Observation of UHE Cosmic Rays from the ANITA Balloon-borne Radio Interferometer

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ARENA 2010

Nantes France

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arxiv:1005.0035v2

ANITA-1 Trigger Design

Power Requirement

Level 0 Trigger:

The band power is 2.3σ above the noise level.

Spectral Requirement

Level 1 Trigger:

3 of 8 bands pass the L0 trigger condition.

Geometric Requirement

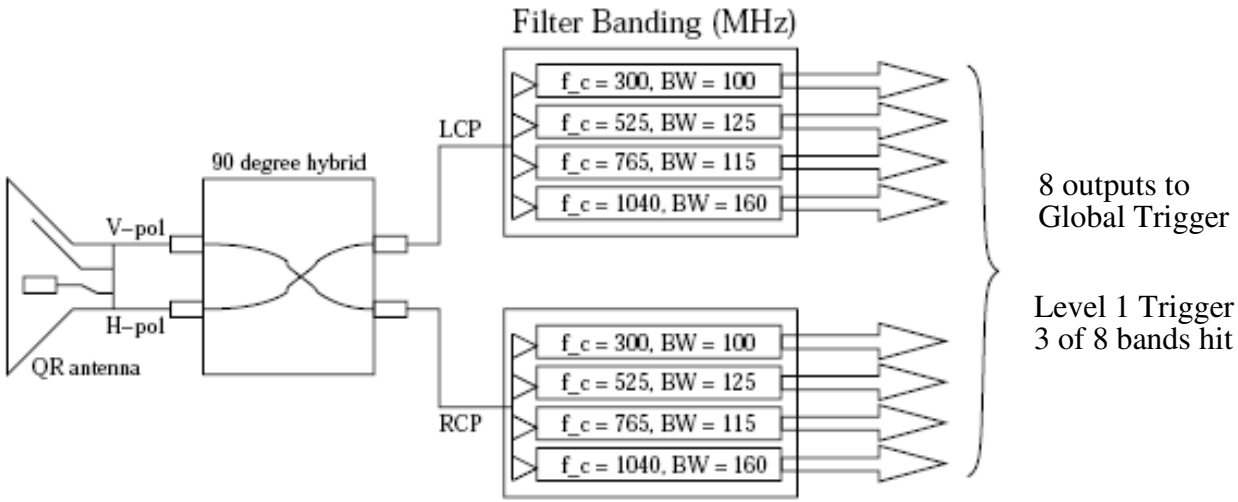
Level 2 Trigger:

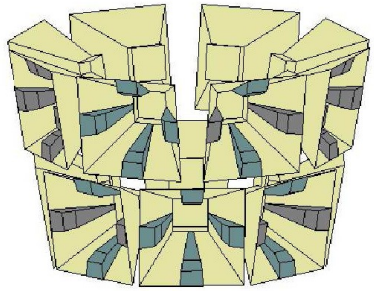
A top or bottom cluster has two adjacent antennas with L1 trigger

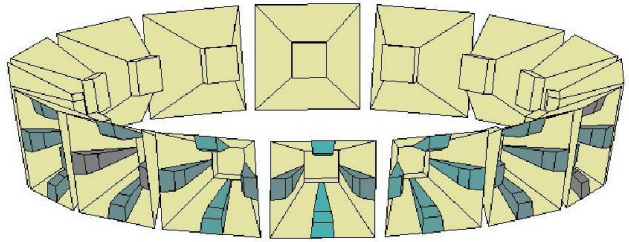
Geometric Requirement

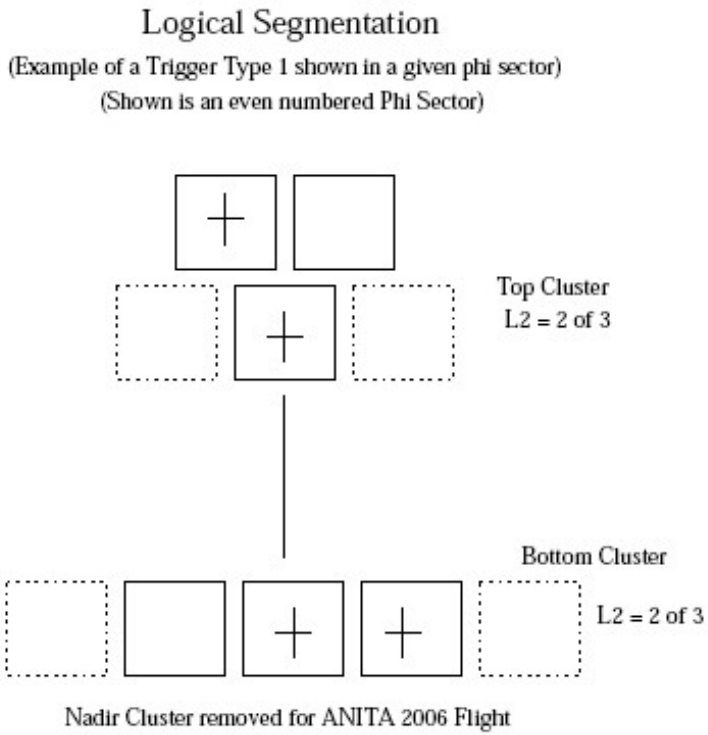
Level 3 Trigger:

Top and bottom antennas in a phi sector have L2 triggers.









ANITA Event Recording

SURF (Sampling Unit for Radio Frequencies)

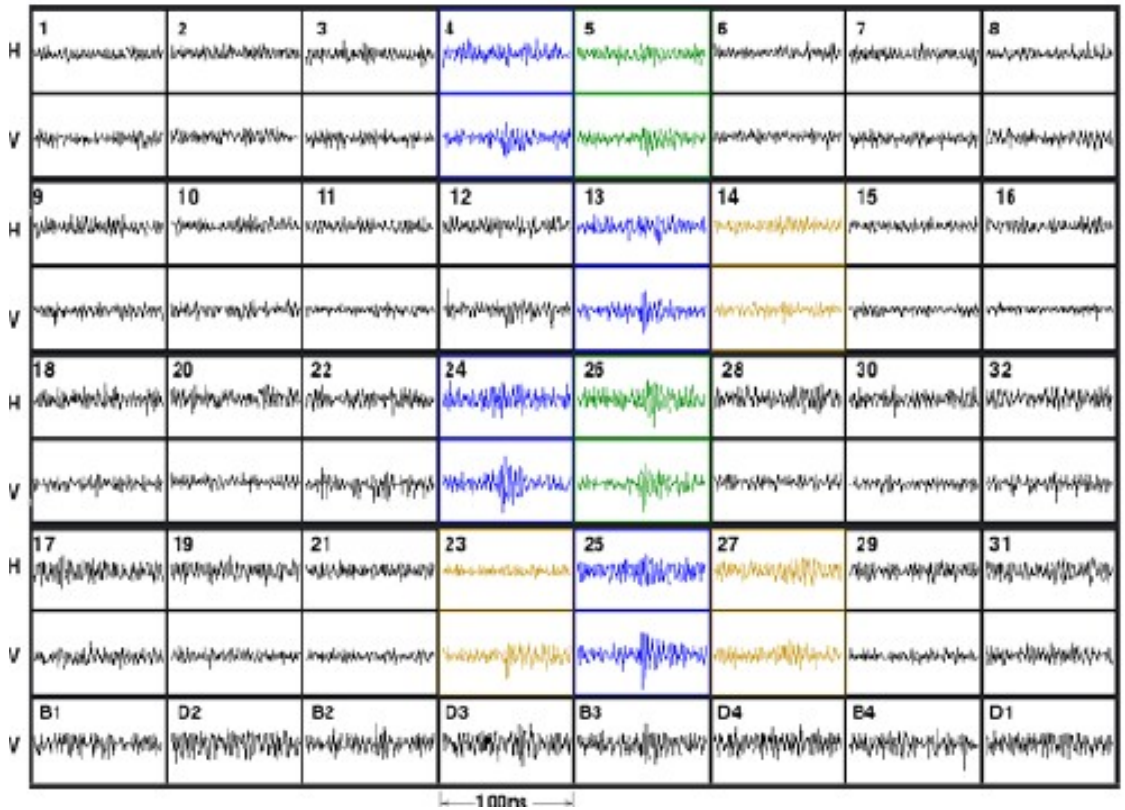
- 2.6 Gsa/s
- 0.385 ns/sample
- 100 ns waveform record length
- 260 samples per waveform
- 10 MHz spectral resolution

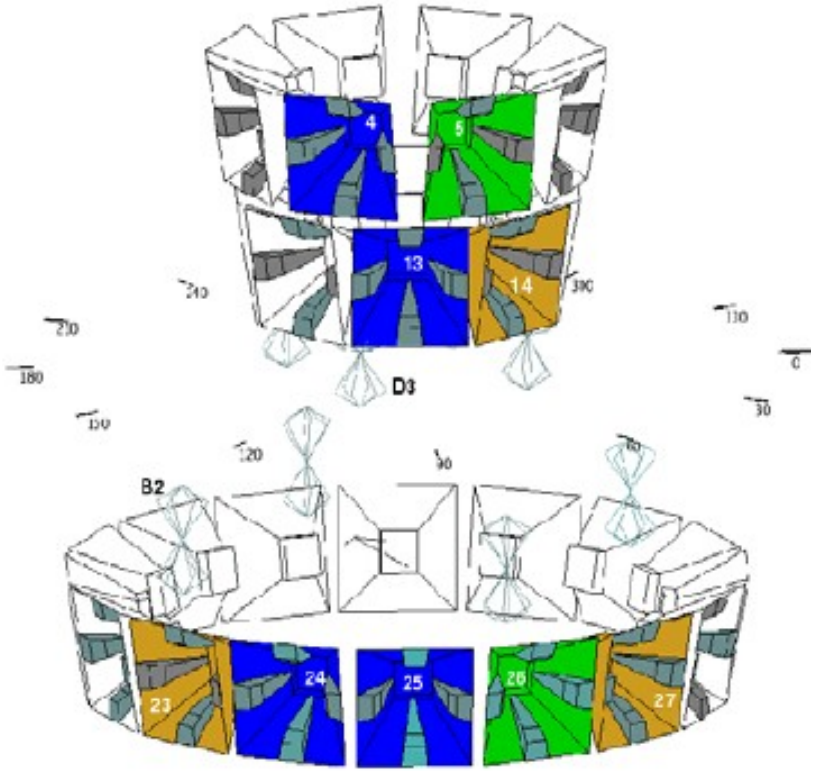
Payload View

L3 Trigger

L2 Trigger

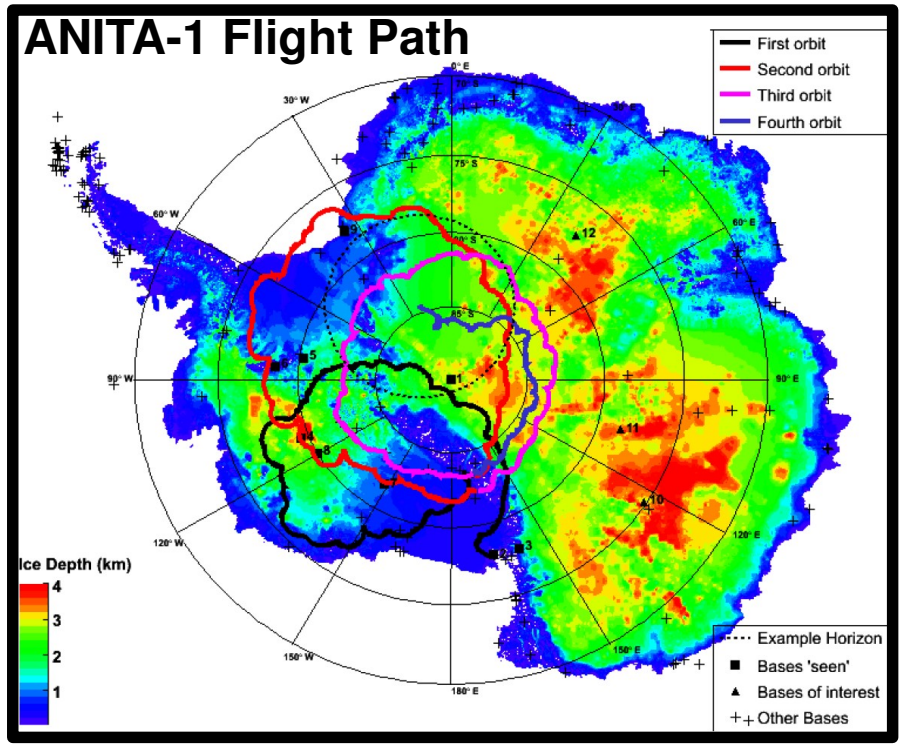
L1 Trigger

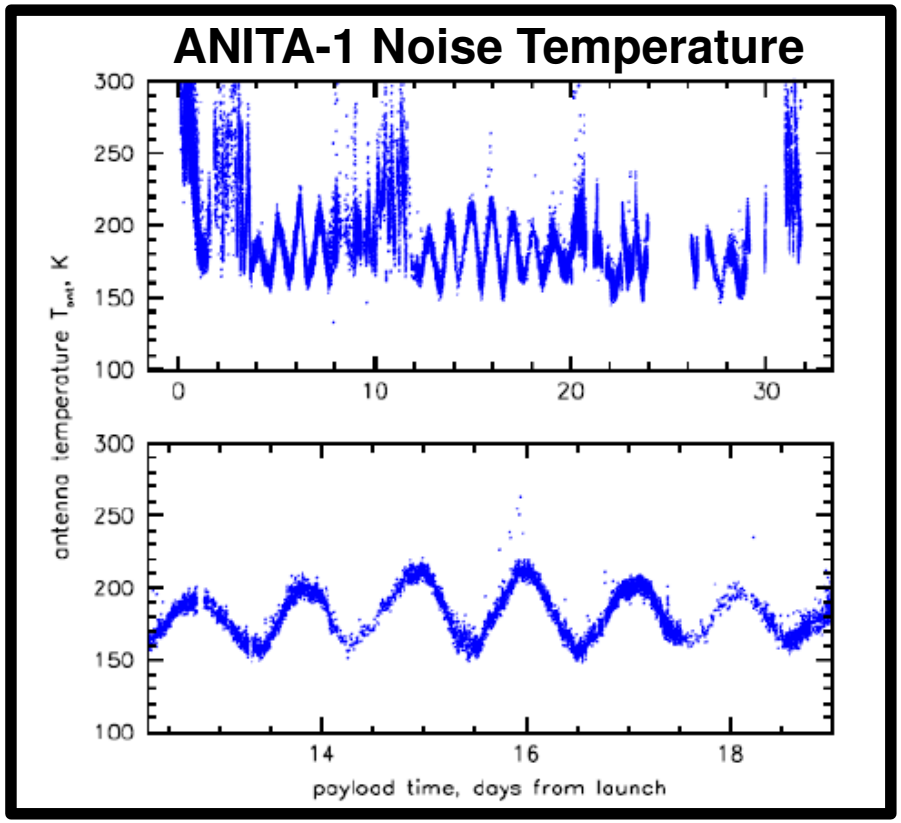


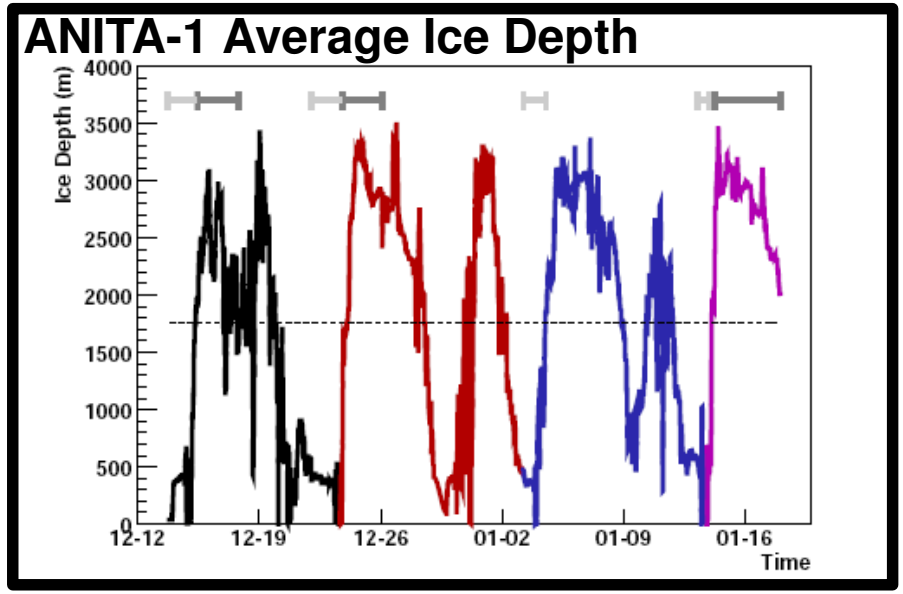


ANITA-1 Flight Performance

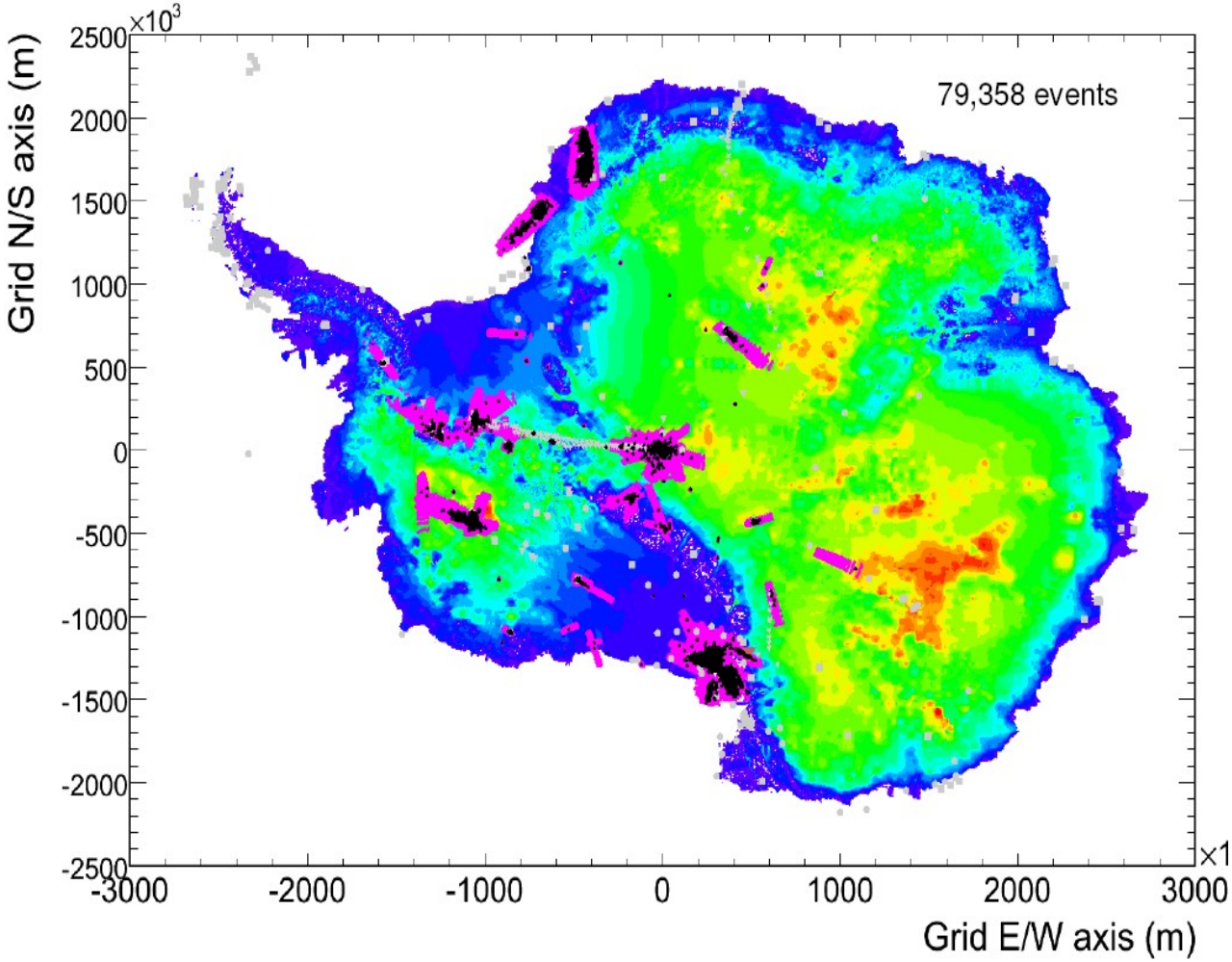
- 35 day flight
- 17.4 days live time
- 8.2 million events
- Anomalous flight path
- but we did get some good quiet data.







Summary of UCLA ANITA-1 Analysis



79,358 Events Reconstructed

14 EAS Events +2 EAS events above horizon

No neutrino candidates.

Cosmic-Ray Candidate Event Locations

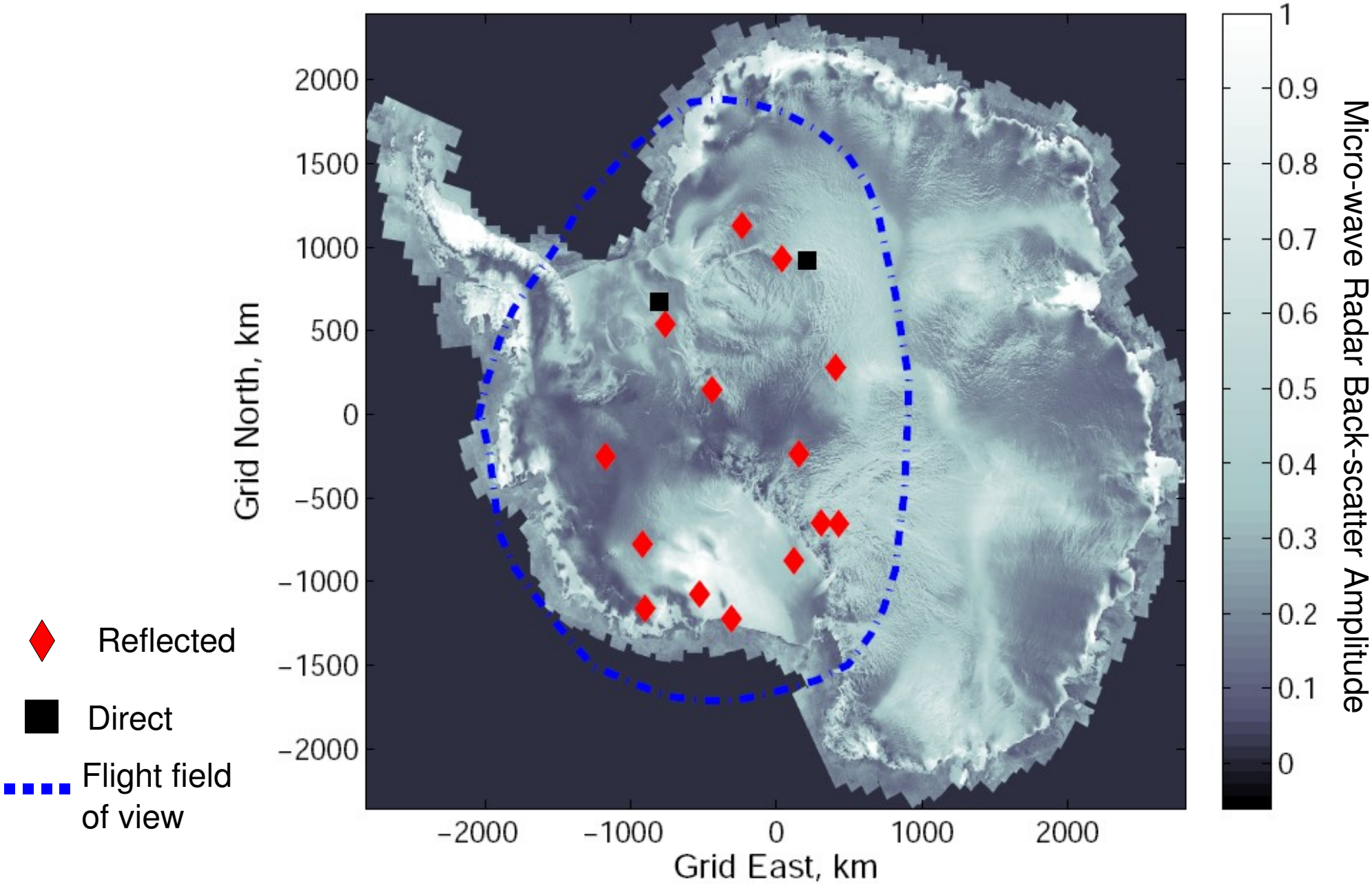
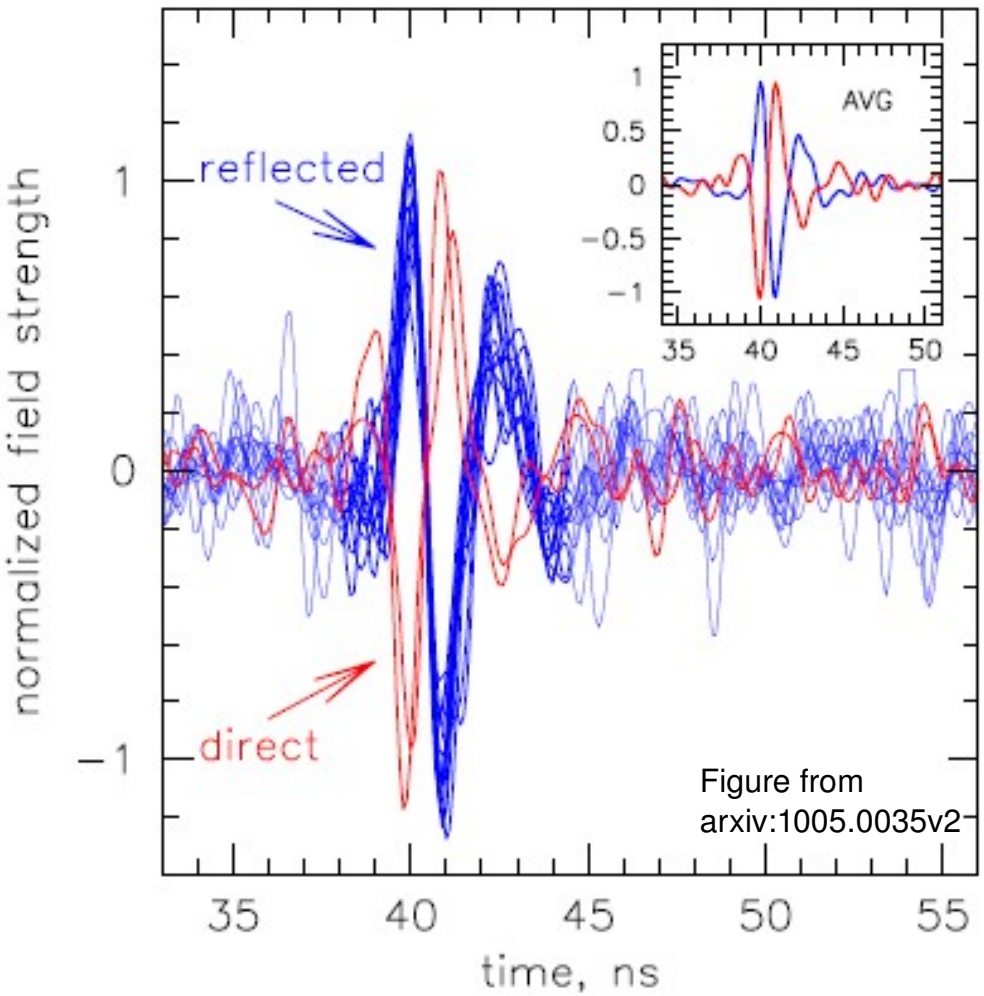
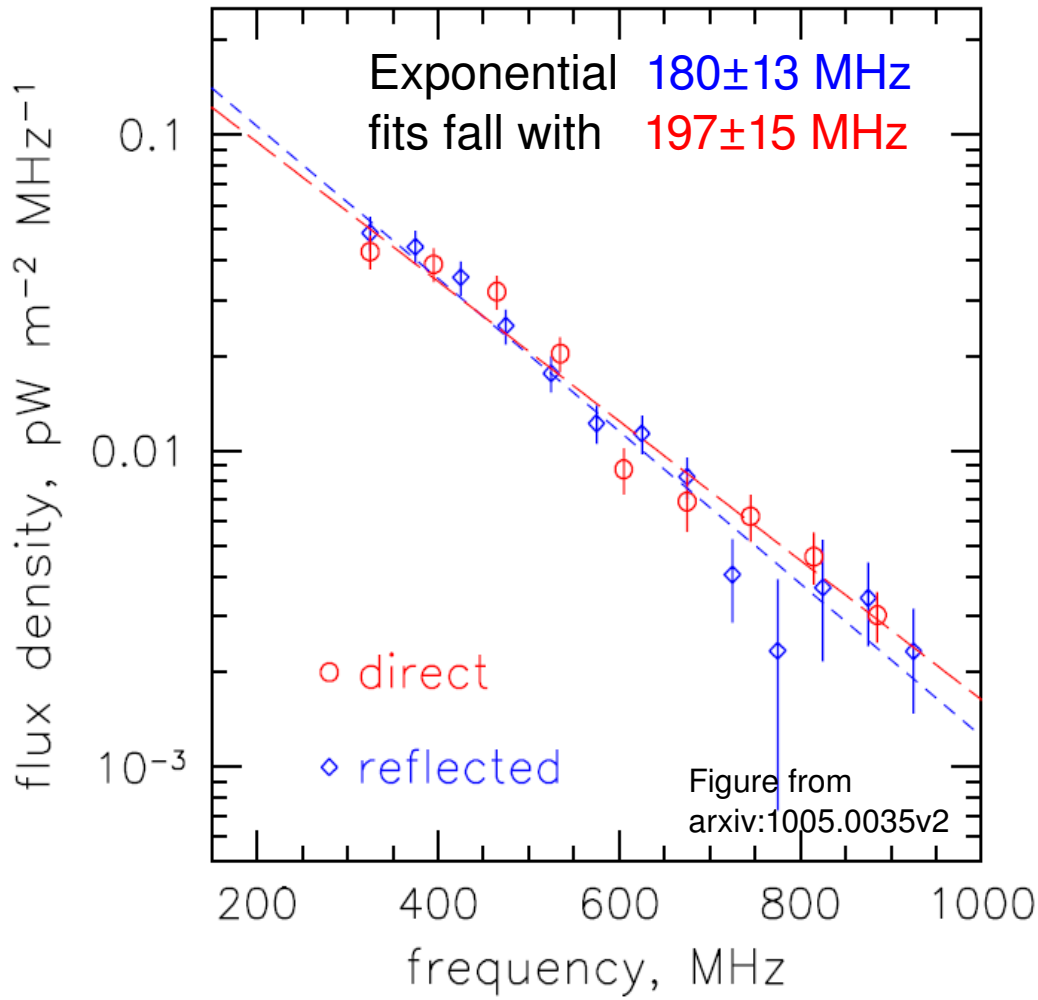


Figure from arxiv:1005.0035v2

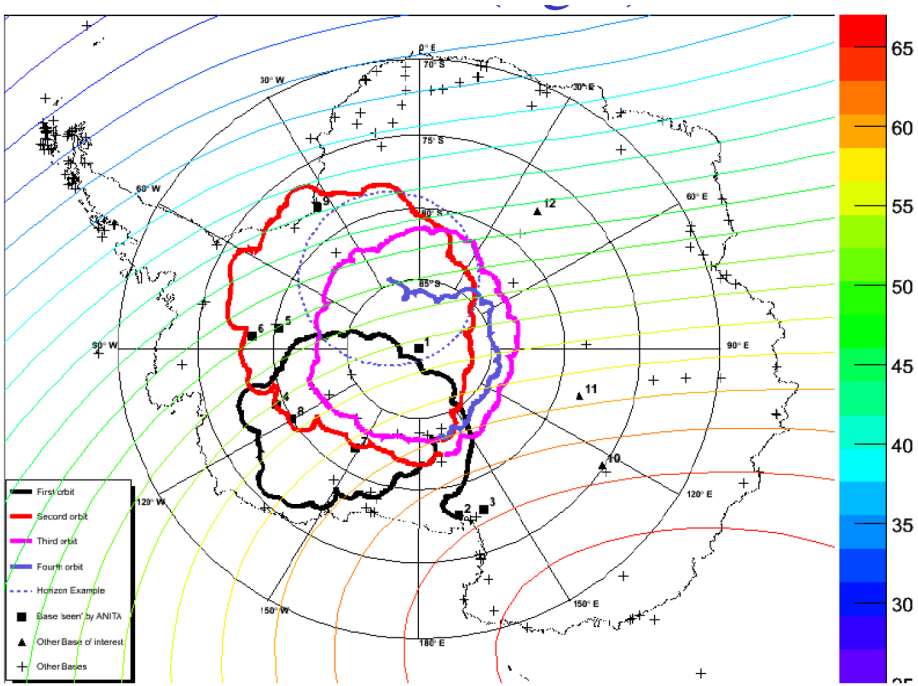
Cosmic-Ray Candidate Event Pulses

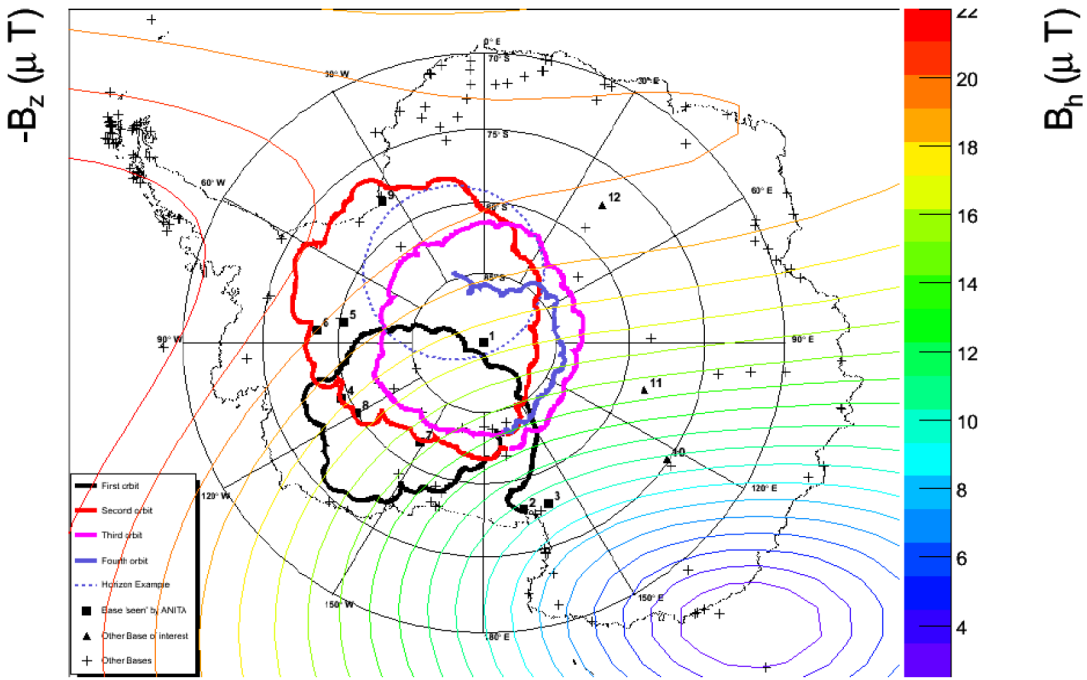
(Instrument response deconvolved)





Geomagnetic Field Direction

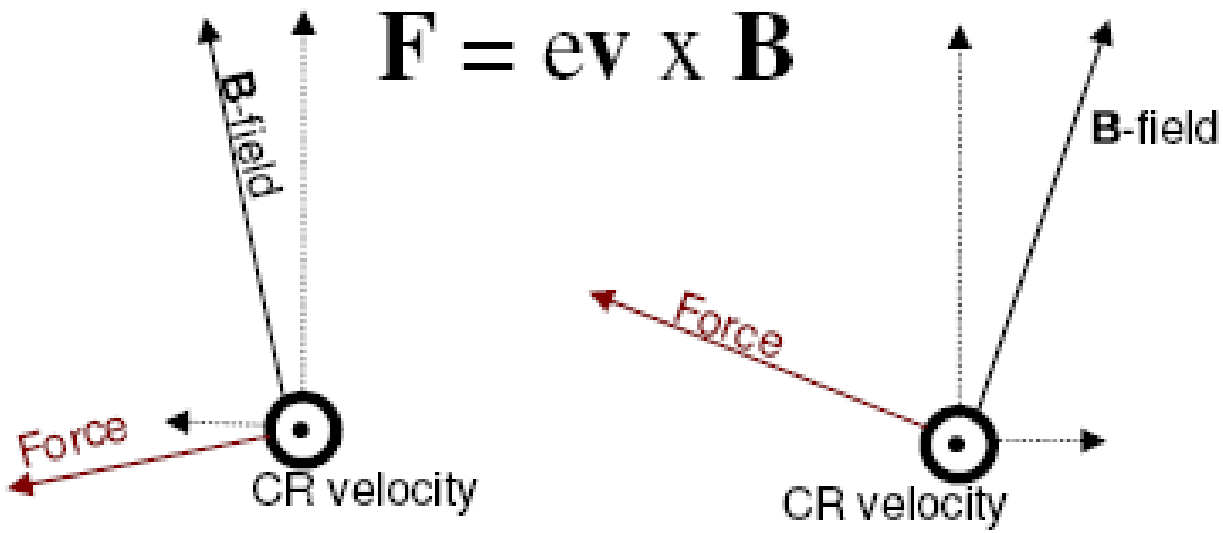




Extended Air Shower Tests

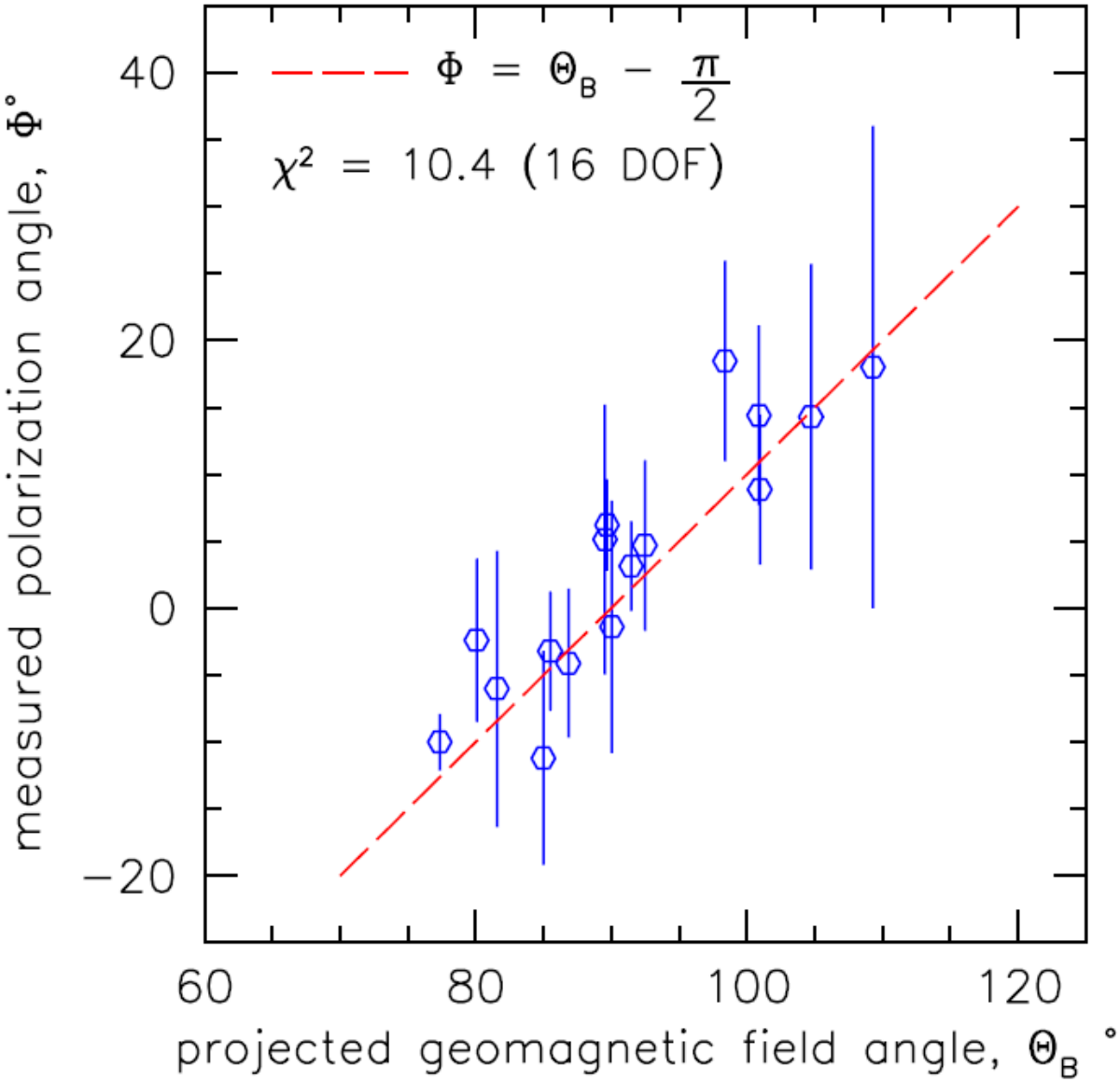
- CR moves towards payload.
- e+ and e- always curve away from each other due to dominant vertical B-field.
- H-pol emission always has the same polarization.

- V-pol magnitude and sign determined by the horizontal magnitude of the B-field.

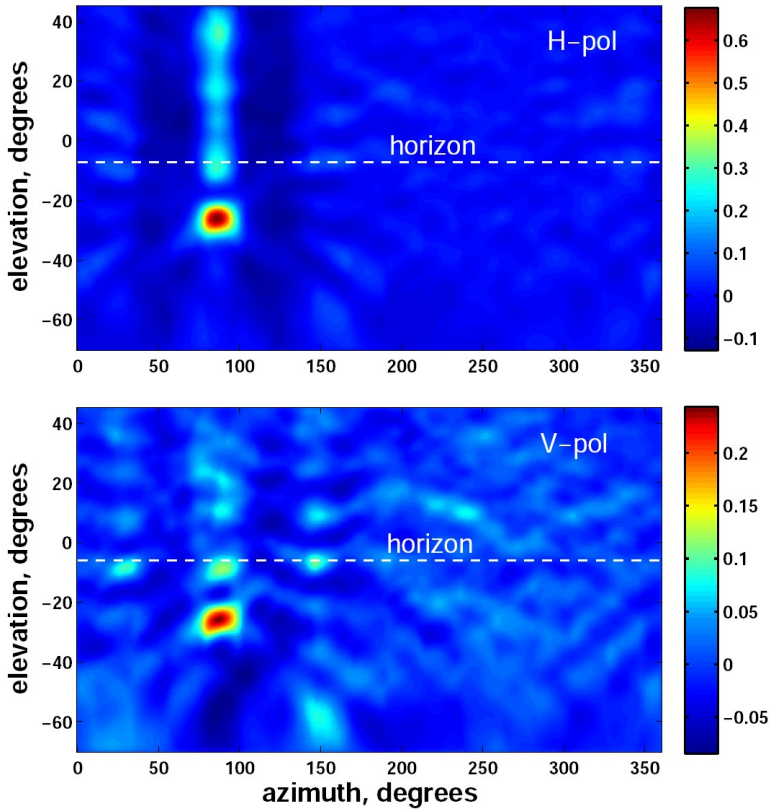


Figures: Stephen Hoover and Eric Grashorn

Correlation of Polarization Angle to Geo-Magnetic Field Angle



Interferometric image for a cosmic ray event



Figures from arxiv:1005.0035v2

Data Driven Energy Estimation

Measured electric field model

Energy dependence

Obliquity factor

Roughness factor

$$\mathcal{E} = A_0 \left(\frac{E_{sh}}{10^{19}\ \mathrm{eV}}\right)\left(\frac{R_{ref}}{R + R_{X_{max}}}\right) F(\theta_{sh})\ \cos(\theta_z)\frac{B_\perp}{B_{ref}}\ G(\nu, R)\ \mathcal{F}(\theta_z)$$

Reference amplitude

Radial falloff

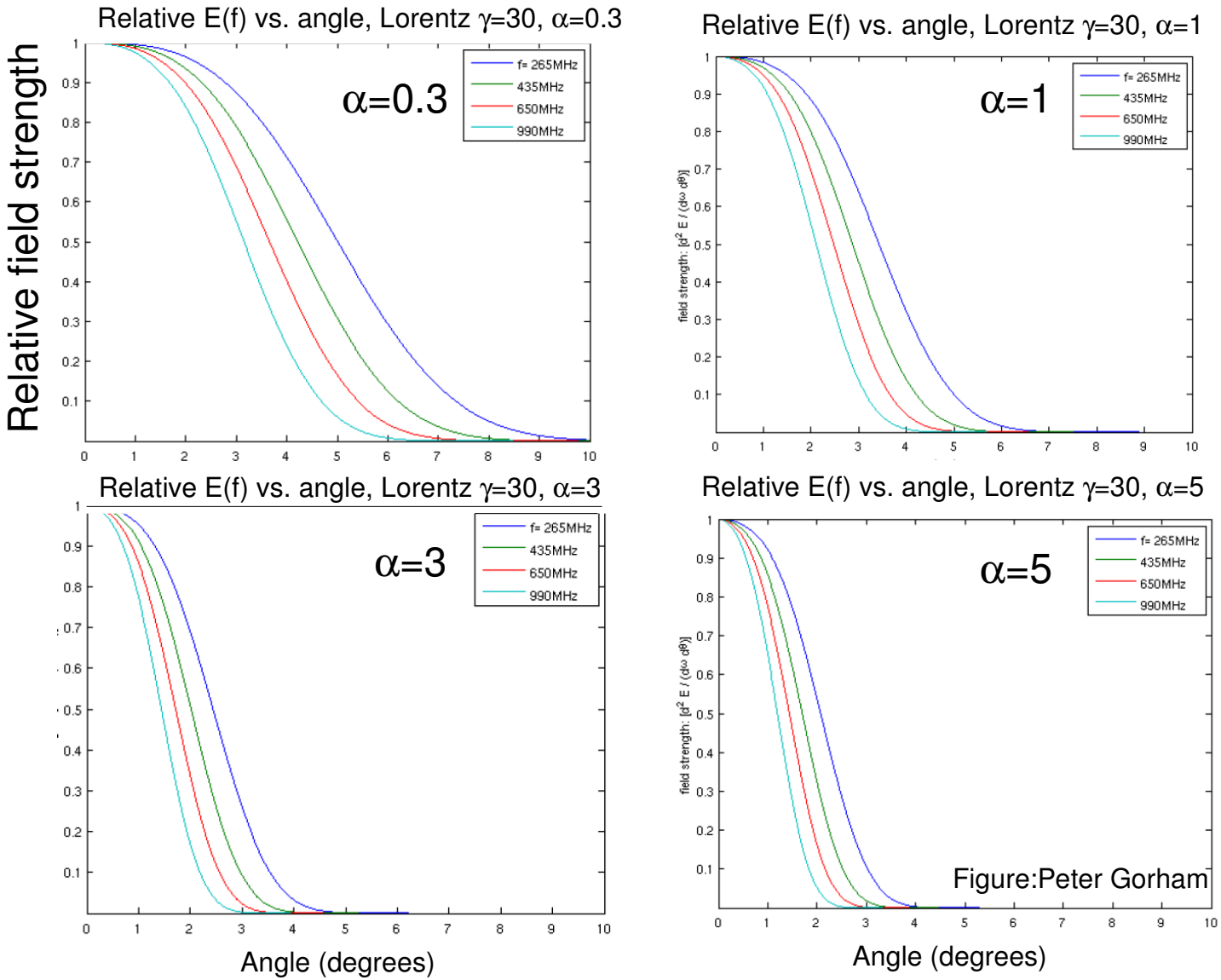
Shower radio Angular distrib.

Magnetic field factor

Fresnel Coeff.

Free parameters

Angular Distribution



- Angular dependence:
  - Double Lorentzian based on fits to intrinsic synchrotron emission (from J.D. Jackson's *Classical Electrodynamics*)
- Overall power law imposed to account for first-order coherence effects
  - Center remains normalize, power function squeezes or stretches the distribution
  - Power varied from 0.2 up to 6

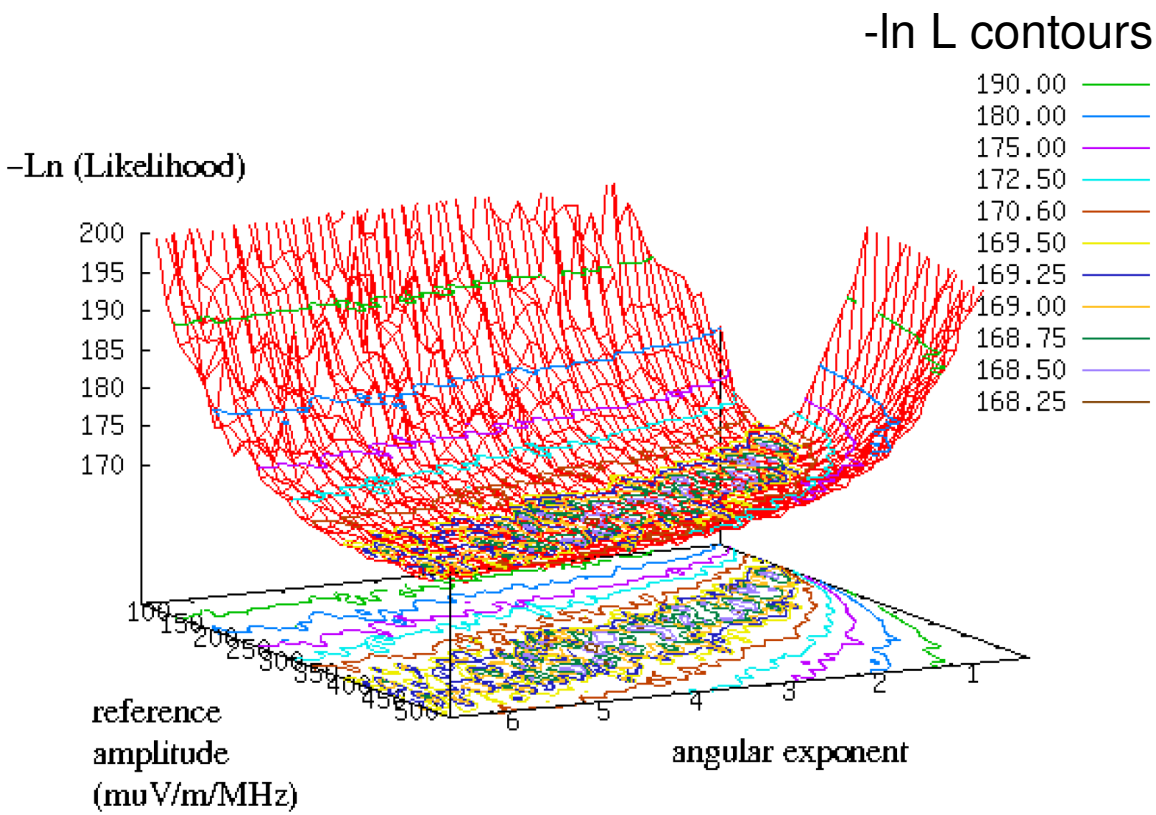
$$F(\theta)=\left[\left(\frac{1}{1+(\theta/\theta_b)^p}\right)\left(\frac{1}{1+(\theta/\theta_c)^q}\right)\right]^{\alpha}$$

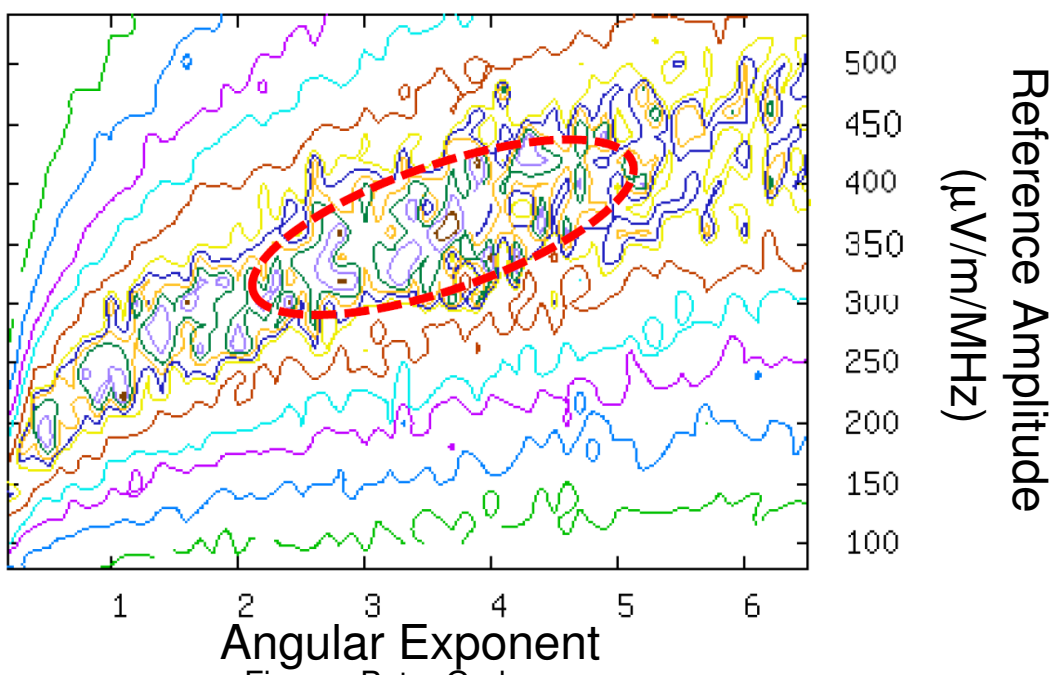
Likelihood function

$$L = \prod_{n=1}^{14} p_n(R_n) \prod_{n=1}^{14} p_n(A_n) \times p(N_{total}) \times p(A|A_{prior})$$

- R_n= distance to specular point for each event
- A_n= observed amplitude vs. frequency
- N_{total}= number of observed events (14) taken as a Poisson distribution.
- A = reference radio signal strength for model
- A_{prior}= distribution function for prior observed radio signal strength factors.

Likelihood Analysis Results





Figures:Peter Gorham

Noise due to MC statistics

Best fit parameters:

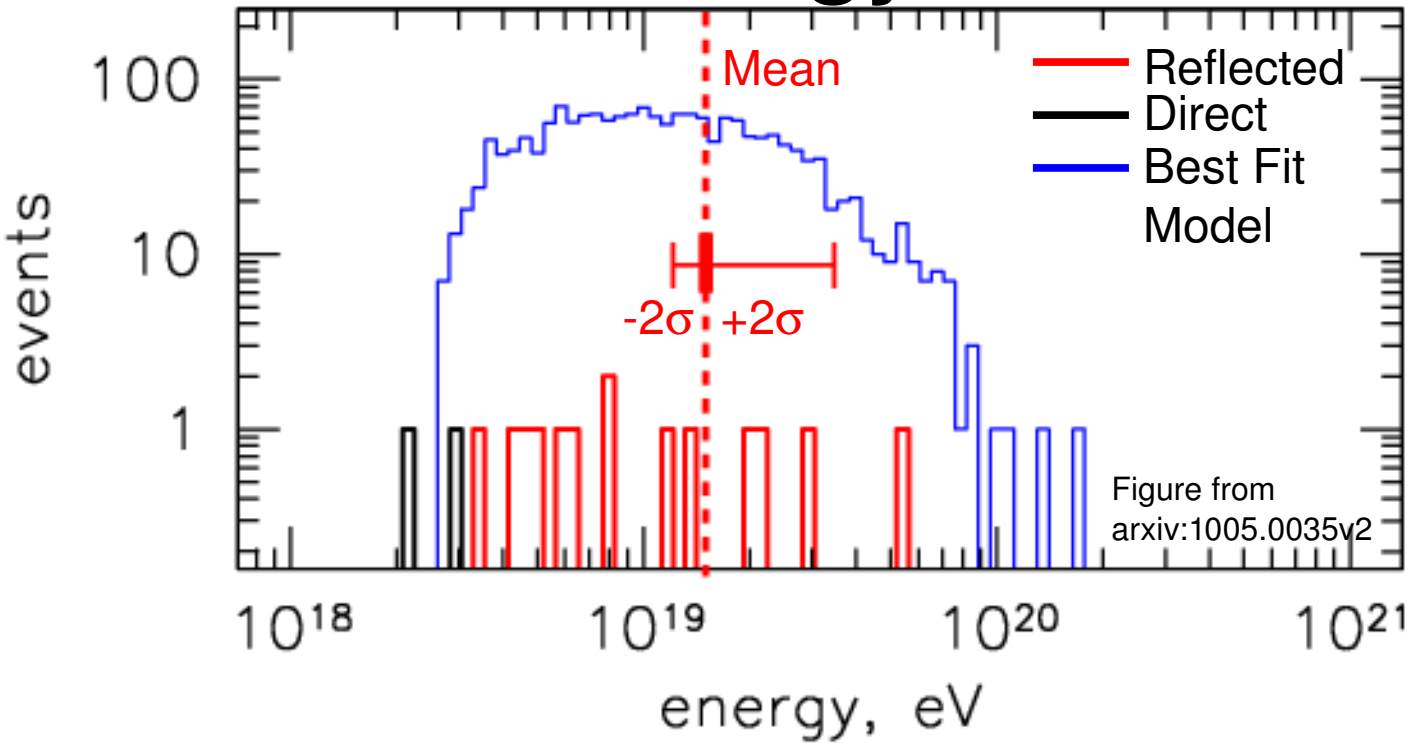
Reference Amplitude

360^{+100}_{-250}

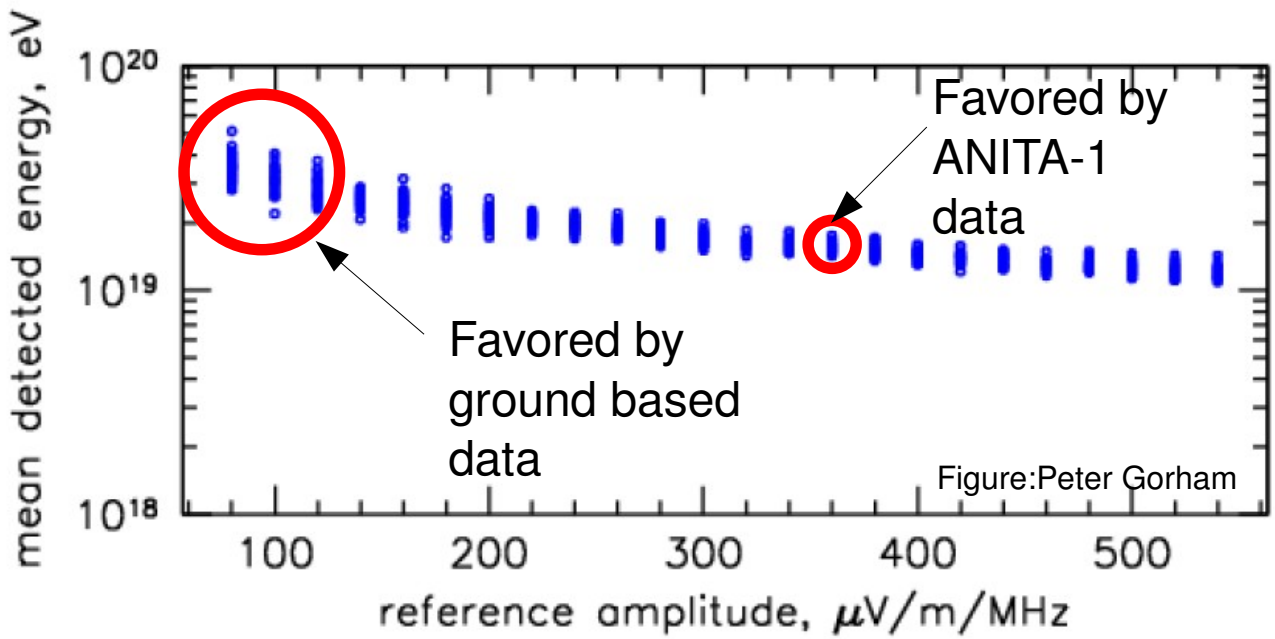
angular exponent

$3.9^{+0.4}_{-3.0}$

Event Energy Best Fit Results



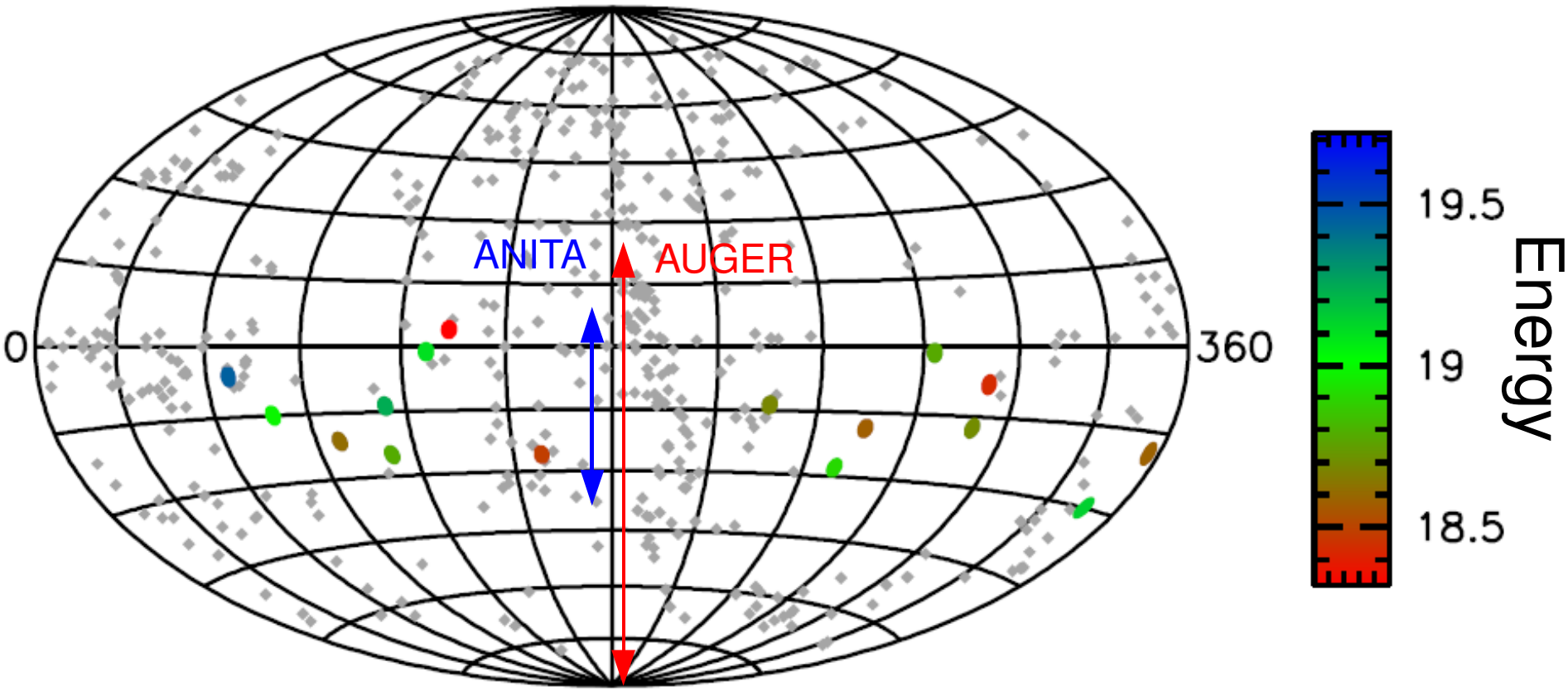
Event energies lie around the GZK cutoff



Ground based data favors higher energies but other parts of the model don't fit.

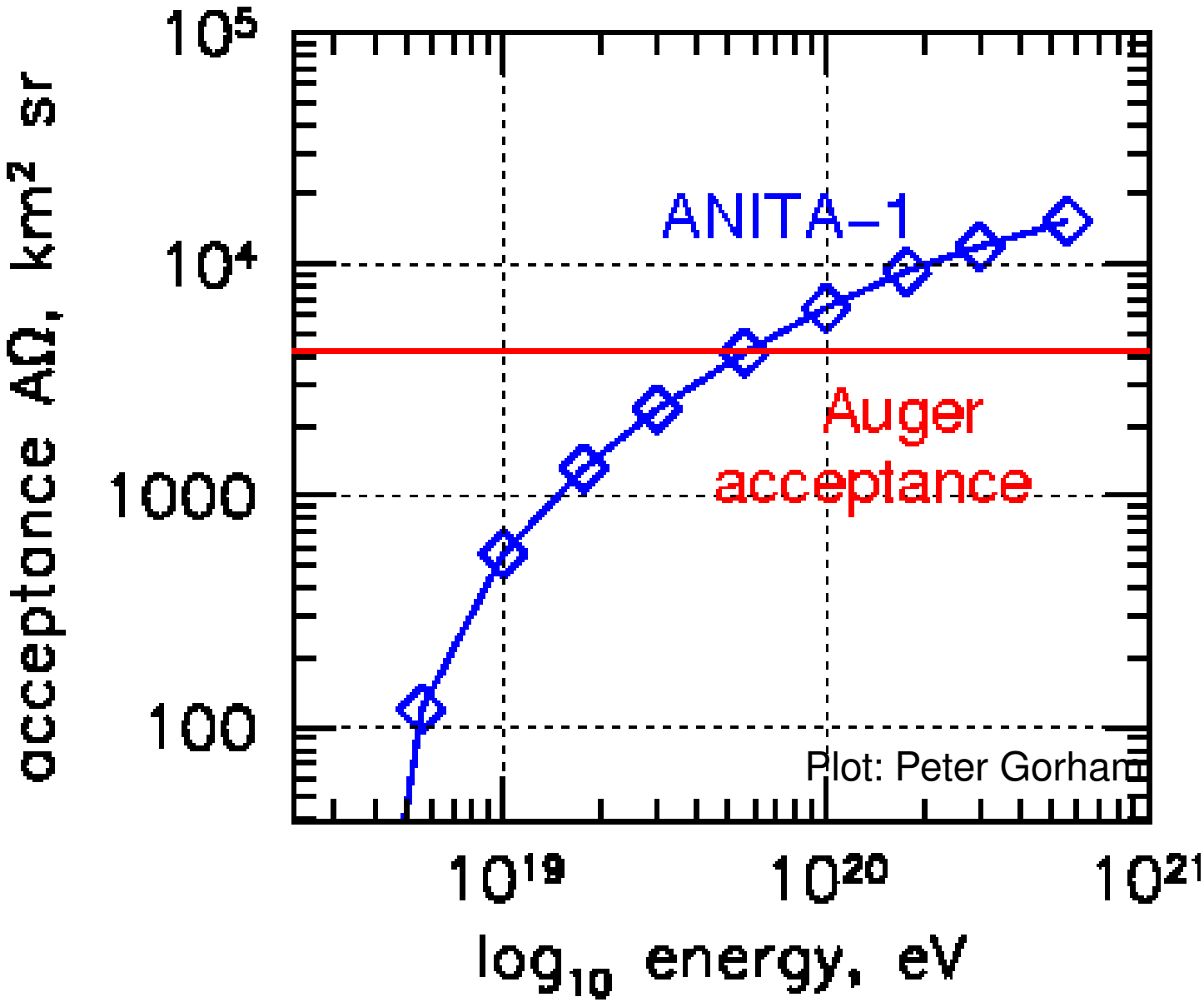
Cosmic Ray Event Sky Map

in celestial coordinates (α,δ)



- ANITA exposure lies between declination of -35° to +5°
- AUGER exposure lies between declination of -90° to +25°
- 2° error ellipses
- Véron-Cetty AGN shown in gray.
- No correlation to Auger UHECR events nor V-C AGN.
- Intergalactic magnetic field deflection still significant for ANITA UHECR events.

ANITA Acceptance Compared to Auger

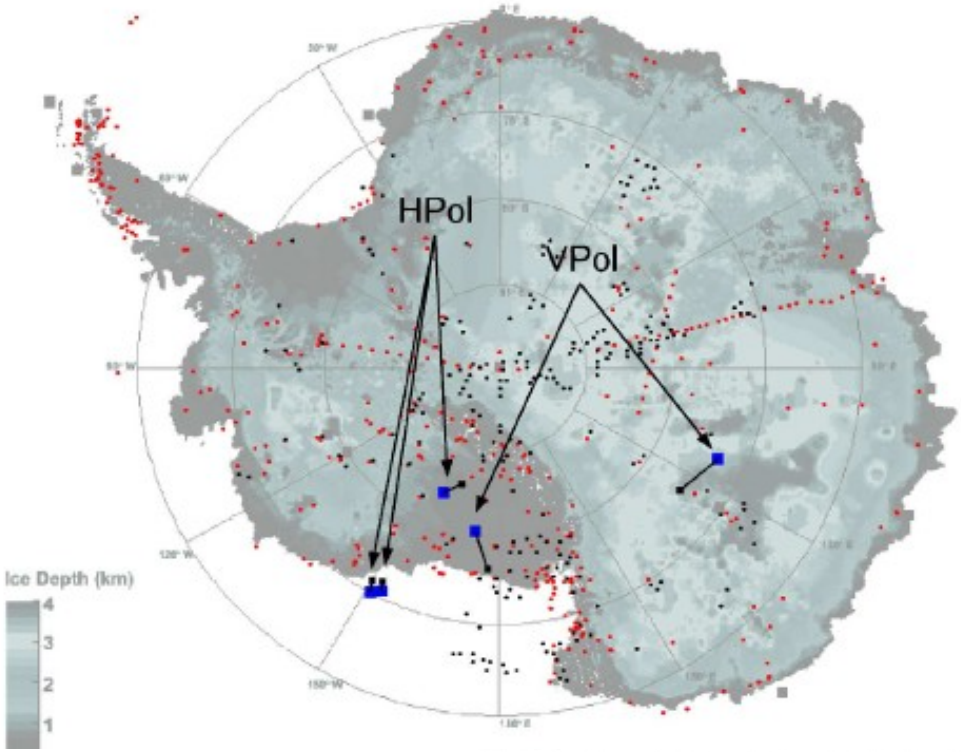


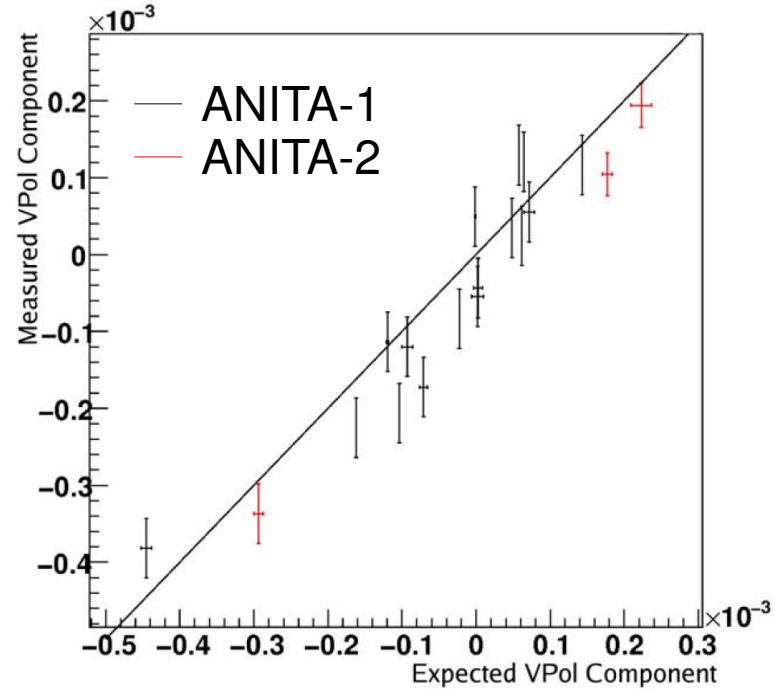
ANITA acceptance increases with event energy.

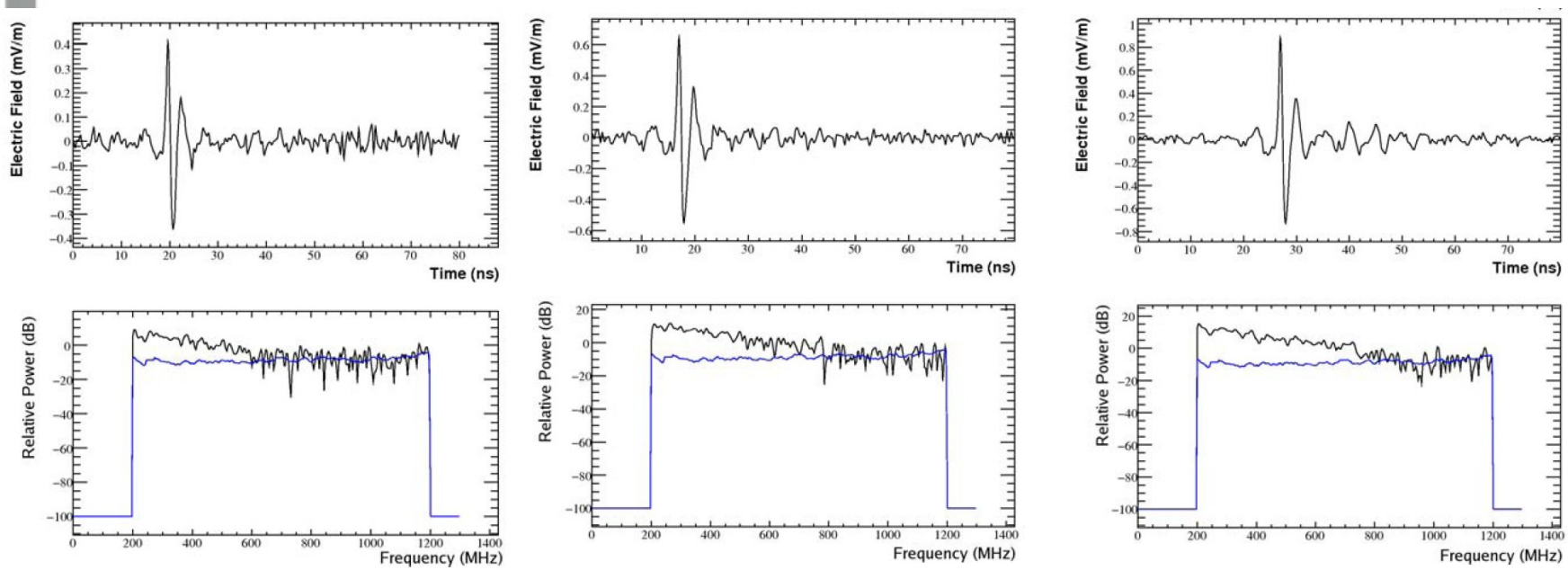
Higher exposures could yield higher sensitivity to super-GZK events.

New 30 day flight with optimized trigger could yield 60-80 events above 10^{19} eV with ~10 above GZK cutoff.

ANITA-2 Cosmic Ray Events

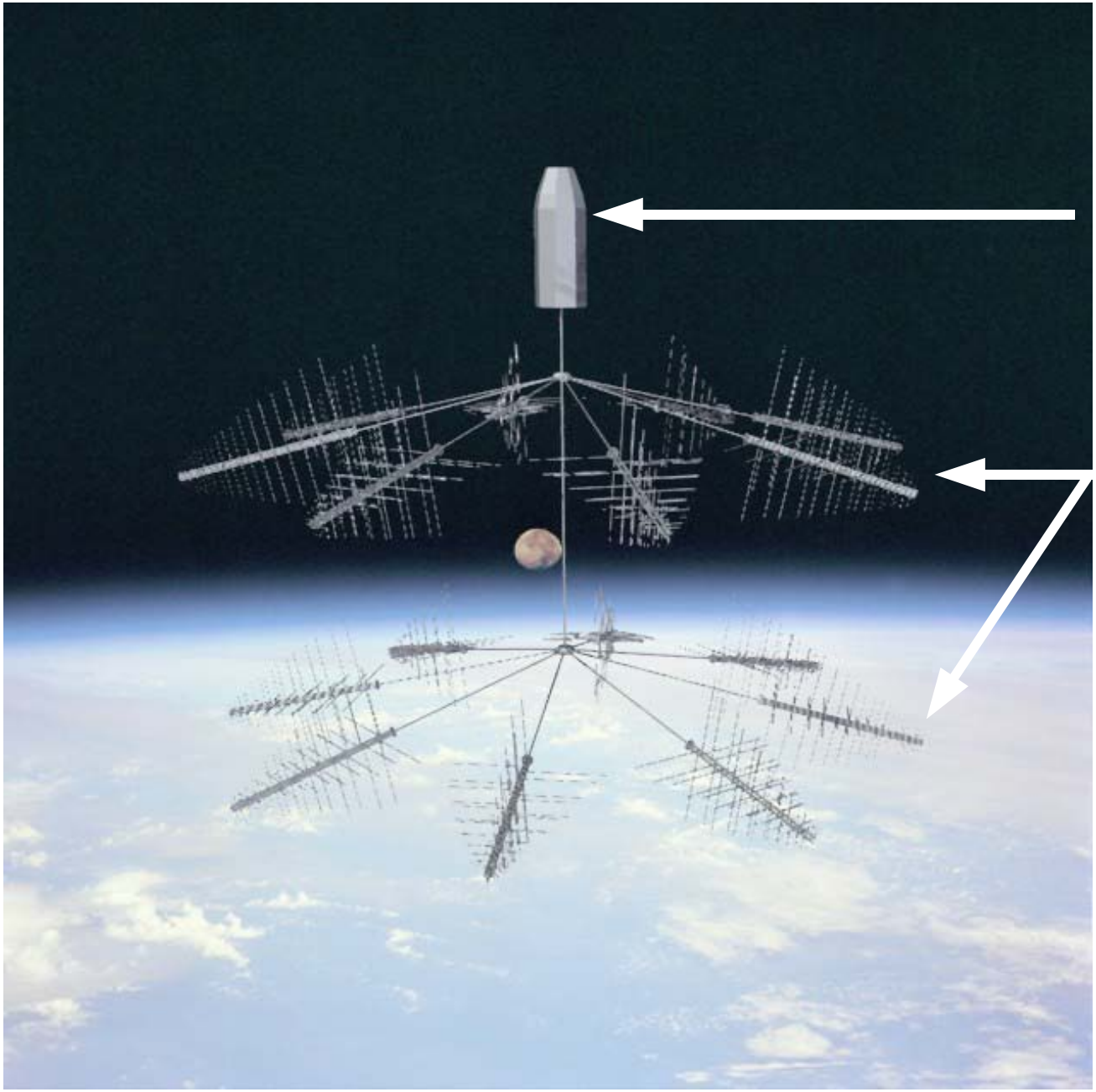






Figures from Abigail Goodhue PhD Thesis

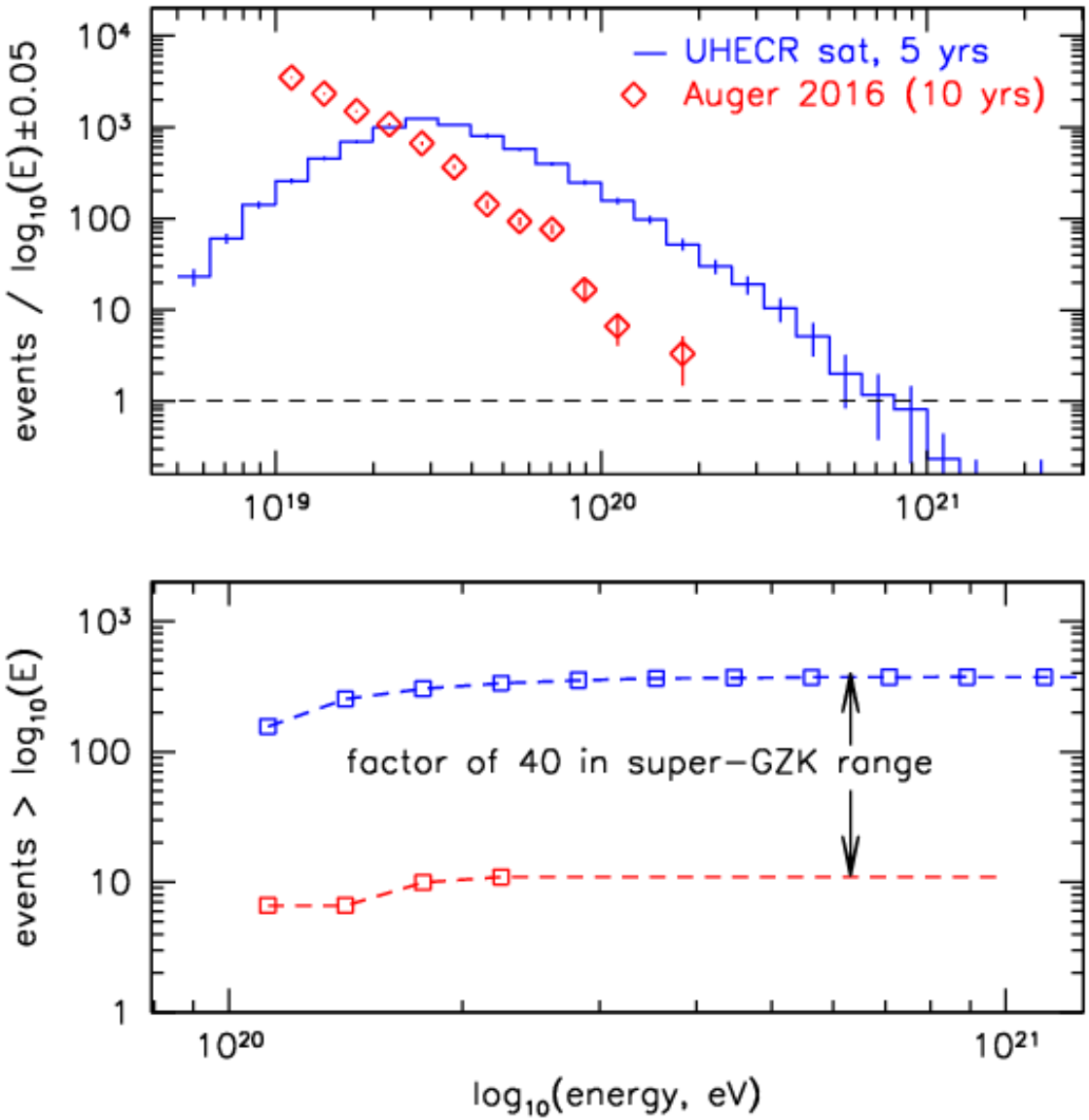
Potential for a UHECR Satellite



Taurus Fairing Envelope

Dual-polarized LPDA antennas

Scientific Potential



Compare to current gnd-based (Auger) after ~10 yrs exposure

5 yr mission gives factor of 40 improvement ~400 events above 100 EeV, compared to ~10 by year 2016

If spectrum rebounds above 300 EeV (as predicted) we would see much more

Assumed spectrum is conservative, source spectra can significantly raise tail of spectrum

Add to this ~10-15% more direct (eg, unreflected) events

Conclusions

-ANITA is able to self-trigger on geo-synchrotron cosmic ray events.

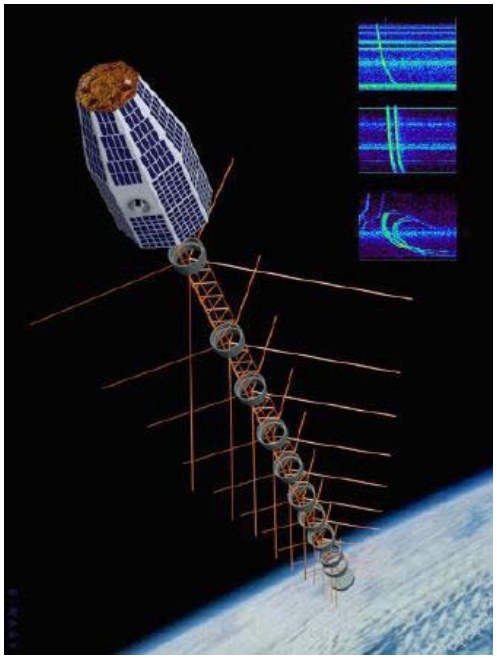
-Sensitivity to events near and above the GZK-cutoff.

Outlook

Simulations indicate that after trigger optimization a new 30 day flight could yield 60-80 events above 10^{19} eV and ~10 events above the nominal GZK cutoff.

Radio detection technique could yield the next level of sensitivity for super-GZK cosmic rays.

Backup Slides

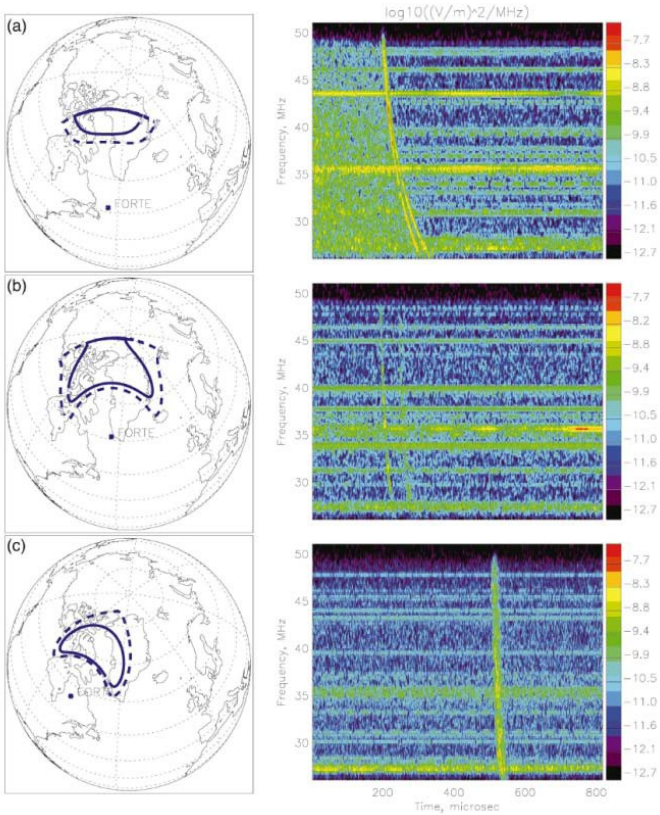


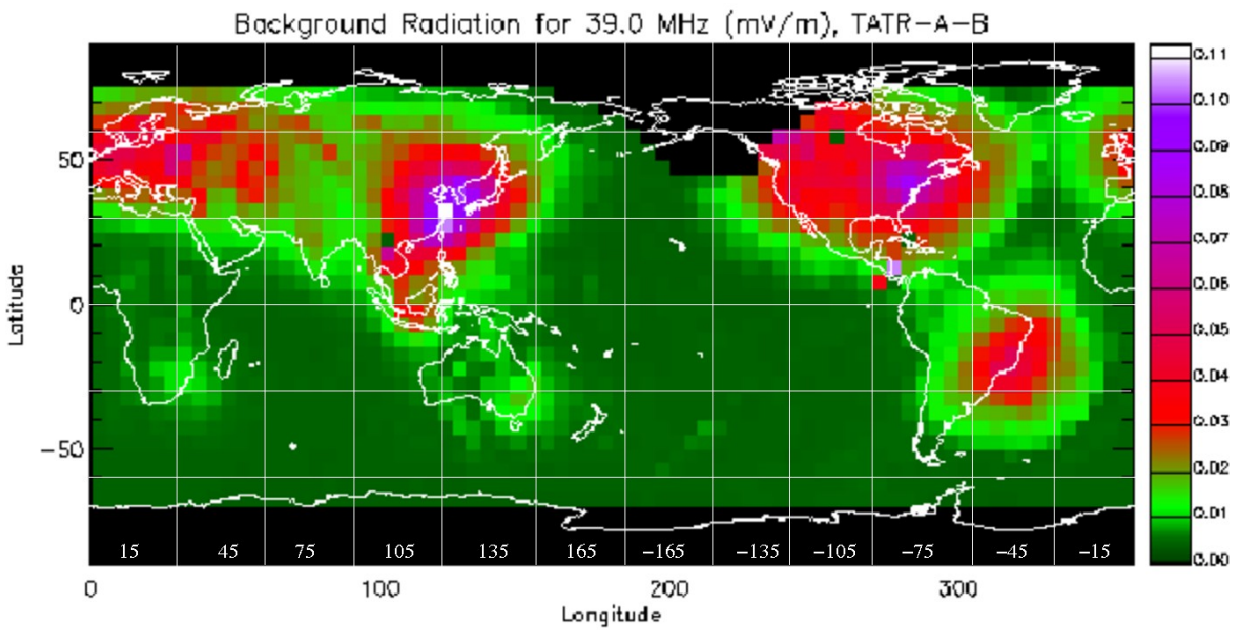
FORTE Satellite

FORTE data provides RFI map.

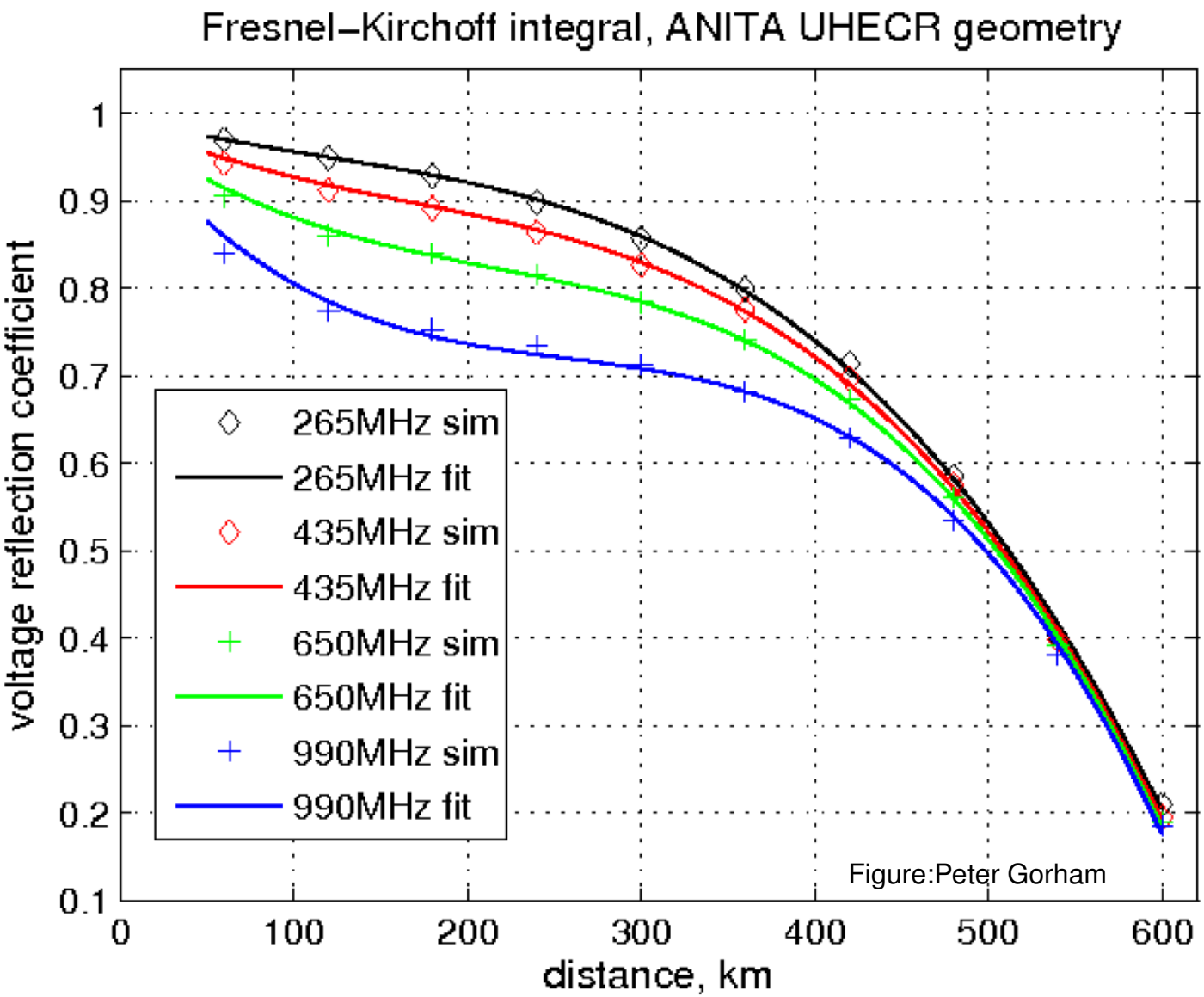
Could have UHECR events in the data set. Potential for digging them out using geo-magnetic field and polarization angle correlation.

Provides clear evidence for VHF reflections off land and sea from lighning events.



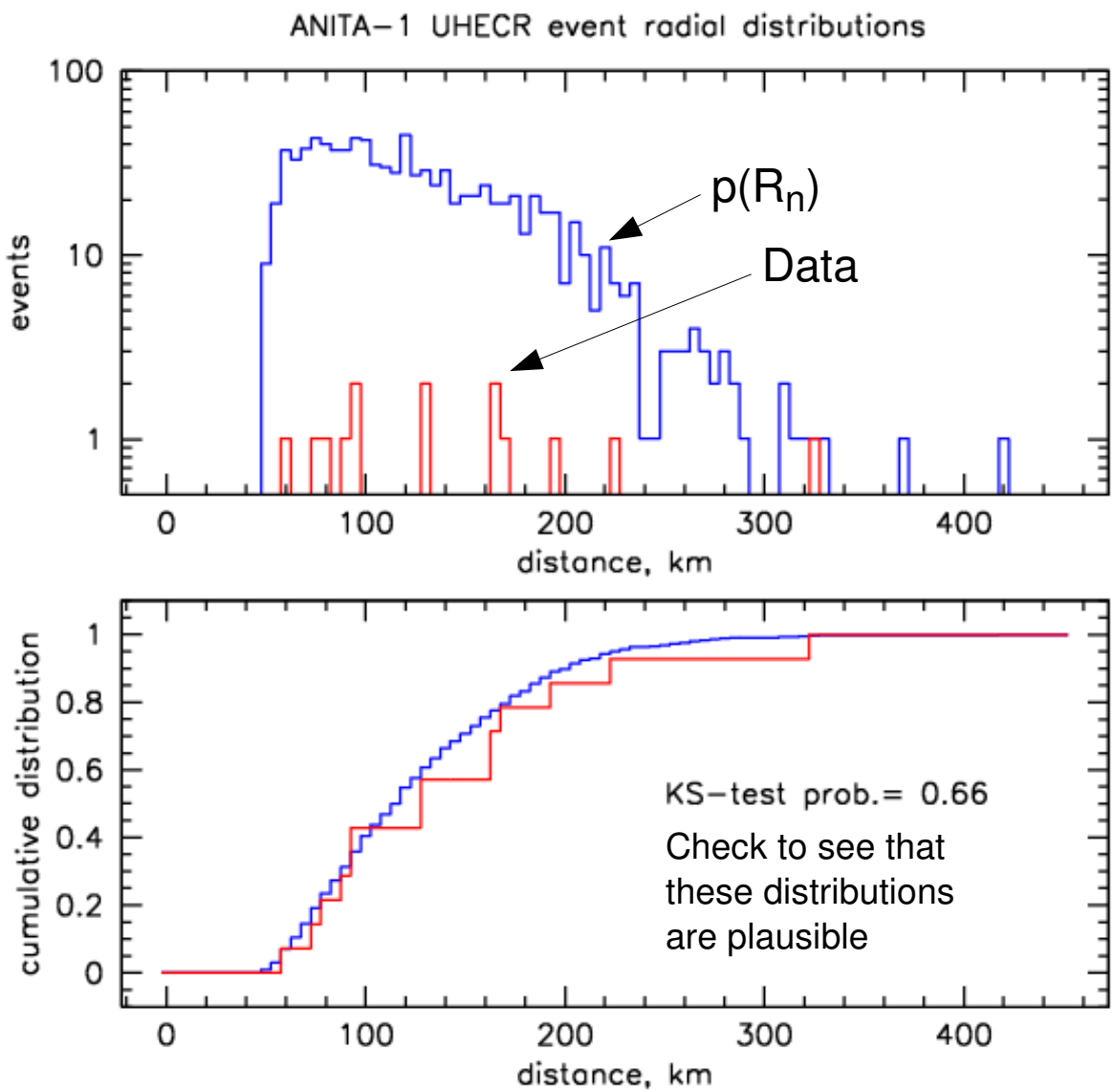


Surface Roughness Model



Determined from Kirchoff physical optics on roughness estimated from Taylor dome, Radarsat

Event probability



Determining probabilities:

–Use MC to generate R, A distributions, number of events from Auger spectrum

–Use fitted parameters to get observed event probabilities.

Prior reference amplitude

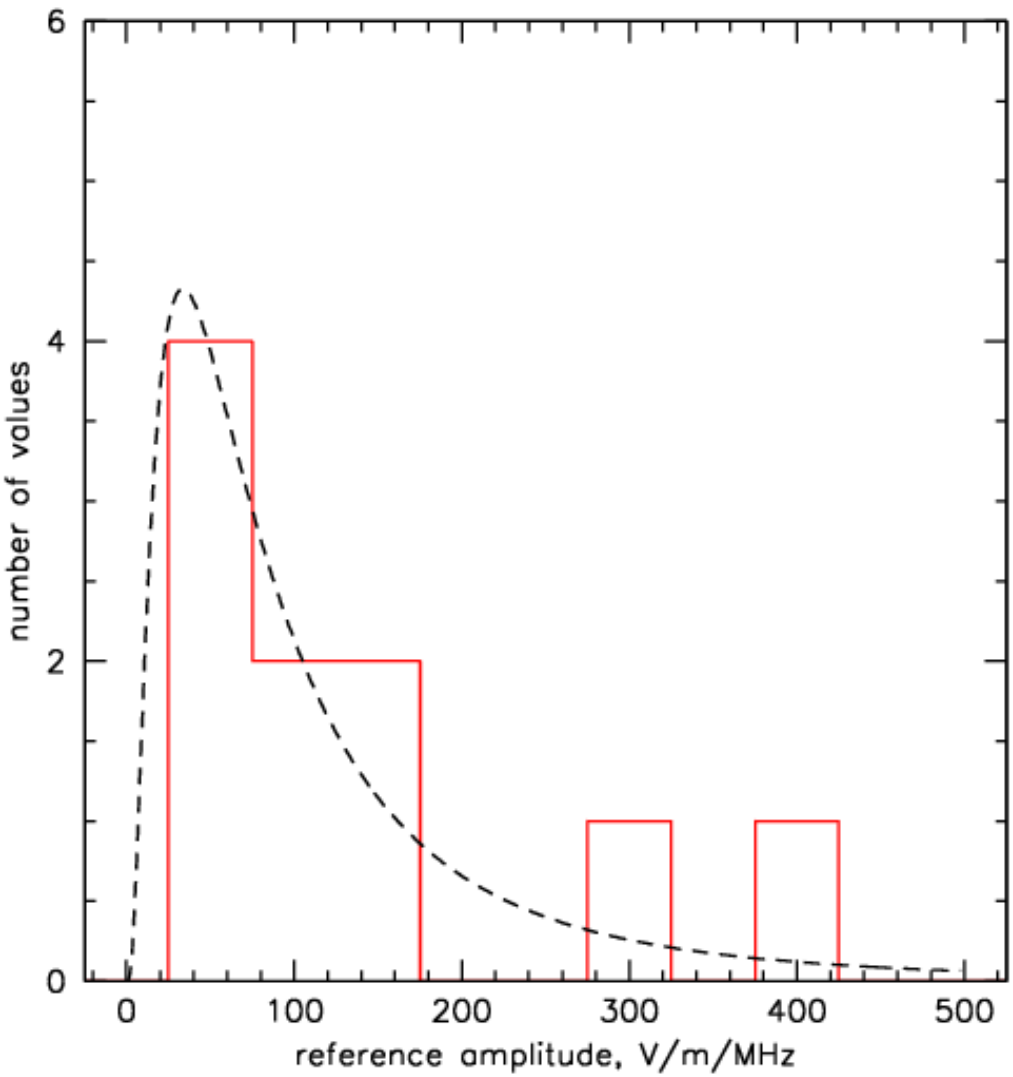


Figure:Peter Gorham

- Prior distribution of reference amplitudes :
  - –Allan 1971: 277 or 126 muV/m/MHz
  - –Prah75: 64 or 29
  - –HF 05 (REAS2?): 49 or 112
  - –HEU 2008 (REAS3?): 165 or 390
  - –LOPES 2009 (data): 37 or 78

- "Or" comes from spectral index used to scale to 265 MHz, two values prevalent

- Fit to lognormal distribution to provide a "Bayesian" prior