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Gravitational Waves Carry Information about the Infalling Matter out of Black Holes: a Resolution of the Black Hole Information Paradox

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Abstract

The black hole information paradox is one of the most puzzling paradoxes in physics. Black holes trap everything that falls into them, while their mass may leak away through purely thermal Hawking radiation. When a black hole vanishes, all the information locked inside, if any, is just lost, thus challenging the principles of quantum mechanics. However, some information does have a way to escape from inside the black hole, that is, through gravitational waves. Here, a concise extension of this notion is introduced. When a black hole swallows something, whether it is a smaller black hole or an atom, the system emits gravitational waves carrying the information about the "food". Although most of the signals are too weak to be detected, the information encoded within them will persist in the universe. This speculation provides an explanation for a large part, if not all, of the supposed "information loss" in black holes, and thus reconciles the predictions of general relativity and quantum mechanics.

Keywords: Black holes; information paradox; Hawking radiation; information loss;

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gravitational waves; entropy

General relativity points out that black holes (BHs) are regions of space-time within which everything is trapped, while quantum mechanics predicts that the BHs would evaporate through featureless Hawking radiation [1, 2]. Then the supposed “information loss” would destroy the unitarity of quantum mechanics. Physicists have proposed a variety of hypotheses to solve this problem, while there has been no final resolution yet [3].

More than a century ago, Albert Einstein predicted the existence of gravitational waves (GWs), which were first directly detected in 2015 from a binary BH merger event [4]. The waveforms from the inspiral, merger of the two initial BHs and the ringdown of the final BH carry to us the information about the masses, spins and some orbital elements [4-8]. From a different perspective, binary BH merger equals the infall of a smaller BH into a larger one. One may wonder, if the information of the smaller BH can be transmitted out of the larger one’s boundary (event horizon) through GWs, then why that of other matter can’t?

GWs are generated by time variations of the mass quadrupole and higher-order multipole moments of the source [4, 9]. When GWs are emitted, energy is carried away and thus the system pulsations are reduced. The GWs from a massive point particle falling into a BH are being calculated with increasing accuracy [5, 10-12]. The efficiency at which the energy is emitted out with GWs depends on the symmetric mass ratio of the binary system [10]. When system asymmetry increases, higher multipoles will have increasing relative importance [4, 13, 14].

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Now we can imagine an extremely asymmetric binary system with a mass ratio of approximately 1×10^{-57}: an infalling water molecule (H_2O, hydrogen-1 and oxygen-16) and a 15 $M_\odot$ BH. In the present paper, only the GWs from the falling matter are discussed for simplicity. During the infalling process, the GWs from the H_2O molecule can be seen as single-sourced GWs containing weaker contributions from subdominant multipoles, or as the superposition of separated waves from three atoms (H, O and H). When the molecule falls with angular momentum, more detailed information would be encoded in the waveform [15, 16]. If a spherical oxygen-18 atom (^{18}O) with similar mass falls together with the H_2O molecule, the GWs from them would be substantially different, largely because their mass distributions and, when they spin, angular momentum are different. Together with more contributions from higher multipoles, the information about atomic or molecular species is encoded in the GWs.

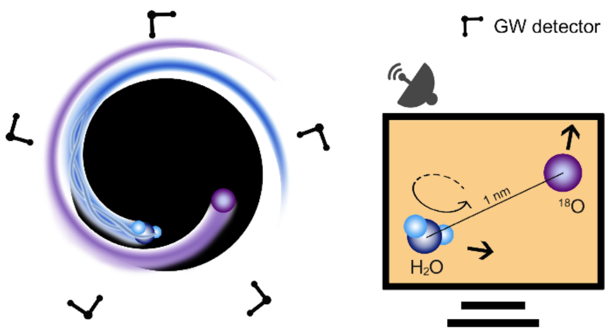

Fig. 1. An ideal scene of GW emission and detection. An asymmetric spinning H_2O molecule and a spherical ^{18}O atom fall nonradially into a BH, which radiates GWs carrying the specific information of the particles. Information about the particle type, location, velocity and angular momentum would spread and persist in the endless universe and could be theoretically

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detected by human beings. The figure is not drawn to scale.

The macroscopic quantities, which correspond to the microscopic ones, such as mass distribution and temperature, will be reflected in the GW signals. Then it is inferred that every infalling macroscopic object has its specific gravitational waveforms, no matter it is an encyclopedia, a cup of hot tea, or a spinning neutron star. When a massive star collapses to form a BH, the collapse process may be near-spherical as a whole, while the motion of the inner substances is nonspherical. Thus the corresponding information will also be sent out through GWs before the BH settles down.

Based on the above analysis, we can obtain several qualitative deductions. First, Hawking radiation could lead to the complete mass loss of a steady BH, but not of all the matter that has fallen in it, for part of the mass has already lost in the form of GW energy before the BH turns steady again. Second, when matter falls within a BH, the surface area of the wobbling horizon will transitorily decrease owing to the asymmetric-to-symmetric mass distribution and mass loss of the dynamic system. Third, the gravitational radiation results in the space-time ripples thus leading to the entropy increase of the university. Fourth, most, if not all, of the matter information is emitted out through GWs during the falling process, and will persist in the space-time till the end of the universe, rather than preserved inside the event horizon till the end of the BH.

In short, this paper gives a concise resolution of the black hole information paradox, which reconciles general relativity and quantum mechanics in the most mysterious celestial body. However, much more quantitative work is needed to complement this preliminary hypothesis.

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