Hunting UHE neutrinos with ANITA

Linda Cremonesi

Rutherford Appleton Laboratory seminar
May 2nd 2018
Outline

• Motivations

• ANITA

• Neutrino(s) in a haystack

• UHE cosmic rays and mysterious events

• Future
Motivations
UHE neutrinos and ANITA

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protons

neutrinos

π^0

\pi^+ / \pi^-

\gamma

\gamma

\mu

\nu_e

\nu_\mu

photons
UHE (>E18 eV) neutrinos

“We can probe distances and energies that other particles can’t reach!”

“WOW 300 TeV centre of mass energy!”

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“UHE neutrinos and ANITA”
More motivations

• Implications for neutrino mixing (arXiv:1702.05238)
• Neutrino decay - JCAP 10 (2012) 020
• Lorentz invariance - Phys. Rev. D 86, 103006
• Sterile neutrinos - arXiv:1802.01611
Cosmogenic neutrinos

We know cosmic ray energy spectrum over 11 orders of magnitude. Their sources (especially at the highest energies) are still mostly unknown.

\[ \nu \text{ from GZK} \]
\[ p(E > 10^{19.5} \text{eV}) + \gamma_{CMB} \rightarrow \Delta^+ \]
\[ \Delta^+ \rightarrow \pi^+ + n/\pi^0 \]
\[ \pi^+ \rightarrow \mu^+ + \nu_\mu \]
\[ \mu^+ + \rightarrow e^+ + \nu_e + \bar{\nu}_e \]

\[ \nu \text{ from photo-disintegration} \]
\[ A + \gamma_{CMB} \rightarrow (A - 1) + n \]
\[ n \rightarrow p + e^- + \bar{\nu}_e \]
We know cosmic ray energy spectrum over 11 orders of magnitude. Their sources (especially at the highest energies) are still mostly unknown.
ANITA

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“UHE neutrinos and ANITA”
ANITA collaboration

11 Institutions, ~50 collaborators in a 18 hour time zone
NEUTRINOS = VPOL
Askaryan radiation

- Coherent radio emission from EM cascades in a dielectric!
- Measured at SLAC ESA in 2006 by ANITA collaboration
- Fired bunches of \(10^9\) electrons at 28.5 GeV into 7000 kg of ice

\[ F_0 = 2.8 \times 10^{19} \text{ eV} \]

\[ (E/E_0)^{21.8 \pm 1.4} \]

END STATION A side view

Approximately to scale

ANtarctic Impulsive Transient Antenna

Not to scale, angles don't reflect reality

NEUTRINOS = VPOL
COSMIC RAYS = HPOL

Ice

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“UHE neutrinos and ANITA”
ANITA instrument

- TDRSS & Iridium antennas
- GPS antennas
- Instrument box
- 48 quad-ridged horn antennas
- Solar panels
ANITA instrument

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ANITA-4 taking off
ANITA-4 flight path
ANITA-4 flight path

Calibration pulser at WAIS to optimise pointing resolution

Launched Dec 2nd 2016 from NASA LDB facility, near McMurdo

Landed Dec 30th 2016 125km from South Pole
ANITA-4 Recovery

- Partial recovery done on Jan 10th 2016
- Full recovery done in December 2017
ANITA Flights

ANITA-1 (2006-2007) 35 days
ANITA-2 (2008-2009) 30 days
ANITA-3 (2014-2015) 22 days
ANITA-4 (2016) 30 days

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“UHE neutrinos and ANITA”
How ANITA sees the world

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“UHE neutrinos and ANITA”
How ANITA sees the world

Interferometric Map

Zoomed Map

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“UHE neutrinos and ANITA”
Needle(s) in a haystack
The challenge

- ~100 million events
- (maybe) a few neutrinos
- Tens of cosmic rays
The challenge

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- (maybe) a few neutrinos
- Tens of cosmic rays

NB: We don’t know what the source is!
Backgrounds

- Continuous waves
- Payload blasts
- Thermal noise
- Anthropogenic impulsive events
Continuous Waves

- Satellites and human bases using communications in the bands:
  - 260 MHz
  - 380 MHz

- How to get rid of this?
  - ANITA-3: software
  - ANITA-4: hardware
Payload blasts

- Impulsive radio frequency emissions generated by electronics on board
- Exact origin is unknown
- Removed by simple cuts
Vast majority of ANITA events are thermal noise
Use Fisher discriminant based on impulsivity variables

- Background sideband: above horizon triggers
- Simulation: cosmogenic neutrinos following the Kotera mix max model
Clustering

• From previous cuts, ~500k events

• Look for isolated singlets and doublets

• Remove anything that clusters with human bases

• Remove anything which forms a cluster of 3 or more
What’s left?

- One V-POL candidate
- Background estimate: $0.7^{+0.5}_{-0.3}$ per polarisation
- No known human activity within 260km

![Event Location Diagram]

![Coherently-Deconvolved Graph]
Neutrino limit

Limit on all-flavour-sum diffuse UHE neutrino flux

Limit on all-flavour-sum diffuse UHE neutrino flux
UHE cosmic rays

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“UHE neutrinos and ANITA”
UHECR

ANITA1: 16 UHECR
14 reflected + 2 direct
ANITA-2: 2 UHECR
H-pol trigger was off
ANITA-3: 25 UHECR
ANITA-4: analysis in progress

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And ANITA-3 mystery event

Chord length: 5500-7000 km (20-30,000 km water equivalent)
1600 km SM interaction length @ 1 EeV

Background estimate < 10^{-2}

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“UHE neutrinos and ANITA”
ANITA-1 mystery event

(A) evt. 5152386, EL = -4.3
(B) evt. 7122397, EL = -3.4
(C) evt. 21684774, EL = -2.3
(D) evt. 3985267, EL = -27.4

A strong H-pol non-inverted signal seen!
- Expected background events: 4x10^{-4}
- 27.4 deg below horizon, E = 0.6 ± 0.4 EeV

Mysterious neutrinos

• Diffuse neutrinos:
  • SM cross-section needs to be suppressed by a one order of magnitude to explain these events
  • SM cross-section greatly suppressed for extremely low values of Bjorken-x
  • Possible sterile neutrinos explanation
    \( \sigma_{\nu_s} \sim \theta^2 \sigma_{\nu} \) : arXiv:1802.01611

• Powerful transient source search with 1.5 degree error:
  • No concurrent GRBs
  • SN2014dz, type Ia SN at \( z=0.017 \), 5 hours after initial discovery
    (a posteriori chance association 2.7\( \sigma \))
Future

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“UHE neutrinos and ANITA”
What about the future?

• ANITA-5 proposal: new hardware to try out! (J. Nam ICRC2017)

• ARA: 3 deployed stations + 3 more coming this Antarctic summer (M.Y. Lu ICRC2017)

• Phased array deploying this summer (A. Vieregg ICRC2017)

• ARIANNA: 7 regular + 2 CR stations deployed (S. Barwick ICRC2017)

• GRAND: (K. Fang ICRC2017)
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“UHE neutrinos and ANITA”
What about the future?

- ARIANNA: 7 regular + 2 CR stations deployed (S. Barwick ICRC2017)
- GRAND: proto35 operational (K. Fang ICRC2017)
Summary and future

• The ANITA experiment has a rich physics program:


• ANITA-3 cosmic ray and tau neutrino analysis: arXiv:1803.05088 [astro-ph.HE]


• ANITA-4 is expected to have 4 times better sensitivity than ANITA-3: analysis coming out soon!

• ANITA-5 proposal: new hardware to try out! (J. Nam ICRC2017)
THANK YOU

NASA

LEVERHULME TRUST
Back up
HiCal

Two calibration payloads (HiCals) launched on ANITA’s second pass:
- Periodic calibration pulse
- Use direct and reflected pulse to characterise ice surface and roughness
Neutrinos and Cosmic Rays

Neutrinos and Cosmic Rays

V-pol predominated after refraction

ANITA

ANITA

RF Cherenkov

Geomagnetic Field

Synchrotron Emission (H-pol.)

Shower ~10 m length (20% e⁻ excess)

Diagrams courtesy of Jiwoo Nam

“UHE neutrinos and ANITA”
A neutrino induced cascade produces a coherent radio Cherenkov pulse.

- Incident neutrinos with energies above ~0.5 EeV
- ~680km to horizon -> 1.5x10^6 km^3 interaction volume
- Cosmic ray geo-synchrotron also observed (HPOL)
- Antarctic ice sheet
- 1~4km

ANtarctic Impulsive Transient Antenna (ANITA)
ANITA-4 improvements

- Using Low Noise Amplifiers for all channels
  - Improvement in noise figure (30-40K)
  - 20% improvement in energy threshold
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- Tunable Universal Filter Frontend
  - Reduce Carrier Waves noise coming from Satellites

![ANITA-3 frequency power spectrum](image)

![ANITA-4 frequency power spectrum](image)

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ANITA-4 improvements

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  - 20% improvement in energy threshold

- Tunable Universal Filter Frontend
  - Reduce Carrier Waves noise coming from Satellites

- Trigger on Left and Right Circular Polarisation coincidences
  - Satellite noise predominantly circularly polarised (either LCP or RCP) —> 2.5 improvement in acceptance
### ANITA-3 efficiencies

<table>
<thead>
<tr>
<th>Cut</th>
<th>HPOL data</th>
<th>VPOL data</th>
<th>MC efficiency</th>
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<tr>
<td>None</td>
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<td>38,274,132</td>
<td>1</td>
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<tr>
<td>Data quality</td>
<td>18,811,772</td>
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<td>Blast</td>
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<td>Thermal</td>
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<tr>
<td>Clustering</td>
<td>25</td>
<td>1</td>
<td>0.72</td>
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And ANITA-3 mystery event

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