ICECUBE NEUTRINO OBSERVATORY (ICNO) $7,000,000
-$10,000 / -0.2%

IceCube Neutrino Observatory Funding
(Dollars in Millions)

FY 2019 Actual	FY 2020 (TBD)	FY 2021 Request	Change over FY 2019 Actual Amount	Change over FY 2019 Actual Percent
$7.01	-	$7.00	-$0.01	-0.2%

The IceCube Neutrino Observatory is the world's first high-energy neutrino[1] observatory and is located deep within the ice under the U.S. Amundsen-Scott South Pole Station in Antarctica. With the discovery in 2013 of very high-energy 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 phenomena. The energies and arrival directions of neutrinos are derived from the IceCube data stream and the collaboration has recently focused on studies of neutrino events in the medium to high-energy range. The number of high-energy neutrinos detected by IceCube has already exceeded 150 and so will provide a statistically robust basis for determining the flux of neutrinos from beyond our solar system.

Approximately one cubic kilometer of ice is instrumented with an array of photo-multiplier (PM) tubes to detect light produced when a neutrino interacts with an atomic nucleus in the ice within or near the instrumented volume of ice. Since completion in 2010, the ICNO 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 above the array. Data produced by this initial analysis are batched and sent via 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 PM tubes to detect low to medium energy neutrinos, thus opening the door to studies of neutrino oscillation measurements. The DCA will be upgraded in FY 2023 with seven additional strings of PM tubes under an NSF award issued in FY 2019. This addition will extend the sensitivity of ICNO to a lower energy range which will provide a bridge to studies of lower energy neutrinos measured by other neutrino observatories such as Super-Kamiokande in Japan.

In FY 2013, ICNO observed the first high-energy, astrophysical or cosmic neutrinos – revealing an

[1] Neutrinos are now known to exist over a broad range of energies described in electron-Volts, or eV; their energy range spans from well below 1 eV to 10 EeV (1 GeV = 10^9 eV; 1 TeV = 10^{12} eV; 1 PeV = 10^{15} eV, and 1 EeV = 10^{18} eV). Neutrinos with energies between 100 GeV and 100 TeV are refered to as medium range, and those over 100 TeV are refered to as high-energy neutrinos that generally originate outside the Solar system.

unobstructed view of the Universe at energies at which the Universe is opaque to light. In 2017, new data obtained by ICNO revealed some answers to questions about the origin of high-energy cosmic rays that had puzzled astrophysicists for more than a century. ICNO detected a high-energy neutrino of ~ 290 TeV and its arrival direction was consistent with the location of a known gamma-ray blazar TXS 0506 +056 - the nucleus of a giant galaxy that fires off particles in massive jets of elementary particles, powered by a supermassive black hole at its core. This evidence of the first known source of high-energy neutrinos and cosmic rays has inspired an ongoing quest for more data from similar or other sources. Thus ICNO results opened a new window to the Universe and ICNO exploration of scientific frontiers has already changed and expanded our understanding of the Universe.

Total Obligations for IceCube

(Dollars in Millions)

	FY 2019	FY 2020	FY 2021	ESTIMATES[1]				
	Actual	(TBD)	Request	FY 2022	FY 2023	FY 2024	FY 2025	FY 2026
Operations & Maintenance (GEO)	$3.51	-	$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	**$7.01**	**-**	**$7.00**	**$7.00**	**$7.00**	**$7.00**	**$7.00**	**$7.00**

[1] Outyear estimates are for planning purposes only. The current cooperative agreement ends March 2021.

The ICNO is presently led by the University of Wisconsin, Madison (UWisc) and was constructed with support from four countries (U.S., Belgium, Germany, and Sweden). The science collaboration is much broader, currently consisting of about 300 scientists from 27 U.S. institutions and 25 institutions in 11 other countries (Belgium, Germany, Sweden, Australia, Canada, Denmark, Japan, New Zealand, South Korea, 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 ICNO is the joint responsibility of GEO's OPP and MPS's Division of Physics (PHY). Support for operations and maintenance, education and outreach, and research 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 UWisc management structure for ICNO 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 cadre of senior 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. UWisc 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. UWisc 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., in proportion to the number of PhD-level researchers involved (currently 79:73, resulting in a cost split of 52:48 percent, resepctively). 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 using ICNO data.

NSF provides research support via grants made in response to proposals that undergo the Foundation's normal merit-review process. Approximately $4.0 million is provided annually to investigators at U.S. institutions for research on more refined and specific data analyses and data interpretation (theory support) as well as for work on instrumentation upgrades.

The general operations of South Pole Station, reported in the Antarctic Facilities and Operations narrative, also contribute to supporting the ICNO. 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.

<u>Education and Outreach</u>
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 ICNO operations and maintenance activity in FY 2016. A new cooperative agreement was issued on April 1, 2016 for 60 months to the University of Wisconsin. The required mid-term review was held in March 2019; the external panel of experts found the ICNO management and operations activities to be very effective and recommended continuation for the rest of the current award period. This review also provides an important baseline of information for consideration in developing plans for the future.