Will analogue black hole systems reveal quantum gravity?

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Elementary particles are defined as the most fundamental particles that are not composed of other particles. For example, electron is one of elementary particles, but Hydrogen atom is not an elementary particle because that is composed of one electron and one proton. In some areas of physics such as elementary particle physics, researchers seek theories that describe the behaviors of elementary particles without contradiction with experimental results. Until today, the most successful theory is called Standard Model, and it deals with three fundamental forces, electromagnetic force, weak force, and strong force.

However, as you know, in our universe there exists another fundamental force called gravitational force, and Standard Model does not contain it. You may think that gravity is well described by General Relativity that are proposed by Einstein. Indeed, experimental results agree with the expectation from General Relativity, and for example, GPS uses it for its accuracy. However, researchers are not satisfied with General Relativity as a fundamental theory of gravity. It is because General Relativity is not a quantum theory. In our universe, experiments suggest that the behavior of macroscopic objects and that of microscopic ones are very different, and the theoretical framework that deals with the microscopic world is called quantum theory. Many researchers have tried to quantize General Relativity, but those attempts failed because of divergences that were not able to be handled by usual procedures.

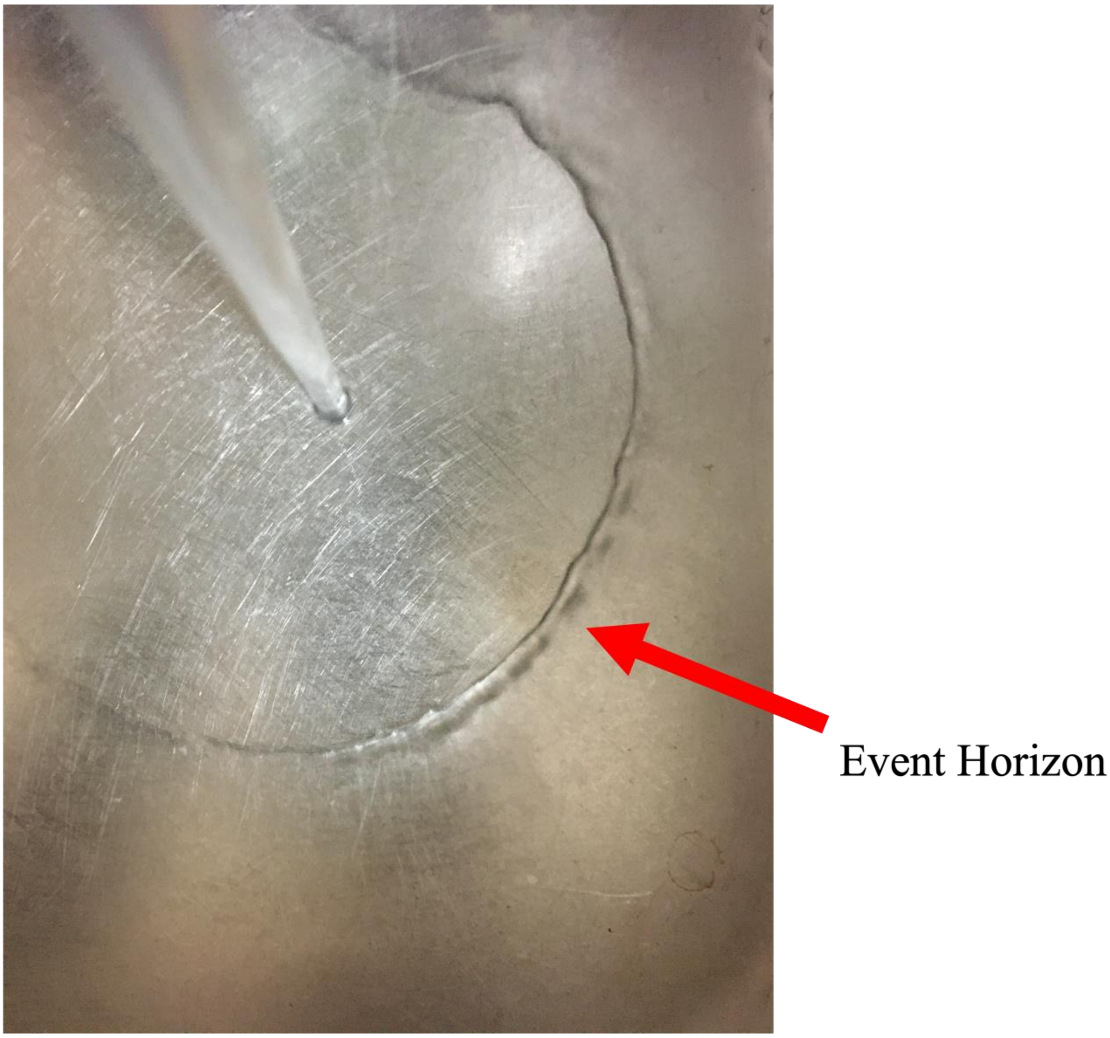
Some theories such as String theory may be possible to treat gravity quantumly, but it is difficult to check it in experiments with today’s technology. However, there are systems that may provide experimental suggestion to quantum gravity. Those are called analogue black holes. A black hole is an object that have so strong gravity that even lights cannot escape from it. The boundary that light cannot come out from once it enters is called the event horizon. Hawking suggested theoretically that there is a particle radiation from near the event horizon, by combining General Relativity and quantum theoretical insights, and it is called Hawking radiation. Since Hawking radiation is a result from General Relativity and quantum theory, it is expected that it has some information on quantum gravity. However, the strength of Hawking radiation from real black holes in the universe is thought to be weaker than that of background noises, so it is difficult to detect it from real black holes. An analog black hole is a system that has a boundary similar to the event horizon of a black hole, from which waves cannot escape.

You may have also heard of white hole. A white hole is the opposite of a black hole. A white hole has a boundary such that nothing can go further inward. It is called the event horizon of a white hole. Although white holes are allowed to exist on the basis of general relativity, it is not known whether they exist in the actual universe. However, in analogue gravity systems, one can also construct white holes. For example, the figure shows water coming from a faucet hitting a sink. You can see a ring of water around the area where the water is hitting. The water falls with great force from above, but the speed of the flow slows down as it moves away from the point of fall. Somewhere along the way, the speed of the water flow and the speed of the wave propagation become the same. This is the ring indicated by the red arrow in the picture. Inside the ring, the water flow is faster than the wave speed, and the wave cannot enter inside the ring. Therefore, this ring can be regarded as the event horizon of white hole.

Fortunately, theoretical research suggests that even in analogue black holes, there are phenomenon similar to Hawking radiation of real black holes. Therefore, it may be possible to get information on quantum gravity by detecting analogue Hawking radiation from analogue black holes. Moreover, in analogue black hole systems, one can construct a system that is composed of one black hole event horizon and one white hole event horizon, between which analogue Hawking radiations are reflected many times and strengthened like lights from lasers. This is called a black hole laser. In black hole lasers, because analogue Hawking radiations are strengthened, one can detect them more easily.

Many types of black hole lasers have been suggested, and recently Katayama has suggested a new type of it that is constructed of an electronic circuit. Previous black hole lasers are constructed of such as water flows or lights in some medium. Electronic circuits are easier to treat than previous ways. Moreover, the proposed circuit uses an element that is used in some quantum computers and its control technology is well developed thanks to research on quantum computer. Therefore, it will be possible to measure analogue Hawking radiations more accurately.

[1] Katayama, Haruna. Quantum-Circuit Black Hole Lasers. Scientific Reports 11, no. 1 (2021): 19137. https://doi.org/10.1038/s41598-021-98456-0.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