically AdS black holes constructible from or related with special D1-D5 brane configurations, the information carriers are distributed across the whole region inside the horizon surface. For more general black holes, especially the Schwarzschild ones, string theories still find no ways to give the relevant information saving mechanism a concrete explanation. We considered in ref. [39] a possibility that, matters inside the Schwarzschild black holes, which we call Schwarzschild contents in this paper, are not positioned on the central point of the hole statically but are experiencing periodical motion of collapsing, collapsing overdone to the other side and collapsing again during which the radial mass profile preserves continuously. We argue that it is just this radial mass profiles' diversity, chosen at arbitrary given times $\tau = \tau_0$, with the future determined by Einstein equation, that leads to the microstates' multiplicity of black holes. The inner metric of these holes when written in the co-moving observer's proper time has the form

$$ds^2 = -(h^{-1}\frac{\dot{m}^2}{m'^2} + 1)d\tau^2 + h^{-1}dr^2 + r^2 d\Omega_2^2 \tag{1}$$

$$h = 1 - \frac{2Gm(\tau, r)}{r},\ r < r_0 \equiv 2Gm_{\text{total}} \tag{2}$$

By looking $m(\tau_0, r)$ as independent coordinate and introducing a wave functional $\Psi[m(\tau_0, r)]$ to denote the amplitude the hole being at profile $m(\tau_0, r)$, we establish in ref. [39] a functional differential equation controlling the form of $\Psi[m(\tau_0, r)]$ through quantisations of the Hamiltonian constraint of the system, thus translate the question of black hole microstates' definition and counting a functional eigenvalue problem. However, due to complexes of the functional differential equation, we get only rough estimations for the eigen-state of 1- and 2-M_{pl} mass black holes. The purpose of this work is to provide an alternative definition for this functional eigenvalue problem and a more convincing proof of the microstate number's exponential area law. Basing on this proof, we will also give a hamiltonian thus explicitly unitary derivation for Hawking radiations.

The classic picture behind our micro-state definition and counting is shown in Fig. 1 schematically. Just as was done in [39], we will still focus on black holes consisting of zero pressure dusts for simplicity. The advantage of this doing is that, we can easily prove that the co-moving observer's geodesic motion $\{u^0 = 1, g_{\mu\nu}u^\mu u^\nu = -1\}$ follows directly as part of Einstein equations $G_\mu{}^\nu = 8\pi G T_\mu{}^\nu$, i.e. $\frac{G_0{}^1}{G_0{}^0} \overset{E.e.}{=} \frac{u^1}{u^0} \overset{g.m.}{=} \frac{\dot{m}}{m'}$. But different from [39], this time we will decompose the radial mass distribution into several concentric shells at the very beginning. We will show that the distinguishable way of this shell decomposition, as well as the total number of all possible quantum state of them are both countable, with the latter equals to $e^{kA/4G}$. In the most simple layering scheme, all contents of the hole are concentrated in one shell, the equations of motion, looking from exterior observers which use time t and feel a Schwarzschild geometry v.s. interior observers which use $'t$ and feel a Minkowskian geometry, can be easily written as