Storing Information in Black Holes

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Do you know black holes? They are super high-density astronomical objects emitting very strong gravity around them. They were originally predicted from general relativity, which describes the relationship between gravity, spacetime and matter. At first, they were considered not to exist, but later it was discovered that they are common in the universe.

Because a black hole contains a tremendous amount of matter and substantial particles are crowded together, quantum mechanics is also important. Quantum mechanics can describe the movement of matter from a microscopic point of view. Considering the quantum mechanical effect, the mass of a black hole gradually decreases and eventually the black hole will evaporate. After evaporation, a black hole will disappear without a trace. This process of black holes' evaporation is called Hawking radiation and it causes what is known as the black hole information paradox. Black holes should contain information about the materials inside. And according to quantum mechanics, information is preserved under any circumstances. What happens to the internal information when Hawking radiation finishes? Does the information vanish? This is the black hole information paradox. Numerous attempts have been made to break the paradox, but none have been conclusive.

In 2020, a theoretical paper with the potential to put an end to this paradox was published[1]. This paper shows a new solution for the semiclassical Einstein equation. It is an equation to describe the relationship between spacetime and matter using general relativity and quantum mechanics. The solution depicts an interior view of a spherical object being crushed by its own gravity. At the end of the solution, a super high-density astronomical object is constructed. This object has almost the same characteristics as the black hole produced by previous solutions. For instance, they have almost the same radius and entropy, which is a fundamental value in thermodynamics. So, they are indistinguishable by current black hole observations and the objects can be thought of as black holes.

What is new about this paper is incorporating the effect of evaporation from the beginning of the black hole formation. Here I would like to go into the details of this solution. During black hole formation, a huge amount of particles which are to construct the black hole fall toward the center. According to general relativity, strong gravity yields a region from which even light cannot escape. This region's boundary is called an event horizon and its radius determined by mass is called a Schwarzschild radius. It may seem that the particles would go inside the event horizon after black hole formation is finished. In this solution, however, the Schwarzschild radius is reduced by the effect of evaporation while the particles fall, and surprisingly they do not enter inside the event horizon. The important point is that there is no particle inside the Schwarzschild radius. General relativity also predicted that there is something called a singularity at the center of a black hole. The singularity is a point with no size and all the mass inside a black hole is crushed and converged at this point. Previous solutions have particles inside the event horizon, and it was the reason for the singularity. Because all the mass inside a black hole gathers at the singularity, it was impossible to describe the inner content of black holes directly. Contrary to previous solutions, the new solution has no singularity and can describe the content of black holes directly.

Why this solution possibly breaks the paradox? The key is the direct description of the components of black holes. Time evolution of inner components is being available through the direct description. Detailed investigation of the time evolution may reveal how the information captured in black holes comes back after Hawking radiation is completed. And if the return of the information is shown, there is a possibility of breaking the paradox. Therefore, by using the direct description of this solution, there is a possibility of breaking the paradox.

The good thing about the new solution goes beyond just breaking the paradox. These days, telecommunications have become more efficient, and the world is flooded with information. Thus, greater information storage is becoming necessary. In the future, it is conceivable that storage would be required which is too enormous to create just by employing modern technology. Here, a black hole becomes a candidate for such enormous storage. If the information sent to the black hole comes back in a form which is understandable to humans, then there is a possibility that the information can be stored in the black hole. And the solution describes how matter condenses to form a black hole under extremely strong gravity. This process occurs universally to any matter by universal gravitation. So, there is a possibility of humans being able to generate black holes at will. Therefore, this new solution and further research in this field will illustrate a new style of information storage that uses black holes. Because black holes can absorb any amount of information, the storage using black holes is expected to have tremendous capacity. In the future, this solution can be an essential idea and may open up a new discipline which explores how to treat black holes as information storage.

references

1. Kawai, H. & Yokokura, Y. Black Hole as a Quantum Field Configuration. *Universe* **6**, 77 (2020).