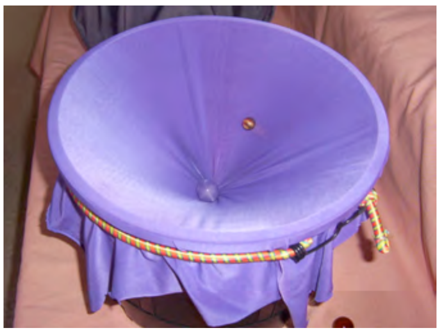
Night Sky Network
Astronomy Clubs bringing the wonders of the universe to the public

Black Holes: No Escape

How space curves around black holes and why it is impossible to escape.

About the Activity

Using a bucket with stretchy fabric stretched over it, allow visitors to experiment with marbles and weights to discover some basics about gravity and black holes. Discuss an Earth-mass black hole and “center of mass”; orbit marbles around black hole.



Topics Covered

How gravity works around black holes

Participants

This activity can be used with adults, teens, and families with children 7 years and older. If working with a school/youth group, 9 years and up. From one to fifteen people can participate.

Materials Needed

- 2 buckets (13”/33 cm plastic planters), from a garden store
- 2.5 pound (1 kg) lead weight, from a fishing or sporting goods store ***See important safety note on lead weights in the Helpful Hints**
- 8 oz (225 g) lead weight
- 4 oz (100 g) lead weight
- 2 Pee-wee marbles
- 2 Shooter (one-inch/2.5 cm) marbles
- A few regular marbles
- 2 bungee cords
- 2 18" (45 cm) squares stretch fabric squares - Can be found at a fabric store. Make sure the fabric is lightweight and quite stretchy in all directions.
- 4 feet (1.5 meters) of string
- Fishing bobber (sports store)
- Large towel or blanket

Location and Timing

- Pre-Star Party: As an introduction to the night’s observing.
- Scout troop or classroom: Form teams of 8 to 10 people and provide each team with a set of materials.
- Science Fair or Science Museum: Set up one or more tables with the demonstration materials. Have a club member at each table.
- This activity takes abou t 10 minutes

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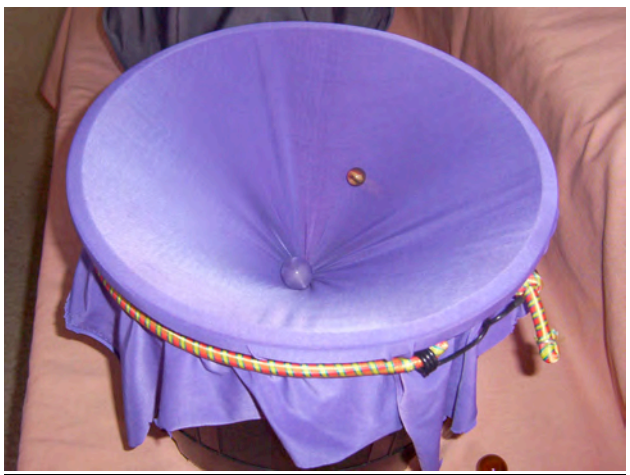
Set Up Instructions

- Secure the fabric onto one bucket with the bungee cords. Make sure the smoothest side of the fabric is facing up. The fabric on the bucket needs to be evenly stretched and stretched to approximately the same tension as you will make on the Black Hole bucket, below.

- **For Black Hole Bucket:** Attach the middle of the string to the fishing bobber so that 2 equal pieces are hanging. Place the bobber in the middle of a sheet of stretchy fabric and tie a rubber band tightly around the fabric and bobber so that the string sticks out. Thread the ends of the string through the holes in the bottom of the bucket and tie a knot. Then tie the bungee cord around the bucket and tuck the edges of the fabric under. It should look like the picture below.



- The buckets MUST be placed on a level surface. It is helpful to set up on or over a "non-roll" surface, like grass, carpet, a blanket, or large towel, to avoid having to chase marbles all during the presentation.

Detailed Activity Description

INTRODUCTION: Mass curves Space – Reason for gravitational acceleration

Introduction

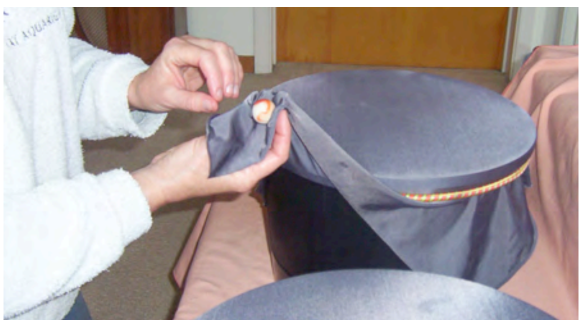
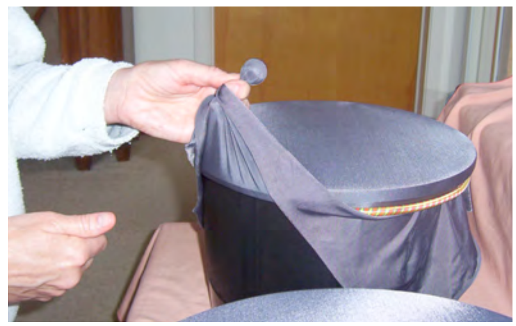
How does gravity work?
In the 1600's Isaac Newton developed the universal law of gravitation describing it as a force of attraction between objects that decreases with distance, and Albert Einstein in the early part of the last century developed the concept that matter curves space around it and this is why there is the force of gravity (as well as correctly predicting the existence of things like black holes and gravitational lensing of light). This concept has been verified by abundant observational evidence (see "Background Information").

This is one of a set of activities that illustrates various effects of gravity, or curved space. How much space curves, depends on two things:

1) How much mass is present. More mass, more curvature, therefore stronger gravitational attraction.
2) What the distance is from the center of the mass. Farther from the center of a massive object, space is less curved; therefore the gravitational attraction is less.

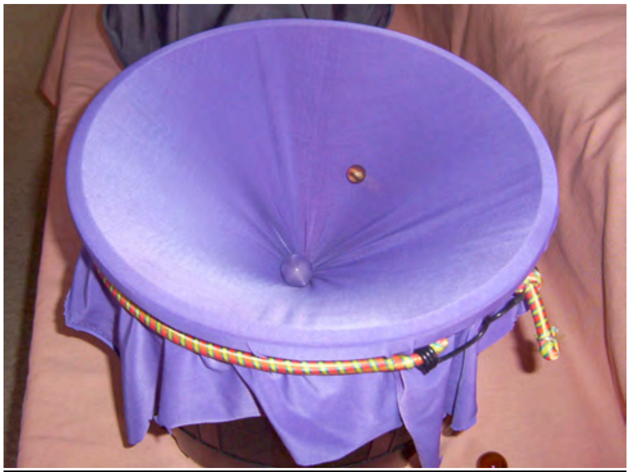
Take the two buckets covered with fabric and two different sized weights. Place one weight in the center of the fabric on each bucket.
Notice that the more massive weight curves the fabric, representing space, more than the less massive weight.
Notice also that space is curved the most nearest the weight and less curved toward the edge of the bucket.

Why we can't escape from the region of a black hole

Leader's Role	Participants
Key message for your visitors to take home: Space is curved completely around black holes – we cannot escape. To Say: Massive objects curve space. But a REALLY massive object, like a black hole curves space so severely that space is warped and twisted completely around it. To Do: Take a 1" marble and wrap the tag end of fabric around it.  	
To Say: Black holes are formed when really massive stars die, explode in a supernova and their remaining mass collapses down inside an area only a few miles across. Let's imagine that the Earth could become a black hole - how small do you think the Earth would become? To Do: Show 1" marble *To Say:* Let's say all the mass of the Earth was squeezed inside of this marble. This marble would represent the dimensions of a black hole that had the mass of Earth. Could anyone really pick this up?	Guesses No!

NOTE TO PRESENTER: *Imagining that the Earth could become a black hole (which it cannot), a one-inch marble correctly represents the approximate size of the event horizon of an Earth-mass black hole. Earth has a radius of about 4,000 miles.*	

Leader's Role	**Participants**
To Say: How severely space is curved depends on 2 things: the mass of the object and the distance from its center. We are standing on the surface of the real Earth. Which direction is the center of the Earth? How far away is the center if the Earth is about 8000 miles in diameter? *That's where Earth's center of mass is – 4,000 miles away.*	Point to ground; 4,000 miles
To Do: Bring out the assembled black hole bucket. *To Say:* This represents a black hole with the mass of Earth. (indicating the bucket with black hole) Let's take this Earth-mass black hole far out in space. We are floating in space near this black hole. How far are you from the center of mass of this black hole? (point to someone) If we moved ourselves 4000 miles away from this black hole, we would feel the same gravitational pull as we did when we were standing on the real Earth because we are 4000 miles away from the center of mass in both cases. But we are here far out in space, just a few feet from this Earth-mass black hole – would space be curved a lot more and would the pull of the black hole on us be stronger here? What would we have to do to stay out of the black hole? Near the black hole, the fabric of space would be curved completely around the tremendous mass of this black hole – warping space completely around it. (Point to the assembled black hole.) *These marbles will represent tiny satellites orbiting the black hole. Can you put one in orbit? Do you have to push it faster or slower than putting things into orbit around the other weights?*	A few feet. Yes. Orbit really fast. Participants put marbles into orbit. Faster.

Leader's Role	**Participants**
 *To Say:* Now, if we were to get too near and pass through this boundary of space and into the region of the black hole, we would be trapped inside. Space is curved all around us and this causes the force of gravity to be so strong, we would be pulled apart and crushed into an unimaginable density, becoming a part of the black hole. So here's the black hole. If we stay out here (indicate the edge of the bucket) and we are orbiting fast enough, we can stay out, but if we stop orbiting, fall in, and pass through this boundary, we're trapped.	Push marbles in orbit around the "black hole". Drop marbles from edge of bucket into black hole.
Presentation Tip: MISCONCEPTION WARNING #1: Many children and adults hold the misconception that a black hole will suck in everything. Emphasize that as long as an object, such as a star, is orbiting fast enough, it will not be pulled into the black hole. The Sun orbits the center of our Galaxy where there is a giant black hole – but we are very far away and orbiting fast enough to stay out (26,000 light years away and orbiting at 220 km/sec or 137 mi/sec). MISCONCEPTION WARNING #2: Many people think it is easy to travel to a black hole. This is addressed below.	
To Say: NASA doesn't actually send probes to black holes and no one has ever visited one – they are too far away. The nearest black hole is many light years away – many trillions of miles. Scientists study them from here with giant telescopes in space. NASA wants to search for black holes in our galaxy and other galaxies to learn what happens near black holes and what role they may have played in the formation of early galaxies in the universe.	

Helpful Hints

***If you purchase lead weights, you MUST coat them before using them.** Lead is a substance known to cause health problems and birth defects or other reproductive harm. Use Plasti-Dip™, with an undercoating of gray Plasti-Dip™ primer or similar products available at many paint and tool stores and online from http://www.quiltershusband.com/qhhtm/qhplastidip.htm.

1) The concept of "mass" may be difficult for your audience. Ask what they think it means. You might want to define "mass" as the amount of material that is in an object – the property that gives an object "weight" in a gravitational field.

2) When you or your visitors roll the marbles across the fabric of space, roll them so they do not bounce.

3) **If you are working with children,** a few pointers:
   - Give just one child the marble(s) and have the kids pass them around.
   - You might want to make it into a game:
     - ♣ If the marble falls off the edge of the bucket, the child's turn is over and they must pass the marbles to the next child.
     - ♣ After one child takes three marble rolls, their turn is over.
     - ♣ The winner is the child who can get the marble to orbit the longest time.
   - Try to make sure they have clean hands, if possible – dirty, sticky, or greasy hands will transfer to the marbles and the marbles will not roll as well
   - Keep a small container of water and paper towels nearby to rinse and dry the marbles as necessary

4) Let your visitors experiment with the weights and marbles – they will discover a lot with your guidance!

5) Some people may ask why the fabric of space is not black or why the weights or marbles are not always the right colors for what they represent. You can say that this is one of the limits of making models of the universe – we have to imagine some things. If the fabric was black, it would be harder to see the curvature of the fabric of space.

Background Information

A good basic discussion of Newtonian gravity as it relates to these demonstrations can be found at:
http://csep10.phys.utk.edu/astr161/lect/history/newtongrav.html

Einstein's general relativity states that space (actually space-time) is curved by the presence of massive objects and the path that mass, as well as light, takes through space is determined by this curvature. For more explanation and observational evidence for general relativity:
http://www.nasa.gov/worldbook/gravitation_worldbook.html
http://curious.astro.cornell.edu/question.php?number=649
And this article, "Gravity as Curved Space"
http://theory.uwinnipeg.ca/mod_tech/node60.html

More information about Black Holes from NASA:
http://cfa-www.harvard.edu/seuforum/blackholelanding.htm

CURVED SPACE vs. GRAVITATIONAL FORCE:
How much space curves around *one* object depends on its mass, and the curvature of space decreases with distance from the center of its mass. This curving of space determines how another object will move around this object.

How objects move through space around *each other* is actually dependent on the mass of *both* objects involved and the distance between them. For example, a pair of stars orbiting each other will orbit their common center of mass – the "balance point" between them. Space curves around *both* objects, so they tug on each other – this mutual tug is commonly referred to as "gravitational force".

This is a subtle difference and is only obvious in these demonstrations under the activity "Wobbling stars and binaries", where you have two objects <u>not</u> extremely different in mass. Objects "extremely" different in mass would be like the difference in mass between a person and the Earth or between the Earth and the Sun.

EVENT HORIZON DEFINITION: The region of space around a black hole from which nothing can escape, not even light. No information about events occurring inside the event horizon is available to the rest of the universe.