

S P A C E

The Milky Way's Monster, Unveiled

Astronomers have come closer than ever before to seeing our galaxy's mysterious supermassive black hole

By Lee Billings on October 31, 2018



The GRAVITY instrument on the European Southern Observatory's Very Large Telescope has discovered new details about the Milky Way's central supermassive black hole. This illustration visualizes some of them, chiefly newfound hot clumps of gas that orbit the black hole at 30 percent the speed of light. Credit: ESO/Gravity Consortium/L. Calçada

Just in time for Halloween, astronomers have delivered the best-yet view of a real-life cosmic monster—Sagittarius A*, a supermassive black hole lurking at the center of the Milky Way. Or, rather, a view of hot clumps of gas that orbit it, teetering on the edge of oblivion. The results reveal new, previously unknown properties of our galaxy's largest black hole and point the way toward a deeper understanding of gravity.

Black holes, like all truly terrifying monsters, can scarcely be comprehended, let alone seen. Even Einstein doubted they existed, despite his theory of general relativity predicting that they must. They are knots of gravitation bound so tightly that within them spacetime dissolves; spectral shadows so voracious they devour light itself. Yet they can be glimpsed indirectly, like apparitions at the corner of your eye. Most spectacularly, when they eat stars or other black holes they can give off gravitational waves, ripples in the fabric of reality that scientists first directly detected in 2016. Scientists can also measure a black hole's mass through swarms of stars orbiting around it—showing, for example, Sagittarius A* has somehow swallowed the equivalent of four million suns. (Those in other galaxies can be far larger, tipping the scales at billions of solar masses.) And, ironically, although black holes do not shine, the gas and dust that piles up in spinning accretion disks around their maws can be heated to billions of degrees, becoming hundreds of times more luminous than a star and occasionally ejecting even brighter sprays of radiation. When they come from supermassive black holes, those outbursts can shape and perhaps even sterilize a galactic host—and such black holes seem to squat at the center of every large galaxy. For more than 40 years astronomers have warily studied such circumstantial evidence like bones and ashes scattered at the threshold of a dragon's lair.

Now, an international team of scientists has studied the Milky Way's monster using an instrument called GRAVITY to combine the infrared light from four eight-meter telescopes at the European Southern Observatory's Very Large Telescope in Chile. Combining light from multiple telescopes is a technique called interferometry, and can dramatically boost the sensitivity and precision of astronomical observations. The results appeared October 31 in *Astronomy & Astrophysics*. "This is a major breakthrough," says Reinhard Genzel, an astrophysicist at Max Planck Institute for Extraterrestrial Physics and leader of the group. "We have observed the galactic center by using four telescopes as a gigantic single telescope with an effective 130-

meter diameter to make interferometric images about a thousand times fainter than what has been done before.” This is not the first breakthrough from GRAVITY: In May of this year the team successfully measured the relativistic distortion of light from a star, S2, during the its closest approach to Sagittarius A* in its 16-year-orbit around the monstrous black hole.

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This latest discovery unfolded during and shortly after those same observations of S2, when GRAVITY team members Oliver Pfuhl and Jason Dexter, both study co-authors at Max Planck, noticed three flares, or “hot spots,” that emanated from Sagittarius A*’s accretion disk between mid-May and late July. To appreciate the GRAVITY team’s feat, imagine looking up at the moon from the Earth and discerning on the lunar surface a quarter coin (Sagittarius A*—or at least its shadow) sitting on a beach ball decorated with Christmas lights (Sagittarius A*’s accretion disk and accompanying flares).

These hot spots are thought to be “magnetic thunderstorms” that occur when intense magnetic fields form filaments that snap apart and reconnect, releasing copious energy to heat nearby gas within a black hole’s accretion disk. Each hot spot is akin to a short-lived, 10-million-kilometer-wide lightbulb—after perhaps an hour, it cools and shears apart in the whirling, turbulent maelstrom. That would make studying them exceedingly challenging—particularly if their emissions were being warped and occluded by various extreme relativistic effects predicted to arise in the vicinity of a black hole. Those same effects, in turn, could be studied to put Einstein’s theory of gravity to increasingly stringent tests, potentially leading to new physics.

Such outbursts have been detected before, but for the first time GRAVITY allowed the astronomers to precisely measure the flares’ positions and motions before they dissipated, showing each one moved at 30 percent light-speed in a roughly 45-minute

orbit around some unseen central object weighing four million suns. GRAVITY's data also measured each flare's polarization, which shifted in accordance with each spot's motion through the disk's powerful magnetic fields, further reinforcing the orbital interpretation. "When we saw the first one, we had to ask ourselves, 'Is this real or not?' but then we found two more," Pfuhl says. "They all showed the same rotation, the same orientation and the same scale, which reassured us."

When first presented with the data, Genzel initially reacted with shock. "I couldn't believe my eyes," he says. "No one believed we could do this—we didn't really think we could do it, either—but there it was, this beautiful orbital motion." Besides being fortunate enough to catch multiple flares in the act, the GRAVITY team also seems to have been blessed with a quirk of geometry—their best estimates of the hot spots' orbits suggest Sagittarius A*'s accretion disk is coincidentally oriented almost face-on rather than edge-on to Earth, allowing astronomers to study its swirling hot spots much like meteorologists use satellite views to track thunderstorms in a hurricane. "This is like winning the lottery, because the a priori probability that you would see something like this face-on is very low," Genzel says. "It almost seems that somebody has arranged this for us; I guess the galactic center is a place for lucky people."

One person relatively unsurprised by the result is Avi Loeb, an astrophysicist at Harvard University who was not directly involved with GRAVITY's studies. More than a decade ago, while working with then-postdoc Avery Broderick (now at the Perimeter Institute for Theoretical Physics in Canada), Loeb developed models of hot spots around Sagittarius A* and suggested methods for observing their orbital motion. "Seeing is believing," he says. "This is fully consistent with what we expected.... Most everyone I talked to about this back then regarded our hot spot model as naive, but amazingly enough nature has proved kinder than many of my colleagues."

The most important overlap between such predictions and GRAVITY's observations is that Sagittarius A*'s hot spots seem to be perched just above a long-predicted point of no return—an “innermost stable orbit” for material at the accretion disk's inner cusp. Beyond this boundary any object will precipitously plunge down through the black hole's event horizon—the proverbial end of the line past which even light cannot escape—effectively passing out of the observable universe and into the unknown. Because the exact location of any black hole's innermost orbit depends on its most basic properties, GRAVITY's measurement is telling us something profound and new about Sagittarius A*. “By themselves, black holes are simple objects—mass, spin and [electric] charge is all you get,” says Andrea Ghez, an astronomer at the University of California, Los Angeles, who leads a team that has used the twin Keck telescopes in Hawaii to compete with Genzel's group for more than a decade. “The innermost stable orbit is tied to the black hole's mass and spin—and we already know [Sagittarius A*'s] mass—so if you believe the hot spot is emitting from there, you could pin this black hole's spin and measure this fundamental property. That fundamental property is tied to how these things grow, which tells you how they form and evolve over time. Black holes are basic constituents of our universe, so when you study them, you are asking about the building blocks of the cosmos.”

Unfortunately, for now further empirical validation of GRAVITY's result may be limited to that instrument alone. In 2012 NASA pulled the plug on an initiative to give the Keck telescopes an interferometric capability similar to that used by GRAVITY on the Very Large Telescope; without it, independent observations—and confirmation—from Ghez's team will likely have to wait until sometime in the 2020s when two as-yet-unbuilt 30-meter-class U.S. observatories, the Giant Magellan Telescope and the Thirty Meter Telescope, are slated to debut.

In the meantime, GRAVITY will observe the galactic center for more flares beginning next spring, and additional corroboration may come from the realm of radio astronomy. The Event Horizon Telescope, which seeks to image the enigmatic shadow of Sagittarius A* by interferometrically linking radio observatories from around the world, should soon publish early results from its first full-scale observing run performed last year. That work probes much closer to the black hole, where gravity traps light in a revolving ring just outside the event horizon. But according to the