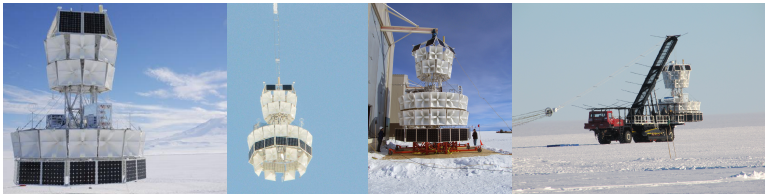


ANITA After Four Flights

Cosmin Deaconu



TeVPA 2017, Columbus, Ohio



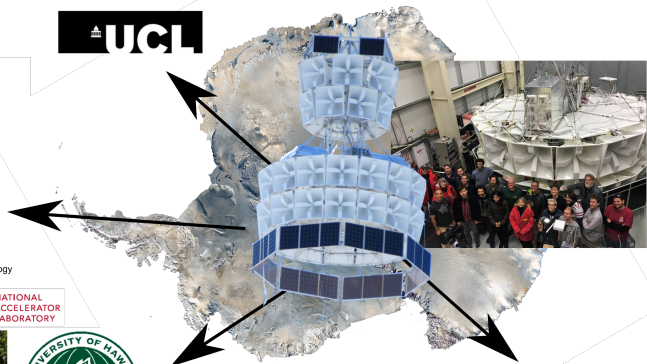
- ▶ This talk:
 - ▶ Overview of ANITA
 - ▶ Published results
- ▶ In this session:
 - ▶ Oindree Banerjee (OSU): Trigger improvements in the ANITA-4
 - ▶ Andrew Ludwig (UChicago) : The ANITA-4 flight and ongoing analysis and calibration
- ▶ Also relevant, but in the past:
 - ▶ Abby Vieregg's plenary from Tuesday

ANtarctic Impulsive Transient Antenna

12 institutes, 3 countries, 4 continents

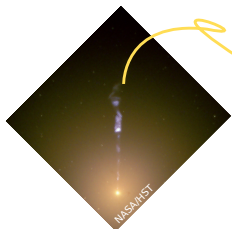


國立臺灣大學
National Taiwan University

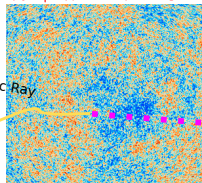
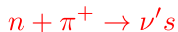
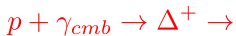


Motivation: Detect Cosmogenic ν 's Via Askaryan Effect

Cosmic Accelerator

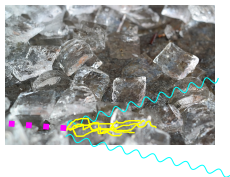


GZK Process



"guaranteed" source of extremely-high-energy neutrinos

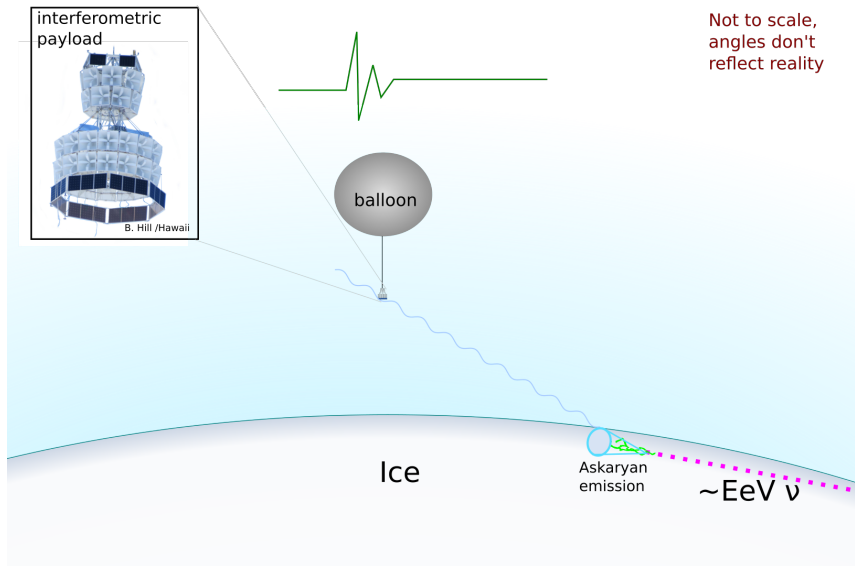
Askaryan Effect



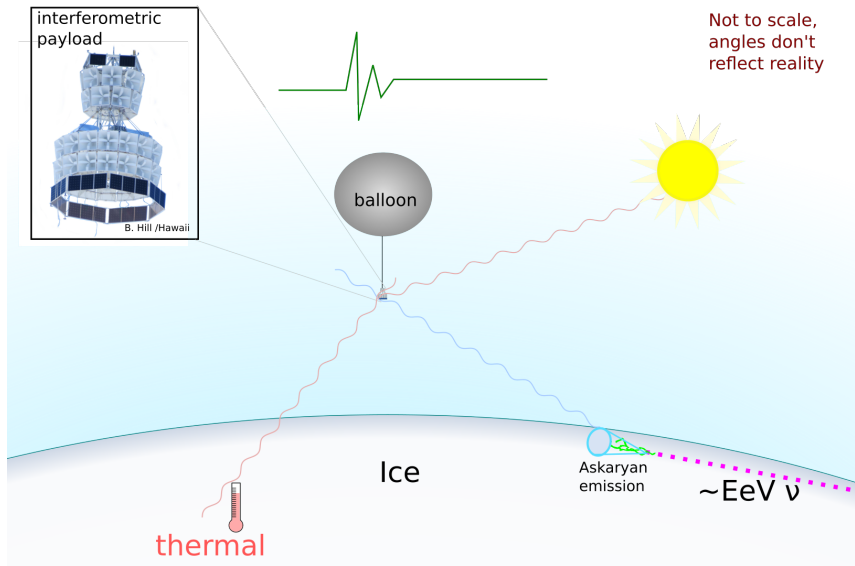
High-energy cascade in dielectric produces coherent RF emission below ~ 1 GHz

Both astrophysics (understand sources) and high-energy physics (measure cross-section at 1 EeV) motivations

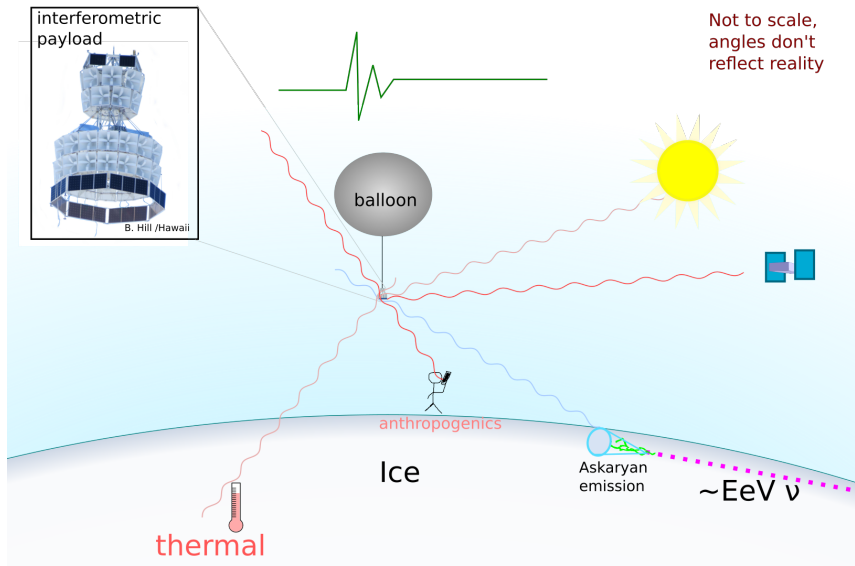
Concept



Concept

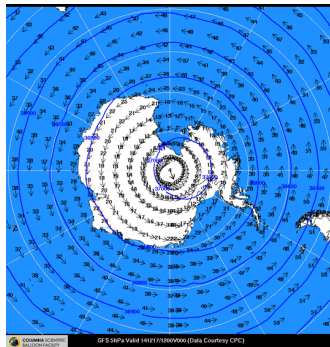


Concept



Ballooning in Antarctica

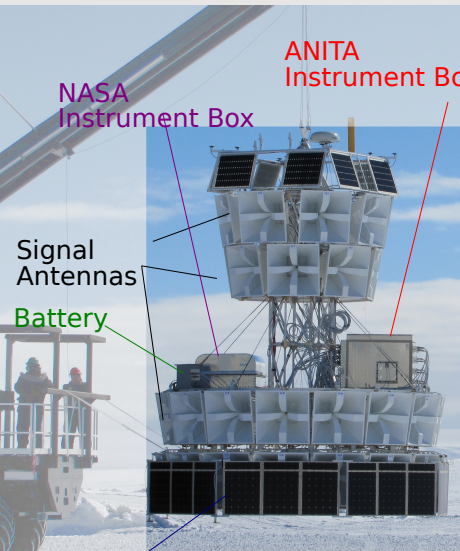
- ▶ Go to Antarctica not just for ice but also for wind patterns, perpetual sun, few people.
- ▶ At float (35-40 km), balloon grows to size of a football stadium, instruments $\mathcal{O}(10^6 \text{ km}^3)$ of ice.
- ▶ Severe weight and power limitations – 96 high-gain antennas and scope channels, housekeeping, telemetry, position, etc. with 600 W and 4000 lb



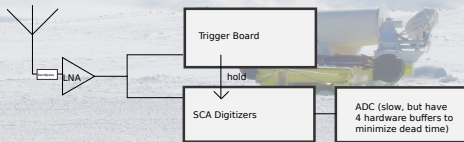
Wind patterns over Antarctica



Instrument



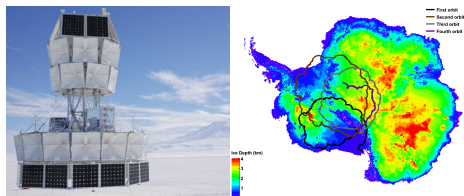
- ▶ Signal (ANITA band is $\sim 200\text{-}1200$ MHz) from antennas split into digitizer and trigger circuits.
 - ▶ Tunnel diodes for L0 trigger. FPGA takes $\mathcal{O}(10^5 - 10^6)$ Hz singles rate $\rightarrow \mathcal{O}(50)$ Hz global rate.
 - ▶ Switched Capacitor Array digitizers for ~ 2.6 GSa/s digitization of $\mathcal{O}(100)$ ns.



Solar Panels (drop down after takeoff)

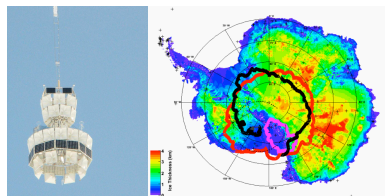
The First Two ANITA flights

ANITA-1 (2006-2007)



- ▶ 35 days in-air (ANITA record)
- ▶ Trigger used multiple bands, circular polarization trigger.
- ▶ 32 antennas, 8 million events recorded

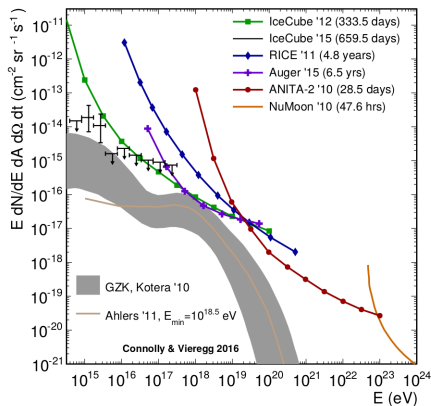
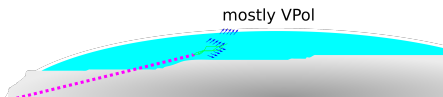
ANITA-2 (2008-2009)



- ▶ 30 days in-air, better flight path
- ▶ Trigger used multiple bands, VPol only (better ν acceptance)
- ▶ 40 antennas, 27 million events recorded

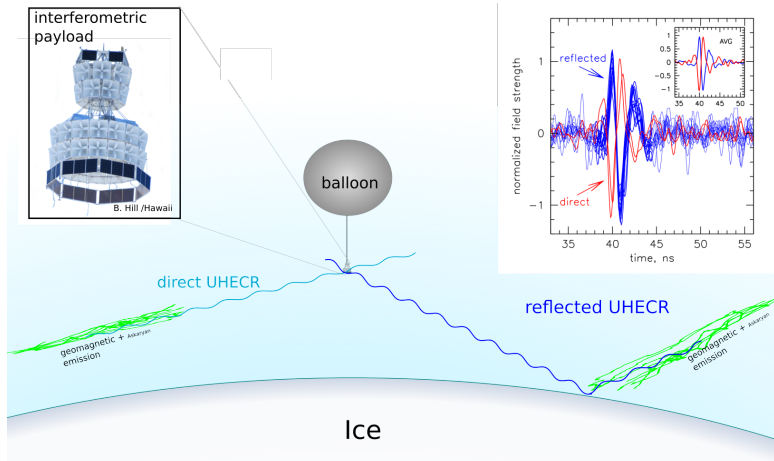
Askaryan ν Results

- ▶ Look for isolated, impulsive, predominantly VPol events (see A. Ludwig's talk for more detail on analysis technique)
- ▶ VPol due to geometry of emission cone for ice-skimming neutrinos
- ▶ Papers:
 - [10.1103/PhysRevD.85.049901](https://arxiv.org/abs/10.1103/PhysRevD.85.049901)
 - [10.1103/PhysRevD.82.022004](https://arxiv.org/abs/10.1103/PhysRevD.82.022004)
 - [10.1103/PhysRevLett.103.051103](https://arxiv.org/abs/10.1103/PhysRevLett.103.051103)



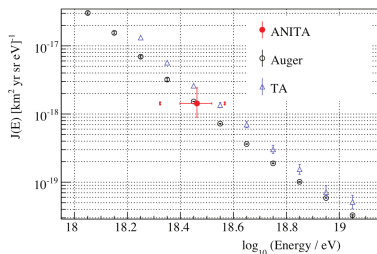
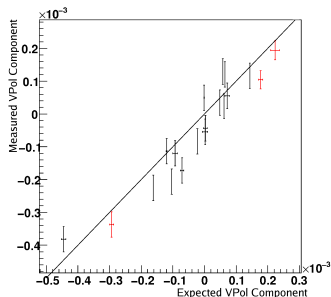
UHE Cosmic Ray Search

- ▶ ANITA-1 saw 16 isolated events predominantly in HPol, identified as emission from extensive air showers
 - ▶ “Direct” ~horizontal CR’s: miss ground.
 - ▶ “Reflected” down-going CR’s: point to ground, **opposite polarity**

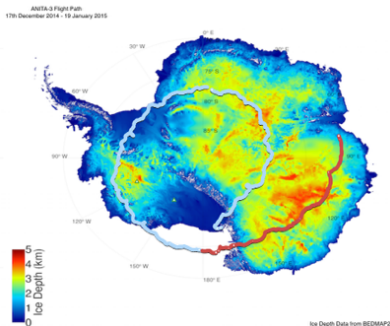


UHE Cosmic Ray Search

- ▶ Dominant RF in extensive air showers from charge splitting by Earth's magnetic field.
- ▶ Polarization from B-field and shower direction. B-field in Antarctica \sim vertical \rightarrow mostly HPol. Reflection affects polarization.
- ▶ Check geomagnetic hypothesis by querying local magnetic field and checking polarization angle
- ▶ Switch to VPol-only in ANITA-2 \rightarrow just saw 3 CR's
- ▶ Papers:
[10.1103/PhysRevLett.105.151101](https://arxiv.org/abs/10.1103/PhysRevLett.105.151101)
[10.1016/j.astropartphys.2016.01.001](https://arxiv.org/abs/10.1016/j.astropartphys.2016.01.001)



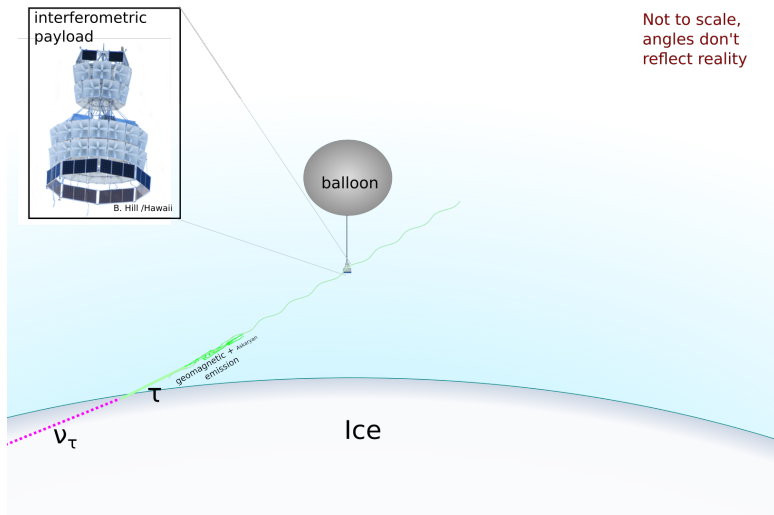
ANITA-3 (2014-2015)



- ▶ 22 days in-air
- ▶ Independently full-band trigger on HPol and VPol (more sensitive to UHECR's)
- ▶ 48 antennas, ~78 million events recorded
- ▶ Complications from new military comm satellites → significant improvements to data analysis required. Results soon.

Sensitivity To Upward-Going τ Showers?

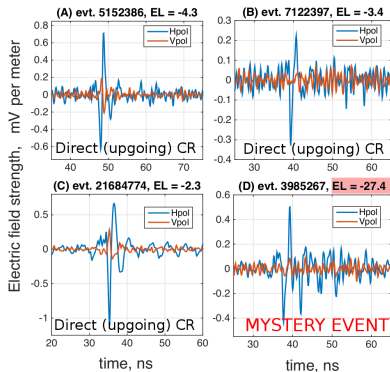
- ▶ ν_τ creates τ which escapes atmosphere and decays, producing shower



Mystery Event

- ▶ Strange event from ANITA-1
- ▶ Mostly HPol, polarity with direct cosmic ray event, **but clearly points to ice** (27 degrees below horizontal).
- ▶ Polarization angle more consistent with unreflected signal (adding Fresnel coefficients worsen agreement with geomagnetic expectation)
- ▶ Looks like a τ candidate, but chord length through Earth in tension with SM, and also tension with AUGER and IceCube.

Shower estimate 0.6 ± 0.2 EeV

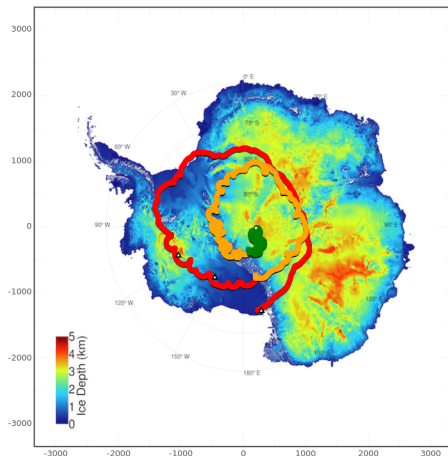


Phys. Rev. Lett. 117, 071101 (2016)
ICRC '17, Romero-Wolf

ANITA-4 (2016-2017)

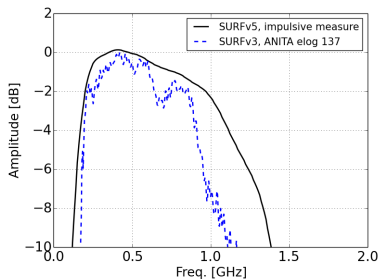
- ▶ Flew in December for 4 weeks (see A. Ludwig's talk).
- ▶ Disks recovered! ~ 100 million events recorded.
- ▶ Key upgrades (see O. Banerjee's talk) :
 - ▶ New trigger, with better sensitivity to non-SM νN cross-sections
 - ▶ Dynamic, tunable hardware notch filter to kill CW

ANITA Course

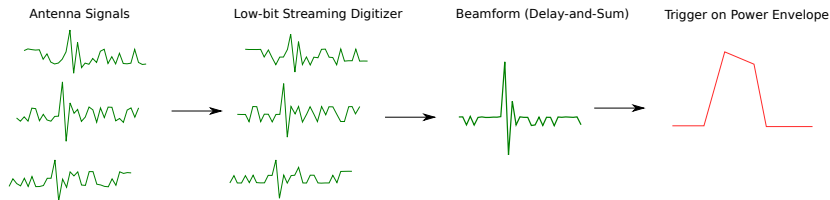


Future of ANITA

- ▶ ANITA-3 and 4 will be analyzed within coming year
- ▶ ANITA-5?
 - ▶ Proposal submitted for 2020-2021 season
 - ▶ New (much nicer) digitizers, which were not quite ready in time for ANITA-4
 - ▶ Beam-forming trigger (do interferometry in real time for trigger)



Old vs. new digitizer bandwidth. E. Oberla



Conclusion

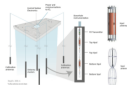
- ▶ ANITA-1 and 2 have the best current Askaryan Neutrino search limits around 10 EeV
- ▶ ANITA can also self-trigger on cosmic rays
- ▶ Mysterious event from ANITA-1 a potential τ neutrino candidate, but at odds with SM.
- ▶ Analysis of ANITA-3 and ANITA-4 should see more CR candidates, set better neutrino limits, maybe shed light on our mystery event.
- ▶ ANITA-5 might be in the future, which will have improved hardware and incorporate lessons from the first four ANITA flights.

Backup Slides

Askaryan Experiments

In-Ice Antennas

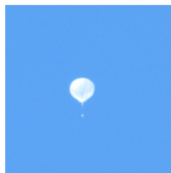
e.g. ARA, ARIANNA, RICE



volume 10^2 km^3

Balloon

e.g. ANITA



10^6 km^3

Lunar Regolith

e.g. GLUE, NuMoon



10^6 km^3

threshold

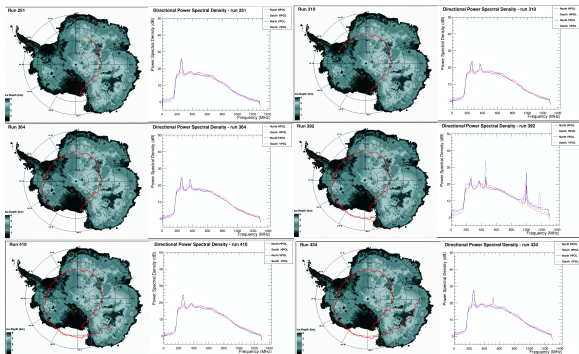
10
PeV

100
PeV

1 EeV

100
ZeV

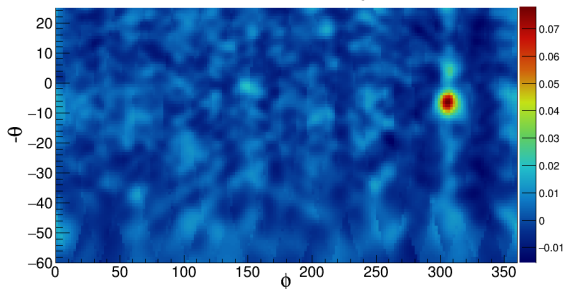
Improved Signal Filtering for ANITA-3



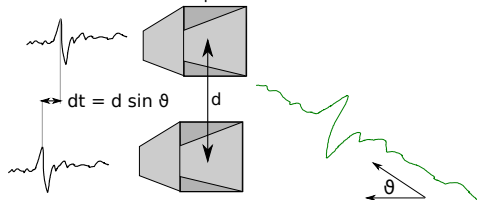
- ▶ The MUOS satellites launched by the US military between ANITA-2 and ANITA-3 resulted in reduced live-time (due to trigger masking of directions with excess rates) and analysis complications.
- ▶ Filtering not so trivial with our 100 ns, $\mathcal{O}(256)$ sample traces
- ▶ Previously used “brick-wall” filters, which severely affected signal. Techniques using time-domain phasor removal in use now.

Interferometry

Interferometric Map



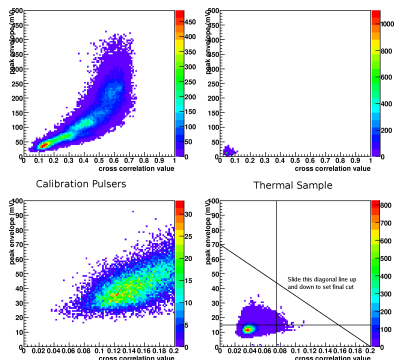
Calibration pulsar from ANITA-3



- ▶ For each incoming angle, figure out geometric time delays between antennas. Fill interferometric map with sum of cross-correlation at appropriate time delay.
- ▶ Peak gives likely incoming direction relative to payload

Analysis Cuts

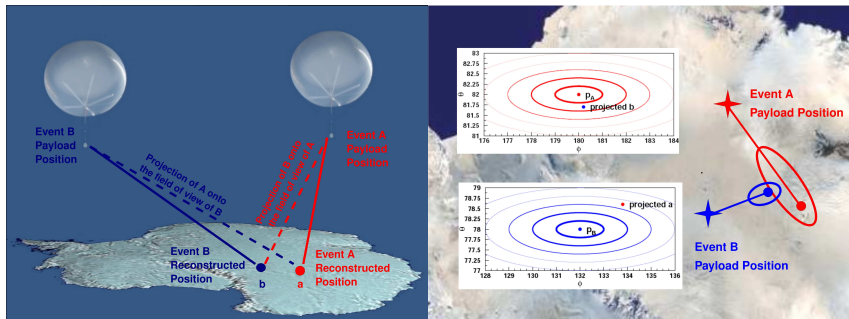
- ▶ Cut out any:
 - ▶ Remaining CW
 - ▶ Thermal noise, which does not have the same plane-wave coherence, especially from sun
 - ▶ Other weird things (digitizer glitches, self-triggered “payload blasts”, etc.)
- ▶ We have very many features; in past just used a handful and Fisher Discriminant, but investigating more sophisticated ML techniques.
- ▶ Left with candidates and anthropogenic impulses.



Example of distribution used for cuts (ANITA-2, A. Vieregge)

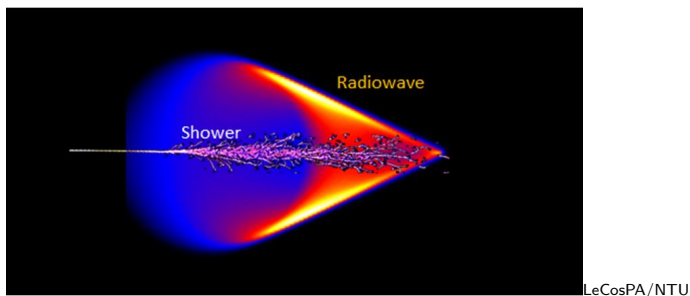
Clustering

- ▶ Look for isolated events. Things close to each other are likely anthropogenic.
- ▶ Then estimate number of single-cluster anthropogenic sites (tricky)



A. Romero-Wolf

Radio-detection via Askaryan Effect



- ▶ High-energy cascade in dielectric medium develops $\mathcal{O}(20\%)$ negative charge excess.
- ▶ From far away, at wavelengths longer than shower width ($\mathcal{O}(10\text{cm})$), appears as single moving charge going faster than light velocity in medium.
- ▶ Potential media: glacial ice, sand, salt, lunar regolith, Jupiter's atmosphere.

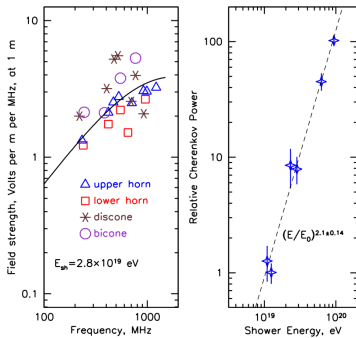
Askaryan Effect in Ice

PRL 99, 171101 (2007)

PHYSICAL REVIEW LETTERS

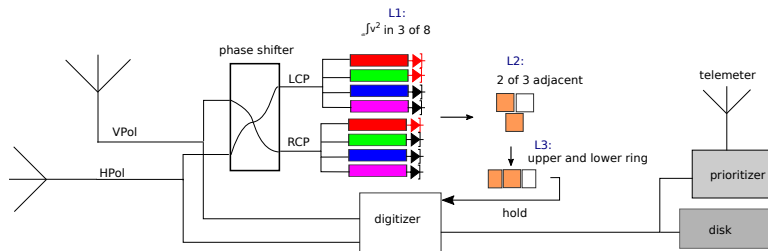
week ending
26 OCTOBER 2007

Observations of the Askaryan Effect in Ice

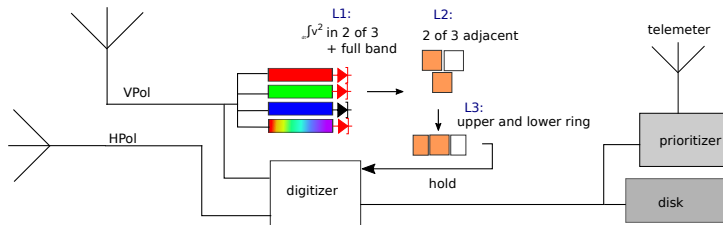


Attenuation length ~ 1 km

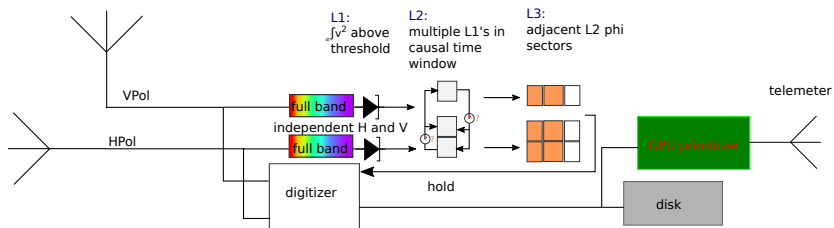
ANITA-1 Trigger



ANITA-2 Trigger



ANITA-3 Trigger



ANITA-4 Trigger

