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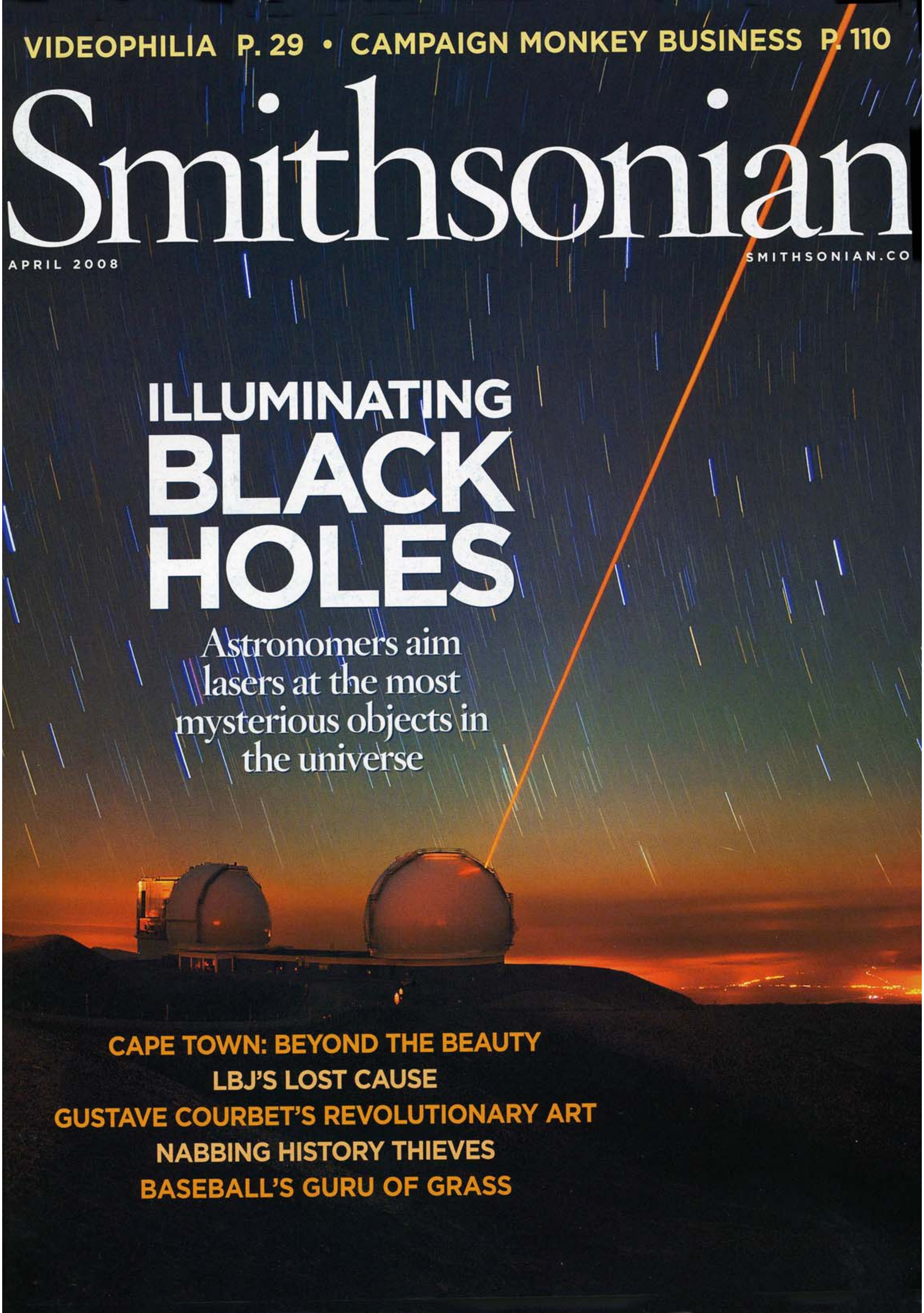


ILLUMINATING BLACK HOLES

Astronomers aim lasers at the most mysterious objects in the universe

CAPE TOWN: BEYOND THE BEAUTY

LBJ'S LOST CAUSE

GUSTAVE COURBET'S REVOLUTIONARY ART

NABBING HISTORY THIEVES

BASEBALL'S GURU OF GRASS

HOMING IN ON BLACK HOLES

To gain insight into the most mysterious objects in the universe, astronomers shine a light at the chaotic core of our own Milky Way

BY ROBERT IRION

FROM THE SUMMIT of Mauna Kea, nearly 14,000 feet above the Pacific Ocean, the Milky Way tilts luminously across the night sky, an edge-on view of our galaxy. Parts of the great disk are obscured by dust, and beyond one of those dusty blots, near the teapot of the constellation Sagittarius, lies the center of the Milky Way. Hidden there is a deeply mysterious structure around which more than 200 billion stars revolve.

Behind me atop the craggy rocks of this dormant volcano on the island of Hawaii are the twin domes of the W. M. Keck Observatory. Each dome houses a telescope with a giant mirror that is almost 33 feet wide and, like a fly's eye, is made of interlocking segments. The mirrors are among the world's largest for gathering starlight, and one of the telescopes has been equipped with a dazzling new tool that greatly increases its power. Fewer than 100 people have seen this technology in action. I gaze at the nearest of the Milky Way's graceful spiral arms as I wait for technicians to flip the switch.

Then, suddenly and with the faint click of a shutter sliding open, a golden-orange laser beam shoots into the sky from the open dome. The ray of light, 18 inches wide, appears to end inside one of the blackest spots in the Milky Way. It actually ends 55 miles above the surface of the earth. The signal it makes there allows the telescope to compensate for the blur of Earth's atmosphere. Instead of jittery pictures smeared by the constantly shifting rivers of air over our heads, the telescope produces images as clear as any obtained by satellites in space. Keck was one of the first observatories to be outfitted with a laser guide; now half a dozen others are beginning to use them. The technology provides astronomers with a sharp view of the galaxy's core, where stars are packed as tightly as a summer swarm of gnats and swirl around the darkest place of all: a giant black hole.

Without question, the Milky Way's black hole is the strangest thing in our galaxy—a three-dimensional cavity in space just ten times the physical size of our sun but with four million times the mass, a virtual bottomless pit from which nothing can escape. Every major galaxy, it turns out, has a black hole at its core. Now, for the first time, scientists have the chance to study the havoc these mind-boggling entities wreak. For the next decade, Keck astronomers will track thousands of stars caught in the gravity of the Milky Way's black hole. They will try to figure out how stars are born close to the black hole and how it distorts the fabric of space itself. "I find it amazing that we can see stars whipping around our galaxy's black hole," says Taft Armandroff, director of the Keck Observatory. "If you had told me as a graduate student that I'd see that during my career, I'd have said it was science fiction."

To be sure, the evidence for black holes is entirely indirect; astronomers have never actually seen one. Albert Einstein's general theory of relativity predicted that the gravity of an extremely dense body could bend a ray of light so severely that it could not escape. Something the mass of our sun, for instance, could trap light if it shrank into a ball just one and a half miles across. For Earth to become a black hole, its entire mass would have to fit into a sphere no bigger than a pea.

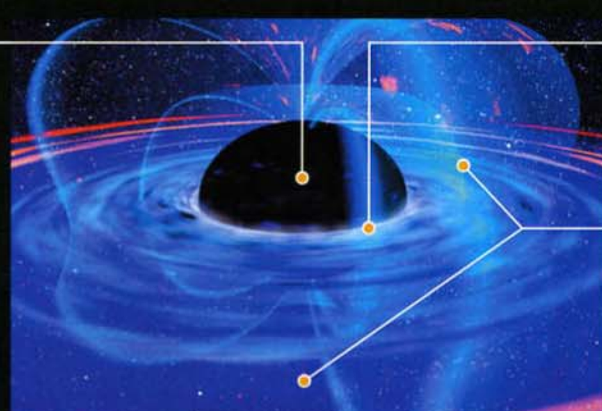
In 1939, J. Robert Oppenheimer and another physicist calculated that such drastic compression could happen to the biggest stars after they ran out of hydrogen and other fuel. Once the stars sputtered out, the scientists posited, the remaining gas would collapse under its own gravity into an infinitely dense point. Telescope observations backed up the theory in the 1960s and 1970s. Astronomers discovered quasars—extremely bright beacons billions of light-years away. A few researchers suggested the only possible power source for something so luminous would be a concentration of millions of suns in a small volume—pulled together by what scientists later dubbed a supermassive black hole. Astronomers then found stars that seemed to whip around invisible companions in our Milky Way, and they concluded that only the pull of gravity from small black holes could keep the stars in such tight orbits. Containing several times the mass of our sun, these are called stellar-mass black holes.

The Hubble Space Telescope added to the evidence for black holes in the 1990s by measuring how quickly the innermost parts of other galaxies rotate—up to 1.1 million miles per hour in big galaxies. The startling speeds pointed to cores containing up to a billion times the mass of the sun. The discovery that supermassive black holes are at the core of most, if not all, galaxies was one of Hubble's greatest achievements. "At the beginning of the Hubble survey, I would have said black holes are rare, maybe one galaxy in 10 or 100, and that something went wrong in the history of that galaxy," says Hubble scientist Douglas Richstone of the University of Michigan. "Now we've shown they are stan-

ANATOMY OF A BLACK HOLE

Though no one has ever seen a black hole, the effects of its gravitational pull are visible across the universe.

SINGULARITY
The center of a black hole, called a singularity, is infinitely dense. Nothing, not even light, can escape its gravity—making it impossible to observe directly. What happens to all the space dust, planets and even stars that are pulled into the black hole's singularity? "The ultimate fate is not known," says astrophysicist Avi Loeb.



EVENT HORIZON
The edge of a black hole, or its event horizon, is where the gravity becomes strong enough to hold light.

ACCRETION DISK
The gas and dust and other matter that are drawn toward a black hole form an accretion disk. The matter heats up as it spirals toward the event horizon, radiating X-rays that reveal the black hole's location and mass.

NASA / SCIENCE PHOTO LIBRARY / PHOTO RESEARCHERS; PP. 44-45 LAURIE HATCH

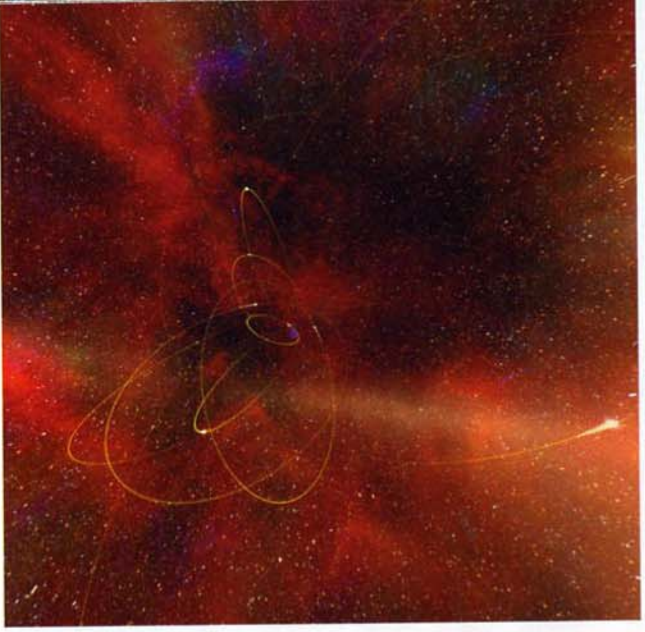
OUR GALAXY'S black hole emits X-rays (made visible here in an image from the Chandra satellite telescope) as matter swirls toward it.

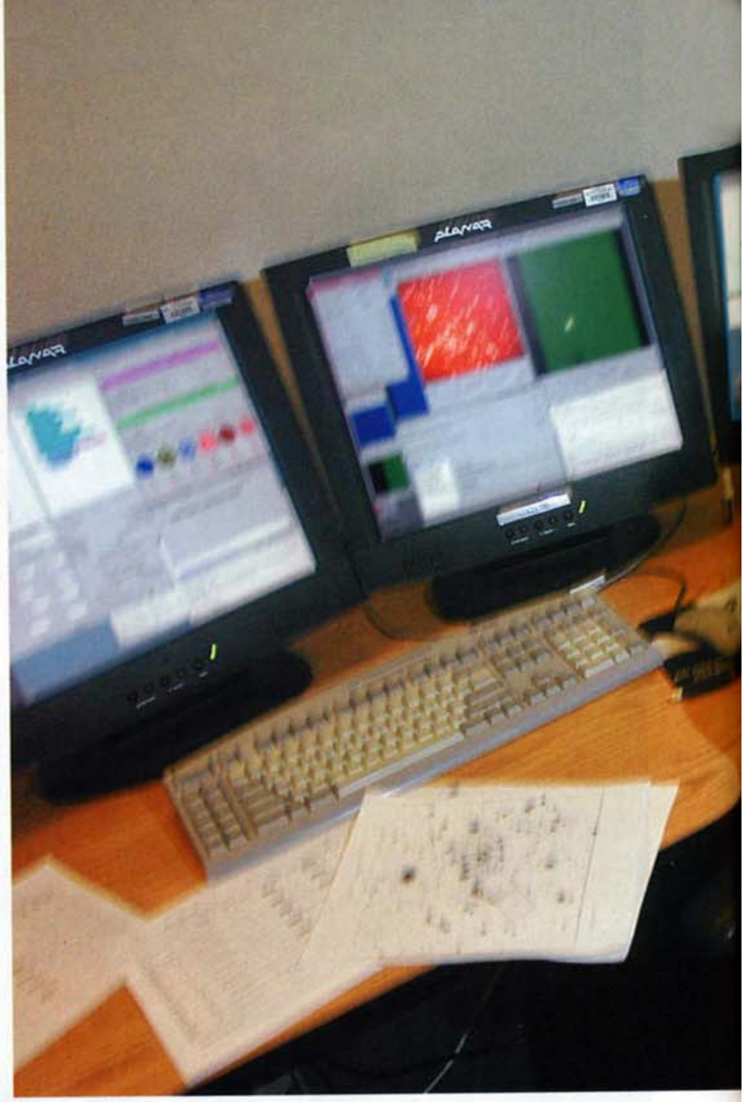
dard equipment. It's the most remarkable thing."

Even from Hubble, though, the Milky Way's core remained elusive. If our galaxy harbored a supermassive black hole, it was quiet, lacking the belches of energy seen from others. Hubble, scheduled to be serviced later this year, can track groups of stars near the centers of distant galaxies, but because of its narrow angle of view and our galaxy's thick dust clouds, it can't take the same pictures in our galaxy. Another approach would be to track individual stars in the black hole's vicinity using infrared light, which travels through dust, but the stars were too faint and too crowded for most ground-based telescopes to resolve. Still, some astronomers in the 1990s ventured that observations of the Milky Way's core might be possible, proving beyond doubt that a black hole exists there. A number of tantalizing questions could then be addressed: How do stars live and die in that wild setting? What does a black hole consume? And can we witness, at the heart of the Milky Way, the warped space and time predicted by Einstein nearly a century ago?

THE KECK CONTROL ROOM is 20 miles from the telescope, in the ranching town of Waimea. To the researchers there, the spectacular laser is visible only as a wan beam in a live video feed on a computer monitor. The astronomers check their notebooks and watch screens full of telescope data, weather readings and the latest picture of the stars they're targeting. They use a video link to talk to the telescope operator, who will spend all night at the summit. Things are going so smoothly that there isn't much to do. The telescope will stay locked on the same spot in the sky

ROBERT IRION *directs the University of California at Santa Cruz science-writing program and wrote about planets in October 2006.*





> "It was clear there were a few stars that were just hauling," Ghez recalls. "Clearly, they were extremely close to the center."

for four hours; the laser's working fine, and a camera attached to the telescope takes one 15-minute exposure after another in an automated sequence. "This is just about the dullest kind of observing there is," University of California at Los Angeles astronomer Mark Morris says apologetically.

Even so, there's tension in the room. This team of astronomers, led by Andrea Ghez of UCLA, is in a heated competition with astronomers at the Max Planck Institute for Extraterrestrial Physics in Garching, Germany. For more than a decade, Garching astrophysicist Reinhard Genzel and his colleagues have studied the black hole at the center of the Milky Way using the New Technology Telescope and the Very Large Telescope array in Chile. Ghez, 42, pushes her students to get the most out of each observation session at Keck. Four years ago she was elected to the National Academy of Sciences—quite an honor for someone still in her 30s. "It's easy to be at the forefront of astronomy if you have access to the best telescopes in the world," she says.

Several years ago the American and the German teams independently deduced that only a giant black hole could explain the behaviors of stars at the Milky Way's core. Stars circling a hefty mass—whether a black hole or some large star—travel through space much faster than those circling a smaller mass. In visual terms, the larger mass creates a deeper funnel in the fabric of space around which the stars revolve; like leaves circling a whirlpool, the deeper the whirl- pool, the faster the leaves spin. Other astronomers had seen fast-moving stars and clouds of gas near the center of the Milky Way, so both Ghez and Genzel suspected a dense cluster of matter was hidden from view.

ANDREA GHEZ (at the Keck control center) tracks the orbits (top left) of stars near the Milky Way's central black hole. "It's hard to believe black holes exist," she says. "It's such an exotic state of the universe."

By painstakingly compiling infrared photographs taken months and years apart, the two teams tracked the innermost stars, those within one light-month of the galaxy's center. Combined, the images are like time-lapse movies of the stars' motions. "Early on, it was clear there were a few stars that were just hauling," Ghez recalls. "Clearly, they were extremely close to the center." Something was trapping the stars in a deep whirlpool. A black hole made the most sense.

The clincher came in 2002, when both teams sharpened their images using adaptive optics, technology that compensates for the atmosphere's blur. The scientists followed stars that orbit perilously close to the galaxy's center and found that the fastest star's top speed was 3 percent of the speed of light—about 20 million miles per hour. That's a startling speed for a globe of gas far bigger than our sun, and it convinced even the skeptics that a supermassive black hole was responsible.

LEFT: BOARD OF TRUSTEES OF THE UNIVERSITY OF ILLINOIS / DENVER MUSEUM OF NATURE & SCIENCE

PP. 48-49 LUCY PEMONI / GETTY IMAGES

THE BLUR OF EARTH'S atmosphere has plagued telescope users since Galileo's first studies of Jupiter and Saturn nearly 400 years ago. Looking at a star through air is like looking at a penny on the bottom of a swimming pool. Air currents make the starlight jitter back and forth, just as a penny's image seems to dart around the pool's bottom.

In the 1990s, engineers learned to erase the distortions with a technology called adaptive optics. They had computers analyze the jittering pattern of incoming starlight on a millisecond by millisecond basis, and used those calculations to drive a set of pistons on the back of a thin and pliable mirror. The pistons flexed the mirror hundreds of times each second, adjusting the surface to counteract the distortions and form a sharp central point instead of a fuzzy blob.

The technology had one severe limitation. The computers needed a strong, clear guiding light to track, as a kind of reference point. The system worked only if the telescope was aimed close to a bright star or planet, limiting astronomers to just 1 percent of the sky.

By creating an artificial guide star in any part of the sky, the Keck Observatory's laser removes that barrier. The laser beam is tuned to a frequency that lights up sodium atoms, which are left by disintegrating meteorites in a thin layer of the atmosphere. Keck's computers analyze the distortion in the column of air between the telescope mirror and the laser-created star.

Inside the telescope's 101-foot-tall dome, the laser system sits within a bus-size enclosure. The laser starts out with a jolting 50,000 watts of power, amplifying the light beam within a dye solution made from 190-proof ethanol. But by the time the light is adjusted to its correct color and its energy is channeled along a single path, its power dwindles to about 15 watts—still bright enough that the Federal Aviation Administration requires the observatory to shut down the laser if an airplane flies near its path. From several hundred feet away the laser looks like a dim amber pencil beam. A bit farther and it isn't visible at all. As far as the rest of the island is concerned, there is no laser show at Mauna Kea.

IDENTIFYING A BLACK HOLE is one thing; describing it is another. "It's difficult to paint a picture that relates to the world as we understand it, without using mathematical complexity," Ghez says one afternoon at the Keck control center. The next day, she asks the older of her two sons, 6-year-old Evan, if he knows what a black hole is. His quick response: "I don't know, Mommy. Shouldn't *you*?"

Mark Morris thinks that "sinkhole" makes an apt metaphor for a black hole, particularly "a three-dimensional sinkhole. If you were in space near the black hole," he says, "you would see things disappear into it from all directions."

Both Ghez and Morris like to visualize what it would be like to be near the black hole looking outward. "This is the thriving city center of the galaxy, compared to the suburbs where we are," says Ghez. "Stars are moving at tremendous speeds. You'd see things change on a time scale of tens of minutes." Morris picks up on this theme. "If you look at the night sky from a beautiful mountaintop, it takes your breath away how many stars there are," he says. "Now, multiply that by a million. That's what the sky at the galactic center would look like. It would be like a sky full of Jupiters, and a few stars as bright as the full moon."

In this magnificent setting, the laws of physics are wonderfully twisted. Ghez and Morris hope to gather the first evidence that stars do indeed travel along the weird orbital paths predicted by Einstein's relativity theory. If so, each star would trace something like a Spirograph pattern over time, gradually altering the point of its closest approach to the black hole. Ghez thinks she and her colleagues are about eight years away from spotting that shift.

With each new finding, the Milky Way's core becomes more perplexing and fascinating. Both Ghez's and Genzel's teams were startled to discover many massive young stars in the black hole's neighborhood. There are scores of them, all just five to ten million years old—infants, in cosmic terms—and they are roughly ten times as massive as our sun. No one is entirely sure how they got so close to the black hole. Elsewhere in the galaxy, gestating stars require a cold, calm womb within a large cloud of dust and gas. The galactic core is anything but calm: intense radiation floods the area, and the black hole's gravity should shred gaseous nurseries before anything incubates there. As Reinhard Genzel put it at a conference a few years ago, those young stars "have no damn right to be there." It's possible some of them were born farther out and migrated inward, but most theorists think they're too young for that scenario. Morris thinks the intense gravity compresses spiraling gas into a disk around the black hole, creating the new suns in a type of star birth not seen in any other galactic environment.

These young stars will self-destruct a few million years from now. And when they do, the most massive ones will leave behind small black holes. Morris theorizes that hundreds of thousands of these stellar-mass black holes, accumulated from past generations of stars, swarm around the central supermassive black hole. The stellar-mass black holes are only about 20 miles wide, so collisions between them would be rare. Instead, Morris says, "You'll have black holes swinging past each other in the night, and stars moving through this destruction derby. A near miss between one of the black holes and a star could scatter the star into the supermassive black hole or out of the galactic center entirely." Theorists think the supermassive black hole may gobble a star once every tens of thousands of years—an event that would ignite the center of the galaxy with radiation. "It would be a spectacular event," Morris says.

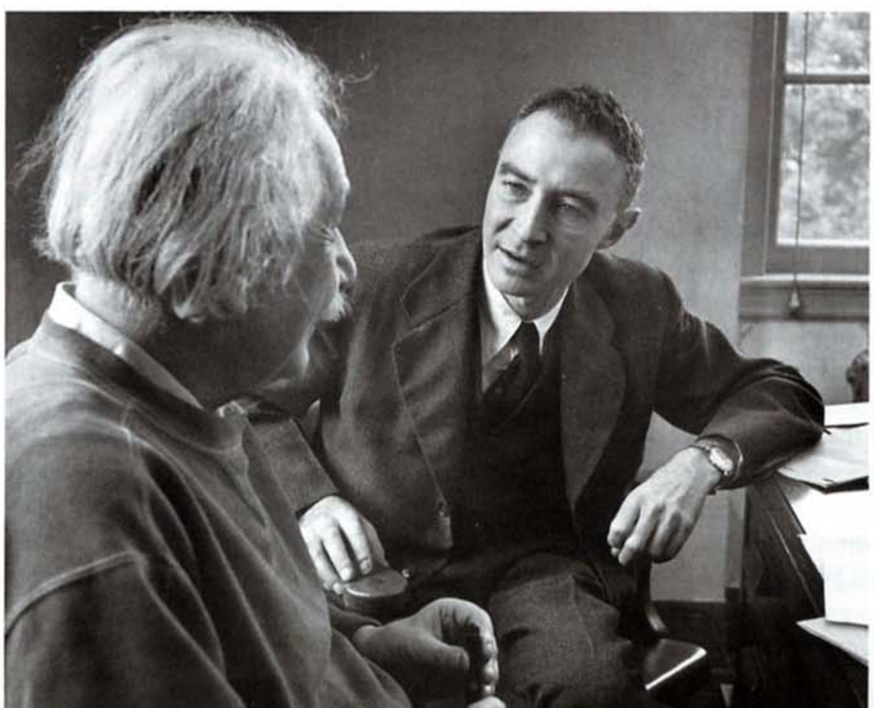
ASTRONOMERS SEE SIGNS of these meals by examining the Milky Way's interior with X-ray and radio telescopes, which detect the shock waves of past explosions. Giant black holes in other galaxies are too far away for astronomers to study in such depth, says Avi Loeb, director of the Institute for Theory and Computation at the Harvard-Smithsonian Center for Astrophysics in Cambridge, Massachusetts. That's why he hangs on every announcement from the Ghez and Genzel teams. "The advances made by the observers in such a short time have been truly remarkable," he says. "We theorists are all cheerleaders for them."

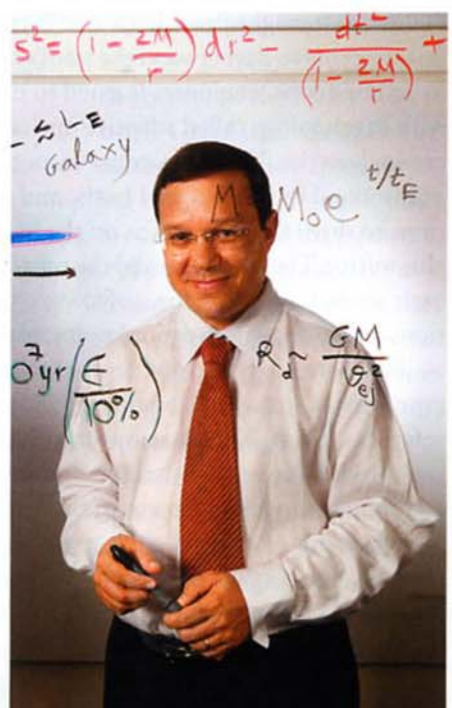
Loeb and others are painting a new picture of how the universe and its 100 billion galaxies have evolved since the big bang 13.7 billion years ago. They believe that all galaxies started with as-yet-unexplained "seed" black holes—tens to thousands of times the mass of our sun—that grew exponentially during violent feeding cycles when galaxies collided, which they did more frequently when the universe was younger and galaxies were closer together. In a collision, some stars catapult into deep space and other stars and gases plummet into the combined black hole at the galaxies' center. As the black hole grows, Loeb says, it turns into a raging quasar with gas heated to billions of degrees. The quasar then blasts the rest of the gas out of the galaxy entirely. After the gas is depleted, Loeb says, "the supermassive black hole sits at the center of the galaxy, dormant and starved."

It appears that our Milky Way, with its modest-sized black hole, has absorbed only a few smaller galaxies and has never fueled a quasar. However, a fearsome collision looms. The closest large galaxy, called Andromeda, is on a collision course with the Milky Way. The two will start to merge about two billion years from now, gradually forming a massive galaxy that Loeb and his Harvard-Smithsonian colleague T. J. Cox call "Milkomeda." The galaxies' supermassive central black holes will collide, devouring torrents of gas and igniting a new quasar for a short time in this sedate part of the universe. "We are late bloomers in that regard," Loeb notes. "It happened to most other galaxies early on."

Our galaxy's fearsome future aside, Loeb hopes that soon—perhaps within a decade—we'll have the first image of

PHYSICISTS PREDICTED black holes before they were discovered (below: Albert Einstein and J. Robert Oppenheimer). Today theorists (below right: Avi Loeb) chart our galaxy's destiny.





ALFRED EISENSTAEDT / TIME LIFE PICTURES / GETTY IMAGES; JARED LEEDS

OUR GALAXY'S fate looks something like this (above: galaxies NGC 2207 and IC 2163, which began to merge 40 million years ago) because of its attraction to Andromeda.

VASSAR COLLEGE / NASA

the Milky Way's supermassive black hole, thanks to an emerging global network of "millimeter wave" telescopes. Named for the wavelength of infrared light they detect, the instruments technically won't see the black hole itself. Rather, they'll act in concert to photograph the shadow the black hole casts on a curtain of hot gas behind it. If all goes well, the image should show a black shadow, possibly with a distinctive shape. Theorists expect the black hole to be spinning. If so, according to the counterintuitive dragging of space predicted by Einstein's general theory of relativity, our view of the shadow will be distorted into something like a lopsided and squashed teardrop. "It would be the most remarkable picture we could have," says Loeb.

ON THE FOURTH AND final night of Ghez's planned observations, wind and fog at the Mauna Kea summit keep the telescope domes closed. So the astronomers take another look at their data from the previous nights. Passing the time, graduate student Tuan Do downloads a song to his computer and reads the lyrics to his amused colleagues. It's called "Supermassive Black Hole," by the British rock band Muse, who sing "o, o, you set my soul alight."

Images from the first two nights ranged from good to excellent, says Ghez; the third night was "respectable." She's says she's content: her students have enough to keep them busy, and Do identified a few more big young stars to add to the team's analysis. "I feel incredibly privileged to work at something I have this much fun at," she says. "It's hard to believe that black holes really exist, because it's such an exotic state of the universe. We've been able to demonstrate it, and I find that really profound."

She spends most of her time overseeing the command center at Waimea, but she has been to the top of Mauna Kea to see the laser in action. As we talk about the mesmerizing sight, it is clear that Ghez appreciates an irony: astronomers love the dark and often complain about any source of light that might interfere with their observations. Yet here they are, casting a beacon of light into the heavens to help illuminate the blackest thing humanity can ever hope to see. ○

Watch stars orbit our black hole at Smithsonian.com/blackhole