

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 of 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

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>

POSTVISIT ACTIVITY

Black Holes: Myth or Reality?

GRADE LEVEL

Grades 7–12

Learning Goals/Objectives

Students will address their own misconceptions about black holes.

NATIONAL STANDARDS

Science as Inquiry
Physical Science
Science and Technology

Classroom Activity

PREPARATION TIME

None

ACTIVITY TIME

45–60 minutes

MATERIALS

Chart paper
Computers with Internet access

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

POSTVISIT ACTIVITY

Exploring Black Holes Through Web sites

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

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_BHExplorerer.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 <i>Black Holes: The Other Side of Infinity</i> 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