Radio Detection of Ultra-High Energy Neutrinos: An Overview

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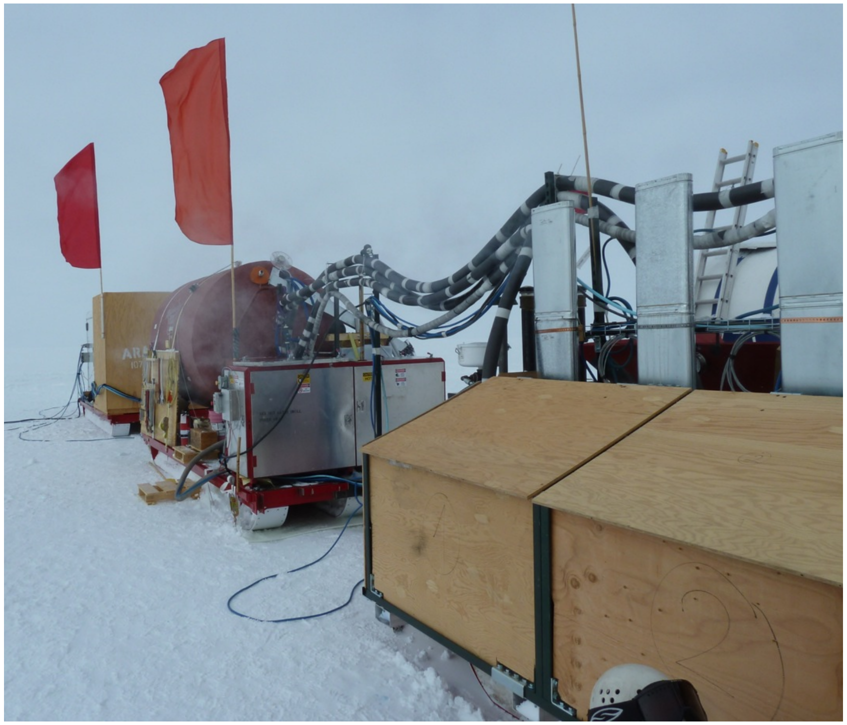
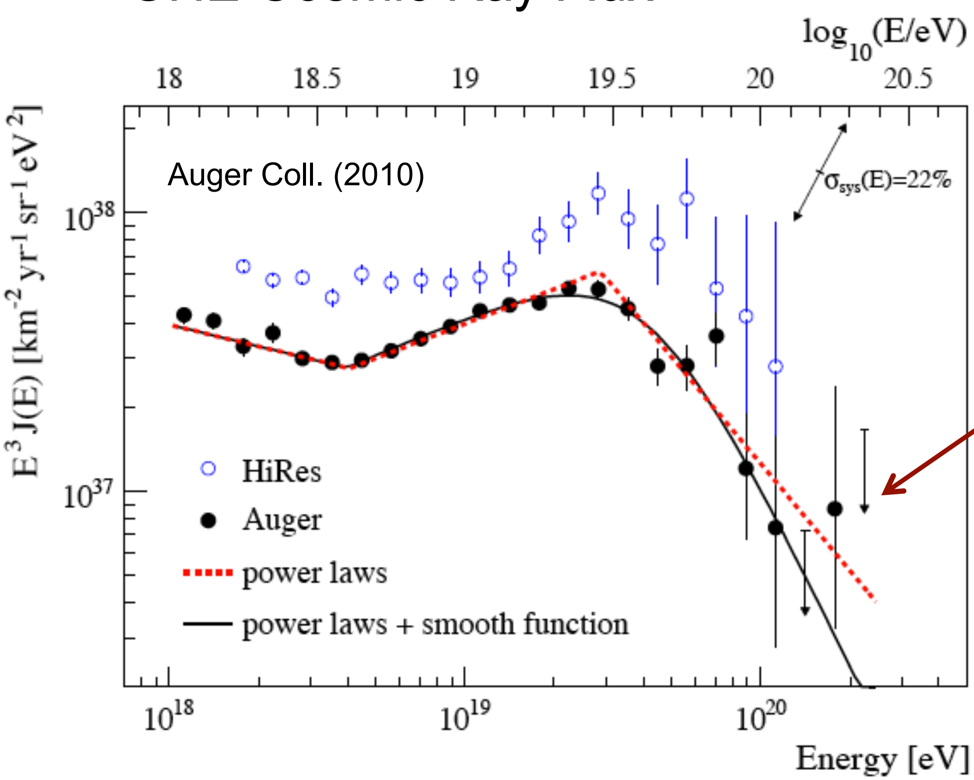
Harvard CfA
6 March 2013



Neutrinos: The Ideal UHE Messenger

UHE Cosmic Ray Flux



- Photons lost above 100 TeV (pair production on CMB & IR)
- Protons and Nuclei suffer curvature induced by B fields
- But: we know there are sources up to 10^{20} eV!!

UHE Neutrino Detectors:

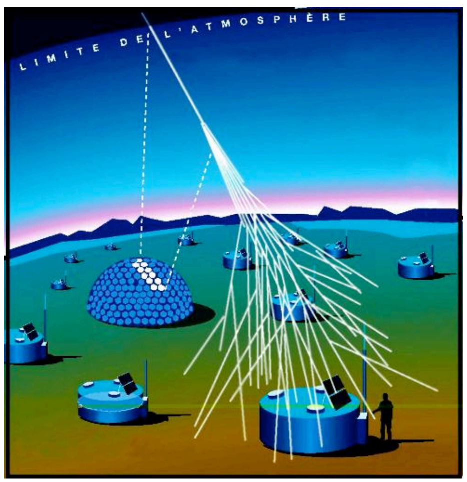
- Highest energy observation of extragalactic sources
- Very distant sources
- Deep into opaque sources

Neutrino Production: The GZK Process

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

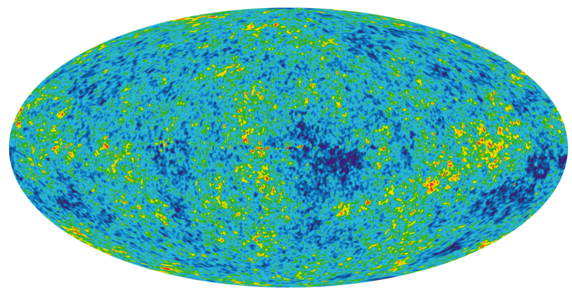
$$p + \gamma_{cmb} \rightarrow \Delta^{+} \rightarrow n + \pi^{+}$$
$$\rightarrow \mu^{+} + \boxed{\nu_\mu}$$
$$\rightarrow e^{+} + \boxed{\bar{\nu_\mu} + \nu_e}$$

cosmic rays



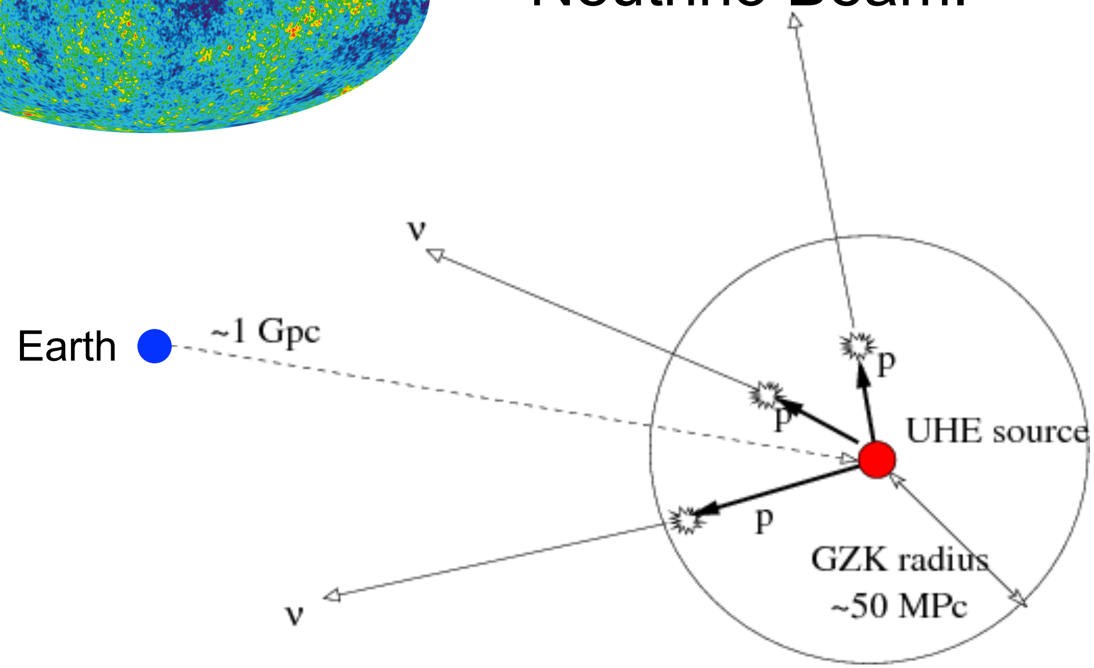
+

CMB



= Neutrino Beam!

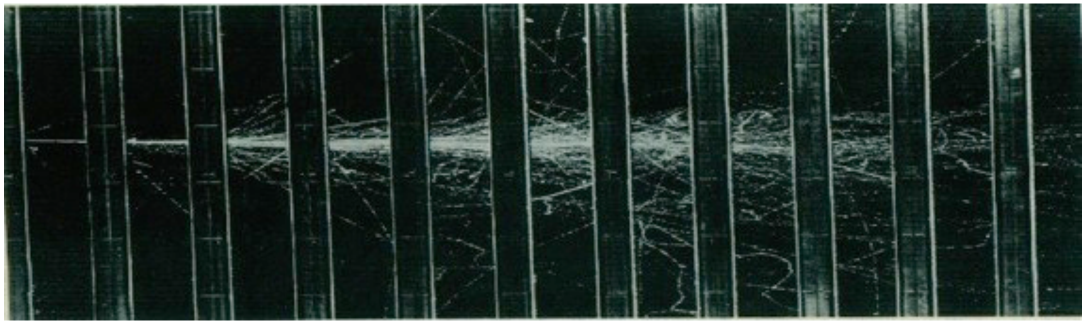
Discover the origin of high energy cosmic rays through neutrinos?



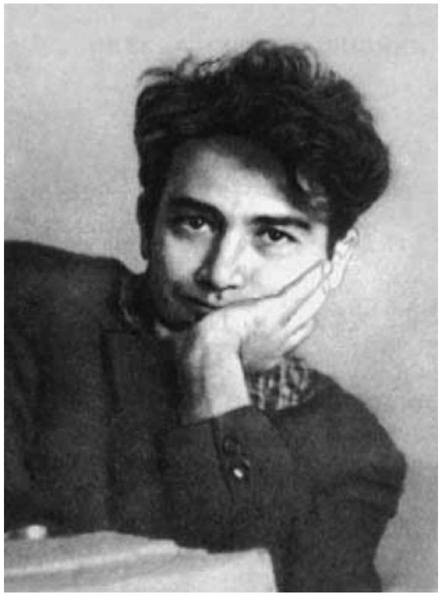
Detection Principle: The Askaryan Effect

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

e^+, e^-, γ ⟶

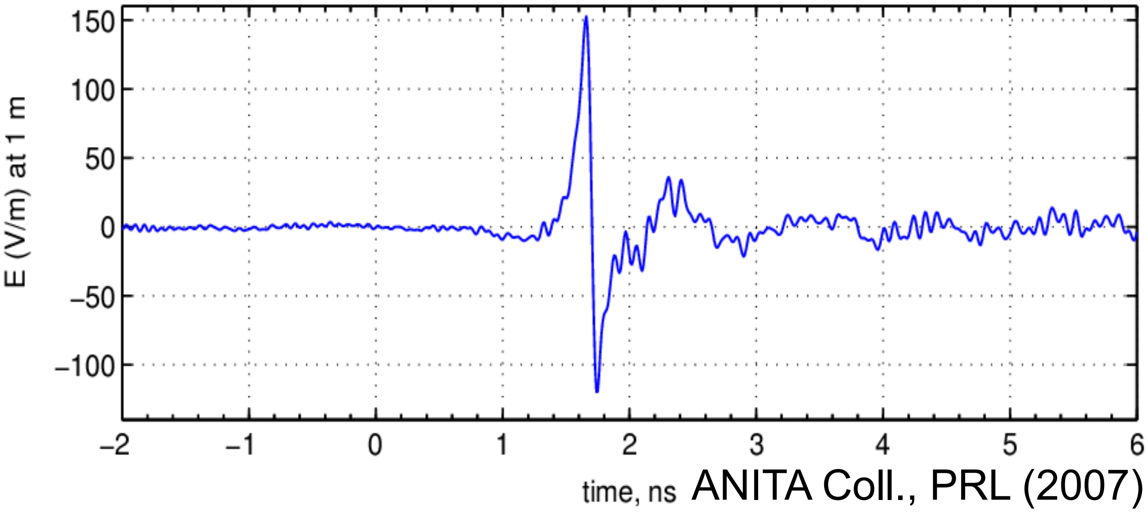


Typical Dimensions:
$L \sim 10$ m
$R_{moliere} \sim 10$ cm



G. Askaryan

Askaryan Effect Observed with at SLAC



ANITA Coll., PRL (2007)

Askaryan Effect Observed at SLAC

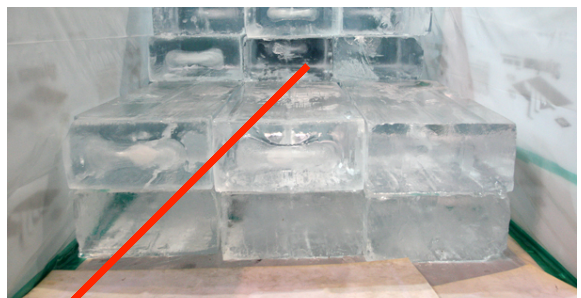
ANITA Coll., PRL (2007)

Beamtest at SLAC: proof of Askaryan effect in ice

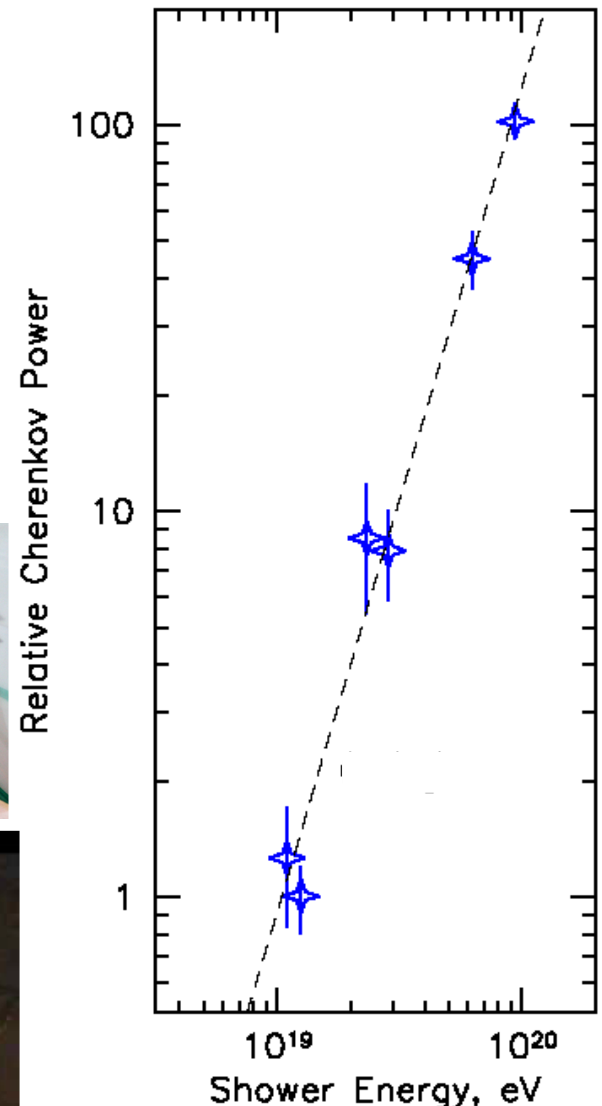
28.5 GeV shower x 10^9 particles/shower

- Coherent ($P \sim E^2$)
- Linearly Polarized

Askaryan Effect also seen in the lab in sand and salt



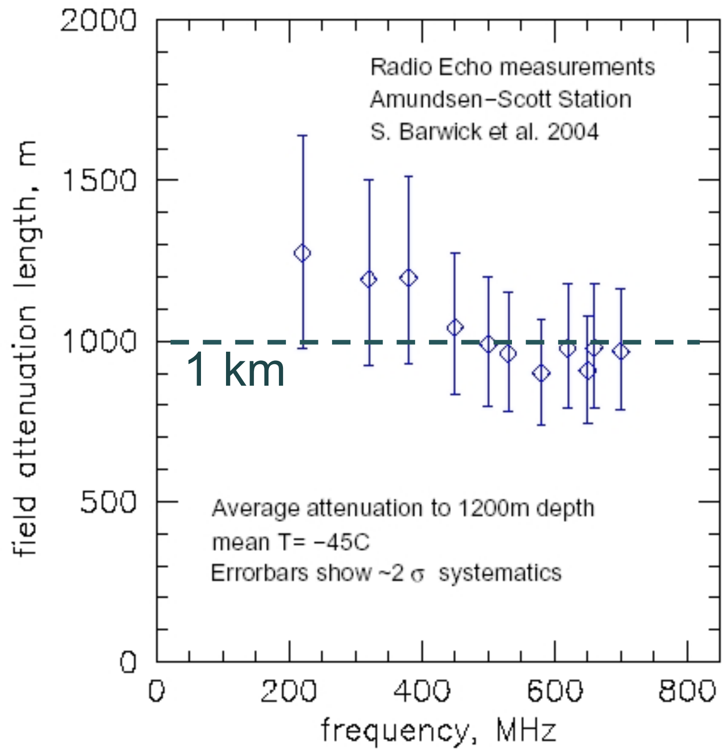
7.5 tons of ice

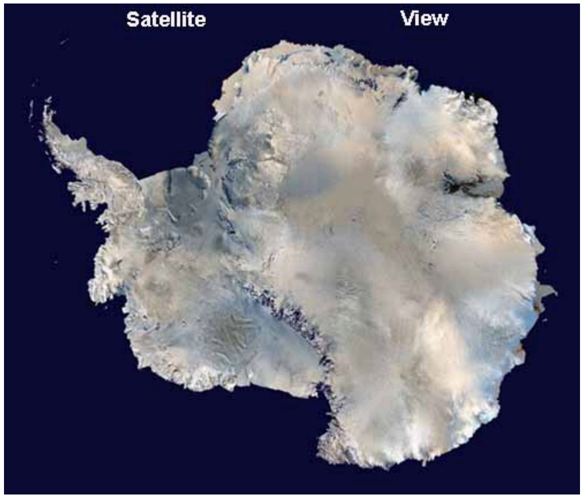


UHE Neutrino Detector Requirements

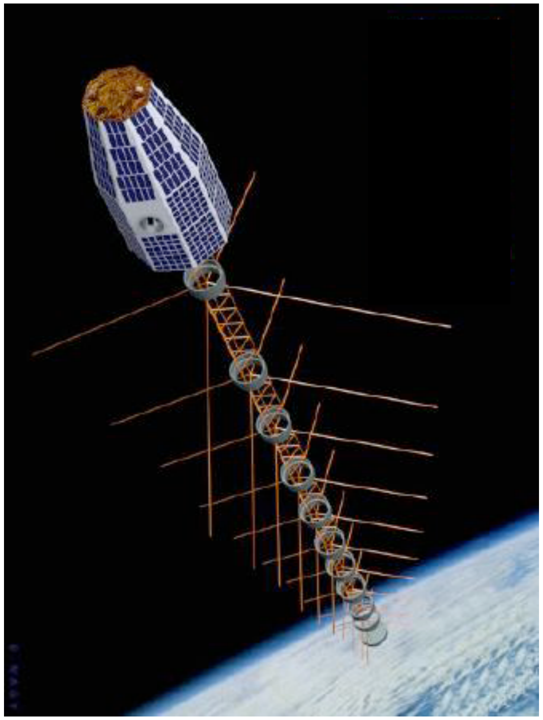
- ~1-10 GZK neutrinos/km^2/year
- L_{int} ~ 300 km
  → ~ 0.01 neutrinos/km^3/year
- Need a huge (>> 100 km^3), radio-transparent detector
- 3 media: salt, sand, and ice
- Long radio attenuation lengths in south pole ice
  – 1 km for RF (vs. ~100 m for optical signals used by IceCube)

→ Antarctic ice is good for radio detection of UHE neutrinos!





Pioneering Experiments



FORTE (97-99)
Greenland Ice
Log periodic antenna
20-300 MHz
A=10^5 km^2sr

GLUE/Goldstone (1999)
Lunar Regolith
2 GHz
A=6x10^5 km^2sr

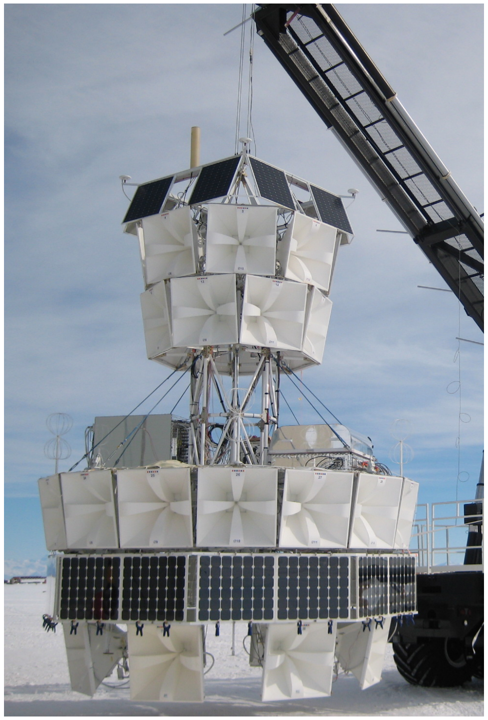
RICE 1999-present
South Pole
100-1000 MHz
V=10 km^3sr

ANITA-I & ANITA-II

NASA Long Duration Balloon, launched from Antarctica

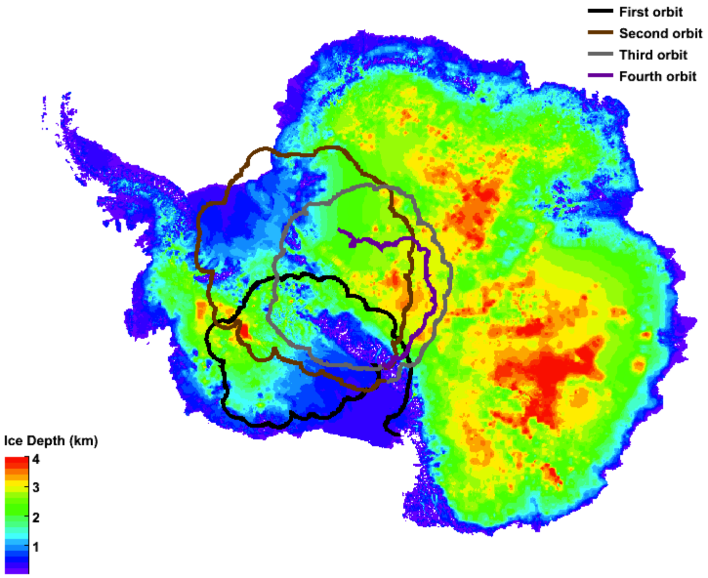
ANITA-I: 35 day flight 2006-07

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

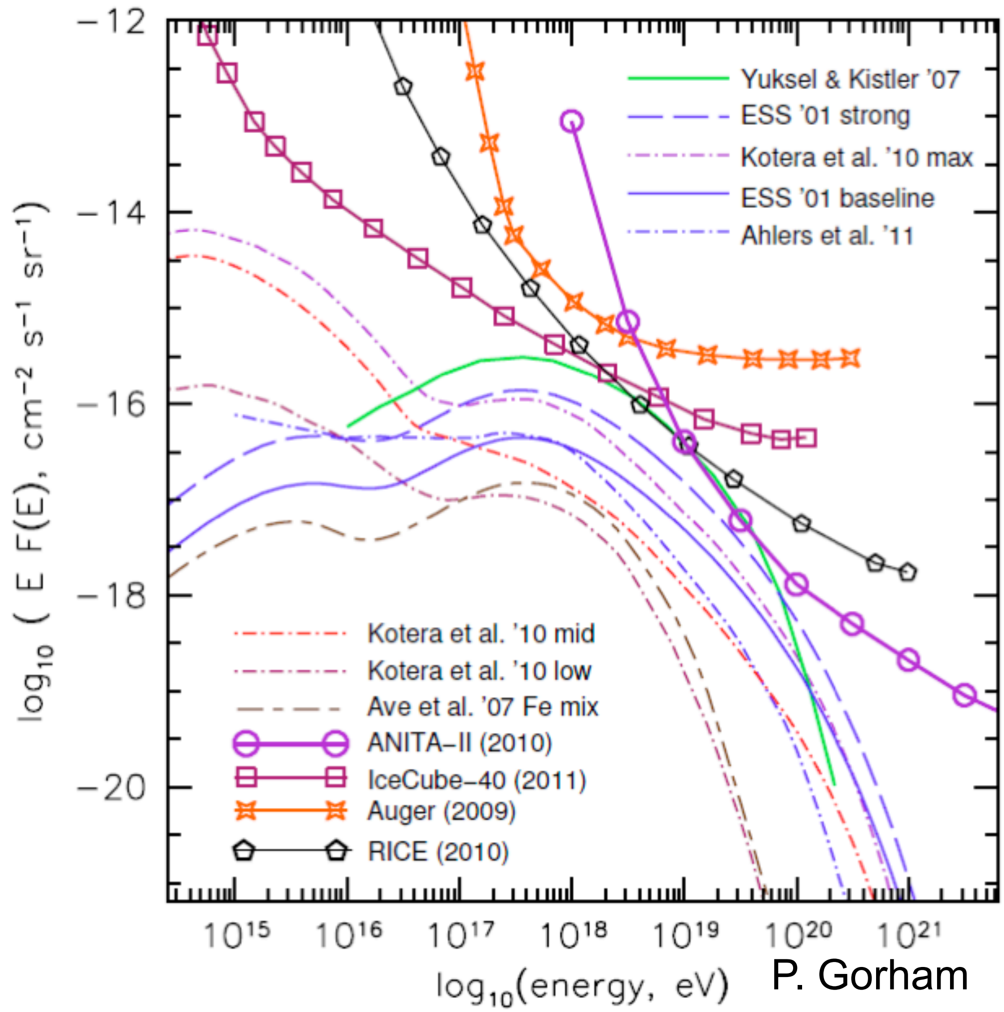


UHE Neutrino Search Results:

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

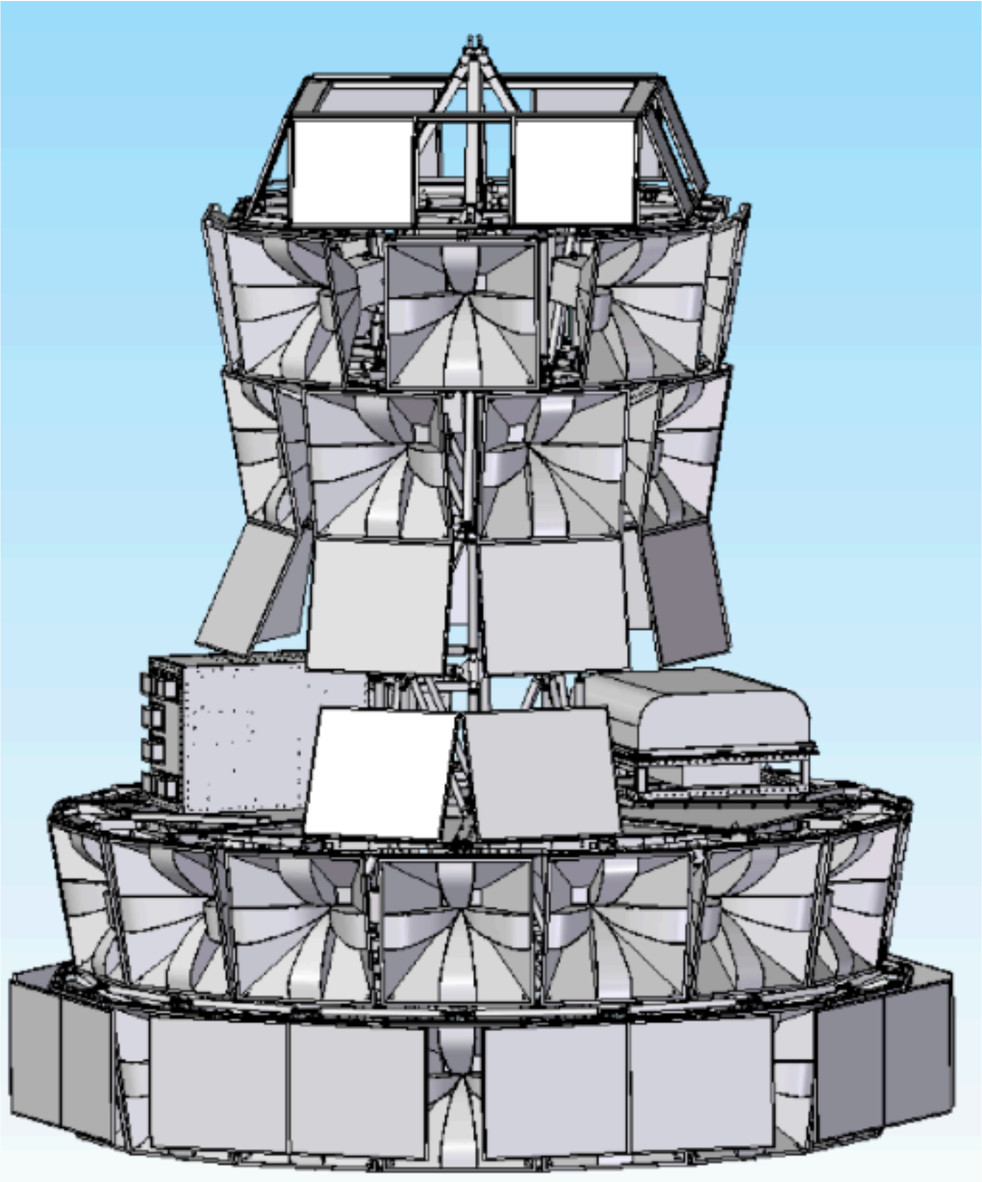
Current Constraints

- 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 neutrino observatory?



P. Gorham

ANITA-III: 2013-2014



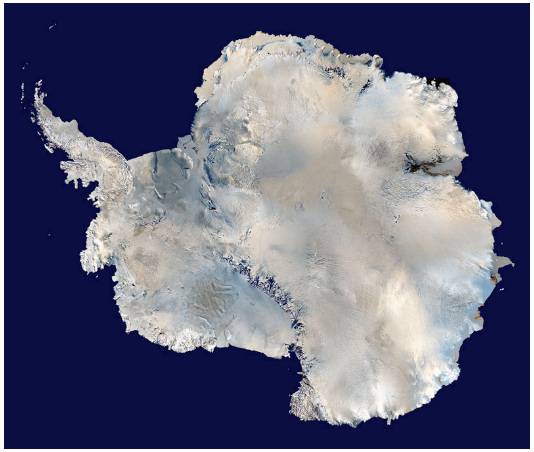
- Flight scheduled this year (December 2013)
- More antennas
- Digitize longer traces
- New: interferometric trigger
- Lower noise front-end RF system

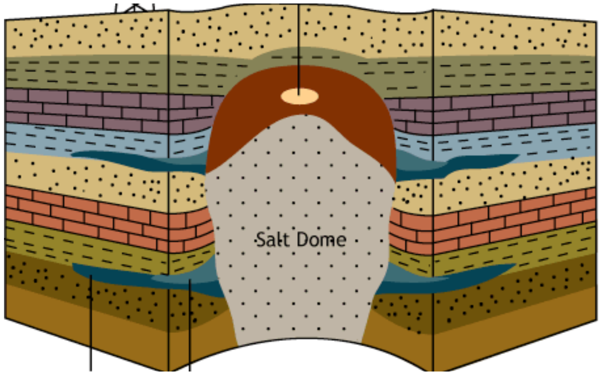
→ Factor of 5 improvement in neutrino sensitivity compared to ANITA-II

Beyond ANITA-III: Going to the Ground

Learned from ANITA: Go to the ground

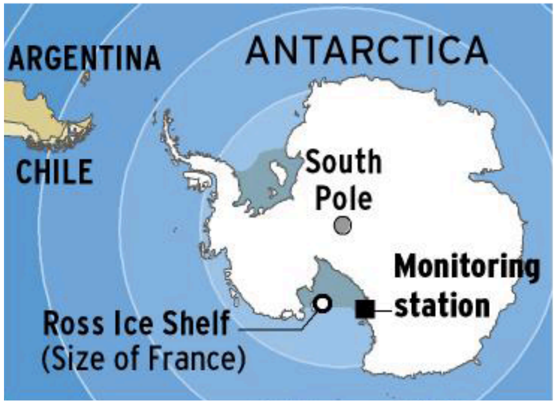
- Much more livetime
- Understandable man-made background
- Lower energy threshold
- Use more antennas than on a balloon
- But: smaller instrumented volume

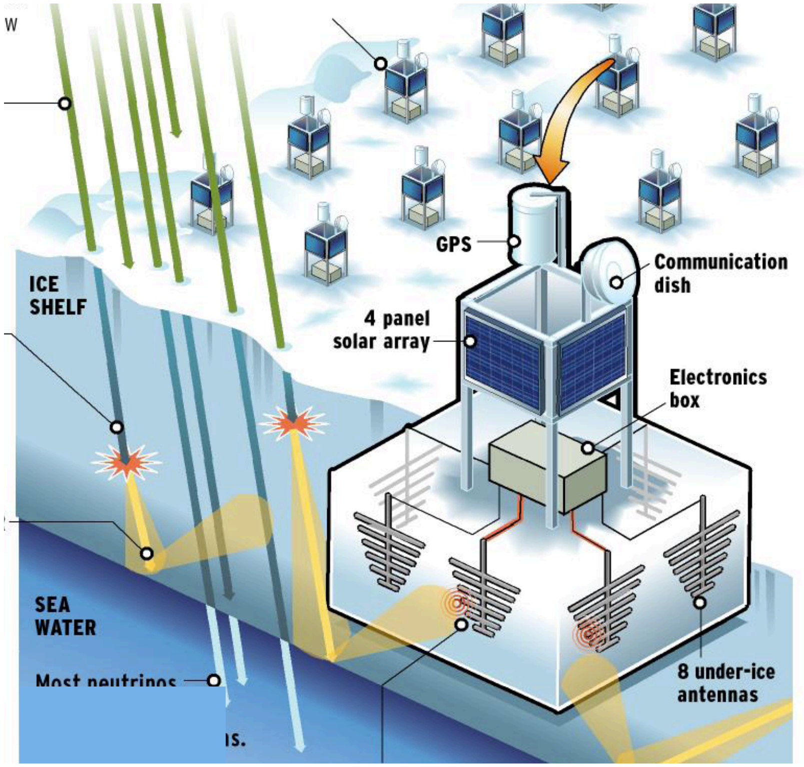




ARIANNA

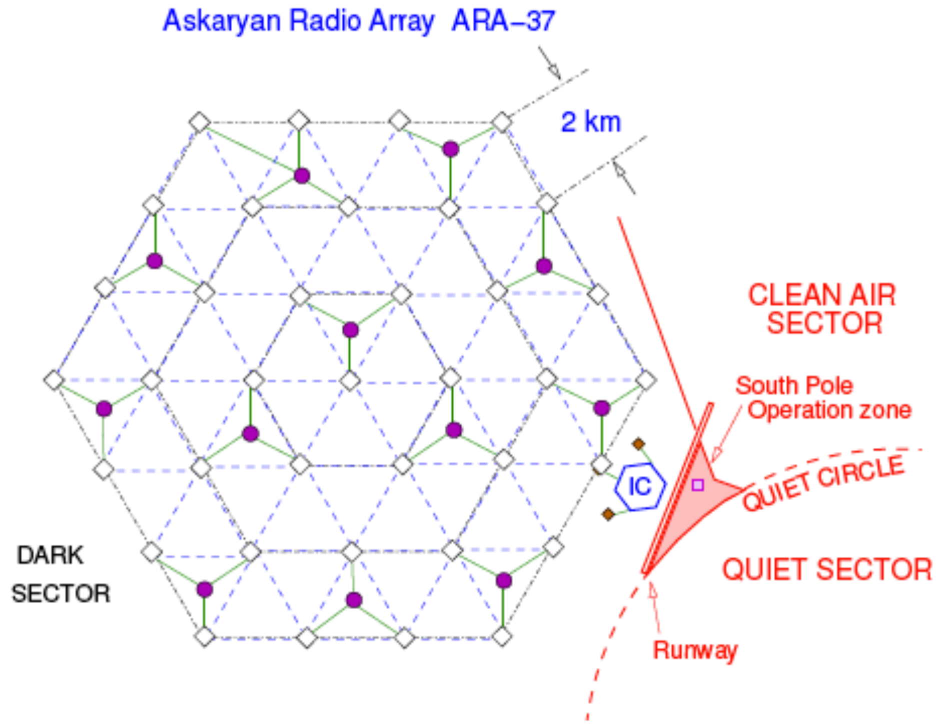
- Idea: Ground-based array of antennas on the surface of the Ross Ice Shelf
- Currently: 4 stations operating well, 3 more coming
- Plan: future proposal for many more stations





ARIANNA Coll. See arXiv:1207.3846

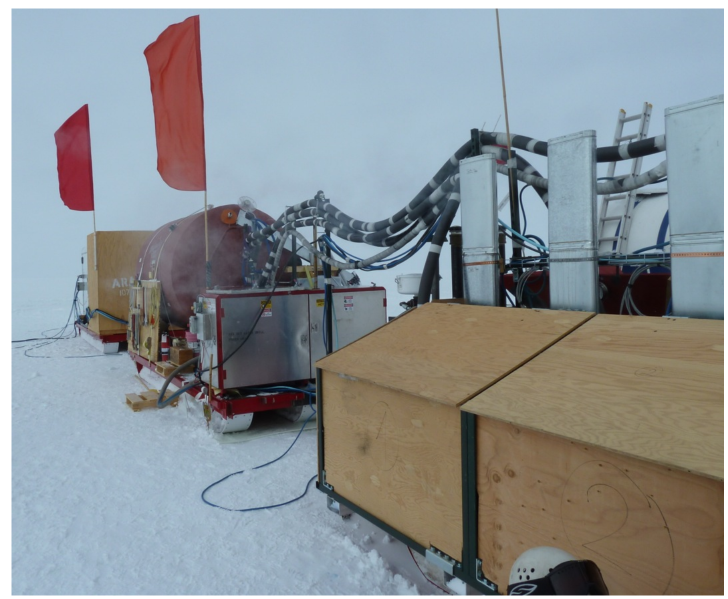
ARA: Askaryan Radio Array



- Idea: 37-station array of antennas buried 200m below the surface at the South Pole
- Currently: 3 stations + testbed deployed and working
- Plan: pending proposal for the next stage of deployment

V Pol Antennas

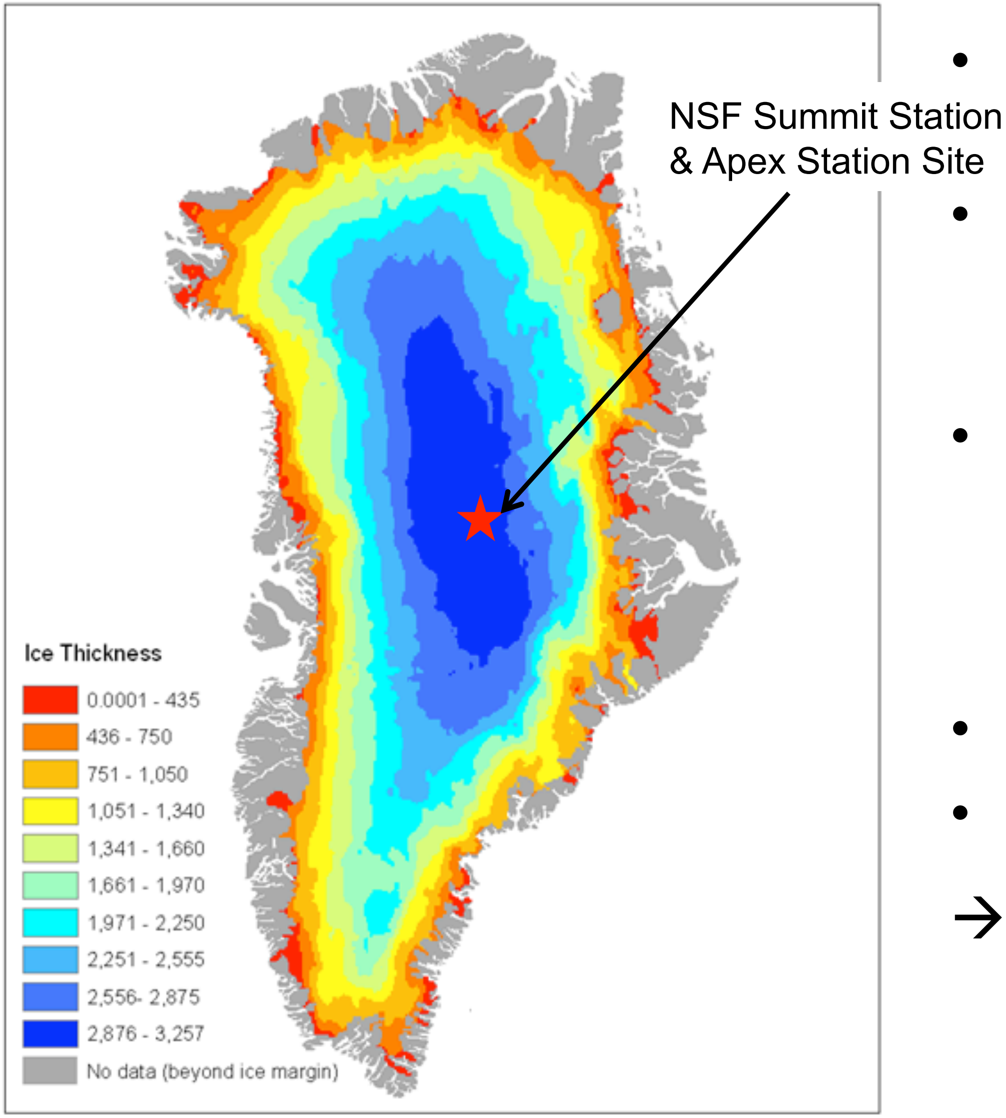
H Pol Antennas



ARA Collaboration. Astropart. Phys. (2011)

Greenland Site Characterization

Greenland Ice Thickness



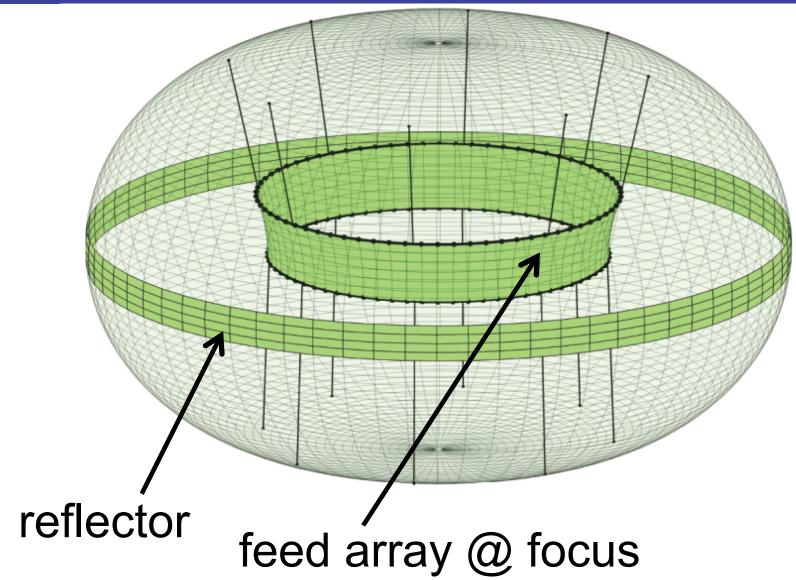
Kansas Univ. CRESIS

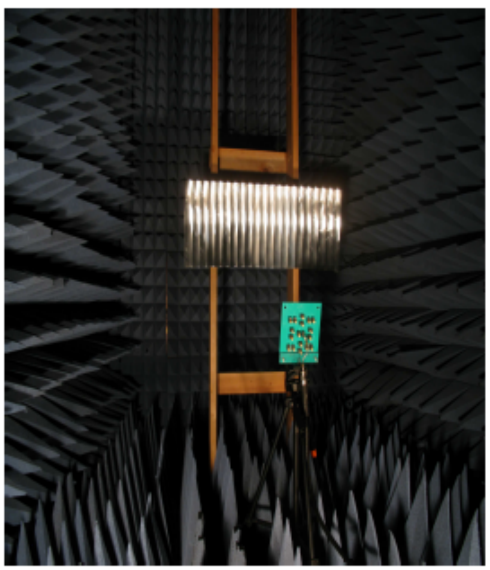
- 3 km thick ice at Summit and Apex Stations
- Evidence for water layer at the bottom (reflections add to effective volume)
- Measurements by glaciologists (Paden et al.) suggest comparable radio properties to the best Antarctic ice
- Radio quiet site?
- Logistical advantages?

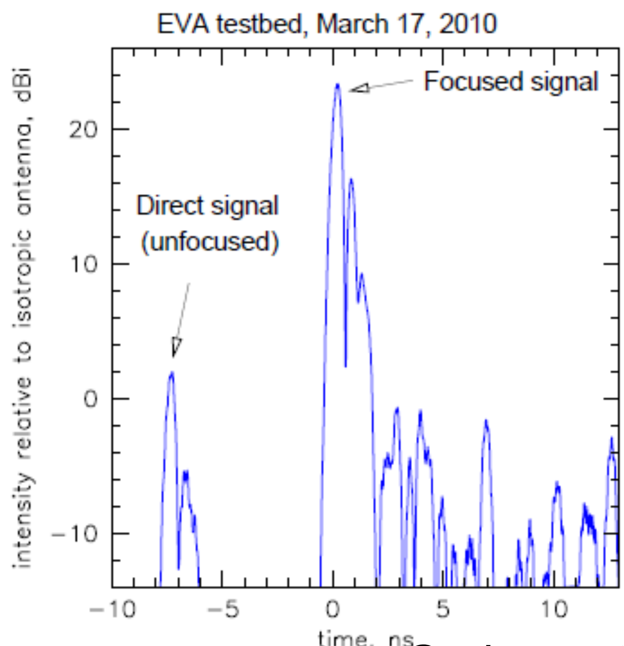
→ Site characterization visit June 2013 – directly measure radio properties

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 summer 2014
- Full Balloon: similar sensitivity to full, 3-year ARA, and ARIANNA



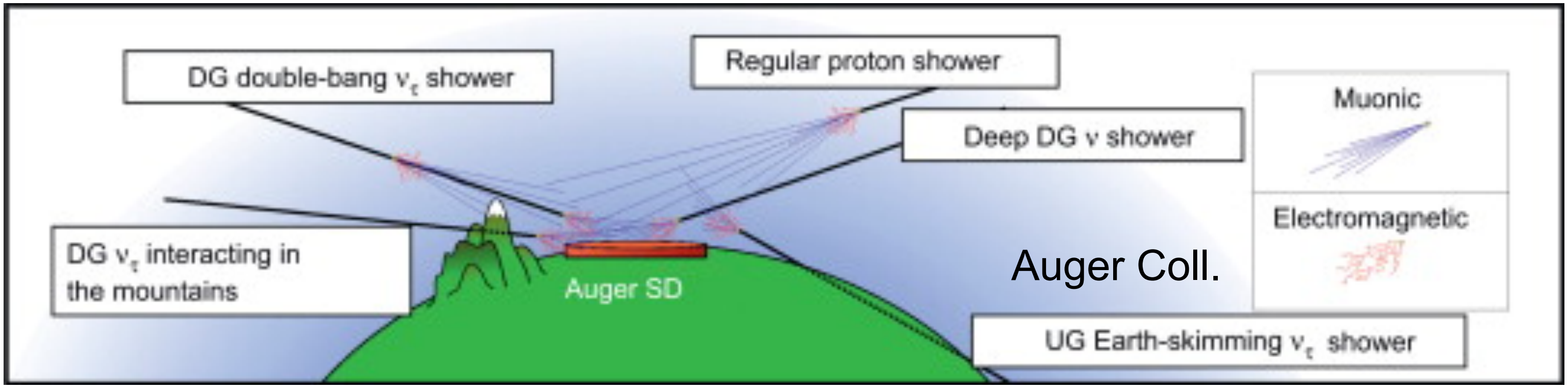




Gorham et al. Astropart. Phys. (2011)

Other Ways of Seeing UHE Neutrinos

- Auger: Earth-skimming neutrinos and deep downgoing showers



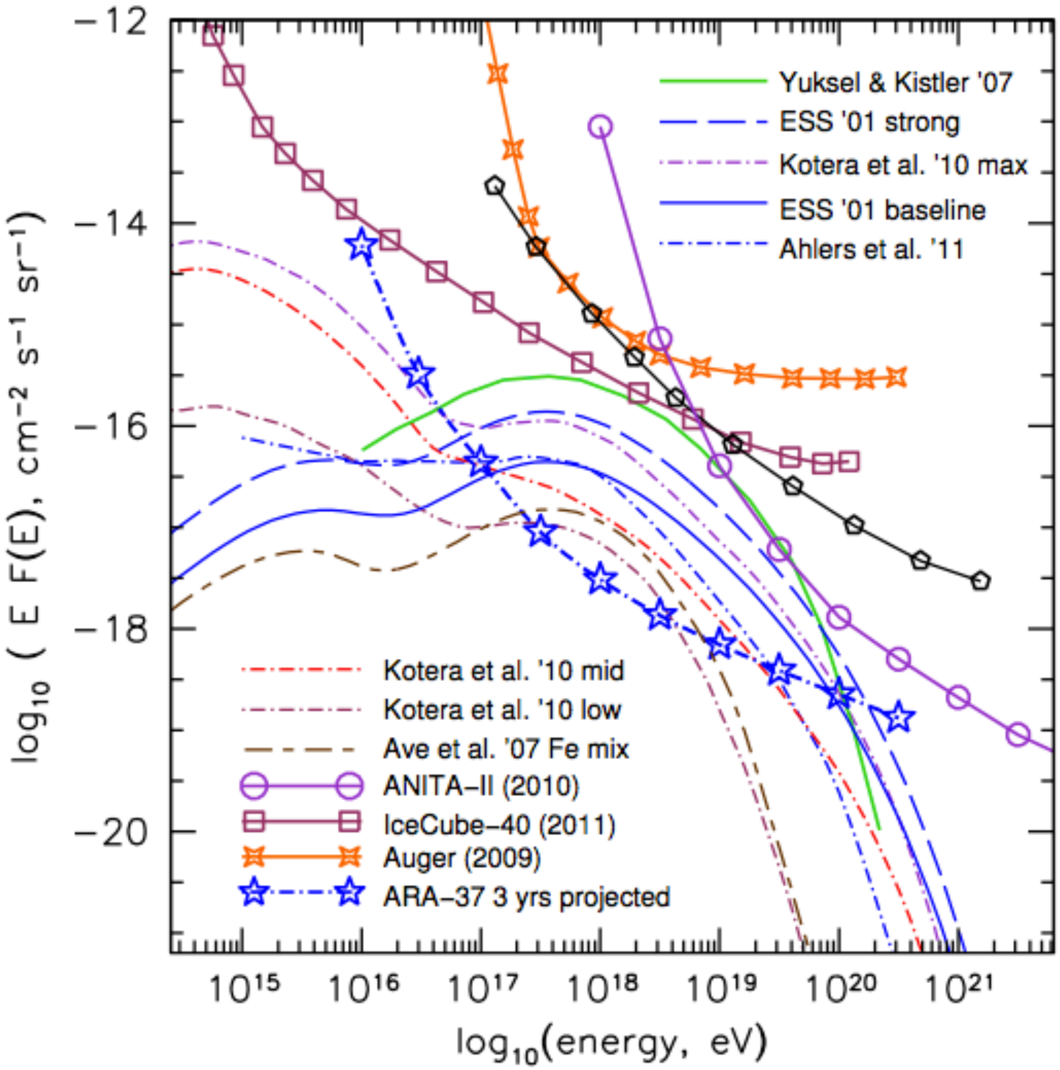
Auger Coll.

- SKA: sensitivity to neutrinos interacting in the lunar regolith

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

- It is an exciting time in the search for UHE neutrinos!
- Probing lots of fundamental particle physics and astrophysics
- Radio technique has been proven, current results begin to constrain models
- ANITA-III this year
- Large forward-looking efforts in initial stages: ARIANNA, ARA, EVA
- In 5 years, we hope to have a real UHE neutrino observatory and to observe for many more years