Viewpoint: Neutron Star Merger Seen and Heard

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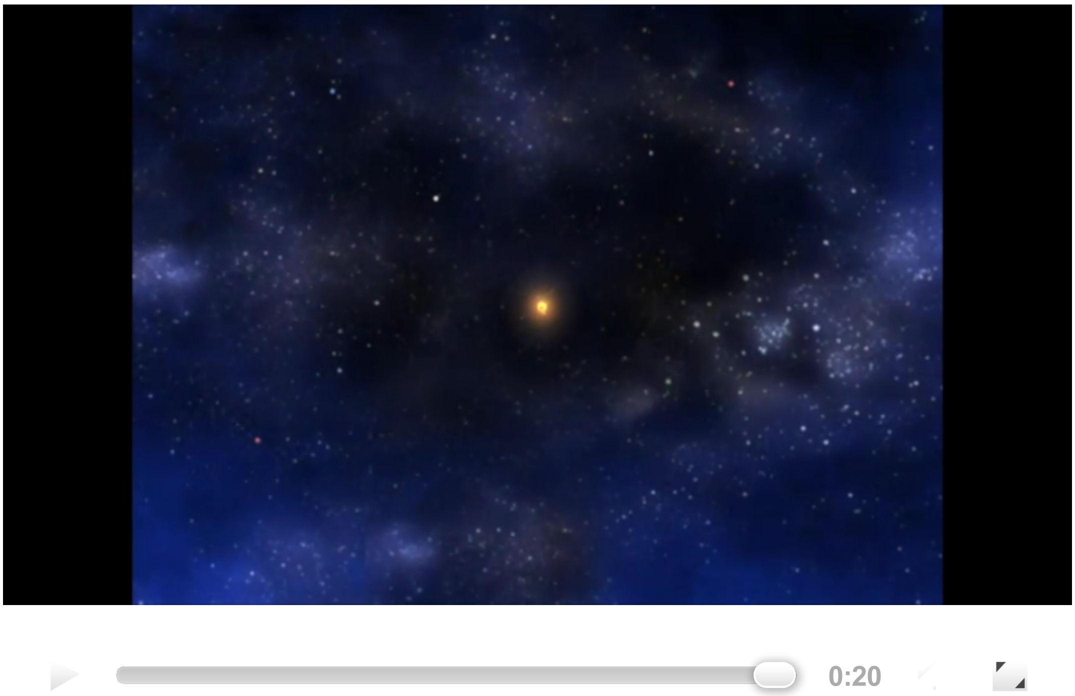
For the first time, researchers have detected both light and gravitational waves from the same event in space.



NASA/Goddard Space Flight Center

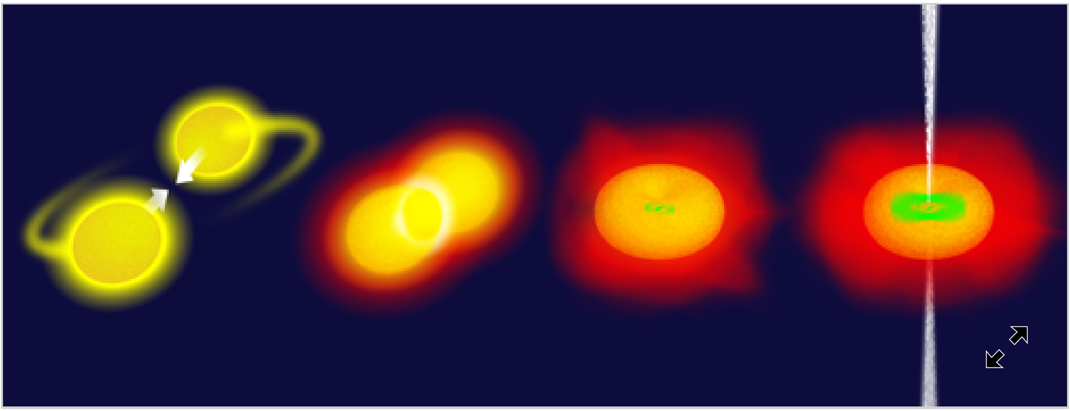
Video 1: (Animation appears online only.) Artistic animation of a binary neutron star merger resulting in a gamma-ray burst and emission of gravitational waves.

Over thousands of years, astronomy has evolved from hand-drawn maps of the night sky to breathtaking telescope images of the far-away cosmos. Yet despite this advance in technology, most of our information about the Universe has come from photon messengers. This changed in September 2015 with the detection of gravitational waves from a black hole merger at the Laser Interferometer Gravitational-Wave Observatory (LIGO) [1], an achievement that was recognized with **this year's Nobel Prize in Physics**. The chirp-like signal, caused by a traveling ripple through spacetime, gave us a new way to sense the Universe, like being able to hear, when before we could only see. Now LIGO and its sister experiment, Virgo, have broken ground yet again with their joint detection of gravitational waves from the merger of two neutron stars [2] (see Video 1). Unlike a black hole merger, which is practically invisible, a neutron star merger event (Fig. 1) is accompanied by emission across the electromagnetic spectrum. Data from multiple telescopes show that the detected merger produced another cosmological spectacle, a short gamma-ray burst [3]. This long-awaited ability to simultaneously compare the sights and “sounds” from the same object in space opens up entirely new ways to explore the relationship between gravity, light, and matter.

Neutron stars are among the most exotic objects in the Universe. A typical neutron star has a mass greater than that of our Sun but a diameter of just over 10 miles. These compact objects also rotate extremely fast, with some completing a rotation within milliseconds. The first binary neutron star system was discovered in 1974 by Russell Hulse and Joseph Taylor. Observations of radio-wave pulses from the stars showed that their orbit was shrinking at a rate of 10 mm per year—exactly the amount expected if the binary loses energy from the emission of gravitational waves [4]. These measurements provided the first proof that such waves exist, and Hulse and Taylor were recognized with the 1993 Nobel Prize in Physics.

Radio surveys have now revealed roughly a dozen binary neutron star systems, all within our Galaxy. None of these binaries will merge for millions of years [5], but binaries outside our Galaxy surely exist, and scientists believe they have indirect evidence for extragalactic mergers in the form of short gamma-ray bursts (GRBs). These intense flashes of gamma rays last roughly a second, yet can contain as much energy as the Sun emits in a trillion years. This is a similar amount of energy as that expected from a binary neutron star merger, which is why researchers associate such mergers with GRBs.

The LIGO/Virgo results provide the first direct evidence that this assumption is correct. To detect a passing gravitational wave, LIGO, in the US, uses two L-shaped interferometers separated by 3000 km, while Virgo, in Italy, uses one such interferometer. In August 2017, just weeks after the recently upgraded Virgo joined LIGO's search, the two experiments detected a gravitational-wave signal whose shape matched that predicted from the merger of two compact objects. The LIGO and Virgo collaborations' analysis of roughly 100 seconds of data indicates that the objects were between 1 and 2 solar masses, consistent with known neutron star masses. Compared with LIGO's first detection, this event was much closer—130 million light years away instead of a billion light years away—and it resulted in a stronger signal. Moreover, with three interferometers, the scientists were able to localize the merger event to a 28-square-degree patch of sky, which is 20 times smaller than the localization of LIGO's first detection.



APS/**Alan Stonebraker**, adapted from simulations by NASA/AEI/ZIB/M. Koppitz and L. Rezzolla

Figure 1: The final stages of a binary neutron star merger. From left to right, two inspiralling neutron stars eventually merge into a single mass, releasing energy in various forms, including gravitational waves, matter, and light. Most mergers are thought to... **Show more**

This directional information allowed the LIGO and Virgo teams to correlate the gravitational-wave signal with a short GRB, which was detected 1.7 s later and from the same direction in the sky by two gamma-ray telescopes, Fermi and INTEGRAL [3]. The short time delay between the two signals clearly associates short GRBs with neutron star mergers. It also constrains the speed of gravitational waves, which are predicted by general relativity to have the same speed as light. Many other telescopes also tracked the “afterglow” of the explosive merger at radio, infrared, optical, and x-ray wavelengths [6], pinpointing the merger to galaxy NGC 4993 in the constellation Hydra.

The fact that the loudest, closest, and most precisely localized gravitational-wave detection so far was also made so soon after the LIGO and Virgo collaborations began their joint search confirms what scientists had predicted: there is a large population of neutron star mergers out there for us to observe [7]. Several more events are expected this year and dozens more over the next several years. With the signal from each new event, researchers will be able to extract such properties as the stars’ mass, spin, size, and shape, which will lead to tighter constraints on the neutron star equation of state. They will also be able to test whether the final state of a neutron star merger is an even heavier neutron star or a black hole. In addition, researchers may gain a better handle on the background from all neutron star mergers in the Universe, which provides unique information about stellar populations and merger physics.

More general physics tests are also on the horizon. The gravitational-wave signal from a merger is a “standard siren,” meaning all sources have the same intrinsic loudness. The signal can therefore be used to figure out the distance of a merger-containing galaxy. Such measurements can in turn be used to determine the Hubble constant [8], which describes the expansion of the Universe—though many more detections are needed to achieve the precision of the current best estimates of the constant. Also, because neutron star mergers last a lot longer than black hole mergers, they enable far more sensitive searches for deviations from general relativity, which have been predicted by alternative theories of gravity.

But the true headline news of the LIGO/Virgo result is the detection of both gravitational waves and electromagnetic signals from the same source. This will enable entirely new cosmological tests. For example, we can now explore how electromagnetic signals from merging objects are affected by the objects’ mass and spin, two quantities that can be directly gleaned from analyzing gravitational waves. Similarly, the luminosity of the electromagnetic signal and its delay relative to a gravitational wave can be used to probe the physics of gravity (such as the equivalence principle) in ways that were not possible through either type of observation alone.

Our movie of the Universe is no longer silent but is instead accompanied by a gravitational-wave cacophony. We are entering the new and much anticipated era of “multimessenger” astronomy [9], in which we can observe a source through both gravitational waves and photons. The history of astronomy shows that new observational tools often lead to the discovery of phenomena we never imagined. So take a seat, grab some popcorn, and enjoy what is bound to be a great show.

This research is published in ***Physical Review Letters*** and ***The Astrophysical Journal Letters***.

Correction (16 October 2017): An earlier version of the article stated that the end product of the observed neutron star merger was a black hole. In fact, further analysis is needed to characterize the end product. The article has been updated accordingly.

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About the Author

Maura McLaughlin received her Ph.D. from Cornell University in 2001. In 2006, after an NSF Distinguished Postdoctoral Fellowship at the University of Manchester, UK, she joined the faculty of West Virginia University, where she is the Eberly Family Distinguished Professor of Physics and Astronomy. A significant aim of her research program is to use neutron stars to detect gravitational waves by timing the arrival of pulses from an array of ultraprecise millisecond pulsars. She is chair of the North American Nanohertz Observatory for Gravitational Waves (NANOGrav) collaboration and co-director of the NANOGrav Physics Frontier Center.

Subject Areas

Astrophysics

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GW170817: Observation of Gravitational Waves from a Binary Neutron Star Inspiral

B. P. Abbott *et al.* (LIGO Scientific Collaboration and Virgo Collaboration)

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