LASER INTERFEROMETER GRAVITATIONAL-WAVE (LIGO)
www.ligo.caltech.edu

Laser Interferometer Gravitational-Wave Observatory Funding
(Dollars in Millions)

FY 2022 Actual	FY 2023 Estimate Base	FY 2024 Request	Change over FY 2023 Estimate Base Amount	Percent
$45.00	$45.00	$50.00	$5.00	11.1%

Brief Description

Monitoring millisecond changes in the geometry of space-time using kilometer-scale laser interferometry, LIGO can map the rippling gravitational traces of energetic and violent events such as the coalescence of neutron stars and black holes. LIGO also searches for other sources of gravitational radiation due to phenomena such as the wobbling of fast-spinning neutron stars, vibration of cosmic strings, supernova explosions, and possibly the Big Bang itself. LIGO comprises two main sites, one in Livingston Parish, Louisiana and one in Hanford, Washington. At each site, an L-shaped vacuum chamber with two four-kilometer-long arms joined at right angles houses an optical interferometer. The interferometers are used to measure minute relative changes in the distances between mirrors at the ends of the arms that are caused by a passing gravitational wave (GW). The predicted distortion of space caused by a GW from a likely source is about one part in 10^{21}, meaning that the expected length change over a four-kilometer distance is only about 1/1000th the diameter of a proton.

Meeting Scientific Community Needs

LIGO, the most sensitive GW detector ever built, leads the expanding worldwide effort to study the cosmos through the direct observation of gravitational radiation. LIGO's four-kilometer 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 the two widely separated sites enhances LIGO's ability to discriminate between a GW and local sources of noise.

LIGO has had two significant historic accomplishments: the direct detection of GWs arising from the collision and coalescence of a pair of black holes (2015), and the detection of the GW signal arising from the collision of two neutron stars (2017). The latter enabled subsequent observations of the GW source by more than 70 telescopes around the world, which significantly added to our understanding of the mechanisms by which heavy elements are produced. The 2017 Nobel Prize in Physics was awarded to LIGO pioneers Barry C. Barish, Kip S. Thorne, and Rainer Weiss "for decisive contributions to the LIGO detector and the observation of gravitational waves." In total, LIGO has observed more than 90 GW candidate sources.

The LIGO Scientific Collaboration (LSC), an open collaboration that organizes the major international groups doing LIGO-related research, has more than 120 collaborating institutions in 19 countries with more than 1,400 participating scientists. The LSC helps to establish priorities for scientific operation, carries out data analysis and validation of scientific results, and contributes to improvements in instrumentation at the LIGO facilities. Additionally, LSC members explore future technologies and participate with LIGO in activities that promote STEM education and public outreach programs. NSF supports LSC activities in the U.S. at a level of nearly $10 million per year through regular disciplinary program funds.

Status of the Facility

The broader scientific community is eager for more GW detections. LIGO's GW detection rate scales as the third power of its sensitivity, so LIGO prioritizes efforts aimed at improving performance over operation for extended observing periods. Efforts are underway at both LIGO sites to lead and coordinate the technical efforts intended to improve interferometer sensitivity.

LIGO conducted a third observational run, begun in April 2019 and lasting about 11 months, at about 80 percent of the estimated design sensitivity of the interferometers. LIGO researchers are now working to remediate those limitations. They have also installed new elements that will further enhance the sensitivity of the apparatus when LIGO's fourth year-long observational run begins in May 2023. These new elements are expected to boost LIGO's sensitivity by at least 25 percent compared to the third observing run.

During periods of observation, LIGO issues public alerts when it detects candidate GW events, reaching a vast and growing cadre of ground- and space-based observatories that are primed to make follow-up electromagnetic observations. Simultaneous observations by the two LIGO interferometers and Virgo (a GW detector located outside of Pisa, Italy, and funded by the Italian and French governments) enables localization of GW sources on the sky so that they can be observed by conventional telescopes at optical, radio, and other wavelengths. This has opened a new era of multi-messenger astronomy, where the synthesis of complementary information obtained from gravitational and electromagnetic observations is leading to powerful new insights about astrophysical phenomena. Many other NSF-funded electromagnetic observatories are crucial participants in this observational community.

Virgo and the Kamioka Gravitational Wave Detector (KAGRA) are foreign-led efforts that, like LIGO, are intended to directly observe GWs. Virgo will have a sensitivity of about two-thirds that of LIGO. KAGRA—a more ambitious, but technically challenging effort in Japan—may result in an even more sensitive apparatus (due to its location deep underground and its pioneering use of cryogenic optics), although the timescale for completion is at least a few years off. Virgo participated in joint observing during LIGO's third observing run, at a sensitivity about half that of LIGO's. KAGRA also participated in the end of run three in 2020, albeit at very modest sensitivity. Both detector groups plan to participate with LIGO in the fourth observing run, currently planned for Q3 2024.

Other efforts complement LIGO's capabilities by searching for GWs in frequency bands outside LIGO's sensitivity range (roughly 0-1000 Hz). NANOGrav (a U.S.-Canadian effort supported by NSF), along with similar efforts in Europe and Australia, is now searching for GW signals in the roughly nano-Hz to micro-Hz band. However, the expected global network of two U.S. LIGO sites, plus Virgo, KAGRA, and the anticipated LIGO-India facility (to be constructed and operated by the Government of India using interferometer components contributed by NSF) is the only experimental avenue for measuring GW source locations with sufficient angular resolution to allow complementary electromagnetic observations.

Governance Structure and Partnerships

NSF Governance Structure

NSF oversight is led by a program officer in the MPS Division of Physics (PHY), who works cooperatively with staff from BFA, the Office of the General Counsel, and the Office of Legislative and Public Affairs. Within BFA, the Large Facilities Office provides advice and assists with agency oversight and assurance. The MPS facilities team and the Chief Officer for Research Facilities also provide high-level guidance, support, and oversight.

External Governance Structure

LIGO is managed by the California Institute of Technology under a cooperative agreement with NSF. A subaward to the Massachusetts Institute of Technology supports a team of scientists and engineers that is fully integrated into all LIGO activities. The LIGO management organization coordinates significant involvement by the user community, represented by the LSC, and arranges collaborative activities with other major GW detector activities in Asia, Europe, and Australia. External review committees organized by NSF help provide oversight through annual reviews.

Partnerships and Other Funding Sources

Advanced LIGO is a completed $205.0 million project that supported the development and installation of interferometer components and computing hardware that increased LIGO's sensitivity by about a factor of eight. The United Kingdom (UK), Germany, and Australia provided components and services to the Advanced LIGO project valued at about $20.0 million.

A+ is a further upgrade that is partially complete. NSF awarded $20.47 million during FY 2018-FY 2019 to complete final designs and construct the A+ upgrade. The UK is contributing about 10 million British Pounds and additional key hardware and effort are being provided through in-kind contributions from Australia. Some of the A+ enhancements were installed during 2022 and will be operated during the fourth observing run. Realization of the full A+ capability (roughly a two and half fold increase in sensitivity over Advanced LIGO) is planned during LIGO's multi-year fifth observing run, which is tentatively planned for 2025-2028.

LIGO-India would be constructed through a transfer to India of Advanced LIGO components, valued at approximately $50.0 million, which were originally intended as a second Hanford interferometer. This transfer would enhance the source localization capabilities of the global GW network. NSF signed a Memorandum of Understanding with India's Departments of Atomic Energy and Science and Technology in March 2016, agreeing to partner in this undertaking. The formal start of construction is pending approval by the Government of India Cabinet.

Funding

Total Obligations for LIGO

(Dollars in Millions)

	FY 2022 Actual	FY 2023 Estimate Base	FY 2024 Request	ESTIMATES[1]				
				FY 2025	FY 2026	FY 2027	FY 2028	FY 2029
Operations & Maintenance	$45.00	$45.00	$50.00	$50.00	$50.00	$50.00	$50.00	$50.00

[1] Outyear estimates are for planning purposes only. The current cooperative agreement ends on January 2024.

LIGO operation and maintenance is entirely supported by NSF, which is requesting $50.0 million for FY 2024. The FY 2024 budget increase is primarily due to increases in labor and material costs, and infrastructure investments needed to extend the operating life of the buildings and equipment at the Hanford and Livingston sites.

Reviews and Reports

Reviews of observatory operation are held annually. Special-purpose reviews using external expert panels have also been held as needed, examining topics such as LIGO's computing plans, ultra-high vacuum system needs, education and outreach planning, and long-term storage of the interferometer components set aside for possible deployment to India. The most recent annual review was held in February 2023. Recommendations from annual reviews are routinely used to inform LIGO's operations planning and NSF's oversight thereof.

Renewal/Recompetition/Disposition

NSF will implement a new five-year award for LIGO operations in January 2024. NSF's invitation to Caltech to submit a renewal proposal for LIGO operation was done in accordance with NSF policy that considered the implications for competing the management of LIGO in comparison to soliciting a renewal proposal from the current management entity. No disposition is planned at this time.