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.

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.

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

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