Radio Detection of Ultra-high Energy Neutrinos

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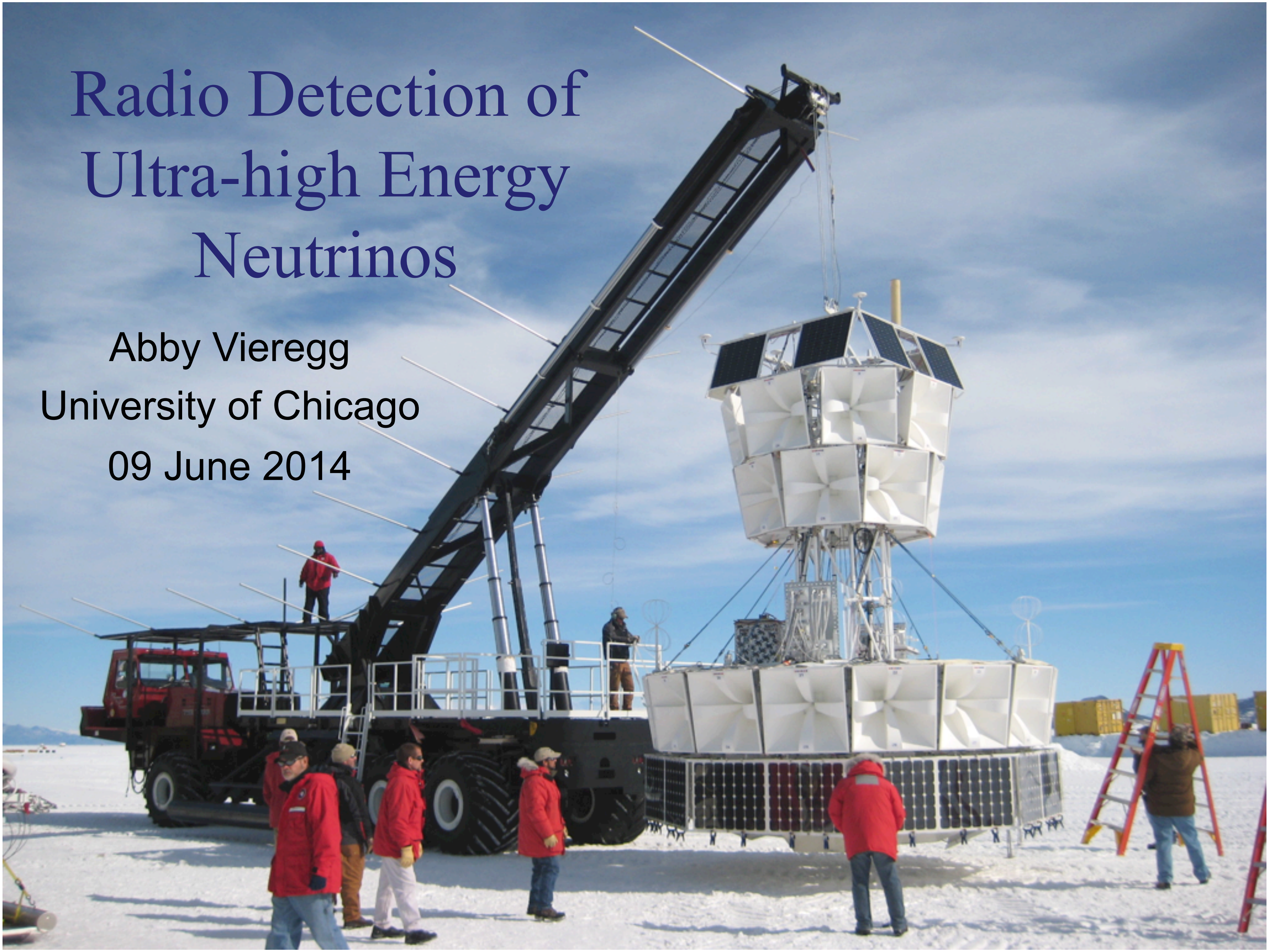
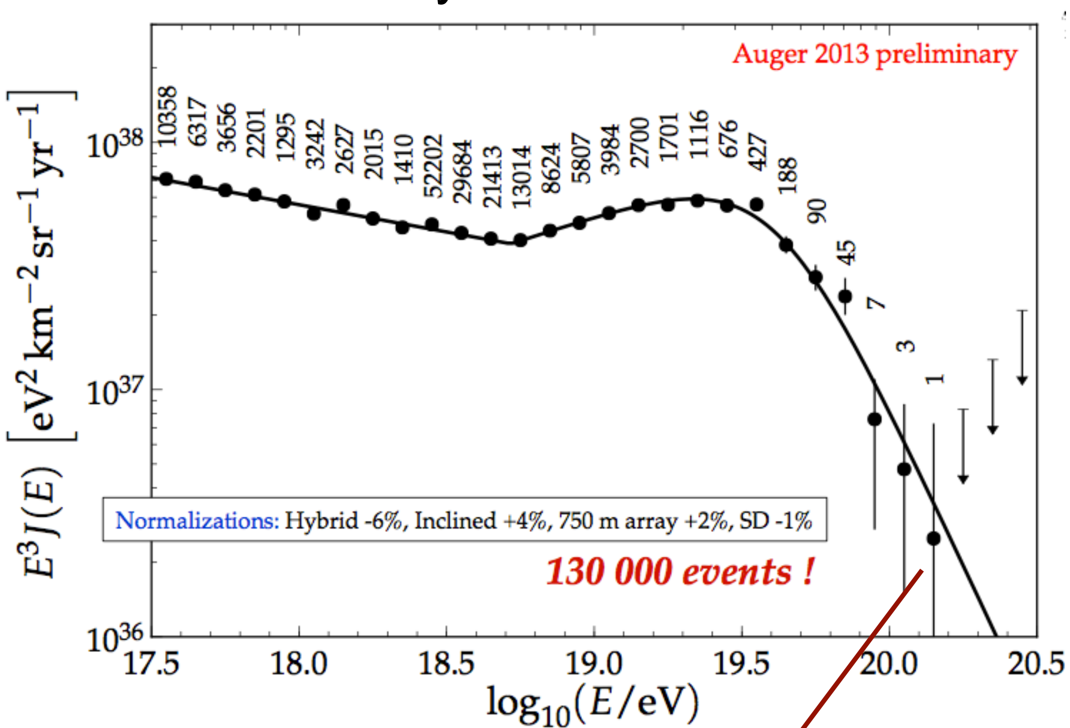
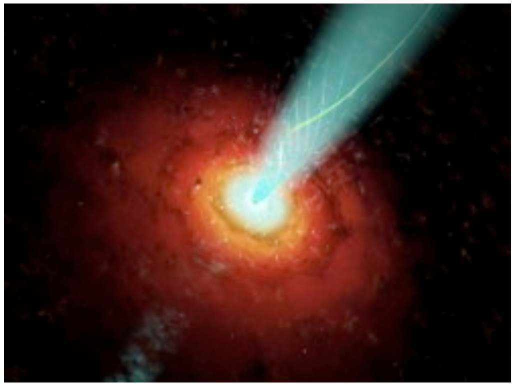
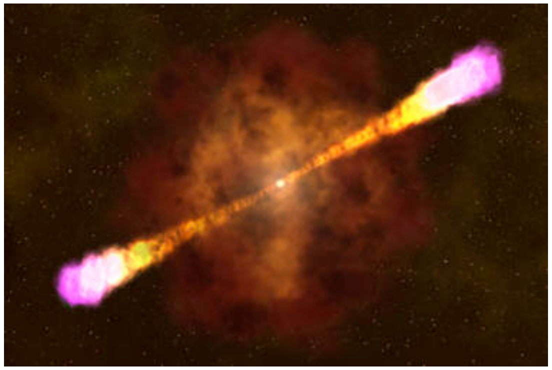


The Ultra-High Energy Universe

UHE Cosmic Ray Flux







- We know there are sources up to 10^{20} eV (1 Joule)!!
- How are these particles accelerated?
  - Active Galactic Nucleii (black holes accreting mass)?
  - Blazars (Jets emitted in our direction by AGN)?
  - Gamma Ray Bursts (most luminous events in the universe)?

(Reminder: IceCube <10^{15} eV)

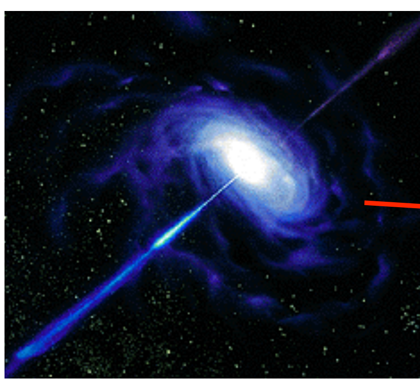
Neutrinos: The Ideal UHE Messenger

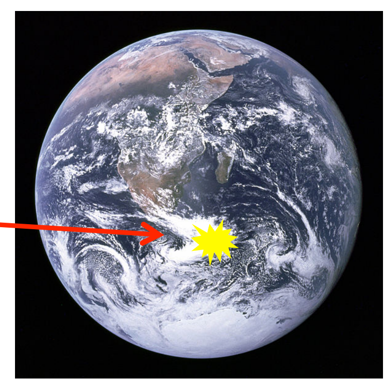
Possible Messenger Particles:

- Photons lost above 100 TeV (pair production on CMB & IR)
- Protons and Nuclei deflect in magnetic fields
- Neutrons decay
- Neutrinos: point back to sources, travel unimpeded through universe

UHE Neutrino Detectors:

- Open a unique window into the universe
  - Highest energy observation of extragalactic sources
  - Very distant sources
  - Deep into opaque sources
- How does the high energy universe evolve?



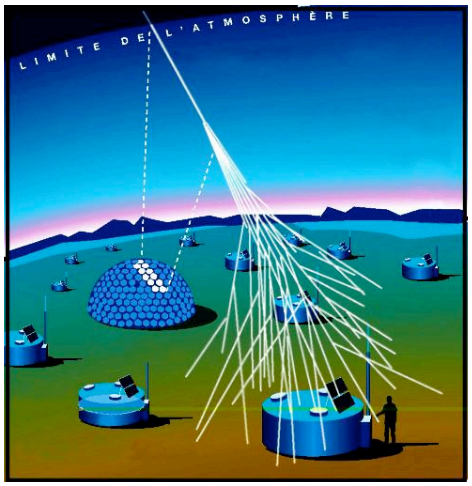


Neutrino Production: The GZK Process

GZK process: Cosmic ray protons (E> $10^{19.5}$ eV) interact with CMB photons

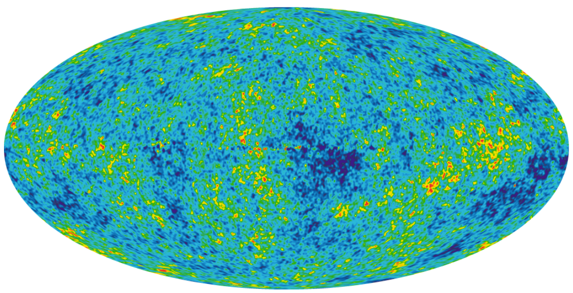
$$p + \gamma_{cmb} \rightarrow \Delta^+ \rightarrow n + \pi^+$$
$$\rightarrow \mu^+ + \boxed{\nu_\mu}$$
$$\rightarrow e^+ + \boxed{\bar{\nu_\mu} + \nu_e}$$

cosmic rays

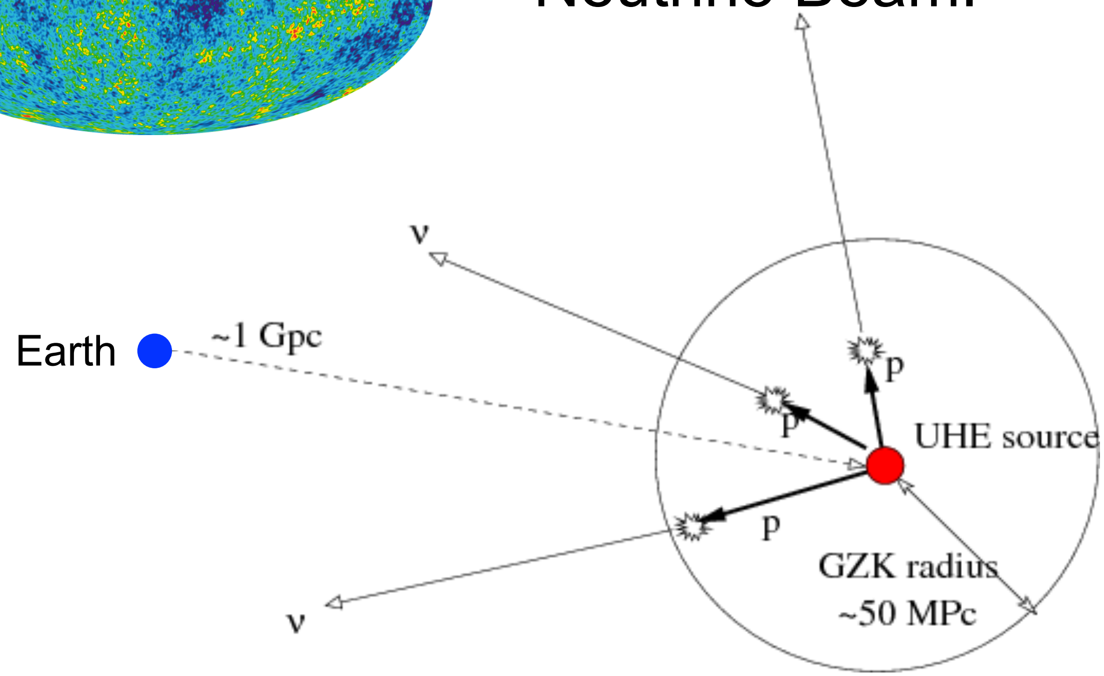


+

CMB



= Neutrino Beam!

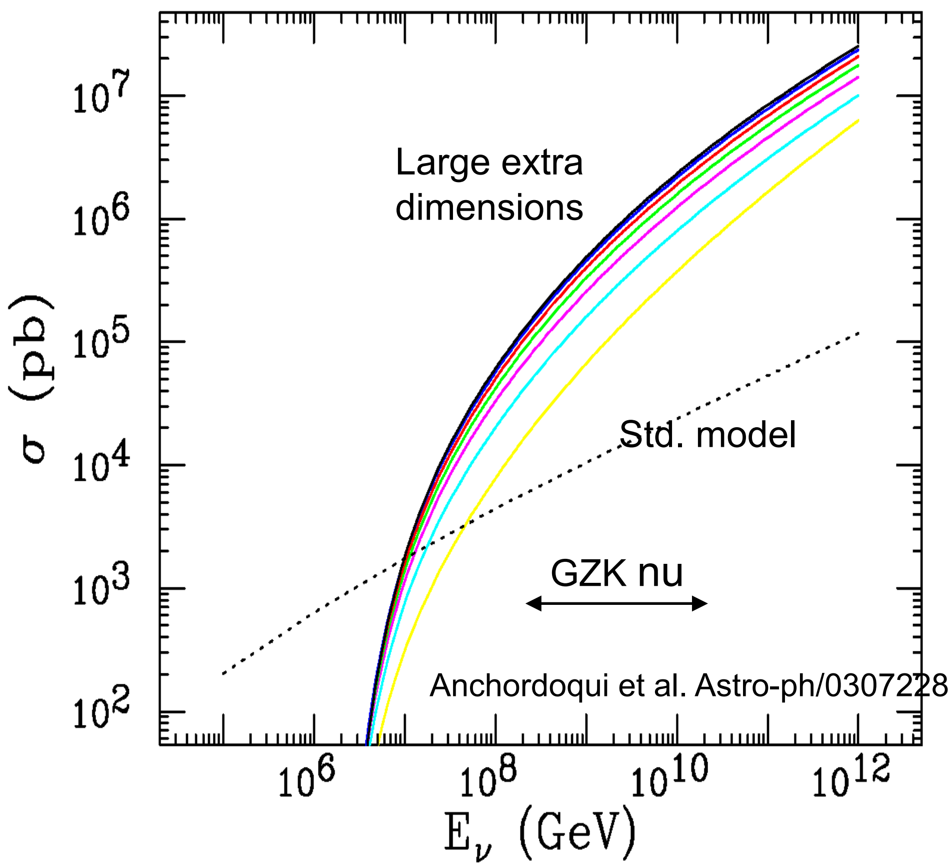


Discover the origin of high energy cosmic rays through neutrinos?

What is the high energy cutoff of our universe?

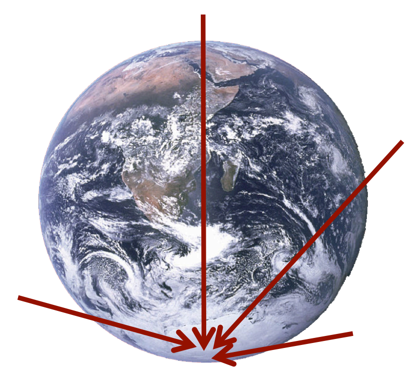
Why is UHE Neutrino Astronomy Interesting?

A Particle Physics Case



Probe particle physics interactions at energies not achievable on earth

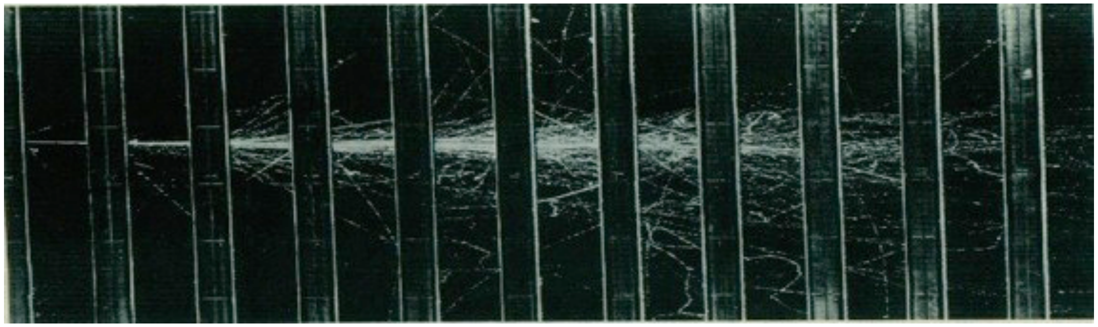
- E_{CM} is ~200 TeV (LHC "only" 14 TeV)
  - Measure neutrino-nucleon cross section in a new regime
    - L_{int} ~ 300 km: use Earth-shielding as cross-section analyzer (count events with different path lengths through the earth)
    - Probe exotic models



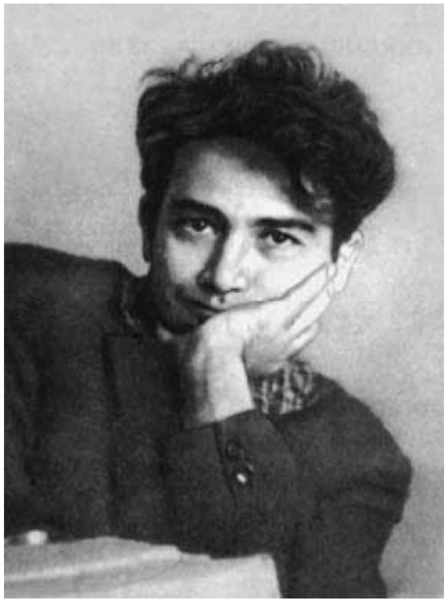
Detection Principle: The Askaryan Effect

- EM shower in dielectric (ice) → moving negative charge excess
- Coherent radio Cherenkov radiation ($P \sim E^2$) if λ > Moliere radius

e^+, e^-, γ ⟶

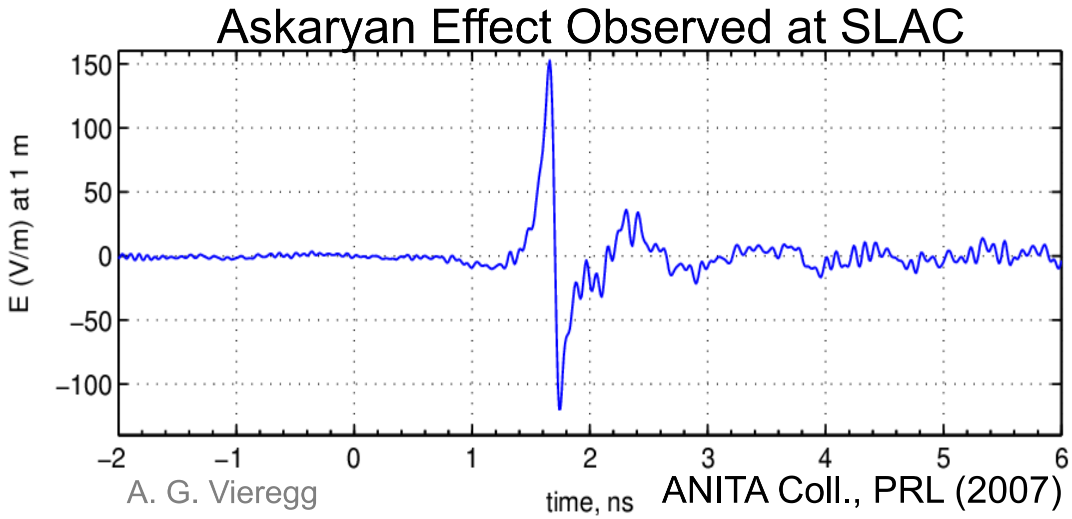


Typical Dimensions:
L ~ 10 m
$R_{moliere}$ ~ 10 cm



G. Askaryan

→ Radio Emission is much stronger than optical for UHE showers



ANITA Coll., PRL (2007)

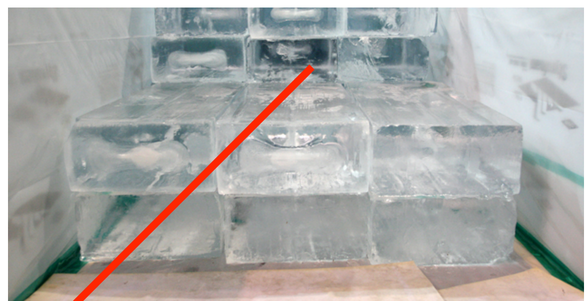
Askaryan Effect Observed at SLAC

Beamtest at SLAC: proof of Askaryan effect in ice

28.5 GeV shower x 10^9 particles/shower

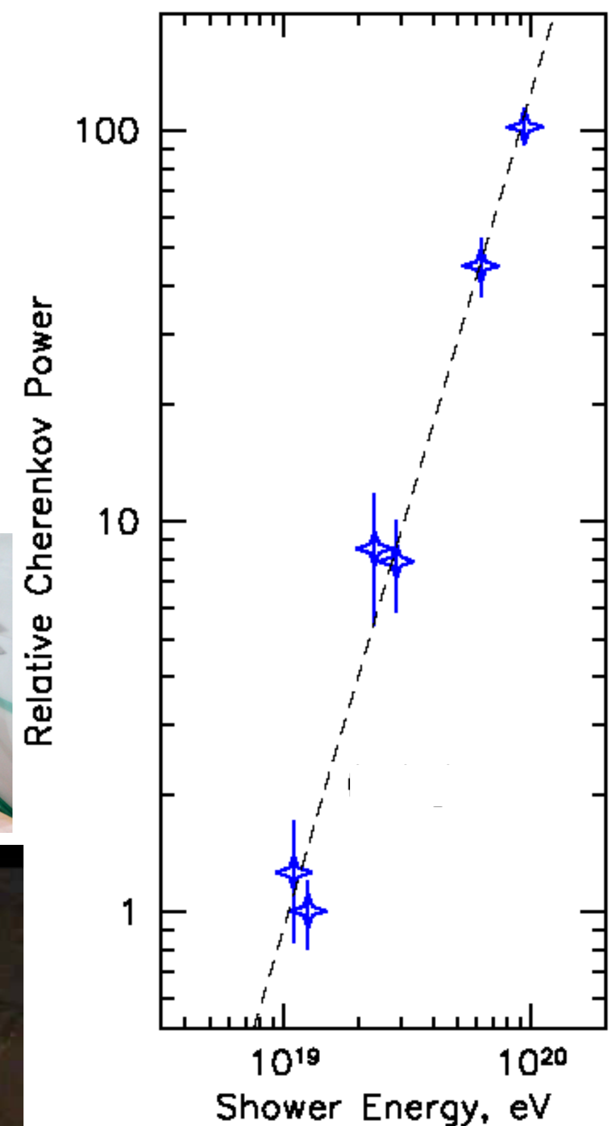
- Coherent (P ~ E^2)
- Linearly Polarized

Askaryan Effect also seen in the lab in sand and salt



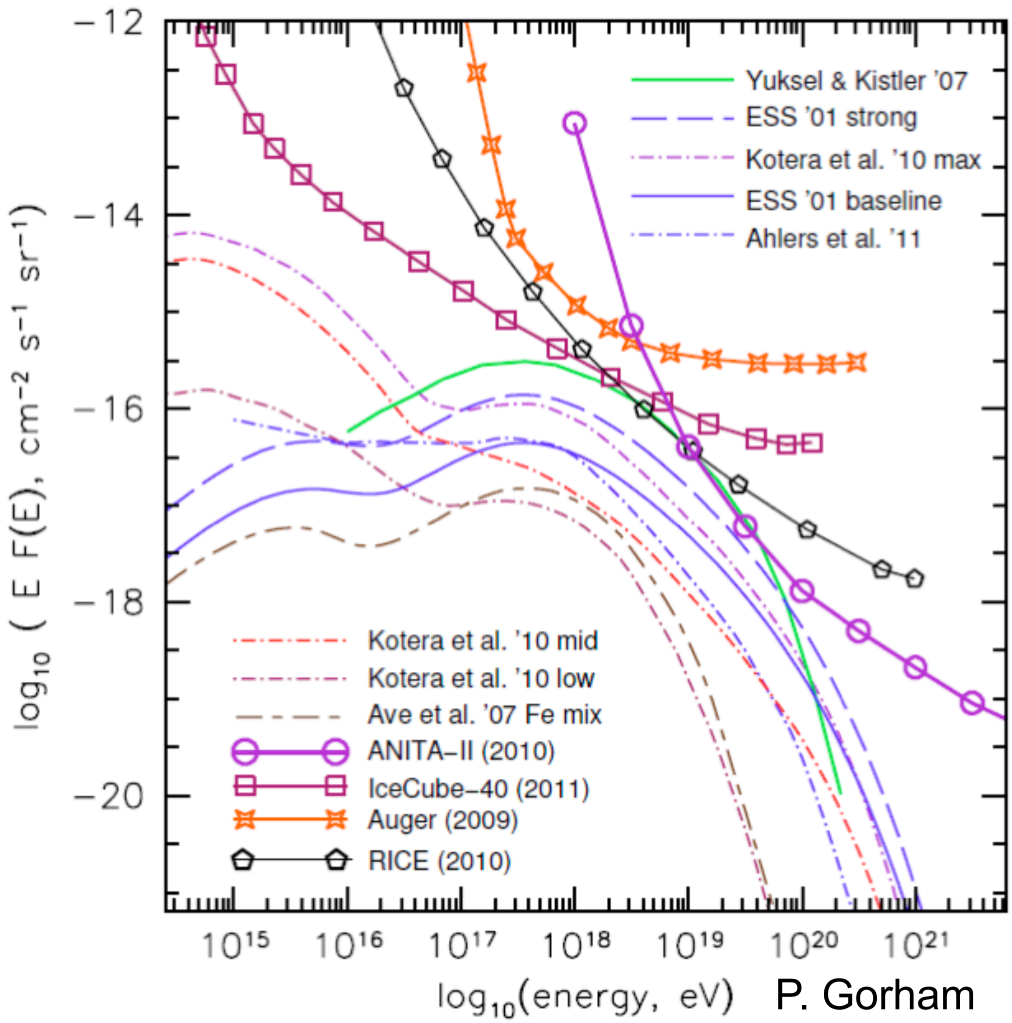
7.5 tons of ice

ANITA Coll., PRL (2007)



Models & Current Constraints

- Best current limits:
  - >10^{18} eV: Radio Detection, ANITA
  - <10^{18} eV: Optical Detection, IceCube
- Starting to constrain some models (source evolution and cosmic ray composition)
- How do we get a factor of ~100 to dig into the interesting region and make a real UHE neutrino observatory?
- Why bother? Not a fishing expedition! There is a floor on the expectation.



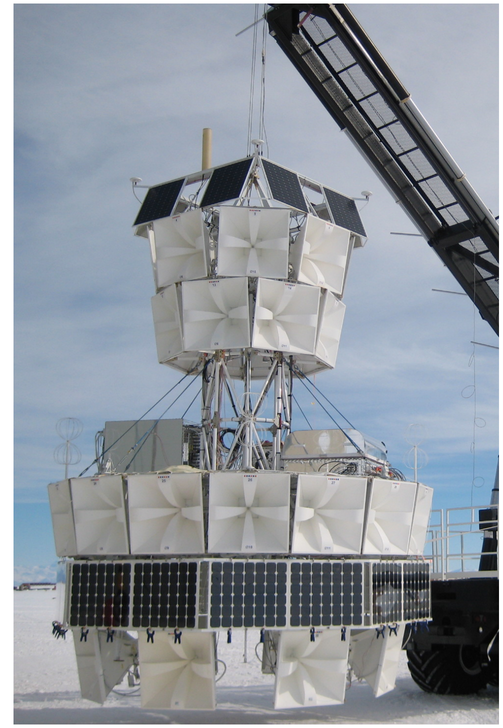
P. Gorham

ANITA-I & ANITA-II: Best Limit > 10^{19} eV

NASA Long Duration Balloon, launched from Antarctica

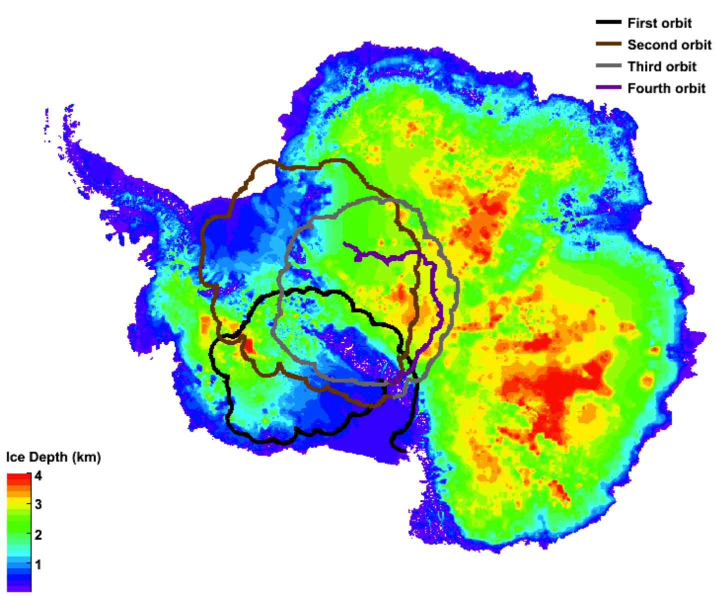
ANITA-I: 35 day flight 2006-07

ANITA-I: 30 day flight 2008-09



Instrument Overview:

- 40 horn antennas, 200-1200 MHz
- Direction calculated from timing delay between antennas
- In-flight calibration from ground
- Threshold limited by thermal noise



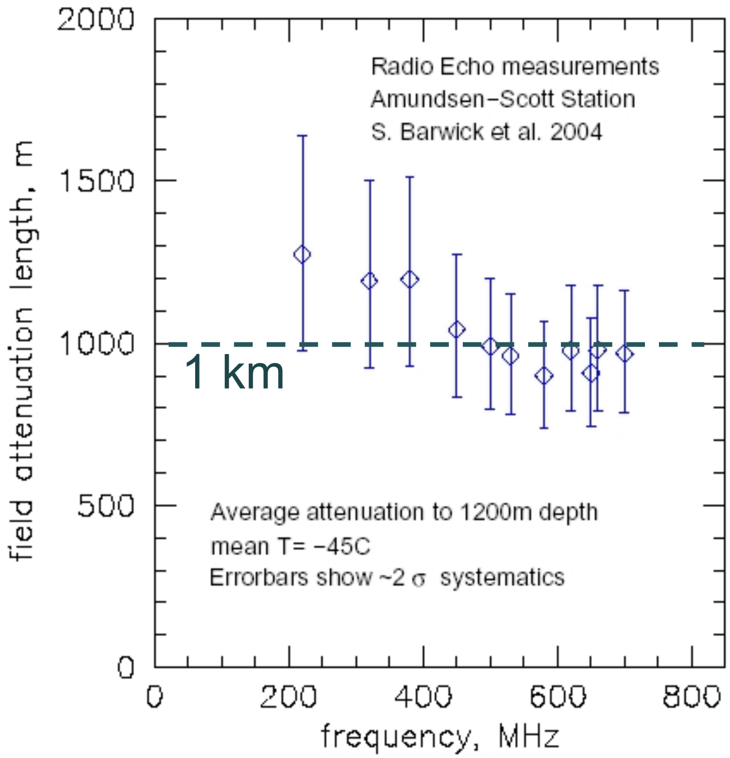
UHE Neutrino Search Results:

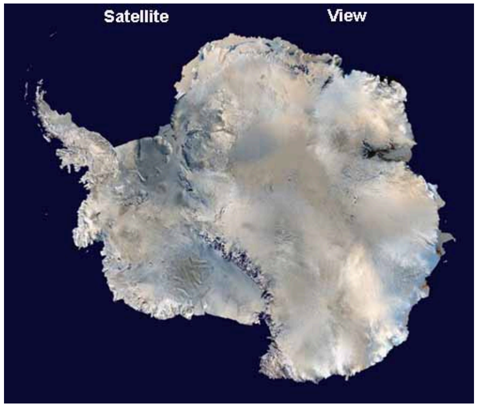
	ANITA-I	ANITA-II
Neutrino Candidate Events	1	1
Expected Background	1.1	0.97 +/- 0.42

UHE Neutrino Radio Detector Requirements

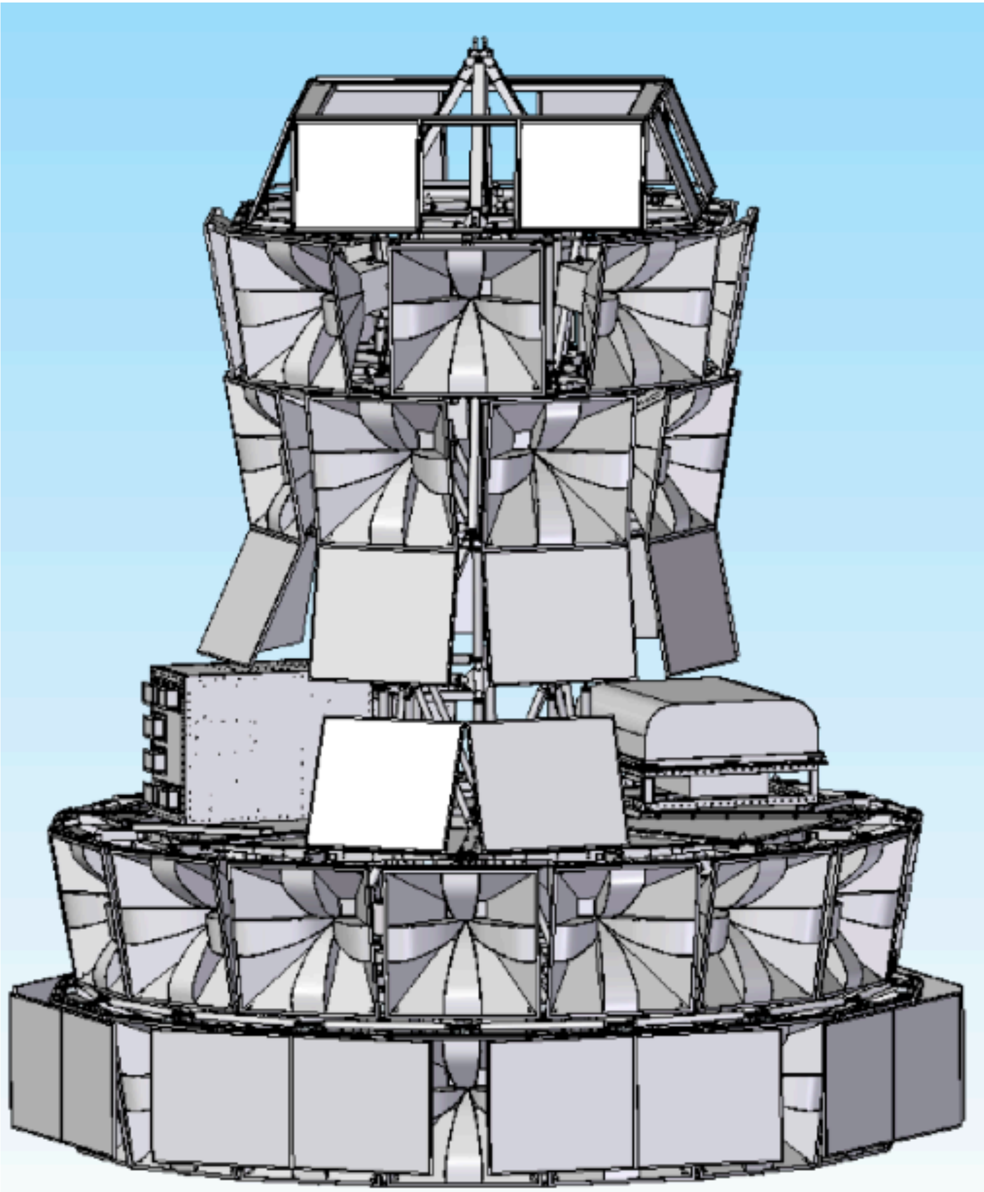
- ~1-10 GZK neutrinos/km^2/year
- L_{int} ~ 300 km
  → ~ 0.01 neutrinos/km^3/year
- Need a huge (>> 100 km^3), radio-transparent detector
- 3 media: salt, sand, and ice
- Long radio attenuation lengths in south pole ice
  - 1 km for RF (vs. ~100 m for optical signals used by IceCube)

→ Ice is good for radio detection of UHE neutrinos!





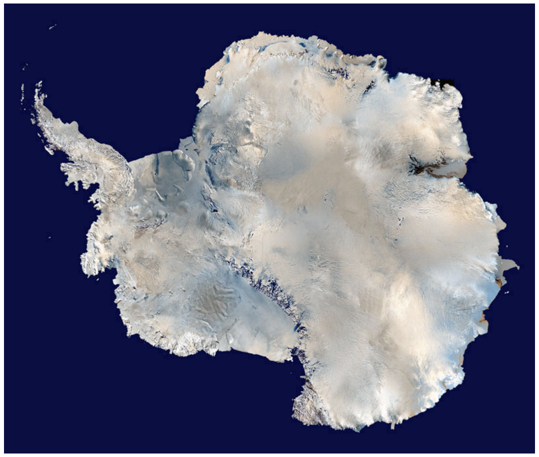
ANITA-III: 2014-2015



- Flight scheduled this year
- More antennas
- Digitize longer traces
- New: interferometric trigger
- Lower noise front-end RF system

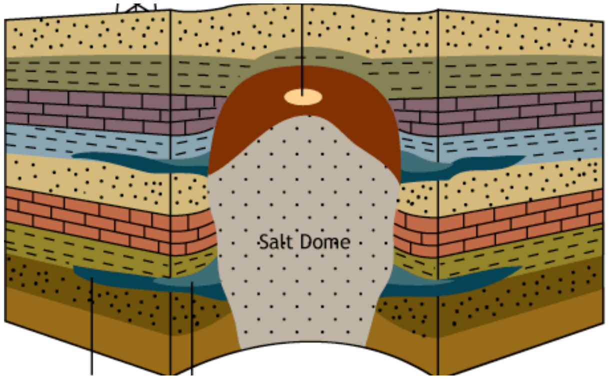
→ Factor of 5 improvement in neutrino sensitivity compared to ANITA-II

Beyond ANITA: Going to the Ground



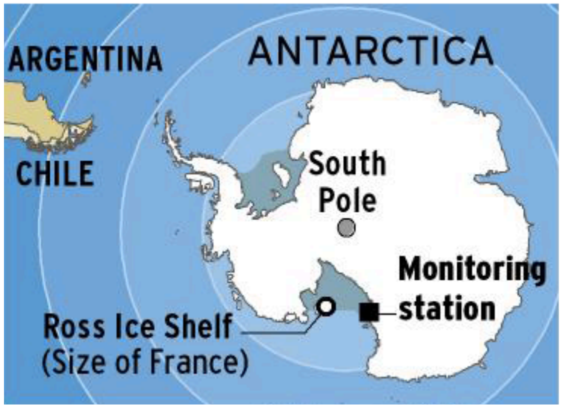
Why go to the ground?

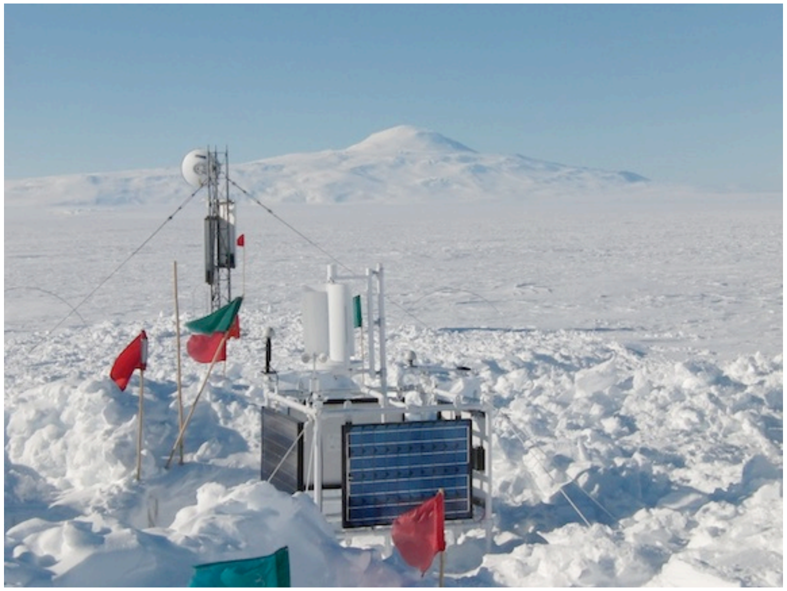
- Much more livetime
- Understandable man-made background
- Lower energy threshold
- Use more antennas than on a balloon
- But: smaller instrumented volume

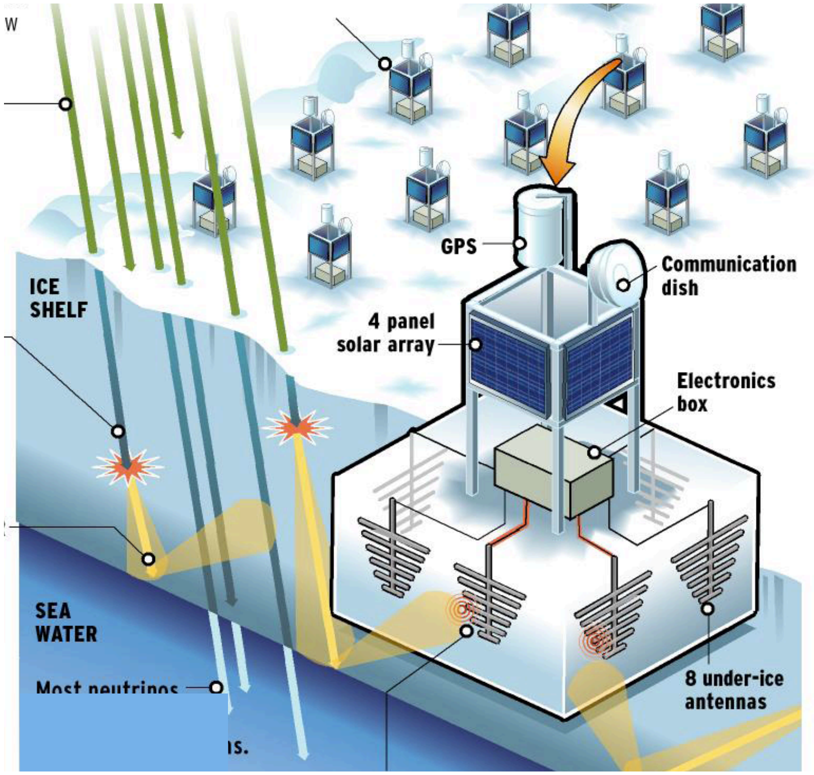


ARIANNA

- Idea: Ground-based array of antennas on the surface of the Ross Ice Shelf
- Currently: 3 stations operating well, 4 more coming in December
- Plan: proposal submitted for full array (1000 detectors)
- Solar Power: stations have operated through 58% of the year on solar power alone

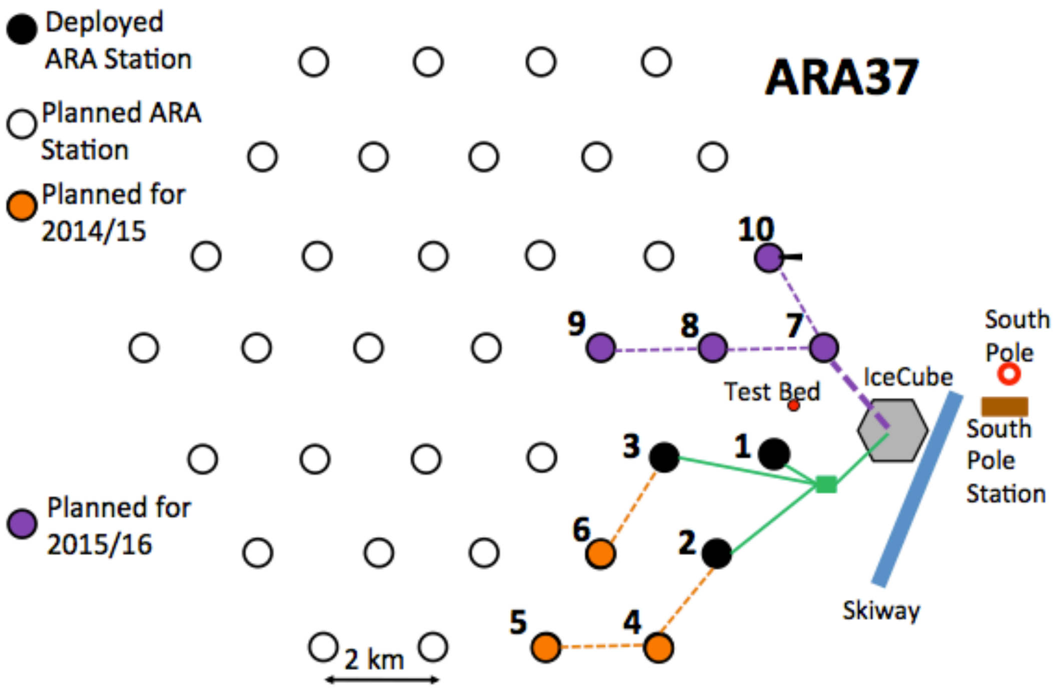






ARIANNA Coll. See arXiv:1207.3846

ARA: Askaryan Radio Array



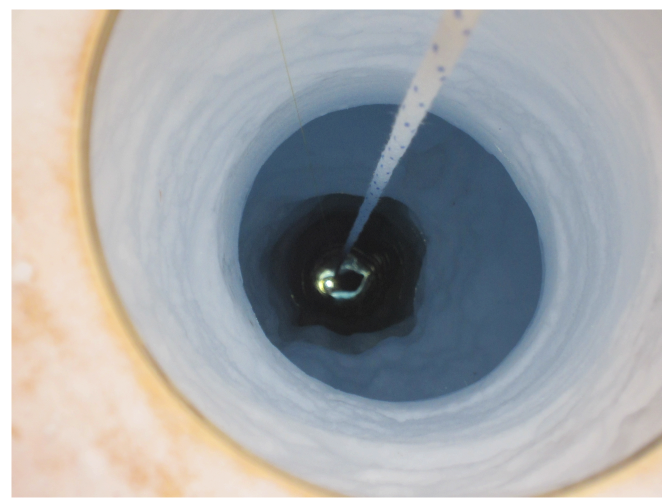
Idea: 37-station array of antennas buried 200m below the surface at the South Pole

Currently: 3 stations + testbed deployed and working

Plan: Proposal pending for next stage of deployment (10 stations)

V Pol Antennas

H Pol Antennas



ARA Collaboration. Astropart. Phys. (2012)

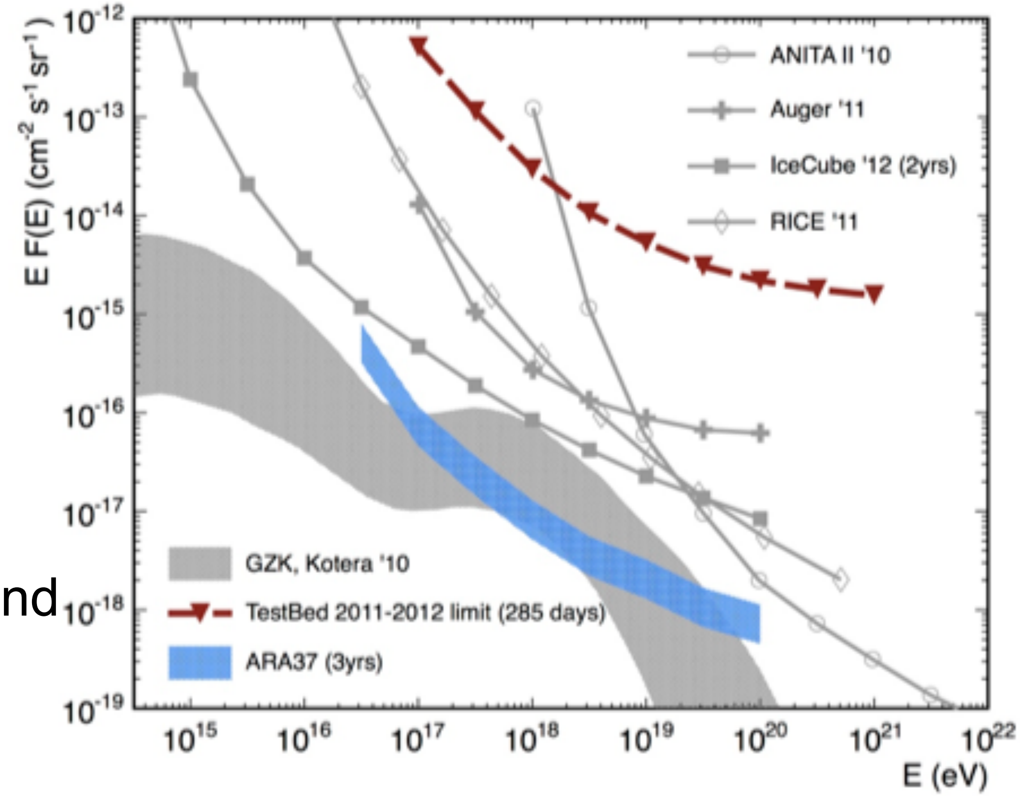
ARA Testbed Data Analysis

- 2011 and 2012 testbed station data
- Three independent blind analyses, look at 10% sample
- Cut-based analysis:
  - Reconstruction cuts

    → reject thermal noise background
  - Impulsiveness cuts

    → reject continuous wave background
  - Directionality cuts

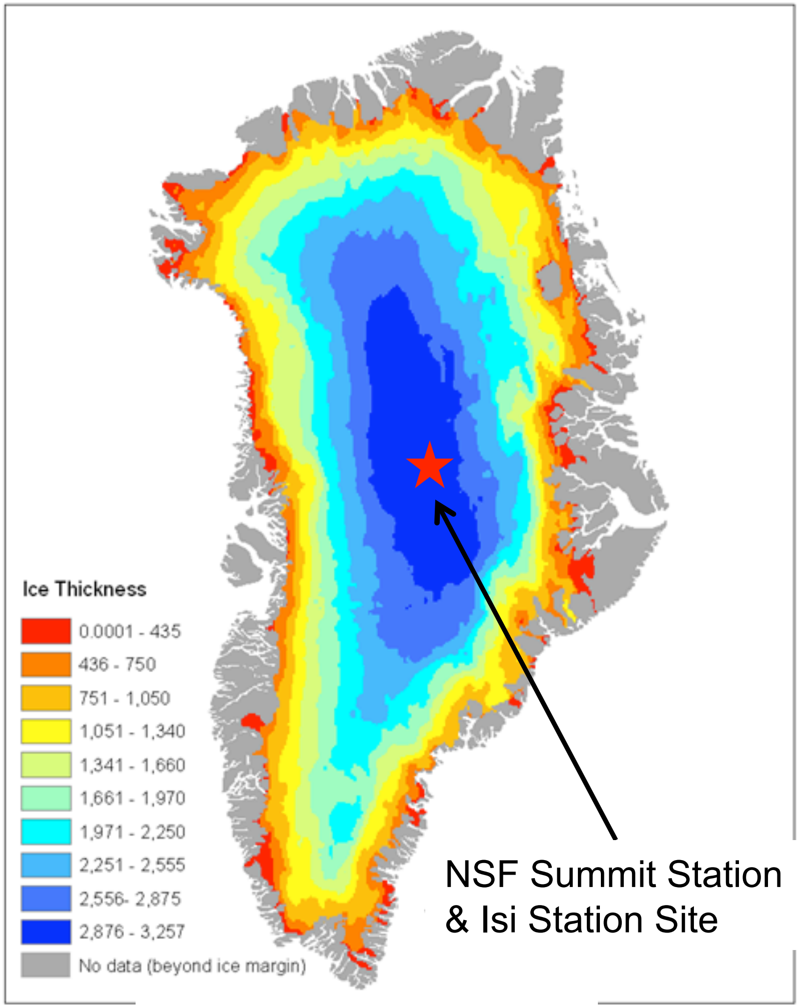
    → reject man-made background
- Future: much more volume instrumented, trigger and analysis improvements for full 37-station array



ARA Collaboration: arXiv:1404.5285

Greenland Neutrino Observatory

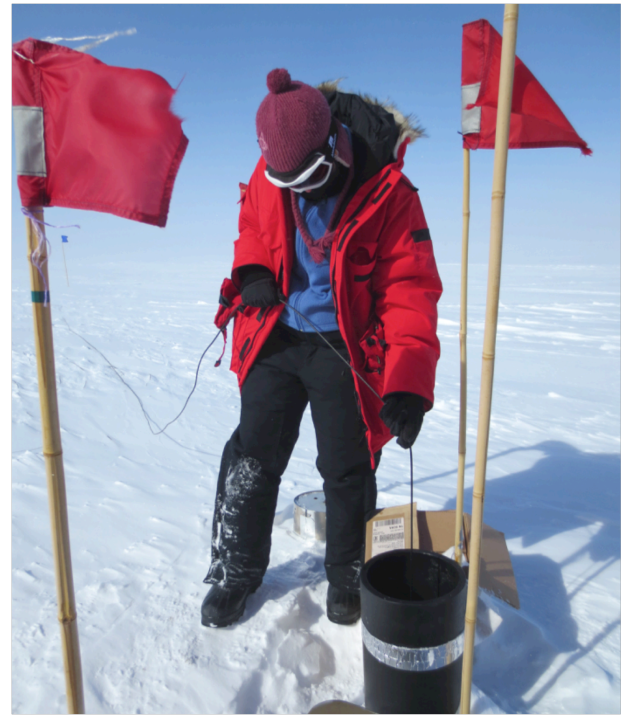
Greenland Ice Thickness



Kansas Univ. CRESIS

- Idea: array of 100 near-surface stations at Summit Station, Greenland
- 3 km thick ice
- Year-round NSF operated station with LC-130 access and annual overland traverse
- Northern Sky Coverage
- Use power from Summit Station, could use solar (10 mo/year) for large array
- Plans for a new station with expanded capacity, construction begins 2014

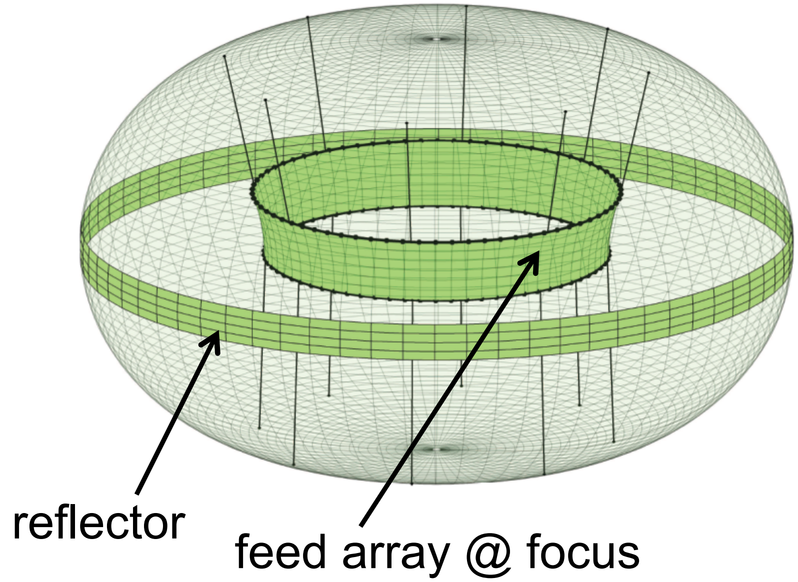
Summit Site Characterization June 2013



- Measured the attenuation length of the ice: 997 +/-150m for top 1.5 km of ice at 300 MHz
  - Comparable to South Pole, better than other sites
- Measured firn properties: shallower surface layer than South Pole
- First-pass measurement of RF backgrounds
- Plan: deploy first neutrino-hunting station in 2015

EVA: ExaVolt Antenna

- Idea: Turn an entire NASA super pressure balloon into the antenna
- Currently: 3 year NASA grant for developing 1/5 scale engineering test, full RF + float test
- Full Balloon: similar sensitivity to full, 3-year of ground-based arrays

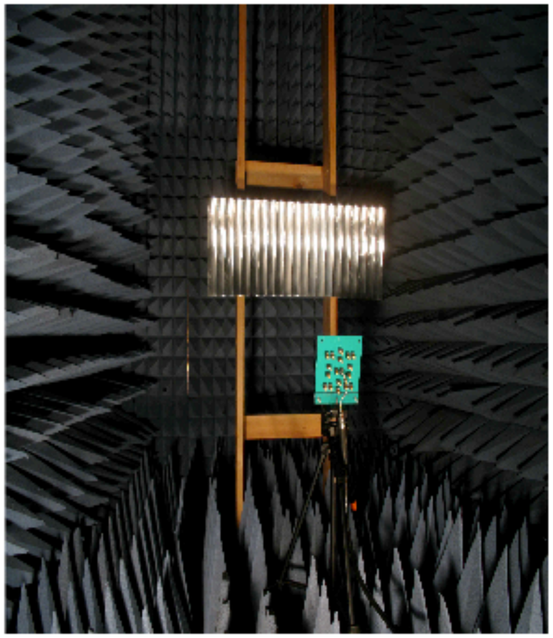


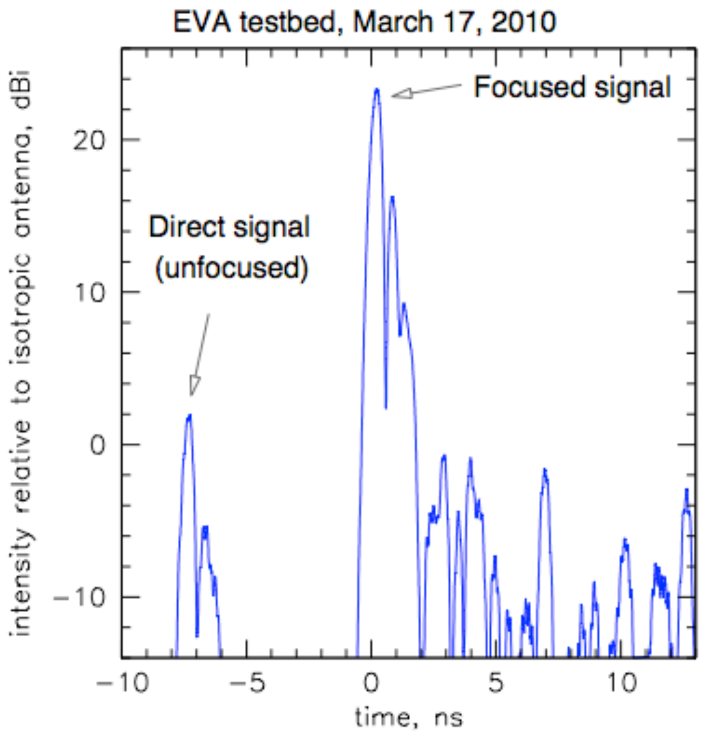
Gorham et al. (2011)

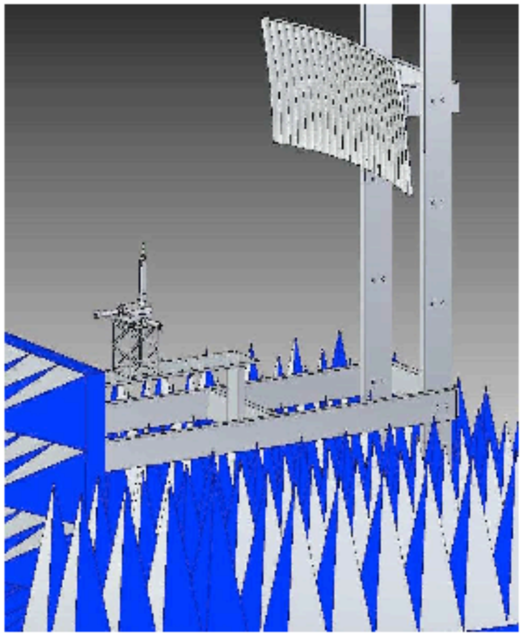
→ Feed design: dual-polarization, broadband, sinuous antennas on inner membrane

EVA Scale Model Test Results

- Microwave scale model testbed
- 1/35 and 1/26 scale models
- Measured directivity ~22dB





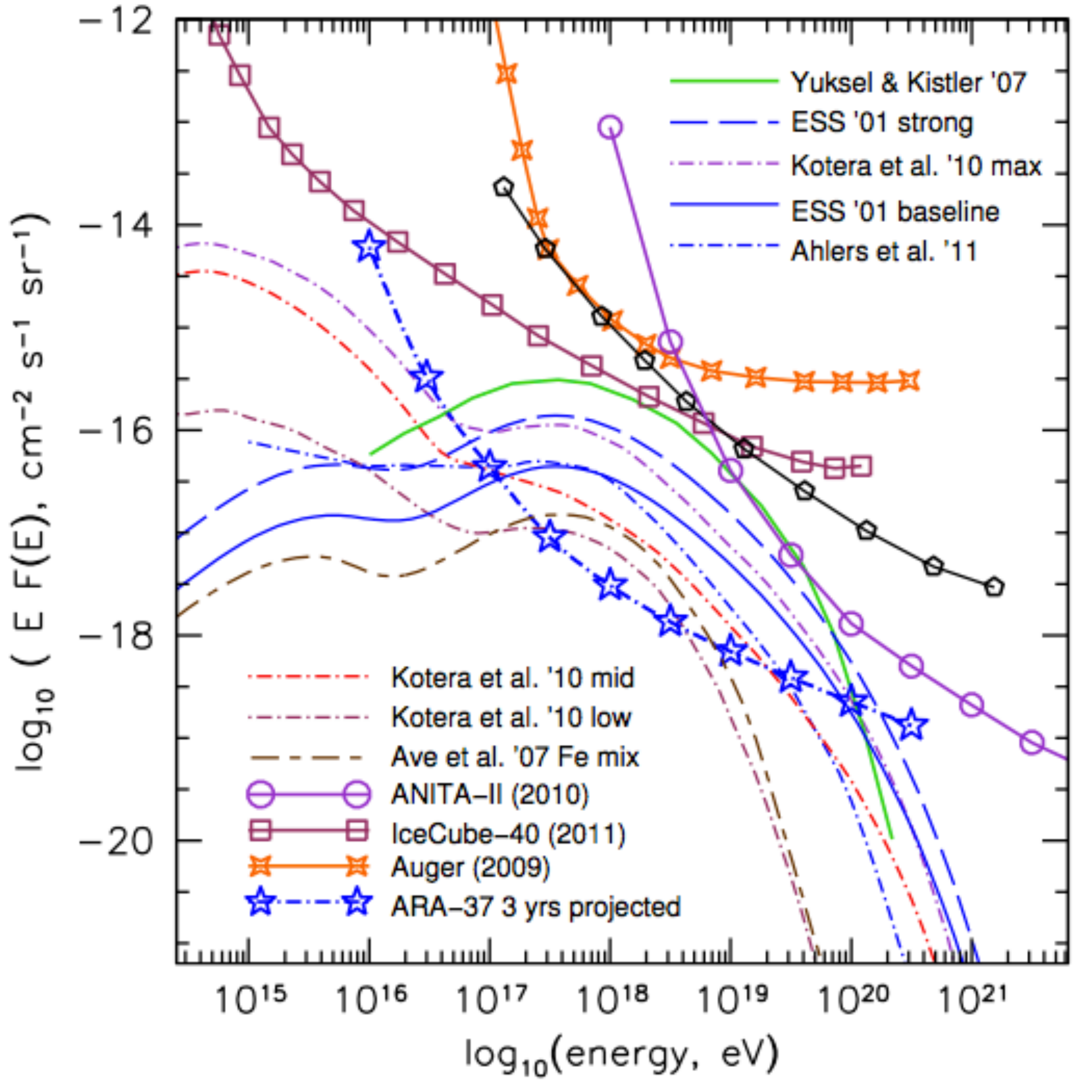


Gorham et al. (2011)

Projected UHE Neutrino Sensitivity

What the sensitivity of a next-generation UHE neutrino detector looks like:

→ With tens of events per year, we'll have a real high-energy neutrino observatory for particle physics and astrophysics



ARA Coll. arXiv:1105.2854

Summary

- Probing lots of fundamental particle physics and astrophysics
- Radio technique has been proven, current results constrain models (see many other talks)
- ANITA-III 2014, IceCube ongoing
- Large forward-looking efforts in initial stages: ARIANNA, ARA, GNO, EVA
- In 5-10 years, we hope to have a real UHE neutrino observatory and to observe for many years