

BLACK HOLES



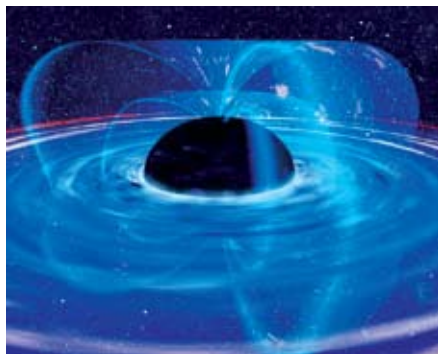
What is a black hole?

Most people think of a black hole as a voracious whirlpool in space, sucking down everything around it. But that's not really true! A black hole is a place where *gravity* has gotten so strong that the *escape velocity* is faster than light. But what does that mean, exactly?

Gravity is what keeps us on the Earth, but it can be overcome. If you toss a rock up in the air, it will only go up a little way before the Earth's gravity slows it and pulls it back down. If you throw it a little harder, it goes faster and higher before coming back down. If you could throw the rock hard enough, it would have enough velocity that the Earth's gravity could not slow it down enough to stop it. The rock would have enough velocity to escape the Earth.

For the Earth, that velocity is about 11 kilometers per second (7 miles/second). But an object's escape velocity depends on its gravity: more gravity means a higher escape velocity, because the gravity will "hold onto" things more strongly. The Sun has far more gravity than the Earth, so its escape velocity is much higher — more than 600 km/s (380 miles/s). That's 3000 times faster than a jet plane!

If you take an object and squeeze it down in size, or take an object and pile mass onto it, its gravity (and escape velocity) will go up. At some point, if you keep doing that, you'll have an object with so much gravity that the escape velocity is faster than light. Since that's the ultimate speed limit of the Universe, anything too close would get trapped forever. No light can escape, and it's like a bottomless pit: a black hole.



The strong magnetic field generated by the material in an accretion disk channels material onto the poles of the black hole - NASA/Dana Berry.

● How do black holes form?

The most common way for a black hole to form is probably in a supernova, an exploding star. When a star with about 25 times the mass of the Sun ends its life, it explodes. The outer part of the star screams outward at high speed, but the inner part of the star, its core, collapses down. If there is enough mass, the gravity of the collapsing core will compress it so much that it can become a black hole. When it's all over, the black hole will have a few times the mass of the Sun. This is called a "stellar-mass black hole", what many astronomers think of as a "regular" black hole.

But there are also monsters, called supermassive black holes. These lurk in the centers of galaxies, and are huge: they can be millions or even billions of times the mass of the Sun! They probably formed at the same time as their parent galaxies, but exactly how is not known for sure. Perhaps each one started as a single huge

star which exploded to create a black hole, and then accumulated more material (including other black holes). Astronomers think there is a supermassive black hole in the center of nearly every large galaxy, including our own Milky Way.



A torus of infalling material obscures the view of a black hole, but high velocity jets are seen racing away from the central accretion disk. ESA/NASA/V. Beckmann.

Stellar-mass black holes also form when two orbiting neutron stars – ultra-dense stellar cores left over from one kind of supernova – merge to produce a short gamma-ray burst, a tremendous blast of energy detectable across the entire observable Universe. Gamma-ray bursts are in a sense the birth cries of black holes.

● What happens when you fall into a black hole?

If you fall into a black hole, you're doomed. Sure, once you fall in you can never get back out, but it turns out you'll probably be dead before you get there.

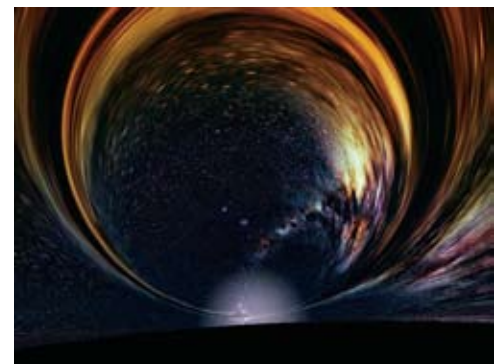
The gravity you feel from an object gets stronger the closer you get. As you approach a stellar-mass black hole feet-first, the force of gravity on your feet can be thousands of times stronger than the force on your head! This has the effect of stretching you, pulling you apart like taffy. Tongue-in-cheek, scientists call this "spaghettification." By the time you reach the black hole, you'll be a thin stream of matter many miles long. It probably won't hurt though: even falling from thousands of kilometers away, the entire gory episode will be over in a few milliseconds.

You may not even make it that far. Some black holes consume matter that falls onto them from an orbiting companion star or, in the case of supermassive black holes, from surrounding gas clouds. As the matter falls in, it piles up into a disk just outside the hole. Orbiting at huge speeds, the matter in this accretion disk gets extremely hot—even reaching millions of degrees. It will spew out radiation, in particular high-energy X-rays. Long before the black hole could rip you apart you'd be fried by the light.

But suppose you somehow manage to survive the trip in. What strange things await you on your way down into forever?

Once you pass the point where the escape velocity is faster than light, you can't get out. This region is called the event horizon. That's because no information from inside can escape, so any event inside is forever beyond our horizon.

If the black hole is rotating, chaos awaits you inside. It's a maelstrom as infalling matter turns back on the incoming stream, crashing into you like water churning at the bottom of a waterfall. At the very core of the black hole the seething matter finally collapses all the way down to a point. When that happens, our math (and intuition) fail us. It's as if the matter has disappeared from the Universe, but its mass is still there. At the singularity, space and time as we know them come to an end.



The intense gravity around a black hole creates multiple images of background objects in a gravitational lens - JILA/University of Colorado, Boulder/A. Hamilton.

Matter falling into a black hole can be heated to millions of degrees

Astronomers use X-ray satellites to observe matter falling into a black hole

● If black holes are black, how can we find them?

The black hole itself may be invisible, but the ghostly fingers of its gravity leave behind fingerprints. Some stars form in pairs, called binary systems, where the stars orbit each other. Even if one of them becomes a black hole, they may remain in orbit around each other. By carefully observing such a system, astronomers can measure the orbit of the normal star and determine the mass of the black hole. Only a few binary systems have black holes, though, so you have to know which binaries to observe. Fortunately, astronomers have discovered a signpost that points the way to black holes: X-rays.

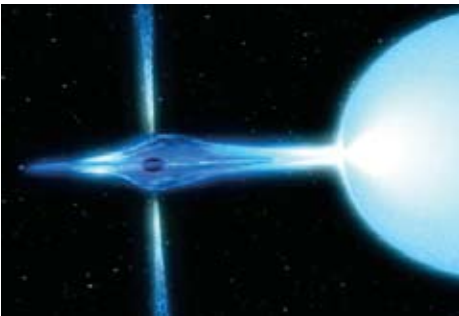
As mentioned above in *What happens when you fall into a black hole?*, if a black hole consumes matter that falls onto it from a companion star, that matter gets very hot and emits X-rays and gamma rays. This is like a signature identifying the source as a black hole. In fact, regions around black holes are so good at emitting this sort of high energy radiation that many thousands can be spotted this way. That's why astronomers want to build spacecraft equipped with special detectors that can "see" this radiation. X-ray observatories such as Chandra, can see stellar black hole binaries in nearby galaxies, as well as in our own Milky Way. Gamma-ray observatories such as Fermi, study jets of charged particles which are accelerated to nearly light speed, creating gamma rays. Fermi will discover thousands of gamma-ray jet emitting black holes, some of which may be billions of light years away.

Are black holes really black?

Surprisingly, black holes may not be totally black!

- *Infalling material can get hot enough to glow.*
- *Sometimes the material falling into a black hole is so bright it can outshine an entire galaxy.*
- *The material falling into supermassive black holes can be so luminous we can see them from distances of billions of light years.*
- *The birth of a stellar-mass black hole produces a flash of radiation so bright it can outshine entire galaxies, and be seen clear across the observable Universe!*

● How do black holes affect things near them?



Material from a normal companion star falls onto a black hole forming an accretion disk and outflowing jets of material - NASA/Honeywell Max-Q Digital Group.

Are we in danger of being gobbled up by a black hole? Actually, no. We're pretty safe.

The gravity from a black hole is only dangerous when you're very close to it. Surprisingly, from a large distance, black hole gravity is no different

than the gravity from a star with the same mass. The strength of gravity depends on the mass of the object and your distance from it. If the Sun were to become a black hole (don't worry, it's way too lightweight to ever do that), it would have to shrink so much that its event horizon would be only 6 km (4 miles) across. From the Earth's distance of 150 million km (93 million miles), we'd feel exactly the same gravity as we did when the Sun was a normal star. That's because the mass didn't change, and neither did our distance from it. But if we got up close to the black hole, only a few kilometers away, we'd definitely feel the difference!

So stellar-mass black holes don't go around tearing up stars and eating everything in sight. Stars, gas, planets, and anything else would have to get up close and personal to a black hole to get trapped. But space is big. The odds of that happening are pretty small.

Things are different near a supermassive black hole in the center of a galaxy. Every few hundred thousand years, a star wanders too close to the black hole and gets torn apart. This produces a blast of X-rays that can be visible for decades! Events like this have been seen in other galaxies, and they are a prime target for satellites such as Chandra to reveal otherwise "dormant" black holes.

Astronomers have found another amazing thing about galaxies: the stars in the inner parts of a galaxy orbit the galactic center faster when the galaxy's central supermassive black hole is more massive. Since those stars' velocities are due to the mass in the inner part of the galaxy – and even a monster black hole is only a tiny fraction of that mass – astronomers conclude that the total mass of the inner region of a galaxy is proportional to the (relatively very small) mass of its central black hole! It's as if the formation of that black hole somehow affected the formation of the billions of normal stars around it. Fermi will investigate a large sample of active galaxies to determine what, if any, influence the jets emitted from supermassive black holes have on the stars near galactic centers.

The nearest known black hole is 1600 light years away!

☉ Can black holes be used to travel through spacetime?

It's a science fiction cliché to use black holes to travel through space. Dive into one, the story goes, and you can pop out somewhere else in the Universe, having traveled thousands of light years in the blink of an eye.

But that's fiction. In reality, this probably won't work. Black holes twist space and time, in a sense punching a hole in the fabric of the Universe. There is a theory that if this happens, a black hole can form a tunnel in space called a wormhole (because it's like a tunnel formed by a worm as it eats its way

through an apple). If you enter a wormhole, you'll pop out someplace else far away, not needing to travel through the actual intervening distance.

While wormholes appear to be possible *mathematically*, they would be violently unstable, or need to be made of theoretical forms of matter which may not occur in nature. The bottom line is that wormholes probably don't exist. When we invent interstellar travel, we'll have to go the long way around.

Astronomers think that at least one black hole is born every day!

☉ What can we learn from black holes?

Black holes represent the ultimate endpoints of matter. They twist and rip space and time, pushing our imagination to its limits. But they also teach us a lot about the way the Universe works.

As matter falls into a black hole, it heats up and emits X-rays. By studying how black holes emit X-rays using observatories like EXIST, scientists can learn about how black holes eat matter, how much they can eat, and how fast they can eat it — all of which are critical to understanding the physics of black holes. EXIST has another advantage:

many black holes are hidden behind obscuring dust, but EXIST can peer through this dust to the black holes on the other side. Current data indicate we may be missing as many as 80% of the black holes in the Universe because of this dust, so EXIST will give astronomers a more accurate census of the black hole population.

What happens at the very edge of a black hole, where light cannot escape, where space and time

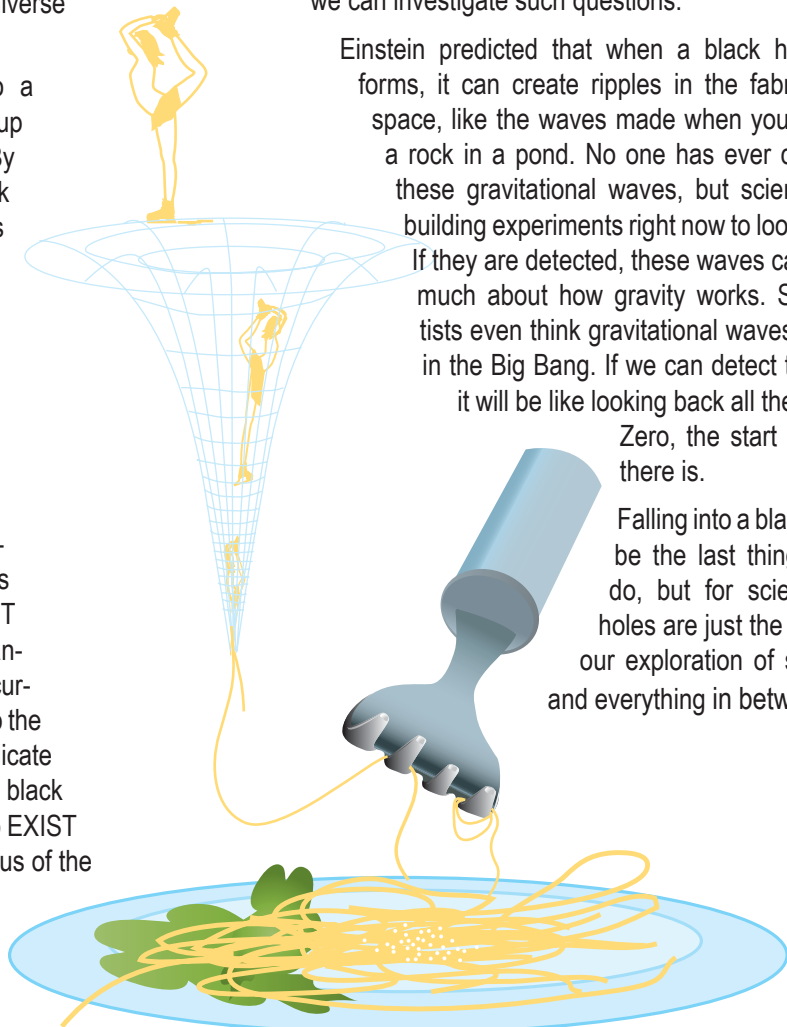
swap places, where even Einstein's General Relativity is stretched to the breaking point? Black holes are a natural laboratory where we can investigate such questions.

Einstein predicted that when a black hole forms, it can create ripples in the fabric of space, like the waves made when you throw a rock in a pond. No one has ever detected these gravitational waves, but scientists are building experiments right now to look for them. If they are detected, these waves can teach us much about how gravity works. Some scientists even think gravitational waves were made in the Big Bang. If we can detect these waves, it will be like looking back all the way to Time Zero, the start of everything there is.

Falling into a black hole would be the last thing you'd ever do, but for scientists, black holes are just the beginning of our exploration of space, time, and everything in between.



The collapse of the core in a massive star triggers a gamma ray burst - NASA/Dana Berry.



Artist's concept of "spaghettification" near a black hole SSU NASA E/PO/A. Simonnet

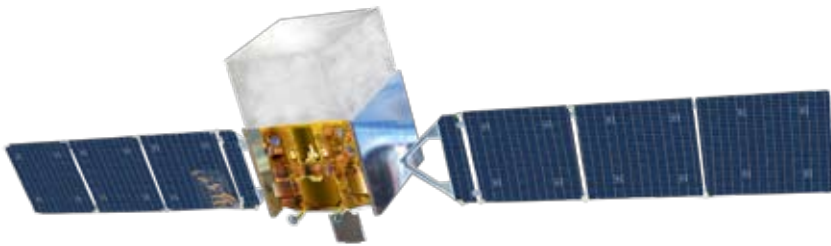
● Where are black holes located?

Black holes are everywhere! As far as astronomers can tell, there are probably millions of black holes in our Milky Way Galaxy alone. That may sound like a lot, but the nearest one discovered is still 1600 light years away — a pretty fair distance, about 16 quadrillion kilometers! That's certainly too far away to affect us. The giant black hole in the center of the Galaxy is even farther away: at a distance of 26,000 light years, we're in no danger of being sucked into the vortex.

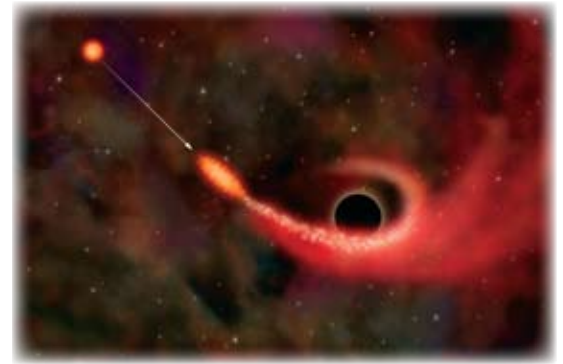
For a black hole to be dangerous, it would have to be very close, probably less than a light year away. Not only are there no black holes that close, there aren't any known that will ever get that close. So don't fret too much over getting spaghetti-fied anytime soon.

Fermi

The Fermi Gamma Ray Space Telescope is a NASA observatory built to study the most energetic and extreme environments in the universe, such as black holes. Fermi was launched into Earth orbit in June, 2008 and is surveying the sky with the most sensitive gamma ray telescope ever built. Fermi is able to observe jets of gamma rays emitted from supermassive black holes in the cores of distant galaxies.



SSU NASA E/PO, A. Simonnet



The neutron star companion of a black hole spirals in and is destroyed as it merges with the black hole - NASA/CXC/M. Weiss

There are probably millions of stellar-mass black holes in our own Milky Way Galaxy, but only one supermassive black hole, right in the center, tipping the cosmic scales at 4 million times the mass of the Sun. But don't worry — at nearly 26,000 light years away, it's too far away for us to fall into it.

Glossary

Accretion Disk: a large amount of material falls into a black hole. The disk is outside the *event horizon* of the black hole. Friction and other forces heat the disk, which then emits light.

Escape Velocity: The velocity needed for an object to become essentially free of the gravitational effect of another object.

Event Horizon: The distance from the center of a black hole where the *escape velocity* is equal to the speed of light.

Gamma-ray Burst: A titanic explosion of high-energy light, thought to be due to the formation of a black hole.

Gravity: The attractive force of an object which depends on its mass, and your distance from it. The more massive an object, or

the closer you are to it, the stronger the force of its gravity will be.

Mass: The quantity of matter that makes up an object.

Supernova: An exploded, or exploding, star.

Wormhole: A theoretical shortcut through space caused when a black hole punches through the fabric of spacetime. While possible mathematically, in reality they probably do not exist.

Credits:

"Black Holes: From Here to Infinity" was developed as part of the NASA Fermi Education and Public Outreach (E/PO) Program at Sonoma State University, CA under the direction of Professor Lynn Cominsky.

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References:

Fermi Main Page: <http://www.nasa.gov/fermi>
SSU E/PO: <http://epo.sonoma.edu>