ASKARYAN RADIO ARRAY THE OHIO STATE UNIVERSITY CCAPP

Ultra-High Energy Neutrino Astrophysics with the Askaryan Radio Array (ARA)

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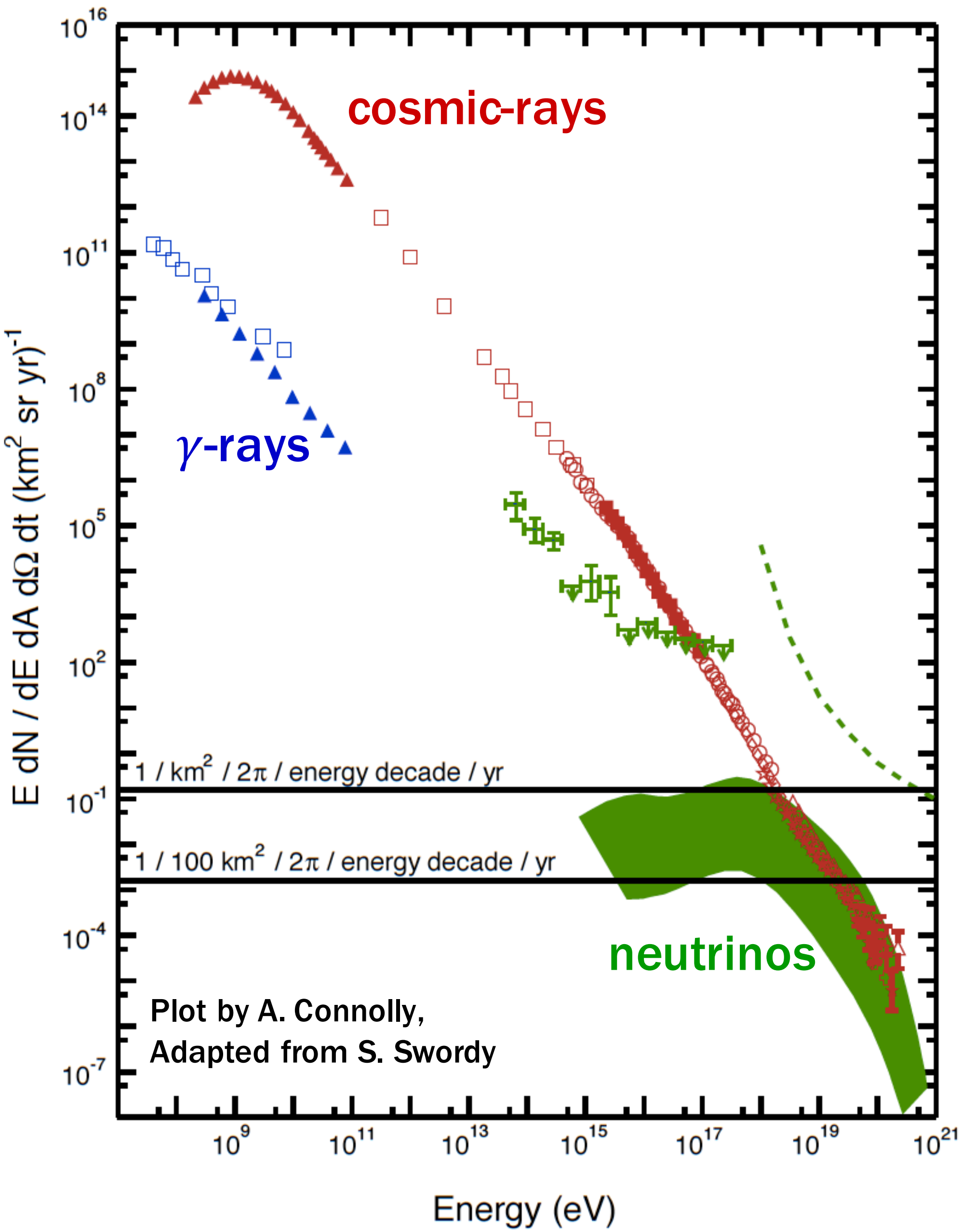
Why Study Neutrinos?



Astrophysical Motivation: Only probes of the highest energies at cosmic distances

- Cosmic rays $>10^{19.5}$ eV attenuated by GZK effect, e.g.

$$p + \gamma \rightarrow \Delta^{+} \rightarrow p(n) + \pi^{0}(\pi^{+})$$

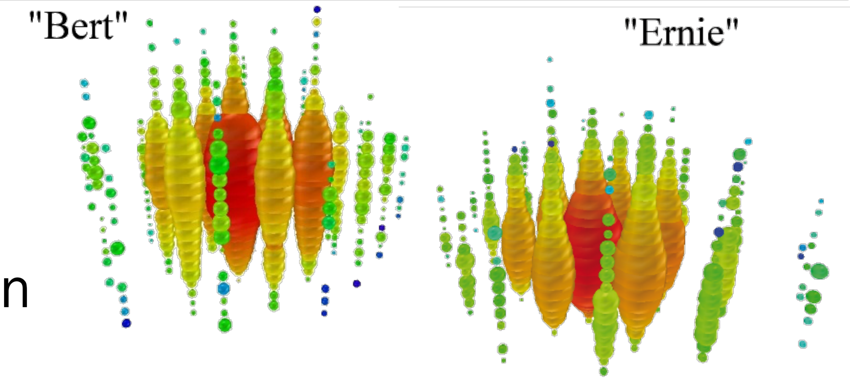
→Extragalactic hadronic sources (>100 MPc) are screened

- Gamma rays pair-annihilate with Extragalactic Background Light (EBL) above ~1 TeV

Particle Physics Motivation: Probe cross-sections at energies above accelerators

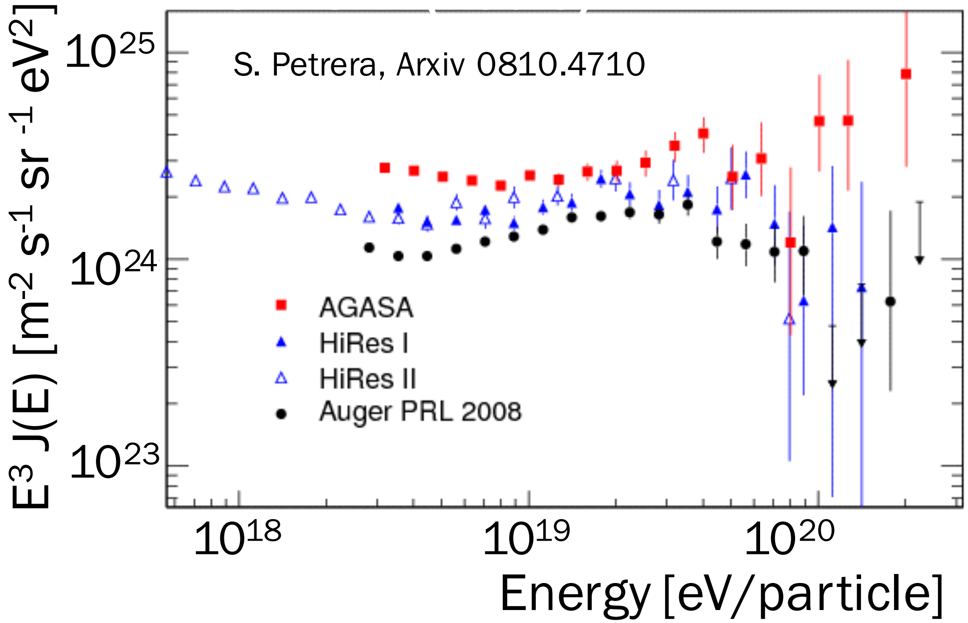
- An EeV (10^{18} eV) neutrino interacting in ice has COM energy of ~60 TeV (note: LHC 13 TeV)

Cosmic Neutrinos



They Exist!

- 2012: IceCube experiment first saw PeV neutrinos which appeared to be of cosmic origin
- Today's discussion: neutrinos x10^3 more energetic—the "UHE" regime

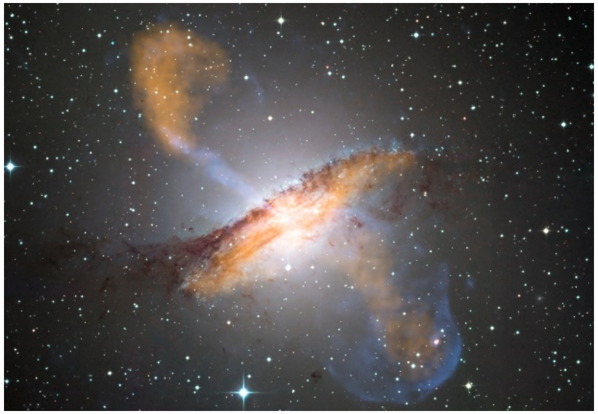


Two Sources of Neutrinos

- "BZ Flux": The pions from the GZK process decay into neutrinos
- "Source Flux": Neutrinos from the CR accelerators
  - Gamma Ray Bursts (GRB)
  - Active Galactic Nuclei (AGN)

Neutrinos have attractive properties

- Weakly interacting: travel cosmic distances unattenuated
- Chargeless: not deflected by (inter) galactic magnetic field → point back to source!



AGN
Centaurus A.
(ESO public image release)

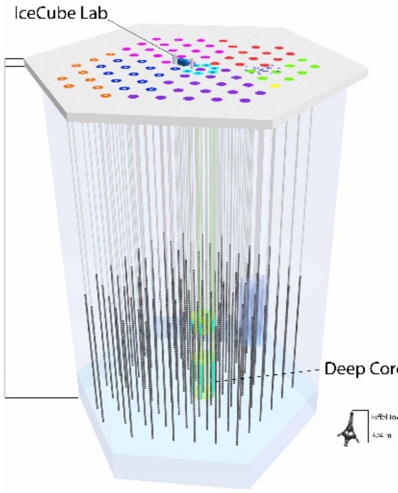
Detecting an UHE Neutrino

Rare Signal

- UHE Neutrinos have low fluxes (~10/km^3/yr) and low cross-sections (interaction length ~300km in rock)
- Need hundreds of km^3 of target volume to enable detection (e.g., dozens per year)
- Several Options:
  - Balloon experiments: radio
  - *In-Situ* experiments: optical, radio
  - Ground based arrays: air shower, radio
- ***In-situ* experiments (like ARA) must instrument the volume sparsely to achieve these large detector volumes**

ANITA-III (radio)

IceCube (optical)

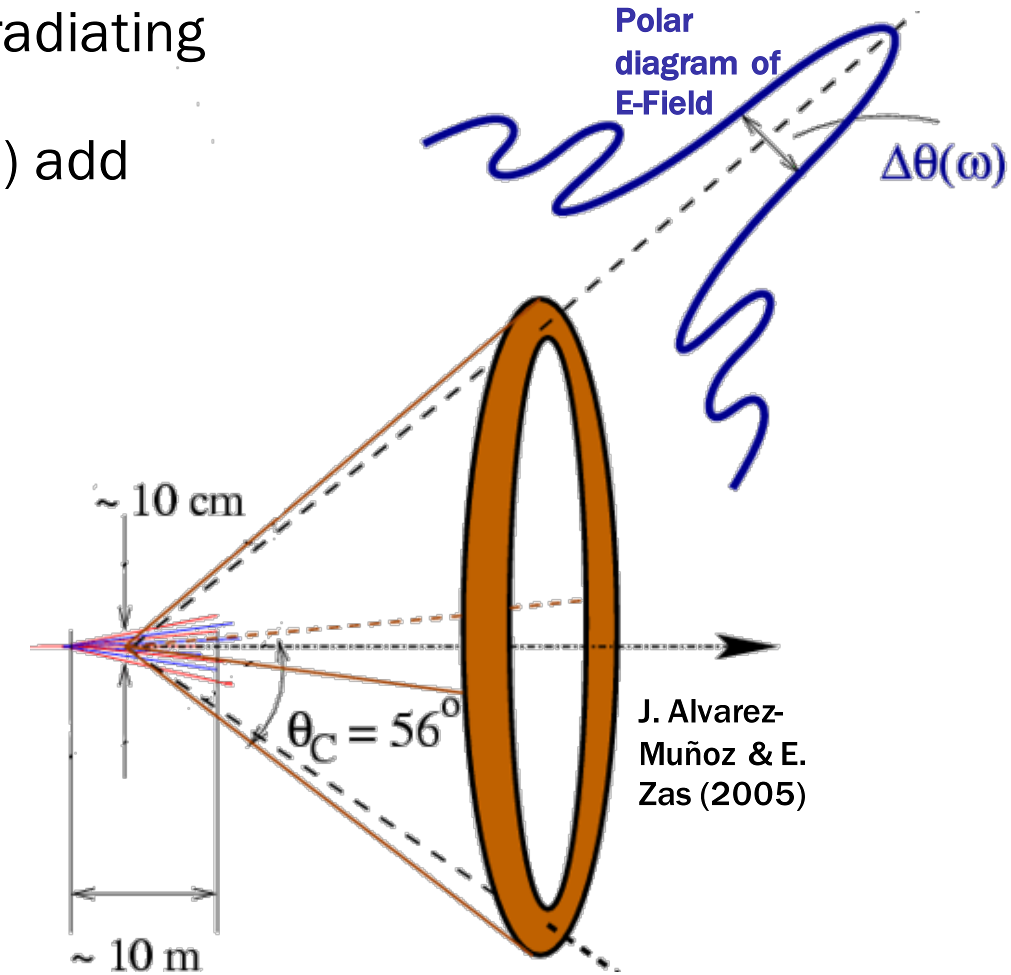


LUNASKA (radio)

Auger (air shower)

Radio: Askaryan Effect

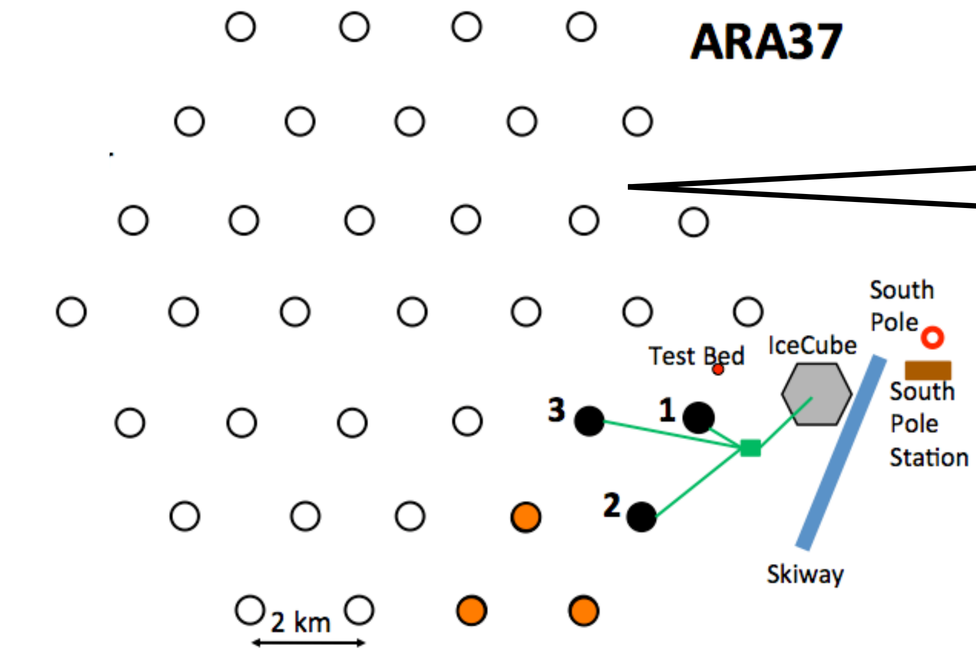
- Neutrino interaction in dense media creates shower of charged particles
- ~20% more electrons than positrons –”bunch” of particles moving through media and radiating
- Wavelengths the size of the bunch (~cm) add coherently, producing a characteristic broadband (200 MHz → 1GHz), bipolar, impulsive radio signal
- Conical emission, strongest signal “on cone”
- **Two requirements for successful experiment**
  - **Radio transparent medium: ice**
  - **Enormous volume: Antarctica**

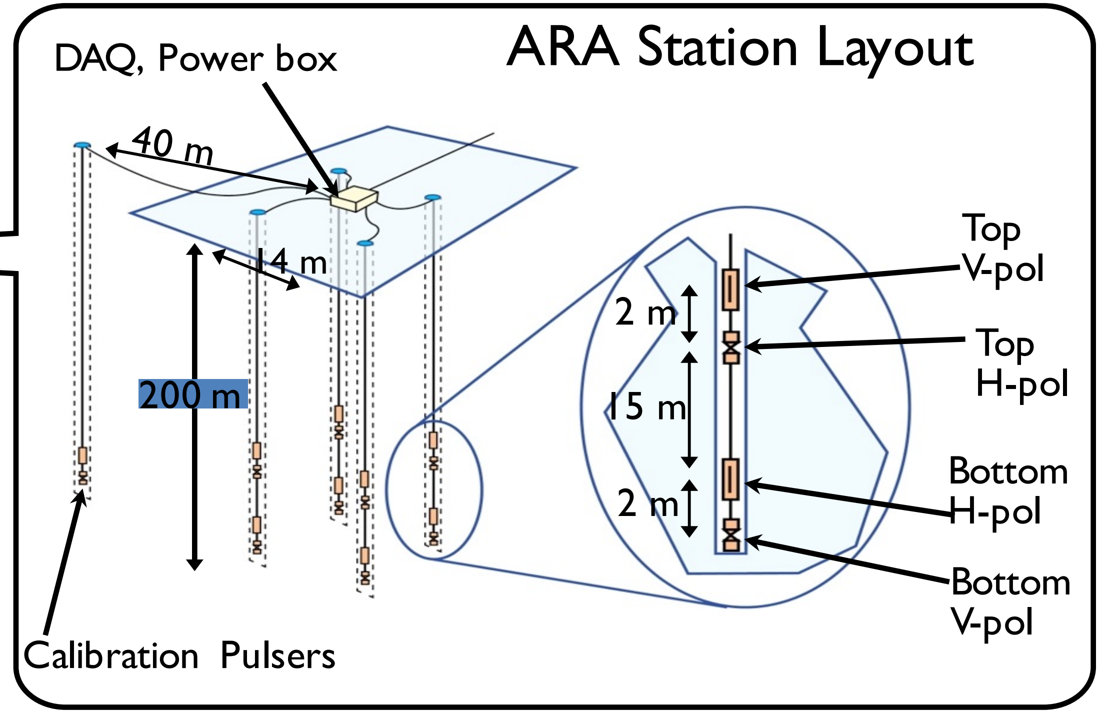


J. Alvarez-Muñoz & E. Zas (2005)

Askaryan Radio Array (ARA)

Deployed Station
To be Deployed in 2017
Planned ARA 37



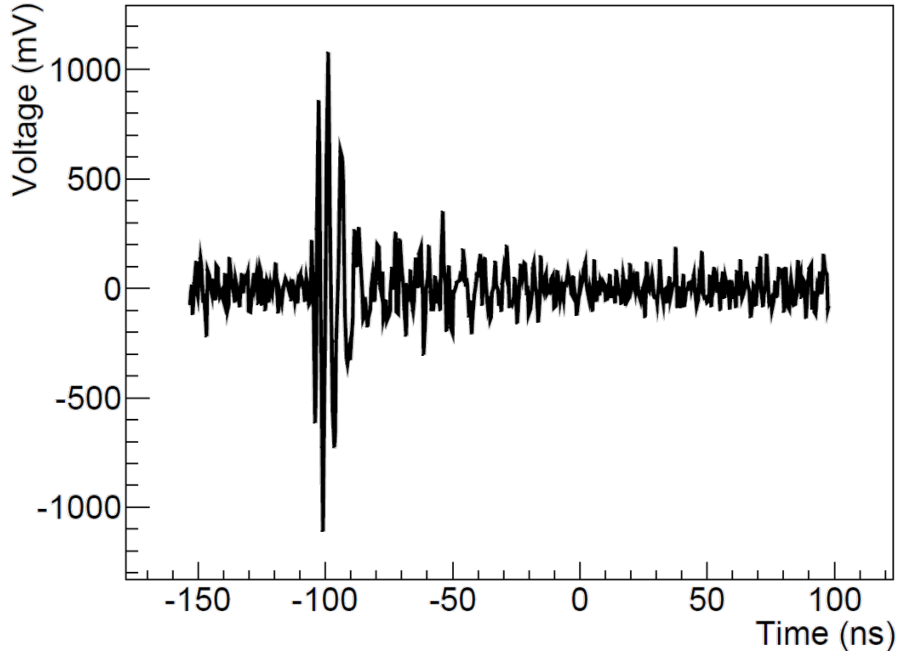


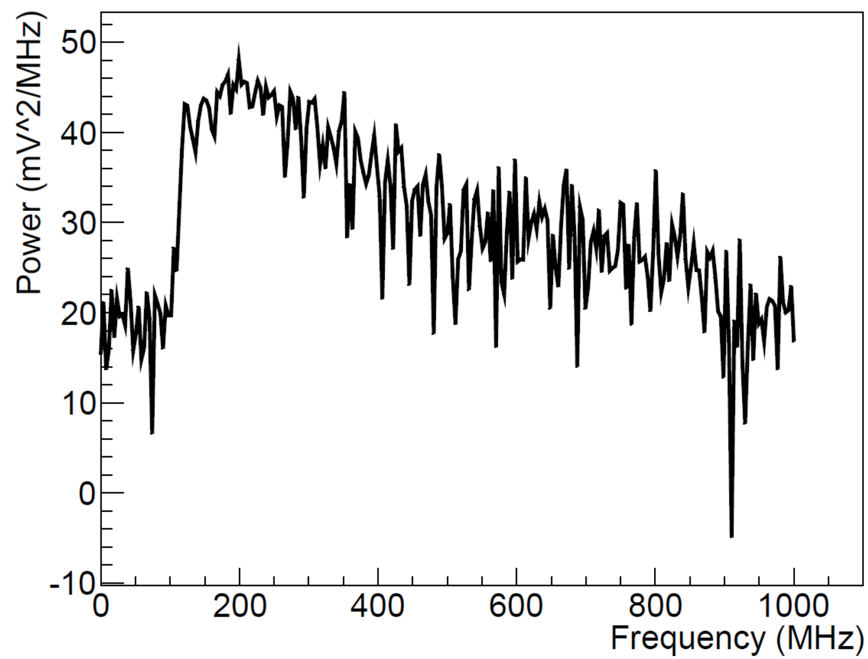
- Station Design
  - 16 antennas deployed on 4 strings; mix of V-pol and H-pol
  - Buried 200 meters deep, all connected to central DAQ with ~3 GHz sampling
- ARA is under phased construction in the ice near South Pole
  - Prototype ("Testbed") + 3 stations deployed so far
  - Next two stations to be deployed in 2017
  - Full array will have 37 stations, cover ~100 km^2 ice

V-Pol Antenna **H-Pol Antenna**

Signal Identification

Calibration Pulser Event
Testbed Station





In Hardware: Signal Should be Impulsive

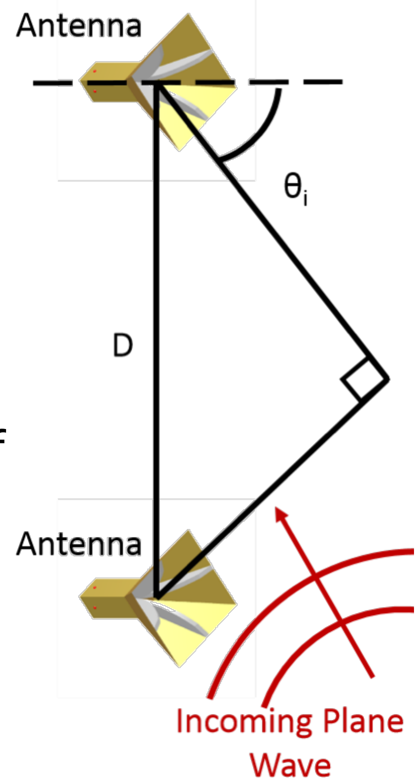
- *ARA Triggers on Power:* integrated power over ~10ns must be > threshold
  - Coincident requirement: requires impulses in multiple antennas within a time window
- *Effective at identifying neutrinos*: pulses have large integrated power over small time windows
- *Good at rejecting thermal noise:* noise would have to fluctuate high in multiple channels

In Software: Signal Must be Broad in Frequency

- *Impulsive signals are broadband*
- Anthropogenic backgrounds are usually narrow band (people talking on radio, for example)

Interferometric Maps

$$\theta_i = \arcsin\left(\frac{c\,\Delta t}{D}\right)$$

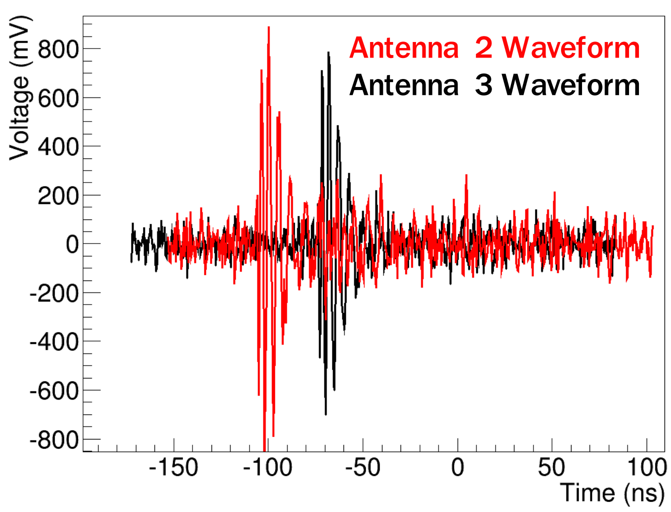


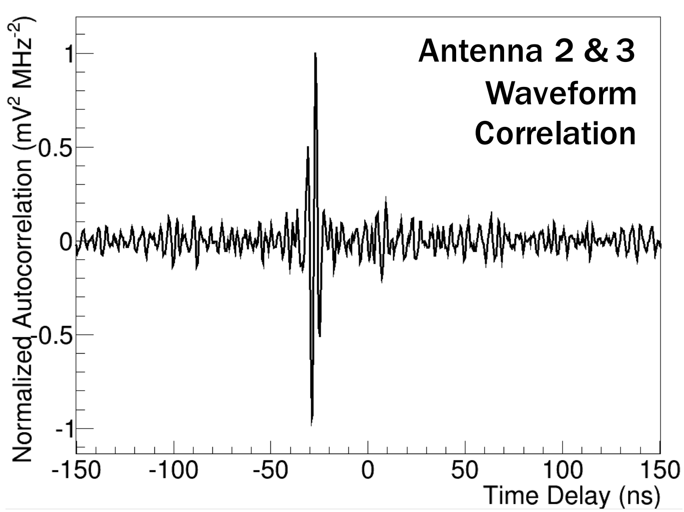
Anatomy of an Interferometer

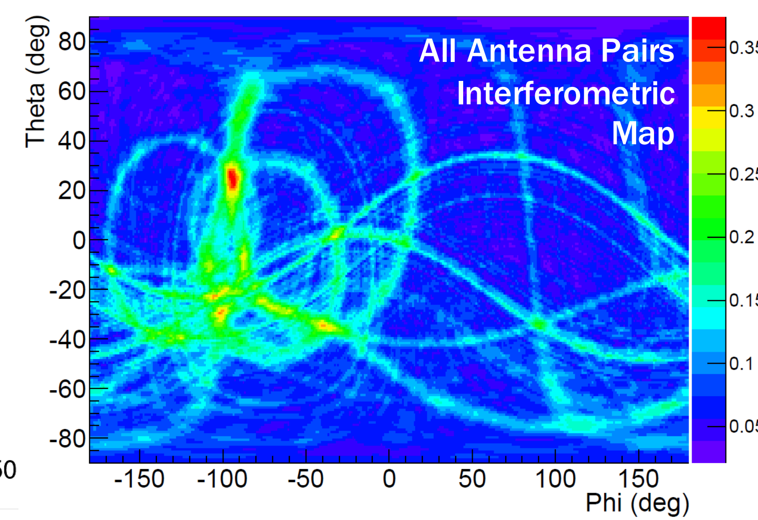
- Timing information translates into geometry information
- The peak of the waveform cross correlation (CCW) identifies the time delays and possible RF source angles
- Plotting the strength of the CCW in 2D (θ,φ) for multiple pairs of antennas gives an interferometric map—this identifies a single reconstruction point

Usefulness of Interferometry

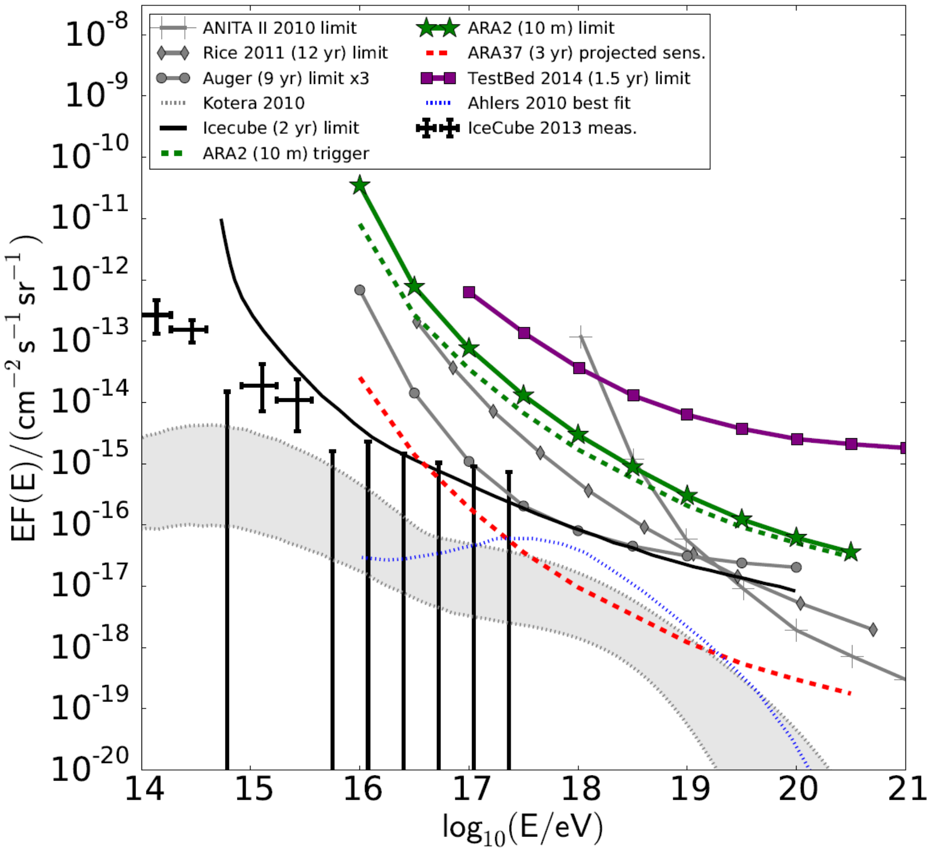
- Used to reject noise in ARA's first diffuse and GRB searches
  - Diffuse neutrinos should not generate repeating RF directions
  - Neutrino RF should not reconstruct to known human campsites







Two Stations Diffuse Limit

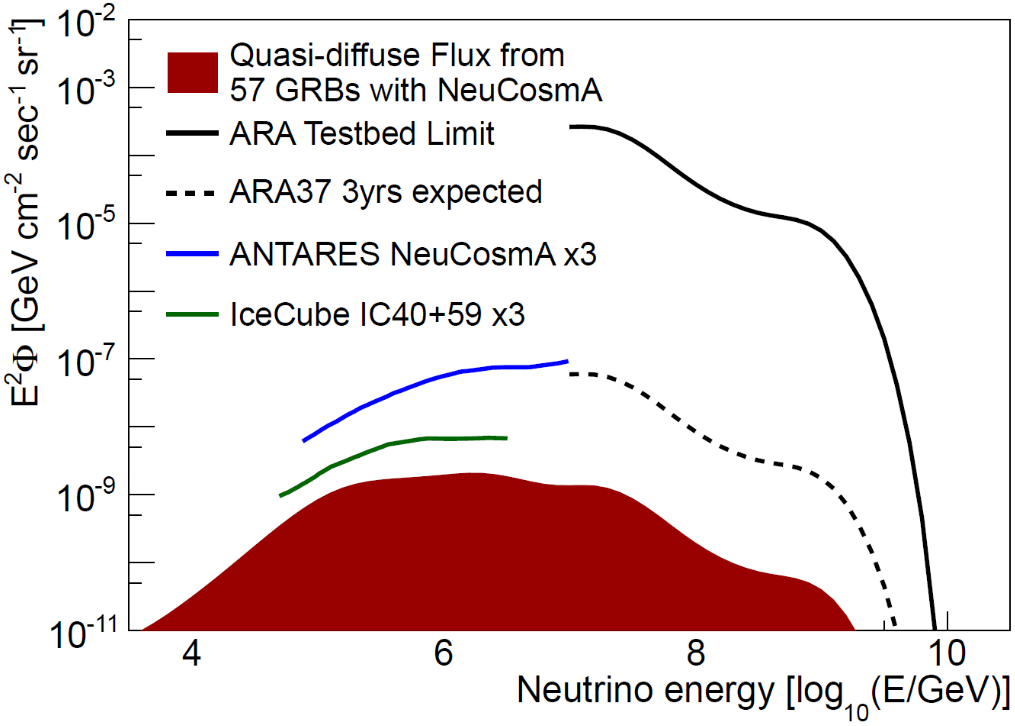


Limits on diffuse neutrino flux from 10 months of two stations.

Predictions for ARA 37 limits (red line) are competitive and capable of model discrimination.

P. Allison et al, for the ARA Collaboration.
Arxiv 1507.08991, accepted to PRD.

Testbed GRB Limit



Limit on the GRB flux from 57 GRBs from 224 days of ARA testbed.

P Allison et al, for the ARA Collaboration.
Arxiv 1507.00100v1

Summary

- Neutrinos are key windows to fundamental physics—important for both astroparticle physics and particle physics purposes
- Next generation detectors like ARA employ radio techniques to instrument the large target volumes necessary for practical detection
- The performance of two ARA stations predicts the full ARA37 will be able to discriminate between leading models for the UHE neutrino flux

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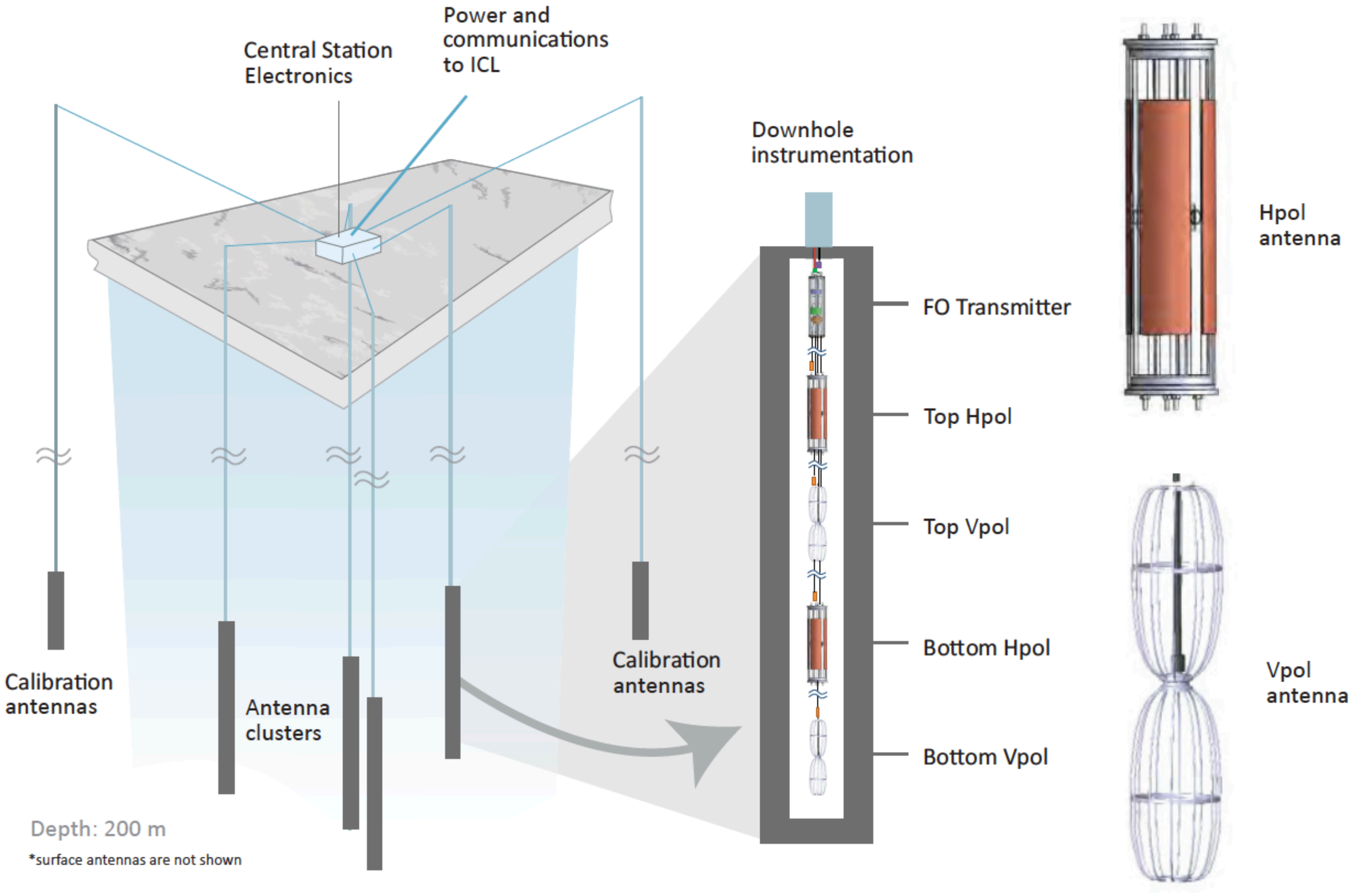
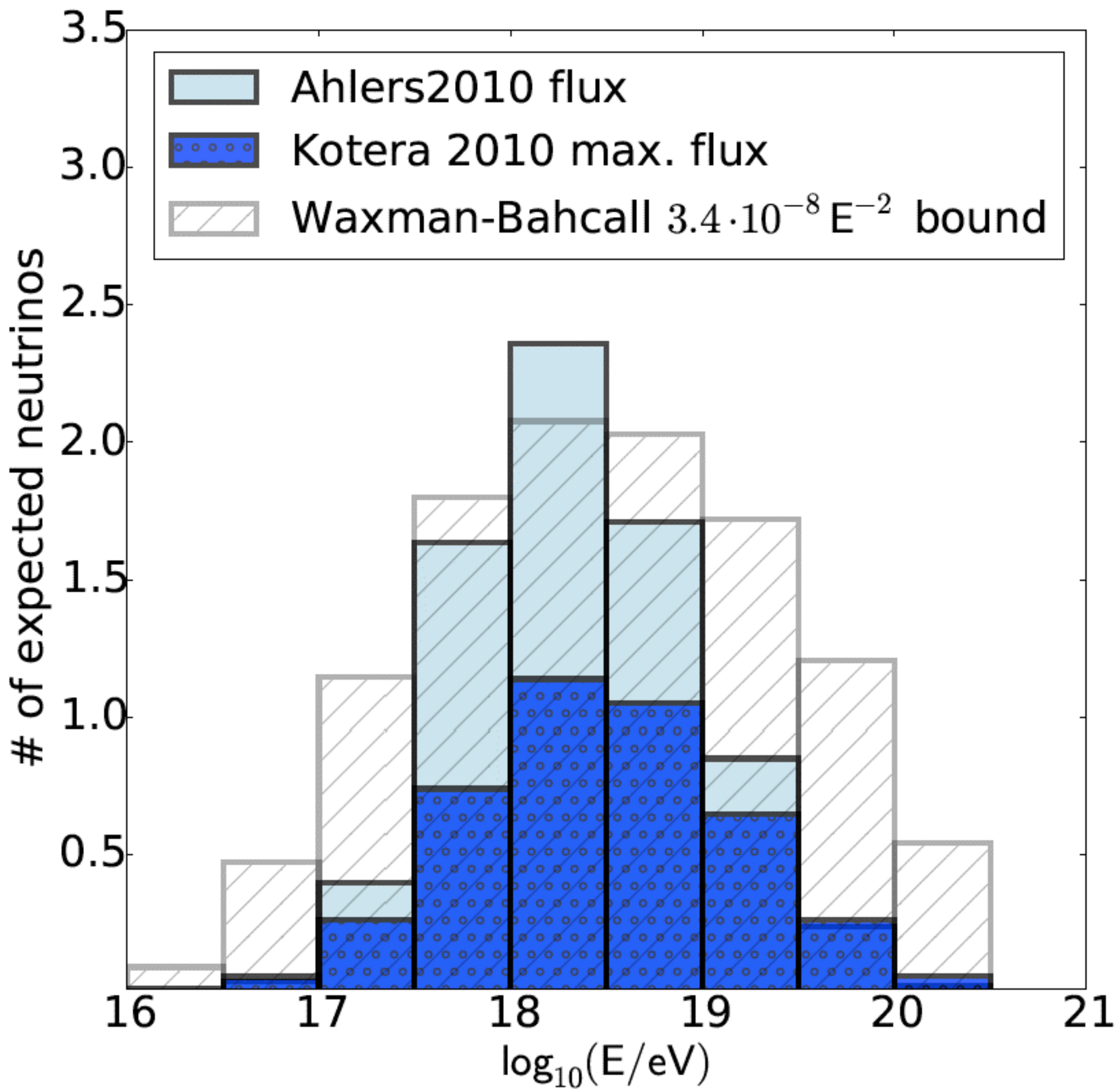
- The OSU Department of Physics
- The OSU Center for Cosmology and Astroparticle Physics
- US-Israel Binational Science Foundation Grant 2012077

Back-up Slides

Backup: Alternate Station Schematic



Predicted Fluxes for ARA37



Projected event numbers for three models of the UHE neutrino flux with 37 stations and 3 years livetime.

Power to discriminate between models after 3 years livetime.

T. Mueres et al, for the ARA Collaboration. Arxiv 1507.08991, accepted to PRD