ICECUBE NEUTRINO OBSERVATORY (ICNO)
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IceCube Neutrino Observatory Funding

(Dollars in Millions)

FY 2022 Actual	FY 2023 Estimate Base	FY 2024 Request	Change over FY 2023 Estimate Base	
			Amount	Percent
$7.26	$7.66	$8.01	$0.35	4.6%

Brief Description

The IceCube Neutrino Observatory cubic-kilometer detector was designed to observe neutrinos from the most violent astrophysical sources in the Universe. Neutrinos—almost massless particles with no electric charge—can travel from their sources to Earth with essentially no attenuation and no deflection by magnetic fields. ICNO is the world's largest high-energy neutrino detector, comprising 5,160 digital optical modules (DOMs) deployed deep within the ice cap under the U.S. Amundsen-Scott South Pole Station in Antarctica. The facility will continue to evolve in its scientific mission as 700 DOMs are added in the coming years.

ICNO has delivered world-leading scientific results—from measuring previously unexplored atmospheric neutrino oscillations to observing cosmic neutrinos with energies exceeding 10 peta-electron volts. In 2013, ICNO observed the first high-energy cosmic neutrinos—key messengers revealing an unobstructed view of the Universe at wavelengths where it is opaque to photons. In 2017, new data obtained by ICNO revealed clues to the origins of high-energy cosmic rays, by tracing the path of a very high-energy neutrino back to a previously known but little-studied blazar—the nucleus of a giant galaxy that fires off massive jets of elementary particles, powered by a supermassive black hole at its core. These discoveries have established ICNO's role in multi-messenger astrophysics for observing the extreme Universe.

Meeting Scientific Community Needs

While the evidence of the first known source of high-energy neutrinos and cosmic rays is compelling, more data are now sought from similar or other sources. The ICNO results opened a new window to the Universe, providing novel insights into the engines that power active galactic nuclei and generate high-energy cosmic rays, gamma ray bursts, and other violent and energetic astrophysical processes. ICNO's exploration of scientific frontiers has already changed and expanded our understanding of the Universe.

Inquiries are underway concerning science questions that may arise from the study of neutrino properties, especially at the lower energies to which ICNO's Deep Core strings have enabled access. For example, to fill in the blanks of the Standard Model of particle physics, scientists have been determining properties of the known types of neutrinos and conducting diligent searches for a hypothesized particle known as the "sterile neutrino." In 2022, for the first time, ICNO scientists proved that *electron antineutrinos* are present in the ICNO data, as well as found evidence of high-energy neutrino emission from a remote active galaxy.

More than 350 physicists from 58 institutions in 14 countries make up the IceCube Collaboration. Of these, about 150 are U.S. scientists supported by OPP and the MPS Division of Physics (PHY). This international team is responsible for the ICNO scientific program, and many of the collaborators contributed to the design, construction, and operation of the detector. The ongoing upgrade of the detector will extend ICNO's overall sensitivity to a lower energy range, which will provide a bridge to studies at other neutrino observatories such as the Super-Kamiokande detector in Japan and other similar (much smaller than IceCube) detectors across the world. The ICNO upgrade will also provide enhanced calibration capabilities to improve the pointing of neutrino events to astrophysical sources and improve the existing 12-year data set.

Status of the Facility

The ICNO year-around operation includes two staff members who carry out "winter-over" duties at the South Pole where the ICNO data are collected and transmitted daily to the University of Wisconsin-Madison (UW-M). These data are then processed and served to the IceCube Collaboration. The summer crew is typically five to six members who complete more extended maintenance activities. A midscale research infrastructure award was issued in 2019 to upgrade ICNO's Deep Core Array with about 700 new digital sensors that will significantly improve measurements of lower-energy neutrino properties. As neutrinos travel through space, they change from one type to another—a quantum mechanical process known as neutrino oscillation. The ICNO Upgrade is intended to provide the first precision measurements of the number of *tau* neutrinos appearing due to these oscillations.

During the COVID-19 pandemic, limitations on the number of personnel who could be deployed to Antarctica restricted the ICNO staffing. These crew size limitations have resulted in a three-year delay to the upgrade project, which was originally targeted to be completed in FY 2023. A new project baseline is now in place extending the upgrade project to be completed in FY 2026.

Governance Structure and Partnerships

NSF Governance Structure

The ICNO facility is managed at NSF by an Integrated Project Team composed of staff from OPP, MPS, the Large Facilities Office, and the Division of Acquisition and Cooperative Support. The GEO facilities team and the Chief Officer for Research Facilities also provide high-level guidance, support, and oversight.

External Governance Structure

The ICNO facility is governed by UW-M and its sub-awardee institutions: University of Maryland College Park, University of Delaware, Michigan State University, Pennsylvania State University, University of Alabama, and Lawrence Berkeley National Laboratory. The ICNO data are used by a broad science collaboration, currently consisting of 58 institutions in 14 countries in Europe, Asia and Oceania.

Partnerships and Other Funding Sources

Operation of ICNO in support of scientific research began in FY 2011. The associated costs are, and will continue to be, shared by the partner funding agencies (NSF and non-U.S.) roughly in proportion to the number of Ph.D. researchers involved in the O&M activities (55 percent U.S. and 45 percent non-U.S. in 2022). The NSF support for O&M, research, and education and outreach is shared by OPP (lead) and PHY, as well as by other in-kind contributions from participating institutions. The work in

support of facility operations is performed by students, postdocs, and senior researchers, who are also participating in research using the data produced by ICNO.

Funding

Total Obligations for ICNO
(Dollars in Millions)

	FY 2022 Actual	FY 2023 Estimate Base	FY 2024 Request	ESTIMATES[1] FY 2025	FY 2026	FY 2027	FY 2028	FY 2029
Operations and Maitenance (GEO)	$3.66	$3.83	$3.99	$4.15	$4.60	$4.60	$4.60	$4.60
Operations and Maitenance (MPS)	3.60	3.83	4.02	4.15	4.60	4.60	4.60	4.60
TOTAL	**$7.26**	**$7.66**	**$8.01**	**$8.29**	**$9.20**	**$9.20**	**$9.20**	**$9.20**

[1] Outyear estimates are for planning purposes only. The current cooperative agreement ends March 2026.

O&M support for ICNO is estimated at approximately $8.01 million in FY 2024. This is a 4.6 percent increase over the FY 2023 Estimate reflecting inflation and the higher cost of operations.

Reviews and Reports

The previous cooperative agreement with UW-M required reviews of the ICNO O&M activities after the second and fourth project years. The mid-term O&M panel review was held in March 2019, and the second, NSF staff "site visit" review was held virtually in March 2020. These reviews found that ICNO continues to be a very important element of the OPP and PHY programs, rated the O&M activities as excellent, and recommended continuing operation of ICNO for the remaining period of the previous award.

With the severe COVID-19 pandemic impacts to the U.S. Antarctic Program operations, the ICNO Upgrade project was halted, and its re-baselining options were thoroughly reviewed in 2021 and 2022. Based on these reviews, the completion of the upgrade project was extended to FY 2026.

Renewal/Recompetition/Disposition

Full operation of ICNO began in 2011 with an anticipated detector lifetime of 25-30 years. In anticipation of the ICNO O&M support cycle completion in 2021 and according to internal NSF guidance, an O&M renewal proposal was solicited from ICNO leadership. The proposal was received in Summer 2020 and fully reviewed according to NSF standard practices. In April 2021, the ICNO O&M Cooperative Agreement with UW-M was renewed for the next five years, 2021-2026.

Currently there are no plans for divestment of this facility.