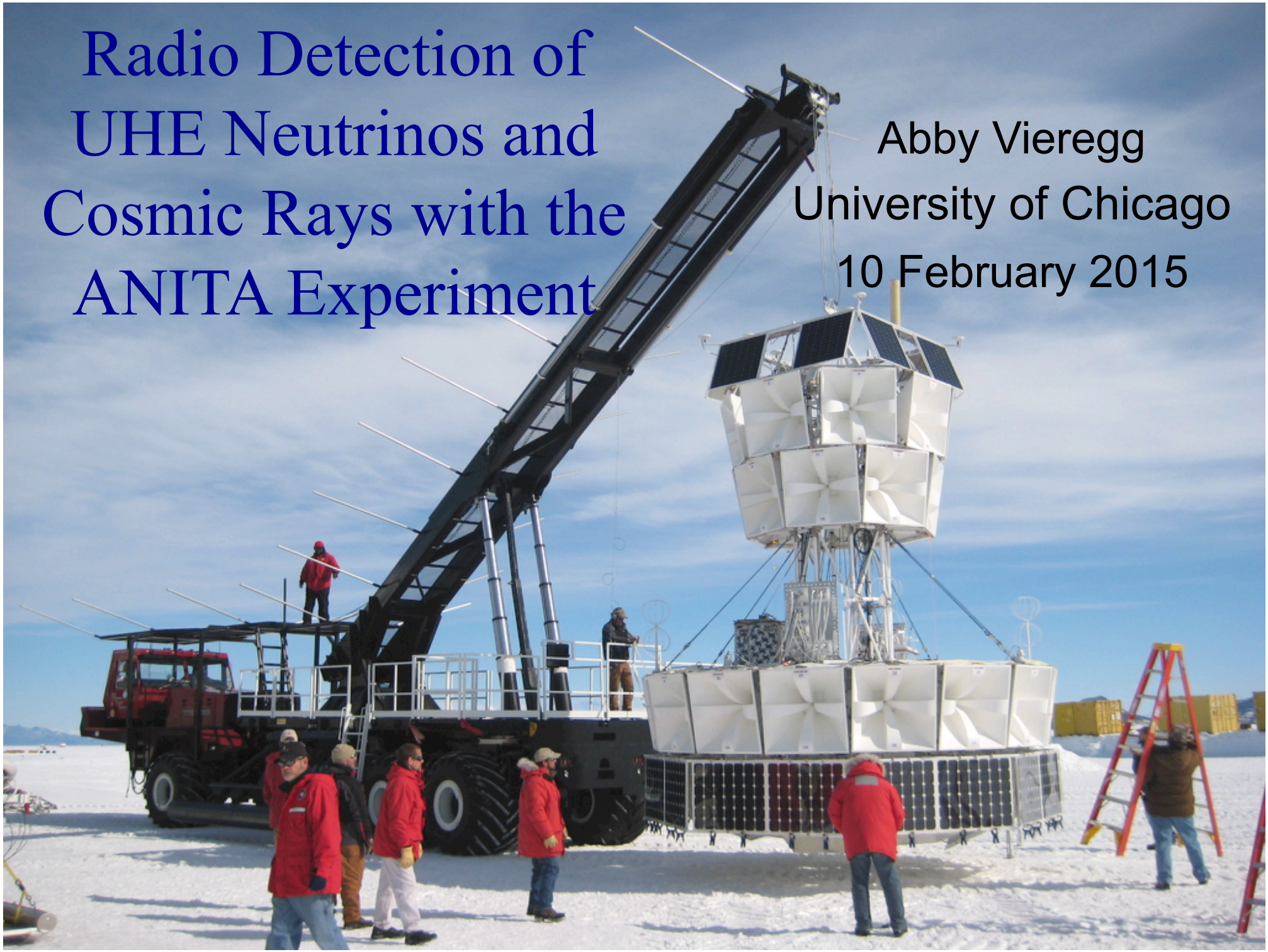
# Radio Detection of UHE Neutrinos and Cosmic Rays with the ANITA Experiment

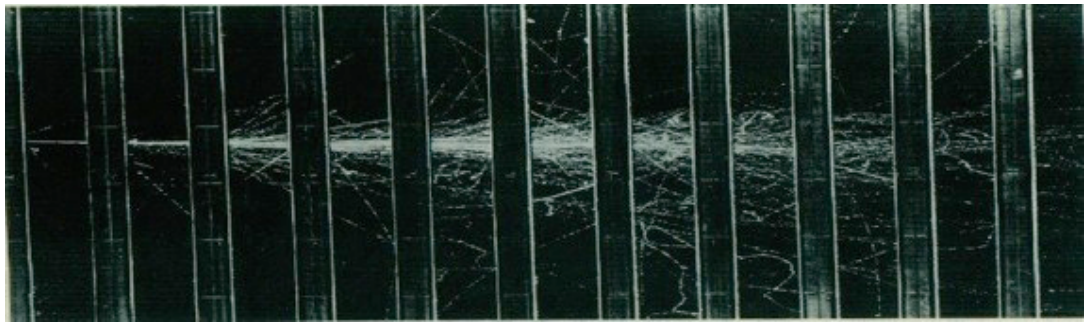
Abby Vieregg
University of Chicago
10 February 2015



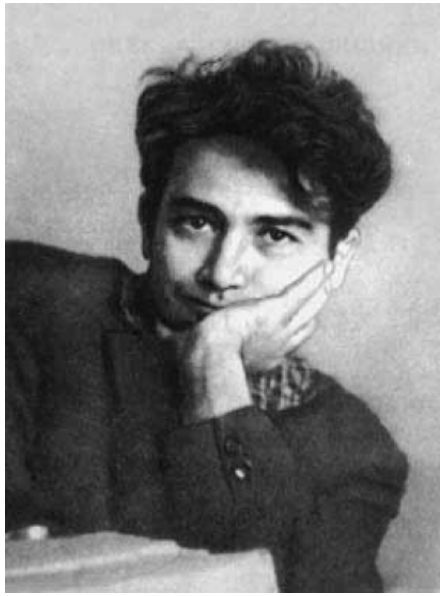
# Detection Principle: The Askaryan Effect

- EM shower in dielectric (ice) → moving negative charge excess
- Coherent radio Cherenkov radiation ($P \sim E^2$) if $\lambda >$ Moliere radius

$e^+, e^-, \gamma$ ⟶

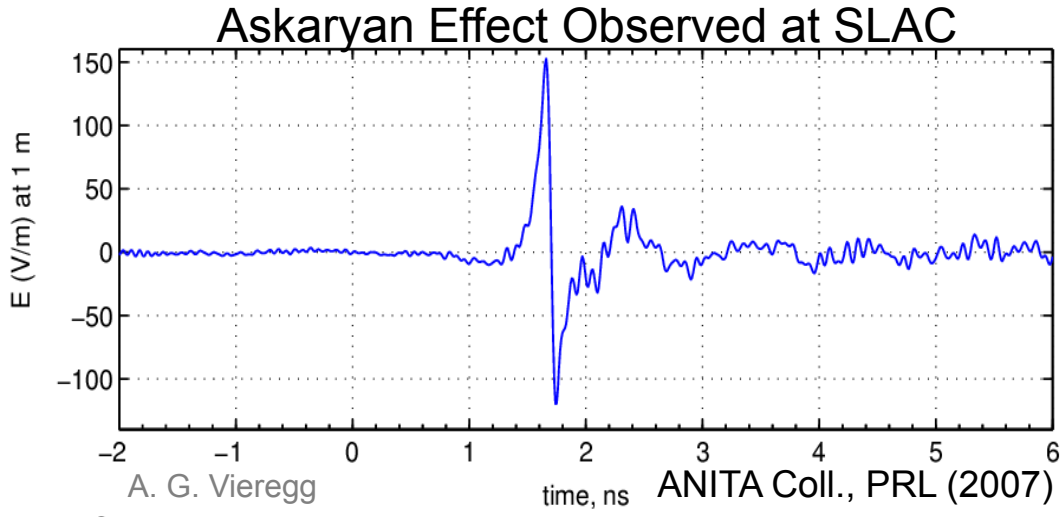


Typical Dimensions:
L ~ 10 m
$R_{moliere}$ ~ 10 cm



G. Askaryan

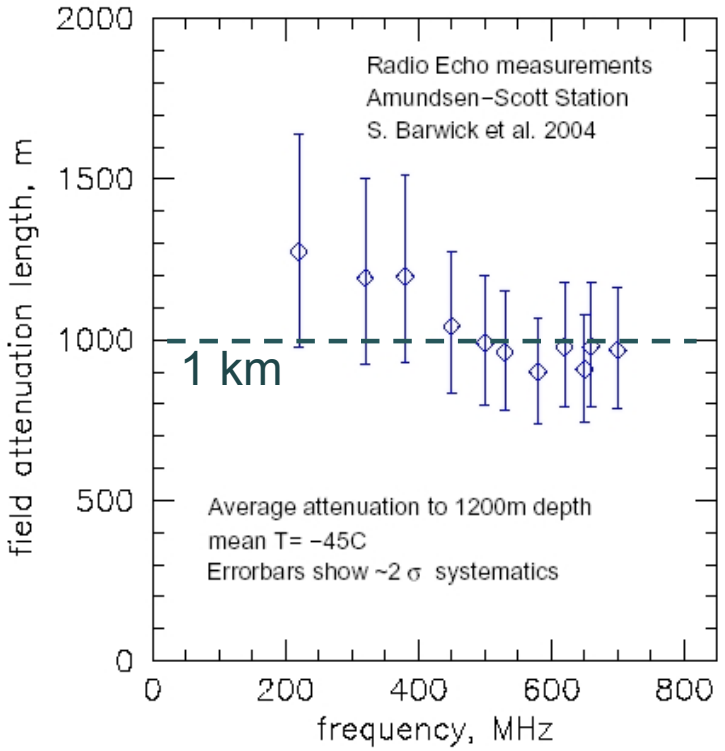
→ Radio Emission is much stronger than optical for UHE showers

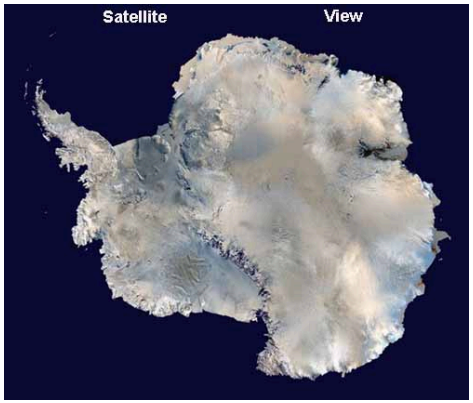


# UHE Neutrino Detector Requirements

- 1 GZK neutrinos/km$^2$/year
- $L_{int}$ ~ 300 km
  → 0.003 neutrinos/km$^3$/year
- Need a huge (> 1000 km$^3$), radio-transparent detector
- 3 media: salt, sand, and ice
- Long radio attenuation lengths in ice
  - 1 km for RF (vs. ~100 m for optical signals used by IceCube)

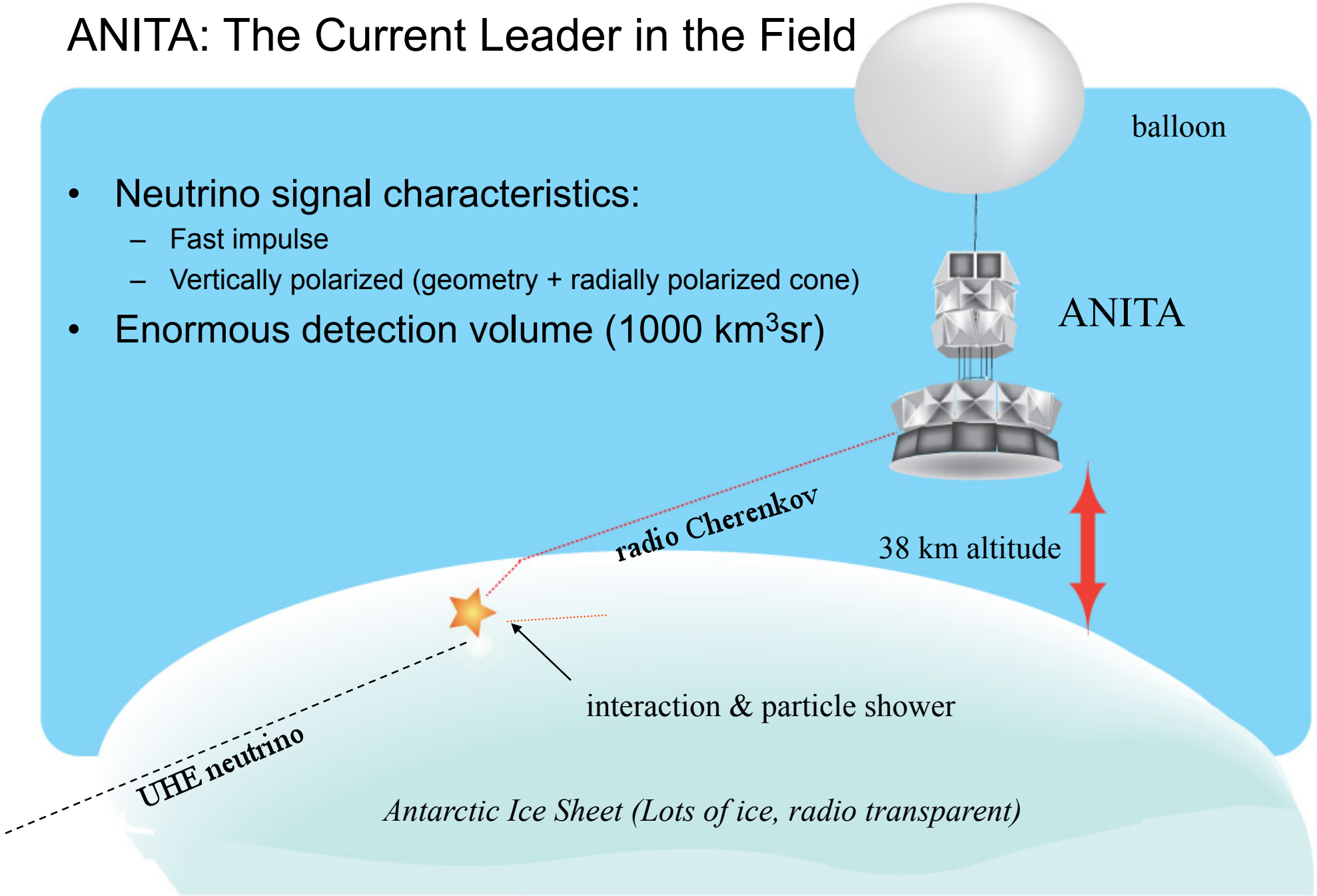
→ Ice is good for radio detection of UHE neutrinos!




# ANITA: The Current Leader in the Field

- Neutrino signal characteristics:
  - Fast impulse
  - Vertically polarized (geometry + radially polarized cone)
- Enormous detection volume (1000 km$^3$sr)



# The ANITA Instrument

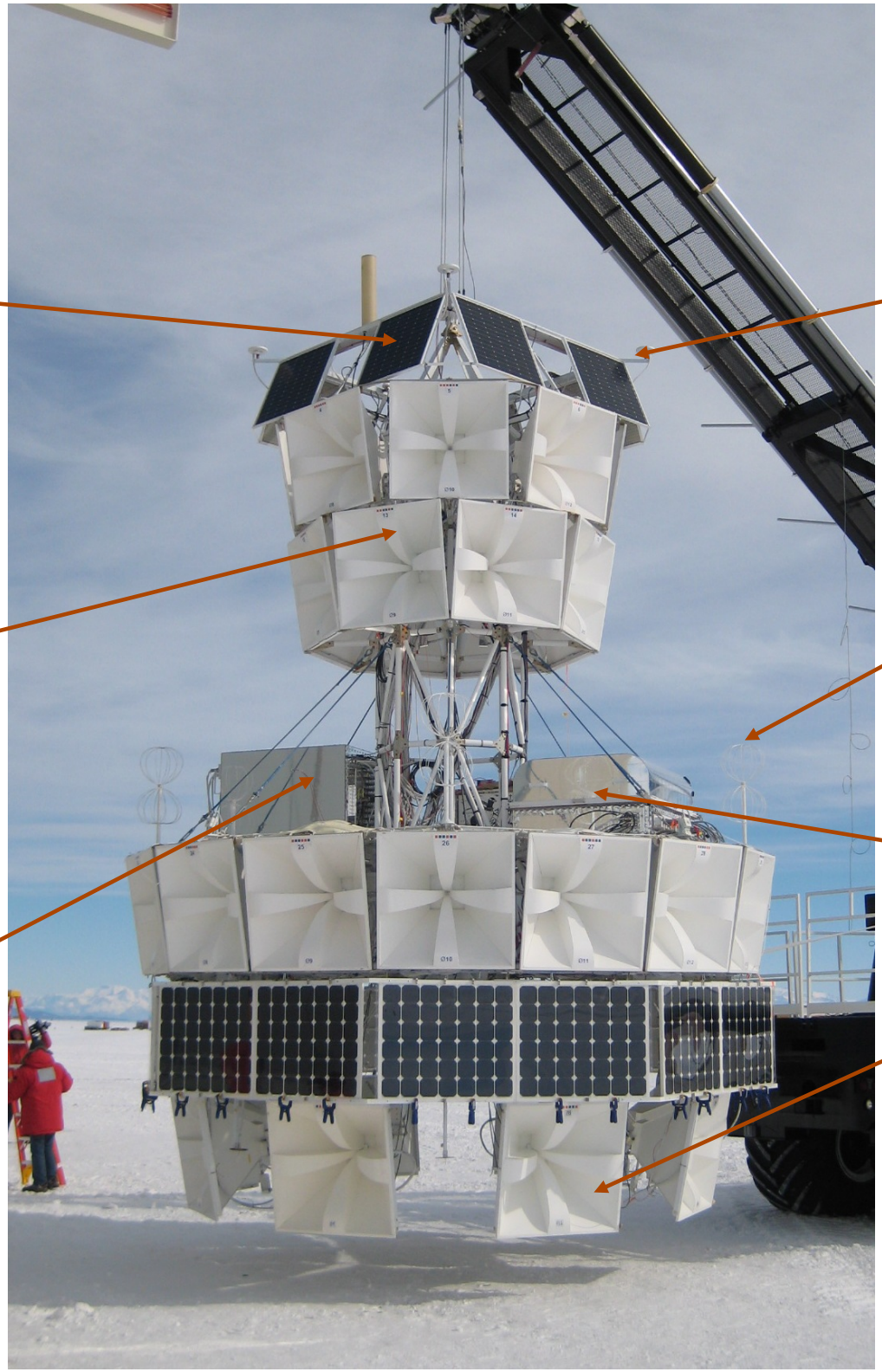
**(ANITA II)**

ANITA-I instrument paper:
ANITA Coll., PRD (2009)

- NASA Long Duration Balloon, launched from Antarctica

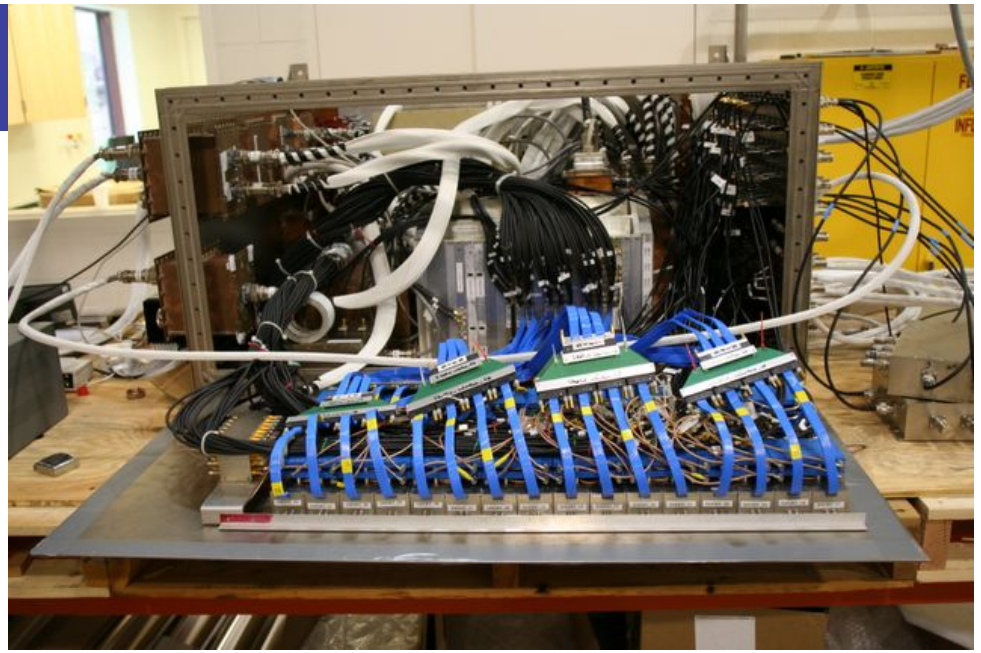
Instrument Overview:

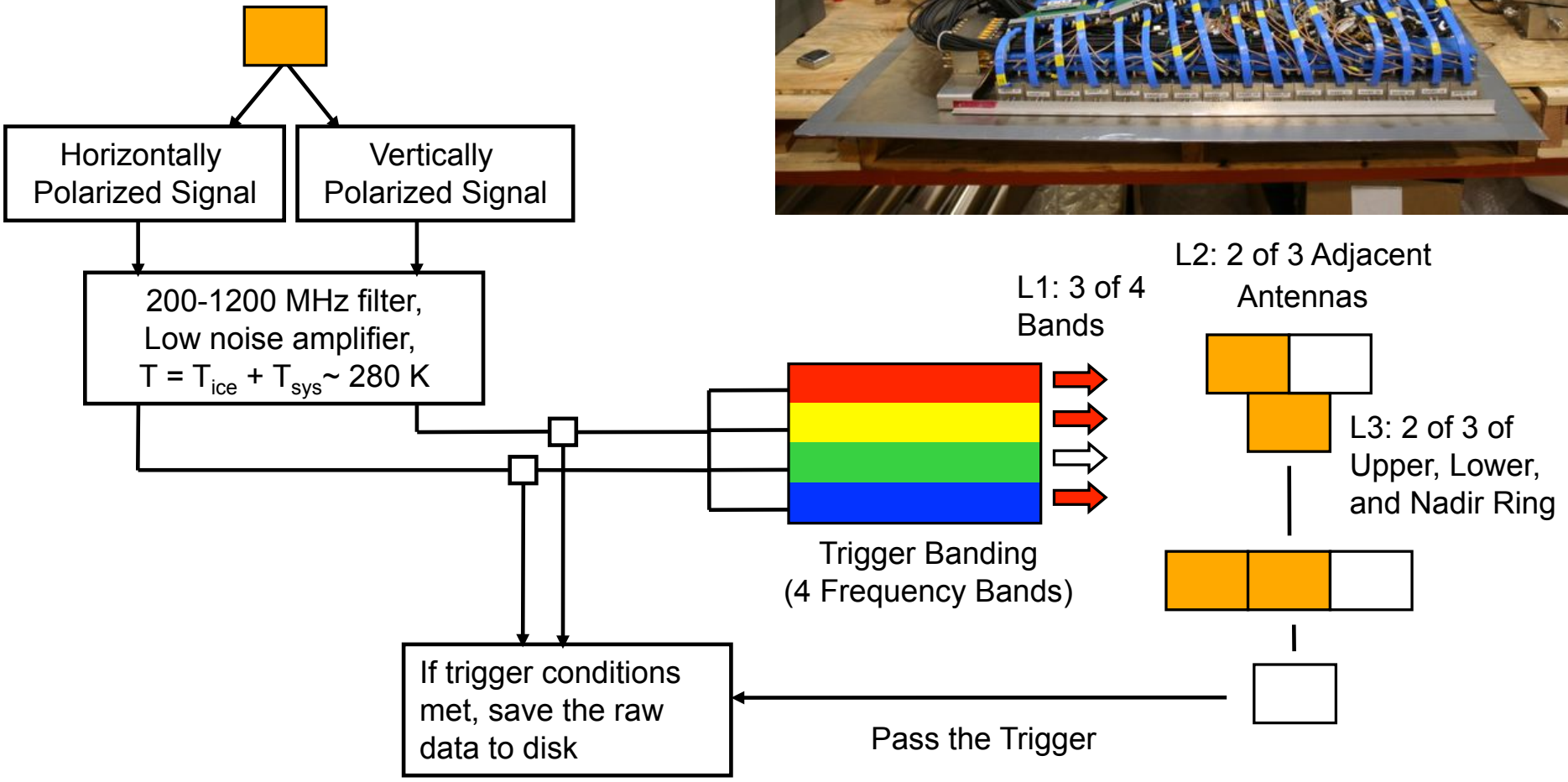
- 40 horn antennas (both polarizations measured)
- Frequency range: 200-1200 MHz
- Direction calculated by timing delay between antennas
- In-flight calibration from ground
- Threshold limited by thermal noise


Solar Panel Array
GPS Antenna Array
Horn Antennas for Detecting Signal
Bicone antennas for onboard pulsing
NASA Science Instrument Package
ANITA Instrument Box (computer, signal processing)
Drop-down antennas (ANITA-II and ANITA-3)

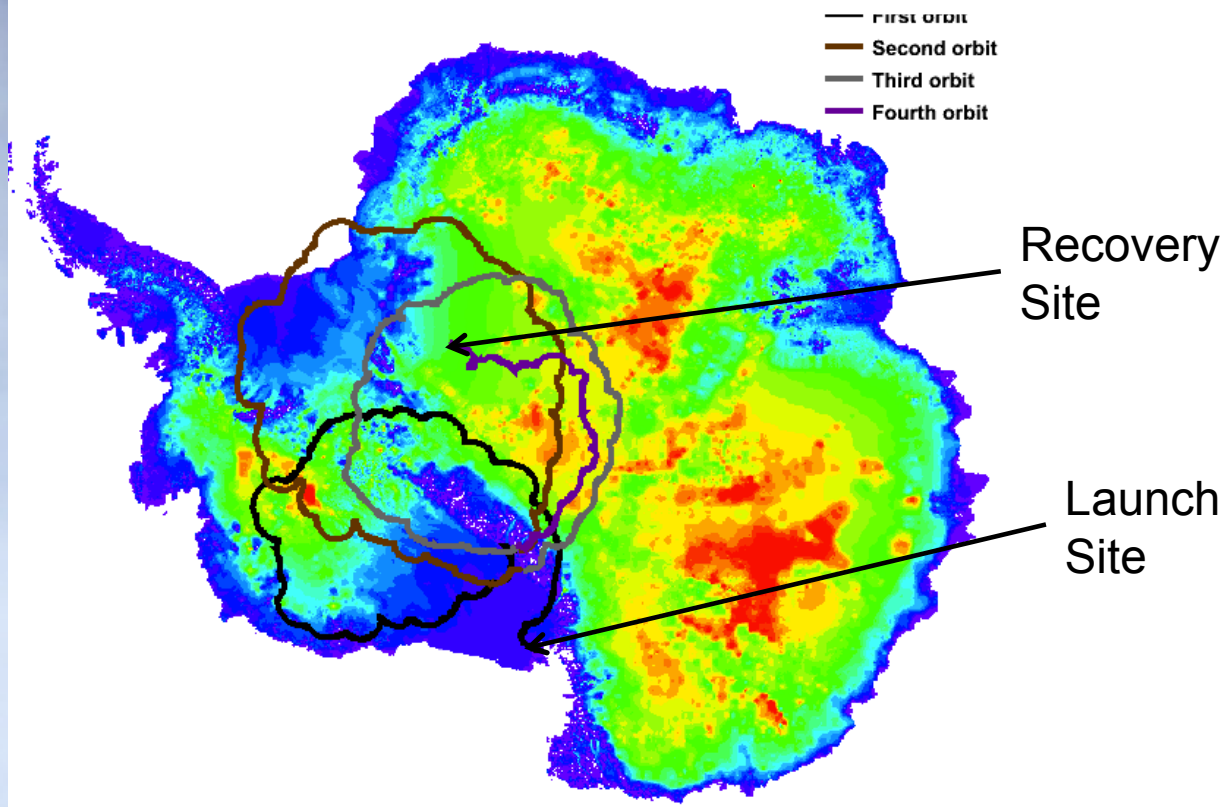
# How ANITA Works

## Data Acquisition and Trigger System





# ANITA-I Flight




- Launched: December 15th 2006
- 35 day flight, Full recovery
- 8 million events recorded

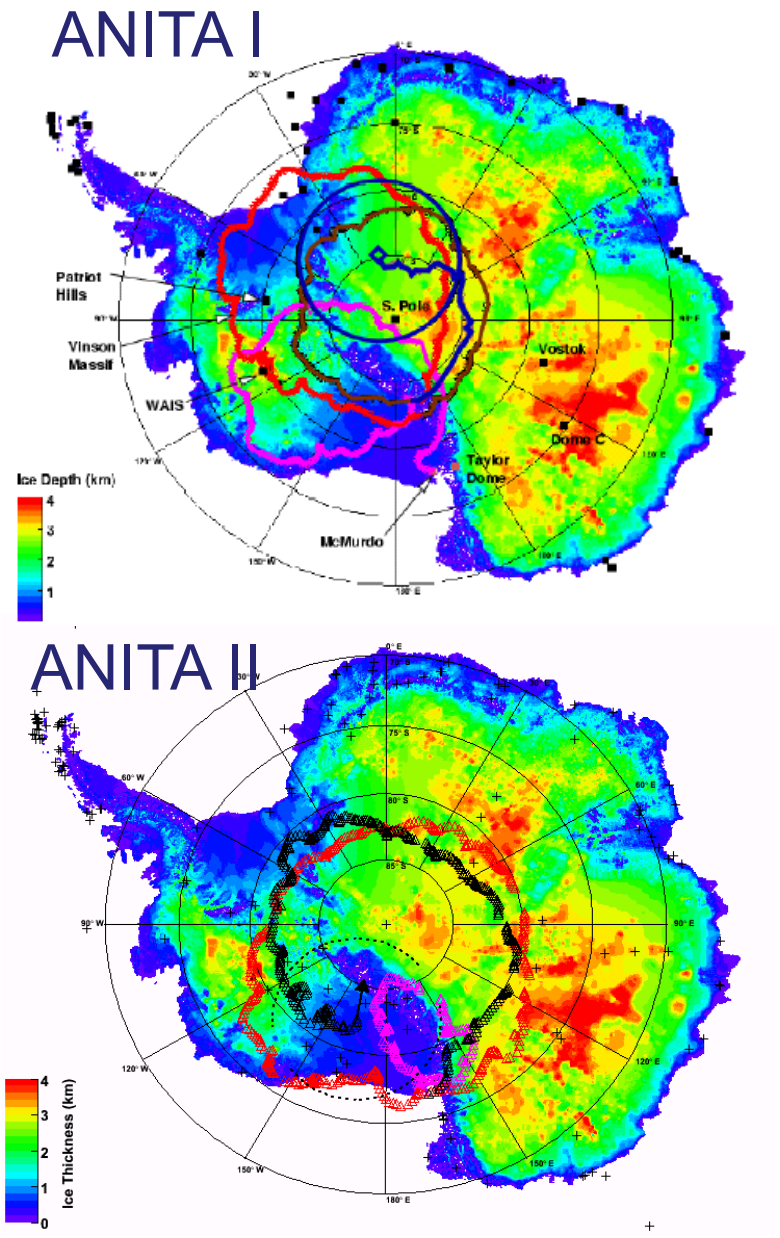

# ANITA-I “landing” → ANITA-II beginning

(D. Braun)

# Improvements for ANITA-II

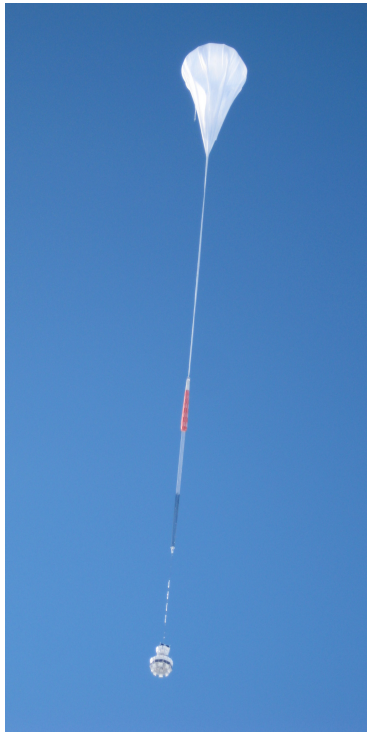
- Problems from first flight:
  - Unusual flight path
  - Repeated CPU crashing
- Improvements:
  - Lower Energy Threshold
    - Reduce front-end amplifier temp (20%)
    - Improve trigger efficiency (30%)
    - 8 more antennas (30%)
  - Increased Exposure
    - Directional trigger masking (30%)
    - Better flight path & more livetime (100%)

→ Total improvement: > 4 in neutrino event rate



# ANITA II Flight

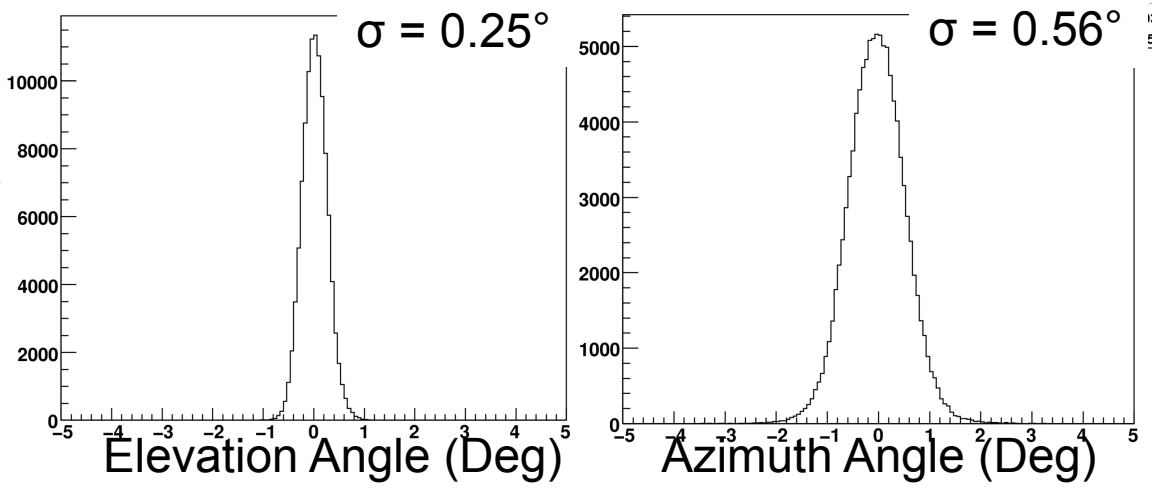
- Launched Dec 21st 2008
- 30 day flight
- 27 million events recorded



# Ground Calibration at Taylor Dome

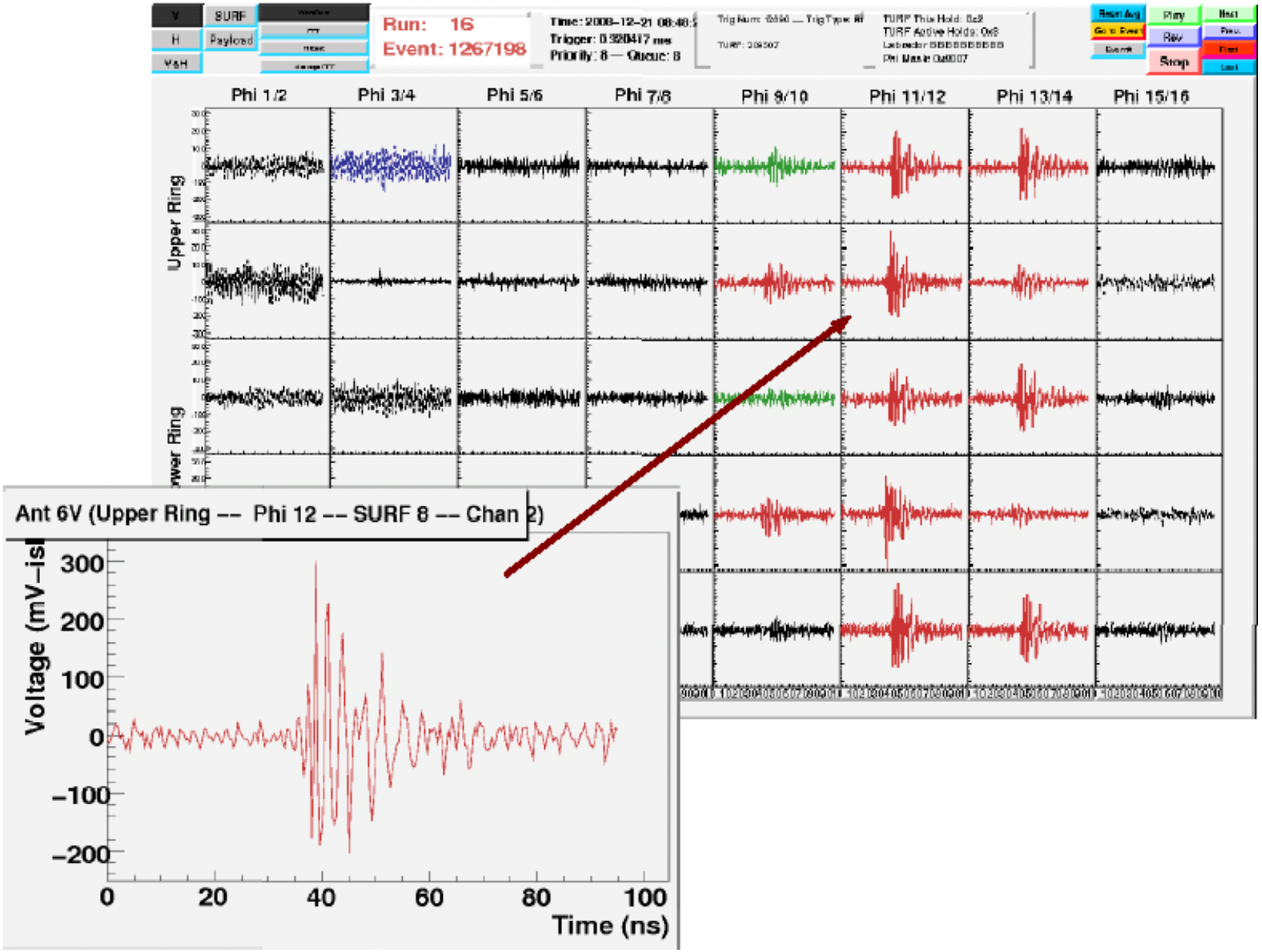
- 100 m deep borehole
  - discone antenna
  - fast, high voltage pulser
  - pulsing on GPS second

- Most important calibration tool:
  - pitch and roll
  - antenna positions
  - surface roughness effects
  - pointing resolution
  - mis-reconstruction efficiency
  - trigger efficiency




Kenn Borek Air
U.S. ANTARCTIC PROGR

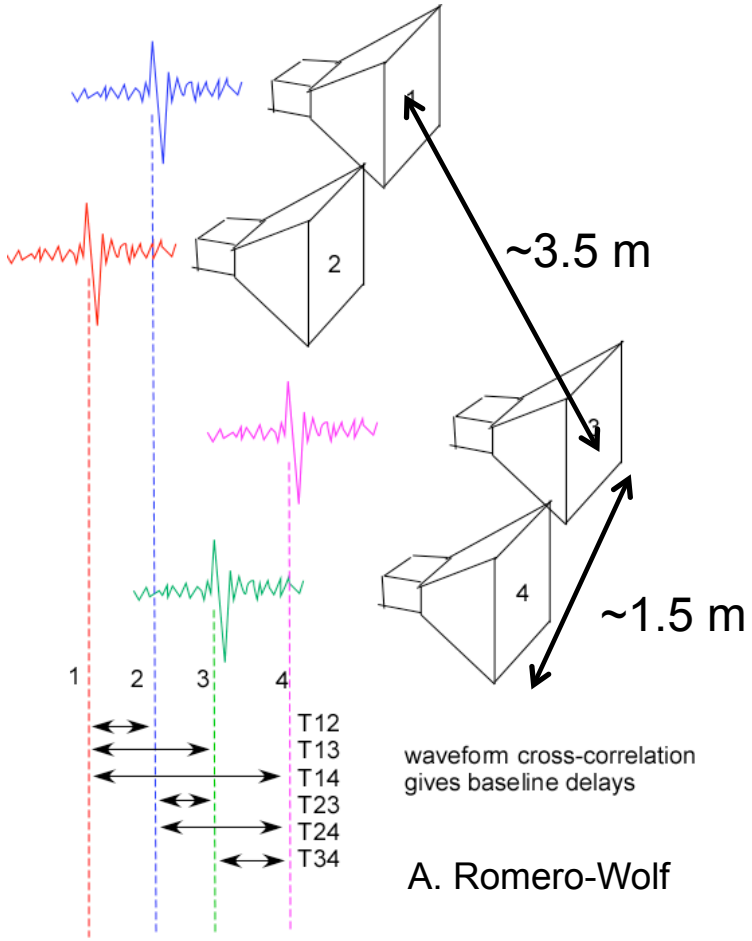
# An ANITA Calibration Event



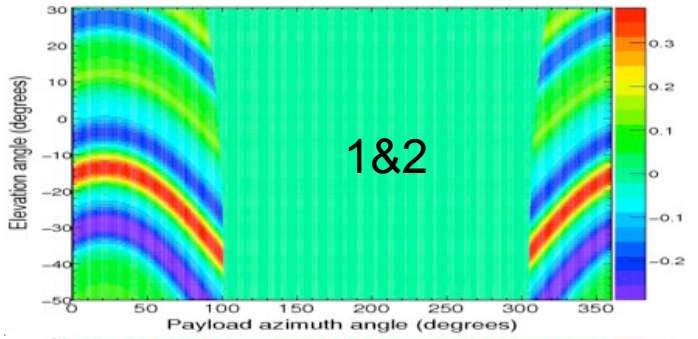
# Event Reconstruction

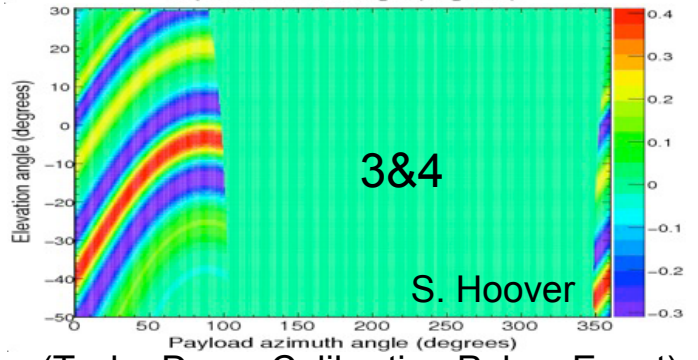
## Making an Interferometric Image:

- cross-correlation of antenna waveforms
- use timing delay given by direction
- sum over the whole payload

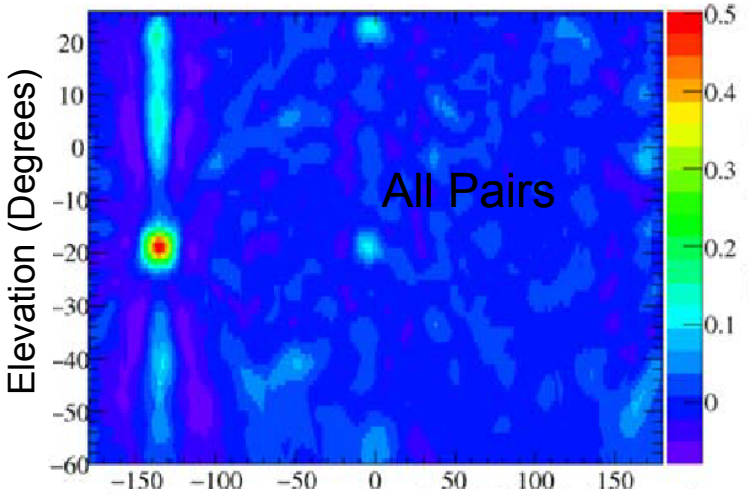



A. Romero-Wolf




(Taylor Dome Calibration Pulser Event)



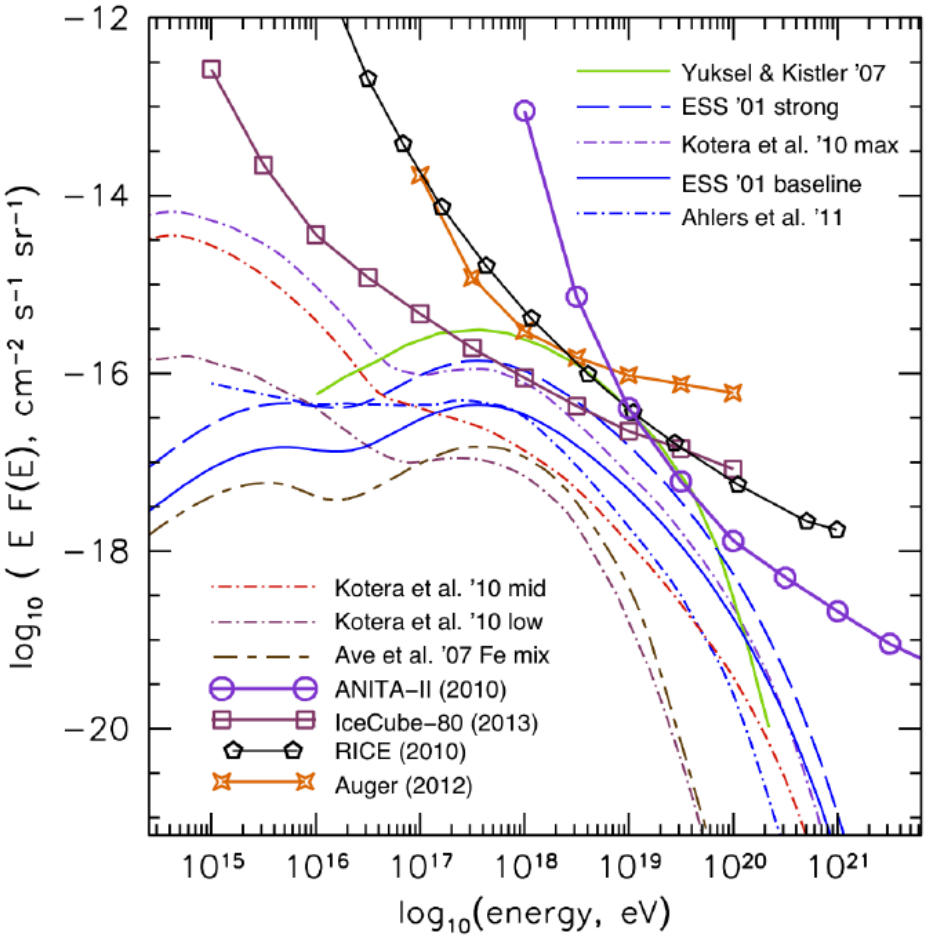
# ANITA-I & ANITA-II: Best Limit > $10^{19}$ eV

UHE Neutrino Search Results:

| | ANITA-I | ANITA-II |
|---|---|---|
| Neutrino Candidate Events | 1 | 1 |
| Expected Background | 1.1 | 0.97 +/- 0.42 |

Combine results with analysis efficiency and Monte Carlo simulation to provide world's best limit on the UHE neutrino flux

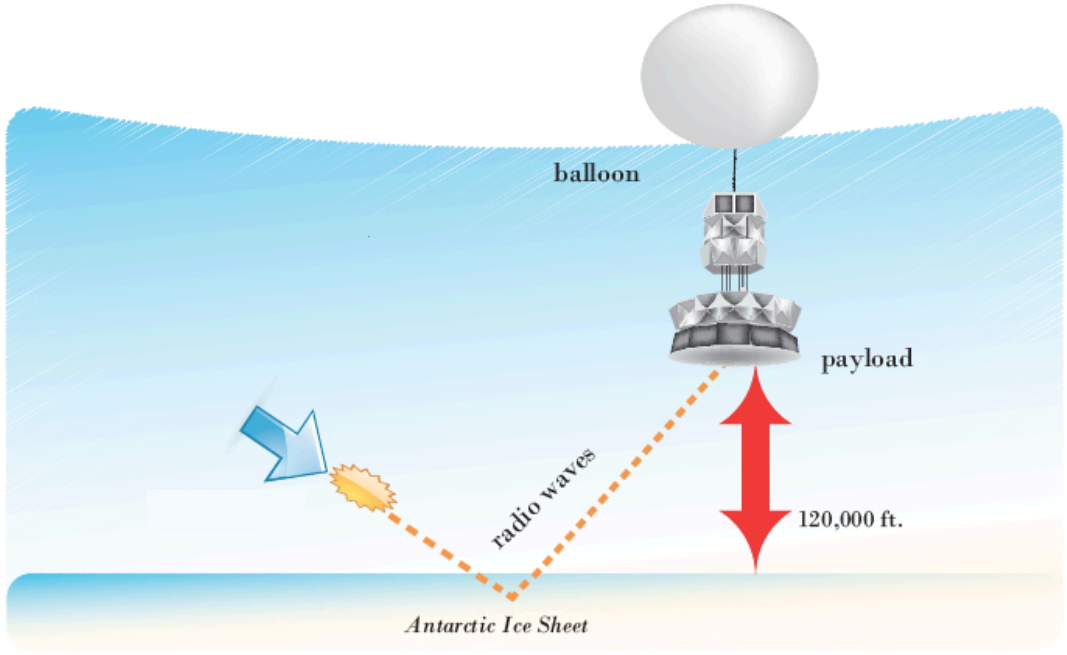
→ Starting to constrain theoretical models



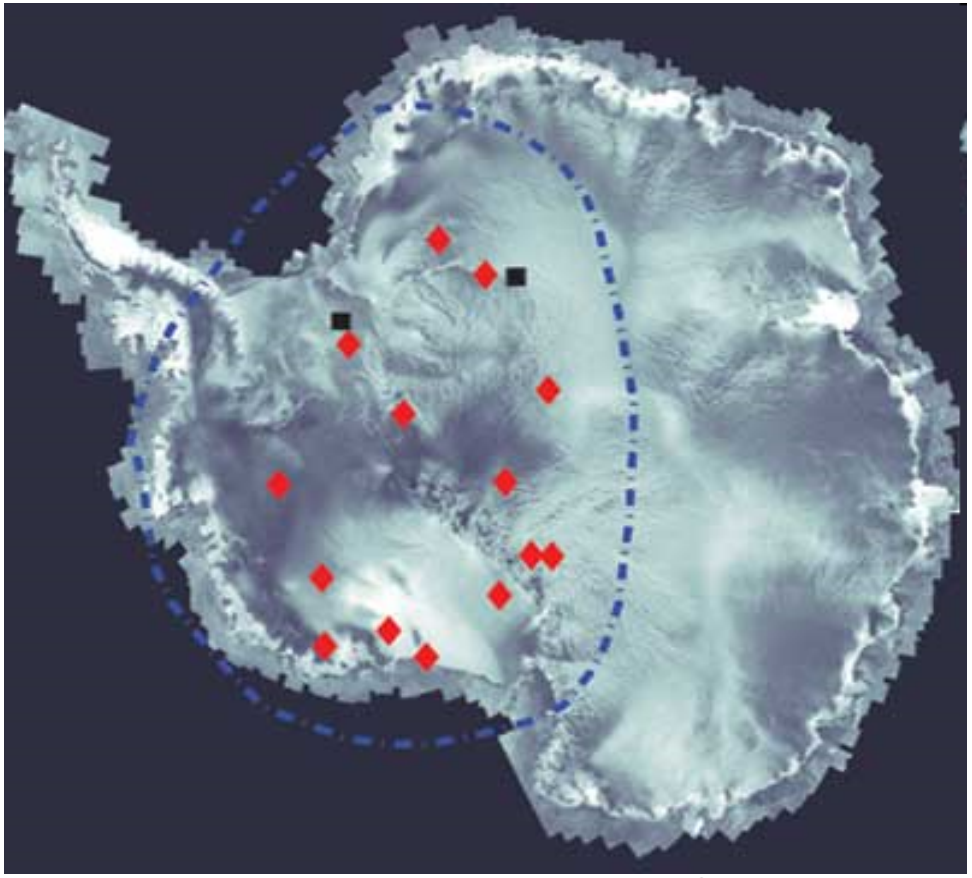

ANITA Coll., PRD 2010

# But What About Horizontal Polarization?

- Reminder: signals from neutrinos strongly favor vertical polarization
  - Only see the top of the Cherenkov cone
  - Fresnel coefficients transmit more V-pol than H-pol
- Reflections from above-horizon sources would favor H-pol over V-pol at the balloon



# ANITA Horizontal Polarization Results

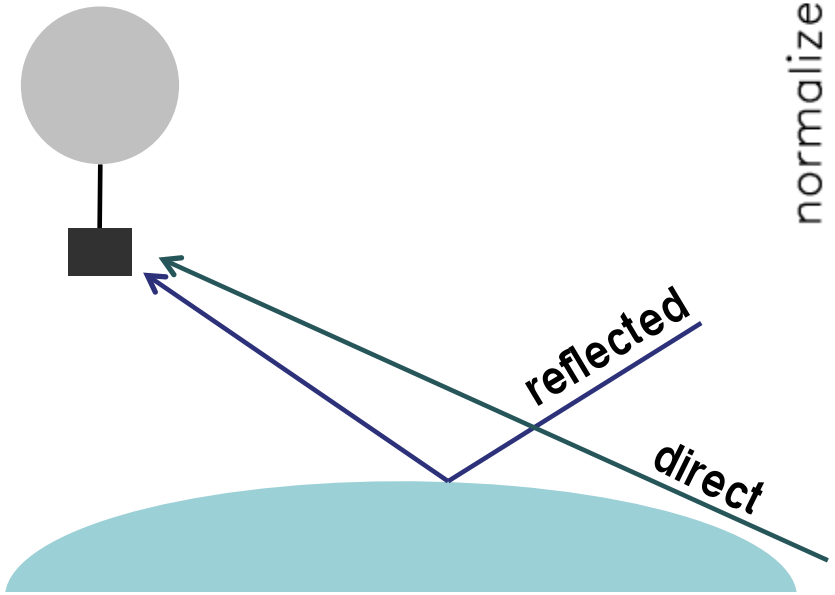


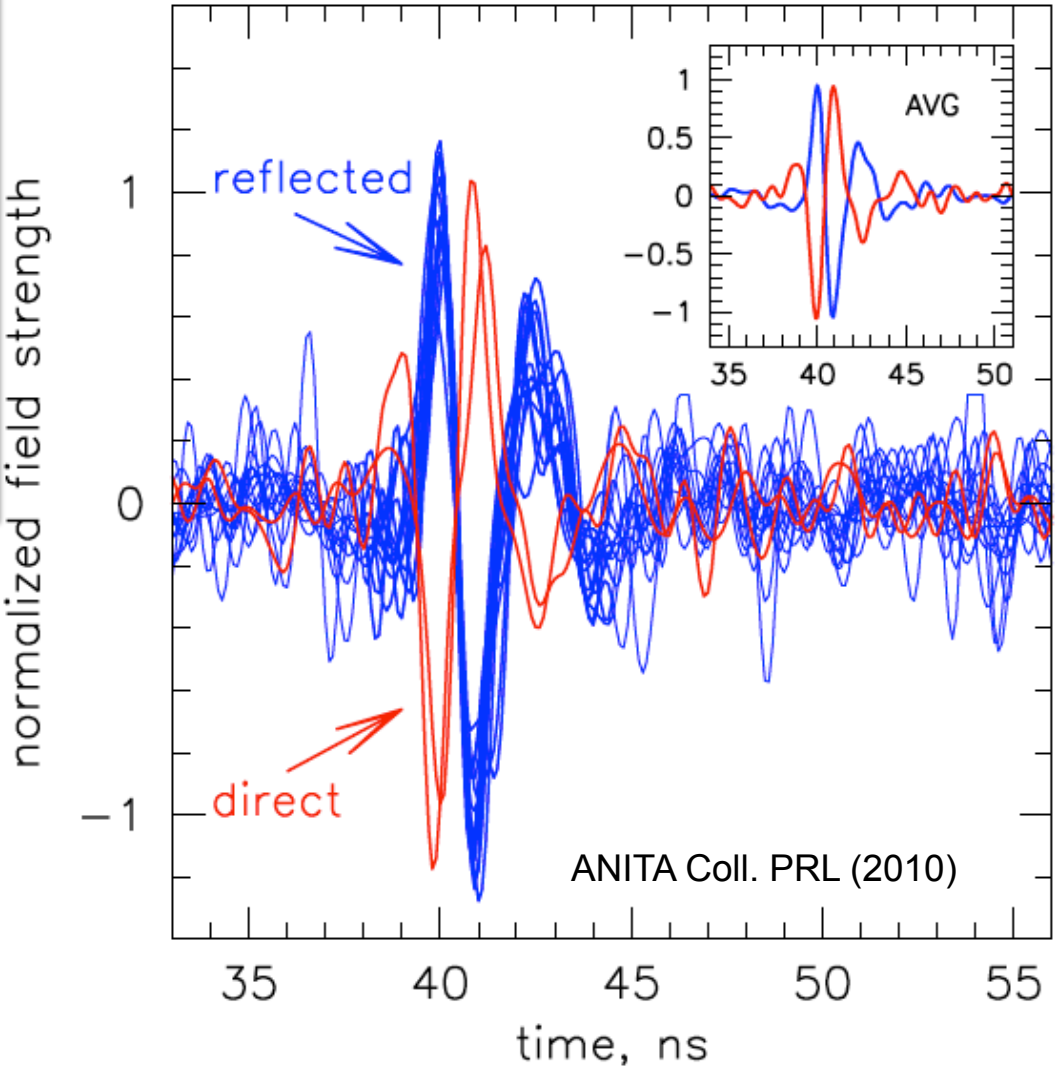
ANITA Coll. PRL (2010)

- ANITA-I detected 16 isolated H-pol events
- ANITA-II did not trigger on H-pol channels
  - Still detected 5 isolated H-pol events
- These events are the first detection of UHE cosmic rays using radio techniques!

# Are They Really Cosmic Rays?

- 14 events that reconstruct to the surface all look the same (blue)
- 2 more above-horizon events (red)
- Reflection of radio inverts



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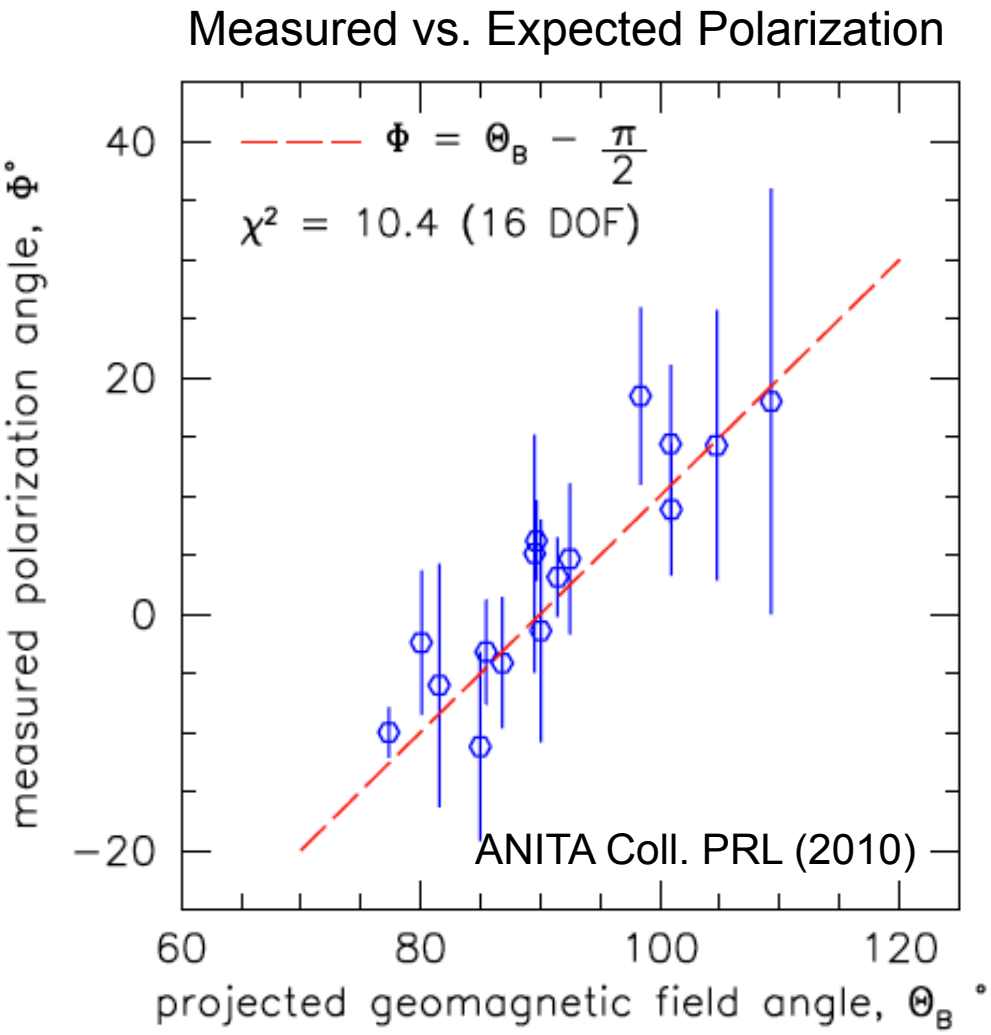
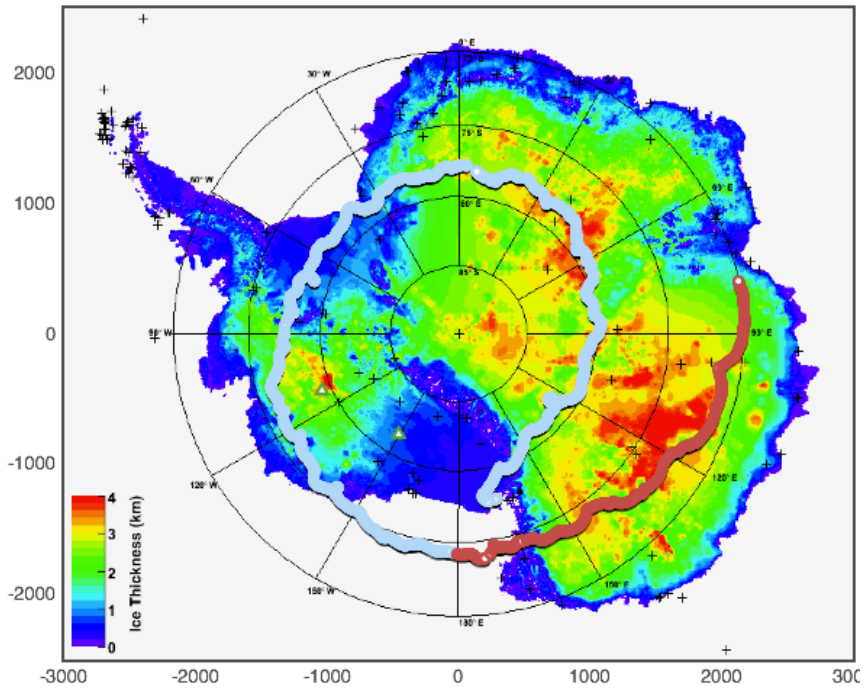



- Radio signal mechanism: geo-synchrotron emission from cosmic ray extended air showers
- Direction of geo-magnetic field determines polarization direction (F=q **v** x **B**)
  - Mostly vertical magnetic field in Antarctica

  → Expect mostly horizontal UHECR events
- Energy: ~$10^{19}$ eV (but determining energy is hard)

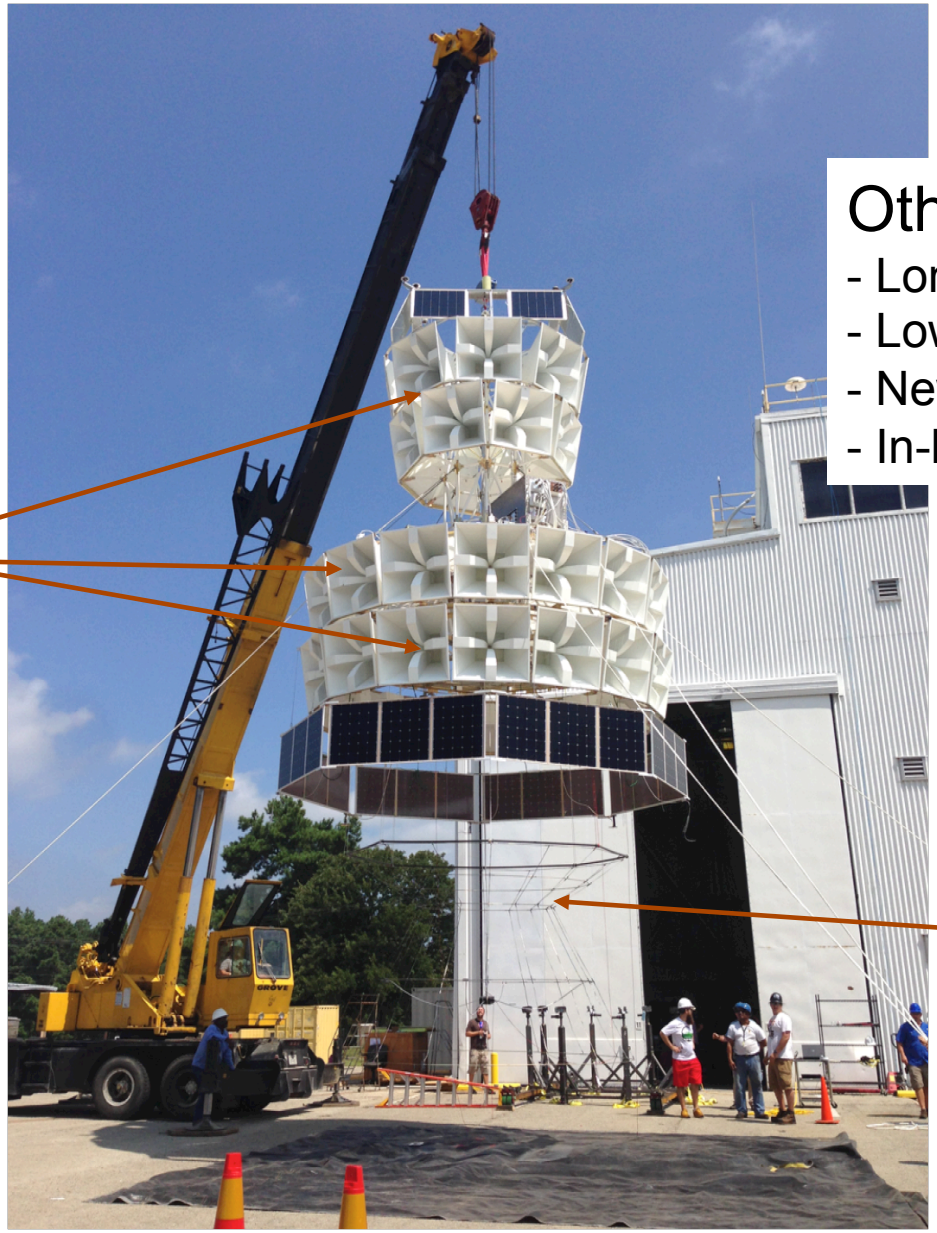
# ANITA-III: December 2014




- Full payload integration July 2014
- Launched December 2014, 22 Day flight
  - Improve to ~200 UHECR events
  - Factor of 5 more sensitivity for neutrinos

A. G. Vie

# ANITA-III Design



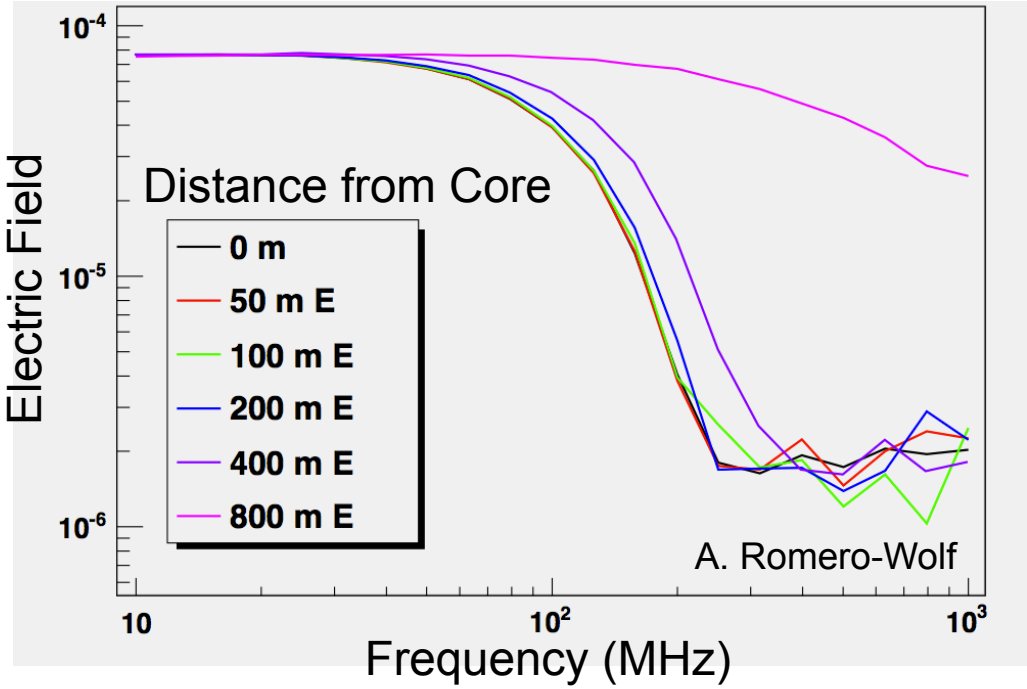
More (48) Antennas

Other Improvements:
- Longer traces digitized
- Lower noise RF chain
- New trigger scheme
- In-house built RF amplifiers

Low-Frequency Antenna for Cosmic Ray Science

# ANITA-III: Low Frequency Antennas

Simulated Cosmic Ray Airshower ($10^{19}$ eV)




Important for cosmic ray science
→ guaranteed signal!

~4m

~2m

Antenna must be deployable post-launch & lightweight

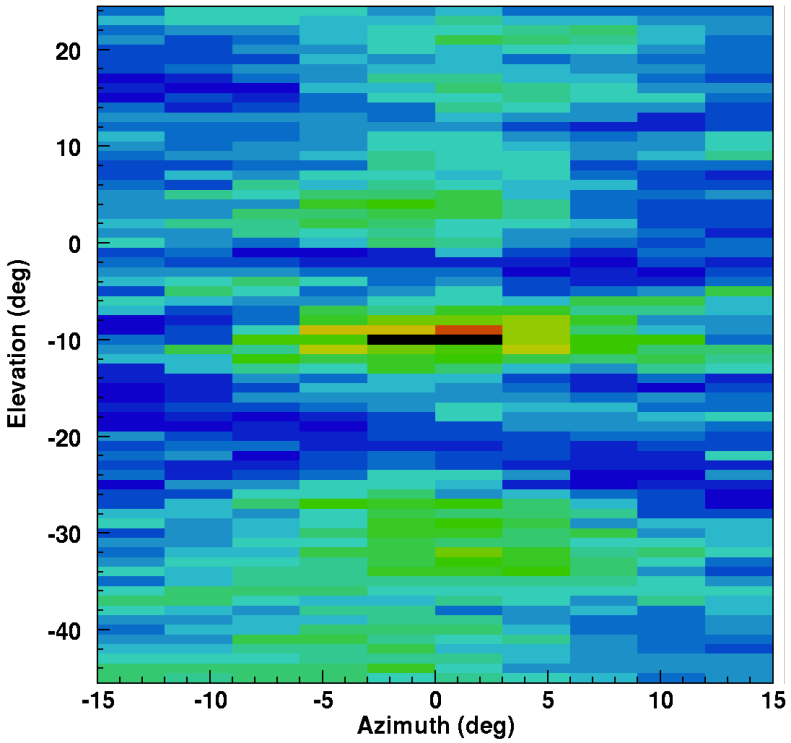
Enormous drop-down antenna

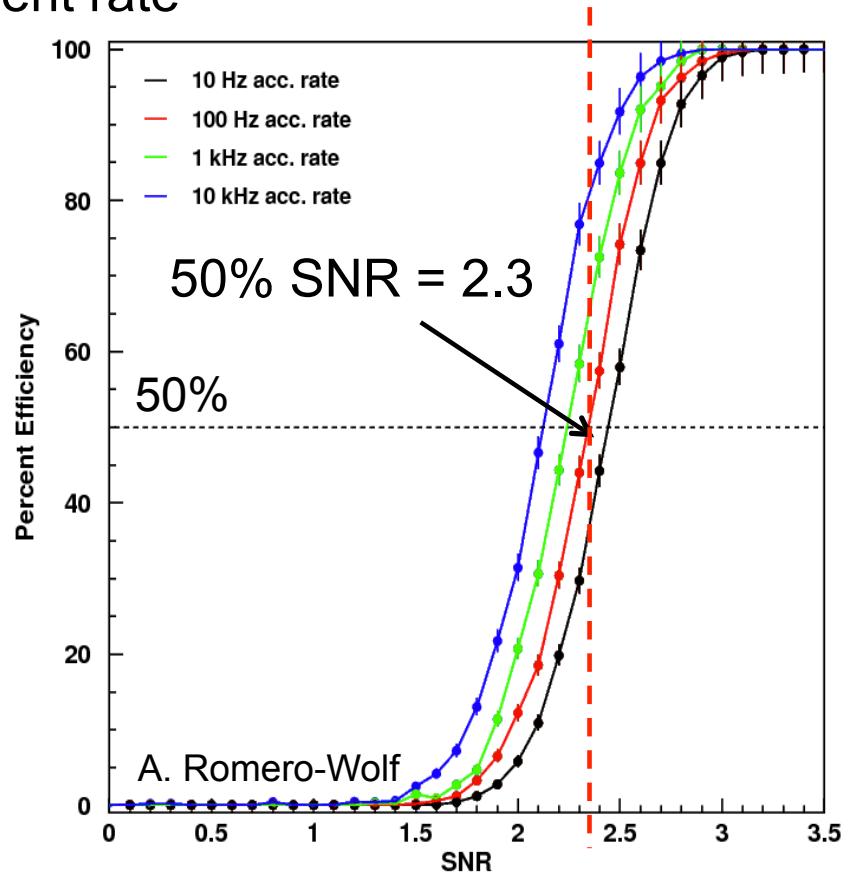
# ANITA-III

- Trigger: replaced multi-band requirement of ANITA-I and ANITA-II with single threshold trigger per antenna to target impulsive events
  - Significant improvement in neutrino efficiency!
  - Lesson learned: need to be very careful about CW rejection from satellites and ground-based sources

# ANITA 4: Coherent Power Sum Trigger

- ANITA-II trigger: 50% efficient at 3.5 sigma
- ANITA-4 trigger: make an interferometric image on the fly
  → 50% efficient at 2.3 sigma
  → Factor of 5 more improvement in event rate



# Summary

- Radio detection technique for UHE neutrinos and cosmic rays opens a new window onto the universe
  - ANITA-III just flew: x20 UHECRs, x5 neutrino sensitivity
  - ANITA-4 funded and planned for December 2016
    - New imaging trigger for improved neutrino event rate
  - Lessons learned
    - Pointing is really important (directional antennas, Nyquist digitization)
    - Calibration is critical
    - CW is everywhere and is important to reject at the trigger level