Description: Black Holes: The Other Side of Infinity introduces audiences to the intriguing world of black holes. Students learn how massive stars end their lives in supernova explosions and how these supernovae lead to the formation of black holes. Powerful telescopes in Hawaii are used to study stars that orbit around black holes, and astronomers are using these observations to better understand the black hole in our own Milky Way galaxy. Students also explore the theoretical concept of a wormhole – the idea that material falling into a black hole can be transported to another part of the Universe via a tube.

Activities: The curvature of space-time, exploring escape velocity.

Process Skills Focus: Inquiry, observation and communication.
Topics: Black holes, gravity.

Scientific Inquiry Standards:

- K.3S.1 Explore questions about living and non-living things and events in the natural world.
- K.3S.2 Make observations about the natural world.
- 1.3S.2 Record observations with pictures, numbers, or written statements.
- 1.3S.3 Describe why recording accurate observations is important in science.
- 2.3S.2 Make predictions about living and non-living things and events in the environment based on observed patterns.

Engineering Design Standards:

- 1.4D.3 Show how tools are used to complete tasks every day.
- 2.4D.3 Describe an engineering design that is used to solve a problem or address a need.

Earth and Space Science Content Standards:

- K.2E.1 Identify changes in things seen in the sky.
- H.2E.3 Describe how the universe, galaxies, stars, and planets evolve over time.

Physical Science Content Standards:

- K.2P.1 Examine the different ways things move.

Practices
2. Developing and using models
4. Analyzing and interpreting data
7. Engaging in argument from evidence

Crosscutting Concepts
1. Patterns
3. Scale, proportion, and quantity
4. Systems and system models
## DCIs

<table>
<thead>
<tr>
<th>Disciplinary Core Idea</th>
<th>K</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>MS</th>
<th>HS</th>
</tr>
</thead>
</table>

### Physical Science

| PS1 | Matter and Its Interaction | n/a | n/a | n/a | n/a | | | |
| PS2 | Motion and Stability: Forces and Interactions | n/a | n/a | n/a | | | | |
| PS3 | Energy | n/a | n/a | n/a | | | | |
| PS4 | Waves and Their Applications in Technologies for Information Transfer | n/a | n/a | n/a | n/a | | | |

### Life Science

| LS1 | From molecules to organisms: Structures and processes | n/a | | | | | | |
| LS2 | Ecosystems: Interactions, Energy, and Dynamics | n/a | n/a | n/a | | | | |
| LS3 | Heredity: Inheritance and Variation of Traits | n/a | n/a | n/a | n/a | | | |
| LS4 | Biological Evolution: Unity and Diversity | n/a | n/a | n/a | n/a | | | |

### Earth & Space Science

| ESS1 | Earth's Place in the Universe | n/a | ✓ | n/a | ✓ | ✓ | | |
| ESS2 | Earth's Systems | n/a | | | | | | |
| ESS3 | Earth and Human Activity | n/a | n/a | | | | | |

### Engineering, Technology, and Applications of Science

| ETS1 | Engineering Design | | | | | | |

### DCI Grade Band Endpoints

**ESS1.A** Patterns of the motion of the sun, moon, and stars in the sky can be observed, described, and predicted. (By end of grade 2).

*The sun is a star that appears larger and brighter than other stars because it is closer. Stars range greatly in their distance from Earth. (By end of grade 5).*

*Patterns of the apparent motion of the sun, the moon, and stars in the sky can be observed, described, predicted, and explained with models. (By end of grade 8).*

**ESS1.B** The solar system consists of the sun and a collection of objects, including planets, their moons, and asteroids that are held in orbit around the sun by its gravitational pull on them. (By end of grade 8).

*The solar system appears to have formed from a disk of dust and gas, drawn together by gravity. (By end of grade 8).*
**Performance Expectations**

1-ESS1-1. *Use observations of the sun, moon, and stars to describe patterns that can be predicted.*

5-ESS1-1. *Support an argument that differences in the apparent brightness of the sun compared to other stars is due to their relative distances from the Earth.*

MS-ESS1-2. *Develop and use a model to describe the role of gravity in the motions within galaxies and the solar system.*

MS-ESS1-3. *Analyze and interpret data to determine scale properties of objects in the solar system.*
The information and activities presented in the *Black Holes: The Other Side of Infinity* Teacher’s Guide have been adapted for use and distribution by OMSI from the following:

Denver Museum of Nature & Science

**GLOSSARY**

**Accretion:** The gradual accumulation of small objects to form a larger object due to their mutual gravitational attraction.

**Accretion disk:** A flattened disk of matter orbiting around an object. Friction between the matter in the disk causes the matter to gradually spiral in and accrete onto the object.

**Black hole:** The end-state of a high-mass star; an extremely massive concentration of matter so dense that even light cannot escape its gravitational field.

**Escape velocity:** The velocity required for one object to be launched from the surface of a body in order for it to escape the gravitational attraction of that body.

**Event horizon:** The outer boundary of a black hole, at which the escape velocity exceeds the speed of light.

**Galaxy:** A structured grouping of billions of stars, gas, and dust, bound together by their collective gravity.

**Gamma radiation:** The most powerful form of electromagnetic radiation, with the shortest wavelengths.

**Gamma-ray burst:** A burst of gamma rays from space, possibly triggered by the birth of black holes.

**Gravity:** The attractive force between any two bodies that is the result of their having mass.
| **Light year:** | The distance that light travels in one year, approximately 5.88 trillion miles. |
| **Schwarzschild radius:** | The radius of a black hole, named for the German astronomer Karl Schwarzschild. |
| **Singularity:** | The center of a black hole, an infinitely dense remnant of a massive star's core collapse. |
| **Speed of light:** | The speed at which light travels: 300,000 kilometers per second (186,000 miles per second). |
| **Supernova:** | An explosion caused by the collapse of the core of a massive star. |
| **Time dilation:** | The slowing of the flow of time, which may be observed for objects that approach the event horizon of a black hole. |
| **Wormholes:** | Theoretical "tubes" in space-time, which could be entered from a black hole. One could potentially enter a wormhole and emerge in another part of the galaxy or maybe even a new Universe. |
Check your comprehension of the planetarium show!

1) Black holes are so dense that not even __________ can escape their gravity.

2) Which scientist developed the idea of space-time?

3) Red supergiant stars die in huge explosions called ______________.

4) What is the event horizon of a black hole?

5) Are black holes common or rare?

6) Nearly all ____________ have a black hole in their center.

7) Powerful telescopes show that ____________ near the center of our own Galaxy move quickly due to the gravity of a black hole.

8) Choose the correct statement:
   a. Black holes have been directly observed.
   b. Black holes have never been directly observed, but we infer their presence due to the gravity they produce.

9) The singularity of a black hole refers to ____________________________
   ____________________________
   ____________________________

10) What is a wormhole?

11) Are wormholes thought to really exist? Why or why not?
Space-Time Curvature

Description: In this activity, students will observe the effects of the curvature of space-time.

TIME REQUIRED

- Advance Preparation: 5 minutes
- Activity: 30 minutes
- Clean Up: 5 minutes

SUPPLIES

- Black spandex-type cloth
- Quilting frame or embroidery hoop
- Balls of various weights and sizes

ADVANCE PREPARATION

- Build your model of space-time. Stretch black spandex material around the quilting frame and secure it. Place the frame between two tables or otherwise support it so that the frame is elevated and the spandex sheet is free to stretch down.

ACTIVITY

- Demonstrate to students what happens to the space-time model when a large, heavy ball such as a baseball or softball is placed in the middle of the model. Students should be able to see that the ball bends or stretches the model to form a "gravity well."
• Replace the large ball with a smaller ball of less mass. Ask students to compare the difference in the space-time model.

• Put the baseball back in the center and ask students to predict what will happen if you put a marble on the model. They should have an idea that if the marble is placed close enough, the marble will roll toward the baseball, thus illustrating the effects of gravity.

• Give students some time to experiment with various sizes and weights of balls on the space-time model. Ask them to manipulate the model, getting a smaller ball to “orbit” around a larger mass. Have them summarize their findings in a science journal.

Escape Velocity

Description: Students study the concept of escape velocity and learn that all objects can behave like black holes if they’re small enough.

TIME REQUIRED

Activity

30 minutes

SUPPLIES

• Whiteboard or other method for displaying information

ACTIVITY

• Point to a variety of everyday objects around the classroom – a backpack, a student, a box of crayons, etc. – and state that all objects can become black holes if they’re compressed to a small enough size.
In order to study black holes, we'll need to understand the concept of escape velocity. Draw or project the following images for your students:

Point to the different arrows: two show objects hitting the surface of the Earth, one shows an object orbiting the Earth, and one shows an object that has escaped from the Earth. Which arrow shows the object that has left the Earth?

Explain that objects can leave the Earth's gravitational field only if they travel very fast. The exact speed needed to leave the Earth depends on the Earth's size and mass, according to the following equation:

\[ V_{\text{escape}}^2 = \frac{2GM}{R} \]

- \( V_{\text{escape}} \) = the speed needed to leave ("escape") the Earth
- \( G \) = a constant equal to \( 6.67 \times 10^{-11} \text{ m}^3 / \text{kg} / \text{s}^2 \)
- \( M \) = the mass of the Earth \( (6 \times 10^{24} \text{ kg}) \)
- \( R \) = the radius of the Earth \( (6 \times 10^6 \text{ m}) \)

Have the students calculate \( V_{\text{escape}} \) for the Earth, using the values for \( G \), \( M \), and \( R \) given above. Remember that the left side of the equation is squared!

\[ V_{\text{escape}} = \sqrt{\frac{2GM}{R}} \]

The students should find that \( V_{\text{escape}} = 11,000 \text{ m} / \text{s} \) (approximately).

Emphasize that the escape velocity of the Earth is really big (that's 11 kilometers per second!).
Black holes have an escape velocity of the speed of light (300,000,000 meters per second). We can use this information to calculate the size a human being would have to be squished to in order to form a human black hole!

Let’s assume that the mass of a human being is roughly 70 kg.

Use the expression for escape velocity to calculate the size of a black hole that has the mass of a human:

\[ V_{\text{escape}}^2 = \frac{2GM}{R} \]

\[
(300,000,000)^2 = \frac{2 \times G \times 70}{R} \\
R = \frac{2 \times G \times 70}{(300,000,000)^2} \\
R = 1 \times 10^{-25} \text{ m} \\
\text{(that’s } 0.000000000000000000000000000001 \text{ m)}
\]

So, if we squished a human to the size of 1 x 10^-25 meters, he or she would have the same gravitational field as a black hole!

Calculate the size that other common objects would have to squished to in order to form black holes:

<table>
<thead>
<tr>
<th>Object</th>
<th>Mass (kg)</th>
<th>Approximate Size (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>The Sun</td>
<td>2 x 10^{30}</td>
<td>3,000</td>
</tr>
<tr>
<td>Earth</td>
<td>6 x 10^{24}</td>
<td>0.009</td>
</tr>
<tr>
<td>The Moon</td>
<td>7 x 10^{22}</td>
<td>0.0001</td>
</tr>
</tbody>
</table>

RESOURCES

NASA Education
http://www.nasa.gov/offices/education/about/index.html

Frequently Asked Questions About Black Holes
http://cosmology.berkeley.edu/Education/BHfaq.html

NASA’s Imagine the Universe
http://imagine.gsfc.nasa.gov