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Black Holes

Albert Einstein thought that a black hole—a collapsed star so dense that even light could not escape its thrall—was too preposterous a notion to be real. Einstein was wrong.

by Michael Finkel • March 21, 2014 • 10 min read • [original](#)

Art by Mark A. Garlick

Our star, the sun, will die a quiet death. The sun's of only average mass, starwise, and after burning through the last of its hydrogen fuel in about five billion years, its outer layers will drift away, and the core will eventually compact to become what's known as a white dwarf, an Earth-size ember of the cosmos.

For a star ten times as big as the sun, death is far more dramatic. The outer layers are blasted into space in a supernova explosion that, for a couple of weeks, is one

of the brightest objects in the universe. The core, meanwhile, is squeezed by gravity into a neutron star, a spinning ball bearing a dozen miles in diameter. A sugar-cube-size fragment of a neutron star would weigh a billion tons on Earth; a neutron star's gravitational pull is so severe that if you were to drop a marshmallow on it, the impact would generate as much energy as an atom bomb.

But this is nothing compared with the death throes of a star some 20 times the mass of the sun. Detonate a Hiroshima-like bomb every millisecond for the entire life of the universe, and you would still fall short of the energy released in the final moments of a giant-star collapse. The star's core plunges inward. Temperatures reach 100 billion degrees. The crushing force of gravity is unstoppable. Hunks of iron bigger than Mount Everest are compacted almost instantly into grains of sand. Atoms are shattered into electrons, protons, neutrons. Those minute pieces are pulped into quarks and leptons and gluons. And so on, tinier and tinier, denser and denser, until...

Until no one knows. When trying to explain such a momentous phenomenon, the two major theories governing the workings of the universe—general relativity and quantum mechanics—both go haywire, like dials on an airplane wildly rotating during a tailspin.

The star has become a black hole.

What makes a black hole the darkest chasm in the universe is the velocity needed to escape its gravitational pull. To overcome Earth's clutches, you must accelerate to about seven miles a second. This is swift—a half dozen times faster than a bullet—but human-built rockets have been achieving escape velocity since 1959. The universal speed limit is 186,282 miles a second, the speed of light. But even that isn't enough to defeat the pull of a black hole.

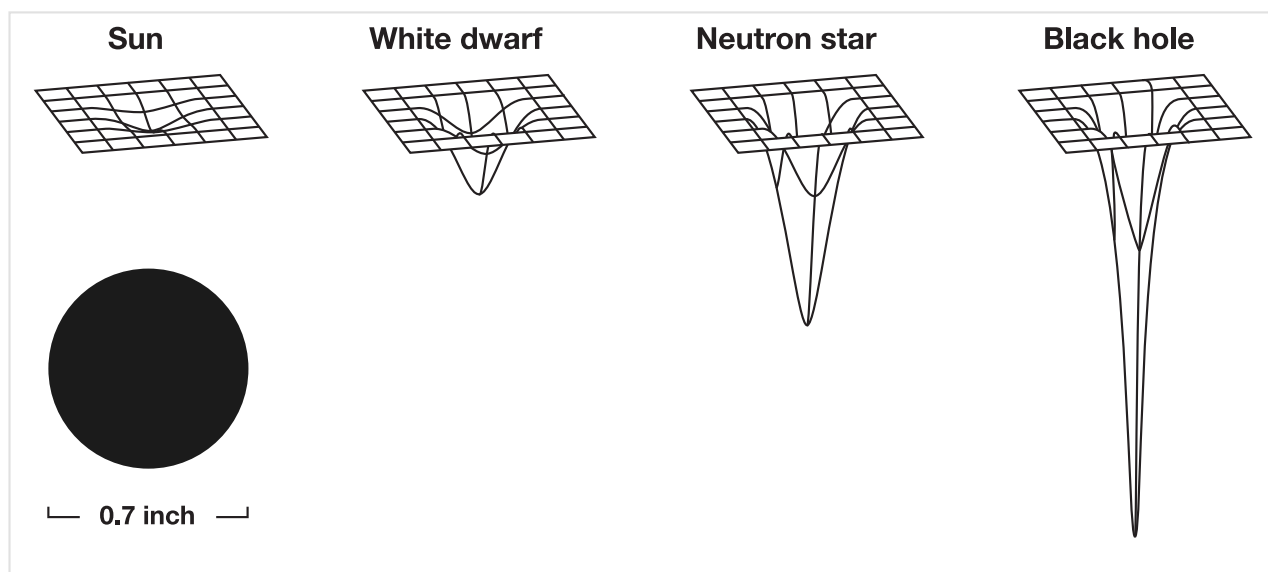
Therefore whatever's inside a black hole, even a beam of light, cannot get out. And due to some very odd effects of extreme gravity, it's impossible to peer in. A black hole is a place exiled from the rest of the universe. The dividing line between the inside and

outside of a black hole is called the event horizon. Anything crossing the horizon—a star, a planet, a person—is lost forever.

THE POWER OF GRAVITY

Einstein showed a century ago that the mass of stars, planets, and all other matter exerts a gravitational force, bending space like a rubber sheet. The greater the mass of an object, the more powerful the effect. The immense mass of a black hole generates a gravitational “sink” from which not even light can escape.

Approximate size of Earth if it collapsed to a black hole; it would weigh the same as Earth today.



Jason Treat and Alexander Stegmaier, NGM Staff

Sources: Avery Broderick, Perimeter Institute for Theoretical Physics, University of Waterloo, Canada; UCLA Galactic Center Group

Albert Einstein, one of the most imaginative thinkers in the history of physics, never believed black holes were real. His formulas allowed for their existence, but nature, he felt, would not permit such objects. Most unnatural to him was the idea that gravity could overwhelm the supposedly mightier forces—electromagnetic, nuclear—and essentially cause the core of an enormous star to vanish from the universe, a cosmic-scale David Copperfield act.

Einstein was hardly alone. In the first half of the 20th century most physicists dismissed the idea that an object could become dense enough to asphyxiate light. To lend it any more credence than one would give the tooth fairy was to risk career suicide.

Still, scientists had wondered about the possibility as far back as the 18th century. English philosopher John Michell mentioned the idea in a report to the Royal Society of London in 1783. French mathematician

Pierre-Simon Laplace predicted their existence in a book published in 1796. No one called these superdense curiosities black holes—they were referred to as frozen stars, dark stars, collapsed stars, or Schwarzschild singularities, after the German astronomer who solved many theoretical equations about them. The name “black hole” was first used in 1967, during a talk by American physicist John Wheeler at Columbia University in New York City.

Around the same time there was a radical shift in black hole thinking, due primarily to the invention of new ways of peering into space. Since the dawn of humanity, we'd been restricted to the visible spectrum of light. But in the 1960s x-ray and radio wave telescopes began to be widely used. These allowed astronomers to collect light in wavelengths that cut through the interstellar dust and let us see, as in a hospital x-ray, the interior bones of galaxies.

What scientists found, startlingly, was that at the center of most galaxies—and there are more than 100 billion galaxies in the universe—is a teeming bulge of stars and gas and dust. At the very hub of this chaotic

bulge, in virtually every galaxy looked at, including our own Milky Way, is an object so heavy and so compact, with such ferocious gravitational pull, that no matter how you measure it, there is only one possible explanation: It's a black hole.

These holes are immense. The one at the center of the Milky Way is 4.3 million times as heavy as the sun. A neighboring galaxy, Andromeda, houses one with as much mass as 100 million suns. Other galaxies are thought to contain billion-sun black holes, and some even ten-billion-sun monsters. The holes didn't begin life this large. They gained weight, as we all do, with each meal. Black hole experts also believe that small holes roam the galactic suburbs, common as backyard deer.

In the course of a single generation of physicists, black holes morphed from near jokes—the *reductio ad absurdum* of mathematical tinkering—to widely accepted facts. Black holes, it turns out, are utterly common. There are likely trillions of them in the universe.

No one has ever seen a black hole, and no one ever will. There isn't anything to see. It's just a blank spot in space—a whole lot of nothing, as physicists like to say. The presence of a hole is deduced by the effect it has on its surroundings. It's like looking out a window and seeing every treetop bending in one direction. You'd almost certainly be right in assuming that a strong yet invisible wind was blowing.

When you ask the experts how certain we are that black holes are real, the steady answer is 99.9 percent; if there aren't black holes in the center of most galaxies, there must be something even crazier. But all doubt may be removed in a matter of months.

Astronomers are planning to spy on one while it eats.

The black hole at the center of the Milky Way, 26,000 light-years away, is named Sagittarius A*. Sgr A*—that's the standard abbreviation; its surname is pronounced A-star—is currently a tranquil black hole, a picky eater. Other galaxies contain star-shredding, planet-devouring Godzillas called quasars.

But Sgr A* is preparing to dine. It's pulling a gas cloud named G2 toward it at about 1,800 miles a second. Within as little as a year G2 will approach the hole's event horizon. At this point radio telescopes around the world will focus on Sgr A*, and it's hoped that by synchronizing them to form a planet-size observatory called the Event Horizon Telescope, we will produce an image of a black hole in action. It's not the hole itself we will see but likely what's known as the accretion disk, a ring of debris outlining the edge of the hole, the equivalent of crumbs on a tablecloth after a hearty meal. This should be enough to dispel most doubts that black holes exist.

More than merely exist. They may help determine the fabric of the universe. Matter hurtling toward a black hole produces a lot of frictional heat. Slide down a fire pole; your hands get hot. Same with stuff sliding toward a black hole. Black holes also spin—they're basically deep whirlpools in space—and the combination of friction and spin results in a significant amount of the matter falling toward a black hole,

sometimes more than 90 percent, *not* passing through the event horizon but rather being flung off, like sparks from a sharpening wheel.

This heated matter is channeled into jet streams that hurtle through space, away from the hole at phenomenal velocities, usually just a tick below the speed of light. The jets can extend for millions of light-years, drilling straight through a galaxy. Black holes, in other words, churn up old stars in the galactic center and pipe scalding gases generated in this process to the galaxy's outer parts. The gas cools, coalesces, and eventually forms new stars, refreshing the galaxy like a fountain of youth.

It's important to clarify a couple of things about black holes. First is the idea, popularized in science fiction, that black holes are trying to suck us all in. A black hole has no more vacuuming power than a regular star; it just possesses extraordinary grip for its size. If our sun suddenly were to become a black hole—not going to happen, but let's pretend—it would retain the same mass, yet its diameter would shrink from 865,000 miles to less than four miles. Earth would be

dark and cold, but our orbit around the sun wouldn't change. This black hole sun would exert the same gravitational tug on our planet as the full-size one. Likewise, if the Earth were to become a black hole, it would retain its current weight of more than six sextillion tons (that's a six followed by 21 zeros) but be shrunk in size to smaller than an eyeball. The moon, though, wouldn't move.

So black holes don't suck. Easy. The next topic, time, is way more of a mind bender. Time and black holes have a very strange relationship. Actually time itself—forgetting about black holes for a moment—is an unusual concept. You probably know the phrase “time is relative.” What this means is that time doesn't move at the same speed for everybody. Time, as Einstein discovered, is affected by gravity. If you place extremely accurate clocks on every floor of a skyscraper, they will all tick at different rates. The clocks on the lower floors—closer to the center of the Earth, where gravity is stronger—will tick a little slower than the ones on the top floors. You never notice this because the variances are fantastically small, a spare billionth of a second here and there. Clocks on

global positioning satellites have to be set to tick slightly slower than those on Earth's surface. If they didn't, GPS wouldn't be accurate.

Black holes, with their incredible gravitational pull, are basically time machines. Get on a rocket, travel to Sgr A*. Ease extremely close to the event horizon, but don't cross it. For every minute you spend there, a thousand years will pass on Earth. It's hard to believe, but that's what happens. Gravity trumps time.

And if you do cross the event horizon, then what? A person watching from the outside will not see you fall in. You will appear frozen at the hole's edge. Frozen for an infinite amount of time.

Though technically not infinite. Nothing lasts forever, not even black holes. Stephen Hawking, the British physicist, proved that black holes leak—the seepage is called Hawking radiation—and given enough time, will evaporate entirely. But we're talking trillions upon trillions upon many more trillions of years. Long enough so that in the far future, black holes may be the only objects remaining in our universe.

While an outside observer would never see you slip into a black hole, what would happen to you? Sgr A* is so large that its event horizon is about eight million miles from its center. There's some debate in the physics community about the moment you cross over. It's possible there exists what's called a fire wall, and that upon reaching the event horizon, you promptly burn up.

General relativity theory predicts, however, that something else happens when you cross the event horizon: Nothing. You just pass through, unaware that you're now lost to the rest of the universe. You're fine. Your watch on your wrist ticks along as usual. It's often said that black holes are infinitely deep, but this is not true. There is a bottom. You won't live to see it. Gravity, as you fall, will grow stronger. The pull on your feet, if you're falling feet first, will be so much greater than the tug on your head that you'll be stretched until you're ripped apart. Physicists call this being "spaghettified."

But pieces of you will reach the bottom. At the center of a black hole is a conundrum called a singularity. To understand a singularity would be one of the greatest

scientific breakthroughs in history. You'd first need to invent a new theory—one that went beyond Einstein's general relativity, which determines the motion of stars and galaxies. And you'd have to surpass quantum mechanics, which predicts what happens to microscopic particles. Both theories are fine approximations of reality, but in a place of extremes, like the interior of a black hole, neither applies.

Singularities are imagined to be extremely tiny. Beyond tiny: Enlarge a singularity a trillion trillion times, and the world's most powerful microscope wouldn't come close to seeing it. But *something* is there, at least in a mathematical sense. Something not just small but also unimaginably heavy. Don't bother wondering what. The vast majority of physicists say, yes, black holes exist, but they are the ultimate Fort Knox. They're impenetrable. We will never know what's inside a singularity.

But a couple of unorthodox thinkers beg to differ. In recent years it's become increasingly accepted among theoretical physicists that our universe is not all there is. We live, rather, in what's known as the multiverse—a

vast collection of universes, each a separate bubble in the Swiss cheese of reality. This is all highly speculative, but it's possible that to give birth to a new universe you first need to take a bunch of matter from an existing universe, crunch it down, and seal it off.

Sound familiar? We do know, after all, what became of at least one singularity. Our universe began, 13.8 billion years ago, in a tremendous big bang. The moment before, everything was packed into an infinitesimally small, massively dense speck—a singularity. Perhaps the multiverse works something like an oak tree. Once in a while an acorn is dropped, falls into the ideal soil, and abruptly sprouts. So too with a singularity, the seed of a new universe. And like a sapling oak, we'll never send a thank-you note to our mother. For the message to escape our universe, it would have to move faster than the speed of light. Again, sound familiar?

The evidence for what could reside in a black hole is compelling. Look to your left, look to your right. Pinch yourself. A black hole might have originated in another universe. But we may be living in it.

Text sources: Abhay Ashtekar, Pennsylvania State University; Avery Broderick and Luis Lehner, Perimeter Institute for Theoretical Physics; Neil Cornish, Montana State University; Ilya Mandel, University of Birmingham, England

Michael Finkel wrote on [Australian Aboriginals](#) in the June 2013 issue. Illustrator Mark A. Garlick's latest book is *Cosmic Menagerie*.

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