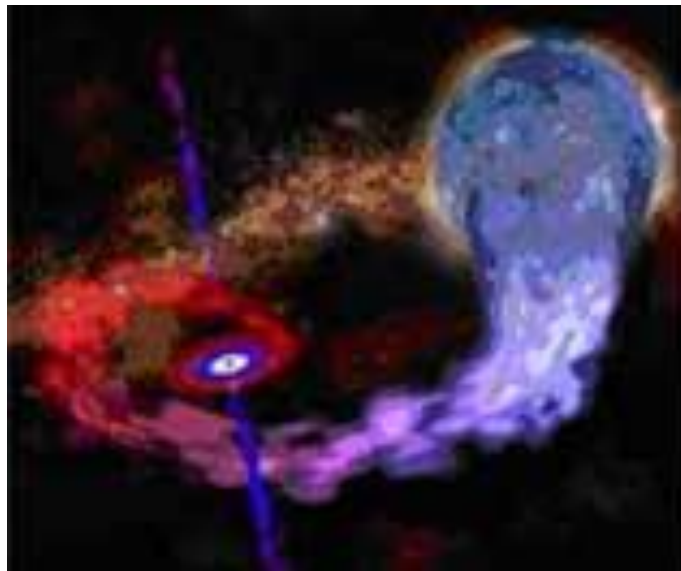




Emera Astronomy Center  
and M. F. Jordan Planetarium

ASTRO.UMAINE.EDU FACEBOOK.COM/JORDANPLANTERARIUM 207-581-1341

## Cosmic Classroom Guide



# Black Holes

COMPILED & EDITED BY LEISA PREBLE



*A Member of the University of Maine System*



# Emera Astronomy Center and M. F. Jordan Planetarium

## Black Holes

Edited by Leisa Preble

Cosmic Classroom .....	2
The Program – Black Holes .....	2
State of Maine Learning Results Guiding Principles .....	2
State of Maine Learning Results Performance Indicators.....	3
Next Generation Science Standards.....	4
Performance Indicators Snapshot.....	5
Classroom Activities:	
Black Holes: The Ultimate Abyss.....	6
Black Hole Detection .....	8
Life Cycle of Stars .....	10
Colors of Stars.....	14
Newton’s Second Law of Motion .....	20
Vocabulary List.....	22
Some good books to use with Black Holes.....	24
Some good web sites to use with Black Holes OD.....	24
Lessons From The World Wide Web .....	25
Astronomy Web Sites Worth a Visit .....	25
Science Background of Black Holes for Teachers.....	26
General misconceptions about Black Holes.....	30

### **Mission Statement:**

The mission of the Maynard F. Jordan Planetarium of the University of Maine is to provide the University and the public with educational multi-media programs and observational activities in astronomy and related subjects.

Material within this Cosmic Classroom package is copyrighted to the University of Maine Maynard F. Jordan Planetarium. Educators are granted permission to make up to 9 copies for personal use. Express written permission is required, and usually will be freely granted, for duplication of 10 or more copies, or for use outside the classroom.

# Cosmic Classroom



Looking for fun and interesting space activities? The planetarium staff has prepared a collection of materials we call the Cosmic Classroom for you to use before and/or after your visit. These materials are entirely for use at your own discretion and are not intended to be required curricula or a prerequisite to any planetarium visit. The Cosmic Classroom is one more way that the Jordan Planetarium extends its resources to help the front line teacher and support the teaching of astronomy and space science in Maine schools.

The lessons in this Cosmic Classroom have been edited and selected for the range of ages/grades that might attend a showing of this program at the Jordan Planetarium. Those activities that are not focused at your students may be adapted up or down in level. Our staff has invested the time to key these materials to the State of Maine Learning Results in order to save you time.

The State of Maine Learning Results performance indicators have been identified and listed for the program, the Cosmic Classroom as a package, and each individual activity within the package. The guide also includes related vocabulary and a list of other available resources including links to the virtual universe. We intend to support educators, so if there are additions or changes that you think would improve, PLEASE let us know.

Thank you, and may the stars light your way.

*The Maynard F. Jordan Planetarium Staff*

## The Program – *Black Holes*

The attraction of Black Holes is more than just gravitational. These mysterious graveyards of dead stars have fascinated generations. *Black Holes* explores the history, physics, and mystery of black holes. This space adventure features rich, expansive panoramas and incorporates several of the latest scientific theories about how black holes are formed and where they are hiding now. Witness the bending of light, the skewing of perception, and the dizzying descent into a black hole. Enjoy some of the most visually stunning three-dimensional effects ever created for the OmniDome planetarium system.

We're very glad that you have chosen to visit our planetarium with your group. We hope that this guide either will help you prepare your group or help you review their experience at the University of Maine's sky theater.

## State of Maine Learning Results Guiding Principles

The lessons in this guide, in combination with *Black Holes OD* help students to work towards some of the Guiding Principles set forth by the State of Maine Learning Results. By the simple act of visiting the planetarium, students of all ages open an avenue for self-directed lifelong learning. A field trip encourages students to think about learning from all environments including those beyond the schoolyard. A Jordan Planetarium visit also introduces visitors to the campus of the largest post-secondary school in Maine and encourages them to think of this as a place which holds opportunities for their future education, enjoyment and success.

Other sites on the University campus, including three museums, explore a variety of subjects, and the Visitors Center is always willing to arrange tours of the campus. A field trip can contribute to many different

disciplines of the school curriculum and demonstrate that science is not separate from art, from mathematics, from history, etc. The world is not segregated into neat little boxes with labels such as social studies and science. A field trip is an opportunity for learning in an interdisciplinary setting, to bring it all together and to start the process of thinking. For a more complete discussion of field trips, please visit the Jordan Planetarium web site at <http://astro.umaine.edu>.

If used in its entirety and accompanied by the Planetarium visit this guide will help students to:

Become **a clear and effective communicator** through

- A. oral expression such as class discussions, and written presentations
- B. listening to classmates while doing group work, cooperation, and record keeping.

Become **a self-directed and lifelong learner** by

- A. introducing students to career and educational opportunities at the University of Maine and the Maynard F. Jordan Planetarium.
- B. encouraging students to go further into the study of the subject at hand, and explore the question of “what if?”
- C. giving students a chance to use a variety of resources for gathering information

Become **a creative and practical problem solver** by

- A. asking students to observe phenomena and problems, and present solutions
- B. urging students to ask extending questions and find answers to those questions
- C. developing and applying problem solving techniques
- D. encouraging alternative outcomes and solutions to presented problems

Become **a collaborative and quality worker** through

- A. an understanding of the teamwork necessary to complete tasks
- B. applying that understanding and working effectively in assigned groups
- C. demonstrating a concern for the quality and accuracy needed to complete an activity

Become **an integrative and informed thinker** by

- A. applying concepts learned in one subject area to solve problems and answer questions in another
- B. participating in class discussion

## State of Maine Learning Results Performance Indicators

In conjunction with the Maynard F. Jordan Planetarium show *Black Holes OD*, this guide will help you meet the following State of Maine Learning Results Performance Indicators in your classroom. This guide has been indexed to the 2007 State of Maine Learning Results.

### Grades 3-5

#### **Science and Technology –**

D3. Matter and Energy

- c. Analyze the effects of heating and cooling processes in systems.

### Grades 6-8

#### **Science and Technology –**

B1. Skills and Traits of Scientific Inquiry

- b. Design and conduct scientific investigation of Newton’s Second Law, using controlled experiments and systematic observations.
- c. Use appropriate tools, metric units and techniques to gather, analyze, and interpret data.

D1. Universe and Solar System

- a. Identify one way in which scientists can identify potential black holes.

D3. Matter and Energy

- a. Describe that all matter is made up of atoms and distinguish between/among elements, atoms, and molecules.
- i. Use examples of energy transformations from one form to another to explain that energy cannot be created or destroyed.

D4. Force and Motion

- c. Show understanding by simulating the effects of gravitational force and other forces on a star in the universe.
- e. Articulate that force is a push or pull on an object.

## 9-Diploma **Science and Technology –**

D1. Universe and Solar System

- c. Outline the age, origin and process of formation of the universe as currently understood by science.

D3. Matter and Energy

- i. Understand how stars are formed and produce energy.

D4. Force and Motion

- b. Use Newton’s Laws to describe the motion of objects.
- d. Explain the ideas of relative motion and frame of reference.

## Next Generation Science Standards

In addition, this guide will also help you meet the following NGSS Performance Indicators in your classroom. This guide has been indexed to the 2013 Next Generation Science Standards.

### **MS-ESS1. Earth’s Place in the Universe.**

- 1. Develop a model of the Earth-sun-moon system to describe the cyclic patterns of lunar phases, eclipses of the sun and moon, and seasons.
  - A. **The Universe and Its Stars.** Patterns of the apparent motion of the sun, the moon, and stars in the sky can be observed, described, predicted, and explained with models.

### **MS-PS1. Matter and its Interactions.**

- A. Structure and Properties of Matter. Substances are made from different types of atoms, which combine with one another in various ways.

### **MS-PS2. Motion and Stability: Forces and Interactions.**

- 2. Plan an investigation to provide evidence that the change in an objects motion depends on the sum of the forces on the object and the mass of the object.

### **MS-PS3. Energy.**

- 4. Plan an investigation to determine the relationships among the energy transferred, the type of matter, the mass, and the change in the average kinetic energy of the particles as measured by the temperature of the sample.

### **HS-ESS1. Earth’s Place in the Universe.**

- 4. Use mathematical or computational representations to predict the motion of orbiting objects in the solar system.

**B. Earth and the Solar System.** Kepler's laws describe common features of the motions of orbiting objects, including their elliptical paths around the sun. Orbits may change due to the gravitational effects from, or collisions with, other objects in the solar system.

## Performance Indicators Snapshot

### The Guide

#### **Grades 3-5**

D3.c.

#### **Grades 6-8**

B1.b.; D1.a.; D3.a, i.; D4.c, e.

#### **Grades 9-D**

D1.c.; D3.i.; D4.b, d.

#### **NGSS**

MS-ESS1-1; MS-ESS1.A

HS-ESS1-4; HS-ESS1.B

MS-PS1.A

MS-PS2-2

MS-PS3-4



## **Black Holes: The Ultimate Abyss**

Credit: Lee Ann Hennig, Thomas Jefferson High School for Science and Technology, Alexandria, Virginia.

### **Objectives and State of Maine Learning Results Performance Indicators:**

#### **MLRs**

1. Learners will be able to understand essential ideas about the composition and structure of the universe and the Earth's place in it. (9-D. Science and Technology. D1.c.)
2. Learners will be able to understand energy types, sources, and conversions, and their relationship to heat and temperature. (6-8. Science and Technology. D3.i.)
3. Learners will be able to understand basic concepts about the structure and properties of matter. (6-8. Science and Technology. D3.a.)
4. Learners will be able to understand motion and the principles that explain it. (9-D. Science and Technology. D4.d.)

#### **NGSS:**

1. Learners will be able to determine the relationships between the energy transferred, the type of matter, the mass, and the change in the average kinetic energy of the particles as measured by the temperature of the sample. (Energy. MS-PS3-4)
2. Learners will be able to understand that substances are made from different types of atoms, which combine with one another in various ways. (Matter and Its Interactions. MS-PS1.A)
3. Learners will be able to plan an investigation to provide evidence that the change in an object's motion depends on the sum of the forces on the object and the mass of the object. (Motion and Stability: Forces and Interactions. MS-PS2-2)

#### **YOU WILL NEED:**

Only research materials are required for this activity. You might want to have a selection of sources on hand in the classroom, but students should go to the library or the Internet for additional research.

- Reference materials on black holes
- A computer with Internet access

#### **PROCEDURES:**

1. Review with your students what they have learned about black holes.
2. Make sure they understand that, while black holes have characteristics in common, they differ with regard to size. Explain that black holes come in three sizes: stellar mass black holes, supermassive black holes, and mini-black holes. Explain further that particular characteristics are associated with each size.
3. Divide the class into three teams, and assign each team to research one of the black-hole types discussed above.
4. Tell students that each team will prepare a presentation based on its research, which should include the following:
  - characteristics of the type of black hole
  - lifetime of the type of black hole
  - locations (or suspected locations) of the type of black hole
  - evidence for existence of the type of black hole
5. Tell students to keep track of the sources for their facts so that they or other interested classmates can go back to those sources for further information.
6. Encourage students to include visuals in their reports.
7. After each team has presented its report, invite students to participate in creating on the chalkboard a compare-and-contrast chart showing the similarities and differences among the three types of black holes.

## ADAPTATIONS:

Have each team member submit a detailed written report on one of the four items included in the team's report: characteristics, lifetime, locations, and/or evidence of existence.

## DISCUSSION:

1. Discuss how Newton's view of gravity differs from Einstein's view of gravity.
2. Describe how a black hole is formed from the time a massive star begins its collapse.
3. Knowing that density is defined as mass per unit volume, discuss the mathematical characteristics of a singularity (values of mass, density, volume, and radius).
4. Describe the steps involved in determining the mass of a black hole. What do you have to measure or observe in order to estimate the mass?
5. If you were observing a probe entering the event horizon of a black hole, you would see it "hovering for an eternity and destroyed in an instant." Discuss the meaning of this phrase as it applies to conditions near a black hole.
6. Discuss the objective of the Gravity Probe B satellite and its relevance to the study of gravity.

## EXTENSIONS:

### ***Fantastic Tales***

Have students discuss the paradoxes associated with black holes and speculate on the possibility of using black holes for time travel. Following the discussion, have students choose from the following activities:

1. Collect several examples of short stories based on black holes. Compare the stories with regard to scientific accuracy and the function of black holes in the plots. In each case, describe how the author portrays the relationship between the characters and the black hole. Is the black hole treated like a character, event, place, or all three?
2. Write an original short story, narrative, poem, song, or news article about space travel near, through, or inside a black hole. Focus on the reactions and experiences of each of the characters as they come face to face with the abyss.
3. Collect examples of references to black holes in music and television. Describe how black holes are used in these works and what reactions they elicit. When have black holes been used as the focus of comedy or as a metaphor for something else (like helplessness or greed)?

### ***Breaking Free***

Astronomers use the term *escape velocity* to refer to the minimum speed necessary to break free from the pull of gravity of a planet, moon, star, or black hole and not be pulled back. To appreciate the limits imposed by mass, have students research and compare the escape velocities for objects on the moon, Earth, Jupiter, the sun, Rigel, a white dwarf, a neutron star, and a black hole. With these comparisons in mind, have the class debate future plans for space exploration.

## EVALUATION:

You can evaluate each group's written product using the following three-point rubric:

- **Three points:** report well-researched, information clearly and logically organized, presentation interesting and lively
- **Two points:** report adequately researched, information sufficiently organized, presentation dull
- **One point:** report insufficiently researched, information inadequately organized, presentation poorly prepared

You can ask your students to contribute to the assessment rubric by determining a minimum number of facts to be presented in a report and setting up criteria for an interesting and lively presentation.





## Black Hole Detection

© 2001-2005 Adler Planetarium & Astronomy Museum

### Objectives and State of Maine Learning Results Performance Indicators:

#### MLRs

1. Learners will identify one way in which scientists can identify potential black holes. (6-8. Science and Technology. D1.a.)
2. Learners will show their understanding by simulating the effects of gravitational force and other forces on a star in the Universe. (6-8. Science and Technology. D4.c.)
3. Learners will be able to explain the role of gravity in forming and maintaining planets, stars, and the solar system. (9-D. Science and Technology. D1.c.)

#### NGSS

1. Learners will be able to develop and use a model to describe the role of gravity in the motions within galaxies and the solar system. (Earth's Place in the Universe. MS-ESS1-1)

#### PURPOSE:

Through kinesthetic activity, students will simulate the motion of stars and identification of black holes as part of star systems.

#### YOU WILL NEED:

- 1 glow in the dark necklace per student
- A balloon to use for modeling a star
- Black backdrops for any windows
- 1 flashlight for teacher and approximately 4 with blue gel covers to give students to represent x-rays from accretion disks
- A big, dark, empty space where students can move freely without harm.

#### PREPARATION:

Teacher will need to cover any windows to prevent as much light as possible from entering the room.

#### PROCEDURE:

1. Review the movement of planets and the Sun within our Solar System. Discuss how the Sun moves in space and extend that to the motion of stars in the Universe.
2. Discuss the various types of stars in the Universe and revisit the Life Cycle of a Star.
3. Explain that stars move within spiral galaxies much as planets move around the Sun. Stars rotate around imaginary lines called axes like the Earth. Some stars, those in binary or multiple star systems, orbit around a common center of mass, like children holding hands and spinning. They also orbit the center of the galaxy in nearly circular orbits. The orbiting stars move perpendicularly to the plane of the galaxy, like merry-go-round horses. The stars move very slowly, however, in comparison with human life spans. It may take a star 200 million years to move around a galaxy once and tens of millions of years to complete one up-and-down bump.
4. Using a balloon, or other spherical object, as a model star with a glow in the dark necklace around the "equator", demonstrate the ways in which a star may move in space. Make sure to include binary star systems.
5. Explain that students will act as stars in the Universe.
6. Turn off the lights and demonstrate with a glow in the dark necklace around your head like a headband, the different motions of stars (such as rotating, revolving, etc.).
7. Have students demonstrate each motion.

8. Explain that sometimes stars in multiple star systems age differently, (the length of time a star lives is indirectly related to its mass: more massive stars live shorter lives and die more quickly), and sometimes one star will become a black hole while the other is still a giant or main sequence star. The mass of the star that becomes a black hole does not go completely away, so the two masses continue to orbit each other at the common center of mass. Some students in the class will represent those black holes in multi-star systems by not wearing the glow-in-the-dark necklaces. Other students with whom the "black holes" are paired will wear the glowing necklace and orbit the black holes. Demonstrate the systems with a partner.
9. Explain that searching for stars that seem to be orbiting around "nothing" is one way scientists can find black holes when they can't "see" them. Then also explain that the black holes could begin collecting dust and gas that comes off of the star orbiting it. This dust can form a whirlpool-like shape called an "accretion disk". The dust heats up as it swirls around, much like your hands heat up when you rub them together. All of this heating up creates x-ray emission. Therefore, you can also use this high-energy kind of light to "see" black holes. Our eyes can't see x-rays, but special telescopes like the Chandra telescope can see x-rays. You can represent this radiation (if you choose) by giving some of the "black holes" flashlights covered with blue gels to represent the light that special telescopes can see.
10. Have students suggest comparisons of the movements to something they already know.
11. Have students discuss the formation of black holes as parts of binary star systems.
12. Divide the class into fourths and have each corner of the room demonstrate a certain motion of stars with the lights off.

#### **EVALUATION:**

In the same small groups, students will create their own small galaxy and demonstrate the movement of stars within that galaxy.

Make sure to explain that there are hundreds of billions of stars in most galaxies, so they are only representing a few of those stars. Also explain that the motions are very sped up since normally it would take hundreds of millions of years for a star or a group of stars to go around the galaxy. However, the goal is for the students to become scientists and determine where in the classroom Universe there are black holes. The other students must decide who will do what motion. They must use at least two motions, including a few multi-star systems containing black holes (a non-necklace wearing student). But they do not have to demonstrate all of them. After all groups are completed, discuss the motions they saw. Determine whether the students were correct in their identifications.

#### **CLOSURE:**

Have all groups do their demonstration together, and stop one group at a time to see some of the simulated motions that occur in the Universe. Discuss how much movement is present in the Universe. What role does gravity play in that motion?



## Life Cycle of Stars

Adler Planetarium & Astronomy Museum  
Astronomy Connections: Gravity and Black Holes

### **Objectives and State of Maine Learning Results Performance Indicators:**

#### **MLRs**

1. Learners will understand how stars are formed and produce energy. (9-D. Science and Technology. D3.i.)
2. Learners will be able to demonstrate the motions of stars and other objects. (6-8. Science and Technology. D1.a. )

#### **NGSS**

1. Learners will be able to describe the patterns of the apparent motion of the sun, the moon, and stars in the sky using models. (The Universe and Its Stars. MS-ESS1.A.)
2. Learners will be able to use mathematical or computational representations to predict the motion of orbiting objects in the solar system. (Earth's Place in the Universe. (HS-ESS1-4)
3. Learners will be able to use Kepler's Laws to describe common features of the motions of orbiting objects, including their elliptical paths around the sun. (Earth's Place in the Universe. (HS-ESS1.B)

#### **PURPOSE:**

This activity enables students to enact the lifecycles of different types of stars, thereby illustrating the rarity of black hole-producing stars.

#### **YOU WILL NEED:**

- 12 Red, 12 Yellow, 4 White, and 2 Blue Balloons (1 balloon/student for a class of 30)
- Wooden beads
- Marbles
- Ball bearings
- Pin (to pop balloons)
- Red, yellow, and black markers for writing on balloons

#### **PREPARATION:**

Place 1 wooden bead inside each red and yellow balloon.

Place 1 marble inside each white balloon.

Place 1 ball bearing inside each blue balloon.

#### **PROCEDURE:**

1. Begin by introducing the ways in which stars come into being and produce energy: through gravity's force and nuclear fusion. Nuclear fusion is the bringing together of atoms to form heavier atoms with a release of energy. This can best be done, perhaps, by asking students to state their ideas of what makes the stars shine.
2. Ask if all stars are the same, and ask students to help make a list of things that might vary between stars: mass, color, heat. Make sure to include "life cycle."
3. Ask if students know how black holes form (answer: *they form when certain kinds of stars die*). Ask how often students think that black holes form, and if they believe our Sun will form a black hole. Don't forget to ask them to explain the reasons behind their ideas! This information will be helpful to you in determining how best to structure your questions through the rest of the lesson.

4. State that the class will do an activity that illustrates how all of these differences in stars' characteristics are related, and will show when, and how often, black holes form.
5. Pass out balloons, distributing different colors, one balloon per student. You should have significantly more red and yellow balloons than blue and white, roughly 80% red and yellow, 15% white, and 5% blue. Explain that the property that causes the main differences between stars is mass. As you pass out balloons, tell students the approximate mass of their star.
6. Ask students which balloons they think represent the hottest stars. Point out that actually red stars are the coolest, and blue stars are the hottest. Ask what color our Sun is (yellow).
7. Ask which color star students believe will live longest, and why. Write prediction on board. Record differing opinions, too.
8. Guide students through the following series of steps. For each age, tell students what to do for their color of balloon. To help students follow the progression, you might write different stages on a board or overhead as you move on, and note important events. Also, ask students to make predictions as you work.

**EVALUATION:**

Discuss as a class what they saw at different stages of each type of stars' life. Which stars became black holes? Why did only those stars become black holes? Which stars deflated and which exploded? What is the main difference between those stars?

**CLOSURE:**

Compare activity to predictions made at beginning of class. Record conclusions drawn from activity next to predictions, pointing out that changing your ideas is part of being a good scientist.

## Life Cycle of Stars Information Chart

	<b>Red Balloons</b>	<b>Yellow Balloons</b>	<b>White Balloons</b>	<b>Blue Balloons</b>
Age of Star	0.4 Solar Mass (2/5 the mass of our Sun): Red stars	1 Solar Mass (the mass of our Sun): Yellow Stars	3 Solar Masses (3 times the mass of our Sun): White	9 Solar Masses (9 times the mass of our Sun): Blue
(start)	Blow up the star to about 3" diameter	Blow up the star to about 3" diameter	Blow up the star to about 3" diameter	Blow up the star to about 3" diameter
5 Million Years	Wait. Do not change diameter of balloon.	Wait. Do not change diameter of balloon.	Wait. Do not change diameter of balloon.	Blow slightly more air into balloon.
10 Million Years	Wait	Wait.	Blow up a little more	Blow up star as fast and as much as you can. When star is fully inflated, teacher pops balloon—a supernova.
500 Million Years	Wait.	Wait (note that planets are forming)	Continue to slowly inflate star. As it gets bigger, star cools, so color it yellow and red (make squiggles on surface with markers).	This popped star has become a black hole; all of the super nova remnants can be thrown out into space.
1 Billion Years	Wait	Blow up a little bit.	Quickly blow up star until fully inflated; pop balloon. Make sure to catch marble	Still black hole!

	<b>Red Balloons</b>	<b>Yellow Balloons</b>	<b>Blue Balloons</b>	<b>White Balloons</b>
8 Billion Years	Wait.	Blow up more. The star is getting cooler, so color it red with marker. It is now a supergiant.	This star has exploded. Holding on to neutron star (marble), throw supernova remnants into space.	Still black hole
10 Billion	Wait	Blow up a little more. Outer envelope dissolves, so cut up balloon. The inside ball becomes a white dwarf, and the bits of balloon represent the planetary nebula.	Neutron star	Black hole
50 billion years	Blow up a little more	Move “planetary nebula” farther away.	Neutron star	Black hole
200 Billion years.	Deflate; star has shrunk and died. Color black. Wooden bead inside is a white dwarf.	Nebula is gone. Discuss that the white wooden bead turns black to show that it has burned out.	Neutron star	Black hole.



## Colors of Stars

Mary Kay Hemenway  
The University of Texas at Austin Department of Astronomy  
The University of Texas McDonald Observatory  
Adapted for UTOPIA by Brad Armosky

### **Objectives and State of Maine Learning Results Performance Indicators:**

#### **MLRs**

1. Learners will be able to analyze the effects of heating and cooling processes in systems. (3-5. Science & Technology. D3.c.)
2. Learners will be able to use appropriate tools, metric units and techniques to gather, analyze, and interpret data. (6-8. Science & Technology. B1.c.)

#### **NGSS**

1. Learners will be able to plan an investigation to determine the relationships among the energy transferred, the type of matter, the mass, and the change in the average kinetic energy of particles as measured by the temperature of the sample. (Energy. MS-PS3-4)

#### The General Idea:

Students observe colors in the flame of a burning candle to explore connections between matter, light, color, and temperature — basic concepts of matter and energy. They elaborate on these basic concepts in a new context of astronomy and stars. When matter gets hot enough, it emits visible light. When heated to the same temperature, light bulb filaments, horseshoes, and stars will emit the same characteristic blend of color (or wavelengths) of light. Stars are different colors — white, blue, yellow, orange, and red. The color indicates the star’s temperature in its photosphere, the layer where the star emits most of its visible light.

#### Getting Ready:

- Choose one of the following StarDate radio program scripts for students to read, or you may read it aloud to them: “Spring Triangle” or “Denebola.”
- Optional: You may wish to check the StarDate Online web site (<http://stardate.org>) for interesting radio scripts that will help students find stars of different colors in the night sky. See the “Elaborate” section of this activity.
- Distribute to each group of students: white paper, crayons or colored pencils (lots of different colors), and one candle in a candle holder. Remind students of your classroom’s safety rules before beginning.

#### What You Need:

- StarDate radio script (“Denebola” or “Spring Triangle”); included.
- Candles and candle holders (e.g., cupcakes)
- Matches
- White paper
- Crayons or colored pencils. Offer students a wide variety of colors.
- Construction paper
- Colored chalk
- String
- Spherical balloons (yellow and white)
- Ruler or meter stick

### What To Do:

Light the candles. Ask the students to draw what they see in the flame, and to pay special attention to the colors they select. Ask students to record the colors they selected to draw the flame. Some students will use a wide variety of blue, yellow, orange, and red to capture the subtle hues in the flame.

*Optional:* If you have a digital camera, ask each group to take a picture (flash off) of their candle flame. Use the camera *after* students have completed their candle flame drawings.

### What To Discuss:

When everyone is finished drawing, ask each group to describe what they saw and respond to the following questions:

1. Which part of the flame do you think is the hottest?

*The blue part is the hottest. Many think that “red” is always the hotter color, so that’s what they expect.*

2. As you watch the candle flame, what things or events in everyday life come to mind?

*Colors of the flame on a gas stove, camp fire, outdoor charcoal grill fire, rocket engine during liftoff, blowtorch, jet engine...*

The answers will usually make the students want to look at their candle flame again, so don’t extinguish the flames until all students have reported (unless it becomes a safety issue). Most will notice that the color of the flame is different close to the wick.

*Optional:* Load the digital images onto a computer to display on a video projector. Each group may refer to these images, as well as their drawings, to describe their flame. In stars, just as in Earth-bound fires, blue is hotter than yellow, and yellow is hotter than red. The Sun is much hotter than a candle flame. Unlike a candle, the Sun uses nuclear fusion as its energy source, not a chemical reaction like burning oil or wood. Stars are different colors because they are different temperatures. They are all “hot” compared to most things on Earth; they range in surface temperature from less than 3000 K to over 50,000 K. Explain to students that when we heat things that don’t easily melt (like metal), they first look normal, then begin glowing “red-hot,” and later become “white-hot.”

### Continuations/Extensions:

#### **Draw scale models of stars**

Because it is difficult to make three-dimensional models that preserve scale, some of the representations of stars in this activity will be flat. On a sidewalk or parking lot, try drawing colored circles in chalk for the larger stars. You can make the smaller ones out of colored construction paper. To begin, students blow up a yellow balloon to represent the Sun, then a white one that is 2.7 times larger (in diameter and circumference) to represent Vega (guide students through solving this problem):

- Measure the circumference of the yellow balloon ( $C_y$ ) using string.
- Calculate the circumference of the white balloon:  $C_w = 2.7 \times C_y$
- Cut a new string to the length of  $C_w$
- Blow up the white balloon until its circumference is  $C_w$ .

Students make paper disks the same diameter and color as these two balloons. Now, they compute how large the disk would be for the larger stars. Making a disk to represent a star is like using a flat picture to represent a person. Stars are spheres of hot gas, round like balloons. Students draw the largest diameters outside (using chalk or tracing the outline with string).

To make a circle:

- Measure a piece of string equal to the calculated diameter.
- Fold the string in half and hold at the center
- Place a piece of chalk where the ends of the string meet and trace a circle.



Use the table provided to scale the star diameters. For example, if you begin with a one centimeter Sun, then Betelgeuse will be 8.3 meters! So, this activity takes a lot of space.

<b>Star</b>	<b>Diameter</b> (Sun's diameter = 1)	<b>Color</b>
Sun	1	Yellow
Betelgeuse in Orion	830	Red
Antares in Scorpius	775	Red
Vega in Lyra	2.7	White
Rigel in Orion	50	Blue
Proxima Centauri C (closest star to the Sun)	0.03	Red
Dubhe (brightest star in the Big Dipper)	14	Orange

Although stars range in mass from less than one-tenth the mass of the Sun to 100 solar masses, the most massive stars are not the largest. Stars like Betelgeuse and Antares have “puffed up” into red giants hundreds of times the Sun’s diameter, yet Betelgeuse is about 20 times more massive than the Sun. There is a lot of empty space inside Betelgeuse. If Betelgeuse is 830 times the Sun’s diameter, air at sea level is almost 25,000 times the average density of Betelgeuse.

**Evaluate:**

**Explore** (20 points)

(20 points) Candle flame drawing: Students represent the flame with a variety of colors, and accurately proportion parts of the flame. Some may include the wick and candle.

**Explain** (40 points)

1. Which part of the candle flame do you think is the hottest? Why?

(20 points) Students draw on prior knowledge / everyday experience and their understanding of science concepts in their explanations.

2. As you watch the candle flame, what things or events in everyday life come to mind?

(20 points) Students list a variety of things and/or events:

For instance: jet engine, blowtorch, hot oven, bread toaster coils, camp fire, Space Shuttle launch, the Sun, sunset colors...

**Elaborate: Make and draw models of stars** (40 points)

Parts 1 and 2: (10 points) Students inflate the yellow balloon to represent the Sun and inflate the white balloon so that its circumference is 2.4 times larger than the Sun balloon.

Parts 3 and 4: (10 points) Students accurately measure and cut out the paper disks, then correctly calculate the scale diameters for the four large stars in the table.

Part 5: (20 points)

Students accurately calculate the model star radii using the table. The radii depend on the scale size they choose for the Sun.

Students use the string and chalk to draw big circles that represent the large stars:

- Measure a piece of string equal to the calculated diameter.
- Fold the string in half and hold at the center.
- Place a piece of chalk where the ends of the string meet and trace a circle.

Name \_\_\_\_\_ Date \_\_\_\_\_

## The Color of Stars Student Worksheet

### **Explore**

Draw the candle flame

### **Explain**

1. Which part of the flame do you think is the hottest? Why?

2. As you watch the candle flame, what things or events in everyday life come to mind?

**Elaborate:** Make and draw scale models of stars

1. Inflate a yellow balloon to represent the Sun.
2. Inflate a white balloon 2.7 times larger than the Sun balloon. The white balloon represents nearby star called Vega. How do you know if the white balloon is 2.7 times bigger?
3. Make paper disks the same diameter and color as the Sun and Vega balloons.
4. Calculate how large the paper disk would be for the larger stars

Star	Model diameter
Betelgeuse	
Antares	
Rigel	
Dubhe	

5. Draw the largest circles outside to represent the four large stars. How do you think you could make the circles using string and chalk?

**Scale Size and Colors of Stars**

Star	Diameter (Sun's diameter = 1)	Color
Sun	1	Yellow
Betelgeuse in Orion	830	Red
Antares in Scorpius	775	Red
Vega in Lyra	2.7	White
Rigel in Orion	50	Blue
Proxima Centauri C (closest star to the Sun)	0.03	Red
Dubhe (brightest star in the Big Dipper)	14	Orange

Use the table to calculate the model star diameters. For example, if you begin with a one centimeter Sun, then Betelgeuse will be 8.3 meters!

## STARDATE CLASSROOM RESOURCES

StarDate: March 7, 2004

### Denebola

Leo, the lion, prowls through our evening sky this month, and stands high overhead around midnight. Its two brightest stars mark opposite ends of the constellation. Regulus, the heart of the lion, is at Leo's western edge. And the second-brightest star, Denebola, marks Leo's tail at the constellation's eastern end. Look for it above and to the left of the full Moon this evening, and to the lower left of the brilliant planet Jupiter.

The name Denebola evolved from the ancient Arabic name Al Dhanab al Asad -- the lion's tail.

Like the Sun, Denebola is a main-sequence star -- a sedate, comfortable star in the prime of life. But Denebola is a blue-white star, which means that its surface temperature is several thousand degrees hotter than the Sun's. And if you placed the two stars side by side, Denebola would appear about 15 times brighter than the Sun.

This means that Denebola's consuming its nuclear fuel at a faster rate, so it'll live a shorter life.

Denebola is about 40 light-years from Earth. In other words, a beam of light -- speeding along at almost six TRILLION miles every year -- takes 40 years to travel from Denebola to Earth. The light we see from Denebola tonight left the star not long after the first humans were launched into space.

If intelligent beings live on planets in orbit around Denebola, they should just now be receiving the television broadcasts of those early missions.

We'll talk about another prominent star tomorrow.

Script by Damond Benningfield, Copyright 1998, 2001, 2004

## STARDATE CLASSROOM RESOURCES

StarDate: March 15, 2004

### Spring Triangle

Summer and winter offer two of the most prominent geometric shapes in the night sky - the Summer Triangle and the Winter Circle. These patterns of bright stars dominate the evening sky during their respective seasons -- and the Winter Circle is STILL in view in the west as darkness falls.

There's no well-recognized shape for spring, but perhaps there should be. Three bright stars form a tall triangle in the east beginning around 9 p.m. The stars are spread pretty far apart, but they still stand out -- especially from cities, where bright lights overpower most of the fainter stars.

The most prominent member of this triangle is Arcturus, the third-brightest star in the night sky. It's in the constellation Bootes, the herdsman. This brilliant yellow-orange star is low in the east in mid-evening, and wheels high across the sky during the night.

It's a type of star known as a giant, which means it's old and bloated -- a preview of what our own Sun will look like in several billion years.

Well to the right of Arcturus, just a little lower in the sky, you'll see Spica, the brightest star of Virgo. And well above Spica and a little to its right is Regulus, in the constellation Leo. These stars are quite similar. Like the Sun, they're both in the prime of life. But they're hotter than the Sun, so they shine brighter and bluer.

Look for the bright but wide-spread "Spring Triangle" in the east beginning around 9 o'clock.

Script by Damond Benningfield, Copyright 2001, 2004

Copyright © 2004 McDonald Observatory. You are free to copy StarDate materials for educational uses. Copies may be distributed to other teachers, placed in your school's library, or used for other educational purposes. However, the copies may not be sold or otherwise distributed for non-educational uses. Document created Jul 28, 2004.



## Newton's Second Law of Motion

Adler Planetarium & Astronomy Museum Astronomy  
Connections: Gravity and Black Holes

### Objectives and State of Maine Learning Results Performance Indicators:

#### MLRs

1.  Learners will be able to articulate that force is a push or pull on an object. (6-8. Science & Technology. D4.e.)
2.  Learners will be able to use Newton's Laws to describe the motion of objects (9-D. Science & Technology. D4. b.)
3. Learners will be able to design and conduct their own scientific investigation of Newton's Second Law, using controlled experiments and systematic observations. (6-8. Science & Technology. B1.b.)

#### NGSS:

1. Learners will be able to plan an investigation to provide evidence that the change in an object's motion depends on the sum of the forces on the object and the mass of the object. (Motion and Stability: Forces and Interactions. MS-PS2-2)

#### The General Idea:

Through active participation, the students will learn and demonstrate Newton's Second Law of Motion.

#### Getting Ready:

Gather supplies listed below.

1. Arrange all building materials on a large table and in boxes beside the table.
2. Place the mass on the cart and put on the in-line skates before class. This lesson lends itself to be adapted for any student need. It has a teacher demonstration and a connection element where students are asked to connect Newton's 2nd Law of Motion to personal experiences.

#### What You Need:

1. In-line skates (optional)
2. Cart on wheels
3. Mass (Recommended: a box of computer or copier paper)
4. Open space to roll cart
5. Place to record predictions and observations (chalkboard or paper and pencils)
6. Scale for weighing demonstrator, mass and cart

#### What To Do:

1. The teacher will discuss the fable of Newton and the apple. There may have been a chance that Newton observed an apple falling from a tree, but not necessarily on his head as conveniently as the story tells us. But Newton did describe the Laws of Motion that still describe motion as we observe it today.
2. Discuss that every object has mass. Define mass as the amount of material or "stuff" that makes up an object.
3. Define Newton's First Law of Motion as "a body at rest stays at rest unless it is made to change by a force acting on it". Point out objects in the room that are at rest and remain that way unless a force is acted on it. Perform few simple demonstrations of the idea, e.g. drop an eraser from an "at rest" position. Allow students to do the same.
4. Define Newton's Second Law as the amount of acceleration (**a**)(change in speed), that a force (**F**) can produce, depends inversely on the mass of the object being accelerated. (**F=ma**). The demonstration will show this.

5. Discuss what a force is and what can produce forces. There are forces created by gravity, by muscles, by magnets...Since every object has mass, the only way it can change from being still to moving is by having a force act on it (in other words by being pushed or pulled.)
6. Explain the cart set up. Both the cart and the demonstrator have a property called mass. Since the weight of an object is directly related to its mass, we can use the relative weight of objects to judge their mass (on Earth.) If an object weighs more, it is more massive and vice-versa.
7. Figure out which weighs more, the mass and cart or the demonstrator. Show or tell the students which is heavier. (You may choose to weigh both the mass and cart, and the demonstrator in front of the class or in private...)
8. Let the students see that the cart and the demonstrator (if using skates) are on wheels, and explain that this is important because the wheels will reduce the effects of other forces, such as friction.
9. Ask the students to predict what will happen when the demonstrator pushes on the cart. Record class predictions on the board.
10. Push the cart, what happened? Record student observations.
11. Now do the same demonstration but remove the mass from the cart. What do the students predict will happen now? Record predictions.
12. Push the cart and record observations.
13. Discuss what happened in the demonstrations. Was there a change in outcomes? What caused that change? Discuss how a change in mass affected the acceleration of an object in the demonstration. How could the demonstration be altered so that the demonstrator would move and not the cart?
14. Assuming that the demonstrator is heavier, and therefore more massive, than the cart and mass, when the cart and mass are pushed, the cart and mass change speed from zero to some small velocity  $\square$  (to the right for example), while the demonstrator moves less than the cart to the left, if wearing skates. When the cart is pushed without the mass, the mass of the cart is much less but the force provided by the demonstrator is still the same (nothing has happened to her muscles.) So, because  $\mathbf{F}=\mathbf{ma}$ , the acceleration changes to make up for the small mass and the cart goes flying to the right and the demonstrator stays in place. This is the concept referred to by Newton's Second Law in #4 above. Ask students to discuss the relationship between mass, acceleration and force at some length to ensure understanding.  
**Note:** To ensure that the demonstrator would move and not the cart, mass would have to be added to the cart until it weighed more than the demonstrator. (Or the demonstrator could push off a wall which in a sense would have a huge mass because it is rooted to the earth.)

#### **EVALUATION:**

- The students have now seen one example of how Newton's Second Law can be shown, but it is up to them to think of an example on their own.
- Have the students work in small groups to create an example of Newton's Second Law.
- They will be responsible for explaining their suggestion to the rest of the class.
- Discuss each group's suggestions. Do they demonstrate the Second Law of Motion?

#### What To Discuss:

Redefine Newton's First and Second Law of Motion. Discuss that a black hole is a body that holds a lot of mass in a very small space. How do they think Newton's laws will work with something massive? Would there need to be a lot of force to create a change in speed, or just a little?

# Vocabulary List

accretion disk	A relatively flat sheet of gas and dust surrounding a newborn star, a black hole, or any massive object growing in size by attracting material.
Big Bang Theory	A theory of cosmology in which the expansion of the universe is presumed to have begun with a primeval explosion (referred to as the "Big Bang").
black hole	An object whose gravity is so strong that not even light can escape from it.
blueshift	An apparent shift toward shorter wavelengths of spectral lines in the radiation emitted by an object caused by motion between the object and the observer which decreases the distance between them.
Escape Velocity	The minimum speed needed for an object to escape the gravitational pull of a massive object.
Event horizon	The distance from a black hole within which nothing can escape. In addition, nothing can prevent a particle from hitting the singularity in a very short amount of proper time once it has entered the horizon.
G – Gravitational Constant	Newton proposed that the property of having mass gives rise to a universal force of attraction between bodies. This is called gravity. And no matter where in the universe two bodies are or what mass they have, the force they each feel is proportional to the product of their masses divided by the square of their separation. The constant of this proportionality is called the universal gravitational constant. It's amazing that no matter where or what, the gravitational force between two bodies divided by $(Mm / r^2)$ is always equal to the same number – G.
Miniature Black Hole	A type of black hole thought to have developed early in the history of the universe. The mass associated with this type of black hole is in the order of magnitude of elementary particles.
Neutron Star	An extremely compact ball of neutrons formed from the central core of a collapsed star, having the mass of a star but smaller than an average planet in size.
Redshift	Light or other electromagnetic radiation may be stretched, making a wavelength longer. Because red has a longer wavelength within the optical spectrum, the stretching of light as objects move away within the universe is referred to as redshift. The cosmological redshift tells astronomers how fast the universe is expanding.
Schwarzschild Radius	The radius of the event horizon around a black hole.
Singularity	In astronomy, a term often used to refer to the center of a black hole, where the curvature of spacetime is maximal. At the singularity, the gravitational tides diverge; no solid object can even theoretically survive hitting the singularity.
Stellar Black Hole	The result of a supernova of a star having enough mass so that the compact remnant of the star has collapsed, crushing its content into a singularity.

Supermassive Black Hole	This type of black hole is thought to lie at the heart of active galaxies and quasars, providing the gravitational powerhouse that explains the source of energy in these objects. This type of black hole has a mass many times larger than that of a single star.
Supernova	The death explosion of a massive star, resulting in a sharp increase in brightness followed by a gradual fading.
Wavelength	The distance between adjacent peaks in a series of periodic waves.
White Dwarf	A star formed from the collapse of a star like our Sun at the end of its life. The mass is condensed into a much smaller size, which greatly increases the temperature.



## Some good books to use with *Black Holes*

### **A Nature Company Guide: Skywatching**

Levy, David H., Time-Life Books, 1995.

*This book provides a general overview and discussion of astronomical objects, including black holes. For students in middle school or above.*

### **The Young Oxford Book of Astronomy**

Mitton, Jacqueline & Simon, Oxford University Press, Inc., 1995.

*This book explains many concepts in astronomy from the Solar System, galaxies, and the Universe, including black holes. Intended for the middle or high school student.*

### **Quasars, Pulsars, and Black Holes.**

Asimov, Isaac. Milwaukee: Gareth Stevens Publishing, 1988.

*A good reference for younger students. Small chunks of information on each page, with graphics to illustrate the points. Easily digestible, and the pictures really help. There are also interesting facts every few pages or so that are fun to read. It also has ideas for further study, such as a reading list, places to visit and places to write, along with a glossary.*

### **Relativity in the Palm of Your Hand**

Neil Ashby, Mercury, May 1996

*Atomic clocks, which rely upon atoms' inherent natural abilities to maintain reliable standards of time, are set in space and monitored by 24 satellites that orbit Earth and which compose the Global Positioning System. These standards, by which our own watches and clocks are set, reflect to us the universal principles of relativity.*

### **Prisons of Light: Black Holes**

Ferguson, Kitty. New York: Press Syndicate of the University of Cambridge, 1996.

*What is a black hole? Could we survive a visit? What do black holes teach us about the universe? This comprehensive, detailed, yet easy-to-read book answers questions about these unseen phenomena whose existence has been proven through physics and mathematics.*

### **Mysteries of Deep Space: Black Holes, Pulsars, and Quasars**

Isaac Asimov. Gareth Stevens Publ., 1994.

*Read about the birth of the sun and other stars, celestial energy, black holes, and quasars. Can you imagine something that spins 33 times a second or is 12 billion light years away? This book helps you understand these concepts and phenomena.*

### **Black Holes and Baby Universes and Other Essays.**

Hawking, Stephen W. Paperback reprint edition, Bantam Books, 1994.

## Some good web sites to use with *Black Holes OD*

### **[amazing-space.stsci.edu/resources/explorations/](http://amazing-space.stsci.edu/resources/explorations/)**

Check out some of the other online explorations at the Amazing Space website

### **[tycho.usno.navy.mil/time.html](http://tycho.usno.navy.mil/time.html)**

Do you want to know what time it is NOW? It's not as easy as you think to get the right answer.

### **[antwrp.gsfc.nasa.gov/htmltest/rjn\\_bht.html](http://antwrp.gsfc.nasa.gov/htmltest/rjn_bht.html)**

Has "Lost in Time" piqued your curiosity about time travel and relativity? Then find your way to this website authored by NASA's astrophysicist, Robert Nemiroff.

### **[www.astr.ua.edu/keel/agn/text.html](http://www.astr.ua.edu/keel/agn/text.html)**

An introduction to AGN (Active Galactic Nuclei), including a brief history, and a glossary at the end. High school and above.

**[starchild.gsfc.nasa.gov/docs/StarChild/universe\\_level2/quasars.html](http://starchild.gsfc.nasa.gov/docs/StarChild/universe_level2/quasars.html)**

This page contains information on quasars written for the 5-8 grade student, with a question at the end and words linked to a glossary of terms.

**[www.cfa.harvard.edu/seuforum/learningresources.htm](http://www.cfa.harvard.edu/seuforum/learningresources.htm)**

This archival site has good resources for teachers, such as how black holes can help teach basic science, how to get students involved, and links to learn more in-depth about the concepts behind black holes.

**[www.nasa.gov/mission\\_pages/chandra/main/index.html](http://www.nasa.gov/mission_pages/chandra/main/index.html)**

Chandra X-ray Observatory Web site

**[imagine.gsfc.nasa.gov/docs/teachers/teachers\\_corner.html](http://imagine.gsfc.nasa.gov/docs/teachers/teachers_corner.html)**

The Teacher's Corner: Multidisciplinary Classroom Activities. Current page of NASA's Imagine the Universe sponsored by Goddard Space Flight Center.

## Lessons From The World Wide Web

Also, a wide variety of lesson plans and activities can be found on the World Wide Web. These sites are dedicated to lesson planning in a variety of subjects.

**[btc.montana.edu/ceres](http://btc.montana.edu/ceres)**

Maintained by the Burns Telecommunications Center, this page links to educational activities and classroom resources

**[spaceplace.jpl.nasa.gov/en/kids/](http://spaceplace.jpl.nasa.gov/en/kids/)**

This California Institute of Technology and NASA Jet Propulsion Laboratory site for kids offers information and activities

**[www.thegateway.org](http://www.thegateway.org)**

Sponsored by The U.S. Department of Education's National Library of Education and ERIC Clearinghouse on Information & Technology, this site offers lesson plans for all subjects and all grades

## Astronomy Web Sites Worth a Visit

**[Astro.umaine.edu](http://Astro.umaine.edu)**

The Maynard F. Jordan Planetarium and Observatory home page

**[stardate.org](http://stardate.org)**

Learn what's going on TODAY in astronomy on the "Star Date" web page, maintained by the University of Texas' McDonald Observatory

**[domeofthesky.com/clicks/constlist.html](http://domeofthesky.com/clicks/constlist.html)**

Find out the names of each constellation and the stories behind those names.

*The Maynard F. Jordan Planetarium does not guarantee that the information given on the above web sites to be accurate, accessible, or appropriate for students.*

The University of Maine does not discriminate on the grounds of race, color, religion, sex, sexual orientation, including transgender status and gender expression, national origin, citizenship status, age, disability, genetic information, or veteran status in employment, education, and all other programs and activities. The following person has been designated to handle inquiries regarding nondiscrimination policies: Director, Office of Equal Opportunity, 101 North Stevens Hall, 207.581.1226.

# Science Background of Black Holes for Teachers

<http://amazing-space.stsci.edu/resources/explorations/blackholes/teacher/index.html>

## **1. What is a black hole?**

A black hole is defined by the escape velocity that would have to be attained to escape from the gravitational pull exerted upon an object. For example, the escape velocity of earth is equal to 11 km/s. Anything that wants to escape earth's gravitational pull must go at least 11 km/s, no matter what the thing is — a rocket ship or a baseball. The escape velocity of an object depends on how compact it is; that is, the ratio of its mass to radius. A black hole is an object so compact that, within a certain distance of it, even the speed of light is not fast enough to escape.

## **2. How is a stellar black hole created?**

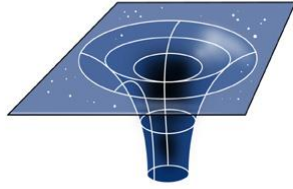
A common type of black hole is the type produced by some dying stars. A star with a mass greater than 20 times the mass of our Sun may produce a black hole at the end of its life. In the normal life of a star there is a constant tug of war between gravity pulling in and pressure pushing out. Nuclear reactions in the core of the star produce enough energy to push outward. For most of a star's life, gravity and pressure balance each other exactly, and so the star is stable. However, when a star runs out of nuclear fuel, gravity gets the upper hand and the material in the core is compressed even further. The more massive the core of the star, the greater the force of gravity that compresses the material, collapsing it under its own weight. For small stars, when the nuclear fuel is exhausted and there are no more nuclear reactions to fight gravity, the repulsive forces among electrons within the star eventually create enough pressure to halt further gravitational collapse. The star then cools and dies peacefully. This type of star is called the "white dwarf." When a very massive star exhausts its nuclear fuel it explodes as a supernova. The outer parts of the star are expelled violently into space, while the core completely collapses under its own weight.

To create a massive core a progenitor (ancestral) star would need to be at least 20 times more massive than our Sun. If the core is very massive (approximately 2.5 times more massive than the Sun), no known repulsive force inside a star can push back hard enough to prevent gravity from completely collapsing the core into a black hole. Then the core compacts into a mathematical point with virtually zero volume, where it is said to have infinite density. This is referred to as a singularity. When this happens, escape would require a velocity greater than the speed of light. No object can reach the speed of light. The distance from the black hole at which the escape velocity is just equal to the speed of light is called the event horizon. Anything, including light, that passes across the event horizon toward the black hole is forever trapped.

## **3. Since light has no mass how can it be trapped by the gravitational pull of a black hole?**

Newton thought that only objects with mass could produce a gravitational force on each other. Applying Newton's theory of gravity, one would conclude that since light has no mass, the force of gravity couldn't affect it. Einstein discovered that the situation is a bit more complicated than that. First he discovered that gravity is produced by a curved space-time. Then Einstein theorized that the mass and radius of an object (its compactness) actually curves space-time. Mass is linked to space in a way that physicists today still do not completely understand. However, we know that the stronger the gravitational field of an object, the more the space around the object is curved. In other words, straight lines are no longer straight if exposed to a strong gravitational field; instead, they are curved. Since light ordinarily travels on a straight-line path, light follows a curved path if it passes through a strong gravitational field. This is what is meant by "curved space," and this is why light becomes trapped in a black hole. In the 1920's Sir Arthur Eddington proved Einstein's theory when he observed starlight curve when it traveled close to the Sun. This was the first successful prediction of Einstein's General Theory of Relativity.

One way to picture this effect of gravity is to imagine a piece of rubber sheeting stretched out. Imagine that you put a heavy ball in the center of the sheet. The weight of the ball will bend the surface of the sheet close to it. This is a two-dimensional picture of what gravity does to space in three dimensions. Now take a little marble and send it rolling from one side of the rubber sheet to the other. Instead of the marble taking a straight path to the other side of the sheet, it will follow the contour of the sheet that is curved by the weight of the ball in the center. This is similar to how the gravitation field created by an object (the ball) affects light (the marble).



#### **4. What does a black hole look like?**

A black hole itself is invisible because no light can escape from it. In fact, when black holes were first hypothesized they were called "invisible stars." If black holes are invisible, how do we know they exist? This is exactly why it is so difficult to find a black hole in space! However, a black hole can be found indirectly by observing its effect on the stars and gas close to it. For example, consider a double-star system in which the stars are very close. If one of the stars explodes as a supernova and creates a black hole, gas and dust from the companion star might be pulled toward the black hole if the companion wanders too close. In that case, the gas and dust are pulled toward the black hole and begin to orbit around the event horizon and then orbit the black hole. The gas becomes heavily compressed and the friction that develops among the atoms converts the kinetic energy of the gas and dust into heat, and x-rays are emitted. Using the radiation coming from the orbiting material, scientists can measure its heat and speed. From the motion and heat of the circulating matter, we can infer the presence of a black hole. The hot matter swirling near the event horizon of a black hole is called an accretion disk.

John Wheeler, a prominent theorist, compared observing these double-star systems to watching women in white dresses dancing with men in black tuxedos within a dimly lit ballroom. You see only the women, but you could predict the existence of their invisible partners because of the women's spinning and whirling motions around a central axis. Searching for stars whose motions are influenced by invisible partners is one way in which astronomers search for possible black holes.

#### **5. Is a black hole a giant cosmic vacuum cleaner?**

The answer to this question is "not really." To understand this, first consider why the force of gravity is so strong close to a black hole. The gravity of a black hole is not special. It does not attract matter at large distances differently than any other object does. At a long distance from the black hole the force of gravity falls off as the inverse square of the distance, just as it does for normal objects.

Mathematically, the gravity of any spherical object behaves as if all the mass were concentrated at one central point. Since most ordinary objects have surfaces, you will feel the strongest gravity of an object when you are on its surface. This is as close to its total mass as you can get. If you penetrated a spherical object with a constant mass density, getting closer to its core, you would feel the force of gravity get weaker, not stronger. The force of gravity you feel depends on the mass that is interior to you, because the gravity from the mass behind you is exactly canceled by the mass in the opposite direction. Therefore, you will feel the strongest force of gravity from an object, for example a planet, when you are standing on the planet's surface, because it is on the surface that you are closest to its total mass. Penetrating the surface of the planet does not expose you to more of the planet's total mass, but actually exposes you to less of its mass. Now remember the size of a black hole is infinitesimally small. Gravity near a black hole is very strong because objects can get extremely close to it and still be exposed to its total mass.

There is nothing special about the mass of a black hole. A black hole is different from our ordinary experience not because of its mass, but because its radius has vanished. Far away from the black hole, you would feel the same strength of gravity as if the black hole were a normal star. But the force of gravity close to a black hole is enormously strong because you can get so close to its total mass!

For example, the surface of the Earth where we are standing is 6378 km from the center of the Earth. The surface is as close as you can get and still be exposed to the total mass of the Earth. Thus, it is where you will feel the strongest gravity. If suddenly the Earth became a black hole (impossible!) and you remained at 6378 km from the new Earth-black hole, you would feel the same pull of gravity as you do today. For example, if you normally weigh 120 lbs, you would still weigh 120 lbs. The mass of the Earth hasn't changed, your distance from it hasn't changed, and therefore you would experience the same gravitational force as you feel on the surface of normal Earth. But with the Earth-black hole, it would be possible for you to get closer to the total mass of the Earth. Let's say that you weigh 120 lbs standing on the surface of normal Earth. As you venture closer toward the Earth-black hole you would feel a stronger

and stronger force. If you went to within 3189 km (half the radius of normal Earth) of the Earth-black hole you would weigh 480 lbs! For the same exercise with the Earth as we normally experience it, if you dug your way to 3189 km of the center, you would weigh less than at the surface, a mere 60 lbs, because there would be less Earth mass interior relative to you!

As another example, consider the Sun. If the Sun suddenly became a black hole (equally impossible!), the Earth would continue on its normal orbit and would feel the same force of gravity from the Sun as usual!

Therefore, to be "sucked up" by a black hole, you have to get very close; otherwise, you experience the same force of gravity as if the black hole were the normal star it used to be. As you get close to a black hole, relativistic effects become important; for example, the escape velocity approximates and eventually reaches the speed of light and some very strange things like the "event horizon effect" begin to happen. For details, consult any popular book on black holes.

### **6. Do all stars become black holes?**

Only stars with very large masses can become black holes. Our Sun, for example, is not massive enough to become a black hole. Four billion years from now when the Sun runs out of the available nuclear fuel in its core, our Sun will die a quiet death. Stars of this type end their history as white dwarf stars. More massive stars, such as those with masses of over 20 times our Sun's mass, may eventually create a black hole. When a massive star runs out of nuclear fuel it can no longer sustain its own weight and begins to collapse. When this occurs the star heats up and some fraction of its outer layer, which often still contains some fresh nuclear fuel, activates the nuclear reaction again and explodes in what is called a supernova. The remaining innermost fraction of the star, the core, continues to collapse. Depending on how massive the core is, it may become either a neutron star and stop the collapse or it may continue to collapse into a black hole. The dividing mass of the core, which determines its fate, is about 2.5 solar masses. It is thought that to produce a core of 2.5 solar masses the ancestral star should begin with over 20 solar masses. A black hole formed from a star is called a stellar black hole.

### **7. How many types of black holes are there?**

According to theory, there might be three types of black holes: stellar, supermassive, and miniature black holes — depending on their size. These black holes have also formed in different ways. Stellar black holes are described in Question 6. Supermassive black holes likely exist in the centers of most galaxies, including our own galaxy, the Milky Way. They can have a mass equivalent to billions of suns. In the outer parts of galaxies (where our solar system is located within the Milky Way) there are vast distances between stars. However, in the central region of galaxies, stars are packed very closely together. Because everything in the central region is tightly packed to start with, a black hole in the center of a galaxy can become more and more massive as stars orbiting the event horizon can ultimately be captured by gravitational attraction and add their mass to the black hole. By measuring the velocity of stars orbiting close to the center of a galaxy, we can infer the presence of a supermassive black hole and calculate its mass. Perpendicular to the accretion disk of a supermassive black hole, there are sometimes two jets of hot gas. These jets can be millions of light years in length. They are probably caused by the interaction of gas particles with strong, rotating magnetic fields surrounding the black hole. Observations with the Hubble Space Telescope have provided the best evidence to date that supermassive black holes exist.

The exact mechanisms that result in what are known as miniature black holes have not been precisely identified, but a number of hypotheses have been proposed. The basic idea is that miniature black holes might have been formed shortly after the "Big Bang," which is thought to have started the Universe about 15 billion years ago. Very early in the life of the Universe the rapid expansion of some matter might have compressed slower-moving matter enough to contract into black holes. Some scientists hypothesize that black holes can theoretically "evaporate" and explode. The time required for the "evaporation" would depend upon the mass of the black hole. Very massive black holes would need a time that is longer than the current accepted age of the universe. Only miniature black holes are thought to be capable of evaporation within the existing time of our universe. For a black hole formed at the time of the "Big Bang" to evaporate today its mass must be about  $10^{15}$ g (i.e., about 2 trillion pounds), a little more than twice the mass of the current *Homo sapien* population on planet Earth. During the final phase of the "evaporation," such a black hole would explode with a force of several trillion times that of our most powerful nuclear weapon. So far, however, there is no observational evidence for miniature black holes.

### **8. When were black holes first theorized?**

Using Newton's Laws in the late 1790s, John Michell of England and Pierre LaPlace of France independently suggested the existence of an "invisible star." Michell and LaPlace calculated the mass and size — which is now called the "event horizon" — that an object needs in order to have an escape velocity greater than the speed of light. In 1967 John Wheeler, an American theoretical physicist, applied the term "black hole" to these collapsed objects.

### **9. What evidence do we have for the existence of black holes?**

Astronomers have found convincing evidence for a supermassive black hole in the center of the giant elliptical galaxy M87, as well as in several other galaxies. The discovery is based on velocity measurements of a whirlpool of hot gas orbiting the black hole. In 1994, Hubble Space Telescope data produced an unprecedented measurement of the mass of an unseen object at the center of M87. Based on the kinetic energy of the material whirling about the center (as in Wheeler's dance, see Question 4 above), the object is about 3 billion times the mass of our Sun and appears to be concentrated into a space smaller than our solar system.

For many years x-ray emission from the double-star system Cygnus X-1 convinced many astronomers that the system contains a black hole. With more precise measurements available recently, the evidence for a black hole in Cygnus X-1 is very strong.

### **10. How does the Hubble Space Telescope search for black holes?**

A black hole cannot be viewed directly because light cannot escape it. Effects on the matter that surrounds it infer its presence. Matter swirling around a black hole heats up and emits radiation that can be detected. Around a stellar black hole this matter is composed of gas and dust. Around a supermassive black hole in the center of a galaxy the swirling disk is made of not only gas but also stars. An instrument aboard the Hubble Space Telescope, called the Space Telescope Imaging Spectrograph (STIS), was installed in February 1997. STIS is the space telescope's main "black hole hunter." A spectrograph uses prisms or diffraction gratings to split the incoming light into its rainbow pattern. The position and strength of the line in a spectrum gives scientists valuable information. STIS spans ultraviolet, visible, and near-infrared wavelengths. This instrument can take a spectrum of many places at once across the center of a galaxy. Each spectrum tells scientists how fast the stars and gas are swirling at that location. With that information, the central mass that the stars are orbiting can be calculated. The faster the stars go, the more massive the central object must be.

STIS found the signature of a supermassive black hole in the center of the galaxy M84. The spectra showed a rotation velocity of 400 km/s, equivalent to 1.4 million km every hour! The Earth orbits our Sun at 30 km/s. If Earth moved as fast as 400 km/s our year would be only 27 days long!

### **11. What is the Advanced Camera for Surveys (ACS)?**

The Advanced Camera for Surveys, which was installed in March 2002, represents the third generation of science instruments flown aboard the Hubble Space Telescope. With its wider field of view, sharper image quality, and enhanced sensitivity, the new camera doubles Hubble's field of view and expands its capabilities significantly. Upgrading the telescope with ACS's cutting-edge technology will make it ten times more effective and prolong its useful life. ACS is expected to outperform all previous instruments flown aboard the Hubble Space Telescope, primarily because of its expanded wavelength range. Designed to study some of the earliest activity in the universe, ACS will see in wavelengths ranging from far ultraviolet to infrared.

On the inside, the new instrument is actually a team of three different cameras each designed to perform a specific function: the wide field camera, the high-resolution camera, and the solar blind camera. For example, with a field of view twice that of WFPC2 (Hubble's current wide field instrument), ACS's wide field camera will conduct broad surveys of the universe. Astronomers will use it to study the nature and distribution of galaxies, which will reveal clues about how our universe evolved. The high-resolution camera will take extremely detailed pictures of the inner regions of galaxies. Among its many tasks will be to search neighboring stars for planets and planets-to be, and to take close-up images of the planets in our own solar system. The solar blind camera, which blocks visible light to enhance ultraviolet sensitivity, will focus on hot stars radiating in ultraviolet wavelengths.

## General misconceptions about Black Holes

Many of these misconceptions are addressed in the activity section entitled: "What Do You Know about Black Holes?" in which the student chooses "myth" or "fact" in response to a series of questions.

### **Black holes exist only in theory.**

Recent observations obtained by the Hubble Space Telescope have given considerable support to the presence of supermassive black holes at the centers of some galaxies, but there is not yet absolute proof. There has been very good evidence for the existence of stellar black holes for at least 20 years, based on the effects of an unseen companion in the double-star system, Cygnus X-1. The existence of black holes seems likely, given our understanding of physical processes, but it is not absolutely confirmed.

### **Black holes are giant cosmic vacuum cleaners that swallow up everything around them.**

In reality, at a given distance from its center a black hole creates the same gravity as would a normal object with the same mass. Therefore, black holes at a distance do not attract matter more strongly than ordinary stars do. However, another important factor that determines the magnitude of the force of gravity is the radius of the object. The mass of a black hole is so compressed that it is possible to get very close to its center

(see <http://amazing-space.stsci.edu/resources/explorations/blackholes/teacher/sciencebackground.html>), where gravity will be enormously strong.

### **Black holes can be detected visually.**

We observe black holes indirectly by the effect they have on material around them, but by definition a black hole cannot be "seen."

### **Our Sun will become a black hole.**

Only stars that are more massive than our Sun might become black holes when they run out of fuel at the end of their lives. The Sun is not massive enough to become a black hole. When the Sun dies, it will lose its outer layers gently and its core will contract to great density (about 1 ton per cubic centimeter), but the gravity of the small core will not be enough to overpower the pressure caused by atomic forces that separate electrons and atomic nuclei. This state of matter is called a white dwarf and it is the fate of our Sun.

### **Black holes and wormholes are connected.**

People often associate wormholes with black holes. The existence of black holes has been inferred by their effect on nearby matter. Astronomers, however, have never observed wormholes. Theory suggests that wormholes are shortcuts through space and time linking two points. People may think wormholes are real because they saw them in science fiction movies and television shows. Wormholes also are associated with white holes, another cosmic object that exists in mathematical theory, but hasn't been observed in nature. White holes, as the theory goes, are regions of space into which nothing can fall.