

NEWS RELEASE

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GRAVITATIONAL WAVES DETECTED 100 YEARS AFTER EINSTEIN'S PREDICTION

LIGO Opens New Window on the Universe with Observation of Gravitational Waves from Colliding Black Holes

LIGO Hanford Observatory team receives a cosmic gift to help celebrate its 20th anniversary in the TriCities.

Tri-Cities, Washington

For the first time, scientists have observed ripples in the fabric of spacetime called gravitational waves, arriving at the earth from a cataclysmic event in the distant universe. This confirms a major prediction of Albert Einstein's 1915 general theory of relativity and opens an unprecedented new window onto the cosmos.

Gravitational waves carry information about their dramatic origins and about the nature of gravity that cannot otherwise be obtained. Physicists have concluded that the detected gravitational waves were produced during the final fraction of a second of the merger of two black holes to produce a single, more massive spinning black hole. This collision of two black holes had been predicted but never observed.

The gravitational waves were detected on September 14, 2015 at 5:51 a.m. Eastern Daylight Time (9:51 UTC) by both of the twin Laser Interferometer Gravitational-wave Observatory (LIGO) detectors, located in Livingston, Louisiana, and Hanford, Washington, USA. The LIGO Observatories are funded by the National Science Foundation (NSF), and were conceived, built, and are operated by Caltech and MIT. The discovery, accepted for publication in the journal *Physical Review Letters*, was made by the LIGO Scientific Collaboration (which includes the GEO Collaboration and the Australian Consortium for Interferometric Gravitational Astronomy) and the Virgo Collaboration using data from the two LIGO detectors.

Based on the observed signals, LIGO scientists estimate that the black holes for this event were about 29 and 36 times the mass of the sun, and the event took place 1.3 billion years ago. About 3 times the mass of the sun was converted into gravitational waves in a fraction of a second—with a peak power output about 50 times that of the whole visible universe. By looking at the time of arrival of the signals—the detector in Livingston recorded the event 7 milliseconds before the detector in Hanford—scientists can say that the source was located in the Southern Hemisphere.

According to general relativity, a pair of black holes orbiting around each other lose energy through the emission of gravitational waves, causing them to gradually approach

each other over billions of years, and then much more quickly in the final minutes. During the final fraction of a second, the two black holes collide into each other at nearly one-half the speed of light and form a single more massive black hole, converting a portion of the combined black holes' mass to energy, according to Einstein's formula $E=mc^2$. This energy is emitted as a final strong burst of gravitational waves. It is these gravitational waves that LIGO has observed.

"Our observation of gravitational waves accomplishes an ambitious goal set out over 5 decades ago to directly detect this elusive phenomenon and better understand the universe, and, fittingly, fulfills Einstein's legacy on the 100th anniversary of his general theory of relativity," says Caltech's David H. Reitze, executive director of the LIGO Laboratory.

LIGO was originally proposed as a means of detecting these gravitational waves in the 1980s by Rainer Weiss, professor of physics, emeritus, from MIT; Kip Thorne, Caltech's Richard P. Feynman Professor of Theoretical Physics, emeritus; and Ronald Drever, professor of physics, emeritus, also from Caltech.

"The description of this observation is beautifully described in the Einstein theory of General Relativity formulated 100 years ago and comprises the first test of the theory in strong gravitation. It would have been wonderful to watch Einstein's face had we been able to tell him," says Weiss.

"With this discovery, we humans are embarking on a marvelous new quest: the quest to explore the warped side of the universe—objects and phenomena that are made from warped spacetime. Colliding black holes and gravitational waves are our first beautiful examples," says Thorne.

The December 1989 proposal for construction of LIGO laid out the strategy to turn promising ideas and earlier laboratory prototype results into monumental detectors of unprecedented precision, capable of opening this new window on the universe. It envisioned two detector design stages. The initial construction, funded in 1992, was to design and build two observatory facilities that could house successive generations of detectors as well as the first detectors, known as Initial LIGO. These would be the pathfinder detectors, utilizing the best of 20th-century technologies, which had a small chance of detecting gravitational waves, whose strength and frequency at Earth were unknown. Concurrently with gaining operating experience through Initial LIGO, an R&D program would evolve technologies and engineering designs toward second-generation detectors, called Advanced LIGO, that were intended to make gravitational-wave detections routinely. Initial LIGO Detectors operated from 2000 to 2010.

The discovery was made possible by the enhanced capabilities of Advanced LIGO, a major upgrade that increases the sensitivity of the instruments compared to the first generation LIGO detectors, enabling a large increase in the volume of the universe probed—and the discovery of gravitational waves during its first observation run. The US National Science Foundation leads in financial support for Advanced LIGO. Funding

organizations in Germany (Max Planck Society), the U.K. (Science and Technology Facilities Council, STFC) and Australia (Australian Research Council) also have made significant commitments to the project. Several of the key technologies that made Advanced LIGO so much more sensitive have been developed and tested by the German UK GEO collaboration. Significant computer resources have been contributed by the AEI Hannover Atlas Cluster, the LIGO Laboratory, Syracuse University, and the University of Wisconsin-Milwaukee. Several universities designed, built, and tested key components for Advanced LIGO: The Australian National University, the University of Adelaide, the University of Florida, Stanford University, Columbia University in the City of New York, and Louisiana State University.

“The Advanced LIGO detectors are a tour de force of science and technology, made possible by a truly exceptional international team of technicians, engineers, and scientists,” says David Shoemaker of MIT, the project leader for Advanced LIGO. “We are very proud that we finished this NSF-funded project on time and on budget.”

At LIGO Hanford Observatory, scientists, engineers and technicians worked along with local contractors from 2008 until 2015 to build the Advanced LIGO detector, guided by more than 15,000 drawings covering over a million named parts. As Initial LIGO was observing between 2009-2010, truckloads of parts were arriving daily, from our colleagues and contractors around the world, to be prepared and assembled into larger detector sub-units with rigorous testing at each step. By October 2010, the Initial LIGO detector was shut down and disassembled, so that the Advanced LIGO sub-units could be installed into the vacuum system for final integration and testing of the new detector. This process was completed at the end of March 2015. From April through August, our commissioning team rapidly learned the intricacies of operating this complex instrument - consisting of several hundred high-performance servo-systems, hundreds of thousands of data channels and approximately one million lines of operating code - and tuned its sensitivity to the level targeted for its first observing run. The detector was then turned over to our Detector Engineering team for stabilization and calibration, so that it could run reliably at high sensitivity. As this state was approached in the first half of September 2015, our Detection Lead Scientist, working with our science and engineering teams, operations specialists and visiting LIGO Fellows, was organizing the last details for the first observing run. Then, in the early morning hours of September 14 in the Pacific Northwest, Nature declared it was time as the gravitational wave, known as GW150914, arrived at Earth. It took 3 minutes for an online analysis code to identify the event. Shortly thereafter, our rapid response team initiated the vetting process for this event.

“Detection of this event brings the curtain down on Act 1 of this play, according to the script we wrote back in 1989,” says Fred Raab, Head of LIGO Hanford Observatory. “It also raises the curtain for Act 2, the beginning of the age of exploration of space and time, the gravitational universe. We don’t know yet how many different actors or acts there will be in this play. But we know the meaning of the play is that humans have a new way to explore the universe we live in.”

LIGO Hanford Observatory has played a large role in educating students throughout its history. More than 70 graduate students and a comparable number of undergraduates

have come to the Tri-Cities from around the world to work on LIGO research. More than 20,000 K-12 students visited the observatory on school field trips and interacted with our staff and visiting students and scientists.

LIGO research is carried out by the LIGO Scientific Collaboration (LSC), a group of more than 1000 scientists from universities around the United States and in 14 other countries. More than 90 universities and research institutes in the LSC develop detector technology and analyze data; approximately 250 students are strong contributing members of the collaboration. The LSC detector network includes the LIGO interferometers and the GEO600 detector. The GEO team includes scientists at the Max Planck Institute for Gravitational Physics (Albert Einstein Institute, AEI), Leibniz Universität Hannover, along with partners at the University of Glasgow, Cardiff University, the University of Birmingham, other universities in the United Kingdom, and the University of the Balearic Islands in Spain.

“This detection is the beginning of a new era: The field of gravitational wave astronomy is now a reality,” says Gabriela González, LSC spokesperson and professor of physics and astronomy at Louisiana State University.

Virgo research is carried out by the Virgo Collaboration, consisting of more than 250 physicists and engineers belonging to 19 different European research groups: 6 from Centre National de la Recherche Scientifique (CNRS) in France; 8 from the Istituto Nazionale di Fisica Nucleare (INFN) in Italy; 2 in The Netherlands with Nikhef; the Wigner RCP in Hungary; the POLGRAW group in Poland and the European Gravitational Observatory (EGO), the laboratory hosting the Virgo detector near Pisa in Italy.

Fulvio Ricci, Virgo Spokesperson, noted that “This is a significant milestone for physics, but more importantly merely the start of many new and exciting astrophysical discoveries to come with LIGO and Virgo.”

At each observatory, the two-and-a-half-mile (4 km) long L-shaped LIGO interferometer uses laser light split into two beams that travel back and forth down the arms (four-foot diameter tubes kept under a near-perfect vacuum). The beams are used to monitor the distance between mirrors precisely positioned at the ends of the arms. According to Einstein’s theory, the distance between the mirrors will change by an infinitesimal amount when a gravitational wave passes by the detector. A change in the lengths of the arms smaller than one-ten-thousandth the diameter of a proton (10^{-19} meter) can be detected.

“In 1992, when LIGO’s initial funding was approved, it represented the biggest investment the NSF had ever made,” says France Córdova, NSF director. “It was a big risk. But the National Science Foundation is the agency that takes these kinds of risks. We support fundamental science and engineering at a point in the road to discovery where that path is anything but clear. We fund trailblazers. It’s why the U.S. continues to be a global leader in advancing knowledge.”

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