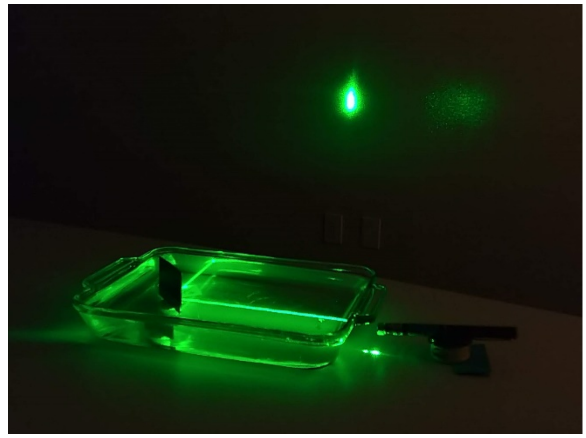
Gravitational Waves in Jello

Demonstration

Collisions in space create ripples in space-time which can be detected using light



Number of Participants: 2-15

Audience: Middle (ages 11-13) and up

Duration: 10-20 mins

Difficulty: Level 2

Materials Required:

- Clear Gelatin (Any food grade variety) - 50 g
- Clear pan (3-quart / 2.84 L recommended)
- Citric acid (Any food grade variety) – 10 g
- Water – 2500 ml
- Mirror 2''- 4''
- Poster Putty or similar sticky tack
- Laser pointer
- 1'' Wooden ball or equivalent
- Spherical cow foam ball or equivalent
- Laser target card (PDF available for download)

Setup:

1. Fill the pan with 625 g cold water.
2. Add 50 g of gelatin, mix well, and let it bloom for 10-15 mins.
3. Simmer 1875 g of water (do not boil) and add 10 g of citric acid
4. Add the hot water mix to the bloomed gelatin.
5. Mix slowly, making sure that all the gelatin has dissolved and there are no air bubbles.
6. Using the Poster Putty, make a stand for the mirror so it has a flat bottom to rest on. Do this by pressing the mirror into the putty and flattening the bottom on an even surface, as shown in figure 1.
7. Carefully transfer the pan to the fridge (do not freeze).

Figure 1. Mirror pressed into putty

8. Insert the mirror/putty combo and the wooden ball opposite each other in the pan and have the mirror stand at a 45° angle.
9. Let the jello cool and harden overnight.
10. Tape the provided laser button down so it continuously shines.
11. From the side of the pan, point the laser at the mirror and secure the laser pointer in place so it doesn't move.

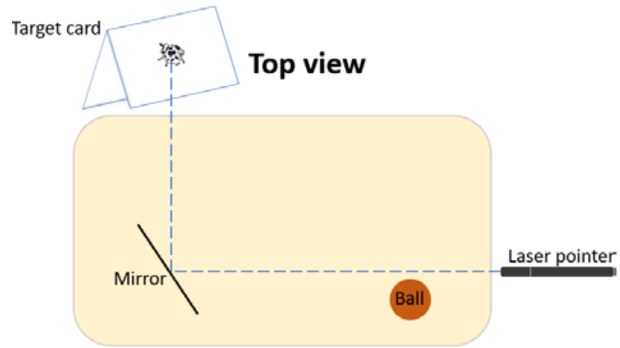


Figure 2. Demonstration setup for steps 8-12

12. Print out the target card from the PDF on thick paper and fold it in half to create a tent card that can stand on its own. Place the target card in front of the reflected beam so that it is centered on the spherical cow like is shown in figure 2.
13. Drop the foam ball on the wooden ball to simulate a collision of two massive objects such as black holes or neutron stars, and watch the reflected beam move on the target card.

Presenter Brief:

Be familiar with why it was groundbreaking to confirm Einstein's prediction of gravitational waves. Understand how LIGO instruments work to detect gravitational waves and confirm the detection. Be familiar with how gravitational waves form in space and travel to eventually reach Earth.

Vocabulary:

- LIGO – Laser Interferometer Gravitational-wave Observatory located in Washington and Louisiana.
- Gravitational waves – Objects moving through space create waves in spacetime around them that move outwards like ripples on a water surface.
- Orbiting binaries – A system of two stars that orbit a common center.
- Interferometer – A tool that works by merging two or more sources of light to create an interference pattern.
- Supernova – A large explosion that happens at the end of a star's life cycle
- Neutron star – Smallest and densest stars that form as a result of the death of giant stars.
- Black hole – An object that has an immense amount of gravity from which nothing, even light, can escape.

Physics & Explanation:

Middle (ages 11-13) and general public:

As massive objects move and orbit around each other in space they distort the fabric of spacetime to create what is known as Gravitational waves. These waves are created because accelerating objects in space create ripples that radiate outward, similar to how a boat creates ripples in a pond. Scientists have been able to indirectly recognize the presence of gravitational waves by watching two objects spinning and noticing that they are slowing down due to the loss of energy from emitting gravitational waves. This loss of energy causes the orbital period to decrease and the orbit to decay, bringing the objects closer to one another as they orbit.[1] Once the objects are close enough, they collide and produce huge amounts of gravitational waves. If the collision was strong enough, it could be detected here on Earth. An illustration of gravitational waves being emitted by two orbiting white dwarf stars can be seen in figure 3.[2] Analog systems can also display this behavior, as shown in Figure 4. In figure 4, Gravitational waves were simulated in a classroom by having two rubber wheels orbit each other on a sheet of spandex.[3] The visual representation of the disturbance shows the waves propagating outward from the orbiting pair.

The gelatin is used to represent spacetime and the collision of the balls represents the collision of blackholes in space. The collision of the balls sends ripples through the jello that resemble the way collisions in space create strong gravitational waves the travel for millions of light years to be detected here on Earth. The vibrations in the jello cause the light to bend and move which can be seen in the movement of the reflected beam of light on the target card.

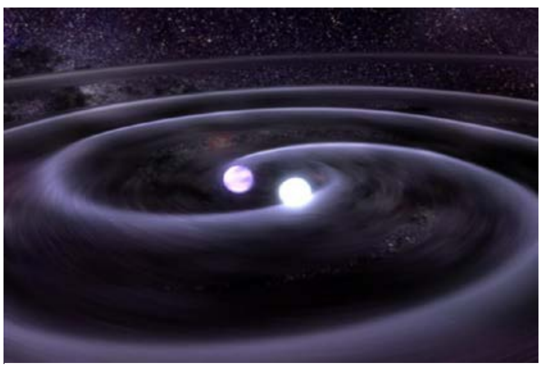


Figure 3. Illustration of gravitational waves produced by two orbiting white dwarf stars in a binary system

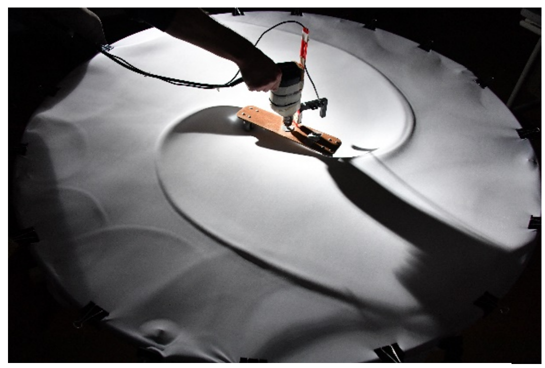


Figure 4. Wave pattern created by rubber wheels that are orbiting each other on a sheet of spandex

Drop the spherical cow on the wooden ball and watch the waves as they travel across the gelatin to eventually bend the laser beam. Observe the movement of the reflected beam on the target card.

Movement of massive objects in space create gravitational waves that travel outward in spacetime and bend light along the way. We detect these waves by using lasers and watching changes in how light moves through space.

Highschool (ages 14+):

The gelatin in the pan represents the fabric of spacetime. Ideally spacetime encompasses everything used in the experiment, such as the laser pointer and the target card, but for the sake of ease, these items are not submerged in the jello. Note that they could be if it weren't too messy. Violent events in space such as black hole collisions, supernovae, or even orbiting neutron stars emit gravitational waves. These energetic processes disrupt spacetime sending ripples of distorted space away from the source. The ripples travel through the universe at the speed of light as they carry information about their origin.

> Drop the spherical cow on the wooden ball and watch the ripples move away from the collision through the gelatin. If possible, record the impact with a phone that has slow motion capabilities to clearly see the ripples. Be sure the reflected laser point is visible in the recording.

The Laser Interferometer Gravitational-Wave Observatory or LIGO for short was able to detect gravitational waves that were the result of two black holes merging 1.3 billion light years away. The collision was so violent that even though it happened 1.3 billion years ago, we were able to detect the gravitational waves that it emitted in 2015. While events that create those gravitational waves can be destructive, by the time they reach earth, they are many magnitudes smaller. For perspective, the waves that LIGO first detected were thousands of times smaller than the nucleus of an atom. There are two LIGO facilities in the U.S., in Washington and Louisiana, and they work together to detect and confirm gravitational waves. A laser beam is sent toward a beam splitter that splits the laser at a 90˚ angle, which is represented by the mirror in this demonstration. Each beam travels down a 4 km interferometer arm and is reflected back using the end mirrors.[4] The laser beams recombine at a detector. The detector can measure changes in the arm length that are as little as 1/10,000 the width of a proton.[5] The apparatus is set up so that the beams coming from each arm cancel each other out when they recombine at the detector, so no signal is produced as is shown in the wave components in figure 5. The presence of gravitational waves causes the length of the arms to change, thus altering the beam waves to create a faint signal when they recombine as is shown in the wave components in figure 6**.**

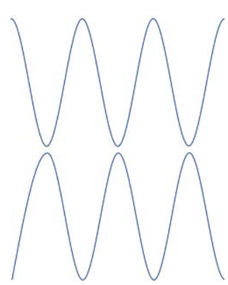


Figure 5. No signal

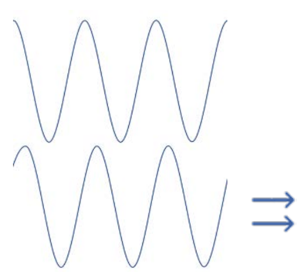


Figure 6. Signal detected

Instead of building an actual interferometer, this demo uses a mirror to mimic the look of interferometer arms as is shown in figure 7 [6] and 8.

Figure 7. LIGO laboratory in Livingston, LA (Caltech/MIT/LIGO Lab)

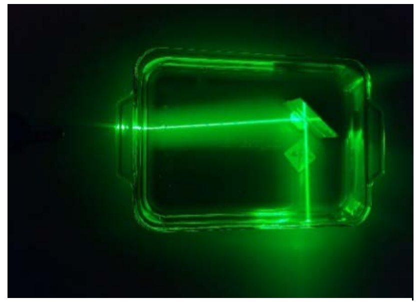


Figure 8. Laser beam going through the gelatin and reflecting off the mirror

Turn on the laser and fix it in place so that it is pointing toward the mirror and is reflected on the target card. Try to get the reflected beam to be centered on the target. Drop the spherical cow ball on the wooden one and watch how the ripple affect the laser beam. Try dropping the ball from different heights and in different places in the pan and note how the movement of the reflected beam changes across the target card. Relate how the movement of the laser due to the ripples is similar to the process that LIGO uses to detect gravitational waves.

Demonstrate the way the reflected beam's movement changes as the ball is dropped from different heights to create a stronger or weaker impact. If possible, take a slow-motion video of the beam on the target card and measure the deviations on the grid.

- The acceleration of objects moving around each other in space create a disturbance in spacetime that radiates outward in the form of gravitational waves. If the objects get involved in a process that is violent and energetic enough, the gravitational waves are strong enough that they can be detected from Earth.
- Gravitational waves stretch and bend light as they travel, so comparing light moving in different directions enables scientists to recognize the presence of the waves and estimate the general direction of the source. The mirror in this demo helps simulate that effect.

For an extra challenge, combine this demo with the 2013 SOCK, more specifically the 4th activity. Using the light sensor module, investigate the audible signal from the reflected laser beam as it moves due to the collisions.

Additional Resources:

- "What Is LIGO?" *Caltech*, www.ligo.caltech.edu/page/what-is-ligo
- *What Is a Gravitational Wave?| Explore*, www.physics.org/article-questions.asp?id=138

- “What Are Gravitational Waves?” *Caltech*, www.ligo.caltech.edu/page/what-are-gw
- “Dropping In With Gravitational Waves Activity | NASA/JPL Edu.” *NASA*, NASA, 17 Oct. 2017, www.jpl.nasa.gov/edu/teach/activity/dropping-in-with-gravitational-waves/
- Sensors, Detectors, and Meters - Oh My!- SOCK 2013, www.spsnational.org/programs/outreach/science-outreach-catalyst-kits/2013/sensors-detectors-and-meters-oh-my

References:

1. What is a gravitational wave? Accessed: 07/02/2019 www.physics.org/article-questions.asp?id=138
2. Illustration of gravitational waves Accessed: 07/02/2019 www.nasa.gov/topics/technology/features/atom-optics.html
3. J. Overduin, J. Perry, R. Huxford, J. Selway*, Classroom Simulation of Gravitational Waves from Orbiting Binaries* (The Physics Teacher, Towson, MD, Dec. 2018) p.587.
4. What is LIGO?
   Accessed: 07/02/2019 www.ligo.caltech.edu/page/what-is-ligo
5. Gravitational Waves Explained
   Accessed: 07/02/2019 www.sciencenews.org/article/gravitational-waves-explained
6. LIGO laboratory in Livingston, LA
   Accessed: 07/02/2019 www.ligo.caltech.edu/image/ligo20150731b