Session 10 – Black Holes

Brief Description

Students learn about black holes, the densest objects in the Universe. They learn that the collapsing core of a star forms a black hole and do an activity that shows how the density of a stellar core increases as the core collapses even though the mass remains the same. They then engage in a kinesthetic activity to model how a black hole affects the objects near it. This session ties into Sessions 6 and 7. Students work in groups of 2 or 3 for the first part of the session, and as a larger group later.

Objectives

- To show that black holes are the end points in the life cycle of the most massive stars.
- To understand that black holes have the same gravity as other objects of the same mass, but are much smaller and are hence denser.
- To show that a black hole's gravity is similar to other objects in the Universe – it is dependent on the mass and distance from the object.
- To understand that nothing can escape from a black hole, not even light.

Concepts Addressed

- Black holes as end points of stellar evolution for the most massive stars
- Gravity
- Escape velocity

Materials

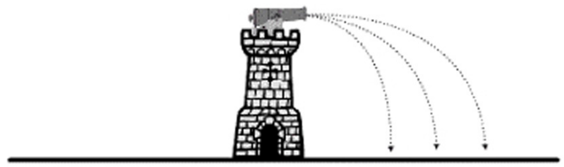
- Blackboard/whiteboard or easel with flipchart
- Chalk or markers
- Round balloons, 1 per group of students
- Roll of aluminum foil
- Balance/scales, 1–2 for the class
- Cloth/flexible tape measure, 1 per group of students
- Student worksheet (included in Appendix E)
- Index cards to use for making up role cards
- Piece(s) of yarn or rope that totals about 20 feet

Other Requirements

- A room or other space where students can move around freely

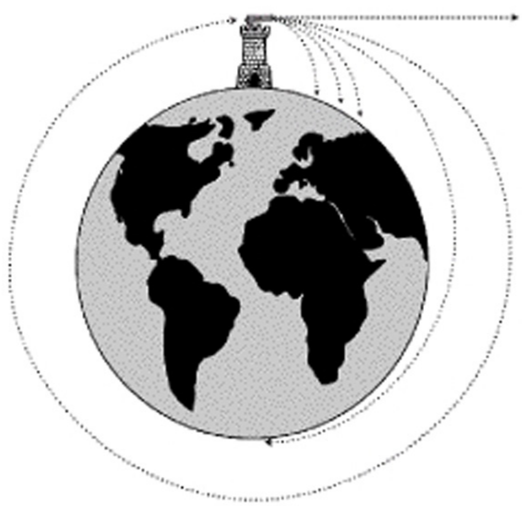
Background

On Earth, when you throw a ball into the air, it falls back to the ground. This is because the Earth's gravity pulls the ball back down. The higher and faster you throw it, the longer it will take to fall back to the ground. The same principle applies to the cannon balls in the following image. The faster the cannon balls are shot, the farther they will go.



Faster cannon balls getting farther as they are shot off a tower.

If you could throw the ball with enough speed, it would not come back down. If you could shoot the cannonball fast enough, it would continue around the planet (in orbit.)



If a cannon ball were shot fast enough, it would go all the way around the Earth.

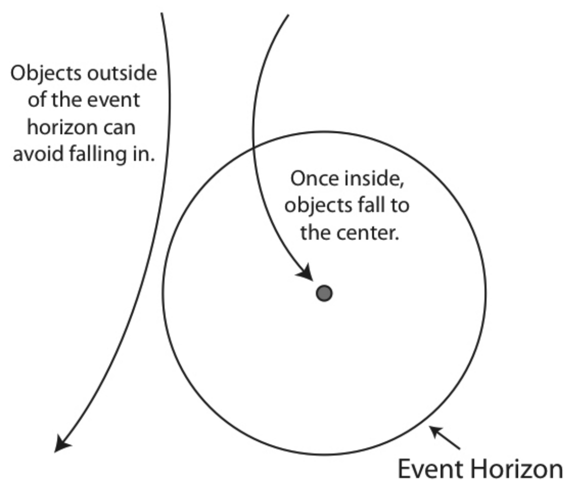
For every body in the Universe, there is a certain speed necessary for objects to escape its gravitational pull. This special speed is called the "escape velocity." Any object going slower will fall back to the surface. The reason we are able to send rockets into space is because they achieve speeds greater than this velocity. On Earth this speed is 11.1 kilometers per second (or 40,200 kilometers per hour), which is the same as 7 miles per second (or 25,000 miles per hour). Other objects have different escape velocities. The escape velocity for any object is dependent on its mass — the more massive something is, the higher the escape velocity from that object. The Moon is smaller than the Earth and the escape velocity is only 2.4 kilometers per second (1.5 miles per second). The Sun, which is much more massive than the Earth, has an escape velocity of 621 kilometers per second (386 miles per second). So, objects need to have more speed to escape from a more massive object.

Black holes are objects so dense that their gravitational pull is very large. The gravitational pull is so high that the escape velocity from black holes exceeds the speed of light! This means that not even light can escape the gravity of black holes. Since Einstein showed that nothing can travel faster than light, nothing can escape from inside a black hole!

There is strong observational evidence for two types of black holes — stellar mass black holes, which are typically 5–15 times as massive as our Sun and are formed when large stars explode as supernovae and collapse; and supermassive black holes that are millions to billions times the mass of our Sun. These are always found at the centers of galaxies. For example, our own galaxy, the Milky Way Galaxy, has a central black hole. This black hole is 3 million times the mass of our Sun, but in size it is only about the size of our solar system. This is very small in relation to the size of our galaxy. The formation of these supermassive black holes is still mysterious and the subject of a great deal of current research.

A third type of black hole, known as an intermediate mass black hole, is also thought to exist. These black holes are predicted to weigh about 1000 times the mass of our Sun. This is an active area of research.

The event horizon of a black hole is the spherical boundary between the black hole and the outside universe. It is the point of no return in the sense that any object (or even any light ray) that strays inside of the event horizon must fall inwards towards the center of the black hole. At the very center of the black hole is a region where the infalling matter is destroyed and our current laws of physics probably become invalid.



The gravitational effect of black holes.

It is important to realize that outside of the event horizon a black hole exerts the same gravitational force on nearby objects as any other object of the same mass. For example, if the Sun were magically crushed until it had a radius of only 3.2 kilometers (2 miles), it would become a black hole but the Earth would feel the same gravitational force and hence remain in the same orbit as before the Sun was crushed. In this sense, black holes are not cosmic vacuum cleaners that reach out and suck everything into them. But our Sun is not big enough to ever become a black hole, so don't worry about that!

Black holes can be very challenging objects to detect as space is also black! If there were no stars or gas near a black hole, we would not be able to detect them. Astronomers detect black holes through their gravitational effect on nearby gas and stars. A particularly important example is when a normal star (like the Sun) is orbiting close to a stellar-mass black hole. In this case, the gravity of the black hole can pull gas from the surface of the star. As the gas spirals into the black hole, it gets extremely hot and emits a large amount of X-rays. These X-rays can be detected by modern X-ray telescopes. Observations also reveal the normal star's "wobble" as it orbits around the unseen black hole.

Session Overview

In the first activity, students model and measure the collapse of a star into a black hole to understand its incredibly high density. Students then engage in a kinesthetic activity to learn that black holes exert their gravitational pull only on objects that get close to them.

Preparation

- Set up stations ahead of time — student stations with activity materials (balloons, aluminum foil, measuring tape, and worksheets), and separate stations with the scales for use during the activity.
- Make up "role cards" for the students for the black hole kinesthetic activity. You can either use index cards or fold up small slips of paper and write the name of a role to play in the activity. For a group of 20 students, a good distribution of roles might be as follows: 4 students are the "black hole," 4 students are the "distant stars" that never feel the black hole, 6 students are "nearby stars" that feel some tug from the black hole, and 6 students are "orbiting stars" that go around the black hole without falling into it.

Activity

I. Discussion (10 minutes)

1. Ask your students what they know about black holes. After a brief discussion where you write down their ideas on the black board or chart, tell them that we are going to do some activities to see if their ideas are correct.

2. Review the general process of stellar evolution from Session 6. Ask them if they remember if/how/when black holes formed during the process of a star's evolution. Confirm (or remind them) that black holes form when the cores of very large stars collapse at the end of the star's life (as they modeled in Session 6). Briefly introduce the concept of a black hole as an object that has a huge mass but is very small (i.e., has incredibly high density) — imagine the mass of a star, but scrunched into the size of a city!

   If appropriate, you can draw some comparisons between heavy but small objects and larger but lighter objects that they may be familiar with to demonstrate that larger doesn't always mean heavier. Some common examples are lead fishing weights (small but very heavy) and balls or other objects made out of styrofoam, which can be very large but still not be heavy. If you have them available, science supply stores have sets of similarly-sized items (cubes, balls, etc) made from different materials to make this point in a different way.

II. Modelling the formation of a black hole (20 minutes)

(*Adapted from Imagine the Universe's activity on black holes*)

Check our online resources for a video about the foil and balloon black hole.

1. Tell students that they will use aluminum foil and balloons to model the collapse of a star on its way to making a black hole. This is similar to the way that the core of a star makes a black hole when the massive star reaches the end of its life. They are going to note what happens to the circumference and mass of the core as it is collapsing on its way to a black hole. Split the students into groups of 2–3 and have them follow your lead as you go through the activity.

2. Distribute the balloons, aluminum foil, measuring tape, and a worksheet to each team of students.

3. Start by blowing up the balloon until the diameter (distance across the balloon) is about 6″, no larger (it is harder to cover a larger balloon with foil). Tie off the end. Now cover the inflated balloon with several sheets of aluminum foil. Be generous with the foil and cover the balloon thoroughly. It works best if you use several 12–15 inch long sheets and wrap around at least twice. Tell the students that the foil covered balloon represents the core of the star.

A participant wrapping her balloon in foil.

4. Using the scales, weigh the balloon. Measure its circumference (distance around the balloon) by wrapping the tape measure around the middle of the balloon. Record these two measurements on the worksheet.

5. Tell the students that they are the "Giant Hands of Gravity." Have the students gently squeeze the balloon. Since it is still inflated, it should resist being squeezed. Tell the students that this is what happens during the normal life of the star — gravity is balanced by pressure within the core of the star.

A participant gently squeezes his balloon.

6. You are now ready to simulate the end of the star's life as the enormous mass of the star's core collapses inward on itself. Tell the students that their star has just died — it has run out of fuel in its core and so the pressure will disappear. Tell the students to simulate this by popping their balloons without crushing the aluminum foil. The sharp end of a pencil should work well. Push the tip gently through the foil to pop the balloon inside.

7. Tell the students to, again, be the "hands of gravity" by gently squeezing their aluminum ball. Instruct them to make the ball approximately 1″ smaller. But ask them to squeeze it carefully so that it stays roughly spherical as it gets small. This time, since there is no pressure to resist the collapse, the aluminum ball will be crushed.

8. After crushing it a little bit, ask the students to measure its circumference and its mass, and note these values on their worksheet. Ask the students to continue to crush their ball little by little (about 1 inch each time), making measurements of the circumference and mass and recording these on their worksheet each time.

A participant weighing and measuring a ball of foil.

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

10. After a few minutes, ask the students to crush their ball as much as they possibly can. They should end up with an aluminum ball that is just an inch or two across.

Participants measure the circumference of their aluminum ball.

11. Discussion: Remind the students that their ball could not be crushed while the balloon was still inflated — this represents a star during its normal life in which pressure (generated by the nuclear fusion in its core) balances gravity. When fusion stops in the core of the star, the pressure can no longer be maintained. This is like popping the balloon. The students should be led to the conclusion that the collapse of the core could start once the pressure in the core vanished.

    Once the collapse started, the core kept a constant mass as it got smaller. Their measurements on their worksheets should show that the mass remained the same even as the circumference got smaller. So this is similar to what happens when a star explodes in a supernova and the leftover core collapses to become a black hole. The core keeps getting smaller and smaller even though it is not losing mass.

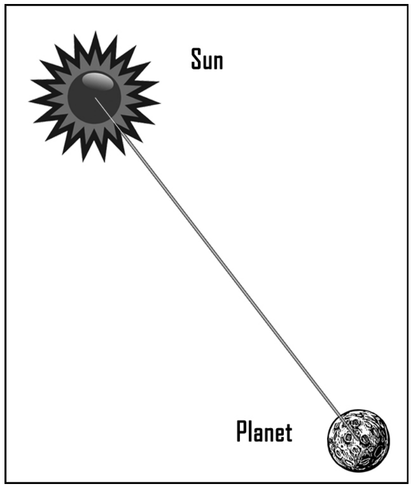
    The students should be told that to make an actual black hole with the effective size of their final (squashed) aluminum ball, you would need to start with several times the mass of the Earth!

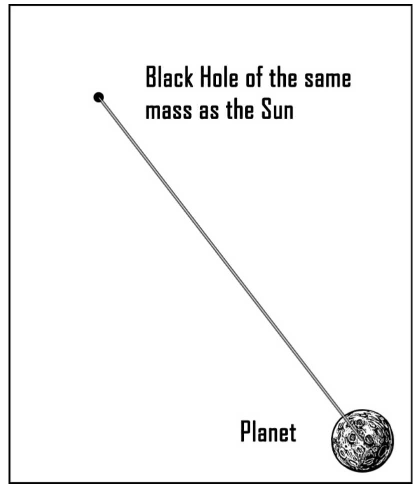
III. Black Hole Effects Kinesthetic Activity (20 minutes)

Check our online resources for a video about this black hole kinesthetic.

Now that they know black holes are very dense objects, review the list of ideas written down on the blackboard or flip chart. If they have mentioned that black holes "suck things in," ask them why they think that may be true. Remind them that the previous activity showed that a black hole has the same mass as the star it originally came from. But it has been scrunched into a much smaller area. Ask them if they think the Sun will "suck" the Earth into it.

A black hole's gravity is just like anything else in the Universe — it is dependent on the mass and distance from the object. You need to get very close to a black hole to notice it is there or to suffer any severe effects! While our Sun will never turn into a black hole, if we could magically replace it with a black hole of the same mass, the orbit of the Earth would not change.





The gravitational attraction for a planet stays the same with both the Sun and a black hole of the exact same mass.

Ask the students if they know why a black hole is called a “black” hole. Do they think anything comes out of a black hole?

Using the information provided in the background material, lead a discussion about escape velocity and how it applies on the Earth, moon and the Sun. Then talk about the escape velocity from the black hole.

Tell them that they are now going to model the effect of a black hole on its surroundings. Hand out the role cards to the students.

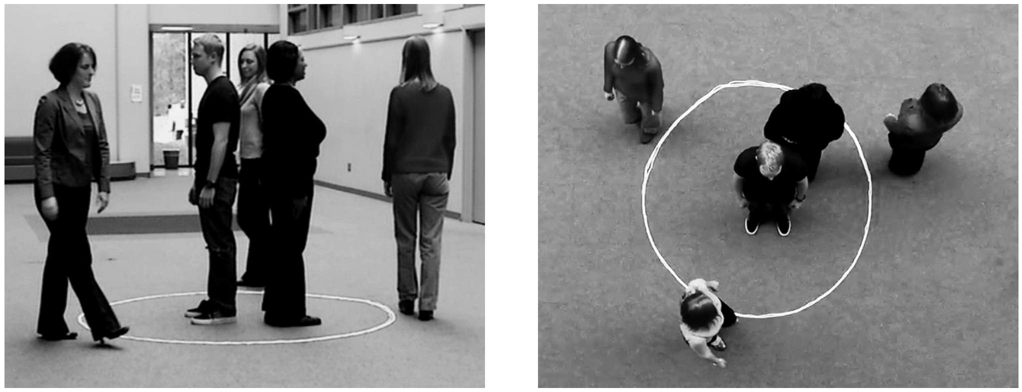
Note to program leader: The description of this activity below assumes a group of 20 students. The distribution of roles is intended to be only an example. Adjust the numbers as needed for the number of participants that you will be working with.

1. Ask the students what role they have been assigned. What happens to them depends on the role they have been assigned, so run through the activity for each group separately the first time around.

2. Have the 4 students who are going to be the black hole stand in the center of the room facing outwards with their arms stretched out. Tell them that they represent the black hole. Their “zone of influence” extends only as far as their arms stretch out.

3. Use the length(s) of yarn or rope to mark a circle that is just outside the reach of this group of students.

4. The 6 students who represent the “orbiting stars” should go around the black hole just outside the rope circle.



Participants in the role of "orbiting star" walk around the black hole just outside the rope circle.

5. Now the 4 students who have been assigned the role of "distant stars" should scatter about the outer edges of the room away from the black hole.

6. The 6 students who will act as the "nearby stars" should be in between the "distant stars" and the "orbiting stars."

7. Now ask the students who represent the "distant stars" to start wandering around the room. These stars at the edges of the room are unaffected by the black hole as they are too far away from it. They never know that there is a black hole in the vicinity and just go about their business.

8. The students who have the role of "nearby stars" will feel some pull from the black hole and their path will be altered slightly. But they don't all get attracted to the black hole and fall into it. These students should wander the space between the "distant stars" and the "orbiting stars," altering their direction a little when they come close to the "orbiting stars."

9. The students who are playing the "orbiting stars" have been captured by the gravitational pull of the black hole. Tell students that these stars behave similarly to how the planets orbit our Sun. These stars orbit the black hole and go around the rope circle.

10. Have the students get into these roles and proceed calmly for a few minutes so that they know what each type of star does.

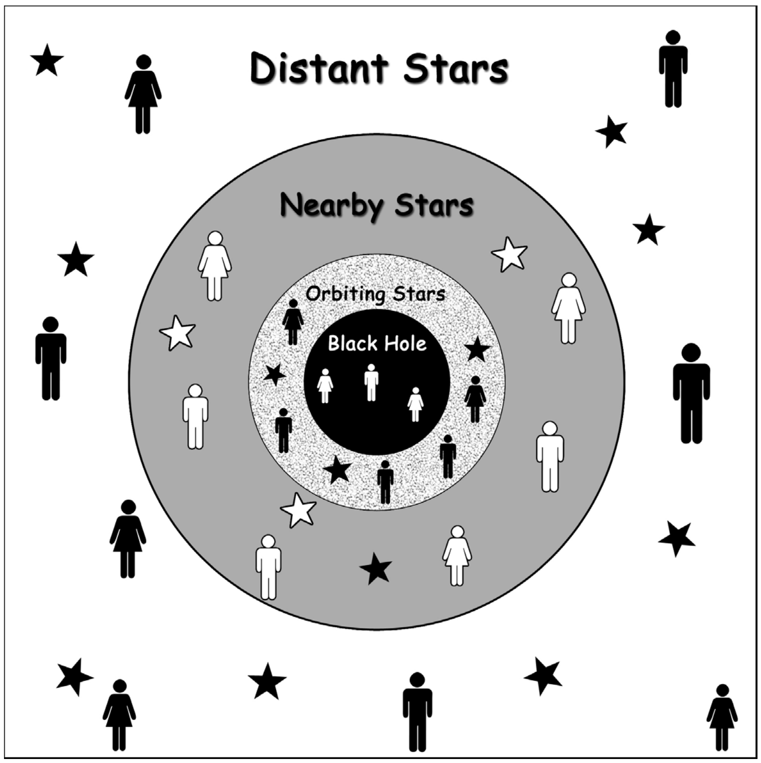
11. Now, call on one of the "nearby stars" to come close to the rope circle and bump (gently!) one of the "orbiting stars." This will push this orbiting star inside the rope circle and it falls into the black hole. When this happens, the students who form the black hole should take this student inside the black hole. This star has now become a part of the black hole and can never escape. The nearby star that bumped the orbiting star can go back to its wandering after delivering the bump.

12. Call on another "nearby star" to come close to the rope circle and bump (gently!) another one of the "orbiting stars" to push it inside the black hole. This nearby star can now take the place of the orbiting star and fall into an orbit around the black hole. You can repeat this once or twice more if you wish. ***Be very careful to emphasize that these interactions***

are caused by very rare alignments between the objects. Therefore make sure that all the students do not end up either orbiting or inside the black hole as that would defeat the point of showing that black holes do not grab and suck up everything in their vicinity!

13. The student who is now inside the black hole cannot get out. Ask the students what will happen to the light from the star that spiraled into the black hole. Can the light get out of the black hole?

14. End this activity by saying "Freeze!" and leading a discussion on what happened. What did the different types of "stars" do? Did the black hole reach out and grab all the stars in the room? The students should get the point that the black hole exerts an influence on only a limited area.



The approximate locations of students for the black hole kinesthetic.

15. To ensure maximum understanding, treat the first run through as a trial run and repeat the activity. Students can switch role cards if they wish so that they can play a different object in this second round.

16. Now ask the students what color they think a black hole is (this is easy!), and why it is this color. They should be led to the idea that it is black because it absorbs all light that falls within the event horizon. They should realize that *nothing* can escape from a black hole, not even light.

    After reminding them that space is also black, ask them how they would go about trying to find a black hole. What happened to the stars that came close to the black hole? They felt a tug or fell into an orbit around the black hole. Lead them to the idea that you have to find black holes by looking at their effect on other objects.

If the stars in this orbit happen to go inside the rope circle (say a passing "nearby star" bumps them a little and nudges them inside the circle), the gas from the surface of the star starts to get ripped off and it starts to spiral into the black hole.

Wrap up the discussion by re-iterating that the mass of black holes is not that different from the stars they formed from, but they are much denser. Also, objects have to come close to a black hole to feel its gravitational effect.

Advance preparations for Session 11

The next session (Session 11) is focused on a visit by a space scientist and making a "cosmic quilt" about what they have learned during the course of this program. See Session 11 for a description of the cosmic quilt and what it entails. Some advance preparation is needed and the steps below are ideally done at the end of Session 10.

- Form teams of two students (pairs) who will work on pieces of the "cosmic quilt." You can either assign topics or ask them to choose topics that they will represent in the quilt. These can include any of the topics studied over the course of the program – light, telescopes, spectroscopes, elements, stars, stages in a star's life, galaxies, or black holes. Each pair of students will create two "quilt" pieces — they should have a pictorial representation of their topic on one piece (a drawing, an image, etc.) and a written description on their other piece (this can be a song, a poem, a straight-up description, etc.). The students should spend some time before the next session thinking about their topics and what they might draw and write for their quilt pieces.

- Let the students know that a scientist will be visiting them for the next session. Ask the students to prepare for the scientist visit by preparing a list of questions they might wish to ask the scientist. These questions can be about their quilt topic or cover anything they have studied over the course of this program. They can also ask the scientist questions about careers in science or any other questions that are relevant to the program.

Suggestions for Running this Session

- Make sure you count out your role cards before the session, and scale them appropriately for your group size. The manual provides suggestions for this distribution.

- The purpose of this activity is to show that a black hole does not gobble up everything around it. Unfortunately, one of the fun parts of this activity for the kids is getting to pull orbiting stars into the black hole. In order to maintain a balance, you may need to monitor and restrain their enthusiasm to ensure that only a few orbiting stars get bumped into the black hole. Likewise, only a few nearby stars should become orbiting stars.

- If you feel that the role of 'nearby stars' is too confusing, or you would like fewer roles overall, it is safe to eliminate the 'nearby star' role entirely. The key points of the activity will be maintained with only the roles of 'black hole,' 'orbiting stars,' and 'distant stars.'

- It can sometimes be hard to keep the attention of those participants who are assigned the role of 'distant stars,' since they don't really have anything to do but watch. It can be very easy to zone out, when you're hanging out in the distant parts of the galaxy! Try to work on keeping them engaged, and don't let them spread out too far.

Misconceptions

- Black holes are not cosmic vacuum cleaners. Outside of the event horizon, they exert the same gravitational pull as any other object of the same mass.

- Gravity affects objects in space with a specific set of rules, and those rules aren't changed when we're talking about a black hole instead of a star. Imagine a planetary system with a large star, with planets orbiting around the star. If that star were replaced with a black hole with the exact same mass, the orbits of those planets would not change. Gravity is directly related to the mass of an object - the bigger an object is, the greater the gravitational force it will exert on the things around it. If the mass does not change, then the gravitational force doesn't change. A black hole will only increase in gravitational effects on the objects around it as it increases in mass. Students are frequently convinced that a black hole "sucks in" all of the objects around it, and we use our kinesthetic activity in this session to address what a black hole can - and cannot - do.

- Whenever we start talking about black holes, people quickly come up with a variety of fantastical ideas about what happens inside a black hole and what black holes can do. But really, we don't know what happens inside a black hole, because we can't get any information from inside of one (remember, we get information from light, and black holes are "black" because light cannot escape). Scientists would love to know what happens inside a black hole! It's a hot topic in astronomical theory and research.

Useful websites for background or activity extension

- **Floating Bowling Balls at Steve Spangler Science**
  A fun demonstration of density using bowling balls.
  http://www.stevespanglerscience.com/experiment/00000067

- **NASA's Universe Education Forum**
  A good discussion about black holes — starts with an introduction to what they are and moves on to how we find them.
  http://www.cfa.harvard.edu/seuforum/blackholelanding.htm

- ***Imagine the Universe!***
  An introduction to black holes
  http://imagine.gsfc.nasa.gov/docs/science/know_l1/black_holes.html

- ***Imagine the Universe!***
  Aluminum Foil, Balloons, and Black Holes
  http://imagine.gsfc.nasa.gov/docs/teachers/blackholes/imagine/page12.html#al

- **Hubblesite: Black Holes**
  An interactive multi-media exploration of black holes
  http://hubblesite.org/discoveries/black_holes/

- **Real Images of [The Material Around] Actual Black Holes**
  The Universe Education Forum has created a Power Point slide show with real images of (the material around) actual black holes. Although black holes themselves are invisible, they reveal themselves by their influence on the matter around them. NASA's Chandra Observatory, which is designed to detect X-ray light, has recorded stunning images of hot gas being pulled into orbit around actual black holes throughout our Universe.
  http://www.universeforum.org/einstein/resource_journeyblackhole.htm