Activity Guide for Classroom Educators

What can teachers do to engage students with the science of *Black Holes* before and after a visit to the exhibition? The activities below are taken from a variety of sources and highlight some of the important themes for navigating and reflecting on the *Black Holes* experience.

<u>Pre-Visit Activities</u>

Black holes are formed when the most massive stars go supernova. Explore the **Kinesthetic Life Cycle of Stars** to find out how stars live and die.

Black holes are found inside galaxies, among the stars. Use cookies and birdseed to build a conceptual model for understanding the **Size and Scale** of black holes in our universe.

A key element of the *Black Holes* visitor experience is the use of ***Black Holes*** **Explorer's Cards** to create a personal **web journal**. Be sure to brief your students beforehand!

<u>Post-Visit Activities</u>

Visitors to *Black Holes* use their Explorer's ID cards to create a personal **web journal** of their experience. Prepare a **Report from the Edge** to reflect on these discoveries.

Telescopes on the ground and in space are collecting evidence for real black holes in our universe. Investigate **the Past, Present, and Future of Black Holes** to learn more about these exciting research missions.

Black holes are a popular topic in both science and science fiction. Explore the ideas presented in popular culture to find out if black holes are **Science Fiction or Fact**.

<u>Supplemental Activities</u>

Scientists infer the presence of black holes by their effects on objects around them. **A Galaxy Full of Black Holes** and **Real Images of Black Holes** will guide you and your students through the evidence for black holes in our universe.

Students can take their own images of black hole targets using real telescopes. The **Observing With NASA** web portal provides access to the MicroObservatory robotic telescopes and suggestions for follow-up activities using these real astronomical images.

The **Black Hole Explorer** board game provides a fun hands-on introduction to black holes.

Black Holes: Space Warps & Time Twists was funded by the National Science Foundation, with additional support from the National Aeronautics and Space Administration

Kinesthetic Life Cycle of Stars

Activity Description
Students kinesthetically model the birth, life, and death of stars in order to understand how black holes form in the core collapse of the most massive stars at the end of their lives. The activity models the basic stages of stellar evolution and the different end states of low- and high-mass stars, introducing the basic physical processes that are needed to create a stellar-mass black hole and explaining why the Sun cannot and will not turn into a black hole.

Original Source
Harvard-Smithsonian CfA and MIT Kavli Institute. Published in *Astronomy Education Review*, September 2008. Available online at http://aer.noao.edu/cgi-bin/article.pl?id=287

Materials Needed
- Group of 8-12 people (ideal, but more or less can work as well)
- (Optional) Images of humans in various stages of life
- (Optional) Images of stars and nebulae in different phases of stellar evolution
- (Optional) A demonstrative poster showing different phases of stellar evolution

Background
When the Universe came into existence ~14 billion years ago, the only elements were hydrogen, helium, and traces of lithium, beryllium, and boron. The heavier elements did not yet exist. Heavy elements are produced by nucleosysthesis - the fusion of nuclei deep within the cores of stars. At some point in time, the first stars were formed, and within their cores the fusion process created heavier and heavier elements; the most massive stars produced nuclei as heavy as iron. When the stars used up their nuclear fuel, they started to evolve. The evolutionary processes of stars depend upon their initial mass. Mid-sized stars eject planetary nebulae, leaving a white dwarf core remnant. More massive stars explode as supernovae, leaving neutron stars or black holes at the centers of the supernovae remnants. [Taken from http://chandra.harvard.edu/edu/formal/stellar_ev/]

Extensions
Explore the links at the end of this guide to discover other classroom activities about stellar evolution from NASA's Astrophysics missions.

Exhibit Connections
Snapshots in the History of Black Holes; Where are Black Holes?; Is It True What They Say About Black Holes?

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Kinesthetic Life Cycle of Stars

This activity was originally published in *Astronomy Education Review*, September 2008. The full article is available online at http://aer.noao.edu/cgi-bin/article.pl?id=287

Activity Overview

In this dynamic model for stellar evolution, students become clumps of gas in a star-forming nebula, and reenact kinesthetically the journey from nursery to death. Through a simplified two-layer model of how stars work, students will:

1. Learn about the basic stages of stellar evolution
2. Learn about the different end states of low- and high-mass stars

By kinesthetically modeling the birth, life, and death of stars, students can make concrete connections to physical processes in the universe, processes that are not explicitly revealed through photographs of stars and nebulae.

Set Up

The only materials necessary for this activity are the students themselves, but the experience can be enriched by the use of additional props, including:

- Images of humans in various stages of life
- Astronomical images of stars and nebulae, showing different phases of stellar evolution
- Illustrated stellar evolution poster (*available at websites listed on pages 5 & 35 of this guide*)

Facilitators should present this activity outside or in an empty room. A standard middle school classroom with furniture pushed to the side will allow appropriate maneuverability. We recommend 8-12 students per stellar model, although the activity has been successful in groups of 6 to 24. Additional details are provided in the full article.

Introducing the Activity

Challenge students to put in order photographs of people in various stages of life. Encourage them to notice details of the images and justify their reasoning by identifying features and patterns in each "stage" (e.g. graying hair, smaller size during infancy). If you wish, ask them to repeat the challenge using photographs of stars and nebulae. Noticing details and comparing characteristics of specific images will be a reasonable task, but putting them in order from youngest to oldest will be difficult and frustrating for students. However, the questions raised by this challenge can motivate the concept that stars, like humans, change in predictable ways as they develop, and the idea that this activity will explore the processes that affect a star's structure and appearance throughout its life.

Facilitators may also wish to provide some introductory reflection around students' ideas about stars. Asking students what they think will happen to our Sun in the future or showing them a picture of actual stars in the sky offers concrete motivation and reference for students to think about actual objects in the universe. By providing a brief introductory overview of objects to be explored, facilitators better equip students to delve into the details of the evolutionary story.

Regardless of how the activity is introduced, it is best to explicitly tell students that they are going to create, with their bodies, a model that explains how stars live and die, and re-create, through their interactions with each other, live-action versions of the photographs taken by astronomers. Students represent clumps of gas and dust many times more massive than the Earth. These clumps move and change only when pushed or pulled by interaction with the surrounding clumps of gas (and dust). The kinesthetic activity explores the ongoing interplay between two such influences—gravitational force, and gas pressure generated by fusion in the star's core. To get students used to the idea of impersonating these clumps of gas, show students an image of a star-forming nebula and ask them to visualize what it would be like to live or move inside that cloud. Once they have imagined the setting of their impending dramatization, they will be in a better mindset for immersing themselves in role-play.

Presentation

Five stages of stellar evolution are described and diagrammed below. In each stage, facilitators should provide a brief narration of the science and physical actions that are about to occur, before "starting the clock." It may be instructive to show a poster illustrating the stages of stellar evolution, or to preview an image that the students will recreate at each stage. Once the action begins, students move into the appropriate formation. Facilitators may need to provide more detailed instruction or hands-on guidance to individual students. Once students have completed the action of a stage, they should stop moving while facilitators summarize the process and begin the next segment of narration.

The "description" column in the table below does not represent verbatim narration, but rather a summary of basic principles involved in each stage. In particular, facilitators should emphasize the interplay between the inward force of gravity pulling the star together and the outward force resulting from fusion in the core.

Stage	Description	Action
Star-Forming Nebula [Gravity rules.]	A cloud of gas and dust forms many stars. A single star is created when clumps of this material (mostly hydrogen gas) are pulled together by the force of gravity.	Students, scattered randomly throughout the room, point in the direction where "the most other clumps" are, and slowly make their way to that point.
Birth of the Star (Protostar) [Gravity rules. Fusion begins.]	As a region of the cloud collapses, gravity pulls the clumps of gas together. The gas in the center becomes hot enough and dense enough to begin fusion. Hydrogen atoms inside the clumps smash into each other, combining to create helium and releasing light and heat. The star begins to shine.	Students clump together, forming a large ball. Those on the outside ("envelope") continue to move toward the center. When students on the inside ("core") start bumping into each other, they face outward.
Life of the Star (Main Sequence) [Gravity and thermal pressure from fusion in balance.]	Fusion in the core generates an outward gas and radiation pressure to balance the inward gravitational force from the outer layers.	Core students, arms slightly bent, and envelope students, arms extended, gently push against each other, palm-to-palm, balancing.

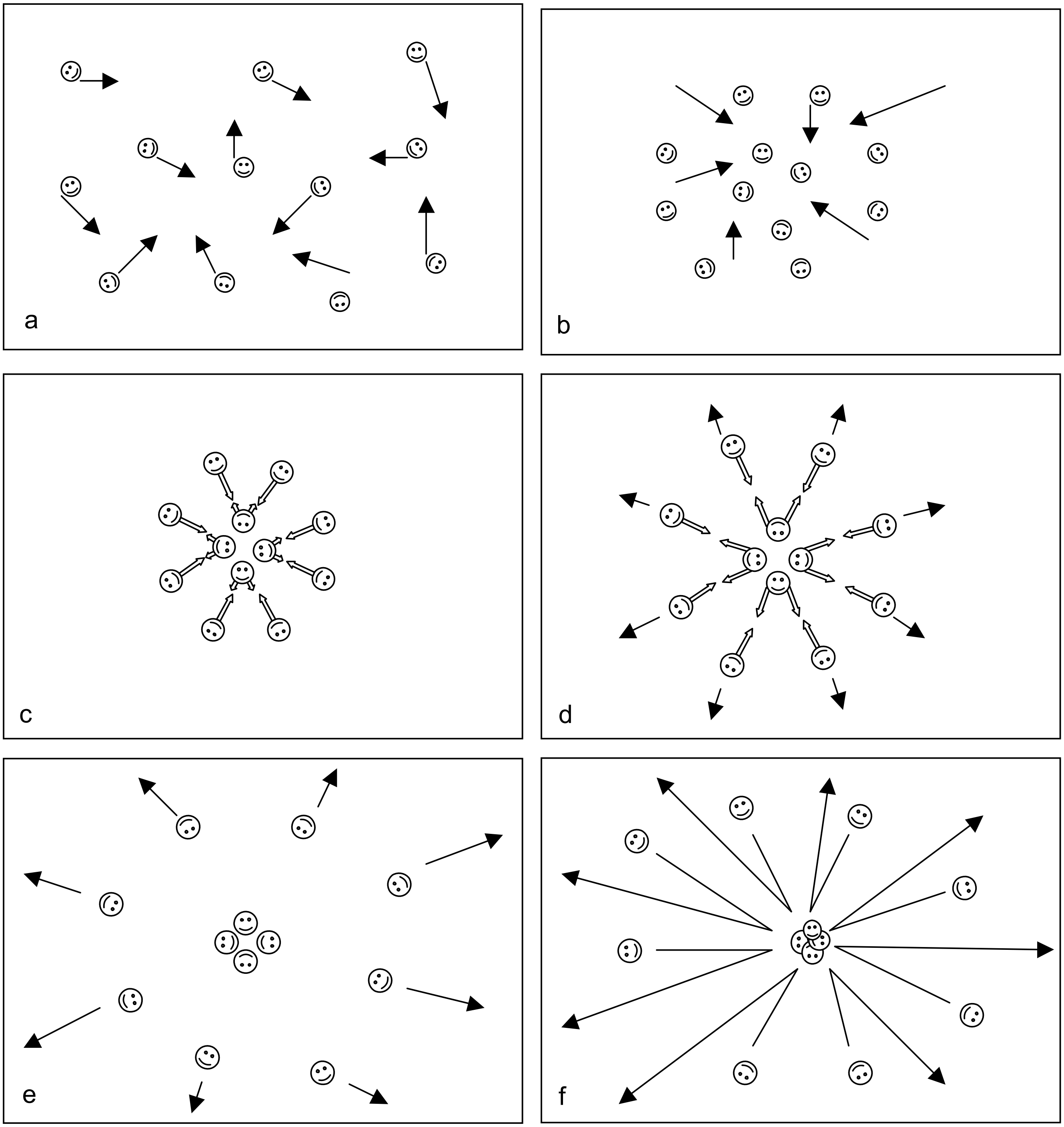
Red Giant [Fusion overtakes gravity.]	As the core nears the end of its fuel supply, the outer layers continue to push inward, increasing the temperature in the core. This produces a new series of fusion reactions that produce enough outward force to overpower the inward gravitational force and expand the star.	Core students fully extend their arms, pushing the envelope students backwards, expanding the star.
Death of a Low-Mass Star (Planetary Nebula with White Dwarf) [Fusion ends; gravity wins.]	As the core runs out of fuel for fusion, it emits one last push outward, ejecting the star's outer layers, which drift away into space. The core then contracts under its own gravity, forming a white dwarf.	Core students push the envelope outward then move together into a tight blob at the center. The envelope students, in a ring-like shape, drift away from the core.
Death of a High-Mass Star (Supernova, with Neutron Star or Black Hole) [Fusion ends; gravity wins.]	The massive core continues to fuse elements and expands the star so it is even larger. Once the core runs out of fuel, it collapses to form a neutron star. The outer layers then collapse as well. As material falls toward the star's center, it bounces off the core and explodes outward through the star. This explosion is called a supernova. In the most massive stars, the collapsed core will become a black hole.	Core students extend their arms, expanding the star. Then, they stop pushing and scrunch together at the star's center. Envelope students rush inward, and bounce off the packed-together students in the core, exploding outward dramatically, revealing the collapsed core.

To transition between the deaths of low- and high-mass stars, facilitators must rewind the clock, to the original star-forming nebula or to the main sequence stage. Recreating all stages of the activity up to the red giant phase, from students' memory, is most effective because it highlights the parallel paths of the two stars and allows students to review and teach back what they have learned.

Additional information and posters about this topic can be found at http://imagine.gsfc.nasa.gov/docs/teachers/lifecycles/stars.html

Illustration of student motion appears on the next page.

Photographs of actual students engaged in the kinesthetic model appear at http://www.flickr.com/photos/24452156@N07/sets/72157605963324609/



a. Star-Forming Nebula (random motion)
b. Protostar (clumping, motion toward the center, core and envelope start to differentiate)
c. Main Sequence (core and envelope pushing in balance)
d. Red giant (core pushing harder, motion outward)
e. Planetary Nebula (core compacted, all other motion outward)
f. Supernova (core compacted, motion inward then outward)

Size and Scale (Where Are Black Holes?)

Activity Description
Students construct a model of our galaxy using birdseed and a cookie, and populate it with black holes. The model represents the size and scale of astronomical objects to create a context for understanding the size, scale, and location of black holes in the Milky Way galaxy.

Original Source
Astronomical Society of the Pacific/Night Sky Network Toolkits: Our Galaxy, Our Universe. Available online at http://nightsky.jpl.nasa.gov/download-view.cfm?Doc_ID=334 (note: the activity presented in the *Black Holes* guide is a simplified version of the online activity)

Materials Needed
- 1 cookie (Oreo or other) per demonstration
- Handful of birdseed (in a plastic bag or film canister)
- Peppercorn
- (Optional) CD with a cotton ball at its center
- (Optional) Accompanying images or Power Point presentation

Background
Because most black holes are formed from the explosion of massive stars, we find black holes in the same places we find stars. Astronomers surmise that our galaxy, like most other large galaxies, contains a million or so stellar mass black holes throughout its disk and one supermassive black hole at its center. Within our Milky Way galaxy, observational evidence only exists for about two dozen of these black holes, partly because we cannot detect black holes that are not "active" and partly because black holes are very small compared with other objects in a galaxy and very far away from Earth. (There are no black holes thought to exist in our solar system.)

Extensions
The Black Hole Survival toolkit developed by the Astronomical Society of the Pacific for the Night Sky Network addresses frequently asked questions about black holes. Download the Power Point presentation "A Galaxy Full of Black Holes" and its accompanying script at http://nightsky.jpl.nasa.gov/download-view.cfm?Doc_ID=260. Also download the Power Point presentation "Real Images of Actual Black Holes" and map of known black holes in our galaxy from http://www.universeforum.org/einstein/resource_journeyblackhole.htm.

Exhibit Connections
Where Are Black Holes?; In Search of Real Black Holes; Got Gravity?

Black Holes: Space Warps & Time Twists was funded by the National Science Foundation, with additional support from the National Aeronautics and Space Administration

Size and Scale (Where Are Black Holes?)

Activity Description

Construct a model of our place in the Milky Way Galaxy and the distribution of stars, with a cookie and some birdseed. Then, populate this mental model with black holes and other astronomical objects.

Activity Background

The activity was initially developed by educators at the Harvard-Smithsonian Center for Astrophysics and the Astronomical Society of the Pacific for use by amateur astronomers at star parties. It has proven to be extremely effective in a variety of venues, including teacher workshops, museums, and classrooms. This text is modified from the professional development DVD "Beyond the Solar System: Expanding the Universe in the Classroom" (available online at http://www.universeforum.org/btss). The activity uses English units rather than metric in order to give visitors an intuitive feel for astronomical scale.

Materials

- 1 Oreo (or other cookie approximately 2 inches in diameter)
- Handful of birdseed (best to keep in plastic bag or film canister)
- Peppercorn
- (Optional) CD with cotton ball at its center
- (Optional) Supplemental images, in Power Point or printed/laminated

Procedure

Follow the steps below to scale the Milky Way galaxy to a 2-inch diameter solar system. The activity includes several parts: setting the scale, populating the model, and making predictions.

Step 1 – The size of the solar system

Supplies: Oreo, given to a volunteer of choice

A prerequisite for this activity is that students have an awareness of the structure of our solar system. The Sun and its family of nine planets is the realm of the familiar universe, and although it is almost impossible to grasp the size and scale of the actual solar system, most people are aware that the Sun and some planets are huge, and that planets are separated by vast distances.

We are going to shrink the size of the Solar System down to the size of an Oreo cookie. Note that the Sun on this scale is an almost microscopic speck of sugar at the center of the cookie—its diameter being roughly 1/10,000 the diameter of the Solar System out to Pluto. The cookie itself defines the flat plane of the planets' orbits around the Sun. Pluto, the outermost planetary object, rolls around the knurled edge of the Oreo.

<u>Step 2 – The size of the Milky Way galaxy</u>

Supplies: CD with a cotton ball at the center

Light takes roughly 11 hours to cross Pluto's orbit from one side of the solar system to the other. Light takes 100,000 years to cross the Milky Way. How does this scale to our Oreo? Depending on the students, this can be done quantitatively or qualitatively.

The Solar System (out to Pluto) is the size of an Oreo cookie

The radius of Pluto's orbit is 4 billion miles = 5.5 light hours = 1 inch (approx.)

At this scale, 1 light year (6 trillion miles) = 133 feet
40 light years = 1 mile

100,000 light years = 2,500 miles or roughly the size of North America.

A spiral galaxy disc such as our Milky Way is typically quite thin compared to its diameter—a ratio of about 1 to 100 (similar to a compact disc). In our model, this translates to a disc thickness of 25 miles (1,000 light years).

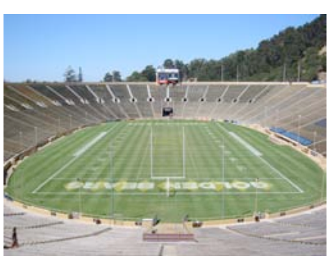
The take-home message for this part of the activity is the huge difference in scale between solar systems (ours and others) and galaxies. Written as an SAT analogy, this relationship would be:

the size of our solar system : the size of our galaxy :: an Oreo cookie : North America

NOTE: It is important to be very explicit that the CD with a cotton ball at its center is NOT the size of the galaxy in this model. Its only purpose is to demonstrate the relative thickness between the Milky Way's diameter and the height of its disk.

<u>Step 3 – The stars in the Milky Way galaxy</u>

Supplies: Birdseed, distributed among volunteers



Our galaxy contains 200–300 billion stars. We can use birdseed to represent the stars. Note that by using birdseed, we have severely exaggerated the size of stars, which are more like small sugar specs than birdseeds. However, birdseed has a tactile quality and is large enough to be held easily and seen individually.

Can we picture 200 billion birdseeds? Take your local sports stadium, and (much to the annoyance of the grounds staff) build a wall 4 feet high around the playing field. Now fill this enclosure with birdseed. That's roughly 200 billion birdseeds.

This birdseed now needs to be distributed within our model. Approximately 1/3 of all stars in our galaxy reside in a central galactic bulge, so 1/3 of the birdseed should be dumped in Kansas. The remaining 2/3 needs to be spread out evenly across North America, 2,500 miles in diameter, and 25 miles thick. Point out that commercial jets fly at 5 miles, or 1/5 of the disc thickness.

Once this is done, the average separation of each seed is approximately two football fields away, in any direction. Our own Sun will be a birdseed floating 8 miles above Buffalo, NY (or a city of choice roughly half way out from the geographical center of North America).

Step 4 – Other Objects in the Milky Way galaxy

Supplies: images and a peppercorn

There is more to a galaxy than stars. It is filled with gas, dust, star-forming regions and has a giant black hole at its center. There are many beautiful images of nebulae and star clusters, but very little concept of scale or location. Here are just a few ideas.

Remember our scale: 1 mile = 40 light years

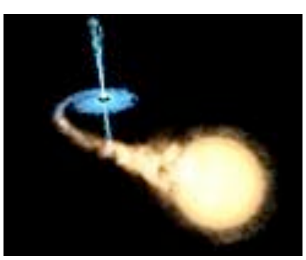
The Orion Nebula (top image), a star-forming region:
40 miles away and 3/4 mile across

Crab Nebula (left image), a supernova remnant:
160 miles away, 1/4 mile across and still expanding

Students can estimate distance and scales of their own favorite objects, perhaps placing them on a map of the North America.

The Milky Way, like most other large galaxies, most likely contains a million or so stellar mass black holes throughout its disc and one supermassive black hole at its center.

Sagittarius A*, the giant black hole at the center of our galaxy, would be the size of a peppercorn in the heart of Kansas.



The stellar mass black holes would be invisible specks, too small to be physically represented in this model. The nearest discovered black hole to Earth is approximately 1,600 light years away (40 miles on our scale).

The two black hole images to the left are artists' illustrations.

Extensions – Using the Model

Human Exploration
Imagine our Sun and solar system contained within that Oreo cookie. The most distant human-made spacecraft is Voyager 1, currently twice as far from the Sun as Pluto. In our model, that is an inch beyond the Oreo's rim.

The nearest star (Alpha Centauri, 4 light years) is the nearest birdseed to ours. If Alpha Cen has a planetary system, we can represent that with a second cookie two football fields away. This extreme separation can be used to discuss topics such as the difficulty of interstellar travel, the challenge of finding planets around other stars, or possibly the likelihood of visits by alien spacecraft.

Making Predictions
Your scale model should be able to reflect aspects of the real sky, such as the distribution of stars. If you look straight up, or straight down, from the point of view of your birdseed above Buffalo, you would see birdseed, but not enough to obscure your view of the ground below or sky above. But if you look toward Kansas, your view would be blocked by a dense band of birdseed. This is the Milky Way—a band of light that is the galaxy's disc seen from the inside.

These exercises were originally placed between steps 3 and 4. The order was modified for the *Black Holes* activity guide to emphasize the size and scale of black holes in our galaxy.

Presentation Tips from the Astronomical Society of the Pacific

- Many people do not know the difference between the solar system, Galaxy, and universe. It is important to establish this difference at the beginning. Many people believe stars are sprinkled among the planets in the Solar System.
- Many people also do not understand:
  - Our Sun is a star; it's just a star that we are very close to. The rest of the stars are tremendously far away.
  - The Solar System is within the Milky Way Galaxy
- Most children and many adults in urban areas have never seen the band of the Milky Way across the sky. Even people who have seen it do not understand that this band they see is the plane of the Galaxy we live in and that all the stars we can see naked eye are within our Galaxy. This activity helps people to understand this concept.
- You must establish with your audience what a light year is. Many people mistakenly use this term as a unit of time rather than a unit of distance.
- This presentation builds a **scale model** of the Milky Way. Some younger visitors may not understand scale models. The Astronomical Society of the Pacific's write-up of this activity contains a recommended strategy for addressing this issue.

Download the full write-up of this activity from the Astronomical Society of the Pacific/Night Sky Network at http://nightsky.jpl.nasa.gov/download-view.cfm?Doc_ID=334

Black Holes Explorer’s Cards

Activity Description
Students use bar code ID cards to create personal web journals by collecting digital artifacts, such as electronic images and audio/video recordings, throughout the exhibition. Be sure to introduce students to these cards before the visit begins and encourage them to collect data for their Explorer’s Journals, to be used in the classroom after their visit.

Original Source
Created for the *Black Holes* exhibition

Materials Needed
- Sample Explorer’s card (image in briefing info)
- Exhibit and journal briefing information
- Access to http://www.BlackHolesExhibit.org/

Background
Cards can be created* at the “Start Here” stations in the exhibition, or pre-printed by museum staff for large group visits. The “Add To Your Journal” station allows card users to preview their web journals, and also send themselves an email reminder with their journal information. A demonstration journal can be viewed at http://www.BlackHolesExhibit.org.

Extensions
Have students use their Explorer’s Card ID numbers to log in to their personalized journals on the *Black Holes* website after your visit! (Data may take up to 24 hours to upload.) The data and discoveries on the journals can be used to prepare a **Report from the Edge** (see next activity—includes journal briefing information).

Exhibit Connections
What Is A Black Hole?; How Do We Find Black Holes?; In Search of Real Black Holes: Take Their Temperature/Explore a Feeding Black Hole/Weigh A Black Hole/Simulate the Universe; Add to Your Journal

** Note to teachers: no identifying information is collected about students using Explorer’s cards, unless they choose to provide their email addresses at the “Add to Your Journal” station.*

Black Holes: Space Warps & Time Twists was funded by the National Science Foundation, with additional support from the National Aeronautics and Space Administration

Exhibit Briefing Information for Teachers

Overview

Black Holes: Space Warps & Time Twists pulls visitors in to the modern search for real black holes—the most mysterious and powerful objects in the universe. A central feature of the exhibition is the visitor's "Explorer's Card" (below) which can be used throughout the gallery to create a personal web journal about black holes. Our research suggests that the personalization provided by these cards can promote more effective usage and learning from the exhibition.

This document provides briefing information about the Explorer's Cards, exhibit components, and the Explorer's Journal, as well as tips for booking a group visit to the exhibition.

Black Holes Explorer's Cards

During their visit, visitors insert their card into various computer stations and collect digital artifacts, such as telescope images or audio/video recordings, from their activity at that station. Each card creates a personal journal with all the digital artifacts collected by the visitor on that card. After leaving the exhibition, visitors use the unique bar code ID on the back of their card to log in to the *Black Holes* exhibit website and see the data and discoveries collected on that card.

For Teachers

Teachers should show their students the card before the visit and brief them about both the cards and the journals. If possible, use the Demo Journal on the *Black Holes* website to show students what sort of data and discoveries they will be collecting. You may wish to provide copies of the exhibit floor plan or walk-through to your chaperones.

If your group is large, museum staff may hand out pre-printed cards to save time and give students more opportunities to explore the exhibit and collect artifacts for their journals. Each card identifies the user through a unique combination of a "nickname" (e.g. Astro Boy; Galactic Girl; Chocolate Star), an "avatar" image, and and ID number. Before entering the exhibition, some students may wish to trade cards with each other to get a card with a nickname they prefer (or if there is time, some may create their own card once they are in the exhibition).

Teachers and chaperones should be sure to remind students that their card is their ticket to accessing their web journal once they leave the exhibit. Note the unique 12-digit ID number on the back of the card. If they lose the card, they lose the login information for their journal!

Exhibit Walk-Through

The tour below highlights the areas where visitors can collect data and discoveries for their web journals, indicated by (*). The journals will be available on the *Black Holes* exhibit website within 24 hours (and sometimes within just a couple of hours) of their visit.

Create Your Black Hole Explorer's Card (*)
At the start of the exhibition, visitors use a touch-screen computer station to choose a nickname and take a digital picture or avatar image to create their own bar-coded *Black Hole Explorer*'s *Card*. Throughout the rest of the exhibit, they can use their Explorer's Card to collect discoveries and generate a personalized website that only they can access (with the PIN number on their card) to share with friends and family. The website serves as part personal diary, part observer's log, and will include data recorded by the visitor including their observations, conclusions, questions, notes, and photos they've captured of their activities within the exhibition. Once visitors are back home, their personal *Black Holes* web journal is also a portal to further online content related to black holes.

What's on the Horizon for Black Hole Research?
In just the last ten years, technological advances in ground-based and space-based instruments have revealed a universe apparently teeming with black holes, and in which black holes play a much greater role in the evolution of the universe than previously imagined. This component comprises a changeable graphic panel and video (updated remotely by Smithsonian Astrophysical Observatory) that highlights a variety of modern black hole research facilities—from the Chandra X-ray Observatory to the CERN Large Hadron Collider. The visitor's online Explorer's Journal provides an opportunity to ask featured "scientists of the month" about these new experiments.

What is a Black Hole? (*)
The strange concept of an object so massive that nothing can escape its gravity was predicted long before any real black holes were ever shown to exist. This interactive visualization lets visitors explore how space and time are distorted near massive objects, and other extremes of gravity predicted by Einstein. What happens to your avatar image as it draws near a black hole?

Where are Black Holes?
Astronomers have discovered evidence of several dozen feeding black holes among the stars within our own Milky Way galaxy. This wall photo of the night sky and Milky Way shows the mapped location of many prominent black holes in our galaxy, using visitor-activated LEDs.

Snapshots in the History of Black Holes
Are space and time constant throughout the universe? Is an inch an inch and a second a second no matter where or when you measure it? This simple question, debated by Shakespeare's characters and in Isaac Newton's day, is a key part of the story of black holes exploration. This multi-sided graphic display presents highlights in our historical understanding of how black holes warp space and stretch time.

In Search of Real Black Holes… Take Their Temperature! (*)
Are black holes hot or cold? If they don't emit any light energy, shouldn't they be cold? But then how do astronomers detect evidence for their presence? At this computer-based interactive, visitors explore gorgeous infrared, visible-light, and x-ray images of nearby galaxies captured by NASA telescopes that detect warm (Spitzer), hot (Hubble), and superhot (Chandra) objects in space. Chandra scientist Dr. Mike Garcia helps visitors discover and record evidence for the hot spots produced by feeding black holes in every galaxy.

In Search of Real Black Holes… Explore a Feeding Black Hole! (*)
Astronomers using radio telescopes have discovered many galaxies that have huge jets of matter streaming in opposite directions, seemingly originating from a tiny region at the center of the galaxy. At this computer station, astronomer Dr. Elizabeth Blanton guides visitors as they investigate and record their thoughts about real astronomical images of these surprising jets created by supermassive black holes at the centers of galaxies.

In Search of Real Black Holes… Weigh a Black Hole! (*)
Guided by black hole researcher Dr. Lincoln Greenhill, visitors at this interactive media station investigate real astronomical data from the Keck telescopes on Mauna Kea, Hawaii. They track the orbits of a cluster of stars whizzing around the center of our own Milky Way galaxy to pinpoint the location of the invisible object causing the stars' motion. Visitors then use a simple orbital model to determine the actual weight of our galaxy's supermassive black hole, and record their results to their online Black Hole Explorer's Journal.

Do Black Holes Matter? Simulate the Universe! (*)
In addition to using telescopes, black hole researchers harness the power of supercomputers to model the formation of galaxies and their resident black holes. This component allows visitors to examine the role black holes play as galaxies collide by investigating a state-of-the-art computer simulation. Visitors compare the scenarios predicted by the computer model to Hubble Space Telescope images of real colliding galaxies.

How Do We Find Black Holes? (*)
Visitors roll steel ball bearings across a table with hidden magnets that distort their paths and try to figure out where the hidden magnets (representing black holes) are located. After completing the activity, visitors record their conclusions on a "map" of the table using a touch screen.

Energy from Gravity
This playful ball machine sculpture by kinetic sculpture artist Jeffrey Zachmann explores the physics of falling and the idea that gravity provides the energy that powers the amazing phenomena around black holes.

Got Gravity? (Black Holes Grow by Eating) (+)
At this teen-developed activity, visitors use one of two different-sized spherical nets (representing black hole event horizons) to capture swirling lightweight foam nuggets (representing matter in our galaxy) to "feed" their black holes.

What's Inside a Black Hole?
This video component presents a compelling visualization of a theoretical journey into a black hole created by astrophysicist Andrew Hamilton. The video is based on actual calculations, using our current understanding of gravity. But since the known laws of nature break down at the center of a black hole, the deeper we fall into the hole in this simulation, the more speculative the view.

Is It True What They Say About Black Holes? (+)
At this teen-developed media station, visitors select a video clip related to black holes from a variety of movies and television shows and make a guess as to the scientific accuracy of the clip before receiving a teen guide’s explanation of scientists’ answers to the same question.

Black Holes Inspire Our Imagination
This display panel explores the role black holes have played in pop culture, as metaphors and as fodder for art, music, and literature.

Black Hole Adventure (*)
Visitors enter one of three “excursion pods” and embark on a fantasy “adventure vacation” to the black hole at the center of our galaxy. There they rendezvous with a mysterious alien wreck containing virtual artifacts to add to their journals. As they make their way toward this “deep space dive,” visitors explore the phenomena around the black hole, including warped space, the slowing of time, and the dangerous magnetic fields and radiation that could leave them stranded on their cosmic adventure. Before they return (and in case they don’t!), visitors record a video message about their trip for their journal.

Black Hole Explorers: Add to Your Journal (*)
At this station visitors can request images of objects in space that harbor black holes, using a real robotic telescope that will take their image that night. They can also send a black hole-themed e-card, ask a question of that month’s featured black hole scientist, or preview their online journals. The results of these activities will be visible on their journals the next day.

Beyond the Exhibit Gallery
After the visiting the exhibit, visitors can use their Explorer’s Card to further explore black holes through their personalized exhibit web pages. In addition to visitors’ own digital artifacts, each website includes interviews with scientists, games, videos, and educational materials, as well as links to ongoing research about black holes and black hole science.

Exhibit Floor Plan
When you book your visit to *Black Holes* ask the museum staff if they have a copy of the exhibit floor plan for their museum. They should be able to provide this, along with an example of the Explorer’s Card to show your students.

Black Holes Explorer's Journal

The personalized web journals created by students in the exhibition can be accessed within 24 hours at http://www.BlackHolesExhibit.org/. To log in, students will need the unique ID number on the back of their Explorer's Cards. When they log in to the journal area of the website, data and discoveries will have been automatically organized into four sections of the journal: My Models, My Evidence, Adventures, and More to Explore. Each section contains a reminder about specific activities in the exhibit, the predictions and artifacts created by the visitor at these stations, and links to related content about black holes.

The journal artifacts can be previewed inside the exhibition at the "Add to Your Journal" stations. A walk-through is provided in the "Report from the Edge" activity in this guide.

Sample Journal Page (My Models, landing page)

Remember: If you lose your card, you also lose your login information!

Report from The Edge

Activity Description
This activity builds on the web journals created by visitors to the *Black Holes* exhibition. Using the data and discoveries collected during the visit, students create a personal report of their predictions and conclusions about the presence of black holes in our universe.

Original Source
Created for the *Black Holes* exhibition school program

Materials Needed
- *Black Holes* Explorer's cards with bar code login ID on the back (from exhibit visit)
- Access to exhibit website at http://www.BlackHolesExhibit.org/
- Journal briefing information and walk-through, if needed

Background
An important goal of the *Black Holes* exhibition is to help visitors explore the nature of science through the study of real black holes in our universe. The Explorer's ID Cards created at the "Start Here" stations are the ticket to this investigation. Every time a student uses his or her card in the exhibition, a piece of data is sent to his or her online Explorer's Journal. The journal has organized these digital artifacts into three main categories (Models, Evidence, and Adventures) and added links and connections to bonus features that will help visitors make sense of the discoveries they have made. And important theme in the exhibit is the process of making predictions and testing them using models and evidence.

Extensions
Rather than creating a traditional science research-style report, students can apply their findings through language arts, technology, or performing arts activities. Ask students to synthesize their findings by creating a class-wide newsletter/paper, podcast, or television broadcast to share their experience in a more playful way. An example of a creative interpretation of black hole science is the Black Hole Adventure station in the exhibition itself—the journey to the black hole at the center of the Milky Way is, of course, impossible, but the station uses real science to inform the fantasy cruise. How might an explorer report back from this adventure?

Exhibit Connections
The whole exhibit, but especially the stations connected to the Explorer's Journal network: What Is A Black Hole?; How Do We Find Black Holes?; In Search of Real Black Holes: Take Their Temperature/Explore a Feeding Black Hole/Weigh A Black Hole/Simulate the Universe; Add to Your Journal

Black Holes: Space Warps & Time Twists was funded by the National Science Foundation, with additional support from the National Aeronautics and Space Administration

Journal Walk-Through

A demo journal is available at http://www.BlackHolesExhibit.org/. The tour below provides a "site map" and description of what you will find in your journal. Remember, the more data you collect in the exhibit, the more personalized your journal will be!

My Models
Black Holes in Theory: Models and Simulations – Explore your discoveries about black hole phenomena. Where do they come from? What do they do to objects and space around them? Scientific models help us test theories and explain evidence.

- Black Holes Modeling Lab
- How Do We Find Black Holes?
- Supernova Model
- Simulate the Universe
- Youth Media Connections

My Evidence
Real Black Hole Data: Evidence and Observations – Compare your black hole predictions to the evidence you collected "in search of real black holes." Are black holes hot or cold? What do they weigh? Do they swallow everything that falls toward them?

- Taking a Black Hole's Temperature
- Explore a Feeding Black Hole
- Weigh a Black Hole
- Youth Media Connections

My Adventures
Black Holes in Imagination: Galactic Adventures – See what happened on your adventure to the black hole at the center of our Milky Way Galaxy. View your snapshots, video postcard, and souvenirs. If you managed to collect treasure from the deep space dive, that will be here too!

- Your Black Hole Adventure
- Black Holes in Pop Culture
- Youth Media Connections

More to Explore
Interactive features for extending and sharing your *Black Holes* experience – See the artifacts you requested at the "Add to Your Journal" station and collect some more! Send an e-card, ask a scientist a question, or take an image of a black hole target with a real telescope. Features include:

- Observing Black Holes with NASA
- Ask a Scientist a Question
- Greetings from a Black Hole

Remember: Until you log in and register on the *Black Holes* website, your card number is the only way of accessing your journal. Do not lose your card!

Science Fiction or Fact

Activity Description
In this activity, students examine representations of black holes from selected movies and television shows. For each clip examined, students should discuss which elements are science fact and which are science fiction.

Original Source
Sonoma State University and the Denver Museum of Nature and Science's Educator's Guide for the planetarium show *Black Holes: The Other Side of Infinity*. Available online at http://fermi.sonoma.edu/teachers/blackholes/index.php

Materials Needed
- Pages 16-17 from the DMNS/SSU Educator's Guide (included)
- Supplemental teacher's guide to analysis of the *Black Holes* media clips (included)
- DVDs or video clips
- Chart paper or whiteboard and markers (if desired)

Background
When *Black Holes* was first being developed, it was obvious that the exhibition would need to include references to science fiction and popular culture. A group of high school students developed an interactive computer activity to explore common misconceptions about black holes through representations in movies and television. After choosing the clips, they created a survey, which was sent out to professional astronomers to weigh in on the accuracy of the scientific ideas presented. The students were surprised to discover that not all of the chosen representations were completely inaccurate! Although each of the clips chosen includes elements of fiction, most of them also include kernels of scientific truth. Another surprising result of the survey was how astronomers' different perspectives colored how they viewed or interpreted each clip. This exercise, like the activity in the exhibit, challenges participants to think critically about how scientific knowledge is represented in a variety of media.

Extensions
This activity was originally created to accompany the planetarium show *Black Holes: The Other Side of Infinity*. It has been expanded to include the video clips presented in the *Black Holes* exhibition. Students may have other clips they wish to explore.

Exhibit Connections
Is It True What They Say About Black Holes?; Black Holes Inspire the Imagination; What's Inside a Black Hole?

Black Holes: Space Warps & Time Twists was funded by the National Science Foundation, with additional support from the National Aeronautics and Space Administration

Section III
Travel Inside the Black Hole at the Center of the Milky Way

Accompanying presentation name:
bh_eduguide_sec3.ppt

Essential Question:
- Can black holes be used to travel through spacetime?

Students will learn…
- that wormholes only exist according to mathematics
- there is no observational evidence for wormholes
- that space can be warped

Activity 4

Duration: 30 minutes

Materials:
Power point or videos with the following movie clips:
- *Contact*: Produced by Warner Brothers 1997: start time: 1:51:20 stop time: 1:59:39
- *Ren & Stimpy Episode: Black Hole* Original Production Number-RS06a

THE OTHER SIDE OF INFINITY BLACK HOLES

Science Fiction or Fact

Brief overview:
In this activity students will analyze various clips from movies and cartoons and decide what is science fact and what is science fiction.

Background Information

Wormholes are a staple of science fiction shows like Star Trek. Although they are never clearly explained on TV, the characters use them to travel from one place to another very quickly, without having to travel through the intervening space. In the public mind, wormholes are then like tunnels or shortcuts through space.

Note: It should be stressed that at the moment, wormholes are firmly in the realm of science fiction. While they are theoretically possible according to Einstein's equations dealing with space and time, in reality there are a number of physical reasons they almost certainly cannot exist. So while they are a fun concept, and useful to get away in a hurry from angry Klingons, they likely exist only in the imagination of mathematicians.

One of the most mind-bending results of Albert Einstein's work using relativity to describe the Universe is that space itself, can act like a fabric. Objects like planets, stars, even us, are embedded in it. We think of gravity as a force that attracts objects to each other, but Einstein envisioned it as a bending, or warping of space. The amount of warping depends on how much mass there is in one place. The bending of space is what we feel as gravity, which is what attracts other masses. The way to think of this is: Matter tells space how to bend, and the bending of space tells matter how to move.

In a black hole, space is bent to the breaking point. It's almost like an infinitely deep hole in space (see activity "The Gravity of the Situation (around black holes)"). Another bizarre prediction of Einstein's equations is that two black holes can "join up," connect through the fabric of space, creating a tunnel between them. This tunnel reminded scientists of the channel left by a worm as it eats its way through an apple, so these became known as "wormholes."

If wormholes were real, you could enter a black hole (presumably in your spaceship), pass through the tunnel, and come out "the other side", having traveled to a point perhaps thousands of light years away without having to bother to go through all that space between the two points.

However, in order to physically pass through a wormhole, you would have to survive the maelstrom of swirling matter and infinitely dense compression that occurs at the singularity – the very center – of the black hole. We don't know of any way to do this, and so it's almost certainly true that travel through a wormhole is not physically possible. This chaotic region inside the black hole is shown near the end of the planetarium show, and the narrator mentions that if you hit it, you're dead. However, from there, the planetarium show "turns off" this aspect of a black hole, mathematically ignoring the destruction inside, so that you can see what would happen if you could actually pass through the black hole and into the wormhole. In reality, we wouldn't be able to turn off these extremely turbulent and destructive forces, so any normal matter would be destroyed long before it reached the singularity, preventing travel through it into the wormhole.

Procedure:

1) The procedure for each video clip is the same. It is best to show the Ren and Stimpy clip first then follow it with the Contact movie clip. Before showing the clips, ask the students to take notes while watching the clip, carefully noting what they think is real and what is science fiction.

2) After each clip, list on the board the "Science Fact" and the "Science Fiction" items the students came up with. After collating each list discuss how this fits into what has been viewed in the planetarium show and what they have learned so far. In the "assessment" section below we have listed the "Science Fact" and the "Science Fiction" for each clip.

3) Overall, the best closing discussion here is that the cartoon, which we all know is not real, has a more scientifically accurate depiction of black hole physics than the movie Contact.

Assessment:

Ren & Stimpy Episode: Black Hole Original Production Number- RS06a

Science Fact	Science Fiction
If a ship could approach a black hole the only thing one could do is scream. Everything would be destroyed due to the strong gravitational field.	Cartoon and characters
Matter spirals into the black hole.	We do not yet have the technology to send space ships to black holes – the nearest one is much too far away.
Spaceship gets stretched out due to tides as it nears the black hole.	Ship would not spring back into shape right before being swallowed by black hole.

Contact, produced by Warner Brothers 1997: start time: 1:51:20 stop time: 1:59:39

Science Fact	Science Fiction
Wormholes are mathematically plausible but physically unrealistic.	We do not yet have the technology to send space ships to black holes – the nearest one is much too far away.
	We do not know how to make a transportation device as depicted in this movie clip.
	We have no observational evidence that supports the depiction of a wormhole that looks like the one in this clip.

Science Fiction or Fact:
Is It True What They Say About Black Holes?

A teacher's guide to analysis of the *Black Holes* media clips

- *The Ren & Stimpy Show*
- *Treasure Planet*
- *The Simpsons*
- *Galaxy Quest*
- *Donnie Darko*
- *The Black Hole*

The charts below are modeled after the template in the SSU/DMNS Educator's Guide and informed by astronomers' responses to surveys conducted during the development of the "Hollywood Presents Black Holes" component. They are not comprehensive. (That is, various elements of fact or fiction may be present in the clip, but not represented in these charts.)

These "answer keys" are for teacher's reference only. Students should create their own charts, based on their experience in the *Black Holes* exhibition and follow-up research. Challenge them to think critically about each clip and support their conclusions with evidence. In many cases, the discussion will be even more important than the particular scientific conclusion.

Although each chart focuses on the particular question asked about each clip in the exhibit, some additional analysis is included. Students may wish to expand their research by exploring additional questions about their chosen clip(s). Even if research is conducted individually, be sure to build in time for group discussion.

Clip Information: *The Ren & Stimpy Show*, Episode 6, "Black Hole" (00:00:00 – 00:02:00)
Question Asked: Do objects get distorted when approaching a black hole?
Scientist Response: 89% True, 11% Partly True, 0% False

As the analysis in the SSU/DMNS Educator's Guide concludes, this clips is a fairly accurate representation of the stretching of objects as they fall towards a black hole. Scientists' main criticisms of this portrayal were admittedly minor: the inconsistencies in the black hole's effect on the ship versus the characters, and the omission of the effects of general relatively on the appearance of the black hole's disk and on the motion of the spacecraft.

Science Fact	**Science Fiction**
Deformable objects would get stretched out ("spaghettified") due to the strong tidal forces near a black hole	The characters and ship were not ripped apart as a result of the stretching (spaghettification)
The force on the front of the spaceship would be greater than the force on the back	The ship takes on a spherical shape as it is stretched
Destruction would be inevitable	A viewer observing from a distance would see the ship move
	The screams were not Doppler shifted

Clip Information: *Treasure Planet* (00:38:22 – 00:39:59)
Question Asked: Do black holes form when a star explodes as a supernova?
Scientist Response: 86% True, 14% Partly True, 0% False

It is easy to miss the comment at the beginning of the clip, exclaiming that the fictional star Pelusa is exploding, but this is a fair portrayal of the supernova phenomenon. Astronomers were careful to note that not all stars explode at the end of their lives, and not all such explosions result in a black hole. To do so, Pelusa would have to be about 100 times the mass of the Sun.

Science Fact	Science Fiction
When the most massive stars explode, their cores collapse to form a black hole	Any exploding or dying star will create a black hole
Supernovae create shock waves in space	A space ship could outrace the ejected debris
Remnants of the explosion are accreted into a disk around the black hole	A wooden ship could survive the intense radiation from the explosion (shock wave)
(Some) black holes have spinning disks of gas around their event horizon	Characters could breathe in space

Clip Information: *The Simpsons*, Ep. 134, “Treehouse of Horror VII” “Homer[3]” (19:30 – 21:04)
Question Asked: Do black holes grow in size?
Scientist Response: 90% True, 10% Partly True, 0% False

The physical representation of the black hole in this clip was inaccurate (black holes are more spherical than funnel-like), as was the scale at which the characters were interacting with it. However, black holes do grow in size, by accreting matter from nearby gas or stars, or by merging with another black hole. This clip is very popular with both visitors and scientists.

Science Fact	Science Fiction
Black holes can gain mass by swallowing matter	Black holes are shaped like large, deep pits or funnels
As a black hole's mass increases, so does its size	Black hole grow in size quickly
A black hole would destroy any objects falling towards it before they reached the center	Homer and Bart were able to get very close to the black hole and walk away
A black hole would stretch objects falling toward it	Homer disintegrated when he fell into the black hole
	A black hole can be created by a puncture

Clip Information: *Galaxy Quest* (01:27:18 – 01:28:18)
Question Asked: Is the physical portrayal of the black hole in this movie accurate?
Scientist Response: 5% True, 67% Partly True, 28% False

The physical portrayal had some technical errors (for example, the disk around a black hole would appear warped due to extreme gravity) but the image of a star being stripped of matter by a nearby black hole was basically accurate. The biggest objections scientists had to this clip were the shape of the black hole (it should have been spherical rather than waterfall-like) and the fact that the space ship traveled through the black hole and existed on "the other side."

Science Fact	**Science Fiction**
(Some) black holes have disks of matter swirling around them	Disk was perfectly flat with a non-spherical event horizon at its center
Black holes accrete matter from companion stars	A space ship could go into a black hole and come back out
Ship was stretched as it fell toward the black hole	Black holes are synonymous with wormholes
Everything moves toward the center of the black hole	Gas around a black hole behaves like a waterfall

Clip Information: *Donnie Darko* (01:38:49 – 01:40:00)
Question Asked: Can humans control time using wormholes?
Scientist Response: 6% True, 18% Partly True, 77% False

This clips equates black holes and wormholes, but they are not the same thing. Wormholes are theoretical, predicted by mathematical equations of gravity, but there is no observational evidence that they exist. The existence of black holes is well supported by strong observational evidence.

Science Fact	**Science Fiction**
Wormholes are mathematically possible	There evidence that wormholes exist
Traveling faster than the speed of light would allow for backward time travel	Wormholes or black holes can be controlled by humans and used to travel through time
Traveling near the speed of light would allow for forward time travel	Black holes and wormholes are the same thing
	Humans can travel near or above light speed
	Wormholes are stable passageways

Clip Information: *The Black Hole* (opening sequence, 00:05:05 – 00:06:15)
Question Asked: Are black holes monsters?
Scientist Response: 35% True, 41% Partly True, 24% False

Astronomers' responses to this clip were very philosophical. A common theme was the questioning of the word "monster." Some of these thought-provoking responses are below.

Science Fact	**Science Fiction**
Most of the scientific statements in this clip were true, except for…	…the entire universe will be swallowed up by a black hole
Black holes exist in nature	We can see black holes directly
Black holes can be destructive	Black holes are malevolent

- Allowing, for the purposes of this question, that a "monster" is any creature poorly understood and dangerous to humans when mishandled, then yes, I'd agree with the clip. Just about all the statements in the clip seem to agree with current knowledge of the physics of black holes. The theorizing that the entire universe could end up in a black hole is nearly impossible, due to conservation of angular momentum, but has a basis of truth -- that there may be enough black holes around that all gravitating mass could eventually end up in one of these black holes. It would take a *really* long time....
- Black holes get a bad rap, just like great white sharks. They are wondrous forces of nature, best observed and admired from a distance! A monster is also something we don't understand and are afraid of. We are learning more about black holes all the time, and that makes them less scary and more fascinating.
- They don't really want to hurt anyone. They are part of the grand design.
- Black holes aren't "monsters" in the common sense of the word, implying an evil, malevolent entity [that] actively destroys planets and stars for sheer amusement. But it could be said that some of them are "monstrously big", particularly the supermassive black holes that inhabit the centers of galaxies and have masses billions of times the mass of our sun. But "monsters"? No.
- One dictionary definition of a monster is: "an animal, plant, of other organism having a structural defect or deformity", or a creature with a frightening appearance. In the sense that a black hole is a star with a structural defect, it is a monster. However, it is not an animal, plant or another organism so the dictionary definition does not apply.
- Meaningless statement. As far as we know, the existence of black holes is a fact of nature. Some of their aspects may seem 'destructive' to some people, other aspects 'creative'. Let's take a more nearby example: are volcanoes 'monsters'? They can certainly have destructive effects when they erupt, but they also create new islands and have other significant geochemical impacts. It wouldn't mean much to call them 'monsters'.
- I said "partly" true because "monster" is not a quantitative estimate, so we should agree on what is means. It is certainly a monster in the common sense of the word, but I don't like these kind of definitions, because they are not "scientific" and scientific language is what we should like to transmit to young students. Furthermore, it is a "monster" if you fall into it, but it could be an "angel" if you look at its wonderful light from a safe distance (as we do in our observations of quasars...)
- [It] depends what you mean by a monster. They are big/ They are quite destructive if you get close. They are inescapable if you are close…but they don't have horns and fangs! :-)

The information below accompanies the use of these clips in the *Black Holes* exhibition:

Hollywood Presents Black Holes was conceived of and developed by the Youth Astronomy Apprentices at the MIT Kavli Institute for Astrophysics and Space Research.

The Past, Present, and Future of Black Holes

Activity Description
After investigating a particular black hole experiment or telescope, students design a presentation, poster, essay, or other creative project to share some aspect of their investigation.

Original Source
Sonoma State University and the Denver Museum of Nature and Science's Educator's Guide for the planetarium show *Black Holes: The Other Side of Infinity*. Available online at http://fermi.sonoma.edu/teachers/blackholes/index.php

Materials Needed
- Pages 18-21 from the DMNS/SSU Educator's Guide
- Activity Supplement with additional telescopes and experiments to explore
- Access to websites and articles about the students' chosen investigations
- Supplies for student projects and reports

Background
Since the early eighteenth century physicists and philosophers have hypothesized about strange objects that challenge our understanding of space and time. In the early 1900s scientists like Albert Einstein and Karl Schwarzchild began to conceive of black holes in a modern way—as distortions of space and time manifested through real objects in space. In the decades that followed, new theories and observations gave way to evidence for real black holes in nature. Beginning with the first x-ray space probes in the 1960s, scientists have been scanning the skies to collect new evidence and refine their models of how black holes work. Today, telescopes and experiments on the ground and in space reveal uncover new information and new questions at an unprecedented rate, setting the stage for an even more exciting and productive future in black hole research.

Extensions
This activity was originally created to accompany the planetarium show *Black Holes: The Other Side of Infinity*. It has been expanded to include the scientific investigations featured in the *Black Holes* exhibition.

Exhibit Connections
Snapshots in the History of Black Holes; What's On the Horizon for Black Hole Research?; In Search of Real Black Holes: Take Their Temperature; In Search of Real Black Holes: Weigh a Black Holes; In Search of Real Black Holes: Explore a Feeding Black Hole

Black Holes: Space Warps & Time Twists was funded by the National Science Foundation, with additional support from the National Aeronautics and Space Administration

Section IV
The Search for Black Holes

Accompanying presentation name:
bh_eduguide_sec4.ppt

Essential Question:
- What can we learn from black holes?
- If black holes are black, how can we find them?

Students will learn…
- black holes are a laboratory in space-time for which scientists can study the great mysteries of the universe.
- science is a never ending process that is constantly revised and improved upon.
- black holes will give us a better understanding of the structure and evolution of the Universe.
- how we find and/or detect black holes.

Activity 5

Duration: 2 class periods

THE OTHER SIDE OF INFINITY
BLACK HOLES

The Past, Present, and Future of Black Holes

Brief overview:

This activity allows students to investigate the different missions and observations that deal with black hole science. This activity asks students to use their creativity to design a presentation about these various topics.

Procedure:

1. Discuss the last two questions ("What can we learn from black holes?" and "If black holes are black, how can we find them?") in the "Commonly Asked Questions about Black Holes" section on page 6.

2. Hand out the student handout. As a homework, individual in-class, or group assignment instruct the students to do one of the following.

   a. Create a presentation that describes one or more of the black hole missions or observations.

   b. Make a poster that explains the past or future black hole missions or observations.

   c. Write an essay about the NASA science missions or any other observational projects.

   d. Be creative; create/design something that will aid a presentation on this topic.

3. In order to complete this project, the students will have to research their topics online. The information provided in the handout is not sufficient to complete the project; this is only enough to give them a start.

4. After they have created their projects, have the students give their presentations. After each presentation, lead a discussion about how this relates to what they have learned about black holes and what additional questions they have about future science discoveries.

Extension activities

GLAST Race game:
http://glast.sonoma.edu/teachers/race.html

Black Hole Board game (Universe Forum):
http://cfa-www.harvard.edu/seuforum/einstein/resource_BHExplorer.htm

Advanced students – GRB Activity #2:
http://swift.sonoma.edu/education/index.html#grb

Student Worksheet
The Past, Present, and Future of Black Holes

Your presentation can be one of the following.

Create a presentation that describes one or more of the black hole missions or observations.

Make a poster that explains the past or future black hole missions or observations.

Write an essay about the NASA science missions or any other observational projects.

Be creative; create/design something that will aid a presentation on this topic.

Please include in your presentation:

- Information about the space mission or observation. For the space mission this should include its name, the origin of the NASA mission's name, what the mission is doing or has done and why. If it's an observational project, include the observer's name (or team names), where it was done, what instruments and techniques they used, and why they did it.
- Discoveries that were made about black holes.
- Discoveries the science community hopes to make with this mission or observation project.

Mission Articles:

Uhuru Explorer Satellite

Uhuru was the first earth-orbiting mission dedicated entirely to celestial X-ray astronomy. It was launched on 12 December 1970 from Kenya (the name "Uhuru" is Swahili for freedom, so-named in honor of the anniversary of Kenyan independence). During its two year mission, it created the first comprehensive and uniform all-sky X-ray survey. It expanded the number of known cosmic X-ray sources to more than 400, which included many black holes, seen in X-rays for the first time.

Uhuru web site at Goddard Space Flight Center:
http://heasarc.gsfc.nasa.gov/docs/uhuru/uhuru.html

Einstein Observatory

Einstein, was a NASA mission which launched on November 13, 1978 and operated for more than two years. It was named after Albert Einstein, whose theories predicted many of the extreme phenomena, such as black holes, that were studied by this mission. It was the first X-ray mission to use focusing optics and relatively high-resolution detectors. Its sensitivity was several hundred times greater than any previous X-ray astronomy mission. During its mission it detected many black holes, and saw for the first time X-ray jets from the supermassive black holes in the centers of galaxies Cen A and M87.

Einstein web site at Goddard Space Flight Center:
http://heasarc.gsfc.nasa.gov/docs/einstein/heao2.html

Hubble Space Telescope

Hubble, launched in April 1990 and still operating today, was nicknamed "The Black Hole Hunter" because of its ability to see gas and stars very close to black holes in the centers of galaxies. It is named after the famous astronomer Edwin Hubble, who first discovered that fuzzy patches of stars in the sky were actually entire galaxies, separate from our own. Its sensitivity using both images and spectroscopy allowed astronomers to map out black holes with unprecedented clarity in ultraviolet, optical, and near-infrared light. It was able to confirm the presence of black holes in many nearby galaxies, and its observations were critical in the discovery that every large galaxy has a central supermassive black hole.

Web resources:
NASA Hubble web site:
http://hubble.nasa.gov/index.php
Hubble outreach site:
http://hubblesite.org/

Chandra X-ray Observatory

NASA's Chandra X-ray Observatory (named in honor of the brilliant astronomer Subrahmanyan Chandrasekhar who was the first to make important calculations about the masses of white dwarfs and neutron stars), was launched onboard the Space Shuttle Columbia on July 23, 1999 and is still operating today. The combination of high resolution, large collecting area, and sensitivity to higher energy X-rays makes it possible for Chandra to study extremely faint sources. Chandra's contribution to black hole astronomy is simply huge. It has mapped thousands of black holes in nearby galaxies, allowing astronomers to see them with unprecedented detail. Its observations confirmed the discovery of intermediate black holes, a new class of black holes with masses from 100 – 1000 times the mass of the Sun. It has studied X-ray emission from the accretion disks around black holes, and from the jets coming from them as well.

Web resources:
Chandra X-ray Center:
http://cxc.harvard.edu/
Chandra Education and Public Outreach site:
http://chandra.harvard.edu/

XMM-Newton Observatory

The X-ray Multi-mirror – Newton mission, launched in December 1999 and still operating today, is especially designed to obtain spectra of X-ray sources such as black holes. It is named in honor of Sir Isaac Newton, the first person to write down equations that accurately described classical gravity. It has studied in detail the X-ray emission from accretion disks around black holes, as well as X-rays from the black holes in active galaxies, and from gamma-ray bursts. It has spied matter as it swirls around black holes just moments before falling in, X-rays from the supermassive black hole in our Milky Way Galaxy, as X-rays from thousands of black holes in other galaxies.

Web resources:
XMM-Newton ESA science site:
http://sci.esa.int/science-e/www/area/index.cfm?fareaid=23
Education and Public Outreach pages:
http://xmm.sonoma.edu/index.html
Goddard Space Flight Center's XMM-Newton page:
http://heasarc.gsfc.nasa.gov/docs/xmm/xmmhp_aboutxmm.html

Swift Explorer Satellite

The Swift mission investigates the almost unimaginably violent explosions called gamma-ray bursts, tremendous supernovae and voracious black holes gobbling down matter at fantastic rates. Swift is a NASA satellite with international collaboration launched on November 20, 2004, and is still operating today. Swift's primary mission is to observe gamma ray bursts, extraordinary explosions of matter and energy that astronomers think signal the births of black holes. These explosions, as huge as they are, fade very rapidly, so Swift must react quickly to study them. The satellite moves so quickly that astronomers decided to name it Swift, after a bird that can dive at high speed to catch its target. It is one of a very few NASA missions that has an actual name and not an acronym!

Web resources:
Swift project site: *http://swift.gsfc.nasa.gov/docs/swift/swiftsc.html*
Swift education and public outreach site: *http://swift.sonoma.edu/*

GLAST

The Gamma-ray Large Area Space Telescope (GLAST) is a NASA satellite with international collaboration planned for launch in 2007. Astronomical satellites like GLAST are designed to explore the structure of the Universe, examine its cycles of matter and energy, and peer into the ultimate limits of gravity: black holes. GLAST detects gamma rays, the highest energy light in the electromagnetic spectrum. GLAST is expected to detect gamma rays from thousands of supermassive black holes in the cores of galaxies that are emitting jets that are pointed towards Earth.

Web resources:
GLAST Project Site at Goddard Space Flight Center: *http://glast.gsfc.nasa.gov/*
GLAST Education and Public Outreach site: *http://glast.sonoma.edu/*
GLAST Large Area Telescope (LAT) Collaboration: *http://www-glast.stanford.edu/*
GLAST Burst Monitor (GBM): *http://f64.nsstc.nasa.gov/gbm/*

Ground-based Observations of Black Holes

Professor Andrea Ghez (UCLA) uses adaptive optics – a technique which sharpens the images from the telescope by correcting for the turbulence of the Earth's atmosphere – on the Keck telescope to image the stars near the center of our Milky Way galaxy. These observations, taken over a ten year period, reveal stars moving at incredibly high speeds, and their orbits indicated that there is a very massive but invisible object at the center of our Galaxy. The mass of this object was calculated to be 4 million times the mass of our sun. The only object known that can be that massive, confined to a relatively small region, but still dark, is a supermassive black hole.

Report by UCLA Astronomer Andrea Ghez at AAAS :
http://universe.nasa.gov/press/2003/030218a.html
Black Hole Encyclopedia:
http://blackholes.stardate.org/directory/factsheet.php?id=1
Keck Observations about the Milky Way:
http://www.keckobservatory.org/news/old_pages/andreaghez.html
UCLA Galactic Center Group:
http://www.astro.ucla.edu/~jlu/gc/pictures/index.shtml

Additional Resources:

History of X-Ray Astronomy:
http://chandra.harvard.edu/chronicle/0202/40years/index.html
List of high-energy satellite missions:
http://heasarc.gsfc.nasa.gov/docs/heasarc/missions/
History of X-Ray Astronomy Field Guide:
http://chandra.harvard.edu/xray_astro/history.html

The Past Present and Future of Black Holes
Activity Supplement

The following research explorations are described in the DMNS/SSU Educator's Guide. Many of these telescopes are also featured in the *Black Holes* exhibition.

- Uhuru Explorer Satellite
- Einstein Observatory
- Hubble Space Telescope
- Chandra X-ray Observatory
- XMM-Newton Observatory
- Swift Explorer Satellite
- Fermi Space Telescope (formerly known as GLAST)
- UCLA Observations with the Keck Telescope

Students may also be interested in the following telescopes and experiments, highlighted in the "What's On the Horizon for Black Hole Research?" kiosk (along with several of the telescopes mentioned above). The descriptions below are taken from this display.

Current Projects

LHC & LIGO

Large Hadron Collider

Can the collision of subatomic particles produce microscopic black holes? The Large Hadron Collider at the European Organization for Nuclear Research (CERN) is testing new theories about the basic forces that shape our universe.

Physicists have theorized that protons in the early universe could have collided to produce miniature black holes. Researchers at the LHC are attempting to recreate these primordial conditions by colliding beams of high-energy protons in a 27-kilometer tunnel deep underground.

If a miniature black hole were created in the detector, it would decay instantly to various particles via a process known as Hawking radiation. This decay would leave behind telltale tracks on the detector. It would also support theories that space may have more than three dimensions.

The Large Hadron Collider is one of the most eagerly awaited experiments of the 21st century!

Web resources: http://public.web.cern.ch/public/en/LHC/LHC-en.html

Laser Interferometer Gravitational-Wave Observatory

Einstein predicted that cataclysmic events in space – like the collision of two black holes – would release vast amounts of energy in the form of gravitational waves. These ripples in the very fabric of spacetime travel out into space like the ripples from a stone tossed into a pond.

Gravitational waves have yet to be detected directly, but the race is on! LIGO, the Laser Interferometer Gravitational-Wave Observatory, consists of two widely-separated detection facilities in Louisiana and Washington state.

The LIGO detectors, funded by the National Science Foundation, are pushing the limits of technology. In order to detect the gravitational waves produced by violent events thousands of light years from Earth, LIGO must be sensitive to vibrations much smaller than the width of an atom!

21st century gravitational wave experiments will provide information about the nature of gravity that cannot be obtained by any other astronomical tools.

Web resources: http://www.ligo.caltech.edu/

Future Projects

JWST, IXO & ALMA

James Webb Space Telescope

Scheduled to launch in 2014, the James Webb Space Telescope (JWST) will study some of the earliest stars and galaxies that formed in the universe. Scientists believe that these first stars were very massive and formed black holes when they exploded as supernovae. Did these early black holes form the seeds for the supermassive black holes we see in the centers of galaxies today?

By studying these early stars and galaxies and comparing them to the galaxies we see today, JWST will shed light on the formation and growth of galaxies and the role black holes play in these processes.

The JWST project is an international collaboration between NASA, the European Space Agency, and the Canadian Space Agency. More than 1000 people in 17 countries are involved in its development.

Web resources: http://www.jwst.nasa.gov/

International X-ray Observatory

The next generation of black hole astronomy is now being planned. An international team of scientists and engineers from NASA, the European Space Agency (ESA), and Japan's Aerospace Exploration Agency (JAXA) is developing a new X-ray telescope, proposed for launch in 2021.

The International X-ray Observatory (IXO) will use new X-ray optics and detector technologies to study many aspects of black holes – from the event horizons of stellar mass black holes to the giant jets emitted by supermassive black holes – in unprecedented detail.

What happens close to a black hole? When and how did supermassive black holes grow? How do black holes affect the structure and evolution of galaxies?

IXO will build on the discoveries of today's X-ray telescopes to help answer many emerging questions in modern astrophysics.

Web resources: http://ixo.gsfc.nasa.gov/

Atacama Large Millimeter/submillimeter Array

No one has yet seen a black hole directly. Over the next few years, astronomers using large networks of short-wavelength radio telescopes will attempt to image the dark event horizon of the giant black hole at the heart of our Milky Way galaxy.

The Atacama Large Millimeter/submillimeter Array (ALMA) is an array of 66 radio antennae being built in the high mountain desert of the Chilean Andes. With ALMA's superior resolving power, astronomers will study the dusty regions surrounding galactic cores, looking for evidence of active black holes heating up the dust.

When combined with other millimeter-wavelength telescopes around the globe, ALMA may actually resolve the event horizon of the supermassive black hole in our galaxy's center. This feat is equivalent to being able to see a football on the surface of the Moon – from Earth!

Web resources: http://www.almaobservatory.org/

Supplemental Activities

Stellar Evolution Activities *(Extension to Kinesthetic Life Cycle of Stars)*

Chandra Education Center (Chandra X-ray Observatory)
http://chandra.harvard.edu/edu/formal/stellar_ev/

Imagine the Universe! (NASA Goddard Space Flight Center)
http://imagine.gsfc.nasa.gov/docs/teachers/lifecycles/stars.html

Amazing Space (Hubble Space Telescope)
http://amazing-space.stsci.edu/eds/tools/topic/stars.php

Black Hole Presentations *(Extension to Size and Scale)*

A Galaxy Full of Black Holes
http://nightsky.jpl.nasa.gov/download-view.cfm?Doc_ID=260

Real Images of Actual Black Holes
http://www.universeforum.org/einstein/resource_journeyblackhole.htm

Additional Activities

Observing With NASA: Control a Telescope
Take real images of a black hole target: http://mo-www.cfa.harvard.edu/OWN/

Black Hole Explorer Board Game
http://www.universeforum.org/einstein/resource_BHExplorer.htm

Education Resources on the *Black Holes* Website
http://web-bh.cfa.harvard.edu/ATE_education/BH_education.aspx

Fermi Black Holes Resource Area
http://fermi.sonoma.edu/teachers/blackholes/index.php

Imagine the Universe! Black Holes Information & Activity Books
http://imagine.gsfc.nasa.gov/docs/teachers/blackholes/blackholes.html

Black Holes: Space Warps & Time Twists was funded by the National Science Foundation, with additional support from the National Aeronautics and Space Administration

Additional Resources

Recommended Reading

Black Holes and Time Warps: Einstein's Outrageous Legacy
By Kip Thorne. Published 1994 by W W Norton & Company.
Recommended for general adult readers.

Icarus at the Edge of Time
By Brian Greene. Published 2008 by Random House.
Recommended for children.

Gravity's Fatal Attraction: Black Holes in the Universe
By Michael Begelman and Martin Rees. Published 1998 by W. H. Freeman.
Recommended for science educators.

Recommended Websites

Learn More on the *Black Holes* Exhibit Website
http://web-bh.cfa.harvard.edu/LearnMore/learn_more.aspx

Black Holes: Gravity's Relentless Pull
http://hubblesite.org/explore_astronomy/black_holes/

Black Hole Encyclopedia
http://blackholes.stardate.org/

No Escape: The Truth About Black Holes
http://amazing-space.stsci.edu/resources/explorations/blackholes/

Black Hole Images from the Chandra X-ray Observatory
Black holes: http://chandra.harvard.edu/photo/category/blackholes.html
Active galaxies: http://chandra.harvard.edu/photo/category/quasars.html

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