Gravitational wave analysis confirms theory of merging black holes

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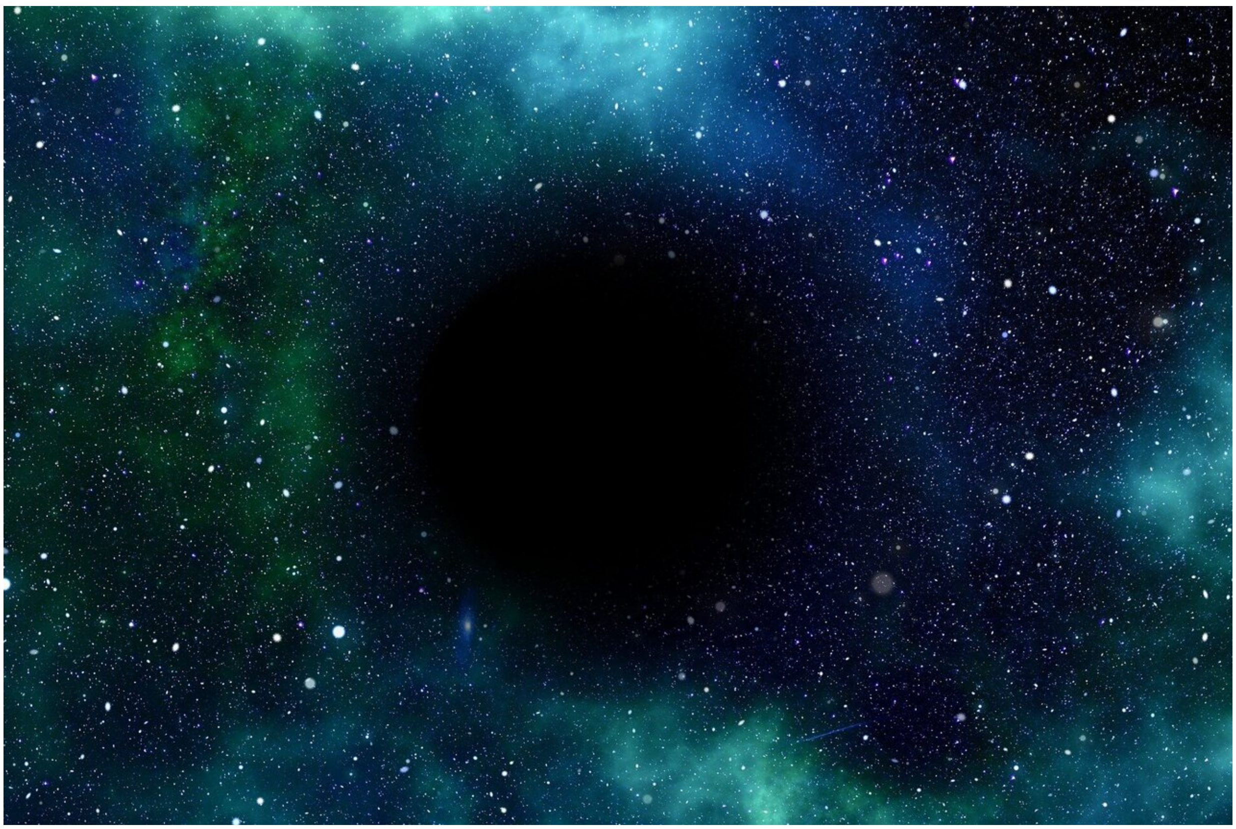

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Ten years after scientists first detected gravitational waves emerging from two colliding black holes, the LIGO-Virgo-KAGRA collaboration, a research team that includes Columbia astronomy professor

Maximiliano Isi, has recorded a signal from a nearly identical black hole collision.

Improvements in the detection technology allowed the researchers to see the black holes almost four times as clearly as they could a decade ago, and to confirm two important predictions: That merging black holes only ever grow or remain stable in size—as the late physicist Stephen Hawking predicted—and that, when disturbed, they ring like a bell, as predicted by Albert Einstein's theory of general relativity.

"This unprecedentedly clear signal of the black hole merger known as GW250114 puts to the test some of our most important conjectures about black holes and gravitational waves," Isi said.

In 1971, Stephen Hawking predicted that a black hole's event horizon—its outer boundary, beyond which nothing, including light, can escape—could never decrease in size.

In 2021, using data from the gravitational wave detector LIGO, Isi and his collaborators studied gravitational waves—high-energy ripples in the fabric of space-time—emitted by the collision of two merging black holes to observationally confirm Hawking's theory. The New York Times wrote at the time that if Isi's confirmation had arrived before Hawking passed away, it may have helped him earn the Nobel Prize.

The new results, published in *Physical Review Letters*, confirm this earlier result with much higher precision, offering further evidence that the surface area of a merged black hole is never less than the sum of the two initial black holes that created it. The new paper was able to achieve this unprecedented precision by using data from both LIGO detectors, one of which is located in Washington state and the other of which is in Louisiana.

The researchers were also able to isolate and analyze the gravitational waves emitted by the black holes after they merged. By measuring the waves' pitch and duration, they were able to learn more details about the merged black hole's structure and properties. (The process works in much the same way that analyzing the pitch of a sound emitted by a hollow instrument can tell you about the size and shape of both the instrument and the object that struck it.)

The researchers confirmed that the merged black hole was consistent with what is known as a "Kerr black hole." The mathematician Roy Kerr, working in the 1960s, solved Einstein's space-time equations, positing a detailed mathematical solution of what the exact gravity, space, and time of a black hole should be.

Physicists believe that all black holes must be described by Kerr's solution, but confirming this is famously challenging. By studying the vibrations of the final black hole in this exceptionally clear signal, Isi and the LIGO Collaboration have obtained the most direct evidence yet that black holes behave like Kerr predicted.

"Over the next decade, gravitational wave detectors like LIGO will continue to improve, giving us a sharper view of black holes and their mysteries," Isi said, "I can't wait to see what we find out."

More information: GW250114: testing Hawking's area law and the Kerr nature of black holes, *Physical Review Letters* (2025). DOI: 10.1103/kw5g-d732

Provided by Columbia University

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