



Overview and results from first four flights of ANITA

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Outline

- Motivation
- Overview of radio technique
- ANITA strategy
- Results
- Future



Complementary probes of UHE sources





Complementary probes of UHE sources

Cosmic rays produce neutrinos with they interact with cosmic microwave background light



THE OHIO STATE UNIVERSITY



Current Radio Neutrino Projects





Pure ice is low-loss for radio: field attenuation lengths ~1 km



Gurgen

1962

Askaryan,

Radio Cerenkov Technique

- Shower develops 20% charge asymmetry
- Cerenkov radiation
- Coherent for $\lambda \gg 10$ cm

\rightarrow **RADIO** Power \propto E_{shower}²

Confirmed experimentally in sand, salt, ice: PRL 86, 2802 (2002); PRD 72, 023002 (2005); PRD 74, 043002 (2006); PRL 99, 171101 (2007)







Where does ANITA fit in

- Coherence and long attenuation lengths make this most promising technique for UHE regime long term
- High altitude
 - \rightarrow High threshold
- ANITA can view
 1.5M km³ at once

 \rightarrow Sensitivity to rare fluxes





Highest energy neutrinos bring unique science program

- Flux measurement will uniquely probe UHE sources at cosmic distances
 - What is ultimate energy of the astrophysics accelerators
 - Redshift evolution \rightarrow source type
 - Composition
- Particle physics
 - Interactions beyond LHC center-of-mass energies
 - Unique probe of Lorentz Invariance Phys.Rev. D86 (2012) 103006

The Ohio State University





University of Hawaii, University of California, Los Angeles, University of Delaware, Jet Propulsion Laboratory, University of Kansas, National Taiwan University, The Ohio State University, Washington University in St. Louis, University College London



THE OHIO STATE UNIVERSITY







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ANITA-4 Launch



Each flight, we have reduced thresholds through improvements to antenna designs, trigger mechanisms and filtering







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ANITA-4 Landing





PC: Christian Miki

Voltage



What data looks like

• ANITA-3 data in monitoring software





Signatures of an UHE neutrino

- Impulsive event with right properties (e.g.polarization)
- Not consistent with being from anthropogenic noise





Interferometry Astropart. Phys. 60 (2015) 72-85



 For each pair of antennas in same polarization, signals arrive with relative delays depending on their incoming direction

Analysis Search Techniques



Phys.Rev. D85 (2012) 049901 Search for isolated, impulsive event This plot from ANITA-2 published result

New binned approach



- Each bin has a different signal, background
- Search for events that stand out among their friends

ANITA 3 Results Phys.Rev. D98 (2018) no.2, 022001



 Observations consistent with cosmic ray expectation plus backgrounds

ANITA 4 Results imminent...

Two anomalous events

- Since ANITA-I, have observed cosmic rays (~20/flight) Astropart.Phys. 77 (2016) 32-43
 - from sky (direct)
 - from ice (reflected)
- Have reported two events pointing to ice with "wrong" polarity (that expected from direct)
- Arrive at steep angles (27 deg. and 35 deg. down)



Phys.Rev.Lett. 117 (2016) no.7, 071101

& arXiv:1803.05088 [astro-ph.HE]

Anomalous events

- Anthropogenic backgrounds?
 - Backgrounds estimated at <0.015
- Paper suggests $\nu_\tau \to \tau \to air$ shower candidate
 - Would need dramatic reduction in UHE v $\sigma \dot{s}$
- Neutrino burst?
- Exotic physics?
 - Even attempts at exotic physics scenarios struggle to explain a preference for steep events

Look for ANITA paper detailing explanations we have pursued within the Standard Model

Future

- ANITA-V proposed, on a bit of a delay due to current environment
 - Interferometry at trigger level to reduce thresholds further
- Next-generation balloon, such as EVA
 - EVA underwent successful prototype test
 - Made it to advanced stage in review
 - Will be exciting to pursue new ideas once field reaches discovery phase and beyond

arXiv:1807.08892 [astro-ph.HE]

ANITA as a CHAMP detector

- ANITA can search for new physics in the form of charged massive particles (CHAMPs)
- Can probe masses, lifetimes inaccessible by the LHC (~1 TeV, 1 ns)
- Signature upward going showers with "wrong" polarity, but still expect more shallow than steep

Also discussed in: arXiv:1809.09615 [astro-ph.HE]







Summary

- ANITA plays a crucial and unique role in probing neutrinos at the highest energies
 - UHE astronomy at cosmic distances
 - Tests of fundamental physics
- Continually making advances in analysis and trigger designs to increase the power with which we can reach more neutrinos

Thank you!