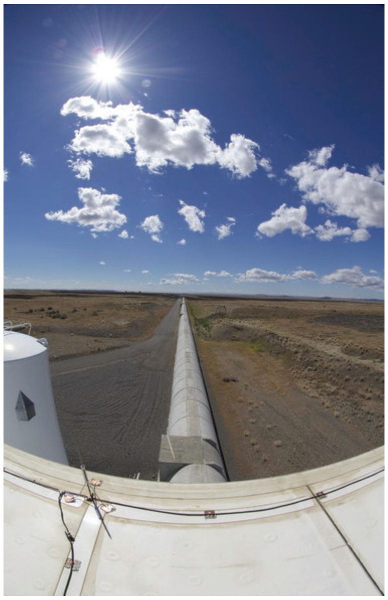
National Science Foundation

LIGO FACTSHEET

NSF and the Laser Interferometer Gravitational-Wave Observatory



In 1916, Albert Einstein published the paper that predicted gravitational waves – ripples in the fabric of space-time resulting from the most violent phenomena in our universe, from supernovae explosions to the collision of black holes. For 100 years, that prediction has stimulated scientists around the world who have been seeking to directly detect gravitational waves.

In the 1970s, the National Science Foundation (NSF) joined this quest and began funding the science and technological innovations behind the Laser Interferometer Gravitational-Wave Observatory (LIGO), the instruments that would ultimately yield a direct detection of gravitational waves.

On February 11, 2016, NSF organized a press conference for scientists from LIGO to announce the observatory's first detection:gravitational waves arriving on Earth from black holes merging approximately 1.3 billion light-years away. The discovery confirmed Einstein's predictions about gravitational waves, and revealed one of the most powerful collisions known to science.

On October 3, 2017, three of the observatory's early leaders—Rainer Weiss, Kip S. Thorne, and Barry C. Barish—won the Nobel Prize in Physics for their work.

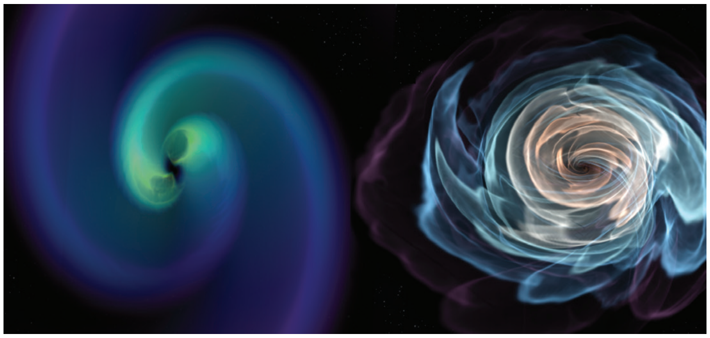
Two weeks later, LIGO scientists joined colleagues from Europe's Virgo gravitational wave detector and representatives from telescopes across the globe to announce the joint observation of a binary neutron star collision in the galaxy NGC4993. The effort was another historic first – in combining gravitational detection and electromagnetic observations, astronomers captured the collision in unprecedented detail, providing insights only available because all of the facilities worked together.

That was the birth of multi-messenger observations, a new era in astronomy where cataclysmic events are revealed by more than their photons.

What is LIGO?
LIGO consists of two widely separated laser interferometers located within the United States – one in Hanford, Washington, and the other in Livingston, Louisiana – each housed inside an L-shaped, ultra-high vacuum tunnel. The twin LIGO detectors operate in unison to detect gravitational waves. Caltech and MIT led the design, construction and operation of the NSF-funded facilities.

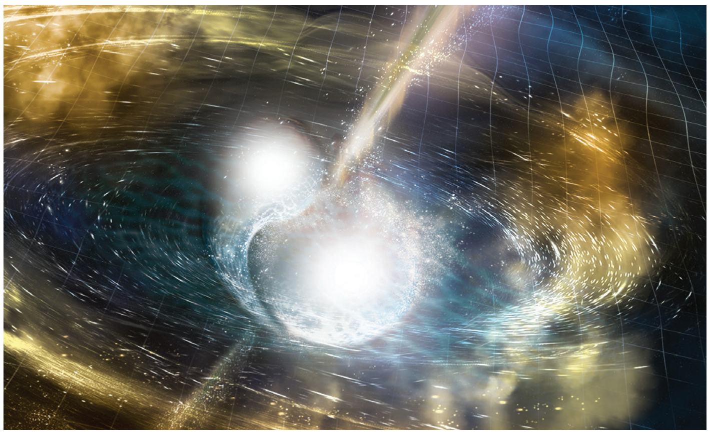
What are gravitational waves?
Gravitational waves are distortions of the space and time which emit when any object that possesses mass accelerates. This can be compared in some ways to how accelerating charges create electromagnetic fields (e.g. light and radio waves) that antennae detect. To generate gravitational waves that can be detected by LIGO, the objects must be highly compact and very massive, such as neutron stars and black holes. Gravitational-wave detectors act as a "receiver." Gravitational waves travel to Earth much like ripples travel outward across a pond. However, these ripples in the fabric of space-time carry information about their violent origins and about the nature of gravity – information that cannot be obtained from other astronomical signals.

How does LIGO work?
Einstein himself questioned whether we could create an instrument sensitive enough to capture the gravitational wave phenomenon. Inside the vertex of the L-shaped LIGO vacuum systems, a beam splitter divides a single



entering laser beam into two beams, each traveling along a 4-km-long arm of the L. The beams reflect back and forth between precisely positioned and exquisitely configured mirrors that are suspended, like a child on a swing, near each end and near the vertex on either side of the beam splitter.

As a gravitational wave passes by, the lengths of the paths that the divided laser beams take along each arm will actually stretch ever-so slightly – by only 1/10,000th of the diameter of a proton. It's this signal change – occurring at both interferometers within 10 milliseconds of one another – that indicates a gravitational wave. From that minute change, scientists are further able to identify the wave's source and, very broadly, where in the universe it originated.



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Worldwide commitment to world-class research

The LIGO Scientific Collaboration (LSC), which carries out this work, is a group of more than 1,000 scientists at universities around the United States and in 14 countries. The LSC network includes the LIGO interferometers and the GEO600 interferometer, a project located near Hannover, Germany, designed and operated by scientists from the Max Planck Institute for Gravitational Physics, along with partners in the United Kingdom funded by the Science and Technology Facilities Council (STFC). Additionally, a new node of the LIGO network in India may be operational around 2025.

The LSC works jointly with the Virgo Collaboration—which designed and constructed the Virgo interferometer, with 3-km-long arms and is located in Cascina, Italy. After undergoing an enhancement, Advanced Virgo made its first joint detection with LIGO in August 2017, witnessing a collision of binary black holes.

International partners have contributed equipment, labor and expertise to LIGO, including Britain's Science & Technology Facilities Council (STFC) supplying the suspension assembly and some mirror optics; the Max Planck Society of Germany providing the high-power, high-stability laser; and an Australian consortium of universities supported by the Australian Research Council offering systems for initially positioning and measuring in place the mirror curvatures to better-than-nanometer precision.

NSF investment

LIGO is one of the largest experiments NSF has ever funded. It was the largest NSF investment ever undertaken when the National Science Board gave the go-ahead to fund initial construction in 1990. Since LIGO's inception, NSF has invested approximately $1.1 billion in construction and upgrades, in operational costs, and in research awards to individual scientists, who study LIGO data to learn more about our universe.

NSF supports basic research that drives innovation and innovators that transform our future

Basic research offers no promises and is often risky, but it is also potentially revolutionary. LIGO is a perfect example. The direct detection of gravitational waves is not only an historic moment in science, it also has spawned other scientific innovations. For example, laser techniques developed by LSC scientists have had many external applications. The same technique used to stabilize LIGO's sensitive laser frequencies also helps to build the semiconductors in our computers and cell phones. Other spin-offs are being realized in areas such as measurement science, seismic isolation, vacuum technology, mirror coatings and optics.

As is often the case with research in fundamental science, few would have invested in LIGO from the beginning. However, this discovery significantly changes what we can learn about the universe. With plans to further increase LIGO's sensitivity over the next year and the potential addition of other countries' interferometers to the network, LIGO provides an opportunity to detect more gravitational waves and also hone-in more precisely on the whereabouts of the universe's most violent phenomena.

Credits (top to bottom): (front top) Caltech/MIT/LIGO Lab; Karan Jani, Georgia Tech; A. Simonnet, Sonoma State University.