ICECUBE NEUTRINO OBSERVATORY (IceCube) **$7,000,000**
$0 / 0%

IceCube Neutrino Observatory Funding
(Dollars in Millions)

FY 2018 Actual	FY 2019 (TBD)	FY 2020 Request	Change over FY 2018 Actual Amount	Change over FY 2018 Actual Percent
$7.00	-	$7.00	-	-

IceCube is the world's first high-energy neutrino observatory and is located deep within the ice cap under the U.S. Amundsen-Scott South Pole Station in Antarctica. With the discovery in 2013 of the very high-energy (PeV) 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. The energy and arrival direction of high-energy neutrinos ranging in energy from 100 GeV to 10 PeV (1 GeV is 10^9 electron Volts [eV]; 1TeV is 10^{12} eV; and 1 PeV is 10^{16} 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 number of neutrinos, detected by IceCube in the range between 100 TeV and 10 PeV has already exceeded 150, and so will provide a statistically robust basis for determining the extrasolar neutrino flux.

Approximately one cubic kilometer of ice is instrumented with photo-multiplier (PM) tubes to detect neutrino-induced, charged reaction products that are produced when a high-energy neutrino interacts in the ice within or near the cubic kilometer fiducial volume. Since completion in 2010, the IceCube detector has been taking data in its final configuration with an uptime of well over 99 percent. 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.

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 below 250 GeV. The DCA closes the energy gap between the IceCube Neutrino Observatory and the Super-Kamiokande detector in Japan, and allows effective observations of high-energy neutrinos entering from the sky of the southern hemisphere.

IceCube high energy neutrino observations recently helped to reveal a source for the first time ever, of very high energy cosmic rays. An IceCube telegram on September 22, 2017, reported a well-reconstructed track of a ~290 TeV extraterrestrial muon neutrino that pointed to the location of a bright flaring blazar (a quasi-stellar radio source associated with a supermassive black hole at the center of an active giant galaxy). Three scientific spacecraft (Fermi-LAT, AGILE, SWIFT) and one ground-based telescope (MAGIC) then reported ~100 GeV-level gamma-ray observations from a direction that was consistent within 0.1° from the location of the blazar, previously located by the Fermi Large Area Telescope. Archived IceCube data revealed detection of previous emissions from the blazar. Thus multi-messenger astrophysics, initiated by IceCube findings, provided a first exciting answer to a 106-year old scientific mystery regarding the origin of cosmic rays.

Total Obligations for IceCube
(Dollars in Millions)

	FY 2018 Actual	FY 2019 (TBD)	FY 2020 Request	ESTIMATES[1] FY 2021	FY 2022	FY 2023	FY 2024	FY 2025
Operations & Maintenance (GEO)	$3.50	-	$3.50	$3.50	$3.50	$3.50	$3.50	$3.50
Operations & Maintenance (MPS)	3.50	-	3.50	3.50	3.50	3.50	3.50	3.50
Total	**$7.00**	**-**	**$7.00**	**$7.00**	**$7.00**	**$7.00**	**$7.00**	**$7.00**

[1] Outyear estimates are for planning purposes only.

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 over 300 scientists from 23 U.S. institutions and 24 institutions in 11 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 OPP and MPS's Division of Physics (PHY). Support for operations and maintenance, research and education, and outreach are shared by OPP and PHY, as well as other external 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 by the Collaboration 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.

<u>Operations Costs</u>

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 (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.

Approximately $4.0 million annually is provided in NSF support for U.S. institutions working on more refined and specific data analyses, data interpretation (theory support), and instrumentation upgrades is provided in response to merit-reviewed proposals, through research grants.

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

Renewal/Recompetition/Termination

NSF re-competed the IceCube operations and maintenance award in FY 2016. The new award was issued on April 1, 2016 for 60 months. The award's mid-term panel review is currently scheduled for March 2019 and will provide an important basis for future recompetition considerations.