Results from ANITA

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on behalf of the ANITA Collaboration

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ANITA Collaboration

ANtarctic Impulsive Transient Antenna
12 institutes, 3 countries, 4 continents

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Results from ANITA
Science Motivation: Ultra-High-Energy $\nu$’s ($>EeV$)

Both astrophysics (understand sources, composition) and high-energy physics (measure EeV cross-section) motivations. Expected flux is very low, so need big detector.
Detection Mechanism: Radio Emission from Askaryan Effect in Ice

- **Askaryan (charge-excess) radiation**: Fast-moving charge density in dielectric → coherent emission ($\propto E^2$) at long (radio) wavelengths
  - Charge excess from annihilation of positrons with electrons in material
  - At wavelengths larger than lateral width, don’t resolve individual charges
- Radio attenuation length in ice is $\sim 1$ km

![Graphs and images related to detection mechanism and results from ANITA tests.]
ANITA Experiment Concept

interferometric payload

balloon

Ice

Askaryan emission

Not to scale, angles don’t reflect reality

\[ \sim \text{EeV } \nu \]
ANITA Experiment Concept
Go to Antarctica not just for ice but also for favorable wind patterns, perpetual sun, few people.

At float (35-40 km), balloon grows to size of a football stadium, $O(10^6 \, \text{km}^2)$ of ice visible.

Severe weight and power limitations – 600W, 4000 lb
ANITA Instrument

- Signal (\(\sim 180-1200\) MHz) split into digitization and trigger paths
  - Tunnel diode first-level trigger. FPGA takes \(O(10^5-6)\) Hz singles rate \(\rightarrow O(50)\) Hz global rate
  - Switched Capacitor Array digitizers, \(\sim 2.6\) GSa/s, \(O(100)\) ns.

Breakdown of Instrument:

- Bias Tee
- Front-end Amplification
- Square-Law Detector
- Instrument Box
- cPCI Crate
- Disk Storage (Helium Drives)
- GPS Antennas, NASA SIP, Sun Sensors, etc.
### Timeline of Completed ANITA flights

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- Independent H + V trigger, with causal timing requirement between antennas
- Increased data rate with GPU prioritizer
- Complications from new military comm satellites → loss of volume, significant improvements to data analysis required.
- Calibration pulses sent from launch site (LDB Facility) and remote site (WAIS divide)

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Results from ANITA
ν Signal and Backgrounds (Fake ν’s)

Askaryan Emission from ν’s

- Impulsive signal (few ns)
- Broadband
- Plane-wave
- Linearly polarized; mostly vertically-polarized (VPol) due to interaction geometry (Earth opaque to EeV ν’s) and transmission through air-ice boundary (Fresnel coefficients).

Continuous Wave (CW) Signals

Anthropogenic narrow-band signals (from satellites and bases) contaminate most data

Thermal Noise

Incoherent random noise, that sometimes by chance looks impulsive

Self-triggered “payload blasts”

RF emission produced on payload; does not satisfy plane wave condition

Impulsive Anthropogenic Emission

Transformers, engines, etc. produce broadband impulsive emission that can mimic ν’s. These are the worst.
Sketch of analysis

Three independent $\nu$ analyses for ANITA-III.

Basic flow:

1. Filter waveforms (reduce CW) and remove events failing quality cuts

2. Form correlation map, where we calculate channel cross-correlations with different direction assumptions

3. From peaks of correlation map, form coherent waveforms, generate features (e.g. impulsivity, linear polarization fraction) used to cut out thermal noise

4. Use pointing information to point to continent; select regions with little anthropogenic activity.
ANITA-III Askaryan $\nu$ Results

- arXiv:1803.02719 (submitted to PRD)
- Most sensitive search found one candidate on a background of $0.7^{+0.5}_{-0.3}$ events
- Consistent with background, so set limit, but the event looks pretty good (very isolated, very impulsive, thick ice, right polarization)
Another Signal: Radio Emission from Extensive Air Showers (EAS)

- Earth’s magnetic field separates charges in EAS’s, produces radio emission
  - “Direct” ~horizontal CR’s: miss ground.
  - “Reflected” down-going CR’s: point to ground, opposite polarity

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Results from ANITA
**ANITA-III EAS Search**

- Polarization from B-field and shower direction. B-field in Antarctica $\sim$vertical $\rightarrow$ mostly horizontally-polarized (HPol).
- Can check geomagnetic hypothesis by querying local magnetic field and checking consistency of polarization angle.
- Physics sideband for $\nu$ searches, but dedicated search also performed.
- Nearly 30 EAS candidates among all the ANITA-III searches.
Sensitivity to Upward-Going $\tau$ Showers?

- $\nu_\tau$ creates $\tau$ which escapes atmosphere and decays, producing shower
- Would have elevation of a reflected UHECR, but polarity of direct
**Anomalous “Mystery” Events**

- Anomalous event found in ANITA-I. **Another found in ANITA-III** (arxiv:1803.05088).
- Mostly HPol, matches UHECR template, polarity consistent with direct cosmic ray event, **but clearly points to ice.**
- Would like to call it a \( \tau \) candidate, but chord length through Earth in tension with SM cross-section and flux in tension with Auger and IceCube limits.
- No satisfying interpretation yet; now that we have two events much harder to dismiss as a background.

Top-Left: Anomalous A-III event
Top-Right, Bottom-Left: Direct UHECR candidates
Bottom-Right: A reflected UHECR candidate
ANITA-IV (2016)

- ~100 million events recorded, under process of being analyzed.
- Key upgrades:
  - New trigger that requires linear polarization without preference for H or V (better sensitivity to non-SM $\nu N$ cross-sections)
  - Dynamic, tunable hardware notch filters to reduce CW, greatly increasing livetime
- Analysis expected to be completed sometime this year.
  - Major analysis goal is to reduce anthropogenic background by using additional discriminators other than location.
  - Expectation is that it will be the most sensitive ANITA yet.
Future: ANITA-V?

- Proposal submitted
- New digitizers, with more even sampling, better bandwidth, and longer length
- Beam-forming trigger (use interferometry in real time with a streaming digitizer)

Interferometric Trigger

- Antenna Signals
- Low-bit Streaming Digitizer
- Beamform (Delay-and-Sum)
- Trigger on Power Envelope

Old vs. new digitizer bandwidth. E. Oberla
Conclusion

- ANITA I-III combined set the best limits on UHE $\nu$ flux above $10^{19.5}$ eV.
- Many EAS’s from CR’s detected in ANITA-III.
- One of the ANITA-III EAS’s is anomalous in the same way as an event from ANITA-I.
- Stay tuned for ANITA-IV, which should have better sensitivity and hopefully shed some light on previous results.
- The proposed ANITA-V will have substantial hardware improvements.

Questions?
(Some) Anomalous Event Explanations

**$\nu_\tau$-induced EAS**

+ Would produce upward-going EAS
  - Chord through Earth not compatible with SM cross-section
  - Tension with IceCube and Auger results

**Askaryan Radiation from $\nu$**

+ Could produce impulsive emission
+ Not in tension with other results
  - Polarization likely would be rare coincidence

**Funny reflection of UHECR EAS**

+ Apparent upward-going EAS shower
  - Hard to invert polarity but maintain coherence
  - Would likely have seen effect in data from HiCal (trailing balloon with HV pulser)

**Transition Radiation from UHECR EAS**

+ Could produce impulsive emission
  - Random polarization, likely insufficient power

**Some Other Exotic Particles (heavy $\nu$ DM, sterile $\nu$)**

+ Could produce upward-going EAS
  - New physics
  - Tension with IceCube and Auger

**Anthropogenic Background**

+ No physics to explain
  - We consider it unlikely
The Raw Data (a Calibration Pulse, Not a $\nu$)

- 48 dual-polarization horn antennas
- Sampled at $\approx 2.6$ GHz’s
- 100 ns per event
- 50 Hz global trigger rate
- $\mathcal{O}(10^7)$ RF triggers per flight (ANITA-III and IV)
We assume anthropogenic emission is spatially clustered on the continent, so we only consider isolated events as candidates.

For each signal-like event, we measure a direction with some pointing resolution.

One example clustering algorithm:
- Project all interesting events to continent and accumulate to form a “clustering map.” Use to compute overlap integral of each event with all other events.
- Isolated events will have overlap integrals close to zero.

Other methods to tackle anthropogenics include pairwise event clustering or a binned continent analysis.
ANITA-III Block Diagram

Seavey Antenna (x48)

Front-end Amplification

HPol

40 dB LNA

Bias Tee

180-1200 MHz bandpass

Second-Stage Amplification

3 dB attenuator

40 dB LNA

Bias Tee

40 ft LMR-240

Instrument Box

Instrument Box

Square-Law Detector

amp
diode

trigger path

digitizer path

180-1200 MHz bandpass

Flight Computer

GPS Antennas, NASA SIP, Sun Sensors, etc.

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Results from ANITA

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ANITA-III Trigger

L1: \( \int v^2 \) above threshold

L2: multiple L1's in causal time window

L3: adjacent L2 phi sectors

VPol
HPol
digitizer
full band
independent H and V
full band

GPU prioritizer
telemeter
disk

L1: \( \int v^2 \) above threshold

L2: multiple L1's in causal time window

L3: adjacent L2 phi sectors
ANITA-IV Trigger

- **ANITA-IV Trigger**
- **LCP**
- **RCP**
- **phase shifter**
- **tunable notches**
- **digitizer**
- **full band**
- **L0: \( \sqrt{v^2} \) above threshold**
- **L1: LCP-RCP coincidence**
- **L2: 2 out of 3 upgoing**
- **L3: adjacent L2 phi sectors**
- **hold**
- **GPU prioritizer**
- **disk**

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Askaryan Experiments

In-Ice Antennas
- e.g. ARA, ARIANNA, RICE
- phased array
- volume: $10^2 \text{ km}^3$

Balloon
- e.g. ANITA
- 10^6 \text{ km}^3
- threshold: 1 EeV

Lunar Regolith
- e.g. GLUE, NuMoon
- 10^6 \text{ km}^3
- threshold: 100 \text{ ZeV}

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