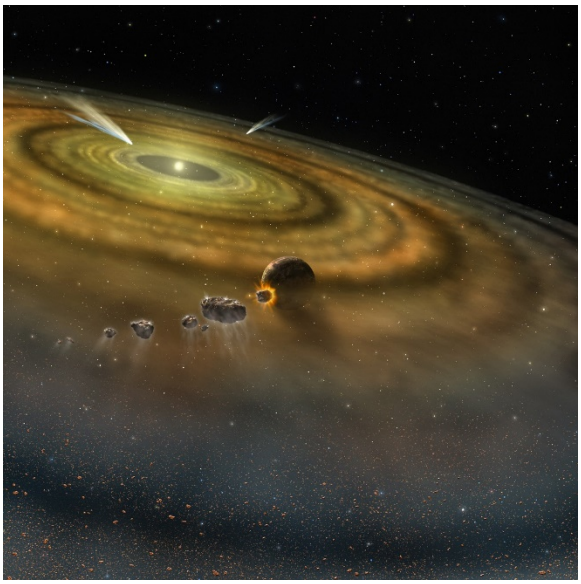
Fabric of the Universe Part 2

Demonstration

Explore solar system formation, tides, and planetary rings using a spandex sheet.



NASA

Number of Participants: 2-10

Audience: Middle (ages 11-13) and up

Duration: 20-30 minutes

Difficulty: Level 3

Materials Required:

- Fiberglass tent pole (7 sections – approximately 175” linear length)
- Spandex fabric (suggested size is 60” x 60”)
- Marbles (30-50)
- Steel ball bearings – ¾ inch (3)
- Wooden balls – 1 inch (5)
- 10 large binder clips (2” wide)

Setup:

1. Assemble the fiberglass rods end-to-end. Carefully bend rod and join ends to form a circle approximately 55” in diameter.
2. Using the binder clips, evenly stretch and clip the spandex over the ring (Figure 1).
3. Lay the assembly over the backs of three evenly-spaced chairs or two tables moved apart from each other.

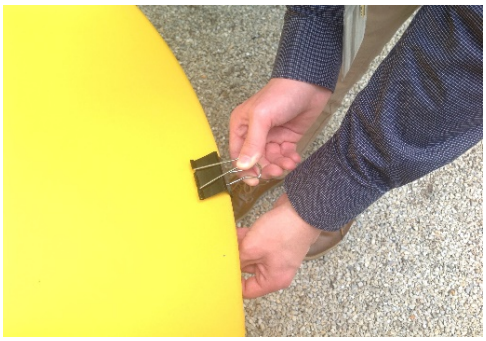


Figure 1

Presenter Brief:

Be familiar with Newton’s three laws of motion. Understand the relationship between Newton’s law of gravitation and centripetal forces. Know how to explain planetary motion via Newtonian mechanics and the conservation of energy.

It is convenient to also know Kepler’s laws of planetary motion and some of the mathematical equations derived from them.

Vocabulary:

- Force ($\boldsymbol{F}$) – A push or pull that tends to change an object's motion.
- Orbit – The path of a celestial object around a massive celestial body.
- Ellipse – A plane curve that surrounds two focal points. In relation to astronomy, objects orbit in ellipses bound by gravity to another object that lies on one of its foci.
- Perigee – The point at which a celestial object is the farthest away from its orbital body.
- Apogee – The point at which a celestial object is the closest to its orbital body.
- Eccentricity ($\boldsymbol{\varepsilon}$) – The deviation of an ellipse from a perfect circle (0 is a circle, 1 is a parabola).

Physics & Explanation:

Middle (ages 11-13) and general public:

After completing "Fabric of the Universe," remove the hook and weight from under the spandex to present these additional demonstrations.

> Have multiple participants evenly place themselves around the spandex and randomly distribute the 30-50 glass marbles, the 5 wooden balls, and the 3 steel ball bearings among them.

Solar systems form when large collections of material (gas, dust, etc.) coalesce under the influence of gravity.

> Instruct participants to gently toss the balls onto the spandex at the same time and make observations about their behavior.

The objects will begin to collect on the spandex. The denser objects (steel ball bearings) will be at the center and the less dense objects (glass marbles and wooden balls) will be around the outside. The marbles and wooden balls may even continue to orbit the initial collection of objects for several seconds.

🔑 Solar systems form when large collections of gas and dust coalesce under gravity. Some objects will collect at the center while some continue to orbit it.

> Collect 15-20 glass marbles together in the center to represent Earth. Using a finger, create a depression in the spandex and orbit around the marbles in a circle – this represents the moon orbiting the Earth.

As you orbit the circular collection of marbles, the shape will elongate into an oval with two tidal bulges.

One bulge will always be on the side closest to your finger and the other will be on the opposite side, as shown in Figure 1. Since the force of gravity depends on distance, the side of the "Earth" closest to your finger experiences more gravitational force than the far side.

To explain why two bulges exist, use the example of two long-haired figure skaters holding hands on ice and spinning around each other. As the skaters spin, their hair will fly out behind them.

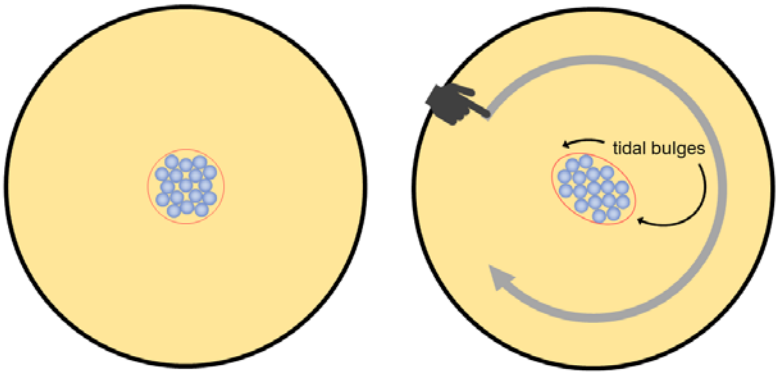


Figure 1

A common misconception is that tides forces are exclusive to water. Tidal forces exist between any two objects. Since water is a liquid, it is just easier than a solid to deform.

Tides result from the difference in gravitational force between the near and far size of an object. This exists between any two objects.

The difference in gravitational force between two sides of an object can be so great that one of the objects deforms so much that it breaks apart.

Orbit the marbles again as previously, except with a larger depression in the spandex. Explain that now the collection of marbles represents the moon and the hand represents the Earth.

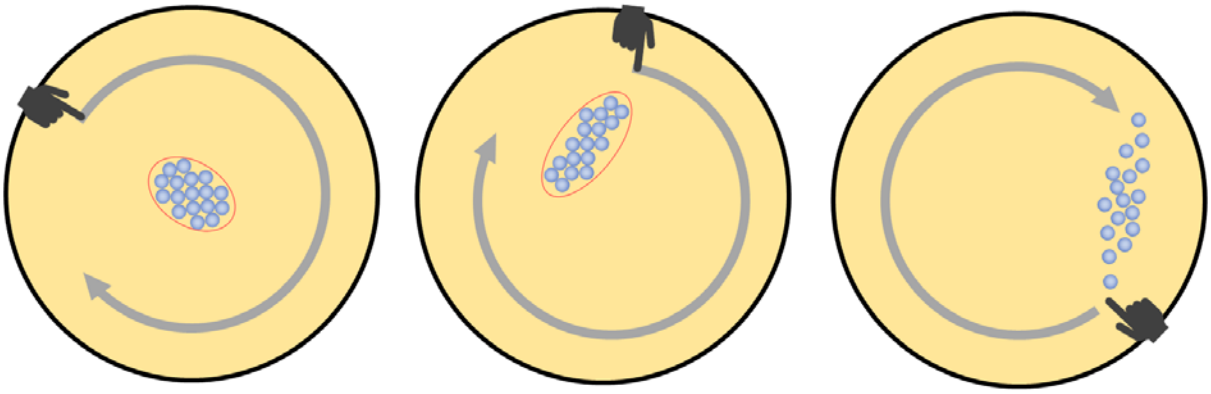


Figure 2: Continue orbiting the collection of marbles with a finger until they form a line and eventually break apart.

With a large enough depression, the collection of marbles will begin to follow your hand until they form a line and eventually break up as shown in Figure 2.

If an object orbits another object too closely, or within the Roche limit, the object will break up. This is the case for the rings of Saturn. The rings are a collection of small rocks which are unable to coalesce into a moon because of tidal forces.

🔑 The tidal force on an object (the difference in gravitational force between two sides of the object) can be strong enough to pull that object apart.

Additional Resources:

- Explaining gravity to kids: https://www.youtube.com/watch?v=aGVXyCrpUn8
- High-school level lessons on orbits: https://ocw.mit.edu/high-school/physics/exam-prep/oscillations-gravitation/orbits-of-planets-satellites/
- 2012 SOCK https://www.spsnational.org/sites/default/files/files/programs/2012/sock/2012-sps-sock-manual-final.pdf
- White, Gary D. *On trajectories of rolling marbles in cones and other funnels*. American Journal of Physics 81, 890.
- White, Gary D. and Walker, Michael. *The shape of "the Spandex" and orbits upon its surface*. American Journal of Physics 70, 48.

Useful Equations:

Newton's Gravity	$\vec{F}_g = \frac{GMm}{r^2}\hat{r}$

$G = 6.674\times10^{-11}\,\frac{m^2}{kg\,s^2}$ (Gravitational constant)

$M = mass\ of\ the\ larger\ body$

$m = mass\ of\ the\ smaller\ body$