Exploring Black Holes and Gravity

How gravity would behave if we could get close to a black hole

About the Activity

Discover how not to fall into a black hole and imagine what would happen if our Sun were replaced with a black hole. Using a bucket with stretchy fabric over it, allow visitors to experiment with marbles and weights to discover some basics about gravity.

Materials Needed

- 2 buckets (13"/33 cm plastic black planters)
- 2.5 pound (1 kg) lead weight, from a fishing or sporting goods store ***See safety note on lead weights in 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- Can be found at a fabric store. Make sure the fabric is lightweight and quite stretchy in all directions.
- Drinking straws
- Large towel or blanket
- Softball

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.
- 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 from 10-15 minutes.

Topics Covered

- Mass curves space around it - more mass, more curvature, so more massive objects exert more gravitational force.
- Harder to reach orbit from a larger mass - a higher initial speed is needed
- At a distance, the same amount of mass will curve space the same amount

Participants

From one person to fifteen participants. Adults, teens, families with children 7 years and up. If a school/youth group, 9 years and up.

Set Up Instructions

- Secure the fabric onto the buckets with the bungee cords. Make sure the smoothest side of the fabric is facing up. The fabric on both buckets needs to be evenly stretched and stretched to approximately the same tension on both.

- 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” below).	
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.	

Are you a Rocket Scientist?

Leader's Role	**Participants' Roles**
Key message for your visitors to take home: Harder to reach orbit from a larger mass – higher initial speed is needed.	
To Do: Place the 4 oz weight in the center of one bucket. Place the 8 oz weight in the center of the second bucket. Place a pee-wee marble next to each weight. Give each participant a clean straw. To Say: Can you jump up and launch yourself off the surface of Earth? Why not? Albert Einstein in the early part of the last century developed the concept that matter curves space around it and this is what causes gravity. The larger the amount of matter (or the larger the mass of the object) the more it curves space and the stronger gravity is. Let's see what that means.	Participant takes the straw No. Guesses: We weigh too much; we can't go fast enough
<u>Presentation Tip:</u> The mass of Earth is 6*10^24 kg or 6 billion trillion tons. The Moon is about 100 times less massive than Earth. So the weights are NOT to scale.	
<u>To Say:</u> Here is the Earth (medium weight) and here is the Moon (small weight). This is the fabric of space. Which one is curving space more? These little marbles represent spaceships that we need to launch from the surface.	The Earth
<u>Presentation Tip:</u> When your visitors blow through the straw, if they continue too long, you might experience a couple of things: • they can get light-headed • a little moisture may come out of the end of the straw. Please warn your visitors to stop if they feel light-headed. Or limit each person to three tries at a time. The fabric is washable in cold water – hang to dry.	

Leader's Role	**Participants' Roles**
<u>To Say:</u> You will blow through the straw to represent the rocket fuel and acceleration you need to propel the spaceship off the surface. You  want your spaceship to either go into orbit or to leave the Earth or Moon to travel to another planet. Which one is going to be harder to escape from? Which one is curving space more?	Earth!
<u>To Say:</u> Line up at the Earth or Moon. Who is a rocket scientist? Who can launch the rocket? Then get in line for the other object. Which one is harder to launch from? Where can you jump higher? Earth or Moon?	Participants form 2 lines – one at each bucket, blow thru straw to launch rocket. Moon!
To Say: If we put the spaceship in orbit (push the pee-wee marble into orbit), and then fire the rockets, (blow on the spaceship) is it easier or harder to get it away from the planet? Yes. Gravity, or the amount space is curved, is based on two things: How much mass and how far you are from the center of mass. Way out here, space is not curved as much as it is near the much more massive object. So it is easier to escape from the planet and keep on going. Besides that, some of you discovered how to be a better rocket scientist and found that if you fire your rockets in the right direction and at the right time, you are taking advantage of the speed and direction of your orbit. So you're on your way to becoming a rocket scientist. Maybe someday you will join NASA in launching probes into space!	Easier! Yeah!

To Do: *place the large weight on one of the buckets.* To Say: *Who wants to try to launch a rocket out of a black hole?* NASA doesn't actually send probes to black holes, Scientists study them from here with giant telescopes in space. NASA wants to learn what happens near black holes and what role they may have played in the formation of early galaxies in the universe. (If kids are there: Maybe you can help when you grow up!)	Oh no! Wow

<u>Presentation Tip:</u> MISCONCEPTION WARNING:
"ESCAPE speed" : This term sometimes causes people to think you can truly escape from Earth's gravitational field (or, for example, from the Sun's gravitation field) – that if you get away from the surface of Earth there will no longer be any gravitational pull.
You can escape from orbiting the Sun, Earth, or Moon, but you will never escape from the object's gravitational field. Gravity extends forever, getting weaker with distance. If you're going fast enough, you can overcome an object's gravitational pull – you can keep going and not get pulled back.

The Sun as a black hole

Leader's Role	**Participants**
Key message for your visitors to take home: Many people believe if the Sun became a black hole, all the planets would be pulled into it. This activity helps explain why not. At some distance from the center of mass, the same amount of mass will curve space the same amount, regardless of its size.	
To Say: What would happen to Earth & the planets if the Sun became a black hole?	Guesses
Will be Sun become a black hole? No. The Sun will not die for billions of years and when it does, it will become a white dwarf. A small compact star about the size of Earth. *To Do:* Show the softball and the weight (a softball weighs almost 7 oz)	
To Say: Both of these are about 8 ounces. Do they have about the same amount of mass? What is different?	Yes. Size!
(Show softball) This represents the Sun (Show medium weight) This represents the Sun collapsed under the influence of gravity – representing a black hole – the Sun won't become a black hole, we're are just imagining it as a black hole.	
Which of these is going to curve space more? Where is the center of the Sun (softball)?	Guesses. In the middle.
To Do: Put softball behind your back and hold out yellow medium weight *To Say:* Where would the center of the Sun be if we crushed all its mass down to become a black hole?	Same place.
Their centers are both going to be in the same place. *To Do:* Place the softball in the center of one bucket and the 8 oz medium weight in the center of the other bucket. 	

NOTE TO PRESENTER: This is not to scale – a black hole of an 8 oz object would be smaller than an atom. This is being used to show that even though the sizes are different, the masses of the Sun and Earth are the same, space is curved the same, so the force of gravity is the same.	
<u>*To Say:*</u> These are not to scale, but what these illustrate is the Sun and the Sun collapsed to be a black hole. Space is curved out here about the same amount by both balls because their masses are about the same. (Indicate a point near the edge of the bucket).	
<u>*To Say:*</u> Who wants to put the Earth into orbit around each of these? Put both into orbit at about this distance away (indicate a place near the edge of the bucket). The speed of the orbits will be approximately the same at the same distance from the center of the object. So, if the Sun did become a black hole, we would not be pulled in – since our distance from the center of the Sun didn't change and the mass of the Sun didn't change, the mass of Earth didn't change, so the curvature of space where we are stays the same, so we would continue to orbit as we do now.	Roll large marbles into orbit around each ball.
<u>*To Say:*</u> What WOULD be different? Would the Moon shine? Would we be able to see the planets? – The planets are reflecting the light of the Sun.	It would be very dark and very cold. No

WRAP-UP: Enjoy your evening!

Leader's Role
To Say: Tonight you will see many things through the telescope that are moving under the influence of gravity, or curved space – binary stars, planets, star-forming nebula, star clusters, galaxies. Enjoy your evening, held to Earth by the force of gravity!

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.