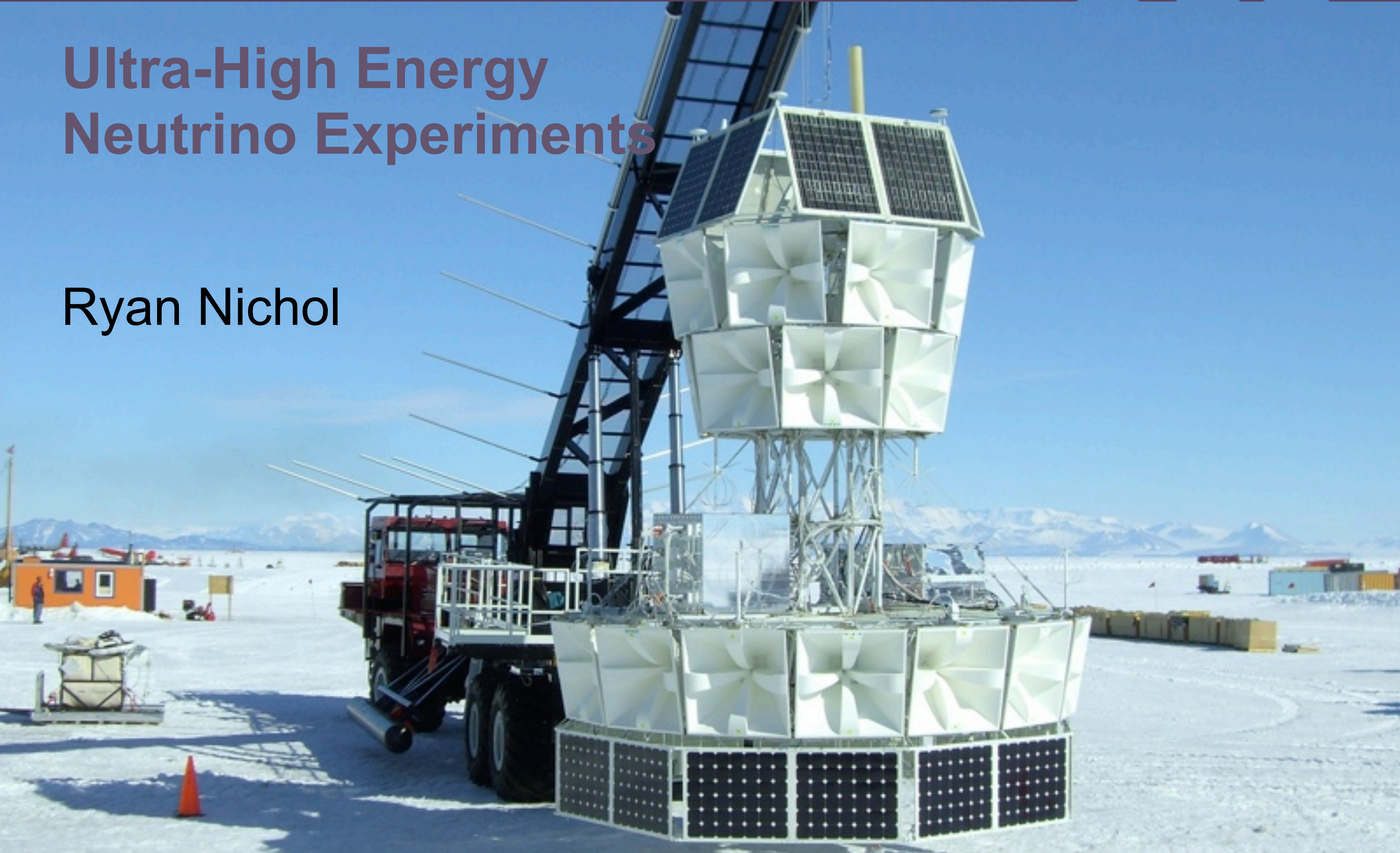
Ultra-High Energy Neutrino Experiments

Ryan Nichol



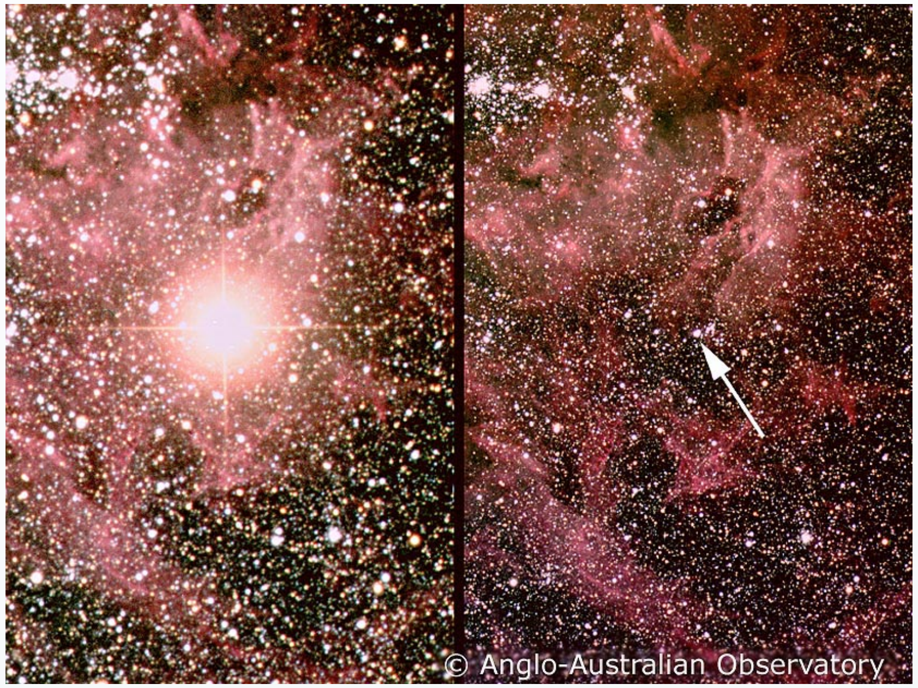
Outline

- Historical Context
- Motivation for Ultra-High Energy Neutrino
  - For Astronomers, Astrophysicists and Particle Physicists
- Possible Detection Methods
  - Acoustic Detection, Air Showers, Optical Cherekov & Radio Cherenkov
- Optical Experiments
- Acoustic Experiments
- Air Shower Experiments (Auger)
- Radio Experiments
- Summary

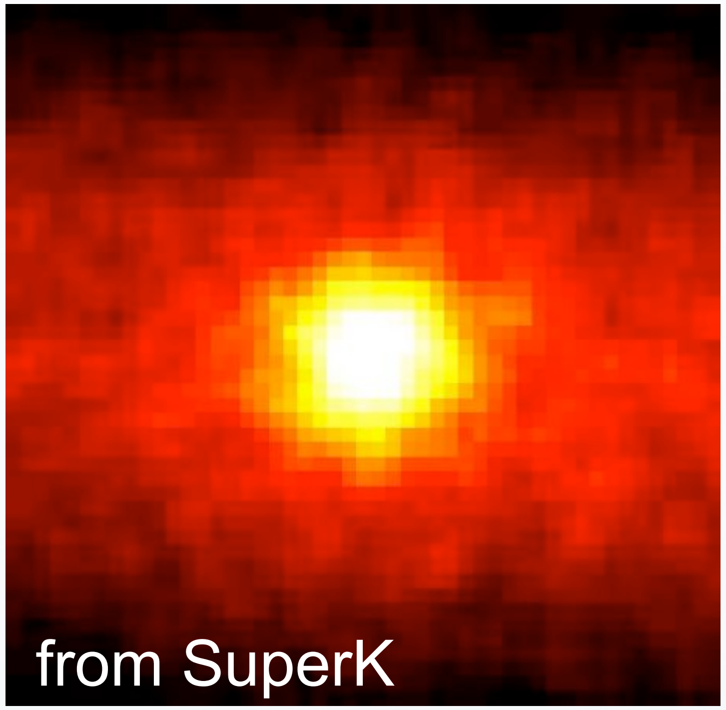
Historical Context

- Only two sources of extra terrestrial neutrinos have ever been observed

SN1987A



The Sun

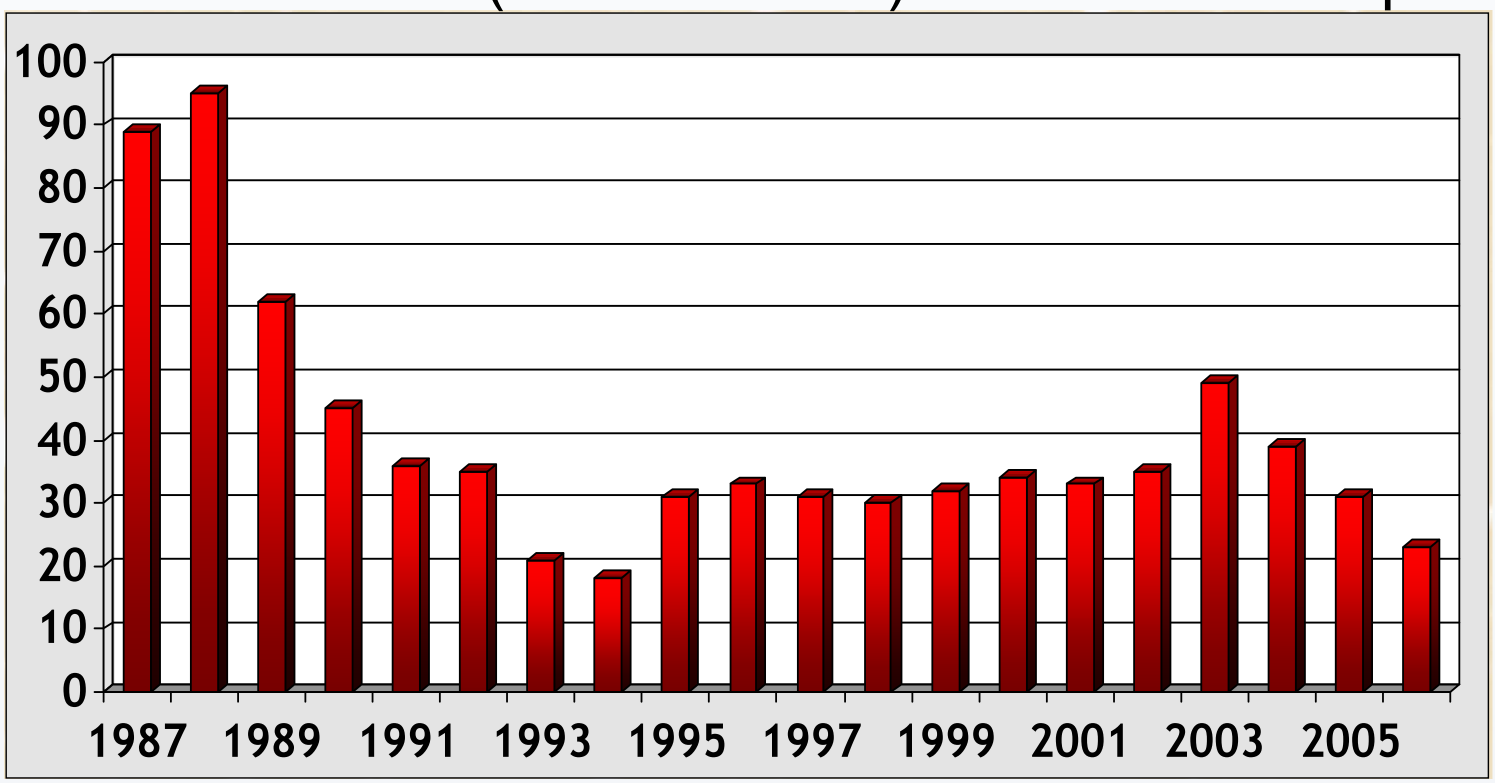


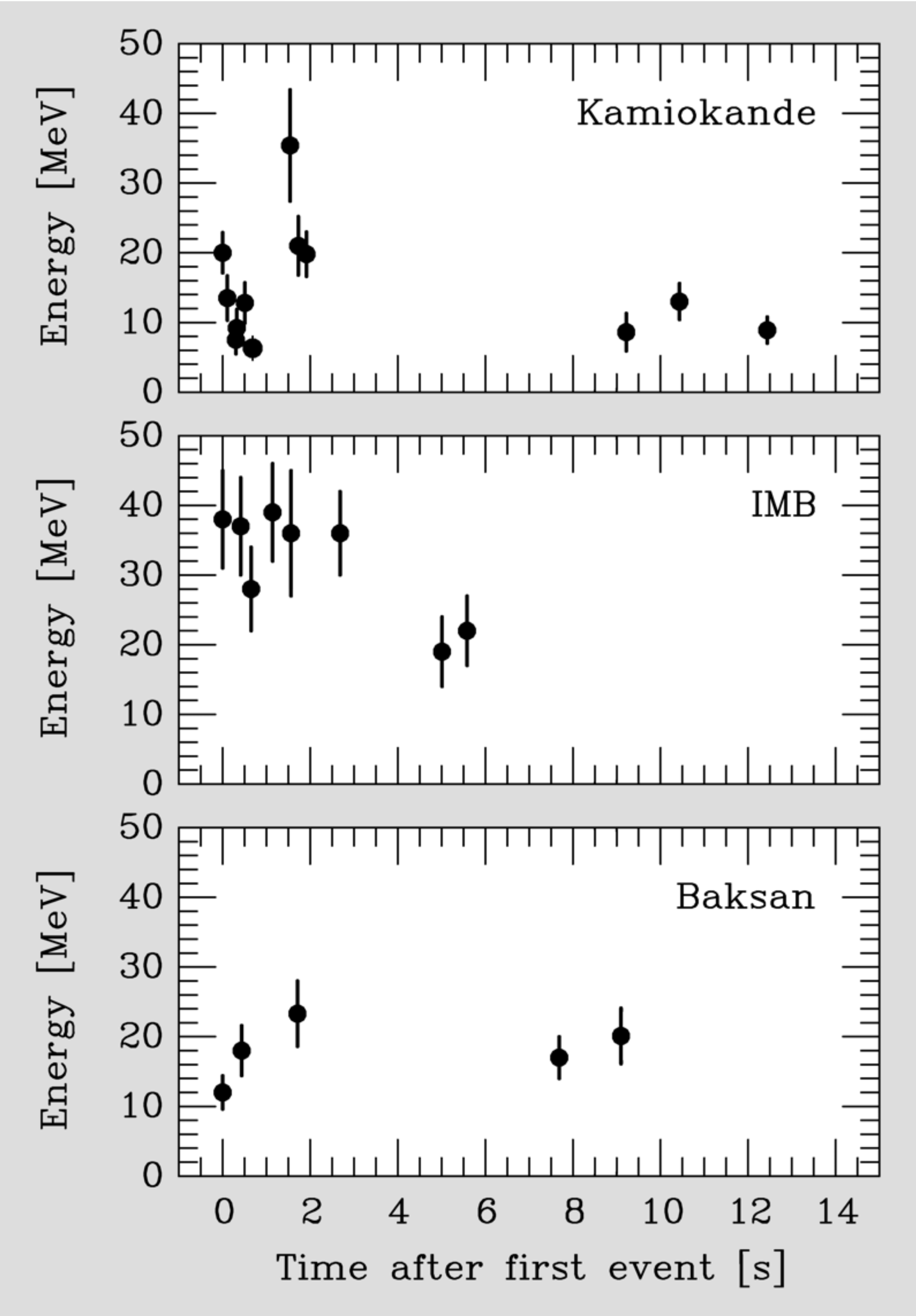
- The detection of these extraterrestrial neutrinos have helped to provide insights into:
  - Nuclear fusion in the Sun, how supernovas work , neutrino masses (both through oscillations and absolute mass limits), ...

More on SN1987A

- A handful of neutrino events sparked a flurry of scientific interest that has lasted over twenty years.

Annual Citations (from SPIRES) of SN 1987A Papers

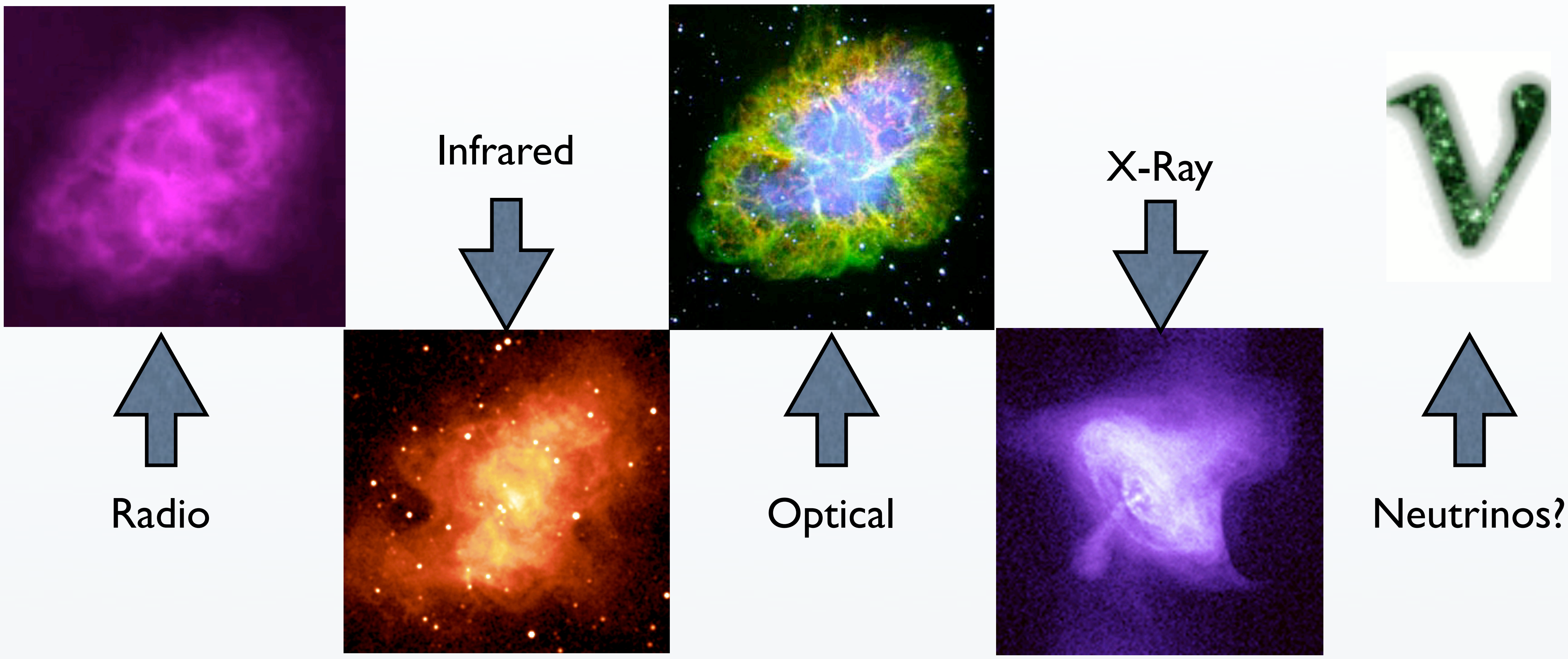




Plots stolen from Georg Raflett

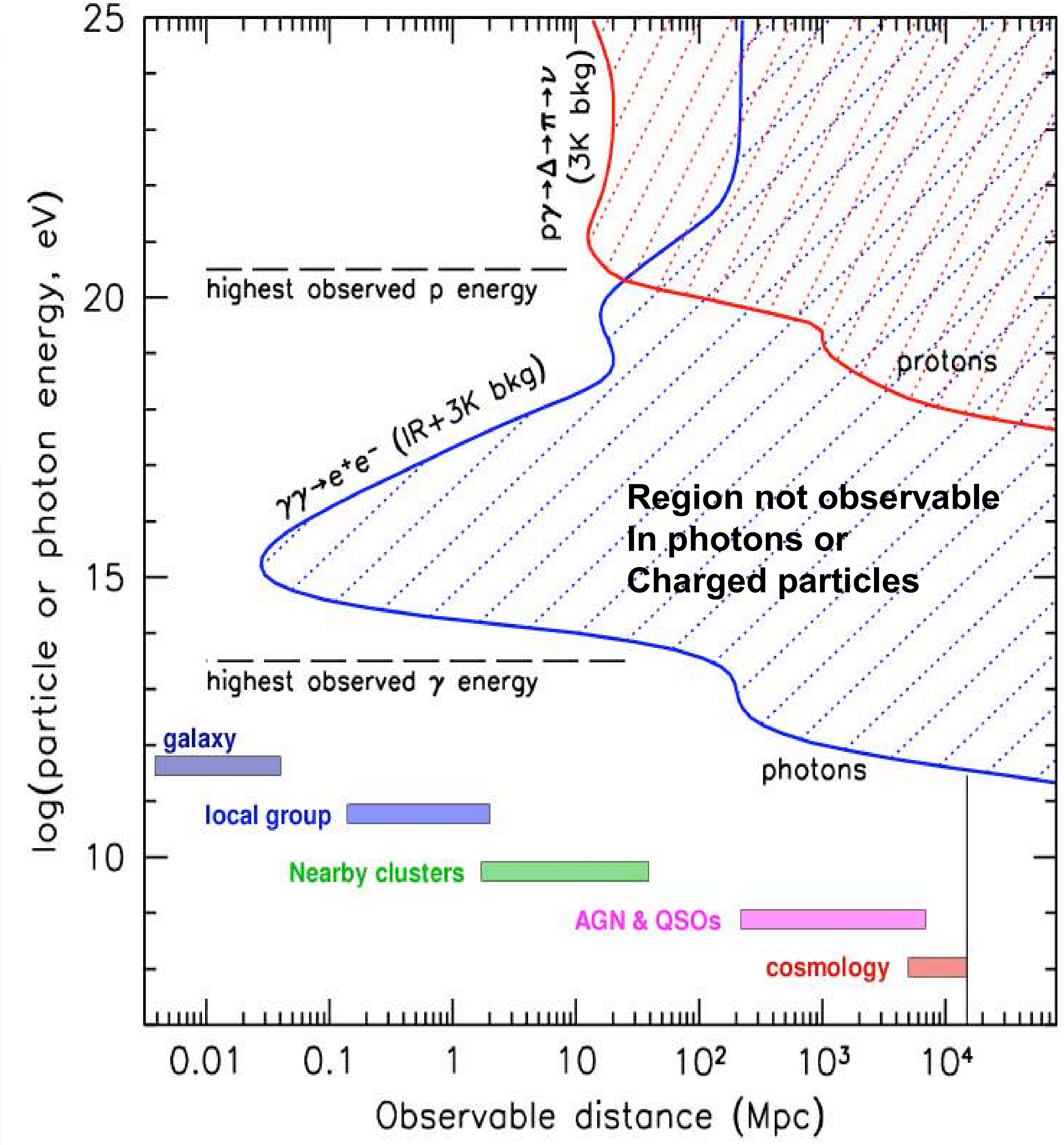
UHE Neutrino Motivation -- for Astronomers

- Why are ultra-high energy neutrinos interesting?
  - The pretty pictures answer.



"The real voyage of discovery consists not in seeking new landscapes, but in having new eyes." **Marcel Proust**

UHE Neutrino Motivation -- for Astrophysicists

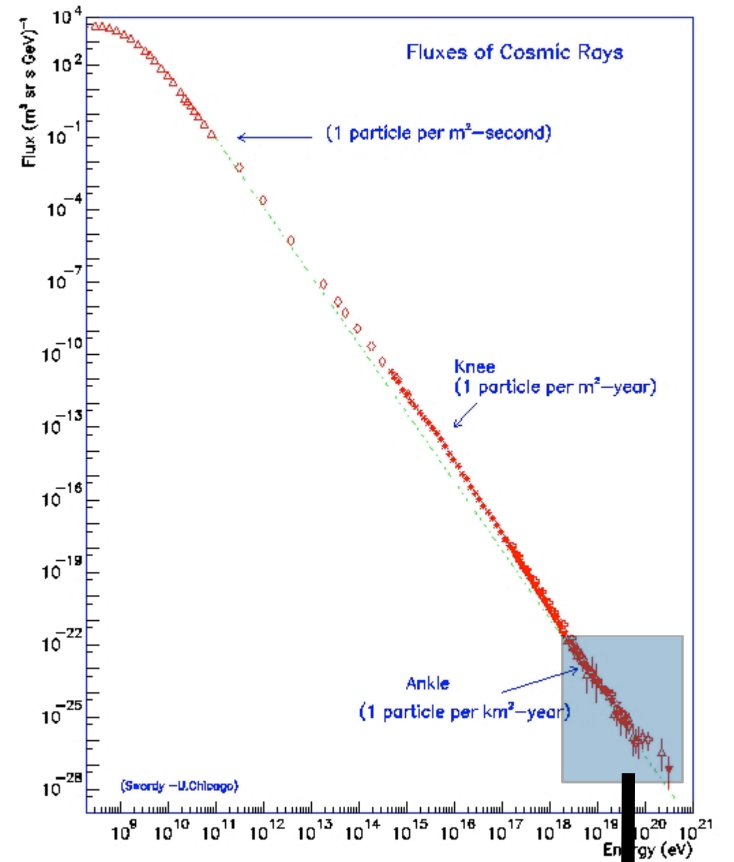


from P. Gorham

- Photons attenuated by:
  - Infrared Background
  - CMB
- Protons:
  - Deflected by magnetic fields
  - Attenuated by CMB
- Neutrinos:
  - Can reach the energies and distances that other particles can't.

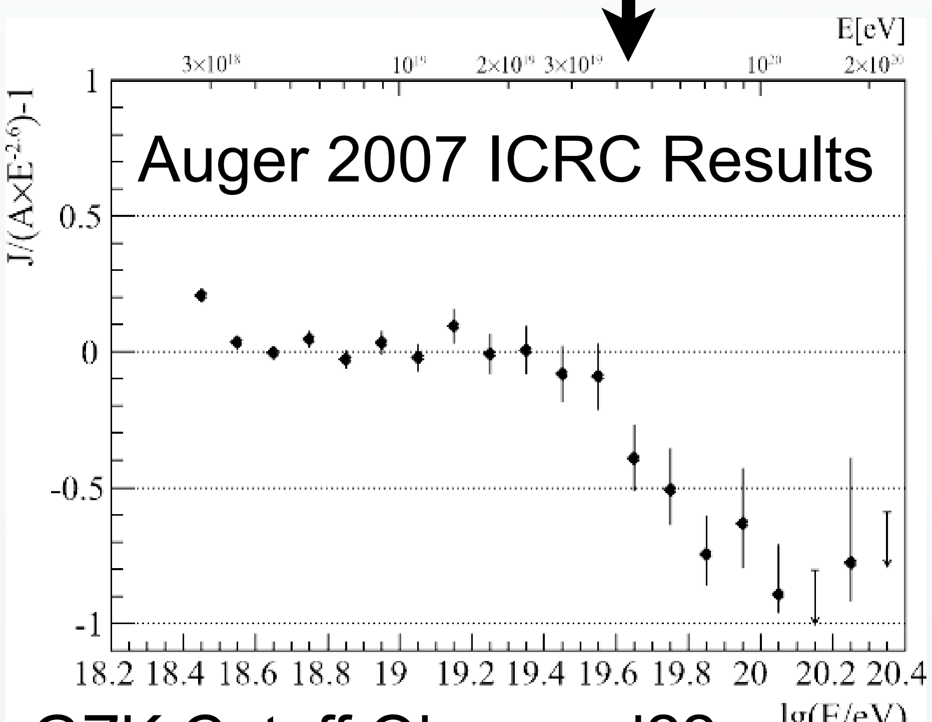
The Particle

Aside: The GZK Effect



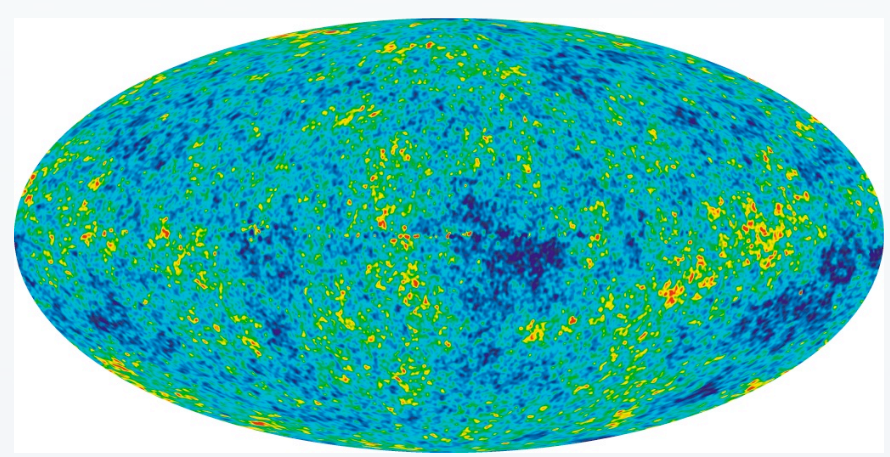
- Greisen-Zatsepin-Kuzmin (GZK) calculated cosmic rays above $10^{19.5}$eV should be slowed by CMB within 50MPc.

$$p + \Upsilon_{CMB} \rightarrow \Delta^{*} \rightarrow n + \pi^{+}$$
$$\searrow \mu^{+} + \nu_{\mu}$$
$$\searrow e^{+} + \bar{\nu}_{\mu} + \nu_{e}$$



GZK Cutoff Observed??

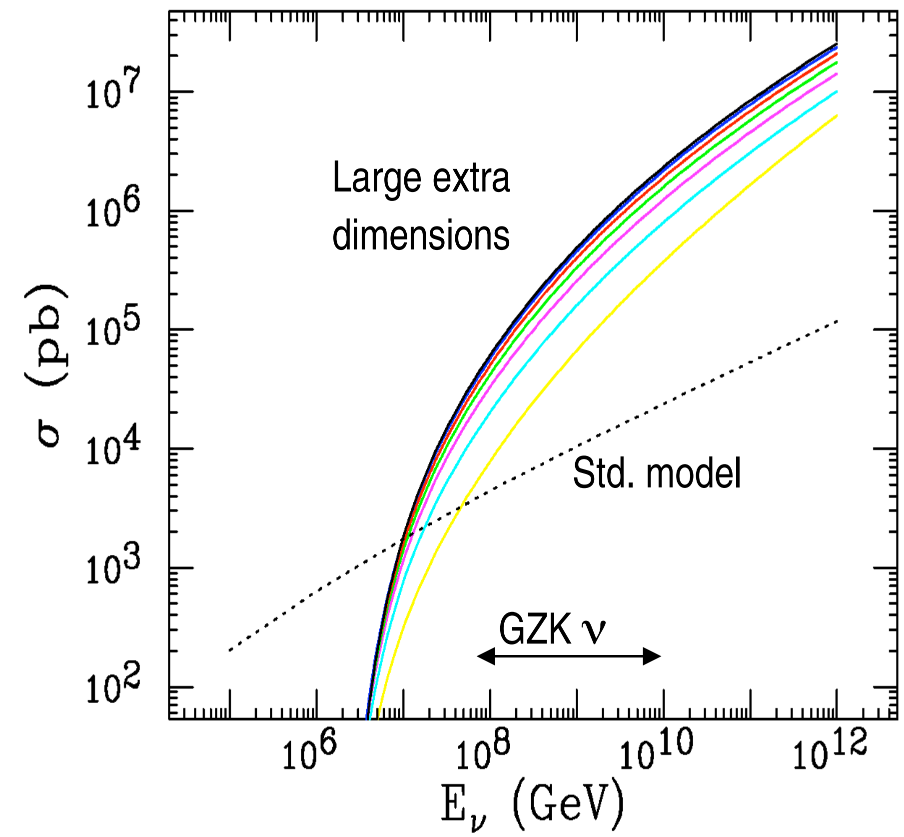
+



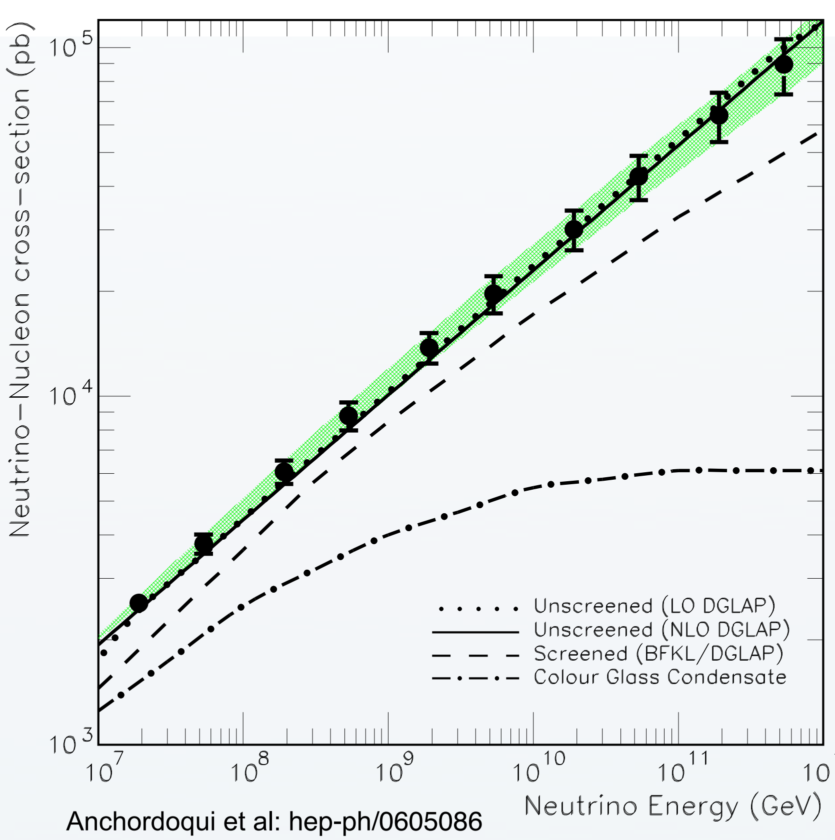
= “Guaranteed” Neutrino ‘Beam’!

UHE Neutrino Motivation -- for Particle Physicists

- 300 TeV (CoM) Neutrino 'Beam'
  - Neutrino-nucleon cross section in new regime
    - Large extra dimensions
    - Micro black holes
  - With flavour tagging can probe:
    - Neutrino Oscillations
    - Neutrino Decay & Decoherence
  - Other/Exotic:
    - Super heavy relic particles
    - Topological Defects
    - Magnetic Monopoles
    - ....



Anchordoqui et al. Astro-ph/0307228



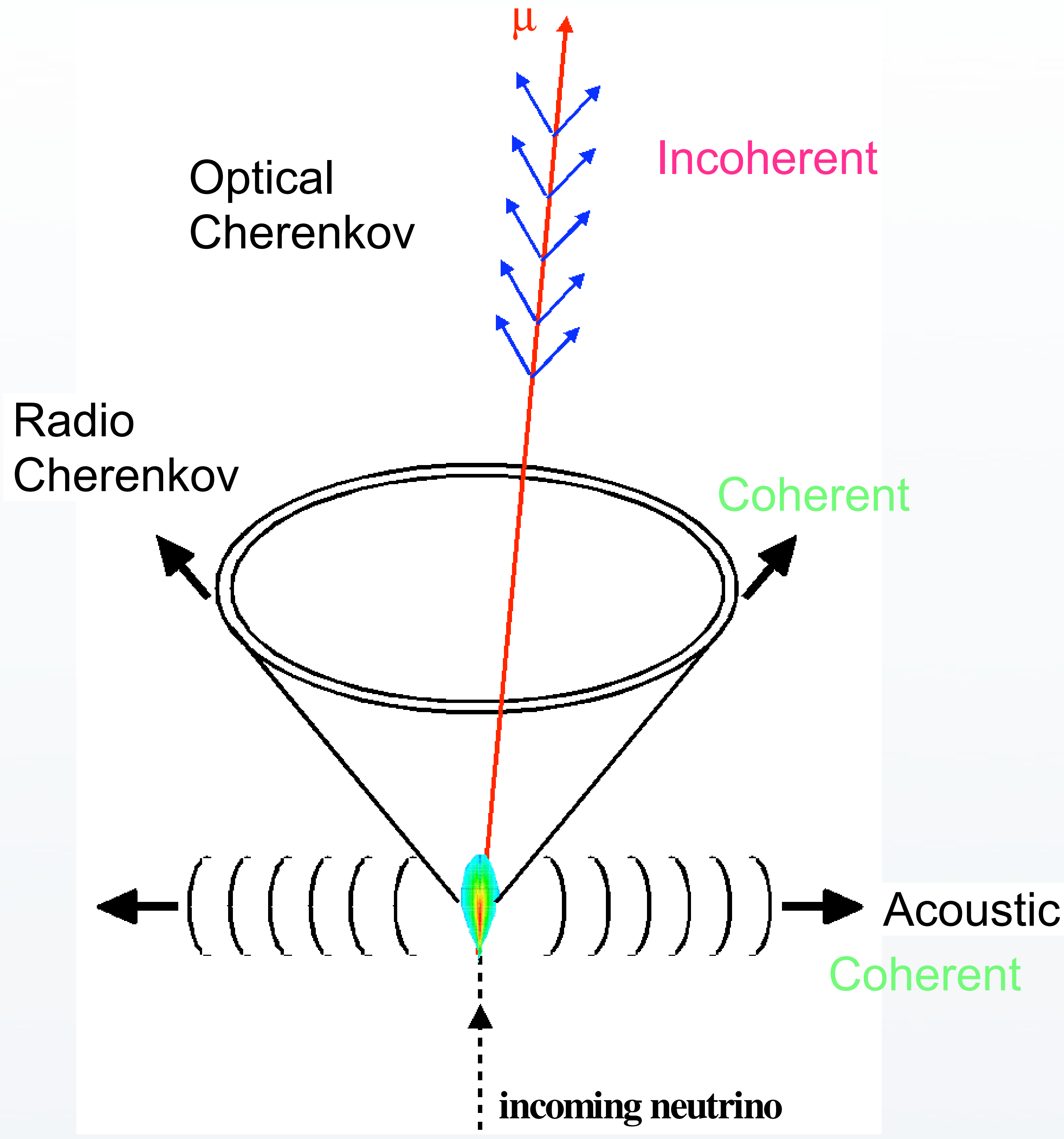
Anchordoqui et al: hep-ph/0605086

How can you detect GZK neutrinos?

- A problem of size
  - Some Numbers:
    - ~10 GZK neutrinos per km^2 per year
    - @ 10^{18} eV the ν-N interaction length ~ 300km
    - ∴ 0.03 neutrino interactions per km^3 per year
- One needs a huge detector volume (>>10 km^3) in order to ensure a neutrino detection.
- Have to use a naturally occurring medium, that is transparent (to some signal). Possibilities,
  - Air, Ice, Salt, Water, The Moon

Possible Detection Methods

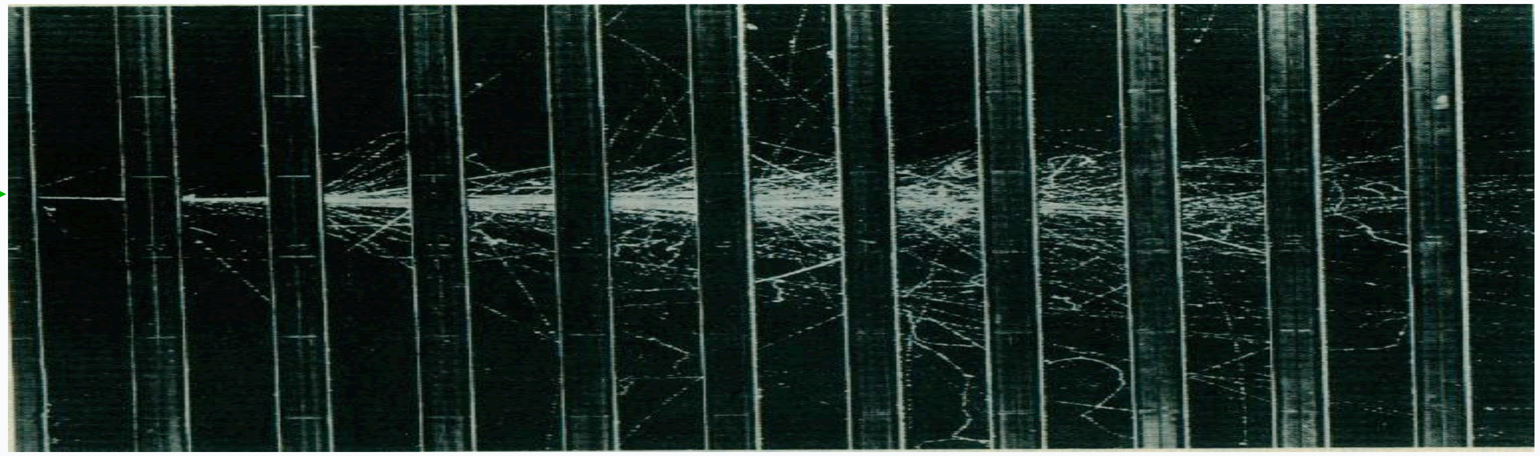
- Optical Cherenkov
  - Mature field but not scalable to huge volumes
- Radio Cherenkov
  - Active field (best candidate for first detection?)
- Acoustic
  - Emerging field, with many R&D efforts
- Air showers
  - Neutrinos travel further before interacting



Askaryan Effect

- In 1962 Gurgen Askaryan hypothesized coherent radio transmission from EM cascades in a dielectric:

$e^{\pm}$ or Υ



Typical Dimensions:
$L \approx 10$ m
$R_{Moliere} \approx 10$ cm

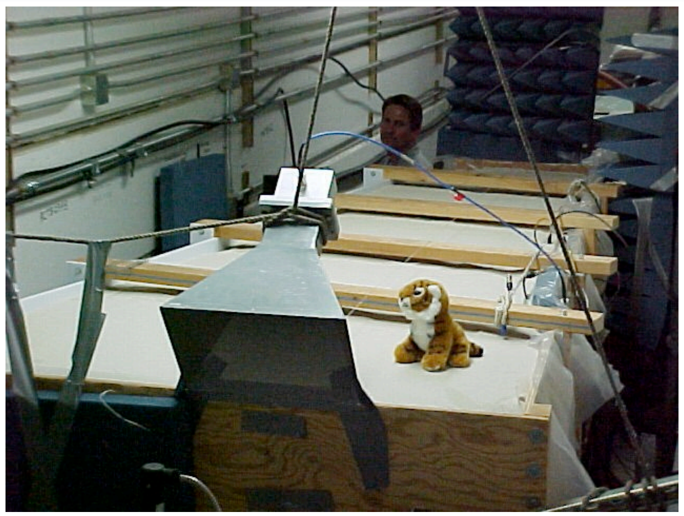
– 20% Negative charge excess:
  - Compton Scattering: $\Upsilon + e^-_{(rest)} \Rightarrow \Upsilon + e^-$
  - Positron Annihilation: $e^+ + e^-_{(rest)} \Rightarrow \Upsilon$

– Excess travelling with, $v > c/n$
  - Cherenkov Radiation: $dP \propto \nu \, d\nu$

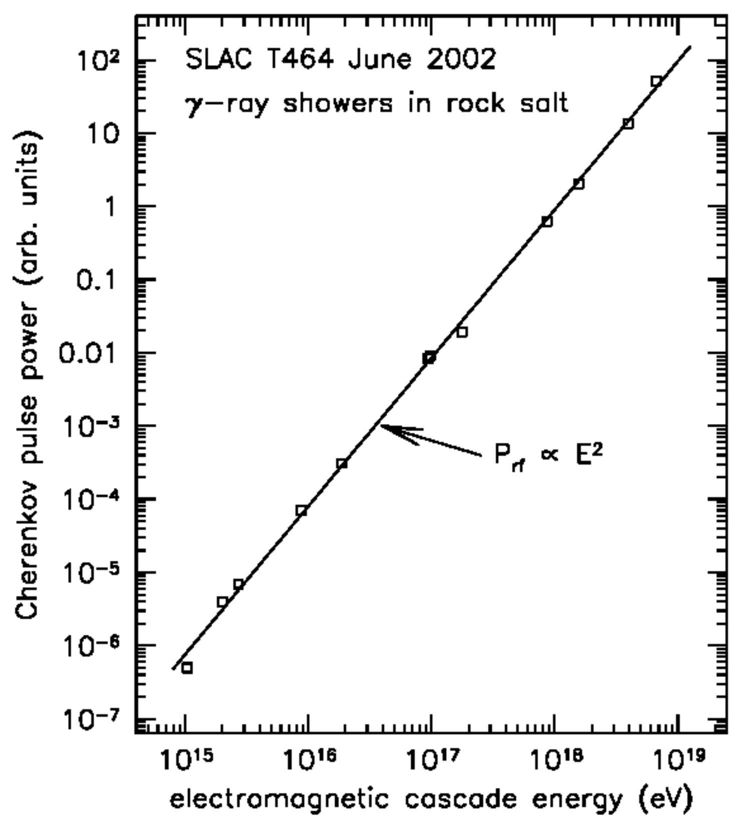
– For $\lambda > R$ emission is coherent, so $P \propto E^2_{shower}$

Experimentally verified in Sand, Salt and Ice

- Askaryan effect experimentally confirmed in beam tests at SLAC 2000, 2003 and 2006



From Saltzberg, Gorham, Walz et al PRL 2001



From Gorham, et al PRL 2007

Coherent signal observed in all three media (but ice ‘looks’ the prettiest)

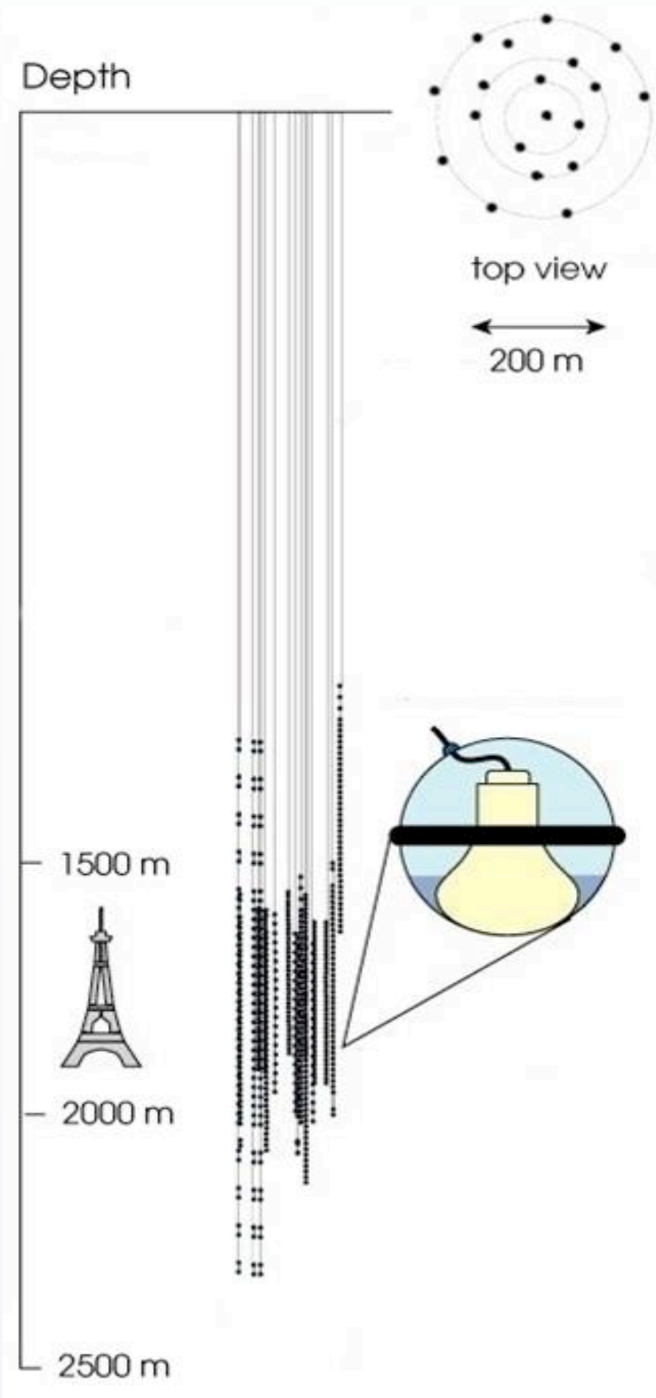
The Experiments (well, some of them)

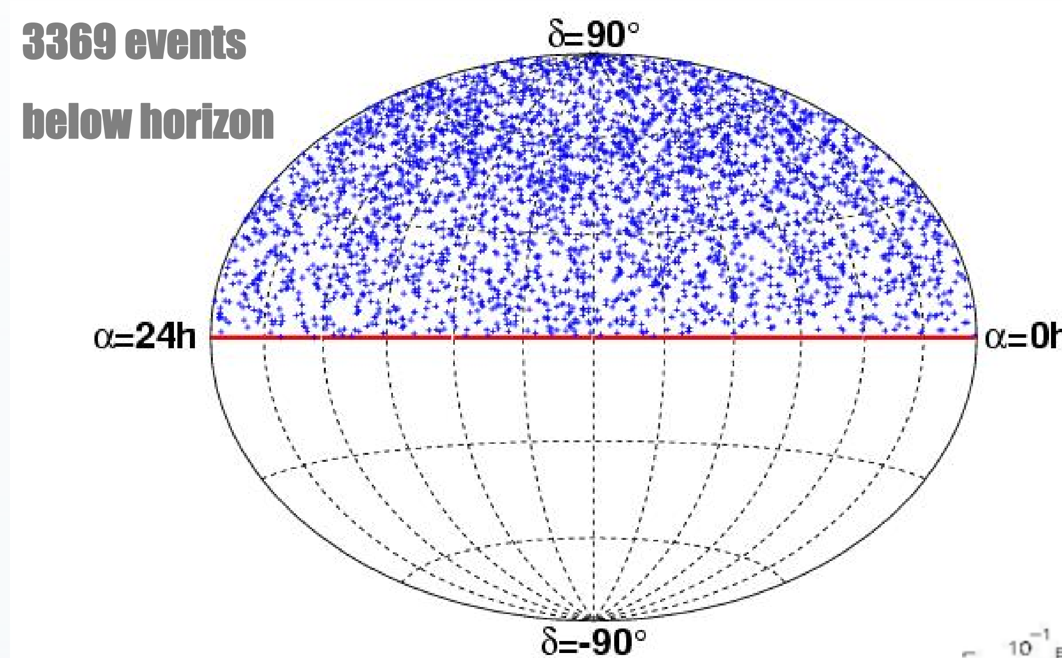
- Optical Cherenkov
  - Dumand, Baikal, Amanda, IceCube, Antares, Nestor, Nemo, Km3net, ...
- Acoustic
  - Saund, ACORNE, SPATS, Amadeus, 0vDE ...
- Air Shower
  - AGASA, HiRes, Auger, ...
- Radio Cherenkov
  - Forte, GLUE, RICE, ANITA, AURA/IceRay, ARIANNA, SalSA, NuMoon, Lunaska, ...

- Colour Key:
  - Completed, Active (published + ongoing), Active (construction), Active (R&D), Proposed

Amanda II

- Optical Cherenkov array located at the South Pole, in operation since 1999



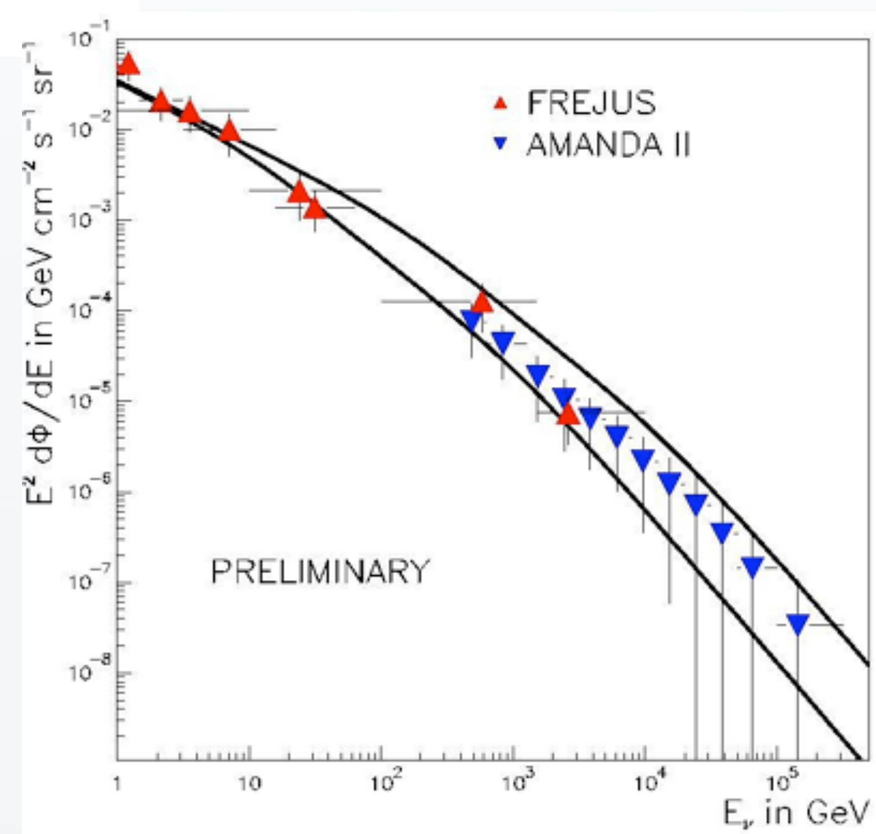


Look for the blue Cherenkov light from up-going muons and particle cascades. Only sensitive to neutrinos from the Northern hemisphere.

No excess observed over the background of atmospheric muons

No cosmic diffuse flux of neutrinos

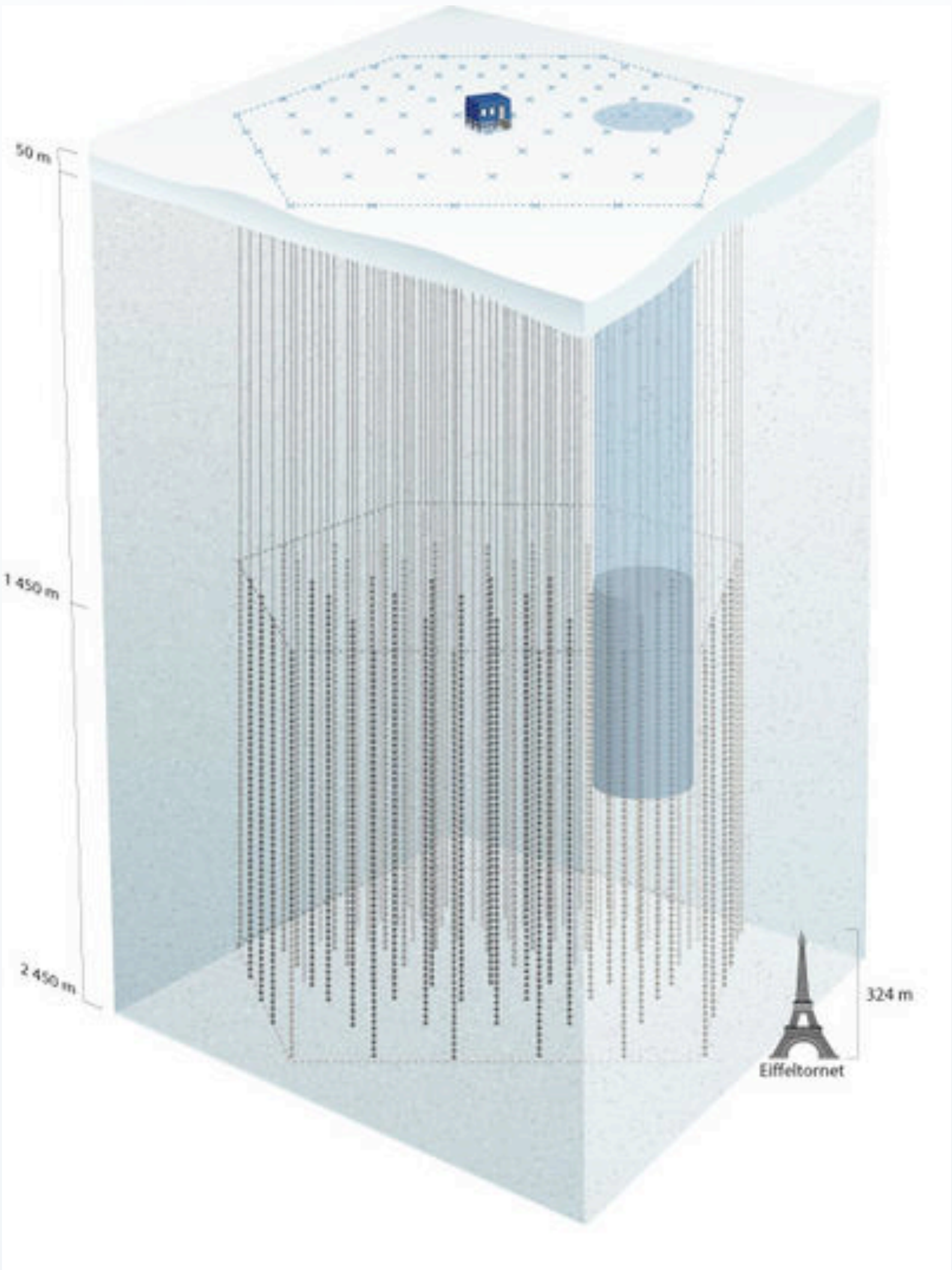
No point sources found

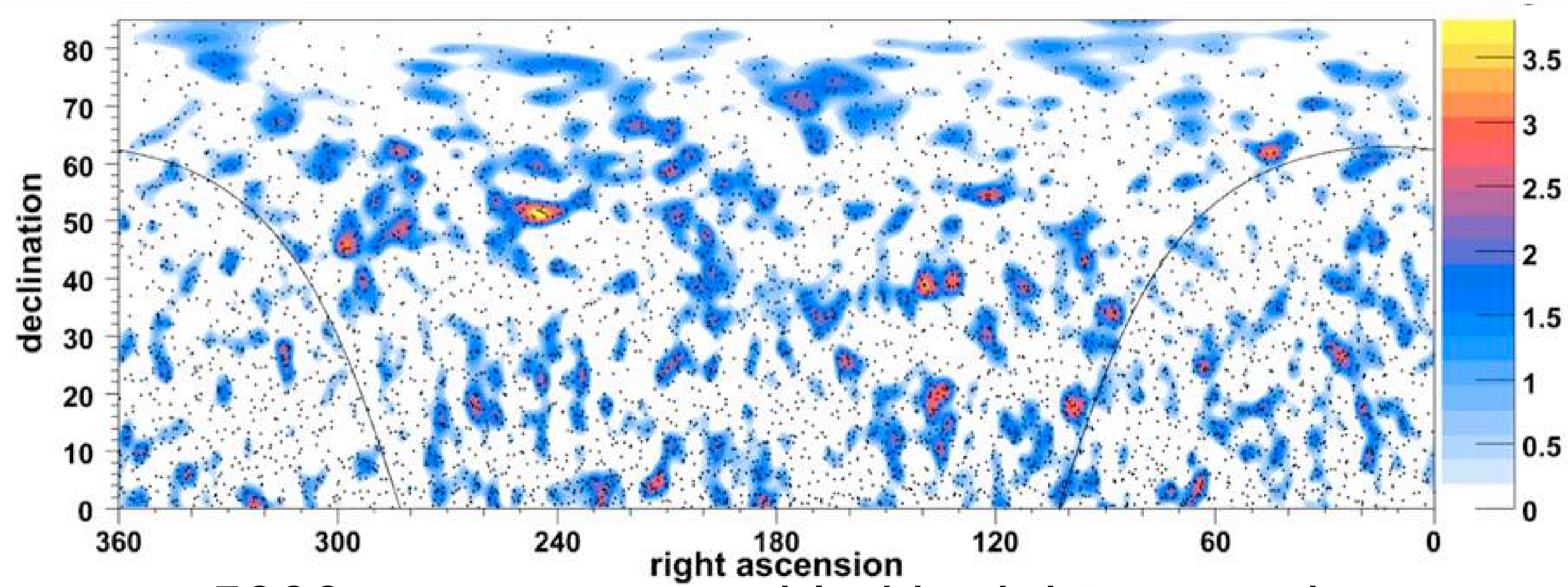


IceCube

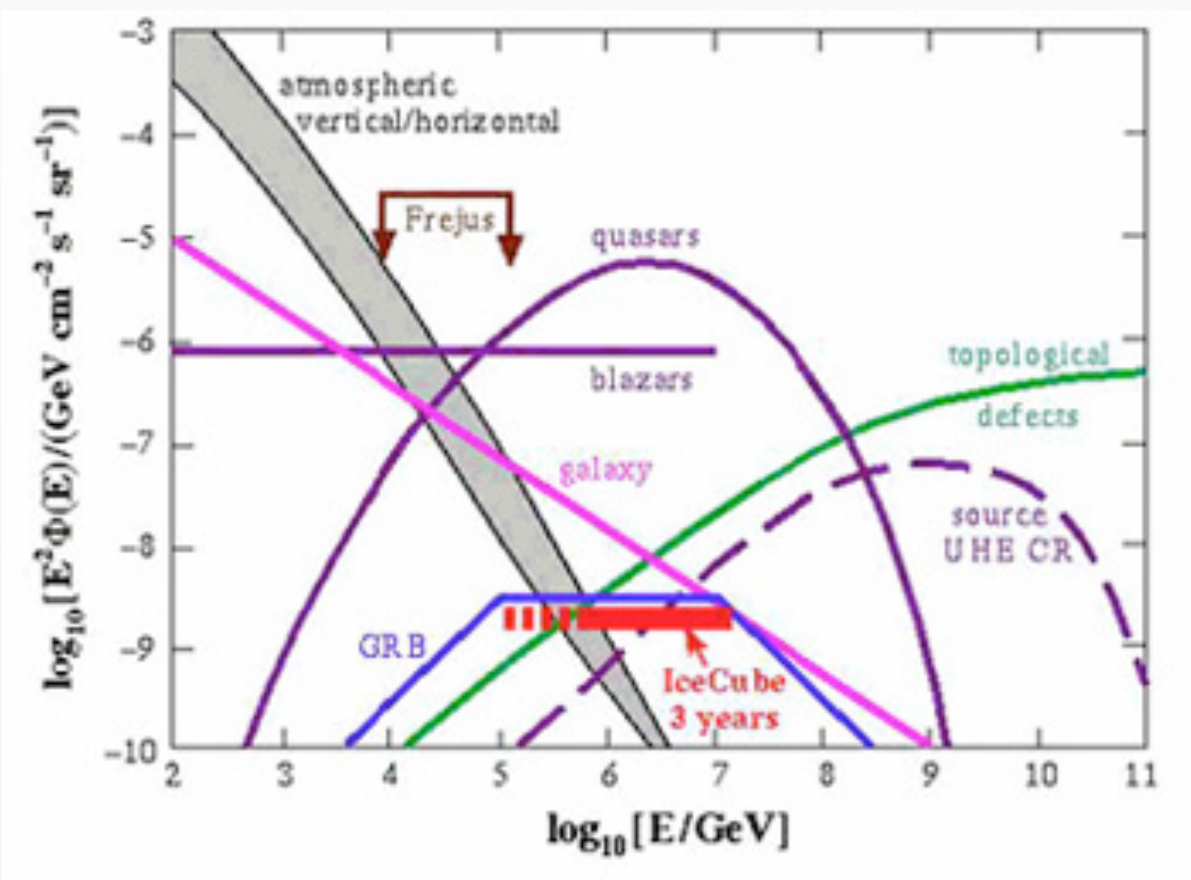
- Under construction at South Pole, 70-80 strings, 160 frozen water tanks (IceTop)
  - Over 50% complete

from S. Klein, Neutrino 2008





5000 ν_μ map, scrambled in right ascension



Optical Cherenkov in the North

- Baikal is the longest operating underwater array
  - Since 1993
  - No significant excess observed above atmospheric neutrino background.
- Three experiments in the Mediterranean, are collaborating towards Km3Net

KM3NeT

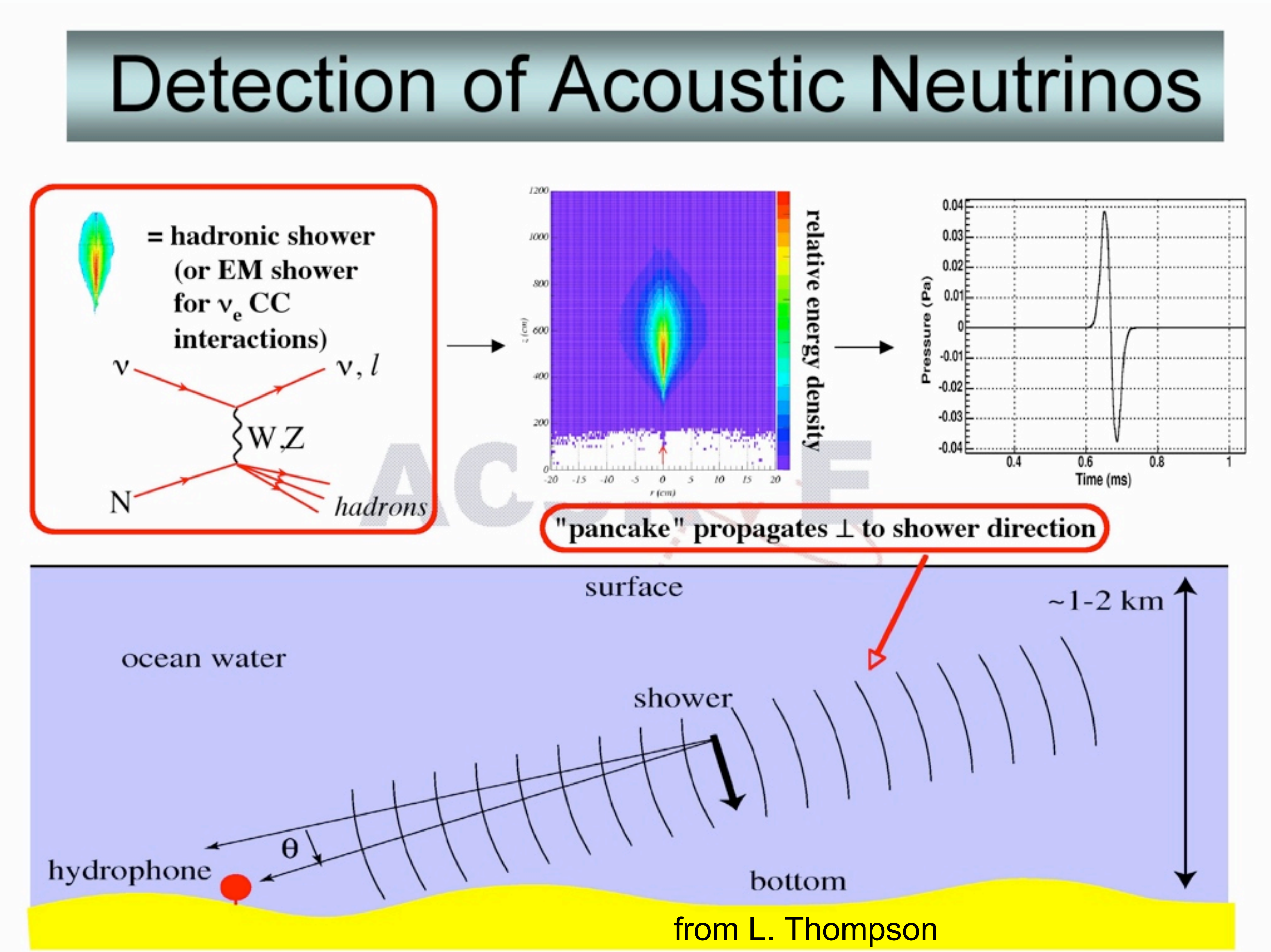
ANTARES

NEMO
NEUTRINO MEDITERRANEAN OBSERVATORY

ΝΕΣΤΩΡ

Acoustic Detection

- Saund and Acorne have set flux limits based on very small hydrophone arrays



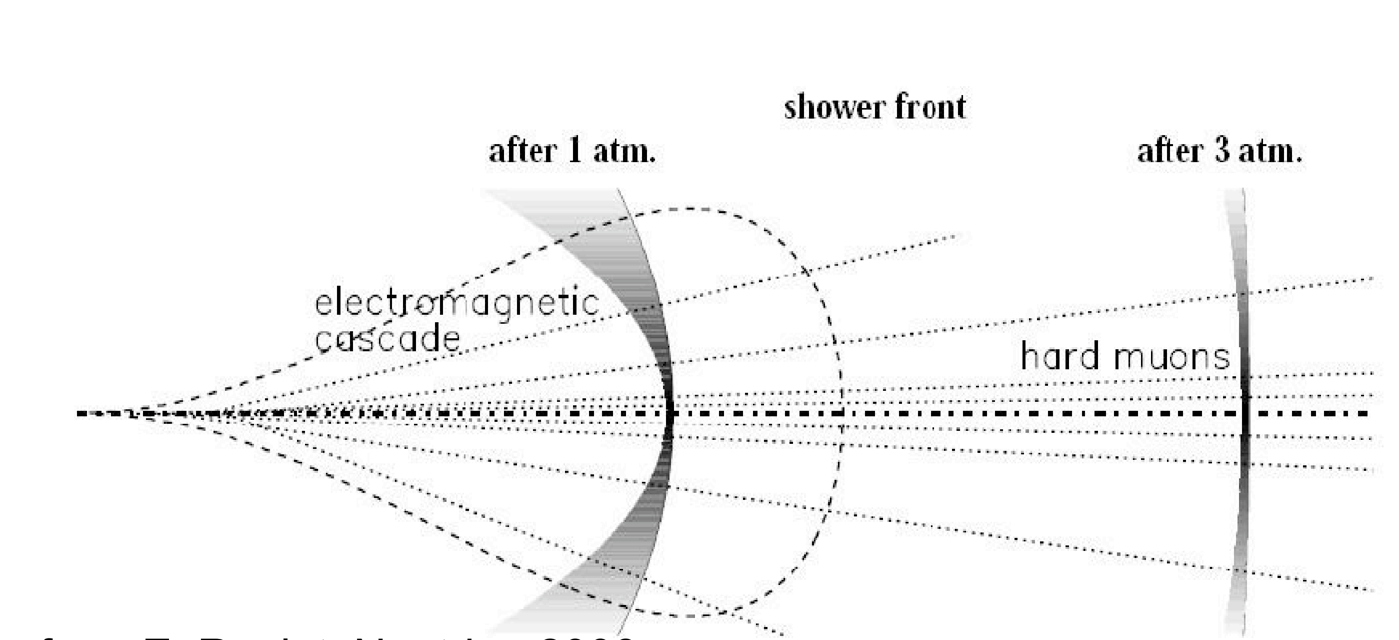
A whole host of R&D projects associated with optical Cherenkov detectors:

- SPATS (IceCube)
- AMADEUS (Antares)
- 0vDE (NEMO)

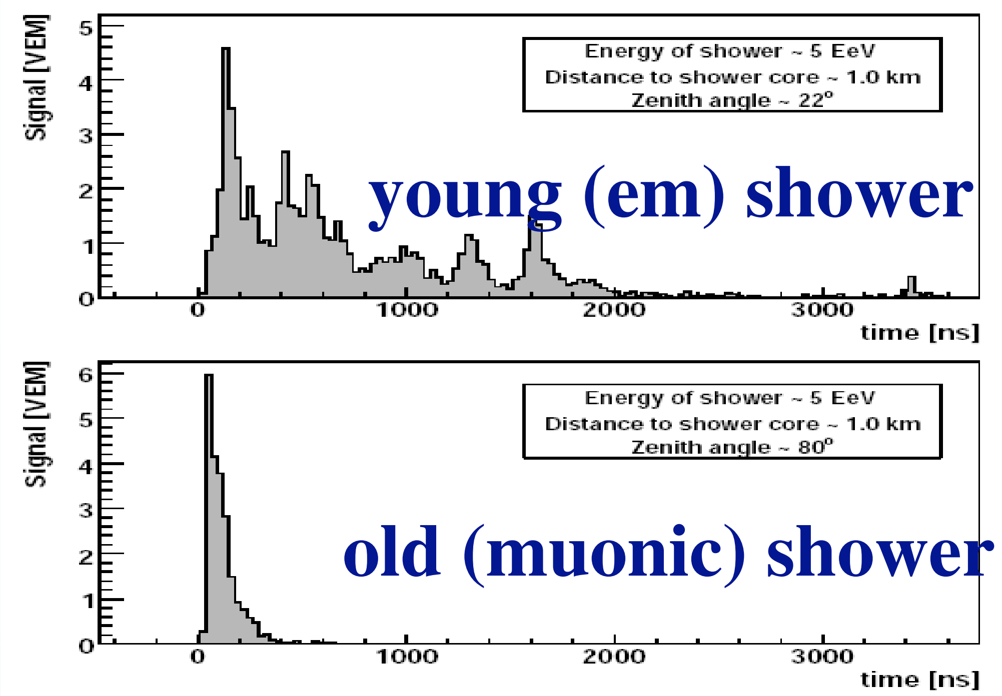
+

Auger

- Auger can detect two types of neutrino event:
  - Deeply interacting horizontal showers
  - Skimming tau neutrinos that interact in the Earth and the tau lepton decays in the air.



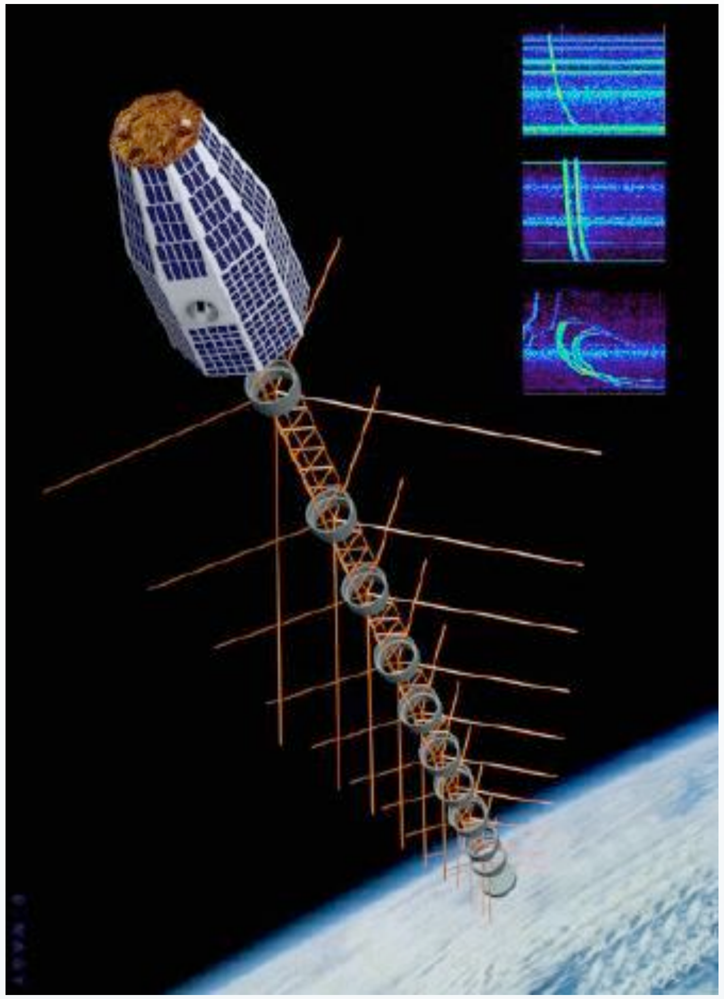
from E. Roulet, Neutrino 2008



- These young horizontal showers are distinct due to the high electromagnetic content
  - Older horizontal showers from interactions high in the atmosphere are almost entirely muonic.

Pioneering Radio Cherenkov Experiments

FORTE



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

GLUE

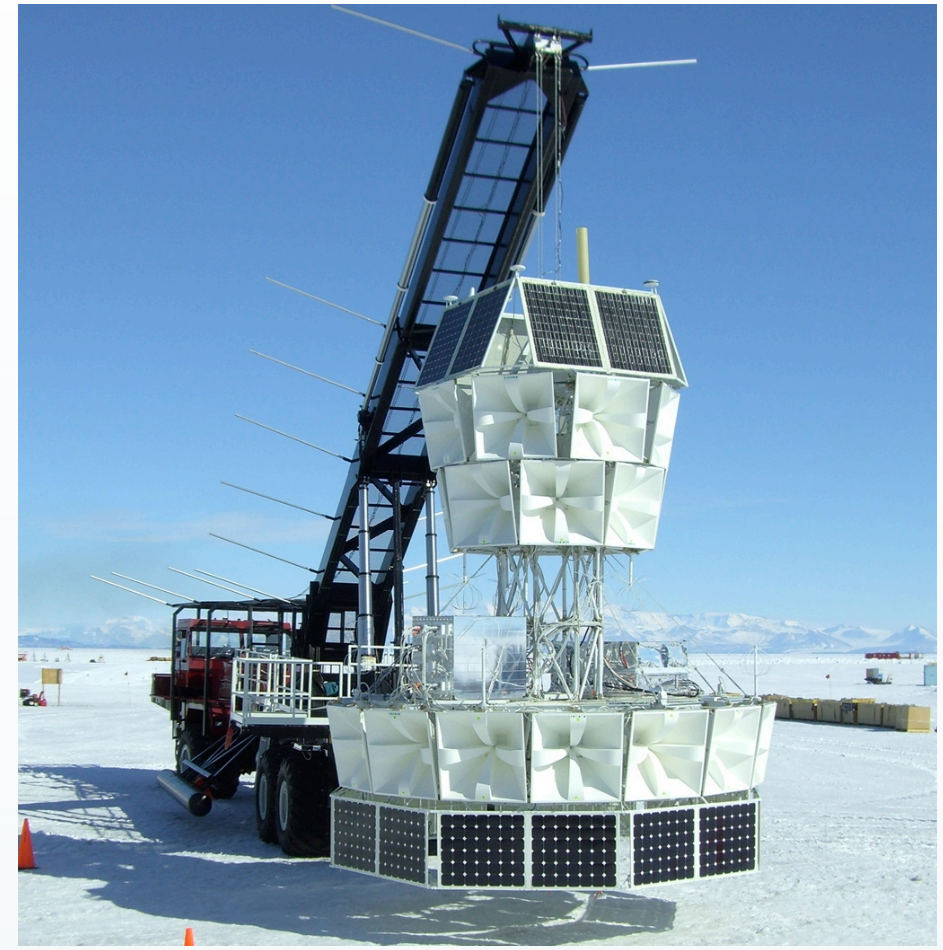
GLUE/Goldstone 99:
In Lunar regolith
~2 GHz
$A=6.10^5$ $km^2.sr$

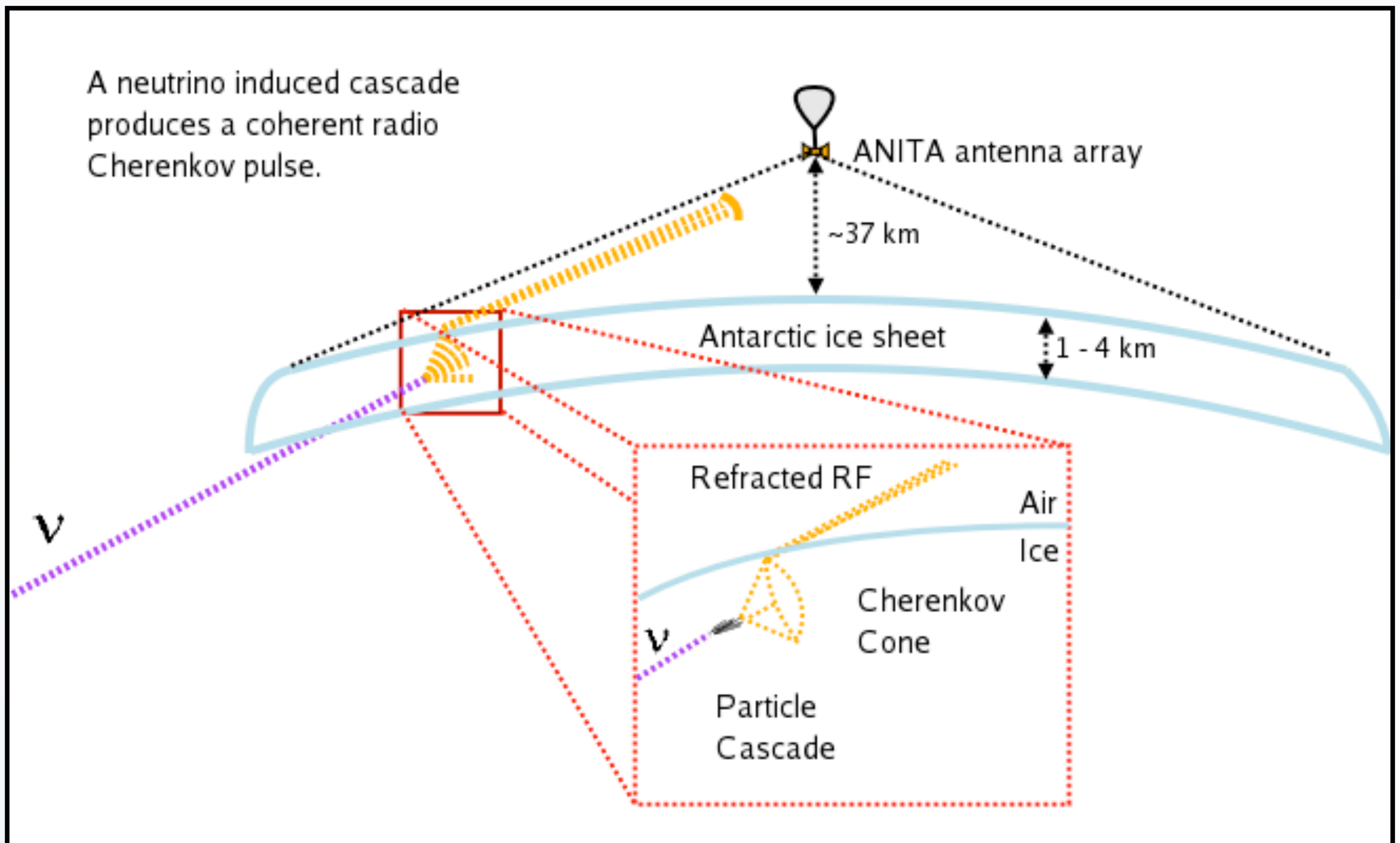
RICE

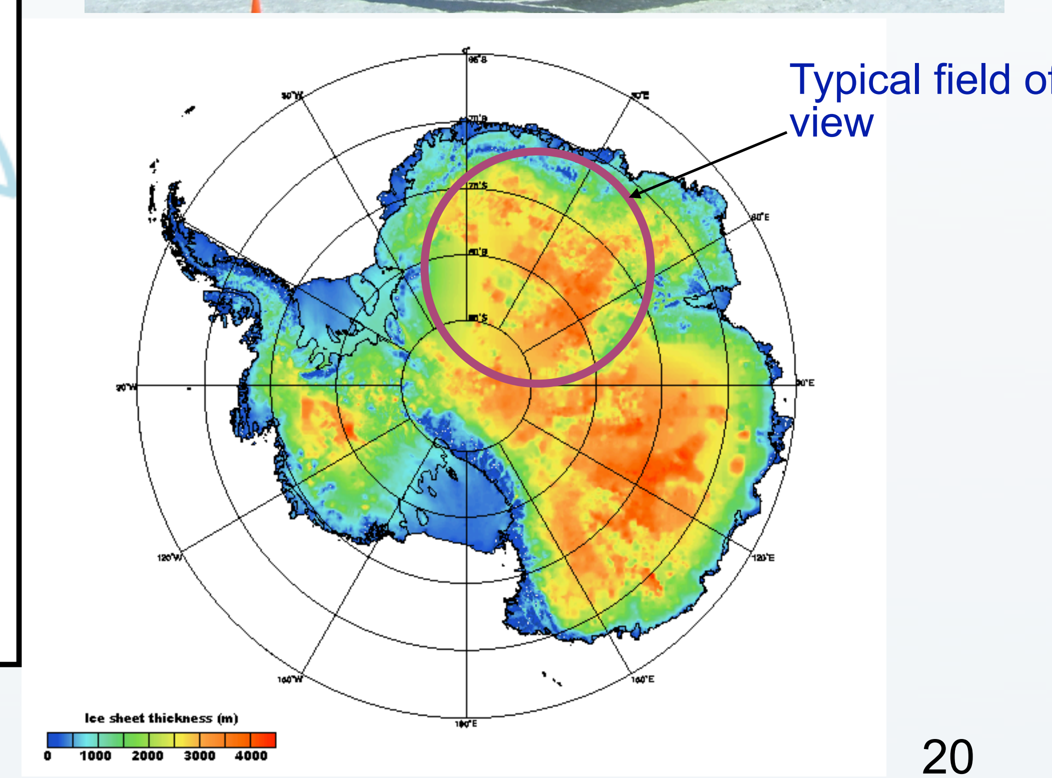
RICE 1999-present
Antennas on
AMANDA strings
100-1000 MHz
dipoles
V~10 km^3. sr
Data up to 2005
published

ANITA

- The ANtarctic Impulsive Transient Antenna
  - A balloon borne experiment
    - 32 dual polarization antennas
    - Altitude of 37km
    - Horizon at 700km
    - Over 1 million km^3 of ice visible
    - Only sensitive to skimming neutrinos





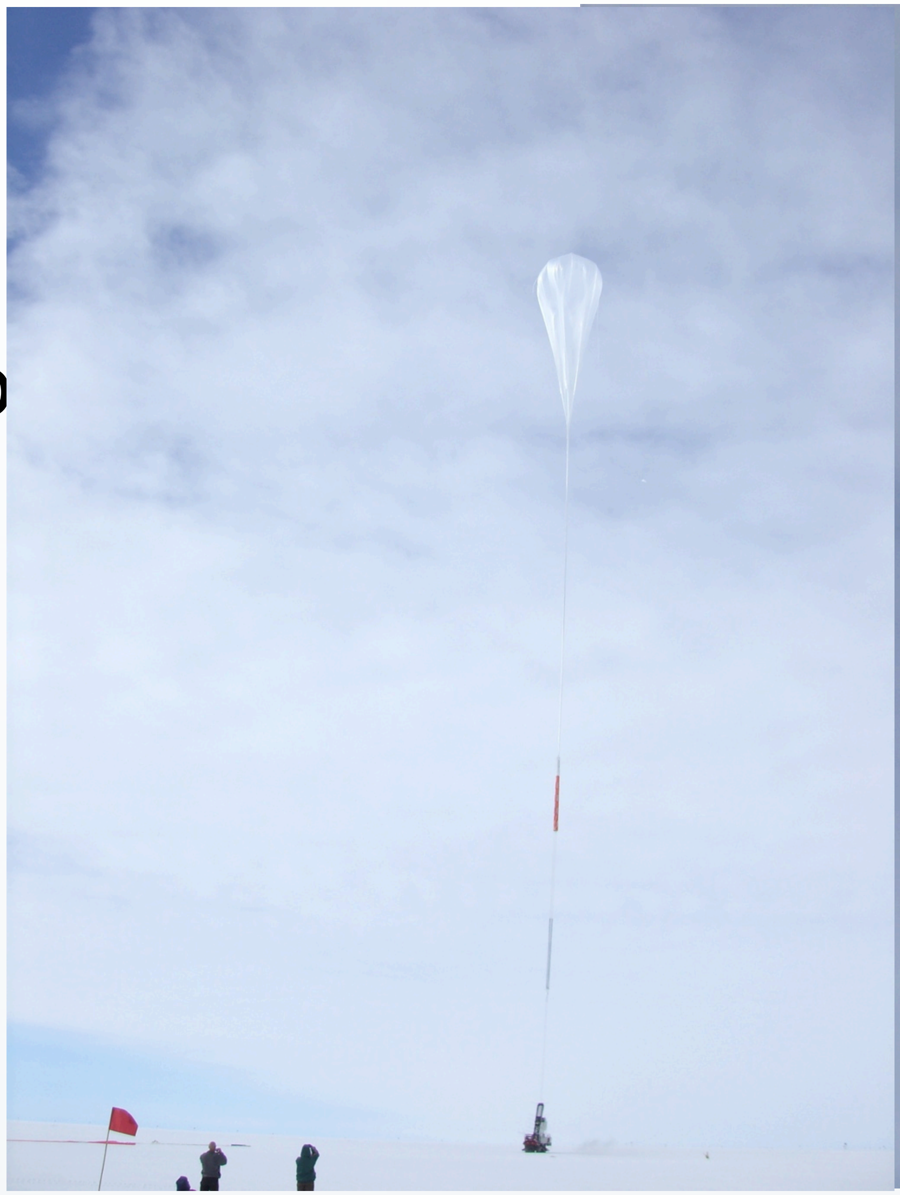


The ANITA Collaboration

- University of Hawaii at Manoa
  Honolulu, Hawaii, USA
- University of California at Irvine
  Irvine, California, USA
- University of California at Los Angeles
  Los Angeles, California, USA
- University College London
  London, UK
- University of Delaware
  Newark, Delaware
- Jet Propulsion Laboratory
  Pasadena, California, USA
- University of Kansas
  Lawrence, Kansas, USA
- University of Minnesota
  Minneapolis, Minnesota, USA
- The Ohio State University
  Columbus, Ohio, USA
- Stanford Linear Accelerator Center
  Menlo Park, California, USA
- National Taiwan University
  Taipei, Taiwan
- Washington University in St. Louis
  St. Louis, Missouri, USA

The Launch

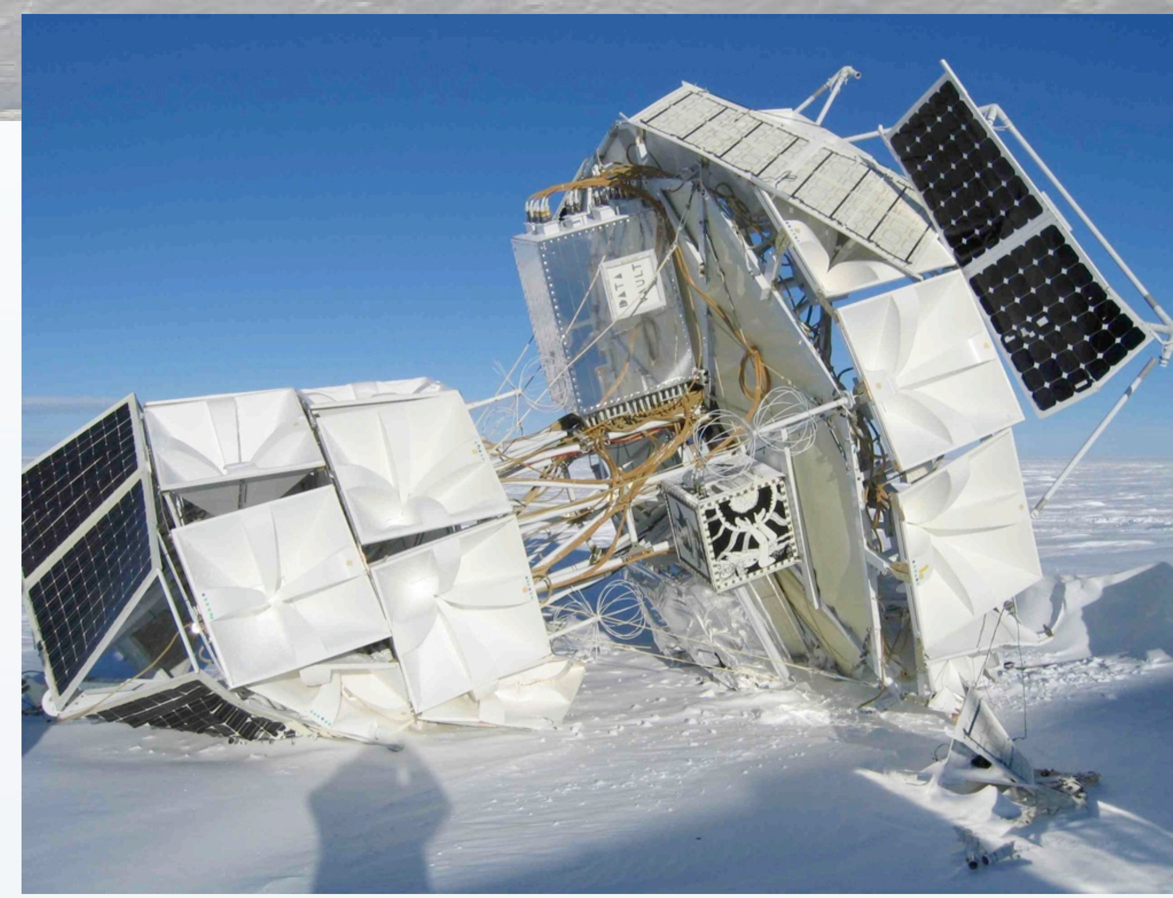
- The Balloon
  - Just 0.02mm thick
  - Takes 100 million litres o helium (and several hours) to fill



Photos from: R. Nichol & J. Kowalski

What Goes Up...

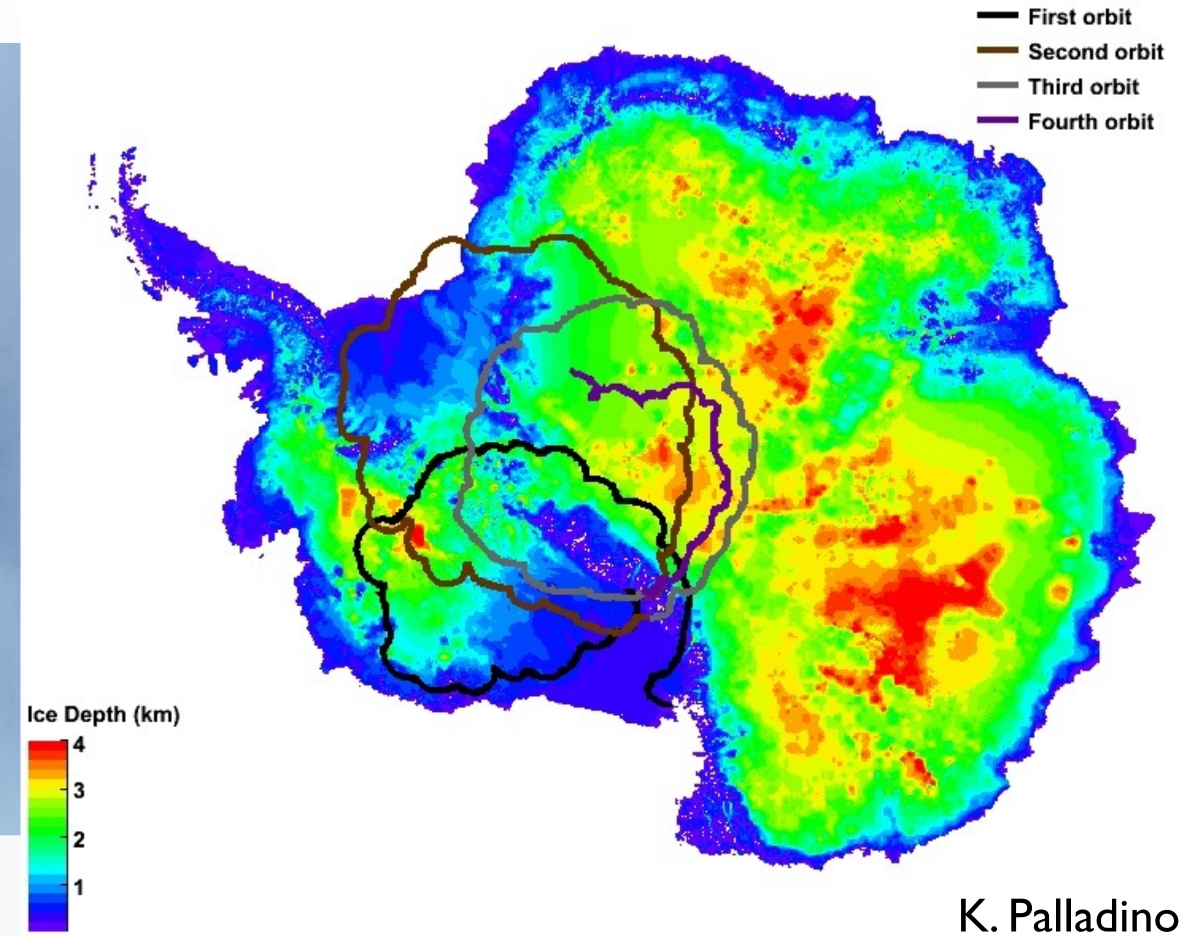
- The Landing:
  - Initiated by detonating small explosive to separate from balloon
  - Descend gently on a parachute to the ground
  - Release parachute to prevent dragging
    - BLAST was dragged for 100 miles this year (ended in a crevice)
    - A few years ago one was dropped from 5000 feet



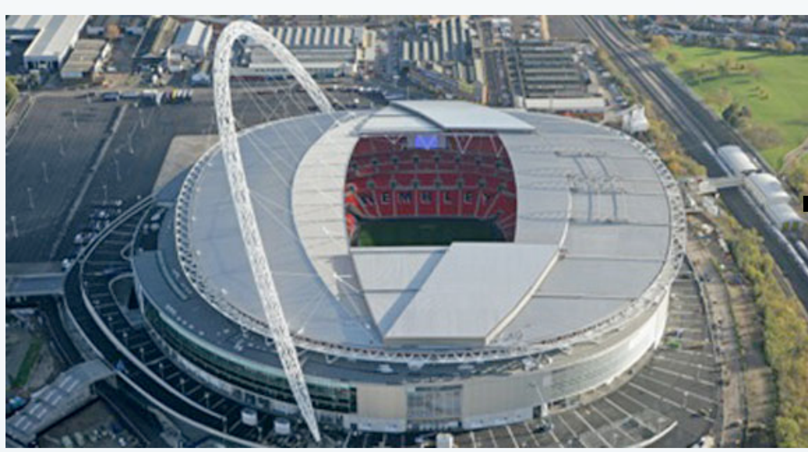
Photos from Dana Braun

The Flight

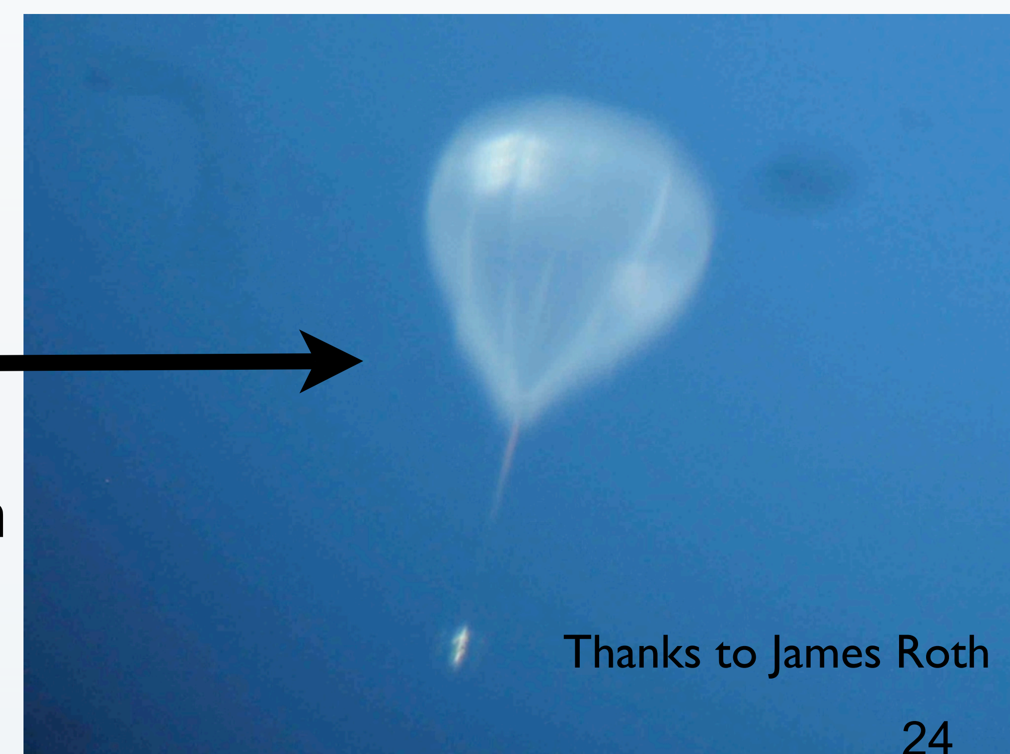
- Lasted 35 days (the record is 42)
  - Three and a half sort of polar orbits
  - Recorded over 8 million triggers
    - Maybe 1 or 2 neutrinos
  - Flew so close to South Pole, someone took a photo



K. Palladino

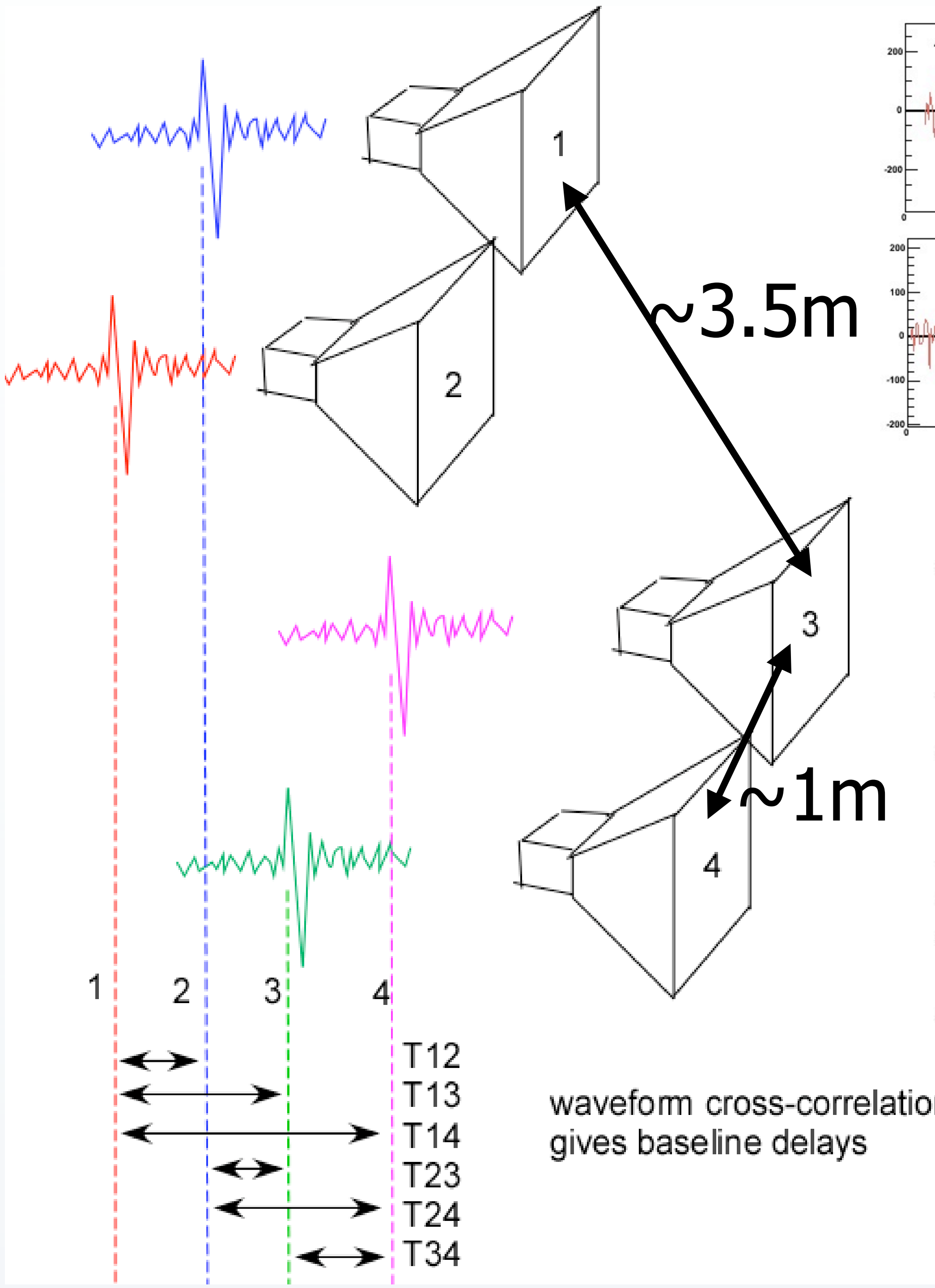


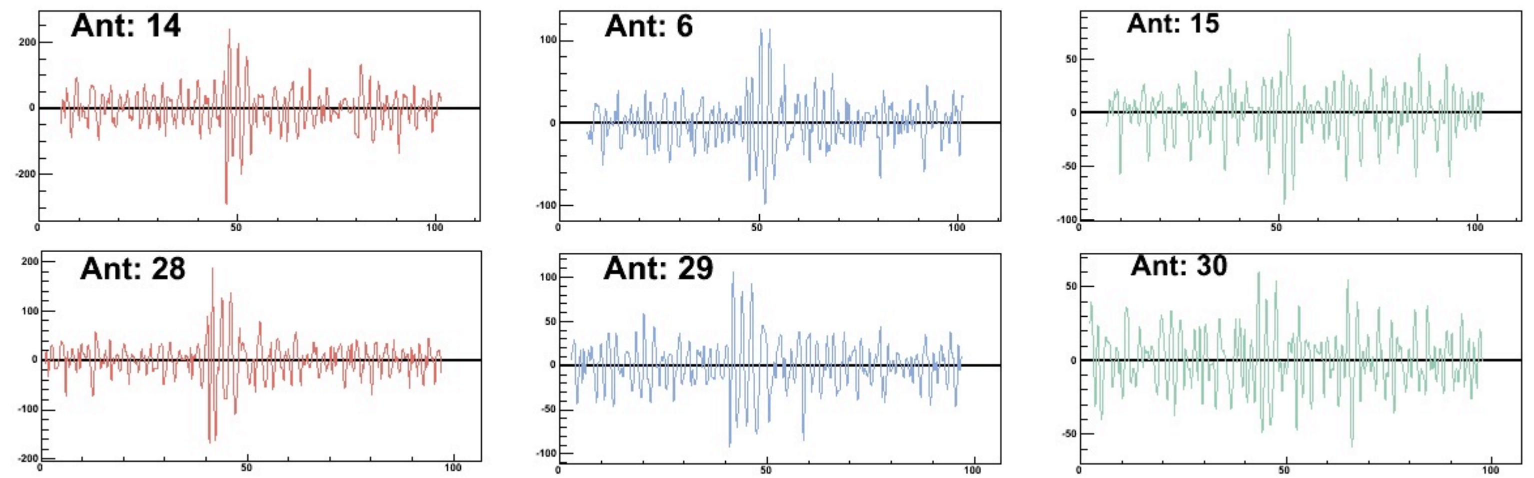
Fits inside the balloon at altitude



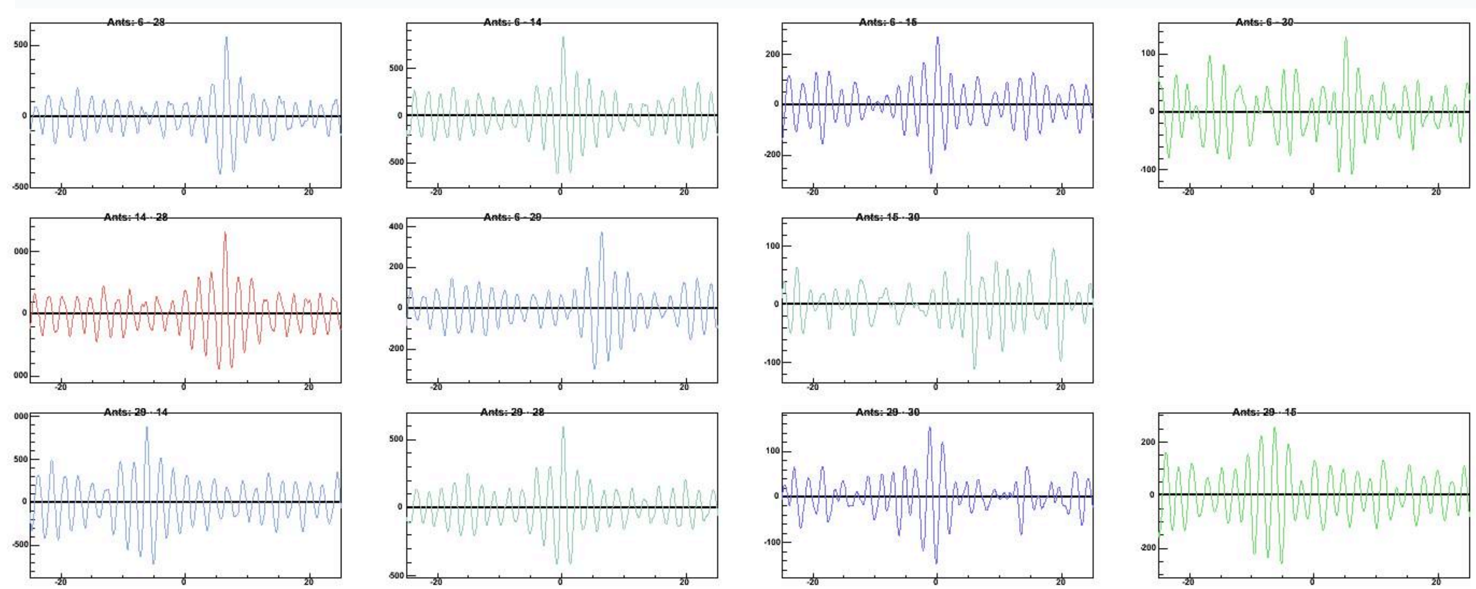
Thanks to James Roth

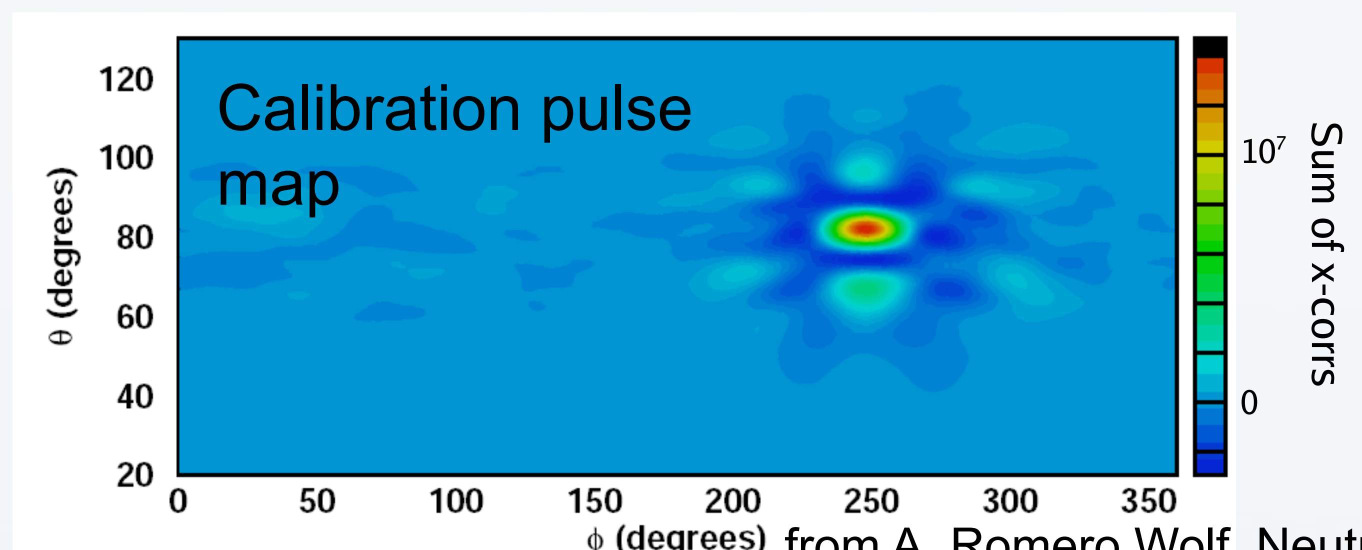
Event Reconstruction





Cross-Correlated Waveforms

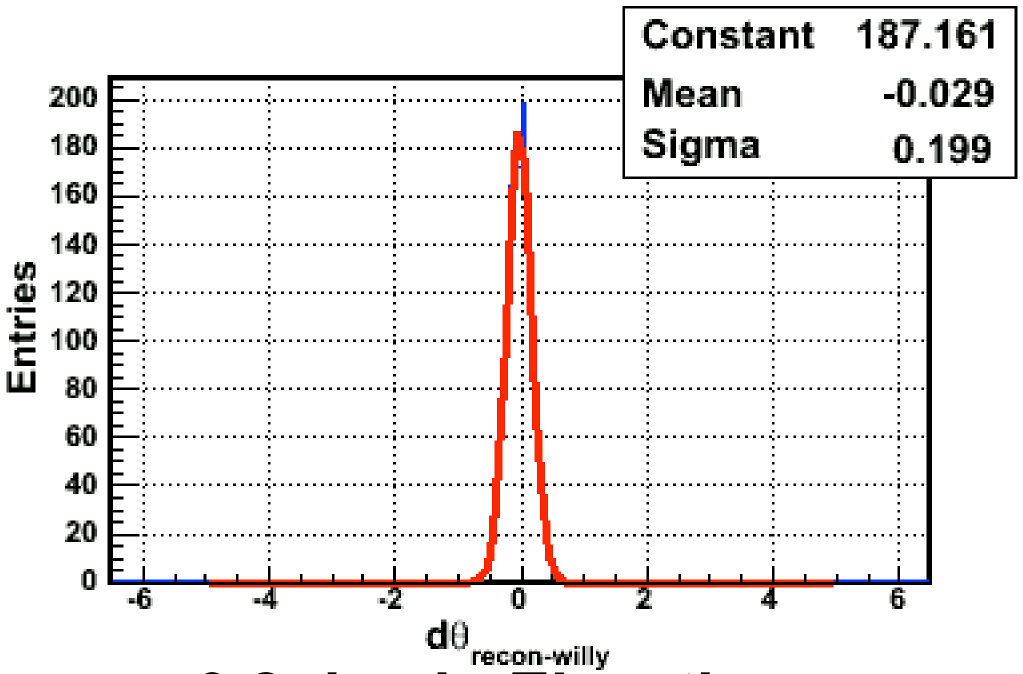




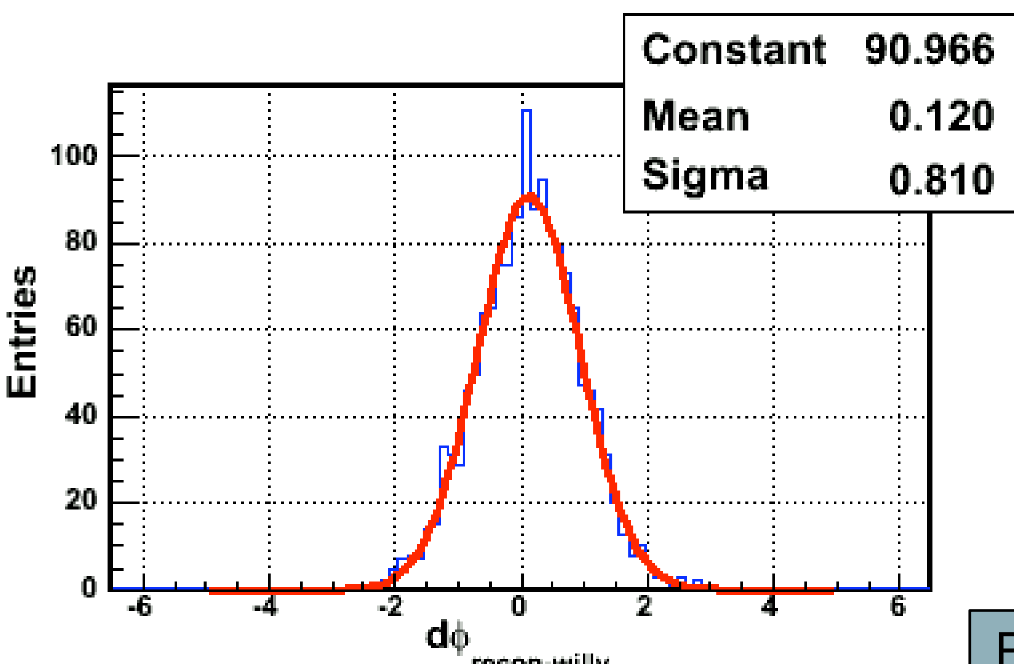
from A. Romero Wolf, Neutrino 2008

Event Reconstruction

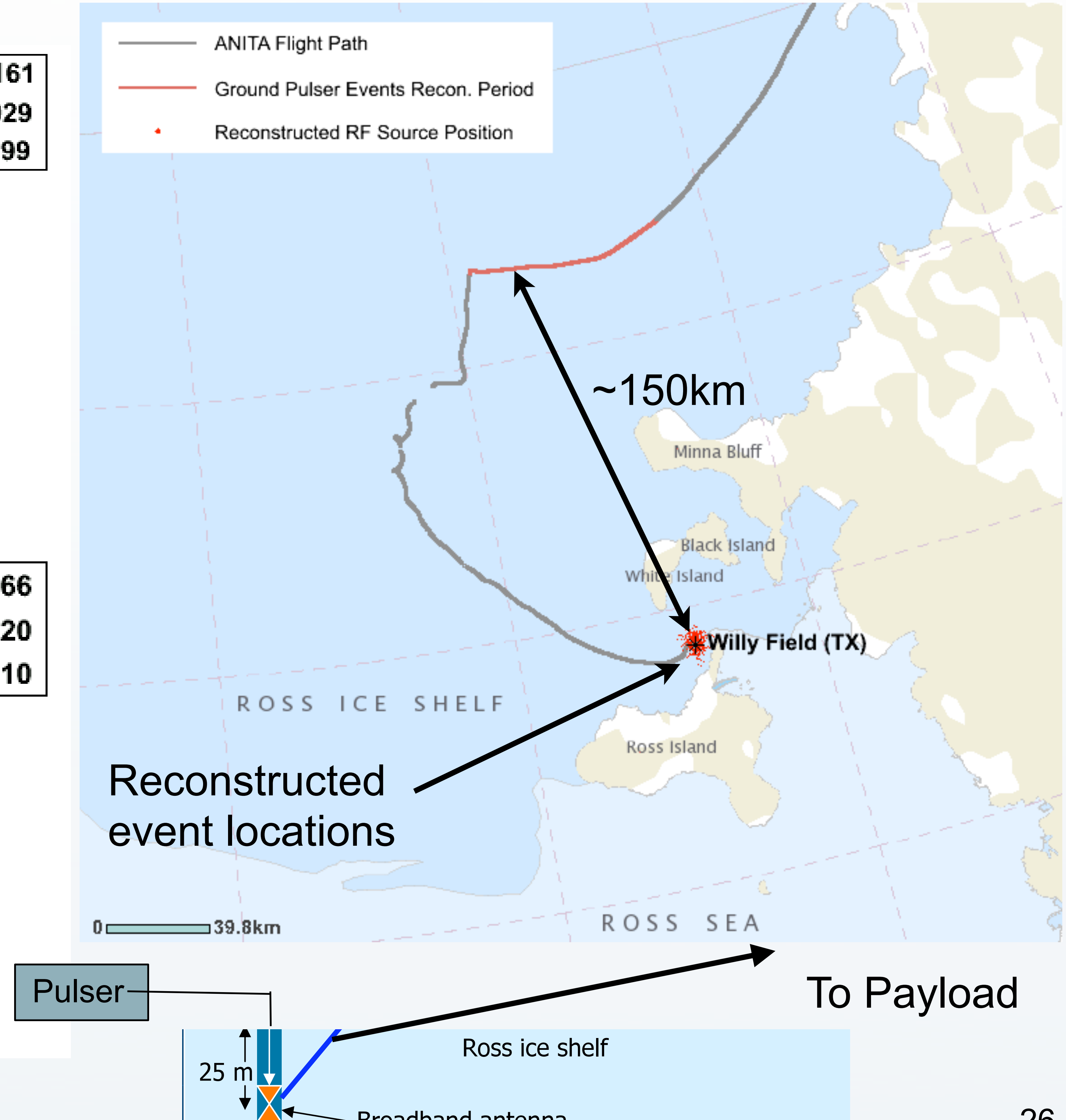
- Use borehole pulser to test event reconstruction.



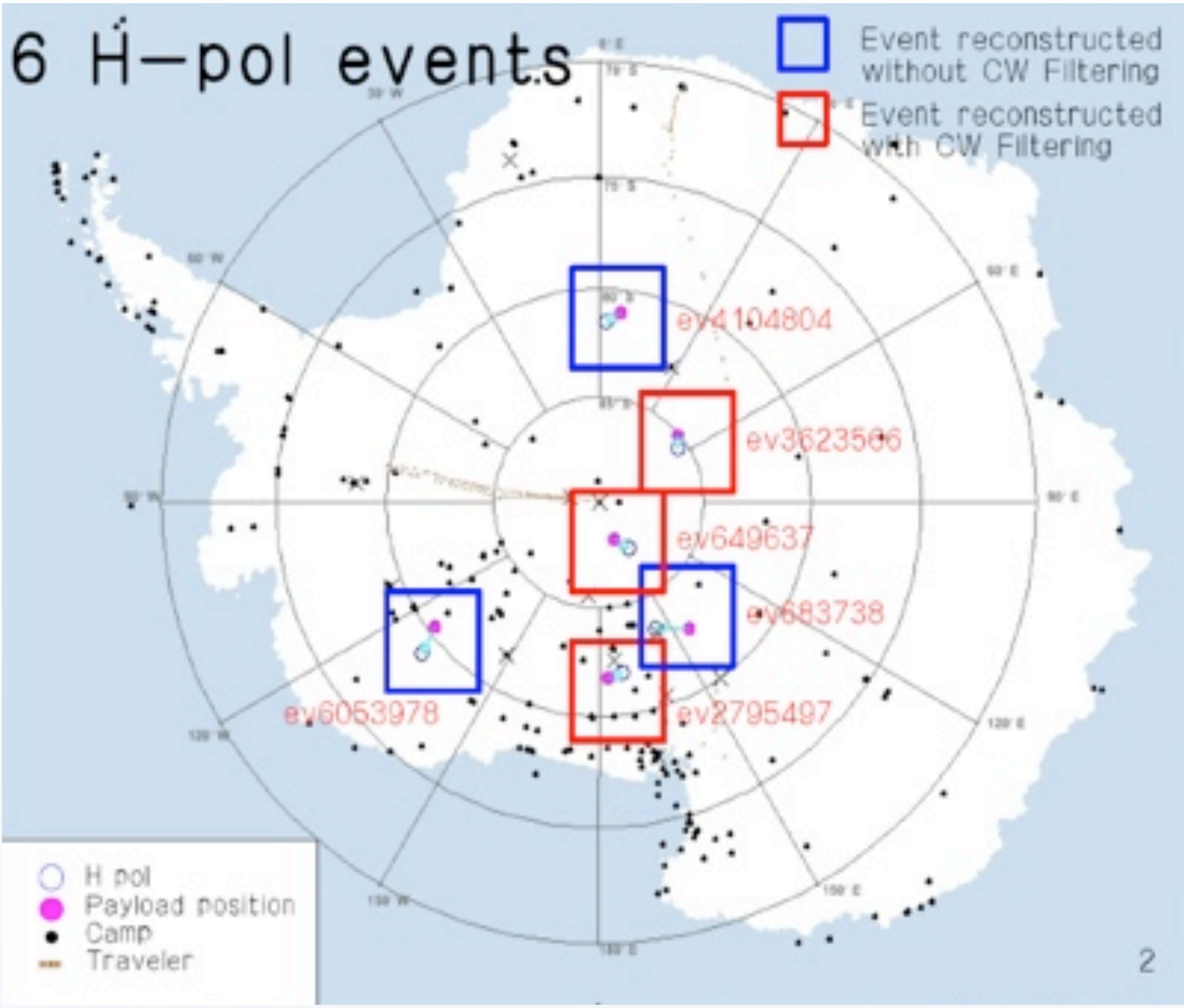
0.2 deg in Elevation



0.8 deg in Azimuth



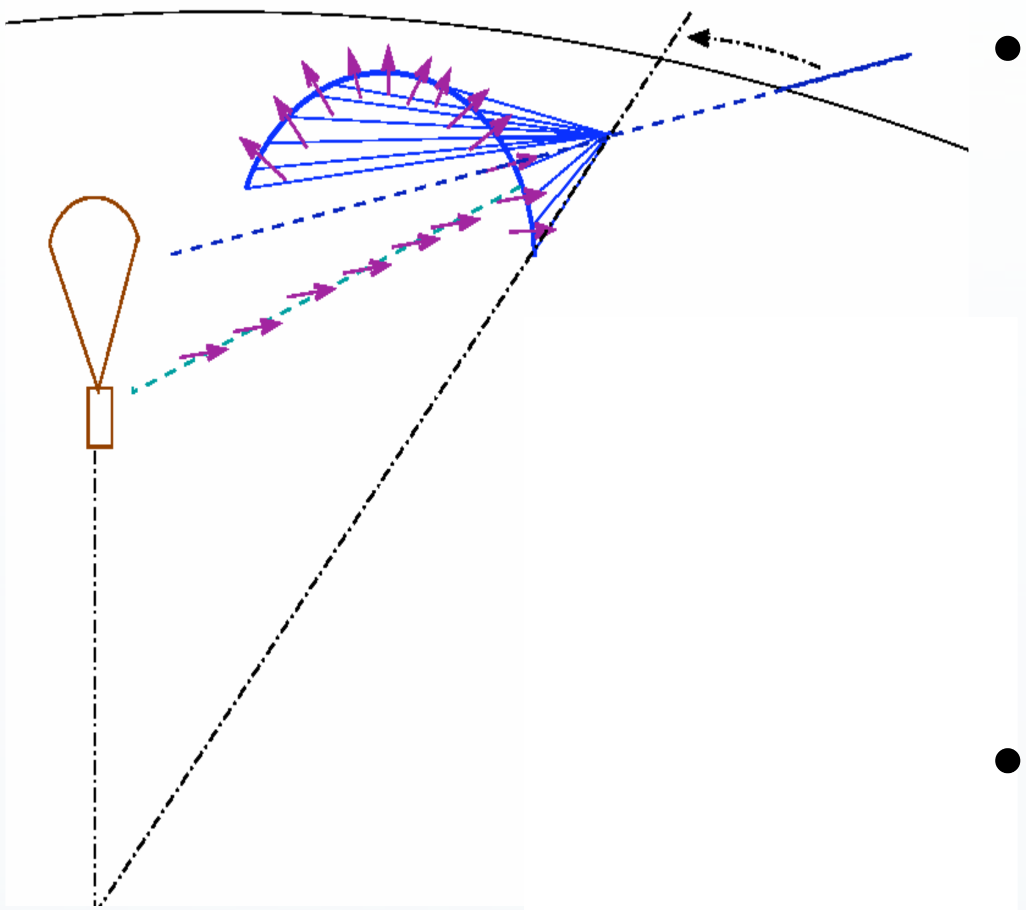
ANITA -- Initial High Threshold Analysis

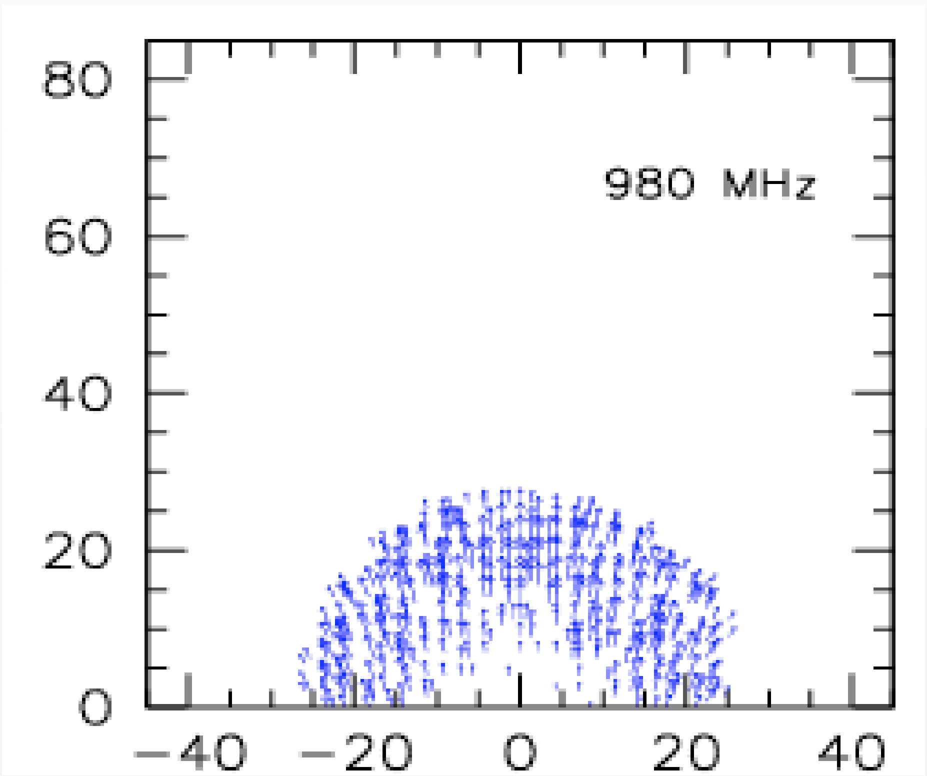


"Camp" = any human-made installation, active or not

- ~19K events (9.6K Vpol & 10K Hpol) are impulsive and reconstruct to Ant. ice
- Exclude all repeating locations (H, V, H+V)
- Exclude single events within 50km of known sites
- After these cuts:
  - 0 Vpol (no Askaryan like neutrino signals)
  - 6 Hpol

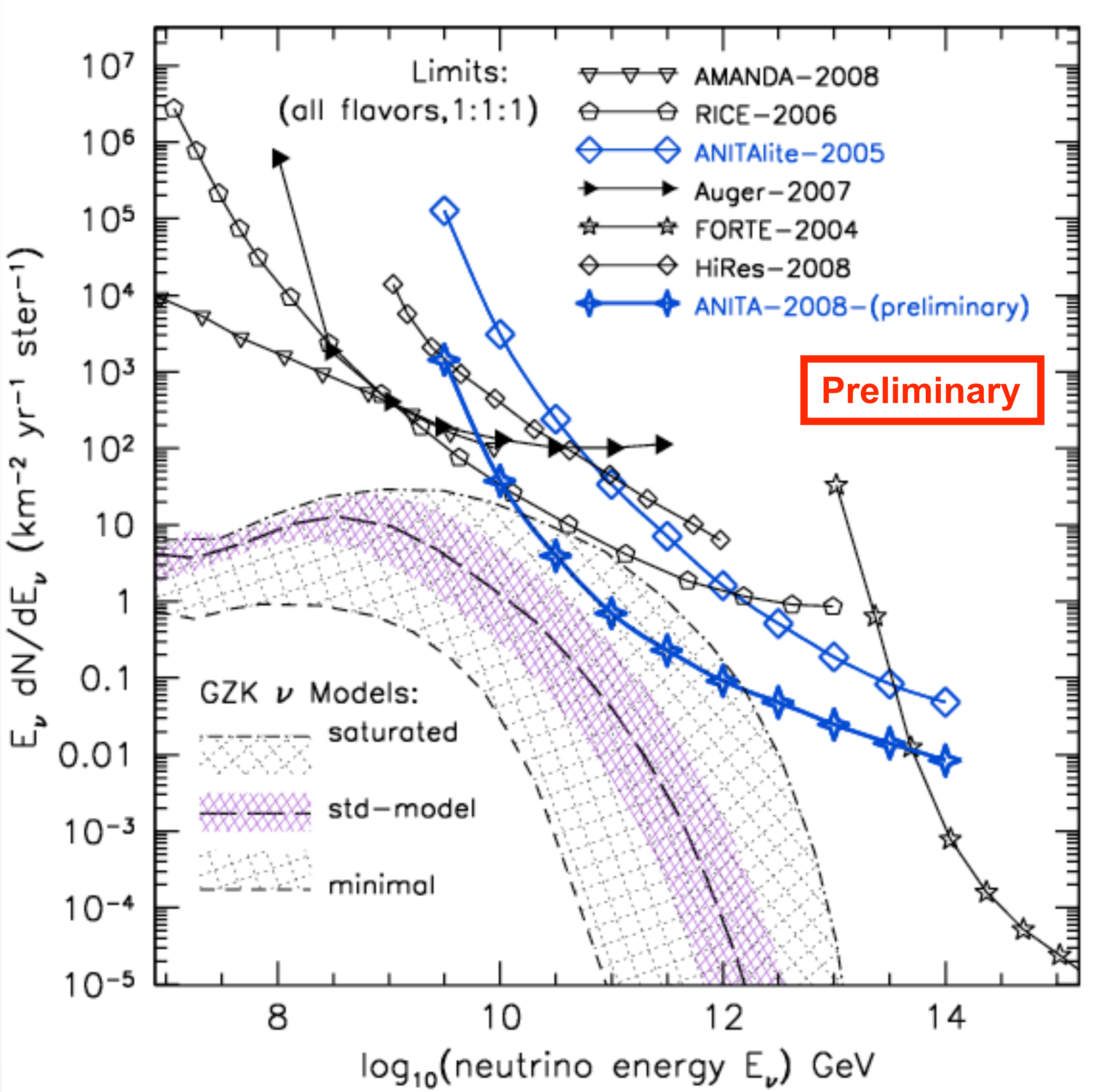
Horizontal Polarisation??





- Askaryan signals strongly favour vertical polarisation
  - Only top of Cherenkov cone escapes TIR at surface
  - Fresnel coefficients transmit more Vpol than Hpol
- Reflections from above the horizon sources would favour Hpol over Vpol at the balloon
- Hpol events are not neutrinos but could be:
  - Air shower radio (geo-synchrotron)
  - Noise (eg. relays) from satellites

ANITA Sensitivity



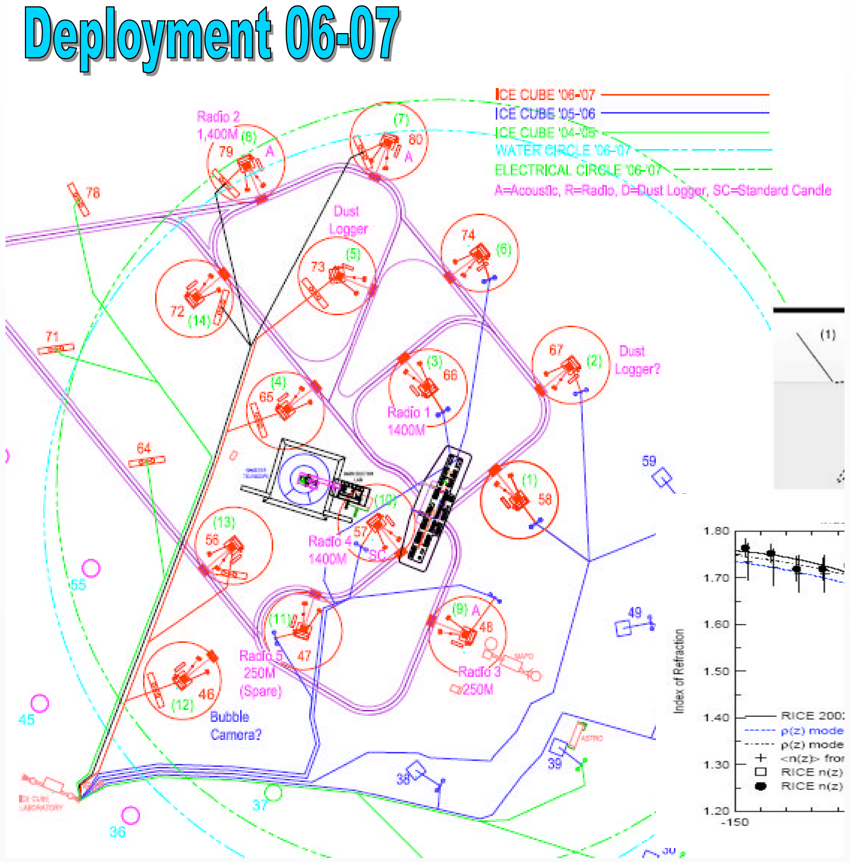
- ANITA-I limit has begun to constrain some of the highest (less likely) GZK models
  - Lower threshold analysis is progressing well.
- ANITA-II (flight scheduled for Dec. 2008) should reach the standard-model range.

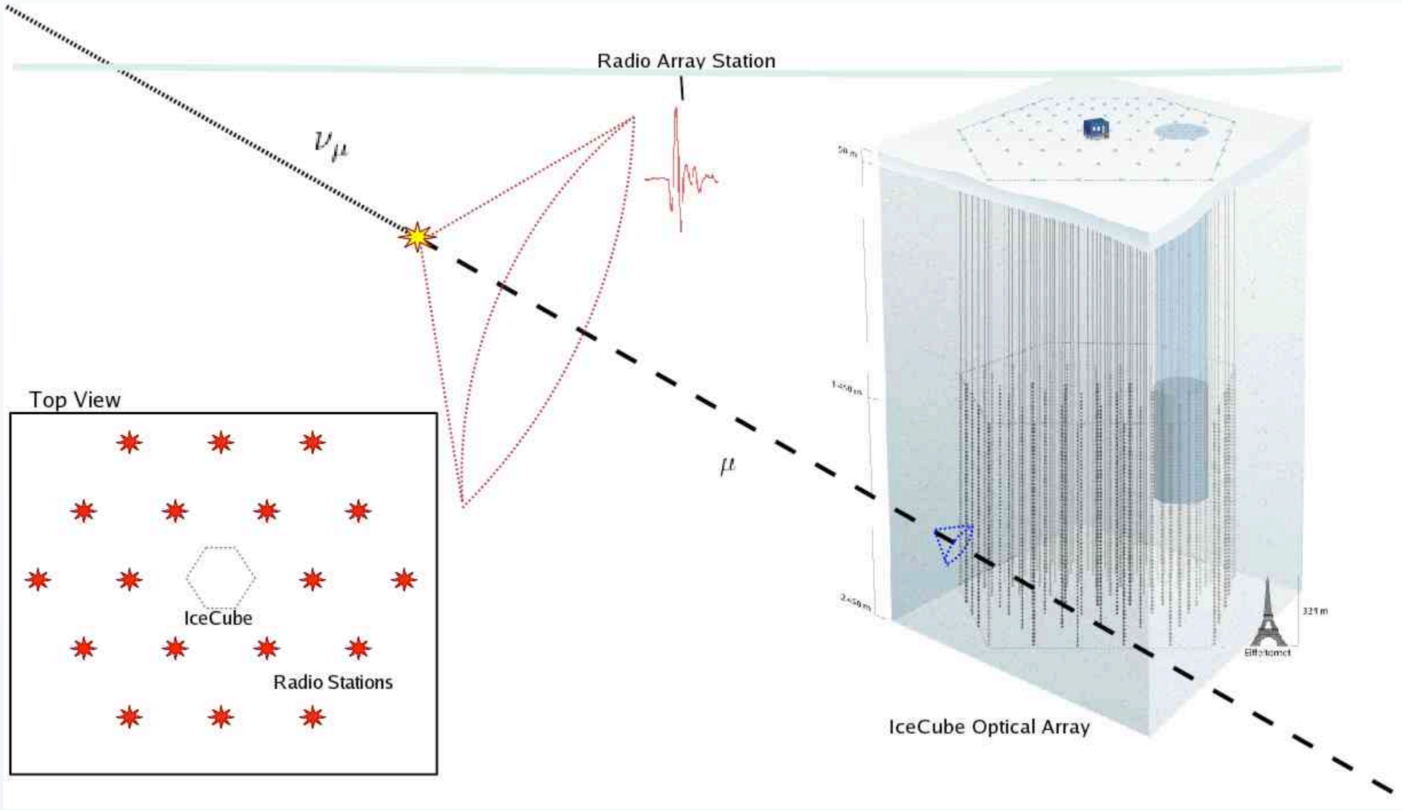
ANITA-II Improvements

- New front end amplification system
  - Lower system temperature by ~40K
- Active direction trigger mask to blank out noise from camps and stations
  - Improve efficiency by ~20% (lower thresholds)
- Switch to vertical polarisation trigger
  - Improve sensitivity by ~30%
- Add third antenna (drop-down) ring
  - Improve sensitivity by ~30%
- Net improvement:
  - Factor of 1.7 in threshold --> x3 in event rate
  - Up to 30% in exposure (flight path dependent)
  - Up to 40% in livetime
  - Total factor > 5 in neutrino event rate

Acoustic and Radio @ IceCube

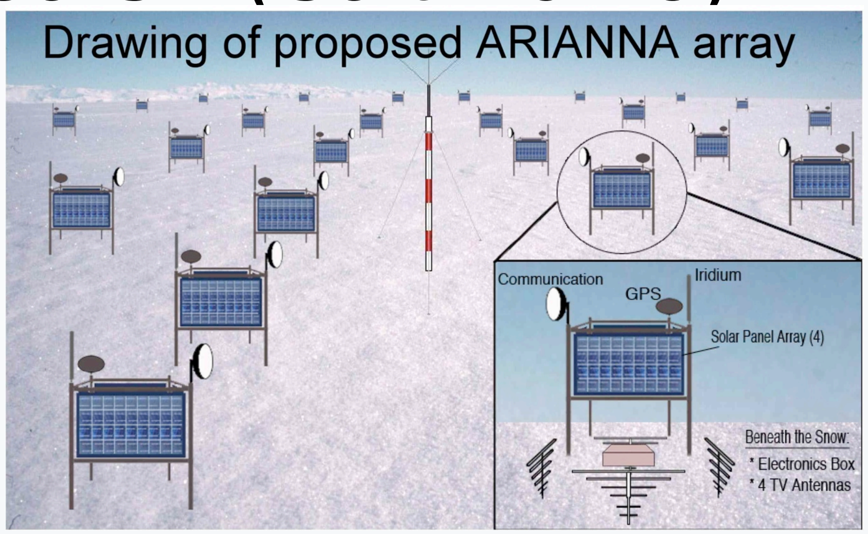
- SPATS and Aura/IceRay
  - Deploy acoustic and radio detectors in conjunction with IceCube
  - Possibility to measure neutrino with all three detection methods simultaneously
  - Need large footprint to detect GZK neutrinos

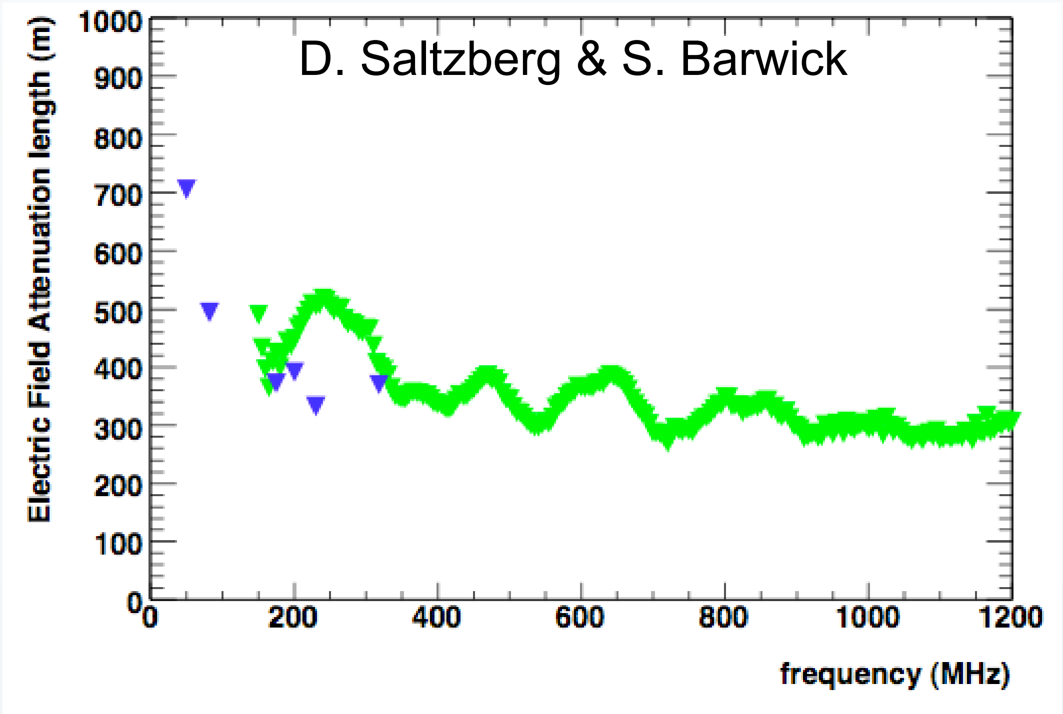


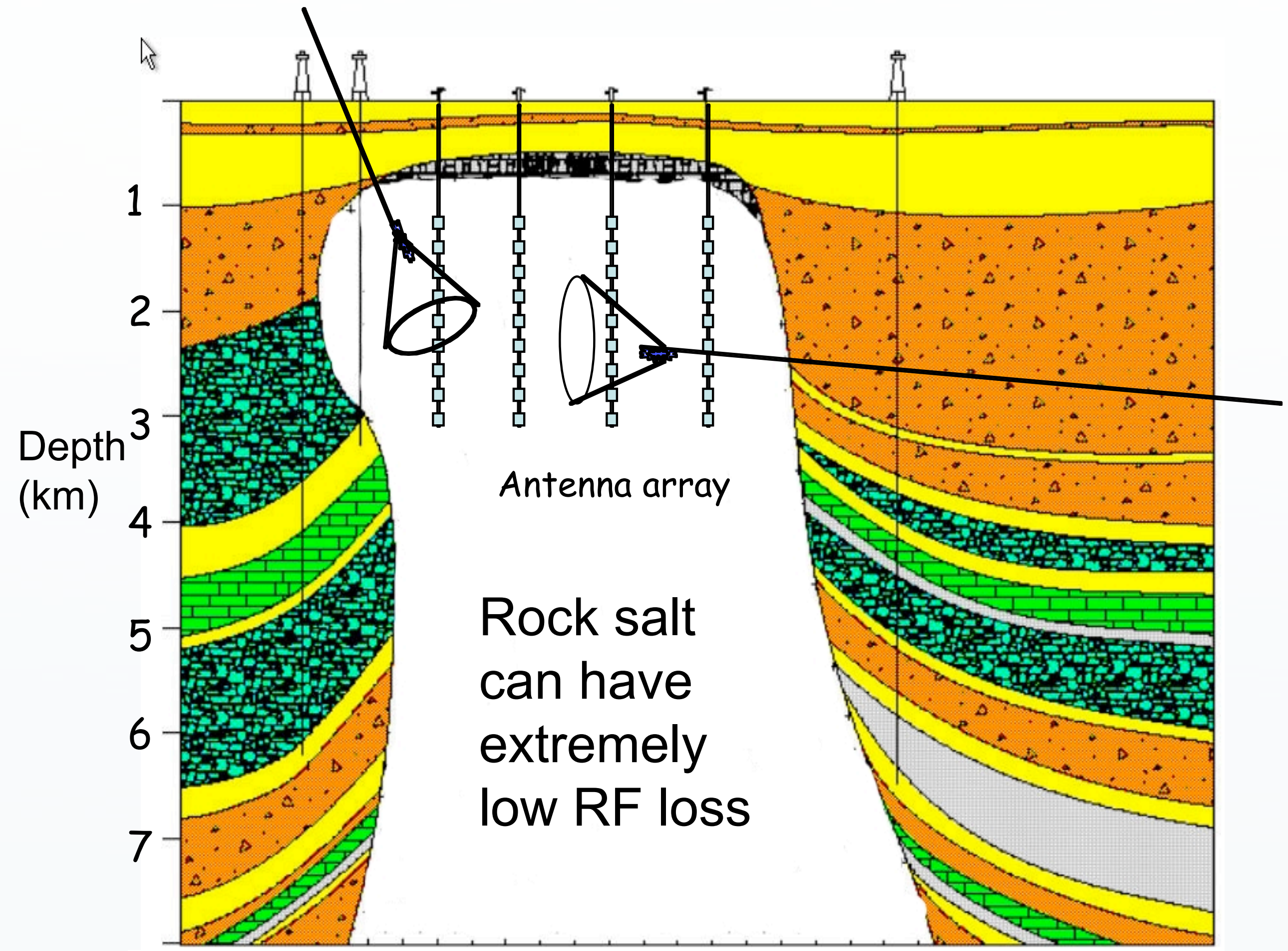


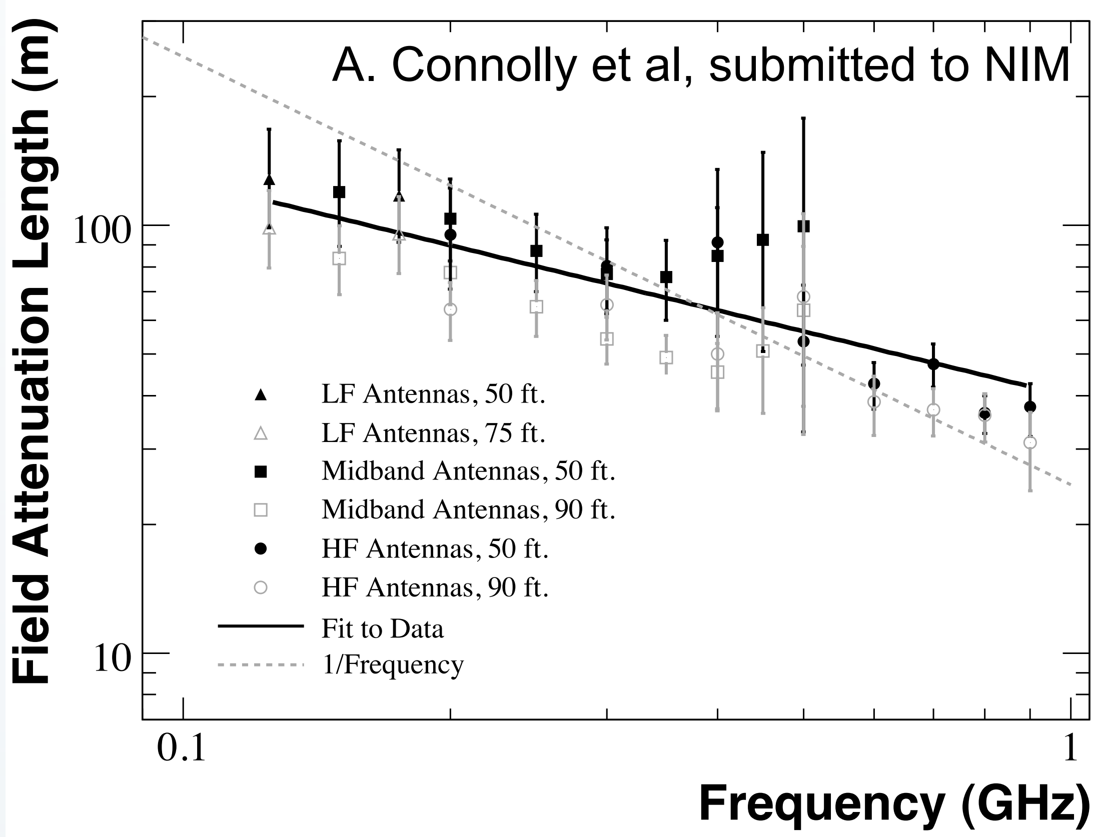
ARIANNA/SalSA

- Two of the proposed next generation radio arrays
  - ARIANNA (Ice Shelf)
  - SalSA (Salt Dome)









Summary

- These are exciting times in the ultra-high energy neutrino field.
- ANITA has completed its first full flight and initial analysis has set the current best limit on the flux of ultra-high energy neutrinos.
  - Second flight (December 2008) will start to constrain GZK neutrino models
- The next generation of neutrino astronomy facilities may finally realise the ambition of probing the universe with “new eyes”
  - Probing fundamental physics at energies beyond the reach of terrestrial accelerators.
- Hopefully soon we will have the first detection of an UHE neutrino.