Black hole scientist: 'Wherever we look, we should see donuts'

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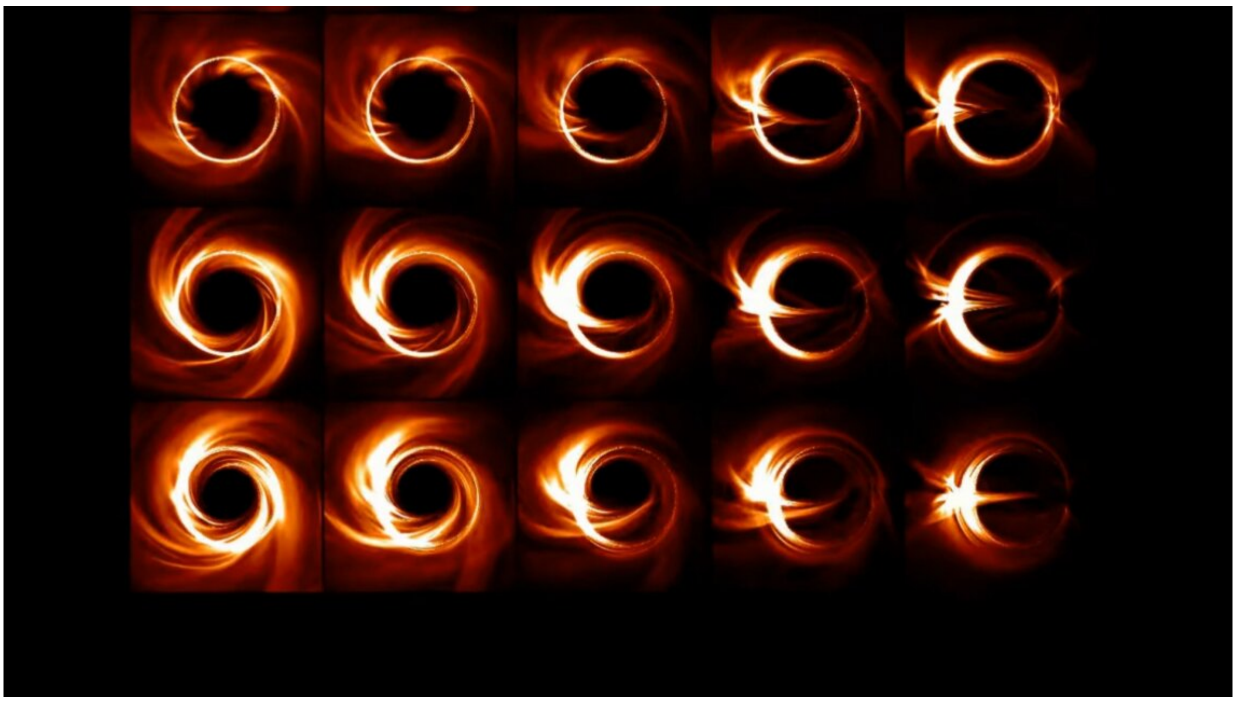

The EHT Collaboration created a flurry of images of Sagittarius A*, using ray tracing, a technique that visualizes the properties of the black hole based on data collected with the radio telescope array and predictions made by Einstein's theory of general relativity. Credit: UArizona's Chi-kwan Chan.Ben Prather/EHT Theory Working Group/Chi-Kwan Chan

Discovering something for the second time doesn't usually have scientists jump out of their seats with excitement. But that's exactly what happened in the case of Sgr A* (pronounced "sadge-ay-star"), the second black hole imaged.

In 2019, the image of M87*, a supermassive black hole in a galaxy more than 50 million light-years from Earth, graced the cover pages of virtually every news outlet across the world. It was the first time an image of a black hole had ever been taken. On Thursday, the Event Horizon Telescope Collaboration presented the second image of such an object—this time of a black hole located at the center of our own Milky Way.

To the casual observer, the two images of an orange glowing ring surrounding a black shadow look almost indistinguishable. Yet, it is precisely this fact that has astrophysicists gushing with awe.

"I wish I could say that when we obtained the first image of a black hole three years ago, it didn't get any better, but this is actually better," said EHT Science Council member Feryal Özel, a professor of astronomy and physics and associate dean for research at UArizona College of Science's Steward Observatory. "We see a bright ring surrounding complete darkness, the telltale sign of a black hole. Now, we can confirm we are looking directly at the point of no return."

A black hole love affair

Özel said she "fell in love" with Sgr A* 20 years ago. She was a graduate student then, working on her dissertation at Harvard University, when she decided to tackle a challenge that few deemed possible to even think about: What would it take, she wondered, to actually look at a black hole directly? What would we see? Would we see anything?

Her research culminated in a seminal paper, which she published in 2000 with Dimitrios Psaltis, a UArizona professor of astronomy and physics and principal investigator of the international Black Hole PIRE Project. In that paper and a follow-up paper published in 2001, she identified M87*, the first black hole ever to be imaged, and Sgr A* as the two ideal black holes that presented even a remote chance of having their pictures taken. This contributed to the groundwork for an Earth-sized observatory that is now the Event Horizon Telescope.

Because M87* is 1,500 times more massive but 2,000 times farther away than Sgr A*, the two appear roughly equal in size in the sky. But despite the fact that they look almost identical, they are entirely different beasts.

M87* boasts a mass of 6 billion suns and is of gargantuan size. Our entire solar system would fit inside its event horizon, also known as a black hole's point of no return. Sgr A*, located a mere 25,000 light-years from Earth, is puny by comparison. At "only" 4 million solar masses, it is small enough to fit into the orbit of Mercury, the planet closest to the sun. If the two black holes were lined up for a photo op, M87* would fill the frame, while Sgr A* would disappear entirely. And while M87* voraciously devours surrounding matter, perhaps entire stars, and launches a jet of energetic particles that torches across its galaxy, Sgr A*'s appetite is minimal in comparison; if it were a person, it would consume the equivalent of a grain of rice every million years, according to the researchers.

One of the most fundamental predictions of Einstein's theory of gravity, Psaltis said, is that the image of a black hole scales only with its mass. A black hole 1,000 times smaller in mass than another will have a very similar image that will just be 1,000 times smaller. The same is not true for other objects, Psaltis explained.

"In general, small things typically look very different from big things, and that's no coincidence," he said. "There is a good reason an ant and an elephant look very different, as one has a lot more mass to support than the other."

In other words, nature's laws of scale dictate that when two entities are of vastly different sizes, they typically look different from each other. Black holes, in contrast, scale without changing their appearance. If they were elephants, they would all look like elephants, whether they were as big as a typical elephant or as tiny as an ant.

Their stark simplicity is what makes the two black hole images so important, Psaltis explained, because they confirm what until now had only been predicted by theory: They appear to be the only objects in existence that only answer to one law of nature—gravity.

"The fact that the light appears like a ring, with the black shadow inside, tells you it's purely gravity," Psaltis said. "It's all predicted by Einstein's theory of general relativity, the only theory in the cosmos that does not care about scale."

If scientists could take a picture of a truly small black hole of about 10 solar masses—which is not possible, because even the Earth-sized EHT does not have the necessary resolution power—and compare it to M87*, which has 6 billion times the mass of the sun, the two would look very similar, according to Psaltis.

"Wherever we look, we should see donuts, and they all should look more or less the same," he said, "and the reason this is important—besides the fact that it confirms our prediction—is that nobody likes it. In physics, we tend to dislike a world where things don't have an anchor point, a defined scale."

The 'Goldilocks black holes'

Black holes are such alien objects that even Albert Einstein struggled to reconcile their existence. Their gravitational pull is so strong not even light can escape, making them impossible to see by definition. The only reason astronomers were able to take these pictures is because they used radio telescopes that detect electromagnetic waves emitted by gas swirling around the black hole.

"If you were in space looking at the black hole, you would see absolutely nothing," Özel said. "The glow is in wavelengths the eye can't see."

That is why M87* and Sgr A* were identified as the only feasible targets for the Event Horizon Telescope in the publication Özel and Psaltis authored more than 20 years ago.

"You could say both are 'Goldilocks of black holes,'" Özel said. "Their environments are just right, and that's why we can see them."

To astrophysicists like Özel and Psaltis, black holes are natural laboratories that allow them to test general relativity and may even bring them closer to a theory unifying gravity with quantum mechanics, which until now has remained elusive.

"Getting to the image wasn't an easy journey," said Özel, who has been a member of the EHT Science Council since its inception and who has led the modeling and analysis group. It took a globe-spanning collaboration, several years, petabytes of data and more involved algorithms than had been dedicated to most scientific endeavors before, to analyze and confirm the final image of Sgr A*.

Moving forward, the EHT Collaboration is particularly interested in how black holes change over time, Özel said.

"If you looked at the source one day versus the next, or one year versus the following year, how would that change, and how much light would it emit in different wavelengths?" she said. "What could we predict about that? And how could we use our observations to understand that black hole's environment?

"One of the key points of this collaborative effort," Özel said, "is to test general relativity and find out where its limit is, if there is one."

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