NATIONAL STANDARDS

SCIENCE AS INQUIRY

Abilities necessary to do scientific inquiry

- identify questions and concepts that guide scientific investigation
- design and conduct scientific investigations
- use technology and mathematics to improve investigations and communications
- formulate and revise scientific explanations and models using logic and evidence
- recognize and analyze alternative explanations and models
- communicate and defend a scientific argument

Understanding about scientific inquiry

PHYSICAL SCIENCE

Structure and properties of matter
Interactions of energy and matter
Motions and forces

EARTH AND SPACE SCIENCE

Origin and evolution of the universe

SCIENCE AND TECHNOLOGY

Understanding about science and technology

HISTORY AND NATURE OF SCIENCE

Science as a human endeavor
Nature of scientific knowledge
Historical perspectives

BLACK HOLES: THE OTHER SIDE OF INFINITY
General Information

Deep in the middle of our Milky Way galaxy lies an object made famous by science fiction—a supermassive black hole. Scientists have long speculated about the existence of black holes. German astronomer Karl Schwarzschild theorized that black holes form when massive stars collapse. The resulting gravity from this collapse would be so strong that the matter would become more and more dense. The gravity would eventually become so strong that nothing, not even radiation moving at the speed of light, could escape. Schwarzschild's theories were predicted by Einstein and then borne out mathematically in 1939 by American astrophysicists Robert Oppenheimer and Hartland Snyder.

WHAT EXACTLY IS A BLACK HOLE?

First, it's not really a hole! A black hole is an extremely massive concentration of matter, created when the largest stars collapse at the end of their lives. Astronomers theorize that a point with infinite density—called a **singularity**—lies at the center of black holes.

SO WHY IS IT CALLED A HOLE?

Albert Einstein's 1915 General Theory of Relativity deals largely with the effects of gravity, and in essence predicts the existence of black holes and singularities. Einstein hypothesized that gravity is a direct result of mass distorting space. He argued that space behaves like an invisible fabric with an elastic quality. Celestial bodies interact with this "fabric" of space-time, appearing to create depressions termed "gravity wells" and drawing nearby objects into orbit around them. Based on this principle, the more massive a body is in space, the deeper the gravity well it will create. Therefore, an object with enormous mass but infinitely small size would create a bottomless pit—a black hole.

CAN A BLACK HOLE SUCK US IN?

A black hole is not like a vacuum, sucking in everything nearby—though it is often compared to one. It is better compared to the relentless force of a waterfall, harder to resist the closer you approach. A black hole's gravity is so strong that anything passing close to it is affected by its strong gravitational attraction. Astronomers theorize that because of this very strong gravity, strange things happen near black holes. They believe that time slows down, and space becomes infinitely warped. The laws of physics, as we know them, would cease to exist.

WHAT IS SCIENCE FICTION VS. SCIENCE FACT?

Einstein's theories infer that tubes, or tunnels, might exist within the strange world of black holes. First named Einstein-Rosen bridges, and later called wormholes, these invisible passageways predicted connections between different regions of space-time. We now know that these wormholes are too unstable to exist, but even if they did, wormholes could not support human "time travel" as science fiction writers would imagine it. The enormous gravity associated with black holes and wormholes would rip apart any matter that came near it. So black holes can't be used for time travel the way they are in movies.

WHAT DOES A BLACK HOLE LOOK LIKE?

Because of their nature, black holes cannot be seen. Black holes do not have a physical surface. Instead, they begin at a central point of singularity and continue out to a spherical boundary. The **event horizon** is the "dividing line," beyond which anything that crosses cannot escape. Outside the event horizon, material falling into the black hole collects into a band of hot gas and dust called an **accretion disk**. Narrow jets of gas shoot out from the accretion disk, emitting detectable radiation.

The physical size of black holes is measured with a special unit called the **Schwarzschild radius**. This radius is defined to be the distance from the point of singularity to the event horizon. The larger the Schwarzschild radius, the more massive the black hole.

IF WE CAN'T SEE THEM, HOW DO WE KNOW THEY'RE OUT THERE?

Black holes—by definition—cannot be seen directly. The only way to find a black hole is to look for its effects on other objects in space around it. Observation of gas jets, radiation, rapidly orbiting objects, and other methods are used to indirectly detect the locations of black holes. Astronomers have observed evidence this way for dozens of black holes in our own galaxy.

Scientists who study black holes focus on how other bodies are affected in the space around them. The first approach to locating black holes involved observing binary star systems. In these systems, two stars orbit each other, moving in generally predictable ways because of the gravitational attraction between the stars. Scientists knew that if they saw a single star moving as if there were a massive object nearby, but with no other star in evidence, then its invisible companion could be a black hole.

Scientists also realized that if the invisible object in a binary system was a black hole, there would be huge gravitational force associated with it. The gas from the visible star—or any nearby gas and dust—would spiral at very high speeds around the black hole before disappearing into it. This action would create enormous heat and X-ray radiation, which could be detected through observations.

In the 1970s, scientists took great interest in gamma-ray bursts as a way to detect black holes. One hypothesis suggested that a binary system consisting of a normal star and a black hole creates gamma-ray bursts when the black hole finally consumes all of its companion star's material. Another widely-accepted theory suggests that gamma rays are released when black holes or neutron stars collide. Gamma-ray bursts are probably also released when a giant star collapses and a black hole is formed

ARE ALL BLACK HOLES THE SAME?

A **stellar mass black hole** forms when a star at least eight times the mass of our Sun explodes at the end if its life in a blaze of glory called a supernova. While the outer layers shoot outward, the inner parts known as the core collapse down … and down … and down. The core's mass is collapsed enough to that it becomes a black hole, so dense that not even light can escape its gravity. Scientists estimate there are probably tens of millions of stellar mass black holes, just in our own galaxy.

Another type of black holes is highlighted in *Black Holes: The Other Side of Infinity*: a **supermassive black hole**. These huge black holes form at the cores of galaxies, where they grow larger and larger, feeding on the gas and dust at the center. We know our own Milky Way galaxy has a supermassive black hole—sometimes called Sagittario—several millions of times the mass of our own Sun. Scientists theorize that all large galaxies have a central supermassive black hole, and that the central black hole and the evolution of the galaxy are intrinsically tied together in ways scientists are still discovering.

Even though they are large, supermassive black holes still can't be seen directly. In order to measure the mass of these supermassive black holes, scientists observe the speeds at which matter orbits them. Using this data, they can deduce how massive the central object must be to produce the velocities observed. In recent years, scientists have intensified their study of the cores of other galaxies, and their efforts have revealed central black holes potentially in excess of 1.2 billion solar masses.

TIMELINE OF BLACK HOLES

1687	Gravity described by Sir Isaac Newton
1783	John Michell theorizes the possibility of an object large enough to have an escape velocity greater than the speed of light
1796	Simon Pierre LaPlace predicts the existence of black holes
1895	Wilhelm Roentgen discovers X-rays
1915	Albert Einstein publishes the General Theory of Relativity describing the curvature of space-time
1916	Karl Schwarzschild defines a black hole and what later becomes known as the Schwarzschild radius
1939	Robert Oppenheimer and Hartland Snyder mathematically prove Schwarzschild's theories
1964	John Wheeler coins the term "black hole"
1965	Scientists discover first good black hole candidate, Cygnus X-1
1970	Stephen Hawking defines modern theory of black holes
1971	Scientists confirm black hole candidate Cygnus X-1 by determining the mass of its companion star
1989	Russian Space Agency launches Granat, using gamma-ray technology for deep imaging of galactic centers
1994	Hubble Space Telescope provides evidence that super-massive black holes reside in the center of galaxies
2004	Swift gamma-ray burst mission launched

BLACK HOLES: THE OTHER SIDE OF INFINITY
Key Terms

accretion: the gradual accumulation of small objects to form a larger object due to their mutual gravitational attraction.

accretion disk: a flattened disk of matter orbiting around an object. Friction between the matter in the disk causes the matter to gradually spiral in and accrete onto the object.

black hole: the end-state of a high-mass star; an extremely massive concentration of matter so dense that even light cannot escape its gravitational field.

escape velocity: the velocity required for one object to be launched from the surface of a body in order for it to escape the gravitational attraction of that body.

event horizon: the outer boundary of a black hole, at which the escape velocity exceeds the speed of light.

galaxy: a structured grouping of billions of stars, gas, and dust, bound together by their collective gravity and orbiting a common center.

gamma radiation: the most powerful form of electromagnetic radiation, with the shortest wavelengths.

gamma-ray burst: a burst of gamma rays from space, possibly triggered by the birth of black holes.

gravity: the attractive force between any two bodies that is the result of their masses.

light year: the distance light travels in one year, approximately 9.46 trillion meters (5.88 trillion miles).

Schwarzschild radius: the radius of an object with a given mass at which the escape velocity equals the speed of light. It is the radius corresponding to the event horizon of a black hole; this radius is three times the mass of the black hole measured in solar masses. Named for German astronomer Karl Schwarzschild.

singularity: the center of a black hole, an infinitely dense remnant of a massive star's core collapse.

speed of light: the speed at which light travels, 300,000 kilometers per second (186,000 miles per second).

supernova: an explosion caused by the collapse of the core of a massive star.

time dilation: the slowing of the flow of time, which may be observed for objects that approach the event horizon of a black hole.

wormholes: theoretical "tubes" in space-time, which could be entered from a black hole, and were predicted based on the simplest solution of Einstein's equations. However, the turbulence predicted inside black holes leads most scientists to agree that wormholes can't really exist.

RESOURCES

Black Holes. Nardo, Don. San Diego: Lucent Books, 2004.

Can Science Solve the Mystery of Black Holes? Oxlade, Chris. Des Plaines, IL: Heinemann Library, 2000.

The Complete Idiot's Guide to Astronomy. DePree, Christopher, and Alan Axelrod. New York: Alpha Books, 1999.

The Complete Idiot's Guide to Understanding Einstein. Moring, Gary. New York: Alpha Books, 2004.

WEB SITES & ACTIVITIES

http://amazing-space.stsci.edu/resources/explorations/
Interactive tutorial about black holes

http://swift.gsfc.nasa.gov/docs/swift/swiftsc.html
Information about the Swift Mission and its search for gamma-ray bursts, one of the earmarks of forming black holes

http://swift.sonoma.edu/educators.html
Resources for educators on black holes, gamma rays, and the Swift Mission

http://www-glast.sonoma.edu/
Information and educational resources about additional international missions studying gamma rays

http://mystery.sonoma.edu/live_from_2-alpha/index.html
Interactive, inquiry-based mystery game using knowledge to identify a black hole

http://www.explorelearning.com/index.cfm?method=cResource.dspView&ResourceID=14
Black hole simulation game—try to get radioactive waste into recycling bins, past black holes using the equation for gravitational force

http://archive.ncsa.uiuc.edu/Cyberia/NumRel/NumRelHome.html
Spacetime Wrinkles Web site—online exhibit about Einstein's Theory of Relativity

http://cosmology.berkeley.edu/Education/BHfaq.html
Frequently asked questions on black holes

http://archive.ncsa.uiuc.edu/Cyberia/Expo/MovieIndex.html
Movies from the Edge of Spacetime, black hole simulations

http://cfa-www.harvard.edu/seuforum/
Black holes informational materials developed by Harvard in association with NASA

http://imagine.gsfc.nasa.gov
NASA's "Imagine the Universe" site, ask an astrophysicist about black holes

DENVER MUSEUM OF NATURE & SCIENCE

THE OTHER SIDE OF INFINITY BLACK HOLES

POSTVISIT ACTIVITY

GRADE LEVEL
Grades 7–12

NATIONAL STANDARDS
Science as Inquiry
Earth and Space Science
Physical Science
Science and Technology

PREPARATION TIME
One hour

ACTIVITY TIME
45 minutes

MATERIALS
Black spandex-type cloth
Quilting frame or embroidery hoop
Balls of various weights and sizes

Space Time Curvature

Learning Goals/Objectives

Students will observe the effects of the curvature of space-time.

Advance Preparation

Build your model of space-time. Stretch black spandex material around the quilting frame and secure it. Place the frame between two tables or otherwise support it so that the frame is elevated and the spandex sheet is free to stretch down.

Classroom Activity

1. Begin the class period with a discussion of gravity and space-time. This activity is best performed when students have a general understanding of Einstein's theories of the curvature of space-time.
2. Demonstrate to students what happens to the space-time model when a large, heavy ball such as a baseball or softball is placed in the middle of the model. Students should be able to see that the ball bends or stretches the model to form a "gravity well."
3. Replace the large ball with a smaller ball of less mass. Ask students to compare the difference in the space-time model.
4. Put the baseball back in the center and ask students to predict what will happen if you put a marble on the model. They should have an idea that if the marble is placed close enough, the marble will roll toward the baseball, thus illustrating the effects of gravity.
5. Give students some time to experiment with various sizes and weights of balls on the space-time model. Ask them to manipulate the model, getting a smaller ball to "orbit" around a larger mass. Have them summarize their findings in a science journal.

Variations/Extensions

Ask students to construct their own models of space-time. These models should be able to demonstrate the same ideas of space-time curvature, but use a different approach and different materials.

Resources

http://www.thebigview.com/spacetime/index.html

DENVER MUSEUM OF NATURE & SCIENCE

THE OTHER SIDE OF INFINITY BLACK HOLES

POSTVISIT ACTIVITY

GRADE LEVEL
Grades 7–12

NATIONAL STANDARDS
Science as Inquiry
Physical Science
Science and Technology

PREPARATION TIME
None

ACTIVITY TIME
45–60 minutes

MATERIALS
Chart paper
Computers with Internet access

Black Holes: Myth or Reality?

Learning Goals/Objectives

Students will address their own misconceptions about black holes.

Classroom Activity

1. Begin with a whole class discussion introducing the topic of black holes. Start a KWL chart to record students' ideas about black holes.
2. Ask students what they already know about black holes. Record *every* idea, as these surely will show what your students know about black holes, and what misconceptions they have.
3. Ask students what they want to know about black holes. This will guide your research and presentations to the students.
4. Discuss with students the difference between hypothesis, fact, and theories. Include how hypotheses and theories are developed.
5. Use the following Web site to research common misconceptions students have regarding black holes: http://amazing-space.stsci.edu/capture/blackholes/
6. Ask students to research and then debate their viewpoint on each of the misconceptions presented on the Web site. Some students may already know the answers. Allow them to find the research to prove their point of view. Ask other students to commit to a point of view and find research to prove or disprove that side of the issue.
7. After students have an opportunity to present their findings of the misconceptions, complete the "what we've learned" part of the KWL chart. Keep the chart up in your classroom for future reference.

Resources

http://amazing-space.stsci.edu/capture/blackholes/
Myth vs. realities of black holes

DENVER MUSEUM OF NATURE & SCIENCE

THE OTHER SIDE OF INFINITY BLACK HOLES

POSTVISIT ACTIVITY

GRADE LEVEL
Grades 7–12

NATIONAL STANDARDS
Science as Inquiry
Science and Technology

PREPARATION TIME
Approximately 30 minutes

ACTIVITY TIME
Approximately one hour

MATERIALS
Computers with Internet access

Exploring Black Holes Through Web sites

Learning Goals/Objectives

Students will use Web sites to locate information pertaining to black holes Advanced Preparation.

Advance Preparation

View various Web sites to find links you wish your students to research. As there are several great resources out there, pick a few to share with your students. View various Web sites to find links you wish your students to research. As there are several great resources out there, pick a few to share with your students.

Classroom Activity

Allow your students some time to explore some of the excellent Web sites available about black holes. Have students search in teams to become "experts" on a particular Web site. Give them time to view and navigate the Web sites, then have students creatively disseminate the information to their fellow classmates. Ask students to share the information in the form of a Power Point presentation, newsletter, magazine, or news show.

Resources

http://amazing-space.stsci.edu/resources/explorations/
Gives students the opportunity to check out *No Escape: The Truth About Black Holes* for an interactive tutorial

http://mystery.sonoma.edu/live_from_2-alpha/index.html
An interactive, inquiry-based simulation which forces students to utilize their knowledge of black holes

http://cfa-www.harvard.edu/seuforum/einstein/resource_BHExplorer.htm
Students can play the black hole game

HOST AN ASTRONOMY DAY AT YOUR FACILITY

- Ask local scientists from museums, planetariums, or universities to offer a lecture series on various astronomy topics.
- Host a star party. Provide telescopes, binoculars, and other safe methods for observing astronomical objects. Help observers build star finders. http://www.adlerplanetarium.org/education/teachers/plans/starfinder/index.shtml
- Enlist the help of volunteers to complete a variety of activity stations around your facility. There are a wealth of hands-on astronomy activities you can use to inspire curiosity about astronomy available on the internet. Possible ideas might include
    - Solar system maps
    - Solar system crafts
    - Moon dials
    - Mars map Cookies

  http://www.dmns.org/main/en/Professionals/School+Groups/Teacher+Resources/Pre-and-Post+Visit+Activities/
- Build Alka-Seltzer rockets or air-launched rockets. Launch rockets outside or in an easy-to-clean place. http://www.funology.com/laboratory/lab041.htm
- Host viewings of astronomy related videos, IMAX films, or planetarium shows for visitors to watch.
- Have volunteers or scientists do demonstrations involving space science. Ideas include spectroscopy, cryogenics, sunspot viewing, and rocket building and launching.
- Ask volunteers to present a meteorites touch cart to explain to visitors the differences between meteorites and rocks
- Enlist volunteers to put on "Space Day" plays or skits. Stage a news report about current events in space.
- Consider hosting a star party at night. Away from city lights, use binoculars and telescopes to look at the Moon or other night sky objects. Local astronomy clubs are great resources for this activity.

SAMPLE TEACHER WORKSHOP OUTLINE

8:00–8:15 a.m.	Registration, check-in, continental breakfast
8:15–8:30 a.m.	Introductions, logistics, agenda review
8:30–9:30 a.m.	General background information about black holes
9:30–10:00 a.m.	Preview *Black Holes: The Other Side of Infinity* at your local planetarium
10:00–10:15 a.m.	Break
10:15–11:30 a.m.	Expert scientist lecture. Check with local universities, museums, or planetariums for speakers.
11:30 a.m.–12:30 p.m.	Lunch
12:30–1:30 p.m.	Stellar evolution lecture and activities http://www.astrosociety.org/education/activities/astroacts06.html http://www.dmns.org/main/minisites/spaceOdyssey/teachersGuide/grades48/pdf/stellarEvolution.pdf
1:30–2:30 p.m.	Gamma-ray bursts lecture and activities. See the following Web site for great information about SWIFT mission. http://swift.sonoma.edu/education/grb/allinoneb.pdf
2:30–2:45 p.m.	Break
2:45–4:15 p.m.	Space time curvature lecture and activities http://www.pbs.org/deepspace/classroom/activity5.html http://einstein.stanford.edu/content/education/TGuide_Part5.pdf
4:15–4:30 p.m.	Wrap-up and evaluations

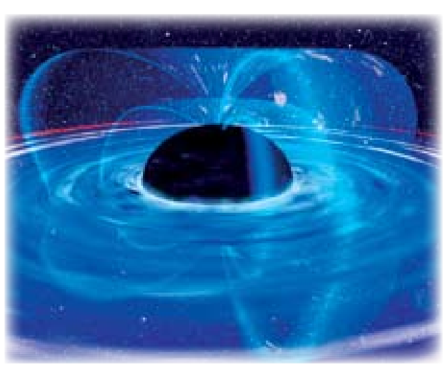
BLACK HOLES

FROM HERE TO INFINITY

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 ways 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.


NASA, Dana Berry

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.

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.

ESA, V. Beckmann (GSFC)

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.

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

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.

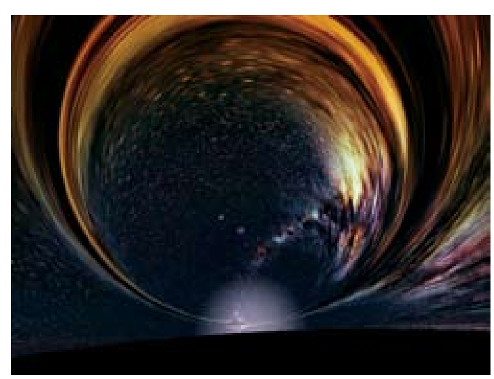
You may not even make it that far. Some black holes greedily gobble down matter, stealing it from an orbiting companion star or, in the case of supermassive black holes, from surrounding gas clouds. As the matter falls in, it piles up into a disk just outside the hole. Orbiting at huge speeds, the matter 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.

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

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.



JILA, University of Colorado, Boulder, CO, A. Hamilton

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.

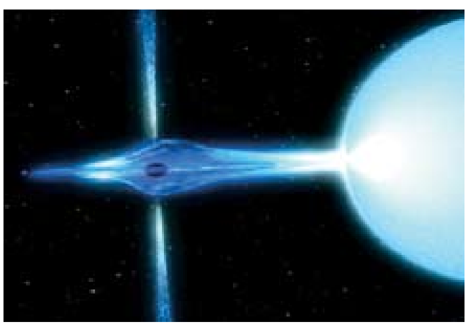
As mentioned above in *What happens when you fall into a black hole?*, if a black hole is "eating" matter from a companion star, that matter gets very hot and emits X-rays. This is like a signature identifying the source as a black hole. That's why astronomers want to build spacecraft equipped with special detectors that can "see" in X-rays. In fact, black holes are so good at emitting X-rays that many thousands can be spotted this way. EXIST is one such spacecraft, designed to be able to detect tens of thousands of black holes, some of which may be billions of light years away. EXIST will create the most sensitive full-sky map locating black holes, including those which may be otherwise hidden from our view by obscuring gas and dust.

Are black holes really black?

Surprisingly, black holes may not be totally black!

- *Infalling material can get hot enough to glow.*
- *Sometimes black holes are so bright they can outshine an entire galaxy.*
- *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?



NASA/Honeywell Max-Q Digital Group/Dana Berry part of an animation

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 EXIST 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. EXIST will probe this suspected "feedback" between galaxy formation and supermassive black holes by investigating black holes in a very large sample of galaxies.

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.

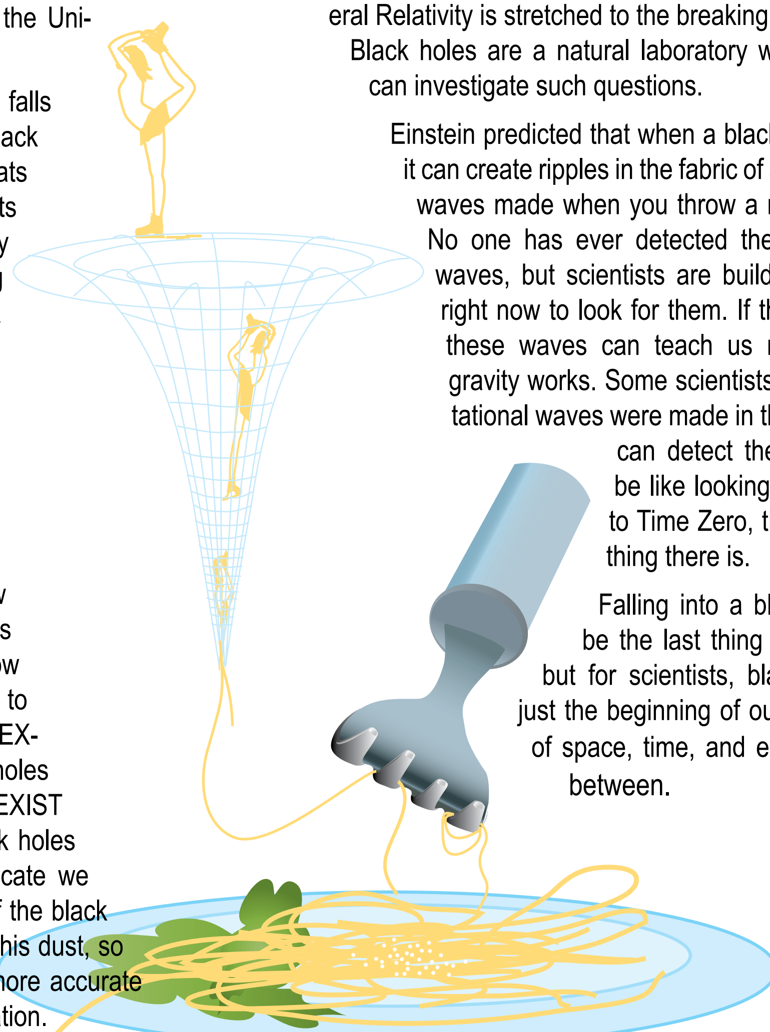
Astronomers think that at least one black hole is born every day!

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.

NASA, Dana Berry

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.

Where are black holes located?

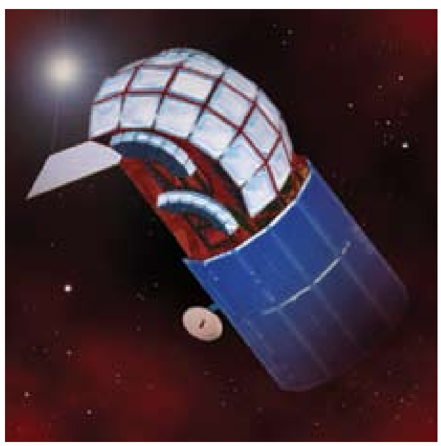
Black holes are everywhere! As far as astronomers can tell, there are probably millions of black holes in our Milky Way Galaxy alone. That may sound like a lot, but the nearest one discovered is still 1600 light years away— a pretty fair distance, about 16 quadrillion kilometers! That's certainly too far away to affect us. The giant black hole in the center of the Galaxy is even farther away: at a distance of 30,000 light years, we're in no danger of being sucked in to the vortex.

NASA/CXC/M.Weiss

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 spaghettified anytime soon.

EXIST

The Energetic X-ray Imaging Survey Telescope (EXIST) is a proposed NASA satellite that will look at the energetic X-rays emitted from black holes and other exotic astronomical objects. It is a strong candidate to be the Black Hole Finder Probe, one of the three "Einstein Probes" in NASA's Beyond Einstein Program. EXIST could be launched early in the next decade, and, with unparalleled sensitivity, will be used to study black holes of all sizes.



SSU NASA E/PO, A. Simonnet

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 30,000 light years away, it's too far away for us to fall into it.

Glossary

Accretion Disk: A disk of matter that forms when 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 EXIST and GLAST Education and Public Outreach (E/PO) Programs at Sonoma State University, CA under the direction of Professor Lynn Cominsky.

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References:

EXIST Main Page: *http://exist.gsfc.nasa.gov*
SSU E/PO: *http://epo.sonoma.edu*

www.nasa.gov