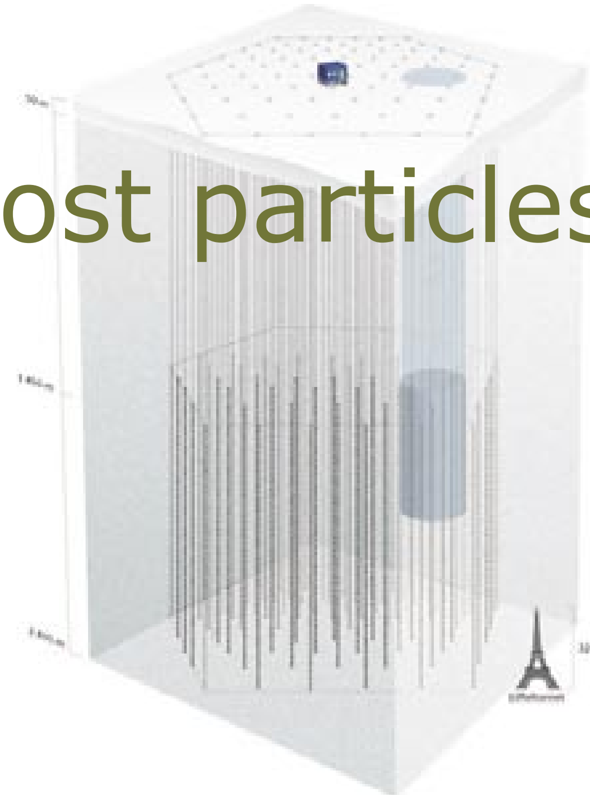
Neutrino Astronomy

Looking for ghost particles

Nearly unaffected by all hindrances, billions of neutrinos reach the earth every second. They do not only reach us, and the earth, they also pass through us unaffectedly, even through the core of the globe, and ultimately come out on the other side and continue the travel through space. Neutrinos are extremely small elementary particles that have one very particular feature: a strong antipathy for interaction with other matter, and without electrical charge.



The IceCube Neutrino Observatory with the air shower IceTop at the surface and the In-ice array. The Amanda telescope is seen inside IceCube as a dark cylinder. Figure: IceCube

Light and nuclei are often swallowed by cosmic dust from their travel, neutrinos travel through space almost unaffectedly. As messengers from their place of origin, they carry information from very distant galaxies, supernovae explosions, and undiscovered objects. It would have been very valuable to be able to detect them, if only we knew how to.

The travel of these ghost particles can sometimes be stopped: by an extremely rare collision with the nucleus of an atom. When colliding with oxygen atoms in ice or water break the nucleus apart, and the neutrino converts to a muon, which is basically a heavy electron. This characteristic has given possibilities to build detectors that can detect the muons and thus, find out something about the origins of the neutrinos. Using modern detection systems scientists can decode the invisible messages from the cosmos.

Several facilities exist to detect the muons after colliding with oxygen atoms.

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All pictures to this article: www.icecube.wisc.edu/

Three of these lie in deep water, two in the Mediterranean Sea, whilst the third deep water detector is in the Russian Baikal Sea, the world's deepest lake. However, possibly the most spectacular type is found at the South Pole plateau. AMANDA (Antarctic Muon And Neutrino Detector Array) and the successor IceCube, have the detectors deep under the Antarctic ice. The project is a collaboration between several institutes in the USA, Europe and Venezuela. Sweden is deeply involved in the project and three different Swedish institutes participate in the science work.

IceCube

The IceCube neutrino Observatory at the Amundsen-Scott base at the South Pole is the first fully funded km^3 sized neutrino detector project. It will consist of an optical sensor array deep in the ice and the IceTop air shower array at the surface. In the ice, 80 strings with 60 Digital Optical Modules (DOMs) each will be deployed between depths 1450 and 2450 m, with 17 m between the different optical modules. The distance between the strings is 125 m. The instrumented deep ice part will cover about one km^3.

The IceTop air shower array will consist of two ice Cherencov tanks placed close to each IceCube string. Each tank is instrumented with two DOMs of the same kind used in the deep ice. The surface array will be used for calibration and background studies as well as for cosmic ray studies using the combined detector. This is a unique feature of the IceCube Neutrino Observatory. The originally AMANDA telescope located inside the volume of IceCube will be an integrated part of the IceCube array and will extend the reach of the IceCube detector to low energies. This may prove important especially for searches for low energy neutrinos from e.g. neutralino annihilation in the Sun. The IceCube telescope is modular and new strings will be added into the data acquisition system as soon as they are deployed and commissioned, given an increasing sensitivity year by year.

The deployment

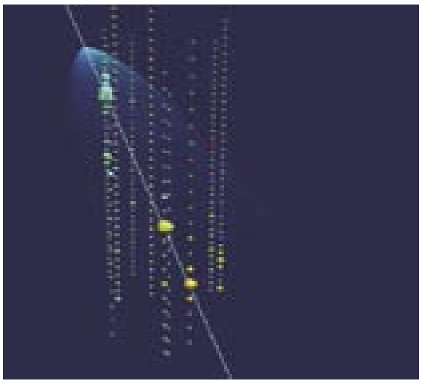
The deployment of the IceCube Neutrino takes place during the austral summer, running November to February. A new more powerful hot water drill has been developed with a heat power of 5 MW compared with 2 MW for the AMANDA drill. This new drill melts a 60 cm wide hole to 2500 m deep in lesser than 40 hours. The hole is water filled from about 50 m below the surface and allows a deployment time for the DOMs of more than 24 h. Water in the hole refreezes from the top down, in a process as taking about one week near the top and about two weeks near the bottom. In the first season (2004/2005) the first string was successfully deployed. During the second deployment season experience from the first season give an increasing speed for the deployment and in 2005/2006 eight new strings been deployed. This is very encouraging and a deployment rate of 14 or more strings and IceTop stations per year seems within reach. The final strings are expected to be deployed 2011.

How it works

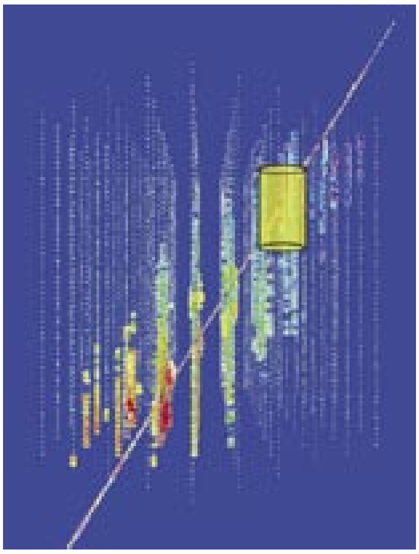
After the muon's birth they are able to travel several kilometres through the ice. The muon emits almost undetectably weak, blue light rays outward from its sides. Taken together, all these emitted rays form a hollow cone behind the muon. In the darkness of the Antarctic ice, this glow can be detected up to 100 m away. The IceCube detector, frozen in a depth of 1450 to 2450 m, is optimized in order to see this light. The detector is powerful light sensors, which are packed into pressure-resistant glass spheres and attached to steel cables and placed deep into the ice and watching for these small cones of light.

When a muon flies through the IceCube detector, each light sensor registers the passing cone of light within one billionth of a second. The sensors convert the light into electrical signals, which travel to the surface of the Earth.

The laboratory for AMANDA is at the South Pole, as is its computer control centre, which stores and processes the data. Scientists at the centre supervise the data recording and do the initial analysis on it. Complex computer programmes investigate the chronological order



Cerenkov cone passing through array



The path of the light is reconstructed using the times of detection. The earliest hits are displayed in red and subsequent ones in orange, yellow, green . . . .

and intensity of the signals. From this information, scientists can calculate the most important information: which direction the initial neutrino came from.

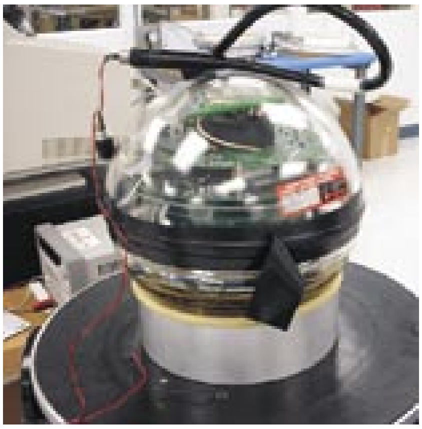
What can the physicists discover? Huge energy-jets that generate cosmic irradiation? The origin of the dark material? The birth of a supernova? Or something totally different, something not found in the catalogue of their expectations?

Sweden and the Neutrino research.

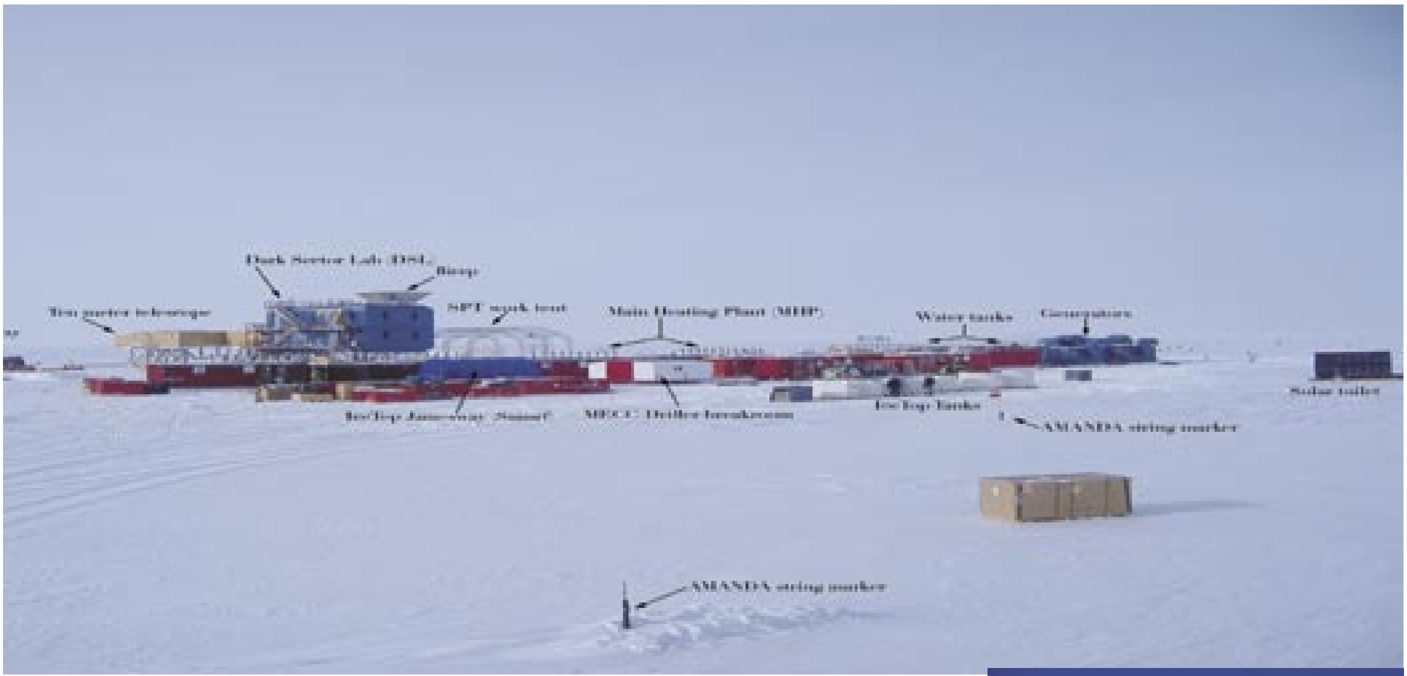
Swedish groups are very active in the AMANDA/IceCube projects and have much greater influence on this project than what is normal for Sweden in the most internationally scientific collaborations. The Swedish contribution to AMANDA equipment was nearly a quarter of the total investment cost; while the Swedish contribution for the construction of IceCube is 36 MSEK divided from several sources.

To build the telescopes the Swedish Polar Research Secretariat has supported drilling technicians during the drilling periods. Swedish groups designed the electronics for the first AMANDA optical modules, which were partly built and tested in Sweden. Uppsala University has designed and built the trigger system for AMANDA, and the Amplifier system for the PMT signal at the surface has been designed and built by Stockholm University. During the 1997/1998 deployments a TV camera built and developed by Stockholm University was successfully deployed with the last string to 2350 metres depth.

In 2004, Sweden started building and testing the first 970 of the 5200 optical modules for IceCube. The modules are built at Stockholm University and tested in a special low temperature laboratory at Uppsala University. In the nine deployed strings sixty-one of the Swedish modules are deployed, all behaving well.



Optical modules for IceCube.



The IceCube facilities at the South Pole plateau

The electrical cables used for strings 5-9 in AMANDA were developed and produced by Ericsson Network Technologies AB and thanks to this involvement Ericsson was able to get the order for 80 IceCube cables to a value of 80 MSEK.

The Swedish groups have actively taken part in the ice analysis and the filtering and reconstruction of the first neutrino candidates in AMANDA-B4. Sweden has also been responsible for the WIMP (Weakly Interacting Massive Particle) searches, developed statically methods for handling systematic errors and been involved in point source analysis. At the moment the Swedish groups are involved in the WIMP search, the search for ultra High Energy events, several basic detector quality investigations and the development of a new ice model.

Swedish researchers are also very active participants in the administration of the projects, and have had several key positions in the organisation that build and manage the project.

A little bit of history

The neutrino was first postulated in December, 1930 by Wolfgang Pauli to explain the energy spectrum of beta decays, the decay of a neutron into a proton and an electron. Pauli theorized that an undetected particle was carrying away the observed difference between the energy and angular momentum of the initial and final particles. Because of their "ghostly" properties, the first experimental detection of neutrinos had to wait until 1956, 26 years after they were first discussed. The first experiment to detect electron neutrinos produced by the Sun was carried out in 1968 and in 1996 the AMANDA neutrino telescope observed the first neutrinos at the South Pole.

References:
P.O. Hulth 4306020555 Maintenance & Operation cost for IceCube Neutrino Observatory
www.icecube.wisc.edu/

Where are they coming from?

From what we know today, a majority of the neutrinos floating around were born around 15 billions years ago, soon after the birth of the universe. Since this time, the universe has continuously expanded and cooled, and neutrinos have just kept on going. Theoretically, there are now so many neutrinos that they constitute a cosmic background radiation whose temperature is 1.9 degree Kelvin (-271.2 degree Celsius). Other neutrinos are constantly being produced from nuclear power stations, particle accelerators, nuclear bombs, general atmospheric phenomena, and during the births, collisions, and deaths of stars, particularly the explosions of supernovae.

Neutrino fundamentals

An enoumous black hole throws large gas bubble out to space. The hole lay in NGC 4438 in the Virgo group 50 millions light year from the Earth. Copyright: NASA/Kenny/Yale.

Neutrinos, like quarks and electrons, are elementary particles, fundamental building blocks of matter. But, unlike their subatomic cousins, neutrinos have no electric charge, nearly no mass, and little affinity for matter. You can't see neutrinos, but you can tell they've been around by the wreckage they leave behind.
Like any particle with no charge, neutrinos can be detected only when their interactions produce charged particles. Although a neutrino interaction is rare, when it does happen, it can produce a negatively charged particle called a "muon." Because that muon moves along the same path as the incoming neutrino did, researchers can tell which direction the neutrino came from by examining the muon's trail.

Neutrinos are products of nuclear reactions, the collisions of subatomic protons and neutrons that fuel the sun and ignite violent deep-space phenomena like supernovas and black holes. The neutrinos ejected from the sun carry much less energy than those generated by the furious explosions of dying stars and the voracious appetite of black holes. It's these high-energy neutrinos that IceCub researchers covet most.

While light and particulate matter produced by such events interact with gas and dust clouds on their astral voyages, neutrinos pass through space unmolested. They even escape the magnetic fields that bend the path of charged particles, hopelessly obscuring their point of origin. Ejected from celestial events millions of light-years away, these cosmic messengers bring news of far-flung galactic incidents, offering clues to the evolution and structure of the universe itself.

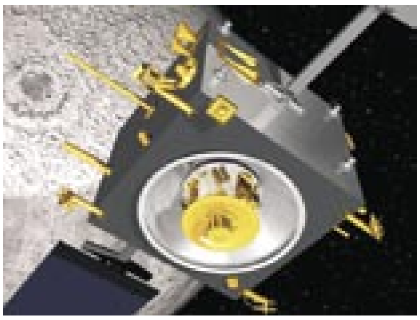
As neutrinos bombard the sunken detectors, a few interact with subatomic particles in the ice and rock and create muons. Essentially a heavy electron, the negatively charged muon emits a faint blue light that illuminates the phototubes.

Acting like light bulbs in reverse, the phototubes collect a muon's light and convert it into electrical signals, which are sent to computers above the ice that store and process the data. The signals announce the presence of a neutrino arrival, as well as its rate, frequency, and path. Researchers hope to trace the muon's path back to the neutrino's cosmic origins.

Searching for neutrinos from the Moon?

Space- and particle physicists with Swedish Space Physics, University of Uppsala and University of Växjö have shown that the Moon can be used as a giant detector for cosmic neutrinos with extreme high energy, several thousands times more energy rich than can be made in the particle accelerators at Earth.

The method that has been proposed is that a satellite orbiting detects the radio impulses that have been formed when the particles hit the Moon. Investigations of material returned from the Moon have shown that that this material has physical characteristics that are suitable to make radio pulses from the particles. However, the radiation is so weak that one needs neither very large radio telescope on Earth nor radio antennas near the source. This means antennas placed at a satellite by the moon. Calculations have shown that advanced radio equipment onboard a satellite orbiting the Moon can catch the pulses, and analyse them. A Russian moon satellite for this purpose is in the planning phase and onboard you will find a unique Swedish instrument that can measure signal characteristics better than any instruments before.



Advanced radio equipment onboard a satellite orbiting the Moon, like Smart 1, can catch the pulses, Figure: Swedish Space Corporation