

## MAJOR MULTI-USER RESEARCH FACILITIES

### Major Multi-User Research Facilities Funding

(Dollars in Millions)

	FY 2015 Actual	FY 2016 Estimate	FY 2017 Request	Change over FY 2016 Estimate	
				Amount	Percent
<b>Total Research and Related Activities</b>	<b>\$963.10</b>	<b>\$979.67</b>	<b>\$1,036.16</b>	<b>\$56.49</b>	<b>5.8%</b>
Operations and Maintenance of Existing Facilities	736.77	697.25	732.08	34.83	5.0%
Federally Funded Research and Development Centers	215.51	212.88	215.58	2.70	1.3%
Operations and Maintenance of Facilities under Construction	7.12	55.04	81.00	25.96	47.2%
R&RA Planning and Concept Development	3.70	14.50	7.50	-7.00	-48.3%
<b>Major Research Equipment and Facilities Construction</b>	<b>\$146.89</b>	<b>\$203.31</b>	<b>\$195.12</b>	<b>-\$8.19</b>	<b>-4.0%</b>
<b>Total, Major Multi-User Research Facilities</b>	<b>\$1,109.99</b>	<b>\$1,182.98</b>	<b>\$1,231.28</b>	<b>\$48.30</b>	<b>4.1%</b>

Totals may not add due to rounding.

The FY 2017 Budget Request for major multi-user facilities is \$1,231.28 million, of which \$1,214.88 million is discretionary funding and \$16.40 million is new mandatory funding. The new mandatory funding is within the Federally Funding Research and Development Centers (\$1.30 million) and Operations and Maintenance of Existing Facilities (\$15.10 million) lines in the above table.

NSF investments provide state-of-the-art tools for research and education. These include multi-user research facilities and instrumentation networks such as observatories, accelerators, detectors, telescopes, research vessels, aircraft, and simulators. In addition, investments in cyber-enabled and geographically distributed user facilities are increasing as a result of rapid advances in computer, information, and communication technologies. NSF's investments are coordinated with those of other organizations, federal agencies, and international partners to ensure they are complementary and well integrated. Planning, operations, and maintenance of 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 2015	FY 2016	FY 2017	Change over	
	Actual	Estimate	Request <sup>1</sup>	FY 2016 Estimate	Percent
<b>Operations and Maintenance of Existing Facilities</b>	<b>\$736.77</b>	<b>\$697.25</b>	<b>\$732.08</b>	<b>\$34.83</b>	<b>5.0%</b>
<b>Engineering</b>					
National Nanotechnology Coordinated Infrastructure (NNCI)	15.02	15.46	15.46	-	-
Natural Hazards Engineering Research Infrastructure (NHERI)	18.24	12.50	12.50	-	-
<b>Geosciences</b>					
Academic Research Fleet <sup>2</sup>	79.87	83.80	82.80	-1.00	-1.2%
Geodesy Advancing Geosciences and EarthScope (GAGE)	11.58	11.58	13.08	1.50	13.0%
International Ocean Discovery Program (IODP)	48.00	48.00	48.00	-	-
Ocean Observatories Initiative (OOI)	55.00	55.00	50.00	-5.00	-9.1%
Polar Facilities and Logistics	314.54	286.57	307.07	20.50	7.2%
Seismological Facilities for the Advancement of Geoscience & EarthScope (SAGE)	24.35	24.35	26.95	2.60	10.7%
<b>Mathematical and Physical Sciences</b>					
Arecibo Observatory	8.01	8.20	8.30	0.10	1.2%
Cornell High Energy Synchrotron Source (CHESS) <sup>3</sup>	21.97	18.03	20.00	1.97	10.9%
Gemini Observatory	20.61	19.88	20.42	0.54	2.7%
IceCube Neutrino Observatory	6.90	6.90	7.00	0.10	1.4%
Large Hadron Collider (LHC)	18.00	18.00	18.00	-	-
Laser Interferometer Gravitational Wave Observatory (LIGO)	33.00	39.43	39.43	-	-
National High Magnetic Field Laboratory (NHMFL) <sup>4</sup>	35.92	22.78	35.78	13.00	57.1%
National Superconducting Cyclotron Laboratory (NSCL)	23.00	24.00	24.50	0.50	2.1%
Other Facilities <sup>5</sup>	2.77	2.77	2.79	0.02	0.7%
<b>Federally Funded Research and Development Centers<sup>6</sup></b>	<b>\$215.51</b>	<b>\$212.88</b>	<b>\$215.58</b>	<b>\$2.70</b>	<b>1.3%</b>
National Center for Atmospheric Research (NCAR)	98.70	99.70	101.00	1.30	1.3%
National Optical Astronomy Observatory (NOAO)	25.50	21.60	21.83	0.23	1.1%
National Radio Astronomy Observatory (NRAO) <sup>7</sup>	83.31	82.08	75.25	-6.83	-8.3%
Other Astronomical Facilities <sup>7</sup>	-	-	11.50	11.50	N/A
National Solar Observatory (NSO) <sup>8</sup>	8.00	9.50	6.00	-3.50	-36.8%
<b>Operations and Maintenance of Facilities under Construction</b>	<b>\$7.12</b>	<b>\$55.04</b>	<b>\$81.00</b>	<b>\$25.96</b>	<b>47.2%</b>
Daniel K. Inouye Solar Telescope (DKIST) <sup>9</sup>	7.00	11.00	16.00	5.00	45.5%
National Ecological Observatory Network (NEON)	0.12	44.04	65.00	20.96	47.6%
<b>R&amp;RA Planning and Concept Development</b>	<b>\$3.70</b>	<b>\$14.50</b>	<b>\$7.50</b>	<b>-\$7.00</b>	<b>-48.3%</b>
Pre-construction Planning <sup>10</sup>	3.70	14.50	7.50	-7.00	-48.3%
<b>Major Research Equipment and Facilities Construction<sup>11</sup></b>	<b>\$146.89</b>	<b>\$203.31</b>	<b>\$195.12</b>	<b>-\$8.19</b>	<b>-4.0%</b>
<b>Total, Major Multi-User Research Facilities</b>	<b>\$1,109.99</b>	<b>\$1,182.98</b>	<b>\$1,231.28</b>	<b>\$48.30</b>	<b>4.1%</b>

Totals may not add due to rounding.

<sup>1</sup> The FY 2017 Request for major multi-user facilities is \$1,231.28 million, of which \$1,214.88 million is discretionary funding and \$16.40 million is new mandatory funding. The new mandatory funding is within the NCAR (\$1.30 million), GAGE (\$1.50 million), SAGE (\$2.60 million), and Polar Facilities and Logistics (\$11.0 million) lines in the above table.

<sup>2</sup> Academic Research Fleet funding includes ship operations and upgrades. Regional Class Research Vessels (RCRV) funding is no longer included on this line as it is proposed for an FY 2017 MREFC new construction start.

<sup>3</sup> Forward funding for the Cornell High Energy Synchrotron Source (CHESS) of \$1.97 million in FY 2015 reduced the amount required in FY 2016.

<sup>4</sup> Forward funding for the National High Magnetic Field Laboratory (NHMFL) of \$11.88 million in FY 2015 reduced the amount required in FY 2016.

<sup>5</sup> Other Facilities includes ongoing MPS support for the Center for High Resolution Neutron Scattering (CHRNS).

<sup>6</sup> Federally-Funded R&D Centers do not include support for the Office of Science and Technology Policy Institute (STPI), which is an FFRDC but not a multi-user research facility.

<sup>7</sup> Funding for the National Radio Astronomy Observatory (NRAO) includes operations and maintenance support for the Atacama Large Millimeter Array (ALMA). The decrease in FY 2017 is due to the separation of the Green Bank Observatory and the Very Long Baseline Array from NRAO and ALMA; this funding is now included under "Other Astronomical Facilities" in this table.

<sup>8</sup> National Solar Observatory (NSO) totals presented do not include \$5.0 million in FY 2015, \$9.0 million in FY 2016, and \$14.0 million in FY 2017 for operations and maintenance support for the DKIST facility construction project. That funding is captured within the total presented on the MREFC line.

<sup>9</sup> Of total DKIST funding presented, \$5.0 million in FY 2015, \$9.0 million in FY 2016, and \$14.0 million in FY 2017 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.

<sup>10</sup> Pre-construction planning includes funding for potential next generation multi-user facilities. This line reflects funding for Antarctic Infrastructure Modernization for Science (AIMS) for all three years and the Large Hadron Collider (LHC) upgrade for FY 2017 only. The LHC upgrade will be funded at \$2.50 million in FY 2017.

<sup>11</sup> Funding for MREFC Projects in this table include support for concept and development associated with ongoing and requested MREFC projects, i.e. RCRV, provided through the R&RA account. RCRV funding is \$2.13 million in FY 2015, \$3.0 million in FY 2016, and \$2.0 million in FY 2017.

**NSF Facilities Investments in FY 2017**

The following pages contain information on NSF’s ongoing facilities in FY 2017.

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 - 17
IceCube Neutrino Observatory .....	Facilities - 20
International Ocean Discovery Program (IODP).....	Facilities - 23
Large Hadron Collider (LHC) .....	Facilities - 26
Laser Interferometer Gravitational Wave Observatory (LIGO) .....	Facilities - 29
National High Magnetic Field Laboratory (NHMFL).....	Facilities - 32
National Nanotechnology Coordinated Infrastructure (NNCI) .....	Facilities - 35
National Superconducting Cyclotron Laboratory (NSCL).....	Facilities - 38
Natural Hazards Engineering Research Infrastructure (NHERI).....	Facilities - 40
Ocean Observatories Initiative (OOI).....	Facilities - 44
Polar Facilities and Logistics.....	Facilities - 47
Seismological Facilities for the Advancement of Geoscience and EarthScope (SAGE) .....	Facilities - 51

Federally Funded Research and Development Centers (FFRDCs)

National Center for Atmospheric Research (NCAR) .....	Facilities - 54
National Optical Astronomy Observatory (NOAO).....	Facilities - 58
National Radio Astronomy Observatory (NRAO) .....	Facilities - 61
National Solar Observatory (NSO).....	Facilities - 65
Other Astronomical Facilities.....	Facilities - 69

Other Facilities Funding

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

**ACADEMIC RESEARCH FLEET**

**\$84,800,000**  
**-\$2,000,000 / -2.3%**

**Academic Research Fleet**

(Dollars in Millions)

FY 2015	FY 2016	FY 2017	Change over	
			FY 2016 Estimate	
Actual	Estimate	Request	Amount	Percent
\$82.00	\$86.80	\$84.80	-\$2.00	-2.3%

The U.S. Academic Research Fleet includes 16 vessels in calendar year 2015, and 18 vessels in calendar year 2016. 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 for Geosciences (GEO) by the Division of Ocean Sciences (OCE). In addition to operations, OCE has undertaken selected construction projects based on inter-agency planning and coordination as discussed in the *Federal Oceanographic Fleet Status Report*<sup>1</sup> published in May 2013.

**Total Obligations for the Academic Research Fleet**

(Dollars in Millions)

	FY 2015	FY 2016	FY 2017	ESTIMATES <sup>1</sup>				
				Actual	Estimate	Request	FY 2018	FY 2019
Operations & Maintenance	\$79.87	\$83.80	\$82.80	\$80.80	\$80.80	\$80.80	\$80.80	\$80.80
<i>RV Sikuliaq O&amp;M</i> <sup>2</sup>	3.50	5.00	5.00	5.00	5.00	5.00	5.00	5.00
Fleet Modernization								
Regional Class Research Vessel	2.13	3.00	2.00	-	-	-	-	-
<b>Total, Academic Research Fleet</b>	-	-	<b>\$84.80</b>	<b>\$80.80</b>	<b>\$80.80</b>	<b>\$80.80</b>	<b>\$80.80</b>	<b>\$80.80</b>

Totals may not add due to rounding.

<sup>1</sup> Outyear funding estimates are for planning purposes only.

<sup>2</sup> As discussed in the *RV Sikuliaq* paragraph below, 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 2016 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). 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 2017 Request of \$82.80 million will support approximately 1,500 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.
- 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*<sup>2</sup> and the *Final Recommendations of the Interagency Ocean Policy Task Force*<sup>3</sup> 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*<sup>4</sup> published in 2009, and *Critical Infrastructure for Ocean Research and Societal Needs in 2030*<sup>5</sup> published in 2011. In coordination with UNOLS and the other federal agencies that invest in ocean research, the Interagency Working Group on Facilities and Infrastructure (IWG-FI) published a *Federal Oceanographic Fleet Status Report*<sup>6</sup> in May 2013, reviewing the status and describing plans for modernizing the federal and academic oceanographic research and survey fleet. In January 2015, The National Academy of Sciences Report *Sea Change 2015-2025 Decadal Survey of Ocean Sciences*<sup>7</sup> identified the U.S. Academic Research Fleet as having "the strongest match between current infrastructure and the decadal science priorities" and emphasized the overall importance of ships in all of the science priorities. Ship operations and technical services proposals undergo external review by peers every five years. Detailed annual reports describing activities accomplished are provided by the operating institutions and budgets are negotiated yearly since they are dependent on the number of days the ships will be at sea in support of NSF-funded research programs. No Business System Reviews of Academic Research Fleet operating institutions are currently scheduled for 2016.

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<sup>2</sup> [www.whitehouse.gov/sites/default/files/national\\_ocean\\_policy\\_implementation\\_plan.pdf](http://www.whitehouse.gov/sites/default/files/national_ocean_policy_implementation_plan.pdf)

<sup>3</sup> [www.whitehouse.gov/files/documents/OTPF\\_FinalRecs.pdf](http://www.whitehouse.gov/files/documents/OTPF_FinalRecs.pdf)

<sup>4</sup> [www.nap.edu/catalog/12775/science-at-sea-meeting-future-oceanographic-goals-with-a-robust](http://www.nap.edu/catalog/12775/science-at-sea-meeting-future-oceanographic-goals-with-a-robust) <sup>5</sup>  
[www.nap.edu/catalog/13081/critical-infrastructure-for-ocean-research-and-societal-needs-in-2030](http://www.nap.edu/catalog/13081/critical-infrastructure-for-ocean-research-and-societal-needs-in-2030)

<sup>7</sup> [www.nap.edu/catalog/21655/sea-change-2015-2025-decadal-survey-of-ocean-sciences](http://www.nap.edu/catalog/21655/sea-change-2015-2025-decadal-survey-of-ocean-sciences)

### **Fleet Modernization**

Oversight: The NSF coordinator for Fleet modernization activities is the program director for Ship and Submersible Support, within the Integrative Programs Section (IPS) in OCE, with additional IPS staff providing project management assistance as required.

Regional Class Research Vessel (RCRV): In March 2012, NSF leadership approved the request to advance the RCRV to the Conceptual Design Review (CDR) phase as a candidate Major Research Equipment and Facilities Construction (MREFC) project. On February 1, 2013, NSF made an award to Oregon State University (OSU) as the lead institution for advancement to CDR. Funds for CDR were provided from the Research and Related Activities account. In December 2013, OSU successfully completed all CDR requirements in accordance with NSF's Large Facilities Manual.<sup>8</sup> Approval for advancement to the Preliminary Design Phase was provided in March 2014. The Preliminary Design Review (PDR) was held in August 2014. The PDR Panel recommended the project be approved to advance to the Final Design Phase. Initial funds to initiate construction are requested in FY 2017, contingent on continued satisfactory progress by the awardee, the project's consistency with overall NSF goals and strategic direction, and the availability of funds. Personnel from the NOAA Office of Marine and Aviation Operations, as well as ONR, continue to participate in the review of the RCRV design and project management. In addition, NSF is an active participant in the IWG-FI Ship Subcommittee, which developed the update to the 2013 *Federal Oceanographic Fleet Status Report*, an action in the *National Ocean Policy (NOP) Implementation Strategy*.<sup>9</sup> 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. *Sikuliaq* has successfully completed ice trials in the Bering Sea and three science cruises in the Arctic Ocean. All final MREFC project activities will be closed out by the end of March 2016.

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* provides a sophisticated and significantly larger platform for scientists, as well as graduate and undergraduate students to participate in complex multidisciplinary research activities and enables the training of the next generation of scientists with the latest equipment and technology. The *Sikuliaq* greatly expands research capabilities in the Arctic providing up to 270-300 science days at sea annually. The ice-strengthened hull allows the vessel to operate in seasonal ice up to one meter thick and an anti-roll tank permits it to operate effectively in the open waters of the Bering Sea, Gulf of Alaska, and North Atlantic.

### **Other Ongoing Activities**

Major overhaul and upgrade to the submersible Human Occupied Vehicle *ALVIN* was completed in FY 2013. The *ALVIN* Upgrade project was scoped in two phases. Phase I was the integration of a new titanium 6,500-meter-capable personnel sphere with existing *ALVIN* vehicle components. Phase I

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<sup>8</sup> [www.nsf.gov/pubs/2015/nsf15089/nsf15089.pdf](http://www.nsf.gov/pubs/2015/nsf15089/nsf15089.pdf)

<sup>9</sup> [www.whitehouse.gov/administration/eop/oceans/implementationplan](http://www.whitehouse.gov/administration/eop/oceans/implementationplan)

completion provided a maximum depth capability of 4,500 meters, the limit of the legacy *ALVIN* components retained during Phase I. Phase II would provide upgrades to permit operations to a depth of 6,500 meters, but there has been no implicit or explicit commitment to proceed with Phase II at this time. Sea trials for operation of the Phase I vehicle in November 2013 supported certification for operations to 3,800 meters, and approximately 100 dives in support of science were made in 2014. Further sea trials to support certification to 4,500 meters were successfully completed in January 2015.

**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 Business System Reviews (BSR), and site inspections. In 2013, NSF retired *R/V Cape Hatteras*, operated by a consortium of Duke University and the University of North Carolina from its homeport at the Duke University Marine Laboratory. In 2014, NSF retired *R/V Point Sur*, operated by Moss Landing Marine Laboratories, San Jose State University. For the *R/V Sikuliaq*, a re-compete clause in ten years (2024) was included in the initial cooperative agreement for operations.

**ARECIBO OBSERVATORY****\$8,300,000**  
**+\$100,000 / 1.2%****Arecibo Observatory**  
(Dollars in Millions)

FY 2015	FY 2016	FY 2017	Change over	
			FY 2016 Estimate	
Actual	Estimate	Request	Amount	Percent
\$8.01	\$8.20	\$8.30	\$0.10	1.2%

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 subject matter experts from outside the observatory are consulted for reviews. NSF does not provide awards targeted specifically for use of Arecibo, although some Arecibo users are supported through NSF or NASA grants to pursue scientific programs that require use of the facility.

Arecibo has a staff of about 122 full-time-equivalent positions at the beginning of FY 2016. A total of 97 permanent staff work for Arecibo. This includes approximately 20 scientists who, along with engineers, technicians, and operators, are available to help visiting investigators with observing programs. In addition, there are management, administrative, and clerical positions, as well as maintenance staff, and several postdoctoral scholars and students. 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 2015	FY 2016	FY 2017	ESTIMATES <sup>1</sup>				
				Actual	Estimate	Request	FY 2018	FY 2019
Operations & Maintenance (MPS)	\$4.01	\$4.10	\$4.20	\$4.20	\$4.20	\$4.20	\$4.20	\$4.20
Operations & Maintenance (GEO)	4.00	4.10	4.10	4.10	4.10	4.10	4.10	4.10
<b>Total, Arecibo</b>	<b>\$8.01</b>	<b>\$8.20</b>	<b>\$8.30</b>	<b>\$8.30</b>	<b>\$8.30</b>	<b>\$8.30</b>	<b>\$8.30</b>	<b>\$8.30</b>

Totals may not add due to rounding.

<sup>1</sup> Outyear funding estimates are for planning purposes only. The current cooperative agreement ends in FY 2016. NSF is exploring an extension through FY 2017.

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 2017 is based on the 2006 AST Senior Review recommendations, an external review of the MPS/AST portfolio conducted in 2012, and guidance from a third-party cost review of AST facilities. Based on Senior Review recommendations, MPS/AST has ramped down support for Arecibo, whereas GEO/AGS ramped up support through FY 2015.



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*,<sup>10</sup> was released in August 2012 and included recommendations about all of the major AST telescope facilities. The MPS/AST 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.

GEO/AGS is currently conducting a portfolio review of GEO/AGS Geospace research and infrastructure investments, including facilities such as Arecibo. The GEO/AGS portfolio review is expected to be completed in early FY 2016. This review completion and the re-evaluation timescale recommended by the MPS/AST Portfolio Review 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 Q2 FY 2016, is likely to be followed by a formal review to evaluate environmental impacts of viable divestment options, including the possible impacts of potential partnerships. In addition, in October 2015, NSF issued Dear Colleague Letter NSF 16-005<sup>11</sup> requesting the community to propose viable concepts for the long-term operation of Arecibo Observatory. NSF is presently evaluating the responses submitted for the January 15, 2016 deadline.

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 approximately \$3.70 million in FY 2016 and FY 2017, 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. Follow-on activities to this 2013 grant were conducted in 2014/2015.



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

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

<sup>10</sup> [www.nsf.gov/mps/ast/ast\\_portfolio\\_review.jsp](http://www.nsf.gov/mps/ast/ast_portfolio_review.jsp)

<sup>11</sup> [www.nsf.gov/pubs/2016/nsf16005/nsf16005.jsp](http://www.nsf.gov/pubs/2016/nsf16005/nsf16005.jsp)

techniques. Arecibo also sponsors a major outreach program in Puerto Rico via the Angel Ramos Foundation Visitor Center as well as summer workshops for K-12 teachers. This center attracts more than 80,000 visitors each year; over 1.4 million people have visited since its opening in 1997. Approximately 25 percent of these visitors are K-12 students. Exhibits at the visitor center are being updated in Q1 FY 2016, and physical renovations to the visitor center building are scheduled to begin in Q2 FY 2016. These improvements are funded by the Angel Ramos Foundation and the Ana G. Méndez University System, and have been formally approved by the NSF. With the funds mentioned above from the Puerto Rico Department of Education, Arecibo has hosted numerous teacher workshops, the most recent June 1-5, 2015, and has trained approximately 500 teachers. This program integrates formal activities at the Angel Ramos Foundation Visitor Center into the STEM curriculum in Puerto Rico. Arecibo also hosts several meetings each year within a wide variety of scientific disciplines.

**Operations and Maintenance:** Arecibo administers observing time to the astronomy and aeronomy communities via competitive observing proposals and conducts educational and public outreach programs at all levels. Observing hours among science programs are based on the quality of the observing proposals. The telescope is currently oversubscribed, counting ongoing astronomy surveys, new astronomy projects, solar system observations, and atmospheric sciences programs. About 80 percent of astronomy users conduct their observing remotely via networked control software, while radar observations typically employ on-site users.

**Management and Oversight**

- **MPS/AST, \$4.20 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, which continues into FY 2017, 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
- **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. Commissioning of an ionospheric high-frequency heating facility is underway at Arecibo in Q1 FY 2016.
- **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 principal investigator of the operations award resides at SRI headquarters in Menlo

Park, CA, but makes frequent site visits to Puerto Rico. The principal on-site management staff include the Arecibo site director, resident at the telescope site, a deputy director in the areas of Radio Astronomy and Planetary Radar, and a deputy director for Education and Public Outreach. The position of Arecibo site director is currently open, and is the subject of a broadly-based search being conducted by the managing organization.

- 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 early CY 2016. (A program plan review was not held in 2014, but was instead superseded by the mid-term management review held in late CY 2014; 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 was received early in calendar year 2015. Various recommendations of the panel are currently being incorporated into Arecibo Observatory operations.

#### **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. NSF is exploring an extension through September 30, 2017. The direction beyond that time will be determined after carrying out the study of divestment alternatives, receiving the recommendations of the GEO/AGS Geospace portfolio review, and evaluating the response to NSF 16-005, all of which were discussed above. There is potential for substantial change to the notional budgets shown above for FY 2018 and beyond, following completion of the evaluation process during FY 2016.

**CORNELL HIGH ENERGY SYNCHROTRON SOURCE****\$20,000,000**  
**+\$1,970,000 / 10.9%****Cornell High Energy Synchrotron Source**

(Dollars in Millions)

FY 2015	FY 2016	FY 2017	Change over	
			FY 2016 Estimate	
Actual	Estimate <sup>1</sup>	Request	Amount	Percent
\$21.97	\$18.03	\$20.00	\$1.97	10.9%

<sup>1</sup> Forward funding of \$1.97 million in FY 2015 reduced the amount needed in FY 2016.

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, engineering, and environmental sciences. Emphasis areas include soft matter and thin film studies, solution scattering, nanomaterials, high-pressure science, structural biology, time-resolved studies of materials, and X-ray studies of structural materials. Stewardship and oversight of CHESS is provided through the NSF Division of Materials Research within the Directorate for Mathematical and Physical Sciences (MPS/DMR), as well as the Directorates for Biological Sciences (BIO) and Engineering (ENG).

The FY 2017 Request supports operations of CHESS as a national user facility and is consistent with the planned annual funding level at \$20.0 million. (Forward funding of \$1.97 million in FY 2015 reduced the amount needed in FY 2016.) Support for CHESS has shifted over the past years from research and development to a national user facility, thus the facility's 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 2015	FY 2016	FY 2017	ESTIMATES <sup>2</sup>				
	Actual	Estimate <sup>1</sup>	Request	FY 2018	FY 2019	FY 2020	FY 2021	FY 2022
Operations & Maintenance (MPS)	\$11.97	\$8.03	\$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)	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00
<b>Total, CHESS</b>	<b>\$21.97</b>	<b>\$18.03</b>	<b>\$20.00</b>	<b>\$20.00</b>	<b>\$20.00</b>	<b>\$20.00</b>	<b>\$20.00</b>	<b>\$20.00</b>

Totals may not add due to rounding.

<sup>1</sup> Forward funding of \$1.97 million in FY 2015 reduced the amount needed in FY 2016.<sup>2</sup> Outyear funding estimates are for planning purposes only. The current cooperative agreement ends in March 2019.

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

CHESS supports users from academia, industry, and national laboratories. CHESS 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 Department of Energy (DOE)-supported synchrotron facilities such as the Advanced Photon Source and the National Synchrotron Light Source. X-ray detectors developed at CHESS are now in use at 3<sup>rd</sup> and 4<sup>th</sup> Generation X-ray sources around the world, including the world's first hard X-ray laser, DOE's Linear Coherent Light Source. CHESS-developed undulators, that cost an order of magnitude less than current technology, are being installed at CHESS. The undulators will increase X-ray flux by an order of magnitude and enable CHESS to pursue time-resolved and high resolution imaging experiments not previously possible. The Cornell undulators and other innovations such as high flux X-ray optics are impacting synchrotron science worldwide.

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

CHESS supports and enhances Ph.D. level graduate education, postdoctoral research, and research experiences for undergraduates and for K-12 students and science teachers. 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 MPS, ENG, and BIO through a cooperative agreement with Cornell University. A MPS/DMR program director is the primary contact with the facility and leads an internal NSF team of program directors. NIH provides additional support for CHESS operations through the Macromolecular Diffraction at the Cornell High Energy Synchrotron Source (MacCHESS) award. A Joint Operating Group (JOG) was established to better coordinate the CHESS and MacCHESS awards. The JOG serves as a vehicle to keep interested parties informed and includes program directors in MPS, ENG, and BIO at NSF, as well as NIH program directors.
- External structure: The Cornell Laboratory of Accelerator-based Sciences and Education (CLASSE), which reports to Cornell's Vice-Provost for Research, administers CHESS. The principal investigator serves as the CHESS Director and reports to the Director of CLASSE. The CHESS Director receives guidance primarily from the CHESS executive committee, from an external policy and advisory board, the CHESS diversity committee, and the users' executive committee.
- Reviews: NSF provides oversight by monitoring annual plans and reports including user metrics, as well as by conducting monthly phone conferences with the director. NSF uses annual site visit reviews to assess the user program, in-house research, long-term plans to contribute significant research developments both nationally and internationally, 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 NIH attend these site visits. Recent and upcoming reviews include:
  - A Management Review focusing on CHESS operations and strategic planning, July 9-10, 2014.
  - Annual site review by external panel of site visitors, October 26-27, 2015
  - Annual site review, fall of 2016.

### **Renewal/Recompetition/Termination**

A comprehensive renewal review was conducted in FY 2013. The National Science Board authorized an award to Cornell for the operation of CHESS of up to five years in duration and up to \$100 million. The end date of the award is March 2019.

**GEMINI OBSERVATORY**

**\$20,420,000**  
**+\$540,000 / 2.7%**

**Gemini Observatory**  
(Dollars in Millions)

FY 2015 Actual	FY 2016 Estimate	FY 2017 Request	Change over	
			FY 2016 Estimate Amount	Percent
\$20.61	\$19.88	\$20.42	\$0.54	2.7%

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 drives cosmic acceleration, the nature of non-luminous matter, the processes that give rise to the formation and evolving structures of galaxies, and the formation of stars and their planetary systems. The current generation of large optical/infrared telescopes is central to these studies, owing to their unsurpassed sensitivity and exquisite spatial resolution. Technological advances incorporated into the design of the Gemini telescopes optimize their imaging capabilities and infrared performance as well as their ability to rapidly reconfigure the attached instrumentation in response to changing atmospheric conditions.

The Gemini telescopes help educate and train astronomy and engineering students through internship programs for undergraduates in both Hawaii and Chile. 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 host sites 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 also provide guidance and support to the Imiloa Science Center, a public astronomy and cultural center in Hilo, Hawaii.



The laser at Gemini-South produces synthetic guide stars on the sky, which the GeMS adaptive optics system uses to correct wide-field images for atmospheric turbulence. Credit: Gemini/AURA.

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

**Total Obligations for the Gemini Observatory**

(Dollars in Millions)

	FY 2016		FY 2017	ESTIMATES <sup>1</sup>				
	Actual	Estimate	Request	FY 2018	FY 2019	FY 2020	FY 2021	FY 2022
Operations & Maintenance	\$20.61	\$19.88	\$20.42	\$21.03	\$21.66	\$22.31	\$22.98	\$23.67

<sup>1</sup> Outyear funding estimates are for planning purposes only. The current cooperative agreement ends in December 2016.

Laser guide star systems, which greatly improve the ability to correct for atmospheric blurring, are available at both facilities. The advanced “multi-conjugate” adaptive optics system on Gemini South continues to lead the world, providing near-infrared images that exceed the quality available from orbiting observatories, and which cover a field-of-view on the sky that is wider than any competing system. Commissioned in 2014, the state-of-the-art Gemini Planet Imager is in regular use for directly imaging and characterizing planets orbiting nearby stars. Additional 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*,<sup>12</sup> 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 in the Directorate for Mathematical and Physical Sciences (MPS/AST) conducted a community-based review of its portfolio. The resulting Portfolio Review Committee (PRC) report, *Advancing Astronomy in the Coming Decade: Opportunities and Challenges*<sup>13</sup> 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 \$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 FY 2017 Budget Request for Gemini is higher than that recommended by the PRC.

The FY 2017 Request includes the full U.S. contribution to baseline operations at the level agreed to by the international partners (\$18.56 million in FY 2017), and a contribution of \$1.86 million to the Gemini Instrument Development Fund. Funding levels through FY 2021 have been agreed to by the post-2015 Gemini partners through a Gemini Board resolution in May 2015, and are reflected in the out-year estimates.

<sup>12</sup> [www.nap.edu/catalog.php?record\\_id=12951](http://www.nap.edu/catalog.php?record_id=12951)

<sup>13</sup> [www.nsf.gov/mps/ast/ast\\_portfolio\\_review.jsp](http://www.nsf.gov/mps/ast/ast_portfolio_review.jsp)

### **Management and Oversight**

- **NSF Structure:** NSF has one seat on the Gemini Board, currently occupied by the MPS/AST division director. An additional NSF staff member serves as the executive secretary to the board. Programmatic oversight is the responsibility of an NSF program officer. 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, which was 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. The Board includes the director of the U.S. National Optical Astronomy Observatory (NOAO) in order to facilitate increased cooperation between NOAO and Gemini and to provide an improved voice for the general U.S. astronomical community. Gemini is currently managed by the Association of Universities for Research in Astronomy, Inc. (AURA) on behalf of the partnership through a cooperative agreement with NSF. AURA conducts its own management reviews through standing oversight committees.
- **Reviews:** NSF conducts periodic reviews of the management and operation of the observatory 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 with AURA for the operation of Gemini was awarded in March 2011 and again in August 2014. These extended the agreement through December 31, 2015 and through December 31, 2016, respectively. This one-year extension of the existing cooperative agreement to the end of 2016 resulted from a need to shift the re-competition away from other major NSF observatory management competitions being held in 2014 and 2015.

### **Renewal/Re-competition/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 ultimately result in a reduction in total staffing from about 200 in FY 2011 to fewer than 160 by the end of FY 2018. Recently, Australia, a 6.3 percent partner in 2015, moved to a more limited participation on a year-to-year basis. Korea has a similar arrangement and has elected to continue its 2015 limited term collaboration with the observatory to the end of 2016. Discussions with Korea regarding full partnership have progressed rapidly during the last 18 months and arrangements are now being made for that nation to assume most of Australia's share in FY 2017. The international partners are currently negotiating a new agreement for the post-2015 years, and NSF expects this new agreement to be finalized in early 2016.

The current NSF cooperative agreement 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, cost savings from a shift in nightly telescope operations from the remote telescope site to the base facility at sea level in Hawaii and Chile, a re-design of the data archive, decreased development and outreach activities, and a tighter focus on serving the partner user communities at the expense of internal scientific research activities. In February 2012 the National Science Board (NSB) approved the funding recommendation for this plan through 2015 and approved a one-year extension approved in May 2015. Re-competition of the management and operation of Gemini was conducted in 2014-2015. Proposals were solicited in August 2014 and received in February 2015. Face-to-face meetings between NSF and the proposing organizations in July 2015 supplemented an extensive review of these proposals by a panel of experts in April 2015. NSB approval of NSF's selection of an entity to manage and operate the observatory under a new cooperative agreement from January 1, 2017 to December 31, 2022 will be sought in February 2016.



**GEODESY ADVANCING GEOSCIENCES AND EARTHSCOPE** **\$13,080,000**  
**+\$1,500,000 / 13.0%**

**Geodesy Advancing Geosciences and EarthScope**

(Dollars in Millions)

FY 2015	FY 2016	FY 2017	Change over	
			FY 2016 Estimate	
Actual	Estimate	Request	Amount	Percent
\$11.58	\$11.58	\$13.08	\$1.50	13.0%

New mandatory funding (\$1.50 million) will support one-time investments to enhance infrastructure at this facility.

Geodesy Advancing Geosciences and EarthScope (GAGE) comprises a distributed, multi-user, national facility for the development, deployment, and operational support of modern geodetic instrumentation to serve national goals in basic research and education in the Earth sciences with a focus on studies of Earth's surface deformation at many scales with unprecedented temporal and spatial resolution. GAGE facilities support fundamental research and discovery on continental deformation, plate boundary processes, the earthquake cycle, the geometry and dynamics of magmatic systems, continental groundwater storage, and hydrologic loading. GAGE is managed and operated for NSF by UNAVCO, Inc., a consortium of 108 U.S. universities and non-profit institutions with research and teaching programs in geophysics and geodesy and 100 associate members from foreign institutions. GAGE was formed in late FY 2013 from part of the EarthScope program and UNAVCO. In FY 2017, an 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 2015 Actual	FY 2016 Estimate	FY 2017 Request	ESTIMATES <sup>1</sup>				
				FY 2018	FY 2019	FY 2020	FY 2021	FY 2022
Operations & Maintenance	\$11.58	\$11.58	\$13.08	\$11.58	\$11.58	\$11.58	\$11.58	\$11.58

Totals may not add due to rounding.

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

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

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

**Geodetic Infrastructure**

- The EarthScope Plate Boundary Observatory (PBO) includes more than 1,100 continuous Global Positioning System (GPS) stations (422 of which transmit data in real-time with subsecond latency)

distributed across the U.S., and concentrated on the active plate boundaries in the western contiguous U.S. and southern Alaska. Data recovery for the PBO GPS network typically averages in excess of 95 percent. PBO also includes 75 borehole strainmeters and 78 borehole seismometers deployed along the San Andreas Fault and above the Cascadia subduction zone and volcanic arc. Tiltmeters (25) and pore pressure sensors (23) are also collocated with the other borehole instruments.

- Global GPS Arrays outside of the PBO footprint are supported by GAGE in partnership with investigators. Nearly 840 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 670 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 157 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 2016, 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**

**\$7,000,000**  
**+\$100,000 / 1.4%**

**IceCube Neutrino Observatory**

(Dollars in Millions)

FY 2015	FY 2016	FY 2017	Change over	
			FY 2016 Estimate	
Actual	Estimate	Request	Amount	Percent
\$6.90	\$6.90	\$7.00	\$0.10	1.4%

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 10<sup>9</sup> electron Volts [eV]; 1TeV is 10<sup>12</sup> eV; and 1 PeV is 10<sup>16</sup> eV) are derived from the IceCube data stream. The IceCube Collaboration has recently focused on studies of neutrino events with a deposited energy of 1 TeV and above. The "deposited energy" here is the calculated energy that is released within the detector fiducial volume representing an energy level of the incoming neutrino. These high-energy neutrinos can be produced either by the interaction of cosmic rays in the Earth’s atmosphere, the so-called atmospheric neutrinos, or 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 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.

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

**Total Obligations for IceCube**

(Dollars in Millions)

	FY 2015	FY 2016	FY 2017	ESTIMATES <sup>1</sup>				
	Actual	Estimate	Request	FY 2018	FY 2019	FY 2020	FY 2021	FY 2022
Operations & Maintenance (GEO)	\$3.45	\$3.45	\$3.50	\$3.45	\$3.45	\$3.45	\$3.45	\$3.45
Operations & Maintenance (MPS)	3.45	3.45	3.50	3.45	3.45	3.45	3.45	3.45
<b>Total, IceCube</b>	<b>\$6.90</b>	<b>\$6.90</b>	<b>\$7.00</b>	<b>\$6.90</b>	<b>\$6.90</b>	<b>\$6.90</b>	<b>\$6.90</b>	<b>\$6.90</b>

Totals may not add due to rounding.

<sup>1</sup> Outyear funding estimates are for planning purposes only. The current cooperative agreement ends in March 2016.

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

**Management and Oversight**

- NSF Structure: Oversight of the IceCube Neutrino Observatory is the joint responsibility of the Geosciences Directorate's 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 are 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 a two-year term, with an option to be renewed once for at most four consecutive years. At lower levels, project management includes international collaboration representatives, as well as participation by staff at collaborating U.S. institutions. UW has in place an external Scientific Advisory Committee and a Software and Computing Advisory Panel that meet annually and provide written advice to the project. UW leadership, including the Chancellor, provides additional awardee-level oversight.

**Operations Costs**

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

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

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**

NSF began a process for re-competition of the operations and maintenance award in late FY 2015. A solicitation for re-competition, conducted in accordance with NSF policy, was issued in July 2015. The present award was extended to allow time for the competition process and now expires in March 2016. A new award is expected to be in place by March 31, 2016.

**INTERNATIONAL OCEAN DISCOVERY PROGRAM**

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

**International Ocean Discovery Program**

(Dollars in Millions)

FY 2015	FY 2016	FY 2017	Change over	
			FY 2016 Estimate	
Actual	Estimate	Request	Amount	Percent
\$48.00	\$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 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 program management structure focuses on maximizing facility efficiency, while retaining the intellectual cooperation and exchange with NSF’s international partners. NSF, the Ministry of Education, Culture, Sport, Science and Technology (MEXT) of Japan, and the European Consortium for Ocean Research Drilling (ECORD) continue to provide drilling platforms. The IODP platforms provide sediment and rock samples (cores); in-situ monitoring, sampling, and measurement from borehole observatories; shipboard and shore-based descriptive and analytical facilities; down-hole geophysical and geochemical measurements (logging); and opportunities to conduct experiments to determine in-situ conditions beneath the sea floor.



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

**Total Obligations for IODP**

(Dollars in Millions)

	FY 2015	FY 2016	FY 2017	ESTIMATES <sup>1</sup>				
	Actual	Estimate	Request	FY 2018	FY 2019	FY 2020	FY 2021	FY 2022
Operations & Maintenance	\$48.00	\$48.00	\$48.00	\$48.00	\$48.00	\$48.00	\$48.00	\$48.00

Totals may not add due to rounding.

<sup>1</sup> 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 the IODP Science Support Office represent additional NSF IODP science integration costs, made minimal to NSF because of international contributions to the program. NSF also provides support for U.S. scientists to sail on IODP drilling platforms and to participate in IODP advisory panels through an associated program. The annual costs for the associated science integration and science support (not included in the table above) are approximately \$8.50 million.

## Major Multi-User Research Facilities

The 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.

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

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

Over 3,500 scientists from 52 nations have participated on Ocean Drilling Program, Integrated Ocean Drilling Program, and International Ocean Discovery Program expeditions since 1985, including approximately 1,500 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 Science 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 cooperative agreement for the IODP U.S. Science Support Program (USSSP).
- External Structure: NSF provides the *JOIDES Resolution* as the light IODP drillship through a cooperative agreement with Texas A&M University. MEXT provides the *Chikyu* as the heavy IODP drillship through the Japan Agency for Marine-Earth Science and Technology (JAMSTEC), while the British Geological Survey manages ECORD drilling contributions through single-use Mission-Specific Platforms. Each entity providing an IODP drilling platform is responsible for sample and data storage, publications, and other science costs associated with the respective platform operations.
- IODP *JOIDES Resolution* operations are determined by the JRFB, utilizing advice and recommendations provided by the Science Evaluation Panel (SEP) and the Environmental Protection and Safety Panel (EPSP). Representation on the panels is determined by contribution level to *JOIDES Resolution* operations and exchange with other facility boards.
- Reviews: Performance of the *JOIDES Resolution* facility is reviewed yearly by an NSF panel, in consultation with the JRFB. Substantive review of management performance regarding *JOIDES Resolution* operations will occur in the third year of the cooperative agreement (FY 2017) to guide



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

**Renewal/Recompetition/Termination**

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

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

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

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**

**\$20,500,000**  
**+\$2,500,000 / 13.9%**

**Large Hadron Collider**

(Dollars in Millions)

FY 2015 Actual	FY 2016 Estimate	FY 2017 Request	Change over FY 2016 Estimate	
			Amount	Percent
\$18.00	\$18.00	\$20.50	\$2.50	13.9%

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. LHC consists of a superconducting particle accelerator, approximately 16.5 miles in circumference, providing two counter-rotating 7 TeV (1TeV=10<sup>12</sup> electron volts) proton beams. It can also provide colliding beams of heavy ions, such as lead. During 2011 and 2012 (“Run 1”), LHC operated at 4 TeV per beam as a result of a limitation in the electrical connections between the superconducting magnets. After the connections were upgraded during a nearly two-year shutdown, Run 2 began in mid-2015 and will continue through the end of 2018 at 6.5 – 7 TeV per beam, exploring a new energy region not accessible during Run 1.

Four large particle detectors collect the data delivered by LHC. They characterize the reaction products produced in the high-energy proton-proton 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. 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.

LHC data have resulted in major scientific discoveries. Foremost of these was the July 4, 2012, announcement by the CMS and ATLAS collaborations of the discovery of a particle having properties consistent with the long-sought Higgs boson, a prediction of the Standard Model of particle physics whose existence is a consequence of the theoretical framework describing the origin of the masses of elementary particles. This achievement was recognized by the award of the 2013 Nobel Prize in Physics to Francois Englert and Peter Higgs. On July 14, 2015, the LHC-b experiment reported the discovery of a class of particles known as pentaquarks, a new way to aggregate quarks (the fundamental building blocks of ordinary matter) in a way never before observed. The resumed program of operation at higher energy and higher intensity in 2015 is expected to significantly enhance the chances of more groundbreaking discoveries at the LHC. For example, the LHC program includes searches for particles predicted by a powerful theoretical framework known as supersymmetry, which may provide clues as to how the known forces – weak, strong, electromagnetic, and gravitational – evolved from different aspects of the same “unified” force in the early universe.

**Total Obligations for LHC**

(Dollars in Millions)

	FY2015	FY2016	FY 2017	ESTIMATES <sup>1</sup>				
	Actual	Estimate	Request	FY 2018	FY 2019	FY 2020	FY 2021	FY 2022
Operations & Maintenance	\$18.00	\$18.00	\$20.50	\$20.50	\$20.50	\$20.50	\$20.50	\$20.50

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

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

The May 2014 report<sup>14</sup> of the Particle Physics Project Prioritization Panel (P5) recommended to DOE and NSF that the highest priority strategic goal for the U.S. particle physics 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 (nearly ten times the luminosity of initial operation), for operation commencing in mid-2026, in order to make precision measurements that may reveal new physics beyond the Standard Model. This will necessitate significant enhancements to the detectors in order to exploit this scientific opportunity. NSF is working with the ATLAS and CMS detector collaborations to plan for this. The obligations profile shown in the table above includes additional funding during FY 2017 – FY 2020 to enable research and development and planning that could possibly lead to a major construction upgrade beginning in FY 2020.

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**

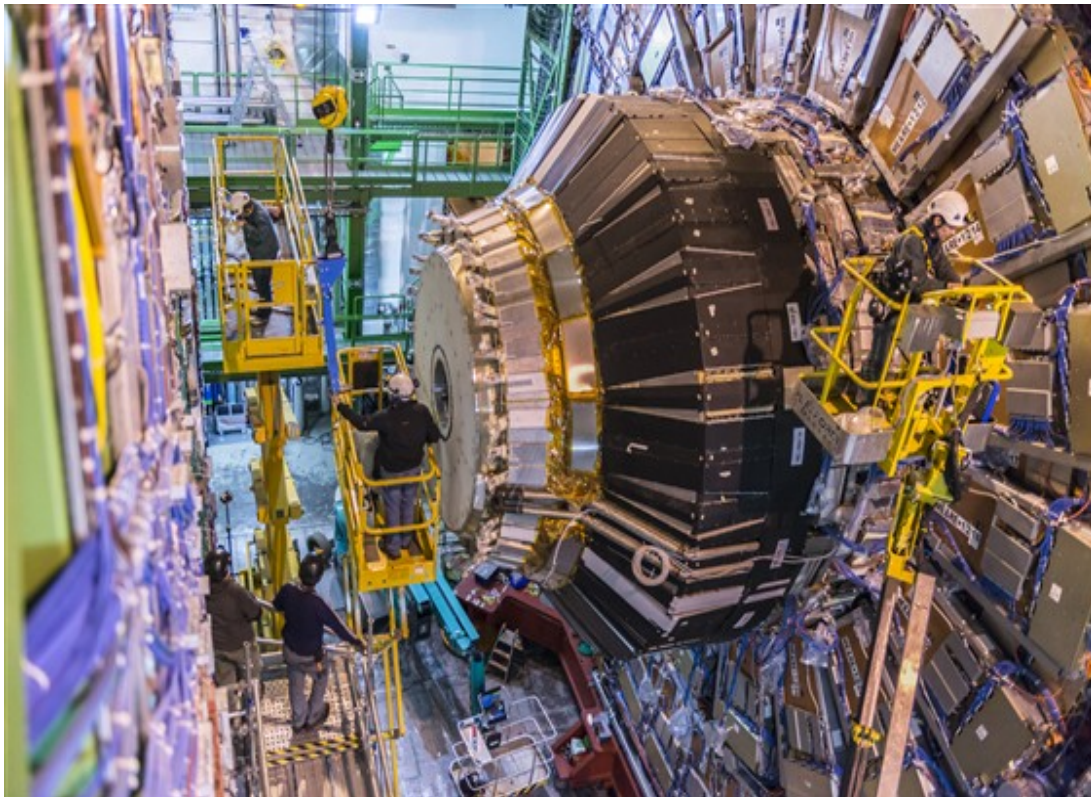
- **NSF Structure:** A program director in the Directorate for Mathematical and Physical Sciences, Division of Physics (MPS/PHY) is responsible for day-to-day project oversight. The Division of Acquisition and Cooperative Support provides financial and administrative support. An integrated project team with representatives from MPS, the Large Facilities Office, the Office of Budget, Finance, and Award Management, and other experienced program officers contribute to planning activities that may lead to a major construction upgrade.
- **External Structure:** U.S. program management occurs through a Joint Oversight Group (JOG) created by NSF and DOE. The JOG has the responsibility to see that the U.S. LHC program is effectively managed and executed to meet commitments made under the LHC international agreement and its protocols. NSF operations support is provided through cooperative agreements with Princeton University for US-CMS and with Columbia University for US-ATLAS.
- **Reviews:** There is one major management/technical review each year with a panel of external, international experts, a follow-up review six months later, as well as bi-weekly telephone reviews by NSF/DOE program directors to monitor progress. NSF and DOE jointly conduct separate external reviews of the detector upgrade activities. The next major management/technical review is scheduled

<sup>14</sup> [http://science.energy.gov/~media/hep/hepap/pdf/May-2014/FINAL\\_P5\\_Report\\_053014.pdf](http://science.energy.gov/~media/hep/hepap/pdf/May-2014/FINAL_P5_Report_053014.pdf)

for April 2016. Two JOG review meetings per year monitor overall program management.

**Renewal/Recompetition/Termination**

Because of the planned incremental program of enhancements to the accelerator along with parallel upgrades to the detectors, the LHC project is expected to be scientifically productive for at least 15 to 20 more years. 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 during FY 2017. Through an internal competition process among the research community, the ATLAS collaboration selected Stony Brook University to lead NSF-funded operations in the next cooperative agreement beginning in FY 2017. Princeton University will continue to lead CMS operations.



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 2015 Actual	FY 2016 Estimate	FY 2017 Request	Change over FY 2016 Estimate	
			Amount	Percent
\$33.00	\$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 kilometer (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 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 LIGO’s ability to discriminate a gravitational wave signal from noise.

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 March 2015, the Advanced LIGO (AdvLIGO) upgrade was completed. Funded through the Major Research Equipment and Facilities Construction (MREFC) account, this activity resulted in the design, fabrication, and installation of improved apparatus expected to enhance LIGO’s sensitivity ten-fold. LIGO’s operating budget supported the initial commissioning of this apparatus, as well as a program of periodic scientific operation of the LIGO observatories interleaved with continuing engineering studies that enhance operating performance. The overall goal of this activity is to achieve a ten-fold sensitivity improvement by late 2017. Operations support funds basic infrastructure maintenance, analysis and dissemination of data obtained from the interferometers, and



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

## Major Multi-User Research Facilities

maintenance of computational resources for data storage and analysis. Operations funding also enables complementary research and development, which is expected to lead to further enhancements in operational performance, and education and outreach activities.

In order to meet its cutting-edge performance requirements for the AdvLIGO construction project, substantial connections with industry resulted. Innovations across a diverse range of technologies have led to new techniques with broad applications (for example, preparation of stainless steel for ultra-high vacuum application, adaptive laser beam shaping), and in other cases, have resulted in patents and commercial products (in-vacuum electrical connectors, high power electro-optic modulators).

The LIGO Science Education Center (LIGO SEC), located on the Livingston Observatory site, hosts 50 hands-on inquiry-based learning exhibits and reaches over 15,000 students, teachers, and members of the public each year. These activities benefit from a partnership with Southern University Baton Rouge (SUBR), the San Francisco Exploratorium, the Baton Rouge Area Foundation (BRAAF), and other collaborating educational entities. Trained docents from SUBR assist participants and serve as collegiate-age role models for young visitors. LIGO SEC programs are supported both through LIGO's operations cooperative agreement and through grants to SUBR and BRAAF.

### Total Obligations for LIGO

(Dollars in Millions)

	FY 2015	FY 2016	FY 2017	ESTIMATES <sup>1</sup>				
	Actual	Estimate	Request	FY 2018	FY 2019	FY 2020	FY 2021	FY 2022
Operations & Maintenance	\$33.00	\$39.43	\$39.43	\$39.43	\$39.43	\$39.43	\$39.43	\$39.43

<sup>1</sup> Outyear funding estimates are for planning purposes only. The current cooperative agreement ends in September 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 contributing to instrumental improvements at the LIGO facilities, as well as fostering education and public outreach programs. NSF supports LSC activities at \$7.0 to \$8.0 million per year, which is provided through regular disciplinary research program funds.

The first scientific operation of both upgraded interferometers commenced in September 2015 and has successfully demonstrated extended operation with a four-fold sensitivity increase relative to the previous LIGO apparatus. By the latter part of 2017, both interferometers are expected to be more than ten times more sensitive than the original LIGO apparatus and will begin gathering more than one year of concurrent data.

Acting on the advice of a 2014 external review panel that assessed LIGO's computing strategy, a no-cost extension of the AdvLIGO MREFC project was approved by NSF to enable the project to purchase computing hardware immediately, or prior to when needed, in order to benefit from continuing technical innovation and price/performance advances. Consequently, the last computing purchases through MREFC construction funding will be deferred until mid-2017.

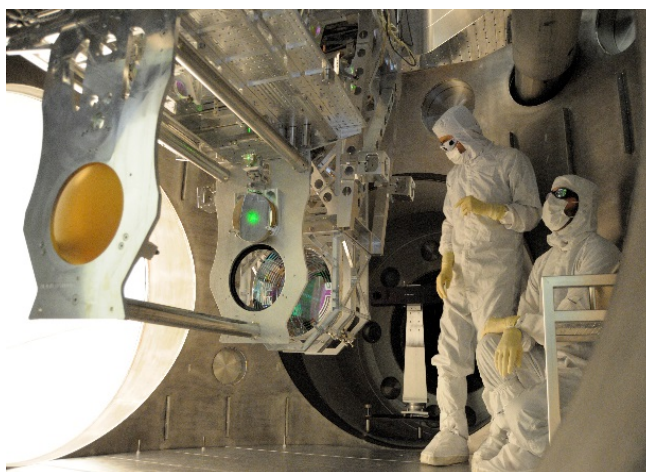
NSF has determined operating budget requirements by assessing cost data from initial LIGO interferometer operation and scaling appropriately to reflect the increased support needed to support the more complex AdvLIGO apparatus. NSF continually assesses the appropriate level of financial support by monitoring actual expenditures contained in quarterly financial reports from LIGO and through annual external reviews of operation.

### **Management and Oversight**

- NSF Structure: NSF oversight is coordinated internally by the LIGO program director in the NSF Directorate for Mathematical and Physical Sciences, Division of Physics (MPS/PHY), who also chairs the PHY AdvLIGO Integrated Project Team (IPT), comprised of the Physics Division Director, MPS Facilities Coordinator, staff from the Large Facilities Office, Office of General Counsel, Office of Legislative and Public Affairs, Office of International Science and Engineering, and program directors from elsewhere in NSF.
- External Structure: LIGO is managed by California Institute of Technology under a cooperative agreement. The management plan specifies significant involvement by the user community, represented by the LSC, and collaboration with the other major gravitational-wave detector activities in Asia, Europe, and Australia. External peer-review committees organized by NSF help provide oversight through annual reviews.
- Recent Reviews:
  - LIGO and AdvLIGO Computing Review, May 2014
  - LIGO Annual Review and AdvLIGO Interim Review, June 2014
  - LIGO and AdvLIGO Computing Review, May 2015
  - LIGO Annual Review and AdvLIGO Completion Review, June 2015
  - An annual review of LIGO operations is planned for mid-2016

### **Renewal/Recompetition/Termination**

LIGO began operating under a five-year cooperative agreement in early FY 2009, which ran concurrently with the AdvLIGO MREFC project. Following approval by the National Science Board in August 2013, the cooperative agreement was renewed at the beginning of FY 2014 for five additional years, overlapping the conclusion of AdvLIGO construction and the start of commissioning and scientific operation. NSF will perform a rigorous review of LIGO prior to the expiration of the current operating award to determine whether it is in the best interest of U.S. science and engineering to re-compete that award. The projected lifetime of the LIGO facility was originally 20 years. Infrastructure refurbishments recently accomplished or planned during the current award will extend the facility life by an additional 15 to 20 years, to beyond 2030.



Installation of the green (532nm) Arm Length Stabilization(ALS) subsystem for AdvLIGO. Credit: Caltech/MIT LIGO Laboratory.

**NATIONAL HIGH MAGNETIC FIELD LABORATORY**

**\$35,780,000**  
**+\$13,000,000 / 57.1%**

**National High Magnetic Field Laboratory**

(Dollars in Millions)

FY 2015 Actual <sup>1</sup>	FY 2016 Estimate <sup>1</sup>	FY 2017 Request	Change over FY 2016 Estimate	
			Amount	Percent
\$35.92	\$22.78	\$35.78	\$13.00	57.1%

<sup>1</sup> Forward funding from FY 2013 to FY 2014 reduced the FY 2015 Request by just over \$9.0 million to \$24.04 million. Subsequent forward funding of \$11.88 million from FY 2015 to FY 2016 reduced the amount needed in FY 2016.

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 (FT-ICR) spectrometer. The 21 Tesla magnet, the heart of the spectrometer, was installed in June 2014 and has been running continuously. The FT-ICR instrument opened for user operations in October 2015. The 21 Tesla FT-ICR is unprecedented in sensitivity and selectivity, capable of analyzing chemical samples of great complexity, such as biological fluids, biofuels, and raw and weathered petroleum. This will impact areas such as chemistry, molecular biology, and earth science.

The FY 2017 Request will allow the facility to continue operations, focus on magnet development, and strengthen education, training, user support, and in-house research. NSF provided \$11.88 million in forward funding in FY 2015, thus reducing the level needed in FY 2016. The FY 2017 Request is consistent with the originally planned funding level. 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 2015	FY 2016	FY 2017	ESTIMATES <sup>2</sup>				
	Actual	Estimate <sup>1</sup>	Request	FY 2018	FY 2019	FY 2020	FY 2021	FY 2022
Operations & Maintenance	\$35.92	\$22.78	\$35.78	\$35.78	\$35.78	\$35.78	\$35.78	\$35.78

<sup>1</sup> Forward funding of \$11.88 million in FY 2015 reduced the amount needed in FY 2016.

<sup>2</sup> 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 Oak Ridge National Laboratory, which hosts the Spallation Neutron Source, and Argonne National Laboratory, which hosts the Advanced Photon Source. International collaboration is strong; NHMFL delivered and commissioned a 26 Tesla series connected hybrid resistive/superconducting magnet to the Helmholtz-Zentrum Berlin (HZB), where it will be used for neutron scattering experiments. Collaborations also exist with the International Thermonuclear Experimental Reactor (ITER) in France, and national magnet labs in France, the Netherlands, Germany, and China.

NHMFL provides a unique interdisciplinary learning environment. The Center for Integrating Research and Learning 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. An in-depth review of all NHMFL safety procedures and protocols was initiated in response to a serious safety incident in October 2015. An independent Investigative Committee (IC) was established by the FSU Vice President for Research to find the root cause of the incident and to provide recommendations according to the best practices on Environmental, Health, and Safety (EHS).
- **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”<sup>15</sup> was presented to the National Science Board (NSB) in May 2014. Public town halls were held at several professional meetings by both DMR and CHE. The report will inform future plans

<sup>15</sup> [www.nap.edu/catalog/18355/high-magnetic-field-science-and-its-application-in-the-united-states](http://www.nap.edu/catalog/18355/high-magnetic-field-science-and-its-application-in-the-united-states)

## *Major Multi-User Research Facilities*

for investments in this area, providing several recommendations with respect to scientific priorities and new magnet developments.

- Reviews: NSF monitors annual plans and reports including user metrics and conducts monthly teleconferences with the director. NSF conducts annual external reviews, which assess the user programs, in-house research, long-term plans to contribute significant research developments both nationally and internationally, and operations, maintenance, and new facility development. Annual reviews also assess the status of education training and outreach, operations and management efficiency, and diversity plans. Recent and upcoming reviews include:
  - Business Systems Review, January 26-28, 2015.
  - Annual site review by external panel of site visitors, June 3-4, 2015.
  - In fall 2015, NSF-DMR program directors visited all three NHMFL sites (FSU and UF sites in October 7-8, 2015 and the pulsed field facility in October 28-29, 2015).
  - Renewal proposal site visit, fall 2016.

### **Renewal/Recompetition/Termination**

After a comprehensive review in FY 2012, NSB authorized a five-year award and up to \$168,380,000 for the operation and management of NHMFL. The end date of the current award is December 31, 2017. In May 2015, NSB authorized the NSF Director, at her discretion, to waive re-competition and to provide for NSB consideration a renewal award. A proposal will be reviewed starting in summer 2016 for a potential award renewal beginning in FY 2018.

**NATIONAL NANOTECHNOLOGY COORDINATED  
INFRASTRUCTURE**

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

**National Nanotechnology Coordinated Infrastructure**

(Dollars in Millions)

FY 2015	FY 2016	FY 2017	Change over	
			FY 2016 Estimate	
Actual	Estimate	Request	Amount	Percent
\$15.02	\$15.46	\$15.46	-	-

Over the past decade (2004-2015), the National Nanotechnology Infrastructure Network (NNIN) has enabled major discoveries, innovations, and contributions to education and commerce. It has 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. Building on this prior investment, NSF conducted and completed a competition for the new National Nanotechnology Coordinated Infrastructure (NNCI), as the successor program to NNIN. The NNCI represents a new model in which NSF selects and manages each university site in the network rather than a single lead institution with collaborating partners as in the previous NNIN. The new model allows for more competition and flexibility in awardee selection and management, and provides more agility in addressing emerging user facility needs in nanoscale research and education. A coordinating office will be selected competitively from among the selected sites in early FY 2016 to enhance their impact as a national infrastructure of user facility sites.

**Total Obligations for NNCI**

(Dollars in Millions)

	FY 2015	FY 2016	FY 2017	ESTIMATES <sup>1</sup>				
	Actual	Estimate	Request	FY 2018	FY 2019	FY 2020	FY 2021	FY 2022
Operations & Maintenance	\$15.02	\$15.46	\$15.46	\$15.46	\$15.46	\$15.46	\$15.46	\$15.46

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

Fifty-five proposals were received in response to the NNCI solicitation NSF 15-519. After a two-stage review process of mail/panel review and virtual reverse site review, a total of 16 NNCI site awards to universities for user facilities were made as cooperative agreements in FY 2015. Awards were selected by considering the technical merits and emerging capabilities in nanoscale research and education, and the geographic distribution of recommended sites. Among the 16 NNCI sites, eight are new, and eight have served previously as NNIN sites. Nine of the awards include at least one additional regional partner institution as subawardees. The 16 sites are located in 15 states and involve 27 universities across the Nation. Three of the award sites are in Experimental Program to Stimulate Competitive Research (EPSCoR) states, one partner institution is a Historically Black College and University (HBCU), and two partner institutions are community colleges. A provisional website for the NNCI sites and community has been established at <http://nnci.net>.

NSF awards to individual sites range from \$500,000 to \$1.60 million per year. Total five-year funding for the NNCI program is \$76.86 million and is provided by all seven NSF directorates, the Office of International Science and Engineering, and the EPSCoR program. In the past, NSF supported the NNIN at a similar total annual funding level.

The individual NNCI award sites have autonomy in their operation and management but will be required to act in concert with the coordinating office. The overall collection of sites and their capabilities provide

users with cost-effective access both to the specialized tools, processes, and expertise for complex multi-step fabrication at the nanoscale level for structures, materials, devices, and systems, as well as to the associated instrumentation for nanoscale characterization, analysis, and probing. The program makes 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 award sites are intended to support a rich user base with broad accessibility and affordable user fee structure. NSF funds leverage those of university and other resources to grow the numbers of external users, including those from companies and academia. Sites embrace a culture of open access to researchers for any research project of merit, with protection of intellectual property, and mechanisms for encouraging non-traditional users from diverse disciplines. They also have an organizational structure that facilitates coordination of complex process steps and tools for integrated tasks and acceptance of experimental risks associated with non-standard processes and materials.

The broad spectrum of domain capabilities in this coordinated program 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.

Nanotechnology facilities provide unique opportunities to infuse innovative education with research at the frontiers of the field. Award sites are providing focused strategies for integrating pioneering 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 have integrated study and dissemination of those aspects into their proposals that can leverage their user community base, which relate to the capabilities of their respective user facilities.

### **Management and Oversight**

- **NSF Structure:** Post-award oversight is performed under the guidance of the NSF lead program officer and directorate working group members to monitor progress of the award and award accomplishments.
- **External Structure:** The coordinating office (CO) is currently being competed through externally reviewed supplemental requests from among the interested awarded sites. 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 establish a comprehensive web portal to ensure close linkage among the individual facility websites to present a unified interface to the user community of overall tools, instruments, and capabilities. The portal will help coordinate and disseminate best practices for national-level education and outreach programs, as well as instruction across sites in social and ethical implications of nanotechnology, including issues related to environment, health, and safety. The CO will harmonize capabilities for modeling and simulation across sites and interaction with NanoHUB of the NSF-supported Network for Computational Nanotechnology (NCN). It will establish uniform methods for assessment and quantifiable metrics of site performance and impact. It will also engage all sites in a planning process to explore emerging areas of nanoscale science, engineering, and technology that can lead to new research opportunities and future growth of the external user base. The CO is expected to be funded at \$700,000 annually.
- **Reviews:** Reviews will be conducted through annual reverse site visits at NSF; on-site reviews, particularly for the larger funded sites, may be held. A Business Systems Review will be held once

within the five-year period of the award. The awardees will submit comprehensive annual project reports to NSF in advance of each annual review. The annual project reports will contain a program plan and budget for the next year's funding increment. Each annual review of a site will focus on the quality of performance and management under the cooperative agreement. Data collection will be consistent with NSF policies for information collection.

**Renewal/Recompetition/Termination**

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

**NATIONAL SUPERCONDUCTING CYCLOTRON LABORATORY**

**\$24,500,000**  
**+\$500,000 / 2.1%**

**National Superconducting Cyclotron Laboratory**

(Dollars in Millions)

FY 2015 Actual	FY 2016 Estimate	FY 2017 Request	Change over FY 2016 Estimate	
			Amount	Percent
\$23.00	\$24.00	\$24.50	\$0.50	2.1%

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. NSCL funding 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 NSCL-conducted research benefit society in numerous areas, including new tools for radiation treatments of cancer patients, assessments of health risks to astronauts, and homeland security. K500 was the first cyclotron to use superconducting magnets, and K1200 is the highest-energy continuous beam accelerator in the world. Through the Coupled Cyclotron Facility (CCF), heavy ions are accelerated by the K500 and then injected into the K1200, enabling the production of rare unstable isotopes at much higher intensities. The laboratory has commissioned an MSU-funded reaccelerator facility (ReA3) that enables experiments at very low energies – a domain of particular interest to nuclear astrophysics. This is the only facility in the world to provide radioactive beams in this energy regime. Two experiments with the ReA3 facility were completed in October 2015.

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 five to ten days.



Graduate students Joshua Bradt and Eric Lunderberg check the diagnostic station on the ReA3 beamline at NSCL. Credit: NSCL.

**Total Obligations for NSCL**

(Dollars in Millions)

	FY 2015	FY 2016	FY 2017	ESTIMATES <sup>1</sup>				
	Actual	Estimate	Request	FY 2018	FY 2019	FY 2020	FY 2021	FY 2022
Operations & Maintenance	\$23.00	\$24.00	\$24.50	\$24.50	\$24.50	\$24.50	\$24.50	\$24.50

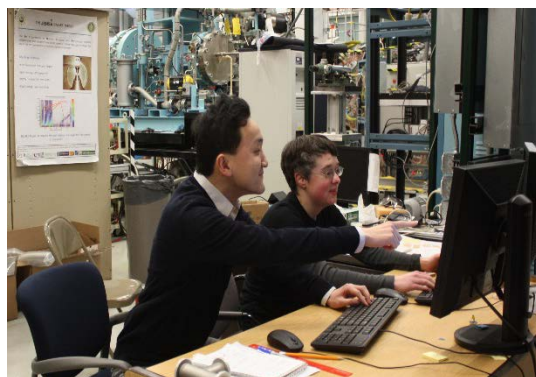
<sup>1</sup> Outyear funding estimates are for planning purposes only. The current cooperative agreement ends in September

**Management and Oversight**

- **NSF Structure:** MSU operates NSCL under a cooperative agreement with NSF. NSF oversight is provided through annual site visits by the cognizant program officer of the NSF Directorate for Mathematical and Physical Sciences, Division of Physics (MPS/PHY) and other staff, accompanied by external experts. The NSF program officer monitors lab operations and plans through monthly phone conferences with the NSCL director. NSF uses the annual site visit reviews to assess the user program, operations, maintenance, facility efficiency, national and international research developments, and in-house research programs.
- **External Structure:** MSU provides additional support. NSCL is managed by a director and three associate directors (for experimental research, education & outreach, and operations) as well as a chief scientist. The director has authority to appoint associate directors and designate responsibilities, notifying NSF of changes. NSCL’s research program is guided by a program advisory committee of external experts as well as an in-house expert and the chairperson of the NSCL user group. Opportunities for proposal submission occur every nine to twelve 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:**
  - In FY 2016, a 5-year review looked at results and achievements related to intellectual merit and broader impacts for FY 2012 – FY 2015 as well as made an in depth review of proposed research, operations, and maintenance funding for FY 2017 – FY 2021.
  - In early FY 2017, an annual review is tentatively planned.

**Renewal/Recompetition/Termination**

MSU has submitted a proposal for a five-year renewal award for the research program and operation of NSCL from FY 2017 through FY 2021. The proposal has been merit reviewed and a new cooperative agreement is under consideration. NSCL will transition to the new Facility for Rare Isotope Beams (FRIB), which is being built by the Department of Energy (DOE) on the NSCL site. FRIB is scheduled to become operational in FY 2022 and will use much of the NSCL beamlines, instrumentation, and general infrastructure. NSF anticipates ending support for the operations component of NSCL when CCF operations cease so that FRIB can be integrated into the NSCL beamlines and become operational. MSU will be the performing institution under a cooperative agreement with DOE for the future FRIB. To facilitate interagency planning and coordinate the transition from the NSF-funded NSCL to the DOE-funded FRIB, a Joint Oversight Group (JOG) of DOE and NSF personnel has been meeting since 2010. DOE and NSF will coordinate 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.



Postdoc Kenjiro Miki and Assistant Professor Ulrike Hager at the JENSA (Jet Experiments in Nuclear Structure and Astrophysics) station. *Credit: NSCL.*

**NATURAL HAZARDS ENGINEERING RESEARCH  
INFRASTRUCTURE**

**\$12,500,000  
\$0 /0.0%**

**Natural Hazards Engineering Research Infrastructure**  
(Dollars in Millions)

FY 2015 Actual	FY 2016 Estimate	FY 2017 Request	Change over FY 2016 Estimate	
			Amount	Percent
\$18.24	\$12.50	\$12.50	-	-

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

Beginning in FY 2016, NHERI will be operated for five years 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. Building upon NEES, 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. Research conducted using NHERI will support the National Earthquake Hazards Reduction Program and the National Windstorm Impact Reduction Program.

NHERI will be established by NSF through up to eleven individual cooperative agreements and will consist of the following four components:

- Network Coordination Office (NCO);
- Cyberinfrastructure (CI) Operations;
- Computational Modeling and Simulation Center (SimCenter); and
- Eight Experimental Facilities (EF), including a new post-disaster, rapid response research facility.

As the outcome of the NSF 14-605 competition, eight awards were made for NHERI in FY 2015:

- Cyberinfrastructure, at the University of Texas at Austin (<http://DesignSafe-Ci.org>)
- Twelve-Fan Wall of Wind, at Florida International University
- Large-Scale, Multi-Directional, Hybrid Simulation Testing Capabilities, at Lehigh University
- Large Wave Flume and Directional Wave Basin, at Oregon State University
- Geotechnical Centrifuges, at the University of California, Davis
- Large, High-Performance Outdoor Shake Table, at the University of California, San Diego
- Boundary Layer Wind Tunnel, Wind Load and Dynamic Flow Simulators, and Pressure Loading Actuators, at the University of Florida, and



- Large, Mobile Dynamic Shakers for Field Testing, at the University of Texas at Austin

In August 2015, NSF issued solicitation NSF 15-598 to compete the final three components of NHERI: the Network Coordination Office, Computational Modeling and Simulation Center, and Post-Disaster, Rapid Response Research Facility. Awards will be completed in spring 2016.

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



The 12-fan Wall of Wind at Florida International University (FIU), one of the NHERI experimental facilities, will enable better engineering against tornadoes, hurricanes, and other windstorms. *Photo Credit: Courtesy of FIU.*

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 a portfolio of computational modeling and simulation software and educational modules that reflects a balance of community-prioritized, new capabilities for earthquake, wind, and multi-hazard engineering research and education. The SimCenter awardee will deliver this portfolio to the CI awardee for integration onto the CI awardee's software service delivery platform.

EF awardees will provide well-maintained and fully functioning facilities, services, and staffing to enable earthquake engineering, wind engineering, and post-disaster, rapid response research requiring experimental work and data collection. Experimental data generated by EF resources and their 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 education programs. The support for such activities primarily will be provided through the existing 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 supports 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.

## Major Multi-User Research Facilities

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 2015	FY 2016	FY 2017	ESTIMATES <sup>1</sup>				
	Actual	Estimate	Request	FY 2018	FY 2019	FY 2020	FY 2021	FY 2022
Operations & Maintenance	\$18.24	\$12.50	\$12.50	\$12.50	\$12.50	\$12.00	\$12.00	\$12.00

<sup>1</sup> 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 provides advice and assistance.
- **External Structure:** Each NHERI awardee is 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.
- **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.<sup>16</sup> One study, a workshop held by the National Research Council on the Grand Challenges in Earthquake Engineering Research, was completed in FY 2011 and the second study was completed in FY 2012. These studies provided input to NSF for the determination of support for future earthquake engineering research infrastructure beyond FY 2014. The plan to support a smaller “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.<sup>17</sup> The plan would result in a lower

<sup>16</sup> <http://nsf.gov/pubs/2010/nsf10071/nsf10071.jsp>

<sup>17</sup> [www.nsf.gov/pubs/2012/nsf12107/nsf12107.jsp](http://www.nsf.gov/pubs/2012/nsf12107/nsf12107.jsp)

annual operations budget, reflected in the \$8.0 million reduction from FY 2014 in the FY 2015 Budget Request, from \$20.0 million to \$12.0 million, and allow additional investments to be made in earthquake engineering research.

- In 2012, the National Institute of Standards and Technology and NSF jointly supported a workshop that led to a roadmap report for measurement science research and development for windstorm and coastal inundation impact reduction, which was published in January 2014.<sup>18</sup>
- 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.
- Based on the above studies and report, NSF established the plan for NHERI in FY 2014. This led to the release of solicitations NSF 14-605 and NSF 15-598 to establish NHERI through two competitions. NHERI operations awards are supported for a five-year period with an option for an additional five years. During this period, the NCO awardee will be responsible, working with the natural hazards engineering research and education community, to develop a five-year NHERI Science Plan. ENG will separately support the development of a post-NHERI decadal science plan for natural hazards engineering research, education, and research infrastructure. NSF will use this decadal science plan as input for natural hazards engineering research infrastructure support beyond 2019.

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<sup>18</sup> [www.nist.gov/customcf/get\\_pdf.cfm?pub\\_id=915541](http://www.nist.gov/customcf/get_pdf.cfm?pub_id=915541)

**OCEAN OBSERVATORIES INITIATIVE****\$50,000,000**  
**-\$5,000,000/ -9.1%****Ocean Observatories Initiative**

(Dollars in Millions)

FY 2015	FY 2016	FY 2017	Change over	
			FY 2016 Estimate	
Actual	Estimate	Request	Amount	Percent
\$55.00	\$55.00	\$50.00	-\$5.00	-9.1%

The Ocean Observatories Initiative (OOI) began in FY 2009 as a Major Research Equipment and Facilities Construction (MREFC) project. In FY 2016, OOI transitioned from the MREFC construction effort to the 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 enables researchers to examine complex, interlinked physical, chemical, biological, and geological processes operating throughout the coastal regions and to investigate a spectrum of phenomena and processes including episodic, short-lived events (meteorological, tectonic, volcanic, geological, geophysical, and ecological), and more subtle, long-term changes and emergent phenomena in ocean systems (circulation patterns, climate change, ocean acidity, geophysical events, and ecosystem trends).

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

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

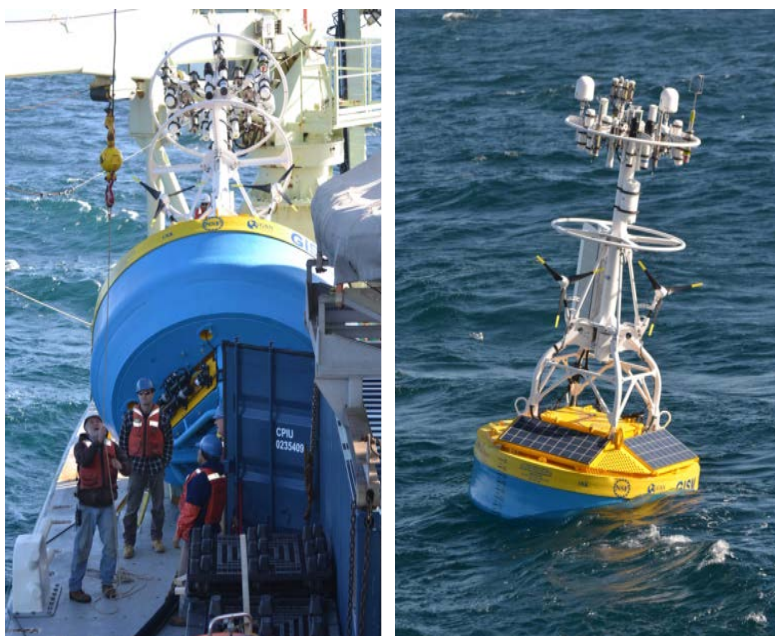
- ***Ocean-Atmosphere Exchange.*** Quantifying the air-sea exchange of energy and mass, especially during high winds, is critical to providing estimates of energy and gas exchange between the surface and deep ocean, and improving the predictive capability of storm forecasting and climate-change models.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

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.

**Current Status**

In FY 2016, the OOI infrastructure is operating, transmitting ocean data to storage, and incrementally delivering processed datasets and data products via the website. Refurbishment and redeployments of the moorings, instruments, and platforms are planned and being executed. Data quality management is maturing and the OOI Science Team is conducting outreach to the science community on the quality assurance/quality control (QA/QC) methods and procedures being used. The OOI Operations and Maintenance (O&M) budget for FY 2017 is \$50.0 million. This funding request includes the costs for all parts, labor, equipment, ship time, and cyberinfrastructure to manage, operate, and maintain the OOI. Deployed Coastal OOI instruments are visited and replaced twice per year. The Cabled and Global instruments are replaced annually. 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.



OOI Global Surface Mooring Deployed in the Irminger Sea. Credit: Allison Heater, Woods Hole Oceanographic Institution.

**Total Obligations for OOI**

(Dollars in Millions)

	FY 2015	FY 2016	FY 2017	ESTIMATES <sup>1</sup>				
	Actual	Estimate	Request	FY 2018	FY 2019	FY 2020	FY 2021	FY 2022
Operations & Maintenance	55.00	55.00	50.00	44.00	44.00	44.00	44.00	44.00

Totals may not add due to rounding.

<sup>1</sup> Outyear funding estimates are for planning purposes only.

## *Major Multi-User Research Facilities*

The Consortium for Ocean Leadership (OL) is the awardee for OOI Operations and Maintenance. OL has major sub-awardees 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 Global Arrays at the four OOI Global sites. Rutgers University manages the OOI data as well as the cyberinfrastructure and Education and Public Outreach. Raytheon Corporation provides project management support, systems engineering, and software services for the OOI cyberinfrastructure.

### **Management and Oversight**

- **NSF Structure:** The Division of Ocean Sciences (OCE) in the Directorate for Geosciences (GEO) manages OOI operations located within the Integrative Programs section. The oversight includes the review of observatory metrics and data quality management, as well as integration of the OOI with any new science or infrastructure proposals.
- **External Structure:** 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 science user workshops in FY 2016 and FY 2017. The OOI Program has a Science Oversight Committee which provides input and guidance to Ocean Leadership for OOI infrastructure planning and management.
- **Reviews:** In 2015, NSF conducted two reviews (March and May) of the construction completion. Annual operations and maintenance reviews will take place in FY 2016 and FY 2017.

### **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 have been and will continue to be supported by OCE, with temporary support from the Division of Integrative and Collaborative Education and Research (ICER) from FY 2015-FY 2017. Support for research utilizing observatory data will be through the standard NSF proposal submission process to existing science programs in OCE, however, because the data is freely available over the internet, researchers around the world will have access to the unique data sets OOI will produce regardless of the source of their support.

### **Education and Outreach**

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

### **Renewal/Recompetition/Termination**

The OOI O&M cooperative agreement with OL ends in FY 2017. A re-competition for the O&M for OOI will be conducted in FY 2016.

**POLAR FACILITIES AND LOGISTICS**

**\$312,070,000**  
**+\$11,000,000 / 3.7%**

**Polar Facilities and Logistics**

(Dollars in Millions)

	FY 2015 Actual	FY 2016 Estimate	FY 2017 Request	Change over FY 2016 Estimate	
				Amount	Percent
Polar Facilities	\$193.93	\$194.14	\$202.14	\$8.00	4.1%
Polar Logistics	124.30	106.93	109.93	3.00	2.8%
<b>Total, Polar Facilities and Logistics</b>	<b>\$318.23</b>	<b>\$301.07</b>	<b>\$312.07</b>	<b>\$11.00</b>	<b>3.7%</b>

Totals may not add due to rounding.

New mandatory funding (\$11.0 million) will support one-time investments to enhance infrastructure.

**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 NSF and by U.S. mission agencies, for year-round work at three U.S. stations, on two research ships, and at a variety of remote field camps. Support to other agencies includes mission-essential satellite communications support at McMurdo Station for the Joint Polar Satellite System (JPSS), and the National Aeronautics and Space Administration’s (NASA) Ground Networks for the relay of data. Through a partnership with the National Oceanic and Atmospheric Administration (NOAA), NASA, and the European Organization for the Exploitation of Meteorological Satellites (EUMETSAT), PLR supports the 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 South Pole Remote Earth Science and Seismological Observatory (SPRESSO), the most seismically-quiet station on earth and a key site contributing to U.S. activities associated with the Comprehensive Test Ban Treaty and to U.S. Geological Survey (USGS) and NSF efforts for global seismic monitoring; and access to sites that are key to precise orbit determinations for optimizing use of the Global Navigation Satellite System (GNSS).

All support for these activities is provided by 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 2015 Actual	FY 2016 Estimate	FY 2017 Request	ESTIMATES <sup>1</sup>				
				FY 2018	FY 2019	FY 2020	FY 2021	FY 2022
Antarctic Infrastructure and Logistics	\$193.93	\$194.14	\$202.14	\$194.14	\$194.14	\$194.14	\$194.14	\$194.14
<b>Total, Polar Facilities</b>	<b>\$193.93</b>	<b>\$194.14</b>	<b>\$202.14</b>	<b>\$194.14</b>	<b>\$194.14</b>	<b>\$194.14</b>	<b>\$194.14</b>	<b>\$194.14</b>

Totals may not add due to rounding.

<sup>1</sup> 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* has returned to service and 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.<sup>19</sup> The NSF response to the USAP BRP report was released in March 2013.<sup>20</sup>



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

### **Current Status**

- All facilities (stations, research vessels, and field camps) are currently operating normally.
- The USAP BRP report concluded that ushering in a new age of Antarctic science simply by expanding traditional methods of logistical support would be prohibitively costly. Instead, it recommended numerous ways to more efficiently and cost-effectively support research while maintaining high standards of safety and increasing the flexibility to support evolving science foci in the future. Continued progress is planned to implement BRP recommendations, including investment in prioritized lifecycle acquisitions. Priority will also be given to site work that would be needed to support implementation of the Antarctic Infrastructure Modernization for Science (AIMS) project, currently in the early stages of design. While overall project scope is still being refined, the AIMS project is preparing plans for redevelopment of McMurdo Station to be a smaller, more efficient facility. Also in

<sup>19</sup> [www.nsf.gov/od/opp/usap\\_special\\_review/usap\\_brp/rpt/index.jsp](http://www.nsf.gov/od/opp/usap_special_review/usap_brp/rpt/index.jsp)

<sup>20</sup> [www.nsf.gov/od/opp/usap\\_special\\_review/usap\\_brp/rpt/nsf\\_brp\\_response.pdf](http://www.nsf.gov/od/opp/usap_special_review/usap_brp/rpt/nsf_brp_response.pdf)



planning stages are replacing major logistic facilities concerning the airplane runway and vessel operations; upgrading facilities for fuel containment, utilities distribution, and fire protection; upgrading satellite communications systems to support operations and research; and possible replacement of the Palmer Station pier to ensure long-term access to unique research in the peninsula region. 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.
- Contracts for fixed and rotary wing support are managed as assisted acquisitions by the Department of Interior, Office of Aviation Services. A five-year contract for helicopter support was awarded to PHI, Inc. of Lafayette, Louisiana, in May 2013. The current five-year contract for fixed-wing aviation services, currently held by Kenn Borek Air of Calgary, Canada, is up for renewal and will be re-competed in the spring of 2016.
- 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 2015 Actual	FY 2016 Estimate	FY 2017 Request	ESTIMATES <sup>1</sup>				
				FY 2018	FY 2019	FY 2020	FY 2021	FY 2022
U.S. Antarctic Logistical Support	\$67.52	\$67.52	\$67.52	\$67.52	\$67.52	\$67.52	\$67.52	\$67.52
Arctic Research Support and Logistics	56.78	39.41	42.41	39.41	39.41	39.41	39.41	39.41
<b>Total, Polar Logistics</b>	<b>\$124.30</b>	<b>\$106.93</b>	<b>\$109.93</b>	<b>\$106.93</b>	<b>\$106.93</b>	<b>\$106.93</b>	<b>\$106.93</b>	<b>\$106.93</b>

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;

## *Major Multi-User Research Facilities*

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**

**\$26,950,000**  
**+\$2,600,000 / 10.7%**

**Seismological Facilities for the Advancement of Geoscience and EarthScope**

(Dollars in Millions)

FY 2015	FY 2016	FY 2017	Change over	
			FY 2016 Estimate	
Actual	Estimate	Request	Amount	Percent
\$24.35	\$24.35	\$26.95	\$2.60	10.7%

New mandatory funding (\$2.60 million) will support one-time investments to enhance infrastructure at this facility.

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, 21 educational affiliates, three U.S. affiliates, and 128 foreign affiliates. SAGE was formed in late FY 2013 from part of the EarthScope program and the IRIS facility. The FY 2017 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 2015	FY 2016	FY 2017	ESTIMATES <sup>1</sup>					
				Actual	Estimate	Request	FY 2018	FY 2019	FY 2020
Operations & Maintenance	\$24.35	\$24.35	\$26.95	\$24.35	\$24.35	\$24.35	\$24.35	\$24.35	\$24.35

Totals may not add due to rounding.

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

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

**Instrumentation Services**

- The Global Seismographic Network (GSN) consists of over 150 permanently-installed broadband digital seismic stations, most of which have real-time data access. GSN is operated in partnership with the U.S. Geological Survey (USGS).
- Portable Seismology (PS) includes a pool of over 5,200 portable seismometers that are made available to the earth science research community for a wide range of principal investigator-driven experiments largely funded through the NSF merit review process.
- Polar Support Services (PSS) supports the development of specialized seismic equipment for use in harsh environments and provides instrumentation, training, and field support for experiments in the polar regions. 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

## *Major Multi-User Research Facilities*

foundation for multi-scale integrated studies of continental lithosphere and deep Earth structure. Over 1,700 TA stations operated across the lower 48 states and southern Ontario and Quebec, Canada, between 2004 and 2015; TA is now being deployed to Alaska and western Canada.

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

### **Data Services**

- SAGE Data Services (DS) manages an archive of over 350 terabytes of seismic, magnetotelluric, and other data from all SAGE components, the EarthScope program, and numerous affiliated networks; operates automated and manual systems to ensure the quality of all data stored in the archive; and provides systems to give the national and international research community timely access to these data. In the last quarter of FY 2015, nearly 20,000 unique users downloaded over 100 TB of data from the SAGE archive.

### **Education and Public Outreach**

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

### **Special Emphasis Areas**

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

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

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

The EarthScope, Geophysics, GeoPRISMS, and Tectonics Programs in the Division of Earth Sciences (EAR); the GeoPRISMS and Marine Geology and Geophysics Programs in the Division of Ocean Sciences (OCE); and the Geology and Geophysics Program and the Glaciology Program in the Antarctic Research

Section of 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 DS to solve major Earth science problems.

### **Management and Oversight**

- NSF Structure: 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. In FY 2015, the GSN underwent external review by an international committee, which concluded in part that "...continued federal funding of the GSN and broad community participation are essential to the future of basic and applied seismological research and the use of this research in support of agency missions."

### **Renewal/Recompetition/Termination**

Funding for the current cooperative agreement for SAGE began in FY 2014 and ends in FY 2018. In FY 2016, in keeping with the phased integration and recompetition plan presented to and concurred with by the National Science Board in December 2009, NSF 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 Geodesy Advancing 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**

**\$101,000,000**  
**+\$1,300,000 / 1.3%**

**National Center for Atmospheric Research**

(Dollars in Millions)

FY 2015	FY 2016	FY 2017	Change over	
			FY 2016 Estimate	
Actual	Estimate	Request	Amount	Percent
\$98.70	\$99.70	\$101.00	\$1.30	1.3%

New mandatory funding (\$1.30 million) will support one-time investments to enhance infrastructure at this facility.

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 2015, NCAR supported a total of 751.1 full time equivalents (FTEs), of which 326.8 are funded under the NSF primary award to UCAR.

**Number of FTEs Supported at NCAR**

FTEs	Primary Award <sup>1</sup>	All Funding
Career Scientists	75.3	107.7
Scientific Support <sup>2</sup>	222.3	511.2
Other Staff <sup>3</sup>	29.2	132.2
<b>Total</b>	<b>326.8</b>	<b>751.1</b>

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

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

<sup>3</sup> Other Staff includes administrative positions, managers, paid visitors, pilots, and 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 2015	FY 2016	FY 2017	ESTIMATES <sup>1</sup>				
	Actual	Estimate	Request	FY 2018	FY 2019	FY 2020	FY 2021	FY 2022
Aircraft Support	\$9.31	\$9.40	\$9.52	\$9.40	\$9.40	\$9.40	\$9.40	\$9.40
Computational Infrastructure	28.21	28.50	28.87	28.50	28.50	28.50	28.50	28.50
Other Facility Support	20.22	20.42	20.69	20.42	20.42	20.42	20.42	20.42
Research & Education Support	40.96	41.38	41.92	41.38	41.38	41.38	41.38	41.38
<b>Total, NCAR</b>	<b>\$98.70</b>	<b>\$99.70</b>	<b>\$101.00</b>	<b>\$99.70</b>	<b>\$99.70</b>	<b>\$99.70</b>	<b>\$99.70</b>	<b>\$99.70</b>

Totals may not add due to rounding.

<sup>1</sup> 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 2015, NCAR received approximately \$38.88 million in support from other federal agencies, including the National Oceanic and Atmospheric Administration (NOAA), the Department of Energy (DOE), and the Federal Aviation Administration (FAA), and \$17.74 million from non-federal sources.

Major Investments in FY 2017: In FY 2017, 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.

## Major Multi-User Research Facilities

**Research and Education Support:** Total funding for research and education support at NCAR is estimated to be \$41.92 million in FY 2017. 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 atmospheric composition, weather, and climate, 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.

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



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

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,<sup>21</sup> 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 (DACs), provide oversight of NCAR and the cooperative agreement with 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 effective implementation of the NCAR strategic mission to the benefit of the atmospheric and geospace

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<sup>21</sup> [www.spark.ucar.edu](http://www.spark.ucar.edu)



research community. In addition, other research sponsors, such as NOAA, the National Aeronautics and Space Administration (NASA), 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 periodically to evaluate AGS oversight of NCAR. The most recent COV was conducted in FY 2015 with the next anticipated in FY 2019. A Business Systems Review was conducted in FY 2011, and the next review will take place in FY 2016. No significant issues were raised in either of the most recent reviews.

**Renewal/Recompetition/Termination**

Based on a thorough review of NCAR's performance as a center and UCAR's management of NCAR undertaken in 2011, UCAR was awarded a new cooperative agreement to manage NCAR for the five-year period FY 2014-2018. It is anticipated that the cooperative agreement for management of NCAR will be recompleted prior to the next award period, beginning in FY 2019.

**NATIONAL OPTICAL ASTRONOMY OBSERVATORY**

**\$21,830,000**  
**+\$230,000 / 1.1%**

**National Optical Astronomy Observatory**

(Dollars in Millions)

FY 2015	FY 2016	FY 2017	Change over	
			FY 2016 Estimate	
Actual	Estimate	Request	Amount	Percent
\$25.50	\$21.60	\$21.83	\$0.23	1.1%

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 ground-based optical and infrared (OIR) astronomy to coordinate/integrate/operate observational, technical, and data-oriented capabilities available throughout the U.S. OIR system of federal and non-federal assets.

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

NOAO facilities, telescopes, and data systems, are open to all qualified astronomers regardless of institutional affiliation. They serve nearly 1,200 U.S. and foreign scientists annually. Doctoral dissertation students and non-thesis graduate students from U.S. institutions use NOAO facilities for research projects. In FY 2015 NOAO employed 300 personnel in Arizona and Chile, including 45 support scientists and 10 postdoctoral fellows.

The Division of Astronomical Sciences in the Directorate for Mathematical and Physical Sciences (MPS/AST) conducted a community-based review of its portfolio in 2011-2012. The resulting Portfolio Review Committee (PRC) report, *Advancing Astronomy in the Coming Decade: Opportunities and Challenges*<sup>22</sup> was released in August 2012 and included recommendations about all of the major AST telescope facilities.

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

<sup>22</sup> [www.nsf.gov/mps/ast/ast\\_portfolio\\_review.jsp](http://www.nsf.gov/mps/ast/ast_portfolio_review.jsp)

As of October 1, 2015, the PRC recommendations have been implemented. The 2.1-meter telescope has a new operator, the California Institute of Technology, for a research program on cosmic transient phenomena. Starting in FY 2016, the NOAO base operations and maintenance budget excludes NSF funding for the Mayall and WIYN telescopes. 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 2015	FY 2016	FY 2017	ESTIMATES <sup>1</sup>				
	Actual	Estimate	Request	FY 2018	FY 2019	FY 2020	FY 2021	FY 2022
NOAO Base O&M	\$20.00	\$17.50	\$18.03	\$18.57	\$19.12	\$19.70	\$20.29	\$20.90
<i>Tucson Operations</i>	<i>10.50</i>	<i>8.50</i>	<i>8.76</i>	<i>9.02</i>	<i>9.29</i>	<i>9.57</i>	<i>9.85</i>	<i>10.15</i>
<i>Chilean Operations</i>	<i>8.00</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>9.55</i>
<i>Kitt Peak Operations</i>	<i>1.50</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>	<i>1.19</i>
Special Projects: WIYN and Mayall	5.50	4.10	3.80	2.10	1.00	1.00	1.00	1.00
<b>Total, NOAO</b>	<b>\$25.50</b>	<b>\$21.60</b>	<b>\$21.83</b>	<b>\$20.67</b>	<b>\$20.12</b>	<b>\$20.70</b>	<b>\$21.29</b>	<b>\$21.90</b>

Totals may not add due to rounding.

<sup>1</sup> Outyear funding estimates are for planning purposes only. The current cooperative agreement ends in September 2020.

Partnerships and Other Funding Sources: The managing organization for NOAO is the Association of Universities for Research in Astronomy, Inc. (AURA), which is comprised of 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. 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.nao.edu](http://www.nao.edu).

NOAO Base O&M: \$18.03 million, \$530,000 above the FY 2016 Estimate.

Tucson Operations: \$8.76 million, \$260,000 above the FY 2016 Estimate: Tucson operations covers the headquarters, offices, laboratories, and workshops in Tucson, Arizona.

## *Major Multi-User Research Facilities*

Chilean Operations: \$8.24 million, \$240,000 above the FY 2016 Estimate: This supports administration and labs in La Serena, Chile and mountain operations on Cerro Tololo and Cerro Pachón.

Kitt Peak Operations: \$1.03 million, \$30,000 above FY 2016 Estimate: 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): \$3.80 million, \$300,000 below the FY 2016 Estimate.

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

Mayall Telescope: \$2.80 million, \$300,000 below the FY 2016 Estimate: The decrease from FY 2016 is balanced by an equivalent increase in DOE support for the telescope. DOE identified the Mayall telescope as the preferred platform for the Dark Energy Spectroscopic Instrument (DESI) to carry out a dark energy science survey sponsored by DOE. For FY 2016 through FY 2018, the Mayall telescope will be in transition in preparation for DESI installation. During the transition period, funding from NSF will decrease while support from DOE will increase to the point where DOE is expected to assume full operations costs starting in FY 2019.

### **Management and Oversight**

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

### **Renewal/Recompetition/Termination**

In FY 2013 NSF began the process of competing the award for the management and operation of NOAO. The competition was completed with the issuance of a new cooperative agreement with AURA starting October 1, 2015 and ending in FY 2020.

**NATIONAL RADIO ASTRONOMY OBSERVATORY**

**\$75,250,000**  
**-\$6,830,000 / -8.3%**

**National Radio Astronomy Observatory**

(Dollars in Millions)

FY 2015 Actual	FY 2016 Estimate	FY 2017 Request <sup>1</sup>	Change over FY 2016 Estimate	
			Amount	Percent
\$83.31	\$82.08	\$75.25	-\$6.83	-8.3%

<sup>1</sup> The funding decrease in FY 2017 is due to the separation of the Green Bank Observatory (GBO) and the Very Long Baseline Array (VLBA) from the new NRAO cooperative agreement, expected to begin in early FY 2017. The FY 2017 Request for GBO and VLBA is presented in the Other Astronomical Facilities narrative.

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

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

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*,<sup>23</sup> 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*,<sup>24</sup> 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 VLA. Two other telescopes, the Robert C. Byrd Green Bank Telescope (GBT) and the Very Long Baseline

<sup>23</sup> [www.nap.edu/catalog.php?record\\_id=12951](http://www.nap.edu/catalog.php?record_id=12951)

<sup>24</sup> [www.nsf.gov/mps/ast/ast\\_portfolio\\_review.jsp](http://www.nsf.gov/mps/ast/ast_portfolio_review.jsp)

## Major Multi-User Research Facilities

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 Green Bank Observatory (GBO) (comprising GBT and the Green Bank site and facilities) and VLBA were partitioned from the NRAO management competition to facilitate other unconstrained partnership discussions separate from the open management competition. In FY 2014 and FY 2015, AST continued these other partnership discussions, and NSF brought a general engineering contractor on-board for all its engineering and environmental reviews. In FY 2016, that contractor is producing feasibility reports for divestment alternatives, which will provide the results of baseline structural and environmental surveys of the GBO and VLBA. Should viable options be identified and the decision made to divest, NSF will embark on formal reviews (in FY 2016 and FY 2017) to evaluate environmental impacts of these alternatives, including potential impacts of partnership opportunities.

Including the ALMA operations staff located at NRAO, staff in FY 2017 will consist of 337 full-time equivalent positions (FTEs) in the operations and maintenance components: 153 in telescope operations, 26 in science support and research, 43 in development programs, 62 in computing and data management, 32 in administrative services, and 22 in the director's office. These numbers exclude staff at the partitioned GBT and VLBA telescopes which will be managed and operated separately from NRAO. In addition, the NRAO managing organization, Associated Universities, Inc. (AUI), employs local ALMA operations staff in Chile, currently consisting of approximately 220 FTEs.

### Total Obligations for NRAO

(Dollars in Millions)

	FY 2015	FY 2016	FY 2017	ESTIMATES <sup>1</sup>				
	Actual	Estimate	Request	FY 2018	FY 2019	FY 2020	FY 2021	FY 2022
Operations & Maintenance <sup>2</sup>	\$43.14	\$41.73	\$32.00	\$32.96	\$33.95	\$34.97	\$36.02	\$37.10
<i>Telescope Operations</i>	17.63	17.07	12.53	12.91	13.29	13.69	14.10	14.53
<i>Development</i>	2.73	2.60	1.73	1.78	1.84	1.89	1.95	2.01
<i>Science Operations</i>	5.37	5.16	5.27	5.43	5.59	5.76	5.93	6.11
<i>Administrative Services</i>	13.99	13.59	9.92	10.21	10.52	10.84	11.17	11.49
<i>Directors Office</i>	3.42	3.31	2.55	2.63	2.71	2.79	2.87	2.96
ALMA Operations	40.17	40.35	43.25	44.55	45.88	47.26	48.68	50.14
<b>Total, NRAO</b>	<b>\$83.31</b>	<b>\$82.08</b>	<b>\$75.25</b>	<b>\$77.51</b>	<b>\$79.83</b>	<b>\$82.23</b>	<b>\$84.70</b>	<b>\$87.24</b>

Totals may not add due to rounding.

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

<sup>2</sup> The funding decrease, starting in FY 2017, is due to the separation of the Green Bank Observatory (GBO) and the Very Long Baseline Array (VLBA) from the new NRAO cooperative agreement, expected to begin in early FY 2017. The FY 2017 Request for GBO and VLBA is presented in the Other Astronomical Facilities narrative.

The FY 2017 Request for NRAO is below the FY 2016 Estimate due to the partitioning of GBO and VLBA. GBO and VLBA are presented in the "Other Astronomical Facilities" narrative in the Facilities chapter of this document.

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 2015, NRAO received approximately \$280,000 from non-AST sources at NSF, \$1.42 million from other federal agencies, and \$3.33 million from U.S. universities, foreign scientific and technical institutes, and other non-federal and industrial sources. The development of new telescopes, instrumentation, and sensor techniques is conducted in partnership with relevant industries through competitive sub-awards to various large and small aerospace companies, radio antenna manufacturing firms, and specialized electronics and computer hardware and software

companies.

Education and Public Outreach: NRAO supports a comprehensive outreach program that makes information about radio astronomy available to the public.<sup>25</sup> With over 150 students involved per year, NRAO facilities are used by graduate students carrying out dissertation research and work experience programs and by undergraduate students participating in the Research Experiences for Undergraduates (REU) program. NRAO also supports a visitor and education center and conducts active educational and public outreach programs. The VLA visitor center attracts over 20,000 public visitors each year.

Telescope operations, \$12.53 million: This encompasses support for direct telescope and array operations of the VLA including maintenance, infrastructure upgrades, and telescope management.

Development, \$1.73 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, \$5.27 million: This area includes telescope time allocation, staff research, science training and education, and science community outreach.

Administrative services, \$9.92 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, \$2.55 million: This includes support for the Director's office, news and public information, and managing organization costs.

ALMA Operations, \$43.25 million: In FY 2015, NRAO completed construction of the international ALMA Observatory, funded through the Major Research Equipment and Facilities Construction (MREFC) account. Early operations funding for ALMA began in FY 2005 and ramps up to full operations on FY 2017. Operations funding supports a share of observatory operations in Chile, a technical development program, and the North American ALMA Science Center (NAASC). NRAO created the NAASC in 2006 to provide technical and scientific support for, and easy access by, the broad astronomical community that uses ALMA. The NAASC also organizes summer schools, workshops, and courses in techniques of millimeter and submillimeter astronomy.

### **Management and Oversight**

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

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<sup>25</sup> <https://public.nrao.edu/>

## *Major Multi-User Research Facilities*

director. An international ALMA review committee advises the ALMA Board.

- Reviews: NSF conducts annual reviews of the NRAO Program Operating Plan and strategic planning documents, ALMA operations, and the AUI Management Report. A Business Systems Review was conducted in FY 2012.

### **Renewal/Recompetition/Termination**

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



The Atacama Large Millimeter/submillimeter Array (ALMA) is in science operations following the completion of construction in 2015. 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.*



**NATIONAL SOLAR OBSERVATORY**

**\$20,000,000**  
**+\$1,500,000 / 8.1%**

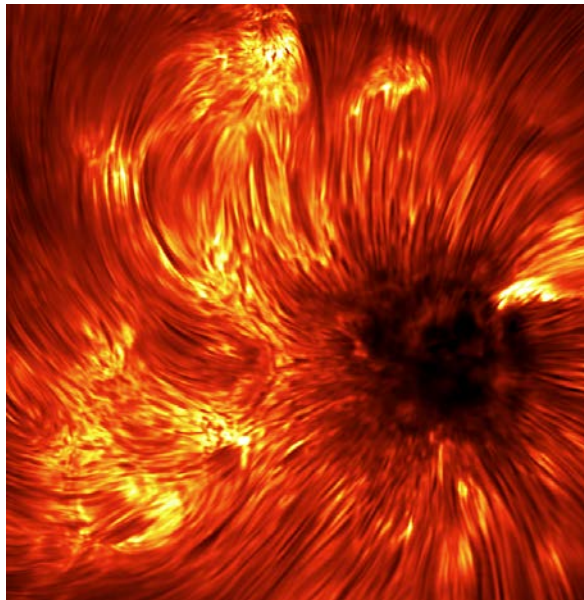
**National Solar Observatory**

(Dollars in Millions)

FY 2015	FY 2016	FY 2017	Change over	
			FY 2016 Estimate	
Actual	Estimate	Request	Amount	Percent
\$13.00	\$18.50	\$20.00	\$1.50	8.1%

The FY 2017 Budget Request for the National Solar Observatory (NSO) is \$20.0 million. This is a \$1.50 million (8.1 percent) increase above the FY 2016 Estimate and includes a one-time request to partially fund a Remote Operations Building (ROB) for the Daniel K. Inouye Solar Telescope (DKIST), should an ongoing environmental review process select this alternative. 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 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.

As a Federally Funded Research and Development Center (FFRDC), NSO currently operates facilities in New Mexico and Arizona as well as a coordinated worldwide network of six telescopes specifically designed to study solar oscillations. NSO also provides leadership to the solar community through management of the construction of DKIST. (See the Major Research Equipment and Facilities Construction (MREFC) chapter for more information.) NSO makes 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 chromospheric emission above a sunspot as traced by the Ca II line at 854.2 nm. Image taken with the IBIS instrument on the Dunn Solar Telescope. Credit: K. Reardon, NSO.

NSO telescopes are open to all astronomers regardless of institutional affiliation based on peer-reviewed observing proposals. In FY 2015, 57 unique observing programs from 17 U.S. and 13 foreign institutions were carried out using NSO facilities. Students were involved in 21 percent of these programs, which included five Ph.D. thesis projects. Nearly 18 terabytes of NSO synoptic data were downloaded from the NSO Digital Library, with approximately 37 percent of downloads coming from U.S. science institutions (.gov, .edu, and .mil), nine percent from other U.S. sources (.com, .net, etc.), and the remaining 54 percent of downloads coming from international sources. NSO employed approximately 120 staff members in FY 2015, including 65 FTEs employed on the DKIST construction project funded via the MREFC account as mentioned above.

In 2010, the National Research Council (NRC) conducted its sixth decadal survey in astronomy and astrophysics. In their report, *New Worlds, New*

*Horizons in Astronomy and Astrophysics*,<sup>26</sup> 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 within the Directorate for Mathematical and Physical Sciences (MPS/AST) conducted a community-based review of its portfolio. The resulting Portfolio Review Committee (PRC) report, *Advancing Astronomy in the Coming Decade: Opportunities and Challenges*,<sup>27</sup> 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 NSF as part of the NSO request. A university-based consortium is seeking to support continued operations of the McMath-Pierce at a minimum level beyond FY 2017; however, this consortium has yet to secure the funding necessary to take over operations of the telescope. Active partnership discussions are also under way for continued operations of the DST located at NSO’s Sacramento Peak facility. A consortium led by New Mexico State University has shown interest in taking over limited operations of the facility, and NSF is actively working with the consortium in this partnership.

In FY 2014, the NSF contracted with a general engineering firm to produce divestment 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 studies will serve to inform 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. NSF expects the engineering study to be completed early in calendar year 2016. After viable options are identified, NSF will embark on formal reviews (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 2015 Actual	FY 2016 Estimate	FY 2017 Request	ESTIMATES <sup>1</sup>				
				FY 2018	FY 2019	FY 2020	FY 2021	FY 2022
NSO Base Operations	\$7.78	\$6.75	\$5.74	\$4.73	\$3.70	\$3.82	\$3.92	\$4.04
NSO Education & Public Outreach	0.22	0.25	0.26	0.27	0.30	0.31	0.32	0.33
DKIST Operations <sup>2</sup>	5.00	9.00	14.00	14.00	16.50	17.01	17.54	18.08
GONG Refurbishment	-	2.50	-	-	-	-	-	-
<b>Total, NSO</b>	<b>\$13.00</b>	<b>\$18.50</b>	<b>\$20.00</b>	<b>\$19.00</b>	<b>\$20.50</b>	<b>\$21.14</b>	<b>\$21.78</b>	<b>\$22.45</b>

Totals may not add due to rounding.

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

<sup>2</sup> Total Research and Related Activities account funding for DKIST consists of \$14.0 million in FY 2017 funded through NSO, plus \$2.0 million per year in FY 2011 to FY 2020 for cultural mitigation activities as agreed to during the compliance process that is not funded through NSO. See the MREFC chapter for more information on DKIST.

<sup>26</sup> [www.nap.edu/catalog.php?record\\_id=12951](http://www.nap.edu/catalog.php?record_id=12951)

<sup>27</sup> [www.nsf.gov/mps/ast/ast\\_portfolio\\_review.jsp](http://www.nsf.gov/mps/ast/ast_portfolio_review.jsp)

Partnerships and Other Funding Sources: The managing organization for NSO is the Association of Universities for Research in Astronomy, Inc. (AURA), which comprises 39 U.S. member institutions and seven international affiliate members. NSO partners include the U.S. Air Force, the National Oceanic and Atmospheric Administration (NOAA), the National Aeronautics and Space Administration (NASA), and industrial entities. Other funding entities include universities and institutes, which collaborate with NSO on solar instrumentation development and on the design and development of DKIST. New telescopes, instrumentation, and sensor techniques are developed through industry sub-awardees in aerospace, optical fabrication, and information technology.

Previously, the Air Force was the most significant source of external funding to NSO; however, with NSO's involvement in the Sacramento Peak facility winding down and the relocation of personnel to Boulder, CO, Air Force support for NSO operations has been reduced to zero for FY 2016 and into the foreseeable future. In addition, the Air Force Weather Agency (AFWA), which was previously a supporter of the NSO's Global Oscillations Network Group (GONG) facility, is no longer contributing to the funding of GONG operations. Due to the increasing national and international awareness of the impacts of space weather on critical infrastructure and society in general, the importance of operational space weather forecasting has become apparent to U.S. policy makers. This importance was highlighted by the recent (October 29, 2015) rollout of the National Space Weather Strategy<sup>28</sup> and the associated National Space Weather Action Plan.<sup>29</sup> 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 AFWA and the NOAA Space Weather Prediction Center (SWPC). The FY 2016 plan for NSO includes a one-time \$2.50 million investment in GONG to increase its robustness for future space weather predictions.

NSO Base Operations, \$5.74 million, \$1.01 million below the FY 2016 Estimate: 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, the NSO Directorate recently relocated to the campus of the University of Colorado in Boulder. Boulder has become a national center of solar and space physics. This relocation places 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 NSO Directorate activities as well as the NSO synoptic program operations at a steady level of about \$4.0 million (\$2.0 million each) per year.

DKIST Operations, \$14.0 million, \$5.0 million above the FY 2016 Estimate: Support for DKIST operations is through the Research and Related Activities account (R&RA), while DKIST construction support is through the MREFC account. (See the MREFC chapter for more information on construction.) The FY 2017 Request for DKIST Operations represents the third 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, which is expected to begin in 2019.

The Request also includes \$2.50 million above previous forecasts for partial funding of a DKIST Remote Operations Building (ROB); the remainder of the approximately \$6.20 million required for the ROB will be recovered from reduced lease costs in FY 2017 and from deferring data-center hardware purchases until later in the operations development. The need for an operations facility located on Maui was identified in the early stages of DKIST development. The ROB would act as an extension of the NSO Data Center in

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<sup>28</sup> [www.whitehouse.gov/sites/default/files/microsites/ostp/final\\_nationalspaceweatherstrategy\\_20151028.pdf](http://www.whitehouse.gov/sites/default/files/microsites/ostp/final_nationalspaceweatherstrategy_20151028.pdf)

<sup>29</sup> [www.whitehouse.gov/sites/default/files/microsites/ostp/final\\_nationalspaceweatheractionplan\\_20151028.pdf](http://www.whitehouse.gov/sites/default/files/microsites/ostp/final_nationalspaceweatheractionplan_20151028.pdf)

## *Major Multi-User Research Facilities*

Boulder, CO whereby the ROB receives, buffers, and transmits the estimated 12 terabytes per day gathered by the DKIST facility and will serve as a base of operations for NSO personnel. In FY 2015, AURA demonstrated to NSF that construction of a dedicated ROB would result in significant savings to the Federal government as compared to leasing space over the planned 45-year lifetime of DKIST. Should an ongoing environmental review process select the ROB alternative, it would result in reduced total operations costs by eliminating out-year lease payments.

Education and Public Outreach, \$260,000, \$10,000 above the FY 2016 Estimate: 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](http://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 uses visiting and users committees for the purposes of self-evaluation and prioritization. The visiting committee, composed of nationally prominent individuals in science, management, and broadening participation, reviews for AURA all aspects of the management and operations of NSO. The users committee, composed of scientists with considerable experience with the observatory, reviews for the NSO director all aspects of NSO that affect user experiences at the observatory.
- **Reviews:** In addition to reviews held mid-way through all cooperative agreements, NSF conducts periodic and ad hoc reviews, as needed, by external committees. 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 for management and operations (see below).

### **Renewal/Recompetition/Termination**

On August 14, 2014, the National Science Board (NSB) authorized a renewed cooperative agreement with AURA for management and operation of NSO for a period of 10 years from October 1, 2014 through September 30, 2024. Concurrent with the NSB approval process, the AURA proposal for NSO management and operations underwent an extensive budgetary review by personnel from NSF, which lasted from March 2014 through May 2015. This extended period of the review required the extension of the existing cooperative agreement through May 31, 2015. Upon completion of the review, the renewed cooperative agreement between the NSF and AURA was put into place June 1, 2015.

**OTHER ASTRONOMICAL FACILITIES**

**\$11,500,000**  
**+\$11,500,000 / NA%**

**Other Astronomical Facilities**

(Dollars in Millions)

FY 2015 Actual	FY 2016 Estimate	FY 2017 <sup>1</sup> Request	Change over	
			FY 2016 Estimate Amount	Percent
-	-	\$11.50	\$11.50	N/A

<sup>1</sup> Beginning in October 2016, funding for these facilities as stand-alone entities will be provided separately from National Radio Astronomy Observatory (NRAO) funding.

Prior to FY 2017, the National Radio Astronomy Observatory (NRAO) operated major radio telescopes at the Green Bank Observatory (GBO) in Green Bank, West Virginia, including the Robert C. Byrd Green Bank Telescope (GBT), and at 10 telescope array sites spanning the U.S. from the Virgin Islands to Hawaii, together constituting the Very Long Baseline Array (VLBA). This narrative presents the FY 2017 Budget Request for GBO and VLBA.

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*,<sup>30</sup> the NRC committee recommended that “NSF-Astronomy should complete its next senior review before the mid-decade independent review that is recommended in this report, so as to determine which, if any, facilities NSF-AST should cease to support in order to release funds for (1) the construction and ongoing operation of new telescopes and instruments and (2) the science analysis needed to capitalize on the results from existing and future facilities.” In response to this recommendation, the Division of Astronomical Sciences (AST) in the Directorate for Mathematical and Physical Sciences (MPS) conducted a community-based review of its portfolio. The resulting Portfolio Review Committee (PRC) report, *Advancing Astronomy in the Coming Decade: Opportunities and Challenges*,<sup>31</sup> was released in August 2012 and included recommendations about all of the major AST telescope facilities.

In 2012, the Portfolio Review Committee recommended divestment of the GBT and VLBA from AST funding because of a less compelling mapping than other facilities onto the science questions of the 2010 decadal survey. As announced in a Dear Colleague Letter, NSF 13-074,<sup>32</sup> NSF partitioned GBT and VLBA from the competition for NRAO management and operations, increasing flexibility for exploring cost-efficient operational models and sustainable partnerships for GBO (comprising GBT and the Green Bank site and facilities) and VLBA. Existing partnerships are described below, and additional partner discussions with governmental and non-governmental entities are ongoing. In FY 2016, an engineering firm is producing feasibility reports for divestment alternatives of both GBO and VLBA; these reports include baseline structural and environmental surveys of GBO and VLBA. Should viable options be identified and the decision made to divest, NSF will embark on formal reviews (in FY 2016 and FY 2017) to evaluate environmental impacts of these alternatives, including potential impacts of partnership opportunities.

In FY 2016, AST anticipates receiving a proposal from Associated Universities, Inc. (AUI) to continue management and operation of GBO and VLBA in FY 2017 and FY 2018, separate from the management and operation of NRAO. Previously, the obligations for GBO and VLBA were heavily matrixed and not separable from the overall obligation for NRAO. Hence, NSF funding for GBO and VLBA in years prior

<sup>30</sup> [www.nap.edu/catalog.php?record\\_id=12951](http://www.nap.edu/catalog.php?record_id=12951)

<sup>31</sup> [www.nsf.gov/mps/ast/ast\\_portfolio\\_review.jsp](http://www.nsf.gov/mps/ast/ast_portfolio_review.jsp)

<sup>32</sup> <http://nsf.gov/pubs/2013/nsf13074/nsf13074.jsp>

## Major Multi-User Research Facilities

to FY 2017 are included in the NRAO narrative within the Facilities chapter of the FY 2017 Budget Request. This table below does not separate funding for GBO and VLBA, since the detailed breakdown between the two is the subject of the expected proposal and will depend on anticipated and achieved partnerships. Notional funding beyond FY 2018 is shown as flat, although it is expected that the out-year numbers will change significantly as partnerships evolve.

### Total Obligations for Green Bank and VLBA

(Dollars in Millions)

	FY 2015	FY 2016	FY 2017	ESTIMATES <sup>2</sup>				
	Actual	Estimate	Request <sup>1</sup>	FY 2018	FY 2019	FY 2020	FY 2021	FY 2022
Operations & Maintenance		-	\$11.50	\$11.85	\$11.85	\$11.85	\$11.85	\$11.85

<sup>1</sup> Beginning in October 2016, funding for these facilities as stand-alone entities will be provided separately from National Radio Astronomy Observatory (NRAO) funding.

<sup>2</sup> Outyear funding estimates are for planning purposes only. The operating award (currently under review) for GBO and VLBA is expected to run through the end of September 2018.

**Partnerships and Other Funding Sources:** In FY 2016, GBO and VLBA receive about \$6.0 million from other sources, roughly two-thirds from non-federal partners and one-third from other federal sources. Many of these partnerships involve guaranteed allocations of observing time on the GBT or VLBA. In FY 2017, the GBO partnership with the radio astronomy space mission is expected to end, but other partner discussions are ongoing.

**Education and Public Outreach:** The Green Bank Science Center at GBO now about 40,000 visitors per year and carries out dedicated programs for professional educators and school groups. The continuation of this program in the future will be one of the subjects of the anticipated proposal from AUI.

**GBO and VLBA Operations and Maintenance, \$11.50 million:** This supports direct telescope operations, including maintenance, infrastructure, telescope management, and Education and Public Outreach.

### **Management and Oversight**

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

### **Renewal/Recompetition/Termination**

GBO and VLBA are currently supported through the cooperative agreement for NRAO, which ends on September 30, 2016. A six month transition award, starting on April 1, 2016, will provide for implementation costs of separating GBO and VLBA from NRAO. On October 1, 2016, this Request will provide for GBO and VLBA as stand-alone entities through an award (under review) expected to run through September 2018. Management of GBO and VLBA after FY 2018 will be based on the outcome of partnership discussions and the engineering/environmental review process described above.

## **OTHER FACILITIES FUNDING**

### **Major Research Equipment and Facilities Construction Account Projects**

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

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

### **Preconstruction Planning**

Within the R&RA account, funds are provided for preconstruction studies for prospective 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*