

MAJOR MULTI-USER RESEARCH FACILITIES

Major Multi-user Research Facilities Funding

(Dollars in Millions)

	FY 2014 Actual	FY 2015 Estimate	FY 2016 Request	Change Over FY 2015 Estimate	
				Amount	Percent
Total Research and Related Activities	\$977.26	\$973.01	\$1,001.78	\$28.77	3.0%
Operations and Maintenance of Existing Facilities	745.41	717.00	737.91	20.91	2.9%
Federally Funded Research and Development Centers	199.51	207.01	202.83	-4.18	-2.0%
Operations and Maintenance of Facilities Under Construction	23.89	45.00	55.04	10.04	22.3%
R&RA Planning and Concept Development	8.45	4.00	6.00	2.00	50.0%
Major Research Equipment and Facilities Construction	\$200.00	\$200.76	\$200.31	-\$0.44	-0.2%
Total, Major Multi-User Research Facilities	\$1,177.26	\$1,173.77	\$1,202.09	\$28.33	2.4%

Totals may not add due to rounding.

NSF investments provide state-of-the-art tools for research and education, such as multi-user research facilities, distributed instrumentation networks and arrays, accelerators, telescopes, research vessels, aircraft, and earthquake simulators. In addition, investments in internet-based and 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, agencies, and countries to ensure complementarity and integration. Planning, operations, and maintenance of multi-user facilities are funded through the Research and Related Activities (R&RA) account, and most major construction projects are 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 large 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 2014	FY 2015	FY 2016	Change over	
	Actual	Estimate	Request	FY 2015 Estimate	Amount Percent
Operations and Maintenance of Existing Facilities	\$745.41	\$717.00	\$737.91	-\$1.99	-0.3%
Engineering					
National Nanotechnology Infrastructure Network (NNIN)	15.30	-	-	-	N/A
National Nanotechnology Coordinated Infrastructure (NNCI)	-	15.46	15.46	-	-
George E. Brown Jr. Network for Earthquake Engineering Simulation (NEES)	18.14	-	-	-	N/A
Natural Hazards Engineering Research Infrastructure (NHERI)	-	12.00	12.50	0.50	4.2%
Geosciences					
Academic Research Fleet ¹	83.00	85.00	85.00	-	-
Geodesy Advancing Geosciences and EarthScope (GAGE)	11.58	11.58	12.33	0.75	6.5%
International Ocean Discovery Program (IODP)	50.00	48.00	48.00	-	-
Ocean Observatories Initiative (OOI) ²	49.30	55.00	55.00	-	-
Polar Facilities and Logistics	310.00	295.47	302.90	7.43	2.5%
Seismological Facilities for the Advancement of Geosciences and EarthScope (SAGE)	24.35	24.35	25.10	0.75	3.1%
Mathematical and Physical Sciences					
Arecibo Observatory	8.00	8.00	8.20	0.20	2.5%
Cornell High Energy Synchrotron Source (CHESS)	20.04	20.00	20.00	-	-
Gemini Observatory	19.58	20.61	19.77	-0.84	-4.1%
IceCube	6.90	6.90	6.90	-	-
Large Hadron Collider (LHC)	17.37	18.00	18.00	-	-
Laser Interferometer Gravitational-Wave Observatory (LIGO)	36.43	39.43	39.43	-	-
National High Magnetic Field Laboratory (NHMFL)	42.26	24.04	34.66	10.62	44.2%
National Solar Observatory (NSO) ³	8.00	8.00	9.50	1.50	18.8%
National Superconducting Cyclotron Laboratory (NSCL)	22.50	22.50	22.50	-	-
Other Facilities ⁴	2.66	2.66	2.66	-	-
Federally Funded Research and Development Centers⁵					
National Center for Atmospheric Research (NCAR)	96.60	98.20	99.00	0.80	0.8%
National Optical Astronomy Observatory (NOAO)	25.50	25.50	21.75	-3.75	-14.7%
National Radio Astronomy Observatory (NRAO) ⁶	77.41	83.31	82.08	-1.23	-1.5%
Operations and Maintenance of Facilities under Construction					
Daniel K. Inouye Solar Telescope (DKIST) ⁷	2.00	7.00	11.00	4.00	57.1%
National Ecological Observatory Network (NEON)	21.89	38.00	44.04	6.04	15.9%
R&RA Planning and Concept Development					
Pre-construction Planning ⁸	1.86	4.00	6.00	2.00	50.0%
Concept and Development for MREFC Projects	6.59	-	-	-	N/A
Major Research Equipment and Facilities Construction	\$200.00	\$200.76	\$200.31	-\$0.45	-0.2%
Total, Major Multi-User Research Facilities	\$1,177.26	\$1,173.77	\$1,202.09	\$28.32	2.4%

Totals may not add due to rounding.

¹ An additional \$1.86 million in FY 2014, \$2.0 million in FY 2015, and \$3.0 million in FY 2016 for Research Class Regional Vessels (RCRV) is included in pre-construction planning.

² OOI transitioned from MREFC construction to operations and maintenance phase in FY 2015 and thus is now included in the GEO Facilities section.

³ The total presented does not include \$5.0 million in FY 2015 and \$9.0 million in FY 2016 for operations and maintenance support for the DKIST facility construction project. That funding is captured within the total presented on the DKIST line under Operations and Maintenance of Facilities under Construction.

⁴ Other Facilities includes support for other materials research facilities.

⁵ Federally-Funded R&D Centers do not include support for the Science and Technology Policy Institute (STPI), which is an FFRDC but not a multi-user research facility.

⁶ Operations and maintenance of the Atacama Large Millimeter Array (ALMA) are included in NRAO.

⁷ Of the total DKIST funding presented, \$5.0 million in FY 2015 and \$9.0 million in FY 2016 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.

⁸ Pre-construction planning includes R&RA funding for potential next-generation major multi-user facilities, including RCRV and Antarctic Infrastructure Modernization for Science (AIMS).

NSF Facilities Investments in FY 2016

The following pages contain information on NSF’s ongoing facilities in FY 2016.

Facilities

Academic Research Fleet	Facilities - 4
Arecibo Observatory.....	Facilities - 8
Cornell High Energy Synchrotron Source (CHESS).....	Facilities - 12
Gemini Observatory.....	Facilities - 14
Geodesy Advancing Geosciences and EarthScope (GAGE).....	Facilities - 18
IceCube Neutrino Observatory	Facilities - 21
International Ocean Discovery Program (IODP).....	Facilities - 24
Large Hadron Collider (LHC)	Facilities - 27
Laser Interferometer Gravitational Wave Observatory (LIGO)	Facilities - 30
National High Magnetic Field Laboratory (NHMFL).....	Facilities - 33
National Nanotechnology Coordinated Infrastructure (NNCI)	Facilities - 35
National Solar Observatory (NSO).....	Facilities - 38
National Superconducting Cyclotron Laboratory (NSCL).....	Facilities - 42
Natural Hazards Engineering Research Infrastructure (NHERI).....	Facilities - 44
Ocean Observatories Initiative (OOI).....	Facilities - 48
Polar Facilities and Logistics.....	Facilities - 52
Seismological Facilities for the Advancement of Geoscience and EarthScope (SAGE)	Facilities - 56

Federally Funded Research and Development Centers (FFRDCs)

National Center for Atmospheric Research (NCAR)	Facilities - 59
National Optical Astronomy Observatory (NOAO).....	Facilities - 63
National Radio Astronomy Observatory (NRAO)	Facilities - 67

Other Facilities Funding

Major Research Equipment and Facilities Construction Account Projects	Facilities - 71
Preconstruction Planning	Facilities - 71

ACADEMIC RESEARCH FLEET**\$88,000,000**
+\$1,000,000 / 1.1%**Academic Research Fleet**

(Dollars in Millions)

FY 2014	FY 2015	FY 2016	Change over	
			FY 2015 Estimate	
Actual	Estimate	Request	Amount	Percent
\$84.86	\$87.00	\$88.00	\$1.00	1.1%

The U.S. Academic Research Fleet includes 20 vessels in calendar year 2014, and 19 vessels in calendar year 2015. These vessels range in size, endurance, and capabilities, enabling NSF and other federally funded scientists to conduct ocean science research with a diverse fleet capable of operating in coastal and open ocean waters. Funding for the Fleet 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 of 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* published in May 2013.

Total Obligations for the Academic Research Fleet

(Dollars in Millions)

	FY 2014 Actual	FY 2015 Estimate	FY 2016 Request	ESTIMATES ¹				
				FY 2017	FY 2018	FY 2019	FY 2020	FY 2021
Operations & Maintenance	\$83.00	\$85.00	\$85.00	\$85.00	\$85.00	\$85.00	\$85.00	\$85.00
<i>RV Sikuliaq O&M</i> ²	2.00	3.50	5.00	5.00	5.00	5.00	5.00	5.00
Fleet Modernization	-	-	-	-	-	-	-	-
Regional Class Research Vessel	1.86	2.00	3.00	1.00	-	-	-	-
Total, Academic Research Fleet	\$84.86	\$87.00	\$88.00	\$86.00	\$85.00	\$85.00	\$85.00	\$85.00

Totals may not add due to rounding.

¹ Outyear funding estimates are for planning purposes only.

² As discussed in the *RV Sikuliaq* narrative, operations and maintenance for the *RV Sikuliaq* are now included in Fleet Operations and Maintenance. Because the Academic Fleet is operated as a shared multi-agency resource where agencies pay for time uses on vessels, the annual OCE operating budget for any single vessel may vary significantly from year to year. Thus, estimates for the *RV Sikuliaq* for FY 2015 and beyond are provided as a rough guide of likely costs.

The U.S. Academic Research Fleet serves as the main platform for the collection of data and testing of hypotheses about the structure and dynamics of the ocean. 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.

The Fleet 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; NSF supports approximately 60 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 both NSF and other federal and state agencies. Within NSF, 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 Division of Polar Programs (PLR), 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 2016 Request of \$88.0 million will support approximately 2,100 ship operating days.

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 operations rate negotiations. In addition, NSF oversees the Fleet through site visits, ship inspections, and participation at UNOLS Council and 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. No Business System Reviews of Academic Research Fleet operating institutions are currently scheduled for 2015.
- 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 research will be needed far into the future. Documents supporting this need include the *National Ocean Policy* and the *Final Recommendations of the Interagency Ocean Policy Task Force* 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* published in 2009, and *Critical Infrastructure for Ocean Research and Societal Needs in 2030* published in 2011. In coordination with UNOLS and the other federal agencies which invest in ocean research, the Interagency Working Group on Facilities and Infrastructure (IWG-FI) published a *Federal Oceanographic Fleet Status Report* in May 2013, reviewing the status and describing plans for modernizing the federal and academic oceanographic research and survey fleet. 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.

Fleet Modernization

Oversight: The NSF coordinator for Fleet modernization activities is the Program Director for Ship Acquisition and Upgrades, 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 account. In December 2013, OSU successfully

completed all CDR requirements in accordance with NSF's Large Facilities Manual. 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. Construction could start as early as 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. Management and oversight would be similar to the R/V *Sikuliaq* project. NSF is continuing discussions with the NOAA Office of Marine and Aviation Operations to explore the potential for collaboration between the two agencies on the design of the RCRV and the modernization efforts being considered for the NOAA mid-size vessels. In addition, NSF is an active participant in the IWG-FI Ship Subcommittee, which developed the update to the 2013 *Federal Oceanographic Fleet Status Report*, an action in the *National Ocean Policy (NOP) Implementation Strategy*.¹ The RCRV would address requirements across the government agencies for research vessels in support of ocean science research as discussed in the Fleet Status Report Update. Decisions on proceeding to further development stages will be based upon NSF, National Science Board (NSB), and interagency reviews.

R/V *Sikuliaq*, formerly the Alaska Region Research Vessel (ARRV): The Research Vessel *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 Glostén 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. Activities remaining in the construction portion of the project include ice trials to be conducted in the Bering Sea in 2015 and warranty items closeout, including the warranty dry docking inspection.

Research in the Arctic is needed on topics ranging from climate change, ocean circulation, ecosystem studies, and fisheries research, to natural hazards and cultural anthropology. The *Sikuliaq* will provide a sophisticated and significantly larger platform for scientists, as well as graduate and undergraduate students to participate in complex multidisciplinary research activities and will enable the training of the next generation of scientists with the latest equipment and technology. The *Sikuliaq* is expected to greatly expand research capabilities in the Arctic with up to 270-300 science days at sea annually. The ice-strengthened hull will allow the vessel to operate in seasonal ice up to one meter thick and an anti-roll tank will permit it to operate effectively in the open waters of the Bering Sea, Gulf of Alaska, and North Atlantic. Due to its size and projected operating area, the *Sikuliaq* will operate as a Global Class vessel within the U.S. Academic Research Fleet.

Other Ongoing Activities

Major overhaul and upgrade to the submersible Human Occupied Vehicle *ALVIN* was completed in FY 2013. The *ALVIN* Upgrade Project is 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

¹ www.whitehouse.gov/administration/eop/oceans/implementationplan

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 are scheduled for January 2015.

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. Awardees are subject to additional oversight measures, including quarterly safety and financial reporting, the use of NSF BSRs, 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 University. For the *R/V Sikuliaq*, a re-compete clause in 10 years (2024) was included in the initial cooperative agreement for operations.

ARECIBO OBSERVATORY

\$8,200,000
+\$200,000 / 2.5%

Arecibo Observatory
(Dollars in Millions)

FY 2014 Actual	FY 2015 Estimate	FY 2016 Request	Change over FY 2015 Estimate	
			Amount	Percent
\$8.00	\$8.00	\$8.20	\$0.20	2.5%

The Arecibo Observatory (Arecibo), formerly the National Astronomy and Ionosphere Center, is a center for multidisciplinary research and education enabled by world-class observational facilities. The observatory’s principal facility is the world’s largest single-dish radio/radar telescope, 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 subawardees Universities Space Research Association (USRA) and Universidad Metropolitana (UMET) under a cooperative agreement with NSF that began on October 1, 2011. 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 topic experts from outside the observatory are consulted for reviews. NSF does not provide awards targeted specifically for use of Arecibo, although many users are supported through NSF or NASA grants to pursue scientific programs that require use of the facility.

Arecibo has a staff of about 122 full-time-equivalent positions at the beginning of FY 2015. A total of 97 permanent staff work for Arecibo. This includes 15 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. There are 25 individuals involved at the Angel Ramos Foundation Visitor Center, including 18 temporary tour guides.

Total Obligations for the Arecibo Observatory
(Dollars in Millions)

	FY 2014	FY 2015	FY 2016	ESTIMATES ¹				
	Actual	Estimate	Request	FY 2017	FY 2018	FY 2019	FY 2020	FY 2021
Operations & Maintenance (MPS)	\$4.50	\$4.00	\$4.10	\$4.10	\$4.10	\$4.10	\$4.10	\$4.10
Operations & Maintenance (GEO)	3.50	4.00	4.10	4.10	4.10	4.10	4.10	4.10
Total, Arecibo	\$8.00	\$8.00	\$8.20	\$8.20	\$8.20	\$8.20	\$8.20	\$8.20

Totals may not add due to rounding.

¹ Outyear funding estimates are for planning purposes only. The current cooperative agreement ends in September 2016.

Arecibo is jointly supported by the NSF Directorate for Mathematical and Physical Sciences, Division of Astronomical Sciences (MPS/AST) and the NSF Directorate for Geosciences, Division of Atmospheric and Geospace Sciences (GEO/AGS). Planned AST support through FY 2016 is based upon the 2006 AST Senior Review recommendations, guidance from a third-party cost review of AST facilities, and a third-party estimate of Arecibo’s non-scientific costs. Based on Senior Review recommendations, AST has been ramping down support for Arecibo. At the same time AGS has significantly increased support, with funding proposed to ramp up to parity with AST in FY 2015 and beyond. (More on AGS activities at Arecibo can be found below under Management and Oversight.)

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*, 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, 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*,² was released in August 2012 and included recommendations about all of the major AST telescope facilities.

The PRC recommended that support for Arecibo should be continued at funding levels near those currently planned, with a re-evaluation later in the decade, based on science opportunities and budget forecasts at that time. These re-evaluation timescales are roughly coincident with the expiration of the cooperative agreement at the end of FY 2016. In view of the long lead time required for conducting a management competition, NSF has contracted a feasibility study for divestment alternatives, which will provide a baseline structural and environmental survey of conditions at Arecibo. This study, to be completed in FY 2015, is likely to be followed by a formal review to evaluate environmental impacts of viable divestment options, including the possible impacts of potential partnerships.

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 was increased to \$3.60 million for FY 2013, with more observing time allocated to the NASA Program. NASA support is expected to continue at the level of about \$3.70 million in FY 2015 and FY 2016, subject to the availability of funds. A grant to the Visitor Center from the Puerto Rico Department of Education was finalized in 2013. This award was for \$1.90 million over seven months; part of this was to train teachers, as described in the next section, while part of it was to enable larger numbers of Puerto Rican school children to visit the site.



An aerial 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.*

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. 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. With the funds mentioned above from the Puerto Rico Department of Education, Arecibo hosted three teacher workshops which trained a total of 428 teachers. This program integrates formal activities at the Angel Ramos Foundation Visitor Center

² www.nsf.gov/mps/ast/ast_portfolio_review.jsp

into the STEM curriculum in Puerto Rico. Arecibo also hosts several meetings each year within a wide variety of scientific disciplines.

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 current average oversubscription rate of the telescope is approximately 3.5, counting ongoing astronomy surveys, new astronomy projects, solar system observations, and atmospheric sciences programs. About 80 percent of astronomy users conduct their observing remotely via networked control software, while radar observations typically employ on-site users.

In January 2014, a magnitude 6.4 earthquake off the coast of Puerto Rico damaged one of the cables supporting the platform structure high above the main dish. As a safety measure, the platform was not moved until structural repairs could be effectuated, requiring a significant modification to the telescope's operational plans and schedule. Repairs were completed, and the telescope returned to full service on March 11, 2014. During this unscheduled maintenance period, a formal pulsar drift scan program was able to effectively use the telescope.

Management and Oversight

- **MPS/AST, \$4.10 million:** AST funds basic operations costs and science programs in passive radio astronomy and solar system radar astronomy. As recommended by the 2006 AST Senior Review, funding for Arecibo has been gradually reduced, declining to a lower baseline of \$4.0 million in FY 2015. The modest increase in FY 2016 is a planned inflationary adjustment that was part of the baseline published in the solicitation for the Arecibo management competition carried out in FY 2010 and FY 2011. Arecibo operational scope has changed in response to decreased AST support. AST is currently determining its plan for support of Arecibo beyond FY 2016.
- **GEO/AGS, \$4.10 million:** The incoherent scatter radar at Arecibo is part of an NSF-supported network of radars strategically distributed to observe the transport of radiative energy and charged particles, from their origins at the sun to their deposition in Earth's upper atmosphere. The unique sensitivity of the Arecibo incoherent scatter radar system allows it to measure the density, temperature, and motion of plasma in Earth's ionosphere with unrivaled time and spatial resolution. Arecibo is also the only aeronomy observatory located at tropical mid-latitudes, where many important ionospheric processes take place. An ionospheric high-frequency heating facility is currently under construction at Arecibo with completion anticipated in FY 2015. This heating facility is part of an expanded scope in aeronomy funded by AGS.
- **NSF Structure:** Ongoing oversight is provided by the lead NSF program officer in AST, in close cooperation with an assigned 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 as they arise, the program officers work closely with other offices at NSF, particularly the Division of Acquisition and Cooperative Support; the Office of General Counsel; and the Large Facilities Office of the Office of Budget, Finance, and Award Management. The AST and AGS program officers conduct periodic site visits and frequent 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 Arecibo director, resident at the telescope site, is the principal investigator of the operations award for the facility. Three deputy directors in the areas of

Atmospheric Sciences, Planetary Radar, and Puerto Rican EPO report to the Arecibo director.

- Reviews:
 - A review of the proposal for management and operations of Arecibo was held in 2010, resulting in an award to SRI (see below) from October 2011 to September 2016.
 - A Business Systems Review involving two of the partner organizations of Arecibo, SRI and UMET, was conducted in late 2012.
 - AST and AGS jointly conduct annual external reviews of Arecibo program plans; the most recent review was held in October 2013. The next program review will be held in late CY 2015. (A program plan review was not held in 2014, but was instead superceded by the mid-term management review: see next bullet below).
 - AST and AGS jointly conducted a mid-term management review of the Arecibo cooperative agreement in November 2014. The panel report is expected to be received early in calendar year 2015.

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 is in effect through September 30, 2016. The direction beyond that time will be determined after carrying out the study of divestment alternatives discussed above.

CORNELL HIGH ENERGY SYNCHROTRON SOURCE**\$20,000,000**
\$0 / 0.0%**Cornell High Energy Synchrotron Source**

(Dollars in Millions)

FY 2014	FY 2015	FY 2016	Change over	
			FY 2015 Estimate	
Actual	Estimate	Request	Amount	Percent
\$20.04	\$20.00	\$20.00	-	-

The Cornell High Energy Synchrotron Source (CHESS) is a high-intensity, high-energy X-ray user facility supported by NSF with interagency support from the National Institutes of Health (NIH). 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, and environmental sciences. Areas of emphasis 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).

The FY 2016 Request supports operations of CHESS as a national user facility and is consistent with funding levels in previous years. Support for CHESS has shifted over the past years from research and development to a national user facility, thus the activities are evolving. Funding will allow continued operation of the facility in support of high energy X-ray synchrotron users.

Total Obligations for CHESS

(Dollars in Millions)

	FY 2014	FY 2015	FY 2016	ESTIMATES ¹				
	Actual	Estimate	Request	FY 2017	FY 2018	FY 2019	FY 2020	FY 2021
Operations & Maintenance (MPS)	\$10.00	\$10.00	\$10.00	\$10.00	\$10.00	\$10.00	\$10.00	\$10.00
Operations & Maintenance (BIO)	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00
Operations & Maintenance (ENG)	5.04	5.00	5.00	5.00	5.00	5.00	5.00	5.00
Total, CHESS	\$20.04	\$20.00	\$20.00	\$20.00	\$20.00	\$20.00	\$20.00	\$20.00

Totals may not add due to rounding.

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

CHESS is a national user facility accessed on the basis of competitive proposal review. The primary function of CHESS staff is to maintain and operate the facility and to assist users. Users number about 750 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 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 is developing 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 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, the Department of Energy's (DOE) 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 optic are impacting synchrotrons science world-wide.

- 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. Their education and outreach program annually impacts over 6,000 people of all ages, including over 1,300 visitors touring the Cornell facilities. Each year there are about 60 Ph.D. degrees 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 Directorate for Mathematical and Physical Science (MPS), Engineering (ENG), and Biological Sciences (BIO) through a cooperative agreement with Cornell University. The MPS Division of Materials Research (MPS/DMR) program director is the primary contact with the facility, and leads an internal NSF team of program directors. Additional support for CHESS operations is provided by NIH.
- **External structure:** CHESS is administered by the Cornell Laboratory of Accelerator-based Sciences and Education (CLASSE), which reports to Cornell's Vice-Provost for Research. 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. The 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, and 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 from the community, representatives from the NIH attend these site visits. Recent and upcoming reviews include:
 - A Management Review focusing on CHESS operations and strategic planning was held July 9-10, 2014.
 - The next annual site visit review will be held in the fall of 2015.

Renewal/Recompetition/Termination

A comprehensive renewal review was conducted in FY 2013 for a five year renewal award covering the period April 1, 2014 – March 31, 2019.

GEMINI OBSERVATORY

\$19,770,000
-\$840,000 / -4.1%

Gemini Observatory

(Dollars in Millions)

FY 2014 Actual	FY 2015 Estimate	FY 2016 Request	Change over FY 2015 Estimate	
			Amount	Percent
\$19.58	\$20.61	\$19.77	-\$0.84	-4.1%

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 4,200 meters elevation, 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 questions being investigated by today’s astronomers are the age and rate of expansion of the universe, the origin of the “dark energy” that is manifested in the cosmic acceleration,



Night at the Gemini North telescope on Mauna Kea, Hawaii. The transparent-dome effect is created by the stacking of many images obtained throughout a night of observing. The central regions of our Milky Way galaxy seen against an incredibly dark sky provide a stunning backdrop to the telescope. *Credit: Gemini Observatory/AURA.*

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 planetary systems. The current generation of large optical/infrared telescopes is central to these studies, owing to their unsurpassed sensitivity and spectral and 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 Gemini telescopes help educate and train U.S. astronomy and engineering students. An estimated 10 percent of the roughly 500 U.S. users per year are students. Gemini also provides an engaging focal point for public outreach and student training in all of the partner countries, and maintains "sister city" arrangements between the site hosts of Hilo, Hawaii and La Serena, Chile. Gemini-sponsored activities attract students and teachers at all levels of elementary through high school education. Gemini staff members provide guidance and support to the Imiloa Science Center, a public astronomy and cultural center in Hilo, Hawaii.

Total Obligations for the Gemini Observatory

(Dollars in Millions)

	FY 2014 Actual	FY 2015 Estimate	FY 2016 Request	ESTIMATES ¹				
				FY 2017	FY 2018	FY 2019	FY 2020	FY 2021
Operations & Maintenance	\$19.58	\$20.61	\$19.77	\$20.61	\$20.61	\$20.69	\$21.28	\$21.89

¹ Outyear funding estimates are for planning purposes only. The current cooperative agreement ends on December 31, 2015.

The international partnership that operates Gemini currently consists of the U.S., Canada, Australia, 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/or complex optical systems, engineering, electronics, electro-mechanical systems, and computing, among others. Continued development in these technological areas is reflected in the instrumentation and facilities renewal activities that are incorporated into the overall budget of the Gemini Observatory.

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 with near-infrared images that exceed the quality available with orbiting observatories and offer a wider field of view than is provided by any competing system. Commissioned during the past year and now in regular use for directly imaging and characterizing planets orbiting nearby stars is the state-of-the-art Gemini Planet Imager, while improvements to the multi-object spectrograph in Chile have greatly increased its utility in the far red spectral region.

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 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.

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*,³ 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) conducted a community-based review of its portfolio. The resulting Portfolio Review Committee (PRC) report, *Advancing Astronomy in the Coming Decade: Opportunities and Challenges*⁴ was 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

³www.nap.edu/catalog.php?record_id=12951

⁴www.nsf.gov/mps/ast/ast_portfolio_review.jsp

Major Multi-User Research Facilities

\$17.0 million per year. Given the withdrawal of the United Kingdom and Australia from the Gemini partnership (see below), and the NRC recommendation that the U.S. increase its partner share in Gemini, the budget request for Gemini remains somewhat higher than that recommended by the PRC.

The FY 2016 Request includes the full U.S. contribution to baseline operations at the level agreed to by the international partners (\$18.02 million in FY 2016), and a contribution of \$1.75 million to the Gemini Instrument Development Fund. Future requirements are being considered in the context of NSF's overall actions on the 2012 Portfolio Review recommendations and discussion of the post-2015 international agreement with Gemini partners; these considerations are likely to change the out-year funding estimates slightly.

Management and Oversight

- **NSF Structure:** NSF has one seat on the Gemini Board, currently occupied by the division director of the Directorate for Mathematical and Physical Sciences/Division of Astronomy (MPS/AST). An additional NSF staff member serves as the executive secretary to the board. Programmatic oversight is the responsibility of an NSF program officer in MPS/AST. 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, and approves funding actions, reports, and contracts.
- **External Structure:** The observatory is governed by the Gemini Board, established by the International Gemini 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. In FY 2013, NSF appointed the Director of the U.S. National Optical Astronomy Observatory (NOAO) as one of these members in order to facilitate increased cooperation between NOAO and Gemini and to provide an improved voice for the general U.S. astronomical community. Gemini is currently managed by the Association of Universities for Research in Astronomy (AURA), Inc., on behalf of the partnership through a cooperative agreement with NSF. AURA conducts its own management reviews through standing oversight committees.
- **Reviews:** NSF conducts periodic reviews of the management and observatory programs as requested by the Gemini Board. The most recent mid-term management review was held in September 2008. NSF conducted a Business System Review (BSR) of the observatory in March 2009, and several other AURA facilities, including its centralized administrative services, were the subject of a BSR in 2013. The current cooperative agreement to AURA for the operation of Gemini was awarded after a renewal proposal review in March 2011 and extends through December 31, 2015.

Renewal/Recompetition/Termination

The United Kingdom withdrew from the Gemini partnership at the end of 2012 in the midst of a major restructuring of that country's scientific priorities. This required the observatory to adjust its operations model to an approximately 24 percent reduction in budget, which will result in a reduction in total staffing from about 200 in FY 2011 to less than 160 by the end of FY 2017. More recently, Australia, a 6.3 percent partner, has declared that it is unable to commit to a specific funding level beyond 2015, but wishes to move to a more limited participation on a year-to-year basis. Discussions with a new potential international partner have progressed rapidly during the past year and arrangements are now being made for that group to assume the full 6.3 percent share of Australia in FY 2017. The technical contents of a new international agreement for the post-2015 years have been agreed on among the partners, but any further delays in formal signature of the agreement by the governments could have significant impact on the partnership and the NSF budget..

The current NSF cooperative agreement to AURA for managing the Gemini Observatory includes the transition to the new operations model. Reductions in project scope that accompany the decline in budget

include a reduced instrument complement on each telescope, a reduction in labor for the scheduling queue, decreased development and outreach activities, and a tighter operational focus on serving the partner user communities vs. internal scientific research activities. The funding recommendation for this plan was approved by the National Science Board in February 2012.

In order to provide the most competitive atmosphere for managing Gemini after the end of the current cooperative agreement in December 2015, NSF postponed issuance of a solicitation for proposals until summer 2014. This delay moved the Gemini solicitation beyond the timeframe for the other major U.S. optical observatory, NOAO. Delaying the Gemini solicitation necessitated a one-year extension of the current Gemini cooperative agreement with AURA until December 2016, an action that has been described to the National Science Board and which entails a review now underway. Proposals for the ensuing competed agreement for managing the observatory are due February 27, 2015. Review of those proposals will lead to an award that is targeted to take effect January 1, 2017 and will cover a six-year period through December 31, 2022.

GEODESY ADVANCING GEOSCIENCES AND EARTHSCOPE

\$12,330,000
+\$750,000 / 6.5%

Geodesy Advancing Geosciences and EarthScope

(Dollars in Millions)

FY 2014	FY 2015	FY 2016	Change over	
			FY 2015 Estimate	
Actual	Estimate	Request	Amount	Percent
\$11.58	\$11.58	\$12.33	\$0.75	6.5%

The Geodesy Advancing Geosciences and EarthScope (GAGE) comprise 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, Inc., a consortium of 107 U.S. universities and non-profit institutions with research and teaching programs in geophysics and geodesy and 93 associate members from foreign institutions. GAGE was formed in late FY 2013 from part of the EarthScope program and UNAVCO. In FY 2016, a small increase is requested to allow GAGE to continue providing service to the community consistent with that in previous years.

Total Obligations for GAGE

(Dollars in Millions)

	FY 2014	FY 2015	FY 2016	ESTIMATES ¹				
	Actual	Estimate	Request	FY 2017	FY 2018	FY 2019	FY 2020	FY 2021
Operations & Maintenance	\$11.58	\$11.58	\$12.33	\$12.33	\$12.33	\$12.33	\$12.33	\$12.33

Totals may not add due to rounding.

¹ Outyear funding estimates are for planning purposes only. The current cooperative agreement ends September 30, 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 (430 of which transmit data in real-time) distributed across the United States, and concentrated on the active plate boundaries in the western contiguous U.S. and southern Alaska. 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. Nearly 600 continuous GPS observations from around the world are maintained, monitored, and data compiled into the GAGE data system. GAGE supports 62 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 > 100 station Caribbean region GPS and meteorological sensor network (COCONet) to support tectonic, volcano, tropical storm, and sea level change investigations.
- Community GPS receiver and geodetic technology pool includes a pool of over 650 GPS receivers, ancillary equipment, and six terrestrial laser scanners (TLS), 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. Additional supplemental funding for these activities is provided through the Division of Polar Programs (PLR).
- 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 140 terabytes of 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 100s 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.

Besides 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 annual 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), 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 Deep Earth Processes 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 107 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 mid-award 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 2017, in keeping with the phased integration and recompetition plan presented to the National Science Board in December 2009, NSF intends to solicit proposals for a future facility or facilities to support the Earth sciences research and education community currently supported by GAGE and the related Seismological Facilities for the Advancement of Geoscience and EarthScope (SAGE). NSF is currently considering the precise form of this solicitation, and any possible future facility/facilities are currently being considered within NSF and through discussions with the GAGE and SAGE support communities.

ICECUBE NEUTRINO OBSERVATORY

\$6,900,000
\$0 / 0.0%

IceCube Neutrino Observatory

(Dollars in Millions)

FY 2014 Actual	FY 2015 Estimate	FY 2016 Request	Change over FY 2015 Estimate	
			Amount	Percent
\$6.90	\$6.90	\$6.90	-	-

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]; 1 TeV is 10¹² eV; and 1 PeV is 10¹⁶ eV) are derived from the IceCube data stream. The IceCube Collaboration has studied neutrino events down to a deposited energy of 1 TeV. High-energy neutrinos may be produced either by the interaction of cosmic rays in the Earth’s atmosphere, the so-called atmospheric neutrinos, or in the vicinity of distant astrophysical accelerators like black holes and neutron stars, the so-called astrophysical neutrinos. Astrophysical neutrinos remain the dominant component above 10 TeV.



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 up-time 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 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.*

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. In essence, the DCA closes the energy gap between the IceCube Neutrino Observatory and the Super-Kamiokande detector in Japan, and also allows effective observations of high-energy neutrinos entering from the sky of the southern hemisphere.

Major Multi-User Research Facilities

Total Obligations for IceCube

(Dollars in Millions)

	FY 2014	FY 2015	FY 2016	ESTIMATES ¹				
	Actual	Estimate	Request	FY 2017	FY 2018	FY 2019	FY 2020	FY 2021
Operations & Maintenance (GEO)	\$3.45	\$3.45	\$3.45	\$3.45	\$3.45	\$3.45	\$3.45	\$3.45
Operations & Maintenance (MPS)	3.45	3.45	3.45	3.45	3.45	3.45	3.45	3.45
Total, IceCube	\$6.90	\$6.90	\$6.90	\$6.90	\$6.90	\$6.90	\$6.90	\$6.90

Totals may not add due to rounding.

¹ Outyear funding estimates are for planning purposes only. The current cooperative agreement ends on September 30, 2015.

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 16 U.S. institutions and 22 institutions in nine other countries (Germany, Belgium, Sweden, New Zealand, Australia, Canada, Japan, 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 Division of Polar Programs (PLR) and the Mathematical and Physical Sciences Directorate's Division of Physics (PHY). Support for operations and maintenance, research, and education and outreach is shared by PLR 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 one or two year terms. 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.
- **Reviews:** NSF will begin a process for re-competition of the operations and maintenance award in FY 2015. A new award is expected to be in place for FY 2016.

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.

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 next-generation leaders in astrophysics, including undergraduate students, graduate students, and postdoctoral research associates; K-12 teacher scientific/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 institutions; and enhanced public understanding of science through broadcast media and museum exhibits (such as the Adler Planetarium) 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

A solicitation for re-competition, conducted in accordance with NSF policy, will be issued early in 2015. The present award, which expires in September 2015, may be extended to allow time for the competition process.

THE INTERNATIONAL OCEAN DISCOVERY PROGRAM

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

International Ocean Discovery Program

(Dollars in Millions)

FY 2014 Actual	FY 2015 Estimate	FY 2016 Request	Change over	
			FY 2015 Estimate Amount	Percent
\$50.00	\$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 new IODP represents an international partnership of the scientists, research institutions, and funding organizations of 26 nations to explore the evolution and structure of Earth as recorded in the ocean basins. The new program management structure is streamlined and focused on maximizing facility efficiency, while retaining the intellectual cooperation and exchange of the previous drilling programs. 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. 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 2014 Actual	FY 2015 Estimate	FY 2016 Request	ESTIMATES ¹				
				FY 2017	FY 2018	FY 2019	FY 2020	FY 2021
Operations & Maintenance	\$50.00	\$48.00	\$48.00	\$48.00	\$48.00	\$48.00	\$48.00	\$48.00

Totals may not add due to rounding.

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. 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 an IODP Support Office represent additional NSF IODP science integration costs, made minimal to NSF because of international contributions to the program. In addition, NSF provides support for U.S. scientists to sail on IODP drilling platforms and to participate in IODP advisory panels through an associated grants program. The annual costs for the associated science integration and science support (not included in the table above) are approximately \$8.0 million.

The new IODP scientific program includes emphasis on 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.

An umbrella IODP Forum provides a venue for all IODP entities to exchange ideas and views on the scientific progress of the program. In the simplified new IODP management structure, each drillship is governed by independent facility boards, each unique and optimized for their respective drilling platform. In the case of the *JOIDES Resolution* Facility Board (JRFB), two advisory panels review proposals and give 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, Belgium, Canada, Denmark, Finland, France, Germany, Iceland, Ireland, Israel, Italy, the Netherlands, Norway, Poland, Portugal, 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.

Over 3,400 scientists from 51 nations have participated on Ocean Drilling Program, Integrated Ocean Drilling Program, and International Ocean Discovery Program expeditions since 1985, including more than 1,450 U.S. scientists from over 150 universities, government agencies, and industrial research laboratories. Samples and data have been distributed to at least 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 Support Office under the NSF Ocean Drilling Program (ODP). NSF's ODP is located within the Integrative Programs section, with two 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 NSF ODP grants program.
- 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.
- Reviews: Performance of the *JOIDES Resolution* facility will be reviewed by NSF panel yearly in consultation with the JRFB. Substantive review of management performance regarding *JOIDES Resolution* operations will occur in the third year of the cooperative agreement to guide 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

After competitive selection, Texas A&M University was selected in FY 2014 to be the *JOIDES Resolution* operator under a 5 year (FY15- FY19) 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 2013, to facilitate and support the activities of U.S. scientists participating in IODP activities, an IODP Science Support Office was selected at the University of California, San Diego through a competitive process for a 5 year (FY 2014- FY 2018) cooperative agreement.

The *JOIDES Resolution* operations and science support cooperative agreements contain a provision for annual external review of performance by an independent panel. Intensive mid-award reviews will be conducted for both cooperative agreements and will consider whether they should be extended or re-competed.

LARGE HADRON COLLIDER

\$18,000,000
\$0 / 0.0%

Large Hadron Collider
(Dollars in Millions)

FY 2014 Actual	FY 2015 Estimate	FY 2016 Request	Change over	
			FY 2015 Estimate Amount	Percent
\$17.37	\$18.00	\$18.00	-	-

The Large Hadron Collider (LHC), an international project 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. The LHC consists of a superconducting particle accelerator providing two counter-rotating beams of protons, approximately 16.5 miles in circumference, each beam with up to 7 TeV (1TeV=10¹² electron volts) of energy. It can also provide colliding beams of heavy ions, such as lead. Data-taking with colliding proton beams at 4 TeV ended in December 2012 at which point the LHC was reconfigured to deliver heavy ion collisions for six weeks. In March 2013, the LHC began a 20-month period of extensive repairs and enhancements that will enable it to operate at the full design energy of 7 TeV per beam, commencing in spring 2015.

Four large particle detectors collect the data delivered by the LHC. They characterize the reaction products produced in the high-energy proton-proton collisions and heavy ion beam collisions, which 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 and CERN is responsible for meeting the 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. During the 20-month maintenance period noted above, the detectors are also undergoing an extensive series of repairs and enhancements to prepare for resumed operation with more intense and higher energy beams (>6.5TeV/beam) during 2015-2018.

The successful operation during 2012 of the accelerator complex, the ATLAS and CMS detectors, and the world-wide LHC computing grid culminated in the first major discovery at the LHC. On July 4, 2012, the CMS and ATLAS collaborations announced the discovery of a particle consistent with the long-sought Higgs boson. Further study of the properties of this new particle suggest that it is probably the Higgs boson that is predicted in the Standard Model of particle physics, which provides a deeper understanding of the origin of mass of known elementary particles. This achievement was recognized by the 2013 Nobel Prize in Physics to Francois Englert and Peter Higgs for the “theoretical discovery of a mechanism that contributes to our understanding of the origin of mass.” 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. The resumed program of operation at higher energy and higher intensity planned to start in 2015 is expected to significantly enhance the chances of more ground-breaking discoveries at the LHC.

Total Obligations for LHC

(Dollars in Millions)

	FY2014	FY2015	FY 2016	ESTIMATES ¹				
	Actual	Estimate	Request	FY 2017	FY 2018	FY 2019	FY 2020	FY 2021
Operations & Maintenance	\$17.37	\$18.00	\$18.00	\$20.00	\$20.00	\$20.00	\$20.00	\$20.00

¹ Outyear funding estimates are for planning purposes only. The current cooperative agreements end in December 2016 (CMS) and January 2017 (ATLAS).

A world-wide 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.

In addition to preparing for resumed accelerator operation in 2015, experimenters have also commenced construction activities for a “Phase 1” upgrade of the detectors following the conclusion of 2015-2018 accelerator operation. The goals of this upgrade are primarily to repair expected radiation damage and to benefit from advances in detector technology while maintaining existing detector capabilities. The May 2014 report of the Particle Physics Project Prioritization Panel (P5) recommended to DOE and NSF that the highest priority strategic goal for U.S. particle physics within a global context should be continued support for involvement in the LHC program, including a further planned upgrade of the accelerator to very high luminosity operation, commencing in 2023. This would necessitate significant refurbishments and enhancements to the detectors in order to exploit this scientific opportunity. NSF has commissioned an advisory panel to seek community advice regarding how best to implement the P5 recommendations.

Through the participation of young investigators, graduate students, undergraduates, and minority 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.
- **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 Columbia University for ATLAS.
- **Reviews:** There is one major management/technical review each year with a panel of external, international experts, one minor follow-up review six months later, as well as bi-weekly telephone reviews by NSF/DOE program directors to monitor progress. NSF and DOE jointly conduct separate external reviews of the Phase 1 upgrade activities. The next major management/technical review is scheduled for April 2015. Two JOG review meetings per year monitor overall program management.

Renewal/Recompetition/Termination

The LHC project is expected to continue at least through the end of the next decade. In December 2011, new cooperative agreements were negotiated with the ATLAS and CMS collaborations to extend funding for five years to support their role in the international collaborations. It is anticipated that the U.S.

ATLAS and CMS collaborations will submit renewal proposals during 2016 for a continuation of support for five years beyond the current agreements, beginning in FY 2017.



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 2014 Actual	FY 2015 Estimate	FY 2016 Request	Change over FY 2015 Estimate	
			Amount	Percent
\$36.43	\$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 neutron stars or black holes, will produce gravitational radiation. Detection of these gravitational waves is of great importance for fundamental physics, astrophysics, and astronomy. The Laser Interferometer Gravitational-Wave Observatory (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, a large vacuum chamber with two 4-km arms joined at right angles houses an optical interferometer. The interferometers are used to measure minute changes in the distances between mirrors at the ends of the arms caused by a passing gravitational wave. 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 change over the apparent 4-km length is only on the order of 4×10^{-18} meters, or about 1/1000th the diameter of a proton. The 4-km length for LIGO, the largest for any optical interferometer, was chosen to make the expected signal as large as possible within terrestrial constraints. Looking for coincident signals from both interferometers simultaneously increases the likelihood for gravitational wave detection.

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, in addition to increasing noise immunity, greatly enhance LIGO’s angular resolution of candidate gravitational wave sources, facilitating follow-up investigations using optical and radio telescopes.

In April 2008 construction began on the Advanced LIGO (AdvLIGO) Major Research Equipment and Facility Construction (MREFC) project, which is designed to increase the sensitivity of LIGO tenfold. AdvLIGO is being built within the existing LIGO observatory. LIGO’s current and projected operations and maintenance expenses are designed to sustain operation of the LIGO laboratory while construction is underway, as well as to commission and operate the upgraded apparatus following the completion of construction in 2015. These include support for basic infrastructure costs not directly related to the AdvLIGO construction project, analysis and dissemination of data obtained from the



An aerial view of the Livingston, Louisiana LIGO site. Credit: Caltech/MIT LIGO Laboratory.

interferometers, maintenance of computational resources for data storage and analysis, complementary research and development expected to enhance operational performance and reduce technical risk, and education and outreach activities associated with the laboratory.

The LIGO Science Education Center at the Livingston site is the focal point for augmenting teacher education at Southern University and other student teacher activities state wide through the Louisiana Systematic Initiative Program. The LIGO Science Education Center’s programs include funding for an external evaluation firm that provides both assistance in aligning future activities with proposed goals and evaluating outcomes.

In order to meet its cutting-edge performance requirements, substantial connections with industry have resulted from the undertaking of the AdvLIGO project. Innovations across a diverse range of technologies have led to new techniques with broad applications, and in other cases have resulted in patents and commercial products.

Total Obligations for LIGO

(Dollars in Millions)

	FY 2014	FY 2015	FY 2016	ESTIMATES ¹				
	Actual	Estimate	Request	FY 2017	FY 2018	FY 2019	FY 2020	FY 2021
Operations & Maintenance	\$36.43	\$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 FY 2018.

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, including establishing priorities for scientific operation, data analysis and validation of scientific results, and for 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.

The Advanced LIGO MREFC Project is expected to be substantially complete before April 2015. The LIGO Livingston Observatory interferometer has successfully demonstrated that it meets acceptance requirements for the completion of construction, and the LIGO Hanford Observatory is following closely behind. The first scientific operation of both interferometers is planned for the fall of 2015, as part of the overall plan to interleave engineering studies that tune up the detection sensitivity with periods of scientific operation intended to directly observe gravitational waves. Already, the LIGO Livingston Observatory has demonstrated robust operation with more than twice the sensitivity of the initial LIGO apparatus, and the 2015 run is planned at better than triple the initial LIGO sensitivity. By 2018, both interferometers are expected to operate at better than ten times the initial LIGO sensitivity.



Installation of a quantum-mechanical squeezing experiment at LIGO in 2011. The temporary experiment allowed LIGO to increase its sensitivity by more than 20 percent over most of its frequency range. Such research is conducted by LIGO Laboratory and the LIGO Scientific Collaboration to reduce risk in the Advanced LIGO construction project. Credit: Caltech/MIT LIGO Laboratory.

Major Multi-User Research Facilities

Acting on the advice of an external review panel that assessed LIGO computing strategy, a no-cost extension of the Advanced LIGO MREFC project has been approved by NSF in order to enable the project to purchase computing hardware immediately prior to when it is needed in order to benefit from continuing technical innovation and price/performance advances. Consequently, the last computing purchases will be deferred until mid-2017.

Upon completion of the AdvLIGO construction stage in April 2015, LIGO operations will expand to encompass commissioning and operation of the new instrumentation. NSF has determined operating budget requirements by assessing cost data from initial LIGO interferometer operation and scaling appropriately to reflect the increased support that will be needed to support the more complex AdvLIGO apparatus.

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), who also chairs the PHY AdvLIGO Integrated Project Team (IPT), comprised of the Physics Division Director, MPS Facilities Coordinator, staff from the NSF Office of General Counsel, Office of Legislative and Public Affairs, International Science and Engineering, program directors from elsewhere in NSF, as well as the Large Facilities Office.
- **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 an annual review.
- **Reviews after 2010:**
 - AdvLIGO Annual Review, April 2011
 - LIGO Annual Review and AdvLIGO Interim Review, November 2011
 - LIGO Annual Review and AdvLIGO Interim Review, November 2012
 - LIGO Annual Review and AdvLIGO Interim Review, May 2013
 - LIGO Computing Review, May 2014
 - LIGO Annual Review and AdvLIGO Interim Review, June 2014
 - Additional reviews of LIGO operation and AdvLIGO construction are planned during 2015

Renewal/Recompetition/Termination

LIGO began operating under a new five-year cooperative agreement in early FY 2009. 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. As a condition of approval of this award (and a possible future award), the National Science Board stipulated that the operation of LIGO be recompeted no later than 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.

NATIONAL HIGH MAGNETIC FIELD LABORATORY

\$34,660,000
+\$10,620,000 / 44.2%

National High Magnetic Field Laboratory
(Dollars in Millions)

FY 2014	FY 2015	FY 2016	Change over	
			FY 2015 Estimate	
Actual ¹	Estimate	Request	Amount	Percent
\$42.26	\$24.04	\$34.66	\$10.62	44.2%

¹ Amount includes \$9.63 million in forward funding from FY 2013 to FY 2014. This reduced the funding needed in FY 2015.

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 1,300 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 of the 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. Both magnets enable scientists to get new insights into the electronic structures of novel materials such as graphene, topological insulators, high temperature superconductors, and more. 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 by the American Recovery and Reinvestment Act of 2009 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 Spectrometer (FT-ICR). The magnet was delivered in 2014. Once commissioning is completed in 2015, the FT-ICR will be unprecedented in sensitivity and selectivity. This instrument will be capable of analyzing chemical samples of great complexity, such as biological fluids, biofuels, and raw and weathered petroleum. This will impact areas such as chemistry, molecular biology, and earth science.

The FY 2016 Request will allow the facility to continue operations, focus on magnet development, and strengthen education, training, user support, and in-house research. A potential impact of this investment is the successful construction of an all superconducting magnet that would make high magnetic fields attainable at lower operating costs than current technology. This would open the door for many laboratories to access 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. 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. New insights into mapping the brain and neurochemistry may result.

Total Obligations for NHMFL

(Dollars in Millions)

	FY 2014	FY 2015	FY 2016	ESTIMATES ²				
	Actual ¹	Estimate	Request	FY 2017	FY 2018	FY 2019	FY 2020	FY 2021
Operations & Maintenance	\$42.26	\$24.04	\$34.66	\$35.78	\$35.79	\$35.79	\$35.79	\$35.79

¹ Amount includes \$9.63 million in forward funding from FY 2013 to FY 2014. This reduced the amount needed in FY 2015.

² Outyear funding estimates are for planning purposes only. The current cooperative agreement ends in December 2017.

NHMFL collaborates with more than 60 private sector companies as well as national laboratories, including those supported by the Department of Energy (DOE), such as the Spallation Neutron Source and the Advanced Photon Source at Argonne National Laboratory. 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 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 the NHMFL executive committee, NHMFL science council, and NHMFL diversity committee and recommendations from an external advisory committee and the users' executive committee.
- 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:
 - Annual site review by external panel of site visitors, February 2014.
 - NSF initiated a community study through the National Research Council on opportunities in high magnetic field research. The 2013 report "High Magnetic Field Science and Its Application in the United States" was presented to the National Science Board in May 2014. Public town halls were held at several professional meetings by both DMR and CHE. The report will inform future plans for investments in this area.
 - Business Systems Review in December 2014 and January 2015.
 - Annual site review by external panel of site visitors, scheduled for June 3-4, 2015.

Renewal/Recompetition/Termination

A review was held in FY 2012 for a five year renewal award covering FY 2013 – FY 2017.

**NATIONAL NANOTECHNOLOGY COORDINATED
INFRASTRUCTURE**

\$15,460,000
\$0 / 0.0%

National Nanotechnology Coordinated Infrastructure
(Dollars in Millions)

FY 2014 Actual	FY 2015 Estimate	FY 2016 Request	Change over FY 2015 Estimate	
			Amount	Percent
-	\$15.46	\$15.46	-	-

Over the past decade of its authorized award life, the National Nanotechnology Infrastructure Network (NNIN) has enabled major discoveries, innovations, and contributions to education and commerce. NNIN provided researchers from academia, small and large companies, and government with open access to university user facilities with leading-edge fabrication and characterization tools, instrumentation, and expertise within all disciplines of nanoscale science, engineering, and technology. In FY 2015, following a thorough process to seek input from the nanotechnology research community, NSF is moving forward with an open competition, NSF program solicitation 15-519, for a new National Nanotechnology Coordinated Infrastructure (NNCI) as the successor to NNIN. The competition for individual sites will consider large and small university-based user facilities, including those at minority-serving institutions, that are geographically distributed and with diverse and complementary capabilities to support current and anticipated future user needs across the broad spectrum of nanoscale science, engineering, and technology domains. A coordinating office will then be selected competitively at a later stage from among the selected sites to enhance their impact as a national infrastructure of user facility sites.

Total Obligations for NNCI
(Dollars in Millions)

	FY 2014 Actual	FY 2015 Estimate	FY 2016 Request	ESTIMATES ¹				
				FY 2017	FY 2018	FY 2019	FY 2020	FY 2021
Operations & Maintenance	-	\$15.46	\$15.46	\$15.46	\$15.46	\$15.46	\$15.46	\$15.46

¹ Outyear funding estimates are for planning purposes only. FY 2015 is the first year of funding for the program.

The selected individual sites will have autonomy in their operation and management, but will be required to act in concert with the coordinating office. Some sites may choose to partner with facilities at regional or smaller institutions that would bring specific capabilities for users and benefits to student training. The overall collection of selected sites and their capabilities will provide users with cost-effective access both to the specialized tools, processes, and expertise to support complex multi-step fabrication at the nanoscale level for structures, materials, devices, and systems, as well as to the associated instrumentation for characterization, analysis, and probing at these dimensions. The program aims to make these capabilities broadly available to the Nation’s researchers in academia, industry, and government to help catalyze new discoveries in science and engineering and to stimulate technological innovation. The individual sites will support a rich user base with broad accessibility and affordable user fee structure. NSF funds will leverage those of university and other resources to grow the numbers of external users, including those from companies as well as from academia. Sites will 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 will also have an organizational structure that allows coordination of complex process steps and tools for integrated tasks, and acceptance of experimental risks associated with non-standard processes and materials.

Major Multi-User Research Facilities

The broad spectrum of domain capabilities in this coordinated program is intended to encompass: physical-, chemical-, and biological-based nanostructures, materials, devices, and systems; electronic, optical, photonic, magnetic, mechanical, thermal, chemical, bioengineering, biomedical, and fluidic nanodevices and systems; nanoscale building blocks and nanostructured materials, composites, coatings, and surfaces; geophysical, geochemical, and environmental nanostructures and processes; synthetic biology, and fabrication in soft matter including biological interfaces; heterogeneous integration of complex, three-dimensional nanoscale systems to create new functionality; hierarchical design and fabrication to build nanoscale systems across multiple dimensional scales, including modeling and simulation tools that complement and support these activities; prototyping, process integration, and testing of manufacturing concepts, including high-speed roll-to-roll fabrication processes; and other areas, as appropriate.

Nanotechnology facilities provide unique opportunities to infuse innovative education with research at the frontiers of the field. Sites will provide focused strategies for integrating forefront science and engineering with education, including plans for assessing effectiveness and spreading promising practices. Sites having particular expertise in the social and ethical implications of nanotechnology will be encouraged to integrate 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.

Management and Oversight

- NSF structure: Post-award oversight will be under the guidance of the NSF lead program officer and directorate working group members to monitor progress of the award and award accomplishments. This will consist of an annual review by a reverse site visit at NSF, although some 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.
- External structure: A coordinating office (CO), to be located at one of the awarded institution sites, will be competed and chosen to provide the coordinating function. The CO director will be a key individual for developing management strategies and operational plans in concert with the site directors of the individual user facilities, and will serve as a principal contact person with NSF. The CO will be responsible for establishing a comprehensive web portal to ensure close linkages among the individual facility websites such that they present a unified face to the user community of overall capabilities, tools, and instrumentation. It will also work with all sites on methods to guide users regarding which site or sites, which instruments, and which processes would enable users to complete their projects most successfully. The CO will help to coordinate and disseminate best practices for national-level education and outreach programs across sites, as well as the study and dissemination of social and ethical implications of nanotechnology. It will seek to harmonize capabilities for modeling and simulation in nanoscale fabrication and characterization across sites, and provide effective coordination with the NSF-supported Network for Computational Nanotechnology (NCN). The CO will establish an external advisory board of distinguished members from academia, industry, and government to provide advice and guidance through the CO.

Renewal/Recompetition/Termination

- The National Nanotechnology Initiative (NNI) 2014 Strategic Plan emphasizes the importance and

critical need for the U.S. to sustain a dynamic infrastructure and toolset to advance nanotechnology, and in particular the academic infrastructure represented by NNIN.⁵ In addition, the President's Council of Advisors on Science and Technology (PCAST) 2014 Report to the President and Congress on the Fifth Assessment of the NNI recommends strong support for nanoscale infrastructure networks, such as NNIN, to ensure the effective training of a new generation of transdisciplinary scientists and engineers.⁶ NSF sought input from the science and engineering community on a possible future nanotechnology infrastructure support program through a Dear Colleague Letter (NSF 14-068).⁷ A workshop⁸ attended by recognized national experts was then conducted to develop a vision of how such a future program could be structured and to identify the key needs for the user communities over the coming decade. With this background and community input, NSF has created the NNCI program.

- The initial NNCI award commitments will be 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.

⁵ http://nano.gov/sites/default/files/pub_resource/2014_nni_strategic_plan.pdf

⁶ www.whitehouse.gov/sites/default/files/microsites/ostp/PCAST/pcast_fifth_nni_review_oct2014_final.pdf

⁷ www.nsf.gov/pubs/2014/nsf14068/nsf14068.jsp?org=ENG

⁸ www.src.org/newsroom/src-in-the-news/2014/656/

NATIONAL SOLAR OBSERVATORY

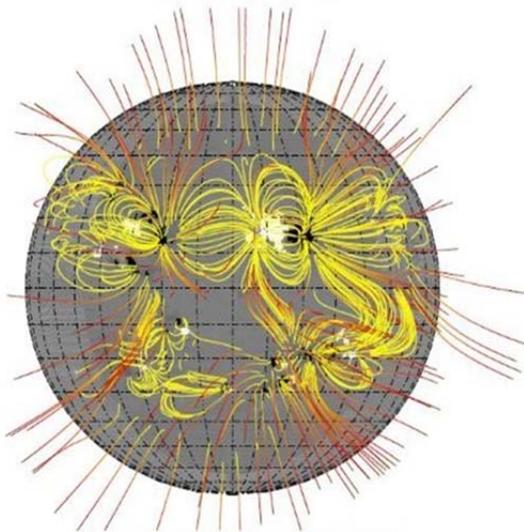
\$18,500,000
+\$5,500,000 / 42.3%

National Solar Observatory
(Dollars in Millions)

FY 2014 Actual	FY 2015 Estimate	FY 2016 Request	Change over FY 2015 Estimate	
			Amount	Percent
\$8.00	\$13.00	\$18.50	\$5.50	42.3%

The FY 2016 Budget Request for the National Solar Observatory (NSO) is \$18.50 million. This is a \$5.50 million (42.3 percent) increase above the FY 2015 Estimate and includes a one-time request to refurbish NSO infrastructure for space weather prediction. This increase also 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 2019.

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 construction of DKIST. (See the Major Research Equipment and Facilities Construction (MREFC) chapter for more information.) NSO makes available to qualified scientists the world's largest collection of optical and infrared solar telescopes and auxiliary instrumentation for observation of the solar photosphere, chromosphere, and corona. NSO also 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 solar magnetic field as derived from magnetograms produced by NSO's SOLIS Vector Spectromagnetograph (VSM) Instrument. Credit: Tadesse et al. 2013, *Astronomy & Astrophysics*, 550, A14.

NSO telescopes are open to all astronomers regardless of institutional affiliation on the basis of peer-reviewed observing proposals. In FY 2014, 65 unique observing programs from 21 U.S. and 14 foreign institutions were carried out using NSO facilities. Students were involved in 18 percent of these programs, which included 11 Ph.D. thesis projects. Over 32 terabytes of NSO synoptic data were downloaded from the NSO Digital Library, with approximately 52 percent of the downloads coming from U.S. science institutions (.gov, .edu, and .mil), two percent from other U.S. sources (.com, .net, etc.), and the remaining 46 percent of the downloads coming from international sources. Approximately 137 staff members were employed at NSO in FY 2014, including 50 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*,⁹ 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) conducted a community-based review of its portfolio. The resulting Portfolio Review Committee (PRC) report, *Advancing Astronomy in the Coming Decade: Opportunities and Challenges*,¹⁰ 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) through 2017 and a 50 percent reduction in funding of the NSO synoptic program. At present, the plan is for the McMath-Pierce telescope to be divested to a small university-based consortium, with short-term transition funding provided by AST as part of the NSO request. By the end of 2017, it is expected that the university-based consortium will have secured the necessary funding for continued operations of the McMath-Pierce at a minimum level. Active partnership discussions are also under way for continued operations of the DST at the NSO’s Sacramento Peak facility. In FY 2014, the NSF contracted with a general engineering firm to produce feasibility studies that will provide baseline structural, historical, and environmental surveys of the McMath-Pierce telescope and the various NSO facilities on Sacramento Peak. The purpose of these studies is twofold. First, the study will serve to inform the NSF and potential partners of the current state of the facility. Second, the study will explore various divestment options and provide an assessment of the potential costs involved. After viable options are identified, the NSF will embark on formal reviews (in FY 2015 and FY 2016) to evaluate the impacts of these alternatives, including partnership opportunities that could involve further environmental assessments.

Total Obligations for NSO
(Dollars in Millions)

	FY 2014 Actual	FY 2015 Estimate	FY 2016 Request	ESTIMATES ^{1,2}				
				FY 2017	FY 2018	FY 2019	FY 2020	FY 2021
NSO Base Operations	\$7.78	\$7.75	\$6.75	\$5.74	\$4.74	\$3.70	\$3.82	\$3.93
NSO Education & Public Outreach	0.22	0.25	0.25	0.26	0.27	0.30	0.31	0.32
DKIST Operations ²	-	5.00	9.00	11.50	14.50	17.00	17.50	18.04
GONG Refurbishment	-	-	2.50	-	-	-	-	-
Total, NSO	\$8.00	\$13.00	\$18.50	\$17.50	\$19.50	\$21.00	\$21.63	\$22.28

Totals may not add due to rounding.

¹ Outyear funding estimates are for planning purposes only. The current cooperative agreements ends on March 31, 2015.

² Total FY 2016 Research and Related Activities account funding for DKIST consists of \$9.0 million through NSO, as shown above, and \$2.0 million per year for FY 2011 through 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 (AURA), Inc., which comprises 39 U.S. member institutions and seven international affiliate members. NSO partners include the U.S. Air Force Research Laboratory

⁹ www.nap.edu/catalog.php?record_id=12951

¹⁰ www.nsf.gov/mps/ast/ast_portfolio_review.jsp

Major Multi-User Research Facilities

(AFRL), U.S. Air Force Weather Agency (AFWA), NASA, and industrial entities. The Air Force is the most significant source of external funding to the NSO, providing \$1.20 million in operational support for FY 2014. Approximately \$400,000 is provided by AFRL in exchange for NSO support for AFRL staff at the Sacramento Peak facility. The remaining \$800,000 is provided by AFWA in support of Global Oscillations Network Group (GONG) operations that are used for operational space weather prediction. Other funding entities include universities and institutes, which collaborate with NSO on solar instrumentation development and on the design and development of DKIST. New telescopes, instrumentation, and sensor techniques are developed through industry sub-awardees in aerospace, optical fabrication, and information technology.

NSO Base Operations, \$6.75 million: NSO Base Operations includes operations at Sacramento Peak Observatory in Sunspot, New Mexico, facilities based on Kitt Peak, Arizona, 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. In addition, NSO Base Operations funds the NSO Directorate, which is currently in the process of relocating from Tucson, AZ to a new location on the campus of the University of Colorado, Boulder. Boulder, CO has become a national center of solar and space physics. The NSO relocation will place the NSO headquarters squarely in the center of the solar community. The funding profile for NSO Base Operations is ramping down in anticipation of the divestment of redundant facilities by the end of 2017. By the end of this ramp, NSO Base Operations will fund the NSO Directorate activities as well as the NSO synoptic program operations at a steady level of approximately \$4.0 million (\$2.0 million each) per year.

DKIST Operations, \$9.0 million: The request for DKIST Operations represents the second year of a five-year funding ramp that will bring the NSO budget to a level commensurate with requirements to operate 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 2019. DKIST construction is not funded here, but instead through the MREFC account. In this FY 2016 request, DKIST takes over the majority share of the NSO Operations budget.

GONG Refurbishment, \$2.50 million: There is increasing national and international awareness of the impacts of space weather on critical infrastructure and society in general. As part of this increased awareness, the importance of operational space weather forecasting is becoming apparent to U.S. policy makers. Space weather forecasting requires both accurate models of the heliospheric environment and precise observational data inputs to those models. The NSO's GONG program provides operational data products on a routine basis that are used as inputs to predictive space weather models from federal agencies such as AFWA and the NOAA Space Weather Prediction Center (SWPC). A one-time refurbishment of the GONG infrastructure in FY 2016 will provide a reliable, operations-ready, array of solar stations allowing for nearly continuous data coverage.

Education and Public Outreach, \$250,000: 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-based information portal at www.nso.edu.

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 employs 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. An extensive NSO review in FY 2008 led to the award of a new cooperative agreement in early FY 2010. A Business Systems Review was held in Spring 2013. A re-baseline review for the DKIST project, described in the DKIST narrative in the MREFC chapter, was held in October 2012. An extensive review of NSO was conducted in January 2014 as part of the renewal of the cooperative agreement.

Renewal/Recompetition/Termination

The National Science Board (NSB) authorized a cooperative agreement with AURA for management and operation of NSO for October 1, 2009 through March 31, 2014. Since NSO is the home for the DKIST construction project, and DKIST is not expected to begin operation until 2019, it was determined that competition of the NSO cooperative agreement should take place after DKIST has achieved full operations, expected in FY 2019. Thus, the current cooperative agreement was first extended through December 31, 2014, and a proposal for the longer-term renewal of the agreement was requested from AURA. This proposal was received by NSF in October 2013, underwent merit review in January 2014, and was approved by the NSB on August 14, 2014. The current cooperative agreement has been extended to March 31, 2015 as negotiations between NSF and the managing organization for the renewed cooperative agreement are ongoing.

NATIONAL SUPERCONDUCTING CYCLOTRON LABORATORY

\$22,500,000
\$0 / 0.0%

National Superconducting Cyclotron Laboratory

(Dollars in Millions)

FY 2014 Actual	FY 2015 Estimate	FY 2016 Request	Change over	
			FY 2015 Estimate Amount	Percent
\$22.50	\$22.50	\$22.50	-	-

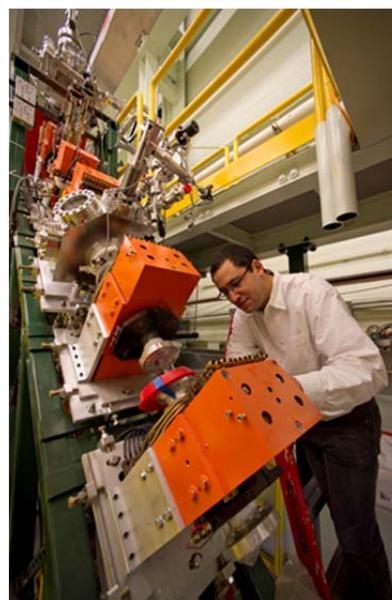
The National Superconducting Cyclotron Laboratory (NSCL) at Michigan State University (MSU) is a university-based national user facility. With two linked superconducting cyclotrons, K500 and K1200, it is the leading rare isotope research facility in the U.S. and is among the world leaders in heavy ion nuclear physics and nuclear physics with radioactive beams. Funding for NSCL also supports the MSU faculty and staff research program.

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 new tools for radiation treatments of cancer patients, the assessment of health risks to astronauts, 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 completed construction and commissioning of an MSU-funded reaccelerator facility (ReA3) that will enable experiments at very low energies – a domain of particular interest to nuclear astrophysics. This is the only facility in the world to provide radioactive beams in this energy regime.

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.

The coupled cyclotron facility supports a broad experimental program. 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 one to three days.



Research Physicist Fernando Montes inspects a beamline at the reaccelerated beam facility (ReA3) at NSCL. Credit: NSCL.

Total Obligations for NSCL

(Dollars in Millions)

	FY 2014	FY 2015	FY 2016	ESTIMATES ¹				
	Actual	Estimate	Request	FY 2017	FY 2018	FY 2019	FY 2020	FY 2021
Operations & Maintenance	\$22.50	\$22.50	\$22.50	\$22.50	\$22.50	\$22.50	\$20.00	\$15.00

¹ Outyear funding estimates are for planning purposes only. The current cooperative agreement ends in FY 2016.

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.
- External Structure: NSCL is managed by a director and three associate directors (for experimental research, education, and operations) as well as an associate laboratory director for users. 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 includes the chairperson of the full NSCL user group. The procedure for users includes writing and submitting proposals to the NSCL director and oral presentations. Opportunities for proposal submission occur every six to nine months so that the beam hour backlog is no longer than one year. Optimally the laboratory can provide about 5000 beam hours to the scientific community each year, with actual output depending upon facility reliability factors and available funds.
- Reviews:
 - A 5-year review in FY 2011 covered results and achievements related to intellectual merit and broader impacts for the past five years (FY 2007 – FY 2011) and future funding for the next five years (FY 2012 – FY 2016).
 - Latest Review: An annual review of the science, operations, and future funding was in June 2014.
 - Next Review: An annual review is tentatively planned for June 2015.

Renewal/Recompetition/Termination

Over the next several years, NSCL will transition to the new Facility for Rare Isotope Beams (FRIB), which will be built by the Department of Energy (DOE) on the site of the present NSCL and will make use of much of the NSCL beamlines and general infrastructure. MSU will be the performing institution under a cooperative agreement with DOE for the future FRIB. To facilitate interagency planning and allow for a smooth transition from the NSF-funded NSCL to the DOE-funded FRIB, a Joint Oversight Group (JOG) of DOE and NSF personnel has been established. NSF anticipates eventually phasing out funding for operations and maintenance for the NSCL facility, as indicated in the table above for FY 2016 through FY 2021. DOE and NSF will coordinate transfer of facility stewardship as it transitions from NSCL to FRIB. NSF will continue to support individual investigators carrying out research at the new FRIB.

**NATURAL HAZARDS ENGINEERING RESEARCH
INFRASTRUCTURE**

\$12,500,000
+\$500,000 / 4.2%

Natural Hazards Engineering Research Infrastructure
(Dollars in Millions)

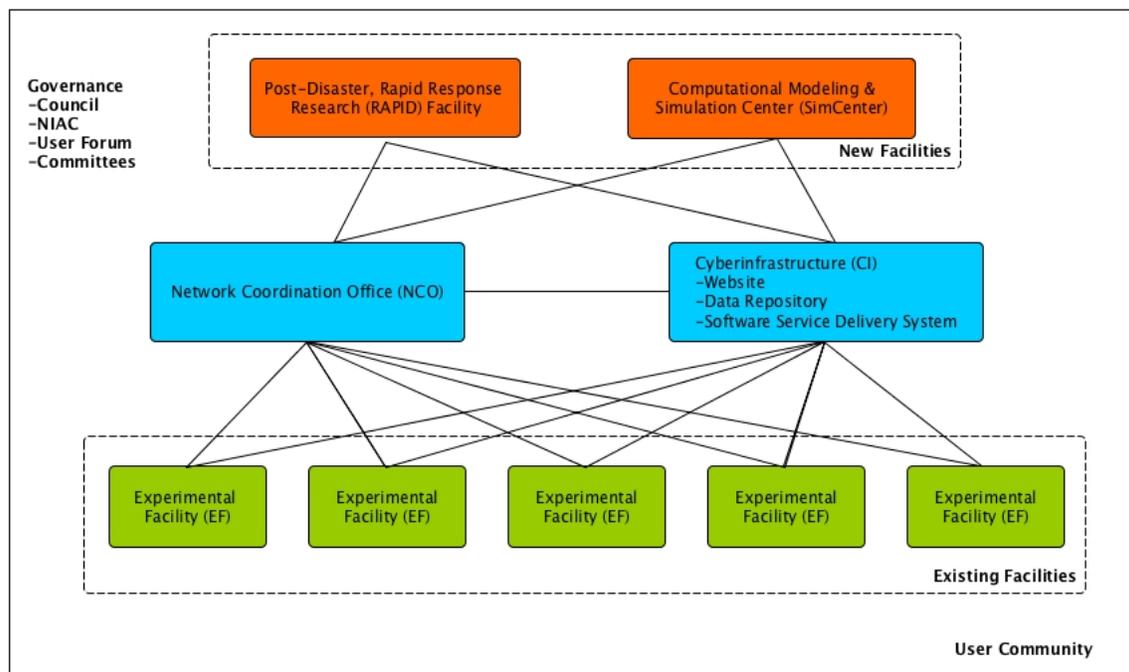
FY 2014 Actual	FY 2015 Estimate	FY 2016 Request	Change over FY 2015 Estimate	
			Amount	Percent
-	\$12.00	\$12.50	\$0.50	4.2%

The Natural Hazards Engineering Research Infrastructure (NHERI) is the next generation of National Science Foundation (NSF) support for 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 an operations phase to support research, innovation, and education activities from October 2004 through September 2014. NEES was supported by NSF during FY 2010-FY 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 has been extended to continue support for cyberinfrastructure operations during the NSF open competition to establish NHERI via program solicitation NSF 14-605.

During FY 2015 to FY 2019, NHERI will be operated as a distributed, multi-user, national research facility aiming to provide the natural hazards engineering research community with access to research infrastructure (earthquake and wind engineering experimental facilities, cyberinfrastructure, computational modeling and simulation tools, and research data), coupled with education and community outreach activities. NHERI will enable 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 mitigation. NHERI will also continue to contribute to the National Earthquake Hazards Reduction Program and the National Windstorm Impact Reduction Program.

NHERI will be established by NSF through up to ten individual cooperative agreements and will consist of the following four components, as shown in Figure 1:

- Network Coordination Office (NCO);
- Cyber-Infrastructure (CI) Operations;
- Computational Modeling and Simulation Center (SimCenter); and
- Up to seven Experimental Facilities (EF), including a new post-disaster, rapid response research (RAPID) facility.



Notional Concept for NHERI (from program solicitation NSF 14-605).

The NCO awardee will serve as the national and international scientific leader, community focal point, and network-wide coordinator for governance and community-building activities. Key activities will 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 users access to the EFs, leading development of community science plans, running NHERI-wide education and community outreach programs, and building strategic partnerships.

The CI awardee will serve 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, software service delivery platform with computational modeling, simulation, and educational tools, collaboration tools, access to computing resources, and user training and support. The CI awardee will establish and implement a NHERI-wide cybersecurity plan with all NHERI awardees.

The SimCenter awardee will develop and deliver to the CI awardee for integration onto the CI awardee's software service delivery platform, 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.

EF awardees will provide well-maintained and fully functioning facilities, services, and staffing to enable earthquake engineering, wind engineering, or post-disaster, rapid response research requiring experimental work and data collection. Experimental data generated by EF resources and its users will be archived and maintained in the publicly accessible NHERI data repository. The awardees and the natural hazards engineering community will 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.

Along with direct operations and maintenance support for NHERI awardees, NSF will provide separate support for research to be conducted at the NHERI experimental facilities through ongoing research and

Major Multi-User Research Facilities

education programs. The support for such activities primarily will be provided through the Engineering for Natural Hazards (ENH) research program in the Civil, Mechanical and Manufacturing Innovation (CMMI) division in the Directorate for Engineering (ENG). The ENH program will support basic research in multi-hazard engineering involving experimental and computational simulations at the NHERI facilities, addressing important challenges in multi-hazard mitigation for constructed civil infrastructure. With the aim of integrating research and education, NHERI will engage students through on-site use of experimental facilities, telepresence technology, experimental and analytical data, and computational resources. Coordinated by the NCO awardee, NHERI awardees will also run an annual Research Experiences for Undergraduates (REU) program and a Summer Institute.

Total Obligations for NHERI

(Dollars in Millions)

	FY 2014	FY 2015	FY 2016	ESTIMATES ¹				
	Actual	Estimate	Request	FY 2017	FY 2018	FY 2019	FY 2020	FY 2021
Operations & Maintenance	-	\$12.00	\$12.50	\$12.50	\$12.00	\$12.00	\$12.00	\$12.00

¹ Outyear funding estimates are for planning purposes only. FY 2015 is the first year of funding for the program.

Management and Oversight

- **NSF structure:** The NSF program manager for NHERI is located within ENG/CMMI. The Deputy Director of the Large Facilities Office in the Office of Budget, Finance and Award Management will provide advice and assistance.
- **Awardee structure:** Each NHERI awardee will be led by a principal investigator (PI), who will be responsible for the overall award operations. The NCO awardee will coordinate NHERI and be responsible for convening NHERI governance. Governance will be 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.
- **NSF Oversight and 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, with the review to be conducted within the first two years of the award.

Renewal/Recompetition/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 10-071.¹¹ One study, a workshop held by the National Research Council on the Grand Challenges in

¹¹ <http://nsf.gov/pubs/2010/nsf10071/nsf10071.jsp>

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 “second generation” 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 12-107.¹² 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 February 2013, NSF released solicitation NSF 13-537 in an effort 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. In 2012, 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 2014.¹³
- Based on the above studies and report, NSF established the plan for NHERI in FY 2014. NHERI operations awards will be supported for a five-year period. During this period, the NCO awardee will be responsible, working with the natural hazards engineering research and education community, to develop by September 30, 2017, a decadal science plan for natural hazards engineering research, education, and research infrastructure for 2020 – 2029. NSF will use this decadal science plan as input for natural hazards engineering research infrastructure support beyond 2019.

¹² www.nsf.gov/pubs/2012/nsf12107/nsf12107.jsp

¹³ www.nist.gov/customcf/get_pdf.cfm?pub_id=915541

OCEAN OBSERVATORIES INITIATIVE**\$55,000,000**
\$0 / 0.0%**Ocean Observatories Initiative**

(Dollars in Millions)

FY 2014 Actual	FY 2015 Estimate	FY 2016 Request	Change over FY 2015 Estimate	
			Amount	Percent
\$49.30	\$55.00	\$55.00	-	-

The Ocean Observatories Initiative (OOI) began in FY 2009 as a Major Research Equipment and Facilities Construction (MREFC) Project. In FY 2015, OOI transitioned from the MREFC construction effort to the long term OOI Program Operations & Maintenance phase.

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 will provide the ocean scientists, educators and the public the means to collect sustained, time-series data sets that will enable researchers to examine complex, interlinked physical, chemical, biological, and geological processes operating throughout the coastal regions and open ocean. The OOI infrastructure will make interdisciplinary measurements 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 will provide the public, educators, students and researchers with: (1) OOI long-term time series data sets; (2) an in-situ ocean laboratory capability to allow OOI users to develop and apply new technologies by connecting their instruments or concepts to the OOI network via new proposals; and (3) OOI tools that will support graduate and undergraduate classroom applications of the OOI, as well as public outreach through informal education.

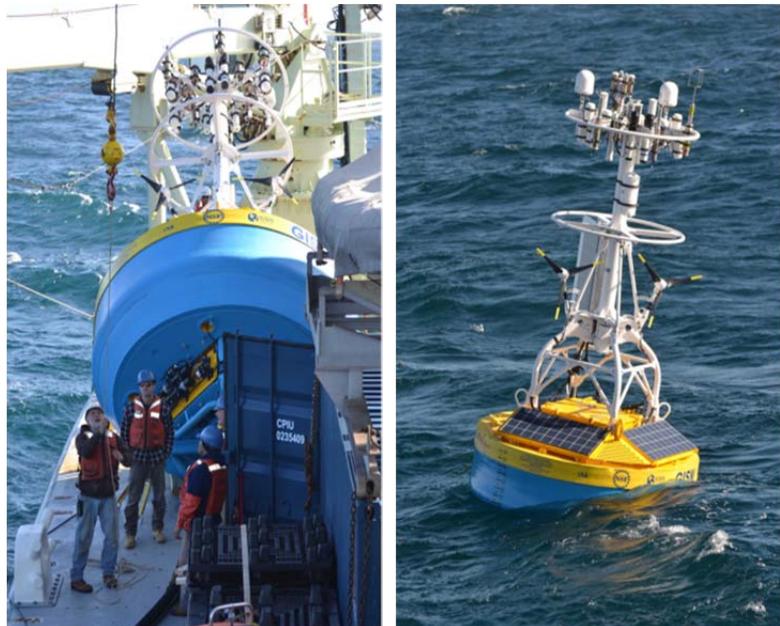
The overarching scientific themes of the OOI span six multi-disciplinary domains, and each theme incorporates a multitude of research questions.

- *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

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

- 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.

All data/metadata will be freely available to the public via the Internet. All OOI data including science, engineering and derived data products will flow through the OOI cyberinfrastructure. The OOI website will provide all raw data, metadata, and data processed via conventional algorithms through a data subscription service or direct retrieval from OOI storage or national data archives. The OOI website will provide science educators with a suite of tools (middleware) allowing them to enhance their graduate and undergraduate education activities and engage the general public using ocean observation data from the OOI.



OOI Global Surface Mooring Deployed in the Irminger Sea – September 2014 (one of 41 OOI instrumented moorings). Credit: Allison Heater, Woods Hole

Current Status

Many OOI assets have been deployed and are transmitting data. However, because of weather requirements final deployments will extend into Spring of 2015. The OOI operations and maintenance (O&M) budget for FY 2016 is \$55.0 million. This request includes the parts, labor, equipment, and ship time required to operate and maintain the OOI moorings and instruments. As assets are deployed, they transition to operations and are supported from the Research and Related Activities account. Deployed OOI instruments are typically visited and replaced twice per year. The O&M budget also includes science, engineering, and management staff to deliver scientific data of known quality, as well as the planning and engineering execution required for safe operations of the facility.

Total Obligations for OOI

(Dollars in Millions)

	Prior Years ¹	FY 2014 Actual	FY 2015 Estimate	FY 2016 Request	ESTIMATES ²				
					FY 2017	FY 2018	FY 2019	FY 2020	FY 2021
<i>R&RA Obligations:</i>									
Concept & Development	\$74.90	-	-	-	-	-	-	-	-
Operations & Maintenance	36.80	49.30	55.00	55.00	55.00	55.00	55.00	55.00	55.00
Subtotal, R&RA Obligations	\$111.70	\$49.30	\$55.00	\$55.00	\$55.00	\$55.00	\$55.00	\$55.00	\$55.00
<i>MREFC Obligations:</i>									
Implementation	252.99	27.50	-	-	-	-	-	-	-
ARRA	105.93	-	-	-	-	-	-	-	-
Subtotal, MREFC Obligations	\$358.92	\$27.50	-	-	-	-	-	-	-
TOTAL Obligations	\$470.62	\$76.80	\$55.00	\$55.00	\$55.00	\$55.00	\$55.00	\$55.00	\$55.00

Totals may not add due to rounding.

¹ Concept & Development funding and Implementation funding are cumulative of all prior years; Operations & Maintenance funding reflects FY 2013 Actuals only.² Outyear funding estimates are for planning purposes only.

The Consortium for Ocean Leadership (OL) is the awardee for OOI operations and maintenance. OL has major subawardees on the project 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 four OOI Global sites with their subawardee Scripps Institution of Oceanography (UC San Diego). Rutgers University manages the OOI data as well as the cyberinfrastructure and the 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 will include the review of observatory metrics, data quality management as well as integration of the OOI with any new science or infrastructure proposals.
- **External Structure:** Based on a request from NSF, the University National Oceanographic Laboratory System (UNOLS) Council established the Ocean Observatory Science Committee (OOSC). The OOSC provides guidance and science user perspectives on the operations and maintenance for OOI and several other NSF-funded ocean observatories. The OOSC will conduct two user workshops for the OOI in FY 2016. The OOI program will have a science oversight committee to provide input and guidance to Ocean Leadership for OOI infrastructure planning and management.
- **Reviews:** NSF conducted a review of the project's revised cyberinfrastructure architecture and user interface plans in November 2014. In December 2014 the Project Team presented the Concept of Operations document to NSF and the external community Ocean Observatory Science Committee for review. An external review will be conducted in spring 2015 after completion of the Southern Global Array deployments in support of construction closeout planning. During the Operations and Maintenance phase for OOI, annual external panel reviews will be conducted with participation by the OOSC to represent the user community. The review will coincide with annual work planning and decision making for the next fiscal year. This will allow for input on decisions with respect to technology refresh and instrument upgrades or replacements.

Operations Costs

Operations and maintenance in support of scientific research began in FY 2013 with the deployment of the first OOI instruments. The associated costs are and will continue to be supported by the Division of Ocean Sciences (OCE), with temporary support from the Division of Integrative and Collaborative Education and Research (ICER) from FY 2015-FY 2017. These costs are anticipated to total \$55.0 million once the observatory is fully operational in FY 2015. Support for research utilizing observatory data will be through existing 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 will produce regardless of the source of their support.

Education and Outreach

Rutgers University, in partnership with the University of Maine, leads OOI's Education and Public Engagement activities. With its unique access to the ocean, OOI education activities are intended to allow researchers, students, and the public to explore the ocean's depths in near real time. To enable this vision, a series of educational tools will be developed which will provide easy and broad access to OOI data and data products. In addition, the tools will support incorporation of OOI's research data into educational materials.

Renewal/Recompetition/Termination

The OOI operations and maintenance cooperative agreement award with OL ends in FY 2017. A recompetition for the operations and maintenance of the OOI program will be conducted in FY 2016.

POLAR FACILITIES AND LOGISTICS

\$302,900,000
+\$5,430,000 / 1.8%

Polar Facilities and Logistics

(Dollars in Millions)

	FY 2014 Actual	FY 2015 Estimate	FY 2016 Request	Change over FY 2015 Estimate	
				Amount	Percent
Polar Facilities	\$196.99	\$191.31	\$195.11	\$3.80	2.0%
Polar Logistics	113.02	106.16	107.79	1.63	1.5%
Total, Polar Facilities and Logistics	\$310.01	\$297.47	\$302.90	\$5.43	1.8%

Totals may not add due to rounding.

Polar Facilities

The Division of Polar Programs (PLR) within the Directorate for Geosciences (GEO) provides the infrastructure needed to support U.S. research conducted in Antarctica, including research funded 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. One example of 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), PLR supports relay of real-time satellite-based weather information that informs global forecasting. In addition, PLR 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. PLR 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 U.S. Geological Survey’s (USGS) South Pole Remote Earth Science and Seismological Observatory (SPRESSO), the most seismically-quiet station on earth; and access to the Global Navigation Satellite System (GNSS).

All support for these activities is provided by PLR, 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 2014	FY 2015	FY 2016	ESTIMATES ¹				
	Actual	Estimate	Request	FY 2017	FY 2018	FY 2019	FY 2020	FY 2021
Antarctic Infrastructure and Logistics	\$196.99	\$191.31	\$195.11	\$195.11	\$195.11	\$195.11	\$195.11	\$195.11
Total, Polar Facilities	\$196.99	\$191.31	\$195.11	\$195.11	\$195.11	\$195.11	\$195.11	\$195.11

Totals may not add due to rounding.

¹ Outyear funding estimates are for planning purposes only.

PLR 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* is expected to provide icebreaking services for the McMurdo Station resupply effort through the end of her extended service life (in approximately 2022).

Management and Oversight

- NSF Structure: PLR staff, including subject matter experts in operational and scientific disciplines, have overall responsibility for funding and managing Polar Facilities under the USAP that NSF budgets for and manages on behalf of the Nation. This includes planning all activities and overseeing contractors. PLR'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 Antarctica and the Southern Ocean. Research is conducted in a broad array of geo- and bio- sciences, including earth system science, as well as 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 support contract was competed and awarded to Lockheed Martin Corporation in December 2011. There are many separate subcontractors for supplies and technical services, and other services are procured through separate competitively-bid contracts.
- Reviews: PLR 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 PLR and the Office of Budget, Finance, and Award Management (BFA). In addition, PLR's performance is reviewed externally by Committees of Visitors and the GEO Advisory Committee. The USAP Blue Ribbon Panel (BRP) released a report on its review of the program in July 2012.¹⁴ The NSF response to the USAP Blue Ribbon Panel report was released in March 2013.¹⁵



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) program, currently in the early stages of design. While overall project scope is still being refined, the AIMS project is preparing plans for, among other things, possible replacement of the Palmer Station pier for long-term access to unique research and redevelopment of McMurdo Station to be a smaller, more

¹⁴ www.nsf.gov/od/opp/usap_special_review/usap_brp/rpt/index.jsp

¹⁵ www.nsf.gov/od/opp/usap_special_review/usap_brp/rpt/nsf_brp_response.pdf

Major Multi-User Research Facilities

efficient facility. The latter includes: replacing major logistic facilities concerning the airplane runway and vessel operations; upgrading facilities for fuel containment, utilities distribution and fire protection; and upgrading satellite communications systems to support operations and research. Additional information is included in the PLR narrative in the GEO chapter.

Renewal/Recompetition/Termination

- In FY 2012, Lockheed Martin 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.
- A new contract for helicopter support was awarded to Petroleum Helicopters, Inc., the incumbent, in May 2013. The award term is for one year, with the possibility of four additional one-year options exercised on the basis of performance.
- 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 2014	FY 2015	FY 2016	ESTIMATES ¹				
	Actual	Estimate	Request	FY 2017	FY 2018	FY 2019	FY 2020	FY 2021
U.S. Antarctic Logistical Support	\$68.94	\$67.52	\$67.52	\$67.52	\$67.52	\$67.52	\$67.52	\$67.52
Arctic Research Support and Logistics	44.08	38.64	40.27	40.27	40.27	40.27	40.27	40.27
Total, Polar Logistics	\$113.02	\$106.16	\$107.79	\$107.79	\$107.79	\$107.79	\$107.79	\$107.79

Totals may not add due to rounding.

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; 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 PLR 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.

Management and Oversight

- NSF Structure: PLR 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: PLR 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 PLR and BFA. PLR's performance is externally reviewed by Committees of Visitors and the GEO Advisory Committee.

Current Status

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

Renewal/Recompetition/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 EARTHSCOPE

\$25,100,000
+\$750,000 / 3.1%

Seismological Facilities for the Advancement of Geoscience and EarthScope

(Dollars in Millions)

FY 2014 Actual	FY 2015 Estimate	FY 2016 Request	Change over FY 2015 Estimate	
			Amount	Percent
\$24.35	\$24.35	\$25.10	\$0.75	3.1%

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 122 U.S. universities and non-profit institutions with research and teaching programs in seismology, 22 educational affiliates, two U.S. affiliates, and 125 foreign affiliates. SAGE was formed in late FY 2013 from part of the EarthScope program and the IRIS facility. The FY 2016 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 2014	FY 2015	FY 2016	ESTIMATES ¹				
	Actual	Estimate	Request	FY 2017	FY 2018	FY 2019	FY 2020	FY 2021
Operations & Maintenance	\$24.35	\$24.35	\$25.10	\$25.10	\$25.10	\$25.10	\$25.10	\$25.10

Totals may not add due to rounding.

¹ Outyear funding estimates are for planning purposes only. The current cooperative agreement ends on September 30, 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.
- 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, and incorporates equipment from the former Program for Array Seismic Studies of the Continental Lithosphere (PASSCAL) and EarthScope USArray/Flexible Array (FA) activities.
- 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. Additional supplemental funding for these activities is provided through the Division of Polar Programs (PLR).
- 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. TA incorporates over 400 stations across the lower 48 states, Alaska, and 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. MT comprises seven backbone stations and 21 transportable instruments used for short-term deployments.
- 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 200 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.

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 U.S. Geological Survey (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 the Division of Polar Programs (PLR) provide most of the funds, totaling approximately \$15.0 million per year, for NSF-sponsored research making use of SAGE. Funds permit

deployment of portable seismic instruments and use of data managed by Data Services to solve major Earth science problems.

Management and Oversight

- NSF Structure: The Division of Earth Sciences (EAR), 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 122 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 mid-award 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 2017, in keeping with the phased integration and recompetition plan presented to and concurred with by the National Science Board in December 2009, NSF intends to solicit proposals for a future facility or facilities to support the Earth sciences research and education community currently supported by SAGE and the related Geodetic Facilities for the Advancement of Geoscience and EarthScope (GAGE). NSF is currently considering the precise form of this solicitation, and any possible future facility/facilities are currently being considered within NSF and through discussions with the SAGE and GAGE support communities.

FEDERALLY FUNDED RESEARCH AND DEVELOPMENT CENTERS (FFRDCS)

NATIONAL CENTER FOR ATMOSPHERIC RESEARCH

\$99,000,000
+\$800,000 / 0.8%

National Center for Atmospheric Research

(Dollars in Millions)

FY 2014	FY 2015	FY 2016	Change over	
			FY 2015 Estimate	
Actual	Estimate	Request	Amount	Percent
\$96.60	\$98.20	\$99.00	\$0.80	0.8%

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 105 degree-granting academic institutions.

As of December 2014, NCAR supported a total of 782.9 full time equivalents (FTEs), of which 336.2 are funded under the NSF primary award to UCAR.

Number of FTEs Supported at NCAR

FTEs	Primary Award ¹	All Funding
Career Scientists	75.7	104
Scientific Support ²	224.8	533.7
Other Staff ³	35.7	145.2
Total	336.2	782.9

¹ The primary award supports substantial infrastructure that does not include staff costs.

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, Mechanics.

NCAR provides facilities, including world-class supercomputing services, research aircraft, a transportable ground-based radar system, atmospheric sounding, and other surface sensing systems, to university, NCAR, and other atmospheric researchers. NCAR operates several facilities dedicated to the study of the Sun and solar phenomena (e.g., the Mauna Loa Solar Observatory), space weather, and the responses of the upper atmosphere to the Sun's output.

Total Obligations for NCAR

(Dollars in Millions)

	FY 2014	FY 2015	FY 2016	ESTIMATES ¹				
	Actual	Estimate	Request	FY 2017	FY 2018	FY 2019	FY 2020	FY 2021
Aircraft Support	\$9.17	\$9.46	\$9.47	\$9.47	\$9.47	\$9.47	\$9.47	\$9.47
Computational Infrastructure	26.07	26.90	26.91	26.91	26.91	26.91	26.91	26.91
Other Facility Support	21.77	21.01	21.02	21.02	21.02	21.02	21.02	21.02
Research & Education Support	39.59	40.83	41.60	41.60	41.60	41.60	41.60	41.60
Total, NCAR	\$96.60	\$98.20	\$99.00	\$99.00	\$99.00	\$99.00	\$99.00	\$99.00

Totals may not add due to rounding.

¹ 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 2014, NCAR received approximately \$38.50 million in support from other federal agencies, such as the National Oceanic and Atmospheric Administration (NOAA), and the Federal Aviation Administration (FAA), and \$13.30 million from non-federal sources.

Major Investments in FY 2016: In FY 2016, 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 and impacts of changes in that composition on the climate system, 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.

Aircraft Support: NCAR operates two NSF aircraft: a C-130Q Hercules and a Gulfstream-V (G-V, also known as the High-Performance Instrumented Airborne Platform for Experimental Research, or HIAPER), 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 climate, weather, 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 observing platforms through its Earth Observing Laboratory (EOL), including a large, deployable, dual-wavelength Doppler radar, upper atmosphere observing capabilities, an advanced coronagraph, and other experimental systems.

Research and Education Support: Total funding for research and education support at NCAR is estimated to be \$41.60 million in FY 2016. 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 climate processes and global climate change;
- 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 and response to global environmental change.

Research collaborations among NCAR staff and university colleagues are integral to its success as an institution, and serve 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 weather and climate information tailored to the specific needs of stakeholders in a variety of sectors, including energy, aviation, and agriculture.



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

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.

In addition, 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,¹⁶ 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), along with the Division of Acquisition and Cooperative Support (DACCS), provide oversight of NCAR and the cooperative agreement with the University Corporation for Atmospheric Research (UCAR) for NCAR's management. 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. These include a provision that UCAR submit for AGS approval an annual program plan that details how resources will be used. In addition, NCAR summarizes its past year's accomplishments in an annual scientific report. Annual strategic planning between AGS, UCAR, and NCAR ensure that scientific and facility priorities remain consistent with those of NSF.
- **External Structure:** UCAR works in partnership with NSF and the university community to ensure

¹⁶ www.spark.ucar.edu

Major Multi-User Research Facilities

effective implementation of the NCAR strategic mission to the benefit of the research community. In addition, other research sponsors, such as NOAA, the National Aeronautics and Space Administration (NASA), the Department of Energy (DOE), the Department of Defense (DOD), the Environmental Protection Agency (EPA), and the FAA support research collaboration wherever it enhances NCAR's NSF-supported research goals or facilities missions.

- **Reviews:** A Committee of Visitors (COVs) is convened every three years to evaluate AGS oversight of NCAR. The most recent COV was conducted in FY 2012 with the next anticipated in FY 2015. A Business Systems Review was conducted in FY 2011, and the next review will take place in FY 2016. No significant issues were raised in either of the most recent reviews. Based on a thorough review of NCAR's performance as a center and UCAR's management of NCAR, UCAR was awarded a new five-year cooperative agreement to manage NCAR beginning in FY 2014. It is anticipated that the management of NCAR will be re-competed prior to the next award period, which will begin in FY 2019.

Renewal/Recompetition/Termination

- The award to manage NCAR was last re-competed in FY 2007, and the new award began on October 1, 2008. During 2011, AGS conducted a series of six site visits to NCAR with a total of 38 external reviewers to examine NCAR's science programs and management. Each site visit team reported that NCAR continues to serve a critical role in the ongoing success of the atmospheric and related sciences communities and that the Center and staff remain at the forefront of their respective fields.
- Based on the strong endorsement of reviewers and UCAR's conduct during the award period, AGS informed the National Science Board in May 2012 that UCAR would be permitted to submit a proposal to renew the award for a further five years, after which it would be competed again. UCAR's proposal was received in September 2012 and was reviewed by an eight-member panel with expertise in research, management, and business from the academic, public, and private sectors. The panel found that the proposal scored highly in each evaluation category and recommended without reservation that the proposal be funded in full. In May 2013, AGS presented the results of the proposal review to the National Science Board, which subsequently authorized the Acting Director of NSF to renew the award for the five-year period from October 2013 – September 2018. NSF expects that any future award for the management and operation of NCAR will be subject to full and open competition.

NATIONAL OPTICAL ASTRONOMY OBSERVATORY

\$21,750,000
-\$3,750,000 / -14.7%

National Optical Astronomy Observatory

(Dollars in Millions)

FY 2014	FY 2015	FY 2016	Change over	
			FY 2015 Estimate	
Actual	Estimate	Request	Amount	Percent
\$25.50	\$25.50	\$21.75	-\$3.75	-14.7%

The National Optical Astronomy Observatory (NOAO) was established in 1982 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 optical and infrared (OIR) science and system integration on behalf of the astronomical community. 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, and 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 International Gemini Observatory and to other U.S. OIR telescopes that offer public access. NOAO manages national community involvement in the development of potential future infrastructure projects. 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 telescopes are open to all astronomers regardless of institutional affiliation on the basis of peer-reviewed observing proposals. 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 telescopes for research projects. In FY 2014 NOAO employed 350 personnel in Arizona and Chile, including 45 support scientists and 10 postdoctoral fellows.

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*, 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) conducted a community-based review of its portfolio. The resulting Portfolio Review Committee (PRC) report, *Advancing Astronomy in the Coming Decade: Opportunities and Challenges*¹⁷ 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 (Wisconsin-Indiana-Yale-NOAO) telescope. The first two of these telescopes are NOAO

¹⁷www.nsf.gov/mps/ast/ast_portfolio_review.jsp

Major Multi-User Research Facilities

facilities that have been fully available (except for closure due to weather or maintenance) for astronomical community access. The WIYN telescope is owned and operated by a collaboration among three institutions, University of Wisconsin, Indiana University, and NOAO. (Yale University withdrew from the consortium in 2014.) NOAO's share of the WIYN telescope time for public access is 40 percent.

The PRC recommendations are being implemented consistent with the plan presented in the solicitation for management and operation of NOAO which was published in July 2013 (see recompetition discussion below). The 2.1-meter telescope is no longer available for community access (since September 2014), and proposals from outside organizations to take over its operation are being evaluated. Starting in FY 2016, NSF funding for the Mayall and WIYN telescopes will be removed from the NOAO base operations and maintenance budget. Any subsequent NSF support for these telescopes will be as special projects with supplemental funding to NOAO.

Total Obligations for NOAO

(Dollars in Millions)

	FY 2014	FY 2015	FY 2016	ESTIMATES ¹				
	Actual	Estimate	Request	FY 2017	FY 2018	FY 2019	FY 2020	FY 2021
NOAO Base O&M	\$18.50	\$20.00	\$17.50	\$17.76	\$18.29	\$18.83	\$19.40	\$19.98
<i>Tucson Operations</i>	<i>10.50</i>	<i>12.00</i>	<i>8.00</i>	<i>8.24</i>	<i>8.49</i>	<i>8.74</i>	<i>9.00</i>	<i>9.27</i>
<i>Chilean Operations</i>	<i>7.00</i>	<i>7.00</i>	<i>8.50</i>	<i>8.49</i>	<i>8.74</i>	<i>9.00</i>	<i>9.27</i>	<i>9.55</i>
<i>Kitt Peak Operations</i>	<i>1.00</i>	<i>1.00</i>	<i>1.00</i>	<i>1.03</i>	<i>1.06</i>	<i>1.09</i>	<i>1.13</i>	<i>1.16</i>
Special Projects (WIYN and Mayall)	5.50	5.50	4.25	4.50	1.00	1.00	1.00	1.00
LSST Development ²	1.50	-	-	-	-	-	-	-
Total, NOAO	\$25.50	\$25.50	\$21.75	\$22.26	\$19.29	\$19.83	\$20.40	\$20.98

Totals may not add due to rounding.

¹ Outyear funding estimates are for planning purposes only and are consistent with the amounts in the NOAO Management Solicitation, NSF 13-582, and with potential partnerships. The current cooperative agreement ends in FY 2015.

² Funding for LSST development is zero after FY 2014 because the start of construction through the MREFC account began in late FY 2014.

Partnerships and Other Funding Sources: The managing organization for NOAO is the Association of Universities for Research in Astronomy (AURA), Inc., which is comprised of 39 U.S. member institutions and seven 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. Along with the WIYN telescope mentioned above, 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 of 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, visitors centers, and a web-based information portal at www.noao.edu.

NOAO Base O&M: \$17.50 million; -\$2.50 million from FY 2015.

Tucson Operations: \$8.0 million; -\$4.0 million from FY 2015: Tucson operations covers the headquarters, offices, laboratories, and workshops in Tucson, Arizona. The reductions in FY 2016 are consistent with the solicitation for management and operation of NOAO, and have been described in NOAO planning documents in FY 2014 and FY 2015.

Chilean Operations: \$8.50 million; +\$1.50 million from FY 2015: This supports administration and labs in La Serena, Chile and mountain operations on Cerro Tololo and Cerro Pachón. The increase in FY 2015 is to make the Chilean operation more robust to respond to equipment failures in a timely way.

Kitt Peak Operations: \$1.0 million; no change from FY 2015: 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): \$4.25 million; -\$1.25 million from FY 2015.

WIYN telescope: \$1.0 million; no change from FY 2015: 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 may begin as early as FY 2015 using existing instrumentation on WIYN.

Mayall Telescope: \$3.25 million; -\$1.25 million from FY 2015: Discussions regarding potential partnerships are underway.

Management and Oversight

- **NSF Structure:** An NSF program officer in the Division of Astronomical Sciences (AST) provides continuing oversight, including consultation with an NSF Program Review Panel of external reviewers that meets twice 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 FY 2009 NSF cooperative agreement. AURA receives management advice from an observatory council composed of members of its scientific and management communities. NOAO employs separate visiting and users committees for the purposes of self-evaluation and prioritization. The visiting committees, composed of nationally

Major Multi-User Research Facilities

prominent individuals in science, management, and broadening participation, review for AURA all aspects of the management and operations of the observatories. Users committees, composed of scientists with considerable experience with the observatories, review for the NOAO director 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 Business Systems Review was carried out in FY 2013.

Renewal/Recompetition/Termination

A management review of AURA's performance was carried out in August 2006. In response to the review, the National Science Board extended the previous cooperative agreement with AURA for eighteen months, through September 30, 2009. A proposal for renewal of the cooperative agreement was received from AURA in December 2007 and underwent review in 2008. The National Science Board authorized a new cooperative agreement with AURA for the management and operation of NOAO for the period October 1, 2009, through March 31, 2014, which has been extended to September 30, 2015. The extension is to accommodate a competition for the management and operation of NOAO and will allow for the implementation of PRC recommendations that will alter the scope of work to be managed under a new cooperative agreement to begin in FY 2016. A solicitation was published in July 2013 (NSF 13-582) for competition for the management of NOAO, with the new management award slated to begin at the start of FY 2016.

NATIONAL RADIO ASTRONOMY OBSERVATORY

\$82,080,000
-\$1,230,000 / -1.5%

National Radio Astronomy Observatory

(Dollars in Millions)

FY 2014 Actual	FY 2015 Estimate	FY 2016 Request	Change over	
			FY 2015 Estimate Amount	Percent
\$77.41	\$83.31	\$82.08	-\$1.23	-1.5%

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 major radio telescopes in Green Bank, West Virginia; near Socorro, New Mexico; and at 10 telescope array sites spanning the U.S. from the Virgin Islands to Hawaii. NRAO 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 1,500 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, Observatory staff consists of 474 full-time equivalent positions (FTEs) in the operations and maintenance components of the Observatory: 293 in telescope operations, 23 in science support and research, 23 in development programs, 76 in computing and data management, 33 in administrative services, and 26 in the Director’s office. In addition, the NRAO managing organization, Associated Universities, Inc. (AUI), employs the local ALMA Operations staff in Chile, currently consisting of approximately 200 FTEs.

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*,¹⁸ 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) conducted a community-based review of its portfolio. The resulting Portfolio Review

¹⁸ www.nap.edu/catalog.php?record_id=12951

Committee (PRC) report, *Advancing Astronomy in the Coming Decade: Opportunities and Challenges*,¹⁹ was released in August 2012 and included recommendations about all of the major AST telescope facilities.

The PRC Committee report gave very high priority ranking to two NRAO telescopes: ALMA and the Karl G. Jansky Very Large Array (VLA). The Robert C. Byrd Green Bank Telescope (GBT) and the Very Long Baseline Array (VLBA) were recommended for divestment from AST funding because of less compelling mapping onto the science questions of the 2010 decadal survey. In FY 2012 and FY 2013, AST began to engage actively in facility partnership discussions for GBT and VLBA with other federal agencies and with university-based groups. The GBT and VLBA were partitioned from the NRAO management competition to facilitate other unconstrained partnership discussions separate from the open management competition. In FY 2014, AST continued these other partnership discussions, and NSF brought a general engineering contractor on-board for all its engineering and environmental reviews. In FY 2015, that contractor is producing feasibility reports for divestment alternatives, which will provide the results of baseline structural and environmental surveys of the GBT and VLBA. Should viable options be identified and the decision made to divest, NSF will embark on formal reviews (in FY 2015 and FY 2016) to evaluate environmental impacts of these alternatives, including potential impacts of partnership opportunities.

Total Obligations for NRAO

(Dollars in Millions)

	FY 2014	FY 2015	FY 2016	ESTIMATES ¹				
	Actual	Estimate	Request	FY 2017	FY 2018	FY 2019	FY 2020	FY 2021
Operations & Maintenance	\$43.14	\$43.14	\$41.73	\$32.00	\$32.96	\$33.95	\$34.97	\$36.02
<i>Telescope Operations</i>	17.63	17.63	17.07	13.09	13.48	13.88	14.30	14.73
<i>Development</i>	2.73	2.73	2.60	1.99	2.05	2.12	2.18	2.24
<i>Science Operations</i>	5.37	5.37	5.16	3.96	4.08	4.20	4.33	4.46
<i>Administrative Services</i>	13.99	13.99	13.59	10.42	10.73	11.05	11.38	11.73
<i>Directors Office</i>	3.42	3.42	3.31	2.54	2.62	2.70	2.78	2.86
ALMA Operations	34.27	40.17	40.35	43.25	44.55	45.88	47.26	48.68
Total, NRAO	\$77.41	\$83.31	\$82.08	\$75.25	\$77.51	\$79.83	\$82.23	\$84.70

Totals may not add due to rounding.

¹ Outyear funding estimates are for planning purposes only and are consistent with forecasts in the solicitation for the NRAO management competition, which was released in FY 2014 (NSF 14-568). The current cooperative agreement ends in September 2015.

The overall funding request for NRAO in FY 2016 decreased slightly from FY 2015. The planned ramp up to full ALMA operations, including projected increases in power costs in Chile, is the only increase. Anticipated reduced funding for the rest of NRAO in FY 2017 reflects the partitioning of the VLBA and GBT whose management and operation will be under separate consideration.

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 2014, NRAO received approximately \$280,000 from non-AST sources at NSF, \$3.10 million from other federal agencies, and \$4.55 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

¹⁹ www.nsf.gov/mps/ast/ast_portfolio_review.jsp

hardware and software companies.

Education and Public Outreach: NRAO supports a comprehensive outreach program that makes information about radio astronomy available to the public.²⁰ 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 sites also support visitor and education centers and conduct active educational and public outreach programs. The Green Bank Science Center and the visitor center at the VLA together attract over 60,000 public visitors each year.

Telescope operations, \$17.07 million: This encompasses support for direct telescope and array operations of GBT, VLA, and VLBA, including maintenance, infrastructure upgrades, and telescope management.

Development, \$2.60 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, \$5.16 million: This area includes telescope time allocation, staff research, science training and education, and science community outreach.

Administrative services, \$13.59 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.

Director's office, \$3.31 million: This includes support for the Director's office, news and public information, and managing organization costs.

ALMA Operations, \$40.35 million: NRAO is engaged in construction and operation of the international ALMA Observatory, which is in the very final stages of construction funded through the Major Research Equipment and Facilities Construction account. The remaining construction activity will be completed before the beginning of FY 2016. Early operations funding for ALMA began in FY 2005 and ramps up to full operations in FY 2017. A funding profile through FY 2015 was authorized by the National Science Board in February 2011.

As part of ALMA Operations, in 2006 NRAO created the North American ALMA Science Center (NAASC) to support the broad user community in fully realizing the scientific capabilities of ALMA. NAASC is increasing its activity in conjunction with the ramp up in ALMA operations. NAASC serves two key functions: (1) supporting basic ALMA operations as an ALMA Regional Center, providing day-to-day support for ALMA operations carried out in Chile, and (2) providing easy access and strong support to the broad astronomical community that will be using ALMA. NAASC organizes summer schools, workshops, and courses in techniques of millimeter and submillimeter astronomy.

Management and Oversight

- **NSF Structure**: In consultation with community representatives, dedicated AST program officers carry 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. AST program officers participate in the international ALMA Board and attend AUI/NRAO governance and advisory committee meetings. To address issues as they arise, AST

²⁰ <https://public.nrao.edu/>

Major Multi-User Research Facilities

works closely with other NSF offices, such as the Office of General Counsel, the Office of International and Integrative Activities, 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 construction and operations, and the AUI Management Report. A Business Systems Review and mid-term Management Review were conducted in FY 2012.

Renewal/Recompetition/Termination

A management review of AUI's performance and plans for NRAO and ALMA was carried out in 2008. In response, the National Science Board authorized renewal of the cooperative agreement with AUI for the management and operation of NRAO for the period October 1, 2010 through September 30, 2015. Following a solicitation issued in FY 2014 (NSF 14-568), competition of NRAO and ALMA management and operation is underway for a new cooperative agreement to begin in early FY 2016. The current award term will undergo a concomitant one-year extension.

As announced in a Dear Colleague Letter, NSF 13-074, NSF has partitioned GBT and VLBA from the NRAO management competition in order to sustain the scientific and operational synergies of North American ALMA and the VLA, while increasing flexibility for exploring cost-efficient operational models and sustainable partnerships for GBT and VLBA.



The Atacama Large Millimeter/submillimeter Array (ALMA) is in science operations following the completion of all major construction activities in 2014. ALMA, an international partnership between North America, Europe, and East Asia, provides orders-of-magnitude improvement in observing sensitivity and image quality over previous facilities. *Credit: NRAO/AUI.*

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 large 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.

Major Multi-User Research Facilities