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Gravitational waves + new clues from space reveal new way to make a black hole

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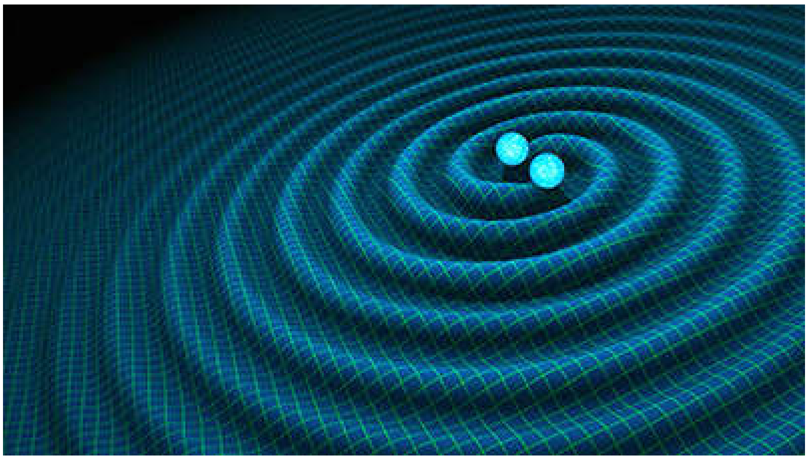
For the first time, two neutron stars are caught in the act of colliding

For the first time, scientists worldwide and at Penn State University have detected both gravitational waves and light shooting toward our planet from one massively powerful event in space -- the birth of a new black hole created by the merger of two neutron stars. This detection is important because it marks the beginning of a new era of "multi-messenger" as well as "multi-wavelength" space exploration -- an era when gravitational-wave detectors are triggering a global network of other types of instruments to focus their special detection powers simultaneously on one fleetingly explosive point in space.



Artist impression of gravitational waves generated by binary neutron stars. Credit: R. Hurt, Caltech/JPL

All the previous gravitational-wave detections since the first in September 2015 had been the result of two merging black holes -- objects much more massive than a neutron star -- which have left only gravitational waves as fleeting clues of their merger. "The evidence that these new gravitational waves are from merging neutron stars has been captured, for the first time, by observatories on Earth and in orbit that detect electromagnetic radiation, including visible light and other wavelengths," said Chad Hanna, assistant professor of physics and of astronomy & astrophysics and Freed Early Career Professor at Penn State. Hanna has served as co-chair of the Compact Binary Coalescence Group of the Laser Interferometer Gravitational Wave Observatory (LIGO), and is one of the primary data analysts involved in this research.

"Several graduate students and post-docs on my Penn State research team were among the first in the world to see the alert triggered by LIGO when this new gravitational wave arrived," Hanna said. "Cody Messick -- a graduate student -- sent the first email to the broader collaboration notifying everyone of what had happened." Penn State's LIGO team, along with other members of the LIGO and Virgo collaborations, quickly alerted a worldwide network of observatories whose scientists then commandeered their telescopes and other detectors to look for more evidence. "Because we now have three gravitational-wave detectors -- the two LIGO detectors in the United States plus the Virgo detector in Europe -- we were able to triangulate the location of the source of the waves sufficiently well for several observatories to find the counterpart" Hanna said.

NASA's Swift, Hubble, Chandra and Spitzer missions, along with dozens of ground-based observatories, later captured the fading glow of the blast's expanding debris. Numerous scientific papers describing and interpreting these new observations are being published in "Science," "Nature," "Physical Review Letters" and "The Astrophysical Journal." Penn State scientists are leaders and innovators in many of the scientific collaborations contributing to these new multiwavelength discoveries. Penn State has earned a reputation rivaled by only a few other educational institutions for the breadth and depth of the contributions its scientists have made and are continuing to make in discoveries that enrich our understanding of the universe and its effect on our planet.

"We applaud this latest achievement of our many Penn State scientists and students who have helped to build and are helping to develop this innovative new technology and its system of international collaboration among many research teams worldwide," said Nicholas P. Jones, Penn State's Executive Vice President and Provost. "With their knowledge, skills, and creativity, our scientists are contributing to the evolution of this new way of exploring the universe."

Penn State scientists are leaders in the development and operation of NASA's Swift Gamma Ray Burst Explorer satellite. Two of Swift's three instruments were built with Penn State leadership, and Penn State continues to lead Swift's Mission Operations Center, which is located on the University Park Campus. "Swift's rapid response time enabled us to use it to rapidly search for and detect the electromagnetic counterpart of this gamma-ray burst after its detection by LIGO," said Jamie Kennea, associate research professor of astronomy and astrophysics, the leader of the Swift Science Operations Team at Swift's Mission Operations Center, located at Penn State's University Park campus.

"We saw ultraviolet light resulting from this gravitational-wave event as part of Swift observations of almost 750 different locations in the sky. Then, as this light rapidly faded from view, we intensely observed it with Swift's ultraviolet/optical telescope, the UVOT," Kennea said. "Because ultraviolet light from objects in space can be detected only by telescopes located outside Earth's atmosphere, Swift's UVOT telescope provided unique data on this event. These new data now present new questions for theorists to solve."

Penn State astronomers also are among the leaders in the development and use of NASA's orbiting Chandra X-ray Observatory. Gordon Garmire, Evan Pugh Professor Emeritus of Astronomy and Astrophysics, is the principal investigator of the team that built one of the primary instruments on board the satellite. He also is a co-discoverer of high-energy gamma rays and is responsible for developing many of the data-analysis algorithms used today in high-energy astrophysics.

Penn State's Institute for Gravitation and the Cosmos, directed by Eberly Professor of Physics Abhay Ashtekar, includes Penn State's Center for Particle and Gravitational Wave Astrophysics, where leading scientists in both theoretical and experimental physics collaborate. The center's faculty are prominent participants in eight major international projects that are making rapid-response observations -- using extremely high-energy protons and nuclei, neutrinos, gamma-rays, X-rays and gravitational waves -- as quickly as possible after gravitational waves are discovered by the LIGO and Virgo detectors. These projects are the Pierre Auger Cosmic Ray Observatory, the IceCube Neutrino Observatory, the Swift Gamma-Ray Burst Explorer satellite, the Chandra X-ray Observatory, the XMM-Newton X-ray Observatory, the Laser Interferometric Gravitational Wave Observatory (LIGO), the North American Nanohertz Observatory for Gravitational-waves (NANOGrav) and the High Altitude Water Cherenkov (HAWC) TeV gamma-ray detector.

Long before it was possible to detect gravitational waves, highly respected theories about the kinds of evidence that two merging neutron stars could produce were developed by Peter Mészáros, Penn State's Eberly Family Chair in Astronomy & Astrophysics and Professor of Physics, together with his colleague Martin Rees. "Our theories predicted that neutron star binaries, which would inevitably merge as they emit gravitational waves, would produce a short and distinctive burst of gamma rays at the moment of their merger," Mészáros said. "Previously, as anticipated, gamma ray detectors had observed bursts of gamma rays such as were expected from neutron star mergers. However, we never before have had the important independent confirmation of the merger of two neutron stars that we now have obtained with this new gravitational wave detection. For the first time, exactly the evidence we needed has been provided by the gamma-ray detections that coincided with this new gravitational-wave burst."

The scientists now have not only gravitational-wave detectors but also a wealth of other types of observatories collaborating in this effort to capture a range of multimessenger signals from the sources that produce gravitational waves. "In order to facilitate this effort, Penn State is spearheading the new Astrophysical Multimessenger Observatory Network (AMON) in our Institute for Gravitation and the Cosmos," Mészáros said. These combined detection capabilities give us a much better tool, which we now can begin to use to gauge -- much more accurately than previously was possible -- the age of the universe and how fast it is expanding."

[Barbara K. Kennedy]