A NEW WINDOW IceCube ON THE UNIVERSE

http://icecube.wisc.edu

IceCube, a telescope under construction at the South Pole, will peer through the earth to open a new window onto the universe. Like its predecessor, AMANDA (see below), IceCube will search for neutrinos from the most violent astrophysical sources: events like exploding stars, gamma ray bursts, and cataclysmic phenomena involving black holes and neutron stars. The IceCube telescope is a powerful tool to search for dark matter, and could reveal the new physical processes associated with the enigmatic origin of the highest energy particles in nature.

Rather than using light, this “new window” on the universe opens using a novel astronomical messenger called a neutrino. IceCube will probe the universe by detecting these elusive subatomic particles hurtling through space. Since the 1950s scientists have built a compelling scientific case for doing astronomy and particle physics using high-energy neutrinos. The challenge has been one of technology to build the kilometer-sized observatory needed to do the science.

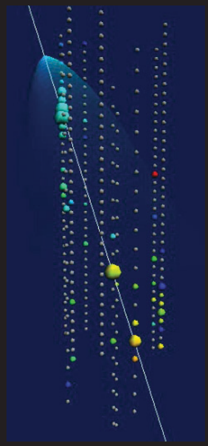
During the last decade, an international collaboration of scientists constructed and operated the first high-energy neutrino telescope. Completed in the year 2000, the Antarctic Muon and Neutrino Detector Array (AMANDA) has transformed part of the Antarctic icecap into a particle detector. AMANDA scientists positioned about 750 optical sensors deep in this ice. The faint flashes of light created by neutrinos moving through the transparent ice are detected by these optical sensors. Its setting in the remote polar ice is one of many reasons *Scientific American* distinguished AMANDA as the “weirdest” of its “seven wonders of modern astronomy” (1999).

IceCube will encompass a cubic kilometer of ice. Theorists anticipate that an instrument of this size is required to study neutrinos from distant astrophysical sources. AMANDA demonstrated the viability of a neutrino telescope in ice by detecting high-energy neutrinos produced in the earth’s atmosphere near the North Pole! With AMANDA as its proof-of-concept, an international collaboration is constructing IceCube to peer deep into the cosmos.

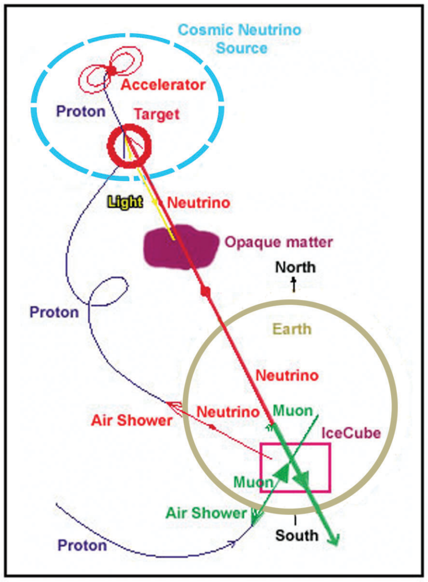
Why use neutrinos to peer into the universe?

Neutrinos are produced by the decay of radioactive elements and elementary particles such as pions. Unlike other particles, neutrinos are antisocial, difficult to trap in a detector. The existence of neutrinos was first suspected in 1930 when scientists observed that energy and momentum were missing from the decay of radioactive nuclei. It was not until 1955 that neutrinos were finally observed, a discovery for which Frederick Reines received the Nobel Prize. In 2001, experiments observing the sun revealed that neutrinos have tiny but definitely non-zero masses. This mysterious particle remains a hot topic in particle physics, astrophysics and cosmology.

It is the feeble interaction of neutrinos with matter that makes them uniquely valuable as astronomical messengers. Unlike photons or charged particles, neutrinos can emerge from deep inside their sources and travel across the universe without interference. They are not deflected by interstellar magnetic



The IceCube telescope and its predecessor, AMANDA, use optical sensors to locate the sources of high-energy neutrinos. This picture shows the on-line display of a neutrino event recorded by AMANDA.

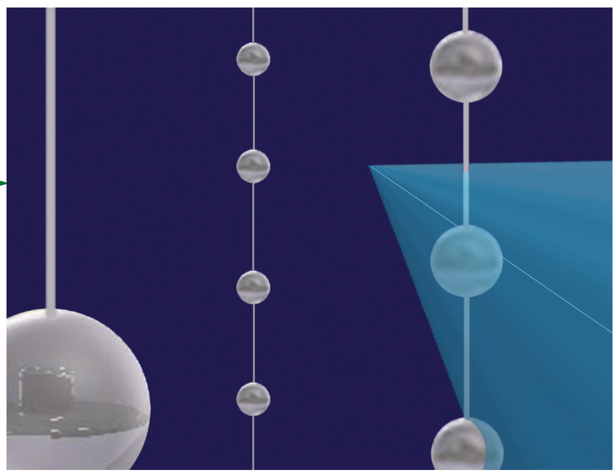


Neutrinos emitted by distant cosmic sources can travel directly through intervening matter in space and the earth to the IceCube telescope embedded below the surface of the South Pole.

fields and are not absorbed by intervening matter. However, this same trait makes cosmic neutrinos extremely difficult to detect; immense instruments are required to find them in sufficient numbers to trace their origin.

Muons—how to see the invisible neutrino

Although trillions of neutrinos stream through your body every second, none may leave a trace in your lifetime. We actually use large volumes of ice below the South Pole to watch for the rare neutrino that crashes into an atom of ice. This collision produces a particle—dubbed a “muon”—that emerges from the wreckage. In the ultra-transparent ice, the muon radiates blue light that is detected by IceCube’s optical sensors. The muon preserves the direction of the original neutrino, thus pointing back to its cosmic source. It is by detecting this light that scientists can reconstruct the muon’s, and hence the neutrino’s, path.



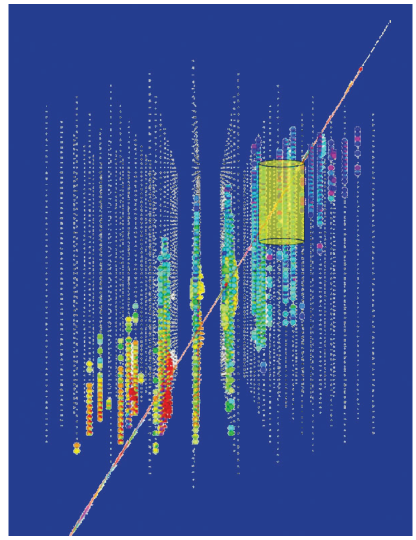
Emerging from a crash with a neutrino, a muon preserves the neutrino’s trajectory and emits blue light that the telescope’s sensors detect.

The picture is radically complicated by the fact that most muons seen by IceCube have nothing to do with cosmic neutrinos. Unfortunately, for every muon from a cosmic neutrino, IceCube detects about a million more muons produced by cosmic rays in the atmosphere above the detector. To filter them out, telescopes such as AMANDA and IceCube take advantage of the fact that neutrinos interact so weakly with matter. Because neutrinos are the only known particles that can pass through the earth unhindered, AMANDA and IceCube look through the earth and to the northern skies, using the planet as a filter to select neutrinos.

Why Antarctic Ice?

A neutrino telescope must be:

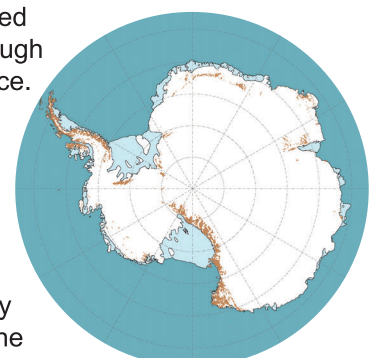
- large enough that some of the rare galactic and extra-galactic neutrinos interact as they pass by;



IceCube will encompass AMANDA (yellow cylinder). Its much larger size improves both the accuracy with which we can project the origin of a detected neutrino, and our capacity to measure its energy. Here, the color coding of the sensors, following the rainbow from red to purple, labels passage of time along the particle track

- transparent enough to allow light to travel through a widely spaced array of optical sensors;
- dark enough to avoid the interference of natural light;
- deep enough below the earth’s surface to avoid interference from southern hemisphere cosmic rays; and
- cheap enough to build.

Only dark oceans or deep fields of ice meet all these constraints. Indeed, Antarctic polar ice has turned out to be an ideal medium for detecting neutrinos. It is exceptionally pure, transparent and free of radioactivity. A mile below the surface, blue light travels a hundred meters or more through the otherwise dark ice.



Map of Antarctica, from USARC Atlas of Antarctic Research. Covered by a deep ice cap, the South Pole is the perfect location for IceCube.

True, it is difficult to find a more remote location for a telescope. But experience with AMANDA has clearly demonstrated that the South Pole’s advantages outweigh its relative inaccessibility. AMANDA and IceCube:

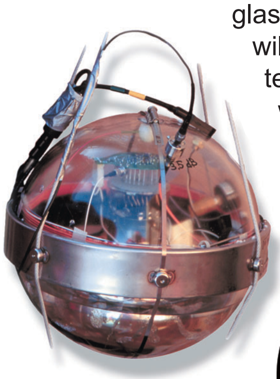
- deploy sensors from the solid, stable surface of the ice rather than from a ship;
- collect the data in electronic instruments housed directly above the telescope rather than miles away at a shore station; and
- exploit the infrastructure of the recently renovated U.S. Amundsen-Scott South Pole Station.

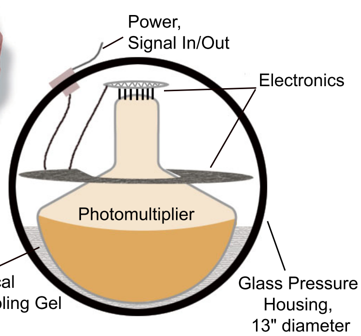
The summer drilling camp at Amundsen-Scott South Pole Station.

Frozen in the ice, IceCube not only will be the largest and most durable particle detector, but a real bargain at just 25 cents per ton!

How does IceCube "see" a neutrino?

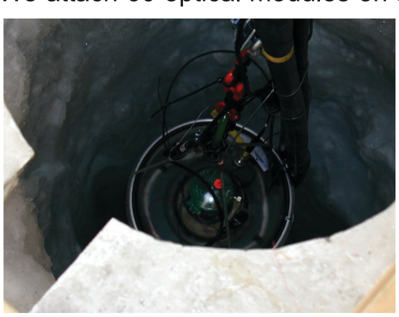
Like its predecessor, AMANDA, the basic component of IceCube is the sensor that transforms light into electrical signals. A sensor is a photomultiplier tube housed in a glass pressure vessel; IceCube will boast nearly 5000. The technology used in IceCube will be more advanced than that of AMANDA. IceCube will have "smart" sensors, meaning that each sensor will contain a computer chip connected through the internet to computers in scientists' offices! It is not too fanciful to think of the device as a cubic-kilometer, continuously sensing computer.



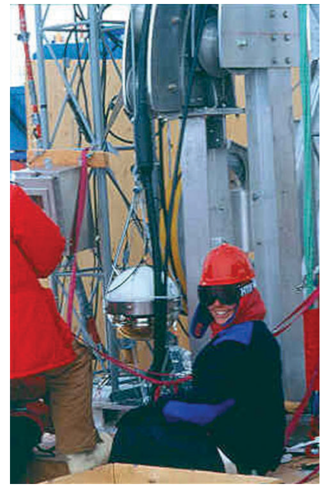


Each optical module consists of a photomultiplier tube housed in a glass pressure vessel.

We attach 60 optical modules on a long electrical cable—like beads on a string—that is connected to a signal processing facility on the surface. To position this string of modules, drillers use a 5 megawatt jet of hot water to melt a hole a bit wider than half a meter and 2.4 kilometers deep. We then have roughly a day to lower the string of sensors before the water refreezes. IceCube will take advantage of improved drilling technology developed during the construction of AMANDA to meet an ambitious deployment schedule of 80 strings with 60 optical sensors each in just 6 years. Improved digital sensor technology, combined with the overall size of the telescope, will greatly increase the scientific potential of IceCube over its trail-blazing predecessor, AMANDA.



Optical modules are strung on electrical cables like beads on a string and frozen more than 1500 meters below the surface of the ice.

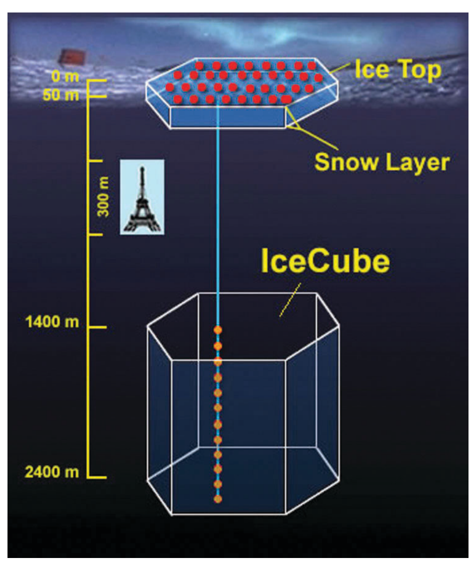


Eva Dahlberg preparing a module to be lowered into a temporary hole in the ice.

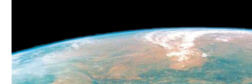
Endless frontiers

Having no electrical charge and interacting weakly with matter, neutrinos are special astronomical messengers. Only they can carry information directly from violent cosmological events at the edge of the universe or from the hearts of black holes.

The history of astronomy shows that work in new energy regions has invariably resulted in the discovery of totally unexpected phenomena. By peering through a new window on the universe, IceCube promises findings that will open new frontiers of understanding.



IceCube will occupy a volume of one cubic kilometer. Here we depict one of the 80 strings of optical modules (number and size not to scale). IceTop, located at the surface, comprises an array of sensors to detect air showers. It will be used to calibrate IceCube and to conduct research on high-energy cosmic rays.



RESEARCH

DISCOVERY

Education and outreach

A physics graduate student, Jodi Cooley (right), describes to high school physics students the workings of a photomultiplier tube, the optical sensor housed in each glass module.

AMANDA and IceCube scientists and engineers are not only building and analyzing data from these remote and unique instruments. They also are enabling others to experience the excitement of learning and discovery that they feel. They believe that, parallel with the transformations in science that accompany the development of major new instruments, there should be improvements in the ways all students and the public learn about and participate in science. The IceCube Education Resource Center is helping these scientists develop excellent educational resources, and generate meaningful ways to communicate with people—young and old, in all walks of life, and with different levels of interest in this new frontier of particle astrophysics.

Participating Institutions

- Chiba University, Japan
- Clark Atlanta University, USA
- DESY - Zeuthen, Germany
- Institute for Advanced Study, USA
- Lawrence Berkeley National Laboratory, USA
- South Pole Station, Antarctica
- Southern University and A & M College, USA
- Stockholm Universitet, Sweden
- Universität Mainz, Germany
- Universität Wuppertal, Germany
- Université Libre de Bruxelles, Belgium
- Université de Mons-Hainaut, Belgium
- University of Alabama, USA
- University of California–Berkeley, USA
- University of Delaware, USA
- University of Kansas, USA
- University of Maryland, USA
- University of Pennsylvania, USA
- University of Wisconsin–Madison, USA (lead)
- University of Wisconsin–River Falls, USA
- Uppsala Universitet, Sweden
- Vrije Universiteit Brussel, Belgium

Agencies supporting AMANDA/IceCube include:

- German Ministry of Research and Education
- German Research Foundation (DFG)
- Knut and Alice Wallenberg Foundation, Sweden
- National Fund for Scientific Research, Belgium
- Swedish Natural Science Research Council
- Swedish Polar Research Secretariat
- University of Wisconsin Alumni Foundation
- U.S. National Energy Research Scientific Computing Center (supported by the Office of Energy Research of the U.S. Department of Energy)
- U.S. National Science Foundation, Office of Polar Programs
- U.S. National Science Foundation, Physics Division

LEARNING

EDUCATION

IceCube