

MAJOR MULTI-USER RESEARCH FACILITIES

Major Multi-User Research Facilities Funding

(Dollars in Millions)

	FY 2016 Actual	FY 2017 (TBD)	FY 2018 Request	Change over FY 2016 Actual	
				Amount	Percent
Total Research and Related Activities	\$1,009.79	-	\$963.50	-\$46.29	-4.6%
Operations and Maintenance of Existing Facilities	727.14	-	676.94	-50.20	-6.9%
Federally Funded Research and Development Centers	218.59	-	203.76	-14.83	-6.8%
Operations and Maintenance of Facilities under Construction	46.47	-	81.00	34.53	74.3%
R&RA Planning and Concept Development	17.59	-	1.80	-15.79	-89.8%
Major Research Equipment and Facilities Construction	\$241.48	-	\$182.80	-\$58.68	-24.3%
Total, Major Multi-User Research Facilities	\$1,251.27	-	\$1,146.30	-\$104.97	-8.4%

NSF investments provide state-of-the-art tools for research and education. These include major multi-user research facilities such as instrumentation networks, observatories, accelerators, detectors, telescopes, research vessels, aircraft, and simulators. In addition, investments in cyber-enabled and geographically distributed user facilities are increasing as a result of rapid advances in computer, information, and communication technologies. NSF's investments are coordinated with those of other organizations, federal agencies, and international partners to ensure they are complementary and well integrated. Planning, operations, and maintenance of major multi-user facilities are funded through the Research and Related Activities (R&RA) account, with most construction funded through the Major Research Equipment and Facilities Construction (MREFC) account.

This chapter provides descriptions of each major multi-user research facility supported through the R&RA account and provides funding information by life cycle phase for each facility. The information presented for each facility follows the overall framework established by NSF for major facility projects. Information on projects under construction funded through NSF's MREFC account is provided in the MREFC chapter.

Major Multi-User Research Facilities

Major Multi-User Research Facilities Funding, by Project

(Dollars in Millions)

	FY 2016 Actual	FY 2017 (TBD)	FY 2018 Request	Change over FY 2016 Actual	
				Amount	Percent
Operations and Maintenance of Existing Facilities	\$727.14	-	\$676.94	-\$50.20	-6.9%
Engineering					
National Nanotechnology Coordinated Infrastructure (NNCI)	16.33	-	14.78	-1.55	-9.5%
Natural Hazards Engineering Research Infrastructure (NHERI)	13.00	-	11.75	-1.25	-9.6%
Geosciences					
Academic Research Fleet ¹	82.79	-	77.80	-4.99	-6.0%
Geodesy Advancing Geosciences and EarthScope (GAGE)	13.18	-	12.22	-0.96	-7.3%
International Ocean Discovery Program (IODP)	48.00	-	48.00	-	-
Ocean Observatories Initiative (OOI)	54.98	-	31.00	-23.98	-43.6%
Polar Facilities and Logistics	293.82	-	283.16	-10.66	-3.6%
Seismological Facilities for the Advancement of Geoscience & EarthScope (SAGE)	25.64	-	24.19	-1.45	-5.7%
Mathematical and Physical Sciences					
Arecibo Observatory	8.90	-	7.72	-1.18	-13.3%
Cornell High Energy Synchrotron Source (CHESS) ³	20.03	-	16.00	-4.03	-20.1%
Gemini Observatory	19.88	-	21.03	1.15	5.8%
IceCube Neutrino Observatory	8.71	-	7.00	-1.71	-19.6%
Large Hadron Collider (LHC) ²	20.00	-	22.30	2.30	11.5%
Laser Interferometer Gravitational Wave Observatory (LIGO)	39.43	-	39.43	-	-
National High Magnetic Field Laboratory (NHMFL)	35.34	-	34.77	-0.57	-1.6%
National Superconducting Cyclotron Laboratory (NSCL)	24.00	-	23.00	-1.00	-4.2%
Other Facilities ³	3.10	-	2.79	-0.31	-10.0%
Federally Funded Research and Development Centers⁴	\$218.59	-	\$203.76	-\$14.83	-6.8%
National Center for Atmospheric Research (NCAR)	105.60	-	89.90	-15.70	-14.9%
National Optical Astronomy Observatory (NOAO)	21.99	-	20.67	-1.32	-6.0%
National Radio Astronomy Observatory (NRAO) ⁵	81.50	-	76.34	-5.16	-6.3%
Other Astronomical Facilities ⁶	-	-	11.85	11.85	N/A
National Solar Observatory (NSO) ⁷	9.50	-	5.00	-4.50	-47.4%
Operations and Maintenance of Facilities under Construction	\$46.47	-	\$81.00	\$34.53	74.3%
Daniel K. Inouye Solar Telescope (DKIST) ⁸	13.50	-	16.00	2.50	18.5%
National Ecological Observatory Network (NEON)	32.97	-	65.00	32.03	97.1%
R&RA Planning and Concept Development	\$17.59	-	\$1.80	-\$15.79	-89.8%
Pre-construction Planning ⁹	17.59	-	1.80	-15.79	-89.8%
Major Research Equipment and Facilities Construction¹⁰	\$241.48	-	\$182.80	-\$58.68	-24.3%
Total, Major Multi-User Research Facilities	\$1,251.27	-	\$1,146.30	-\$104.97	-8.4%

¹Academic Research Fleet funding includes ship operations and upgrades. Regional Class Research Vessels (RCRV) funding is no longer included on this line as it is proposed for an FY 2017 MREFC new construction start.

² Large Hadron Collider (LHC) funding on this line includes \$6.30 million in FY 2018 for planning for a potential LHC upgrade.

³ Other Facilities includes ongoing MPS support for the Center for High Resolution Neutron Scattering (CHRNS).

⁴ Federally-Funded R&D Centers do not include support for the Office of Science and Technology Policy Institute (STPI), which is an FFRDC but not a multi-user research facility.

⁵ Funding for the National Radio Astronomy Observatory (NRAO) includes operations and maintenance support for the Atacama Large Millimeter Array (ALMA). The substantial drop in support shown is due to the separation of the Green Bank Observatory and the Very Long Baseline Array from NRAO and ALMA; this funding is now included under "Other Astronomical Facilities" in this table.

⁶ Other Astronomical Facilities funding includes the Green Bank Observatory and the Very Long Baseline Array, removed from NRAO and ALMA.

⁷ National Solar Observatory (NSO) totals presented do not include \$11.50 million in FY 2016, and \$14.0 million in FY 2018 for operations and maintenance support for the DKIST facility construction project. That funding is captured within the total presented Initial Operations and Maintenance During Construction line.

⁸ Of total DKIST funding presented, \$11.50 million in FY 2016 and \$14.0 million in FY 2018 is for operations and maintenance support provided through the National Solar Observatory, and for all years, \$2.0 million is for cultural mitigation activities as agreed to during the environmental compliance process. For more information, see the DKIST narrative in the MREFC chapter.

⁹ Pre-construction planning includes funding for potential next generation multi-user facilities. This line reflects funding for Antarctic Infrastructure Modernization for Science (AIMS) for FY 2016 and FY 2018 and for Regional Class Research Vessels (RCRV) for FY 2016 only. RCRV funding is \$3.09 million in FY 2016. AIMS funding is \$14.50 million in FY 2016, and \$1.80 million in FY 2018.

¹⁰ Funding for MREFC Projects in this table include support for concept and development associated with ongoing and requested MREFC projects, i.e. RCRV, provided through the R&RA account.

NSF Facilities Investments in FY 2018

The following pages contain information on NSF’s ongoing facilities in FY 2018.

Facilities

Academic Research Fleet	Facilities - 4
Arecibo Observatory.....	Facilities - 8
Cornell High Energy Synchrotron Source (CHESS).....	Facilities - 12
Gemini Observatory.....	Facilities - 15
Geodesy Advancing Geosciences and EarthScope (GAGE).....	Facilities - 19
IceCube Neutrino Observatory	Facilities - 22
International Ocean Discovery Program (IODP).....	Facilities - 25
Large Hadron Collider (LHC)	Facilities - 28
Laser Interferometer Gravitational Wave Observatory (LIGO)	Facilities - 31
National High Magnetic Field Laboratory (NHMFL).....	Facilities - 34
National Nanotechnology Coordinated Infrastructure (NNCI)	Facilities - 37
National Superconducting Cyclotron Laboratory (NSCL).....	Facilities - 39
Natural Hazards Engineering Research Infrastructure (NHERI).....	Facilities - 41
Ocean Observatories Initiative (OOI).....	Facilities - 45
Polar Facilities and Logistics.....	Facilities - 48
Seismological Facilities for the Advancement of Geoscience and EarthScope (SAGE)	Facilities - 52

Federally Funded Research and Development Centers (FFRDCs)

National Center for Atmospheric Research (NCAR)	Facilities - 55
National Optical Astronomy Observatory (NOAO).....	Facilities - 59
National Radio Astronomy Observatory (NRAO)	Facilities - 62
National Solar Observatory (NSO).....	Facilities - 65
Other Astronomical Facilities.....	Facilities - 69

Other Facilities Funding

Major Research Equipment and Facilities Construction Account Projects	Facilities - 72
Preconstruction Planning	Facilities - 72

ACADEMIC RESEARCH FLEET**\$77,800,000**
-\$8,080,000 / -9.4%**Academic Research Fleet**

(Dollars in Millions)

FY 2016 Actual	FY 2017 (TBD)	FY 2018 Request	Change over FY 2016 Actual	
			Amount	Percent
\$85.88	-	\$77.80	-\$8.08	-9.4%

The U.S. Academic Research Fleet (ARF) included 18 vessels in calendar year 2016 with the Office of Naval Research (ONR) delivering two new ocean class vessels into the fleet. The vessels in the ARF range in size, endurance, and capabilities, enabling NSF and other federally and state-funded scientists to conduct ocean science and technology research with a diverse fleet capable of operating in coastal and open ocean waters. Funding for ARF includes investments in ship operations; shipboard scientific support equipment; oceanographic instrumentation and technical services; and submersible support. Funding levels reported here reflect investments in the Directorate for Geosciences (GEO) by the Division of Ocean Sciences (OCE). In addition to operations, OCE has undertaken selected construction projects based on inter-agency planning and coordination as discussed in the *Federal Oceanographic Fleet Status Report*¹ published in May 2013.

Total Obligations for the Academic Research Fleet

(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	\$82.79	-	\$77.80	\$77.80	\$77.80	\$77.80	\$77.80	\$77.80
Fleet Modernization								
Regional Class Research Vessel	3.09	-	-	-	-	-	-	-
Total, Academic Research Fleet	\$85.88	-	\$77.80	\$77.80	\$77.80	\$77.80	\$77.80	\$77.80

¹ Outyear funding estimates are for planning purposes only.

ARF serves as the main platform for the collection of data, testing of hypotheses about the structure and dynamics of the ocean, and the development and testing of novel technological instrumentation. Scientists contribute to advances in many areas including climate variability, marine ecosystems, fisheries, and ocean-related natural hazards, such as tsunamis, through use of these facilities. Participating graduate and undergraduate students interact with scientists and marine technicians, enabling them to gain first-hand exposure to ocean science field research. Increasingly, technological innovations allow research conducted at sea to be transmitted via satellite back to the classroom, broadening the educational impact of the vessels.

ARF is supported through an interagency partnership, principally with the Office of Naval Research (ONR) and the National Oceanic and Atmospheric Administration (NOAA). The operating costs for the fleet are divided proportionally among the vessel users based on usage; in CY 2016 NSF supported approximately 64 percent of the total, which includes the Ocean Observatories Initiative's use of the fleet. NSF coordinates with ship-operating and ship-user academic institutions both directly and through the University-National Oceanographic Laboratory System (UNOLS) organizational structure.

Support for scientists using the fleet is provided by NSF and other federal and state agencies. Within NSF,

¹ www.nopp.org/wp-content/uploads/2010/03/federal_oceanographic_fleet_status_report.pdf

science is funded through competitive peer-reviewed proposals, most typically funded within OCE and through selected programs in the Division of Earth Sciences (EAR), the Division of Atmospheric and Geospace Sciences (AGS), the Office of Polar Programs (OPP), and the Directorate for Biological Sciences (BIO). Approximately 25 percent of OCE proposals request ship time. Not reflected in this number is the science that utilizes samples or data collected on prior cruises, scientists piggy-backing on scheduled cruises to accomplish additional science, international scientists sailing with the U.S. Academic Research Fleet, and science funded by other agencies.

The FY 2018 funding level will support approximately 1,675 ship operating days, which reflects the entry of R/V *Neil Armstrong* and R/V *Sally Ride*, the two new vessels delivered by ONR in 2016, into the fleet.

Fleet Operations/Management and Oversight

- Oversight: NSF provides oversight to the Academic Research Fleet through cooperative agreements with each ship-operating institution and through a separate cooperative agreement with the UNOLS Office. NSF is the cognizant agency for ship day-rate negotiations for ARF, regardless of owner. In addition, NSF oversees the fleet through Business Systems Reviews, site visits, ship inspections, and participation at the UNOLS Council and various Committee meetings by NSF program directors. Several program directors within OCE at NSF, at NOAA, and at ONR are involved in the activities and oversight of the Academic Research Fleet.
- After an in-depth review of the application of rate structures on ARF ship-related activities, NSF and ONR are in the process of transitioning the accounting of Fleet activities into a Specialized Service Facility in accordance with OMB's Uniform Guidance for Federal Awards 2 CFR 200.468.
- Management: Management of an institution's ship-operating facilities varies with the scale of the operation, but the core responsibility typically resides with the Director of the Institution, the Marine Superintendent (for all aspects of the facility), and the ship's Captain (for at-sea operations). For larger multi-ship-operating institutions, a Chief of Marine Technicians, schedulers, and finance administrators may also be involved in facility management.
- Reviews: Based on projected science requirements identified in recent reports and workshops, a fleet of vessels supporting ocean science and technological research will be needed far into the future. Documents supporting this need include the *National Ocean Policy*² and the *Final Recommendations of the Interagency Ocean Policy Task Force*³ of July 19, 2010. Two applicable reports by the National Research Council (NRC) include *Science at Sea: Meeting Future Oceanographic Goals with a Robust Academic Research Fleet*⁴ published in 2009, and *Critical Infrastructure for Ocean Research and Societal Needs in 2030*⁵ published in 2011. In coordination with UNOLS and the other federal agencies that invest in ocean research, the Interagency Working Group on Facilities and Infrastructure (IWG-FI) published a *Federal Oceanographic Fleet Status Report*⁶ in May 2013, reviewing the status and describing plans for modernizing the Federal Oceanographic Fleet, which includes both the Academic Research Fleet and the survey ships. This report was updated in March of 2016 (http://www.nopp.org/wp-content/uploads/2016/06/federal_fleet_status_report_final_03.2016.pdf). In January 2015, the National Academy of Sciences Report *Sea Change 2015-2025 Decadal Survey of Ocean Sciences*⁷ identified the U.S. Academic Research Fleet as having "the strongest match between current infrastructure and the decadal science priorities" and emphasized the overall importance of

² https://obamawhitehouse.archives.gov/sites/default/files/national_ocean_policy_implementation_plan.pdf

³ https://obamawhitehouse.archives.gov/files/documents/OPTF_FinalRecs.pdf

⁴ www.nap.edu/catalog/12775/science-at-sea-meeting-future-oceanographic-goals-with-a-robust

⁵ www.nap.edu/catalog/13081/critical-infrastructure-for-ocean-research-and-societal-needs-in-2030

⁶ www.nopp.org/wp-content/uploads/2010/03/federal_oceanographic_fleet_status_report.pdf

⁷ www.nap.edu/catalog/21655/sea-change-2015-2025-decadal-survey-of-ocean-sciences

ships in all of the NAS-identified ocean science and technology priorities. Ship operations and technical services proposals undergo external review by peers every five years. Detailed annual reports describing activities accomplished are provided by the operating institutions and budgets are negotiated yearly since they are dependent on the number of days the ships will be at sea in support of NSF-funded research programs. A Business Systems Review of one Academic Research Fleet operating institution was conducted in 2016.

Fleet Modernization

- Oversight: The NSF coordinator for fleet modernization activities is the Program Director for Ship and Submersible Support, within the Integrative Programs Section (IPS) in OCE, with additional IPS staff providing project management assistance as required.
- Regional Class Research Vessel (RCRV): In March 2012, NSF leadership approved the request to advance the RCRV to the Conceptual Design Review (CDR) phase as a candidate Major Research Equipment and Facilities Construction (MREFC) project. On February 1, 2013, NSF made an award to Oregon State University (OSU) as the lead institution for advancement to CDR. Funds for CDR were provided from the Research and Related Activities (R&RA) account. In December 2013, OSU successfully completed all CDR requirements in accordance with NSF's Large Facilities Manual.⁸ Approval for advancement to the Preliminary Design Phase was provided in March 2014. The Preliminary Design Review (PDR) was held in August 2014. The PDR Panel recommended the project be approved to advance to the Final Design Phase. Initial funds to initiate construction were requested in FY 2017, contingent on continued satisfactory progress by the awardee, the project's consistency with overall NSF goals and strategic direction, and the availability of funds. Personnel from the NOAA Office of Marine and Aviation Operations, as well as ONR, continue to participate in the review of the RCRV design and project management. In addition, NSF is an active participant in the IWG-FI Ship Subcommittee, which developed the 2016 update to the 2013 *Federal Oceanographic Fleet Status Report*. The RCRV would address requirements across government agencies for research vessels in support of ocean science research as discussed in the Fleet Status Report Update of 2016. Decisions on proceeding to further development stages will be based upon NSF, National Science Board (NSB), and interagency reviews. For additional information on RCRV please refer to the MREFC chapter.
- R/V *Sikuliaq*, formerly the Alaska Region Research Vessel (ARRV): The R/V *Sikuliaq* represents NSF's first major contribution to fleet renewal in over twenty years. Construction of the *Sikuliaq* was funded through the MREFC account, partially with American Recovery and Reinvestment Act (ARRA) funds. The project is led by the University of Alaska, Fairbanks (UAF) with engineering support from design through construction provided by UAF's naval architect, The Glosten Associates, Inc. Shipyard construction began in early 2011 and the vessel was successfully launched in October 2012. Delivery of the *Sikuliaq* to UAF took place in June 2014. This was followed by a period of final outfitting, science trials, and transit to the first science operational area. Initial science operations began in late 2014. *Sikuliaq* successfully completed ice trials in the Bering Sea and three science cruises in the Arctic Ocean. All final MREFC project activities were closed out under budget by March 31, 2016.
- Research in the Arctic is needed on topics ranging from natural resources, climate change, ocean circulation, ecosystem studies, and fisheries research, to natural hazards, and cultural anthropology. The *Sikuliaq* provides a sophisticated and significantly larger platform for scientists, as well as graduate and undergraduate students, to participate in complex multidisciplinary research activities and enables the training of the next generation of scientists with the latest equipment and technology. The *Sikuliaq* greatly expands research and technology capabilities in the Arctic, providing up to 270-300 science days at sea annually. The ice-strengthened hull allows the vessel to operate in seasonal ice up to one

⁸ www.nsf.gov/pubs/2015/nsf15089/nsf15089.pdf

meter thick and an anti-roll tank permits it to operate effectively in the open waters of the Bering Sea, Gulf of Alaska, and North Atlantic.

Other Ongoing Activities

Major overhaul and upgrade to the submersible Human Occupied Vehicle *ALVIN* was completed in FY 2013. The *ALVIN* Upgrade project was scoped in two phases. Phase I was the integration of a new titanium 6,500-meter-capable personnel sphere with existing *ALVIN* vehicle components. Phase I completion provided a maximum depth capability of 4,500 meters, the limit of the legacy *ALVIN* components retained during Phase I. Phase II would provide upgrades to permit operations to a depth of 6,500 meters, but there has been no implicit or explicit commitment to proceed with Phase II at this time. Sea trials for operation of the Phase I vehicle in November 2013 supported certification for operations to 3,800 meters, and approximately 100 dives in support of science were made in 2014. Further sea trials to support certification to 4,500 meters were successfully completed in January 2015. *ALVIN* continues to support science missions with approximately 100 dives per year.

Renewal/Re-competition/Termination

Ships supported by NSF are operated by academic institutions, each having a cooperative agreement with NSF. All ship cooperative agreements were renewed in FY 2012 using the NSB-approved criteria and review by an external panel, with upcoming renewals planned for FY 2018. Awardees are subject to additional oversight measures, including quarterly safety and financial reporting, the use of NSF Business System Reviews (BSR), and site inspections. In 2013, NSF retired *R/V Cape Hatteras*, operated by a consortium of Duke University and the University of North Carolina from its homeport at the Duke University Marine Laboratory. In 2014, NSF retired *R/V Point Sur*, operated by Moss Landing Marine Laboratories, San Jose State University. For *R/V Sikuliaq*, a re-compete clause in ten years (2024) was included in the initial cooperative agreement for operations. This clause will be added to all renewals of NSF owned vessels.

ARECIBO OBSERVATORY

\$7,720,000
-\$1,180,000 / -13.3%

Arecibo Observatory

(Dollars in Millions)

FY 2016 Actual	FY 2017 (TBD)	FY 2018 Request	Change over FY 2016 Actual	
			Amount	Percent
\$8.90	-	\$7.72	-\$1.18	-13.3%

The Arecibo Observatory (Arecibo) is a center for multidisciplinary research and education with world-class observational facilities. The observatory’s principal facility is one of the world’s largest single-dish radio/radar telescopes, a 305-meter diameter reflector located near the town of Arecibo in western Puerto Rico on 120 acres of U.S. Government-owned land. Arecibo is currently operated and managed by SRI International and subrecipients Universities Space Research Association (USRA) and Universidad Metropolitana (UMET) under a cooperative agreement with NSF that initially ran from October 1, 2011 to September 30, 2016, and was extended by 18 months to March 31, 2018. The observatory serves over 350 users annually with a wide range of research and observing instrumentation in passive radio astronomy, solar system radar astronomy, and space and atmospheric sciences. A peer-review telescope allocation committee provides merit-based telescope time to users. The committee is common to the three fields, but specific subject matter experts from outside the observatory are consulted for reviews. NSF does not provide awards targeted specifically for use of Arecibo, although some Arecibo users are supported through NSF or NASA grants to pursue scientific programs that require use of the facility.

Currently, Arecibo is staffed at approximately 120 full-time equivalent (FTE) employees, of which about 100 are funded by NSF. The remaining FTEs are supported by a grant from NASA, by the Angel Ramos Foundation Visitor Center, and by other funding sources. Staff include approximately 20 scientists who, along with engineers, technicians, and operators, are available to help visiting investigators with observing programs. In addition, there are management, administrative, and clerical positions, as well as maintenance staff, and several postdoctoral scholars and students.

Total Obligations for the Arecibo Observatory

(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 (MPS)	\$4.80	-	\$3.90	\$3.05	\$2.13	\$1.50	\$1.13	\$1.00
Operations & Maintenance (GEO)	4.10	-	3.82	3.03	2.13	1.50	1.13	1.00
Total, Arecibo	\$8.90	-	\$7.72	\$6.08	\$4.25	\$3.00	\$2.25	\$2.00

¹ Outyear funding estimates are for planning purposes only. The current cooperative agreement, initially scheduled to end in FY 2016, has been extended through 31 March 2018.

Arecibo is jointly supported by the NSF Directorate for Mathematical and Physical Sciences (MPS), Division of Astronomical Sciences (AST) and the NSF Directorate for Geosciences (GEO), Division of Atmospheric and Geospace Sciences (AGS). Planned AST support through FY 2018 is based on the 2006 AST Senior Review recommendations, an external review of the AST portfolio conducted in 2012, and guidance from a third-party cost review of AST facilities.

In 2012, the AST Portfolio Review Committee recommended “continued AST involvement in Arecibo...be

re-evaluated later in the decade in light of the science opportunities and budget forecasts at that time.”⁹ The *New Worlds, New Horizons: Midterm Assessment* (August 15, 2016) reinforced this, with Recommendation 3.1 noting: “The NSF should proceed with divestment from ground-based facilities that have a lower scientific impact....”¹⁰

The Geospace Section (GS) Portfolio Review Committee was charged by the NSF Advisory Committee for Geosciences to review the most promising Geospace science strategies and critical capabilities and to reconcile these with the science goals described by the 2013 Decadal Survey for Solar and Space Physics. The GS is associated with AGS and its portfolio includes grant programs in upper-atmospheric sciences, space science and space weather. This GS portfolio review was carried out using the assumption of an inflation-adjusted, flat budget for GS over the next decade to FY 2026. The GS Portfolio Review Committee recommendations include the reduction of annual AGS Arecibo Observatory funding from \$4.10 million to \$1.10 million by 2020.

GEO commissioned a review from a second panel assembled by the National Academy of Science that assessed the process by which the GS Portfolio Review Committee reached their findings and recommendations. The panel published the results of this review in early 2017 and, for Arecibo, reiterated the recommendations GS Portfolio Review Committee.

Because of these potential changes, NSF is currently preparing an Environmental Impact Statement (EIS) to evaluate proposed operational changes at Arecibo due to funding constraints, pursuant to the National Environmental Policy Act (NEPA). NSF is also completing its compliance obligations with the National Historic Preservation Act (NHPA), and the Endangered Species Act (ESA). A draft version of the EIS (Draft EIS) was released on October 28, 2016.¹¹ In the Draft EIS, NSF evaluated the anticipated environmental impacts stemming from implementation of several proposed alternatives, including: (1) No-Action Alternative; (2) *Alternative 1* - Collaboration with interested parties for continued science-focused operations at Arecibo Observatory (identified in the Draft EIS as the Agency Preferred Alternative); (3) *Alternative 2* - Collaboration with interested parties for continued education-focused operations at Arecibo Observatory; (4) *Alternative 3* - Mothballing of facilities (suspension of operations in a manner such that operations could resume efficiently at some future date); (5) *Alternative 4* - Partial deconstruction and site restoration; and (6) *Alternative 5* - Full deconstruction and site restoration.

Following the 45-day public comment period that ended on December 12, 2016, NSF is preparing a Final EIS. Concurrent with the EIS process, NSF is working with consulting parties under Section 106 of the NHPA to find ways to avoid, minimize, or mitigate any adverse effects on nationally significant historic properties at Arecibo as a result of implementation of any of the proposed alternatives. Likewise, NSF is working with the U.S. Fish and Wildlife Service to evaluate the anticipated impacts from implementation of the proposed alternatives on threatened/endangered species and their habitats.

NSF issued a solicitation on January 25, 2017 requesting proposals to provide continued operations and management of Arecibo for five years, but at reduced funding. After the conclusion of NSF’s compliance with federal statutes for the EIS, and review of responses to the solicitation, NSF will prepare a Record of Decision documenting its chosen course of action with regard to Arecibo Observatory.

Partnerships and Other Funding Sources: Arecibo leverages NSF support with funding from other federal and non-federal sources. Since FY 2010, the NASA Near Earth Object Observation Program has committed \$2.0 million annually to Arecibo in support of the planetary radar program; this increased to \$3.60 million

⁹ www.nsf.gov/mps/ast/ast_portfolio_review.jsp

¹⁰ www.nap.edu/read/23560/chapter/1

¹¹ www.nsf.gov/mps/ast/env_impact_reviews/arecibo/arecibo_drafteis.jsp

Major Multi-User Research Facilities

for FY 2013, with more observing time allocated to the NASA program. NASA support is expected to continue at approximately \$3.60 million in FY 2018.

Education and Public Outreach (EPO): Arecibo hosts a Research Experiences for Undergraduates (REU) site, and Ph.D. students receive training through the use of the facility. Over 350 students have participated in REU programs at Arecibo. In collaboration with the National Radio Astronomy Observatory (NRAO), Arecibo holds a summer school on single-dish radio astronomy techniques. Arecibo also sponsors a major outreach program in Puerto Rico via the Angel Ramos Foundation Visitor Center as well as summer workshops for K-12 teachers. This center attracts more than 80,000 visitors each year; over 1.4 million people have visited since its opening in 1997. Approximately 25 percent of these visitors are K-12 students. Exhibits at the visitor center were updated, and physical renovations to the visitor center building were completed in FY 2016. These improvements were funded by the Angel Ramos Foundation and the Ana G. Méndez University System, and were formally approved by the NSF. With funds received from the Puerto Rico Department of Education, Arecibo has hosted numerous teacher workshops and has trained approximately 500 teachers. This program integrates formal activities at the Angel Ramos Foundation Visitor Center into the STEM curriculum in Puerto Rico. Arecibo also hosts several meetings each year within a wide variety of scientific disciplines.



An image of the Arecibo Radio Telescope in Puerto Rico. The platform suspension structure, including the Gregorian dome that houses the main suite of research instruments, is visible over the 305-meter primary reflector dish below. *Credit: Arecibo Observatory/NSF.*

Operations and Maintenance: Arecibo administers observing time to the astronomy and aeronomy communities via competitive observing proposals, and conducts educational and public outreach programs at all levels. Observing hours among science programs are based on the quality of the observing proposals. The telescope is currently oversubscribed, counting ongoing astronomy surveys, new astronomy projects, solar system observations, and atmospheric sciences programs. About 75 percent of astronomy users conduct their observing remotely via networked control software, while radar observations typically employ on-site users.

Management and Oversight

- AST, \$3.90 million: AST funding will maintain basic operations costs and science programs in passive radio astronomy. As recommended by the 2006 AST Senior Review, AST funding for Arecibo has been gradually reduced. The reduction will continue in FY18.
- AGS, \$3.82 million: AGS funding will support basic operations costs and science programs in aeronomy and space physics, including space weather.
- NSF Structure: Ongoing oversight is provided by the lead NSF program officer in AST, in close cooperation with a program officer in AGS, and in consultation with community representatives. The program officers make use of detailed annual program plans, long-range plans, quarterly technical and financial reports, and annual reports submitted to NSF by SRI. They also attend SRI governance committee meetings, as appropriate. To address issues that arise, program officers work closely with other NSF offices. This includes the Division of Acquisition and Cooperative Support and the Large Facilities Office, both within the Office of Budget, Finance, and Award Management; and the Office of General Counsel. The AST and AGS program officers conduct periodic site visits and frequent,

- regular, teleconferences.
- External Structure: Management is via a cooperative agreement with SRI and its sub-awardees, USRA and UMET. The awardees provide management and oversight through their own advisory and visiting committees, including an Arecibo Observatory Users Committee, a Scientific Management Advisory Committee, a Council of Puerto Rican Chancellors and Stakeholders, and an Executive Governing Committee. The principal investigator of the operations award resides at SRI headquarters in Menlo Park, CA, but makes frequent site visits to Puerto Rico. The principal on-site management staff include the Arecibo site director, resident at the telescope site, a deputy director in the areas of Radio Astronomy and Planetary Radar, and a deputy director for Education and Public Outreach.
 - Reviews:
 - A proposal review for the management and operations of Arecibo occurred 2010, resulting in an award to SRI (see above) from October 2011 to September 2016, extended by 18 months to March 31, 2018.
 - AST and AGS jointly conduct annual external reviews of Arecibo program plans; the most recent such review was held in January 2017.

Renewal/Competition/Termination

The current cooperative agreement with SRI for the management of Arecibo was awarded on October 1, 2011, when SRI succeeded the previous managing organization, Cornell University. This followed a competitive process for a new five-year cooperative agreement, consistent with National Science Board policy. This agreement was in effect through September 30, 2016, and was extended through March 31, 2018. As discussed previously, the direction beyond that time will be determined after carrying out the EIS process and evaluating the responses to the solicitation for management and operations beyond March 31, 2018. As can be seen in the obligations table above, outyear funding estimates are reduced from recent levels and are consistent with the NSF funding profile provided in the FY 2017 management competition solicitation.

CORNELL HIGH ENERGY SYNCHROTRON SOURCE**\$16,000,000**
- \$4,030,000 / -20.1%**Cornell High Energy Synchrotron Source**

(Dollars in Millions)

FY 2016 Actual	FY 2017 (TBD)	FY 2018 Request	Change over FY 2016 Actual	
			Amount	Percent
\$20.03	-	\$16.00	-4.03	-20.1%

The Cornell High Energy Synchrotron Source (CHESS) is a high-intensity, high-energy X-ray user facility in Ithaca, NY. It uses synchrotron light given off by charged particles, both electrons and positrons, as they circulate in a ring at nearly the speed of light. CHESS provides capabilities for X-ray research in physics, chemistry, biology, materials, engineering, and environmental sciences. Emphasis areas include soft matter and thin film studies, solution scattering, nanomaterials, high-pressure science, structural biology, time-resolved studies of materials, and X-ray studies of structural materials. Stewardship and oversight of CHESS is provided through the NSF Division of Materials Research within the Directorate for Mathematical and Physical Sciences (MPS/DMR), as well as the Directorates for Biological Sciences (BIO) and Engineering (ENG).

With support from the state of New York, CHESS is currently upgrading the source ring to a high energy hard X-ray synchrotron source. In FY 2017, NSF conducted a review of the science case for the proposed new X-ray source, named CHESS-U, and determined that this upgrade would not provide a sufficiently unique facility to justify continued stewardship of the source by NSF. This led to the decision to continue funding CHESS operations until March 31, 2019 with a plan to accept a transition proposal in FY 2019. This proposal would establish a partnership model whereby NSF would consider investing in the most unique experimental components but no longer support full operation of the source. Within this FY 2018 allocation, the transition will begin one year early.

Total Obligations for CHESS

(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 (MPS)	\$10.03	-	\$8.00	\$8.00	\$5.00	\$5.00	\$5.00	\$5.00
Operations & Maintenance (BIO)	5.00	-	4.00	-	-	-	-	-
Operations & Maintenance (ENG)	5.00	-	4.00	-	-	-	-	-
Total, CHESS	\$20.03	-	\$16.00	\$8.00	\$5.00	\$5.00	\$5.00	\$5.00

¹ Outyear funding estimates are for planning purposes only. The current cooperative agreement ends in March 2019. NSF will begin transition of CHESS from NSF stewardship to a partnership model in FY 2018, with future obligations dependent on review of a transition proposal.

CHESS is a national user facility accessed through a competitive proposal review process. The primary function of CHESS staff is to maintain and operate the facility and to assist users. Users number about 850 annually and perform a broad array of research including: computationally-enabled scattering studies of complex materials; an analysis of the structure of designer solids including the impact of processing; enabling the engineering of materials through time-resolved synchrotron radiation studies, x-ray imaging, and spectroscopic studies; studying structural materials under operating conditions; and the analyses of macromolecules and biochemistry. The latter topic is done in collaboration with NIH. An annual users meeting and several workshops help disseminate results from the facility.

CHESS supports users from academia, industry, and national laboratories. CHESS has developed a

dynamic testing station for structural materials through collaboration with the U.S. Air Force Research Laboratory and the Office of Naval Research. CHESS collaborates with Department of Energy (DOE) - supported synchrotron facilities such as the Advanced Photon Source and the National Synchrotron Light Source. X-ray detectors developed at CHESS are now in use at 3rd and 4th generation X-ray sources around the world, including the world's first hard X-ray laser, DOE's Linear Coherent Light Source. CHESS-developed undulators, that cost an order of magnitude less than current technology, are being installed at CHESS. The undulators will increase X-ray flux by an order of magnitude and enable CHESS to pursue time-resolved and high resolution imaging experiments not previously possible. The Cornell undulators, and other innovations such as high flux X-ray optics, are impacting synchrotron science worldwide.

CHESS researchers also developed a new Kolsky bar apparatus to study the impact on structure of high strain rates using in-situ diffraction from metals undergoing shock-wave induced strain. This unique capability uses the high flux of CHESS in combination with a new high speed pixel array detector. Understanding high impact deformation is particularly important to the automotive and aerospace industries.

CHESS supports and enhances Ph.D. level graduate education, postdoctoral research, and research experiences for undergraduates and for K-12 students and science teachers. The CHESS education and outreach program annually impacts over 6,000 people of all ages, including over 1,300 visitors touring the Cornell facilities. Each year, about 60 Ph.D. degrees are granted as a result of CHESS research. CHESS is a key training ground for X-ray and accelerator scientists, with CHESS graduates being hired to staff other X-ray facilities in the U.S. and around the world.

Management and Oversight

- NSF Structure: CHESS is supported by MPS, BIO, and ENG through a cooperative agreement with Cornell University. A MPS/DMR program director is the primary contact with the facility and leads an internal NSF team of program directors. NIH provides additional support for CHESS operations through the Macromolecular Diffraction at the Cornell High Energy Synchrotron Source (MacCHESS) award. A Joint Oversight Group (JOG) was established to better coordinate the CHESS and MacCHESS awards. The JOG serves as a vehicle to keep interested parties informed and includes program directors in MPS, BIO, and ENG at NSF, as well as NIH program directors.
- External structure: The Cornell Laboratory of Accelerator-based Sciences and Education (CLASSE), which falls under Cornell's Vice Provost for Research, administers CHESS. The principal investigator serves as the CHESS Director and reports to the Director of CLASSE. The CHESS Director receives guidance primarily from the CHESS executive committee, from an external policy and advisory board, the CHESS diversity committee, and the users' executive committee.
- Reviews: NSF provides oversight by monitoring annual plans and reports including user metrics, as well as by conducting monthly phone conferences with the director. NSF uses annual site visit reviews to assess the user program, in-house research, long-term plans to contribute significant research developments both nationally and internationally, as well as the operations, maintenance, and facility development. Annual reviews also assess the status of education, training and outreach; operations and management efficiency, and diversity plans. In addition to a panel of experts composed of members from the research community, representatives from NIH attend these site visits. Recent and upcoming reviews include:
 - Review of science case for state funded upgrade of CHESS (CHESS-U), October 26-28, 2016.
 - Program Director site visit, October 2017.
 - Review of Transition Proposal, March 2018.

Renewal/Recompetition/Termination

The end date of the current CHESS award is March 2019. In FY 2017, NSF conducted a review focused on the science case for the state-supported on-going upgrade of CHESS. The outcome led to NSF's decision to transition from a stewardship role of CHESS to one focused on partnership to enable the best science. Initial plans were to accept a transition proposal in FY 2019. The current plan is for the transition to begin in FY 2018, or one year early. At the FY 2018 Request level, support will total \$16.0 million with DMR providing \$8.0 million and BIO and ENG providing \$4.0 million each.

GEMINI OBSERVATORY

\$21,030,000
+\$1,150,000 / 5.8%

Gemini Observatory

(Dollars in Millions)

FY 2016 Actual	FY 2017 (TBD)	FY 2018 Request	Change over FY 2016 Actual	
			Amount	Percent
\$19.88	-	\$21.03	\$1.15	5.8%

The Gemini Observatory consists of twin optical/infrared 8-meter telescopes, one each in the northern and southern hemispheres. Gemini North sits atop Mauna Kea, Hawaii at an elevation of 4,200 meters, while Gemini South is located on the 2,700-meter summit of Cerro Pachón, Chile. This siting of the two telescopes provides complete coverage of the sky and complements observations from space-based observatories. Both telescopes offer superb image quality and employ sophisticated adaptive optics technology to compensate for the blurring effects of the Earth's atmosphere.

Among the fundamental issues being investigated by today's astronomers are the age and rate of expansion of the universe, the origin of the dark energy that drives cosmic acceleration, the nature of non-luminous matter, the processes that give rise to the formation and evolving structures of galaxies, and the formation of stars and their planetary systems. The current generation of large optical/infrared telescopes is central to these studies, owing to their unsurpassed sensitivity and exquisite spatial resolution. Technological advances incorporated into the design of the Gemini telescopes optimize their imaging capabilities and infrared performance as well as their ability to rapidly reconfigure the attached instrumentation in response to changing atmospheric conditions.

The national research agencies that currently form the Gemini international partnership include: NSF, the Canadian National Research Council (NRC), the Argentinean Ministerio de Ciencia, Tecnología e Innovación Productiva, the Brazilian Ministério da Ciência, Tecnologia e Inovação and the Chilean Comisión Nacional de Investigación Científica y Tecnológica (CONICYT). The five agencies are signatories to the Gemini International Agreement which covers all activities related to Gemini. The current Agreement covers the period January 1, 2016 through December 31, 2021.

The Gemini observatory helps educate astronomy and engineering students through undergraduate internship programs in both Hawaii and Chile. Gemini also provides an engaging focal point for public outreach and student training in all of the partner countries. Gemini-sponsored activities attract students and teachers at all levels of elementary through high school education; the unique Gemini-led *Journey Through the Universe* program in Hilo, Hawaii (now in its 13th year) and its sister activity, *Viaje al Universo* in La Serena, Chile, bring astronomy into the classroom through a week-long annual event that involves dozens of astronomers from Gemini as well as from many of the other astronomical facilities at each location. Gemini staff members also provide guidance and support to the 'Imiloa Astronomy Center, a public facility in Hilo that seeks to advance the integration of science and indigenous culture through education.

Laser guide star systems, which greatly improve the ability to correct for atmospheric blurring, are available at both facilities. The advanced multi-conjugate adaptive optics system on Gemini South continues to lead the world, providing near-infrared images that exceed the quality available from orbiting observatories, and which cover a field-of-view on the sky that is wider than any competing system. Over the next 12 months Gemini will be upgrading the lasers at both observatories to more powerful and more reliable devices.

Major Multi-User Research Facilities

The observatory is actively developing new imagers and spectrometers. The state-of-the-art Gemini Planet Imager, GPI, is now in regular use for directly imaging planets orbiting nearby stars; a new spectrograph, the Gemini High-resolution Optical SpecTrograph (GHOST), a workhorse instrument for studying a vast array of astronomical objects, is nearing completion; and a contract has just been signed for a new 8-beam optical/infrared spectrograph, OCTOCAM, that will be used to characterize exotic transient phenomena discovered with the Large Synoptic Survey Telescope (LSST) in the 2020s. This latest instrument selection directly responds to the need for an LSST follow-up instrument, as recommended in the 2012 NSF/Division of Astronomical Sciences (AST) Portfolio Review report *Advancing Astronomy in the Coming Decade: Opportunities and Challenges* (discussed further below), in the 2015 National Academies report *Optimizing the U.S. Ground-Based Optical and Infrared System*, and in the 2016 KAVLI Futures Symposium report *Maximizing Science in the Era of LSST: A Community Based Study of Needed US OIR Capabilities*.

As noted earlier, the international partnership that operates Gemini currently consists of the U.S., Canada, Brazil, Argentina, and Chile, with the U.S. as the majority partner. Construction of the telescopes and their instrumentation involved a large number of industrial entities in these and other countries, with areas of specialization that included large and complex optical systems, engineering, electronics, electro-mechanical systems, and computing. Continued development in these technological areas is reflected in the instrumentation and facilities renewal activities that are incorporated into the overall budget.

The U.S. share of Gemini Observatory observing time is open to proposals by any researcher in the U.S. astronomical community, with peer-review allocation committees providing merit-based telescope time. NSF does not provide awards targeted specifically for the use of Gemini. However, U.S. users are often supported through separate NSF research awards to pursue scientific programs that require the use of the observatory.



The Gemini North Telescope atop Mauna Kea in Hawaii. In this long-exposure photograph, the stars in the night sky appear as arcs due to the rotation of the earth. The reddish “beams” emanating from the top of the Gemini dome are produced by the laser used to support the observatory’s adaptive optics system. As the laser is tracked across the sky, following the target being observed, its narrow beam appears smudged in this time-lapse photograph. *Credit: J. Pollard/Gemini Observatory*

Total Obligations for the Gemini Observatory

(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	\$19.88	-	\$21.03	\$21.66	\$22.31	\$22.98	\$23.67	\$23.67

¹ Outyear funding estimates are for planning purposes only. The current cooperative agreement ends in December 2022.

In 2010, the National Research Council (NRC) conducted its sixth decadal survey in astronomy and astrophysics. In their report, *New Worlds, New Horizons in Astronomy and Astrophysics*¹², the NRC committee recommended that NSF should complete a senior review before the mid-decade to determine which, if any, facilities AST “should cease to support in order to release funds for: (1) the construction and ongoing operation of new telescopes and instruments, and (2) the science analysis needed to capitalize on the results from existing and future facilities”. In response to this recommendation, AST in the Directorate for Mathematical and Physical Sciences (MPS) conducted a community-based review of its portfolio. The resulting Portfolio Review Committee (PRC) report, *Advancing Astronomy in the Coming Decade: Opportunities and Challenges*¹³ released in August 2012, and included recommendations about all of the major AST telescope facilities.

The PRC report ranked Gemini Observatory as a critical component of our nation’s future astronomical research resources and recommended that the U.S. retain a majority share in the international partnership for at least the next several years. However, given the constraints that were considered, the Committee recommended that the maximum U.S. contribution to Gemini operations in 2017 and beyond should be \$17.0 million per year. Given the withdrawal of the United Kingdom and Australia from the Gemini partnership (see below), the NRC recommended that the U.S. increase its partner share in Gemini; therefore the FY 2018 Budget Request is higher than the amount recommended by the PRC.

The FY 2018 Request includes the full U.S. contribution to baseline operations at the level agreed to by the participants in the Gemini International Agreement (\$19.12 million in FY 2018), with an additional contribution of \$1.91 million to the Gemini Instrument Development Fund (equivalent to 10 percent of the operations contribution). Funding levels through FY 2021 have been agreed to by the current Gemini participants and are specified in a Gemini Board resolution from May 2015; the U.S. contributions provided for the out-years reflect a 3 percent increase per year for the period 2016-2021. No commitment has yet been made for FY 2022 and beyond, by any of the Gemini participants, though the FY 2022 figures denote a continuation of the 3 percent annual increase extended to the end of the current cooperative agreement.

Management and Oversight

- **External Structure:** The observatory is governed by the Gemini Board, which was established by the Gemini International Agreement signed by the participating agencies. NSF serves as the executive agency for the partnership, carrying out the project on their behalf. The U.S. holds six of the 13 seats on the Gemini Board, and NSF appoints the five non-NSF members. The Board includes the director of the U.S. National Optical Astronomy Observatory (NOAO) in order to facilitate increased cooperation between NOAO and Gemini and to provide an improved voice for the general U.S. astronomical community. The Gemini Observatory is currently managed by the Association of Universities for Research in Astronomy, Inc. (AURA) on behalf of the partnership through a cooperative agreement with NSF. AURA conducts its own management reviews through standing oversight committees.
- **NSF Structure:** NSF has one seat on the Gemini Board, currently occupied by the AST program officer

¹² www.nap.edu/catalog.php?record_id=12951

¹³ www.nsf.gov/mps/ast/ast_portfolio_review.jsp

Major Multi-User Research Facilities

responsible for Gemini programmatic oversight. An additional NSF staff member serves as the executive secretary to the board. The program officer monitors operations and development activities at the observatory, nominates U.S. scientists to Gemini advisory committees, conducts reviews on behalf of the partnership, participates in various Gemini Board sponsored sub-committees, and approves funding actions, reports, and contracts. The program officer is also the current chair of the Gemini Finance Committee, a subcommittee of the Gemini Board that monitors and assesses the observatory's budget and provides guidance to the Gemini Board.

- Reviews: NSF conducts periodic reviews of the management and operation of the observatory, and of AURA's financial systems, often in collaboration with the Gemini Board. NSF has conducted Business System Reviews (BSRs) of the observatory and AURA's centralized administrative services in 2009 and 2013. In April 2017, NSF conducted a Gemini Accounting System Audit, and plans to conduct a new BSR in 2018.

Renewal/Competition/Termination

The United Kingdom withdrew from the Gemini partnership at the end of 2012 which required the observatory to adjust to an approximate 24 percent reduction in budget. More recently, Australia, a 6.3 percent partner in 2015, moved to a more limited participation on a year-to-year basis. South Korea has a similar arrangement (year-to-year) through the end of 2017, however, discussions with South Korea are currently underway regarding full partnership. The next participant assessment point is scheduled for 2018, at which time partners will establish their levels of participation in the Gemini Observatory beyond December 2021.

The recently expired (end of 2016) NSF cooperative agreement for managing the Gemini Observatory included a plan to negotiate the transition to the new operations model under the reduced budget described above. Reductions in project scope included a decreased instrument complement on each telescope, cost savings from a shift to remote telescope operations from the sea level base facilities in Hawaii and Chile, a redesign of the data archive, and a tighter focus on serving the partner user communities at the expense of internal scientific research activities. These and other transition projects have now been successfully completed.

Prior to the completion of the above transition program, recompetition of the management and operation of Gemini was conducted in 2014-2015. Proposals were solicited in August 2014 and received in February 2015. Face-to-face meetings between NSF and the proposing organizations in July 2015 supplemented an extensive review of these proposals by a panel of experts in April 2015. The National Science Board approved NSF's selection of AURA as the managing organization for the observatory in February 2016, under a new cooperative agreement that covers the period January 1, 2017 to December 31, 2022.

GEODESY ADVANCING GEOSCIENCES AND EARTHSCOPE

\$12,220,000
-\$960,000 / -7.3%

Geodesy Advancing Geosciences and EarthScope

(Dollars in Millions)

FY 2016 Actual	FY 2017 (TBD)	FY 2018 Request	Change over FY 2016 Actual	
			Amount	Percent
\$13.18	-	\$12.22	-\$0.96	-7.3%

Geodesy Advancing Geosciences and EarthScope (GAGE) comprises a distributed, multi-user, national facility for the development, deployment, and operational support of modern geodetic instrumentation to serve national goals in basic research and education in the Earth sciences with a focus on studies of Earth's surface deformation at many scales with unprecedented temporal and spatial resolution. GAGE facilities support fundamental research and discovery on continental deformation, plate boundary processes, the earthquake cycle, the geometry and dynamics of magmatic systems, continental groundwater storage, and hydrologic loading. GAGE is managed and operated for NSF by UNAVCO, a consortium of 113 U.S. universities and non-profit institutions with research and teaching programs in geophysics and geodesy and 105 associate members from foreign institutions. GAGE was formed in late FY 2013 from the geodetic component of the EarthScope facility and related geodetic facilities previous managed by UNAVCO. The FY 2018 Budget Request will allow GAGE to continue providing service to the community consistent with that in previous years.

Total Obligations for GAGE

(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	\$13.18	-	\$12.22	\$12.22	\$12.22	\$12.22	\$12.22	\$12.22

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

The ability to determine position with respect to a well-constrained terrestrial reference frame using space geodetic techniques has, over the last three decades, improved to submillimeter capability. Space geodesy applications are extremely broad and expanding to include important societal research on earthquake and tsunami hazards, volcanic eruptions, hurricanes, coastal subsidence, wetlands health, soil moisture, groundwater distribution, and space weather. Applications of geodetic techniques to understanding the complex interplay between climate dynamics, continental ice sheet and mountain glacier dynamics, crustal isostatic adjustments, and sea level change is of foremost relevance to current global issues confronting humanity.

To serve the research needs of the broad Earth science community, GAGE is organized under three primary service areas and two special emphasis areas:

Geodetic Infrastructure

- The EarthScope Plate Boundary Observatory (PBO) includes more than 1,100 continuous Global Positioning System (GPS) stations (approximately 650 of which transmit data in real-time with subsecond latency) distributed across the U.S., and concentrated on the active plate boundaries in the western contiguous U.S. and southern Alaska. Data recovery for the PBO GPS network typically exceeds 90 percent. PBO also includes 75 borehole strainmeters and 78 borehole seismometers

deployed along the San Andreas Fault and above the Cascadia subduction zone and volcanic arc. Tiltmeters (25) and pore pressure sensors (23) are also collocated with the other borehole instruments.

- Global GPS Arrays outside of the PBO footprint are supported by GAGE in partnership with investigators. More than 900 continuous GPS observations from around the world are now maintained, monitored, and data compiled into the GAGE data system. GAGE supports 59 of the over 250 GPS sites in the National Aeronautics and Space Administration (NASA)-supported Global Navigation Satellite System (GNSS) array that supports satellite orbit and clock corrections and the refinement of the International Terrestrial Reference Frame (ITRF). GAGE is also supporting the development of data distribution systems for a Caribbean region GPS and meteorological sensor network (COCONet) of more than 100 stations that support tectonic, volcano, tropical storm, and sea level change investigations.
- Community GPS receiver and geodetic technology pool includes a pool of over 690 GPS receivers, ancillary equipment, and six terrestrial laser scanners, which can be used by investigators for short- and long-term deployments on qualified research projects.
- Polar Networks supports GAGE's polar GPS networks in Antarctica (ANET) and Greenland (GNET) and development of specialized GPS monumentation, power, and telemetry solutions for use in harsh environments. GAGE also provides portable campaign deployment geodetic instrumentation, training, and field support for experiments in the polar regions.
- Investigator Project Support includes project management, field engineering, and technical support services to plan and execute GPS surveys and permanent station installations. GAGE also maintains a staff focused on geodetic technology equipment testing services to evaluate new geodetic technologies and improve performance for science applications.

Geodetic Data Services

- Geodetic Data Services manages an archive of over 233 terabytes of data from GPS, laser scanning, Synthetic Aperture Radar (SAR), and borehole geophysical instruments from all GAGE components including EarthScope PBO, global continuous GPS networks, and campaign GPS observations; operates automated and manual systems to ensure the quality of all data stored in the archive; and provides systems to give the national and international research community timely access to these data. The archive of SAR imagery maintained and distributed by GAGE to support interferometric SAR imagery of continuous surface deformation at scales of 100 km to 1,000 km is complementary to discrete GPS measurement of displacement. As the U.S. currently has no civilian spaceborne SAR sensor, UNAVCO, as the manager of GAGE, brokers for cost-effective community access to the SAR imagery acquired by foreign SAR satellite systems.

Education and Community Engagement

- The GAGE Education and Community Outreach (ECE) program enables audiences beyond geodesists to access and use geodetic data and research for educational purposes, including technical short courses, student internships, web-based materials, and programs for strengthening workforce development and improving diversity in the geosciences.

Special Emphasis Areas

- Community Activities include scientific and technical workshops that bring together the international seismic community and publications designed to communicate GAGE activities and results to the community.
- External Affairs maintains outreach efforts to policymakers and planning for coordination with the international geodesy community.

Beside its role in providing the observational data essential for basic Earth science research, GAGE also plays a significant role providing geodetic infrastructure support to NASA investigators and the international community through activities in maintaining a subset of the Global GNSS Network (GGN); which supports the refinement of the ITRF and corrections to satellite orbits and clocks, all contributing to the capability for millimeter-level geodetic positioning, subtle observations of Earth's time-varying gravity field, and detection of millimeter-level changes in sea level.

Commercial surveyors and engineering firms download GAGE facility real-time GPS data daily to support precision positioning. The economic impact of this service to the commercial sector has not been quantified, but is likely substantial.

Management and Oversight

- **NSF Structure:** The Division of Earth Sciences (EAR) in the Directorate for Geosciences, through its Instrumentation & Facilities program (IF), provides general oversight of GAGE to help assure effective performance and administration. The program also facilitates coordination of GAGE programs and projects with other NSF-supported facilities and projects, and with other federal agencies, and evaluates and reviews the performance of UNAVCO in managing and operating GAGE. The Integrated Activities section head and division director in EAR provide other internal oversight.
- **External Structure:** GAGE is managed and operated by UNAVCO, which is incorporated as a non-profit consortium representing 113 U.S. universities and non-profit organizations with research and teaching programs that rely on geodetic technologies for Earth Science research. Each voting member institution of the Consortium appoints a member representative, and these member representatives elect the nine members of the UNAVCO Board of Directors, seven of which are drawn from member institutions, and two directors-at-large. The board members, who serve two-year terms, vet all internal program decisions associated with GAGE management and operation, through consultation with UNAVCO staff and GAGE advisory committees (one for each major GAGE component and additional *ad hoc* working groups appointed for special tasks). The Board of Directors appoints a president of UNAVCO to a renewable two-year term. The president is responsible for UNAVCO operations, all of which are managed through the UNAVCO Corporate Headquarters in Boulder, Colorado.
- **Reviews:** All major ongoing geoscience facilities routinely undergo reviews of their management, in addition to peer review of proposals for new or continued support. The formal NSF merit review of the five-year proposal for the GAGE facility took place in 2012 and 2013 and was also the most recent review of UNAVCO. Although the *ad hoc* reviewers and two independent review panels had a number of specific recommendations at the working level for GAGE, overall the review found that GAGE was a critical facility for U.S. and international earth sciences. Furthermore, the reviewers found that UNAVCO is a well-managed and effective organization that has, through its commitment to the collection and open dissemination of the highest quality geodetic data, transformed the discipline of geodesy and its geoscience applications.

Renewal/Recompetition/Termination

The initial cooperative agreement for GAGE began October 1, 2013, and will expire September 30, 2018. In FY 2016, in keeping with the phased integration and recompetition plan presented to and concurred with by the National Science Board in December 2009, NSF solicited proposals to manage and operate one or more components of a new facility to support the Earth sciences research and education community. These components are currently supported by GAGE and the related Seismological Facilities for the Advancement of Geoscience and EarthScope (SAGE). The new distributed, multi-user, national facility would support the development, deployment, management, and operational support of modern geodetic, seismic, and related geophysical instrumentation and provide services to serve national goals in basic research and education in the Earth sciences. NSF is currently reviewing proposals received in response to this facility solicitation.

ICECUBE NEUTRINO OBSERVATORY

\$7,000,000
-\$1,710,000 / -19.6%

IceCube Neutrino Observatory

(Dollars in Millions)

FY 2016 Actual	FY 2017 (TBD)	FY 2018 Request	Change over FY 2016 Actuals	
			Amount	Percent
\$8.71	-	\$7.00	-\$1.71	-19.6%

IceCube is the world’s first high-energy neutrino observatory, located deep within the ice cap under the U.S. Amundsen-Scott South Pole Station in Antarctica. With the discovery in 2013 of the first neutrinos from beyond our solar system, the Observatory has demonstrated that it represents a new window on the universe, providing unique data on the engines that power active galactic nuclei, the origin of high-energy cosmic rays, the nature of gamma ray bursts, the activities surrounding supermassive black holes, and other violent and energetic astrophysical processes.

Approximately one cubic kilometer of ice is instrumented with photomultiplier (PM) tubes to detect neutrino-induced, charged reaction products produced when a high-energy neutrino interacts in the ice within or near the cubic kilometer fiducial volume. The energy and arrival direction of high-energy neutrinos ranging in energy from 100 GeV to 10 PeV (1 GeV is 10⁹ electron Volts [eV]; 1TeV is 10¹² eV; and 1 PeV is 10¹⁶ eV) are derived from the IceCube data stream. The IceCube Collaboration has recently focused on studies of neutrino events with a deposited energy of 1 TeV and above. The deposited energy here is the calculated energy that is released within the detector fiducial volume representing an energy level of the incoming neutrino. These high-energy neutrinos can be produced either by the interaction of cosmic rays in the Earth’s atmosphere, the so-called atmospheric neutrinos, or near distant astrophysical accelerators like black holes and neutron stars, the so-called cosmic neutrinos. Astrophysical neutrinos remain the dominant component above 10 TeV. The number of these cosmic neutrinos (100 TeV - 10 PeV) detected by IceCube has already exceeded 50.



The Observatory includes a Deep Core Array (DCA) with tightly spaced digital optical modules to detect lower energy neutrinos (down to about 10 GeV), thus opening the door to studies of neutrino oscillation measurements and studies of Weakly Interacting Massive Particles (WIMPs) below 250 GeV. The DCA closes the energy gap between the IceCube Neutrino Observatory and the Super-Kamiokande detector in Japan, and allows effective observations of high-energy neutrinos entering from the sky of the southern hemisphere.

The IceCube project has transformed one cubic kilometer of natural Antarctic ice into a particle detector. The sensors keep watch for momentary flashes of blue light made by subatomic particles called muons; some are produced in collisions of neutrinos with atomic nuclei inside or near the detector. Since completion in 2010, the IceCube detector has been taking data in its final configuration with an uptime of well over 99 percent. IceCube detects one neutrino every 6 minutes in a background of 2700 cosmic ray muons per second. To handle the high data rates, initial analysis of the data is performed by a cluster of computers housed in a two-story building placed on top of the array. The filtered data is sent over geostationary satellites to the IceCube Research Center at the University of Wisconsin. *Credit: USAP Photo Library, Sven Lidstrom (sic), NSF.*

Total Obligations for IceCube

(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 (GEO)	\$5.23	-	\$3.50	\$3.50	\$3.50	\$3.50	\$3.50	\$3.50
Operations & Maintenance (MPS)	3.48	-	3.50	3.50	3.50	3.50	3.50	3.50
Total, IceCube	\$8.71	-	\$7.00	\$7.00	\$7.00	\$7.00	\$7.00	\$7.00

¹ Outyear funding estimates are for planning purposes only. The current cooperative agreement ends in FY 2021.

The IceCube Neutrino Observatory is presently led by the University of Wisconsin (UW) and was constructed with support from four countries (U.S., Belgium, Germany, and Sweden). The science collaboration is much broader, currently consisting of 23 U.S. institutions and 24 institutions in eleven other countries (Belgium, Germany, Sweden, Australia, Canada, Denmark, Japan, Korea, New Zealand, Switzerland, and the United Kingdom). NSF’s foreign partners contribute a pro rata share of operations and maintenance costs based on the number of PhD-level researchers involved.

Management and Oversight

- **NSF Structure:** Oversight of the IceCube Neutrino Observatory is the joint responsibility of the Geosciences Directorate’s Office of Polar Programs (OPP) and the Mathematical and Physical Sciences Directorate’s Division of Physics (PHY). Support for operations and maintenance, research and education, and outreach are shared by OPP and PHY, as well as other organizations and international partners. NSF provides oversight through regular site visits by NSF managers and external reviewers.
- **External Structure:** The UW management structure for IceCube includes leadership by the project’s principal investigator supported by the director of operations and two associate directors (one for science and instrumentation and one for education and outreach). A collaboration spokesperson is selected from the senior international scientific leaders for a two-year term, with an option to be renewed once for at most four consecutive years. At lower levels, project management includes international collaboration representatives, as well as participation by staff at collaborating U.S. institutions. UW has in place an external Scientific Advisory Committee and a Software and Computing Advisory Panel that meet annually and provide written advice to the project. UW leadership, including the Chancellor, provides additional awardee-level oversight.

Operations Costs

Full operations and maintenance in support of scientific research began in FY 2011. The associated costs are and will continue to be shared by the partner funding agencies – U.S. (NSF) and non-U.S. – proportional to the number of PhD researchers involved (currently about 55:45). The current NSF award for operations and maintenance constitutes the bulk of the U.S. contribution to general operation of the facility. In addition, work in support of facility operations is performed by students, postdocs, and senior researchers who are participating in research on the data produced by the Observatory.

NSF support for U.S. institutions working on more refined and specific data analyses, data interpretation (theory support), and instrumentation upgrades is provided through the Research and Related Activities (R&RA) account in response to merit-reviewed proposals (approximately \$4.0 million annually provided jointly by GEO and MPS).

The general operations of South Pole Station, reported in the Polar Facilities and Logistics narrative, also contribute to supporting IceCube. The cost of IceCube operations shown in the table herein includes only those that are project-specific and incremental to general South Pole Station operations. The expected operational lifespan of the IceCube Neutrino Observatory is 25 years, beginning in FY 2011.

Education and Outreach

IceCube provides a vehicle for helping to achieve national and NSF education and outreach goals. Specific outcomes include the education and training of future leaders in astrophysics, including undergraduate students, graduate students, and postdoctoral research associates; K-12 teacher scientific and professional development, including development of new inquiry-based learning materials and use of the South Pole environment to convey the excitement of astrophysics and science generally to K-12 students; increased opportunity for involvement of students in international collaborations; increased diversity in science through partnerships with minority serving institutions; and enhanced public understanding of science through broadcast media and museum exhibits (such as the Adler Planetarium in Chicago, Illinois) based on IceCube science and the South Pole environment. NSF supports evaluation and measurement-based education and outreach programs under separate grants to universities and other organizations that are selected following standard NSF merit review.

Renewal/Recompetition/Termination

NSF re-competed the IceCube operations and maintenance award in FY 2016. The new award was issued on April 1, 2016 for 60 months. Actual obligations for FY 2016 are higher than original estimates due to the extension of the previous cooperative agreement to allow time for the 2016 competition.

INTERNATIONAL OCEAN DISCOVERY PROGRAM

\$48,000,000
\$0 / 0.0%

International Ocean Discovery Program

(Dollars in Millions)

FY 2016 Actual	FY 2017 (TBD)	FY 2018 Request	Change over FY 2016 Actual	
			Amount	Percent
\$48.00	-	\$48.00	-	-

The International Ocean Discovery Program (IODP) began in FY 2014 as the replacement for the Integrated Ocean Drilling Program and the prior Ocean Drilling Program. The IODP represents an international partnership of the scientists, research institutions, and funding organizations of 26 nations to explore the evolution, structure, and behavior of Earth as recorded in the ocean basins. The program management structure focuses on maximizing facility efficiency, while retaining the intellectual cooperation and exchange with NSF’s international partners. NSF, the Ministry of Education, Culture, Sport, Science and Technology (MEXT) of Japan, and the European Consortium for Ocean Research Drilling (ECORD) continue to provide drilling platforms. The IODP platforms provide sediment and rock samples (cores); in-situ monitoring, sampling, and measurement from borehole observatories; shipboard and shore-based descriptive and analytical facilities; down-hole geophysical and geochemical measurements (logging); and opportunities to conduct experiments to determine in-situ conditions beneath the sea floor.



JOIDES Resolution underway for a science expedition, March 10, 2009. Credit: NSF

Total Obligations for IODP

(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	\$48.00	-	\$48.00	\$48.00	\$48.00	\$48.00	\$48.00	\$48.00

¹ Outyear funding estimates are for planning purposes only.

Annual operations and maintenance support for operating the *JOIDES Resolution*, the most-used IODP platform, represents NSF’s primary contribution to the program. The *JOIDES Resolution* is leased from an offshore drilling contractor under a long-term contract. The FY 2018 Request of \$48.0 million for operations and maintenance of the *JOIDES Resolution* maintains level funding for this international research facility, and will continue to enable full-schedule vessel operations. Another commercial contractor provides down-hole-logging services. Maintaining databases and core repositories, preparing scientific publications emerging from *JOIDES Resolution* IODP expeditions, and management of international program proposal review through the IODP Science Support Office, represent additional NSF IODP science integration costs, made at minimal cost to NSF because of international contributions to the program. NSF also provides support for U.S. scientists to sail on IODP drilling platforms and to participate in IODP advisory panels through an associated program. The annual costs for the associated science integration and science support (not included in the table above) are approximately \$8.50 million, funded separately through OCE.

Major Multi-User Research Facilities

The IODP scientific program emphasizes the following research themes:

- Climate and Ocean Change: Reading the Past, Informing the Future;
- Biosphere Frontiers: Deep Life, Biodiversity, and Environmental Forcing of Ecosystems;
- Earth Connections: Deep Processes and Their Impact on Earth's Surface Environment; and
- Earth in Motion: Processes and Hazards on Human Time Scales.

The umbrella IODP Forum provides a venue for all IODP entities to exchange ideas and views on the scientific progress of the program. In the current IODP, each drillship is governed by independent facility boards, each of which is unique and optimized for their respective drilling platform. In the case of the *JOIDES Resolution* Facility Board (JRFB), two advisory panels review proposals and provide science and safety advice. A U.S. scientist leads the JRFB, with other members from the scientific community, funding agencies, and the facility operator. The other IODP platforms utilize the JRFB advisory panels for drilling proposal review.

IODP participants include the United States, Japan, ECORD (Austria, Canada, Denmark, Finland, France, Germany, Ireland, Italy, the Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, and the United Kingdom), Brazil, the People's Republic of China, Korea, India, Australia, and New Zealand, with all participants except Japan providing financial contributions to *JOIDES Resolution* operations. Japan provides program support through substantial investment in *Chikyu* operations, with U.S. and Japanese scientists enjoying reciprocal rights on each drilling vessel, and through curation of *JOIDES Resolution* core samples at Japan's Kochi Core Center.

Over 3,700 scientists from 52 nations have participated on Ocean Drilling Program, Integrated Ocean Drilling Program, and International Ocean Discovery Program expeditions since 1985, including approximately 1,600 U.S. scientists from over 150 universities, government agencies, and industrial research laboratories. Samples and data have been distributed to well over 1,000 additional U.S. scientists. Scientists from these groups propose and participate in IODP cruises, are members of the program's advisory panels and groups, and supply data for planning expeditions and interpretation of drilling results.

Management and Oversight

- **NSF Structure:** The Division of Ocean Sciences (OCE) in the Directorate for Geosciences (GEO) manages IODP operations of the *JOIDES Resolution* and the IODP Science Support Office under the NSF Ocean Drilling Program (ODP). NSF's ODP is located within the Integrative Programs Section, with 1.5 program officers dedicated to its oversight. One of the program officers has responsibility for two cooperative agreements supporting *JOIDES Resolution* operations and the IODP Support Office, while the other oversees the cooperative agreement for the IODP U.S. Science Support Program (USSSP).
- **External Structure:** NSF provides the *JOIDES Resolution* as the light IODP drillship through a cooperative agreement with Texas A&M University. MEXT provides the *Chikyu* as the heavy IODP drillship through the Japan Agency for Marine-Earth Science and Technology (JAMSTEC), while the British Geological Survey manages ECORD drilling contributions through single-use Mission-Specific Platforms. Each entity providing an IODP drilling platform is responsible for sample and data storage, publications, and other science costs associated with the respective platform operations.
- **IODP *JOIDES Resolution* operations** are determined by the JRFB, utilizing advice and recommendations provided by the Science Evaluation Panel (SEP) and the Environmental Protection and Safety Panel (EPSP). Representation on the panels is determined by contribution level to *JOIDES Resolution* operations and exchange with other facility boards. NSF is a member of the JRFB.
- **Reviews:** Performance of the *JOIDES Resolution* facility is reviewed yearly by an NSF panel, in consultation with the JRFB. Substantive review of management performance regarding *JOIDES Resolution* operations occurred in the third year of the cooperative agreement (FY 2017) to guide

potential renewal or re-competition decisions. Review of scientific progress in broader thematic areas is conducted under the authority of the IODP Forum.

Renewal/Recompetition/Termination

In FY 2013, to facilitate support for drilling proposal review, advisory panel meeting logistics, and other integrative activities for scientists participating in IODP activities (e.g. websites), the IODP Science Support Office was selected at the University of California, San Diego through a competitive process for a five-year (FY 2014-FY 2018) cooperative agreement.

In FY 2014, through a competitive process, Texas A&M University was selected to be the *JOIDES Resolution* operator under a five-year (FY 2015-FY 2019) cooperative agreement. This cooperative agreement contains language encouraging the awardee to facilitate novel partnerships involving support of *JOIDES Resolution* operations between the U.S. scientific drilling community and commercial industry, thereby providing new intellectual opportunities and potential reduction in overall facility cost.

In FY 2015, to facilitate support for U.S. scientists participating on IODP platforms (i.e., salary and travel support) and for U.S. IODP education and outreach efforts, a new cooperative agreement was awarded, after competitive selection, to the Lamont-Doherty Earth Observatory (LDEO) of Columbia University for operation of the U.S. Science Support Program for a five-year period (FY 2015-FY 2019).

LARGE HADRON COLLIDER**\$22,300,000**
+\$2,300,000 / 11.5%**Large Hadron Collider**

(Dollars in Millions)

FY 2016 Actual	FY 2017 (TBD)	FY 2018 Request ¹	Change over FY 2016 Actual	
			Amount	Percent
\$20.00	-	\$22.30	\$2.30	11.5%

¹ Includes funding for High-Lumosity LHC Upgrade planning.

The Large Hadron Collider (LHC), an international instrument at the CERN (the European Organization for Nuclear Research) laboratory in Geneva, Switzerland, is the most powerful particle accelerator ever constructed. It produces the highest energy particle beams ever created, making it the premier facility in the world for research in elementary particle physics. LHC consists of a superconducting particle accelerator, approximately 16.5 miles in circumference, providing two counter-rotating proton beams with a design energy of 7 TeV (1TeV=10¹² electron volts) per beam. It can also provide colliding beams of heavy ions, such as lead. During 2011 and 2012 (“Run 1”), LHC operated at 4 TeV per beam as a result of a limitation in the electrical connections between the superconducting magnets. After the connections were upgraded during a nearly two-year shutdown, Run 2 began in mid-2015 and will continue through the end of 2018 at 6.5 TeV per beam, exploring a new energy region not accessible during Run 1.

Four large particle detectors collect the data delivered by the LHC. They characterize the reaction products from high-energy proton-proton and heavy ion beam collisions. These are analyzed to investigate the fundamental properties of matter. More than forty international funding agencies provide support for scientists to participate in experiments at the LHC. CERN is responsible for meeting overall LHC project goals and coordinating international participation. The U.S., through a partnership between the Department of Energy (DOE) and NSF, made major contributions to the construction and operation of two of the largest particle detectors, a Toroidal LHC Apparatus (ATLAS) and the Compact Muon Solenoid (CMS), while NSF additionally supports a small number of researchers who participate in the LHC-b detector.

LHC data have resulted in major scientific discoveries. Foremost of these was the July 4, 2012, announcement by the CMS and ATLAS collaborations of the discovery of a particle having properties consistent with the long-sought Higgs boson, a prediction of the Standard Model of particle physics. Its existence was a prediction of the theoretical framework describing the origin of the masses of elementary particles. The experimental confirmation of this theory was recognized by the award of the 2013 Nobel Prize in Physics to Francois Englert and Peter Higgs. Another important discovery was announced on July 14, 2015, when the LHC-b experiment reported the discovery of a class of particles known as pentaquarks, a new way to aggregate quarks (the fundamental building blocks of ordinary matter) in a way never before observed. On June 28, 2016 the same collaboration reported the observation of tetraquark states, another novel aggregation of quarks into four-quark elementary particles.

The resumed program of operation, which began in 2015, is expected to significantly enhance the chances of more groundbreaking discoveries at the LHC. For example, the LHC program includes searches for particles predicted by a powerful theoretical framework known as supersymmetry, which may provide clues as to how the known forces – weak, strong, electromagnetic, and gravitational – evolved from different aspects of the same “unified” force in the early universe.

Total Obligations for LHC

(Dollars in Millions)

	FY2016	FY2017	FY 2018	ESTIMATES ¹				
	Actual	(TBD)	Request	FY 2019	FY 2020	FY 2021	FY 2022	FY 2023
Operations & Maintenance ²	\$20.00	-	\$22.30	\$22.30	\$20.00	\$20.00	\$20.00	\$20.00

¹ Outyear funding estimates are for planning purposes only. The current cooperative agreements end in December 2021 (CMS) and January 2022 (ATLAS).

² FY 2018 and FY 2019 include funding for High-Luminosity LHC Upgrade planning.

A worldwide cyber-infrastructure, the LHC grid, is dedicated to LHC data processing, allowing scientists to remotely access and analyze vast data sets. The U.S. LHC collaboration continues to be a leader in the development and exploitation of distributed computing. The LHC grid and the Tier 2 computing centers funded by NSF enable U.S. universities to access LHC data and computing resources and thus train students in both state of the art science and computational techniques. The distributed computing tools and techniques developed for the LHC are expected to have broad application throughout the scientific and engineering communities.

The May 2014 report of the Particle Physics Project Prioritization Panel (P5) recommended to DOE and NSF that the highest priority strategic goal for the U.S. particle physics research program, within a global context, should be continued support for involvement in the LHC program. Within the scope of supported activities, they recommended a further planned upgrade of the accelerator to very high luminosity (nearly ten times the luminosity of initial operation). The high-luminosity upgrade will commence operation in mid-2026, and will facilitate precision measurements that may reveal new physics beyond the Standard Model. This will necessitate significant enhancements to the detectors in order to exploit this scientific opportunity. NSF is now working with the ATLAS and CMS detector collaborations to plan for this possibility. If approved, construction and fabrication activities would begin in FY 2020 in order to be ready for installation activities scheduled for 2024.

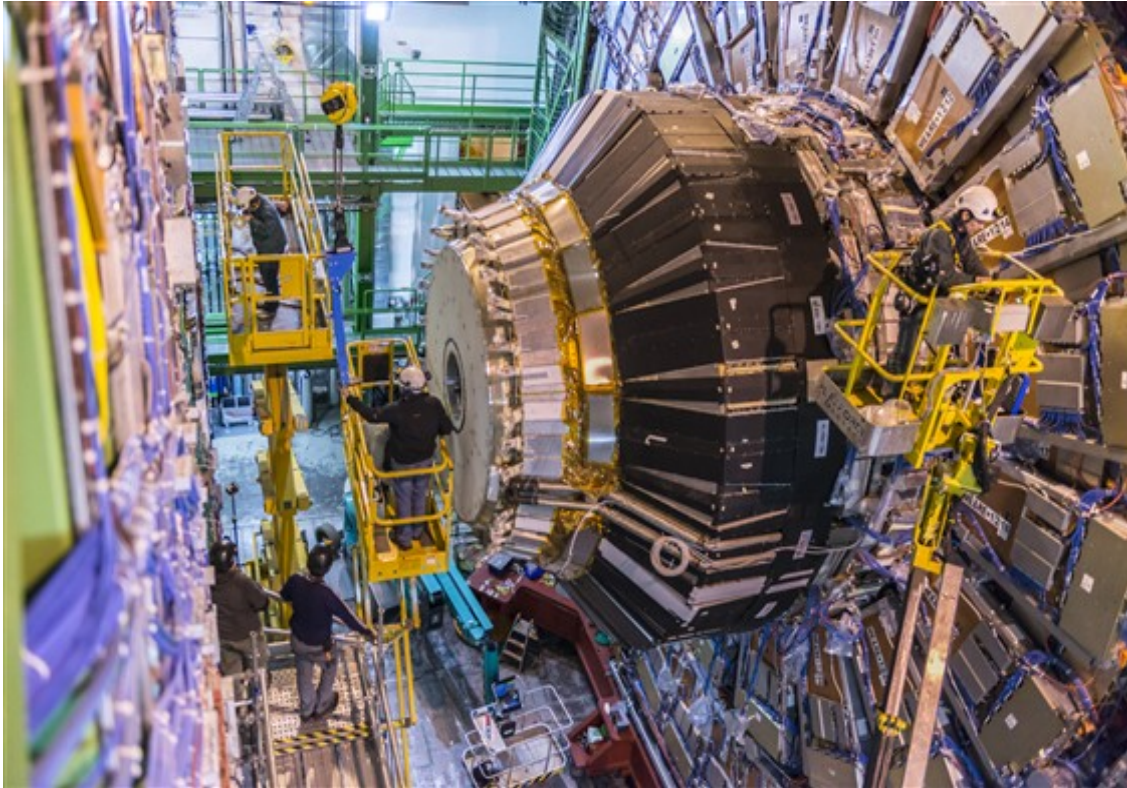
Through the participation of young investigators, graduate students, undergraduates, and minority-serving institutions in this international project, LHC serves the goal of helping to produce a diverse, globally-oriented workforce of scientists and engineers. Innovative education and outreach activities allow high school teachers and students to participate in this project.

Management and Oversight

- **NSF Structure:** A program director in the Directorate for Mathematical and Physical Sciences, Division of Physics is responsible for day-to-day project oversight. The Division of Acquisition and Cooperative Support provides financial and administrative support. An Integrated Project Team, consisting of representatives from the Mathematical and Physical Science Directorate, other experienced program officers, the Large Facilities Office, and other areas of the Office of Budget, Finance, and Award Management, contribute to the planning activities that may lead to a major construction upgrade.
- **External Structure:** U.S. program management occurs through a Joint Oversight Group (JOG), created by NSF and DOE. The JOG has the responsibility to see that the U.S. LHC program is effectively managed and executed to meet commitments made under the LHC international agreement and its protocols. NSF operations support is provided through cooperative agreements with Princeton University for US-CMS and with Stony Brook University for US-ATLAS.
- **Reviews:** There is one major management/technical review each year with a panel of external, international experts, a follow-up review six months later, as well as bi-weekly telephone reviews by NSF/DOE program directors to monitor progress. NSF and DOE conduct separate and joint external reviews of the detector upgrade activities so that each agency is fully cognizant of the activities of the other partner. The most recent major joint management/technical review was held in January 2017. Two JOG review meetings per year monitor overall program management. The most recent JOG was held in April 2017.

Renewal/Recompetition/Termination

Because of the planned incremental program of enhancements to the accelerator, along with parallel upgrades to the detectors, the LHC project is expected to be scientifically productive for at least 15 to 20 more years. Through an internal competition process among the research community, the ATLAS collaboration selected Stony Brook University to lead NSF-funded operations, while Princeton University was re-selected to continue to lead CMS operation. The U.S. ATLAS and CMS collaborations submitted renewal proposals that were successfully reviewed and approved. The new awards took effect in early 2017. The cooperative agreements end in December 2021 (CMS) and January 2022 (ATLAS).



The CMS Detector undergoing maintenance in December 2013. *Credit: CERN.*

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	FY 2017	FY 2018	ESTIMATES ¹				
	Actual	(TBD)	Request	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 (BRAAF), 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 BRAAF. 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.

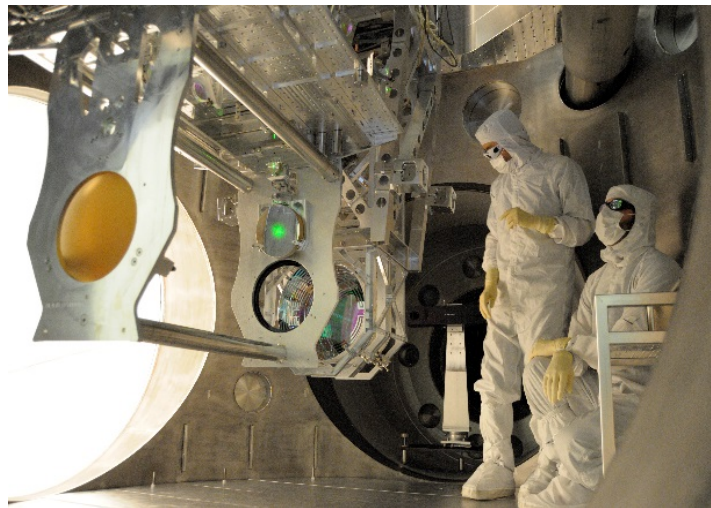
NSF continually assesses the appropriate level of financial support by monitoring actual expenditures contained in quarterly activity-based financial reports from LIGO and through annual external reviews of operation.

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 recompute 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.

NATIONAL HIGH MAGNETIC FIELD LABORATORY

\$34,770,000
-\$570,000 / -1.6%

National High Magnetic Field Laboratory

(Dollars in Millions)

FY 2016 Actual	FY 2017 (TBD)	FY 2018 Request	Change over FY 2016 Actual	
			Amount	Percent
\$35.34	-	\$34.77	-0.57	-1.6%

The National High Magnetic Field Laboratory (NHMFL) is operated by Florida State University (FSU), University of Florida (UF), and Los Alamos National Laboratory (LANL). NHMFL develops and operates high magnetic field facilities that scientists and engineers use for research in condensed matter and material physics, materials science and engineering, chemistry, biology, biochemistry, neuroscience, energy, and the environment. It is the world’s premier high magnetic field laboratory with a comprehensive collection of high-performing magnet systems and extensive support services. The facilities are available to all qualified scientists and engineers through a peer-reviewed proposal process. Users number about 1,500 per year, including faculty and staff at the three host institutions.

The laboratory is an internationally recognized leader in magnet design, development, and construction, including the development of new superconducting materials. Many unique magnet systems were designed, developed, and built by the Magnet Science and Technology (MS&T) Division of NHMFL. Since 2012, the laboratory has held the world’s record for the highest nondestructive, pulsed magnetic field at 100.75 Tesla. The 45 Tesla hybrid magnet currently provides the highest steady-state magnetic fields in the world for user access; this world record has been held for more than a decade. Recently, NHMFL’s new 36 Tesla Series-Connected Hybrid (SCH) magnet has reached its performance specification of 1 ppm stability and homogeneity, enabling the world’s first nuclear magnetic resonance (NMR) spectrum at 1.5 GHz. The previous record was set at 1.0 GHz. These magnets enable scientists to gain new insights into the electronic structures of novel materials such as graphene, topological insulators, and high temperature superconductors. MS&T works with industry and other international magnet laboratories on a variety of technology projects. These include design and construction of high field magnets, component development, coil fabrication, cryogenics, system integration, and testing.

A \$15.0 million award funded through the NSF Directorate for Mathematical and Physical Sciences, Division of Chemistry (MPS/CHE) enabled the purchase of a 21 Tesla magnet for the construction of a Fourier Transform Ion Cyclotron Resonance (FT-ICR) spectrometer. The FT-ICR instrument opened for user operations in October 2015. This 21 Tesla FT-ICR is unprecedented in sensitivity and selectivity, capable of analyzing chemical samples of great complexity, such as biological fluids, biofuels, and raw and weathered petroleum. The system impacts a broad array of research areas, such as chemistry, molecular biology, and earth science.

NHMFL is seeking funding renewal in FY 2018. The renewal proposal will allow the facility to continue operations, focus on transformational next generation magnet technology development, and further strengthen user support, education, training, and in-house research. The FY 2018 Budget Request is consistent with the very positive external review of the renewal proposal. Pending a recommendation to, and approval by, the National Science Board, NSF expects to fund the next cooperative agreement in FY 2018.

Total Obligations for NHMFL

(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 (DMR)	\$33.42	-	\$33.04	\$33.04	\$33.04	\$33.04	\$33.04	\$33.04
Operations & Maintenance (CHE)	1.92	-	1.73	1.73	1.73	1.73	1.73	1.73
Total, NHMFL	\$35.34	-	\$34.77	\$34.77	\$34.77	\$34.77	\$34.77	\$34.77

¹ Outyear funding estimates are for planning purposes only. The current cooperative agreement ends in December 2017. NSF is reviewing a renewal proposal for FY 2018.

A potential impact of continued investment is the successful construction of a high field all-superconducting magnet that would make high magnetic fields attainable at lower operating costs than the current technology. This would open the door for many laboratories across the Nation to have access to high magnetic fields and could be transformational in many research areas, particularly when combined with other probes such as X-rays, neutrons, or terahertz radiation. A major scientific impact of NHMFL for the coming years is expected to come from research on quantum materials conducted by users using the record-setting magnets at NHMFL, building on the recent achievements at NHMFL, such as the observation of Hofstadter's butterfly and fractionally quantized states in graphene; and quantum oscillations from surface states of topological insulators. Another example of a potential breakthrough is in new imaging techniques for studying the brain. Currently, Magnetic Resonance Imaging (MRI) and functional MRI have been based on imaging proton spin density and intrinsic tissue relaxation rates. With higher magnetic field strengths, NHMFL is pushing to use other nuclei, which may result in new insights into mapping the brain and neuroscience.

NHMFL collaborates with more than 60 private sector companies as well as national laboratories. These include those supported by the Department of Energy (DOE), such as Oak Ridge National Laboratory, which hosts the Spallation Neutron Source, and Argonne National Laboratory, which hosts the Advanced Photon Source. International collaboration is strong; NHMFL delivered and commissioned a 26 Tesla series connected hybrid resistive/superconducting magnet to the Helmholtz-Zentrum Berlin (HZB), where it will be used for neutron scattering experiments. Collaborations also exist with the International Thermonuclear Experimental Reactor (ITER) in France, and national magnet labs in France, the Netherlands, Germany, and China.

NHMFL provides a unique interdisciplinary learning environment. The Center for Integrating Research and Learning (CIRL) at NHMFL conducts education and outreach activities, which include a Research Experience for Undergraduates (REU) program, summer programs for teachers, a summer camp for middle school girls, and activities to raise the scientific awareness of the general public.

Management and Oversight

- **NSF Structure:** NHMFL is supported by the MPS Division of Materials Research (MPS/DMR), with the DMR program director as the primary contact for most of the laboratory. The MPS Division of Chemistry (MPS/CHE) supports the Fourier Transform Ion Cyclotron Resonance (FT-ICR) Laboratory, which is overseen by a CHE program director.
- **External Structure:** A consortium of FSU, UF, and LANL operates NHMFL under a cooperative agreement. FSU, as the agreement signatory, is responsible for administrative and financial oversight and for ensuring that lab operations are consistent with the cooperative agreement. The principal investigator, the NHMFL director, reports to the FSU Vice President for Research. Four senior faculty members are co-principal investigators. The NHMFL director receives guidance primarily from NHMFL executive committee, NHMFL science council, and NHMFL diversity committee and recommendations from an external advisory committee and the users' executive committee.
- NSF initiated a community study through the National Research Council on opportunities in high

Major Multi-User Research Facilities

magnetic field research. The 2013 report *High Magnetic Field Science and Its Application in the United States*¹⁴ was presented to the National Science Board (NSB) in May 2014. Public town halls were held at several professional meetings by both DMR and CHE. The report continues to inform future plans for investments in this area, providing several recommendations with respect to scientific priorities and new magnet developments.

- Reviews: NSF monitors annual plans and reports including user metrics and conducts monthly teleconferences with the director. NSF conducts annual external reviews, which assess the user programs, in-house research, long-term plans to contribute significant research developments both nationally and internationally, and operations, maintenance, and new facility development. Annual reviews also assess the status of education training and outreach, operations and management efficiency, and diversity plans. Recent and upcoming reviews include:
 - Renewal proposal site visit, August 29-31, 2016.
 - NSF program director site visit, November 2017.
 - Site visit review with external panel of experts, October 2018.

Renewal/Recompetition/Termination

The end date of the current award is December 31, 2017. In May 2015, the National Science Board determined that it was in the best interest of the U.S. science and engineering to renew rather than re compete the NHMFL award. A renewal proposal was submitted in May 2016 that has been reviewed by external experts and is currently under internal consideration. Pending a recommendation to, and approval by, the National Science Board, NSF expects to fund the next cooperative agreement in FY 2018.



The National High Magnetic Field Laboratory, Tallahassee, Florida site. *Credit: NHMFL*

¹⁴ www.nap.edu/catalog/18355/high-magnetic-field-science-and-its-application-in-the-united-states

**NATIONAL NANOTECHNOLOGY COORDINATED
INFRASTRUCTURE**

\$14,780,000
-\$1,550,000 /-9.5%

National Nanotechnology Coordinated Infrastructure

(Dollars in Millions)

FY 2016 Actual	FY 2017 (TBD)	FY 2018 Request	Change over FY 2016 Actual	
			Amount	Percent
\$16.33	-	\$14.78	-\$1.55	-9.5%

The National Nanotechnology Coordinated Infrastructure (NNCI) program was established in FY 2015 as the successor to the National Nanotechnology Infrastructure Network (NNIN). NNCI comprises 16 independent awards to universities around the Nation as user facility sites in nanotechnology. The NNCI sites provide the Nation’s researchers in academia, small and large companies, and government with open access to leading-edge fabrication and characterization tools, instrumentation, and expertise within all disciplines of nanoscale science, engineering, and technology, thus helping to catalyze new discoveries in science and engineering and to stimulate technological innovation. The NNCI represents a new model in which NSF selects and manages each university site in the network rather than a single lead institution with collaborating partners as in the previous NNIN, thereby providing more flexibility in awardee selection and management, and more agility in addressing emerging user facility needs in nanoscale research and education.

A Coordinating Office at Georgia Technological University was selected in FY 2016 through externally reviewed proposals from among the awarded sites to enhance the impact of NNCI as a national infrastructure network of user facility sites. The Director of the Coordinating Office is a key individual for developing management strategies and operational plans in concert with the Site Directors of the individual user facilities, and serves as a principal contact person with NSF. The individual NNCI sites have autonomy in their operation and management, but are required to act in concert with the Coordinating Office. The Coordinating Office is establishing a comprehensive web portal (www.NNCI.net) to ensure close linkage among the individual facility websites to present a unified face to the user community of overall tools, instruments, and capabilities. It is harmonizing capabilities for modeling and simulation across sites and interaction with NanoHUB of the NSF-supported Network for Computational Nanotechnology (NCN). It is coordinating and disseminating best practices for national-level education and outreach programs, as well as instruction across sites in social and ethical implications of nanotechnology. It is establishing uniform methods for assessment and quantifiable metrics of site performance and impact. It is also engaging all sites in a planning process to explore emerging areas of nanoscale science, engineering, and technology that can lead to new research opportunities and future growth of the external user base.

The broad scope of NNCI sites includes materials, structures, devices, and systems in areas of physics, chemistry, materials sciences, mechanical systems, geosciences, geophysical, geochemical, environmental sciences, biology, life sciences, and synthetic biology. Also included are: fabrication in soft matter, including biological interfaces; biomedicine; electronics; optics; magnetics; molecular synthesis and molecular scale devices; and manufacturing concepts. Modeling and simulation, social and ethical implications of nanotechnology, and education and outreach are additional areas. The individual award sites are intended to support a rich user base with broad accessibility and affordable user fee structure. NSF funds leverage those of universities and other resources to grow the numbers of external users, including users from companies and academia. NNCI sites embrace a culture of open access to researchers for any research project of merit, with protection of intellectual property, and mechanisms for encouraging non-traditional users from diverse disciplines. They also have an organizational structure that facilitates coordination of complex process steps and tools for integrated tasks and acceptance of experimental risks associated with

Major Multi-User Research Facilities

non-standard processes and materials.

Nanotechnology facilities provide unique opportunities to infuse innovative education with research at the frontiers of the field. NNCI sites are providing focused strategies for integrating pioneering science and engineering with education, including plans for assessing effectiveness and spreading promising practices. NNCI sites having particular expertise in the social and ethical implications of nanotechnology have integrated study and dissemination of those aspects into their proposals that can leverage their user community base, which relate to the capabilities of their respective user facilities.

During their first full year of operation, from October 2015 through September 2016, NNCI sites have served a total of 10,675 unique users who performed a significant part of their experimental work using NNCI facilities. Of these, 2,561 (24 percent) were external users: 1,151 external academic, and 1,410 from industry.

Total Obligations for NNCI

(Dollars in Millions)

	FY 2016	FY 2017	FY 2018	Estimates ¹				
	Actual	(TBD)	Request	FY 2019	FY 2020	FY 2021	FY 2022	FY 2023
Operations and Maintenance	\$16.33	-	\$14.78	\$15.46	\$15.46	\$15.46	\$15.46	\$15.46

¹ Outyear funding estimates are for planning purposes only. The current cooperative agreement ends in FY 2019.

Management and Oversight

- **NSF Structure:** Post-award oversight is performed under the guidance of the NSF lead program officer and directorate working group members to monitor progress of the award and award accomplishments.
- **External Structure:** The NNCI Coordinating Office is led by a Director, Deputy Director, and three Associate Directors who manage the network in specific areas: education and outreach programs, societal and ethical implications (SEI) activities, and computational activities and facilitates interactions with nanoHUB/NCN at Purdue University. The core staff is guided by an Executive Committee which includes the 16 NNCI site directors. The Executive Committee meets monthly via teleconference/WebEx and annually in person at the NNCI Conference. The Executive Committee and Coordinating Office are advised by an External Advisory Board comprised of members representing industry, academia, government, education and outreach, SEI, computation and non-traditional disciplines in nanoscience and nanoengineering. Several subcommittees of the Executive Committee have been formed to address high-level issues related to the NNCI network, such as new equipment and research opportunities, workforce development, diversity, and building the user base. An annual NNCI Conference organized by the NNCI CO will be held at different network sites to highlight the research supported by the NNCI facilities and to provide a venue to share best practices.
- **Reviews:** Reviews are being conducted through annual reverse site reviews at NSF; on-site reviews, particularly for the larger funded sites, may be held. A Business Systems Review will be held once within the five-year period of the award. The awardees will submit comprehensive annual project reports to NSF in advance of each annual review. The annual project reports will contain a program plan and budget for the next year's funding increment. Each annual review of a site will focus on the quality of performance and management under the cooperative agreement. Data collection will be consistent with NSF policies for information collection.

Renewal/Competition/Termination

The initial NNCI award is for five years and may be renewed once for an additional five years, subject to external merit review. Limited new competitions may be held, based on availability of funds, to address critical needs in nanotechnology or to replace non-performing sites or the CO.

NATIONAL SUPERCONDUCTING CYCLOTRON LABORATORY **\$23,000,000**
-\$1,000,000 / -4.2%

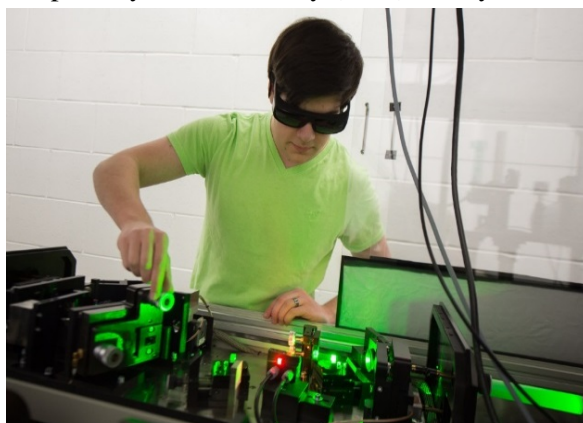
National Superconducting Cyclotron Laboratory

(Dollars in Millions)

FY 2016 Actual	FY 2017 (TBD)	FY 2018 Request	Change over FY 2016 Actual	
			Amount	Percent
\$24.00	-	\$23.00	-\$1.00	-4.2%

The National Superconducting Cyclotron Laboratory (NSCL) at Michigan State University (MSU) is a university-based national user facility. With two linked superconducting cyclotrons, K500 and K1200, it is the leading rare isotope research facility in the U.S. and is a world leader in nuclear physics with the unique capability of producing radioactive beams at energies relevant to nuclear astrophysics. Funding for NSCL also supports the research program of the MSU nuclear science faculty.

NSCL scientists employ a range of tools for conducting advanced research in fundamental nuclear science, nuclear astrophysics, and accelerator physics. Applications of research conducted at NSCL benefit society in numerous areas, including studies on the effects of ionizing radiation on DNA, tests of detectors to be used in space missions, development of data acquisition systems and software, and homeland security. The K500 was the first cyclotron to use superconducting magnets, and the K1200 is the highest-energy continuous beam accelerator in the world. Through the Coupled Cyclotron Facility (CCF), heavy ions are accelerated by the K500 and then injected into the K1200, enabling the production of rare unstable isotopes at much higher intensities. The laboratory has commissioned an MSU-funded reaccelerator facility (ReA3) that enables experiments at very low energies—a domain of particular interest to nuclear astrophysics. NSCL is the only facility in the world to provide radioactive beams in this energy regime. Nearly one third of recently proposed experiments will use the ReA3. The mix of experiments is determined by beam use proposals. An external program advisory committee selects the best proposals at a typical success rate of about 50 percent, with constraints on beam availability. The science output of NSCL is driven by these experiments, with most running five to fifteen days.



Graduate student Andrew Miller aligning instrumentation on an optical table. Credit: NSCL and MSU

Scientists at NSCL work at the forefront of rare isotope research. They make and study atomic nuclei that cannot be found on Earth and perform experimental research using beams of unstable isotopes to extend our knowledge of new types of nuclei, many of which are important to an understanding of stellar processes. Research activities include a broad program in nuclear astrophysics studies, the studies of nuclei far from stability using radioactive ion beams, and studies of the nuclear equation of state. In addition, research is carried out in accelerator physics.

NSCL supports and enhances doctorate graduate education and post-doctoral research experiences. About 10 percent of all doctorates granted in nuclear physics in the U.S. are based on research at NSCL. The lab also provides research experiences for undergraduate students, K-12 students, and K-12 teachers.

Total Obligations for NSCL

(Dollars in Millions)

	FY 2016	FY 2017	FY 2018	ESTIMATES ¹				
	Actual	(TBD)	Request	FY 2019	FY 2020	FY 2021	FY 2022	FY 2023
Operations & Maintenance	\$24.00	-	\$23.00	\$24.50	\$24.50	\$24.50	-	-

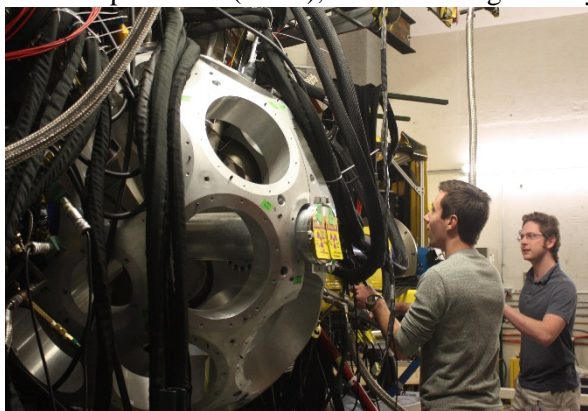
¹ Outyear funding estimates are for planning purposes only. The current cooperative agreement ends in FY 2021, after which the NSF-managed NSCL will transition to the DOE-managed FRIB.

Management and Oversight

- **NSF Structure:** MSU operates NSCL under a cooperative agreement with NSF. NSF oversight is provided through annual site visits by the cognizant program officer of the NSF Directorate for Mathematical and Physical Sciences, Division of Physics (MPS/PHY) and other staff, accompanied by external experts. The NSF program officer monitors lab operations and plans through monthly phone conferences with the NSCL director. NSF uses the annual site visit reviews to assess the user program, operations, maintenance, facility efficiency, national and international research developments, and the in-house research programs.
- **External Structure:** MSU provides additional support for NSCL, which is managed by a director and three associate directors (experimental research, education & outreach, and operations) as well as a chief scientist. The director has the authority to appoint associate directors and designate responsibilities, notifying NSF of changes. NSCL’s research program is guided by a program advisory committee of external experts as well as an in-house expert and the chairperson of the NSCL user group. Opportunities for proposal submission occur once a year and the beam hour backlog is no longer than two years. Optimally the laboratory can provide about 5,000 beam hours to the scientific community each year, with actual output depending upon facility reliability factors and available funds.
- **Reviews:**
 - An in-depth review in FY 2016 covered results and achievements related to intellectual merit and broader impacts for the past four years (FY 2012-FY 2015) as well as a review of proposed research, operations, and maintenance funding for the next five years (FY 2017-FY 2021).
 - The most recent regular annual review took place in April 2017.

Renewal/Recompetition/Termination

With the approval of the National Science Board, NSF established a cooperative agreement with MSU for a five-year renewal award to support the research program and operation of NSCL from FY 2016 through FY 2021. NSCL will transition to the new Facility for Rare Isotope Beams (FRIB), which is being built by the Department of Energy (DOE) on the NSCL site. FRIB is scheduled to become operational in FY 2022 and will use much of the NSCL beamlines, instrumentation, and general infrastructure. NSF anticipates ending support for the operations component of NSCL when CCF operations cease so that FRIB can be integrated into the NSCL beamlines and become operational. MSU will be the performing institution under a cooperative agreement with DOE for the future FRIB. To facilitate interagency planning and to coordinate the transition from the NSF-funded NSCL to the DOE-funded FRIB, a Joint Oversight Group (JOG) of DOE and NSF personnel has been meeting since 2010. DOE and NSF will coordinate this transfer of facility stewardship.



Postdoc Joe Belarge and graduate student Eric Lunderberg set up GRETINA (Gamma-Ray Energy Tracking In-beam Nuclear Array) for an experiment. *Credit: NSCL and MSU.*

**NATURAL HAZARDS ENGINEERING RESEARCH
INFRASTRUCTURE**

\$11,750,000
-\$1,250,000 / -9.6%

Natural Hazards Engineering Research Infrastructure
(Dollars in Millions)

FY 2016 Actual	FY 2017 (TBD)	FY 2018 Request	Change over FY 2016 Actual	
			Amount	Percent
\$13.00	-	\$11.75	-\$1.25	-9.6%

The Natural Hazards Engineering Research Infrastructure (NHERI) is the next generation of NSF support for a multi-user, natural hazards engineering research facility, replacing the George E. Brown, Jr. Network for Earthquake Engineering Simulation (NEES). NEES was established by NSF as a distributed, multi-user, national research infrastructure for earthquake engineering research through support of a facility construction phase during 2000-2004, followed by support of an operations phase for research, innovation, and education activities from October 2004 through September 2014. NEES was supported by NSF during FY 2010–2014 through a cooperative agreement with Purdue University. The NEES infrastructure included 14 earthquake engineering experimental facilities and an integrative cyberinfrastructure. During FY 2015, NSF’s cooperative agreement with Purdue University was extended to continue support for cyberinfrastructure operations during the NSF open competition to establish NHERI via program solicitations NSF 14-605 and NSF 15-598.

NHERI is a distributed, multi-user, national research facility that provides the natural hazards engineering research community with access to research infrastructure (earthquake and wind engineering experimental facilities; post-disaster, rapid response research (RAPID) facility; cyberinfrastructure; computational modeling and simulation tools; and research data), coupled with education and community outreach activities. Building upon NEES, NHERI enables new discovery and knowledge through enhanced capacity to test and derive more comprehensive, complete, and accurate models of how constructed civil infrastructure responds to earthquake and wind loading. This will enable the design of new methodologies, modeling techniques, and technologies for earthquake, windstorm, and multi-hazard risk reduction. Research conducted using NHERI supports two federal interagency programs: the National Earthquake Hazards Reduction Program and the National Windstorm Impact Reduction Program.

During FY 2015 and FY 2016, NHERI was established by NSF through eleven cooperative agreements:

- Network Coordination Office (NCO) at Purdue University,
- Cyberinfrastructure (CI) at the University of Texas at Austin,
- Computational Modeling and Simulation Center (SimCenter) at the University of California, Berkeley,
- Twelve-Fan Wall of Wind at Florida International University,
- Large-Scale, Multi-Directional, Hybrid Simulation Testing Capabilities at Lehigh University,
- Large Wave Flume and Directional Wave Basin at Oregon State University,
- Geotechnical Centrifuges at the University of California, Davis,
- Large, High-Performance Outdoor Shake Table at the University of California, San Diego,
- Boundary Layer Wind Tunnel, Wind Load and Dynamic Flow Simulators, and Pressure Loading Actuators at the University of Florida,
- Large, Mobile Dynamic Shakers for Field Testing at the University of Texas at Austin, and
- RAPID Facility at the University of Washington.

Major Multi-User Research Facilities

The NCO serves as the national and international scientific leader, community focal point, and network-wide coordinator for NHERI governance and community-building activities. Key activities include convening the governance groups, working with the Council of Awardees to develop consensus-based policies and procedures for NHERI and the annual Council work plan, implementing the facility scheduling protocol to provide user access to the experimental facilities, leading development of a community science plan, running NHERI-wide education and community outreach programs, and building strategic partnerships. The NHERI awardees and the natural hazards engineering community work together, through governance and awardee activities, to establish a shared vision for NHERI, set natural hazards engineering research and education agendas and priorities, and make NHERI a value-added and productive research infrastructure.

The CI awardee serves as the integrator for enabling NHERI to be a virtual organization for the natural hazards engineering community, by providing an array of information, resources, and services, including the definitive NHERI website; data repository (Data Depot); software service delivery platform with computational modeling, simulation, and educational tools; collaboration tools; access to high performance computing resources; and user training and support. The CI awardee also establishes and implements the NHERI-wide cybersecurity plan with all NHERI awardees.

The SimCenter is developing a portfolio of computational modeling and simulation software and educational modules that reflects a balance of community-prioritized, new capabilities for earthquake, wind, and multi-hazard engineering research and education. The SimCenter’s tools will be integrated into the CI awardee’s software service delivery platform.

The experimental facilities provide well-maintained and fully functioning facilities, services, and staffing to enable earthquake engineering, wind engineering, and post-disaster, rapid response research requiring experimental work and data collection. Data generated by these experimental resources and their users are archived and shared in the publicly accessible NHERI Data Depot.

Along with direct operations and maintenance support for NHERI awardees, NSF provides separate support for research to be conducted at the NHERI experimental facilities through ongoing research and education programs. The support for such activities is primarily provided through the Engineering for Natural Hazards (ENH) core research program in the Civil, Mechanical and Manufacturing Innovation (CMMI) division in the Directorate for Engineering (ENG). The ENH program supports fundamental research in single and multi-hazard engineering involving experimental and computational simulations at the NHERI facilities, addressing important challenges in mitigating the impact of natural hazards on constructed civil infrastructure. With the aim of integrating research and education, NHERI engages students through on-site use of experimental facilities, telepresence technology, experimental and simulation data, and computational resources. Coordinated by the NCO, starting in FY 2017, NHERI awardees also will run an annual Research Experiences for Undergraduates (REU) program and a Summer Institute.

Total Obligations for NHERI

(Dollars in Millions)

	FY 2016	FY 2017	FY 2018	Estimates ¹				
	Actual	(TBD)	Request	FY 2019	FY 2020	FY 2021	FY 2022	FY 2023
Operations and Maintenance	\$13.00	-	\$11.75	\$12.50	\$12.00	\$12.00	\$12.00	\$12.00

¹ Outyear funding estimates are for planning purposes only. The current cooperative agreement ends in FY 2019.

Management and Oversight

- NSF Structure: The NSF program officer for NHERI is located within ENG/CMMI. The Office Head of the Large Facilities Office in the Office of Budget, Finance and Award Management provides advice and assistance.
- External Structure: Each NHERI awardee is led by a principal investigator (PI), who is responsible for the overall award operations. The NCO awardee coordinates NHERI governance and network activities. Governance is comprised of the following groups: (a) a Council, which consists of the PI of each NHERI award, to provide collective and coordinated leadership for NHERI as a national facility, (b) Network Independent Advisory Committee, with diverse representation from the broad scientific and engineering communities served by NHERI, to provide independent external guidance and advice to the Council, (c) User Forum, consisting of representatives from the broad scientific and engineering communities served by NHERI, and (d) Council-identified committees, comprised of internal awardee staff and/or users, to advise the Council on community priorities and needs for NHERI.
- Reviews: NSF will provide oversight to NHERI awardees through cooperative agreements. Individual and joint awardee operations and activities will be reviewed through quarterly and annual project reports submitted by awardees and site visit reviews conducted by NSF. Site visit reviews will include the following:
 - Site visit merit reviews:
 - Annually for NCO, CI, and SimCenter awardees;
 - For EF awardees: Up to four facilities will receive site visits each year.
 - NSF Business Systems Review, for each awardee, to be conducted within the first two years of the award.

Renewal/Competition/Termination

In FY 2010, NSF supported two studies to assess the need for earthquake engineering experimental and cyberinfrastructure facilities beyond 2014, as described in the Dear Colleague Letter NSF 10-071.¹⁵ One study, a workshop held by the National Research Council on the Grand Challenges in Earthquake Engineering Research, was completed in FY 2011; and the second study was completed in FY 2012. These studies provided input to NSF for the determination of support for future earthquake engineering research infrastructure beyond FY 2014. The plan to support a smaller successor NEES (NEES2) during FY 2015-FY 2019 was presented to the National Science Board at their July 2012 meeting and described in the Dear Colleague Letter NSF 12-107.¹⁶ The plan would result in a lower annual operations budget, reflected in the \$8.0 million reduction from FY 2014 in the FY 2015 Budget Request, from \$20.0 million to \$12.0 million, and allow additional investments to be made in earthquake engineering research.

- In 2012, the National Institute of Standards and Technology and NSF jointly supported a workshop that led to a roadmap report for measurement science research and development for windstorm and coastal inundation impact reduction, which was published in January 2014.¹⁷
- In February 2013, NSF released solicitation NSF 13-537 to compete and operate NEES2 for FY 2015-FY 2019. Based on the merit review of proposals submitted under NSF 13-537, NSF made no award.
- Based on the above studies and report, NSF established the plan for NHERI in FY 2014. This led to the release of solicitations NSF 14-605 and NSF 15-598 to establish NHERI through two competitions. NHERI operations awards are supported for a five-year period. The NCO, working with the natural hazards engineering research and education community, is developing the NHERI Science Plan. ENG will separately support the development of a post-NHERI decadal science plan for natural hazards engineering research, education, and research infrastructure. NSF will use this decadal science plan as input for natural hazards engineering research infrastructure support beyond 2019.

¹⁵ <http://nsf.gov/pubs/2010/nsf10071/nsf10071.jsp>

¹⁶ www.nsf.gov/pubs/2012/nsf12107/nsf12107.jsp

¹⁷ www.nist.gov/customcf/get_pdf.cfm?pub_id=915541

Major Multi-User Research Facilities



The University of California, San Diego (UCSD) outdoor shake table allows large structures to be tested against seismic activity. Here, a wooden building shows damage after testing on the UCSD shake table.

Credit: UCSD/Jacobs School of Engineering

OCEAN OBSERVATORIES INITIATIVE

\$31,000,000
-\$23,980,000/ -43.6%

Ocean Observatories Initiative

(Dollars in Millions)

FY 2016 Actual	FY 2017 (TBD)	FY 2018 Request	Change over FY 2016 Actual	
			Amount	Percent
\$54.98	-	\$31.00	-\$23.98	-43.6%

The Ocean Observatories Initiative (OOI) began in FY 2009 as a Major Research Equipment and Facilities Construction (MREFC) project. In FY 2016, OOI transitioned from the MREFC construction effort to the management and operation phase and is now referred to as the OOI Program.

OOI is a networked ocean-focused research observatory with arrays of instrumented buoys, profilers, gliders, and autonomous vehicles within different open-ocean and coastal regions, as well as a cabled array of instrumented platforms and profilers on or above the seafloor over the Juan de Fuca tectonic plate. This networked system of instruments, platforms, and arrays enables researchers to examine complex, interlinked physical, chemical, biological, and geological processes operating throughout the coastal regions and to investigate a spectrum of phenomena and processes including episodic, short-lived events (meteorological, tectonic, volcanic, geological, geophysical, and ecological), and more subtle, long-term changes and emergent phenomena in ocean systems (circulation patterns, climate change, ocean acidity, geophysical events, and ecosystem trends).

The OOI facility provides the public, educators, students, and researchers with: (1) OOI long-term time series data sets (raw data and metadata are processed via conventional algorithms and quality control methods); (2) an in-situ ocean laboratory capability to allow OOI users to submit proposals for development and application of new technologies by connecting their instruments or concepts to the OOI network; and (3) OOI tools that will support undergraduate classroom applications of the OOI, as well as public outreach through informal education. The OOI delivers all data/metadata and education tools to the public via the internet at www.oceanobservatories.org.

The overarching scientific themes of the OOI span six multi-disciplinary domains, and each theme incorporates a multitude of research questions.

- *Ocean-Atmosphere Exchange*. Quantifying the air-sea exchange of energy and mass, especially during high winds, is critical to providing estimates of energy and gas exchange between the surface and deep ocean, and improving the predictive capability of storm forecasting and climate-change models.
- *Climate Variability, Ocean Circulation, and Ecosystems*. As both a reservoir and distributor of heat and carbon dioxide, the ocean modifies climate, and is also affected by it. Understanding how climate variability will affect ocean circulation, weather patterns, the ocean’s biochemical environment, and marine ecosystems is a compelling driver for multidisciplinary observations.
- *Turbulent Mixing and Biophysical Interactions*. Mixing occurs over a broad range of scales and plays a major role in transferring energy, materials, and organisms throughout the global ocean. Mixing has a profound influence on primary productivity, plankton community structure, biogeochemical processes (e.g., carbon sequestration) in the surface and the deep ocean, and the transport of material to the deep ocean.
- *Coastal Ocean Dynamics and Ecosystems*. Understanding the spatial and temporal complexity of the coastal ocean is a long-standing challenge. Quantifying the interactions between atmospheric and terrestrial forcing, and coupled physical, chemical, and biological processes, is critical to elucidating

Major Multi-User Research Facilities

the role of coastal margins in the global carbon cycle, and developing strategies for managing coastal resources.

- *Fluid-Rock Interactions and the Subseafloor Biosphere.* The oceanic crust contains the largest aquifer on Earth. Thermal circulation and reactivity of seawater-derived fluids modifies the mineralogy of oceanic crust and sediments, leads to the formation of hydrothermal vents that support unique micro- and macro-biological communities, and concentrates methane to form massive methane gas and methane hydrate reservoirs. The role that transient events (e.g., earthquakes, volcanic eruptions, and slope failures) play in these fluid-rock interactions and in the dynamics of benthic and sub-seafloor microbial communities remain largely unknown.
- *Plate-Scale, Ocean Geodynamics.* Lithospheric movements and interactions at plate boundaries at or beneath the seafloor are responsible for short-term events such as earthquakes, tsunamis, and volcanic eruptions. These tectonically active regions are also host to the densest hydrothermal and biological activity in the ocean basins. The degree to which active plate boundaries influence the ocean from a physical, chemical, and biological perspective are largely unexplored.

Current Status

The OOI infrastructure is operating, transmitting ocean data to storage, and incrementally delivering processed datasets and data products via the website. Refurbishment and redeployments of the moorings, instruments, and platforms are planned and being executed. Data quality management is maturing and the OOI Science Team is conducting outreach to the science community on the quality assurance/quality control (QA/QC) methods and procedures being used. The OOI Management & Operation (M&O) budget for FY 2016 was \$54.98 million.

The planned FY 2018 budget is \$31.0 million. The scope of OOI activities at this funding level will be determined through the ongoing re-competition for a new management and operations award as described below in the Renewal/Recompetition/Termination section. The solicitation requests submission of proposals which include the costs for all parts, labor, equipment, ship time, and cyberinfrastructure to manage, operate, and maintain the OOI. Planned OOI Program adjustments include suspension of all Global Array operations and streamlined cyberinfrastructure and management oversight. Deployed Coastal OOI instruments are visited and replaced twice per year.

Total Obligations for OOI

(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	\$55.00	-	\$31.00	\$31.00	\$31.00	\$31.00	\$31.00	\$31.00

¹ Outyear funding estimates are for planning purposes only.

The Consortium for Ocean Leadership (COL) is the current awardee for OOI operations and maintenance, but has publicly announced they will not be part of the recompetition. COL has major sub-awardees on the program team to operate and maintain the marine infrastructure, manage the scientific data, and operate the cyberinfrastructure. The University of Washington operates the OOI Cabled Array. Oregon State University operates the Coastal Endurance Array. Woods Hole Oceanographic Institution operates the Pioneer Coastal Array as well as the Global Arrays at the four OOI Global sites. Rutgers University manages the OOI data as well as the cyberinfrastructure and Education and Public Outreach. Raytheon Corporation provides project management support, systems engineering, and software services for the OOI cyberinfrastructure.

Management and Oversight

- NSF Structure: The Division of Ocean Sciences (OCE) in the Directorate for Geosciences (GEO) manages OOI operations located within the Integrative Programs Section. The oversight includes the

review of observatory metrics and data quality management, as well as integration of the OOI with any new science or infrastructure proposals.

- **External Structure:** The OOI Program has a Science Oversight Committee (SOC) which provides input and guidance internally to Ocean Leadership for OOI infrastructure planning and management. In FY 2017, NSF established the nine member “Ocean Observatories Initiative Facility Board’ (OOIFB) to provide input and guidance regarding the management and operation of the OOI. The OOIFB is independent of the SOC.
- **Reviews:** In December 2016, NSF conducted a review of the OOI Cyberinfrastructure component. NSF is considering a management and operations review in calendar year 2017 before the award end date of December 31, 2017.

Operations Costs

Management and operations in support of scientific research began in FY 2013 with the deployment of the first OOI instruments. The associated costs have been and will continue to be supported by OCE, with temporary support from the GEO’s Division of Integrative and Collaborative Education and Research (ICER) from FY 2015-FY 2017 (now completed). Support for research utilizing observatory data will be through the standard NSF proposal submission process to existing science programs in OCE, however, because the data is freely available over the internet, researchers around the world will have access to the unique data sets OOI is producing regardless of the source of their support.

Education and Outreach

The OOI website and infrastructure provides an education portal to enable undergraduate level tools for education. The internal OOI Science Oversight Committee actively conducts outreach activities regarding the ocean science datasets to researchers, public and education users.

Renewal/Recompetition/Termination

The OOI management and operation cooperative agreement with COL ends December 31, 2017. A re-competition for the award was initiated in FY 2016 and is planned for completion by December 31, 2017.

POLAR FACILITIES AND LOGISTICS**\$284,960,000**
-\$23,360,000 / -7.6%**Polar Facilities and Logistics**

(Dollars in Millions)

	FY 2016 Actual	FY 2017 (TBD)	FY 2018 Request	Change over FY 2016 Actual	
				Amount	Percent
Polar Facilities	\$196.53	-	\$177.85	-\$18.68	-9.5%
Polar Logistics	111.79	-	107.11	-4.68	-4.2%
Total, Polar Facilities and Logistics	\$308.32	-	\$284.96	-\$23.36	-7.6%

Polar Facilities

The Office of Polar Programs (OPP) within the Directorate for Geosciences (GEO) provides the infrastructure needed to support U.S. research conducted in Antarctica, including research funded by NSF and by U.S. mission agencies, for year-round work at three U.S. stations, on two research ships, and at a variety of remote field camps. Support to other agencies includes mission-essential satellite communications support at McMurdo Station for the Joint Polar Satellite System (JPSS), and the National Aeronautics and Space Administration's (NASA) Ground Networks for the relay of data. Through a partnership with the National Oceanic and Atmospheric Administration (NOAA), NASA, and the European Organization for the Exploitation of Meteorological Satellites (EUMETSAT), OPP supports the relay of real-time satellite-based weather information that informs global forecasting. In addition, OPP enables important climate monitoring activities for NOAA at the Clean Air Facility at South Pole Station, one of only five such sites around the globe. OPP also provides support for: NASA's Long Duration Balloon program that enables research in fields ranging from astrophysics to cosmic radiation to solar astronomy; the South Pole Remote Earth Science and Seismological Observatory (SPRESSO), the most seismically-quiet station on earth and a key site contributing to U.S. activities associated with the Comprehensive Test Ban Treaty and to U.S. Geological Survey (USGS) and NSF efforts for global seismic monitoring; and access to sites that are key to precise orbit determinations for optimizing use of the Global Navigation Satellite System (GNSS).

All support for these activities is provided by OPP, including transportation, facilities, communications, utilities (water and power), health and safety infrastructure, and environmental stewardship. The U.S. Antarctic Program (USAP) maintains the U.S. presence in Antarctica in accordance with U.S. policy, and supports Antarctic Treaty administration under State Department leadership.

Total Obligations for Polar Facilities

(Dollars in Millions)

	FY 2016 Actual	FY 2017 (TBD)	FY 2018 Request	ESTIMATES ¹				
				FY 2019	FY 2020	FY 2021	FY 2022	FY 2023
Antarctic Infrastructure and Logistics	\$196.53	-	\$177.85	\$177.85	\$177.85	\$177.85	\$177.85	\$177.85
Total, Polar Facilities	\$196.53	-	\$177.85	\$177.85	\$177.85	\$177.85	\$177.85	\$177.85

¹ Outyear funding estimates are for planning purposes only.

OPP contracts with a prime contractor for science support, operations, the leasing of research vessels, and the maintenance of the Antarctic stations and related infrastructure in New Zealand and Chile. The contractor is selected through a competitive process. Rotary and fixed-wing aircraft used in support of research are also provided through separate competitively-awarded contracts. Other agencies and

contractors provide technical support in areas of expertise such as engineering, construction, and communications. Following a major refurbishment program, the U.S. Coast Guard's (USCG) *Polar Star* returned to service in 2014 and is successfully providing annual icebreaking services for the McMurdo Station resupply effort.

Management and Oversight

- NSF Structure: OPP staff, including subject matter experts in operational and scientific disciplines, have overall responsibility for funding and managing Polar Facilities under the USAP; NSF budgets for and manages USAP on behalf of the Nation. This includes planning all activities and overseeing contractors. OPP's Antarctic Sciences section funds merit-reviewed research proposals for which access to Antarctica is essential to advancing the scientific frontiers and that can only be achieved or are best achieved with research work in/on Antarctica and the Southern Ocean. Research is conducted in a broad array of geo- and bio- sciences, including earth system science, and space and astrophysical sciences. The Antarctic Infrastructure & Logistics section enables research in Antarctica on behalf of the U.S. government through a network of stations, labs, equipment, and logistical resources. The Environment, Health, and Safety section oversees the environmental, health, and safety aspects of research and operations conducted in Polar Regions.
- External Structure: The Antarctic prime support contract is currently held by Leidos Innovations Corporation. There are many separate subcontractors for supplies and technical services, and other services are procured through separate competitively-bid contracts.
- Reviews: OPP evaluates the performance of the Antarctic support contractor annually via an Award Fee Plan, which involves multiple tiers of review, including a Performance Evaluation Board (PEB) composed of representatives from OPP and the Office of Budget, Finance, and Award Management (BFA). In addition, OPP's performance is reviewed externally by Committees of Visitors and the Office of Polar Programs Advisory Committee. The USAP Blue Ribbon Panel (BRP) released a report on its review of the program in July 2012.¹⁸ The NSF response to the USAP BRP report was released in March 2013.¹⁹



Helicopters provide support to field parties in the McMurdo Dry Valleys in southern Victoria Land and at remote field camps. Credit: Kristan Hutchison, RPSC

Current Status

- All facilities (stations, research vessels, and field camps) are currently operating normally.
- The USAP BRP report concluded that ushering in a new age of Antarctic science simply by expanding traditional methods of logistical support would be prohibitively costly. Instead, it recommended numerous ways to more efficiently and cost-effectively support research while maintaining high standards of safety and increasing the flexibility to support evolving science foci in the future. Continued progress is planned to implement BRP recommendations, including investment in prioritized lifecycle acquisitions. Priority will also be given to site work that would be needed to support implementation of the Antarctic Infrastructure Modernization for Science (AIMS) project, currently moving toward the final stages of design. The AIMS project will redevelop McMurdo Station to be a consolidated, more efficient facility. Also included are utilities distribution and fire protection. Plans are under development to upgrade satellite communications systems to support operations and research and to replace the Palmer Station pier to ensure long-term access to unique research in the peninsula region.

¹⁸ www.nsf.gov/od/opp/usap_special_review/usap_brp/rpt/index.jsp

¹⁹ www.nsf.gov/od/opp/usap_special_review/usap_brp/rpt/nsf_brp_response.pdf

Renewal/Re-competition/Termination

- In FY 2012, Lockheed Martin Corporation, now the Leidos Innovations Corporation, was awarded a 13.5 year contract, consisting of a five-year base period and four option periods, exercised on the basis of performance, that total an additional 8.5 years.
- Contracts for fixed and rotary wing support are managed as assisted acquisitions by the Department of Interior, Office of Aviation Services. A five-year contract for helicopter support was awarded to PHI, Inc. of Lafayette, Louisiana, in May 2013. A five-year contract for fixed-wing aviation services, currently held by Kenn Borek Air of Calgary, Canada, is now under competition.
- U.S. policy directs NSF to maintain an active and influential presence in Antarctica, including year-round occupation of South Pole Station and two coastal stations. As the scientific forefronts addressed there evolve over time, so do the research emphases at the three stations and the infrastructure needed to support them.

Polar Logistics

Polar Logistics consists of two activities: the U.S. Antarctic Logistical Support program within the Antarctic Infrastructure and Logistics section, and the Research Support and Logistics program within the Arctic Sciences section.

Total Obligations for Polar Logistics

(Dollars in Millions)

	FY 2016 Actual	FY 2017 (TBD)	FY 2018 Request	ESTIMATES ¹				
				FY 2019	FY 2020	FY 2021	FY 2022	FY 2023
U.S. Antarctic Logistical Support	\$67.52	-	\$71.00	\$71.00	\$71.00	\$71.00	\$71.00	\$71.00
Arctic Research Support and Logistics	44.27	-	36.11	36.11	36.11	36.11	36.11	36.11
Total, Polar Logistics	\$111.79	-	\$107.11	\$107.11	\$107.11	\$107.11	\$107.11	\$107.11

The U.S. Antarctic Logistical Support program funds support activities provided by the U.S. Department of Defense (DoD). DoD operates as a logistical support provider on a cost-reimbursable basis. Major funding elements of DoD support include: military personnel, LC-130 flight operations, and maintenance support through the 109th Airlift Wing of the New York Air National Guard in Scotia, New York, and Antarctica; transportation and training of military personnel supporting the USAP; support for air traffic control, weather forecasting, and ground electronics maintenance through the Space and Naval Warfare Systems Command; the charter of Air Mobility Command airlift and Military Sealift Command ships for the re-supply of McMurdo Station; bulk fuel purchased from the Defense Logistics Agency; and reimbursement for use of DoD satellites for communications.

The Research Support and Logistics program in the Arctic Sciences section of OPP responds to science supported by the section. Funding is provided directly to grantees or to key organizations that provide or manage Arctic research support and logistics. A contractor provides research support and logistics services for NSF-sponsored activities in the Arctic. Additional major support components include: access to USCG and other icebreakers, University-National Oceanographic Laboratory (UNOLS) vessels and coastal boats; access to fixed- and rotary-wing airlift support; upgrades at Toolik Field Station, University of Alaska Fairbanks' field station for ecological research on Alaska's North Slope; safety training for field researchers and funding for field safety experts; global satellite telephones for emergency response and improved logistics coordination; and development of a network of strategically placed U.S. observatories linked to similar efforts in Europe and Canada. In FY 2016, the Directorate for Biological Science's (BIO) Division of Environmental Biology provided funding, approximately \$164,000, through OPP's Arctic support

contractor CH2M Hill and through the University of Alaska, Fairbanks for ongoing logistical support for two BIO funded projects in Alaska.

Management and Oversight

- NSF Structure: OPP has overall responsibility for U.S. Antarctic Logistical Support and Arctic Research Support & Logistics.
 - U.S. Antarctic Logistical Support is budgeted for and managed by the Antarctic Infrastructure and Logistics Section, which includes managers with operational expertise responsible for planning and overseeing all USAP support.
 - Arctic Sciences personnel support merit-reviewed research proposals in social, earth systems, and a broad range of natural sciences; its Research Support & Logistics program responds to research by assisting researchers with access to the Arctic and sharing of plans and results with local Arctic communities.
 - The Environment, Health, and Safety section oversees the environmental, health, and safety aspects of research and operations conducted in polar regions.
- External Structure:
 - DoD operates as a logistical support provider on a cost-reimbursable basis. The agencies cooperate under a Memorandum of Agreement that includes guidance for planning and scheduling and sets forth the terms and conditions for reimbursement to DoD by NSF.
 - The Arctic support contract was re-competed and awarded to the incumbent, CH2M Hill, in September 2011. There are many separate subcontractors for supplies and technical services, and other services are procured through separate competitively bid contracts.
- Reviews: OPP evaluates the performance of the Arctic support contractor informally on an ongoing basis and formally each year using feedback from the research community they support, and by conducting site visits that include representatives from OPP and BFA. OPP's performance is externally reviewed by Committees of Visitors and the Office of Polar Programs Advisory Committee.

Current Status

All facilities (stations, research vessels, and field camps) are currently operating as normal.

Renewal/Re-competition/Termination

NSF re-competed the Arctic support contract and made an award to the incumbent contractor, CH2M Hill, in September 2011. The contract has an initial term of four years and the possibility of two, two-year extensions exercised on the basis of performance.

SEISMOLOGICAL FACILITIES FOR THE ADVANCEMENT OF GEOSCIENCE AND EARTHSOPE

\$24,190,000
-\$1,450,000 / -5.7%

Seismological Facilities for the Advancement of Geoscience and EarthScope

(Dollars in Millions)

FY 2016 Actual	FY 2017 (TBD)	FY 2018 Request	Change over FY 2016 Actual	
			Amount	Percent
\$25.64	-	\$24.19	-\$1.45	-5.7%

The Seismological Facilities for the Advancement of Geoscience and EarthScope (SAGE) comprise a distributed, multi-user, national facility for the development, deployment, and operational support of modern digital seismic instrumentation to serve national goals in basic research and education in the earth sciences, earthquake research, global real-time earthquake monitoring, and nuclear test ban verification. SAGE is managed and operated for NSF by the Incorporated Research Institutions for Seismology (IRIS), a consortium of 124 U.S. universities and non-profit institutions with research and teaching programs in seismology, 21 educational affiliates, three U.S. affiliates, and 127 foreign affiliates. SAGE was formed in late FY 2013 from the seismic components of the EarthScope facility and seismic facilities previously managed by IRIS. The FY 2018 Budget Request will allow SAGE to continue providing service to the community consistent with that in previous years.

Total Obligations for SAGE

(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	\$25.64	-	\$24.19	\$24.19	\$24.19	\$24.19	\$24.19	\$24.19

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

The Earth's interior remains a major scientific frontier holding the key to understanding the origin of the planet. Recent developments in seismic sensor design, and the acquisition, transmission, and storage of data have resulted in dramatic improvements in the resolving power of seismic imaging of the interior. To serve the research needs of the broad earth science community, SAGE is organized under three primary service areas and two special emphasis areas:

Instrumentation Services

- The Global Seismographic Network (GSN) consists of over 150 permanently-installed broadband digital seismic stations, most of which have real-time data access. GSN is operated in partnership with the U.S. Geological Survey (USGS).
- Portable Seismology (PS) includes a pool of over 5,200 portable seismometers that are made available to the earth science research community for a wide range of principal investigator-driven experiments largely funded through the NSF merit review process.
- Polar Support Services (PSS) supports the development of specialized seismic equipment for use in harsh environments and provides instrumentation, training, and field support for experiments in the polar regions.
- The Transportable Array (TA) is a continental-scale seismic observatory designed to provide a foundation for multi-scale integrated studies of continental lithosphere and deep Earth structure. Over 1,700 TA stations operated across the lower 48 states and southern Ontario and Quebec, Canada,

between 2004 and 2015; TA is now being deployed to Alaska and western Canada.

- The Magnetotelluric (MT) component exploits the natural variations in Earth's magnetic and electric fields to provide information on the distribution and composition of fluids in Earth's crust and upper mantle, which gives constraints on Earth's structure that are complementary to those resulting from seismology.
- Instrumentation Services-Coordinated Activities include efforts to develop the next generation of seismic instrumentation for large-scale scientific experiments; global-scale geophysical networks; and training courses to distribute best practices to partners worldwide.

Data Services

- SAGE Data Services (DS) manages an archive of over 430 terabytes of seismic, magnetotelluric, and other data from all SAGE components, the EarthScope program, and numerous affiliated networks; operates automated and manual systems to ensure the quality of all data stored in the archive; and provides systems to give the national and international research community timely access to these data. In the last quarter of FY 2016, more than 17,000 unique users downloaded over 130 TB of data from the SAGE archive.

Education and Public Outreach

- The SAGE Education and Public Outreach (EPO) program enables audiences beyond seismologists to access and use seismological data and research, including student internships, and programs for under-resourced educational institutions.

Special Emphasis Areas

- Community Activities include scientific and technical workshops that bring together the international seismic community and publications designed to communicate SAGE activities and results to the community.
- International Development Seismology (IDS) leverages the core SAGE service areas to provide capacity building and training for earthquake hazard mitigation in developing countries, through technical assistance and research collaborations with scientists at U.S. academic institutions.

Besides its role in providing the observational data essential for basic earth science research, SAGE also provides real-time seismic data to the USGS and the National Oceanic and Atmospheric Administration (NOAA) for global earthquake, volcano, and tsunami monitoring; international seismic monitoring of compliance with the Comprehensive Test Ban Treaty; and bringing seismology to students and the public through the activities of its EPO program.

SAGE is heavily involved in partnership activities, many international in nature. Installation and operation of the GSN has put IRIS in contact with scientists, as well as government and non-governmental organizations, from around the world. Many international GSN stations are designated as the official stations for nuclear test ban monitoring in their host countries. SAGE also provides multi-use resources for other government agencies that have responsibilities for development of a nuclear test ban monitoring capability and for monitoring global seismicity. For these purposes, agencies in partnership with NSF have provided substantial support for accelerated development of the GSN, shared operation and maintenance of the GSN, and accelerated development of the PS instrument pool.

The EarthScope, Geophysics, GeoPRISMS, and Tectonics Programs in the Division of Earth Sciences (EAR); the GeoPRISMS and Marine Geology and Geophysics Programs in the Division of Ocean Sciences (OCE); and the Geology and Geophysics Program and the Glaciology Program in the Antarctic Research Section of OPP provide most of the funds, totaling approximately \$15.0 million annually, for NSF-

sponsored research making use of SAGE. Funds permit deployment of portable seismic instruments and use of data managed by DS to solve major Earth science problems.

Management and Oversight

- NSF Structure: The Division of Earth Sciences (EAR) in the Directorate for Geosciences, through its Instrumentation & Facilities program (IF), provides general oversight of SAGE to help assure effective performance and administration. The program also facilitates coordination of SAGE programs and projects with other NSF-supported facilities, and with other federal agencies, and evaluates and reviews the performance of IRIS in managing and operating SAGE.
- External Structure: SAGE is managed and operated by IRIS, which is incorporated as a non-profit consortium representing 124 U.S. universities and non-profit organizations with research and teaching programs in seismology. Each voting member institution of the Consortium appoints a member representative, and these member representatives elect the nine members of the IRIS Board of Directors. The Board members, who serve three-year terms, vet all internal program decisions associated with SAGE management and operation, through consultation with IRIS staff and SAGE advisory committees (one for each major SAGE component and additional *ad hoc* working groups appointed for special tasks). The Board of Directors appoints a president of IRIS to a renewable two-year term. The president is responsible for IRIS operations, all of which are managed through the IRIS Corporate Office located in Washington, DC.
- Reviews: All major ongoing geoscience facilities routinely undergo reviews of their management, in addition to peer review of proposals for new or continued support. The formal NSF merit review of the five-year proposal for the SAGE facility took place in 2012 and 2013 and was also the most recent review of IRIS. Although the *ad hoc* reviewers and two independent review panels had a number of specific recommendations at the working level for SAGE, overall the review found that SAGE was a critical facility for U.S. and international Earth sciences. Furthermore, the reviewers found that IRIS is a well-managed and effective organization that has, through its commitment to the collection and open dissemination of the highest quality seismological data, transformed the discipline of seismology.

Renewal/Recompetition/Termination

Funding for the current cooperative agreement for SAGE began in FY 2014 and ends in FY 2018. In FY 2016, in keeping with the phased integration and recompetition plan presented to and concurred with by the National Science Board in December 2009, NSF solicited proposals to manage and operate one or more components of a new facility to support the Earth sciences research and education community. These components are currently supported by SAGE and the related Geodesy Advancing Geoscience and EarthScope (GAGE). The new distributed, multi-user, national facility would support the development, deployment, management, and operational support of modern geodetic, seismic, and related geophysical instrumentation and provide services to serve national goals in basic research and education in the Earth sciences. NSF is currently reviewing proposals received in response to this facility solicitation.

FEDERALLY FUNDED RESEARCH AND DEVELOPMENT CENTERS (FFRDCs)

NATIONAL CENTER FOR ATMOSPHERIC RESEARCH **\$89,900,000**
-\$15,700,000 / -14.9%

National Center for Atmospheric Research
(Dollars in Millions)

FY 2016 Actual	FY 2017 (TBD)	FY 2018 Request	Change over FY 2016 Actual	
			Amount	Percent
\$105.60	-	\$89.90	-\$15.70	-14.9%

The National Center for Atmospheric Research (NCAR) is a Federally-Funded Research and Development Center (FFRDC) serving a broad research community, including atmospheric and geospace scientists and researchers in complementary areas of the environmental sciences and geosciences. NCAR is managed under a cooperative agreement between NSF and the University Corporation for Atmospheric Research (UCAR), a university-governed and university-serving organization comprising 110 degree-granting academic institutions.

As of December 2016, NCAR supported a total of 729.9 full time equivalents (FTEs), of which 331.1 are funded under the NSF primary award to UCAR.

Number of FTEs Supported at NCAR

FTEs	Primary Award ¹	All Funding
Career Scientists	71.4	100.6
Scientific Support ²	229.2	500.9
Other Staff ³	30.5	128.4
Total	331.1	729.9

¹ The primary award also includes funding for non-staff costs, such as infrastructure.

² Scientific Support includes associate scientists, project scientists, post docs, software engineers, engineers, system support and technicians.

³ Other Staff includes administrative positions, managers, paid visitors, pilots, and mechanics.

NCAR provides world-class research programs, service, and facilities that enable the research community to advance our understanding of the sun-atmosphere system. These include the NCAR-Wyoming Supercomputing Center, the Mauna Loa Solar Observatory, two research aircraft, a transportable ground-based radar system, atmospheric sounder, and other surface sensing systems.

Total Obligations for NCAR

(Dollars in Millions)

	FY 2016	FY 2017	FY 2018	ESTIMATES ²				
	Actual ¹	(TBD)	Request	FY 2018	FY 2019	FY 2020	FY 2021	FY 2022
Aircraft Support	\$9.96	-	\$8.50	\$8.50	\$8.50	\$8.50	\$8.50	\$8.50
Computational Infrastructure	33.88	-	28.90	\$28.90	28.90	28.90	28.90	28.90
Other Facility Support	15.31	-	13.00	\$13.00	13.00	13.00	13.00	13.00
Research & Education Support	46.45	-	39.50	\$39.50	39.50	39.50	39.50	39.50
Total, NCAR	\$105.60	-	\$89.90	\$89.90	\$89.90	\$89.90	\$89.90	\$89.90

¹ Total includes \$5.90 million funding for FY 2017 activities.

² Outyear funding estimates are for planning purposes only.

Partnerships and Other Funding Sources: NCAR leverages NSF support with funding provided by other federal agencies and non-federal sources. In FY 2016, NCAR received approximately \$41.7 million in support from other federal agencies, including the National Oceanic and Atmospheric Administration (NOAA), the Department of Energy (DOE), and the Federal Aviation Administration (FAA), and \$21.6 million from non-federal sources.

Major Investments in FY 2018: In FY 2018, investments at NCAR will focus on fundamental research aimed at improving our ability to predict atmospheric, chemical, and space weather hazards, and increasing our understanding of the variability in the Earth’s climate system at regional and global scales. In all of these areas, NCAR scientists will work with their university colleagues to further understand the fundamental processes that control the Earth’s climate and weather systems. This will include research thrusts in areas such as the role of the chemical composition of the atmosphere, better understanding of the structure and nature of hurricanes and other severe weather events, and the impacts of the Sun on space weather and weather on Earth. The FY 2018 decrease will require reassessment and refocusing of priorities for support by NSF and NCAR.

Aircraft Support: NCAR operates two NSF aircraft: a C-130Q Hercules and a Gulfstream-V (the ‘G-V’), both of which are highly modified and equipped with specialized instrumentation, to enable the support of research activities designed to provide new insights into atmospheric chemical processes, the dynamics and coupling of the atmosphere’s layers, and interactions between the atmosphere and Earth’s surface. The two aircraft will support several community-originated projects deemed by peer review to be of exceptional scientific merit.

Computational Infrastructure: NCAR operates a petascale supercomputing facility in Cheyenne, Wyoming (the NCAR-Wyoming Supercomputing Center), that supports high-end community modeling programs in atmospheric, solar, and other Earth Systems processes. These include the Community Earth System Model (CESM) and the Weather Research and Forecasting Models (WRF), which use mathematical formulas to simulate and better understand the chemical and physical processes that drive Earth’s climate and weather system. NCAR leads the development of these community models and supports many thousands of users in the U.S. and worldwide. NCAR also maintains extensive data archives, providing access to a vast collection of observational, experimental, and modeling data, together with sophisticated analysis and visualization facilities, and training and support for users of all levels.

Other Facility Support: In addition to the C-130 and G-V aircraft, NCAR provides support for a number of other atmospheric and solar observing platforms through its Earth Observing Laboratory (EOL) and High Altitude Observatory (HAO), including a large, deployable, dual-wavelength Doppler radar, upper atmosphere observing capabilities, an advanced coronagraph, and other experimental systems.

Research and Education Support: As an internationally recognized center of excellence, NCAR operates scientific research programs that include the following areas:

- studies of large-scale atmospheric and ocean dynamics that contribute to an understanding of the past and present Earth System processes;
- global and regional atmospheric chemistry, including atmospheric connections to geochemical and biogeochemical cycles;
- the variable nature of the sun and the physics of the corona and their interaction with the Earth's magnetic field;
- the physics of clouds, thunderstorms, precipitation formation, and their interactions and effects on local and regional weather; and
- examination of human society's impact on atmospheric composition, weather, and climate, and response to global environmental change.

Research collaborations with university colleagues are integral to NCAR's success as an institution, and NCAR serves as a focus and meeting point for the broader atmospheric and related sciences community. NCAR also maintains extensive partnerships and collaborations with the private sector through directed research and technology transfer. This work focuses on developing information and analysis platforms tailored to the specific needs of stakeholders in a variety of sectors, including energy, aviation, and agriculture.

Educational activities include the SOARS (Significant Opportunities in Atmospheric Research and Science) program that integrates research, education, and mentoring to bridge the undergraduate-to-graduate transition and to broaden participation in the atmospheric and related sciences.



The Mesa Laboratory, designed by architect I.M. Pei, in Boulder, CO. *Credit: NCAR.*

NCAR further supports the scientific community by providing fellowships, internships, workshops, and colloquia for students and visiting scientists, and disseminates knowledge of the geosciences. Professional training courses, innovative and award-winning science education websites, as well as the directed activities of NCAR's education and outreach programs, are further examples of how NSF's goal of integrating research and education is attained through NCAR activities.

Management and Oversight

- **NSF Structure:** NSF's Division of Atmospheric and Geospace Sciences (AGS) and the Division of Acquisition and Cooperative Support (DACs), provide oversight of NCAR and the cooperative agreement under which UCAR manages NCAR. The cooperative agreement encourages interactions between NCAR scientists and AGS staff and ensures close coordination between AGS and NCAR management. The agreement contains requirements for AGS's oversight of the NCAR program and UCAR management activities that affect NCAR. UCAR submits for AGS approval an annual program plan for NCAR that details how resources will be used, and an annual report on the previous year's scientific accomplishments and achievements. UCAR also reports annually to NSF on its activities as NCAR's manager. Annual strategic planning between AGS, UCAR, and NCAR ensures that scientific and facility priorities align with those of NSF.
- **External Structure:** UCAR works in partnership with NSF and the university community to ensure effective implementation of the NCAR strategic mission to the benefit of the atmospheric and geospace research community. In addition, other federal agencies (such as NOAA, NASA, DOD, DOE and the FAA), state authorities, and the private sector support research collaboration wherever it enhances NCAR's NSF-supported research goals or facilities missions.

Major Multi-User Research Facilities

- **Reviews:** A Committee of Visitors (COVs) is convened periodically to evaluate AGS oversight of NCAR. The most recent COV was conducted in FY 2015, with the next anticipated in FY 2019. A Business Systems Review was conducted in FY 2011. No significant issues were raised in either of the most recent reviews.

Renewal/Recompetition/Termination

In 2016, AGS conducted a comprehensive review of NCAR's science programs and facilities, and UCAR's management of NCAR. The review was conducted as a series of site visits to NCAR by teams comprising members of the research community with expertise in the atmospheric and related sciences and in the management of scientific centers and facilities. The site visit teams all found that NCAR continues to be a world-leading research center, providing essential services and capabilities that foster excellence throughout the atmospheric and geospace sciences community.

The current cooperative agreement between NSF and UCAR covers the five-year period FY 2014-FY 2018. It is anticipated that the cooperative agreement for management of NCAR will be re-competed prior to the next award period, which will be for the five years beginning in FY 2019.

NATIONAL OPTICAL ASTRONOMY OBSERVATORY

\$20,670,000
-\$1,320,000 / -6.0%

National Optical Astronomy Observatory

(Dollars in Millions)

FY 2016 Actual	FY 2017 (TBD)	FY 2018 Request	Change Over	
			FY 2016 Actual Amount	FY 2016 Actual Percent
\$21.99	-	\$20.67	-\$1.32	-6.0%

The National Optical Astronomy Observatory (NOAO) was established in 1984 by uniting operations of the Kitt Peak National Observatory (KPNO) in Arizona and the Cerro Tololo Inter-American Observatory (CTIO) in Chile. As a Federally Funded Research and Development Center sponsored by NSF, the primary purpose of NOAO is to serve as the U.S. national center for ground-based optical and infrared (OIR) astronomy to coordinate, integrate, and operate observational, technical, and data-oriented capabilities available throughout the U.S. OIR system of federal and non-federal assets.

NOAO’s mission is to enable discovery in ground-based OIR astronomy. In pursuit of this mission, NOAO facilitates access for all qualified professional researchers to state-of-the-art observational capabilities and databases in OIR astronomy. NOAO enables the U.S. research community to pursue a broad range of modern astrophysical challenges from small bodies within the Solar System, to the most distant galaxies in the early universe, to indirect observations of dark energy and dark matter. NOAO is the gateway for the U.S. astronomical community to the Gemini Observatory through the U.S. National Gemini Office (US-NGO). NOAO coordinates community access to telescopes throughout the U.S. OIR system, and it facilitates connecting the scientific user to data archives by developing and maintaining data management capabilities. NOAO integrates community planning for future facilities and instrumentation projects under a national organization. In partnership with the community and NSF, NOAO works with colleges and universities to train the next generation of scientists and engineers, and promotes accomplishments to strengthen education and public awareness of the astronomical sciences.

NOAO facilities, telescopes, and data systems, are open to all qualified astronomers regardless of institutional affiliation. They serve nearly 1,200 U.S. and foreign scientists annually. Doctoral dissertation students and non-thesis graduate students from U.S. institutions use NOAO facilities for research projects. In FY 2016, NOAO employed 300 personnel in Arizona and Chile, including 45 support scientists and 10 postdoctoral fellows.

The Division of Astronomical Sciences in the Directorate for Mathematical and Physical Sciences (MPS/AST) conducted a community-based review of its portfolio in 2011-2012. The resulting Portfolio Review Committee (PRC) report, *Advancing Astronomy in the Coming Decade: Opportunities and Challenges*²⁰, was released in August 2012 and included recommendations about all of the major AST telescope facilities.

The recommendations from the PRC report included divesting NSF support from three nighttime OIR telescopes located on Kitt Peak: The 4-meter Mayall telescope, the 2.1-meter telescope, and the 3.5-meter WIYN telescope, which is owned and operated by a consortium of University of Wisconsin, Indiana University, and NOAO. NOAO’s share of the WIYN telescope time for public access is 40 percent.

²⁰www.nsf.gov/mps/ast/ast_portfolio_review.jsp

Major Multi-User Research Facilities

The PRC recommendations were implemented as of October 1, 2015. The 2.1-meter telescope is now operated by the California Institute of Technology for a research program on cosmic transient phenomena. Starting in FY 2016, the NOAO base operations and maintenance budget excluded NSF funding for the Mayall and WIYN telescopes. Any subsequent NSF support for these telescopes is recorded as special projects with supplemental funding to NOAO.

Total Obligations for NOAO

(Dollars in Millions)

	FY 2016	FY 2017	FY 2018	ESTIMATES ¹				
	Actual	(TBD)	Request	FY 2019	FY 2020	FY 2021	FY 2022	FY 2023
NOAO Base O&M	\$17.61	-	\$18.57	\$19.13	\$19.70	\$20.29	\$20.90	\$21.53
<i>Tucson Operations</i>	8.61	-	9.02	9.29	9.57	9.86	10.15	10.46
<i>Chilean Operations</i>	8.00	-	8.49	8.74	9.01	9.28	9.56	9.84
<i>Kitt Peak Operations</i>	1.00	-	1.06	1.09	1.12	1.16	1.19	1.23
Special Projects: WIYN and Mayall	4.38	-	2.10	1.00	1.00	1.00	1.00	1.00
Total, NOAO	\$21.99	-	\$20.67	\$20.13	\$20.70	\$21.29	\$21.90	\$22.53

¹ Outyear funding estimates are for planning purposes only. The current cooperative agreements ends in September 2020.

Partnerships and Other Funding Sources: The managing organization for NOAO is the Association of Universities for Research in Astronomy, Inc. (AURA), which is comprised of 42 U.S. member institutions and five international affiliate members. A key NOAO partnership is ongoing with the Department of Energy (DOE) to conduct a survey of the southern sky to investigate the nature of dark energy. The five-year Dark Energy Survey began operation in August 2013 on the CTIO 4-meter Blanco telescope. NOAO is a partner in the 4.1-meter SOAR (Southern Astrophysical Research) telescope at CTIO. SOAR partners include the University of North Carolina, Chapel Hill; Michigan State University; and the Ministério da Ciência, Tecnologia, e Inovação do Brasil.

A large number of U.S. universities support their own astronomical facilities at KPNO and CTIO with reimbursed services provided by NOAO. Development of new telescopes, instrumentation, and sensor techniques is done in partnership with universities and with industry through subawards to aerospace, optical fabrication, and information technology companies. NOAO leverages NSF support with funding from other federal agencies and non-federal sources. NOAO typically receives approximately \$10.0 million each year for reimbursed services from partnerships and tenant observatory support, from the Kitt Peak Visitors Center, and from grants from other federal agencies.

Education and Public Outreach: NOAO supports U.S. education goals by promoting public understanding and support of science and by providing education and training at all levels. Over 200 U.S. and foreign graduate students observe on NOAO telescopes yearly and a significant fraction of the observations contribute to Ph.D. dissertations. The observatories introduce undergraduate students to scientific research by providing stimulating environments for basic astronomical research and related technologies through NSF's Research Experiences for Undergraduate Students (REU) program. NOAO has a diverse education program, visitor centers, and a web-based information portal at www.noao.edu.

NOAO Base O&M: \$18.57 million, \$960,000 above the FY 2016 Actual.

Tucson Operations: \$9.02 million, \$410,000 above the FY 2016 Actual: This covers the headquarters, offices, laboratories, and workshops in Tucson, Arizona.

Chilean Operations: \$8.49 million, \$490,000 above the FY 2016 Actual: This supports administration and labs in La Serena, Chile and mountain operations on Cerro Tololo and Cerro Pachón.

Kitt Peak Operations: \$1.06 million, \$60,000 above FY 2016 Actual: This provides support for basic infrastructure on the mountain for the benefit of the tenants. All facilities on the mountain are accounted as tenants.

Special Projects (WIYN and Mayall): \$2.10 million, \$2.28 million below the FY 2016 Actual.

WIYN telescope: \$1.0 million, no change from the FY 2016 Actual: The National Aeronautics and Space Administration (NASA) has identified the WIYN telescope as the preferred platform for an extreme precision Doppler spectrometer as a facility instrument for exoplanet follow up research. This instrument is the key component of a NASA-NSF partnership in Exoplanet Observational Research (NN-EXPLORE), which began in FY 2015 using existing instrumentation on WIYN. A Memorandum of Agreement between the agencies for NN-EXPLORE was signed in FY 2015, and a Joint Oversight Group was formed early in FY 2016.

Mayall Telescope: \$1.10 million, \$2.28 million below the FY 2016 Actual: The decrease from FY 2016 anticipates an increase in DOE support for the telescope. In FY 2015, DOE identified the Mayall telescope as the preferred platform for the Dark Energy Spectroscopic Instrument (DESI) to carry out a dark energy science survey sponsored by DOE, starting in FY 2019. DESI passed the DOE Critical Decision 3 (Approve Start of Construction) milestone in FY 2016.

Management and Oversight

- NSF Structure: An NSF program officer in AST provides continuing oversight, including consultation with an NSF program review panel of external reviewers that meets once a year. The program officer reviews detailed annual program plans, annual long range plans, quarterly technical and financial reports, and annual reports submitted by NOAO. The NSF program officer also attends AURA governance committee meetings. Governance committees are formed from the national astronomical community and provide additional avenues for input of community priorities and concerns. The AST program officer works closely with other offices at NSF, particularly the Office of General Counsel, and the Division of Acquisition and Cooperative Support and the Large Facilities Office in the Office of Budget, Finance, and Award Management.
- External Structure: AURA is the managing organization for NOAO. The NOAO director reports to the president of AURA, who is the principal investigator on the NSF cooperative agreement that began in FY 2016. AURA receives management advice from an observatory council composed of members of its scientific and management communities. NOAO uses a Users Committee, comprised of community scientists, to advise the NOAO director on all aspects of user experiences at the Observatory.
- Reviews: In addition to reviews held mid-way through all cooperative agreements, NSF conducts both periodic and ad hoc external reviews of AURA management. A comprehensive review of the managing organization's performance will be carried out in FY 2019, the fourth year of the five-year cooperative agreement.

Renewal/Competition/Termination

The last competition for management and operation of NOAO was completed with the issuance of a new cooperative agreement with AURA starting October 1, 2015 and ending September 30, 2020.

NATIONAL RADIO ASTRONOMY OBSERVATORY

\$76,340,000
-\$5,150,000 / -6.3%

National Radio Astronomy Observatory

(Dollars in Millions)

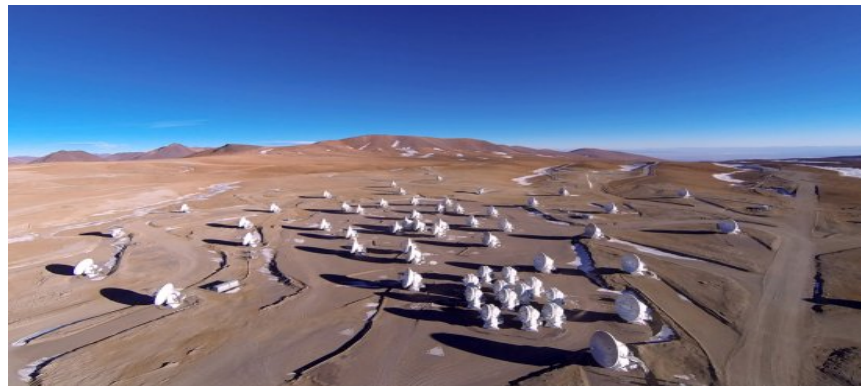
FY 2016 Actual ¹	FY 2017 (TBD)	FY 2018 Request	Change over FY 2016 Actual	
			Amount	Percent
\$81.50	-	\$76.34	-5.16	-6.3%

¹ Includes \$2.11 million provided by the MPS Office of Multidisciplinary Activities for expenses associated with the separation of the Green Bank Observatory and Very Long Baseline Array from NRAO and ALMA.

The National Radio Astronomy Observatory (NRAO) conceives, designs, builds, operates, and maintains state-of-the-art radio telescopes used by scientists from around the world. Operating synergistically with optical, infrared, and x-ray telescopes, NRAO facilities enable discovery over a remarkably broad range of key problems in modern astrophysics that reach from within our solar system to the most distant galaxies in the universe. Using NRAO observing capabilities and data archives, scientists: carry out precision cosmological measurements; test fundamental physics; probe deep into the earliest, most intense, and optically obscured phases of planet, star, galaxy, and black hole formation; reveal the cool gas from which stars form; provide essential tools for studying magnetic fields and high-energy cosmic phenomena; and seek to detect gravitational waves.

As a Federally Funded Research and Development Center headquartered in Charlottesville, Virginia, NRAO operates the Karl G. Jansky Very Large Array (VLA) near Socorro, New Mexico and is also the North American implementing organization for the international Atacama Large Millimeter/submillimeter Array (ALMA). These ground-based observing facilities for radio astronomy are available to any qualified researcher, regardless of affiliation or nationality, on the basis of scientific, merit-reviewed proposals. NRAO facilities annually serve over 2,500 users worldwide; moreover, growing demand for ALMA has resulted in the most proposals ever received for an astronomical facility in response to a single proposal call. NSF does not provide individual investigator awards targeted specifically for use of NRAO facilities, but many users are supported through NSF or NASA grants to pursue scientific programs that require use of NRAO facilities.

Including the ALMA operations staff located at NRAO, staff in FY 2018 will consist of 296 full-time equivalent positions (FTEs) in the operations and maintenance components: 105 in telescope operations, 60 in science support and research, 36 in development programs, 51 in computing and data management, 25 in administrative services, and 19 in education and public outreach. These numbers exclude staff at the partitioned GBT and VLBA telescopes which will be managed and operated separately from NRAO as well as 94 staff in the NRAO common cost pool which provides services to multiple observatories. In addition, the NRAO managing



ALMA is in science operations following the completion of construction in 2015. An international partnership between North America, Europe, and East Asia, ALMA provides orders-of-magnitude improvement in observing sensitivity and image quality over previous facilities. *Credit: NRAO/AUI.*

organization, Associated Universities, Inc. (AUI), employs local ALMA operations staff in Chile, currently consisting of approximately 237 FTEs.

Total Obligations for NRAO

(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	\$43.84	-	\$32.86	\$33.95	\$34.97	\$36.02	\$37.10	\$38.22
<i>Telescope Operations</i>	16.16	-	11.19	11.09	10.92	11.25	11.59	11.94
<i>Development</i>	3.30	-	3.37	3.94	4.56	4.70	4.84	4.99
<i>Science Operations</i>	4.72	-	6.19	6.40	6.59	6.79	6.99	7.20
<i>Administrative Services</i>	14.39	-	9.42	9.74	10.04	10.33	10.64	10.96
<i>Directors Office</i>	2.41	-	2.03	2.10	2.16	2.23	2.30	2.36
<i>Education and Public Outreach</i>	0.75	-	0.66	0.68	0.70	0.72	0.74	0.77
<i>NRAO/GBO/VLBA separation expenses</i>	2.11	-	-	-	-	-	-	-
ALMA Operations	37.66	-	43.48	45.88	47.26	48.68	50.14	51.64
Total, NRAO	\$81.50	-	\$76.34	\$79.83	\$82.23	\$84.70	\$87.24	\$89.86

¹ Outyear funding estimates are for planning purposes only. The current cooperative agreement ends in FY 2026.

The FY 2018 Budget Request for NRAO is below the FY 2016 Actual due to the partitioning of the Green Bank Observatory (GBO) and Very Long Baseline Array (VLBA) from NRAO, and because of funding carried over from the previous award which ended in FY 2016. GBO and VLBA are presented in the “Other Astronomical Facilities” narrative in the Facilities chapter of this document. Due to the favorable exchange rate and fuel prices in Chile, the FY 2016 Actual for ALMA Operations was below the FY 2016 Budget Request and the FY 2018 Budget Request is below the estimate for steady state funding.

Partnerships and Other Funding Sources: NRAO supplements AST support with funding provided by other NSF sources, other federal agencies, and non-federal sources. In FY 2016, NRAO received approximately \$2.25 million from non-AST sources at NSF, \$1.70 million from other federal agencies, and \$4.52 million from U.S. universities, foreign scientific and technical institutes, and other non-federal and industrial sources. The development of new telescopes, instrumentation, and sensor techniques is conducted in partnership with relevant industries through competitive sub-awards to various large and small aerospace companies, radio antenna manufacturing firms, and specialized electronics and computer hardware and software companies.

Telescope operations, \$11.19 million: This encompasses support for direct telescope and array operations of the VLA including maintenance, infrastructure upgrades, and telescope management.

Development, \$3.37 million: Development programs include next generation electronics and detectors for radio astronomy, making fundamental contributions to materials science, the physics of quantum detectors, electromagnetics, photonics, and radio propagation.

Science operations, \$6.19 million: This area includes telescope time allocation, staff research, science training and education, and science community outreach.

Administrative services, \$9.42 million: This includes internal common costs used to allocate common and management expenses across the total pool of observatory activity, such as business services, utilities, and other facility costs at the operating locations, observatory management, and the library.

Major Multi-User Research Facilities

Director's office, \$2.03 million: This supports the director's office and managing organization costs.

Education and Public Outreach, \$660,000: NRAO supports a comprehensive outreach program that makes information about radio astronomy available to the public.²¹ With over 150 students involved per year, NRAO facilities are used by graduate students carrying out dissertation research and work experience programs and by undergraduate students participating in the Research Experiences for Undergraduates (REU) program. NRAO also supports a visitor and education center and conducts active educational and public outreach programs. The VLA visitor center attracts over 20,000 public visitors each year.

ALMA Operations, \$43.48 million: In FY 2015, NRAO completed construction of the international ALMA Observatory, funded through the Major Research Equipment and Facilities Construction (MREFC) account. Early operations funding for ALMA began in FY 2005 and ramps up to steady state operations in FY 2018. Operations funding supports a share of observatory operations in Chile, a technical development program, and the North American ALMA Science Center (NAASC). NRAO created the NAASC in 2006 to provide technical and scientific support for, and easy access by, the broad astronomical community that uses ALMA. The NAASC also organizes summer schools, workshops, and courses in techniques of millimeter and submillimeter astronomy.

Management and Oversight

- **NSF Structure:** In consultation with community representatives, a dedicated AST program officer carries out continuing oversight and assessment for NRAO and ALMA by making use of detailed annual program plans, long-range plans, quarterly technical and financial reports, and annual reports submitted to NSF. The AST program officer participates in the international ALMA Board and attends AUI/NRAO governance and advisory committee meetings. To address issues as they arise, AST works closely with other NSF offices, such as the Office of General Counsel, the Office of International Science and Engineering, the Division of Acquisition and Cooperative Support, and the Large Facilities Office in the Office of Budget, Finance, and Award Management.
- **External Structure:** Management is through a cooperative agreement with AUI. AUI manages the observatory through its own community-based oversight and users committees. The NRAO director reports to the president of AUI. Oversight of the international ALMA project is vested in the ALMA Board, which includes a member from NSF; coordination and management of the merged international efforts are the responsibility of the Joint ALMA Observatory (JAO) whose staff includes an ALMA director. An international ALMA review committee advises the ALMA Board.
- **Reviews:** NSF conducts annual reviews of the NRAO Program Operating Plan and strategic planning documents, ALMA operations, and the AUI Management Report. A Business Systems Review was conducted in FY 2012.

Renewal/Competition/Termination

Following a solicitation issued in FY 2014 (NSF 14-568), management and operation of NRAO, including ALMA, was competed and the National Science Board authorized a cooperative agreement with AUI for the period October 1, 2016 through September 30, 2026.

²¹ <https://public.nrao.edu/>

NATIONAL SOLAR OBSERVATORY

\$19,000,000
-\$2,000,000 / -9.5%

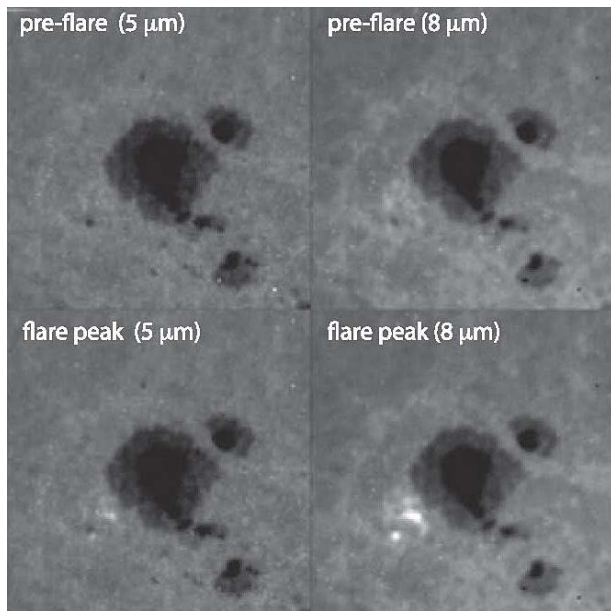
National Solar Observatory

(Dollars in Millions)

FY 2016 Actual	FY 2017 (TBD)	FY 2018 Request	Change over FY 2016 Actual	
			Amount	Percent
\$21.00	-	\$19.00	-\$2.00	-9.5%

The FY 2018 Budget Request for the National Solar Observatory (NSO) is \$19.0 million. This is a \$2.0 million (-9.5 percent) decrease from the FY 2016 Actual. FY 2018 marks the continuation of a five-year funding ramp that will bring the NSO budget to a level commensurate with requirements to operate the Daniel K. Inouye Solar Telescope (DKIST). This profile will fund the development of the DKIST science operations and data center concepts in preparation for full DKIST operations expected to begin in late 2019-early 2020.

As a Federally Funded Research and Development Center (FFRDC), NSO currently operates facilities in New Mexico and Arizona as well as a coordinated worldwide network of six telescopes specifically designed to study solar oscillations. NSO also provides leadership to the solar community through management of the construction of DKIST. (See the Major Research Equipment and Facilities Construction (MREFC) chapter for more information.) NSO makes the world’s largest collection of optical and infrared solar telescopes and auxiliary instrumentation available to qualified scientists to observe the solar photosphere, chromosphere, and corona. NSO provides routine and detailed, synoptic solar data used by individual researchers and other government agencies through the NSO Digital Library. NSO data are also made available to the user community via the Virtual Solar Observatory.



The first simultaneous mid-infrared images at 5.2 μm (left) and 8.2 μm (right) of a solar flare. Image taken with the QWIP instrument on the McMath-Pierce solar telescope. Credit: M. Penn, NSO.

NSO telescopes are open to all astronomers regardless of institutional affiliation based on peer-reviewed observing proposals. In FY 2016, 32 unique observing programs from 25 U.S. and 7 foreign institutions were carried out using NSO facilities. This is a reduction from previous years as NSO ramps down its involvement in Sacramento Peak and McMath-Pierce. Students were part of 13 percent of these programs, which included three Ph.D. thesis projects. Nearly 21 terabytes of NSO synoptic data were downloaded from the NSO Digital Library. NSO employed approximately 120 staff members in FY 2016, including 65 FTEs employed on the DKIST construction project funded via the MREFC account as mentioned above.

In 2010, the National Research Council (NRC) conducted its sixth decadal survey in astronomy and astrophysics. In their report, *New Worlds, New Horizons in Astronomy and Astrophysics*,²² the NRC committee recommended that “NSF-Astronomy

²² www.nap.edu/catalog.php?record_id=12951

should complete its next senior review before the mid-decade independent review that is recommended in this report, so as to determine which, if any, facilities NSF-AST should cease to support in order to release funds for (1) the construction and ongoing operation of new telescopes and instruments and (2) the science analysis needed to capitalize on the results from existing and future facilities.” In response to this recommendation, the Division of Astronomical Sciences within the Directorate for Mathematical and Physical Sciences (MPS/AST) conducted a community-based review of its portfolio. The resulting Portfolio Review Committee (PRC) report, *Advancing Astronomy in the Coming Decade: Opportunities and Challenges*,²³ was released in August 2012 and included recommendations about all of the major AST telescope facilities.

Prior to receiving the PRC report, NSF had instructed NSO to begin divestment of the facilities on Kitt Peak, including the McMath-Pierce solar telescope and the Vacuum Tower (no longer in use), thereby accelerating the already-planned divestment by a few years. The PRC endorsed this decision. The PRC recommended continued operation of the Dunn Solar Telescope (DST) at Sacramento Peak through 2017 and a 50 percent reduction in funding of the NSO integrated synoptic program (NISP). The status of the divestment of NSO operated facilities is as follows:

- *McMath-Pierce solar telescope, Kitt Peak, AZ:* A university-based consortium previously expressed interest in continuing operations of the McMath-Pierce at a reduced level; however, this consortium has not materialized. NSO is in the final year of the ramp down of its participation in McMath-Pierce from \$200,000 in FY 2014 to \$0.0 by the end of FY 2017. NSF completed a divestment options study of NSO facilities on Kitt Peak and anticipates beginning the environmental impact statement (EIS) process in FY 2017. On March 31, 2017, NSO/AURA issued a request for proposals from parties interested in taking over operation of McMath-Pierce for scientific and educational purposes. Applicants submitted letters of intent by the May 1, 2017 deadline.
- *Sacramento Peak Observatory, Sunspot, NM:* This facility includes the DST and associated infrastructure including office space, laboratory space, dining facilities, and housing. Funding for full operations of Sacramento Peak ramps down to the end of FY 2017 at which time NSO will cease operating the facility. A proposal from New Mexico State University (NMSU) to transition operations of the facility from NSO to an NMSU-led consortium was funded in FY 2016. NSF completed a divestment options study of NSO facilities on Sacramento Peak in Q3 of FY 2016. In compliance with the National Environmental Policy Act (NEPA), NSF began preparation of an Environmental Impact Statement (EIS) in Q4 of FY 2016. The EIS is expected to be completed in FY 2018.
- *NSO Integrated Synoptic Program:* NISP consists of the Global Oscillations Network Group (GONG) and the Synoptic Optical Long-term Investigations of the Sun (SOLIS). GONG now has a component of its operations funding provided through a 5-year (FY 2016 – FY 2020) interagency agreement with the National Oceanic and Atmospheric Administration (NOAA). This NOAA funding supports the use of GONG and its data products for operational space weather forecasting (see Partnerships section below).

²³ www.nsf.gov/mps/ast/ast_portfolio_review.jsp

Total Obligations for NSO

(Dollars in Millions)

	FY 2016 Actual	FY 2017 (TBD)	FY 2018 Request	ESTIMATES ¹				
				FY 2019	FY 2020	FY 2021	FY 2022	FY 2023
NSO Base Operations	\$6.75	-	\$4.73	\$3.70	\$3.82	\$3.92	\$4.04	\$4.16
NSO Education & Public Outreach	0.25	-	0.27	0.30	0.31	0.32	0.33	0.34
DKIST Operations ²	11.50	-	14.00	16.50	17.01	17.54	18.08	19.13
GONG Refurbishment	2.50	-	-	-	-	-	-	-
Total, NSO	\$21.00	-	\$19.00	\$20.50	\$21.14	\$21.78	\$22.45	\$23.63

¹ Outyear funding estimates are for planning purposes only. The current cooperative agreement ends in September 2024.

² Total R&RA account funding for DKIST consists of \$14.0 million in FY 2018 funded through NSO, plus \$2.0 million per year in FY 2011 to FY 2020 for cultural mitigation activities as agreed to during the compliance process that is not funded through NSO. See the MREFC chapter for more information on DKIST.

Partnerships and Other Funding Sources: The managing organization for NSO is the Association of Universities for Research in Astronomy, Inc. (AURA), which comprises 42 U.S. member institutions and five international affiliate members. NSO partners include NOAA, NASA, and industrial entities. Other funding entities include universities and institutes, which collaborate with NSO on solar instrumentation development and on the design and development of DKIST. Industry sub-awardees in aerospace, optical fabrication, and information technology develop new telescopes, instrumentation, and sensor techniques.

Due to the increasing national and international awareness of the impacts of space weather on critical infrastructure and society in general, the importance of operational space weather forecasting has become apparent to U.S. policy makers. This was highlighted by the October 29, 2015 rollout of the National Space Weather Strategy²⁴ and the associated National Space Weather Action Plan.²⁵ Space weather forecasting requires both accurate models of the heliospheric environment and precise observational data inputs to those models. NSO's GONG program provides operational data products on a routine basis that are used as inputs to predictive space weather models from the U.S. Air Force and the NOAA Space Weather Prediction Center (SWPC). The FY 2016 support for NSO included a one-time \$2.50 million investment in GONG to increase its robustness for future space weather predictions. NSO is in the process of upgrading the GONG facility with this funding. Also in FY 2016, NSF and NOAA signed an interagency agreement whereby NOAA is providing approximately \$800,000 per year in funding support for GONG operations.

NSO Base Operations, \$4.73 million, \$2.02 million below the FY 2016 Actual: NSO Base Operations includes the offices at NSO's Boulder, CO headquarters and the world-wide NSO Integrated Synoptic Program consisting of the GONG array and the SOLIS (Synoptic Optical Long-term Investigations of the Sun) telescope. By the end of FY 2017, NSO expects to be disengaged from operations at Sacramento Peak Observatory in Sunspot, New Mexico and from the McMath-Pierce and Vacuum Tower facilities based on Kitt Peak, Arizona. The funding profile for NSO Base Operations has been ramping down in anticipation of the divestment of these redundant facilities by the end of 2017. Beginning in FY 2019, NSO Base Operations will fund NSO Directorate activities and operations of the synoptic program at a steady-state level of about \$4.0 million (\$2.0 million each) per year.

DKIST Operations, \$14.0 million, \$2.5 million above the FY 2016 Actual: Support for DKIST operations is through the Research and Related Activities account (R&RA), while DKIST construction support is through the MREFC account. (See the MREFC chapter for more information on construction.) The FY 2018 Budget Request for DKIST Operations represents the fourth year of a five-year funding ramp that will bring the NSO budget to a level commensurate with requirements to operate DKIST. This profile is

²⁴ www.whitehouse.gov/sites/default/files/microsites/ostp/final_nationalspaceweatherstrategy_20151028.pdf

²⁵ www.whitehouse.gov/sites/default/files/microsites/ostp/final_nationalspaceweatheractionplan_20151028.pdf

Major Multi-User Research Facilities

funding the development of the DKIST science operations and data center in preparation for full DKIST operations, which is expected to begin late 2019-early 2020.

Education and Public Outreach, \$270,000, \$20,000 above the FY 2016 Actual: NSO supports U.S. education goals by promoting public understanding and support of science and by providing education and training at all levels. NSO introduces undergraduate students to scientific research by providing stimulating environments for basic astronomical research and related technologies through NSF's separately funded Research Experiences for Undergraduates (REU) program. NSO has diverse education programs, including teacher training and curriculum development, visitor centers, and a web portal at www.nso.edu.

In preparation for the total solar eclipse in August 2017, and with the imminent arrival of DKIST, NSO significantly increased its efforts in education, public outreach, and broadening participation by establishing an Office of Education and Outreach (OEO). In FY 2016, NSO hired a new office head and recently filled a second EPO position, based in Maui, focused on DKIST.

Management and Oversight

- **NSF Structure:** An NSF program officer in AST provides continuing oversight, including consultation with an annual NSF program review panel. The program officer makes use of detailed annual program plans, annual long-range plans, quarterly technical and financial reports, and annual reports submitted by NSO as well as attending AURA Solar Observatory Council meetings. The latter committee is formed from the national solar physics community and provides a window into community priorities and concerns. The AST program officer works closely with other offices at NSF, particularly the Division of Acquisition and Cooperative Support, the Office of General Counsel, and the Large Facilities Office in the Office of Budget, Finance, and Award Management.
- **External Structure:** AURA is the managing organization for NSO. The NSO director reports to the president of AURA, who is the principal investigator on the current NSF cooperative agreement. AURA receives management advice from its Solar Observatory Council, composed of members of its scientific and management communities. NSO uses visiting and users committees for the purposes of self-evaluation and prioritization. The visiting committee, composed of nationally prominent individuals in science, management, and broadening participation, reviews for AURA all aspects of the management and operations of NSO. The users committee, composed of scientists with considerable experience with the observatory, reviews for the NSO director all aspects of NSO that affect user experiences at the observatory.
- **Reviews:** In addition to reviews held mid-way through all cooperative agreements, NSF conducts periodic and ad hoc reviews, as needed, by external committees. In February 2017, NSF held a review of NSO's Annual Progress Report and Program Plan (APRPP). From December 2015 through March 2016, NSF conducted a Business Systems Review (BSR) covering AURA and NSO. Findings and recommendations from the final NSF report were conveyed to AURA on April 1, 2016, and AURA continues to resolve issues and implement recommendations from the report. NSO also participated in reviews of the DKIST project in FY 2016 including: a contingency assessment (Feb. – July 2016) and an Earned Value Management System validation review (Sept. 2016), both of which are described in the DKIST narrative in the MREFC chapter.

Renewal/Competition/Termination

On August 14, 2014, the National Science Board (NSB) authorized a renewed cooperative agreement with AURA for management and operation of NSO for a period of 10 years from October 1, 2014 through September 30, 2024. Because of additional time required to implement the new agreement, the previous cooperative agreement was extended through May 31, 2015. The renewed cooperative agreement between NSF and AURA was put into place June 1, 2015.

OTHER ASTRONOMICAL FACILITIES

\$11,850,000
+\$11,850,000 / NA%

Other Astronomical Facilities

(Dollars in Millions)

FY 2016 ¹ Actual	FY 2017 (TBD)	FY 2018 Request	Change over FY 2016 Actual	
			Amount	Percent
-	-	\$11.85	\$11.85	N/A

¹ Beginning in October 2016, funding for these facilities as stand-alone entities is provided separately from National Radio Astronomy Observatory (NRAO).

Prior to FY 2017, the National Radio Astronomy Observatory (NRAO) operated major radio telescopes at the Green Bank Observatory (GBO) in Green Bank, West Virginia, including the Robert C. Byrd Green Bank Telescope (GBT), and at 10 telescope array sites spanning the U.S. from the Virgin Islands to Hawaii, together constituting the Very Long Baseline Array (VLBA). Beginning in FY 2017, GBO and the VLBA were separated from NRAO. GBO now operates the GBT, and the newly formed Long Baseline Observatory (LBO) operates the VLBA. Associated Universities, Inc. (AUI), remains the managing organization for GBO and LBO through a cooperative agreement with NSF. This narrative presents the combined FY 2018 Budget Request for GBO and LBO.

In 2010, the National Research Council conducted its sixth decadal survey in astronomy and astrophysics. In their report, *New Worlds, New Horizons in Astronomy and Astrophysics*,²⁶ the NRC committee recommended that “NSF-Astronomy should complete its next senior review before the mid-decade independent review that is recommended in this report, so as to determine which, if any, facilities NSF-AST should cease to support in order to release funds for (1) the construction and ongoing operation of new telescopes and instruments and (2) the science analysis needed to capitalize on the results from existing and future facilities.” In response to this recommendation, the Division of Astronomical Sciences (AST) in the Directorate for Mathematical and Physical Sciences (MPS) conducted a community-based review of its portfolio. The resulting Portfolio Review Committee report, *Advancing Astronomy in the Coming Decade: Opportunities and Challenges*,²⁷ was released in August 2012 and included recommendations about all of the major AST telescope facilities.

In 2012, the Portfolio Review Committee recommended, under constrained budgets, divestment of the GBT and VLBA from AST funding because of a less compelling mapping than other facilities onto the science questions of the 2010 decadal survey. As announced in a Dear Colleague Letter, NSF 13-074,²⁸ NSF partitioned GBT and VLBA from the competition for NRAO management and operations, which increased flexibility for exploring cost-efficient operational models and sustainable partnerships for GBO (comprising GBT and the Green Bank site and facilities) and VLBA. Existing partnerships are described below, and additional partner discussions with governmental and non-governmental entities are ongoing. In FY 2016, an engineering firm produced feasibility reports for divestment alternatives of both GBO and VLBA; those reports include baseline structural and environmental surveys of GBO and VLBA. In FY 2017, NSF began a formal environmental review of GBO to develop an Environmental Impact Statement (EIS) considering future alternatives for GBO, and the EIS process is expected to conclude in FY 2018.

In FY 2016, AST received a proposal from AUI, to continue management and operation of GBO and LBO in FY 2017 and FY 2018, separate from the management and operation of NRAO. Previously, the

²⁶ www.nap.edu/catalog.php?record_id=12951

²⁷ www.nsf.gov/mps/ast/ast_portfolio_review.jsp

²⁸ <http://nsf.gov/pubs/2013/nsf13074/nsf13074.jsp>

Major Multi-User Research Facilities

obligations for GBO and VLBA were heavily matrixed and not separable from the overall obligation for NRAO. Hence, GBO and VLBA, which were previously included in the NRAO narrative, were first presented as stand-alone entities in the FY 2017 Budget Request. The table below does not separate funding for GBO and LBO, and the detailed breakdown between the two depends on anticipated and achieved partnerships. Notional funding beyond FY 2018 is shown as flat, although it is expected that the out-year numbers will change significantly as partnerships evolve.

Total Obligations for Other Astronomical Facilities

(Dollars in Millions)

	FY 2016 Actual ¹	FY 2017 (TBD)	FY 2018 Request	ESTIMATES ²				
				FY 2019	FY 2020	FY 2021	FY 2022	FY 2023
Operations & Maintenance	-	-	\$11.85	\$11.85	\$11.85	\$11.85	\$11.85	\$11.85

¹ Beginning in October 2016 (FY 2017), funding for these facilities as stand-alone entities is provided separately from National Radio Astronomy Observatory (NRAO) funding.

² Outyear funding estimates are for planning purposes only. The operating award for GBO and LBO is expected to run through the end of September 2018.

Partnerships and Other Funding Sources: In FY 2018, GBO and LBO are expected to receive approximately \$8.60 million from other sources, roughly half from non-federal partners and half from other federal sources. Thus, the FY 2018 Budget Request represents about 58 percent of the total budget for GBO and LBO. Many of these partnerships involve guaranteed allocations of observing time on the GBT or VLBA. In FY 2016, GBO began a 10-year partnership with Breakthrough Listen and also had funding partnerships with West Virginia University and the North American Nanohertz Observatory for Gravitational Waves (NANOGrav) consortium that are expected to continue through FY 2018. (The NANOGrav funding comes from the NSF award to the NANOGrav Physics Frontier Center.) In addition, the GBO partnership with the RadioAstron space mission is continuing in FY 2017, and other partner discussions are ongoing. In FY 2017, NSF and LBO established an agreement with the U.S. Naval Observatory to provide observing time and data in exchange for substantial support of LBO/VLBA operations.

Education and Public Outreach: The Green Bank Science Center at GBO currently supports nearly 50,000 visitors per year and carries out dedicated programs for professional educators and school groups.

GBO and LBO Operations and Maintenance, \$11.85 million: This encompasses support for direct telescope operations at GBO and LBO, including maintenance, infrastructure upgrades, and telescope management, as well as funds allocated for Education and Public Outreach.

Management and Oversight

- **NSF Structure:** In consultation with community representatives, a dedicated AST program officer carries out continuing oversight and assessment for GBO and LBO by making use of detailed annual program plans, technical and financial reports, and annual reports submitted to NSF. The AST program officer attends AUI governance and advisory committee meetings. To address issues as they arise, AST works closely with other NSF offices, such as the Office of General Counsel, the Office of International Science and Engineering, the Division of Acquisition and Cooperative Support, and the Large Facilities Office in the Office of Budget, Finance, and Award Management.
- **External Structure:** Management is through a cooperative agreement with AUI. AUI manages the observatories through its own community-based oversight and users committees. The GBO and LBO directors report directly to the AUI Vice President for Radio Astronomy.
- **Reviews:** NSF reviewed the proposal for FY 2017 and FY 2018 funding and conducts annual reviews of the Program Operating Plan and reports.

Renewal/Competition/Termination

GBO and LBO are currently supported through a cooperative agreement, which ends on September 30, 2018. A six-month transition award in FY 2016 provided for implementation costs of separating GBO and LBO from NRAO (see the NRAO narrative for more details), and the FY 2018 funding provides for GBO and LBO as stand-alone entities. Management of GBO and LBO after FY 2018 will be based on the further development of collaboration opportunities and the EIS process mentioned above.

OTHER FACILITIES FUNDING

Major Research Equipment and Facilities Construction Account Projects

The MREFC account supports the acquisition, construction, and commissioning of major research facilities and equipment that provide unique capabilities at the frontiers of science and engineering. Projects supported by this account are intended to extend the boundaries of technology and open new avenues for discovery for the science and engineering community. Initial planning and design, and follow-on operations and maintenance costs of the facilities are provided through the Research and Related Activities account (R&RA) and Education and Human Resources (EHR) account.

For information on projects funded through this account, refer to the MREFC chapter of this Budget Request.

Preconstruction Planning

Within the R&RA account, funds are provided for preconstruction studies for prospective major facility projects. This funding generally supports such activities as design, cost estimates, and other actions that prepare potential projects for oversight review, agency decision milestones, and potential implementation.