LASER INTERFEROMETER GRAVITATIONAL-WAVE OBSERVATORY (LIGO) **$45,000,000**
$0

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

FY 2020 Actual	FY 2021 Estimate	FY 2022 Request	Change over FY 2021 Estimate Amount	Percent
$45.00	$45.00	$45.00	-	-

Brief Description

NSF's Laser Interferometer Gravitational-Wave Observatory, the most sensitive gravitational-wave detector ever built, comprises two main facilities, one in Livingston Parish, Louisiana and one in Hanford, Washington. At each facility, an L-shaped vacuum chamber, with two four-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 four-km length is only about 1/1000th the diameter of a proton. LIGO's four-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 between a gravitational wave and local sources of noise.

Scientific Purpose

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 leads the expanding worldwide effort to study the cosmos through the direct observation of gravitational radiation. Two of LIGO's historic accomplishments are the September 14, 2015 measurement of gravitational waves (GWs) arising from the collision and coalescence of a pair of black holes (the first direct detection of this phenomenon, described nearly one century previously by Einstein) and the August 17, 2017 detection of GWs from the collision of two neutron stars. The latter measurement was made by LIGO and the Europe-based Virgo detector, together with some 70 ground and space-based observatories that observed the electromagnetic signals emanating from this spectacular collision, thus inaugurating a new era of multi-messenger astrophysics. LIGO has since been a critical resource in support of NSF's Windows on the Universe Big Idea. 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." Since then, LIGO has observed more than 50 additional GW candidate sources.

Status of the Facility

The broader scientific community is eager for more GW detections. As LIGO's event detection rate scales as the third power of its sensitivity, LIGO prioritizes efforts aimed at improving performance over extended observing. Efforts are underway at both LIGO sites, under leadership of the Advanced LIGO Detector Project Manager (who reports to the LIGO Laboratory Director) to lead and coordinate the technical efforts intended to improve interferometer sensitivity. This is LIGO's highest priority. LIGO conducted a third observational run, begun in April 2019 and lasting about 11 months, at about 80% of Advanced LIGO's calculated design sensitivity. LIGO researchers are now working to further enhance the sensitivity of the apparatus in preparation for a planned fourth year-long observational run that is expected to begin as early as June 2022. LIGO sensitivity will be further augmented as the Advanced LIGO Plus (A+) upgrades are installed; they are predicted to increase LIGO's sensitivity by a factor of 1.6-1.9. Some of the A+ upgrades are expected to be completed prior to the start of the fourth run, further boosting performance.

Virgo and the Kamioka Gravitational Wave Detector (KAGRA) are efforts comparable to LIGO to directly observe GWs. Both efforts lag behind LIGO in achieving sensitivities in the same range as LIGO. When fully commissioned, Advanced Virgo will have a sensitivity of about two-thirds that of Advanced LIGO. KAGRA—a more ambitious, but technically challenging effort under construction 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 observing run 3, at a sensitivity about half as great as the mean LIGO sensitivity. KAGRA also participated in the end of run 3 in 2020, albeit at very modest sensitivity. Both detector groups plan to participate with LIGO in the fourth observing run.

Other efforts complement LIGO's capabilities by searching for GWs in frequency bands outside LIGO's operating range (roughly 0-1000Hz). NANOGrav (a U.S.-Canadian effort supported by NSF), along with similar efforts in Europe and Australia, are 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.

COVID-19 impacts on LIGO operation have been relatively minor. The third scientific observing run was terminated one month earlier than planned, because of pandemic restrictions. LIGO has re-opened, with COVID-19 safety measures in place to ensure the safety of LIGO workers. However, this has resulted in schedule delays for some maintenance and upgrade activities because of pandemic impacts on LIGO's staff and some of its industrial suppliers. Additionally, LIGO's fourth observational run, originally planned to begin in 2021, is now planned to begin no earlier than June 2022. LIGO's educational outreach program transitioned to entirely online activities for teachers and students.

Meeting Intellectual Community Needs

The LIGO Scientific Collaboration (LSC), an open collaboration that organizes the major international groups doing research supportive of LIGO, has more than 100 collaborating institutions in 18 countries with nearly 1,300 participating scientists. The LSC plays a major role in many aspects of the LIGO effort. These include establishing priorities for scientific operation, carrying out data analysis and validation of scientific results, and contributing to instrumental improvements at the LIGO facilities. Additionally, LSC members are exploring future technologies, as well as participating with LIGO in activities that promote STEM education and public outreach programs. NSF supports LSC activities in the United States at a level of approximately $8 million per year through regular disciplinary program funds.

LIGO also publicly issues both human-readable and machine-readable alerts for candidate GW detections, reaching a vast and growing cadre of ground- and space-based observatories that are primed to make follow-up electromagnetic observations of multi-messenger astrophysical phenomena. Many other NSF-funded observatories are crucial participants in this observational community.

Governance Structure and Partnerships

NSF Governance Structure
NSF oversight is provided by a program officer in the MPS Division of Physics (PHY), who works cooperatively with staff from other MPS divisions, the Office of Budget, Finance, and Award Management (BFA), the Office of the General Counsel (OGC), and the Office of Legislative and Public Affairs. Within BFA, the Large Facilities Office (LFO) provides advice to program staff 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. A subaward from California Institute of Technology to Massachusetts Institute of Technology supports a team of scientists and engineers that are fully integrated into all LIGO activities. The LIGO management coordinates significant involvement by the user community, represented by the LSC, and collaborations with the other major gravitational-wave 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 now-completed $205 million MREFC project that funded the development and installation of interferometer components and computing hardware designed to increase LIGO sensitivity (relative to the initial apparatus) by about a factor of 8. The United Kingdom (UK), Germany, and Australia provided components and services to the Advanced LIGO project that are valued at about $20 million.
- LIGO-India, if realized, would be constructed through a transfer to India of Advanced LIGO components, valued at approximately $50 million, 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.
- In FY 2018 and FY 2019, NSF separately awarded $20.47 million to complete final designs and construct the A+ upgrade (PHY-1834382). The UK is contributing about 10 million British Pounds, primarily for core optics and suspension system modifications. Additional key hardware and effort are being provided through in-kind contributions from Australia.

Funding

LIGO operation and maintenance is entirely supported by NSF; NSF is requesting $45.0 million for FY 2022. Current annual operating costs are $45.0 million. The annual budget was negotiated for the FY 2019-FY 2023 period following a 2018 NSF external review of LIGO's proposal for operation.

Total Obligations for LIGO

(Dollars in Millions)

	FY 2020	FY 2021	FY 2022	ESTIMATES[1]				
	Actual	Estimate	Request	FY 2023	FY 2024	FY 2025	FY 2026	FY 2027
Operations & Maintenance	$45.00	$45.00	$45.00	$45.00	$45.00	$45.00	$45.00	$45.00

[1] Outyear estimates are for planning purposes only. The current cooperative agreement ends in September 2023.

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, LIGO ultra-high vacuum system needs, and education and outreach planning. The most recent annual review was held in June 2020. Recommendations from annual reviews are routinely used to inform LIGO's operations planning and NSF's oversight thereof.

Renewal/Recompetition/Termination

NSF implemented a new five-year award for LIGO operation in October 2018. MPS is developing an analysis for consideration by the Director to either compete the management of LIGO, review and fund a renewal proposal from the current management entity, or to divest the facility through stewardship transition or other means. Currently there are no plans for divestment of this facility. LIGO A+ development, design, and implementation are underway concurrently through a separate award, which targets full A+ operation in FY 2024.