Researchers observe stationary Hawking radiation in an analog black hole

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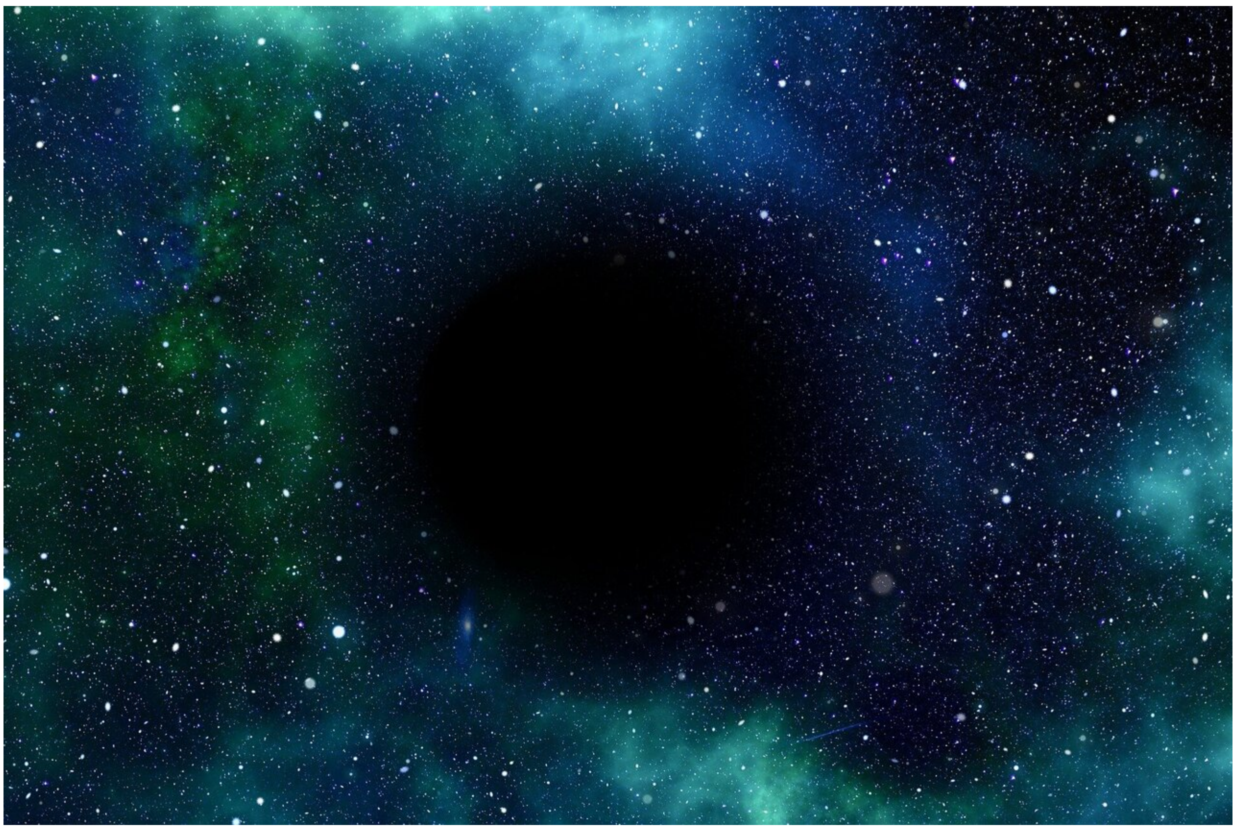

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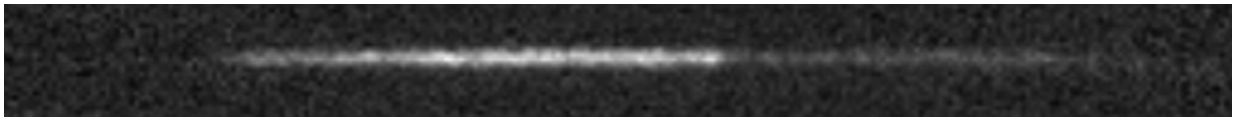
Black holes are regions in space where gravity is very strong—so strong that nothing that enters them can escape, including light. Theoretical predictions suggest that there is a radius surrounding black holes known as the event horizon. Once something passes the event horizon, it can no longer escape a black hole, as gravity becomes stronger as it approaches its center.

Theoretical physicist Stephen Hawking predicted that while nothing can escape from within them, black holes spontaneously emit a limited amount of light, which is known as Hawking radiation. According to his predictions, this radiation is spontaneous (i.e., it arises from nothing) and stationary (i.e., its intensity does not change much over time).

Researchers at Technion- Israel Institute of Technology have recently carried out a study aimed at testing Hawking's theoretical predictions. More specifically, they examined whether the equivalent of Hawking radiation in an "artificial black hole" created in a laboratory setting was stationary.

"If you go inside the event horizon, there's no way to get out, even for light," Jeff Steinhauer, one of the researchers who carried out the study, told Phys.org. "Hawking radiation starts just outside the event horizon, where light can barely escape. That is really weird because there's nothing there; it's empty space. Yet this radiation starts from nothing, comes out, and goes towards Earth."

The artificial black hole created by Steinhauer and his colleagues was approximately 0.1 millimeters long and was made of a gas composed of 8000 rubidium atoms, which is a relatively low number of atoms. Every time the researchers took a picture of it, the black hole was destroyed. To observe its evolution over time, they thus had to produce the black hole, take a picture of it and then create another one. This process was repeated many times, for months.



The analog black hole created by the researchers. Credit: Kolobov et al.

The Hawking radiation emitted by this analog black hole is made of sound waves, rather than light waves. The rubidium atoms flow faster than the speed of sound, so sound waves cannot reach the event horizon and escape from the black hole. Outside of the event horizon, however, the gas flows slowly, so sound waves can move freely.

"The rubidium is flowing fast, faster than the speed of sound, and that means that sound cannot go against the flow," Steinhauer explained. "Let's say you were trying to swim against the current. If this current is going faster than you can swim, then you can't move forward, you are pushed back because the flow is moving too fast and in the opposite direction, so you're stuck. That's what being stuck in a black hole and trying to reach the event horizon from inside would be like."

According to Hawking's predictions, the radiation emitted by black holes is spontaneous. In one of their previous studies, Steinhauer and his colleagues were able to confirm this prediction in their artificial black hole. In their new study, they set out to investigate whether the radiation emitted by their black hole is also stationary (i.e., if it remains constant over time).

"A black hole is supposed to radiate like a black body, which is essentially a warm object that emits a constant infrared radiation (i.e., black body radiation)," Steinhauer said. "Hawking suggested that black holes are just like regular stars, which radiate a certain type of radiation all the time, constantly. That's what we wanted to confirm in our study, and we did."

Hawking radiation is composed of pairs of photons (i.e., light particles): one emerging from a black hole and another falling back into it. When trying to identify the Hawking radiation emitted by the analog black hole they created, Steinhauer and his colleagues thus looked for similar pairs of sound waves, one coming out of the black hole and one moving into it. Once they identified these pairs of sound waves, the researchers tried to determine whether there were so-called correlations between them.

"We had to collect a lot of data to see these correlations," Steinhauer said. "We thus took 97,000 repetitions of the experiment; a total of 124 days of continuous measurement."

Overall, the findings appear to confirm that the radiation emitted by black holes is stationary, as predicted by Hawking. While these findings apply primarily to the analog black hole they created, theoretical studies could help to confirm if they can also be applied to real black holes.

"Our study also raises important questions, because we observed the entire lifetime of the analog black hole, which means that we also saw how the Hawking radiation started," Steinhauer said. "In future studies, one could try to compare our results with predictions of what would happen in a real black hole, to see if 'real' Hawking radiation starts from nothing and then builds up, as we observed."

At some point during the researchers' experiments, the radiation surrounding their analog black hole became very strong, as the black hole formed what is known as an 'inner horizon." In addition to the event horizon, Einstein's theory of general relativity predicts the existence of an inner horizon, a radius inside black holes that delineates a further region closer to its center.

In the region inside the inner horizon the gravitational pull is far lower, thus objects are able to move around freely and are no longer pulled towards the center of the black hole. Yet they are still unable to leave the black hole, as they cannot pass through the inner horizon in the opposite direction (i.e., heading toward the event horizon).

"Essentially, the event horizon is a black hole's outer sphere, and inside it, there's a small sphere called the inner horizon," Steinhauer said. "If you fall through the inner horizon, then you're still stuck in the black hole, but at least you don't feel the weird physics of being in a black hole. You'd be in a more 'normal' environment, as the pull of gravity would be lower, so you wouldn't feel it anymore."

Some physicists have predicted that when an analog black hole forms an inner horizon, the radiation it emits becomes stronger. Interestingly, this is exactly what happened in the analog black hole created by the researchers at Technion. This study could thus inspire other physicists to investigate the effect of the formation of an inner horizon on the intensity of a black hole's Hawking radiation.

More information: Observation of stationary spontaneous Hawking radiation and the time evolution of an analog black hole. *Nature Physics*(2021). DOI: 10.1038/s41567-020-01076-0