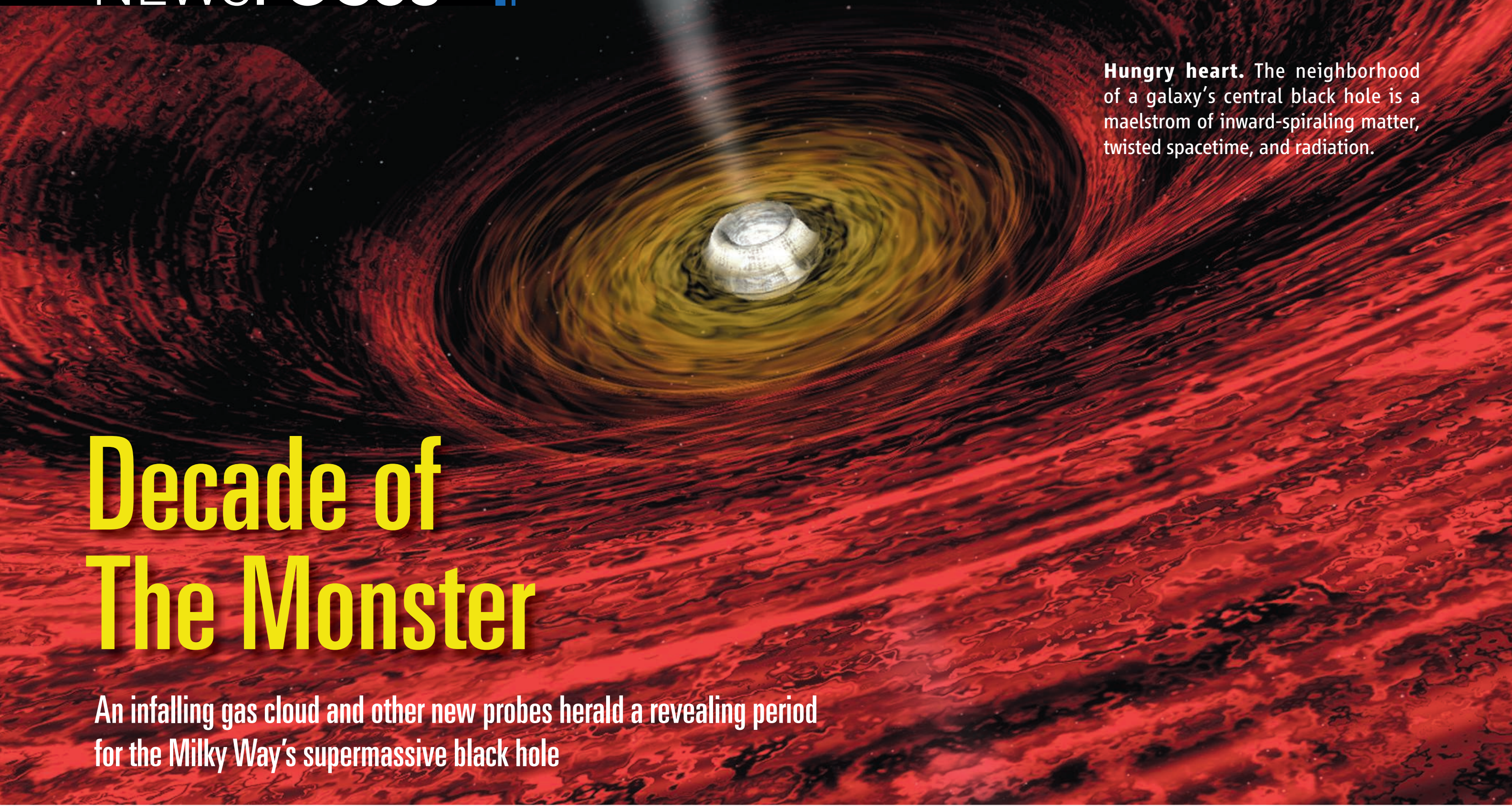


Hungry heart. The neighborhood of a galaxy's central black hole is a maelstrom of inward-spiraling matter, twisted spacetime, and radiation.

Decade of The Monster

An infalling gas cloud and other new probes herald a revealing period for the Milky Way's supermassive black hole

IT COULD BE THE MOST PHOTOGRAPHED snack in the history of the galaxy. Either late this year or early next, the giant black hole at the center of the Milky Way will devour a blob of gas hurtling toward it at more than 2000 kilometers per second.

A vast array of telescopes in space and on the ground is poised to record the feast, which could rouse the Milky Way's gravitational monster from an extended period of dormancy—and reveal why the massive body appears to have been on a near-starvation diet for centuries. The new details may also provide insight about the puzzling dining habits of similar supermassive black holes believed to lie at the core of nearly every heavyweight galaxy.

But before astronomers can attempt to answer these questions, they must nail down several basic properties about the parcel of gas known as G2: its origin, mass, and orbit. Scientists are not even sure when the gas will pass closest to the Milky Way's 4-million-solar-mass central black hole, known as Sagittarius A* (pronounced "A-star").

G2's encounter with the black hole is just the beginning of what is shaping up to be a decadelong effort to unlock the secrets held by Sagittarius A*. Because its enormous gravitational pull traps light, astronomers can never see the heart of the galaxy directly. But they can glean information about its spin, mass, and size by studying the faint flickers of radiation emanating from surrounding gas and dust as they heat up and spiral into the invisible beast.

Now, researchers are assembling a sensitive array of radio telescopes to perform a new trick: recording the black hole's shadow. And a star set to make its closest approach to Sagittarius A* in 2018 promises to probe in unprecedented detail the predicted curvature of spacetime just outside the body, testing Einstein's general theory of relativity in a gravitational regime more extreme than has ever been possible.

Online
sciencemag.org
Podcast interview with author Ron Cowen (http://scim.ag/pod_6127).

Researchers initially predicted that G2 would make its fatal rendezvous in June, coming closer to Sagittarius A* than a distance seven times that between the planet Neptune and our sun. Additional data shifted that prediction to September. Now, a new analysis by Andrea Ghez of the University of California, Los Angeles (UCLA), and her colleagues—one of two teams that have monitored the motion of stars at the galactic center for some 20 years—suggests that closest approach might not happen until March 2014. Ghez presented the findings on 14 March at a seminar celebrating the 20th anniversary of the Keck Observatory in Hawaii.

"The real question is, what is G2 and how much mass it is really going to dump onto the black hole?" Ghez says.

That uncertainty may seem surprising given that G2 has been closely monitored with two of the largest telescopes on Earth since its discovery in 2011 by Stefan Gillessen of the Max Planck Institute for Extraterrestrial Physics in Garching, Germany, and his colleagues. G2, however, is a faint, infrared-emitting source located in the most congested region of the galaxy, the packed metropolis of stars and clumps of gas orbiting Sagittarius A*. As a result, Ghez says, "these are very, very difficult observations to make."

At first, Gillessen and his co-discoverers thought that G2 was a lone gas cloud with the mass of three Earths. In the 11 September 2012 issue of *Nature Communications*, Abraham Loeb and Ruth Murray-Clay of Harvard University suggested that G2 could be a disk of gas orbiting a star, similar to the circumstellar gas disks that give birth to planets. Material boiled off the disk by ultraviolet radiation from other stars and then elongated by the black hole's tidal gravitational forces could produce a gas cloud, including a tail like the one astronomers have observed.

Whether lone cloud or stellar shell, G2 ought to brighten as it heads closer to the galactic center, where intense ultraviolet radiation from closely packed stars should ionize its hydrogen gas and set it aglow in

CREDIT: NASA

the near infrared. However, archival images recorded between 2008 and 2012 showed that G2 maintained an essentially uniform brightness, Gillessen and his colleagues reported on 1 February in *The Astrophysical Journal*.

The discrepancy prompted Nick Scoville of the California Institute of Technology in Pasadena and Andreas Burkert of the Max Planck Institute for Extraterrestrial Physics and the University Observatory Munich to propose a new model. In a paper posted on the arXiv preprint server on 26 February (http://arxiv.org/abs/1302.6591), they suggest the gas is a steady wind blown out by a young star and that radiation from the star itself, not from its neighbors, ionizes the gas. Those properties explain G2's unchanging brightness as it heads ever closer to Sagittarius A*, the team says.

If G2 is held together by the gravity of a star, less material will detach at closest approach and fall onto Sagittarius A*. That could mean fewer fireworks during this go-round, although the star's gravity might keep the cloud intact for several more passages around the black hole, giving it additional opportunities to feed and revive the quiescent beast.

Exactly what astronomers will see also depends on just when the cloud arrives at Sagittarius A*. In some ways, later is better. Telescopes on Earth can't see the Milky Way's center between October and February, when our planet arcs through the part of its orbit that places Sagittarius A* on the far side of the sun. Orbiting telescopes, including NASA's Chandra X-ray Observatory, have a narrower blackout window: between November and January. G2 watchers will be disappointed if anything exciting happens during those times.

Tracking the fireworks

Regardless of when G2 makes its closest approach, the light show is likely to unfold in three stages, Loeb says.

The first fireworks could erupt just as the gas makes its closest approach to the black hole, when the tidal gravitational forces from Sagittarius A* shred the gas into spaghetti-like filaments or droplets. X-ray emission will flare up if G2 continues to move at supersonic speed, producing a bow shock wave as it plows into the denser gas near the black hole, and should peak at closest approach, Loeb says.

The next phase could start a month or two later, when the shredded gas dives inward and strikes a proposed structure called the accretion disk—the swirling doughnut of matter believed to surround and feed the black hole. If the cool gas from G2 slams onto the warm disk, it could generate both x-rays and radio waves. Just how much radiation will be produced depends on the density, temperature, and extent of the disk—all unknown quantities at the moment, Loeb notes. "If we detect this brightening, we could constrain the unknown properties of the [accretion] disk for the first time," he says.

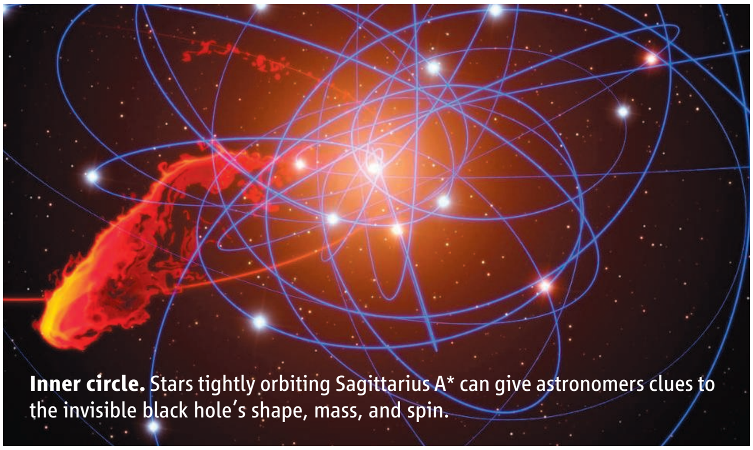
Timing how long the gas takes to travel to the disk may also shed light on conditions near the galactic center, says Avery Broderick of the Perimeter Institute for Theoretical Physics in Waterloo, Canada. By studying how G2 gives up its angular momentum to other gas parcels there, Broderick says, astrophysicists may be able to infer for the first time the viscosity of a gas or plasma far off in space—critical information for understanding the mechanism by which gas falls into and fuels a black hole.

Once the gas gets dumped onto the accretion disk, it could take several months to several decades for the remains of G2 to complete its death march, spiraling downward through the disk and disappearing forever inside the black hole's event horizon. A silent scream of radiation at all wavelengths, including x-rays, infrared light, and radio waves, may accompany its demise, although Loeb says that it may be hard to distinguish from emissions due to other processes that feed the black hole.

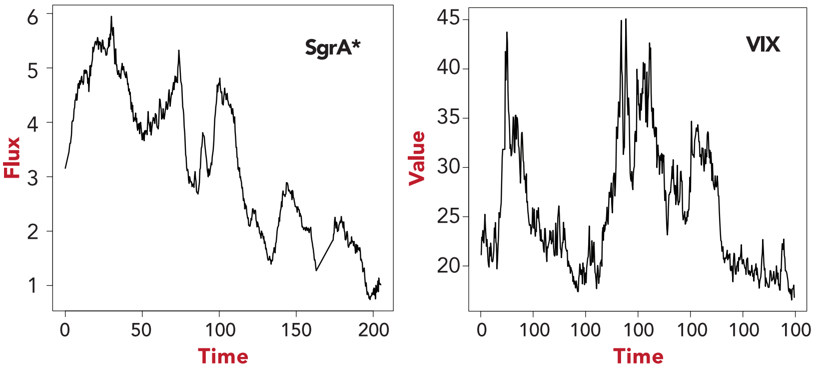
Several astronomers are worried that even the short-term effects of G2 may be tricky to tease out from the normal variability of Sagittarius A*. Though unusually dim, the black hole's accretion disk can sometimes generate a 10-fold increase in infrared light on a timescale of minutes. That flash of light is similar to the predictions of what G2's infall might produce. How can astronomers disentangle the impact of the gas cloud from the black hole's intrinsic fluctuations?

Leo Meyer, a member of Ghez's team, began pondering that question last spring while working with UCLA finance professor Francis Longstaff on methods to predict the behavior of Sagittarius A* using the same kind of time-series analyses used to forecast stock market volatility (see figure, left). "The big question now," Meyer says, "is whether the passage of G2 will lead to something like a stock market crash": a major change in the behavior of Sagittarius A* from an unusually dim bulb to a much more voracious, glowing black hole.

Until recently, astronomers were afraid that the black hole's natural mood swings might make such a transition hard to spot. Research had indicated that Sagittarius A* flipped between two distinct states: a quiescent low state and a high state marked by sharp outbursts of fluctuation. Such bipolar behavior could make it difficult to discern any brightening due to the impact of G2. But after a closer look at the

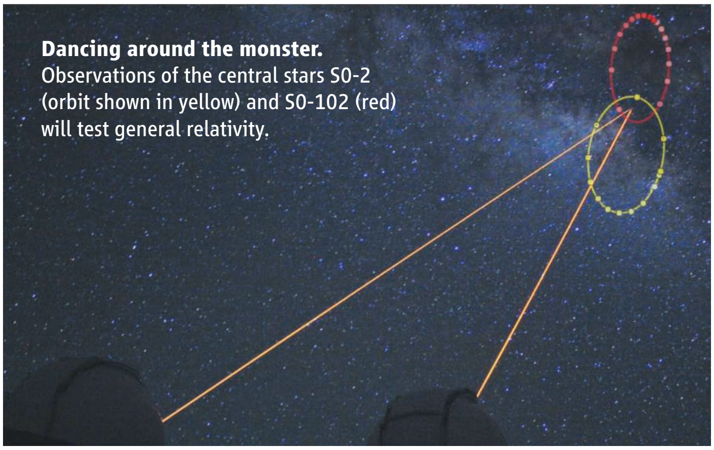


Inner circle. Stars tightly orbiting Sagittarius A* can give astronomers clues to the invisible black hole's shape, mass, and spin.



Bullish. UCLA researchers are modeling fluctuations in the infrared brightness of Sagittarius A* (*left*) using methods developed for studying the Standard & Poor's 500 stock market index (*right*).

CREDITS (TOP TO BOTTOM): ESO/MPE/MARC SCHARTMANN; LEO MEYER/FRANCIS LONGSTAFF/UCLA (DATA SETS FROM W. M. KECK TELESCOPES) data, Meyer and Longstaff concluded that the "low state" readings were instrumental noise from the Keck telescope and that Sagittarius A* was simpler—although more variable—than astronomers had believed. Now, Meyer says he's optimistic that after only a few nights of timely observations at Keck, he and Longstaff will know whether and by how much G2 has boosted the output of Sagittarius A* and shifted the black hole into a new, more active regime.

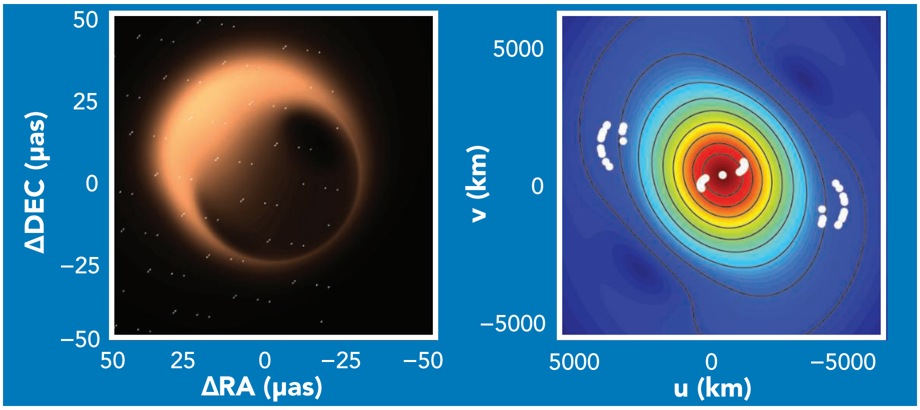


Dancing around the monster. Observations of the central stars S0-2 (orbit shown in yellow) and S0-102 (red) will test general relativity.

New horizons

Even after G2 passes by and hoopla about this gas cloud dies down, aficionados of the galactic center will have a lot to look forward during the rest of the decade.

Two years from now, if all goes according to plan, a network of four radio telescopes known as the Event Horizon Telescope, which has already revealed new insights about the properties of Sagittarius A* and the giant black hole at the center of the nearby galaxy M87, will greatly expand its own horizons (*Science*, 27 January 2012, p. 391). Twenty or so radio dishes from the Atacama Large Millimeter/submillimeter Array (ALMA), the radio array now nearing completion in Chile's Atacama Desert, are scheduled to join the network in 2015 along with the 10-meter South Pole Telescope. Working in tandem, ALMA and the other radio dishes will double the resolution of the Event Horizon Telescope, creating a virtual Earth-sized radio telescope powerful enough to make landmark observations of Sagittarius A* and its accretion disk, says the telescope's coordinator, Sheperd Doeleman of the Massachusetts Institute of Technology Haystack Observatory in Westford, Massachusetts, and the Harvard-Smithsonian Center for Astrophysics in Cambridge, Massachusetts.



Shadow play. Simulation (*left*) shows the arc of light and the shadow formed by hot material near Sagittarius A*. At right, measurements by the Event Horizon Telescope (white spots) are overlaid on simulated data.

The boost in resolution will enable the telescope to make actual images of the region surrounding Sagittarius A* and hunt for a predicted feature known as the black hole's shadow. Although nothing, not even light, can escape a black hole's grasp, matter that gets pulled into the monster gets crushed by the extreme gravity and heats up to billions of degrees, illuminating the region around the black hole. Most of the radiation falls into Sagittarius A*; the light that just misses getting trapped is bent by the monster's gravity into a thin ring or halo that frames the black hole's shadow (see figure, below). Deviations from the halo geometry could indicate that Einstein's theory doesn't accurately describe the way gravity curves or distorts spacetime near a black hole and that the theory might need to be revised.

Objects swooping past Sagittarius A* may provide other important clues. In 2018, a bright star known as S0-2, discovered nearly 2 decades ago, will put Einstein's theory through its paces when it comes within four times the Neptune-sun distance of Sagittarius A*—about half as far as G2's closest approach (see image, top). Two fingerprints of the star—the light it emits and the motion of the star through space—will test relativity in different ways, Ghez notes.

Spectra of the star will reveal the gravitational redshift of the starlight—the amount by which the mass of Sagittarius A* has curved spacetime at the galactic center. The observed redshift can be directly compared with the amount that general relativity predicts.

By precisely monitoring the 3D motion of the star, which circles the black hole about every 16 years, Ghez's team hopes to determine whether the star's closest approach to Sagittarius A* occurs at the same place in its orbit or whether it slowly moves or precesses about the supermassive black hole under the sway of the invisible body's extreme gravity.

The precession is a much smaller fingerprint than gravitational redshift and is much more difficult to measure because of all the other objects—countless stars and clumps of gas—tugging on S0-2 at the Milky Way's crowded center. "If we had a pure system of a black hole and one star, we wouldn't be worried, but the center of the galaxy is simply a mess," Ghez says.

Fortunately, her team recently discovered another central star with a shorter orbit of 11.5 years, Ghez and her colleagues reported in the 5 October 2012 issue of *Science*. Although the star is only one-sixteenth as bright as S0-2, its presence will help distinguish gravitational perturbations on the brighter star's orbit due to Sagittarius A* from those exerted by other stars and gas at the galactic core.

In 1919, astronomers measuring how stars appeared to change position as the sun's gravity bent the path of their light made Einstein a celebrity and transported his theory to the forefront of public imagination. Nearly a century later, a star 26,000 light-years from Earth promises to test Einstein on a far grander scale and determine if the weirdest object in the universe—a supermassive black hole—can alter the fabric of spacetime.

–RON COWEN

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