LASER INTERFEROMETER GRAVITATIONAL-WAVE OBSERVATORY (LIGO)

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Laser Interferometer Gravitational-Wave Observatory Funding

(Dollars in Millions)

FY 2023 Base Plan	FY 2024 (TBD)	FY 2025 Request	Change over FY 2023 Base Plan Amount	Change over FY 2023 Base Plan Percent
$45.00	-	$49.00	$4.00	8.9%

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^{22}, meaning that the expected length change over a four-kilometer distance is only about 1/10,000th 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 securing a larger location and costlier construction. 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 (September 2015), and the detection of the GW signal arising from the collision of two neutron stars (August 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 160 GW candidate sources.

The LIGO Scientific Collaboration (LSC), an open collaboration that organizes the major international groups doing LIGO-related research, has more than 180 collaborating institutions in 20 countries with more than 1,500 participating scientists. The members of the LSC help to establish priorities for scientific operation, carry out data analysis and validation of scientific results, and contribute 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 MPS Division of Physics 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, that began in April 2019 and lasted for 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 further enhanced the sensitivity of the apparatus. LIGO's fourth observational run began in May 2023 and will end in December 2024. These new elements are on track to boost LIGO's sensitivity by at least 25 percent compared to that of 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, that is funded by the Italian and French governments) enable 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. When it achieves its full design potential, Virgo will have a sensitivity of about two-thirds that of LIGO. KAGRA—a more ambitious and 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 CY 2020, albeit at very modest sensitivity. Both detector groups plan to participate with LIGO in the second part of the fourth observing run, currently planned for early 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, search for GW signals in the roughly nano-Hz to micro-Hz band.

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's Research Infrastructure Office and Division of Acquisition and Cooperative Support, the Office of the General Counsel, and the Office of Legislative and Public Affairs. 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 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 provide oversight through annual reviews.

Partnerships and Other Funding Sources

Advanced LIGO is a $205.0 million project, completed in CY 2015, 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 $40.0 million.

Advanced LIGO Plus (A+) is a further upgrade that is partially complete. NSF awarded $20.47 million during FY 2018-FY 2019 to complete the final design 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 FY 2022-23 and are operating 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 CY 2027-2029.

LIGO-India would be constructed through a transfer to India of Advanced LIGO components, valued at approximately $80.0 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. In June 2023, the Government of India approved the construction of the facility.

Funding

Total Obligations for LIGO

(Dollars in Millions)

	FY 2023 Base Plan	FY 2024 (TBD)	FY 2025 Request	**ESTIMATES[1]** FY 2026	FY 2027	FY 2028	FY 2029	FY 2030
Operations and Maintenance	$45.00	-	$49.00	$50.00	$51.00	$52.00	$52.00	$52.00

[1] Outyear estimates are for planning purposes only. The current cooperative agreement ends December 2028.

[2] FY 2025 figure adjusted to align with expected annual cost escalation of new cooperative agreement.

LIGO operation and maintenance is entirely supported by NSF, which is requesting $49.0 million for FY 2025. The FY 2025 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 implemented a new five-year award for LIGO operations in December 2023. 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.