

Cross-Curricular Discussion

After students have had a chance to review the article “Gravitational waves offer new view of dynamic cosmos,” lead a classroom discussion based on the questions that follow. You can copy and paste only the questions that apply to your classroom into a different document for your students. Before starting the discussion, consider having students watch these videos: [Science News answers the question “What are gravitational waves?”](#) and [Stephen Colbert discusses gravitational waves and detectors with theoretical physicist Brian Greene.](#)

BIOLOGICAL SCIENCES

Discussion Questions:

1. What types of waves can humans and other animals detect? [*Sound waves, light waves, waves on a surface, etc.*]
2. What methods do humans and other animals use to detect those waves? How do their natural wave detectors work? [*Have diagrams of how the eye, ears, tactile senses and so on function.*]

Extension Prompts:

3. What can humans and other animals learn about their environment by detecting various types of waves? [*Consider information that can be gleaned from sight, sound and touch, but also consider examples that go beyond human sensory abilities such as bats using sonar, spiders detecting vibrations, insects sensing ultraviolet waves from the sun, snakes detecting infrared waves from prey, for example.*]
4. What extra wave detection abilities do you wish your body had? How might that work, and what would you use it for? [*Student responses will vary.*]
5. Compare and contrast ripples in spacetime with ripples in a food web. [*Student responses will vary.*]

Biological Sciences Question Bank:

What types of waves can humans and other animals detect?

What methods do humans and other animals use to detect those waves?

What can humans and other animals learn about their environment by detecting those various types of waves?

What extra wave detection abilities do you wish your body had? How might that work, and what would you use it for?

Compare and contrast ripples in spacetime with ripples in a food web.

PHYSICAL SCIENCES

Discussion Questions:

To illustrate these concepts as you go, it is very helpful to use a Slinky (approximately \$3.00 at Walmart or similar stores). Have a student stand at one front corner of the classroom and hold one end of the Slinky, while you hold the other end and stretch it across the front of the classroom. The student should keep his or her end still at all times, allowing you to create the desired type of wave. Alternatively, you can hold your end still and ask the student to create wave types. To talk about wave interference, you can use two Slinky toys stretched out side by side. You'll also need a rubber sheet or plastic wrap.

1. What are the major properties of a wave? [*Illustrate amplitude, wavelength, frequency, velocity and so on with the Slinky.*]
2. What is the difference between transverse and longitudinal waves? [*Wiggle the Slinky up and down to make transverse waves. Send one quick compression wave straight through the Slinky toward the student to illustrate longitudinal waves.*]
3. What is the polarization of a transverse wave? [*Vertically polarized waves on a Slinky wiggle up and down, whereas horizontally polarized waves on a Slinky wiggle side to side.*]
4. What is the difference between a traveling and standing wave? [*Traveling waves continue to move forward in space; give the end of the Slinky one quick yank up and back down and do not hold the other end. Standing waves appear to stand in one spot and wiggle back and forth. These waves are the result of the interference of traveling waves. Fix one end of the slinky and move the other end up and down in a continuous pattern.*]
5. What is spacetime from Einstein's theory of general relativity? [*A rubber sheet can be helpful in demonstrating how spacetime warps. If you don't have a rubber sheet, use plastic wrap and stretch it out with help from one or two students. Note that real spacetime includes three dimensions of space joined with the fourth dimension of time, but this simple model shows only two spatial dimensions because nobody makes four-dimensional plastic wrap.*]
6. What are gravitational waves? [*Waves in the fabric of spacetime itself, like waves on the stretched rubber sheet or plastic wrap.*]
7. How are mass and gravity related to spacetime? [*Massive objects warp spacetime; place a tennis ball or baseball on the stretched sheet of rubber or plastic wrap. Warped spacetime is felt by objects as gravity; roll a marble into the area warped by the ball. Since this model is only a two-dimensional sheet, it only shows how mass warps two dimensions of space, but mass similarly warps the third dimension of space plus time as well.*]

Extension Prompts:

8. What are sound waves? Define electromagnetic waves or light. [*Sounds waves are longitudinal waves of air (or another substance) being alternately compressed and stretched. Light travels in transverse waves of wiggling electric and magnetic fields.*]

9. How can two light waves (or two waves of some other type) interfere with each other? *[Stretch two Slinky toys across the front of the classroom parallel to each other, reasonably close but not so close that they will get tangled together. If both are always wiggling up at the same places and times, and both are always wiggling down at the same places and times, the two waves can add together to effectively make a bigger wave. Students will have to imagine the combination of the two Slinky waves. If one Slinky is wiggling up at the places and times that the other is wiggling down, the two waves can effectively cancel each other out. Note that the two waves must have exactly the same frequency and wavelength in order to completely cancel each other out.]*

Physical Sciences Question Bank:

What are the major properties of a wave?

What is the difference between transverse and longitudinal waves?

What is the polarization of a transverse wave?

What is the difference between traveling and standing waves?

What is spacetime from Einstein's theory of general relativity?

What are gravitational waves?

How are mass and gravity related to spacetime?

What are sound waves? Define electromagnetic waves or light?

How can two light waves interfere with each other?

EARTH-SPACE SCIENCES

Discussion Questions:

1. What cosmic events could produce very strong gravitational waves? *[Black holes closely orbiting each other or colliding, neutron stars closely orbiting each other or colliding, stars exploding, the Big Bang and so on.]*

Extension Prompts:

2. How can scientists tell what sort of event gravitational waves are emanating from? *[Mathematical and computer models of different wave sources can show that different types of events generate characteristic gravitational waves with different frequencies and other properties. If the direction of the waves can be determined using three or more gravitational wave detectors, telescopes might detect electromagnetic waves from the same source.]*

3. Could gravitational waves help us learn more about dark matter? Explain. *[They might. If dark matter exists in dense enough "clumps," it could be detected by LIGO when it accelerates. However, scientists don't believe that dark matter resides in clumps dense enough to produce detectable gravitational waves.]*

Earth-Space Sciences Question Bank:

What cosmic events could produce very strong gravitational waves?

How can scientists tell what sort of event gravitational waves are from?

Could gravitational waves help us learn more about dark matter? Explain.

ENGINEERING AND EXPERIMENTAL DESIGN

Discussion Questions:

1. How would you design a simple detector for vibrations (ground vibrations or loud sound waves)?
[Students may spontaneously think along the lines of the optical vibrometer shown later in this guide, or they may think of pens that scribble on paper in response to vibrations, or they may have other ideas.]
2. How does a laser interferometer work? *[A laser beam (all at one wavelength/frequency) is split in half. The two beam halves travel different paths and then recombine. Small differences in the path lengths traveled by the two halves can make the two beams interfere with each other in different ways. When the two beams completely destructively interfere, the light will not be seen (it will be dark). When there is only constructive interference or a mix of both constructive and destructive, differing light patterns will be seen.]*
3. How does a detector for gravitational waves work? *[A large laser interferometer (miles in length) can detect even the very small compressions and expansions of empty space caused by gravitational waves.]*

Extension Prompts:

4. What are some other possible applications of laser interferometers? *[Student responses may vary, but may include measuring the optical flatness of mirrors or measuring small changes in the atmosphere through which one of the beam halves passes.]*
5. How can scientists tell that their gravitational wave detector is really detecting a gravitational wave, and not an earthquake, a passing truck or a frog burping in Toledo? *[LIGO detectors in both Washington state and Louisiana detected nearly identical signals, so it was not local. The signal arrived at the two detectors at almost the same time, indicating that the signal was traveling at the speed of light (as gravitational waves would) and was not more slowly moving waves from an earthquake. LIGO also filters out unwanted frequencies and uses additional monitors to detect other unrelated disturbances.]*
6. Using [Blackline Master 4](#), examine the graph from “[Physicists detect gravitational waves](#),” showing the LIGO signals. Two black holes orbiting each other should produce two gravitational wave peaks per complete orbit – one peak from the first black hole when it passes slightly closer to Earth and the next peak from the second black hole when it passes slightly closer to Earth. Use the graph key and labels, and a ruler as necessary, to answer the following questions.
 - a. Based on the predicted gravitational wave peaks, what is the slowest orbit (longest orbital period/lowest orbital frequency) you can find between 0.30 and 0.425 seconds? Approximate the time between consecutive gravitational wave peaks and multiply by 2 to get the orbital period. *[Approximately 0.06 seconds or 17 orbits/sec near the left side of the graph.]*
 - b. Based on the predicted gravitational wave peaks, what is the fastest orbit (shortest orbital period/highest orbital frequency) you can find between 0.30 and 0.425 seconds? Approximate the time between consecutive gravitational wave peaks and multiply by 2 to get the orbital period. *[Approximately 0.013 seconds or 75 orbits/sec near the right side of the graph.]*

Engineering and Experimental Design Question Bank:

How would you design a simple detector for vibrations (ground vibrations or loud sound waves)?

How does a detector for gravitational waves work?

What are some other possible applications of laser interferometers?

How can scientists tell that their gravitational wave detector is really detecting a gravitational wave, and not an earthquake, a passing truck or a frog burping in Toledo?

Based on the predicted gravitational wave peaks, what is the slowest orbit (longest orbital period/lowest orbital frequency) you can find between 0.30 and 0.425 seconds? Approximate the time between consecutive gravitational wave peaks and multiply by 2 to get the orbital period.

Based on the predicted gravitational wave peaks, what is the fastest orbit (shortest orbital period /highest orbital frequency) you can find between 0.30 and 0.425 seconds? Approximate the time between consecutive gravitational wave peaks and multiply by 2 to get the orbital period.

Cross-Curricular Discussion

Directions: Use this graph from “Physicists detect gravitational waves” to answer the related discussion questions assigned by your teacher.

