An International Gravitational Wave Detector Network

The Advanced Virgo interferometer (Italy) will begin taking data in 2016, joining LIGO's advanced detectors and GEO600 (Germany). Construction of KAGRA (Japan) should reach completion in 2017-2018. Plans for a new LIGO detector in India are well underway. Each interfometer in the network will register the arrival of potentially interesting signals and share these with the entire network. When events appear in multiple detectors, researchers will pinpoint the different arrival times of the signal with sub-millisecond precision. Milliseconds of difference in the arrival times across the global detector array will lead to an estimate of the sky position of the source.

The combination of electromagnetic and gravitational wave observations of certain types of astrophysical events, such as binary neutron star mergers or supernovae, should yield a more complete understanding of these events than would come from either type of signal alone. LIGO provides candidate gravitational wave event 'triggers' to dozens of instruments and facilities that engage in electromagnetic and particle astronomy – allowing them to search for counterpart signals. As the international network of advanced detectors matures, gravitational waves will add a powerful component to the emerging field of multi-messenger astronomy.

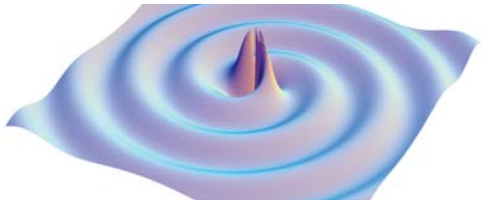
LIGO is operated by Caltech and MIT for the National Science Foundation.

www.ligo.caltech.edu

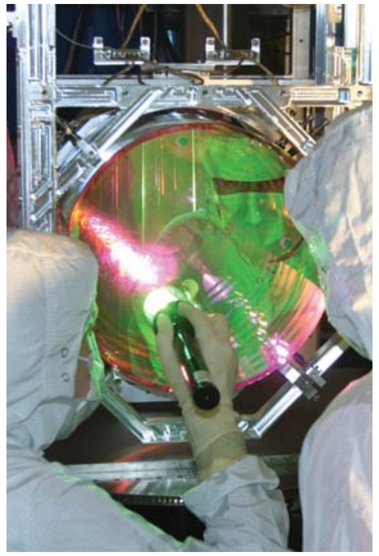
www.ligo.org

Hundreds of researchers in the LIGO Scientific Collaboration sustain the global development of LIGO's instrumentation and data analysis capabilities.

Contact: outreach@ligo-wa.caltech.edu *T1500543* *2015*



The Next Step in Gravitational Wave Astronomy

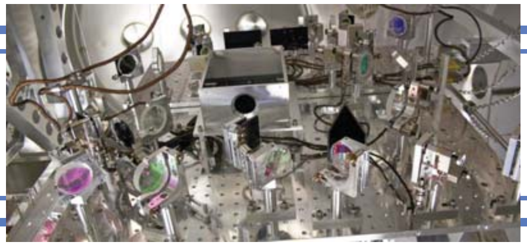


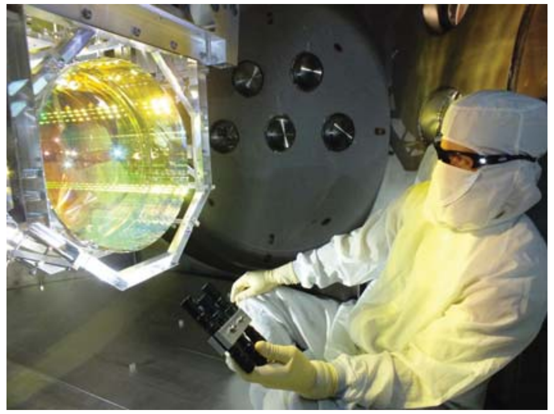
Gravitational waves offer a remarkable opportunity to see the universe from a new perspective, providing access to astrophysical insights that are available in no other way. The Advanced LIGO project has brought about the complete upgrade of LIGO's gravitational wave interferometers, taking these instruments to sensitivities that should make gravitational wave detections a routine occurrence. The U.S. National Science Foundation provided the financial support for Advanced LIGO, which began in 2008 and reached completion in 2015. Funding organizations in Germany, the U.K. and Australia also made significant commitments to the project. Together with Advanced Virgo, a detector founded by France and Italy, Advanced LIGO will bring gravitational wave astronomy to maturity.

LIGO, the Laser Interferometer Gravitational-wave Observatory, operates detector facilities at U.S. locations in Washington and Louisiana. Hundreds of scientists at dozens of institutes around the world advance LIGO's research through membership in the LIGO Scientific Collaboration .

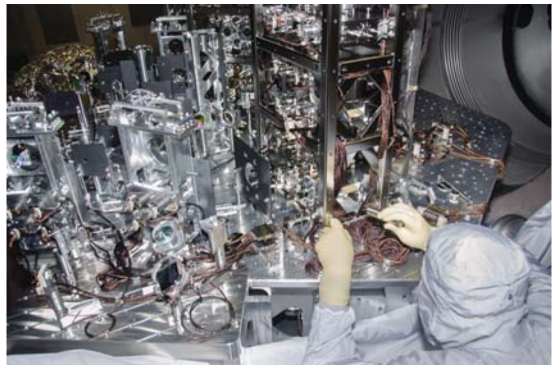
The Advanced LIGO program leveraged years of collaborative research and development in the LIGO Laboratory and the LIGO Scientific Collaboration (LSC) while delivering pioneering technology in LIGO's core subsystems: high performance lasers, optics, vibration isolation, low-noise electronics and digital control systems. The Advanced LIGO detectors are designed to operate with a detection band of 10 Hz to 7 kHz. Their sensing range will reach 600 million light years for neutron star merger gravitational-wave sources and greater distances for black hole mergers. The detectors began operating in 2015.

Examples of Advanced LIGO Technology

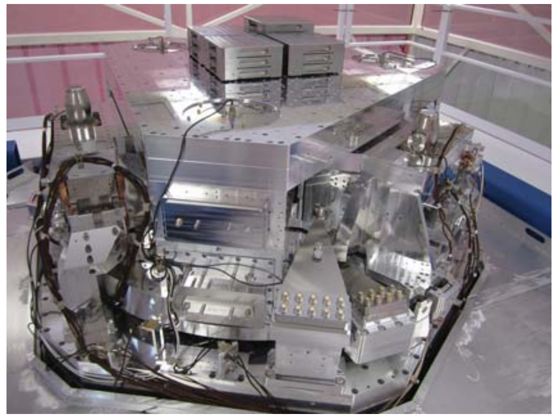




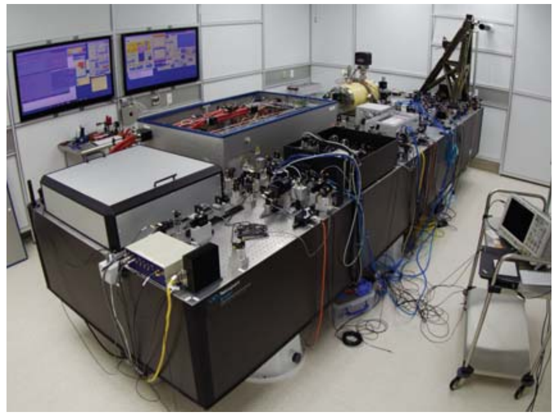
Optics inside LIGO's vacuum system range in size from hundred-gram steering mirrors to the four 40 kg test masses that rest at opposite ends of LIGO's 4 km arms. Core optics are composed of ultra-high purity fused silica and are coated with alternating layers of doped tantala and silica. The coatings provide highly precise reflectivity at green and infrared wavelengths. The test masses scatter less than 10 ppm of incident light, a specification that requires a level of microroughness that's a fraction of an atomic diameter.



Multi-stage optic suspensions provide vibration isolation and host servo-controlled electromagnetic and electrostatic actuators that optimize the positions and angles of the optics. LIGO's four test masses reside in quadruple-stage suspensions that provide extensive seismic isolation. Thin silica fibers suspend the test masses to reduce thermal noise. More than a dozen additional suspensions of varying complexity reside along the detectors' input and output beam paths.



Vibration isolation systems must attenuate ground motion transmitted to the instrument down to the lowest observation frequency (10 Hz) and below. The in-vacuum systems, combined with out-of-vacuum hydraulic isolators, also must provide the capability to align and position optical payloads in the chambers. From 1 to 10 Hz, isolation must limit mirror motion to approximately 10^{-11} meter per root Hz. At 0.1 Hz, microseismic frequencies, the reduction must approach several tenths of a micron per root Hz.



A pre-stabilized laser (PSL) system delivers 1064 nm light to the detector. Built for LIGO by the Albert Einstein Institute and Laser Zentrum Hannover, the system consists of three inline laser stages. These produce a 180-watt beam, stable in amplitude at the parts per billion level. Additional PSL components such as an in-vacuum reference cavity, amplitude and frequency servo controls, and a pre-mode cleaner enhance the beam quality prior to its entrance into the vacuum envelope.

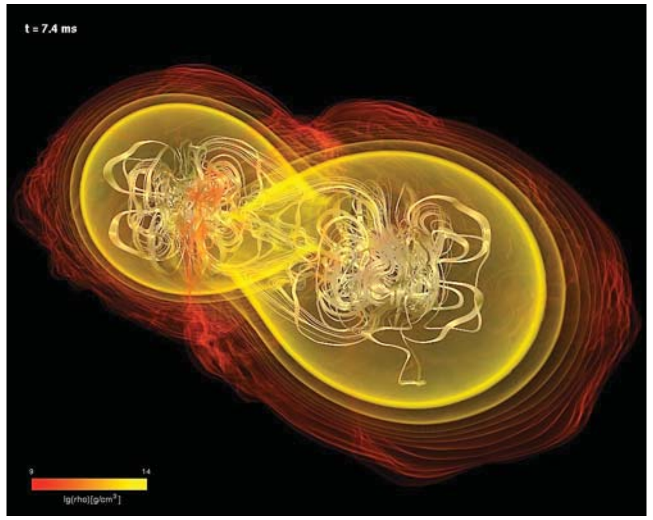
Astrophysics in the Advanced Detector Era

As LIGO continues to optimize the advanced detectors' control systems, their astrophysical reach will grow to exceed half a billion light years.

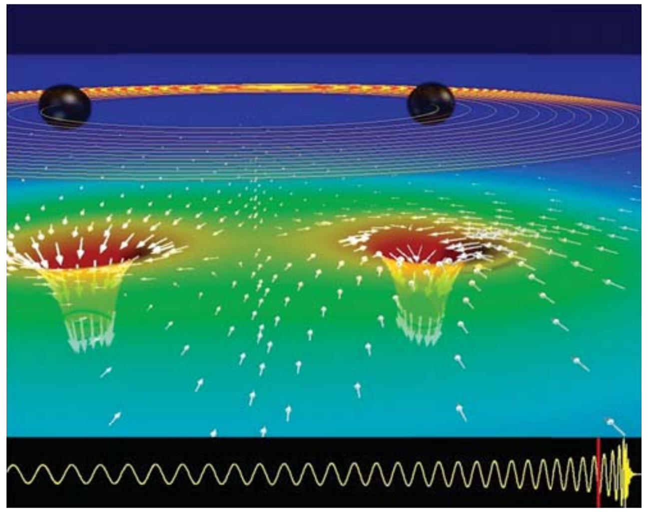
Pairs of neutron stars and/or black holes, locked in compact orbits which shrink and accelerate due to the emission of gravitational radiation, represent LIGO's most promising sources of gravitational wave signals. As LIGO pushes the detectors to their design sensitivities (a performance benchmark expected to be reached by 2018), these signals will appear in the detectors near frequencies of 10 hertz and sweep into the kHz regime as the bodies coalesce. The scarcity of merging binaries in the nearby universe means that LIGO must fully leverage the hardware advances listed overleaf in order to maximize the detectors' range. By surveying many tens of thousands of galaxies, LIGO expects to provide detection rates sufficient for astrophysical studies.

Advances in computational methods have resulted in remarkable simulations of compact binary mergers. Two examples appear in the upper and middle images. Gravitational wave detections will produce data that scientists can use to test these models. LIGO data sets will provide a unique probe of strong gravitational fields, allowing researchers to assess the degree to which strong-field gravity conforms to Einstein's general theory of relativity. The pure spacetime interaction associated with a binary black hole merger could provide a treasure trove of discoveries; up to now such a system has never been observed.

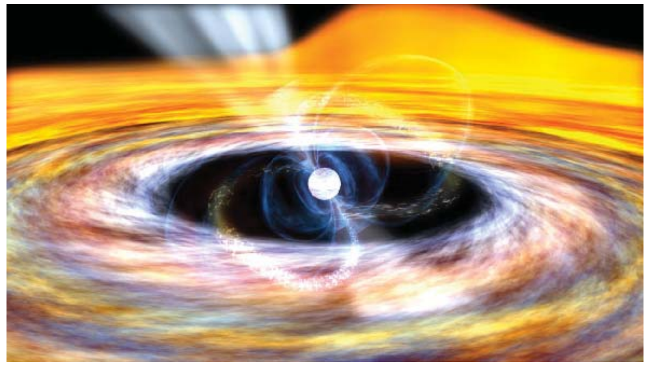
Gravitational waves from spinning pulsars (adjacent image) could transmit information about the interior structure of neutron stars, although the relative weakness of such signals confines LIGO's pulsar searches to the Milky Way. The citizen science Einstein@Home program significantly augments LIGO's capacity for these searches.



Credit: NASA/AEI/ZIB/M. Koppitz and L. Rezzolla



Credit: Caltech/Cornell/SXS/black-holes.org



Credit: NASA / Goddard Space Flight Center / Dana Berry