IceCube Neutrino Observatory

The Cubic Kilometer Detector at the South Pole Amundsen-Scott Station

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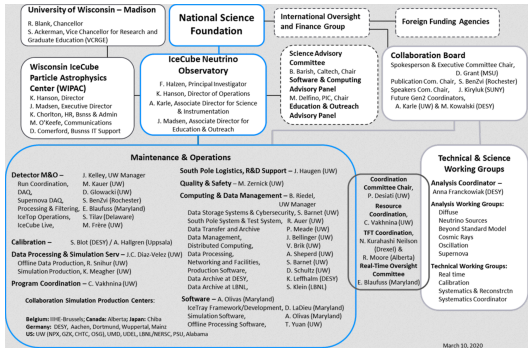
What is IceCube?

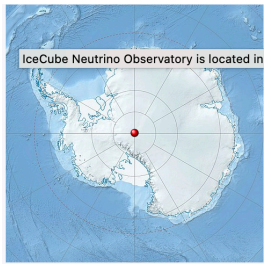
- No! Not that IceCube. The one at the South Pole

Who are the participants in IceCube?

- As of July 2020 there are 53 institutions in 12 counties collaborators in the IceCube International Consortium
- 30 US and Canadian institutions
- 19 European Institutions
- 4 Asias Pacific institutions
- Univ of Wisconsin IceCube Particle Astrophysics Center (WIPAC) is the lead institution



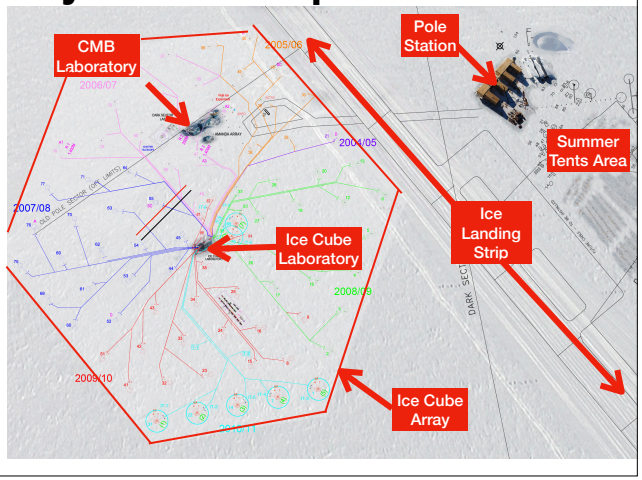
The IceCube is a neutrino detector is made up off an under ice detector array and a computer laboratory to capture data



- The IceCube Laboratory is on the upper left corner of the photo.
- You can see the trails of groomed ice where astronomers trudge to their labs in all weather.
- Vehicles are only used when heavy objects have to be transported

The IceCube array dwarfs the pole station

- IceCube Lab is at the center of neutrino array
- The Cosmic Microwave Background telescopes are about 2/3 of the way to the edge of IceCube
- At a square kilometer it is one of the largest neutrino array in the world



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How are the holes drilled?

- With hot water and a special drill. It is much easier than evacuating a cavity deep in the earth
- Strings of DOMs are lowered and the holes refilled with water

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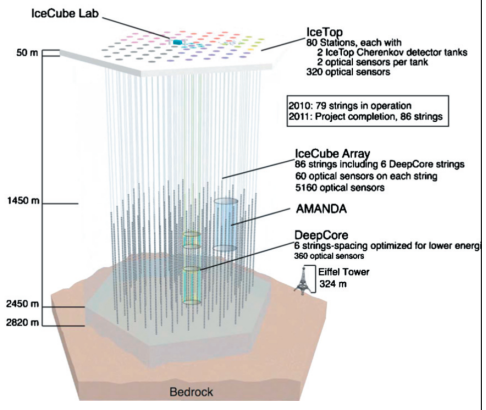
The array has three separate active arrays

- Antarctic Muon and Neutrino DetectorArray (AMANDA) was a proof of concept array and is no longer in use
- IceTop detects cosmic rays that can be ignored in neutrino studies
- IceCube Array is 86 strings each with 60 DOM sensors 17 meters apart for 1 Km
- DeepCore Low-Energy Expansion detects observations below 100 GeV
- Deep Core is in the clearest ice between 1,760-2,450 meters deep
- No DOMs are between 1,850-2107 meters because the ice is not as clear as other depths



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Digital Optical Modules are the detectors that detect photons in the ice

- Photons can travel 125m in the clear ice at the ICL, much farther than water
- The bottom half of the DOM contains the photo multiplier tubes. The top section contains the electronics and connector to the suspension/connector cables
- The holes are refilled with water and allowed to refreeze. Can it be repaired? - Nope. Once it is frozen, it is permanent
- It takes the refrozen ice approximately a year to return to original clarity

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How are neutrinos detected?

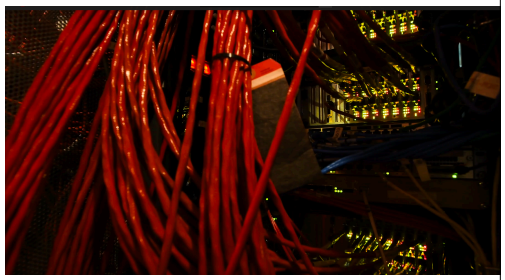
- Neutrinos are electrically neutral leptons, and interact very rarely with matter.
- When they do react with the molecules of water in the ice, they can create charged leptons (electrons, muons, or taus).
- IceCube is sensitive mostly to high-energy neutrinos, in the range of 10^11 to about 10^21 electron volts eV.
- Charged leptons can, if they are energetic enough, emit Cherenkov radiation.
- When a charged particle travels through the ice faster than the speed of light in the ice, a photon can be emitted.
- These photons can be detected by photomultiplier tubes within the digital optical modules (DOMs) in the IceCube.
- The signals from the DOMs are digitized and then sent to the surface of the glacier on a cable and send to the ICL data processing building

How is the data captured and stored?

- The upper deck of the lab contains the computers and control room
- The control room is nothing special, a couple terminals away from the roar of all the servers
- The servers are thru the wall and capture all the data real-time and stores it on hard disks.
- The permanent storage was upgraded from tapes to disks in 2014
- One of the first loads out of the South Pole station at the end of the winters is a huge shipment of hard drives

The data from the DOMs is collected by DOM hubs, sent to the processing farm, and stored on hard disks

- Each DOM hub gathers data from one string of DOMs
- Each string of DOMs has 60 DOMs
- Each red wire, called a Quad, has cabling for 4 DOMs
- All DOMs go into DOM hubs which are all networked together
- These hubs are networked to the processing farms



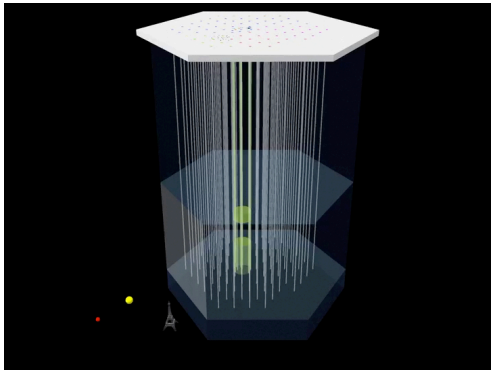
How often are neutrinos detected?

- Cosmic rays generate about 10^6 or one million times more background muons than neutrino-induced muons in IceCube detections
- These cosmic ray associated events can easily be rejected because they are traveling downward
- Most of the additional terrestrial events are caused cosmic ray striking on the other side of the world
- About 75 upward moving are detected a day
- To distinguish between astronomical and terrestrial events, the direction and energy of the neutrinos are estimated by collision by-products
- Excess event for a given direction or excess energy indicate an extraterrestrial source

Only about one extraterrestrial neutrino is detected a month!

How is particle directionality determined?

- Time of photons arrivals and the position of which DOM give the directionality
- Multiple detection on one string of DOMs provides energy estimates
- Pointing accuracy is about 1 degree, about twice the width of the moon
- Note: the neutrino is traveling upward making it interesting



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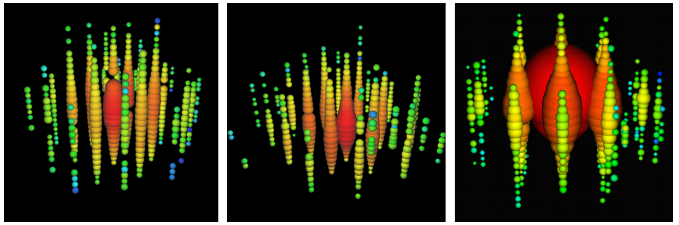
2013 was a banner year when Bert, Ernie, and Big Bird were detected



- Bert and Ernie,left and middle, were about 1 million billion electronvolts, otherwise known as a petaelectronvolt (PeV)
- Big Bird, on right, was 1.95 PeV, the most energetic neutrino ever detected

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IceCube Neutrinos Point to Long-Sought Cosmic Ray Accelerator

- Blazar TXS 0506+056, was first singled out following a neutrino alert sent by IceCube on Sept. 22, 2017
- A blazar is a giant elliptical galaxy with a massive, rapidly spinning black hole at its core
- For the first time this multi messenger event provided evidence for a known blazar as a source of high-energy neutrinos

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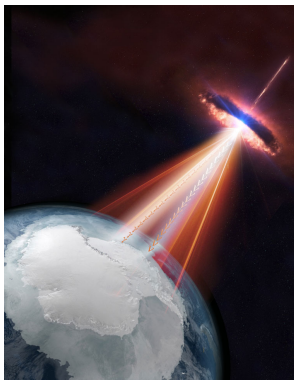
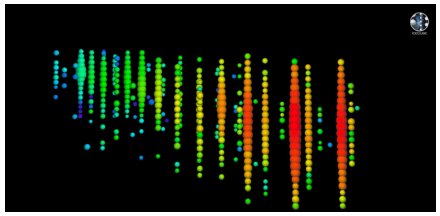
Blazar TXS 0506+056 continued…



- A blazar is a giant elliptical galaxy with a massive, rapidly spinning black hole at its core. A signature feature of blazars is that twin jets of light and elementary particles, one of which is hopefully pointing towards Earth, are emitted from the poles along the axis of the black hole's rotation
- This blazar was just off the left shoulder of Orion and about 4 billion light years from Earth.



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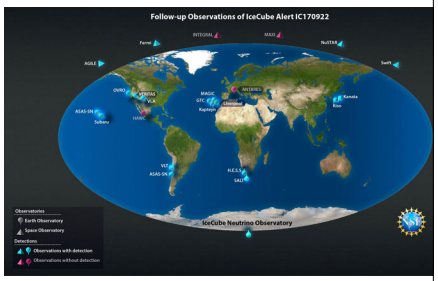
Blazar TXS 0506+056 continued….

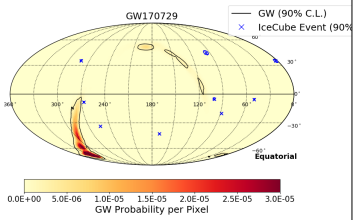
- On Sept. 22, 2017, IceCube alerted the international astronomy community about the detection of a high-energy neutrino
- 20 observatories on Earth and in space made follow-up observations
- Fermi was first to identify gamma-ray activity from TXS 0506+056 within 0.06 degrees of the prediction
- TXS 056+056 is one of the most luminous sources in the known universe and, thus, add support to a multi-messenger observation of a cosmic engine powerful enough to accelerate high-energy cosmic rays and produce the associated neutrinos.



This result was from one single neutrino at the South Pole IceCube Laboratory

What are some other recent scientific results?

- Searching for neutrino emission from 11 LIGO-Virgo gravitational wave sources
  - Gravitational waves and electromagnetic radiation, and neutrinos make excellent messengers
  - Neutrinos are capable of traveling for billions of light-years undisturbed, as are gravitational waves
  - IceCube Collaboration recently performed an analysis to look for neutrino emission that correlates with gravitational waves detected by the LIGO and Virgo Collaborations during their first two observing runs, O1 and O2.



No coincidence was found, but the researchers are already at work on further analyses. "IceCube Search for Neutrinos Coincident with Compact Binary Mergers from LIGO-Virgo's First Gravitational-Wave Transient Catalog," The IceCube Collaboration: M. G. Aartsen et al. 2020 The Astrophysical Journal Letters 898 L10 iopscience.iop.org arxiv.org/abs/2004.02910

Questions and Discussion…

IceCube-Gen2: A Vision for the Future of Neutrino Astronomy in Antarctica

IceCube Explained: Uncharted Cosmos-Mapping the Universe with Icecube

IceCube Home page: https://icecube.wisc.edu/

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