ICECUBE NEUTRINO OBSERVATORY (ICNO) $7,300,000

+$300,000 / 4.3%

IceCube Neutrino Observatory Funding
(Dollars in Millions)

FY 2020 Actual	FY 2021 Estimate	FY 2022 Request	Change over FY 2021 Estimate Amount	Percent
$7.00	$7.00	$7.30	$0.30	4.3%

Brief Description

The IceCube Neutrino Observatory cubic-kilometer detector has now delivered world-leading scientific results—from measuring previously unexplored atmospheric neutrino oscillations to observing cosmic neutrinos with energies exceeding 10 Peta electron volts (PeV). The discovery of these cosmic neutrinos establishes ICNO's role in multi-messenger astrophysics for observing the extreme Universe. ICNO is the world's first gigaton and 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. ICNO will continue to undergo an evolution in its scientific mission as it is upgraded with an additional 700 DOMs in the coming years.

Scientific Purpose

ICNO 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.

The IceCube Laboratory building at South Pole where all data-collecting computer servers are located. *Credit: USAP Photo Library, Sven Lidstrom, NSF.*

In 2013, ICNO observed the first high-energy (over 100 Tera eV (TeV) and up to 10 Peta eV (PeV)) astrophysical (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 some answers to a more than century-old quest for the origins of high-energy cosmic rays, tracing the path of a single 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. While this 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 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 conducting diligent searches with ICNO data for a hypothesized particle known as the "sterile neutrino." None of the searches found evidence for the eV-mass sterile neutrino hinted at by other experiments.

In the ten years since its completion, ICNO has isolated more than 150 high-energy cosmic neutrinos, with energies between 100 TeV and 15 PeV, from more than a million atmospheric neutrinos and hundreds of billions of cosmic-ray muons. [1] Among them is the first detection of a Glashow resonance event, a 6.3 PeV antineutrino interaction with an atomic electron in the ice, producing a W boson. These PeV neutrinos, the highest energy neutrinos observed to date, have a thousand times the energy of the highest energy neutrinos produced with earthbound accelerators and a billion times the energy of the neutrinos detected from supernova SN1987 in the Large Magellanic Cloud, the only neutrinos that had been detected on Earth from outside the solar system prior to the ICNO breakthroughs. However, the most surprising property of these cosmic neutrinos is their large flux rather than their high energy or their origination outside our galaxy.

Status of the Facility

ICNO operations have continued throughout the COVID-19 pandemic period and included two staff members who carried out “winter-over” duties at the South Pole where the ICNO data are collected and transmitted daily to the University of Wisconsin (UW). These data are then managed and served to the IceCube Collaboration by the UW staff, operating remotely.

Meeting Intellectual Community Needs

More than 300 physicists from 52 institutions in 12 countries make up the IceCube Collaboration. Of these, about 130 are U.S. scientists supported by NSF’s Office of Polar Programs (OPP) and MPS’ Division of Physics (PHY). This international team is responsible for the scientific program, and many of the collaborators contributed to the design, construction, and now operation of the detector.

ICNO is currently funded by NSF with the mid-scale research infrastructure award issued in 2019 to add seven additional strings to be deployed deep in the ice for the central DeepCore array. The original project duration was set for the 2019-2024 period, but the COVID-19 pandemic has caused a delay for one more year at least. This addition will extend ICNO's overall sensitivity to a lower energy range which will provide a bridge to studies at other neutrino observatories such as Super-Kamiokande detector in Japan and other similar (much smaller than IceCube) detectors across the world.

Governance Structure and Partnerships

ICNO is managed by UW and includes a broad science collaboration, currently consisting of 53 institutions worldwide (U.S.-28, Canada-2, Europe-19, Asia and Pacific-4) in 12 countries (U.S., Germany, Belgium, Sweden, Australia, Canada, Denmark, Japan, New Zealand, South Korea, Switzerland, and the United Kingdom).

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.—roughly proportional to the number of PhD researchers involved in the Observatory’s maintenance and operations (in 2020, this ratio was about 51% US and 49% non-US). The NSF support for operations and maintenance, research, and education and outreach is shared by the Office of Polar Programs (lead) and the Physics

[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 referred to as medium range, and those over 100 TeV are referred to as high-energy neutrinos that generally originate outside the Solar system.

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

NSF Governance Structure

The ICNO facility is managed at NSF by an Integrated Project Team consisting of program directors and staff from OPP, MPS, BFA's Large Facilities Office, the Cooperative Support Branch in the Division of Acquisition and Contract Support and others in BFA.

External Governance Structure

The ICNO facility is governed by the lead institution, University of Wisconsin in Madison, and its sub-awardee institutions: University of Maryland in College Park, University of Delaware, Michigan State University, Pennsylvania State University, University of Alabama in Tuscaloosa, and Lawrence Berkeley National Laboratory.

Partnerships and Other Funding Sources

The ICNO construction, operations and maintenance, and scientific research are funded through a domestic and international network of public and private organizations, including the Department of Energy, Office of Science. Domestic and international partners involved in the ICNO operation are members of the IceCube Collaboration[2].

Funding

Total Obligations for ICNO

(Dollars in Millions)

	FY 2020 Actual	FY 2021 Estimate	FY 2022 Request	ESTIMATES[1] FY 2023	FY 2024	FY 2025	FY 2026	FY 2027
Operations and Maintenance (GEO)	$3.50	$3.50	$3.65	$3.83	$4.02	$4.15	$4.15	$4.15
Operations and Maintenance (MPS)	3.50	3.50	3.65	3.83	4.02	4.15	4.15	4.15
TOTAL	**$7.00**	**$7.00**	**$7.30**	**$7.66**	**$8.04**	**$8.30**	**$8.30**	**$8.30**

[1] Outyear estimates are for planning purposes only.

A new five-year cooperative agreement (CA) was awarded in 2021. The award increase starting in 2022 reflects the higher cost to operate the larger number of strings in the sensor array.

Reviews

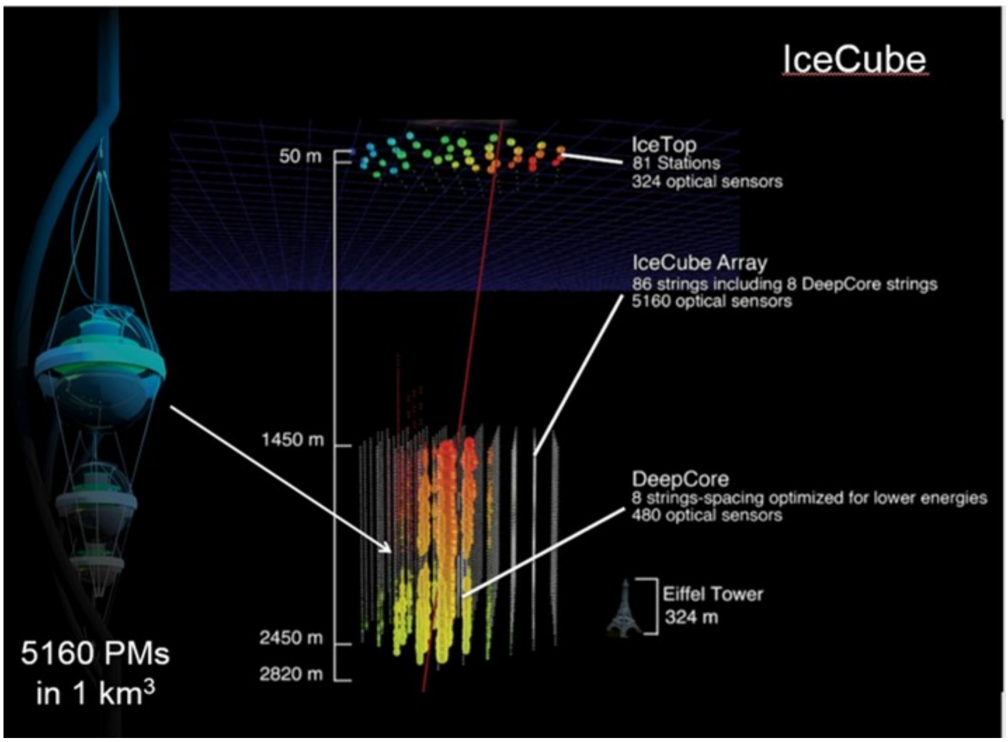
The previous CA with UW required two reviews of the ICNO/O&M activities after the second and fourth project years. The first review was completed in person in March 2019, while the second review was held virtually in March 2020. These reviews found that ICNO continues to be a very important element of the OPP and PHY Programs, rated the O&M activities as excellent, and recommended to continue operating ICNO for the remaining period of the current CA.

[2] icecube.wisc.edu/collaboration/meet-the-collaboration/

Renewal/Recompetition/Termination

The ICNO full operation began in 2011 with an anticipated lifetime of the detector of approximately 25-30 years. The previous ICNO O&M support was recompeted and awarded in April 2016 for five years after a thorough review of the received proposal. The renewal proposal for extending the O&M activities from April 2021 through March 2026 was received at the end of July 2020. In a November 2020 panel review all were unanimous that the current O&M effort was excellent. The new O&M award was issued in April 2021.

Currently there are no plans for divestment of this facility.



IceCube graphical diagram showing how neutrino's interaction within an ice sheet is developed and captured by detector strings. *Credit: IceCube/NSF photo library.*