ANITA: Searching for Neutrinos at the Energy Frontier

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The energy frontier has traditionally led to tremendous breakthroughs in our understanding of how the universe operates — We hope to exploit that very same technique
EeV (10^{18} eV) Science Goals

- **GZK from p+\gamma_{\text{CMB}}**
  - Detection would confirm highest energy cosmic rays are extragalactic and composed of ordinary stuff like protons, helium
  - Provides neutrinos to study predictions of Grand Unified Models, the Holy Grail of Particle Physics
  - Non-detection would be great surprise

- **Supermassive Black Hole/ AGN models**
  - Compared to searches at 1-100 TeV, probes a complementary set of models
  - Salamon and Stecker (‘95), Protheroe(‘97), Mannheim(‘95), Halzen and Zas(‘97)

- **Exotic sources - physics of the early Universe**
  - Topological defects, Heavy Boson decay, Z-burst, micro-Blackholes
GZK Mechanism

• Two predictions
  – 1. There is a brick wall for the highest energy cosmic rays. We should observe energies below about $10^{20}$ eV.
  
  – 2. The reactions that limit the cosmic ray energies produce neutrinos as a by-product

GZK neutrinos are probably the 2nd most likely source of high energy neutrinos!
GZK neutrinos are a “guaranteed” source

- Ultra-high energy cosmic rays:
  - From where??! And How??

- Standard Model:
  - Ordinary charged particles
    accelerated by distant sources: AGN, GRBs…

- If so: GZK neutrinos are the signature
  - Probably necessary and sufficient
to confirm standard GZK model

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GZK cutoff may be observed - or not

**ANITA**
GZK neutrinos probe new physics

Cross-section a factor of 100 larger in $\mu$-BH models

\[ \sigma (\text{mb}) \]

$E_\nu$ (TeV)

$\mu$-Black Holes

Strings

Standard Model
What role does radio detection play?

- Standard model GZK $\nu$ flux: <1 per km$^2$ per day
  - Only 1 in 500 interact in ice

Both AMANDA-II or cubic kilometer array may expect to see 1 event every 2 years in its fiducial volume—requires astronomical level of patience.

- How can we get the $\sim$100-1000 km$^3$ sr yr exposures needed to detect GZK neutrinos at an acceptable rate?

Answer: radio Cherenkov emission

  • economy of scale very competitive
Why is Antarctic Ice so good?

• It does not absorb radio very much - the cold temps help a lot
  – Absorption length = 1000m vs 100m for light
  – Negligible scattering in radio

• There is little unwanted interference from man-made transmitters at balloon altitudes and trajectories

• It preserves linear polarization of Cherenkov light

• There is a lot of it!
Radio Cherenkov has been observed! (2000)

- Use 3.6 tons of sand

From Saltzberg, Gorham, Walz et al  PRL 2001

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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
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—can track particle source

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ANITA
ANtarctic Impulsive Transient Antenna

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Red= worked at pole
ANtarctic Impulsive Transient Antenna

- NASA funding starts 2003
- launch in 2006

600 km radius, 1.1 million km²
ANITA concept

cascade produces UHF–microwave EMP

antenna array on payload

0.1–100 EeV neutrinos

touched RF

ice

cascade

56° Cherenkov cone

1–3 km
ANITA antennas view ~2pi sr with 60 deg overlapping beams

Beam intensity gradient, timing interferometry, and polarimetry used to determine pulse direction & thus original neutrino track orientation
RadarSat completed comprehensive SAR map of Antarctica in late 1990s—feature resolutions of ~10-50m, available public domain

- Can calibrate surface roughness—SAR $\lambda = 5.6$ cm

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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 at } 300 \text{ MHz } \& -60^\circ\text{C (pure ice)}
Existing Neutrino Limits and Potential Sensitivity

- **RICE, AGASA, Fly’s Eye**
  - limits for $\nu_e$ only

- **GLUE limits $\nu_\mu$ & $\nu_e$**
  - ~80 hours livetime
  - Goal: 300 hrs over next 3 years

- **SALSA & ANITA**
  - sensitivity:
    - Based on 2 independent Monte Carlo simulations

Models:
- Topological Defects: Sigl; Protheroe et al.; Yoshida et al.
- AGN: Protheroe et al.; Mannheim
- GZK neutrinos: Engel et al. ‘01
RFI Noise Tests at South Pole

- Ambient noise on the high plateau

Log-Periodic Antenna
Initial Results from Polar Studies

- It looks good so far

Nadir–Zenith noise, 1/26/03 South Pole ski hut at 6km

RF emission from ice

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Polarization 1
Polarization 2
What’s Next? ANITA-lite in 03/04

Piggy-back mission on TIGER payload

Goals: survey RFI at balloon altitudes

Solar Panels

250 lb
250 W

2 Antenna

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ANITA questions & issues

• RF interference?
  – Studies suggest Antarctica is extremely quiet
  – Measure this year with a piggy-back mission

• How will cascade pulses be distinguished?
  – Precise pulse shape
  – Located in the ice
  – Must show linear polarization

• Energy & Angular resolution?
  – Angular resolution: zenith~2°
  – Depth of collision from shape distortion & known ice properties
  – $\Delta E/E \sim 1$ from combination of all of the above
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 (e.g., Vostok)

- Balloon flight path is far from sources of confusing background

Revolutionary concept in EHE neutrino detection!
Future plans

- Goal: 15-30 day first flight, solid constraints (or detection) of GZK flux
- More stringent constraints on other models:
  - TeV scale black holes, AGN neutrinos, topological defects

GZK neutrino detection within reach!