U.S. HOUSE OF REPRESENTATIVES
COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

Unlocking the Secrets of the Universe: Gravitational Waves

Wednesday, February 24, 2016
10:00 a.m. – 12:00 p.m.
2318 Rayburn House Office Building

Purpose

On Wednesday, February 24, 2016, the House Science, Space, and Technology Committee will hold a hearing to discuss the recent and groundbreaking detection of gravitational waves by the National Science Foundation (NSF)-funded Laser Interferometer Gravitational-wave Observatory (LIGO) detectors. It is the confirmation of the existence of gravitational waves, as first predicted by Albert Einstein a century ago. The purpose of the hearing will be to learn more about the discovery, its meaning for American science and innovation, the NSF's role in supporting LIGO, and what new research and applications may be generated by this breakthrough.

Witnesses

- **Dr. Fleming Crim**, Assistant Director, Directorate of Mathematical and Physical Sciences, National Science Foundation
- **Dr. David Reitze**, Executive Director of LIGO, California Institute of Technology
- **Dr. Gabriela González,** Professor of Physics and Astronomy, Louisiana State University
- **Dr. David Shoemaker**, Director, LIGO Laboratory, Massachusetts Institute of Technology

Background

On September 14, 2015, gravitational waves were detected by the twin Laser Interferometer Gravitational-wave Observatory (LIGO) detectors located in Livingston, Louisiana, and Hanford, Washington. On February 11, 2016, scientists published their findings and announced the discovery.[1] The LIGO detectors are funded by NSF, and were conceived, built, and operated by the California Institute of Technology (Caltech) and the Massachusetts Institute of Technology (MIT).[2] The operation was carried out by LIGO's team of scientists, engineers, and staff at Caltech and MIT, and the 1,000 scientists that make up the LIGO Scientific Collaboration, with members from over 80 scientific institutions world-wide.

[1] Abbott *et al*, "Observation of Gravitational Waves from a Binary Black Hole Merger," *Physics*, 12 February 2016.
[2] "Gravitational Waves Detected 100 years After Einstein's Prediction," National Science Foundation. Available at: https://www.nsf.gov/news/news_summ.jsp?cntn_id=137628

Gravitational Waves and the General Theory of Relativity

Gravitational waves are the ripples in the fabric of space-time resulting from the most violent phenomena in our universe, such as black holes or supernovae explosions. The gravitational waves radiate outward like ripples or waves across a pond.

In 1916, Albert Einstein predicted gravitational waves as part of the Theory of General Relativity, which challenged the understanding of gravity that had prevailed for more than 200 years, since the time of Isaac Newton. Newton theorized that gravity affects everything in the universe, that the same force that pulls an apple down from a tree keeps the Earth in motion around the sun. Einstein's research led him to a new Theory of Relativity, the idea that there is no fixed frame of reference in the universe – everything is moving relative to everything else.

Einstein's theory was that what we perceive as the force of gravity is an effect of the curvature of space and time, interwoven into a single whole known as "space-time." In the presence of matter and energy, space-time can evolve, stretch, and warp. Einstein proposed that objects with mass--such as the sun and the Earth--curve the geometry of space-time like a marble placed on an outstretched sheet of fabric or a pebble that causes ripples in a pond. Einstein further postulated that if the gravity in an area of space-time was suddenly changed by intense energy events – such as around black holes or supernova—gravitational energy waves would be emitted to distort space-time like ripples we observe from a pebble in a pond. These waves would travel at light-speed like other forms of energy, and the distortion of space-time should be able to be observed.[3]

Efforts to Detect Gravitational Waves: LIGO and NSF

Scientists have sought experimental evidence of gravitational waves for more than 40 years. In 1979, NSF commissioned Caltech and MIT to design the Laser Interferometer Gravitational-Wave Observatory (LIGO). The National Science Board approved funding for initial construction in 1990. LIGO consists of two interferometers located in Livingston, Louisiana and Hanford, Washington that are operated in unison. The sites were chosen in 1992, and construction began after approval by Congress in 1994. NSF has invested approximately $1.1 billion in construction and upgrades, operational costs, and research awards to scientists who study LIGO data.

The LIGO detectors are made of a laser interferometer (an instrument in which wave interference is employed to make precise measurements of length of displacement in terms of the wavelength) inside an L-shaped ultra-high vacuum tunnel. Inside the vertex of the L-shaped LIGO vacuum systems, a beam splitter divides a single laser beam into two beams, each travelling along a 2.5 mile-long tunnel. The beams reflect back and forth between precise mirrors that are suspended. A gravitational wave could be observed if both LIGO detectors sense the lengths of the paths that the divided laser beams take along each arm are slightly different. If the laser light took a longer time to reach both detectors this means there was a

[3] "Instant Expert: General Relativity, " *New Scientist*, Available at: https://www.newscientist.com/round-up/instant-expert-general-relativity/

disturbance or ripple in space-time caused by a gravity wave. From this small change, scientists are able to identify the wave's source and approximately where in the universe it originated.

Between 2002 and 2010, LIGO operated without detecting any waves. Scientists concluded that the initial design was not sensitive enough, and in 2010, NSF began funding over $200 million in improvements to increase the sensitivity of LIGO (Advanced LIGO). In September 2015, Advanced LIGO began initial test detection runs. On September 14, 2015, during one of the first test runs, the LIGO location in Livingston, Louisiana picked up a gravitational-wave signal, and seven milliseconds later, the observatory in Hanford, Washington detected an identical signal. This signal exactly matched the calculated behavior of gravitational waves produced when two black holes collide. LIGO scientists estimate that the black holes that created the waves were about 29 and 36 times the mass of the sun, and that the collision took place 1.3 billion years ago—only reaching the Earth last September.[4]

The Impact and Future of Gravitational Wave Research

LIGO's scientific impact reaches beyond physics, astrophysics, and astronomy. The effort to design and build the LIGO detectors and to understand the characteristics of the expected gravitational wave signals have resulted in multiple scientific and technological applications and advancements in many fields including mathematics, computer science, and material science. According to LIGO scientists, innovations in areas as diverse as lasers, optics, metrology, vacuum technology, chemical bonding and software algorithm development have resulted directly from LIGO's work.[5]

The discovery by LIGO opens up a new field of gravitational astronomy. Scientists believe that astronomers will be be able to locate where exactly each set of the ripples is coming from, and by pinpointing the sources of gravitational waves will allow astronomers to point other telescopes to that direction, boosting the chances of learning more about the phenomena causing such gravitational waves via other spectra such as x-rays, gamma-rays, radio waves, neutrinos and other tools.[6] Since gravitational waves do not interact with other matter, they travel through the universe unimpeded, unlike electromagnetic radiation, and give scientists a crystal clear view of the gravitational-wave universe. The waves could give scientists a new way to view "dark energy" and "dark matter"– the majority of the universe not visible with today's telescopes.[7]

One of the developers of LIGO, Dr. Kip Thorne, describes the future; "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 space-time. Colliding black holes and gravitational waves are our first beautiful examples."[8]

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[4] "LIGO Fact Sheet," National Science Foundation, Available at: https://www.nsf.gov/news/special_reports/ligoevent/pdfs/LIGO_factsheet_v01.pdf
[5] "Science Impact," LIGO. Available at: https://www.ligo.caltech.edu/page/science-impact
[6] "The Future of Gravitational Wave Astronomy," *Scientific American*, Available at: http://www.scientificamerican.com/article/the-future-of-gravitational-wave-astronomy/
[7] "Why Detect Them?" LIGO. Available at: https://www.ligo.caltech.edu/page/why-detect-gw
[8] "Gravitational Waves Detected 100 years After Einstein's Prediction," National Science Foundation. Available at: https://www.nsf.gov/news/news_summ.jsp?cntn_id=137628

For Further Reading:

http://www.nytimes.com/2016/02/12/science/ligo-gravitational-waves-black-holes-einstein.html?_r=0

http://www.nytimes.com/2016/02/14/opinion/sunday/finding-beauty-in-the-darkness.html

https://www.washingtonpost.com/news/speaking-of-science/wp/2016/02/11/cosmic-breakthrough-physicists-detect-gravitational-waves-from-violent-black-hole-merger/