LASER INTERFEROMETER GRAVITATIONAL-WAVE OBSERVATORY — $39,430,000 / $0 / 0.0%

Laser Interferometer Gravitational-Wave Observatory

(Dollars in Millions)

FY 2016 Actual	FY 2017 (TBD)	FY 2018 Request	Change over FY 2016 Actual Amount	Percent
$39.43	-	$39.43	-	-

Einstein's theory of general relativity predicts that cataclysmic processes involving extremely dense objects in the universe, such as the collision and merger of two black holes, will produce gravitational radiation. On Sept. 14, 2015, the Laser Interferometer Gravitational-Wave Observatory (LIGO) directly observed gravitational radiation from a black-hole merger, verifying this 100-year-old prediction. This is an achievement of historic importance for fundamental physics, astrophysics, and astronomy, as it opens an entirely new observational window on the universe. This achievement was announced to the world in a series of international press conferences on February 11, 2016. LIGO announced detection of a second black-hole merger on June 15, 2016. Its second observing run, now underway, holds the possibility of further detections.

LIGO, the most sensitive gravitational-wave detector ever built, comprises two main facilities, one in Livingston Parish, LA and one in Hanford, WA. At each facility, an L-shaped vacuum chamber, with two 4-km long arms joined at right angles, houses an optical interferometer. The interferometers are used to measure minute relative changes in the distances between the vertex of the L and mirrors at the ends of the arms that are caused by a passing gravitational wave. A passing gravitational wave causes the distance along one arm to lengthen while the other arm shrinks during one half cycle of the wave, and then the first arm shrinks while the other arm lengthens during the second half cycle. The predicted distortion of space caused by a gravitational wave from a likely source is on the order of one part in 10^{21}, meaning that the expected amplitude of the length change over the 4-km length is only about 1/1000th the diameter of a proton. LIGO's 4-km length was chosen to make the expected signal as large as possible within terrestrial and financial constraints. (Longer arms would result in a bigger signal, but would entail larger construction costs.) Looking for coincident signals from both interferometers increases LIGO's ability to discriminate a gravitational wave signal from local sources of noise that can mimic the signal.

Components for a third interferometer, initially intended for installation at Hanford as a further tool to discriminate candidate signals from random noise, have been set aside in response to a proposed initiative from the Government of India to establish a gravitational wave observatory there. If realized, this third interferometer would greatly enhance LIGO's ability to locate gravitational wave sources on the sky, facilitating follow-up investigations using optical and radio telescopes. The prospect of obtaining complementary gravitational wave and electromagnetic signals from the same source is extremely exciting, as it may significantly increase our understanding of supernovae and neutron stars. Such scientific prospects help motivate the NSF Big Idea Windows on the Universe.

The Advanced LIGO upgrade, funded through the MREFC account, resulted in the design, fabrication, and installation of improved apparatus that is expected to increase LIGO's sensitivity 10-fold over a multi-year tune-up period.

Total Obligations for LIGO

(Dollars in Millions)

	FY 2016 Actual	FY 2017 (TBD)	FY 2018 Request	ESTIMATES[1] FY 2019	FY 2020	FY 2021	FY 2022	FY 2023
Operations & Maintenance	$39.43	-	$39.43	$39.43	$39.43	$39.43	$39.43	$39.43

[1] Outyear funding estimates are for planning purposes only. The current cooperative agreement ends in September 2018.

LIGO is pursuing an integrated program of periodic scientific operation of the LIGO observatories, interleaved with engineering studies that continue to enhance operating performance. LIGO's operating budget supported the initial commissioning of this apparatus. Following completion of installation of the Advanced LIGO apparatus in March 2015, LIGO scientists and engineers were able to achieve about four times LIGO’s initial sensitivity by September 2015 in order to make the historic first detection of gravitational waves. Since then, after further commissioning, LIGO has been able to achieve more than a six-fold increase in sensitivity. LIGO is now in the midst of a nine-month long observing run that will search for more gravitational waves through the end of August 2017.

The operations budget also supports basic infrastructure maintenance, analysis, and dissemination of data obtained from the interferometers, and maintenance of computational resources for data storage and analysis. Operations funding also enables strategic research and development in instrument science that is expected to lead to longer-term enhancements to operational performance.

A small part of the operations budget supports education and outreach activities. The LIGO Science Education Center (LIGO SEC), located on the Livingston Observatory site, hosts 50 hands-on inquiry-based learning exhibits and reaches over 15,000 students, teachers and members of the public each year. Its activities benefit from a partnership with Southern University Baton Rouge (SUBR), the San Francisco Exploratorium, the Baton Rouge Area Foundation (BRAF), and other collaborating educational entities. Trained docents from SUBR assist participants and serve as collegiate-age role models for young visitors. LIGO SEC programs are supported both through LIGO's operations cooperative agreement and through grants to SUBR and BRAF. The LIGO Hanford Observatory also promotes a highly successful program of outreach to K-12 students and the general public in that region.

LIGO created a number of connections to industry in order to achieve the demanding technical performance requirements needed to detect gravitational waves. Innovations across a diverse range of technologies have led to new techniques with broad applications (for example, preparation of stainless steel for ultra-high vacuum application, adaptive laser beam shaping, and precision dielectric optical coatings). Other cases have resulted in patents and commercial products (in-vacuum electrical connectors, high power electro-optic modulators).

The LIGO Scientific Collaboration (LSC), an open collaboration that organizes the major international groups doing research supportive of LIGO, has more than 80 collaborating institutions in 15 countries with more than 900 participating scientists. The LSC plays a major role in many aspects of the LIGO effort. These include establishing priorities for scientific operation, data analysis and validation of scientific results, and contributing to instrumental improvements at the LIGO facilities, as well as fostering education and public outreach programs. NSF supports LSC activities at $7.0 to $8.0 million per year, which is provided through regular disciplinary program funds.

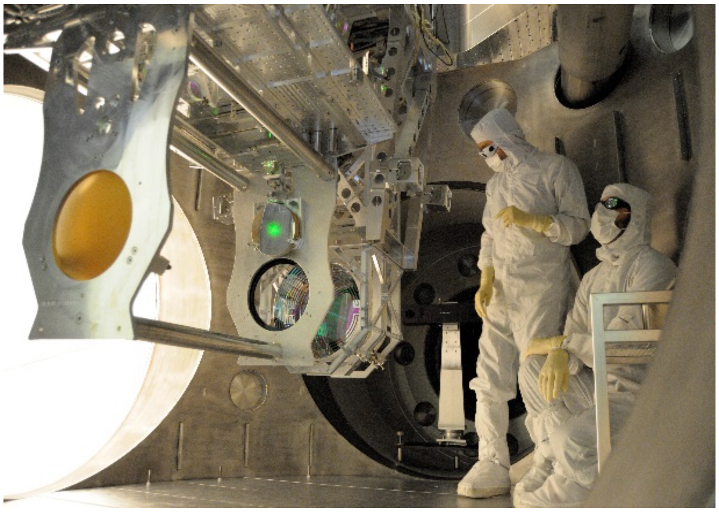
NSF continually assesses the appropriate level of financial support by monitoring actual expenditures contained in quarterly activity-based financial reports from LIGO and through annual external reviews of operation.

Management and Oversight

- NSF Structure: NSF oversight is coordinated internally by the LIGO program director in the NSF Directorate for Mathematical and Physical Sciences, Division of Physics (MPS/PHY). The program director consults regularly with representatives from the NSF Large Facilities Office, the MPS Facilities Coordinator, and the NSF Office of Grants and Agreements.
- External Structure: LIGO is managed by the California Institute of Technology under a cooperative agreement. The management plan specifies significant involvement by the user community, represented by the LSC, and collaboration with the other major gravitational-wave detector activities in Asia, Europe, and Australia. External peer-review committees organized by NSF help provide oversight through annual reviews.
- Recent Reviews: Reviews of observatory operation are held annually. Special purpose reviews using external expert panels have also been held as needed, examining topics such as long-term storage of the interferometer components set aside for possible deployment to India, LIGO computing plans, and LIGO ultra-high vacuum system needs. The last annual review was held in June 2016. A vacuum review is planned for May 2017 and an operations review in June 2017.

Renewal/Recompetition/Termination:

LIGO began operating under a five-year cooperative agreement in early FY 2009, which ran concurrently with AdvLIGO MREFC project. Following approval by the National Science Board in August 2013, the cooperative agreement was renewed at the beginning of FY 2014 for five additional years, overlapping the conclusion of AdvLIGO construction and the start of commissioning and scientific operation. NSF conducted a detailed consideration of whether or not to recompete the management of LIGO and determined that it would be in the best interest of U.S. science and engineering to renew the LIGO operating award at the end of FY 2018. Accordingly, NSF has requested the awardee submit a renewal proposal for review early in FY 2018. The projected lifetime of the LIGO facility was originally 20 years. Infrastructure refurbishments recently accomplished or planned during the current award will extend the facility life by an additional 15 to 20 years, to beyond 2030.



Installation of the green (532nm) Arm Length Stabilization(ALS) subsystem for AdvLIGO. *Credit: Caltech/MIT LIGO Laboratory.*