ANITA: A Balloon-Borne Observatory for Ultra-high Energy Neutrinos

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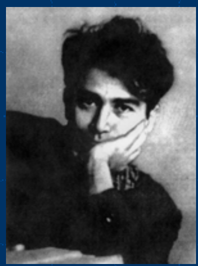
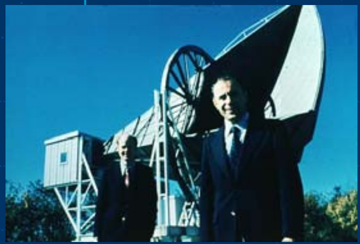
& many other postdocs, students, engineers…

Science roots: the 60's





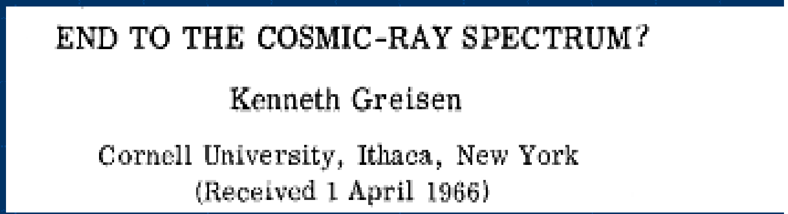
1. **1961: First 10^{20} eV cosmic ray air shower observed**
   - John Linsley, Volcano Ranch, near Albuquerque, NM
2. **1962: G. Askaryan predicts coherent radio Cherenkov from showers**
   - His applications? Ultra-high energy cosmic particles
3. **1965: Penzias & Wilson discover 3K echo of the Big Bang**
   - (thermal noise from bird dung in their dish? NOT! → Nobel prize)
4. **1966: Cosmic ray spectral cutoff at $10^{19.5}$ eV predicted**
   - K. Greisen (US) & Zatsepin & Kuzmin (Russia), independently
   - Cosmic ray spectrum *must end* close to ~10^{20} eV

$$p,\gamma + \gamma(3K) \longrightarrow \text{pions, } e^+e^-$$

"GZK cutoff " process

$$\downarrow$$

GZK neutrinos

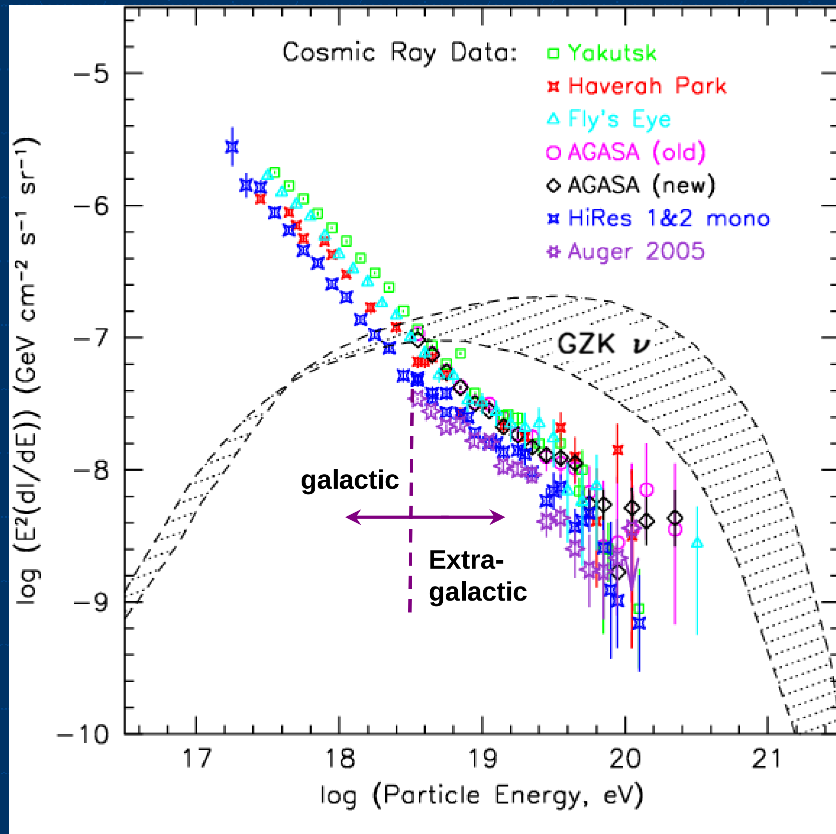

END TO THE COSMIC-RAY SPECTRUM?

Kenneth Greisen

Cornell University, Ithaca, New York
(Received 1 April 1966)

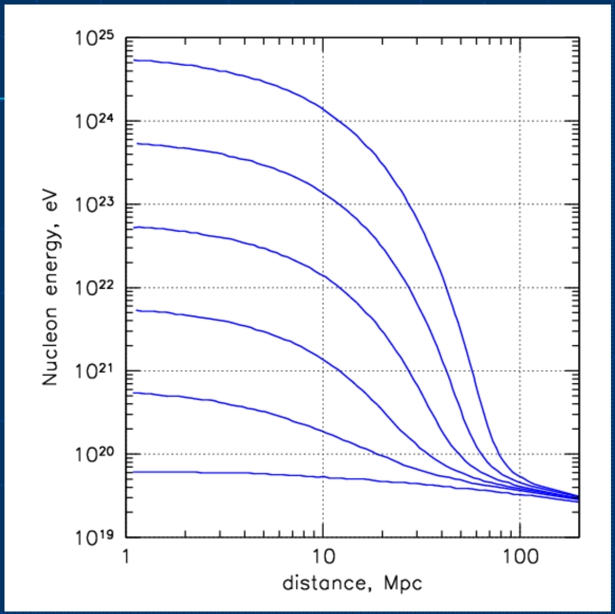
Ultra-high Energy Cosmic rays ➔ require Neutrinos

- Neither origin nor acceleration mechanism known for cosmic rays above 10^{19} eV, **after 40 years!**
- **A paradox**:
  - No <u>nearby</u> sources observed
  - distant sources <u>excluded</u> due to collisions with microwave bkg
- Neutrinos at $10^{17\text{-}19}$ eV <u>required</u>* by standard-model physics
  - Lack of neutrinos:
    - **UHECRs not hadrons?!**
    - **Lorentz invariance wrong?!**
    - **New physics?**

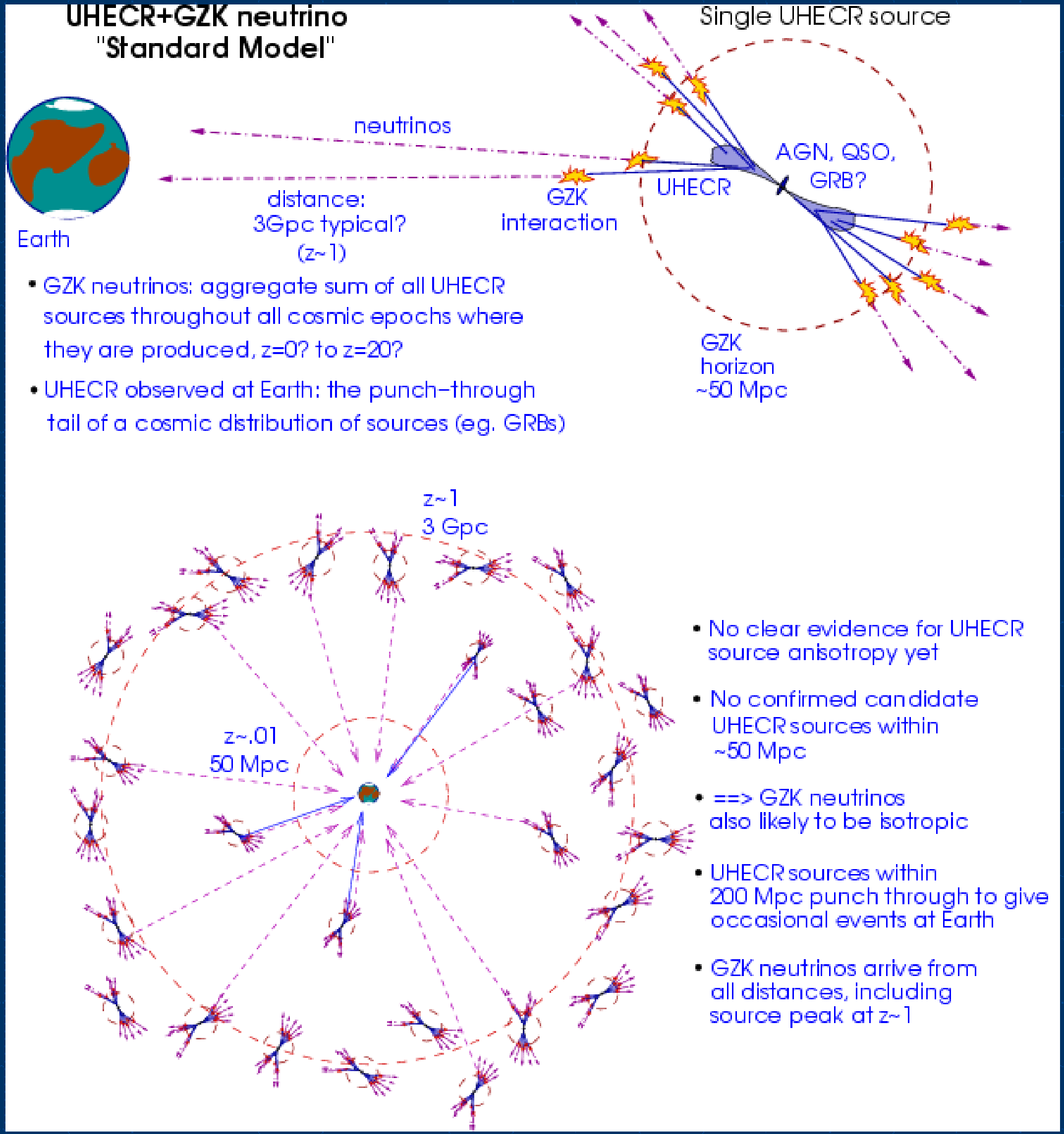


* V. Berezinsky 1970

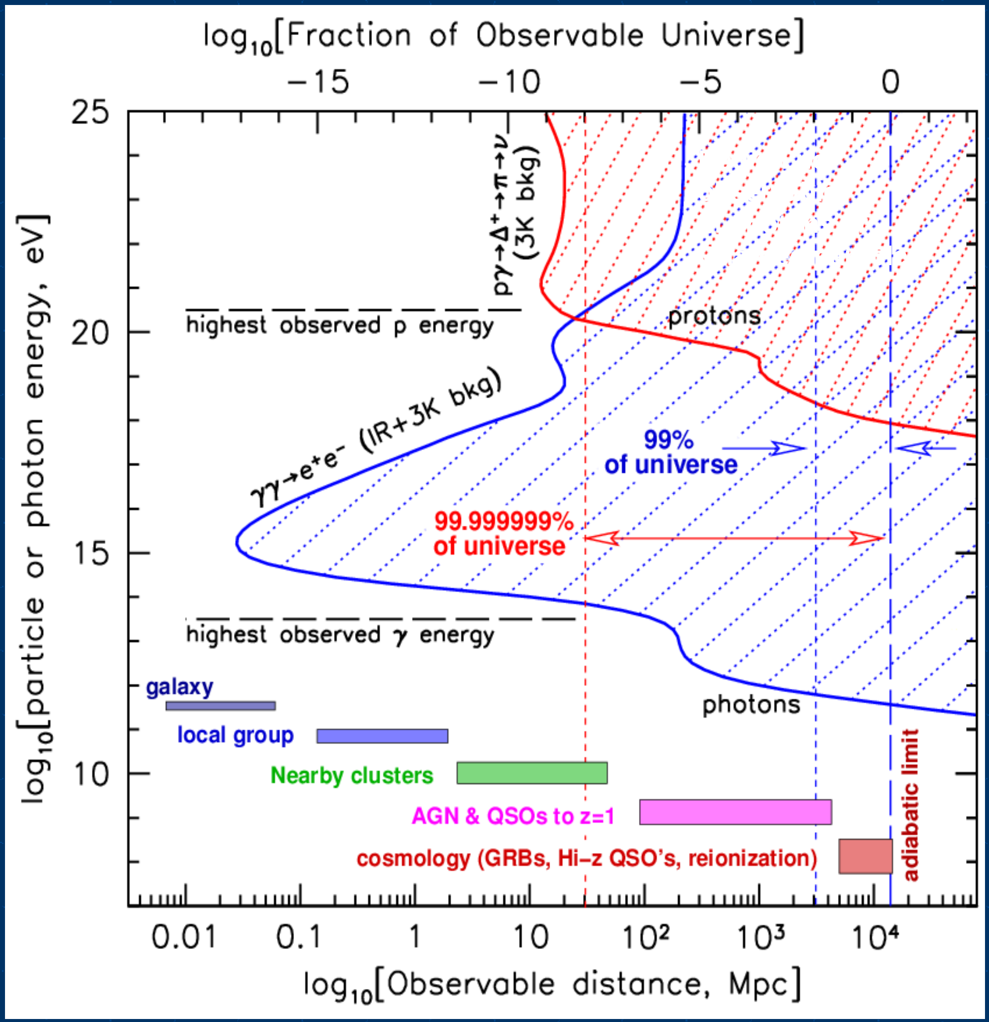
UHECR and the “GZK horizon”



- UHECR retain only secondary info on source spectrum
- Resulting GZK neutrino spectra are more direct



Neutrinos: The only long-range messengers at ultra-high energies



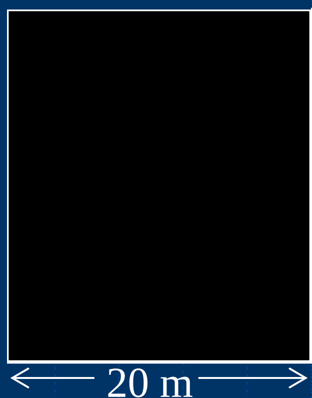
- **Photons lost above 30 TeV:** pair production on IR & 3K μwave background
- **Charged particles:** scattered by B-fields or 3K bkg photons at all energies
- But we know there are sources up to <u>at least</u> <u>10^{20} eV</u>
- ➔ Study of the highest energy processes and particles throughout the universe requires ultra-high energy neutrino detectors

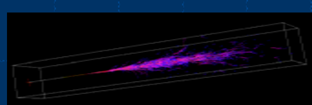
Why go after cosmogenic neutrinos?

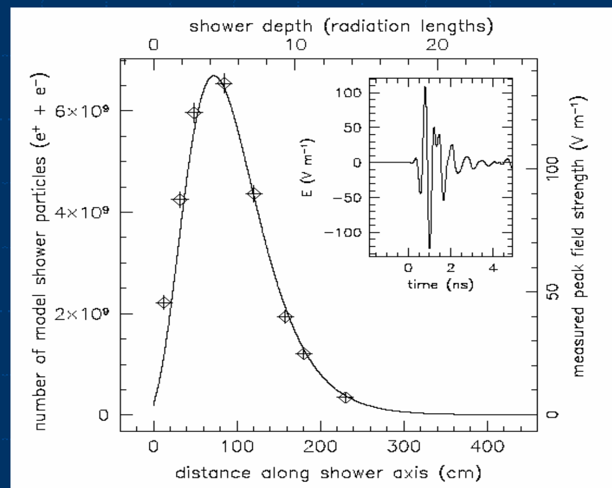
- Their flux is highly constrained by UHECR
  - Can become a quasi-isotropic “test beam” of UHE neutrinos
  - ~100-1000 TeV center-of-momentum energies
  - Weak interaction physics beyond the LHC (14 TeV center of momentum energy)
- Trace particle hyper-accelerators to very early epochs
  - Even at z~15 or more, GZK neutrino energies peak at 10-100 PeV
  - they all point back directly to their sources
- They oscillate in flavor (who ordered that?)!
  - A new kind of messenger, unlike photons—surprises await
- **BUT: proper detector scale not 1 km^3, but 1000+ km^3**

Askaryan Effect: confirmed in 2001 at SLAC

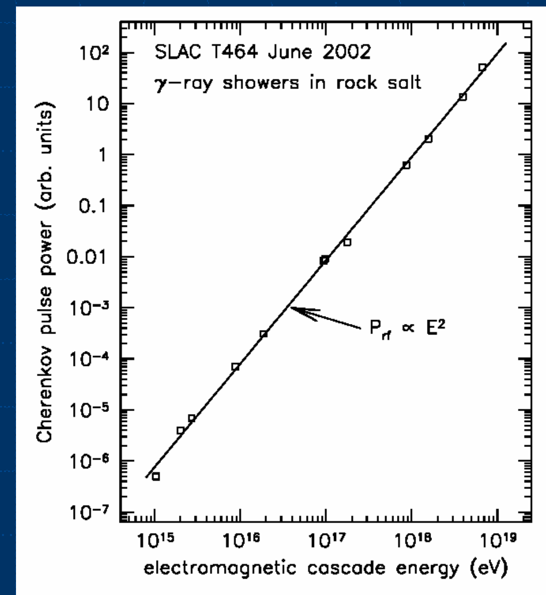
Blue: ~0.01GHz → yellow: 2GHz







Saltzberg & Gorham et al. PRL 2001



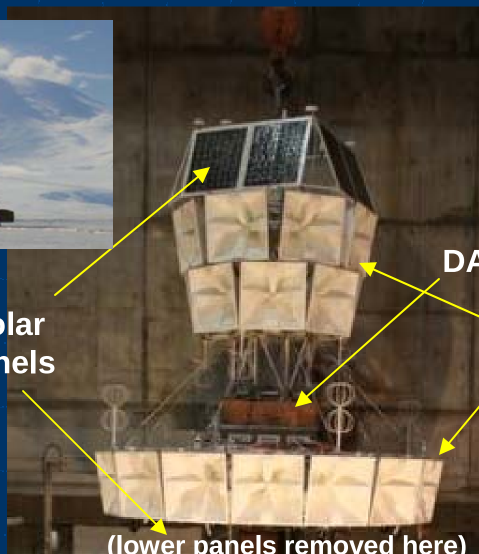
Gorham et al. PRD 2003

- Coherent radio emission from the excess –ve charge in an EM shower
- “shower” is actually a small pancake of HE particles, few mm thick and few cm wide in solids
- At wavelengths longer than ~10-20 cm, appears as a single charge of $Z\sim10^8$

Askaryan effect: experiments

- Parkes 64m dish: Hankins, Ekers, O'Sullivan 1996
  - 10 hours looking for impulses from Lunar regolith, $>10^{20}$ eV
- Radio Ice Cherenkov Experiment (RICE) late 1990's-present
  - AMANDA boreholes with antennas at South Pole, 10^{16-18} eV
- GLUE: Goldstone Lunar Ultra-high energy neutrino expt.
  - 1998-2002, 120 hrs on lunar regolith with 70m+34 m radio dishes
  - $>10^{20}$ eV, best current limit at EHE
- 64m Kalyazin telescope, Russia,
  - Beresnyak, Dagkesamanski, Zheleznyk– further lunar searches, $>10^{20}$ eV
- Fast On-orbit Recording of Transient Events (FORTE)
  - DOE satellite for lightning, set limits based on Greenland observ. $>10^{22}$ eV
- **Antarctic Impulsive Transient Antenna—ANITA**
  - **ANITA-lite flew in 2003-2004, 4 channel prototype**
  - **Full ANITA flight just completed, late January 2007**

Antarctic Impulsive Transient Antenna--ANITA



ANITA Gondola & Payload

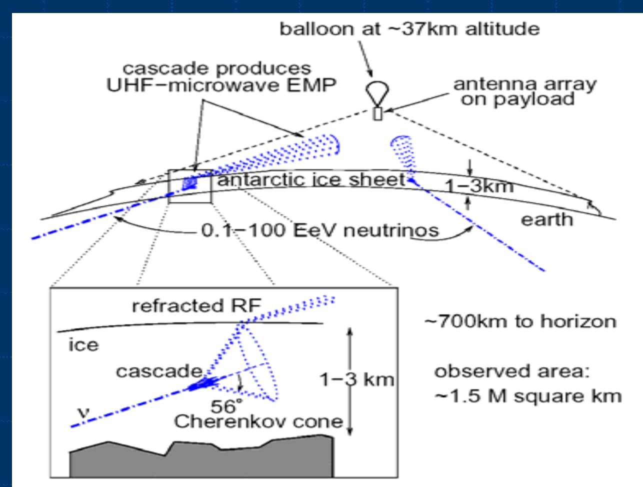
DAQ & flight computer

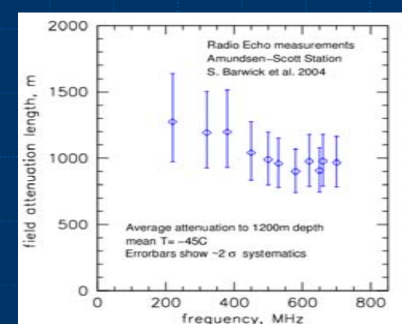
Solar panels

Antenna array

Overall height ~8m

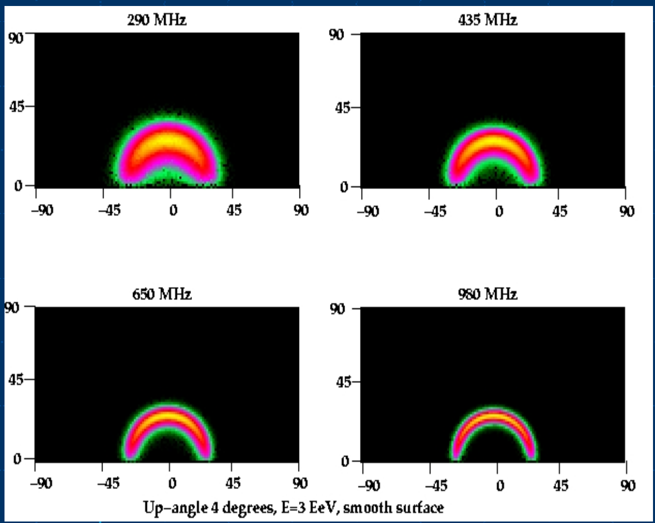
- NASA start in 2003, first full launch in '06-07, baseline 10 day mission (but got 35 days total)
- Ultra-broadband antenna array, views 1.5M km² of ice sheet looking for Askaryan impulses, $\Delta f \sim 0.2$-1GHz

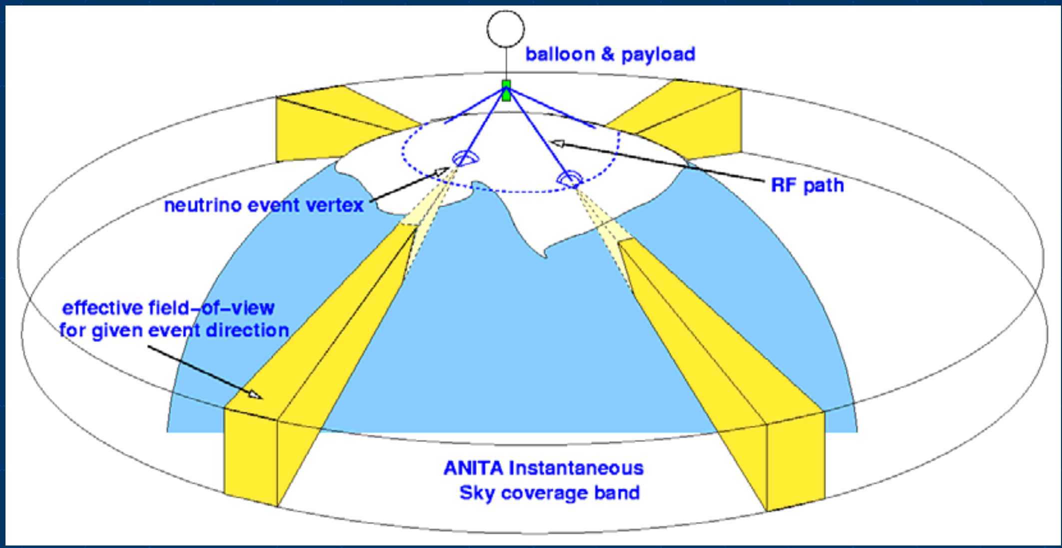


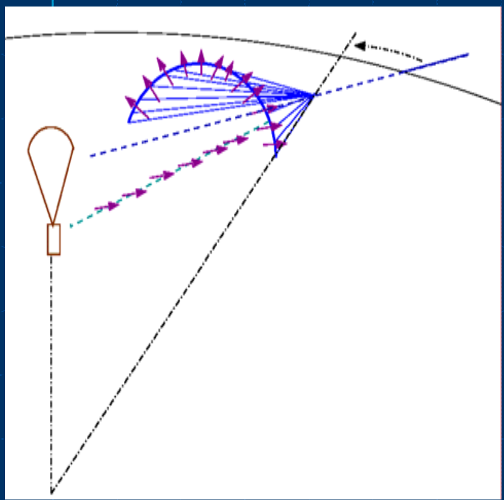


Ice RF clarity:
1.2 km(!) attenuation Length @ 300 MHz

ANITA as a neutrino telescope



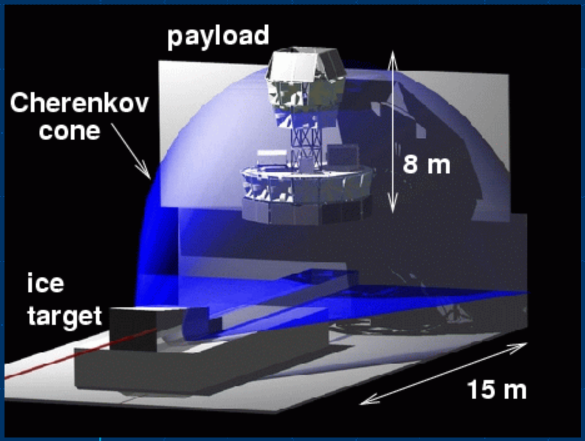




- ANITA sees a band of sky near the “visible” horizon
- The band “nutates” for different longitudes of the balloon
- Pulse-phase interferometer (150ps timing) gives intrinsic resolution of <0.3° elevation by ~1° azimuth for **arrival direction of radio pulse**
- **Neutrino direction** constrained to ~<2° in elevation by earth absorption, and by ~3-5° in azimuth by observed **polarization angle of detected impulse**

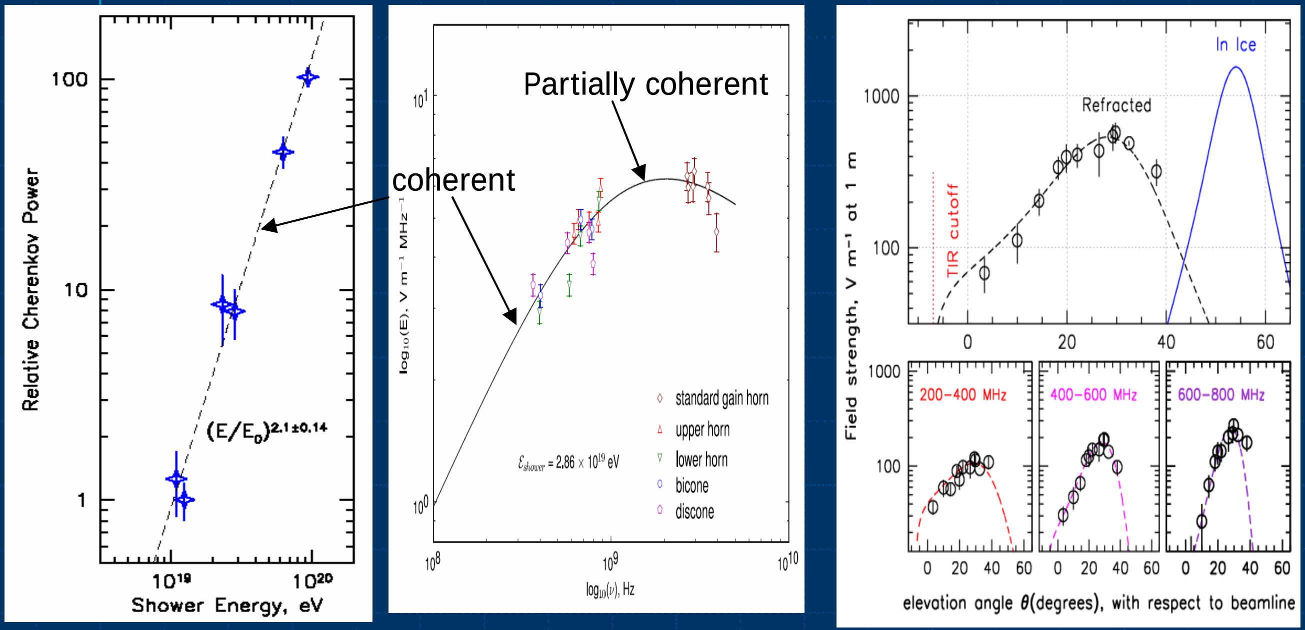
June 2006, SLAC T486: "Little Antarctica"

End Station A, SLAC

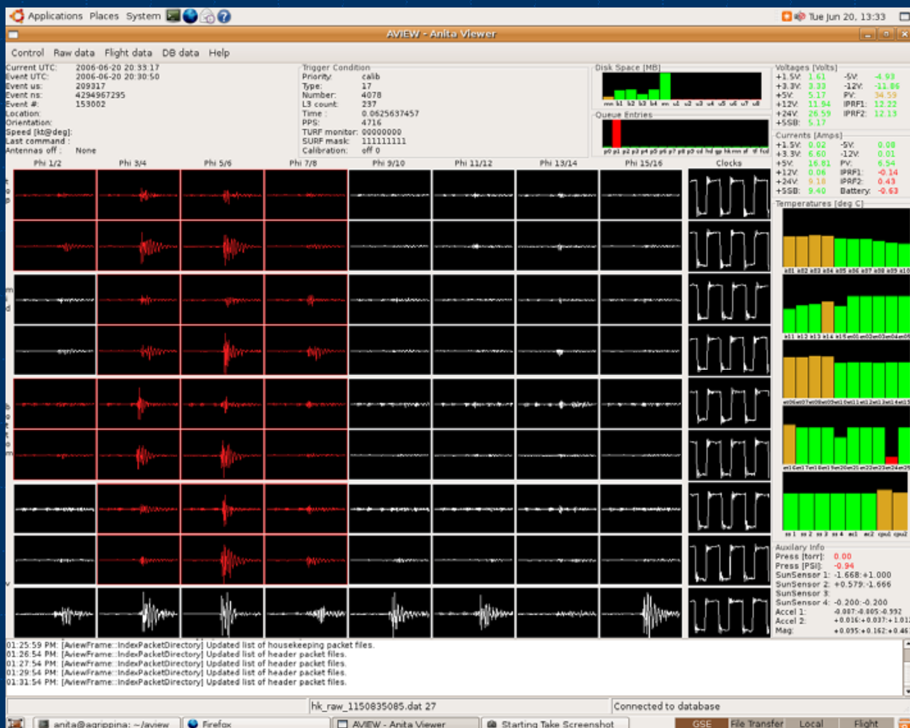


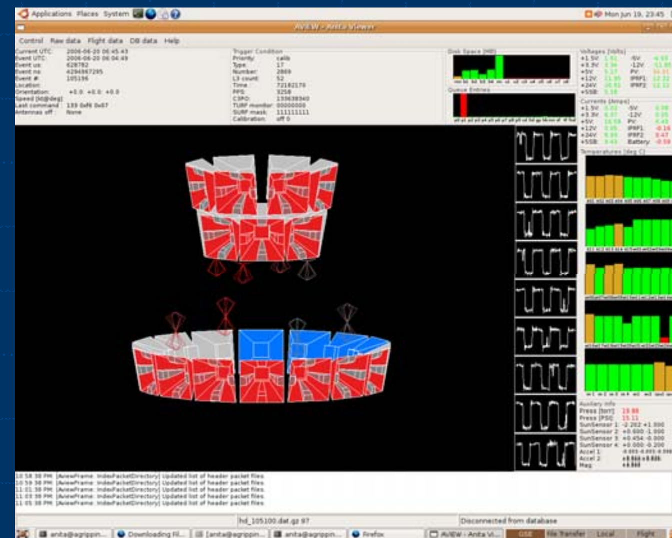
Thanks to P. Chen, C. Hast, SLAC

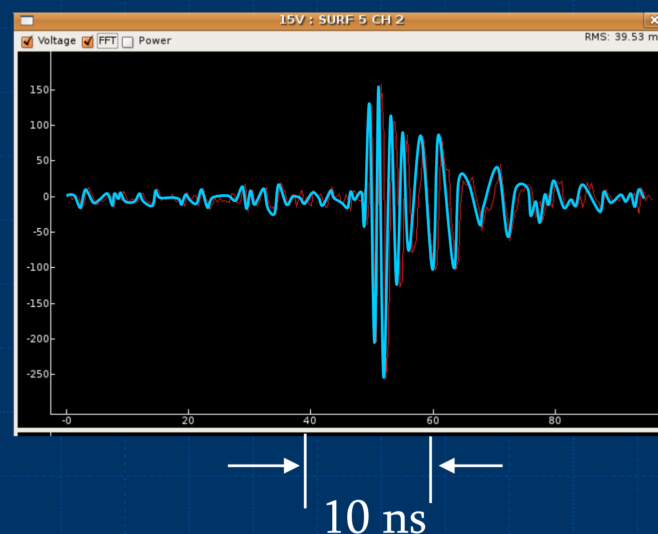
- SLAC e^- showers with composite energy same as UHE neutrinos
  - 10^{8-9} x 28 GeV = 2.8×10^{19} eV
- Coherent radio power consistent with theory
- 1st direct observation of radio Cherenkov cone



ANITA & Askaryan effect in ice







- **Impulses are band-limited, highly polarized, as expected**
- **Very strong--need 20dB 'pads' on inputs--signals are +95dB compared to Antarctic neutrino signals, since we are much closer**

Spacetime fast-forward ($\Delta x,\Delta t$)=(8K miles, 5 months): Nov. 2006, Ross Ice shelf, Antarctica

- The Long Duration Balloon Base at Williams field
  - ~7 miles out on Ross Ice shelf, smooth, flat ice, 80m deep ice
- a first-class field operation, run by NASA's Columbia Scientific Balloon Facility (Palestine Texas) with excellent NSF support

Life in Mactown

We're not in Hawaii anymore (C. Miki photo)

recycling in McMurdo...

"and my father dwelt in a tent..."

J. Kowalski photos

Ice age technology (C. Miki photo)

Local hospitality

Thanks to
Jeff Kowalski

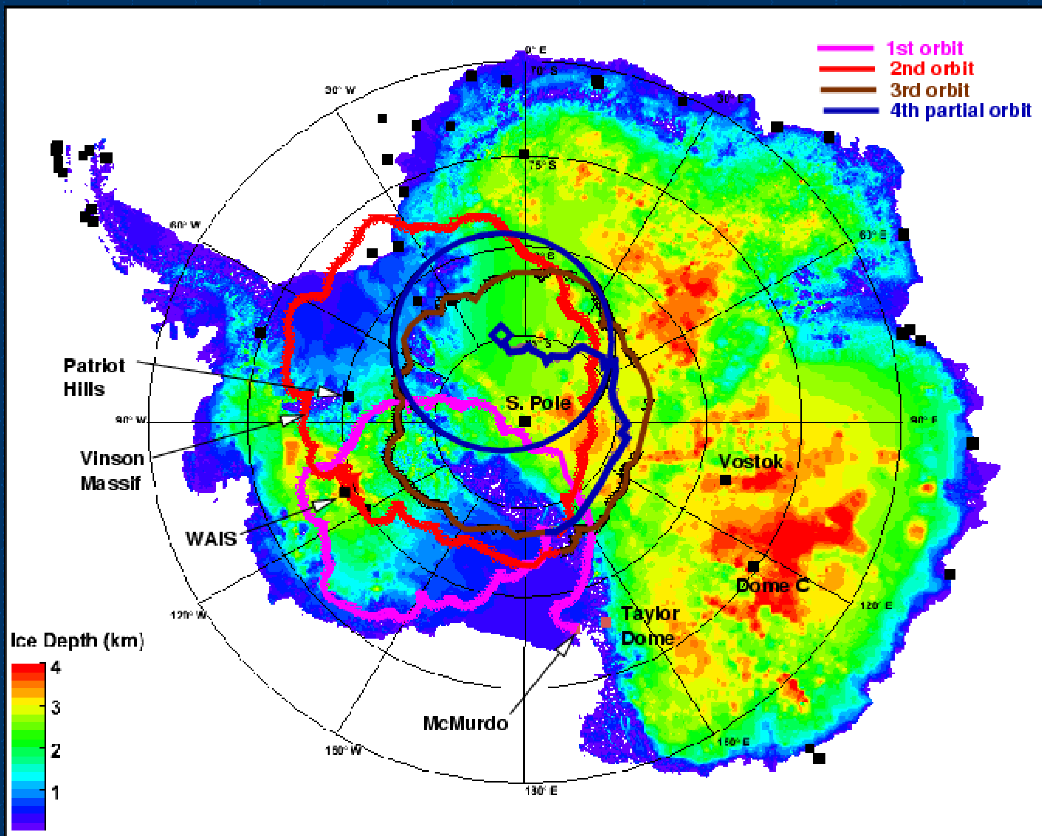
Launch: December 15, 2007

- ANITA at float (123Kft)
  - See through amateur telescope from the South Pole
  - Size of the Rose Bowl (really!)
  - (thanks to James Roth)

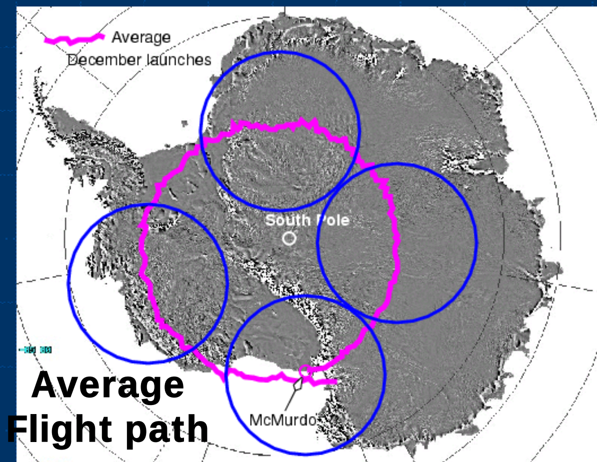
Landing…~360 miles from South Pole

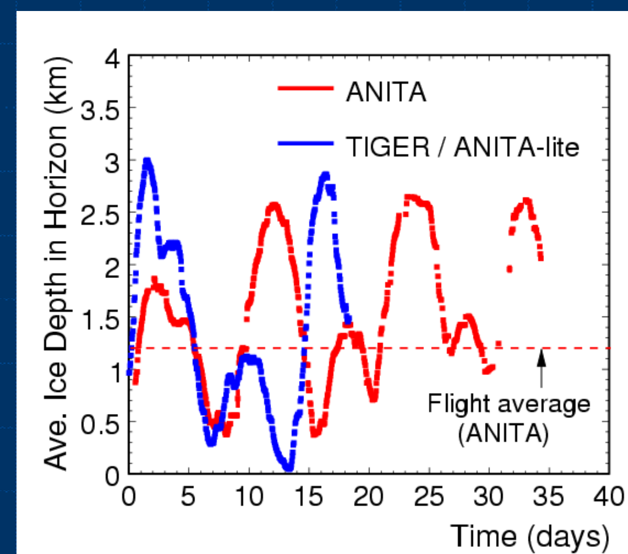
- Ouch! Chute did not release after landing, payload dragged ~1 mile
- BUT: DAQ & data OK → success!

ANITA flight path



K. Palladino, OSU

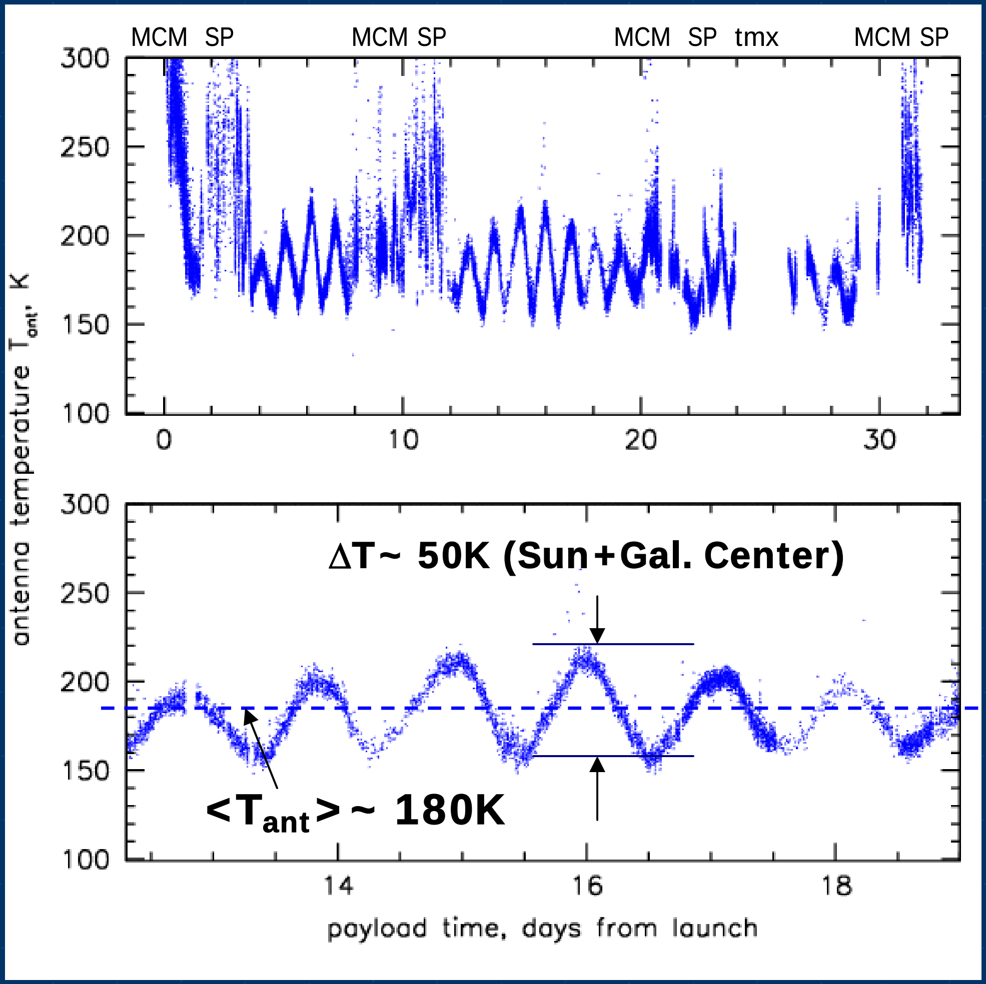




A. Connolly UCLA

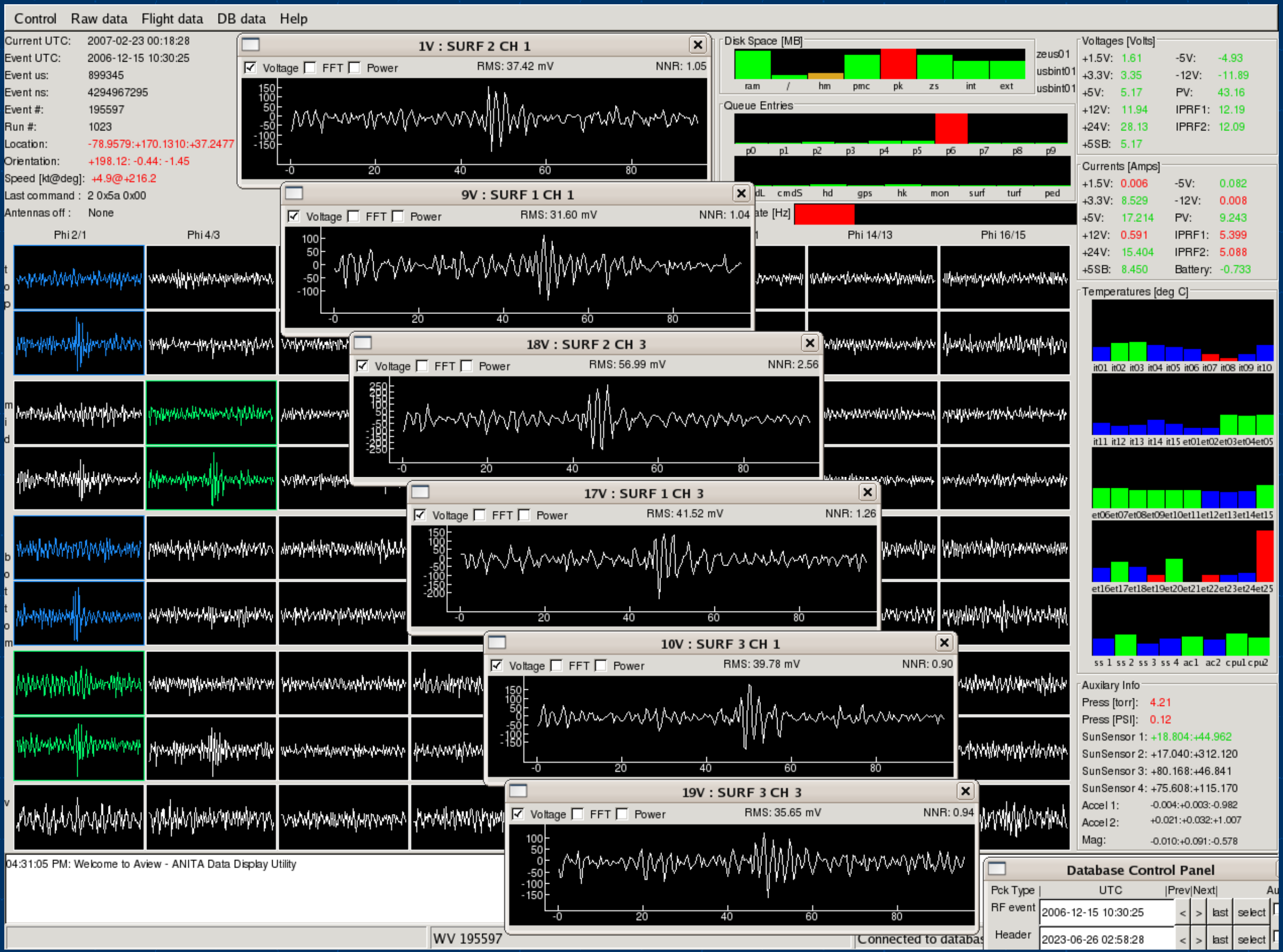
- 35 days, 3.5 orbits
- Anomalous Polar Vortex conditions
- Stayed much further “west” than average
- In view of stations (Pole & MCM) ~50% of time
- But still achieved ~1.2km average depth of ice

Flight sensitivity snapshot



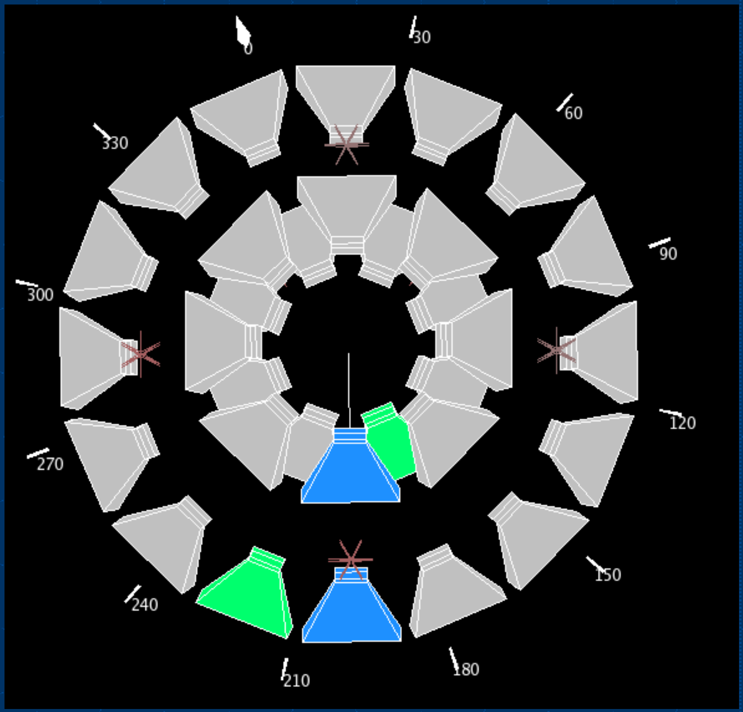
- ANITA sensitivity floor defined by thermal (kT) noise from ice + sky
- Thermal noise floor seen intermittently throughout of flight—but punctuated by station noise
  - South Pole and McMurdo stations!
- Still a significant fraction (~50-60%) of time with pristine conditions

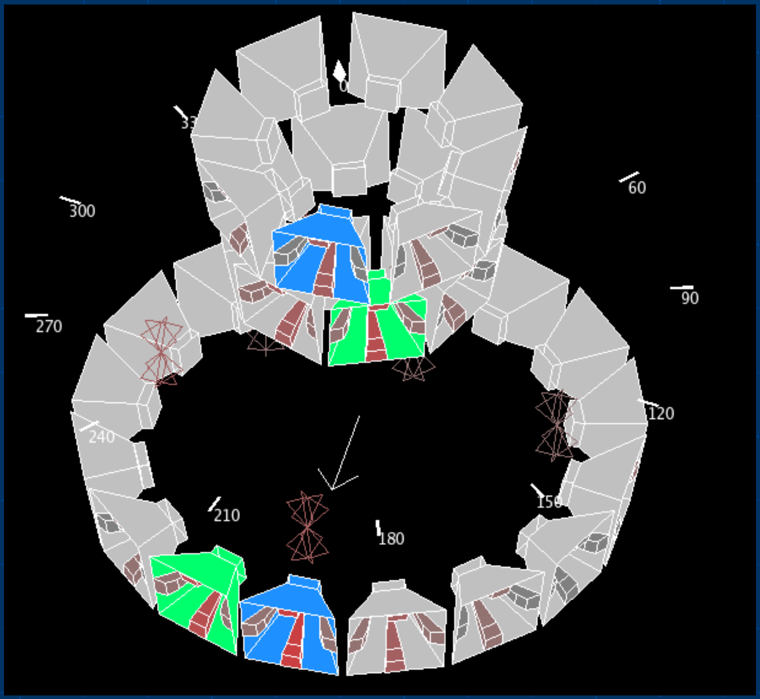
How do we validate? borehole pulser



- ANITA has no physics background to “calibrate” on (eg., no muons)
- Need to prove that we would see neutrino event if they are there
- RF Impulses from borehole antenna at Williams field
- Detected at payload out to 300-400 km, consistent with expected sensitivity
- Gives precise trigger & pointing calibration, verifies sensitivity

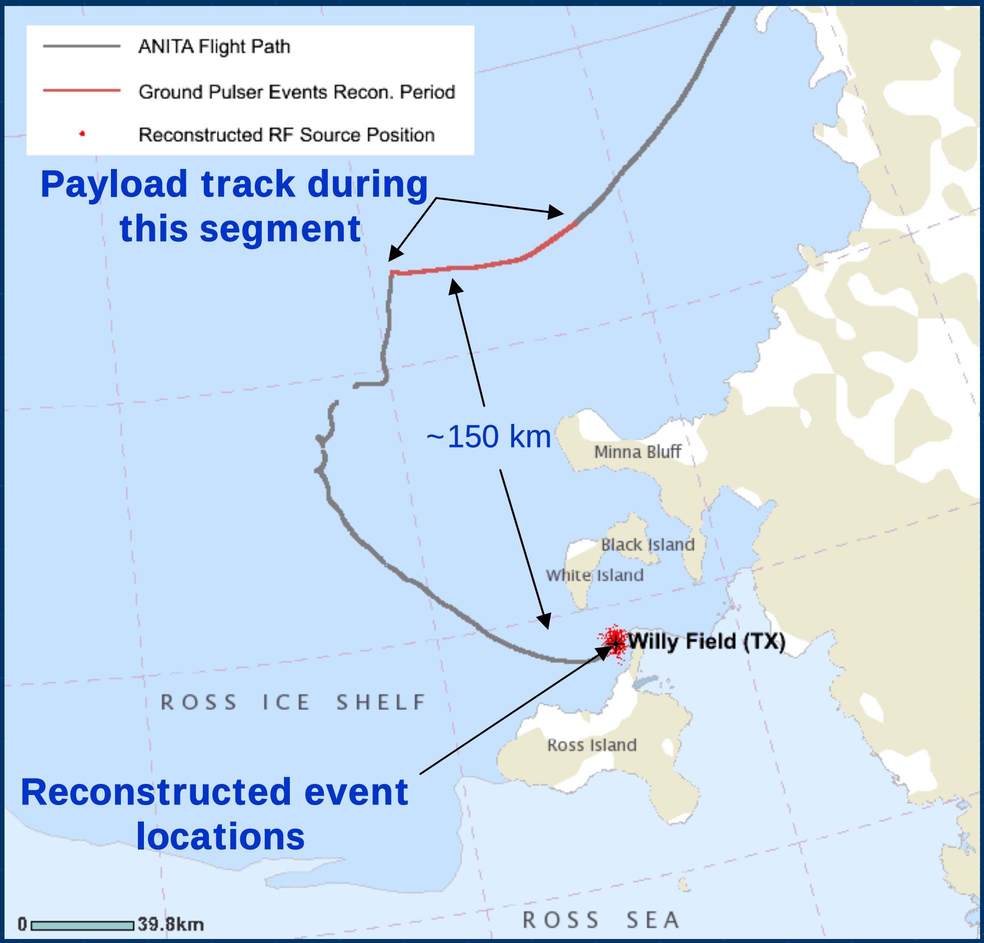
Trigger pattern, borehole pulser



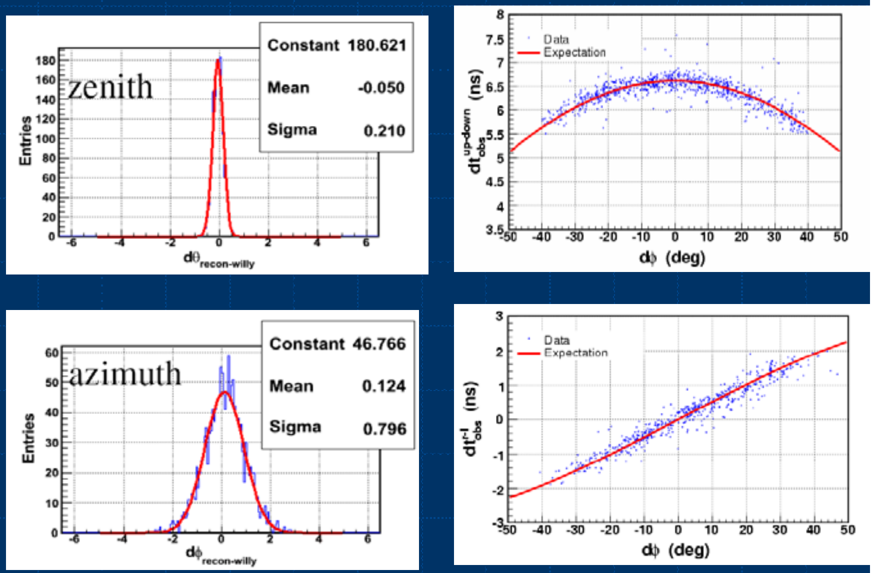


- Trigger pattern requires >3 antennas (9 of 24 signal channels) in both upper and lower 16-antenna rings
- Negligible accidentals, but ~4-5 Hz total from thermal noise
  - Threshold servo down until they get a “dribble” of thermal triggers

ANITA geo-location of borehole cal events

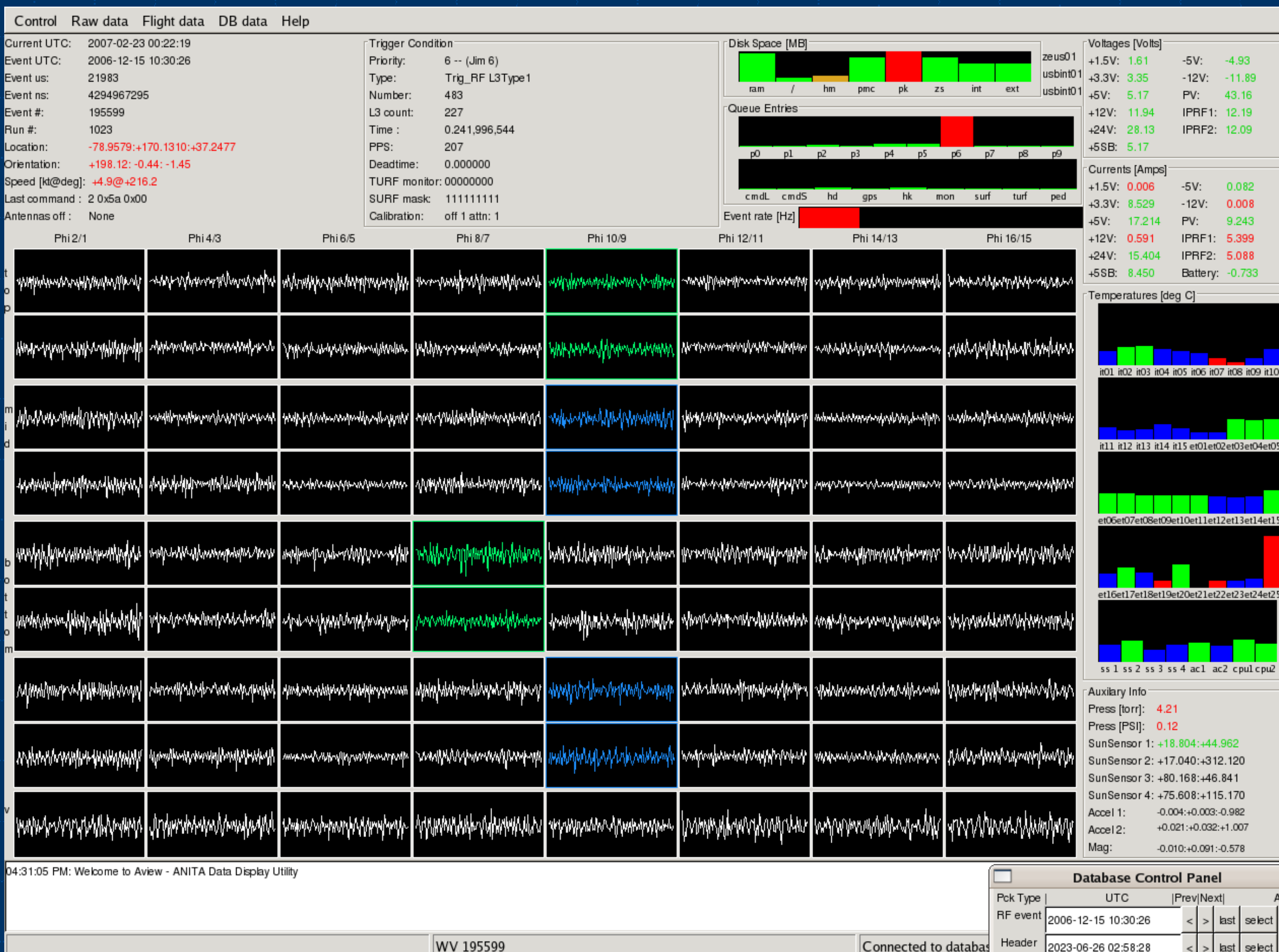


- Expect ~ $c\Delta\tau/2D$ altitude & azimuth
- $\Delta\tau$ ~ 0.1-0.16 ns, D ~ 1m (horizontal) to 3 m (vertical)
- Altitude: 0.21º observed, 0.29º expected
- Azimuth: 0.8º observed, 1.72º expected
- Pulse-phase interferometry works well



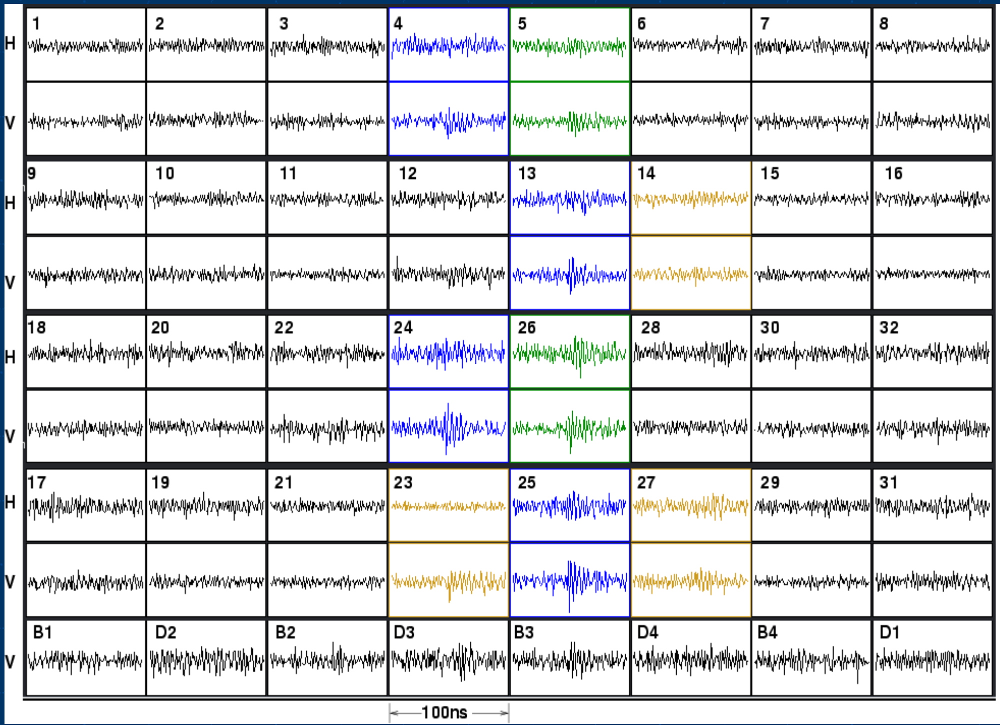
Thanks to JiWoo Nam, UCI

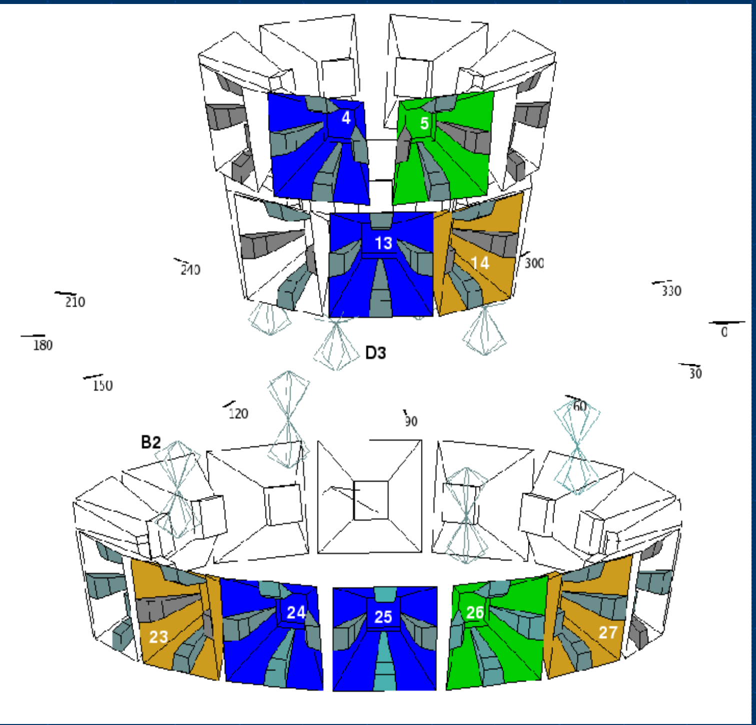
99.99+% of triggers: incoherent thermal noise



- Thermal radio photon bath fluctuations are the “floor” noise for ANITA
  - 5σ rate per antenna is ~1Hz
- But they are uncorrelated, and almost never “point” to anything
  - Random background completely negligible per flight

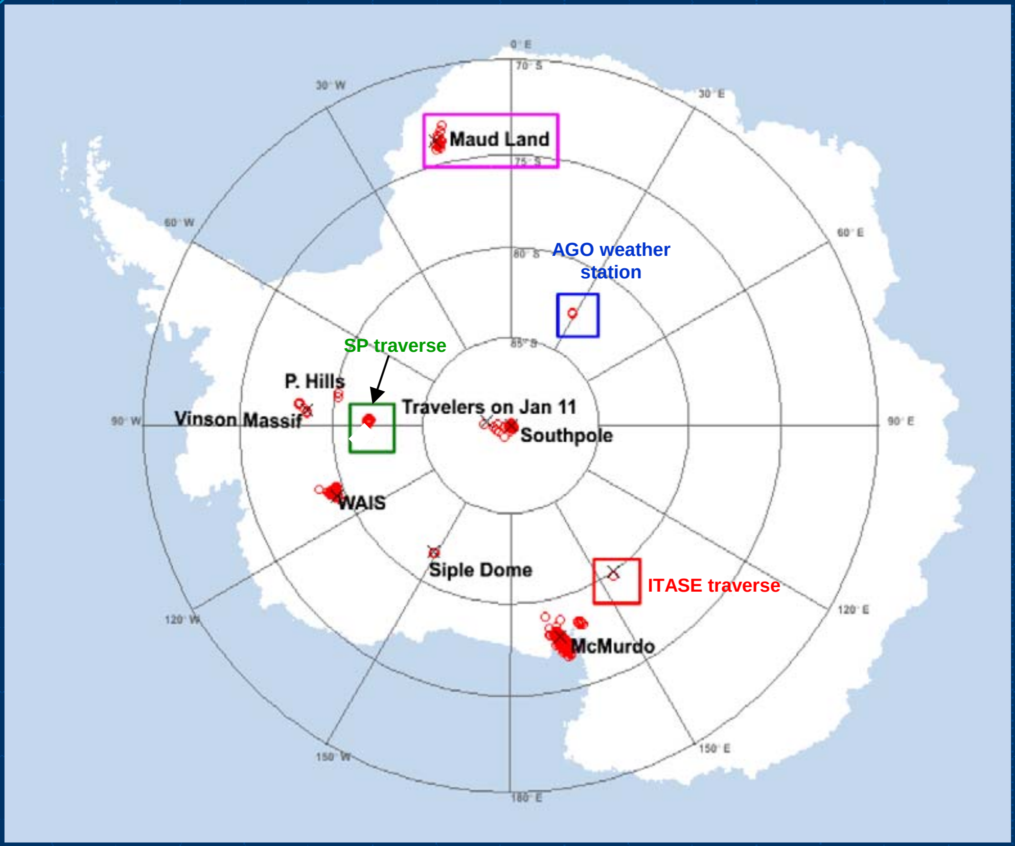
What an ANITA candidate might look like...





- Event 7767328, vertically-pol, 9-10 antennas, no source ID yet...
- More info than you may think: ~80 ps timing; dual polarization; amplitude vs. frequency from 0.2 to 1.2 GHz...
- Preliminary analysis: there are not many (a handful?) of these
- What we know so far: backgrounds in Antarctica are very low!
  - What we don't know yet: is there a signal there as well...

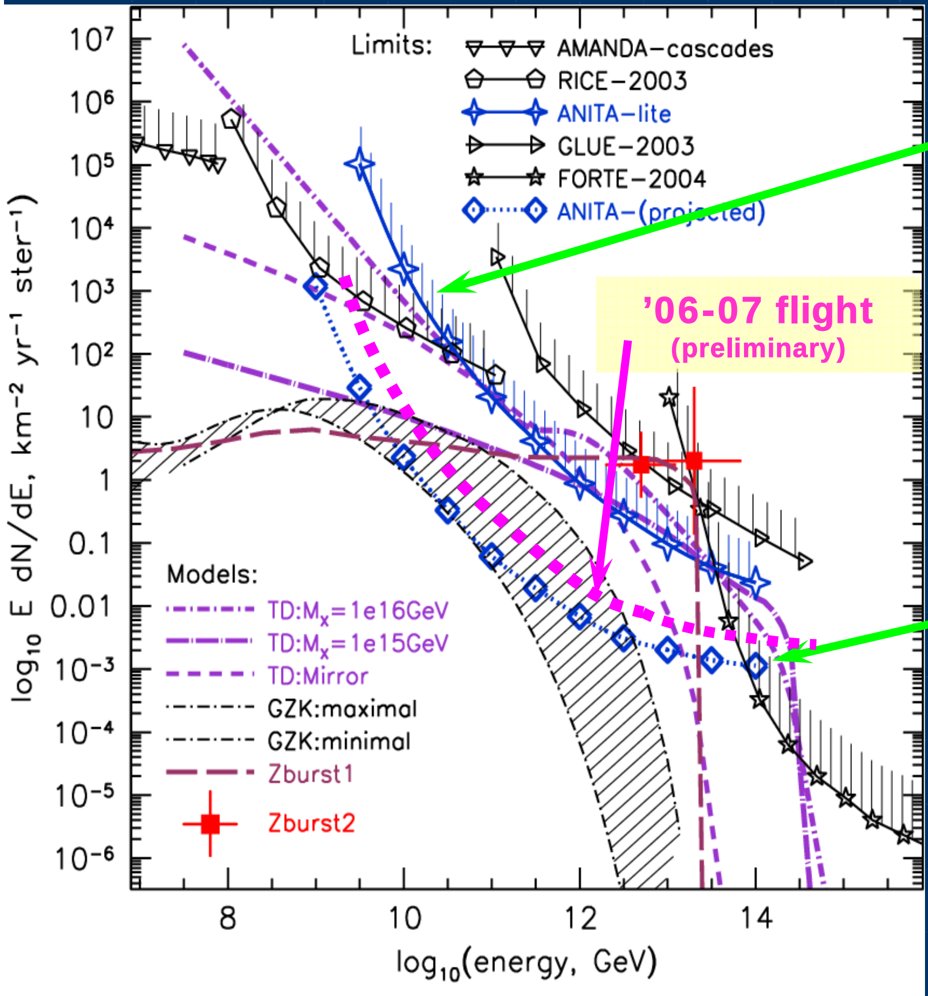
ANITA analysis for neutrino candidates



Preliminary event map, 10% of data
--JiWoo Nam UCI

- ANITA analysis:
  - Its all about the pointing!
  - (mis-)Reconstruction efficiency is key
- Establish angular pointing & reconstruction on pulser events
- Check events against existing camps, known transmitters
- Throw away anthropogenic events, anything that repeats
- Whatever is left is…?

ANITA's potential science impact



Strongest limits: all radio

- ANITA-lite: 18.4 days of data, net 40% livetime with 60% analysis efficiency for detection
  - Z-burst UHECR model ($\nu\nu$ annihilation -->hadrons) excluded:
    - expect 6-50 events, see none
  - Highest Toplogical defect models also excluded
- ANITA projected sensitivity (2-3 flights):
  - ν_e ν_μ ν_τ included, full-mixing assumed
  - 45 days exposure at 67% efficiency assumed
  - We are roughly within a factor of 2 with 1st flight

Summary & Plans

- ANITA may have alreadry recorded first glimpse of the ultra-high energy neutrino universe
- Preliminary results: soon!
  - Blind analyses (esp. Antarctica) move at a glacial pace...
- ANITA II to fly in 2008
  - Better exposure we hope (?), 30-50% improvements in hardware sensitivity expected