ASKARYAN RADIO ARRAY

ICECUBE SOUTH POLE NEUTRINO OBSERVATORY

MICHIGAN STATE UNIVERSITY

Searching for the Highest Energy Neutrinos with the Radio Detection Technique

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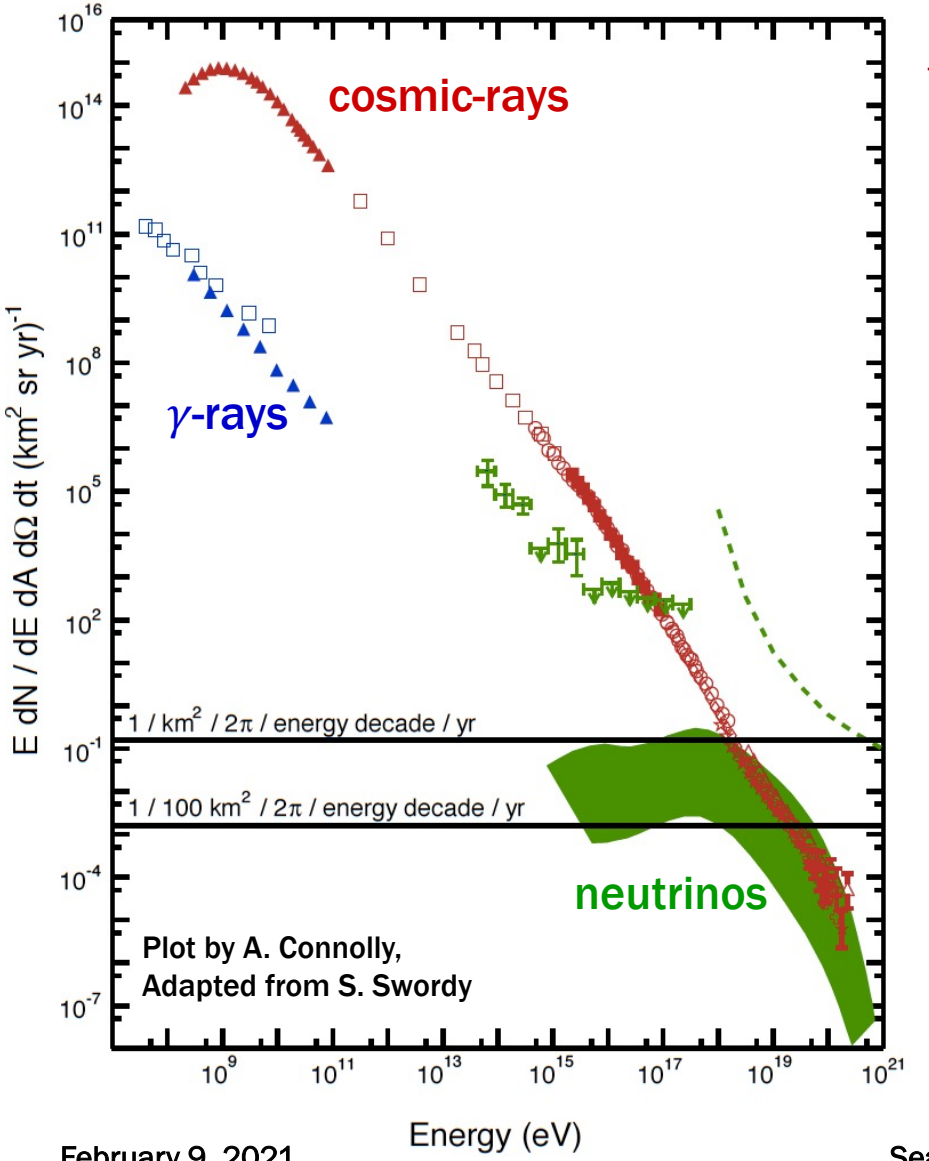
Why Study Neutrinos?



Unique Messengers to distant (>100Mpc) universe

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

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

→ Screens extragalactic (>100 MPc) sources

- γ-rays annihilate w/ CMB @ ~1 TeV

Observational Advantages

- Chargeless = point back to source
- Weakly interacting = no observation horizon

Astronνmy : Neutrinos in a Multimessenger World

arXiv 1903.04334

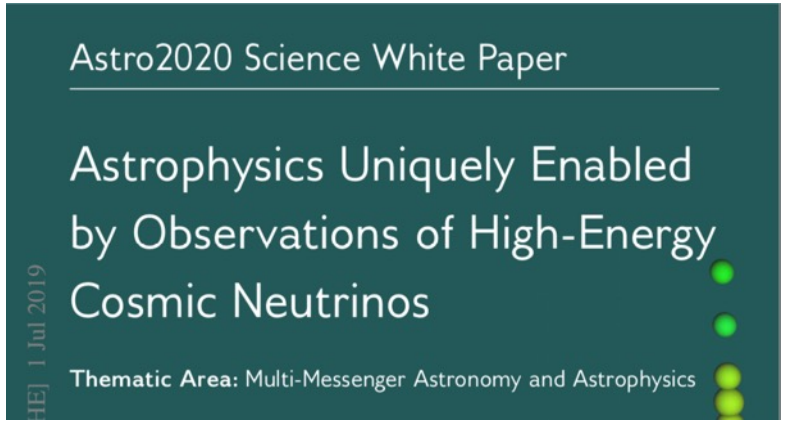
Complimentary Probes

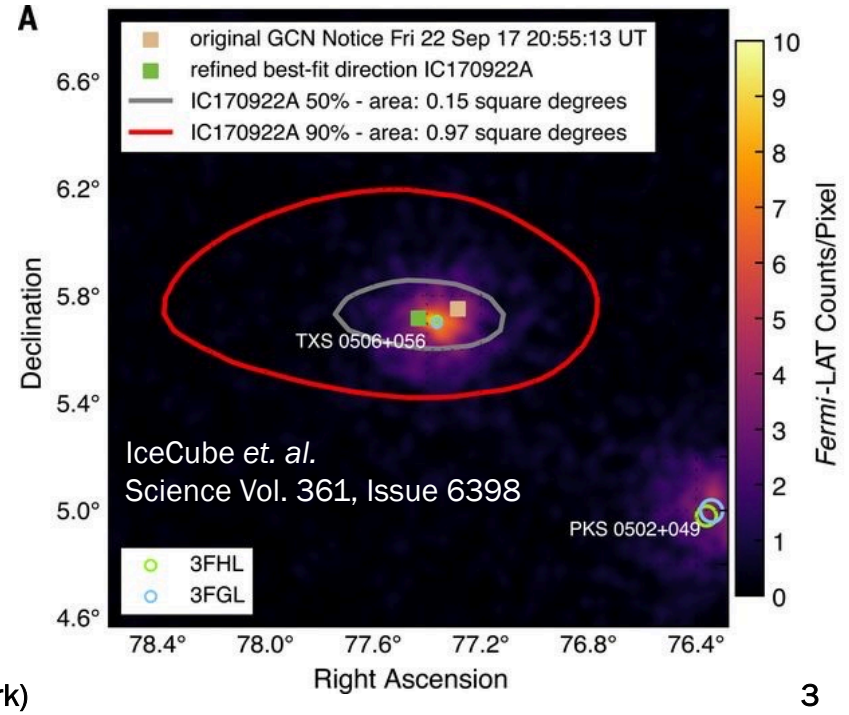
- Cosmic rays: pions from GZK process decay into neutrinos
- Cosmic ray accelerators
  - Gamma Ray Bursts (GRBs)—leptonic vs hadronic models
  - Active Galactic Nuclei (AGN)

Exciting Start!

- 2017—Binary Neutron Star (GW + Light)
- 2018—Flaring Blazar (Neutrino + Light)
- 2021—Neutrino + GW??

Fast, all-sky, broadband follow-up is very important!
(*Fermi*, *Swift*, ZTF, ASAS-SN, etc.)

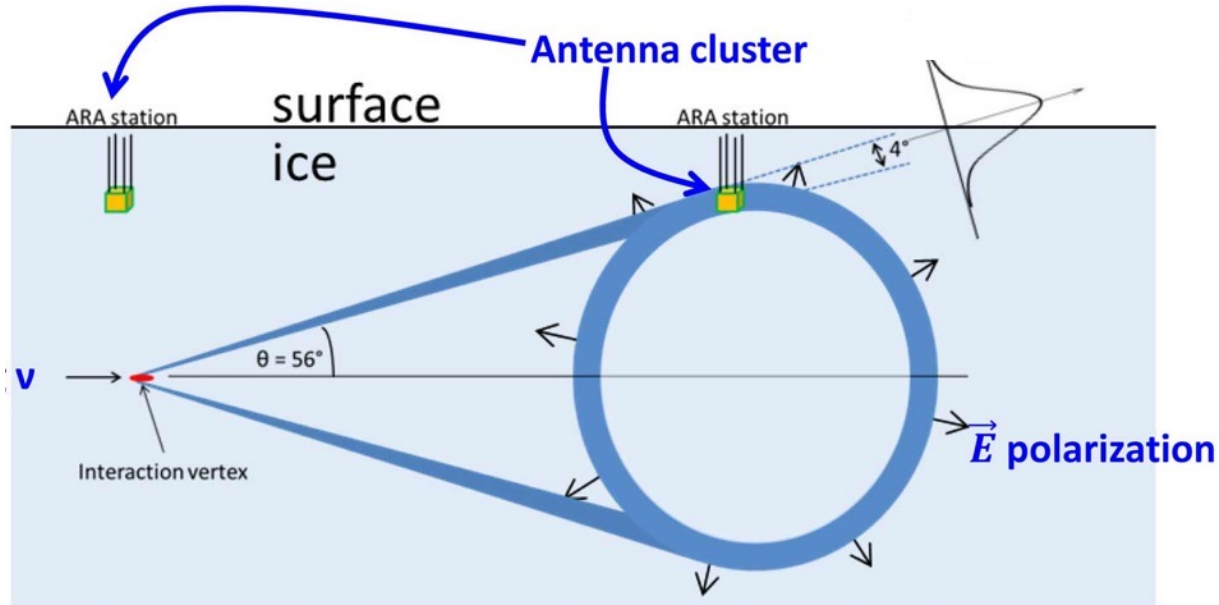


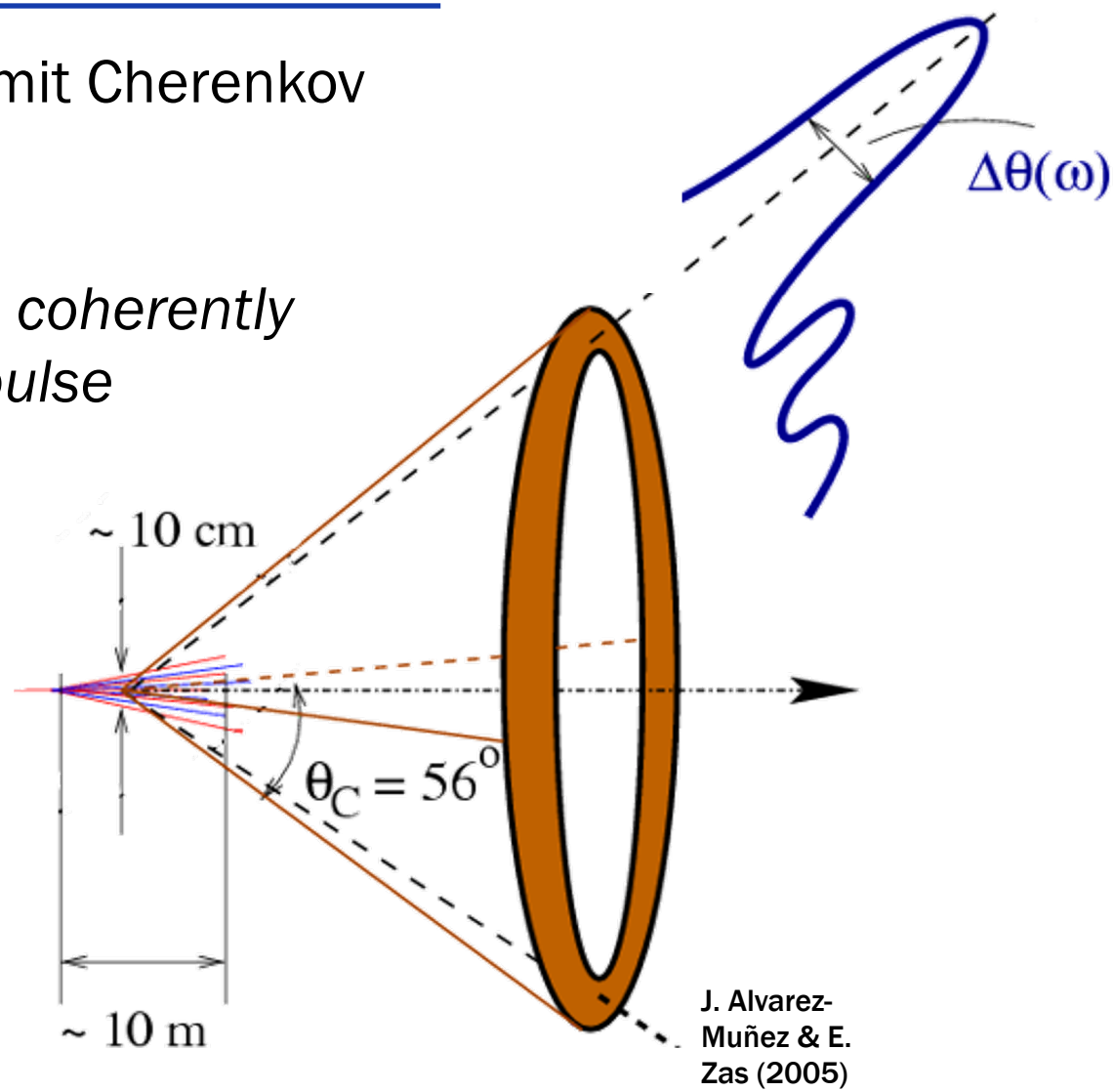


The (Radio) Cherenkov Effect

- Relativistic neutrino-induced particle showers emit Cherenkov radiation in media

- Wavelengths the size of the bunch (~10cm) add *coherently* and form broadband (200 MHz-1.2GHz) radio *pulse*

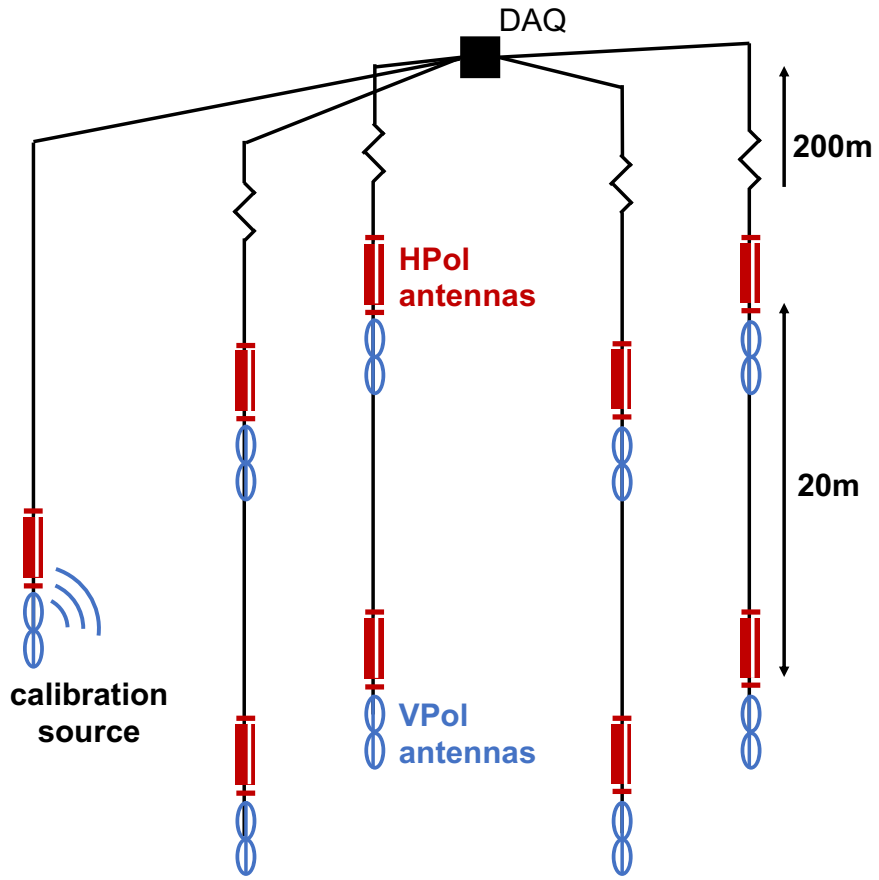


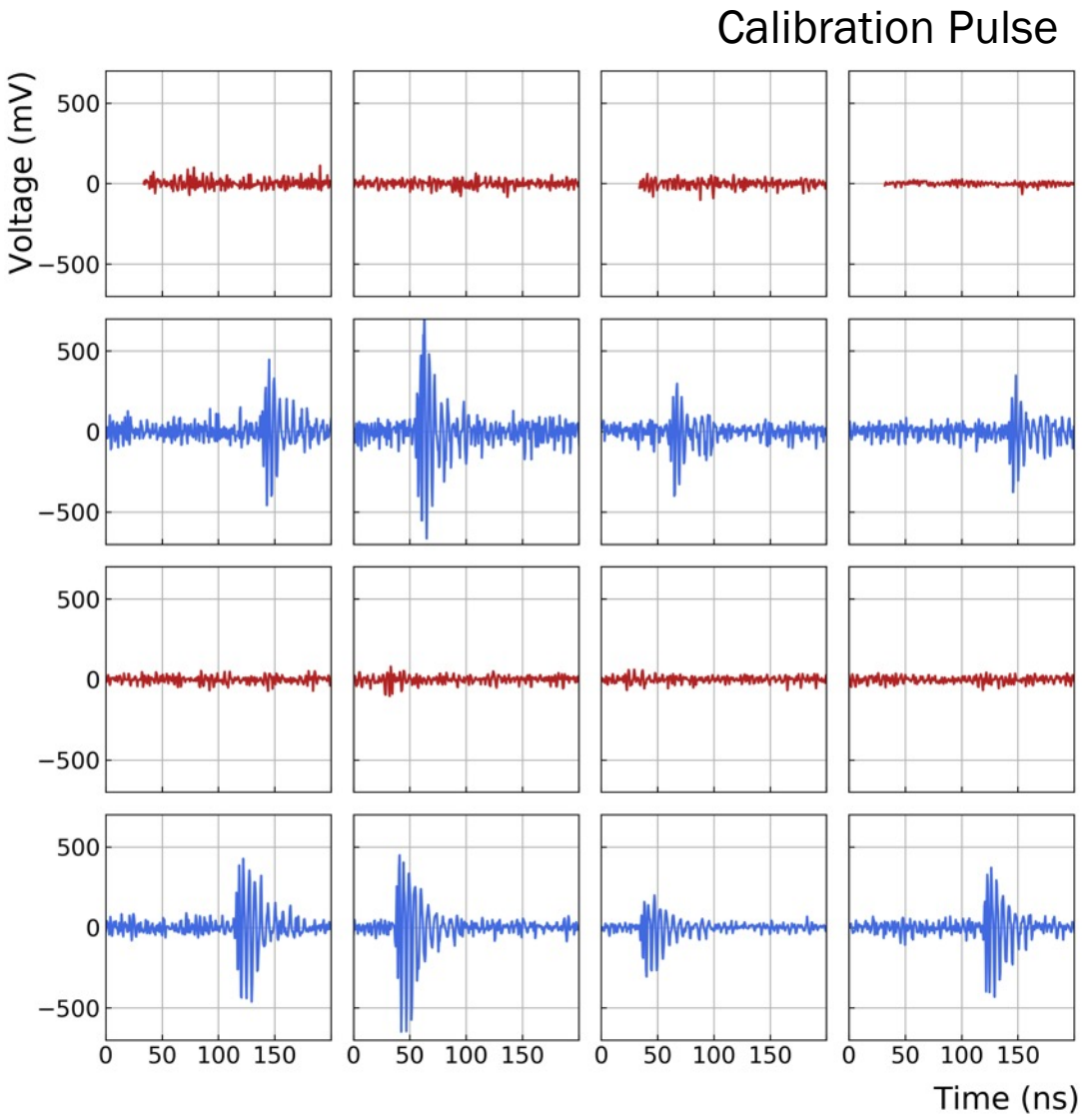


J. Alvarez-Muñez & E. Zas (2005)

Askaryan Radio Array

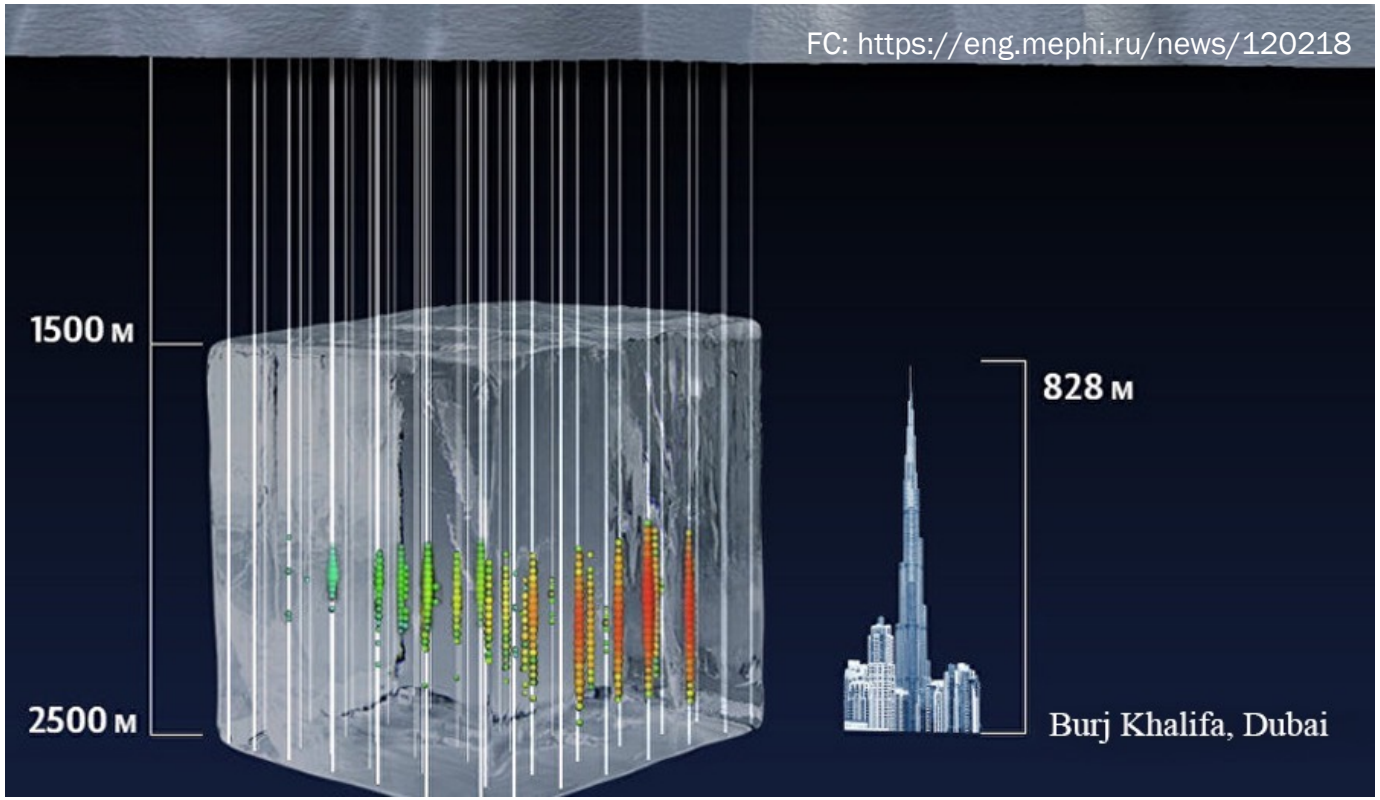
- Cubical lattice (”station”) at 200m depth
- 8 VPol & 8 HPol antennas deployed



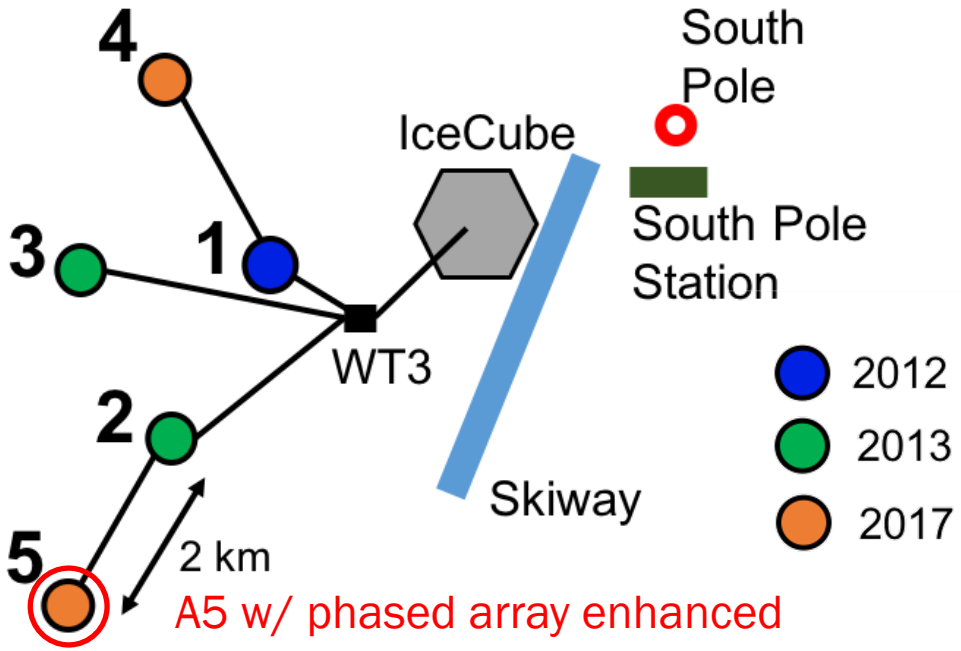


A Question of Scale

Low fluxes (~10/km^3/yr) + low cross-sections (L_{int}~300km in rock)
→ need >1-100 km^3 of target



ARA has 5 stations deployed so far



A5 w/ phased array enhanced triggering, see arXiv 1809.04573

The ARA Collaboration

USA

Cal Poly	University of Kansas
Michigan State University	University of Maryland
The Ohio State University	University of Nebraska
Otterbein University	University of Wisconsin-Madison
University of Chicago	Whittier College
University of Delaware	

International Collaborators

Chiba University

National Taiwan University

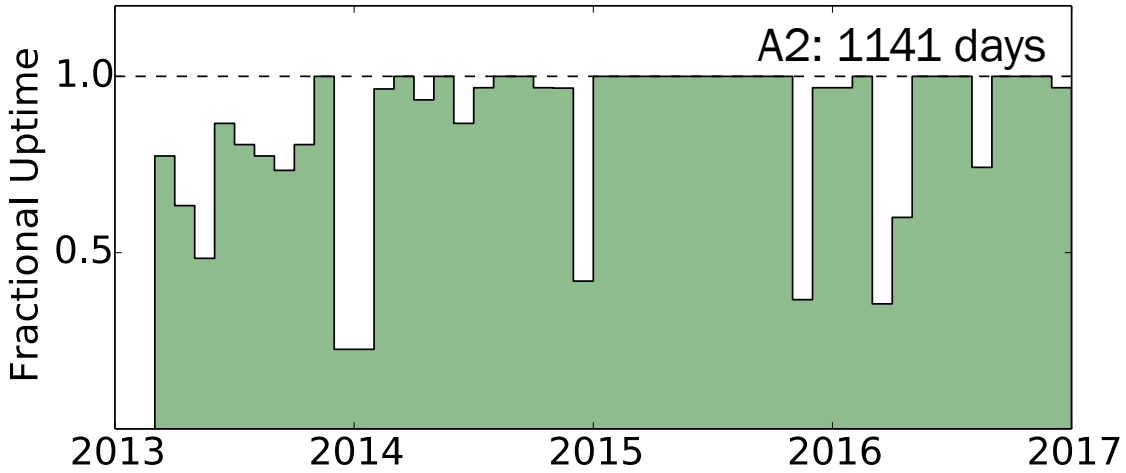
University College London

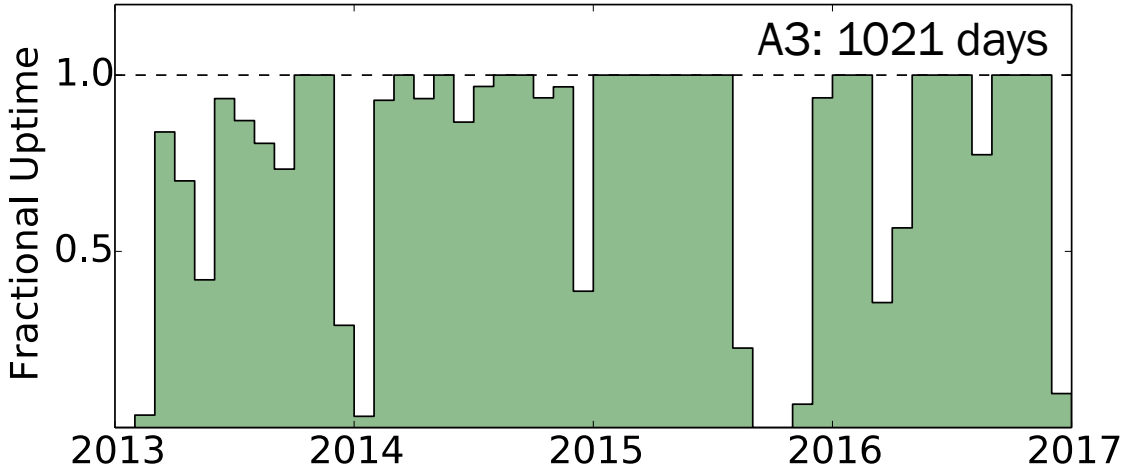
Vrije Universiteit Brussel

Weizmann Institue of Science

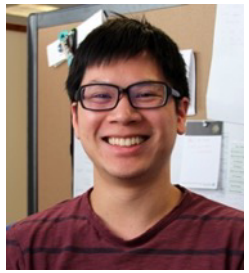
Diffuse Neutrino Search

- A2 and A3 collecting data since Feb 2013 —10 months of data published previously
- Published expansion to the 2013-2016 data set in August 2020 (PRD 102, 043021)-- 5x as much data!





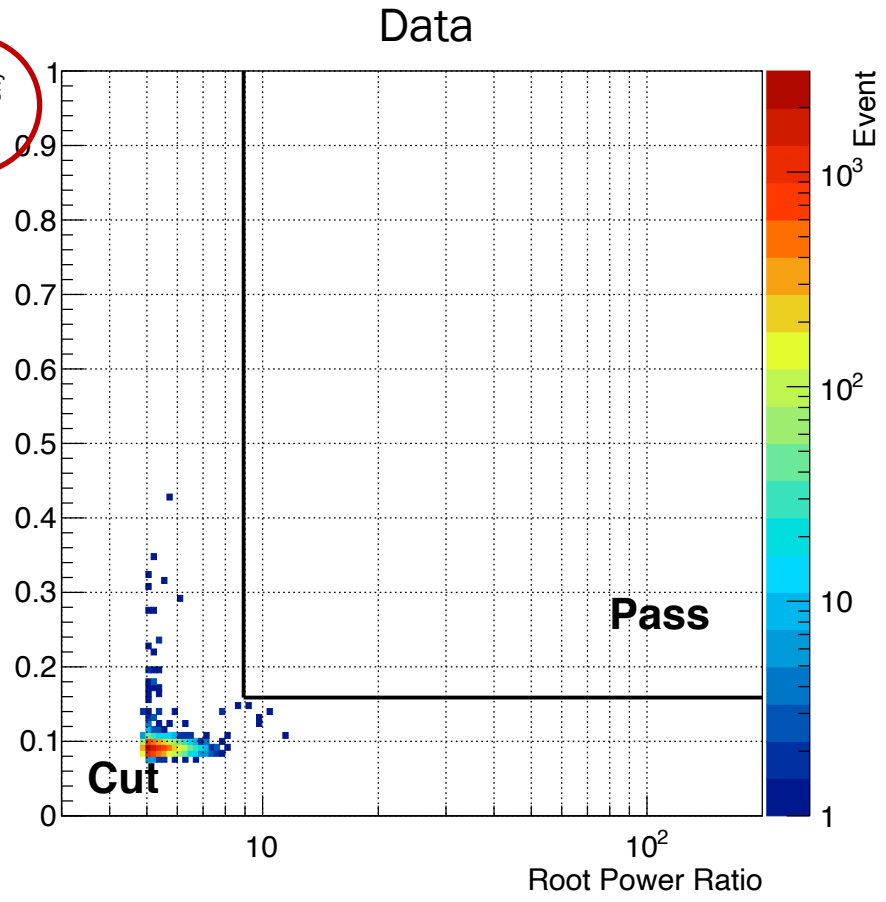
Special thanks to my co-analysts Ming-Yuan Lu and Jorge Torres (>40TB raw data, 580M events)

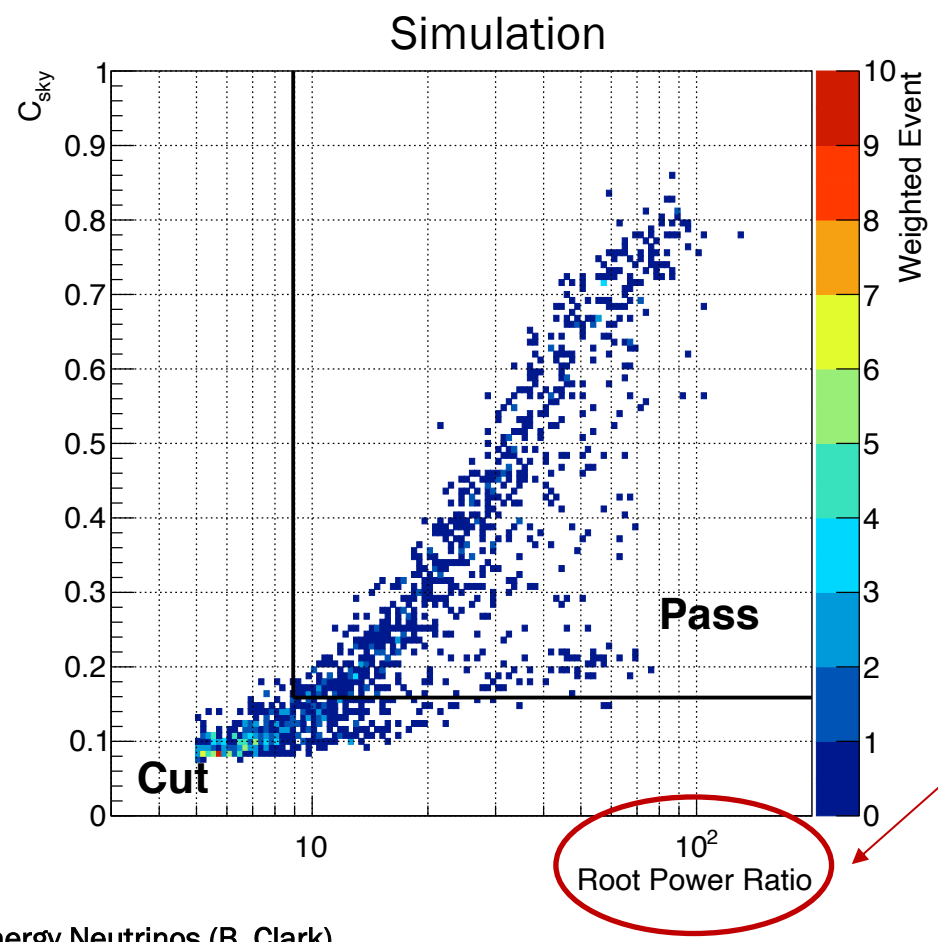


Separating Signal and Background

- Linear discriminant separates backgrounds from neutrinos
- Optimize cut for best limit (~0.1 passing events/year)

"Reconstruction quality" parameter

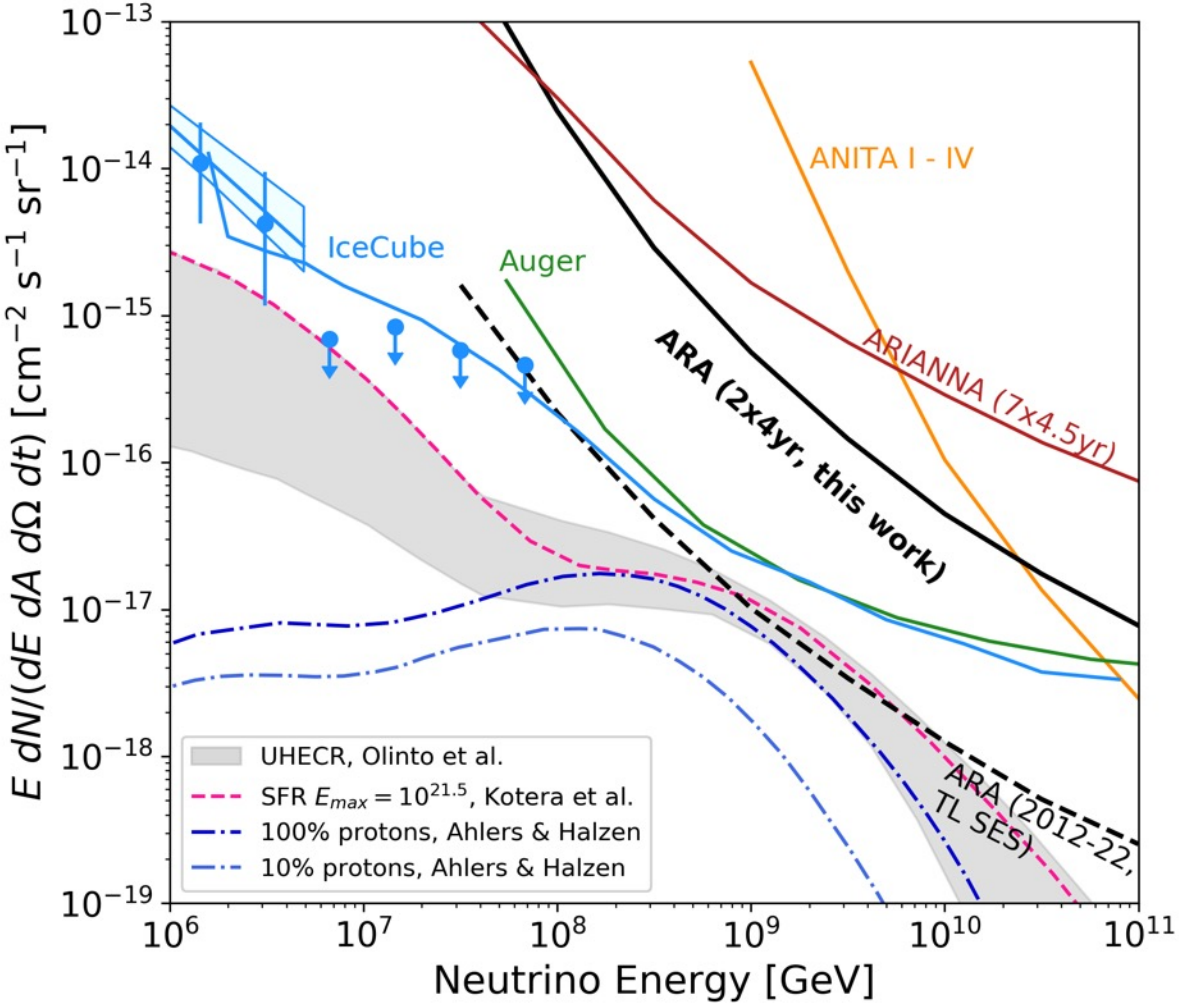




"SNR-like" measure

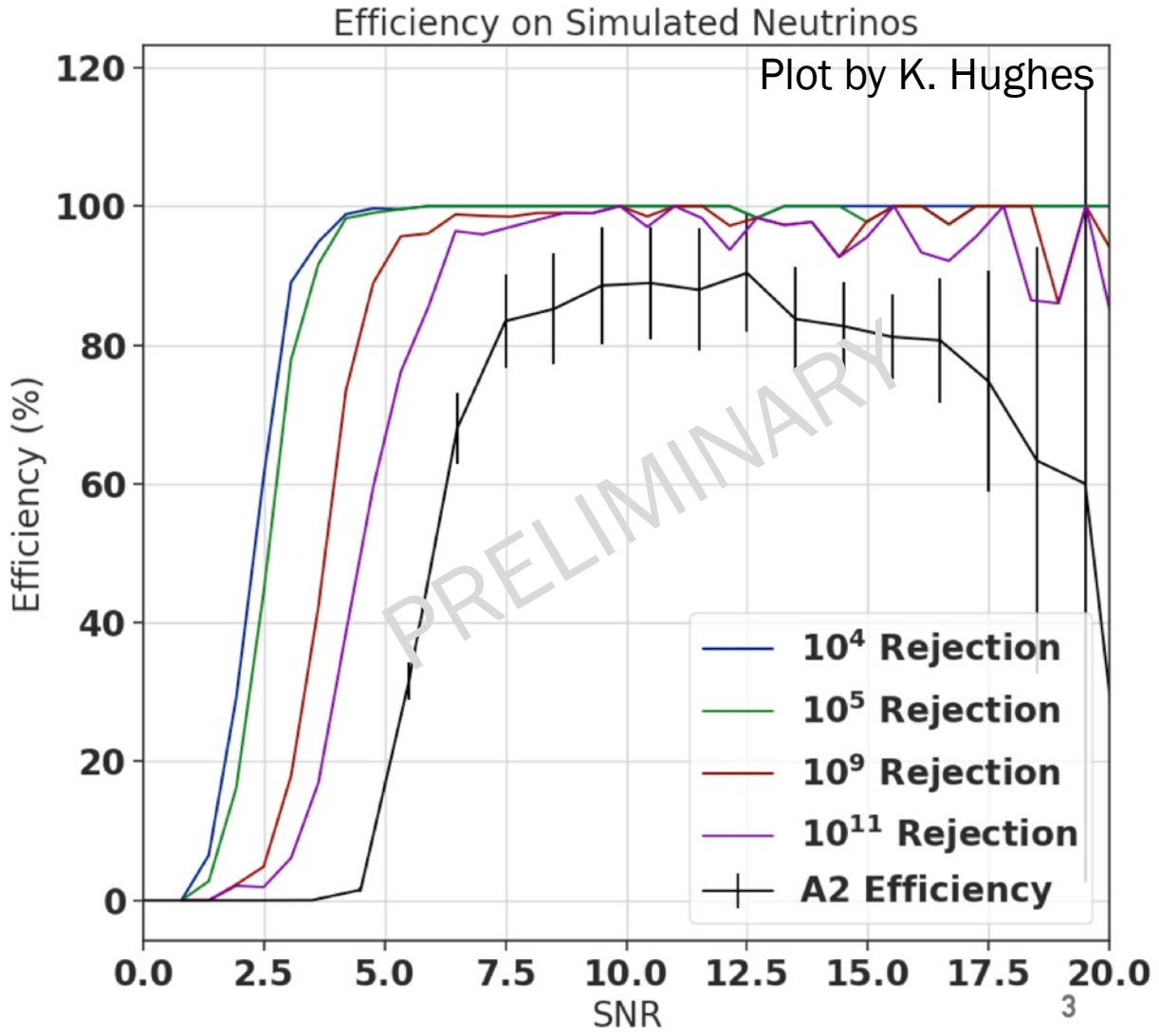
Analysis: Results

- Observe no statistically significant excess on background of 10^{-2}
- Result is best limit set by in-ice radio neutrino detector, and uses *only half the data on archive already*
- By 2022, ARA will have world-leading sensitivity and carve out exciting new parameter space



Improving Analysis Efficiencies

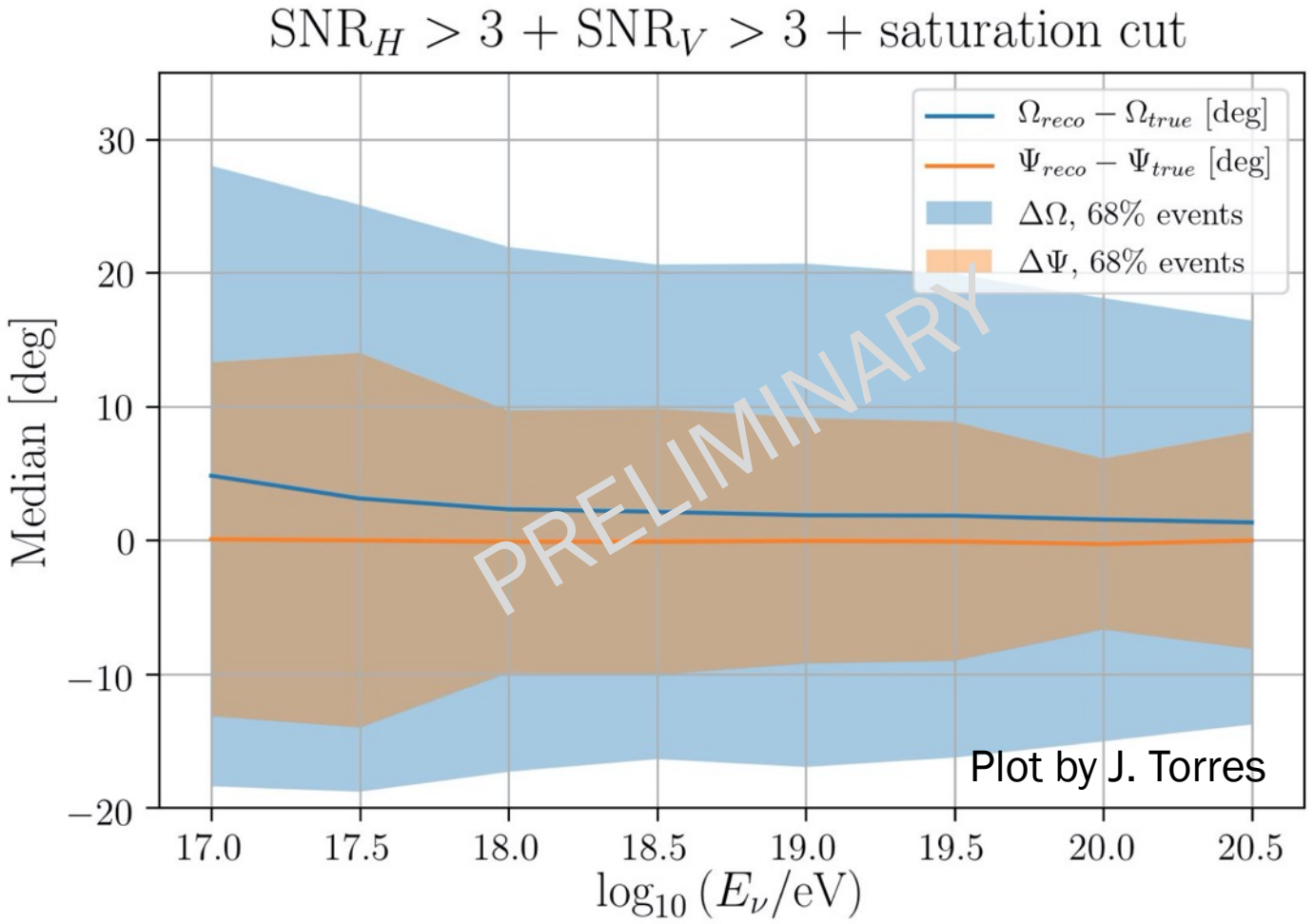
- One of our goals: improve analysis efficiencies
- Project being led by Kaeli Hughes at U Chicago
  - Leverages our low-threshold triggering system at A5
  - Along with a Fisher discriminant



Reconstructing Neutrinos

- One of our other goals: develop and refine reconstruction of neutrino signals
  - Vertex location
  - Polarization angle

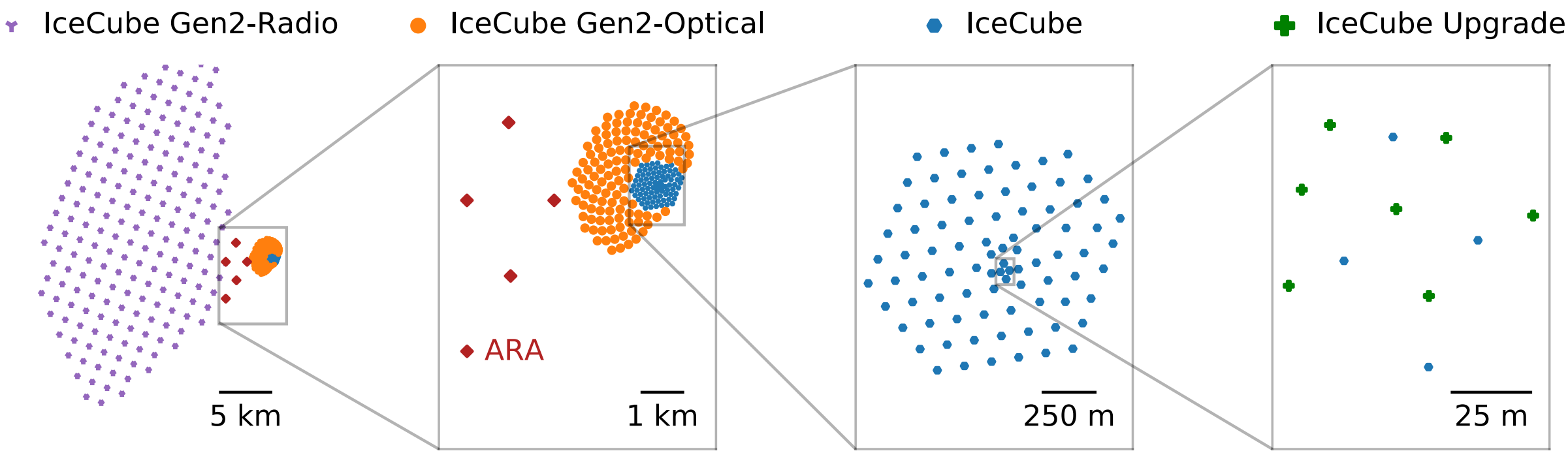
- Work being done in collaboration with J. Torres and A. Connolly at OSU
  - For modest cuts, we are able to reconstruct the signal polarization angles to ~±10°



The Future of Neutrino Astronomy at South Pole

IceCube GEN2

IceCube-Gen2 is planned, including a radio array
(see white paper, arXiv 2008.04323)



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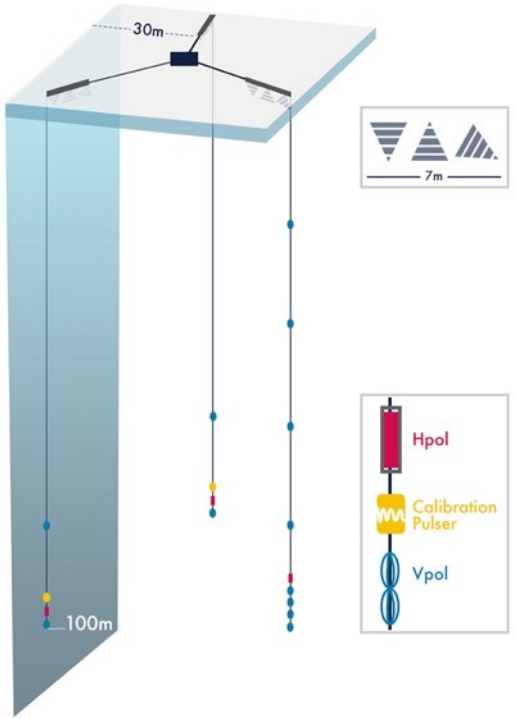

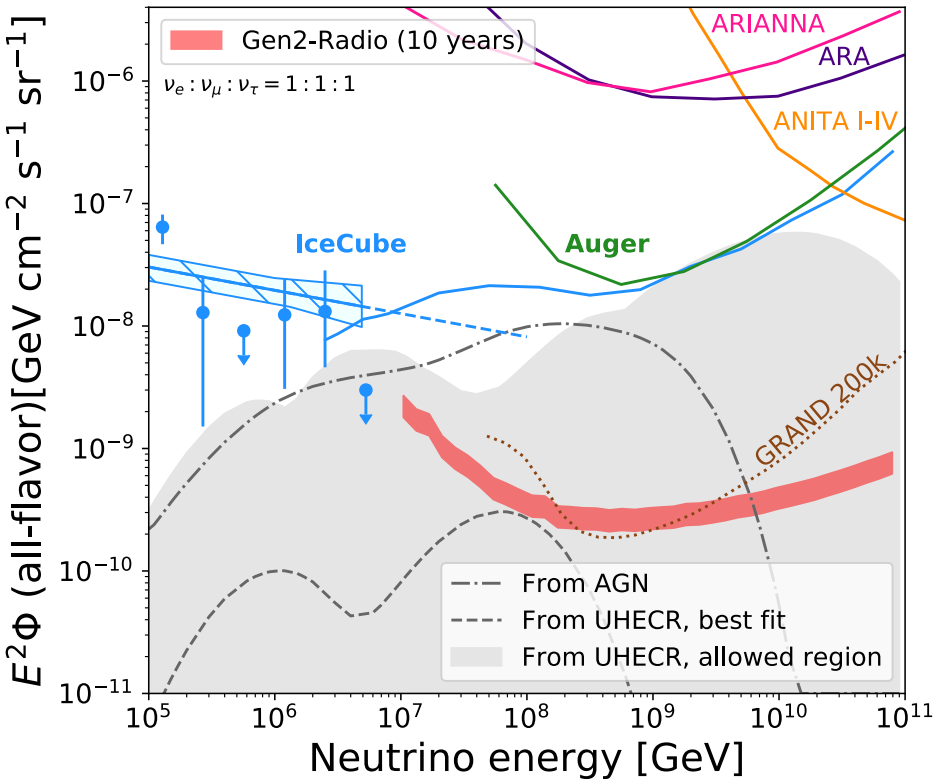

Summary

1. Neutrinos are important and complimentary messengers to the cosmos

2. ARA 2x4yr analysis is best limit by in-ice radio detector, using only ½ of available data; ARA will be world-leading by 2022

3. The future is bright for neutrino astronomy, and new instruments are coming in the next decade (Gen2, etc.)

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- NSF AAPF Award 1903885
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