

Black Hole Educator Guide

The following educational guide is designed to accompany the viewing of the *Black Holes: The Other Side of Infinity* planetarium show produced by the Denver Museum of Nature and Science (DMNS) in conjunction with the National Science Foundation (NSF) and the National Aeronautics and Space Administration's Gamma-ray Large Area Space Telescope (GLAST) mission. The distributor of this show is Spitz Incorporated (<http://www.spitzinc.com/index.html>).

This educator guide has been produced by the NASA Education and Public Outreach (E/PO) Group located at Sonoma State University (SSU) in partnership with the DMNS. The SSU E/PO group supports both the GLAST mission (<http://glast.sonoma.edu>) and the Swift gamma-ray burst explorer mission (<http://swift.sonoma.edu>). The launch of Swift on November 20, 2004 is featured at the beginning of the planetarium show.

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About This Guide

National Science Education Standards



About this guide

This guide addresses many misconceptions and questions that commonly arise when discussing and learning about black holes, and has several classroom activities that will help students understand this exciting topic. The information provided in this guide includes additional resources for educators and students to further their knowledge about black holes. Also provided with this guide is a CD that contains PDF versions of all activities and PowerPoint presentations for each topic section. An electronic version of this guide and its accompanying presentations can be downloaded from <http://glast.sonoma.edu/teachers/blackholes>. This guide can be used for educators and students in grades 7-12.

This guide is split into four sections for ease of use. A presentation for each section has been created for your convenience and is provided on the accompanying CD. The sections included in this guide are:

- *Section I* - The Formation of Black Holes
- *Section II* - The Gravity of the Situation (around black holes)
- *Section III* - Travel Inside the Black Hole at the Center of the Milky Way
- *Section IV* - The Search for Black Holes

National Science Education Standards (NSES)

Unifying Concepts and Processes:

As a result of activities in grades K-12, all students should develop understanding and abilities aligned with the following concepts and processes:

- Systems, order, and organization
- Evidence, models, and explanation
- Constancy, change, and measurement
- Evolution and equilibrium
- Form and function

Content Standards: 5-8	Content Standards: 9-12
<ul style="list-style-type: none">• Science as Inquiry<ul style="list-style-type: none">- Abilities necessary to do scientific inquiry- Understandings about scientific inquiry• Physical Science<ul style="list-style-type: none">- Properties and changes of properties in matter- Motions and forces- Transfer of energy• Earth and Space Science<ul style="list-style-type: none">- Earth in the solar system• Science and Technology<ul style="list-style-type: none">- Understandings about science and technology• Science in Personal and Social Perspectives<ul style="list-style-type: none">- Science and technology in society• History and Nature of Science<ul style="list-style-type: none">- Science as a human endeavor- Nature of science- History of science	<ul style="list-style-type: none">• Science as Inquiry<ul style="list-style-type: none">- Abilities necessary to do scientific inquiry- Understandings about scientific inquiry• Physical Science<ul style="list-style-type: none">- Structure and properties of matter- Motions and forces- Conservation of energy and increase in disorder- Interactions of energy and matter• Earth and Space Science<ul style="list-style-type: none">- Origin and evolution of the universe• Science and Technology<ul style="list-style-type: none">- Understandings about science and technology• History and Nature of Science<ul style="list-style-type: none">- Science as a human endeavor- Nature of scientific knowledge- Historical perspectives

Black Holes: The Other Side of Infinity

Planetarium Show Content Overview



They're one of the most intriguing and mysterious phenomena in the universe, places where time and space are warped to the extreme, and nothing – not even light – can escape the pull of their ferocious **gravity**. Black holes once defied the imagination. But now, the more scientists look for evidence of them, the more they find, and the more they learn about the role of black holes in the Universe. *Black Holes: The Other Side of Infinity* is a stunning presentation of the latest science about black holes visualized using supercomputing technology. The show whisks audiences to a place humans can never venture – to the center of a black hole.

The Search for Black Holes

Though we can't see black holes in the traditional sense, we know they exist because of the telltale signs they emit. The Swift space telescope detects **gamma-ray bursts** that erupt when a black hole is formed after a large star dies in a massive explosion called a **supernova**. In *Black Holes: The Other Side of Infinity*, we learn what triggers this chain of events is gravity, a force so powerful at its most extreme that it can actually warp the fabric of the cosmos.

The Formation of Stellar Mass Black Holes

Black Holes: The Other Side of Infinity leads us through the process of black hole formation by focusing on a particular class of stars called red supergiants. Much more massive than our sun, these stars lead short, violent lives, truncated by the crush of gravity. The star's core becomes so dense that it collapses in on itself. The ensuing catastrophe powers a titanic supernova ex-

pllosion that rocks the cosmos. Left in its wake is a black hole, an object more massive than the Sun,

yet concentrated into a volume millions of times smaller – literally a puncture in the fabric of the cosmos. The gravity of the black hole is so intense, resisting it would be like trying to paddle against the current of a river plunging toward a waterfall. Anything that crosses the black hole's point of no return, its **event horizon**, cannot escape.

Supermassive Black Holes

Though these regular black holes seem fearsome enough, there are others that are even more immense and mind-boggling. These supermassive black holes are millions to billions of times more massive than our Sun. Scientists now believe these supermassive black holes exist in the centers of **galaxies**. *Black Holes: The Other Side of Infinity* shows us how these supermassive black holes form, and how astronomers have detected the presence of one at the center of our own Milky Way galaxy by studying the behavior of the stars around it.

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

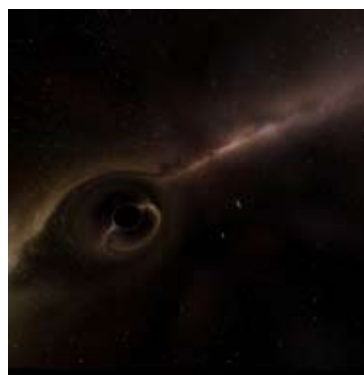
What if we could take a trip into the supermassive black hole at the center of the Milky Way? It's a physical impossibility for humans, but for the first time *Black Holes: The Other Side of Infinity* creates this journey with scientific accuracy, using a course plotted by the observations of astronomers and guided by the equations of Einstein. What we find is a bizarre realm, a maelstrom of light, matter, and energy unlike anything we've ever seen or experienced before.



When galaxies collide, the supermassive black holes at their centers merge into a single black hole of staggering size.



Inside a black hole, a swirling maelstrom of space, time, and energy await the unfortunate traveler.



The gravity of a black hole is so intense that it warps space, twisting light like a giant lens.

How do black holes affect things near them?

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

The gravity from a black hole is only dangerous when you're very close to it. Surprisingly, from a large distance, black hole gravity is no different than the gravity from a star with the same mass. The strength of gravity depends on the mass of the object and your distance from it. If the Sun were to become a black hole (don't worry, it's way too lightweight to ever do that), it would have to shrink so much that its event horizon would be only 6 km (4 miles) across. From the Earth's distance of 150 million km (93 million miles), we'd feel exactly the same gravity as we did when the Sun was a normal star. That's because the mass didn't change, and neither did our distance from it. But if we got up close to the black hole, only a few kilometers away, we'd definitely feel the difference!

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

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

Astronomers have found another amazing thing about galaxies: the stars in the inner parts of a galaxy orbit the galactic center faster when the galaxy's central supermassive black hole is more massive. Since those stars' velocities are due to the mass in the inner part of the galaxy – and even a monster black hole is only a tiny fraction of that mass – astronomers conclude that the total mass of the inner region of a galaxy is proportional to the (relatively very small) mass of its central black hole! It's as if the formation of that black hole somehow affected the formation of the billions of normal stars around it.

What happens when you fall into a black hole?

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

The gravity you feel from an object gets stronger the closer you get. As you approach a stellar-mass black hole feet-first, the force of gravity on your feet can be thousands of times stronger than the force on your head! This has the effect of stretching you, pulling you apart like taffy. Tongue-in-cheek, scientists call this "spaghettification." By the time you reach the black hole, you'll be

a thin stream of matter many miles long. It probably won't hurt though: even falling from thousands of kilometers away, the entire gory episode will be over in a few milliseconds.

You may not even make it that far. Some black holes greedily gobble down matter, stealing it from an orbiting companion star or, in the case of supermassive black holes, from surrounding gas clouds. As the matter falls in, it piles up into a disk just outside the hole. Orbiting at huge speeds, the matter in this **accretion disk** gets extremely hot—even reaching millions of degrees. It will spew out radiation, in particular high-energy X-rays. Long before the black hole could rip you apart you'd be fried by the light. But suppose you somehow manage to survive the trip in. What strange things await you on your way down into forever?

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

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

For more about these topics see section II

Can black holes be used to travel through spacetime?

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

But that's fiction. In reality, this probably won't work. Black holes twist space and time, in a sense punching a hole in the fabric of the Universe. There is a theory that if this happens, a black hole can form a tunnel in space called a **wormhole** (because it's like a tunnel formed by a worm as it eats its way through an apple). If you enter a wormhole, you'll pop out someplace else far away, not needing to travel through the actual intervening distance.

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

For more about these topics see section III

What can we learn from black holes?

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

As matter falls into a black hole, it heats up and emits X-rays. By studying how black holes emit X-rays, scientists can learn about how black holes eat matter, how much they can eat, and how fast they can eat it – all of which are critical to understanding the physics of black holes. Current data indicate we may be missing as many as 80% of the black holes in the Universe because of interstellar dust which obscures our view. Future missions which can peer through this dust will give astronomers a more accurate census of the black hole population. What happens at the very edge of a black hole, where light cannot escape, where space and time swap places, where even Einstein's General Relativity is stretched to the breaking point? Black holes are a natural laboratory where we can investigate such questions.

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

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



NASA/CXC/M. Weiss

About the background information

The preceding information has been adapted from the *Black Holes: From Here to Infinity* fact sheet produced by the SSU E/PO group and the supplemental informational materials produced by the Denver Museum of Nature and Science. The fact sheet is intended for distribution at the planetarium show. If you did not receive a copy of the fact sheet at the show, you may download it from: <http://glast.sonoma.edu/materials.html>.

The informational materials can be found at:

<http://www.dmns.org/main/en/Professionals/Press/CurrentPressReleases/Press+Releases/Planetarium/blackHolesPressKit.htm>

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

The black hole itself may be invisible, but the ghostly fingers of its gravity leave behind fingerprints.

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

As described above in “What happens when you fall into a black hole?”, if a black hole is “eating” matter from a companion star, that matter gets very hot and emits X-rays. This is like a signature identifying the source as a black hole. That's why astronomers build spacecraft equipped with special detectors that can “see” in X-rays. In fact, black holes are so good at emitting X-rays that many thousands can be spotted this way. The first black hole, Cygnus X-1, was identified using data from the first X-ray satellite, Uhuru, in 1972. Since then, many other x-ray satellites have studied black holes, both within our galaxy, the Milky Way, and in the cores of distant galaxies. NASA's Chandra Observatory has found indications of black holes in practically every galaxy that it has studied in detail. And these “supermassive” black holes in distant galaxies often emit jets of particles and light that stretch out over tens of thousands of light years.

When these jets are aimed directly at Earth, we can see gamma rays – light even more energetic than X-rays – beaming right at us. In fact, galaxies with gamma-ray emitting jets are the most commonly observed extragalactic source of high-energy gamma rays. And NASA's GLAST mission should detect thousands of these types of galaxies.

For more about these topics see section IV

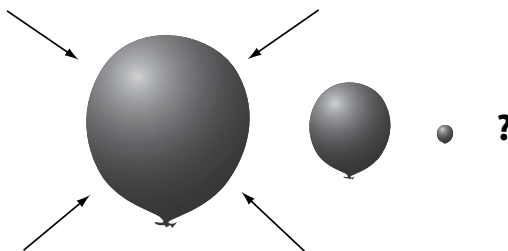
THE OTHER SIDE OF INFINITY BLACK HOLES

Aluminum Foil, Balloons, and Black Holes

Brief Overview:

This activity will allow students to conceptualize what happens when a star

collapses into a black hole, and to gain the following understanding: whatever the mass is inside a black hole, it is not made up of matter as we know it. It is not protons, neutrons, and electrons. They will also get to practice their skills involving exponential notation, circumference, volume, and density!



Procedure:

Before you begin the activity, the following is required:

1. Review the life cycle of a massive star:

<http://xmm.sonoma.edu/lessons/background-lifecycles.html>

2. Discuss what a black hole is and introduce the concept of an event horizon

3. Derive the equation for the event horizon radius (also called the Schwarzschild radius, $R = 2GM/c^2$) from the Newtonian escape velocity equation ($V_{esc} = (2GM/R)^{1/2}$).

[Note: this derivation is not really accurate; the fact you can do it using classical mechanics is a coincidence, but it's OK to do it here]

4. Prepare students to consider mind-blowing concepts: something with no size, but with mass; an imaginary surface which once you cross inside, you cannot get back outside it ever again.

5. Tell students that they are going to attempt to make a black hole with aluminum foil and balloons in this lab. They are going to determine what radius, mass, and density it takes to make this aluminum foil balloon (that will represent a star) into a black hole.

6. Before you begin this lab, blow up the balloon until the diameter is about 15 cm, no larger. Tie off the end. Tell students that this is the core of the star. Cover the inflated balloon with several sheets of aluminum foil. These layers of foil represent the outer layers of your "Model Star." Be generous with the foil and cover the balloon thoroughly. It works best if you use several 30-35 cm long sheets and wrap them around at least twice. Students should construct their own model stars using the materials. On their worksheets, students record their initial measurements of mass and circumference.

7. You are now ready to simulate the enormous mass of the star collapsing inward toward the core. You can tell students that their hands are the "Giant Hands of Gravity." Students will find all sorts of inventive ways to pop their balloons, if a simple squeeze doesn't work for them (the sharp end of a pen or pencil works well). Caution them that they will need to gently shape the aluminum foil back into a "sphere" once they have popped the balloon, however. So they should not stomp on it or do anything that will make it lose its basic round shape. Caution – This is the first trial measurement of a series of 4, so don't squish it so hard you will not be able to see a change in the data gathered in subsequent trials. Students continue filling their worksheets by making successive measurements of the circumference and mass, and they calculate the radius, volume, and density.

Section I The Formation of Black Holes

Accompanying presentation name:
bh_eduguide_sec1.ppt

Essential Questions:

- What is a black hole?
- How do black holes form?
- Where are black holes located?

Students will learn...

- how black holes form.
- how supernova and neutron stars play a role in the birth of black holes.
- what classes or types of black holes there are.
- where scientists have observed black holes

Activity 1

Duration: 40 minutes

Materials:

- Round balloons
- Aluminum foil
- Balance or scales (best if can measure to at least 0.1 grams)
- Cloth (or flexible plastic) tape measure
- Student worksheet

Activity 1 is an adaptation of the Aluminum Foil, Balloons, and Black Holes activity from the *Imagine the Universe! Anatomy of the Black Hole Educator Guide* which can be found at:
<http://imagine.gsfc.nasa.gov/docs/teachers/blackholes/blackholes.html>

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8. By this time, students should be noticing that the mass is really not changing as they squeeze the ball into a smaller and smaller size.

9. Students should notice that as they go to smaller and smaller radii, the densities increase. In most trials seen by the authors, the change in density between the inflated balloon and the smallest size is about a factor of 100.

10. Use the equation $R=2GM/c^2$, where R is the radius of the event horizon, M is the mass of the black hole, G is the universal gravitational constant, and c is the speed of light. $G = 6.67 \times 10^{-8} \text{ cm}^3/\text{g-sec}^2$ and $c = 3 \times 10^{10} \text{ cm/sec}$. This equation gives R, the radius of the event horizon for a black hole of mass M. Think about what this equation says: for any mass, it can be a black hole if it can get small enough. Finding a force to make you small enough is the difficult part! For a typical balloon and foil assembly of 30 grams, the radius it would become a black hole is about

$4 \times 10^{-27} \text{ cm}$. At that size, the density would be about $9 \times 10^{79} \text{ g/cm}^3$!

11. The densest thing students will probably be able to come up with or have any knowledge of is a proton or neutron. Remind them that once you start talking about atoms, they are mostly empty space... with essentially all of the mass in the nucleus. So lead and iron and such are not very dense compared to a proton or neutron. The density of a nucleon (either a proton or neutron) is about $1.5 \times 10^{15} \text{ g/cm}^3$. Comparing this to our collapsed star density as it becomes a black hole, we see that there is no comparison! Our conclusion is this: we may not understand what matter is like inside a black hole, but we know that it is not matter as we know it. It is not protons, neutrons, and electrons – it is not any atom or molecule. We may not be able to conceive of what it may be, but we know what it isn't!



Student Worksheet

Aluminum Foil, Balloons, and Black Holes

Name _____

Date _____

Materials needed per group:
 three 30-35 cm sheets of aluminum foil, 1 balloon, 1 tape measure, 1 scale (that weighs to a tenth of a gram), 1 calculator

Trial	Circumference	Radius	Volume	Mass	Density = $\frac{m}{V}$
1					
2					
3					
4					

Procedure:

1. Blow up the balloon until the diameter is about 15 cm. Tie off the end. Cover the inflated balloon with the sheets of aluminum foil. This will be your “Model Star.”
2. Measure the circumference of the aluminum foil star. Repeat this 3 times, using 3 different paths around the star. Calculate the mean of these 3 measurements. In your data table, record this average value as Trial 1 Circumference.
3. Place the Model Star on the scale. Record the mass (grams) under Trial 1 Mass.
4. Now Supernova! Break your balloon by squeezing it. Gently shape the aluminum foil back into a “sphere”. Measure the circumference of the now collapsed Model Star three times. Average these 3 measurements. Record the value as the Trial 2 Circumference.
5. Obtain the mass of the collapsed Model Star and record the value as Trial 2 Mass.
6. Squeeze the collapsed star a little more. Repeat the procedure for determining the new average circumference and record your data as Trial 3.
7. Repeat the mass measurement and record your value appropriately.
8. Squeeze the collapsed star so that you make it as small as you possibly can. Repeat the circumference and mass measurements and record that data. For each circumference, calculate the radius of the sphere. Remember, this is done by dividing the circumference by 2π . Record the results appropriately in your data table.
9. Now calculate the volume $[(4/3)\pi r^3]$ of the sphere for each radius.

Activity 2

Duration: 60 minutes

Materials for each group of 2 or 3 students:

- Styrofoam ball (1.5 inch or 4 cm in diameter)
- 2 toothpicks
- 1 lightweight sheet of construction paper
- 1 heavier weight sheet of construction paper
- 3 pages of blank or bond white paper
- scissors
- compass
- ruler
- cellophane tape
- colored pencils or pens

(The following activity is an adaptation of the Building Perspectives with Active Galaxies activity from GLAST Education and Public Outreach Group's *Active Galaxy Educator Guide* located on this website:

<http://glast.sonoma.edu/teachers/teachers.html#agn>)

Building Perspectives with Active Galaxies

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Brief Overview:

This activity explains a bit more about what we know about Supermassive Black Holes, mainly the idea that we view them from different angles and these different views are what define the names that scientists have given them. Students will build a model of an active galaxy. From this, they will learn about the geometry of the components of the galaxy and understand that different viewing angles lead to dramatically different appearances of the galaxies.

Background Information:

The type of active galaxy (AG) we see depends on the way that we see it. If we see the accretion disk and gas torus edge on, the galaxy is called a radio galaxy. The torus of cool gas and dust blocks most of the radiation from the inner black hole and its nearby environment, so the most obvious features are the radio emitting jets and giant lobes well outside the galaxy.

If the disk is tipped slightly to our line of sight, we can see higher-energy light from the accretion disk inside the gas torus in addition to the lower energy radio waves.

This kind of AG is called a Seyfert galaxy (named after American astronomer Carl Seyfert, who first catalogued these galaxies in 1943). It looks much like a normal galaxy but with a very bright core, and may be giving off high-energy photons like Xrays. If the galaxy is very far away from us, we may see the core as a star-like object even if the fainter surrounding galaxy is undetected. In this case, the galaxy is called a quasar, which is short for quasi-stellar radio source (so-named because the first ones discovered appeared to be star-like through a telescope, but emitted copious radio waves, unlike "normal" stars). The first quasar to be discovered, dubbed 3C273, was found to be a galaxy at a very large distance by astronomer Martin Schmidt in 1963.

If the tip angle is 90 degrees, we can be looking straight down a jet. This type of active galaxy is called a blazar. From blazars we see very high-energy gamma ray photons. The first blazar to be discovered, BL Lac (and after which we get the term "blazar") was found in 1926 to change in brightness, but was thought to be a normal star! It wasn't until the late 1970s that its galactic nature was truly revealed.

In sum, the basic components of an active galaxy are: a supermassive black hole core, an accretion disk surrounding it, and a torus of gas and dust, and in some (but not all!) highly focused jets of matter and energy. The type of active galaxy we see depends on the way we see the galaxy: radio galaxies, Seyferts, quasars and blazars.

Procedure:

1. Introduce the activity by using the information in the activity Background Information.

2. Discuss these questions with the students before starting the activity:

Do objects look the same from all angles? Are they recognizable from all angles?

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For example, it's not difficult to recognize a book from almost any viewing angle. But is every object like that? How do we recognize objects if viewed from unfamiliar angles? How do we categorize unfamiliar objects if seen from different angles?

3. Explain to the students that they will be building a model of an active galaxy from a Styrofoam ball, construction paper, toothpicks and tape. This model will help them answer the questions on the worksheet. The model building can be done in groups of two or three.

4. Have the students make observations of the model, then sketch them as viewed from different angles. This should be done individually.

Extension Activities:

Compare and contrast the students' drawings to those on the GLAST Active Galaxies Poster (<http://glast.sonoma.edu/images/agn.html>) for the different viewing angles. Discuss how this activity changes their perspectives about how they view and interpret what they see in the Universe.

Additional Extension activities

Tasty Active Galaxy Activity – AGN #1 for younger students:

<http://glast.sonoma.edu/teachers/agn/popup/tastyagnea05.pdf>

Stellar Evolution Activity from Chandra :

http://chandra.harvard.edu/edu/formal/stellar_ev/

Lesson Adaptations:

Visually impaired students may have difficulty constructing the models and drawing them. Put the model in their hands, and let them note by touch how the model feels different if they can only access one part of it at a time (for example, a single cone/jet). They can examine how the model feels different if they keep their hand flat, fingers extended, and can only touch the model that way. In that example, the opening of the cone will feel like a circle, and the torus will feel flat. Have them describe how limiting their ability to touch the model limits their ability to identify its parts.

Answer Key for “Building Perspectives with Active Galaxies”

- 1) 1.5 inches or 4 cm
- 2) If the conical paper jet is properly constructed, it will obscure the Styrofoam ball (black hole).
- 3) For a 4 cm diameter Styrofoam ball, the minimum width of the strip should be 4 cm (1.5 inches).
- 4) If D is the outer diameter of your disk, then the circumference of the torus is πD . For an 8 cm disk, the circumference is then $8 \approx 25.1$ cm
- 5) This answer will depend on the student. In general, looking straight down the jets will hide the black hole, accretion disk and torus. From an angle, the black hole, accretion disk and torus will be visible, and the jets will be elongated. The far jet may be difficult to see. From the side, the black hole and accretion disk are again hidden, this time by the torus. Both jets will be visible and about the same size.

Student Worksheet

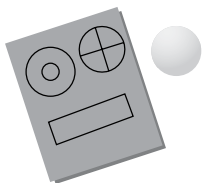
Building Perspectives with Active Galaxies

A. Making a Model of an Active Galaxy

The styrofoam ball represents the black hole at the center of the active galaxy. In the next few steps, you are going to make an accretion disk, cones that represent the jets of the active galaxy, and the torus that surrounds the accretion disk.

1. Accretion Disk: Measure the diameter of your ball, just to be sure of the size. Note the size both in inches and centimeters here (1 in = 2.54 cm)

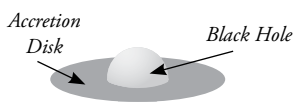
Question 1: Diameter: _____ (in)
_____ (cm)



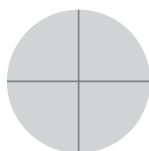
1. What you need



2. Cut out annular disk inner circle



3. Assemble annular disk and styrofoam ball



4. 20 cm circle

With your compass, draw a circle with the diameter of your styrofoam ball on the heavier weight construction paper. Using the same center, draw a concentric circle with twice the diameter. Cut the large circle and then cut out the inner circle to make an annular disk (a ring with a hole in the center). Gently work the styrofoam ball through the inner circle of your annular disk until it is exactly in the middle. This is your accretion disk! You can draw a swirling vortex on it and label "accretion disk" or other appropriate descriptive words that describe the properties of the disk.

2. Jets: With your compass, draw a circle 20 cm in diameter on the lightweight construction paper. With your ruler, draw 2 perpendicular lines through the center as shown. Cut the circle out and cut it in half. Each semicircle will be rolled into a cone to make a jet. Hold the half circle so that the drawn line is on the inside of the cone. Curl up the inner edge of the paper to the drawn line to make your cone. Tape the outside edge.

Make sure the apex of your cone is nice and tight so you can stick it to the styrofoam ball with a toothpick. When you have made both jets, attach them to the styrofoam ball by piercing the apex with a toothpick and sticking the cones symmetrically on the ball above and below the accretion disk.



5. Cut the circle in half



6. Roll it into a cone



7. Tape the edge to form a cone. Repeat 6 & 7 with the other half of the 20 cm circle



8. Attach the cones to the styrofoam ball

Question 2: Look down a jet. Does it obscure the black hole?

Question 3: Using the diameter of your Styrofoam black hole ball you measured above, what is the minimum height your torus strip of paper should be?

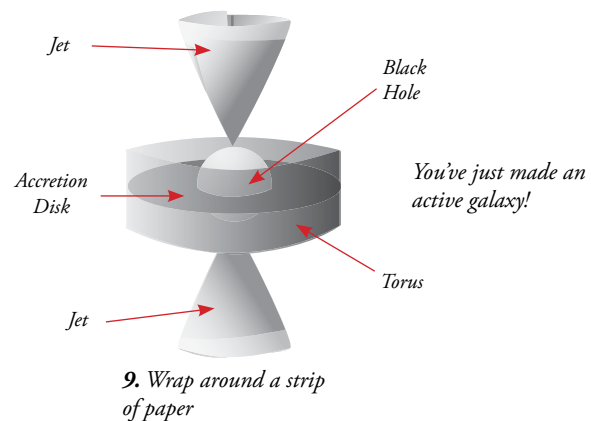
Torus height: _____ (in)
_____ (cm)

Question 4: What should be the length of your torus strip of paper so that it will exactly wrap the accretion disk? In other words, what is the circumference of your accretion disk? (circumference of a circle = $2 \pi r$)

Torus length: _____ (in)
_____ cm)

3. Torus:

Using your ruler, mark the dimensions of your torus strip on the lightweight construction paper and cut it out. Color and label the strip with descriptive terms and then wrap it around the accretion disk so that it has equal height above and below the plane of the disk. When viewed edge on, the torus should obscure the accretion disk and the black hole. Attach it to the accretion disk with tape.



B. Drawing the Active Galaxy Model from Different Perspectives

View your active galaxy model from the following three views:

1. Down a jet
2. At an angle to the jet (not 90 degrees!)
3. 90 degrees from the jet

Question 5: On a separate sheet of paper, sketch what you see from those three angles. Describe how they are alike and how they are different. Attach your drawings to this worksheet before you hand in your work.

Section II

The Gravity of the Situation (around black holes)

Accompanying presentation name:
bh_eduguide_sec2.ppt

Essential Questions:

- How do black holes affect things near them?
- What happens when you fall into a black hole?

Students will learn...

- how massive objects bend the fabric of space-time
- how gravity depends on mass
- what would happen if our sun was replaced by a black hole.
- how black holes are detected by scientists.

Activity 3

Duration: 30 minutes

Materials:

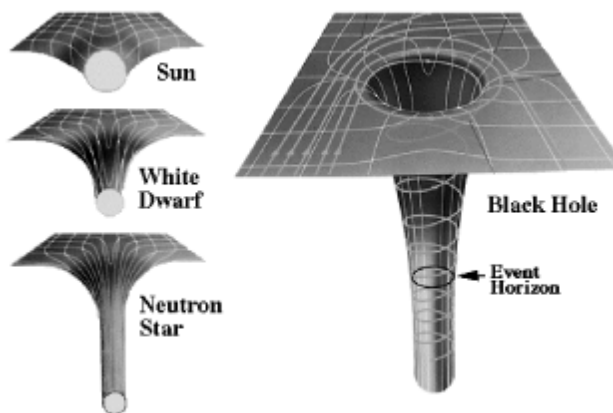
- Embroidery Hoops -23 ½ inches (60 cm) diameter
- Latex Fabric 36 square inches (91 square meters)
- Spherical Lead Weights (2 lbs.)
- Superballs x5 (27 mm to 45 mm)

Black Hole Space Warp

Brief overview:

This demonstration allows for a visual depiction of the effect of a large mass on a two-dimensional representation of the fabric of space-time. In particular, what effect a black hole does or does not have on the other stars around it and how that effect depends on the mass of the black hole. Remember that Newton saw objects with increasing mass as having an increasing escape velocity; Einstein saw them as making deeper “dents” in the fabric of space-time!

A black hole makes such a deep “dent” that it forms a bottomless well. The sides of the well are so steep that even light cannot escape once it has fallen deeper into the well than the event horizon depth.



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Procedure:

- 1) First, the students should be set up in groups of four to five. Start by explaining that the intense gravity around large massive objects dramatically bend the fabric of space-time. This is why things “fall” into black holes and gravitate towards the large objects, just like the Earth and the planets “stick” around the sun in their orbits.
- 2) As you continue to discuss the gravitational effects around black holes, start walking around the room and distributing the fabric hoops, describing them as “the fabric of space-time.” As you pass these out, explain that we are going to do the space-time warp.
- 3) Once all of the hoops have been passed out, make sure the students in each group are all holding onto them such that the hoop is horizontal and the rim of the hoop is facing up like a bowl (so the balls don’t fall out when they are placed on the fabric). Now have the students imagine that they are holding a chunk of space. Ask them to take note of how nice and flat it is.
- 4) Now walk around and explain to them that they better hold on to their hoops because a very massive and dense object is about to fly into their space-time hoops. As you set the 2lb weights into the center of their hoops ask them what this represents (they should say a black hole).

→ **Warning:** tell the students the weights are made of lead, and that they should not touch them. Now hold up two bouncy balls and ask them what they think those should represent (they should say stars). If their first answer isn’t “stars,” ask them if they can think of in space that would orbit around a black hole. Keep asking them questions that lead them to the answer of stars; it’s best not to just tell them the answer.

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5) Now let the students attempt to get the stars to orbit the black hole. Have the group record what they see happening to the spacetime fabric and the stars. Make sure to have them include what the black hole and stars are doing.

6) Once they have recorded their observations, start discussing how this bending of space-time happens with all massive objects, even us! Have them look at how the little bouncy balls actually make a small indentation in the fabric. This is just how less-massive objects bend spacetime.

7) Now tell them that instead of a black hole, imagine now that the weight is the Sun. Now ask them what the bouncy balls represent (the planets). Just like a black hole or any massive object, the Sun keeps the planets gravitationally bound to it.

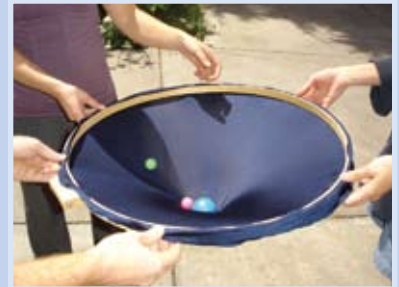
8) Once you have explained the above content let the students play a few minutes more with the hoops. Collect the hoops and lead a discussion about the spacetime warp to conclude the activity.

→ **Warning:** if you have used lead weights to represent the black hole, tell the students that if they touched the weights, they must wash their hands! Or you could wrap the weights in something.



Avoid Misconceptions!

This demonstration is only a 2-dimensional representation of the real thing. To avoid misconceptions make sure you ask your students questions like: What is on the "other side" of the black hole in 3-dimensions? The answer is that space acts the same in all directions - there is not front and back to a black hole, it is a spherical object.



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

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.

THE OTHER SIDE OF INFINITY

BLACK HOLES

THE OTHER SIDE OF INFINITY
BLACK HOLES

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.

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 Past, Present, and Future of Black Holes

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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>

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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-elwww/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/swifisc.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://ff64.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/andraghez.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 OTHER SIDE OF INFINITY
**BLACK
HOLES**

Appendix A

Duration: 30 minutes

Brief overview:

In this activity, students will see why a tunnel through space is shorter than going the long way around.

Students will learn...

- Space can be warped by massive objects
- Wormholes are probably not real, but theoretically could be used to take a shortcut through space

Materials:

- Classroom set of 3" Styrofoam balls
- String, cut into 12" length
- A paper clip or other small weight to attach to the string
- A ruler or measuring tape
- Student worksheet (below)

Create a Wormhole!

Teacher Preparation:

Take one of the Styrofoam balls and drill a hole through it so that the hole goes through the center (in other words, the hole's length is the diameter of the ball). One way to do this is to set it on something that will hold it firmly like a drinking glass. Then take a pencil and push it straight down through the ball. If you want to be extra sure that it goes through the center, you can wrap a string around the circumference of the ball, then rotate the ball and wrap the string around again at right angles to the first loop. The string will cross over itself at two places, which you can mark with a pen. Push the pencil or pen through the ball such that it connects the two marks. Make sure the hole is wide enough that the string can pass through it with the weight attached, or that it is easy to get the string through the hole.

Repeat this for all the balls.

Procedure:

- 1) Talk to the students about wormholes, using the "Background Information" section above. Ask then if they have seen any TV shows or movies using wormholes, and have them describe how they work. Why do wormholes act like a short cut?
- 2) Pass out the materials, including the worksheet. Describe how the ball represents space. If you were an ant on the surface, to walk around to the other side of the ball, you would have to walk around half the circumference. But, if there were a wormhole going through the ball, you could walk across the diameter instead.
- 3) Have them measure the circumference of the ball. They can wrap the string around the ball, making sure it makes a "great circle," or circle of maximum size, around the ball. Mark the string, then measure it with the ruler. Remember that they need to divide it by 2, since they only need to "walk" around half the ball! They should record this number on their worksheet.
- 4) Have them now measure the diameter of the ball. Tie the string to the weight, then pass it through the ball. Mark the string where it just touches the surface of the ball at both sides, then remove it from the ball and measure the distance. Make sure they record the number on their worksheet.
- 5) Ask them which number is bigger. Why? Have them calculate the difference between the two numbers, and then the percentage difference. Knowing that the circumference is equal to π times the diameter, what should that ratio be? (Answer: $\pi/2 = 3.14/2 = 1.57$)
- 6) Now ask them, if you were an ant on the ball, which way would you rather go, around, or through the ball? Remind them that without the hole going through the ball, they are forced to walk around it.
- 7) Explain to them that the surface of the ball is a two dimensional surface, bent into three dimensions. Space itself is like that surface; but it's three dimensional. It's hard (maybe impossible) to really imagine that three-dimensional space can be bent, and let them know it's OK if they have a hard time with it! Even the world's greatest scientists struggle with this concept.
- 8) A wormhole in space is like the hole in the ball, representing a shortcut through space. Remind them again that we don't think wormholes really exist, but it sure would be nice if they do!



Student Worksheet - Create a Wormhole!

Name: _____ Date: _____

In this activity, you will measure the difference between traveling through a wormhole, and going “the long way around.”

Your teacher has given you a Styrofoam ball with a hole drilled through it, a length of string, a weight for the string, and a ruler. The procedure for this activity is outlined below.

Step 1: Imagine you are an ant on the surface of the ball, and you want to go to the other side. You would have to walk halfway around the ball, which is a distance equal to half the circumference of the ball. How far is that?

Measure the circumference of the ball. Wrap the string around the ball, making sure it makes a “great circle,” or circle of maximum size, around the ball. Mark the string, then measure the distance between the marks with the ruler. Remember to divide that number by 2, since as an ant you only need to “walk” around half the ball! Record this number here:

Distance an ant walks around the ball: _____ (cm)

Step 2: Now imagine that the tunnel through the ball is a wormhole through space. As an ant, you can walk through the ball instead of around it! How far is that distance?

Measure the length of the tunnel. First, tie the weight to the string, then pass the string through the hole. Mark the string to measure the distance between the entrance and exit of the tunnel. Pull the string out, and measure it with the ruler. Record that number here:

Distance an ant walks through the ball: _____ (cm)

Step 3: How much distance did you save? First calculate the difference between the two numbers to get the distance saved:

Difference: _____ (cm)

Now calculate the percentage saved. If c is the half-circumference, and d is the diameter, the percent saved is:

$$[(c - d) / d] \times 100$$

Percent saved: _____

In general, given the diameter of a sphere, what is the circumference? What should the half-circumference then be? Calculate that number and record it here:

Calculated half-circumference: _____ (cm)

Compare this to the number you measured. Is it close?

Appendix B – Glossary

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

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

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

Galaxy: A collection of gas, dust and billions of stars held together by their mutual gravity.

Gamma-ray burst: An enormously energetic explosion of high-energy light, some of which is thought to be due to the formation of a black hole.

Gravity: The attractive force of an object that depends on its mass, and your distance from it. The more massive an object, or the closer you are to it, the stronger the force of its gravity will be.

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

Supernova: An exploded, or exploding, star.

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

Appendix C – Resources

General

- Denver Museum of Nature and Science:
<http://www.dmns.org/main/en/>
- GLAST Education and Public Outreach Program:
<http://glast.sonoma.edu>
- Swift Education and Public Outreach Program:
<http://swift.sonoma.edu>
- Black Hole fact Sheet:
<http://glast.sonoma.edu/resources/BFfactsheet05.pdf>



Section 2

- GP-B Educators Guide:
<http://einstein.stanford.edu/> (classroom area)



Section 3

- Black Hole expert Andrew Hamilton's Homepage:
<http://casa.colorado.edu/~ajsh/home.html>

Section 1



- Gamma-ray Burst Educator Guide:
<http://swift.sonoma.edu/education/index.html#grb>
- Active Galaxy Educator Guide:
<http://glast.sonoma.edu/teachers/teachers.html#agn>
- Tasty Active Galaxy Activity (AGN #1 for younger students):
<http://glast.sonoma.edu/teachers/agn/popup/tastyagnea05.pdf>
- Stellar Evolution Activity from Chandra:
http://chandra.harvard.edu/edu/formal/stellar_ev/



Section 4

- GEMS Guide – Invisible Universe: The Electromagnetic Spectrum from Radio Waves to Gamma Rays:
<http://lhsgems.org/GEMSIInvUniv.html>
- GLAST Race game:
<http://glast.sonoma.edu/teachers/race.html>
- Black Hole Explorer Board game:
http://cfa-www.harvard.edu/seuforum/einstein/resource_BHExplorer.htm
- Advanced students – GRB Activity #2:
<http://swift.sonoma.edu/education/index.html#grb>

