Results of the Search for Ultra High-Energy Neutrinos with ANITA-II

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UCLA
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(ANITA-II Launch Day in Antarctica)
ANITA Collaboration

University of California, Irvine
Ohio State University
University of Kansas
Washington University in St. Louis
University of Delaware
University of Minnesota

University of California, Los Angeles
University of Hawaii at Manoa
National Taiwan University
University College London
Jet Propulsion Laboratory
Stanford Linear Accelerator Center
Neutrinos: The Ideal UHE Messenger

- 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 Study:
- Highest energy observation of extragalactic sources
- Very distant sources
- Deep into opaque sources
Neutrino Production: The GZK Process

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

\[ p + \gamma_{\text{cmb}} \rightarrow \Delta^+ \rightarrow n + \pi^+ \]
\[ \rightarrow \mu^+ + \nu_\mu \]
\[ \rightarrow e^+ + \bar{\nu}_\mu + \nu_e \]
Neutrino Cross Section

- Weak interaction at $E_{CM}$ not accessible to LHC: 200 TeV
- $L_{int} \sim 250$ km
  - Use Earth-shielding as cross-section analyzer

![Graph showing neutrino cross-section](image)

- Large extra dimensions
- Std. model
- GZK nu

References:
- Anchordoqui et al. Astro-ph/0307228
Detection Principle: The Askaryan Effect

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

Askaryan Effect Observed with ANITA at SLAC (2006)
Validation at SLAC

ANITA I beamtest at SLAC (June06): proof of Askaryan effect in ice

- Coherent (P ~ E^2)
- Linearly Polarized
The ANITA Concept

- Neutrino signal characteristics:
  - Fast impulse
  - Vertically polarized
- Ice is radio transparent
- Large detection volume (1000 km$^3$*str)
The ANITA Instrument

NASA Long Duration Balloon, launched near McMurdo, Antarctica

- NASA Solar Panel Array
- GPS Antenna Array
- Bicone antennas for onboard pulsing
- NASA Science Instrument Package
- ANITA Solar Panel Array
- ANITA Antenna Array
- 8 Drop-down antennas (ANITA-II only)
- 40 Horn Antennas for Detecting Signal (200-1200 MHz)
- ANITA Instrument Box (computer, signal processing)


→ Signal direction calculation: basic interferometry
→ Threshold limited by thermal noise
ANITA-I Results

- **Vertical Polarization (neutrino search)**
  - Expected Background: 1
  - Observed Events: 1

- **Horizontal Polarization (cosmic rays)**
  - Expected Background: 2
  - Observed Events: 16

- Radio Synchrotron emission of CR air showers seen!
- Direction of geo-magnetic field determines polarization direction ($\mathbf{F} = q\mathbf{v} \times \mathbf{B}$)
  - Mostly Hpol in Antarctica
- CR Energy: order $10^{19}$ eV, work in progress

(S. Hoover)
Improvements for ANITA-II

- Lower Energy Threshold (x 3 events)
  - Reduce front-end amplifier temp (20%)
  - Improve neutrino trigger efficiency (30%)
  - 8 more antennas (30%)

- Increased Exposure (x 2 events)
  - Directional trigger masking (30%)
  - Better flight path & more livetime (x 2)

Total improvement: > 5 in neutrino event rate
But: reduction in cosmic ray event rate (new trigger)
ANITA-II Flight

- 31 day flight
- Launched: Dec 21\textsuperscript{st} 2008
- 27M events
Ground Calibration

~115,000 Calibration impulses from a remote field site during flight.

Critical for analysis!

(R. Nichol)
Making an Interferometric Image:

- cross-correlate antenna waveforms
- use timing delay given by direction
- sum over the whole payload
Blind Analysis Plan

- 2 methods of blinding
  - Hidden signal box
  - Event insertion
- Set cuts on sidebands
- Estimate background and efficiency
- Open hidden box, remove inserted events
- Separate HPol (cosmic rays) from VPol (neutrinos)
Lots of Man-Made & Thermal Noise

- Thermal image using all ANITA-II triggers
  - 99% of events are thermal noise
  - Main cut: size of peak of interferometric image
- “Hot-spot” veto for neutrinos
Separation from Man-Made Events

- 300k events pass thermal cuts
- Cluster with:
  - Other events
  - Known bases of activity
  - “Hot-Spots”
- **Neutrinos are single, isolated events!**
Cluster Multiplicity

- Estimate man-made background using cluster multiplicities, polarization information, and distributions from bases

<table>
<thead>
<tr>
<th>Cluster Multiplicity</th>
<th>Number of Clusters</th>
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<tbody>
<tr>
<td></td>
<td>Camp or Hot-Spot:</td>
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<tr>
<td>10-100</td>
<td>8</td>
</tr>
<tr>
<td>5-9</td>
<td>7</td>
</tr>
<tr>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>0</td>
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<tr>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>1</td>
<td>7</td>
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## Unblinding

<table>
<thead>
<tr>
<th>Cut requirement</th>
<th>Passed</th>
<th>Efficiency</th>
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<tbody>
<tr>
<td></td>
<td>Vpol</td>
<td>Hpol</td>
</tr>
<tr>
<td>Hardware-Triggered</td>
<td>$\sim 26.7M$</td>
<td>-</td>
</tr>
<tr>
<td>(1) Quality Events</td>
<td>$\sim 21.2M$</td>
<td>1.00</td>
</tr>
<tr>
<td>(2) Reconstructed Events</td>
<td>320,722</td>
<td>0.96</td>
</tr>
<tr>
<td>(3) Isolated Singles</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Total Efficiency</td>
<td></td>
<td>0.64</td>
</tr>
</tbody>
</table>

**Analysis Efficiency**

- Neutrino Bin: 0.96
- Cosmic Ray Bin: 0.61

**Background Estimate (Thermal + Man-made):**

- V Pol (neutrino): $0.97 \pm 0.39$ events
- H Pol (cosmic ray): $0.57 \pm 0.19$ events
Candidate Events

3 H Pol events consistent with cosmic rays seen by ANITA-I!

Example waveform:

- Time (ns)
- Electric Field (mV/m)
Cosmic Ray Sky Map

(Approximate Cosmic Ray Acceptance Band Shown)

- **AGN**
- **ANITA-I CR**
- **Neutrino Candidate**
- **ANITA-II CR**
Neutrino Candidates

Ev # 8381355

Ev # 16014510

Field Strength, mV/m

Time, ns

Relative Power, dB

Frequency, MHz

Elevation (Degrees)

Pavload Azimuth (Degrees)
New Limit on the UHE Neutrino Flux

- 2 events on a background of 0.97 +/- 0.39
- (Feldman-Cousins 90% CL)
- Paper Submitted to PRL!
  \( \rightarrow \text{arXiv:1003.2961} \)
The Future: ANITA-III

- Proposal for 2012-2013 flight this week!
  - Improve to over 100 UHECR events
  - Factor of 2 more sensitivity for neutrinos possible
Summary

- 2 Neutrino Candidates on a background of 0.97 +/- 0.39
  - Set new constraints on flux of UHE neutrinos
- 3 cosmic ray events seen
- On the edge of seeing cosmogenic UHE neutrinos?
  - ANITA-III will find out!
Separation from Thermal Noise

- 99% of triggers are thermal noise
- Main cut: peak value of the interferometric image and waveform envelope
- Allow 0.5 background events (from 21M triggers)