Probing Physics at Energy Frontier

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ANITA Collaboration

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http://www.ps.uci.edu/~anita
Neutrinos are like “canaries in a coal mine”

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

\[ \sigma_\nu \sim 100 \sigma_{\text{sm}} \]
For GZK \( E_\nu \)

Models of diffuse EHE Neutrinos

Required exposure to measure 10 events/decade at $E^2(dF/dE) = 10^{-7}$

Exposure ($\text{km}^3 \cdot \text{yr sr}$)
GZK models - representative

![GZK Neutrino Models](image)

**PRELIMINARY**
ANtarctic Impulsive Transient Antenna

www.ps.uci.edu/~anita

- NASA funding started ’03 for first launch in Dec ‘06

600 km radius, 1.1 million km²
ANITA concept

- cascade produces UHF-microwave EMP
- antenna array on payload
- 0.1–100 EeV neutrinos
- refracted RF
- ice
- cascade
- Cherenkov cone
- 56°
- 1–3 km
Shower profile observed by radio (~2GHz)

- Measured pulse field strengths follow shower profile very closely
- Charge excess also closely correlated to shower profile (EGS simulation)
- Polarization completely consistent with Cherenkov

Sub-ns pulse, $E_p \sim 200$ V/m!
New results—SLAC T460 June 2002
Follow up experiment to SLAC T444, with rock-salt target

- Much wider energy range covered:
  - <1PeV up to 10 EeV
- Radio Cherenkov observed over 8 orders of magnitude in radio pulse power
Noise Tests at South Pole

- Ambient noise on the high plateau

Log-Periodic Antenna
Initial Results from Polar Studies

-It looks good, and confirmed by sun/galaxy measurements of ANITA-lite

RF emission from ice

Nadir–Zenith noise, 1/26/03 South Pole ski hut at 6 km
Ice Attenuation at South Pole
- from 200MHz to 700MHz

Jan. 2004
Ice Attenuation at South Pole
- from 200MHz to 700MHz

multifrequency echogram, Amundsen–Scott Station, 400ns pulse

A clean reflection from the bottom implies that the attenuation lengths are very long!
Most of Antarctic ice is -50°C!

Excellent transparency, compare to ~100 meter for light, it is 10x larger.
ANITA-lite

2 Receiver Horns

Electronics

Piggyback on TIGER Launch Dec ‘03

RF Survey of Antarctica
ANITA-lite prior to launch

2 Receiver Horns

Boss Truck
ANITA-lite flight path 03/04

18 days at float altitude
1.25 revolutions, landing near Mawson Station
Data recovered in Feb 04
~10^5 triggered events
ANITA-lite detected Sun & GC

And thermal noise measurements -consistent with galactic+solar+KT²
ANITA-lite timing resolution

Ground antenna transmits calib. pulse to Anita-lite @40km

\[ \Delta t = t_{\text{ANT1}} - t_{\text{ANT2}} \]

\[ \sigma_t = 0.12 \text{ ns per Antenna} \]

Expected Angular Resolution for ANITA

\[ \delta \theta \sim 0.5 \text{ deg} \]

\[ \delta \phi \sim 2 \text{ deg} \]
Duration is too large for $\nu$ - associated with local TRX

Data reveals no obvious $\nu$ signal

Ant 1 - Horizontal

Ant 1 - Vertical

Ant 2 - Horizontal

Ant 2 - Vertical

512ns
ANITA-lite impulse analysis

BACKGROUND
Dominated by payload local noise
Every event fell into distinct categories (4 shown here)

Expected SIGNAL
(superimposed on actual thermal noise)
Signal Characteristics
1. Pulse shape and duration
2. Frequency content
3. 100% linearly polarized
4. Direction must come from ice

Anita-lite analysis only used rough pulse shape and duration to eliminate background
$\nu$-Limits and Projected Sensitivity

PRELIMINARY

$\Phi(E) = \frac{2.3 \cdot l_{\text{int}}(E)}{[V \Omega]_{\text{eff}}(E) \cdot t_{\text{live}} \cdot \epsilon}$

- Anita-Lite Flux Limit (7 days)
- Sorry ….but no Z-burst neutrinos
ANITA sensitivity:
(45 days)

- $\nu_\mu$ & $\nu_e$ included, full-mixing
- 1.5-2 orders of magnitude gain
- 5 events for flux models on lower GZK boundary
Probing Physics Beyond Standard Model w/ ANITA
Reflected and Direct Events

Direct

Reflected

Ignore

Ignore - TIR
Sky coverage increases for reflected events

\[ \sigma = \sigma_{sm} \]
Event ID: Reflected or Direct?

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

\[ E_\nu = 10^{20} \text{ eV}, \quad R_{\text{ice}} = 1\%, \quad R_{\text{ross}} = 100\%, \quad \sigma = 100\sigma_{\text{sm}} \]
Topological Distribution of Reflected Events depends on $L_{att}$

$L_{att} = 1500m @ -50C$

$L_{att} = 3000m @ -50C$
Direct and Reflected Event Rates

Reflected rates are negligible at small cross-sections.

Direct rates do not depend strongly on $\sigma$.

Reflected rates depend sensitively on $\sigma$.
ANITA construction

Antenna and Frame

Upper Ring Assembly
Why is ANITA a good idea?

- Frontier Science and very exciting
  - Win-win with GZK neutrinos
- Scans ice over 600km radius, and enormous detector volume!
- Radio signal can be calculated precisely and has been measured at high energy lab - unique signature!
- Energy resolution is relatively good
- Antenna can be absolutely calibrated by man-made radio transmitter embedded in deep hole (eg, Vostok)

Clean signal
- Linearly polarized, must originate in ice, distinct few ns time structure of pulse, “beam-off” in directions over water
- Balloon flight path is far from sources of confusing background

Revolutionary concept in EHE neutrino detection!
Outlook

• With **AMANDA-II**, the requisite tools to inaugurate **multi-messenger astronomy** are available.

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

• **ANITA** extends search volume to $10^6$ km$^3$. 
Surface Temperatures
Northern/Southern Sky Complementarity

Fraction of time sky visible

ANTARES
Northern Hemisphere

Galactic Center seen 80% of time

\( \nu_\mu \) AMANDA (black=1.0)
~ANITA w/Reflect (white =1.0)

Southern Hemisphere

Galactic Center
ANITA as a neutrino telescope

Pulse-phase interferometer (6 antennas):
gives intrinsic beamsize:
of $\sim 3^\circ$ elevation
by $\sim 10^\circ$ azimuth for arrival pulse

Improves by $\sim$factor of 2 with better pulse timing, beam calibration

Neutrino direction constrained:
$\sim 1-2^\circ$ in elevation by earth absorption, and
$3-5^\circ$ in azimuth by polarization angle
Ice transparency

Loss tangent a strong function of temperature

For cold ice, UHF (0.1-1GHz) best

Antarctic data approaches pure ice values

\[ L_\alpha = \lambda \left[ \pi n \left( \varepsilon''/\varepsilon' \right) \right]^{-1} \sim 6 \text{ km} \text{ at } 300 \text{ MHz} \text{ & } -60^\circ \text{C} \text{ (pure ice, theory)} \]
Schedule for ANITA

03/04 Fly ANITA-lite, measure attenuation lengths in ice
04 analyze data, complete gondola and instrument design
05 Jan : Begin assembly and integration
            June: test partial instrument in New Mexico, mechanical
            Aug: Begin final integration and testing
06 June: NSBF integration in Palestine, TX
            Sept: Ship to Antarctica
            Dec : Integrate and Launch ANITA payload
07 Jan : Recover payload, ship back to mainland

Commensurate with graduate student lifetime!