SOCIETY OF PHYSICS STUDENTS

**Summer Intern Program**

***presents***

# SOCK 2012

( S c i e n c e   O u t r e a c h   C a t a l y s t   K i t )

# The Fabric of the Cosmos

# Table of Contents

# Kit Contents List

*Be sure to check the packing list enclosed in your box for a more detailed list of kit contents.*

**Gravity**

- Spandex
- 8 Tent Poles
- 12 Binder Clips
- 2 Hooks
- 100 Marbles
- 7 Bearing Balls
- 10 Shooter Marbles
- 7 Wooden Balls
- Instructional Video

# The Fabric of the Cosmos
# SOCK2012
# Part 1: Gravity

# Notes: Spandex - The Fabric of Spacetime

**Why Spandex?**

Gravity is one of many invisible fields that truly do make up the "Fabric of the Cosmos" we know today. We've taken this concept very literally and are actually using a piece of fabric – Spandex – to model gravity. Spandex is the same material used to make biking shorts and other athletic clothing, and, as it turns out, it's a very useful tool for mimicking and conceptualizing a simple model for warped spacetime!

**What is the benefit of using a model?**

By using a conceptual model to introduce and teach a topic, rather than just verbally conveying the idea, students are better able to visualize what you want them to understand. Developing and using models is outlined by the Committee on a Conceptual Framework for New K-12 Science Education Standards in *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas* as an essential practice for K-12 science education. The committee emphasizes that "building an understanding of models and their role in science helps students to construct and revise mental models of phenomena" (National Research Council 56). It is important for a student to develop mental models because "better mental models, in turn, lead to a deeper understanding of science and enhanced scientific reasoning" (National Research Council 56). In addition to helping to enhance mental modeling, conceptual models also are used by scientists "to represent their current understanding of a system under study, to aid in the development of questions and explanations, and to communicate ideas to others" (National Research Council 57).

**What is contained in this packet?**

This packet includes a series of short lessons on many topics related to gravitation in a solar system. We have used different combinations of these lessons to fit different time frames, room setups, and age groups, and found great success in customizing the lessons for each of our events. While we think every single lesson is worth doing with a group, you should pick and choose the lessons that best suit the type of outreach event you are planning and fit within time constraints. Each lesson includes a list of learning objectives; some overlap from lesson to lesson and all involve examining the effects of gravity in our solar system and universe! We recommend deciding what messages or lessons you would like to convey to your group, then checking which learning objectives fulfill your needs. Recommended age groups for each presentation are compiled in Table ***1: Suggested Age Levels for activities***Table 1.

# Notes: “Assembling Spacetime”*

You can use the Spandex in one of two ways: assembled on a frame, so that it can be set down and requires no one to hold it or as a loose piece of Spandex that everyone grabs onto. The former is better for smaller groups. How you choose to set up the Spandex depends on the size of the group you are planning to work with, the nature of the event, the level of interaction required, etc. We have provided materials and instructions to make a frame for the Spandex. Among the items received in your SOCK are 1 sheet of Spandex, tent poles, and 12 binder clips. These are the only tools necessary to assemble your own personal patch of spacetime.

- Simply connect the tent poles by fitting the ends of each pole into the silver connecting pieces.
- ***Carefully bend*** the tent poles to make a circle by connecting the two ends (trust us, they will bend enough!). Spread the Spandex over the circle and use binder clips to clamp the edge of the Spandex to the poles. It may help to imagine the circle as a clock face and place the binder clips at the hours. Start with 12 and 6, move to 3 and 9, etc, working in opposite pairs on the imaginary clock face.
- To adjust tension in the Spandex, go around the circle and one-by-one take off a binder clip, pull the Spandex (or loosen it), and replace the binder clip.
- The Spandex frame must be supported at a minimum of three points around the edge to avoid warping the edges of the circle. This can be accomplished by having at least three people hold the Spandex frame or placing the Spandex on three desks. Using an external support system allows for as few as one person to play with the Spandex!


***Figure 1- The Spandex Frame***

*(LEFT) The Spandex on frame, resting on three chairs for optimal support; (RIGHT) A binder clip holding the Spandex onto frame.*

# Notes: Other Tips for using the Spandex

*These tips can be applied to all of the demos provided in our Spandex User Guide.*

- Keeping the Spandex flat is extremely important. Holding the Spandex flat can be tough with smaller children, especially if you're not using the frame. Instruct them to hold the spandex at their waist with their knuckles up. Sometimes suggesting "look at your neighbor, and check if you're holding it at the same height as your neighbor," can help.
- Once you place the point mass, or two masses, at or near the center, students may be inclined to look underneath the Spandex to see what it looks like. Instruct everyone to look underneath at the beginning of the demo, so this does not cause a distraction throughout the lesson.
- Marbles will inevitably fly off the Spandex, we guarantee it! Tell students not to worry about marbles that fall off the Spandex, and simply clean them up afterwards or have a designated SPS volunteer pick them up throughout the lesson. This is particularly important during the "Formation of the Solar System" activity.
- In both the "Roche Limit" and "Tides" activity, it is useful to practice the demos beforehand to see how far away from the marbles the satellite should start. If you have trouble during the "Roche Limit" or "Tides" activity, try making deeper gravity wells with your hand, and keeping your orbit at a constant speed.
- During the "Two Masses" activity, younger students may not understand what the 'value of G' is, so it is worthwhile to explain it in a different light. For example, ask "How can we make the two balls come together faster? How can we make them not come together at all?" This way, they will understand the notion of changing a variable (how tightly the Spandex is stretched) to observe different outcomes.

*Table 1: Suggested Age Levels for activities*

| Age | Single Point Mass | Two Heavy Masses | Rings | Tides | Two Masses | Formation of the Solar System | Density Gradient |
|---|---|---|---|---|---|---|---|
| Elementary School | X | | X | | X | | X |
| Middle School | X | X | X | X | X | X | X |
| High School | X | X | X | X | X | X | X |

# Activity: Introduction to Spandex as a model for Spacetime

*This activity helps students to establish properties of how the masses interact with Spandex that are fundamental to understanding all other activities. Students will establish that a mass causes a 'dent' in the Spandex and draw the parallel to masses denting spacetime, therein causing gravity. Students will establish that the larger the mass, the bigger the dent. Students will establish that two masses will distort each other's natural straight paths, causing their paths to curve around one another.*

**Objectives**

- Students will be able to describe the effect that mass has on spacetime.
- Students will be able to discuss what happens to spacetime as more mass is added.

**Materials**

- Spandex
- Marbles
- 2 Steel Bearing Balls

**Using the Spandex in the Classroom**

***Introduction***

We found that a useful way to introduce students to spacetime is to discuss Newton's gravity first, asking students about what happens when you let go of an object (it will be pulled toward the center of the Earth). To get students to understand that it is being pulled toward the center of Earth, instead of just falling down, draw the Earth on the board with four people, one at the top, one at the bottom, one on the left and one on the right. Ask students to draw hair on the people. The hair should all be pointing toward the center of the Earth. If gravity simply made objects fall down, wouldn't the hair on the person at the bottom be hanging in the same direction as the person standing on top of the Earth? Students should now make the connection that gravity pulls toward the center of the Earth. If not, lead them to this conclusion. Now question students about why gravity pulls things to the center of the Earth. Using Newton's gravity, there is no explanation for *why* gravity pulls towards the center of the Earth, just that it does. Einstein's concept of spacetime helps us understand the *why* that Newton was unable to explain.

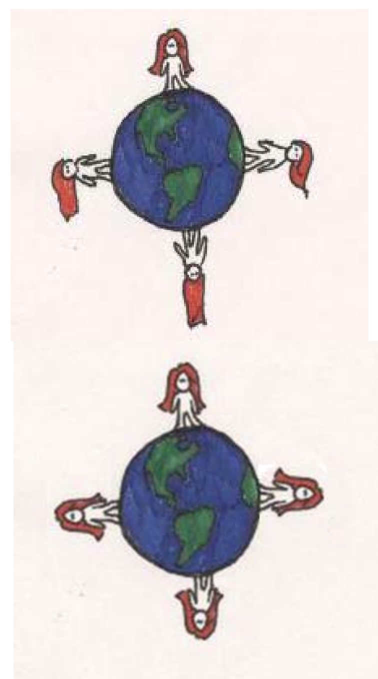


*Figure 2: Gravity on Earth*
*Used to encourage thought about the nature of gravitational attraction*

**Activity:**

1. Decide how you will use the spandex, either supported by people or supported by the frame and get ready to use the slightly stretched spacetime fabric!

2. To begin the lesson, roll a single marble across Spandex. Have students discuss the shape of the path of the marble (straight) and the effect of the marble on the spandex (a small dent). Ask questions as necessary to get the students comfortable with speaking in the group.

3. Now roll one of the larger steel bearing ball across Spandex. Have students discuss the shape of the path, effect on Spandex, and difference from marble. (It still rolls in a straight line, but it makes a much deeper dent, deforming spacetime more.)

4. Roll two marbles towards each other without colliding. Encourage students to discuss with their neighbor what happens to their paths. Their paths should curve around one another, because the first mass distorts spacetime and therefore the path of the second marble. As they continue to roll on the Spandex they will be attracted to one another, and come together. This is one of the most important concepts for students to understand.

5. Keep adding marbles and masses and watch as the Spandex curves more as you add more mass. This in turn draws in more mass, which makes the Spandex curve more, etc. Ask students to discuss what's happening and predict what will happen as you continue to roll marbles.

6. Establish a large mass of marbles as the sun, or substitute the large mass of marbles with a bowling ball, cannon ball, or rock and place it in the center of Spandex. Roll the marbles and balls around the "sun" and help the students investigate orbits by posing the following questions for discussion:
    a. Why does the marble/ball curve?
    b. Why do they end up clumped with the "sun"? Explain how this is like gravity.
    c. Predict: How can you get a marble to keep from crashing into the sun for as long as possible? (Answers might include keeping it far away, and hopefully tangential velocity.) Students should each try to create a stable orbit, and share what worked and why.
    d. Why do our marble orbits decay quickly? Why doesn't this happen with our planets? (On the Spandex friction is the major issue, but many students will initiate poor orbits, and our early solar system was filled with these objects, which is why the sun is so very large and the space around it is nearly empty-- only a couple objects (like earth) haven't crashed into the sun yet.)

# Activity: Single Point Mass*

*The Single Point Mass demonstration represents a large mass, such as the sun or the earth, with satellites orbiting it. Students will roll marbles, which are the satellites, to make orbits and observe their shape. Discussion about Einstein's and Newton's gravity may be explained in greater detail with older students. Emphasis for younger students should be placed on shapes of orbits, what sorts of objects orbit the earth, sun and other planets, etc.*

**Objectives**

- Students will be able to correctly list at least two different path shapes that objects can take when they orbit a point mass. For older students, they should be able to identify that these path shapes correspond to conic sections.
- Students will be able to distinguish between Einstein's and Newton's concepts of gravity giving at least one similarity and one difference.
- Students will be able to describe at least two distinguishing features of comet orbits.

**Materials**

- Spandex
- Hook
- Heavy mass
- Bag to hold mass
- Many marbles
- Washers

**Creating your gravity well in the Spandex fabric**

A bowling ball creates a great spacetime curve, but it is large and in the way. To create a substantial spacetime curve without taking up a lot of space, we have devised a method of suspending a mass under the spandex without damaging the spandex. Place marble on the center of the Spandex, where you want mass to hang from. Pinch the marble from beneath the spandex. Slide the spandex above the marble into the loop of the hook, allowing the circular top of the hook to hold the marble in place. Hang mass from hook. *This only needs to be a few pounds; we have used soup cans or big rocks placed inside a plastic shopping bag,*

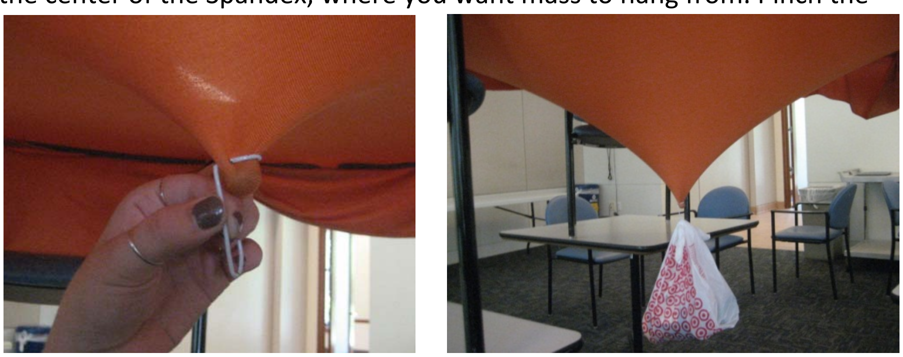


**Figure 3 – Making a 'gravity well' in the Spandex**
*(LEFT) A hook placed around a marble from underneath spandex; (RIGHT) A bag with two soup cans suspended from hook.*

**Exploring with the gravity well in the classroom**

1. Have students hold the Spandex as flat as possible if not using the frame. Try to emphasize strongly that the spandex represents a **2D model** of spacetime, and that the point mass can be thought of as the sun and the marbles as planets, or the point mass could be the Earth and the marbles the moon, asteroids, or other satellites.

2. Hand out marbles; have students predict the shape of the path that the marbles will take when they are rolled around the mass. Have students roll marbles on the spandex to create "orbits"--many different shapes of orbits should be observed.
    a. Ask students to discuss these orbits.
    b. Ask students to try to create certain orbital shapes, i.e. to create a circle or ellipse, try to roll the marble on a tangential path to a circle, to create parabolas or hyperbolas, roll the marble with a little vertical component.
    c. Ask what bodies in the solar system make these different shapes. Some planets and moons are roughly circular, whereas others are more elliptical. Things with hyperbolic orbits and parabolic orbits fly past the object they are orbiting as they have a velocity greater than or equal to escape velocity.
3. Next, try rolling a washer (or coin) on its edge. This will form a slightly different orbit. You may have students guess what would make an orbit like this, or simply explain to them that this makes a comet-like orbit. Make sure students understand the difference between the shaped of planetary and comet orbits.

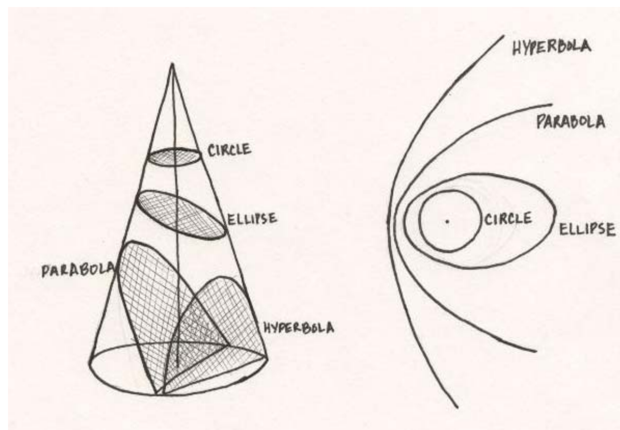



**Figure 4: Using the Spandex to explore attraction of a single point mass** *(LEFT) Marbles orbiting a single point mass. (RIGHT) Diagram of conic sections.*

# Activity: Binary System*

*This demonstration represents a binary star system. Orbits of binary systems are observed by rolling marbles on the spandex while two different heavy masses pull the spandex down.*
*Note: You will need two separate hanging masses. See “Creating your Gravity Well” in previous section.*

**Objectives**

- Students will be able to correctly list at least two characteristics of a binary star system.
- Students will be able to identify orbits seen in a binary system.

**Materials**

- Spandex
- Two hooks
- Two bags to hold masses
- Two heavy masses
- Many marbles

**Advanced Preparation**
This demonstration is a variation of the previous demonstration. It is set up the same way, but instead of hanging one hook in the center of the spandex, there should be two hooks near the center of the spandex but spaced a few feet apart (two feet apart workS well).

**Exploring binary systems in the Classroom**

1. Introduce students to binary star systems, and be sure students understand that this setup represents a binary star system. If possible, you may show them some telescope images, or pull up a website with images of binary star systems.

2. Distribute the marbles to students and ask them to predict the shape of the orbits when they roll the marbles this time. Allow students to roll marbles and observe the shapes of the orbits. Look for traditional conic sections, but also have them try to achieve ‘figure eight’ orbits and other variations from the Single Mass.

3. You may get the question “why don’t binary stars crash into each other?” If someone does not ask this question, raise it and encourage them to discuss. Explain that another property of binary star systems is that they are orbiting around each other and this makes them more stable. Explain to students that we cannot make the masses orbit each other since they are attached to the Spandex, but we can represent this by turning the whole spandex in a circle.

4. In order to demonstrate this redistribute the marbles, and have students hold the spandex in their right hands only. Tell students to begin walking clockwise while holding the spandex. Now have them roll the marbles again. This is a simplistic demonstration designed to get students thinking about complex systems.

5. To check for understanding, ask students to explain why the spandex was rotated, as well as what the point masses represent.

Fun fact to tell students: When you look in the sky, half of the stars you see are actually binary systems. It's more common than you might think!

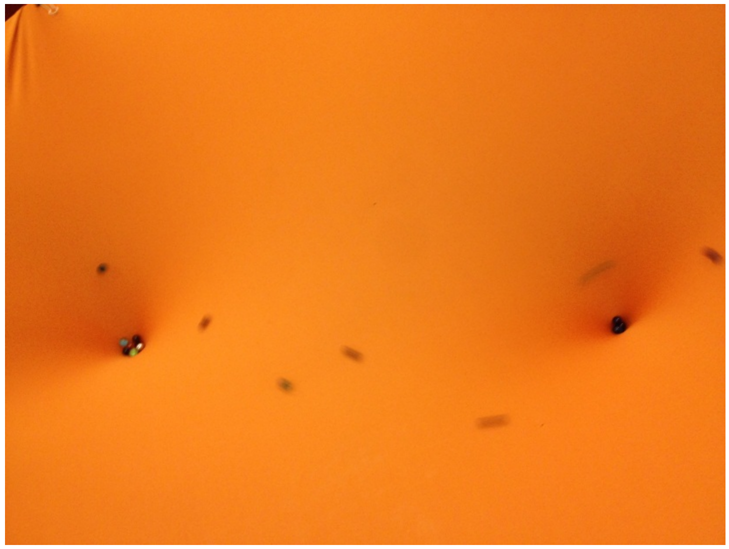


**Figure 5: Marbles orbiting around two point masses**

# Activity: Density Gradient

*The density gradient demonstration allows students to see how objects of different densities arrange themselves within a gravitational field. Students will see the objects of greater density move to the center and the objects of less density move to the outside of the pile.*

**Objectives**

- Students will be able to describe the way objects of different densities arrange themselves in a gravitational field.
- Students will be able to describe where the densest part of Earth and the least dense part of Earth are located.

**Materials**

- Spandex
- 7 steel bearing balls
- 7 wooden balls
- 9-10 glass marbles

**Figure 6- Demonstration of the formation of a density gradient**
*(LEFT) Marbles (spheres) in a cluster that depicts a random distribution of densities; (RIGHT) Here, the spheres have organized with most the dense at center, least dense around edges.*

**Exploring the density gradient concept in the Classroom**

1. Arrange marbles, wooden balls, and bearing balls on the spandex so that they are all mixed together in a group. You will have to be intentional about have the balls randomly distributed, since the bearing balls will naturally move toward the center of the collection.

2. Ask students if objects of different densities are usually arranged randomly in a gravitational field, or if this representation is wrong. If they don't know, tell them to think of the layers of the Earth, what they are made out of, and where they are located.

3. Move your hand slowly in circles on the spandex around the group of balls so that your hand and the group orbit one another. This is a very similar motion to the tides and Roche limit demo, however, it requires a little more physical effort to get all of the objects in the group moving. You maybe have to push deeper into the Spandex or move your hand faster. The objects will arrange themselves so that the steel bearing balls are in the center with the marbles around them and the wooden balls on the outside.

4. Have students discuss whether this is consistent with their predictions.

**Table 2 Densities of marbles used***

| Object | Density (± 0.001) g/cm$^3$ |
|---|---|
| Steel Ball Bearing | 7.692 |
| Large Glass "shooter" marble | 2.33 |
| Wooden ball | 0.699 |

**Measured by SPS SOCK Interns*

# Activity: Formation of the Solar System*

*The formation of the solar system is modeled in this demonstration. Students each hold a few marbles and toss them up onto the spandex all at the same time. The marbles will conglomerate into a group and a few will orbit the larger collection near the center of the spandex briefly.*

**Objectives**

- Students will be able to describe at least two conditions that existed for the formation of the solar system to occur.
- Students will be able to identify the reason the planets spin the same way around the sun.

**Materials**

- Spandex
- All available balls (marbles, steel bearing balls, shooter marbles, etc.)

**In the Classroom**

1. Have students hold the spandex or hold the frame with the spandex. If the frame is not used, make sure to emphasize that holding the spandex flat is imperative for this demonstration to work as a reliable model. This demonstration requires many spheres. If any of the spheres roll towards the edges. Instruct students not to catch them, since it will disturb the flat surface of the spandex when they move their support position.

2. Distribute marbles/bearing balls/shooter marbles/wooden balls to all the students. These represent the dust and debris particles that are in space. Each student should have about a handful.

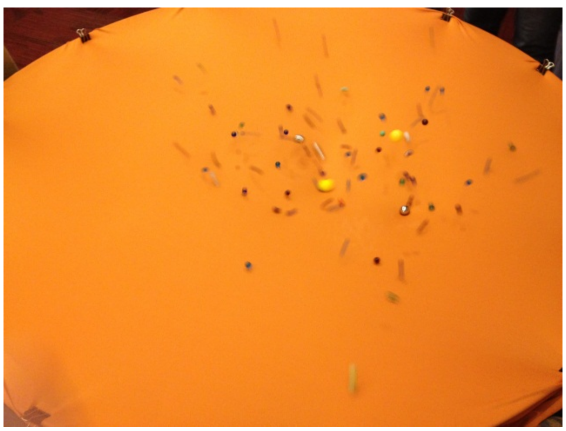
3. Instruct students to gently toss the balls simultaneously onto the Spandex on a count of three. Before the countdown, instruct the students to carefully observe the motions of all the spheres. After the toss, allow the balls to settle.

4. Have students describe what they observed. You may have to repeat the experiment a few times because the settling happens fairly quickly. Students should report that all the spheres immediately begin to move together, with some of the spheres orbiting around the places where many spheres have collected. Try to get the students to express their ideas about what is happening, and what this represents. Use questioning to lead them to the idea that this illustrates a massive central point with other masses that orbit. This is like the sun near the center of our solar system, where most of the mass ends up, and the planets orbiting the sun. Have students point out interesting outcomes. After the discussion it is useful to try the experiment again.

5. Next, repeat the experiment, but instead of tossing the spheres directly out onto the spandex, this time include angular momentum. This is accomplished by instructing the students to toss spheres to the side slightly (either toward the left or right) as they throw them onto the spandex. This time, all of the orbiting bodies should be going in the same direction as they orbit around the places where larger masses have collected. This is a good model of our solar system, since evidence indicates that there was some initial angular momentum in the formation of our solar system.

**Extension – for more advanced students**

You might want to explore an increase or decrease in the strength of gravitation attraction using the spandex model of gravity and repeat the demonstration. To model an increase in the gravitational attraction, the spandex needs to be looser so the objects create a pronounced distortions in the spandex. This will result in more of the marbles staying on the spandex and being in the solar system, and perhaps even increased speed of formation, less 'rogue planets,' etc. To model a decrease in gravitational attraction, pull the spandex tighter, either by stretching it over the frame more tightly or having the people holding the spandex step back slightly. With a more tightly stretched fabric, the marbles will not produce as large a distortion in the spacetime. This also means that marbles will roll off of the spandex easier. If the spandex is too tightly stretch, modeling a situation where the gravitational attraction is too weak (the spandex will be really stretched) the solar system may not be able to form form. Another thing to look for in this demonstration is the formation of binary systems, which we have seen happen once or twice with a small enough (but not too small) gravity!



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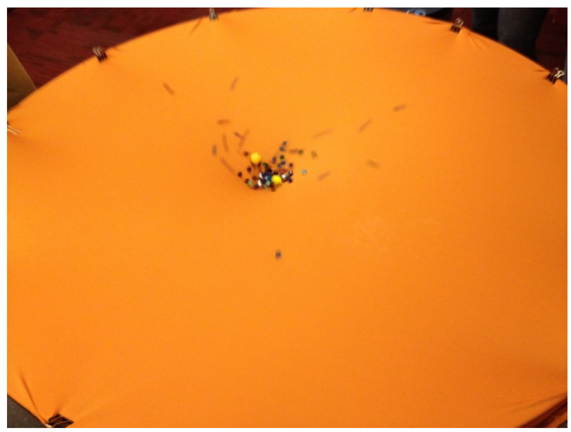

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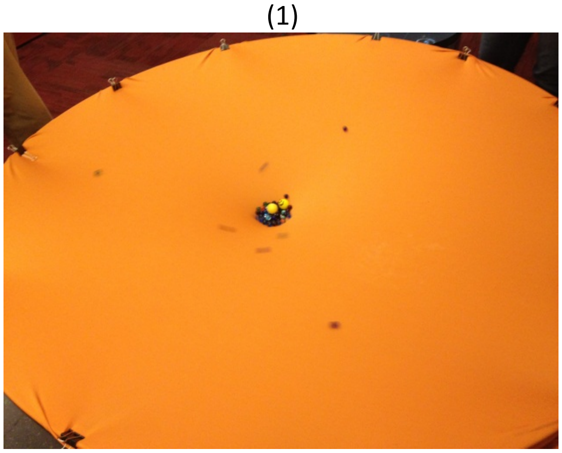

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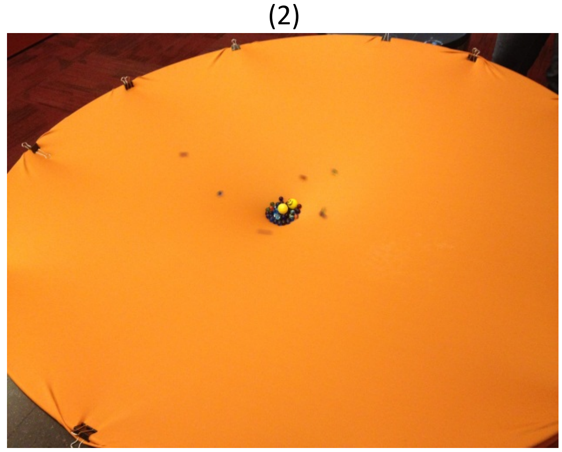

(4)

**Figure 7** The Formation of the Solar System demonstration numbered chronologically.
*(1) tossing marbles straight out onto the spandex; (2) marbles begin to collect into a single location on the spandex; (3) & (4) some marbles orbit around the collection near the center*

# Bonus Activity: Tides*

*The Earth's tides are modeled using a group of marbles. When you use your hand as the moon and circle around the 'Earth', the marbles can be seen elongating in a line toward your hand, representing the tides.*

**Objectives**

- Students will be able to identify the differential forces from the moon's gravity as the cause of tides.
- Students will be able to correctly state that there are two high tides and two low tides per day.

**Materials**

- Spandex
- Marbles
- Golf ball (if desired)

**Exploring tides in the Classroom**

1. Have students hold onto the spandex, forming a circle. It is recommended that the frame be used for this exercise.

2. Place a small group of marbles on the spandex, so that they are touching each other, forming a circular 'blob' in order to resemble a small, flat planet. Explain that this represents the Earth and that you will use your hand to represent the moon. Another alternative is to use a golf ball or other larger sphere to represent the Earth and surround that sphere by a collection of smaller marbles. The smaller marbles represent the water in the oceans that cover the majority of the Earth's surface.

3. Before doing any demonstrations, be sure to ask students what they know about tides. See if they know how many tides there are per day. And ask them to discuss their ideas about the cause of tides.

4. With your hand a small distance away from the "Earth," begin moving in circles around the "Earth" you have created out of marbles. This shows the moon (your hand) orbiting around the Earth (the marbles). Keep orbiting, and you will see the marbles move from their equal distribution around the golf ball, or circular shape and begin to elongate and form more of an oval shape. One "hump" of the oval of marbles will stretch towards your hand, and one will stretch away from your hand. Ask students what these two humps represent. These two "humps" that just formed on the Earth are the two high tides we pass through in a day. The parts that do not have the humps are the low tides.

5. Ask students what is causing the marbles to elongate. This is caused by the gravity of the moon.


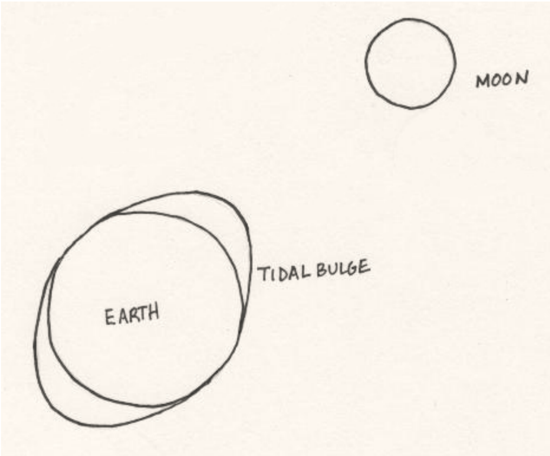


**Figure 8: A demonstration of tidal phenomena** *(LEFT) A demonstration of the tides using hands and marbles. (RIGHT) A diagram of tidal bulges on the Earth.*

**Extension for older students:**
Discuss the fact that these tidal actions vary depending on the relative locations of the Sun, Moon and Earth. These variations are called Spring and Neap tides
*Spring tide* - This is when the tides are higher than average, due to the alignment of the sun and moon.
*Neap tide* - The tides are lower than average, due to the sun and moon being perpendicular to each other.

For more discussion, see “Notes on the Physics of Tides” in Appendix 4.

# Bonus Activity: Roche Limit*

*This demonstration shows the formation of rings (for example, Saturn's rings). It starts with a group of marbles 'orbiting' your hand, with your hand representing the planet and the marbles representing a satellite. As you move your hand closer to the satellite, the satellite breaks up, resulting in rings around the planet. This demonstrates the Roche Limit, which is the closest a satellite can get to a planet before the difference in gravity causes the satellite to break apart.*

**Objectives**

- Students will be able to describe the distance relationship of gravity as an inverse square law.
- Students will be able to describe a characteristic of the Roche limit.
- Students will be able to identify an effect of the Roche limit.

**Materials**

- Spandex fabric
- Marbles
- Hand

**Advanced Preparation**

Place a small group of marbles on the Spandex (10-20), the group of marbles should be slightly smaller than your fist. Practice beforehand to determine a good distance and depth of well.

**Exploring the Roche limit in the Classroom**

1. Have students stand in a circle holding the spandex. To achieve a dynamic system, move your hand (the planet) in a circular path in the spandex, depressing the spandex enough so the marbles (the moon) follow.

2. Ask students to predict what will happen if the moon and planet get closer together. This time, bring your hand in closer to the orbiting marbles and push down harder on the spandex. This will cause the group of marbles to break up but continue orbiting your hand. This represents how rings form around planets. When a moon comes within the Roche Limit, it will break into pieces. In space, these pieces will often form rings.

3. Explain that the strength of gravity is distance dependent, so as the moon and planet get closer together, gravity increases as an inverse square law ($1/r^2$). Gravity keeps increasing and eventually, when the moon gets within the Roche limit of the planet, the difference in the pull of gravity at different points within the moon is strong enough to pull it apart.

4. To make sure students understand this concept, ask them where the moons and the rings of Saturn are located. The moons are farther away from Saturn than the rings are, outside of the Roche limit, while the rings are inside of the Roche limit and therefore closer to Saturn. Make sure students understand that planetary rings are not solid, but they are formed by a lot of pieces all in a ring around the planet.

**Figure 9: The Roche Limit Demonstration** *(Left) a satellite approaches and begins to orbit a "massive body"( the dent produced by pushing on the fabric with your hand and (Right) the satellites reaking apart as they cross the Roche limit.*

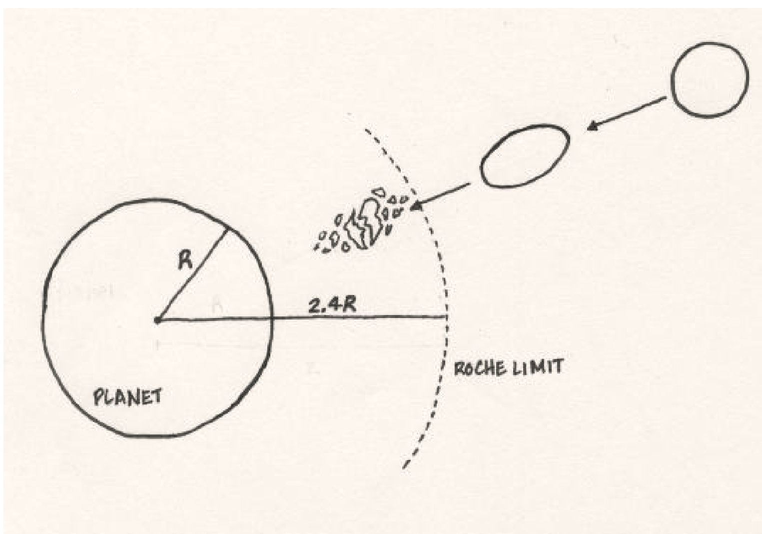


**Figure 10: The Roche Limit**
*This diagram depicts the details of the location of the Roche Limit for a planet with radius 'R'.*

# Bonus Activity: “Big G”- The Gravitational Constant

*This demonstration illustrates the effects of changing the gravitational constant, G. Two masses are dropped on the spandex and allowed to move freely. If G is strong enough (the spandex is loose), the masses will come together. If G is too weak (the spandex is stretched tight), The masses will not be able to come together.*

**Objectives**

- Students will be able to describe the way spacetime causes two masses to move.
- Students will be able to describe one effect of a smaller gravitational constant and one effect of a larger gravitational constant.

**Materials**

- Spandex
- Two steel bearing balls

**Exploring “Big G” in the Classroom**

1. For this activity, it is best NOT to use the frame, but to have students hold onto the spandex. Have a student drop the two balls onto the spandex a foot or two apart from each other. The balls should move toward each other and end up touching. If not, try dropping them closer together.

2. Ask what this is modeling—try to get the discussion around to the point that this observation illustrates the way Einstein explained gravity. If we let the spandex represent the “fabric” of spacetime, then whenever mass is added to the fabric the spacetime becomes deformed, or warped. The bends in spacetime from the two masses is the cause for them to move towards each other.

3. After exploring with the two masses and getting in a good discussion, ask students how they think they could affect the “strength” of gravity in this model. Try to lead them toward the idea that in order to have an effect on the motion of the two masses, that is to change the effect of gravity on the masses, the spandex should be stretched or loosened. When the spandex is stretched to form a more taut surface, the strength of gravity is decreased. Students should observe that the balls do not move together as quickly as they did in the case where the fabric was stretched out less. In more technical terms, this models a decrease in the universal gravitational constant, “Big G”.

4. Once you have discussed the concepts, explore and observe this idea. Have the students all take a step back to stretch the spandex and ask what effect this will have if you drop the balls again now that the effect of gravity on the masses is decreased.

5. Try dropping the masses again and watch them come together. You will see that with this new decrease in the effect of gravity, the masses have a harder time responding to each other’s attractive forces. This change can be seen by looking at the dents the masses make in the spandex. The balls do not sink down as much, therefore they do not cause such drastic bends in spacetime.

6. Now, do the opposite and loosen the spandex, increasing gravity. Drop the masses again, and they will roll towards each other easier. They can now be dropped farther apart and still find each other because there is more gravity.

**For more advanced students:** This is a tricky correlation to make, since the idea of the universal constant of gravitation is a Newtonian concept, and the idea of curvature of spacetime is an idea developed in Einstein's explanations and understanding of gravity. However, you might discuss the implications of changes in the universal constant of gravitation, or "big G" to the way Newton observed gravitation in nature. We see this value in the equation Newton used to describe the force of attraction between any two particles with mass. The number "Big G" appears is directly proportional to the force of attraction. So, if the value of G is decreased, the force of attraction between any two masses is decreased. This corresponds to the spacetime fabric remaining flatter, with shallow indentations and decreased curvature. Likewise if the value of "Big G" increases, the force of attraction between any two masses is increased. This corresponds to the spacetime fabric having deep indentations, or increased curvature.

We should note that the value of the universal constant of gravitation, "Big G", was first measured in 1797 by Henry Cavendish, a remarkable experimental physicist. He was able to measure the very small force of gravitational attraction between two metal spheres. This force the he measured is about a billion times  smaller than the force on the spheres due to the gravitation attraction from the Earth. This not only confirmed Isaac Newton's predictions but also allowed for the determination of mass values for the Earth, Moon and Sun!

# Appendix: Notes on the Physics of Tides

Anyone who has been to a beach has heard the phrases “high tide” and “low tide” to indicate the levels of the ocean throughout the day. There are actually two high tides and two low tides each day. But why there are two high tides may mystify some people.

One easy way to visualize this is to picture two ice-skaters with long hair, as shown in the figure below Imagine the two skaters holding hands and spinning. We can compare this with the system of the Earth and moon. As they spin, they each experience a force in their arms and hands, the point at which they are holding hands.

As they spin faster and faster, we can notice that their hair flies out behind them. This is a simplified illustration of the movement of the ocean as a result of tides.

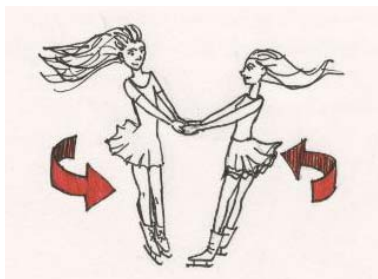

**Figure 20: Two figure skaters spinning**

You may be familiar with a reasonable but grossly oversimplified answer for why there are two tides: that the moon pulls on the ocean on the near-side of the Earth away from the Earth. This seems reasonable, since this is where gravity is strongest. Gravity also pulls the Earth away from the ocean on the far-side of the Earth, but here the gravity is a little weaker. Gravity’s pull is weakest on the ocean on the far side of Earth. So, the more reasonable consideration is to say that the tides are caused by the *difference* in gravitational forces. We have tidal effects because gravity produces a distance-dependent force and the Earth is large enough that the difference from one side of the planet to the other is significant. While this simplified picture seems reasonable, this is not the full picture. One of the most important aspects of the tidal forces that is often overlooked is the consideration that the Earth and moon are in an accelerating system. This means that there are more forces involved in the complicated motion than we considered in our simplistic approach.

Another interesting aspect that most people do not consider is that while the word “tide” usually connotes some aqueous-related phenomenon, it turns out that both the Earth and moon undergo ***land tides*** as well. The tidal bulges of the Earth’s land mass are about 10 cm and the moon has bulges of 20 m at its surface (Carroll).

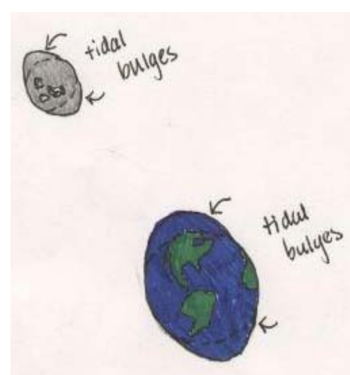


**Figure 21: Sketch of “land tides” on Earth and on the moon**

# Resources, References and Links

***GRAVITY***

- Gravity and Spacetime
  - o http://einstein.stanford.edu/SPACETIME/spacetime2.html
    - This article details Einstein's theories and revelations that introduced and refined his theory of General Relativity, which included his concept of spacetime.
  - o http://www.youtube.com/watch?v=p_o4aY7xkXg
    - This video is a "Minute Physics" video, created by Henry Reich. We love Minute Physics, as they are concise, fun, and relevant videos that anyone can enjoy, from the physics major to the everyday Joe! We have three videos of his in this section, including this one.
- Orbits
  - o http://cse.ssl.berkeley.edu/segwayed/lessons/cometstale/frame_orbits.html
    - This website specializes in comet orbits, which we address using coins as an analogy on the Spandex.
  - o http://www.youtube.com/watch?v=uhS8K4gFu4s&list=PLED25F943F8D6081C&index=6&feature=plcp
    - Another Minute Physics video that explains why the Earth doesn't crash into the sun!
- Binary Systems
  - o http://www.astro.cornell.edu/academics/courses/astro201/binstar.htm
    - This is a very brief description of classification of binary stars. It is useful for the science student to read, however only gives the very basics of binary star classification.
  - o http://chandra.harvard.edu/xray_sources/binary_stars.html
    - This website is from NASA's Chandra X-Ray telescope. It explains a binary system and highlights characteristics and features, and walks through a detailed example with two red giants.
- Roche Limit
  - o http://www.astro.washington.edu/users/smith/Astro150/Tutorials/Roche/
    - This explanation of the Roche limit from the University of Washington's Department of Astronomy is supplemented with lots of clear diagrams, making it easy to follow.
- Tides
  - o http://www.youtube.com/watch?v=gftT3wHJGtg
    - The tides are one of the hardest subjects to conquer, we believe, and once again Minute Physics comes to the rescue, but keep in mind that this is for a stationary system.
- Formation of the Solar System
  - o http://www.windows2universe.org/our_solar_system/formation.html
    - This website is 'brought to you by National Earth Science Teachers Association' and is a very brief paragraph on a theory of the formation of the solar system. This complements our demo very well!
  - o http://www.astronomy.org/astronomy-survival/solform.html
    - This webpage describes a possible sequence of events for the formation of the solar system.


Bradley W. Carroll. *An Introduction to Modern Astrophysics.* 4th Ed. Pearson Education, Inc, 2007.

Gary White, Tony Mondragon ,David Slaughter, Dorothy Coates. *Modelling tidal effects.* American Journal of Physics. Vol. 67. April 1993.

Gary White, Michael Walker. The shape of "the Spandex" and orbits upon its surface. American Journal of Physics. Vol 70. January 2002.