ANITA and ARIANNA - Exploring the Energy Frontier with the Cosmogenic Neutrino Beam

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ARIANNA Institutions: UCI, UCLA, UH, OSU, UCollege-London

INPAC, 2007
**PHOTONS**: not deflected, but: reprocessed in sources, absorbed in IR (100 TeV), and CBR

**PROTONS**: deflection in magnetic fields, GZK cutoff

**NEUTRINOS**: not absorbed or deflected, hard to see
Neutrinos are like “canaries in a coal mine”

Neutrinos are most weakly interacting particles that are stable. They can provide an early warning that something in physics is amiss.
EHE Neutrinos Explore Higher Dimensions

\[ \sigma_{\nu} \sim 100\sigma_{sm} \]

For GZK \( E_\nu \)

CC: \( \sigma_{sm} \)

ANITA-GZK

Cosmogenic (or GZK) Neutrinos

Predictions are secure:

\[ p + \gamma_{\text{cmb}} \rightarrow \Delta \rightarrow n + \pi^+ \]

\( n \rightarrow \text{lower energy protons} \)

\( \pi \rightarrow \mu + \nu \)

However, \( \nu \)-Flux Calculations:

1. Elemental composition \((p, \text{Fe}, n)\)
2. Cosmology \((\Lambda=0.7)\)
3. Injection Spectra, \(E^{-\gamma}\) and \(E_{\text{max}}\)
4. Evolution of sources with redshift, \((1+z)^m\)
   - Star formation, QSO, GRB, little or no
ANITA
EeV astronomy

UCI, UHawaii (P. Gorham - PI), UCLA, OSU, JPL, WashU, UMinn, UKansas, UDelaaware, SLAC
ANITA launched on Dec 15, 2006 and remained aloft for 35 days.

600 km radius, 1.1 million km²

www.ps.uci.edu/~anita
Despite unusual flight path, and instrumental issues that reduced livetime for last 12 days of flight, ANITA-1 represents dramatic leap forward
Borehole (not pictured) had discone TRX

Surface TRX
Hpol, Vpol
Impulsive

Surface Calibration (UCLA)
In Situ Angular Resolution

Excellent timing and angular resolution

\( \sigma_\theta = 0.4 \)  
\( \sigma_\phi = 1.9 \)
Payload Response

Observe 1/r dependence and Fresnel effect

Bore Hole Transmitter

1/dist

w/Fresnel
Absolute RF power and frequency dependence confirmed

Width of cherenkov cone and frequency dependence confirmed
Analysis Strategy

1. 3 ant top, 3 ant bot $>3.5V_{rms}$ in $V_{pol}$
2. Good reconstruction
3. $V_{pol}$ and $H_{pol}$ compatible with $\nu$ expectation
4. Time profile of waveforms consistent with SLAC and GP
   a) Not too long or short
   b) Bandwidth limited charact.
5. FFT consistent with uniform power at all frequencies, no strong lines of RFI
6. Temporally isolated from similar events
7. Avoid “known” sources of RFI
ANITA sensitivity
[Barwick et al, PRL 96(2006)]
• based on 45 days livetime
• assume that no neutrino events are found
Probing Physics Beyond Standard Model w/ ANITA
Reflected and Direct Events

Direct

Reflected

Event ID: Reflected or Direct?

- Based on Topology and distance
- Develop likelihood function to separate reflected from direct events

\[ E_v = 10^{20} \text{ eV}, \quad R_{\text{ross}} = -3 \text{dB}, \quad \sigma = 100\sigma_{\text{sm}} \]
Direct and Reflected Event Rates

For scenario $N_{\nu}=0$

$\phi = S \phi_{\text{ESS}}$
ARIANNA

UCI, OSU, UCLA, UC-London, UHawaii
There is a gap in the Energy response of current detectors between $10^{17}$-$3 \times 10^{18}$ eV.
ARIANNA is designed to span the gap

ARIANNA rates (6 month)
ESS Fe-only ~40 few

See Barwick, Astro-ph/0610631
Neutrino Cross-Section

\[
\frac{\Delta \sigma}{\sigma} = 0.24
\]

If \( N_{ev} = 400 \)

If \( \delta \theta = 0.5^\circ \)

If \( \sigma = 2 \sigma_{\text{GQRS}} \)

2 parameter fit:

Normalization cross-section
ARIANNA Concept

100 x 100 station array, ~1/2 Teraton

Ross Ice Shelf, Antarctica

~300m

Beside the Snow:
- Electronics Box
- 8 TV Antennas

Communication

GPS

Solar Panel Array (4)
ARIANNA Advantages

- Near McMurdo, logistics manageable
- Site has good reflection and absorption properties
- Site protected from RF interference, and likely to stay that way
- Borrow technologies from Auger, ANITA
- Deployment straightforward and stations serviceable
- Design relatively insensitive to many imprecisely known ice properties (eg, localized patches of bad ice, strong scattering, reflection)
- Negligible environmental impact
  - stations removable when project ends
- 24/7/(365/2)
- Teraton Volumes
Satellite Image of Victoria Land and Ross Ice Shelf

Dry Valleys

Ross Island

ARIANNA

30x30 km²

Minna Bluff

Ice Thickness
~624m

south
Reflected and Direct Events-ARIANNA

Direct

Reflected

S. Barwick, 3rd NOVE Workshop (Venice, 2006)
ARIANNA Visualization
Event Reconstruction

- Preliminary studies show that the radio path ambiguity (direct or reflected) is manageable.

\[ \Delta \theta \sim 1 \text{ deg} \]
\[ \delta E/E \sim 1 \]

<table>
<thead>
<tr>
<th>Constant</th>
<th>33.15</th>
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<tr>
<td>Mean</td>
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<tr>
<td>Sigma</td>
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Reflection loss: Ross Ice Shelf
C.S. Neal, J. Glaciology, 24(1979)295

Fig. 4. Reflection coefficient of the ice-water interface. Contours are at 10 dB intervals.
Open shading: Reflection coefficient greater than 0 dB.
Heavy shading: Reflection coefficient less than —20 dB.

Regions of smoother than normal ice-water interface
Corroborating Evidence for Smooth Surfaces

Sonar map of surface beneath Fimbul Ice Shelf

Conclusion: In regions outside of Flow Traces, surface variation is <8 mm!
Camping at ARIANNA Site

David Saltzberg
Site Studies

Amazing fidelity of reflected pulse from sea-water bottom behaves as nearly flawless mirror
1-way Field Attenuation Length

![Graph showing 1-way Field Attenuation Length](image-url)
Protostation Deployed 12/26/06
Protostation Data
between 12/26/06 and 3/21/07 (too little sun)

“Noise” Waveforms

Housekeeping

+12V

Cloudy

Temp

Amplitude (mV)

Time (ns)

GPS-Time (hrs)
“GZK $\nu$-factory” and INPAC

• As ARIANNA expands beyond Phase A in 2011, INPAC could provide machinery for $100M$-class experiment
  – Scientific advisory (panels, reports)
  – Technical advisory (panels, reports)
  – Harness technical and management resources within the UC system
Outlook

• With **AMANDA-II**, the requisite tools to inaugurate **multi-messenger astronomy** are available -> **IceCube** continues this technique.

• To probe the **neutrino fluxes and physics** at highest energies, new techniques are being developed based on **radio cherenkov detection**.

• **ANITA** extends search volume to \(10^6 \text{ km}^3\)
  – Launched from McMurdo Dec 15, 2006, and remained aloft 35 day

• **ARIANNA** spans the impending energy gap
  – Ice studies in Nov' 06 astonishingly good, but not the only contender (SALSA, AURA, Auger, acoustic detection)
  – MRI proposal submitted Jan 2007 for 200 station Phase A
Reflection properties of the Ross Ice Shelf

1. South
Protostation

Block Diagram of Electronics

ARIANNA Protostation Layout
Steven Burwick, UC Irvine
8/22/06
Version 1.2
Sky coverage increases for reflected events

$\sigma = \sigma_{sm}$

Direct Events

Reflected and Direct Events