

Black hole Information Paradox

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Abstract

Any black hole eventually evaporates by emitting Hawking radiation and wipes out all information about the history of its formation. So it seems impossible to trace the initial state of the star from the final state of black hole (assuming that black hole behaves as Quantum system) which goes against to the fundamental unitarity principle of quantum mechanics and leads to information paradox. This **review** article tries to represent how the Fuzzball paradigm of string theory aims to solve the problem by drastically changing the known picture of classical black hole.

Keywords: Black hole, Singularity, Event Horizon, Black hole Evaporation, Fuzzball.

1. Introduction: Stars with mass exceeding Chandrasekhar mass limit collapse by its own gravitational attraction forms objects hidden by a surface of no return called *Event Horizon*. Because all material particles even light after crossing this surface get trapped and faces inevitable catastrophe as the singularity in time so in their future so can't be avoided. so nothing can come out of it so the name "*Black Hole*" as coined by John Wheeler. However Stephen W.Hawking (1975) showed or analysis revealed a strange feature that Black hole can emit radiation (*Hawking Radiation*) when studied/ investigated behavior of Quantum Field Theory in strong gravitational field near Horizon of black hole and the radiation spectrum can be ascribed to a temperature (very low temperature) Another important and interesting observation about black hole is that the area of the event horizon of a black hole never decreases. This observation including the fact of black hole temperature due to Hawking radiation motivates Bekenstein(1973) to recognize that area of event horizon can be regarded or interpreted as some kind of entropy as Entropy in thermodynamics 2nd law never decrease and motivates physicist to study a new branch called black hole thermodynamics. However search for physical interpretation of black hole entropy in terms of no of different possible microstates as is required by thermo dynamical definition hints to the strange feature of that the information is somehow encoded on the surface area of black hole rather than volume contained in by it which contradicts the classical intuition. This curious fact that "Area" seems to be more fundamental than "Volume" in conceiving information according to some scientist may drastically change our idea about the fundamental nature or structure of space itself and expectation that more and more exploration toward plank scale by designing ultra high energy accelerator collider to reveal new physical reality may even fail to make any sense. Now as the Black hole emits radiation it will lose its mass and eventually evaporates (*Black Hole Evaporation*).For a typical Black hole of solar mass evaporation time is almost the age of the universe.

2. The Information Paradox: The final state of the black hole is surprisingly simple and can be completely specified by the its mass, charge and angular momentum. So the final state of black hole is completely independent of its initial chemical and physical compositions and history of its formation. Again when the black hole evaporates whatever information or entropy it contains appear to be lost as nothing left except radiation (which carries no information) after black hole evaporation. Again according to most fundamental principle of Quantum mechanics i.e. *unitary principle*,(which is a statement of probability conservation or conservation of information about the system) final state of a system can be obtained from initial state by applying time

evolution operator U through following equation Or one can construct initial state from final state of the system by applying it in reverse way. But considering the final state of radiation of black hole which is a mixed state it seems impossible to get back the pure initial state of black hole. So if for external observer black hole is supposed to behave as a proper quantum system then this failure to track the past history from its final state leads to a logical contradiction. This is known as *black hole information paradox*.

3.1. Resolution of Information Paradox: One of the most promising theories to resolve the paradox is the theory of *Fuzz ball* based on string theory developed by Prof. Sameer D. Mathur, Strominger and Vafa(1996) were able to construct black hole using *string states* which emits radiation spectrum similar to black hole can have large no of different possible microstates and the most surprising result is that this number exactly matches with the Entropy calculated according to Bekenstein Formula. But it was not sufficient to solve the problem regarding information because still the vacuum was present around the event horizon. Actually the real key to resolve the paradox was found when the structure of such black hole formed by string states was explored or investigated in detail by Indian Scientist Prof. Sameer .D. Mathur(1996). A very curious observation by Sameer D .Mathur(1998) was that the string states expand in size by a process of strings and branes called '*fractionation*' with the increase of gravitational interaction rather contracting by its self-gravity and even exceed the size of the horizon of black hole with same energy. This kind of structure resulted from string states are known as *Fuzz ball*. This *Fuzz ball* emits radiation same as Hawking Radiation from black hole. *Fuzz ball*. This replaces the classical picture of a black hole but without the formation of any Event Horizon and source of radiation is also not from the vacuum near Horizon but from the Fuzz Ball itself (mechanism of particle creation in this case is different from that of hawking picture).

3.2. New Picture of Black hole with no Horizon and no Singularity: Soon a fascinating picture emerged for the states of black holes from string theory research by Stefano Giusto, Samir D. Mathur, Ashish Saxena (2005) which can be explained using Fig (a) below where only 1 dimension is shown instead of 3 dimensions for simplification. In 1- dimension black hole looks like a line where point in the middle represents singularity and points on either side marking the horizon. Now if one assumed the existence of extra dimensions according to string theory and believed that extra dimensions are curled up in a circle then this line representing a hole become or looks like a drinking straw shown in Fig-(b). Now following the steps below of an extraordinary picture emerges.

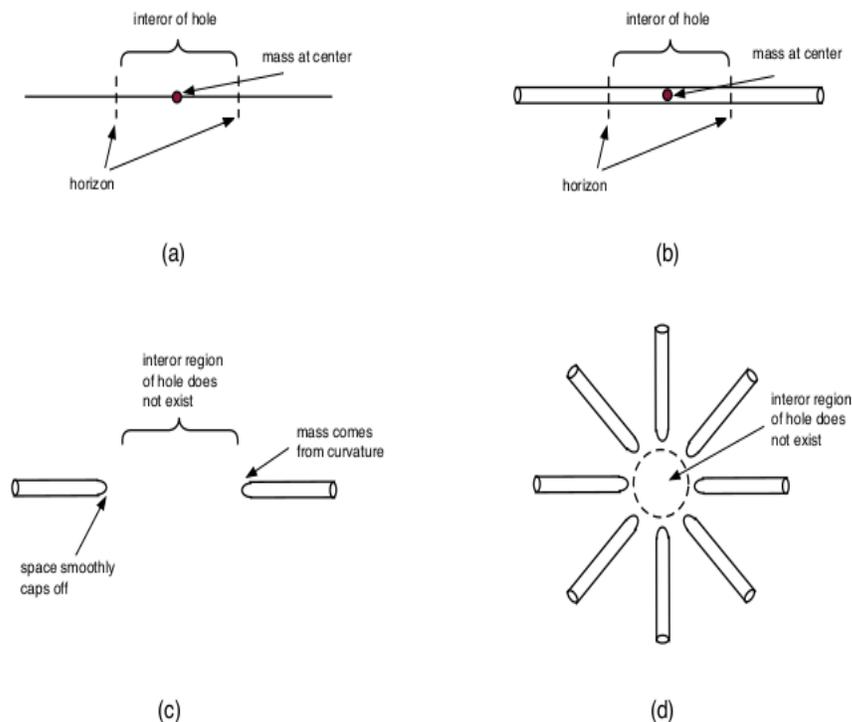


Fig (a) shows black hole in one dimension with horizon and centre. Fig (b) shows black hole with curled up dimension looks like drinking straw. Fig(c) indicates the process of cutting and thronging up the middle region between two points marking the horizon which become non-existent as not being part of space-time. Fig (d) gives the complete picture considering all dimensions.

First, cut out and discard a middle section from the straw – the part inside the horizon and this part become non-existent as they are no longer a part of space-time. Next close the open ends of the straw by adding hemispherical ‘caps’. This gives a smooth space, which has no horizon or singularity. The mass M at the center has now vanished. But the curvature of the ‘caps’ contributes energy. These caps also contain other energy carrying objects of string theory. This energy E makes up the mass M which the hole should have, through the relation $E = mc^2$ as shown in Fig(c) For full 3-dimensional problem, situation turns out to be Fig(d); there is a somewhat different shape to the cap in different directions, and all the possible choices for these caps give all the states of the black hole

4. Conclusion: So we get a nontrivial structure just outside the place where the horizon would have been, but this structure does not ‘fall in’ – there is no place for it to fall into, since space-time ends outside the horizon. The black hole now has a surface just like any other star or planet, exactly what was needed to solve the information paradox! The radiation from the surface of a simple set of fuzz balls was explicitly computed (Cardoso, Vitor and Dias, Oscar J. C. and Hovdebo, Jordan L. and Myers, Robert C 2006). Recent research by Prof. Sameer .D Mathur Borun Chowdhury that the energy spectrum of this radiation exactly agreed with the predicted Hawking radiation for these special states. But the details of the emitted quanta were very

different carrying the imprint of the in falling matter therefore there was no information paradox (Chowdhury, Borun D and Mathur, Samir D 2008).

5. References

1. Hawking S.W (1975) Particle Creation by Black Holes. Commun. Math. Phys. 43, 199—220 © by Springer-Verlag 1975
2. Bekenstein, Jacob D(1973) Black Hole and Entropy. Phys.Rev.D7:2333—2346. <https://link.aps.org/doi/10.1103/PhysRevD.7.2333>.
3. Andrew Strominger, Cumrun Vafa (1996) Microscopic origin of the Bekenstein-Hawking entropy. Physics Letters B 379: Issues 1–4, 99-104, [https://doi.org/10.1016/0370-2693\(96\)00345-0](https://doi.org/10.1016/0370-2693(96)00345-0).
4. Das, Sumit R. and Mathur, Samir D.(1996) Excitations of D-strings, entropy and duality. PhysicsLettersB375:103–110, <http://www.sciencedirect.com/science/article/pii/0370269396002420>
- 5 Samir D. Mathur (1998) Emission rates, the correspondence principle and the information paradox.NuclearPhysicsB529:295–320. <http://www.sciencedirect.com/science/article/pii/S0550321398003368>
6. Stefano Giusto, Samir D. Mathur, Ashish Saxena (2005) 3-charge geometries and their CFT duals.NuclearPhysicsB710, Issues 1–2: 425-463<https://doi.org/10.1016/j.nuclphysb.2005.01.009>.
<http://www.sciencedirect.com/science/article/pii/S0550321305000106>.
7. Cardoso, Vitor and Dias, Oscar J. C. and Hovdebo, Jordan L. and Myers, Robert C (2006) Instability of non super symmetric smooth geometries Phys. Rev. D 73: 064031 <https://link.aps.org/doi/10.1103/PhysRevD.73.064031>.
8. Chowdhury, Borun D and Mathur, Samir D (2008) Radiation from the non-extremal Fuzzball. Classical and Quantum Gravity 25: 135005. <http://dx.doi.org/10.1088/0264-9381/25/13/135005>.