

ICECUBE

Ghosts in the ice: Searching for the Universe's highest energy particles at the South Pole

Darren R. Grant
Department of Physics, Centre for Particle Physics
University of Alberta

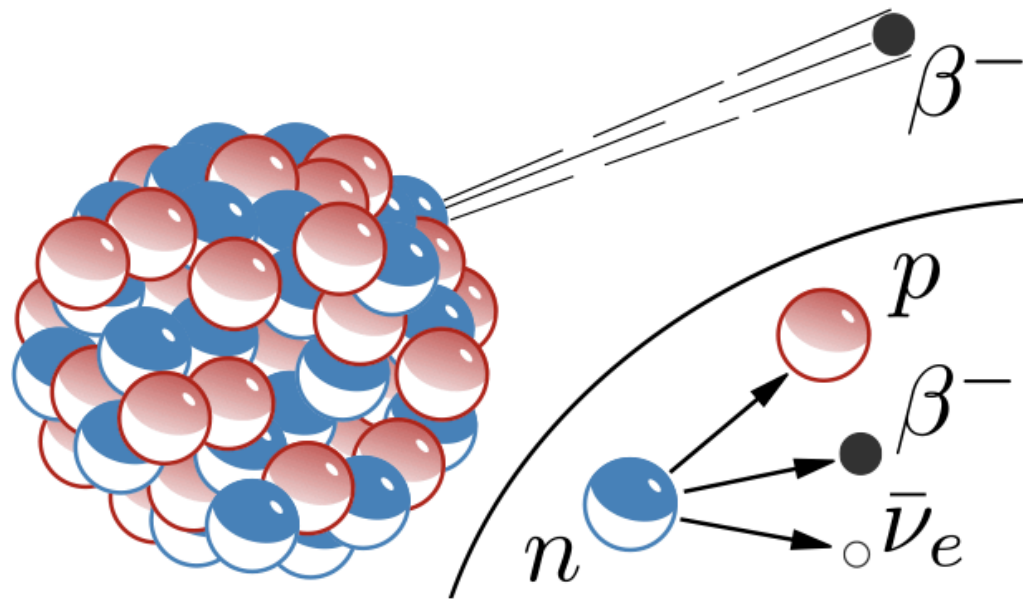
Frontiers of Modern Physics
Vancouver BC
November 24, 2012



UNIVERSITY OF
ALBERTA

Neutrinos: the “ghost” particle

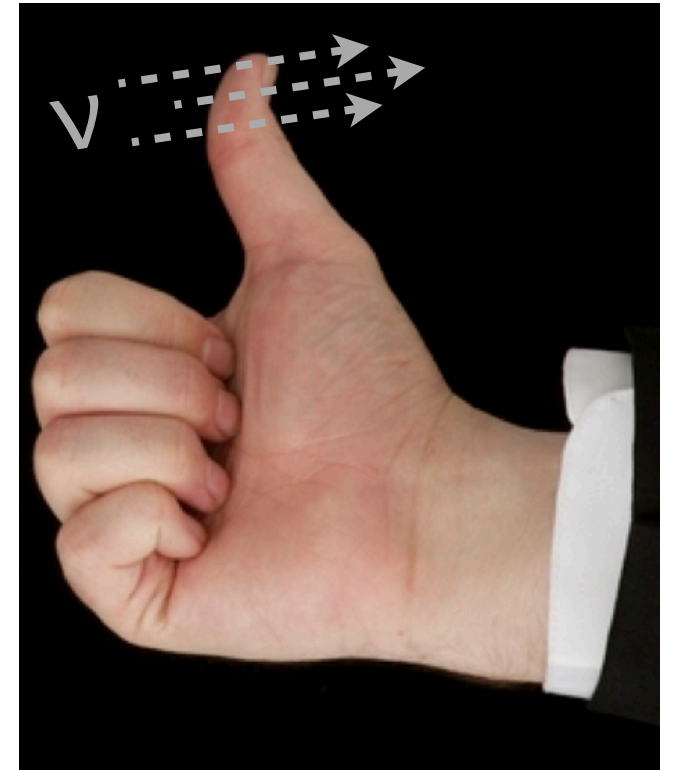
- In 1930 Wolfgang Pauli composes a famous letter as a “desperate attempt” to save the law of conservation of energy for the beta decay process. He suggests, in addition to electrons and protons, atoms contain an extremely light neutral particle which he called the neutron. He suggests this “neutron” is also emitted during beta decay and has simply not yet been observed.
- In 1931 Enrico Fermi renames Pauli’s “neutron” to neutrino, meaning “little neutral one”. Fermi publishes the first successful model of beta decays in which neutrinos are produced in 1934.



Wolfgang Pauli

Neutrinos: the “ghost” particle

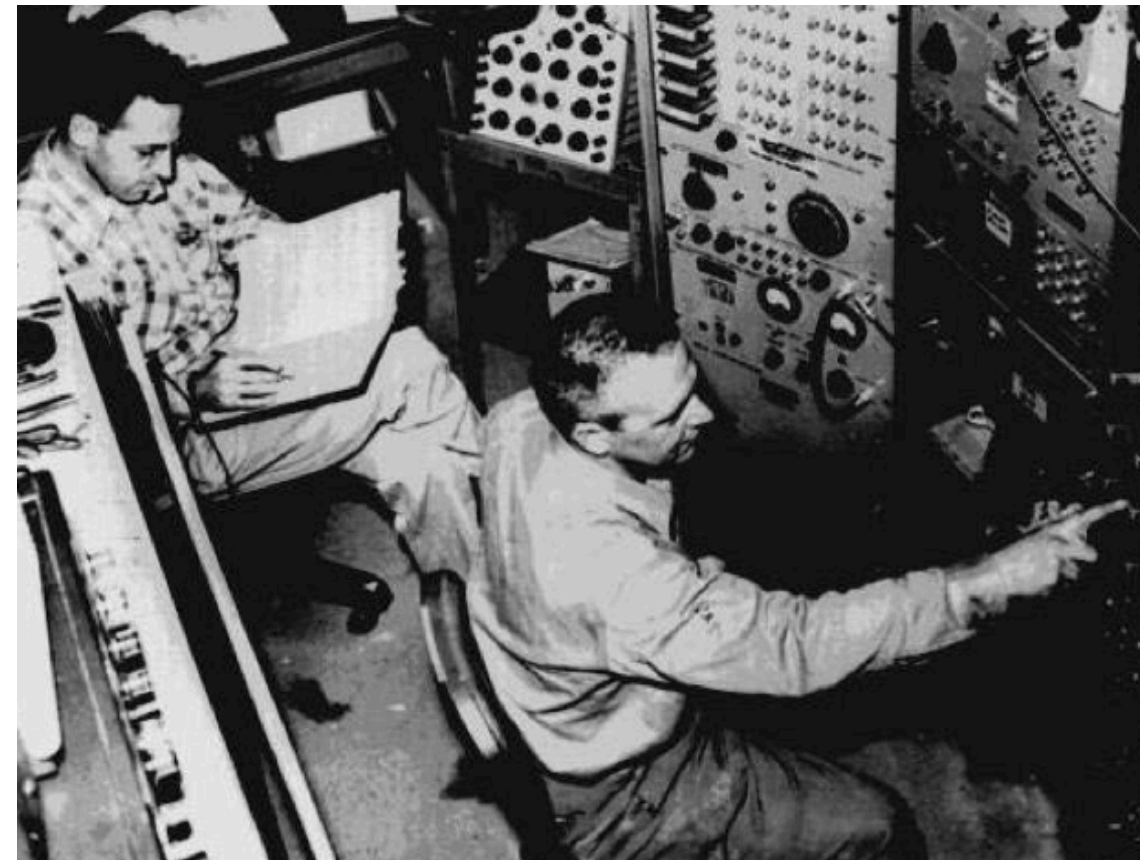
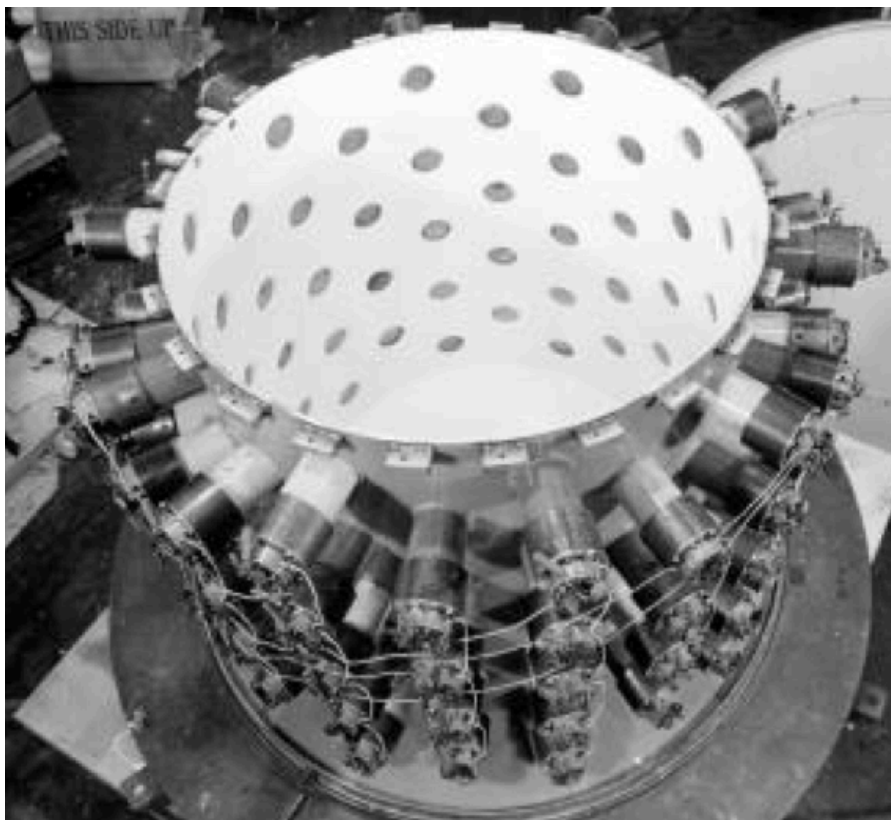
- “Rule of Thumb” - neutrinos interact with only the weak force in nature, meaning they can pass through large amounts of matter with very little probability for interaction 10 billion through your thumb nail per second.
- To guarantee an interaction you would require a column of lead approximately 1 light-year in length.



Ghostbusters: Harold Ramis, D. Aykroyd, B. Murray and E. Hudson. Courtesy of Columbia Pictures.

Neutrinos: the “ghost” particle

- In 1953 Fred Reines and Clyde Cowan find tentative first evidence for the neutrino at a reactor with the Hanford Experiment (Project Poltergeist). Nobel prize awarded in 1995.



Ghostbusters: Reines and Cowan

Neutrinos: the “ghost” particle

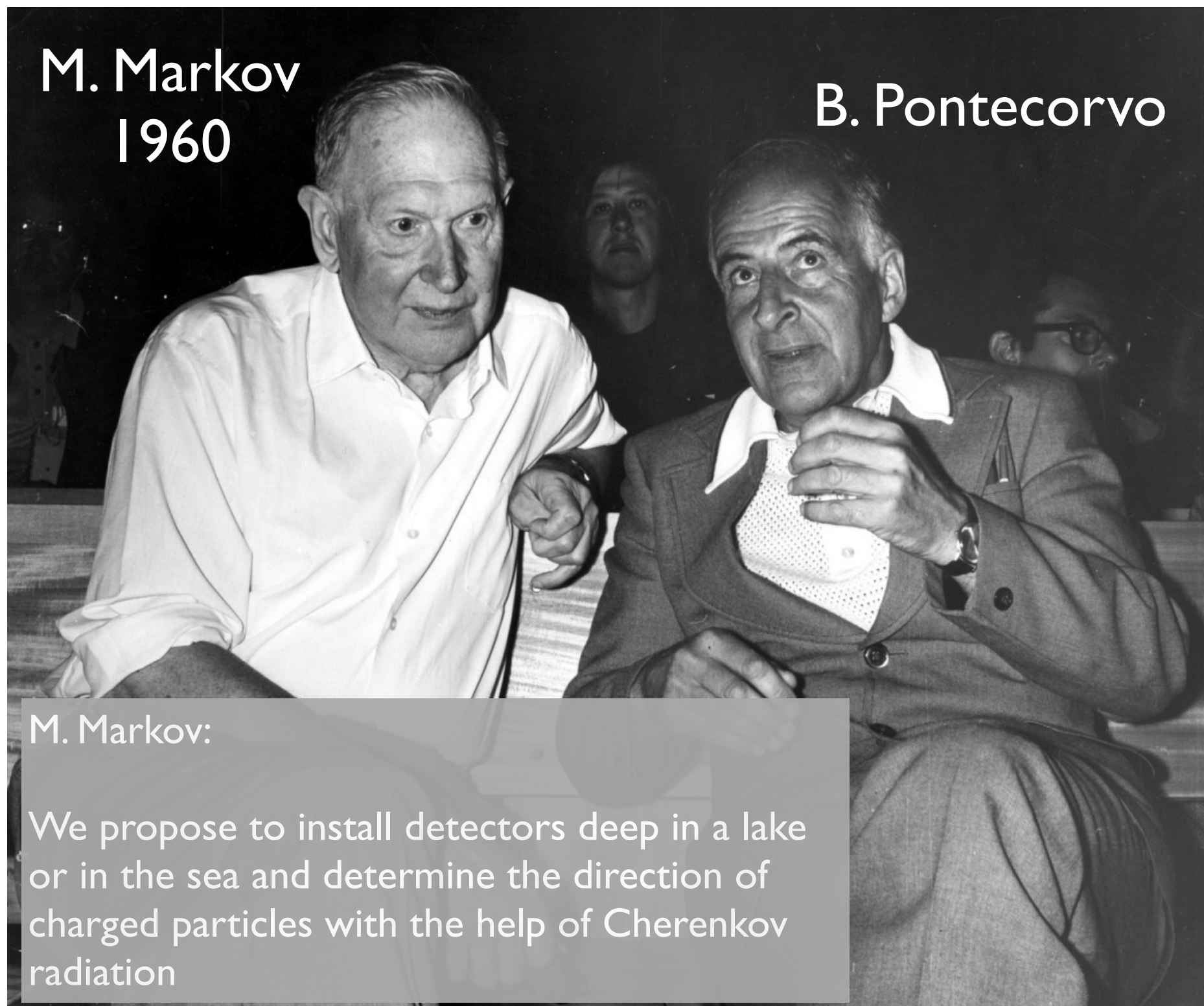
Messengers from space...

- The Homestake Experiment, lead by Ray Davis Jr., designed to make the first measurement of neutrinos from the Sun.
- 100k gallons of perchloroethylene (dry cleaning fluid). Rich in chlorine, interactions with neutrinos changes the chlorine to argon which can be extracted and measured to provide event rate.
- Measured rate is found to be $\sim 1/3$ that predicted to be produced in the Sun, thus creating the “Solar Neutrino Problem”
- Davis is awarded the Nobel Prize in Physics in 2002 for this work.



Ghost buster: Ray Davis Jr. at Homestake

Neutrinos: the “ghost” particle



M. Markov
1960

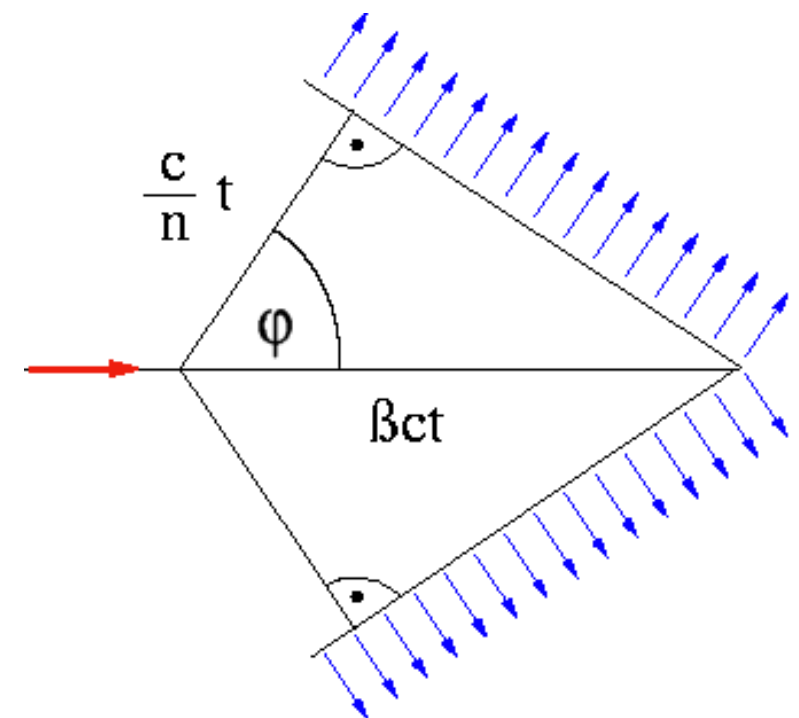
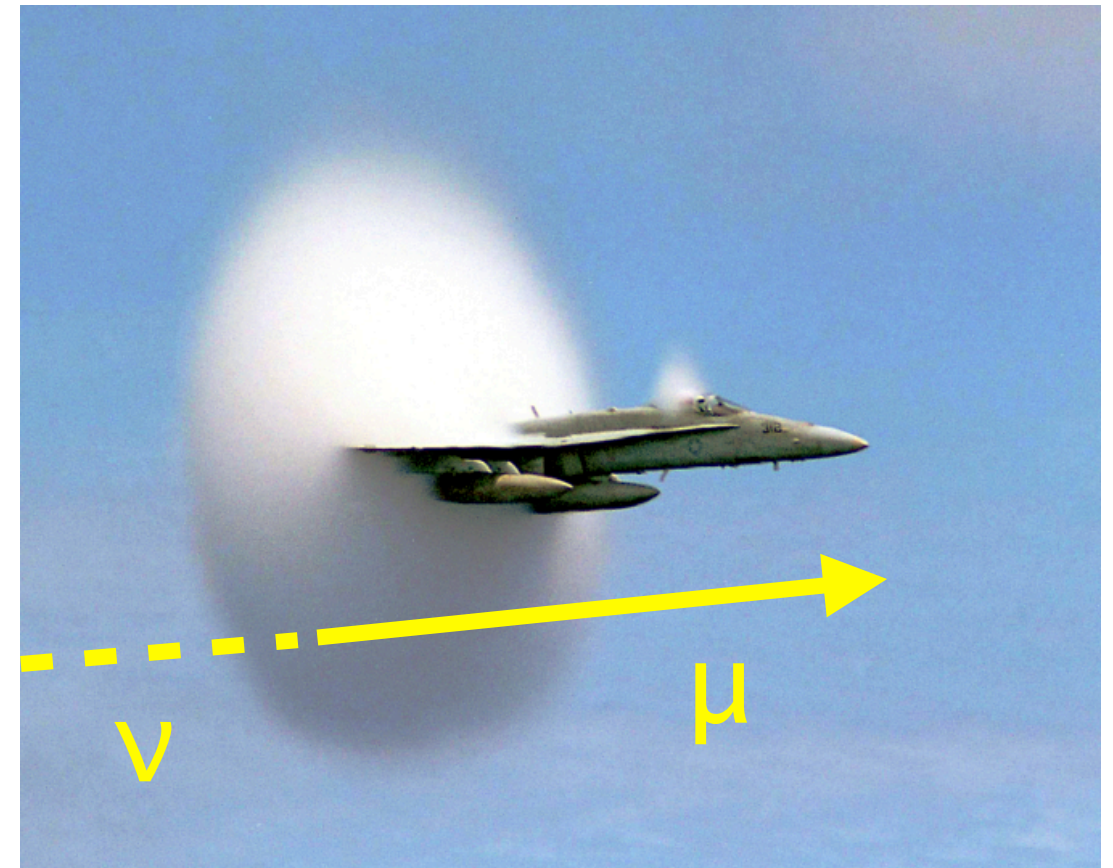
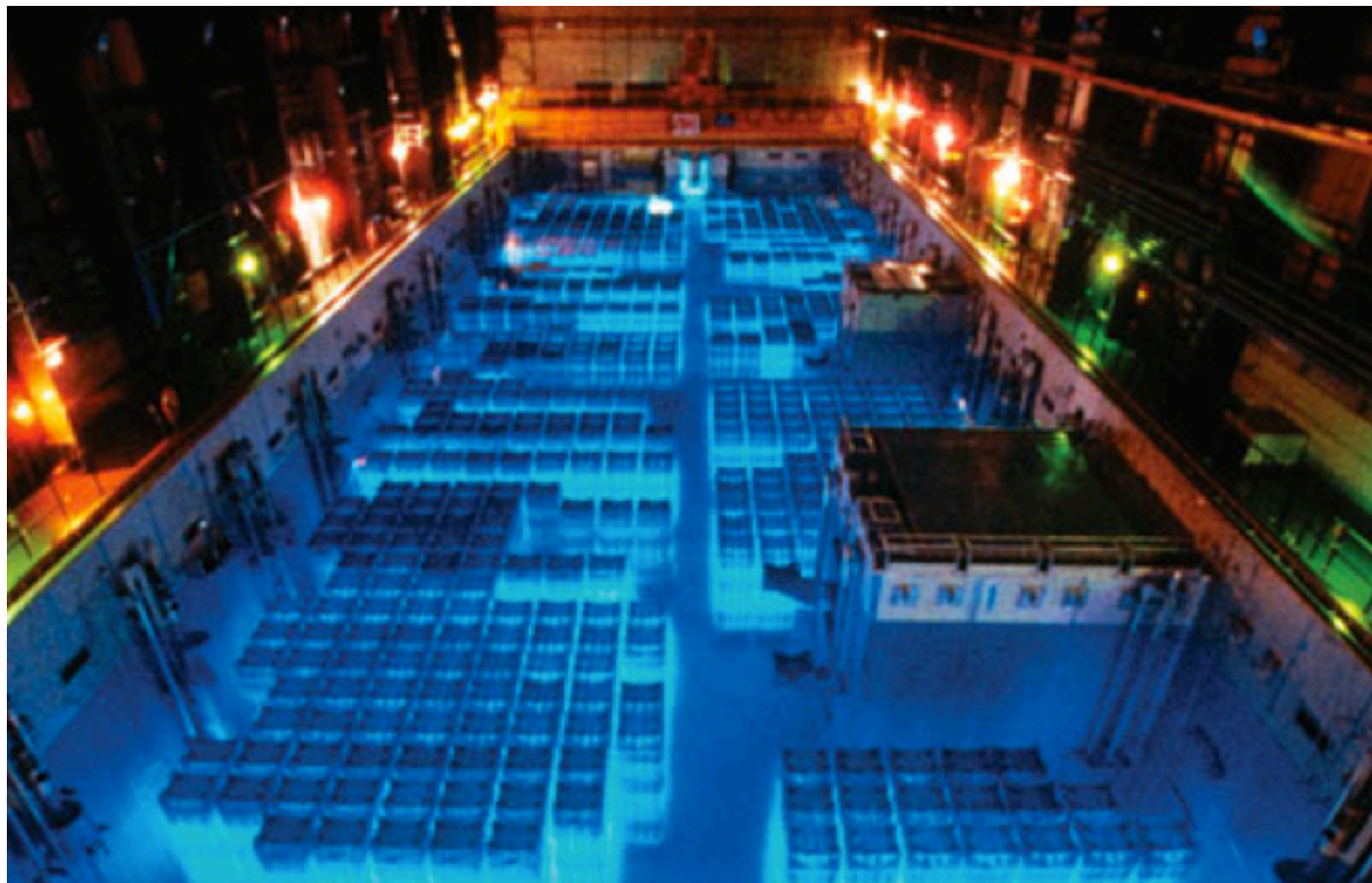
B. Pontecorvo

M. Markov:

We propose to install detectors deep in a lake or in the sea and determine the direction of charged particles with the help of Cherenkov radiation

Cherenkov radiation

- A charged particle moving fast enough to break the speed of light in a medium produces the equivalent of a sonic-boom in light (violet-blue wavelength) along the track the particle traverses.
- Observed, for example, in the cooling pools of nuclear reactors.



Cosmic Rays and the high energy Universe

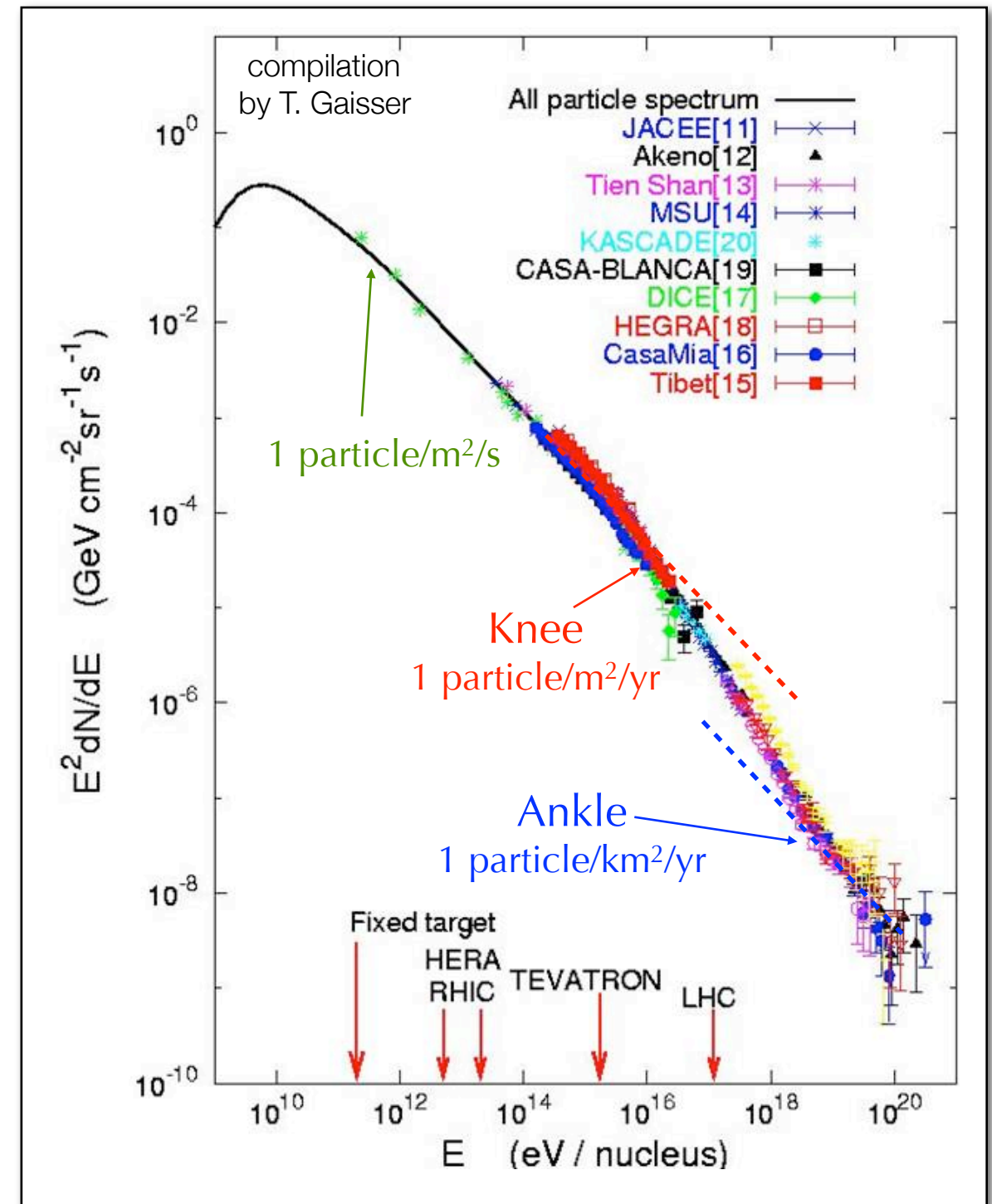
- Victor Hess measures radiation of cosmic origin first in 1912
 - Charged particles, so they don't point back to their sources
 - Clues from spectrum, composition
 - Astrophysical accelerators?
 - How are they accelerated?



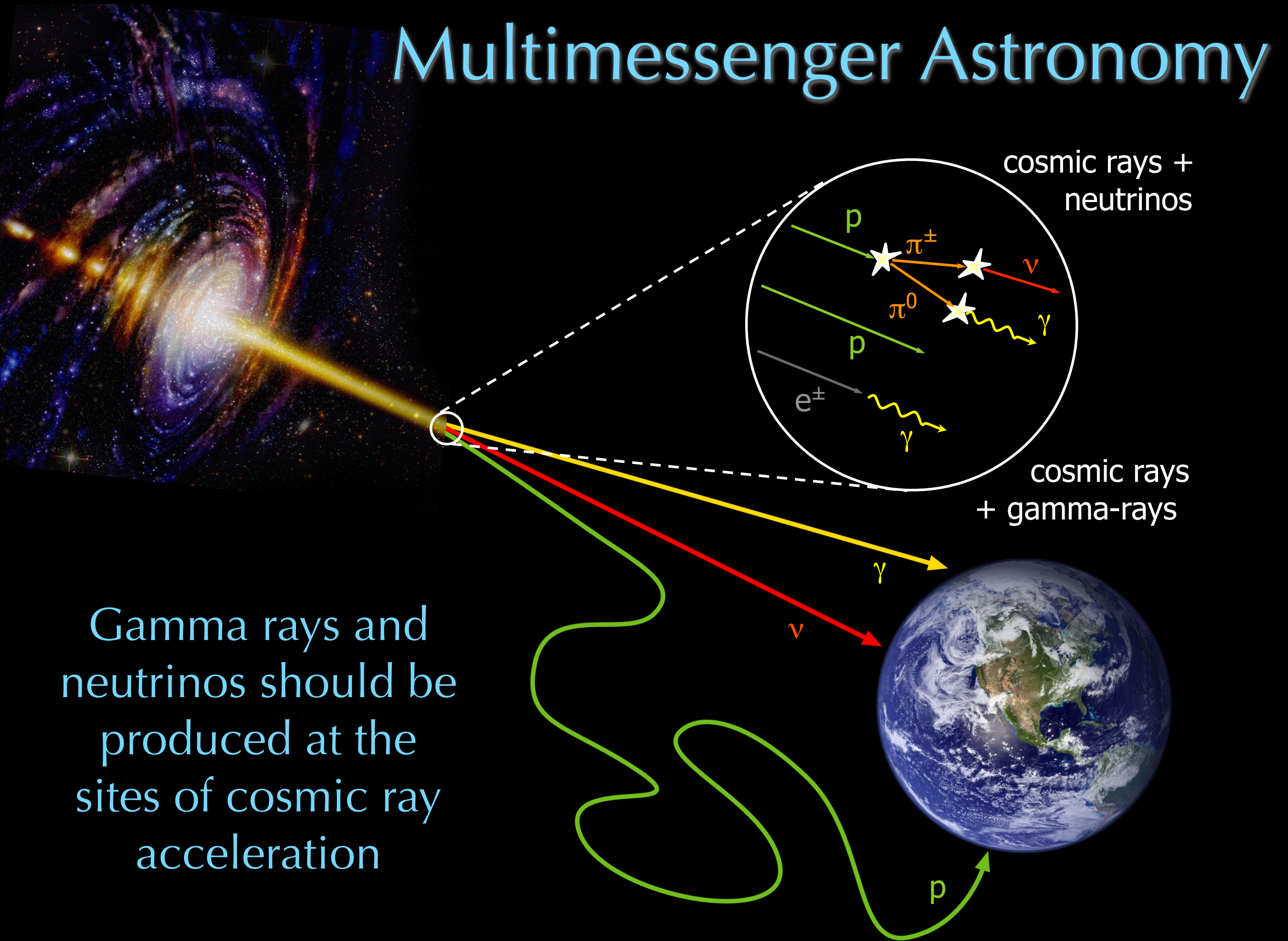
Victor Hess

Cosmic Rays and the high energy Universe

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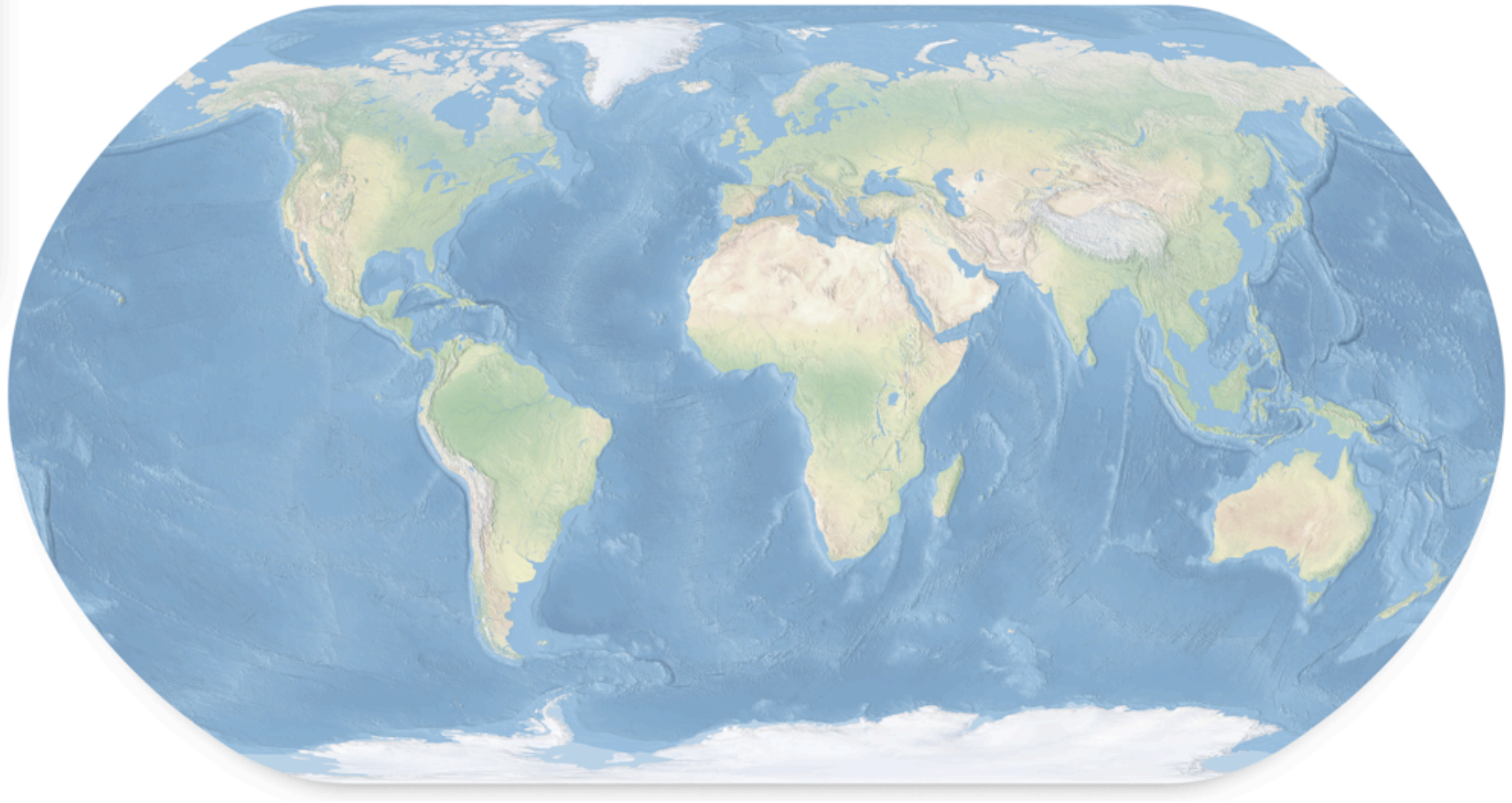


Multimessenger Astronomy



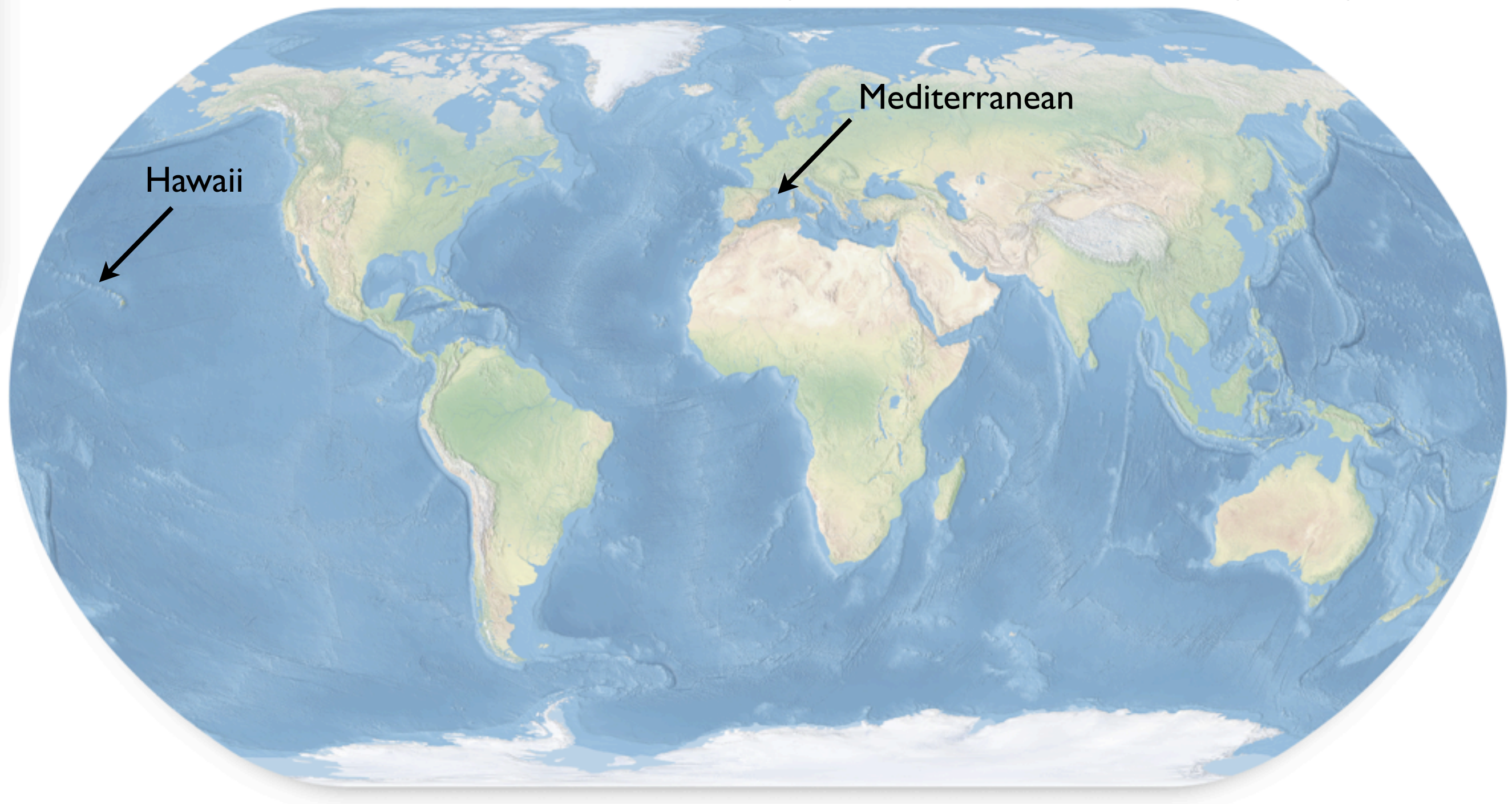
Where in the world?

Very deep site
Stable and clean (low-background) environment
Readily Accessible and Scientifically Ready



Where in the world?

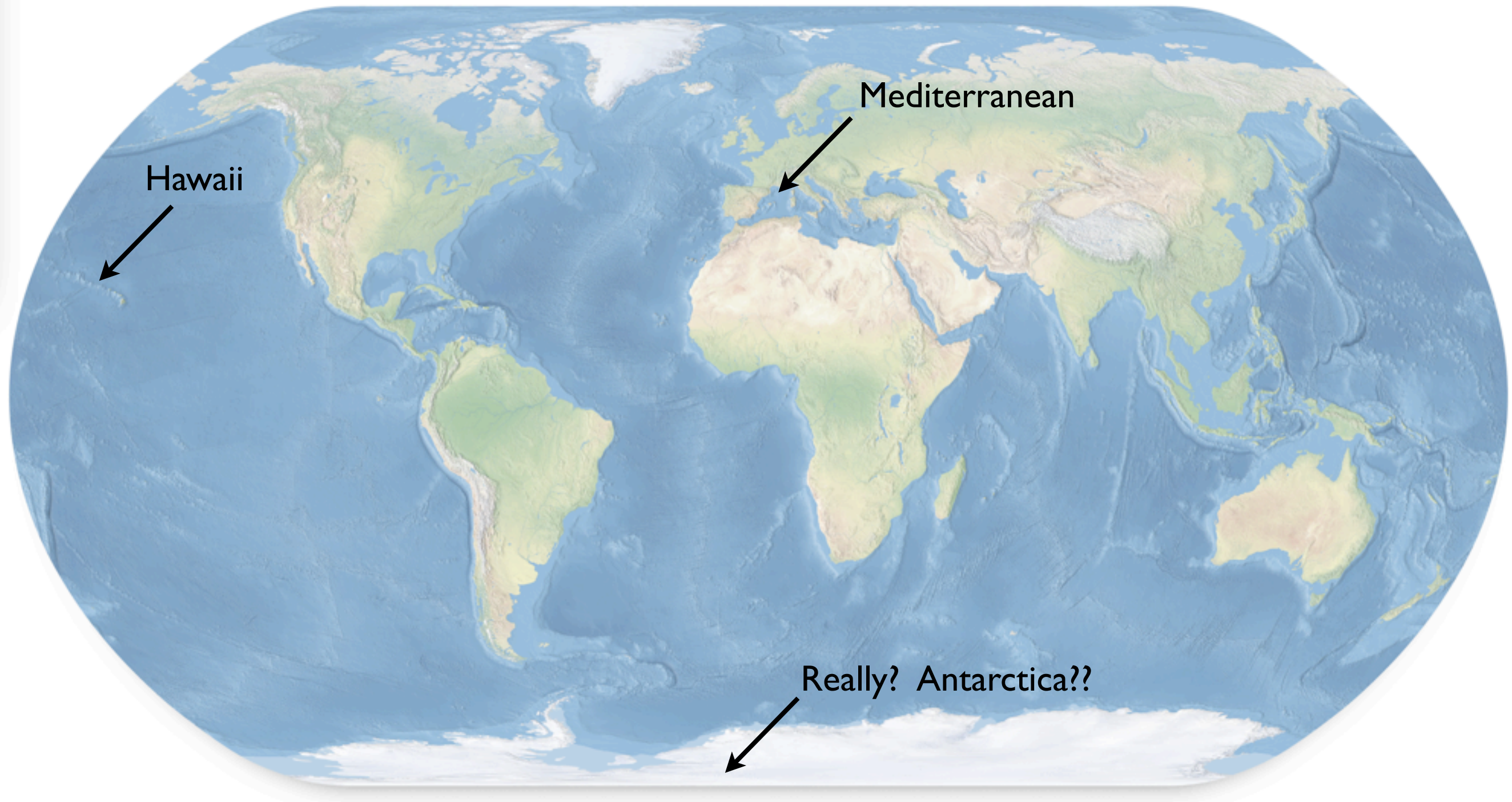
Very deep site
Stable and clean (low-background) environment
Readily Accessible and Scientifically Ready



Oh... and let's choose something warm and exotic so we want to visit...

Where in the world?

Very deep site
Stable and clean (low-background) environment
~~Readily Accessible and Scientifically Ready~~

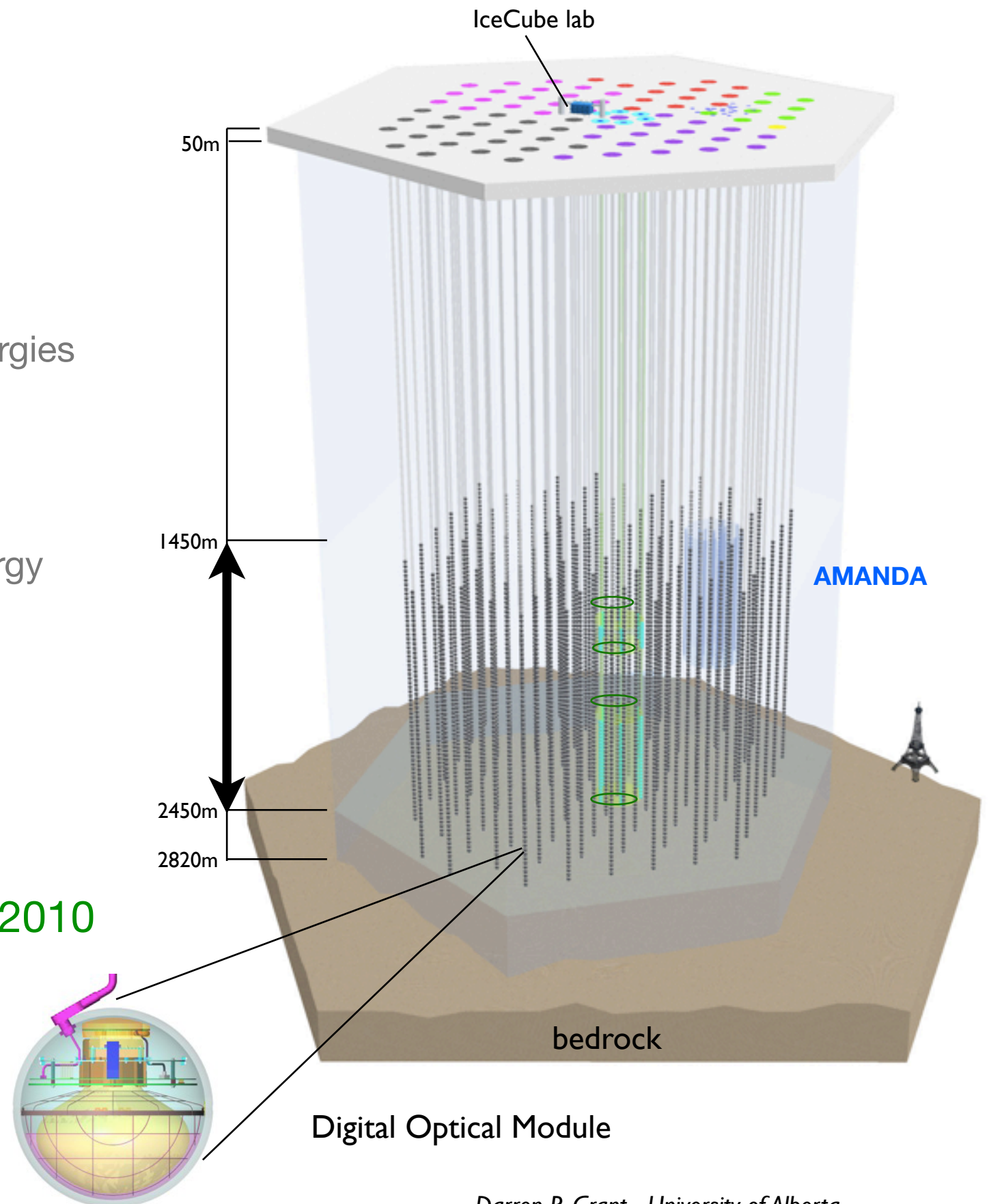


~~Oh... and let's choose something warm and exotic so we want to visit...~~

The IceCube Neutrino Observatory

- Very large scale “hybrid” observatory
 - ~\$272M to construct (NSF, Sweden, Germany, Belgium)
- IceCube:
 - ~1 cubic-km instrumented volume
 - Designed to detect neutrinos with energies between 200 GeV and 10 EeV.
- DeepCore extension:
 - 8 new strings ~\$4M addition.
 - Dense instrumentation lowers the energy threshold to 10 GeV
 - (my pride and joy)
- IceTop:
 - Surface air shower detector array.
 - Threshold approx. 300 TeV

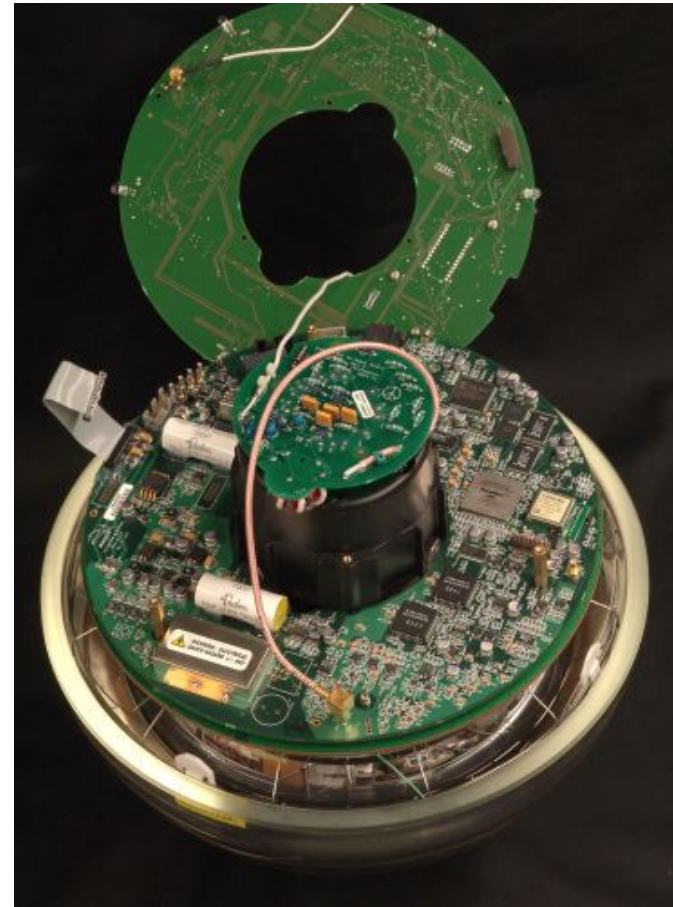
Completed December 18, 2010



The IceCube Detectors

- Digital Optical Module
 - Ultra-sensitive light sensors (photomultiplier tubes) with complete on-board high voltage and data acquisition.
 - Complete signal digitization within the ice.

Photomultiplier Tube

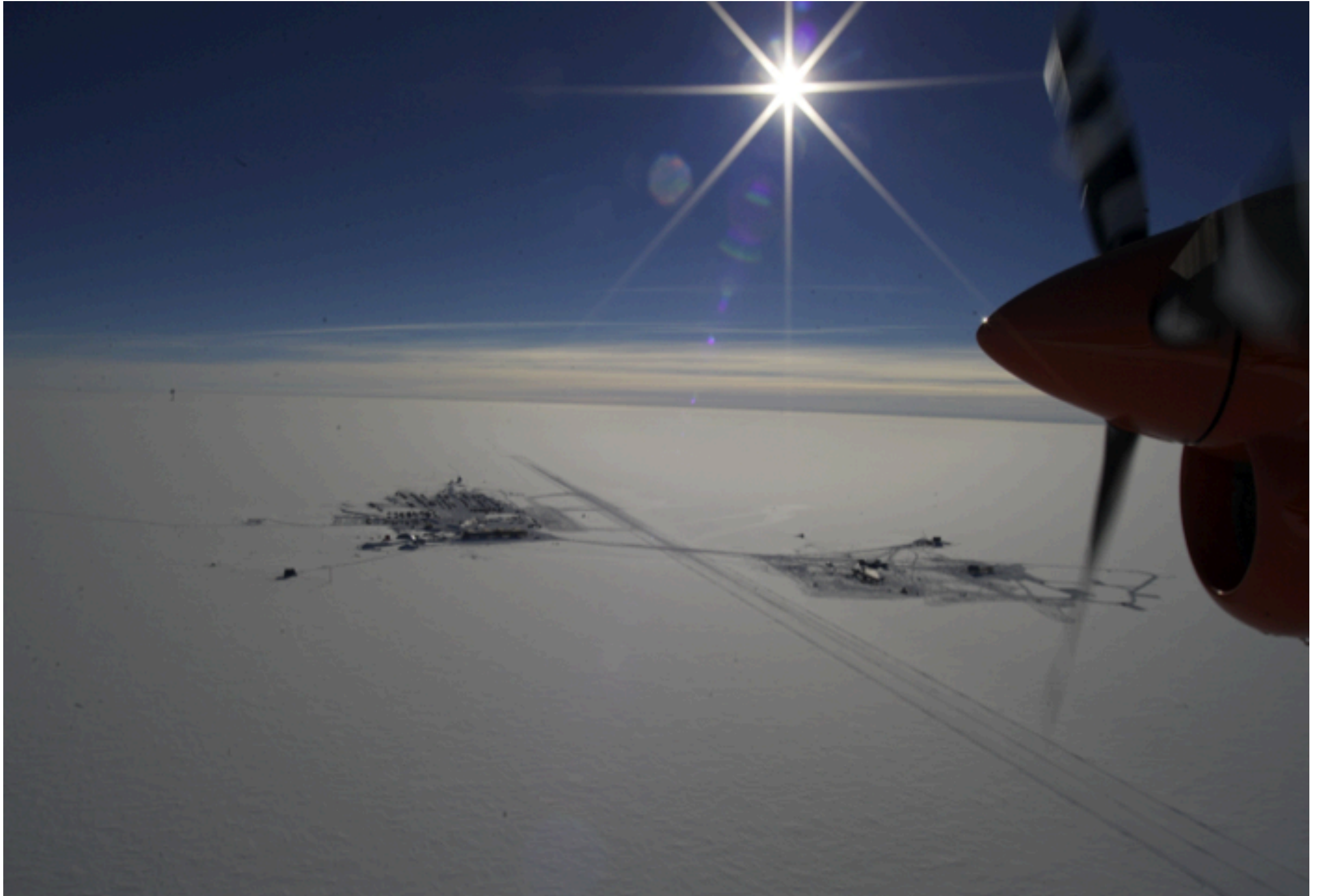




The IceCube Collaboration

38 institutions - 4 continents - ~250 Physicists

Let's build it! Onward to the South Pole...



Amundsen-Scott South Pole Station, Antarctica

First we choose a hero from history for inspiration



Sir Ernest Shackleton

On 2nd attempt misses reaching South Pole by 190 km.
Subsequent ill-fated attempt to traverse the Antarctic continent



Robert Scott

Led the 2nd party of (5) explorers ever to reach the South Pole.
Perish in their return journey from the pole from exhaustion,
starvation and extreme cold.



Roald Amundsen

Led the first Antarctic expedition to ever reach the South Pole.
Returns safely. Is the first man ever reach both poles and
traverse the North-west passage.

First we choose a hero from history for inspiration



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Roald Amundsen ✓

100th Anniversary December 2011!

Led the **first** Antarctic expedition to ever reach the South Pole.
Returns safely. Is the first man ever reach both poles and traverse the North-west passage.

First steps... getting there!

early transport for people and equipment...
(Antarctica direct... many many months)



Roald Amundsen - South Pole Expedition 1911

First steps... getting there!

modern transport for equipment (Antarctica
direct.... still many many months)



First steps... getting there!

modern transport for people...Christ Church NZ to McMurdo Station Antarctica
(direct in 5hrs!)



2nd steps... Landing!

costal Antarctica....

sunny

exotic

warm



2nd steps... Landing!

costal Antarctica....

sunny ✓

exotic

warm



2nd steps... Landing!

costal Antarctica....

sunny ✓

exotic ✓

warm



2nd steps... Landing!

costal Antarctica....

sunny ✓

exotic ✓

warm... relatively (think about where we are planning to head next) ✓



The Polar Trek

early transport for people and equipment...
(South Pole less than direct, again.. many
many months)



POLAR TRANSPORT.

By dog sled. In: "The South Pole", by Roald Amundsen.

Roald Amundsen - South Pole Expedition 1911

The Polar Trek



Amundsen-Scott South Pole Station, Antarctica
modern transport for people and equipment... a 4 hr hop from direct from the coast!

Time to step up camp for the night...

Past...Summer population 5 people



The first men to the South Pole - Roald Amundsen, Olav Olavson Bjaaland, Hilmer Hanssen, Sverre H. Hassel and Oscar Wisting.

Time to step up camp for the night...

Present... summer population ~250 people



IceCube Graduate Student Karen Andeen
"hero photo"

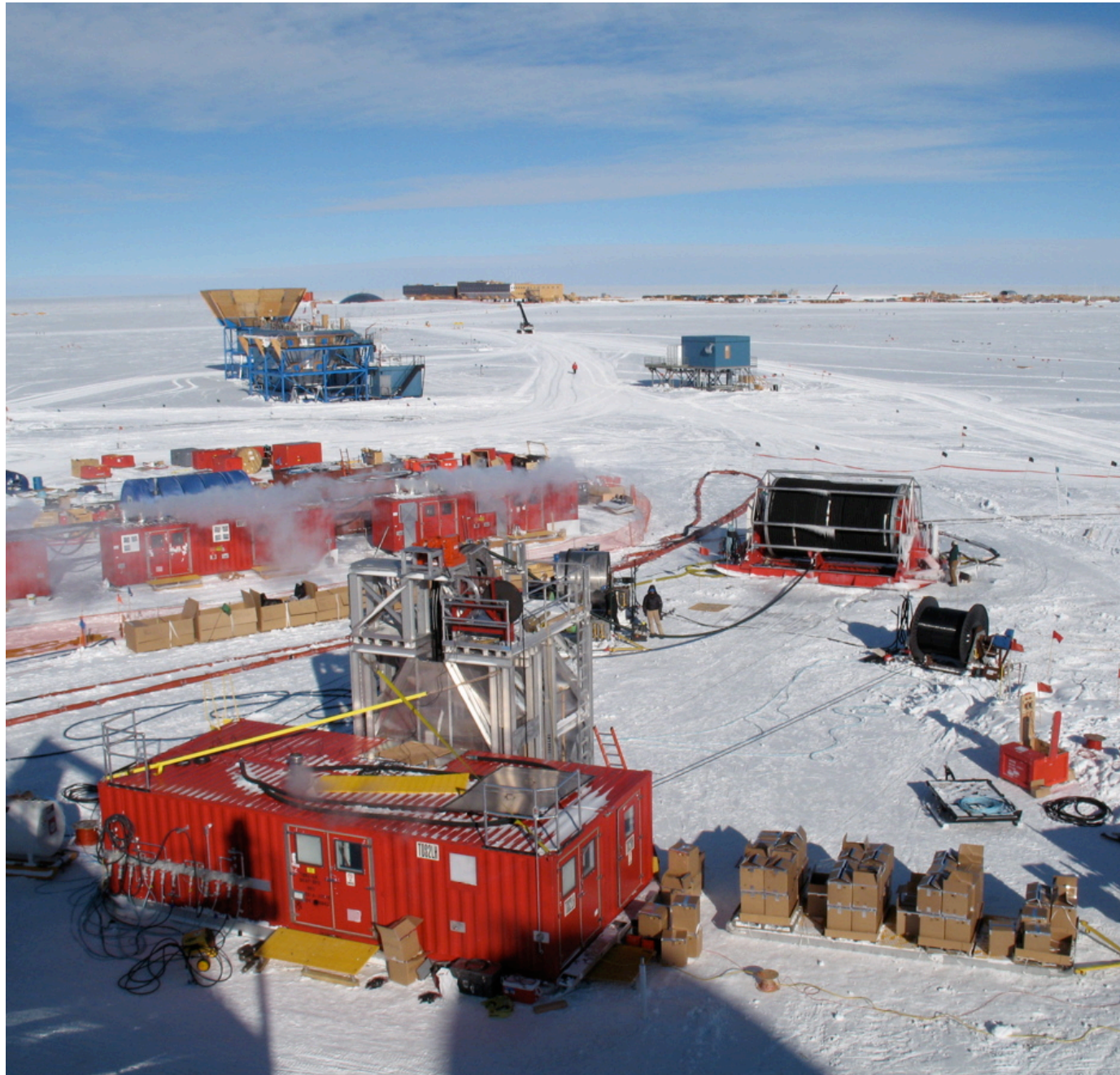
Let's get down to work!

Past...

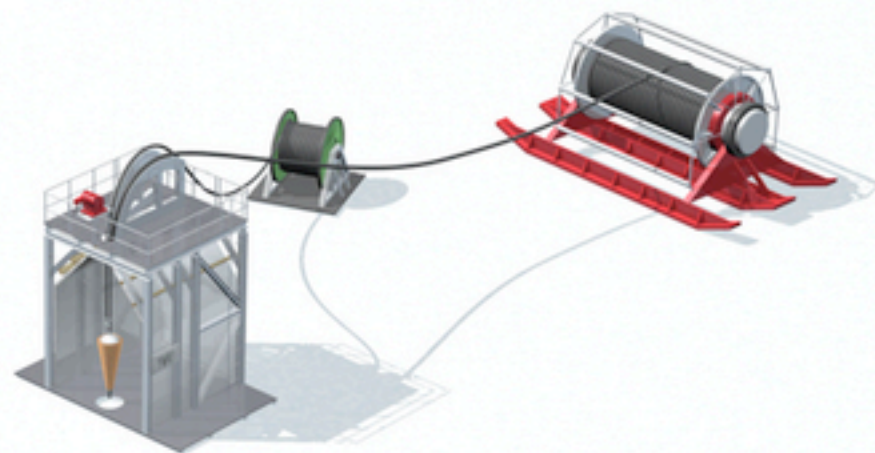


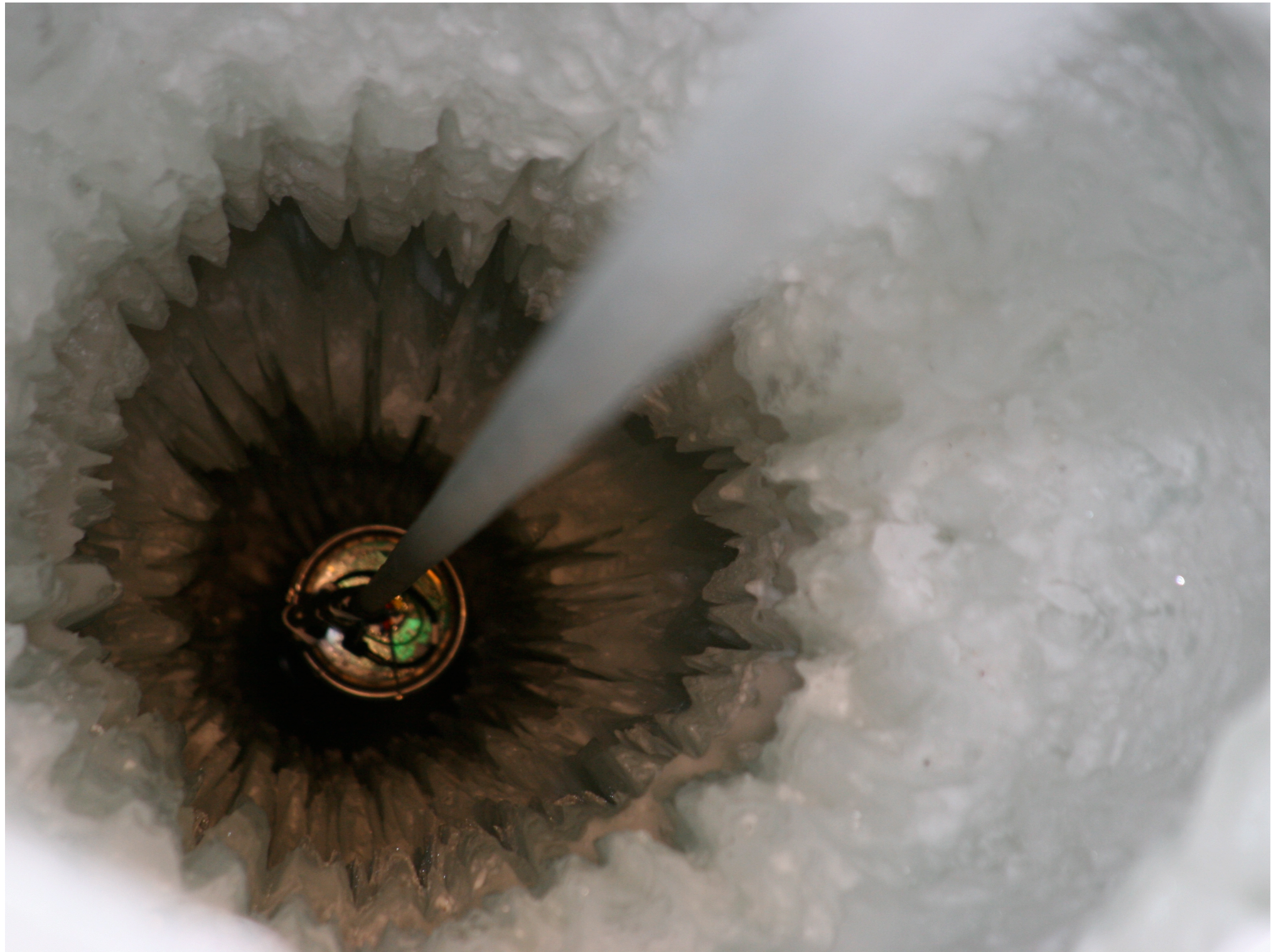
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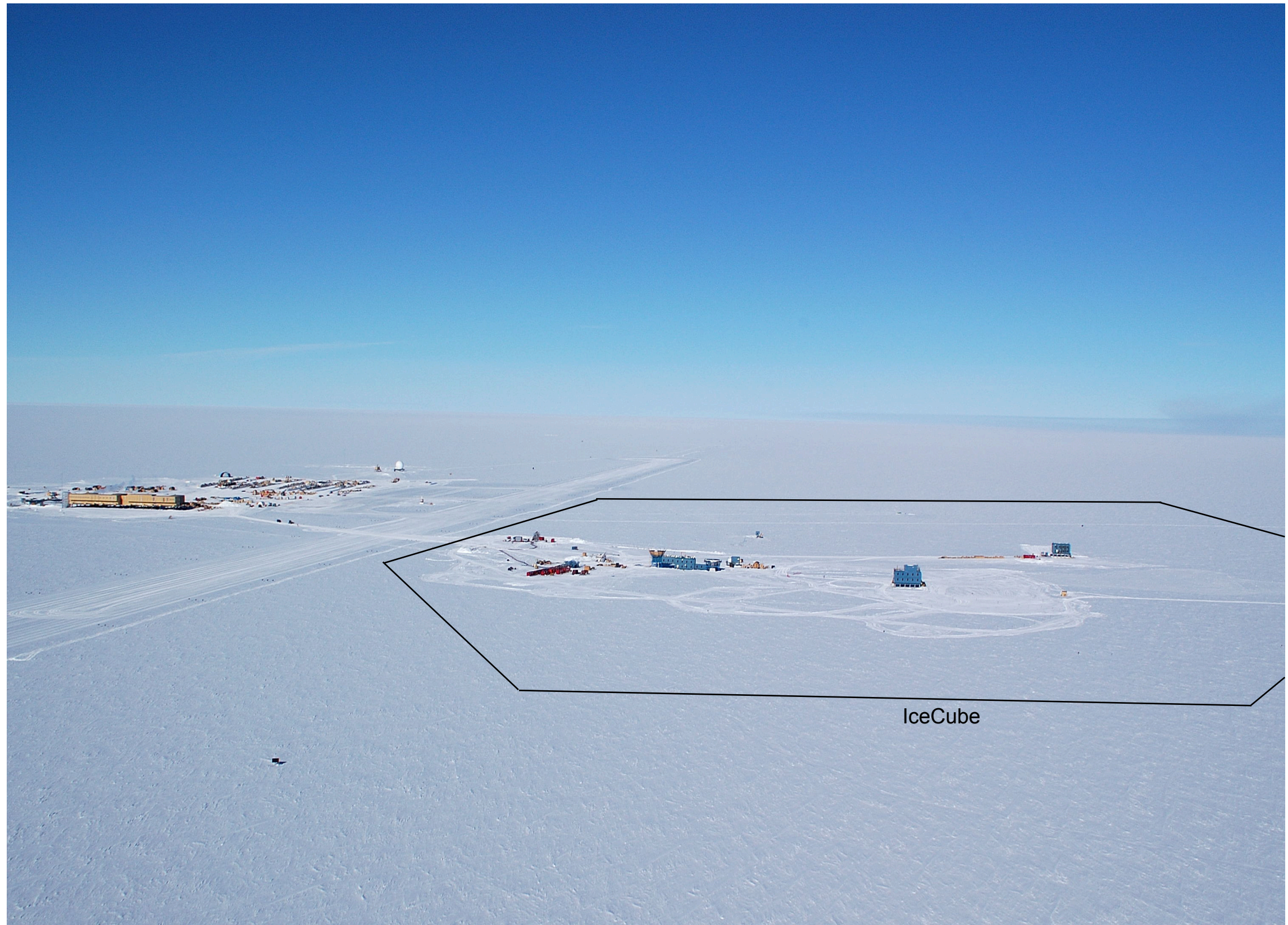
very recent past...



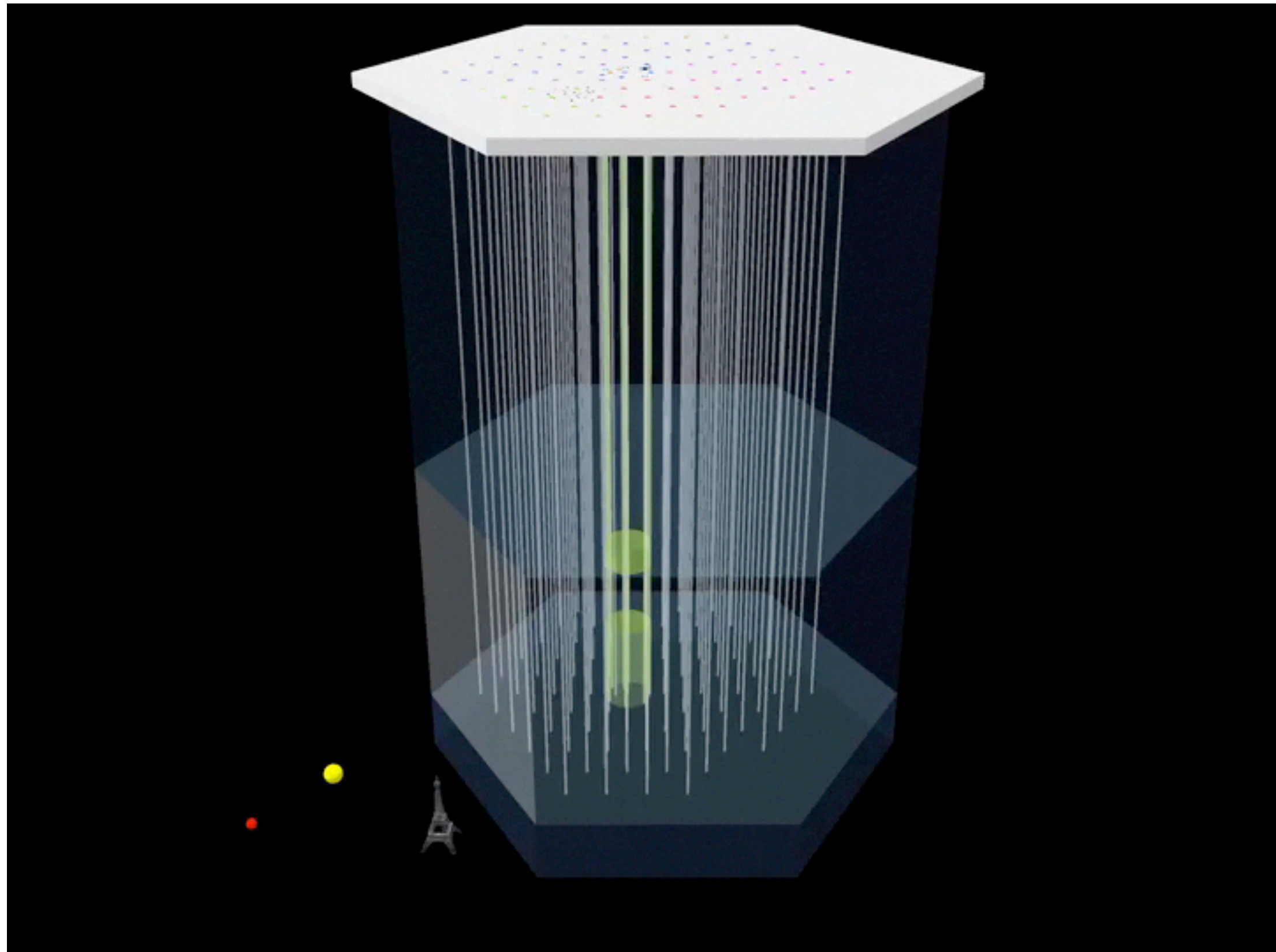
IceCube Drill-Camp, South Pole Station Antarctica



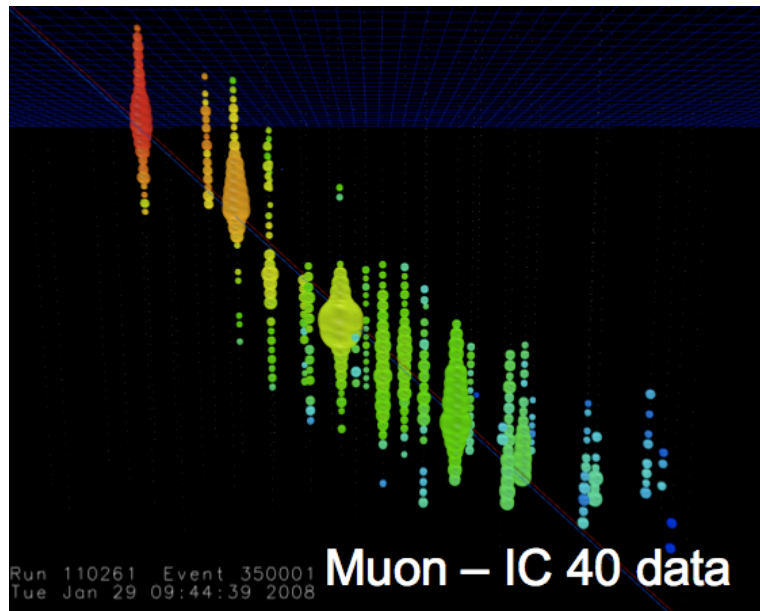




Amundsen-Scott South Pole Station, Antarctica



Neutrino Telescopes - Principle of detection for 3 flavors

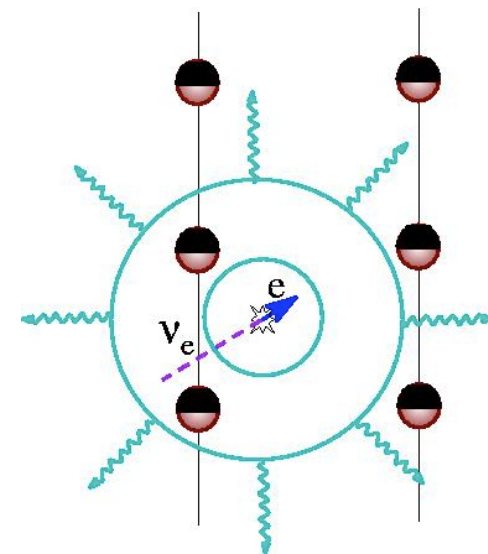
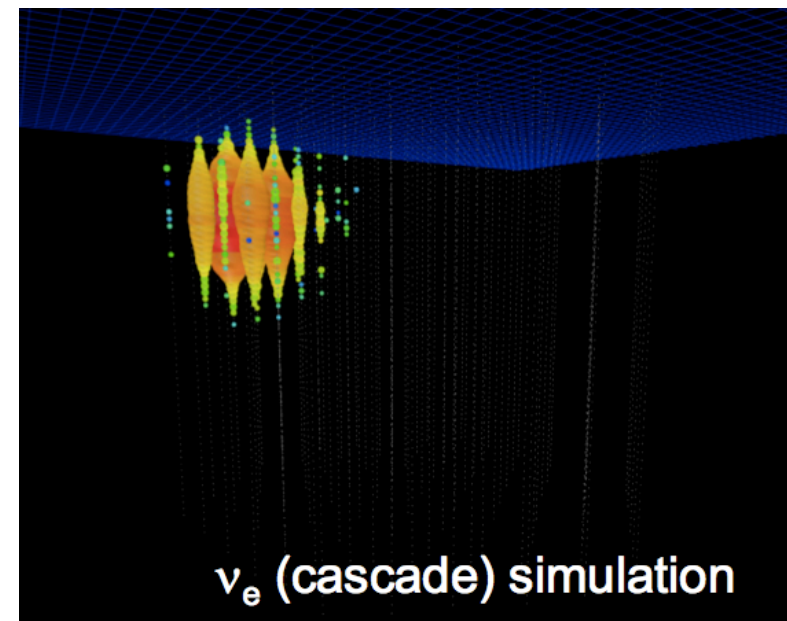
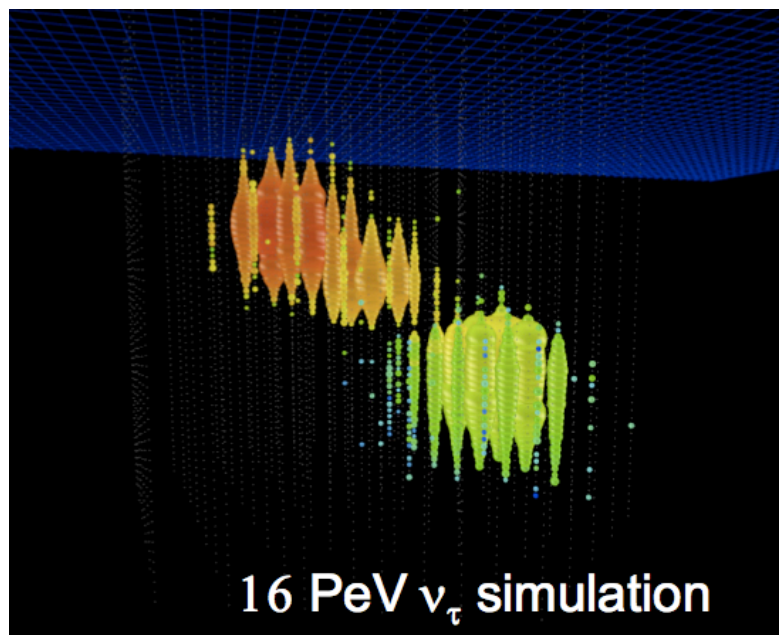


Tracks:

- through-going muons
- pointing resolution $\sim 1^\circ$

Cascades:

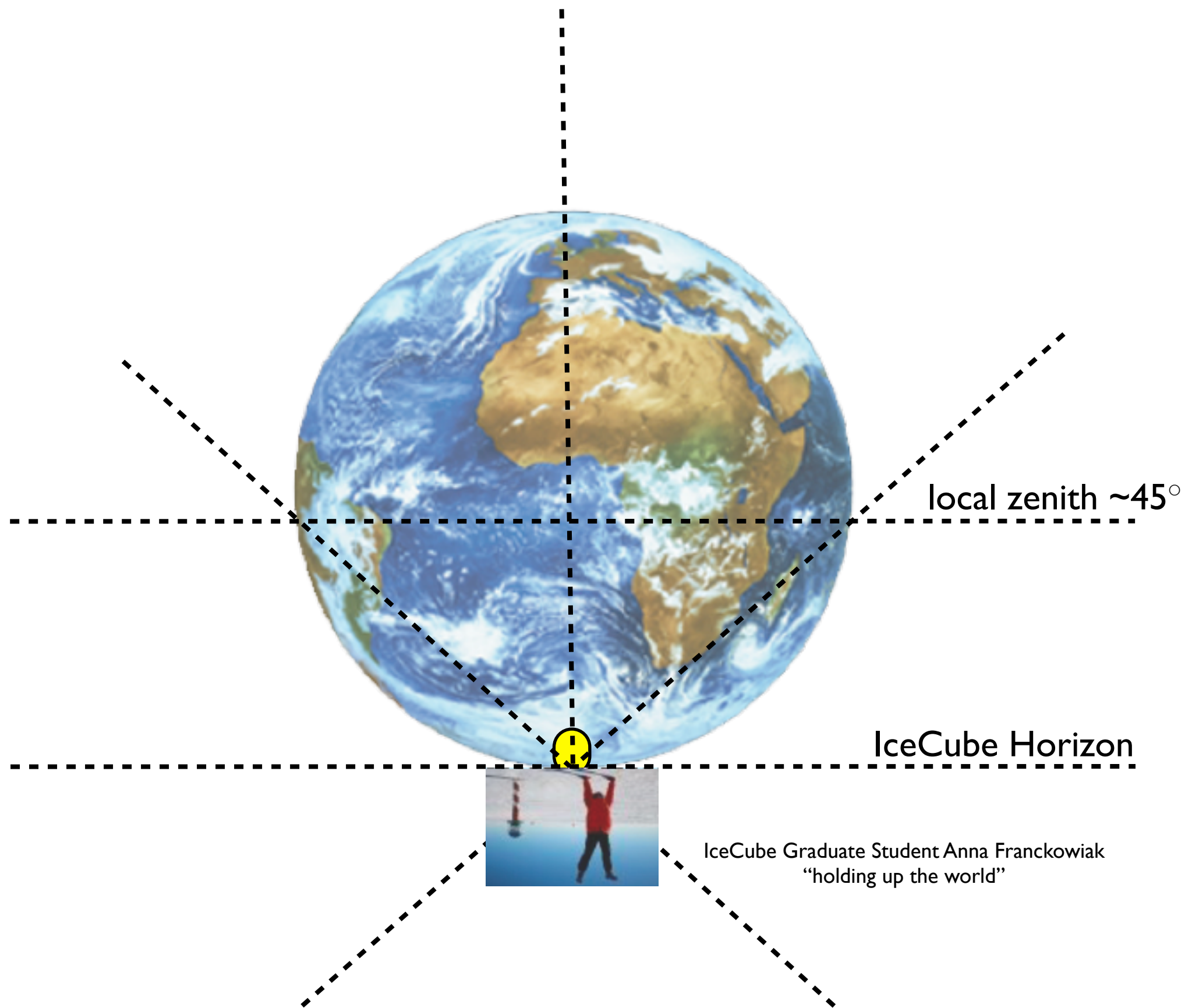
- Neutral current for all flavors
- Charged current for ν_e and low-E ν_τ
- Energy resolution $\sim 10\%$ in $\log(E)$



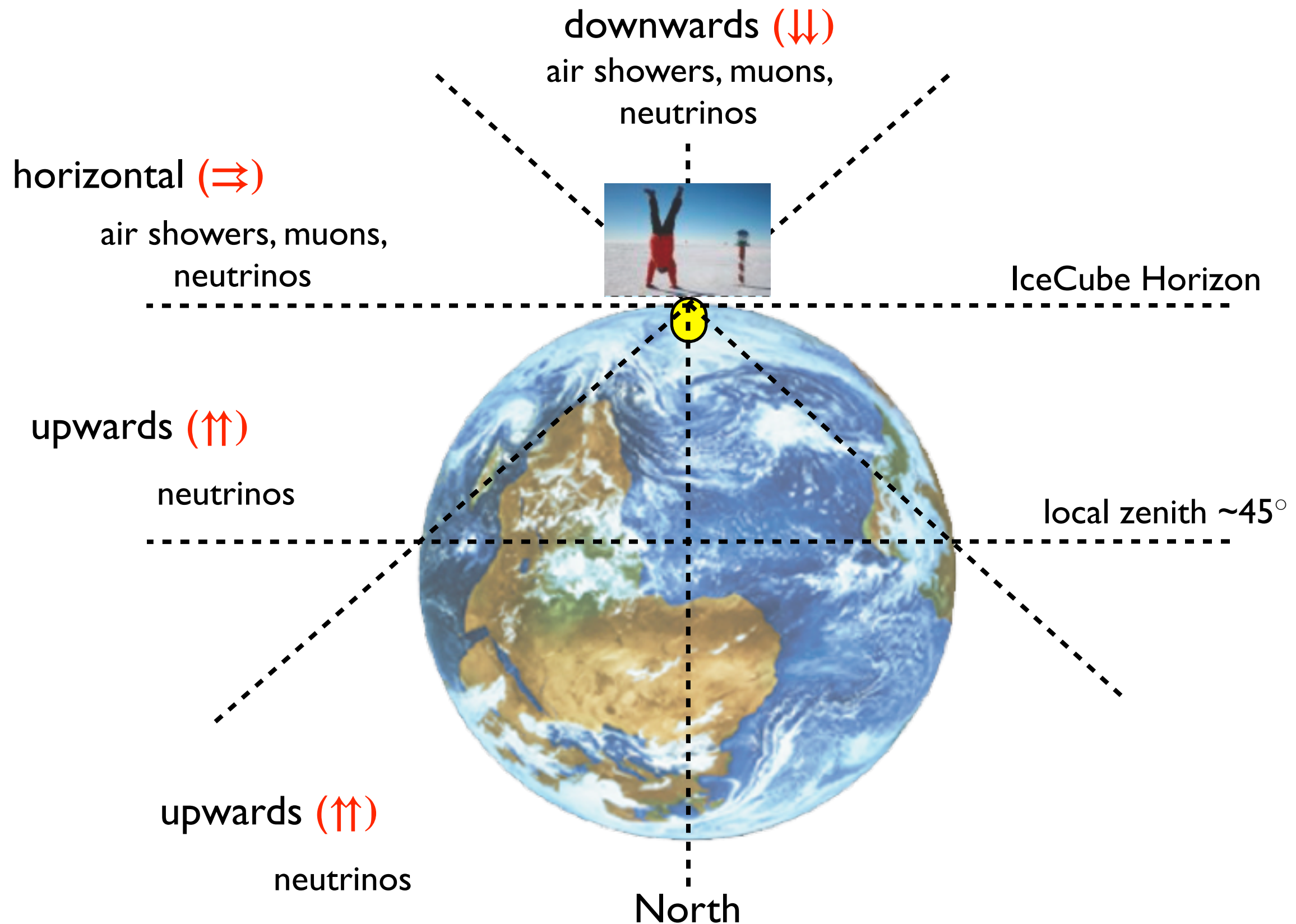
Composites:

- Starting tracks
- high-E ν_τ (Double Bangs)
- Good directional and energy resolution

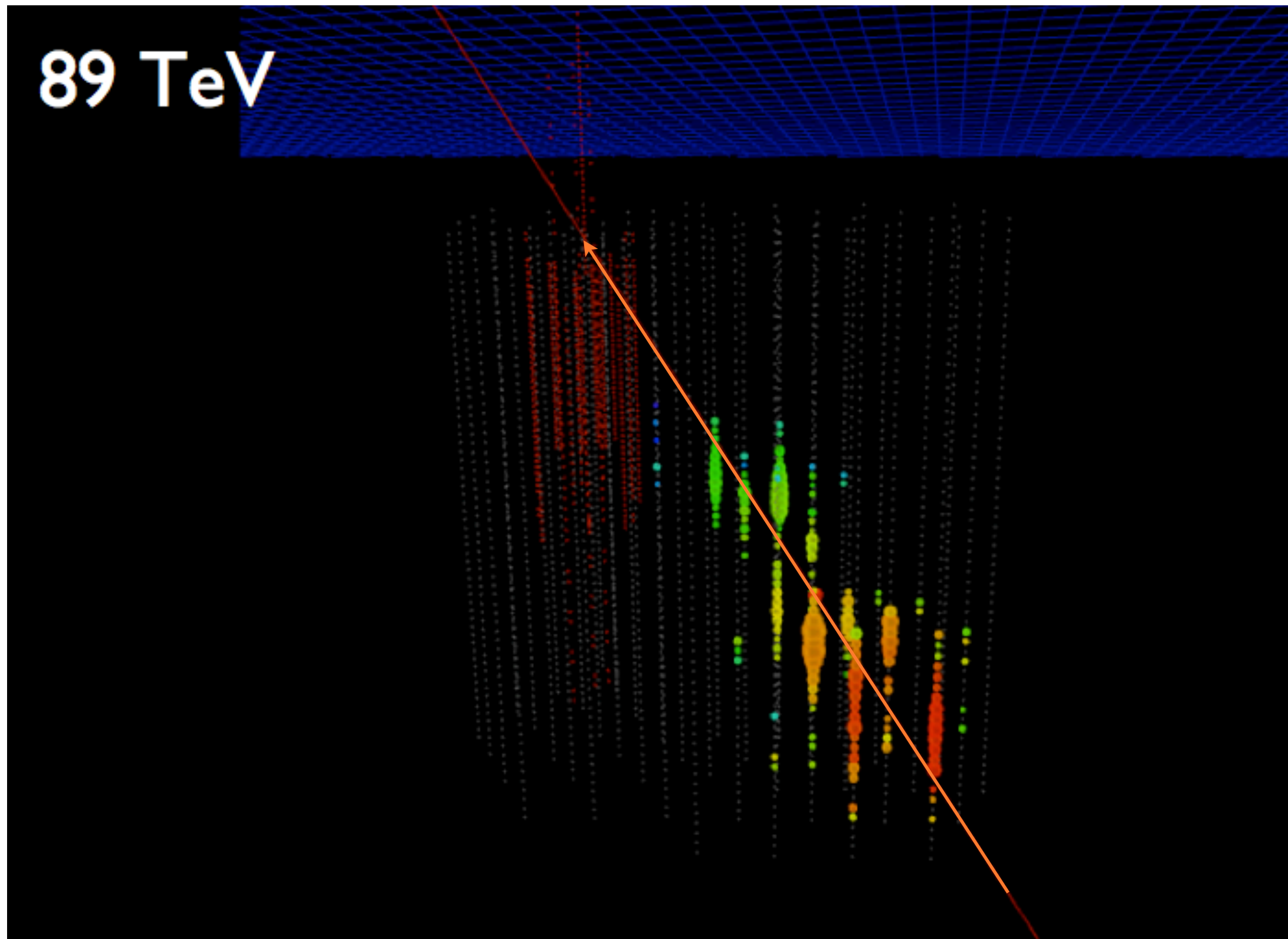
Just to make sure we get things straight...



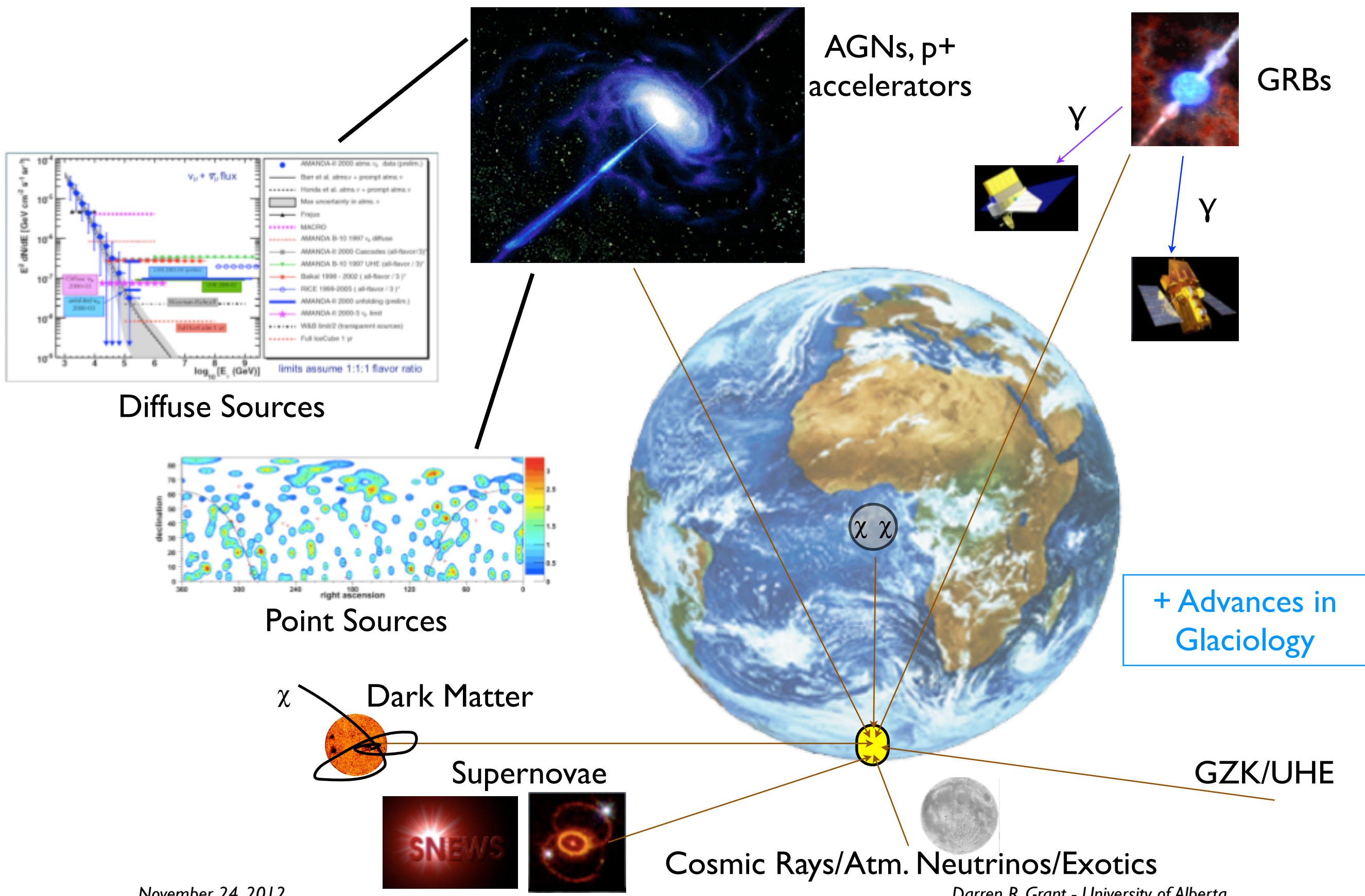
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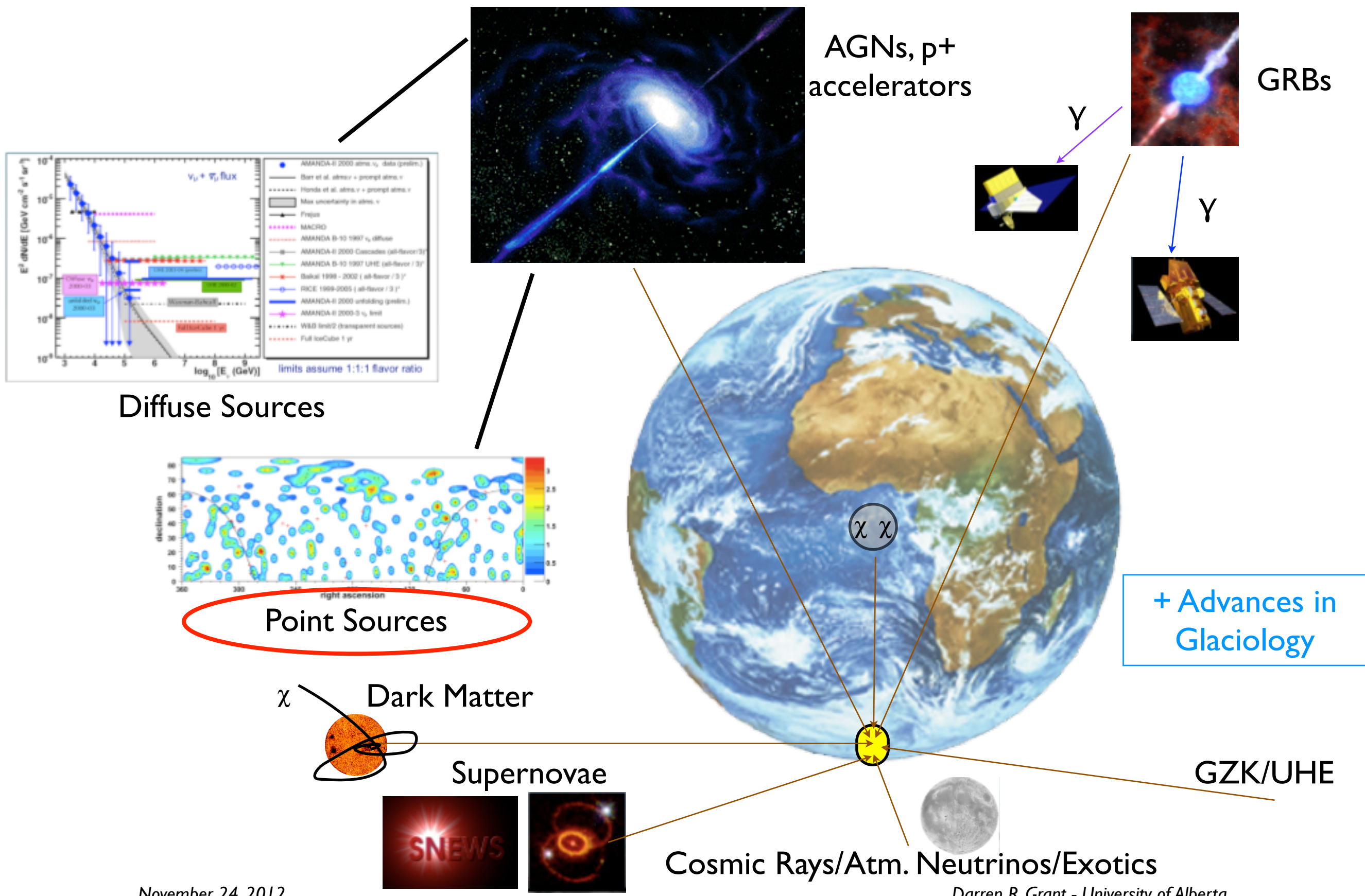
Identifying “ghosts” in the ice...



The IceCube Neutrino Observatory - A Wealth of Science...

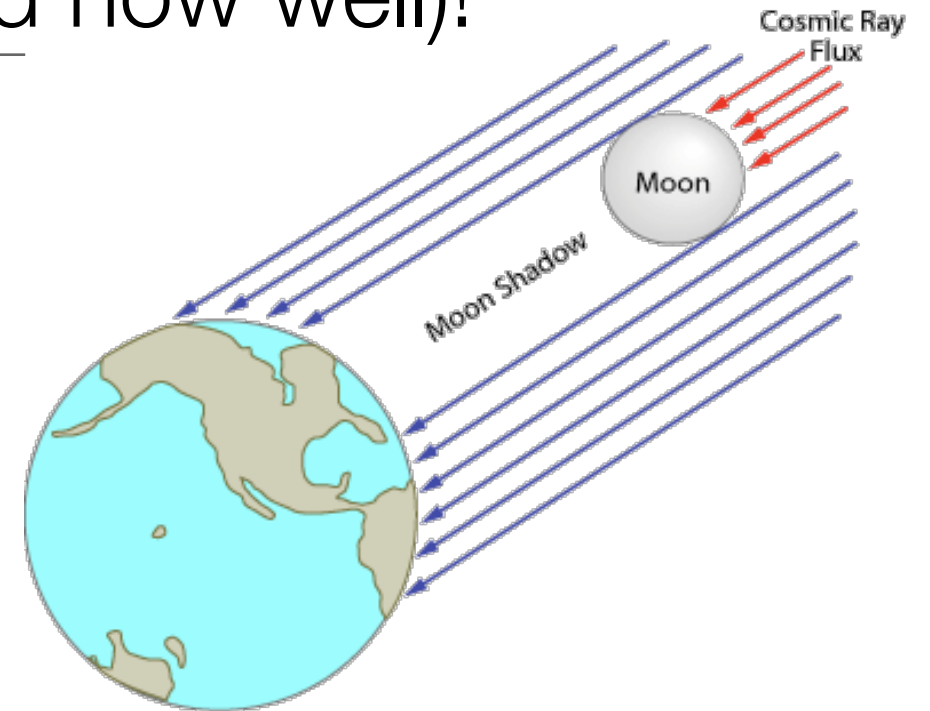


The IceCube Neutrino Observatory - A Wealth of Science...

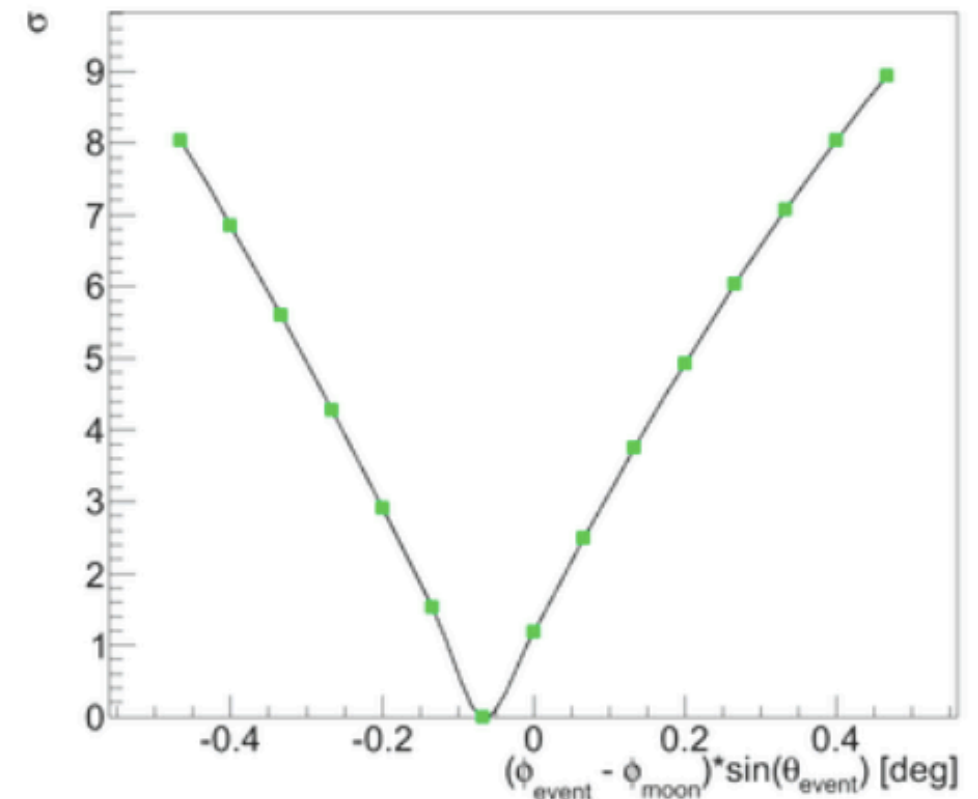
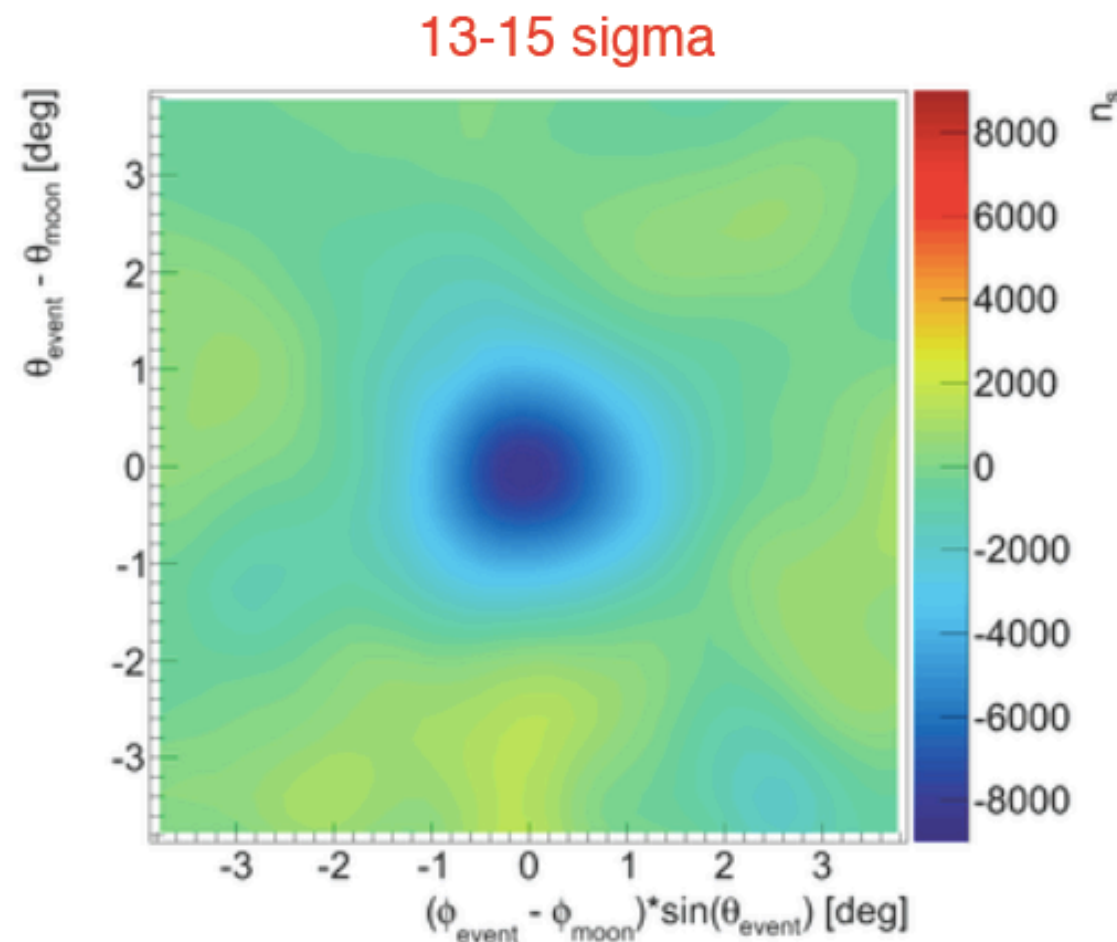


How to know where you are looking (and how well)!

- Existence of the Moon confirmed!
- 13-15 sigma deficit of events from direction of moon in the IceCube 59-string detector (6 months of data) confirms pointing accuracy.
- Validates pointing capabilities with expected angular resolution for IceCube 80-string detector $<1^\circ$ at 1 TeV.

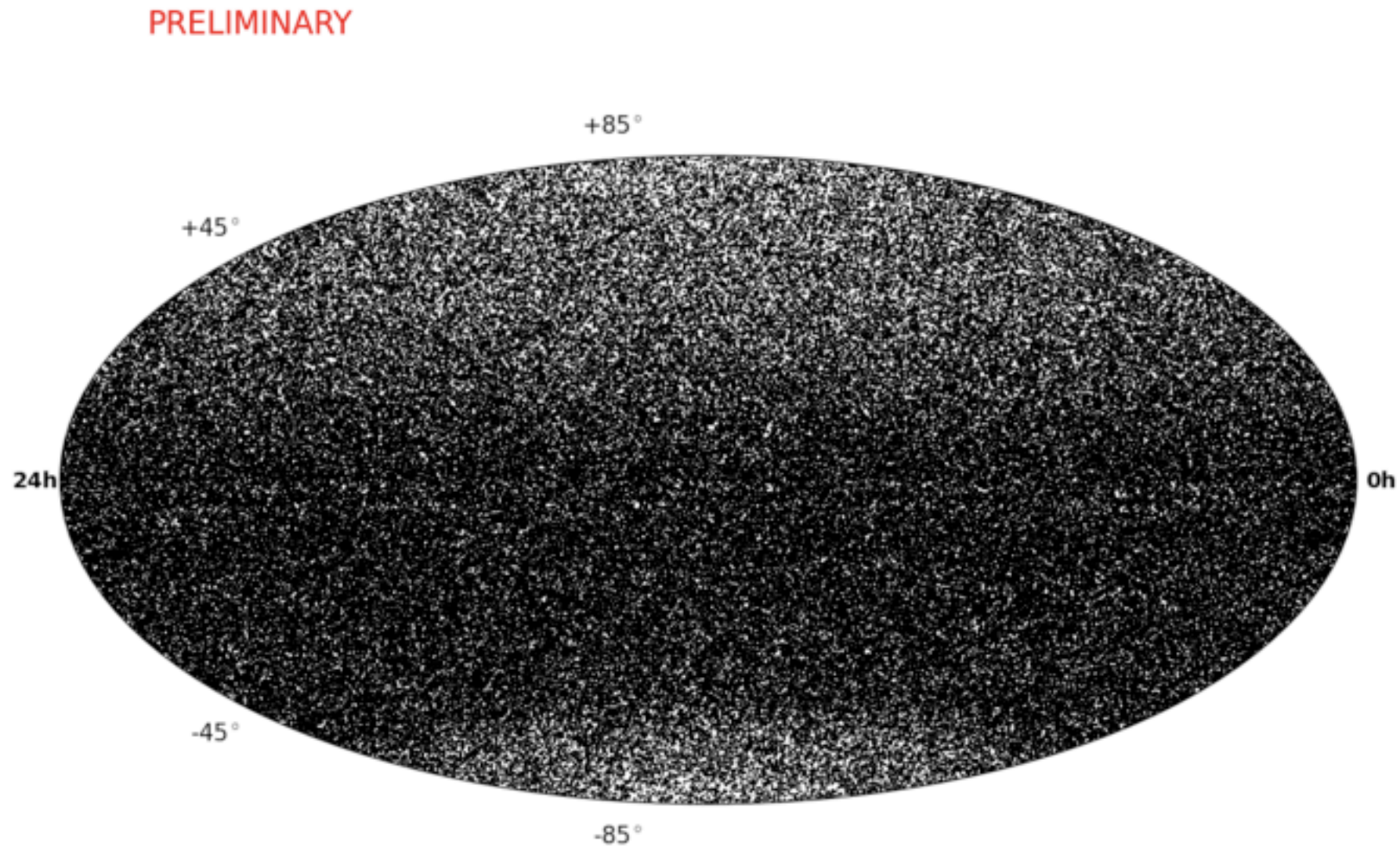


Slice through the significance landscape at zenith = 0 degrees (signal hypothesis)



Most Recently from IceCube Point Source Searches...

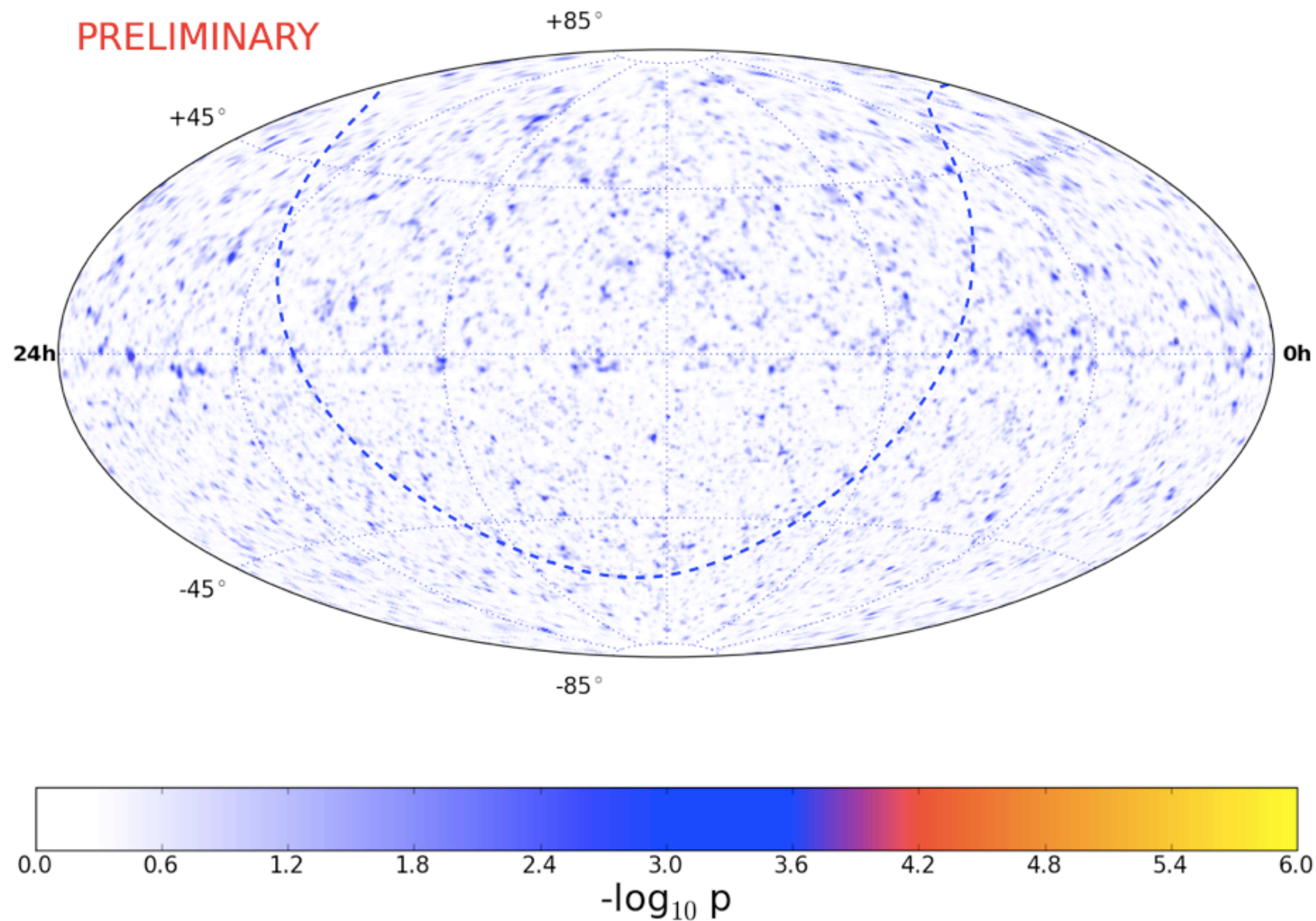
The IC79 + IC59 + IC40 neutrino sky...



Total events (IC40+IC59+IC79): 108317 (upgoing) + 146018 (downgoing)

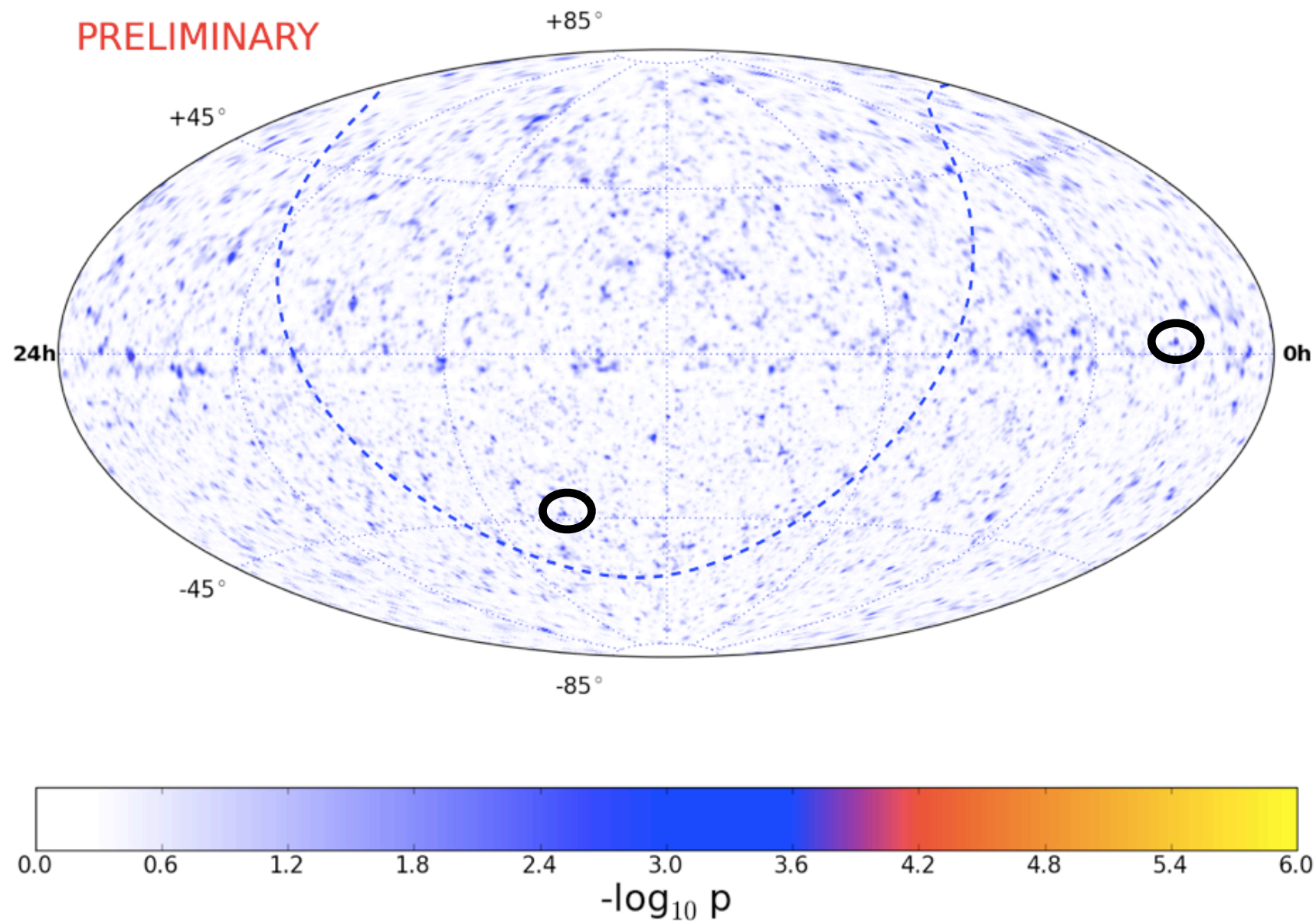
Most Recently from IceCube Point Source Searches...

The IC79 + IC59 + IC40 neutrino sky...



Most Recently from IceCube Point Source Searches...

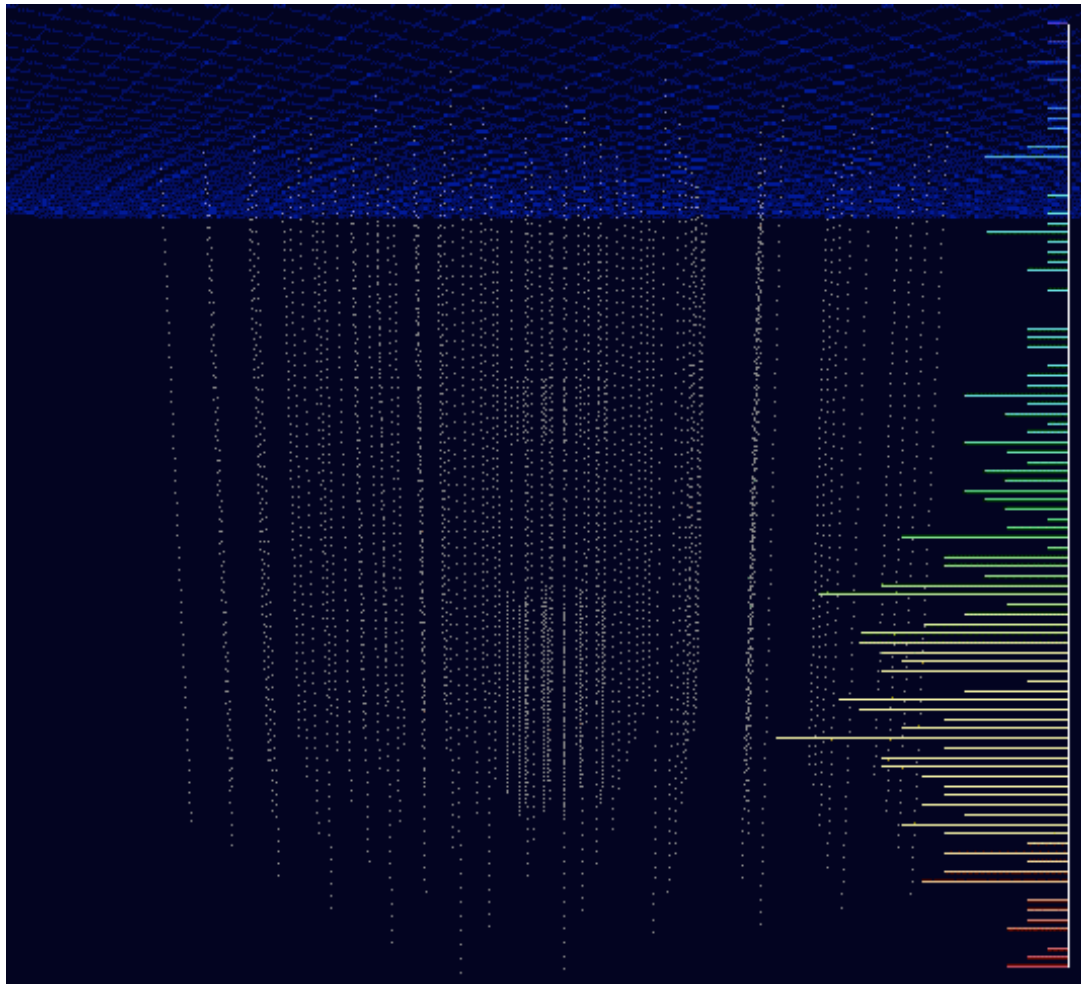
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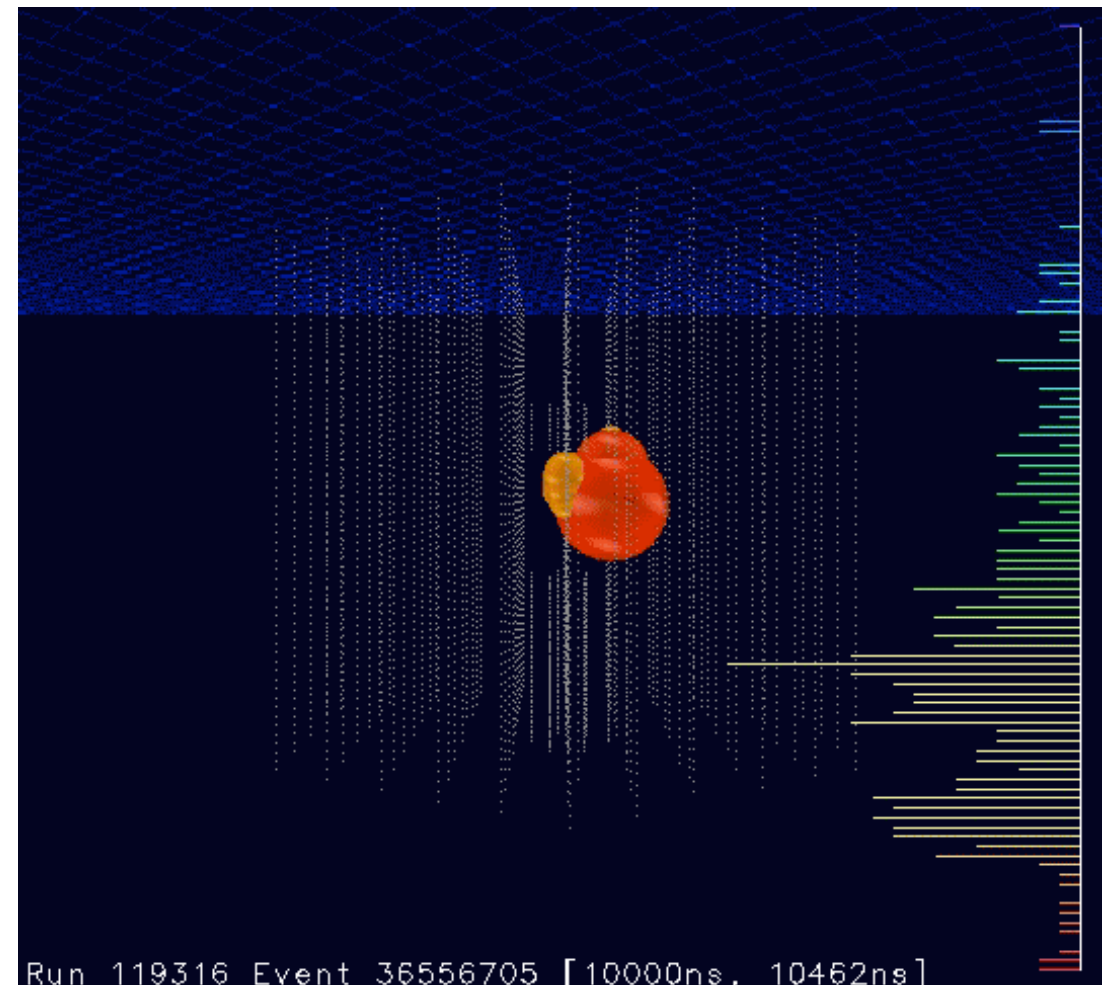
What about ultra-high energy events, are they present?

What about ultra-high energy events, are they present? **YES**

- At these energies the Earth becomes opaque to neutrinos... Look for downward going events
- But downward events are dominated by cosmic ray muons...perform search for cascade events.



“Ernie” ~1300 TeV



“Bert” ~1100 TeV

We came, saw, conquered.... the voyage home

Past...



Roald Amundsen - South Pole Expedition 1911

November 24, 2012

Present...



Darren R. Grant - University of Alberta

Summary

- IceCube is COMPLETE and actively taking data. It is the world's largest neutrino detector (>1 Gigaton!).
- Analyses are underway... discoveries pending!
- Plans developing for future detectors (PINGU and beyond) for very large-scale particle physics program (including proton decay and a supernova neutrino “factory”) in the Antarctic - **stay tuned!**



© [2011] The Pygos Group

November 24, 2012



Darren R. Grant - University of Alberta

Summary

- Looking for more?
 - email:
drg@ualberta.ca
 - Canadian IceCube developments
<http://cpp.phys.ualberta.ca/cpp/>
 - CBC interview Quirks & Quarks
<http://www.cbc.ca/podcasting/index.html?newsandcurrent#quirks>
 - Official IceCube site:
<http://icecube.wisc.edu>

