Why Doesn't the Moon Fall to Earth?

Exploring Orbits and Gravity

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 orbits.

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
- 3 - 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
- Drinking straws
- Fishing bobber (found at sporting goods store)
- Large towel or blanket
- Regulation Softball

Topics Covered

- Paths of the orbits objects take in space is due to curved space
- Farther from center of mass, space curves less: less gravitational force, so orbital rate is slower

Participants

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

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.

Set Up Instructions

- Secure the fabric onto the buckets with the bungee cords. It is easiest to put the bungee cords on first and tuck the fabric under. 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. See the Training Video for details.

- 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.

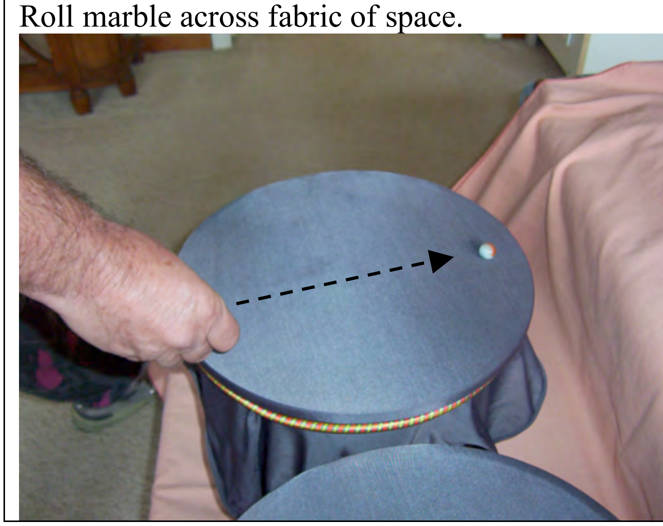
- For Black Hole: Attach the middle of the string to the fishing bobber so that 2 equal pieces are hanging. Place the bobber in the middle of a sheet of stretchy fabric and tie a rubber band tightly around the fabric and bobber so that the string sticks out. Thread the ends of the string through the 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.

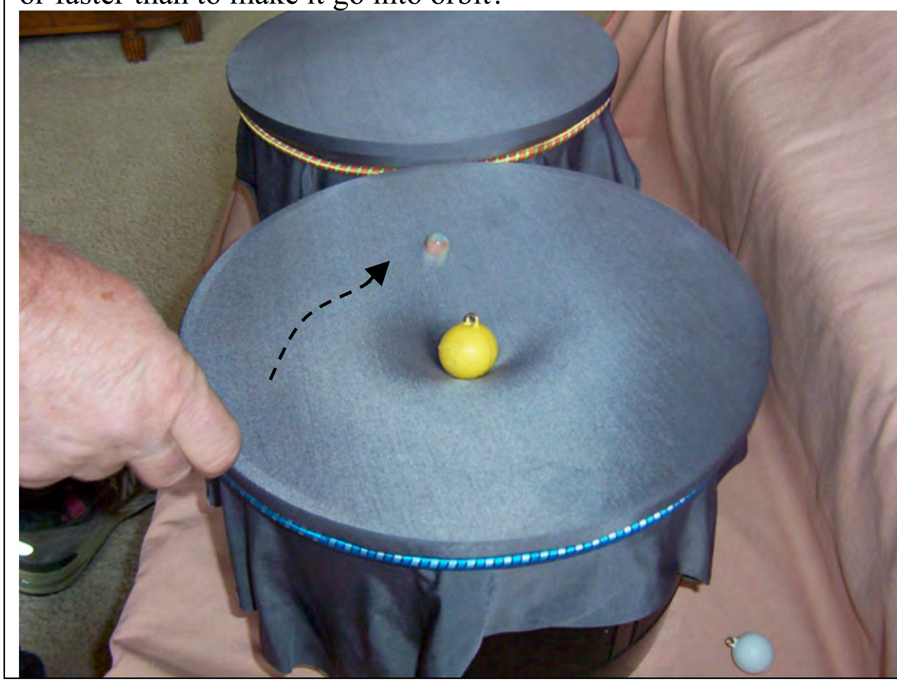
Detailed Activity Description

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" above).
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 Doesn't the Moon Fall to Earth?

Leader's Role	Participants' Roles
Key message for your visitors to take home: Mass curves space causing the path of objects moving through space to be curved – so Earth orbits Sun because space is curved by the Sun. Moon orbits Earth because space is curved by Earth.	
Materials: 2 buckets covered with fabric; bag of marbles; two weights of different mass	
To Say: Now we just made those marbles fall into the Earth. The Moon is like a giant marble – actually a ball of rock – out in space – why doesn't it fall to Earth? Yes, it is orbiting! But why is it orbiting? Einstein's concept that matter curves space around it also determines how objects move around massive objects, like the Moon around Earth or Earth around the Sun. Let's see what that means.	It's orbiting?
To Do: Set out both buckets with no weights on them. Point to one of the buckets. Hand out a few marbles **Presentation Tip:** When you or your visitors roll the marbles across the fabric of space, roll them so they do not bounce. **If working with children**, give one child a marble and then have them pass the marble around.	Take marbles
To Say : This is space, the "fabric" of space. There is space all around us everywhere, in all directions. This just represents one small portion of space. This is a model and is not to scale. Here is a planet moving through space. *To Do:* Roll marble across fabric of space. 	

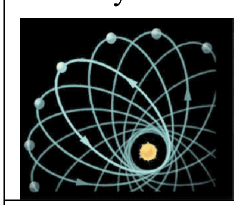
To Say : Does it move straight across? Here, you try. Each person take a turn moving a planet through space. Don't let it bounce! *To Do:* Place 8 oz (medium) weight on fabric. *To Ask:* Now, let's take a star, like the Sun. Is a star more massive than a planet? Let's put in here in space. What happens to the fabric of space? Now, let's move the planet through this area of space again. What happens to it now? Did it go straight across? Here – try pushing the planet across space – can you make it go into orbit around the star? Can you make it escape away from the star? How fast do we need to push the planet to make it escape? Slower or faster than to make it go into orbit? 	Participants roll their marbles. Yes. It curves Path is curved No! Participants roll their marbles and respond.

Leader's Role	**Participants' Roles (Anticipated)**
To Say: So Earth orbits the Sun because the Sun curves space around it. So why doesn't the Moon fall to Earth? Why does the Moon orbit Earth? (You can put the small weight on the other bucket and say it is Earth then put a small marble – the Moon – in orbit around it). 	It's orbiting. Earth curves space too

Presentation Tip:

Someone may ask "Why does the orbit get smaller and smaller?" You need to explain that the friction of the marble rubbing against our fabric of space slows it down. Is there really fabric out in space? No. Space is fairly empty; this is just an illustration of how space curves in the presence of mass and how that influences the movement of objects through space.
We can't see space, just its response to the presence of massive objects. The curved space is revealed by the matter moving through it around the massive object – like around a star or a black hole.

As you and your visitors roll marbles into orbit, you will get all kinds of orbits, more or less circular to highly elliptical, some may immediately crash into the star or planet. You might want to mention or ask your visitors which bodies in our Solar System have these different kinds of orbits – circular orbits (like planets around the Sun), more elliptical orbits (like comets and some asteroids), and orbits that collide with a star (or planet), as happens to some comets. You might even observe some orbits that precess, like Mercury's orbit:



Artist's version of the precession of Mercury's orbit (exaggerated, not to scale).
From:
http://phyun5.ucr.edu/~wudka/Physics7/Notes_www/node98.html

Presentation Tip:
MISCONCEPTION WARNING: Many children and adults hold the misconception that there is no gravity in space. You can escape from orbiting the star, but you will never escape from the star'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.

Why is a Martian year almost twice as long as an Earth year?

<table>
<tr><td>Leader's Role</td><td>Participants' Roles</td></tr>
<tr><td colspan="2">Key message for your visitors to take home: The more distant you are from the center of mass, the less space is curved, so the speed you go will be slower than when you are closer.</td></tr>
<tr><td colspan="2">Materials: 1 bucket covered with fabric; a few medium marbles;
Large weight</td></tr>
<tr><td><u>To do:</u>
Place the 2.5 pound large weight in the center of the bucket. Use medium marbles as planets.
<u>To Say:</u>
Here's a star in space.
Let's put some planets in orbit.
The closer the planet is to the star, - the smaller its orbit is – what happens to the speed of the orbit?
Right – it goes faster.</td><td>Roll marbles.

Speeds up.</td></tr>
<tr><td><u>To Say:</u>
How fast objects move through space due to gravity – how much space is curved at any point – depends on 2 things: how much mass the central object has and your distance from the center of the massive object. (Point to the center of the large weight and point to the marble, indicating the distance of the marble from the large weight.)
</td><td></td></tr>
<tr><td><u>To Say:</u>
Close to the star, space is curved more and out here (pointing to the edge of the bucket), space is curved less.</td><td></td></tr>
</table>

Leader's Role	**Participants' Roles**
Presentation Tip: How objects move through space around *each other* is actually dependent on the mass of *both* objects involved and the distance between the (centers of the) objects. For example, a pair of stars will orbit each other around a common center of mass – the "balance point" between them. Space curves around *both* objects, so they actually tug on each other. But when you have objects near each other that are very different in mass, like a person on the Earth or the Earth orbiting the Sun, the common center of mass will be very close to the center of the more massive object. Depending on your audience, you may want to say this and possibly go into what we mean by "center of mass". (See "Extended Activity: Wobbling Stars and Binaries" at the end of this activity). The "center of mass" between the large weight and the marble is inside of the large weight – very close to the center of the weight. However, this could end up being more of a complication and confusion than clarification at this point.	
<u>*To Say:*</u> If you are far away, out here near the edge of this region of space, and you are in orbit, is your orbit faster or slower than when you are closer? Right! The curvature of space is less, so if you are in orbit, you will be going pretty slow. If you suddenly were able to accelerate and started going a lot faster, what would happen? So how much space is curved at any point depends on what two things?	Slower. You would escape from orbit Mass and distance from center
<u>*To Do:*</u> Take two medium-sized marbles to represent Earth and Mars – make sure they are different colors. <u>*To Say:*</u> Let's make the star in the center the Sun. This marble will represent Mars and this marble Earth. (Hold the marbles on the fabric at different distances from the Sun). Which planet is farther away from the Sun? Which one is going to travel faster through space? Why? Where is space more curved?	Mars Earth Where the Earth is
Presentation Tip: The center of mass is inside the Sun since compared to the Sun, the mass of Mars or even Earth is almost negligible.	

Leader's Role	**Participants' Roles**
To Say: Let's try it. (**TIP:** Place Earth in orbit first, then immediately launch Mars – the planets are less likely to crash into each other) Earth is closer to the Sun (the massive object) and Mars is farther away.	Participants orbit planets
How long does it take Earth to orbit the Sun once? How long is our year?	365 days.
On our model, if we put Earth 2 inches (5 cm) away from the Sun, Mars would only be 3 inches (7.6 cm) away. But Mars has a year almost twice as long as Earth's – why do you suppose that is?	It's farther away?
Yes, it is farther away – it has a little longer distance to go than Earth. In our model, Earth has to travel about 13" (33 cm) to orbit the Sun and Mars only 19" (48 cm), but it is also traveling slower. Why?	Space is curved less.

Presentation Tip / Helpful Hint:
Some people think the only reason the planets farther from the Sun have longer years than Earth is because they are farther away, so they have a longer distance to go in their (somewhat) circular orbit.
Mars travels about 870 million miles (1.4 billion km) to make one orbit of the Sun. Earth travels about 580 million miles (930 million km). So Mars only travels about one and a half times the distance Earth travels, but takes almost twice as long!
Earth is traveling at about 30 km/sec (18 mi/sec) as it goes around the sun. Mars only travels about 24 km/sec (15 mi/s) – slower than Earth.
Jupiter travels about 5 times farther than Earth (about 3 billion miles or 5 million km), but takes almost 12 years to do it. Jupiter only travels about 13 km/sec (8 mi/s) – about 1/2 as fast as Earth.

Extending the activity: **Wobbling stars and binaries**

Key Message for your visitors: All massive objects curve space – if the objects are closer to being the same mass, they will influence each other's movement in space more.

Materials: One bucket with fabric; large marble; medium weight

Presentation Tip:
This is where the concept "center of mass" between two objects comes in.
The "center of mass" could be described as the balance point between two objects – if 2 objects could be attached to either end of a stick.

To Say:
Notice that if we have a large planet orbiting a small star, the star moves too. ALL massive objects cause space to curve – asteroids, planets, stars, black holes – ALL massive objects exert the force of gravity on their surroundings.

This is one way NASA scientists detect planets around other stars – detecting the wobble of the star.
Binary stars – where two stars are orbiting each other – orbit around a common center of mass.

Roll large marble around weight – watch weight wobble.

Leader's Role	**Participants' Roles**
<u>Extending the activity:</u> **How far is the planet from its parent star?**	
Key message for your visitors to take home: How fast the planet is orbiting is a clue to its distance from the star. A planet will orbit a more massive star faster, at the same distance, than it will orbit a less massive star.	
Materials: 2 buckets covered with fabric; large marbles; A medium and a large weight	
<u>To do:</u> Place medium weight on the fabric of one bucket. Place the large weight in the center of the second bucket. Use a large marble as a planet. *<u>To Say:</u>* Now when scientists find a wobbling star, they know it might have planets. But how do they know how far away those planets are from the star? We just found out that the farther a planet is from the star, the slower it travels through space, so the star will wobble slower due to that planet's orbit.	
Let's say we have two stars, one more massive than the other. If we put these planets (large marbles) in orbit around these stars at the same distance, which planet will orbit faster?	The one around the big star.
Let's try.	Roll marbles.
If we move the planets closer and put them into orbit, will they orbit faster or slower?	Faster!
Let's try.	Roll marbles.
So, if we know the mass of the star, and we know how fast the planet is orbiting (or how fast the star is wobbling), scientists have some clues about how far the planet is from the star.	

Leader's Role	**Participants' Roles**
Extending the activity: **What is the mass of the black hole?**	
Key message for your visitors to take home: How fast a star or stars is orbiting an unseen object, like a black hole, is a clue to how massive the central object is.	
Materials: 2 buckets; large marbles; Medium weight and assembled black hole (or use the large weight).	
To do: Place medium weight on the fabric of one bucket. For the other bucket, use the assembled black hole. Use large marbles for stars. *To Say:* If scientists discover a star orbiting an unseen object, they know it must be orbiting something. If the central object is really massive, they have a clue that it might be a black hole. How do they know how massive the central object is? Here we have a regular star (indicate the medium weight). And here we have a black hole (indicate assembled black hole). Let's say this marble is a star. If we put it into orbit around each of these objects, which one is the star going to orbit faster?	The black hole.
Let's try.	Roll marbles.
So, if we detect how fast the star is orbiting the object, scientists have a clue about the mass of the central object. This is one way NASA scientists detect black holes - by a star or stars rapidly orbiting an unseen object.	

WRAP-UP: Enjoy your evening!

Leader's Role	**Participants' Roles (Anticipated)**
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

FAQ's: What are some common questions visitors have about black holes? Review the Black Hole FAQ's page which can be found in the "Where are the Black Holes?" activity and the Q&A section at the end of the script for the PowerPoint Surviving Black Holes. These list common questions and perceptions people have about black holes and how you might answer them. They can be found on the Download Resource page of the Night Sky Network:
http://nightsky.jpl.nasa.gov/download-search.cfm

GRAVITY ASSISTS: Your visitors might ask about how NASA uses gravity assists to add speed to a spacecraft. The Space Place provides a helpful description and activity to illustrate the process:
http://spaceplace.nasa.gov/en/educators/gravityassist.pdf.
For more details about how gravity assists work:
http://saturn1.jpl.nasa.gov/mission/gravity-assist-primer2.cfm
For a more technical description:
http://www2.jpl.nasa.gov/basics/bsf4-1.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.