Science Icebreaker Activities: An Example from Gravitational Wave Astronomy

Michelle B. Larson, Louis J. Rubbo, Kristina D. Zaleski* and Shane L. Larson, The Pennsylvania State University, University Park, PA

At the beginning of a class, workshop, or meeting, an icebreaker activity is often used to help loosen up the group and get everyone talking. When used as a precursor to group learning, the icebreaker fosters communication so later activities function more smoothly. Science-based icebreaker activities serve the purpose of a traditional icebreaker, while also introducing science content to the audience. The content of the icebreaker may or may not be related to the topic of the upcoming class or meeting. Either way, the activity provides a way to get people talking while the participants simultaneously learn something new and interesting.

Several science-related icebreakers have been designed and successfully implemented with students and adults, including a solar activity[1] and a cosmic ray activity.[2] The subject of this article is an icebreaker activity related to gravitational wave astronomy. Icebreakers like these could be designed around any subject, and we encourage others to develop their own subject-specific science icebreakers keeping in mind two primary goals—to help get the group interacting and to introduce some interesting science content.

Since one of the goals of this model for an icebreaker activity is to introduce some science, we begin this paper by discussing a few aspects of the developing field of gravitational wave astronomy (for the benefit of the facilitator). We first point out that gravitational wave detectors do not return a pretty picture but instead return a time series. We then describe the unique gravitational wave signals from three distinct astrophysical sources: monochromatic binaries, merging compact objects, and extreme mass ratio encounters. These signals form the basis of the activity where participants work to match an ideal gravitational wave signal with noisy detector output for each type of source. For a more detailed introduction to gravitational wave astronomy and gravitational wave detectors, see "Gravitational Waves: New Observatories for New Astronomy," also in this issue.

Gravitational Wave Data Analysis

Perhaps the most challenging part of gravitational wave astronomy is recognizing a detection when we have one. Gravitational wave detectors are not imaging detectors. They observe oscillations in spacetime that, for example, are made evident by measuring the relative changes in the light travel times along different arms of an interferometric observatory. What will the gravitational waves from two neutron stars orbiting each other look like? What will two black holes colliding look like? Or the inspiral of a white dwarf into a super-massive black hole? Theoretical calculations allow us to model the expected gravitational wave signal from astrophysical systems (for example, see Figs. 1–3); these models are called *templates*. Templates are the patterns gravitational wave astronomers look for in the detector data.

As with any experiment, gravitational wave detection is complicated by instrumental noise. Noise can originate from a wide range of sources such as vibrations in the Earth's crust due to ocean waves on a shore miles away (for ground-based observatories), or minuscule changes in the laser arm length caused by

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solar wind particles bouncing off the spacecraft (for space-based observatories). Detection involves coaxing the signal out of the noise and having confidence that it has been accurately found. Our confidence will be strengthened by observing very strong signals or by coincidence observations made in several observatories at once. Coincidence detection will eliminate anomalous false detections due to noise in a single detector. In this manner, gravitational wave detectors around the world will work together to confidently identify gravitational wave signals.

The icebreaker activity described in the next few sections models the gravitational wave detection process described above. Participants identify a model signal within a noisy data stream and compare their solution with other groups to provide confidence that the correct signal has been found.

Astrophysical Information

Although gravitational wave observations will not produce beautiful images, the data tell us a lot about the source system. At the level of this icebreaker, participants will become familiar with the idea that astrophysical systems can be distinguished by their gravitational wave signals. This activity will use three different binary systems, described below.

(1) ***Compact star binary system:*** When two massive objects orbit each other they produce gravitational waves. If the system contains two compact stellar objects, such as white dwarfs or neutron stars, the gravitational radiation will be in the frequency range of current (and future) gravitational wave detectors. Two compact objects orbiting in a large circular orbit will produce a monochromatic signal, a signal where the amplitude and frequency does not change noticeably during the observation (Fig. 1).

(2) ***Coalescing binary system:*** As the above binary system loses energy through the emission of gravitational radiation, the orbit will slowly shrink and the two objects will come closer together. In the final minutes the orbital period decreases rapidly, and the two stars spiral together. During this final coalescence phase, the system emits gravitational waves with increasing amplitude and frequency, ending with the final merger of the two objects (Fig. 2).

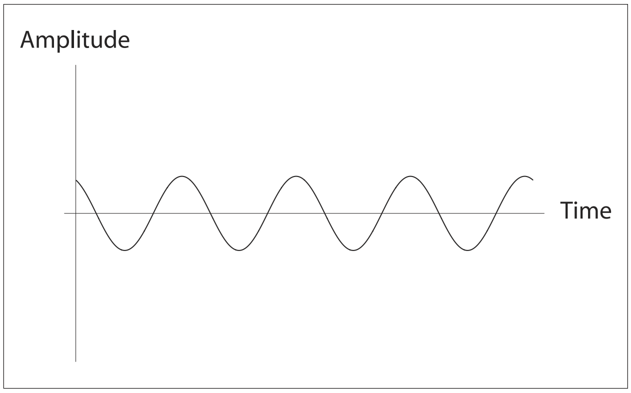

Fig 1. For a binary system where the orbiting objects are far apart, the resulting gravitational wave signal is monochromatic.

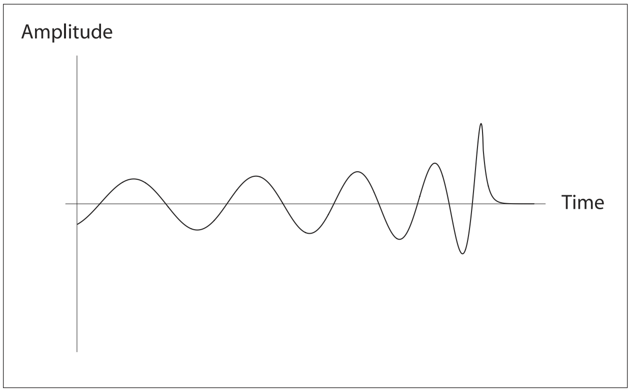

Fig. 2. As gravitational radiation carries energy and angular momentum away from the system, the binary objects slowly inspiral toward each other. In the final minutes of coalescence, the amplitudes and frequency increase rapidly, ending with the merger of the two objects.

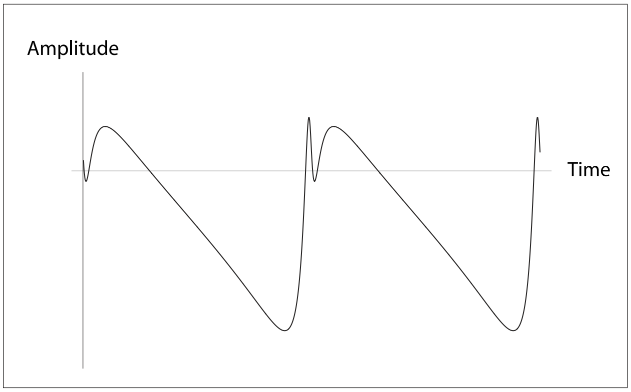

Fig 3. When the ratio of the binary component masses is very large, the gravitational wave signal changes rapidly during the times when the objects are at their closest distance to each other.

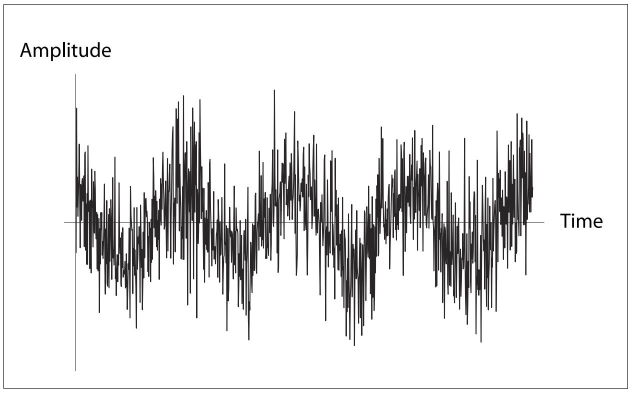

Fig. 4. A simulated noisy monochromatic signal.

(3) ***Extreme mass ratio binary system:*** Unlike the relatively equal mass binary systems described above, the gravitational wave signals from an extreme mass ratio system will be quite different. An example of an extreme mass ratio system is a compact object (i.e. white dwarf, neutron star, or stellar mass black hole) orbiting a super-massive black hole. These systems are typically on very eccentric orbits and emit a burst of gravitational waves at a time when the smaller object is closest to the super-massive black hole. As a result, the gravitational wave signal exhibits a rapid burst of radiation when the two are close together (center of Fig. 3).

Icebreaker Activity

Resources for this activity are available in printable form on the Center for Gravitational Wave Physics' activity page.[3] The materials allow for four activity sets; each set contains one data stream and six templates. Each data stream contains a single source with simulated detector noise added in. As an example, the monochromatic data stream is shown in Fig. 4. The four template files represent monochromatic and coalescing sources and both gravitational wave polarizations of an extreme mass ratio source. The six individual templates within each file have varying signal characteristics, such as period and initial phase. There is also an activity key.

The icebreaker activity can be conducted with only one—or as many as four—of the different activity sets. Depending on the age of your audience and the time available, decide in advance how many sets you would like to include in each icebreaker packet. Print the noisy data signals on transparency film. Print the gravitational wave template files on plain paper. All files contain two images per page. Cut each printed page in half, creating signal and template sets of half-sheet size for each icebreaker packet.

At the beginning of the meeting or class have everyone break into groups of two to four people. Pass out an icebreaker packet (containing one to four activity sets) to each group. Start out by explaining that gravitational wave astronomers will make observations of the universe in a different way from traditional astronomers. Explain that these are simulated gravitational wave signals from sample astrophysical systems; a detailed description of the systems can be saved for after the activity. An explanation of each system is provided in the activity key.

After the introduction, ask the groups to identify the best template/data stream matches. Give them 10 to 15 minutes to complete the task. Do not provide much instruction about what features to use in identifying a match. The participants, with some encouragement, will discover the need to use the axes as reference lines and to look carefully at details such as amplitude, period, and initial phase differences, or other significant features in the signals.

Encourage interaction and allow the groups to move around the room if they choose. Once each group has a matched set, lead a discussion about which template matches which data stream and why. Facilitate discussion about amplitude, period, and other features used when determining their answer. Write each group's matching solution on a chalkboard for everyone to see. If you have differences among the groups, discuss the differences and see if they can come to agreement. If some groups matched the images based on criteria different from what has been discussed, have them explain what they did.

Once the discussion period is over, emphasize that gravitational wave astronomers use methods very similar to these to identify sources in real data. As part of the icebreaker activity, the discussion need not go further than describing the different types of binary systems and how they appear differently in the gravitational wave data. More detailed information can be gathered about the source system (e.g., masses and distance to the source) by measuring the gravitational wave signal wavelength and how the wavelength changes in time. A classroom extension related to these measurements will be discussed in a follow-up paper.[4] Finally, consider giving everyone their own set of images (and a copy of the key) to use at home with their family and friends!

Acknowledgments

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The authors *are all members of the Center for Gravitational Wave Physics, an NSF Physics Frontier Center at The Pennsylvania State University. They work in the emerging field of gravitational wave phenomenology, which sits at the interface between modern gravitational theory, astrophysics, and engineering. Their expertise spans all these fields with the common goal of understanding how gravitational wave observations can reveal the story gravity has to tell about high energy astrophysical phenomena.*

Center for Gravitational Wave Physics, The Pennsylvania State University, University Park, PA 16802; mlarson@gravity.psu.edu; rubbo@gravity.psu.edu; k.d.zaleski@larc.nasa.gov*; shane@gravity.psu.edu

**now at North Carolina State University*