

# Status and Recent Results from Radio Detectors for UHE Neutrinos

Abigail Vieregg  
IPA, Madison  
October 2026

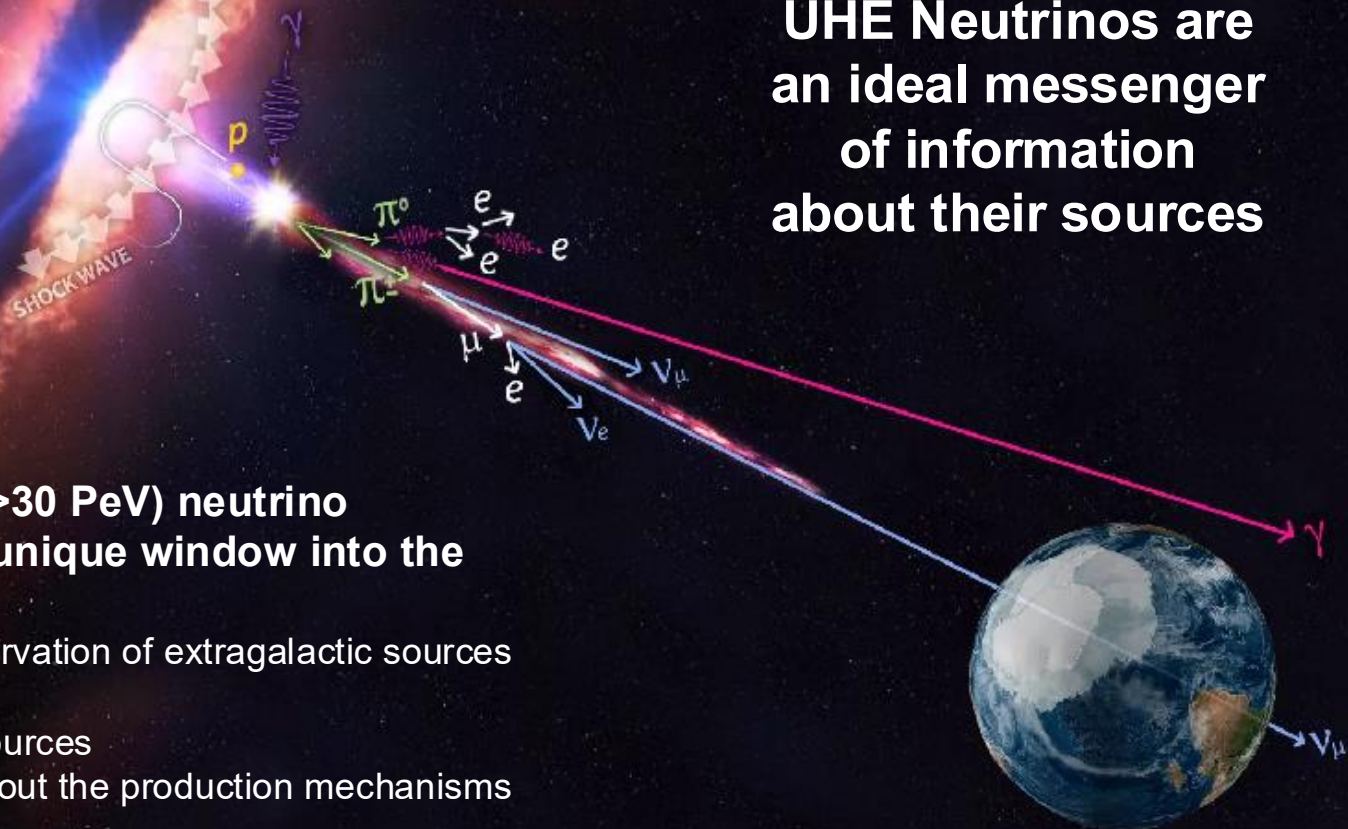


# Neutrinos: A Window to the Ultra-high Energy Universe

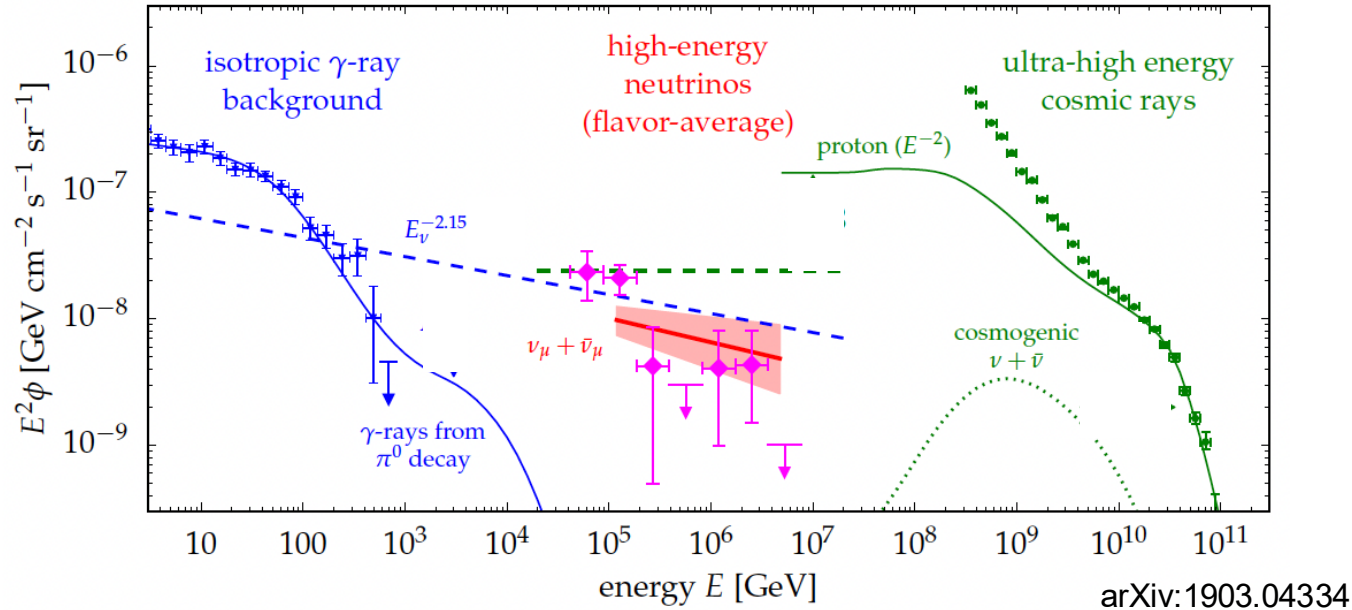
**UHE Neutrinos are  
an ideal messenger  
of information  
about their sources**

**Ultra-high energy ( $>30$  PeV) neutrino  
telescopes open a unique window into the  
universe:**

- Highest energy observation of extragalactic sources
- Very distant sources
- Deep into opaque sources
- Carry information about the production mechanisms



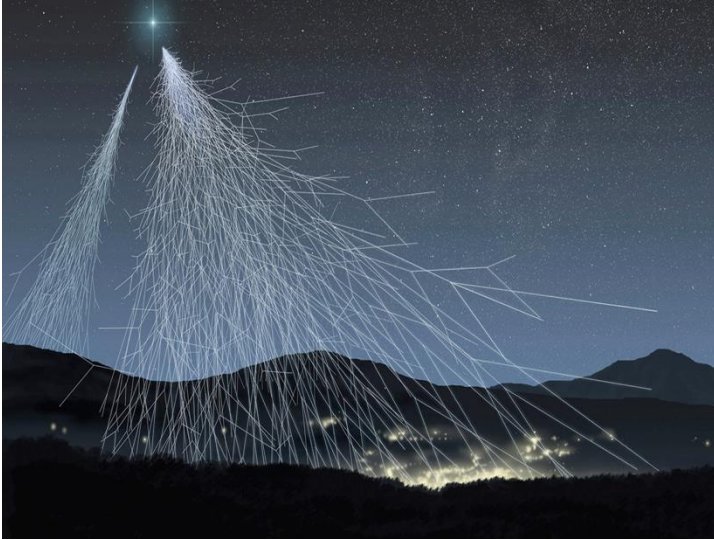
There are sources making particles  $\times 10^4$  more energetic than the neutrinos seen by IceCube



How are these ultra-high energy particles accelerated?

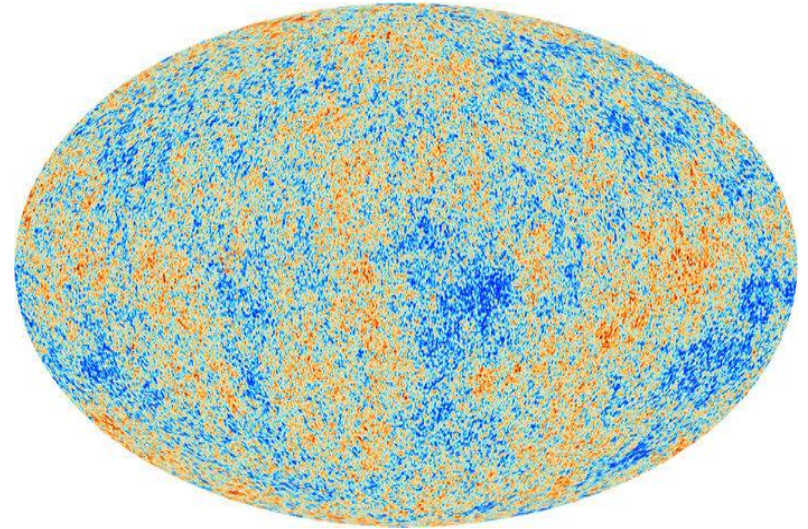
# Neutrino Production at the Highest Energies: The GZK Process

Cosmic Rays ( $E > 10^{19.5}$  eV)



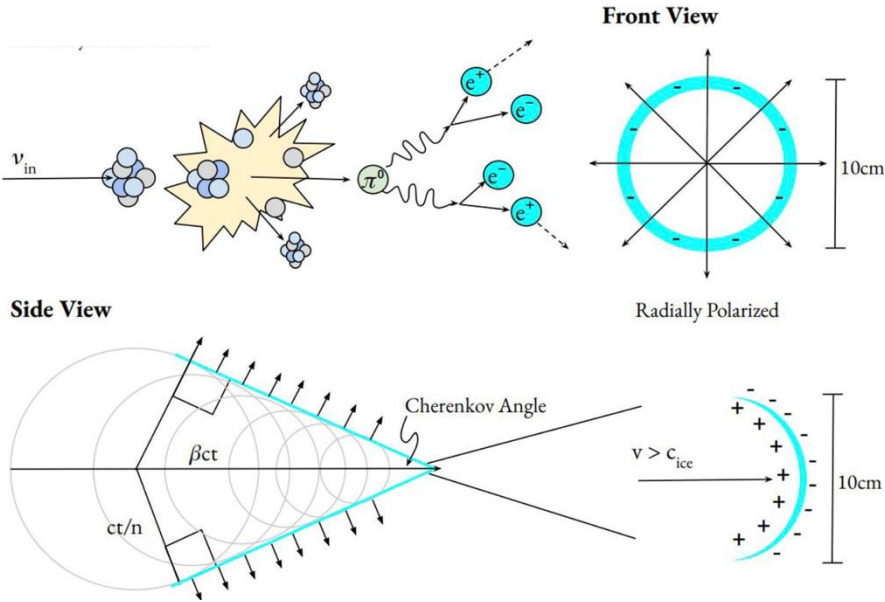
CMB

+



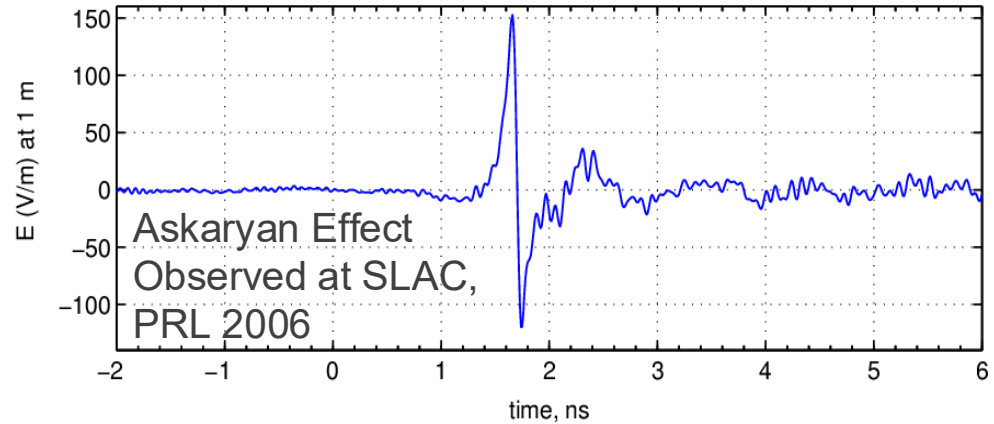
= Neutrino Beam!

# Method 1: Radio Emission from Neutrino Interactions in a Dielectric

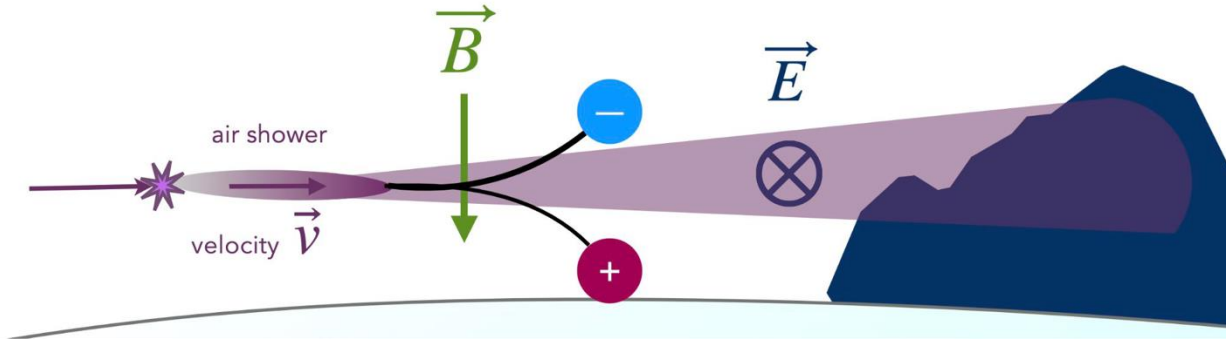


- EM shower in dielectric (ice, sand)  $\rightarrow$  moving negative charge excess
- Coherent radio Cherenkov radiation ( $P \sim E^2$ ) if  $\lambda >$  Moliere radius, called the Askaryan Effect

$\rightarrow$  Radio Emission is stronger than optical for UHE showers



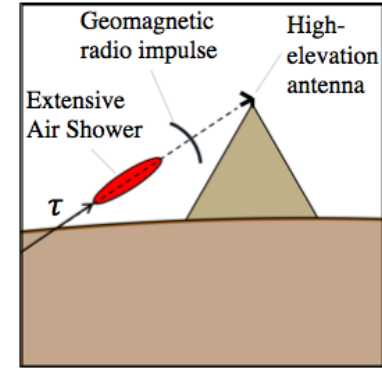
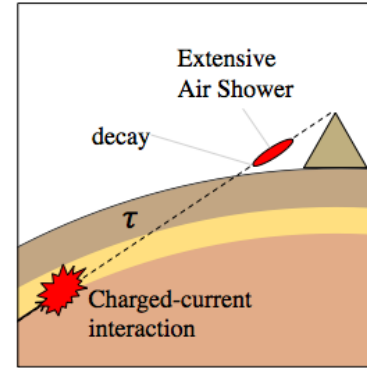
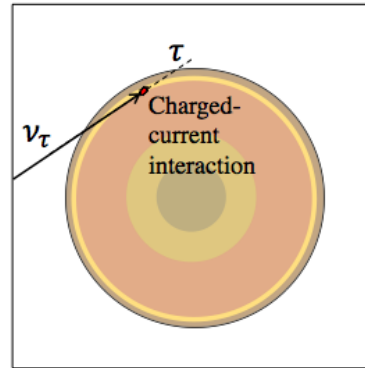
# Method 2: Emission (Radio or Optical) from Tau Neutrino Induced Air Showers



Extensive air showers initiated by high energy particles hitting the atmosphere make geomagnetic radio emission

## Neutrino-induced signals:

- Looks like an upward going cosmic ray air shower
- Observe from surface, a mountain, balloon, or space

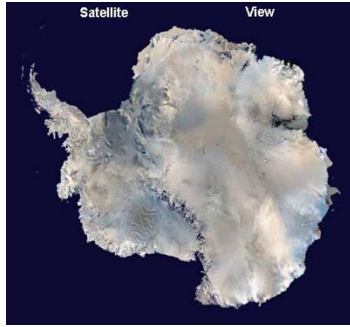


S. Wissel

For other methods of detecting UHE neutrinos, see Dylan Frikken (RET) and Jeffrey Lazar (TAMBO) Talks

# Radio Neutrino Astronomy Across Energy Scales

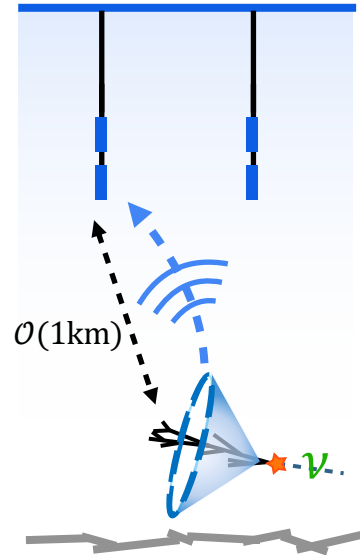
Need a huge ( $\sim 100 \text{ km}^3$ ), radio-transparent detector: glacial ice



We need different instruments to cover the full energy range of expected cosmogenic neutrinos, above the energy range of IceCube and KM3NeT

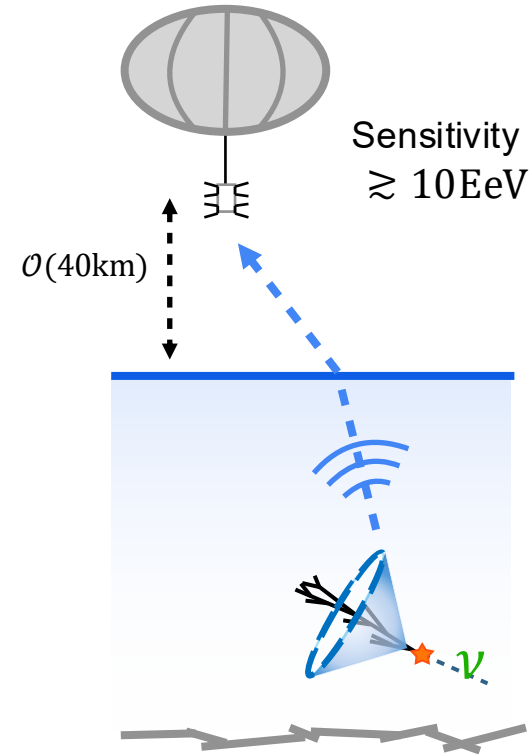
## Ground-based

Sensitivity  
 $\gtrsim 100 \text{ PeV}$



## Balloon-based

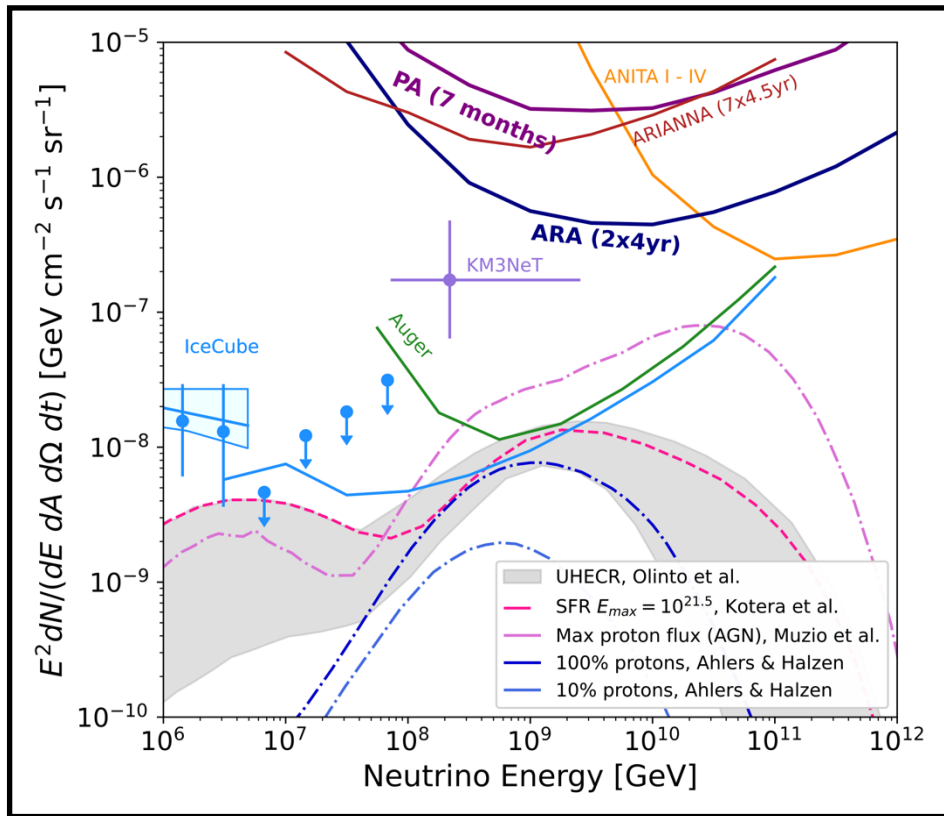
Sensitivity  
 $\gtrsim 10 \text{ EeV}$



P. Windischhofer

# Best Constraints at the Highest Energies

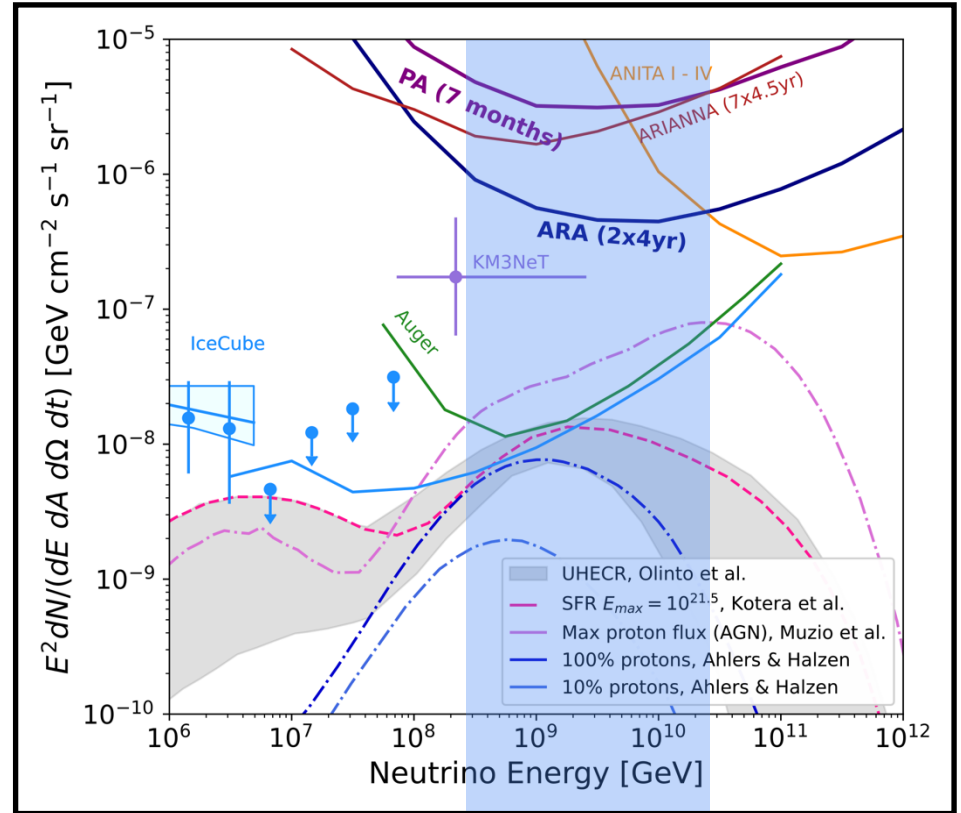
The best sensitivity up to  $10^{19.8}$  eV is from IceCube.



# Best Constraints at the Highest Energies

The best sensitivity up to  $10^{19.8}$  eV is from IceCube.

Small ground-based in-ice radio experiments have provided constraints (e.g. ARA, ARIANNA), and a larger array is currently under construction (RNO-G).

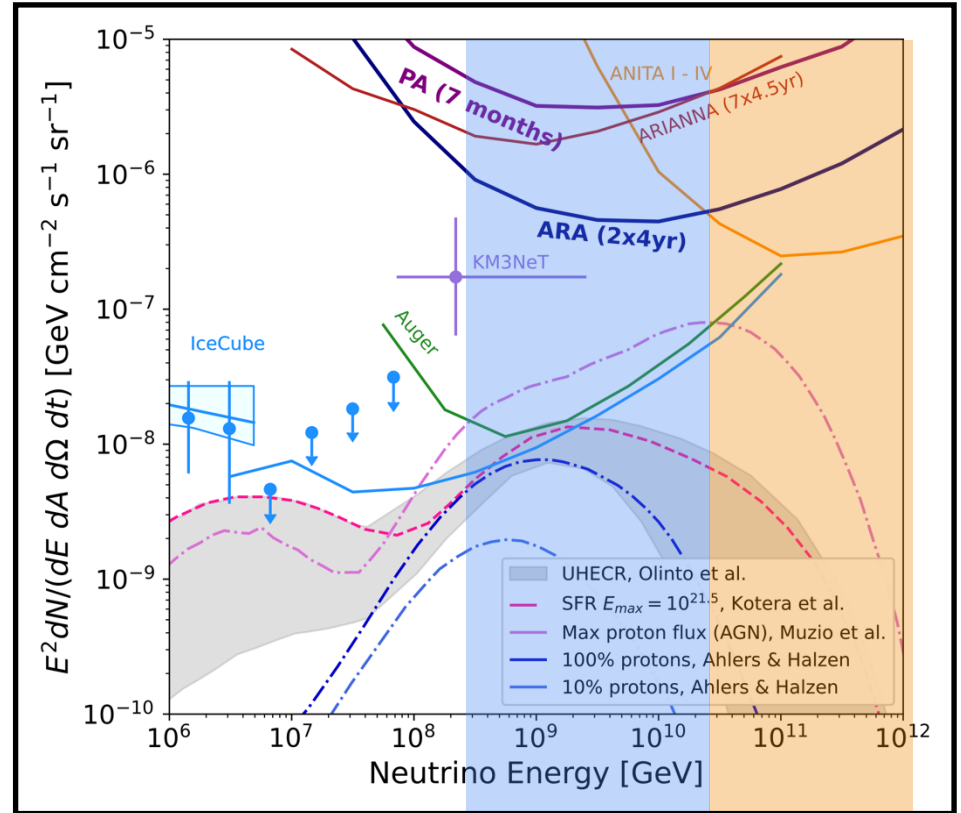


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At the highest energies, the best constraints come from a balloon-borne experiment (ANITA), and the next-generation experiment just flew (PUEO)



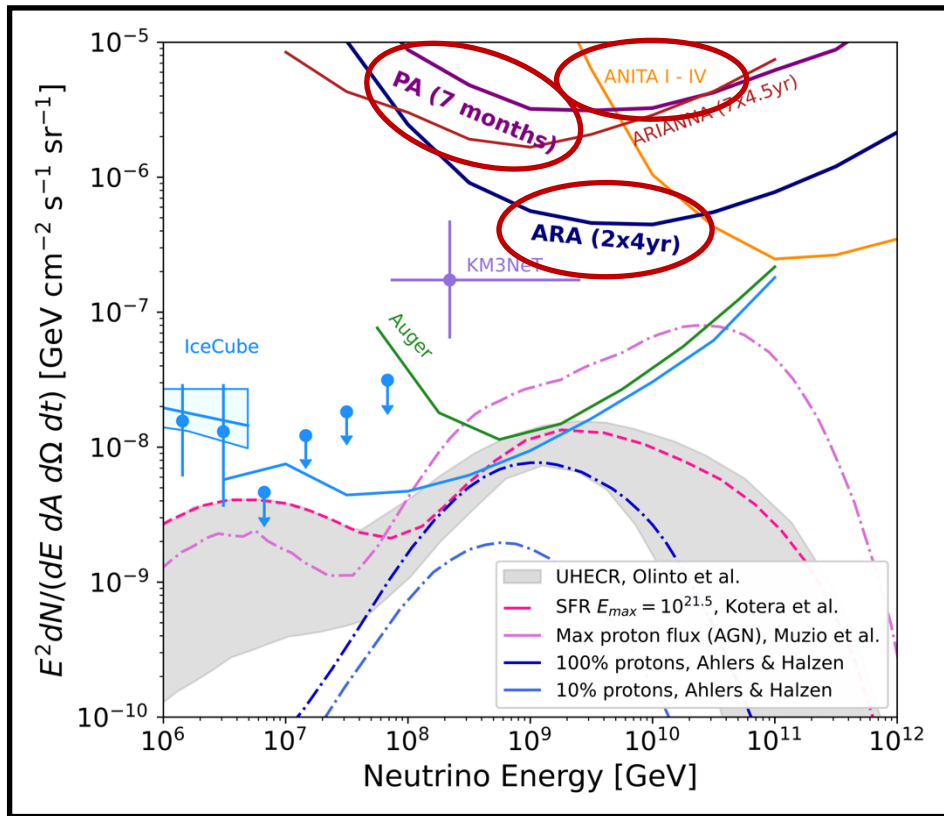
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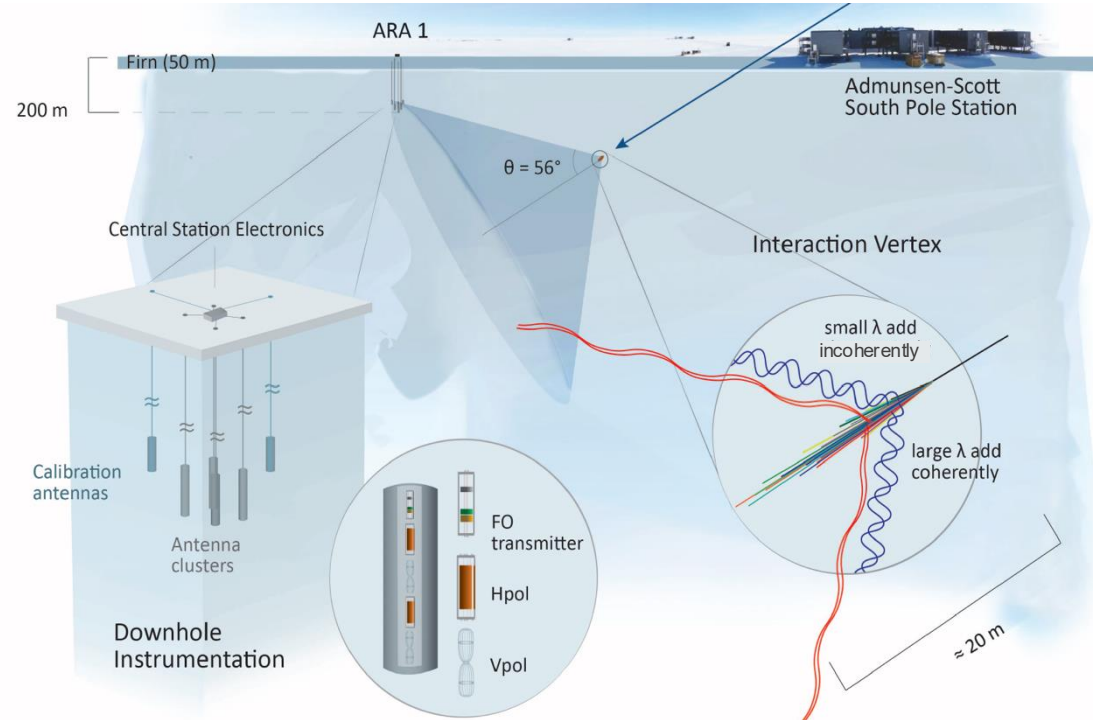
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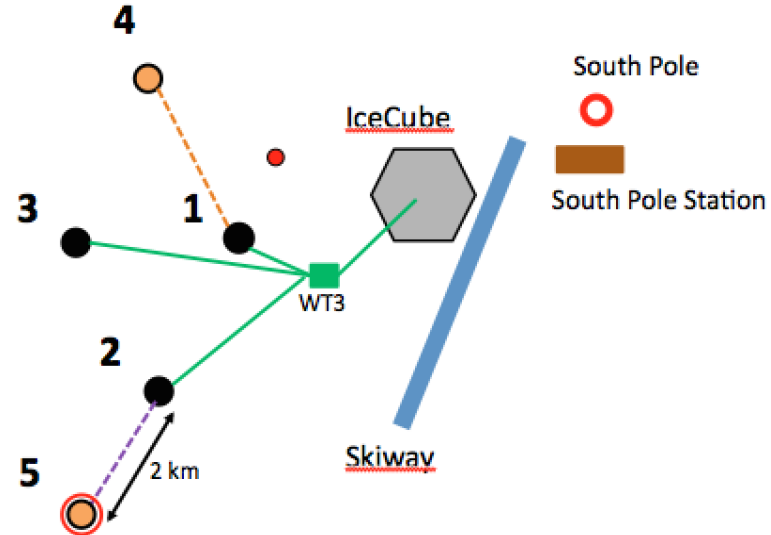
**What is the path to do better than this?**



# The Askaryan Radio Array (ARA)



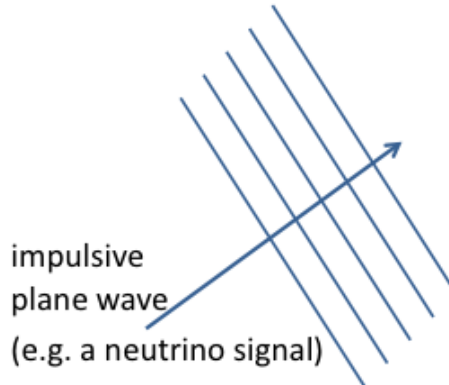
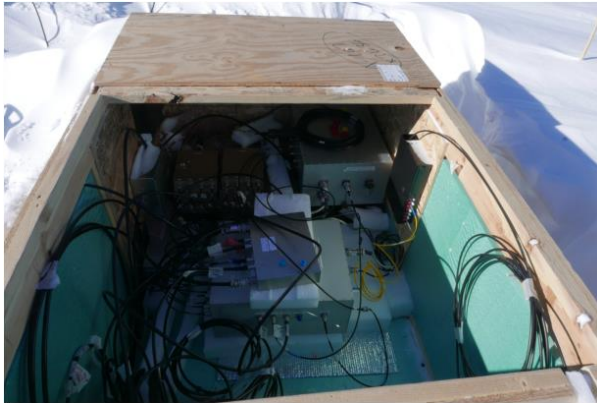
- 5 Stations of Ground-Based Radio Detectors at the South Pole
- Most recent instrumentation install was 2017/18



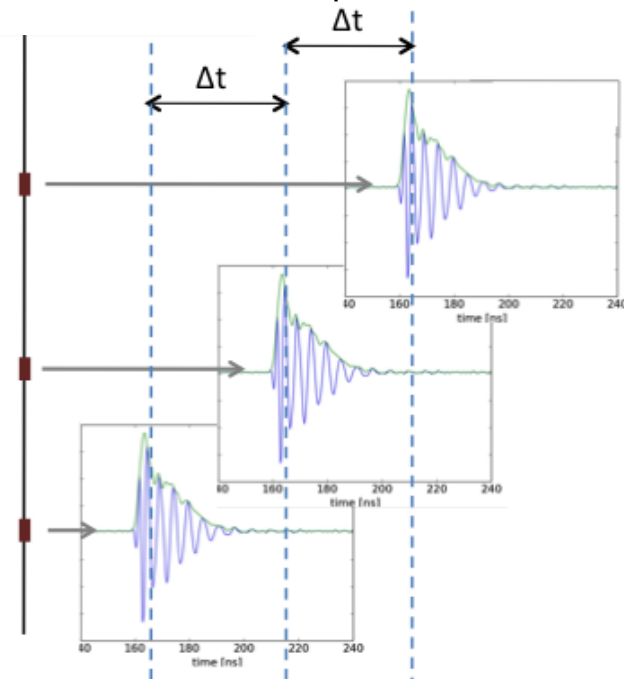
# The Last Station of ARA: A Beamforming Trigger and Digital DAQ

Beamforming at the trigger level increases SNR to trigger on by  $\sqrt{N}$ .

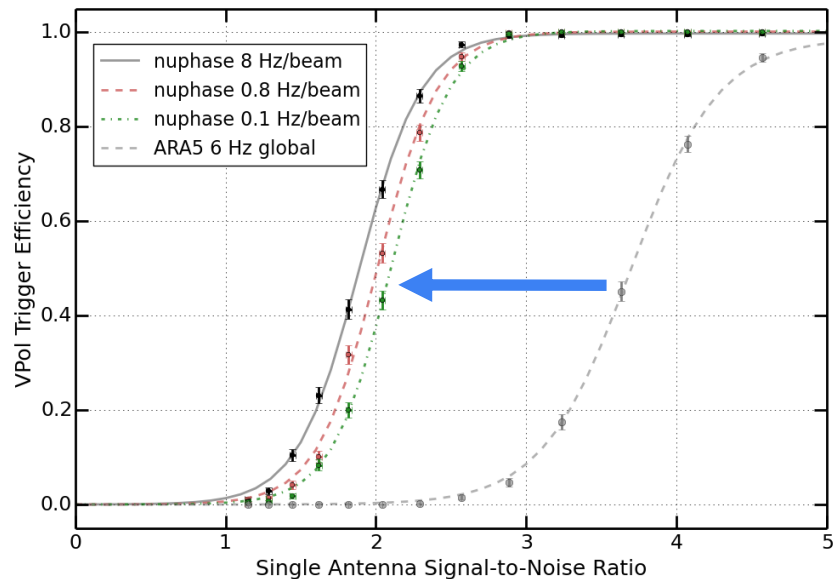
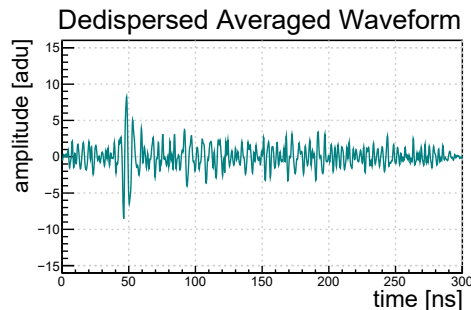
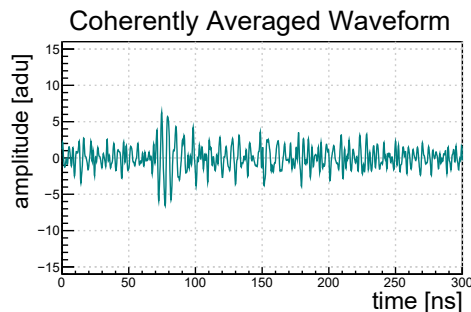
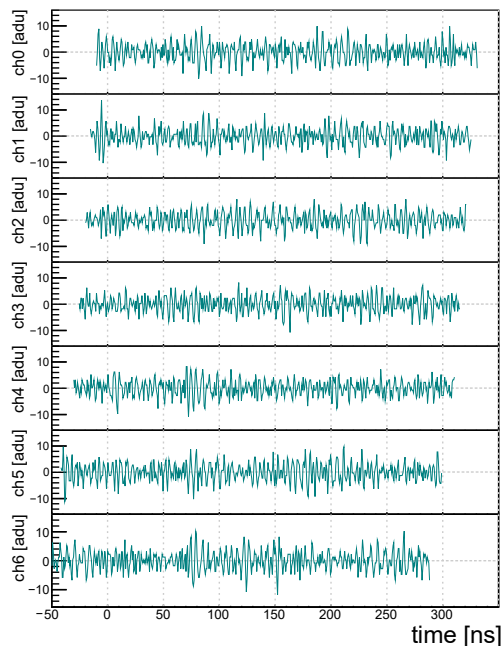
Create many beams simultaneously to cover the entire solid angle of interest



3 Antenna Example, Side View



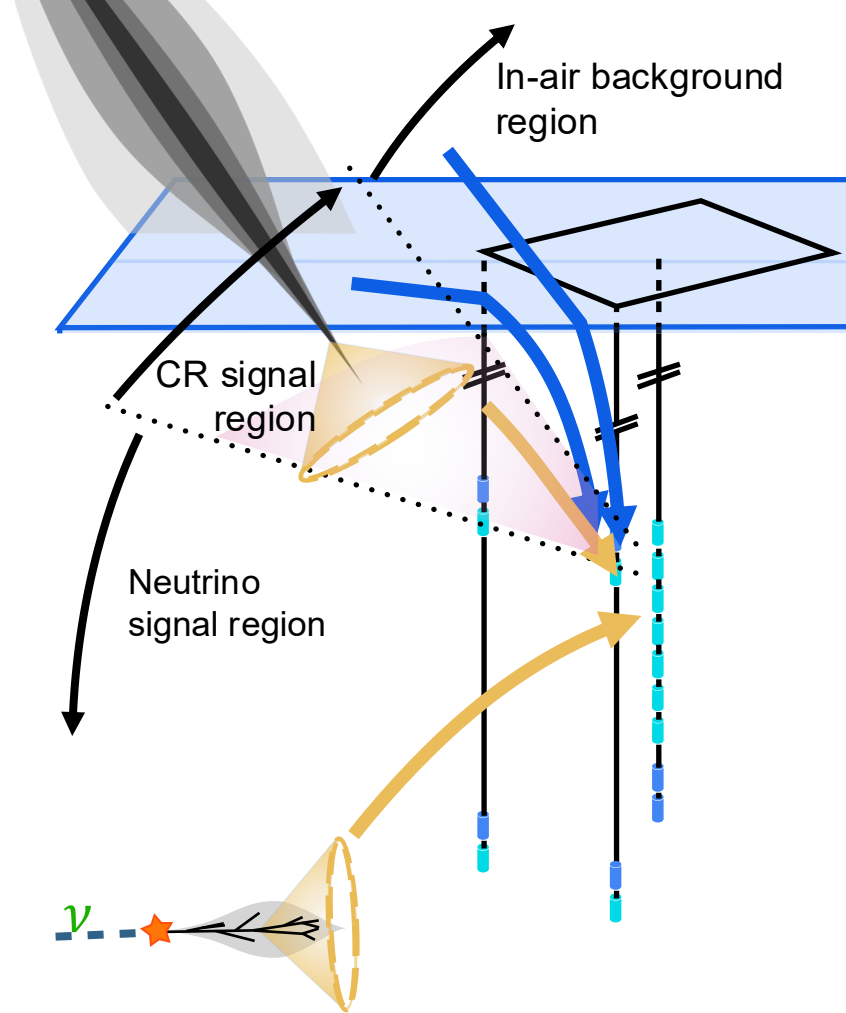
# ARA Beamforming Trigger Performance



ARA Coll., NIM 2018

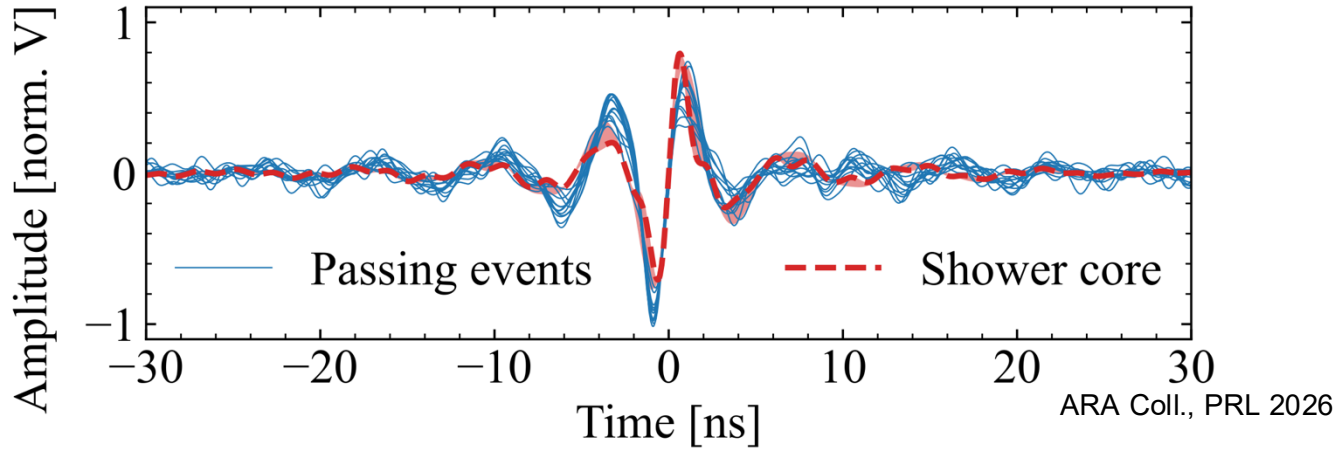
# The First Observation of Askaryan Emission from High Energy Particles in Ice

- What Happens When You Build a More Sensitive Instrument? **You find new things!**
- 13 events ( $5.1\sigma$  above background), seen in the 7 months of the station with the beamforming trigger.



ARA Coll., PRL 136 151003, 2026

# Askaryan Emission from UHE Particles In Ice

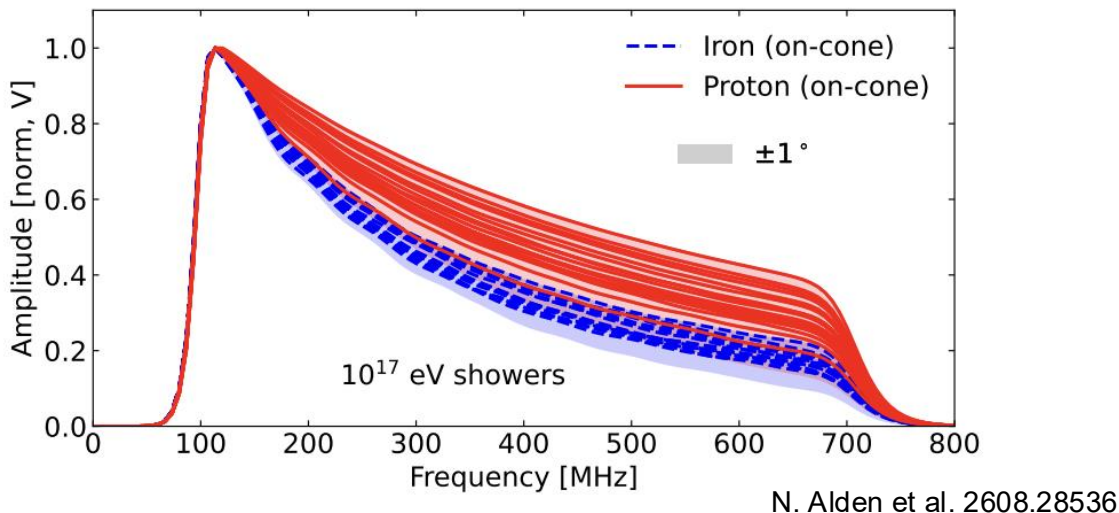


All 13 events additionally have similar event shape, frequency content, the same electric field polarity, and match simulations (signal shape as well as expected event rates) well.

## Why is this important?

- First validation of Askaryan emission models and dense shower physics at these energies
- Calibration and validation of neutrino sensitivity for Askaryan detectors, inform trigger and analysis decisions

# Measuring Cosmic Ray Composition in a New Way?

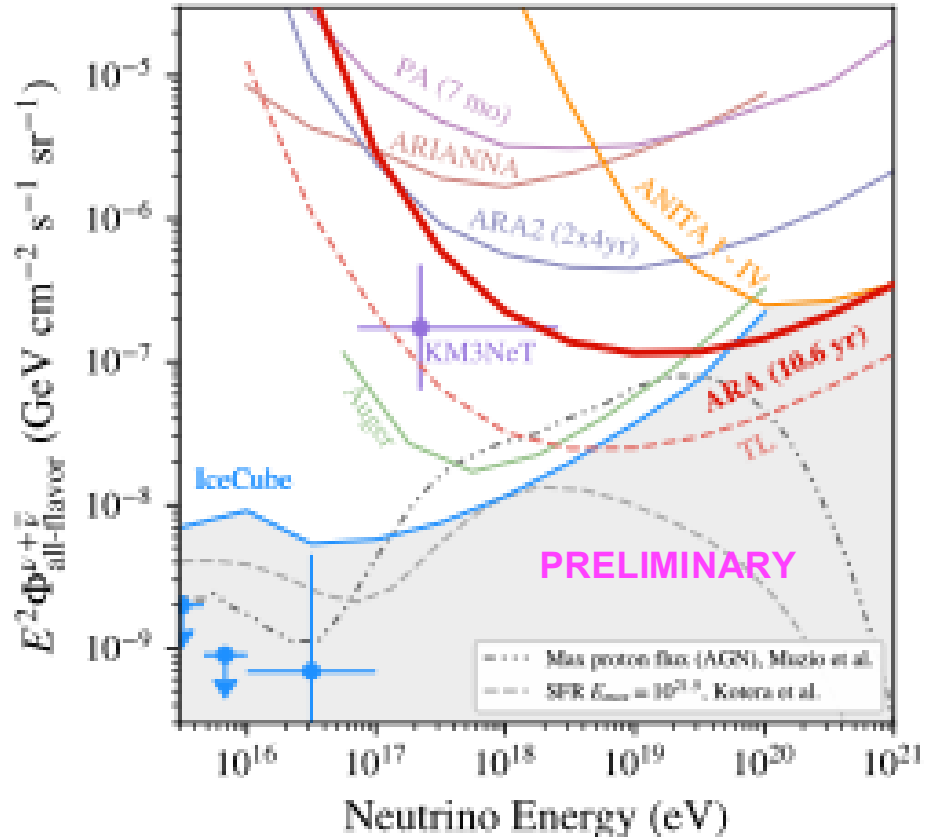


- Energy regime where the transition from galactic to extragalactic origin is expected
- Shape of the Askaryan signal is sensitive to the width of the shower core that reaches the ice. Fundamentally a different measurement than that of air showers.
- The width of the shower core is dependent on a few things, one of which is CR composition

See Nat Alden Talk

# New Constraints on the Diffuse Neutrino Flux from ARA

- 10 Years of ARA Data from all 5 ARA stations: 2013-2023
- Best sensitivity to date above  $10^{19.5}$  eV
- Background estimate across 10 years and 5 stations is:  $0.13 \pm 0.01$
- Unblinding: 1 event observed (further inspection of the event indicates it is likely to be background from the detector itself)



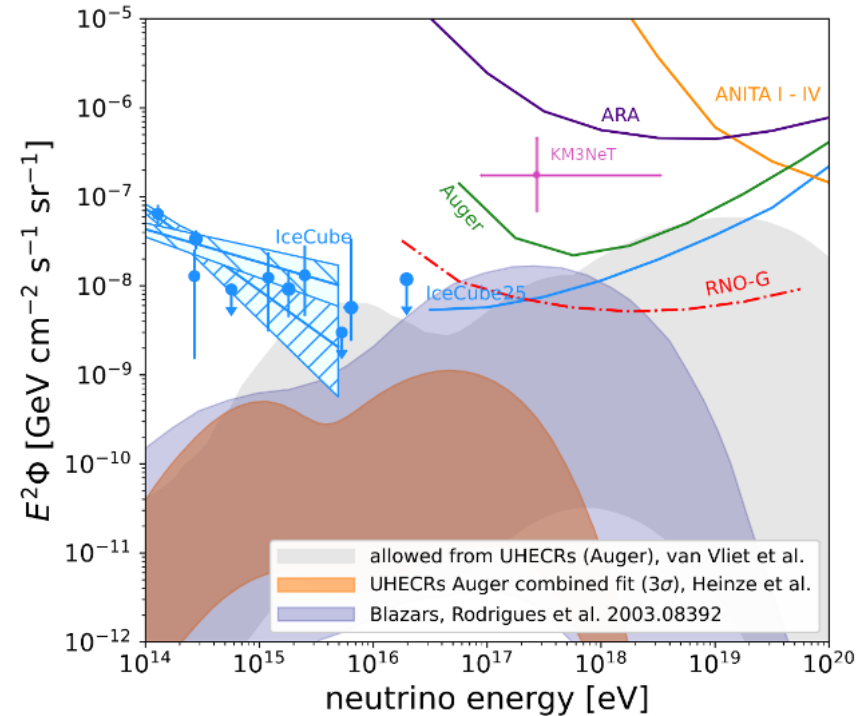
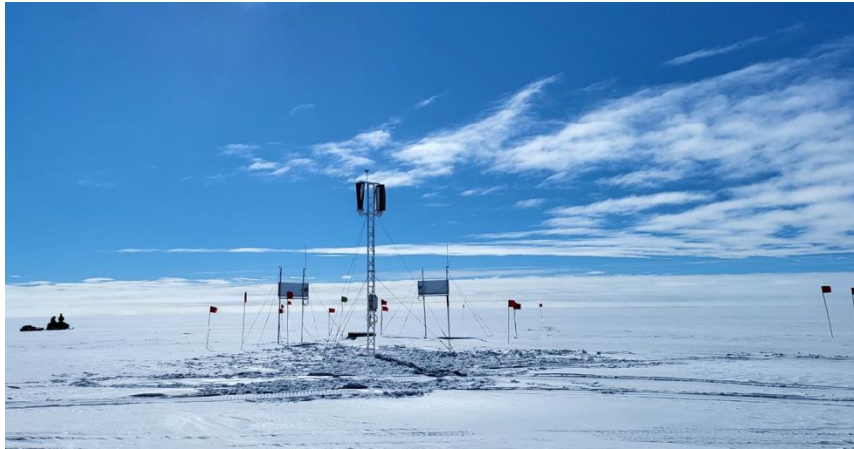
See Alan Salcedo Gomez Talk

# Radio Neutrino Observatory in Greenland (RNO-G)



- Installing at Summit Station in Greenland (first hardware deployed in 2021).
- Designed to be scalable to even larger arrays (IceCube-Gen2 Radio Array)

See Stephanie Wissel Talk



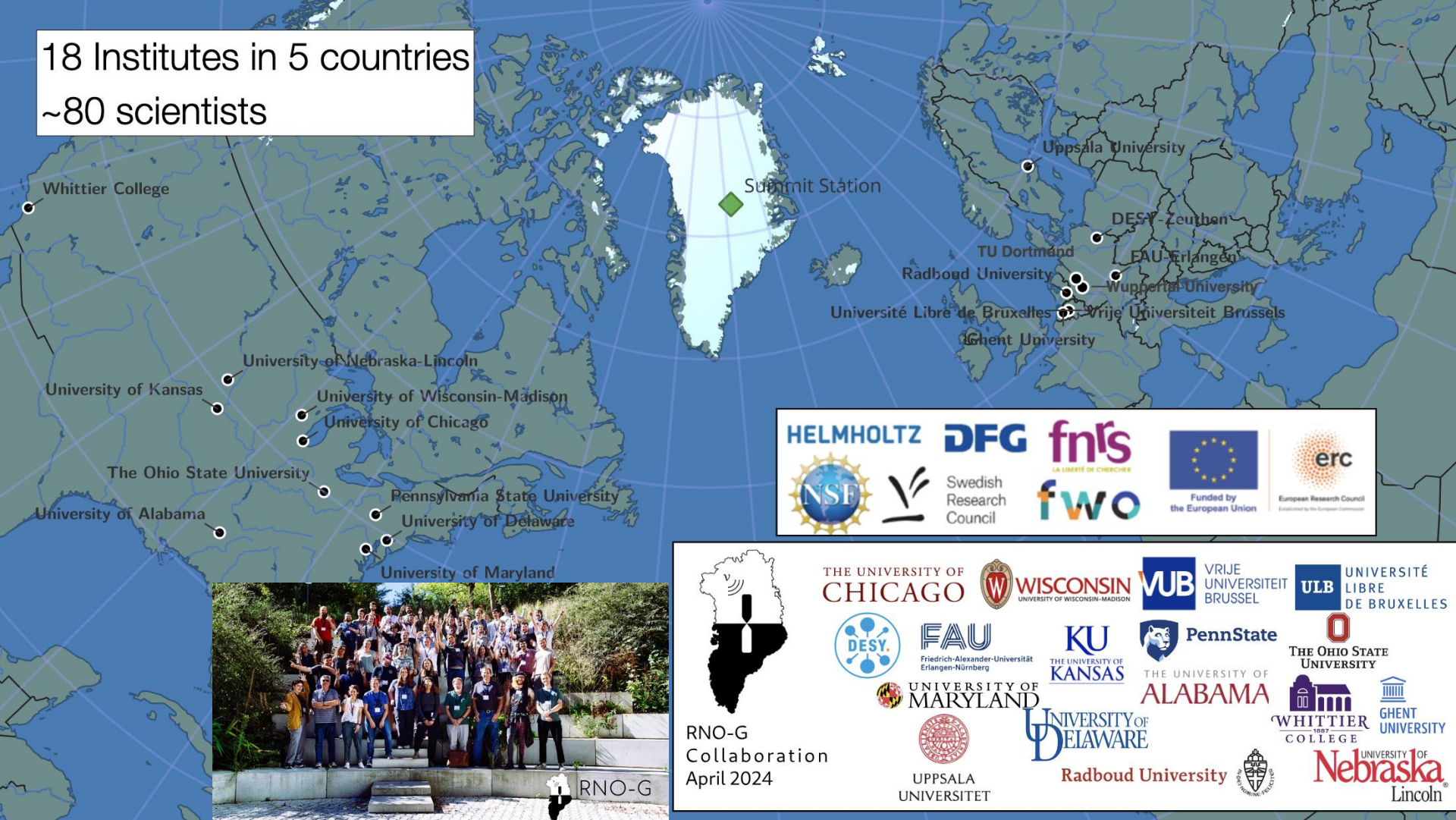
THE OHIO STATE UNIVERSITY



UPPSALA  
UNIVERSITET



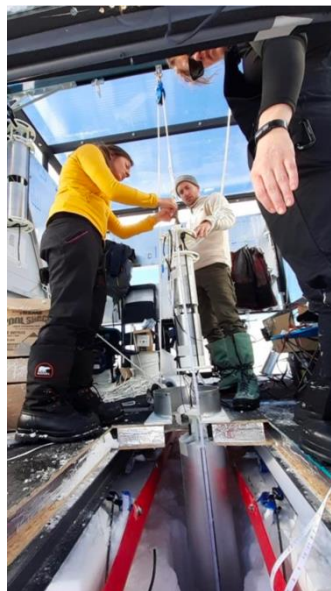
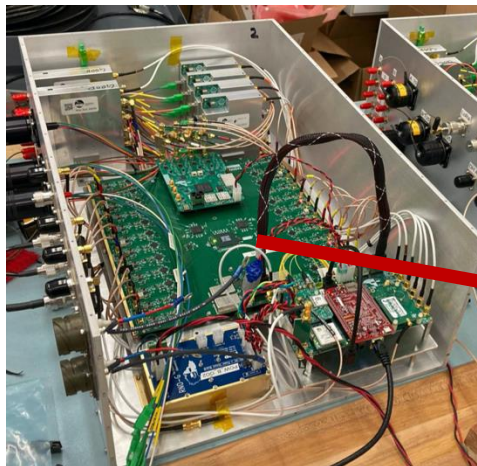
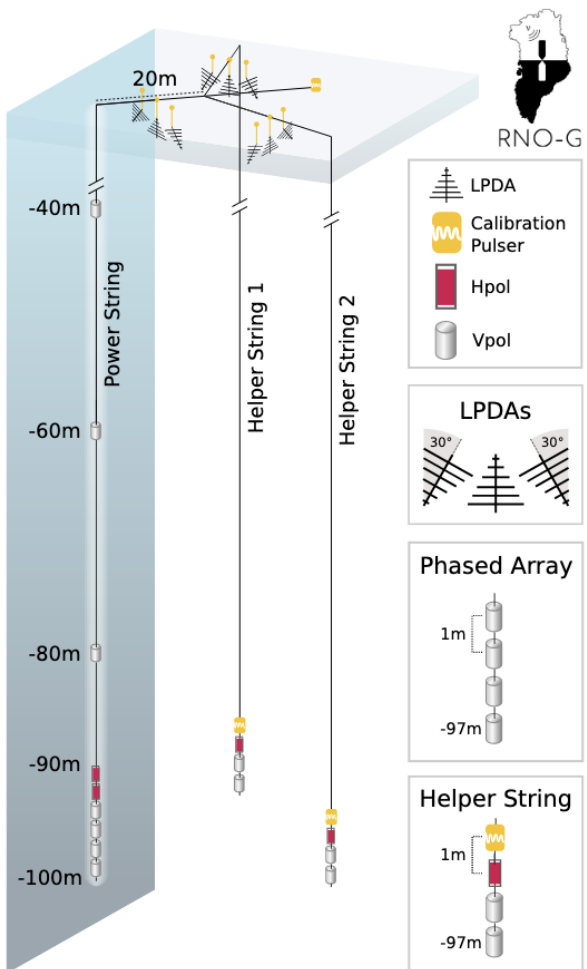
18 Institutes in 5 countries  
~80 scientists



A map of Greenland showing ice thickness in meters. The color scale ranges from 0 (blue) to 3000 (red). The map highlights the Kangerlussuaq and Summit Station locations. The Kangerlussuaq location is marked with a blue star and an arrow. The Summit Station location is marked with a blue star and an arrow. The map also shows the coastline and major rivers.

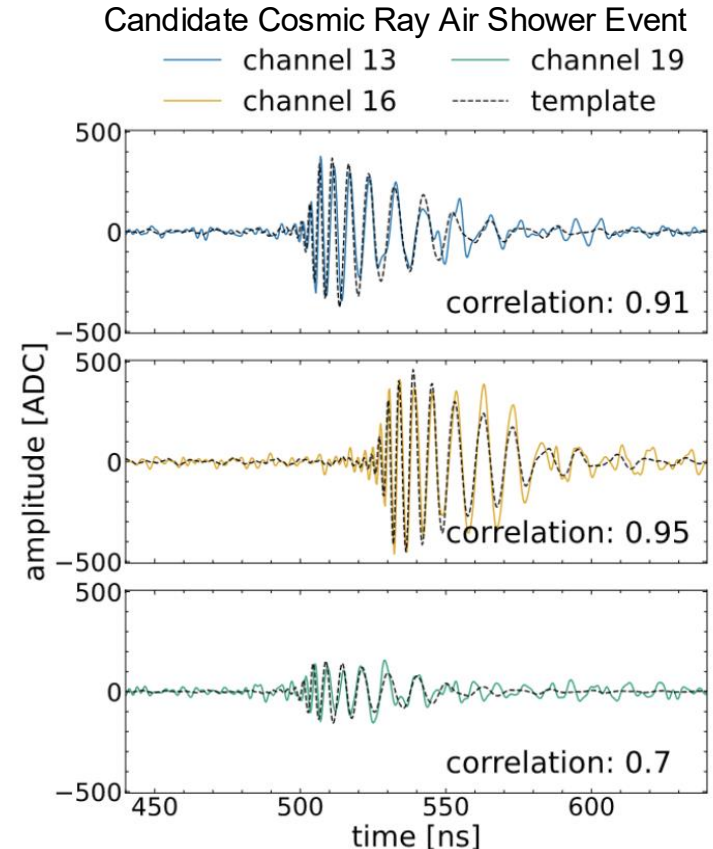
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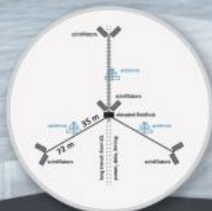


# Moving toward a Neutrino Search in RNO-G

- RNO-G has done extensive calibration and ice model validation with in situ calibration sources and dedicated ice property studies. (See Alex Kriacou and Shoukat Ali Talks)
- RNO-G also sees various things that can be used for calibration in the data: solar flares, surface triboelectric charging due to wind, airplanes
- Cosmic ray air shower events seen in upward-pointing near-surface antennas.
- Search for Askaryan emission from Cosmic Rays in deep channels is underway.
- Calibrating detector sensitivity to a (known) flux of cosmic ray air showers validates neutrino sensitivity.
- First neutrino search is underway.



Submitted to EPJ-C, J. Henrichs



### Cosmic Ray Surface Array

An air shower array that sits on top of the optical array  
One surface station installed above each optical string



### IceCube-Gen2 Optical Module

4x the sensitivity of IceCube's modules  
9,600 new optical modules in total to be deployed in the ice



80 modules on each string, spaced 17 meters apart

50 m

1370 m

2780 m

**IceCube-Gen2:**  
120 new strings of optical modules

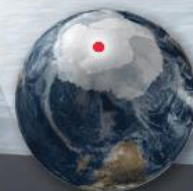
**IceCube:**  
86 strings of optical modules

DeepCore

Antarctic bedrock

IceCube  
(1 km)

IceCube-Gen2  
(5 km)



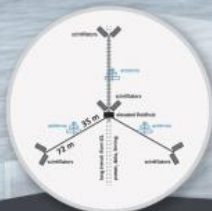
### Amundsen-Scott South Pole Station, Antarctica

A National Science Foundation-managed research facility



### Below-Ice Radio Array

361 detector stations spread over an area of 500 km<sup>2</sup>



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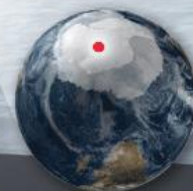
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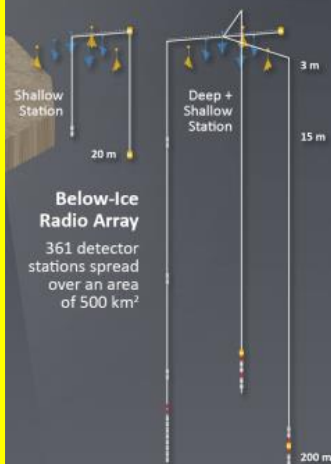
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(1 km)

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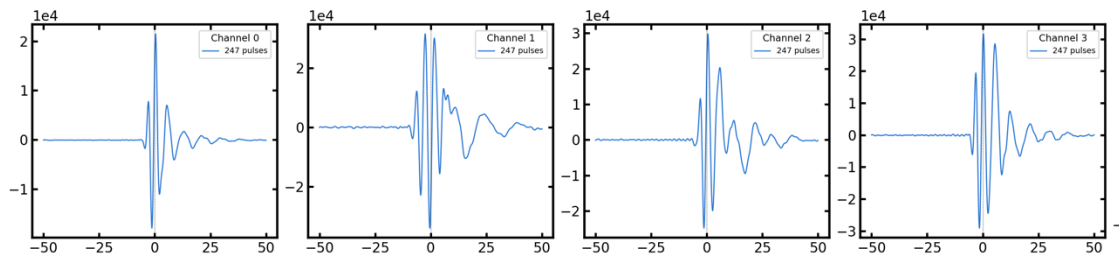
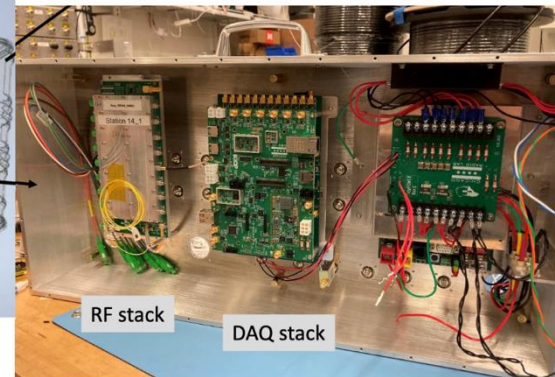
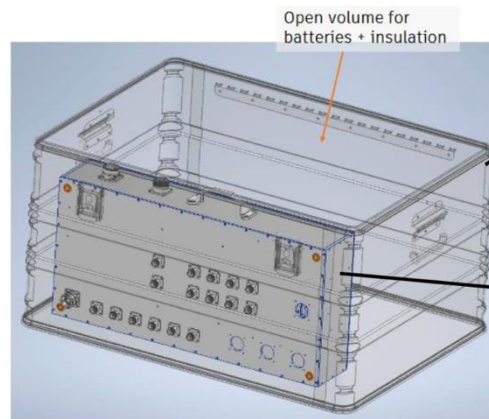
### Amundsen-Scott South Pole Station, Antarctica

A National Science Foundation-managed research facility

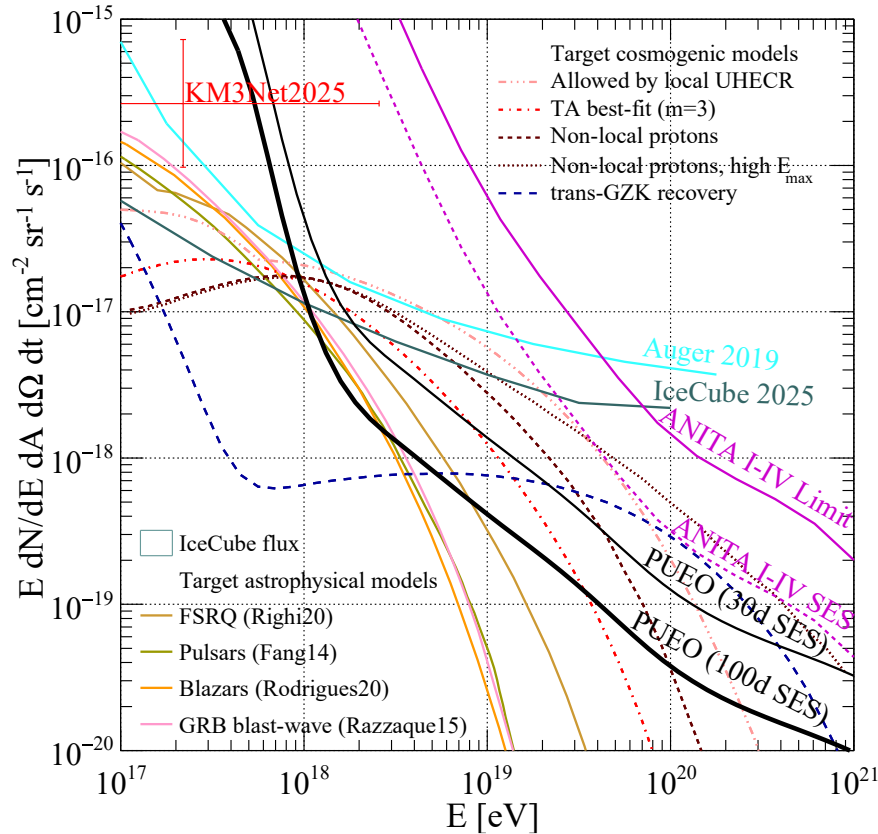


# RNO-G as a Demonstrator for IceCube-Gen2 Radio

- Previous DAQ design worked well enough, but required time-consuming calibration, and could not be scaled to the  $O(100)$  required for Gen2.
- New DiDAQ systems installed in 2026 are working well
- All digital 24-channel DAQ that uses newly-available digitizers.
- Robust, lower maintenance than previous design
- Many other relevant things are being tested with RNO-G: Solar and Wind power, LTE communications, drilling scheme.

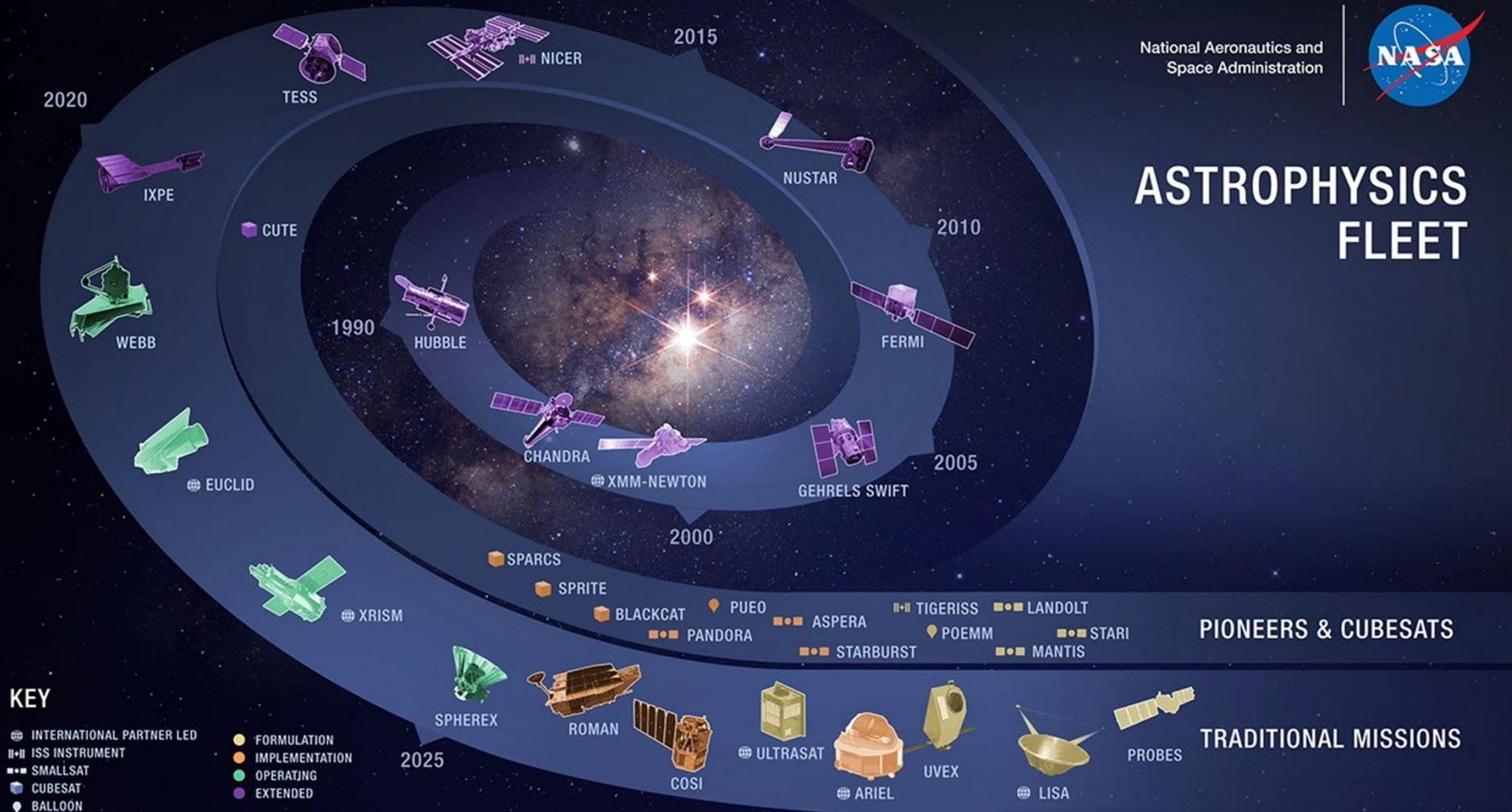


# PUEO: The Payload for Ultrahigh Energy Observations



See Keith McBride Talk

# ASTROPHYSICS FLEET



# ASTROPHYSICS FLEET

**PUEO**

**PIONEERS & CUBESATS**

**TRADITIONAL MISSIONS**

## KEY

- INTERNATIONAL PARTNER LED
- ISS INSTRUMENT
- SMALLSAT
- CUBESAT
- BALLOON

- FORMULATION
- IMPLEMENTATION
- OPERATING
- EXTENDED

2025

2015

2010

2005

2000

1990

2020

TESS

NICER

IXPE

CUTE

WEBB

EUCLID

HUBBLE

CHANDRA

XMM-NEWTON

NUSTAR

FERMI

GEHELS SWIFT

SPARCS

SPRITE

BLACKCAT

PANDORA

PUEO

ASPERA

STARBURST

TIGERISS

POEMM

LANDOLT

STARI

MANTIS

SPHEREX

ROMAN

COSI

ULTRASAT

ARIEL

UVEX

LISA

PROBES

# The PUEO Instrument



- 192-RF-Channel Main Instrument
- 16-antenna, dual-polarization beamforming trigger
- 16-RF-Channel Low Frequency Instrument.
- Triply redundant onboard data storage
- Command and control, data transfer to the ground
- Suite of navigation instruments
- Housekeeping/environment sensor system



# PUEO Builds on Heritage from ANITA

Sensitivity increase is enabled by:

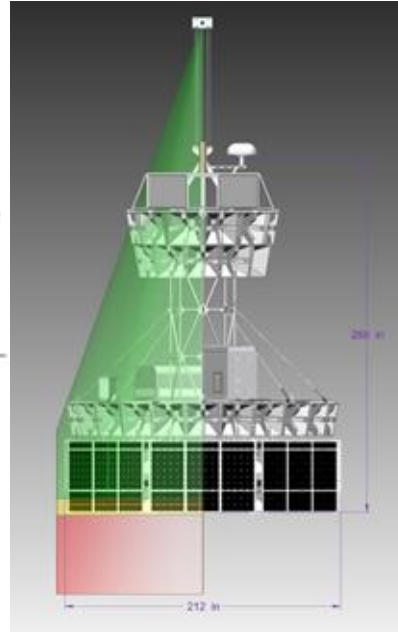
- Beamforming trigger with optimized trigger band
- x2 more antenna collecting area above 300 MHz
- Better performing antennas + RF chain

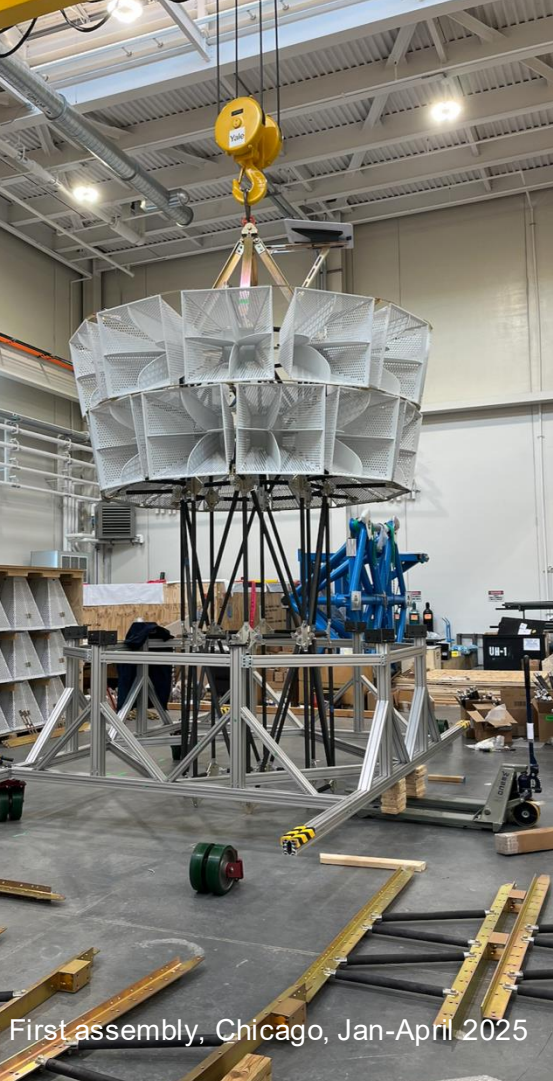




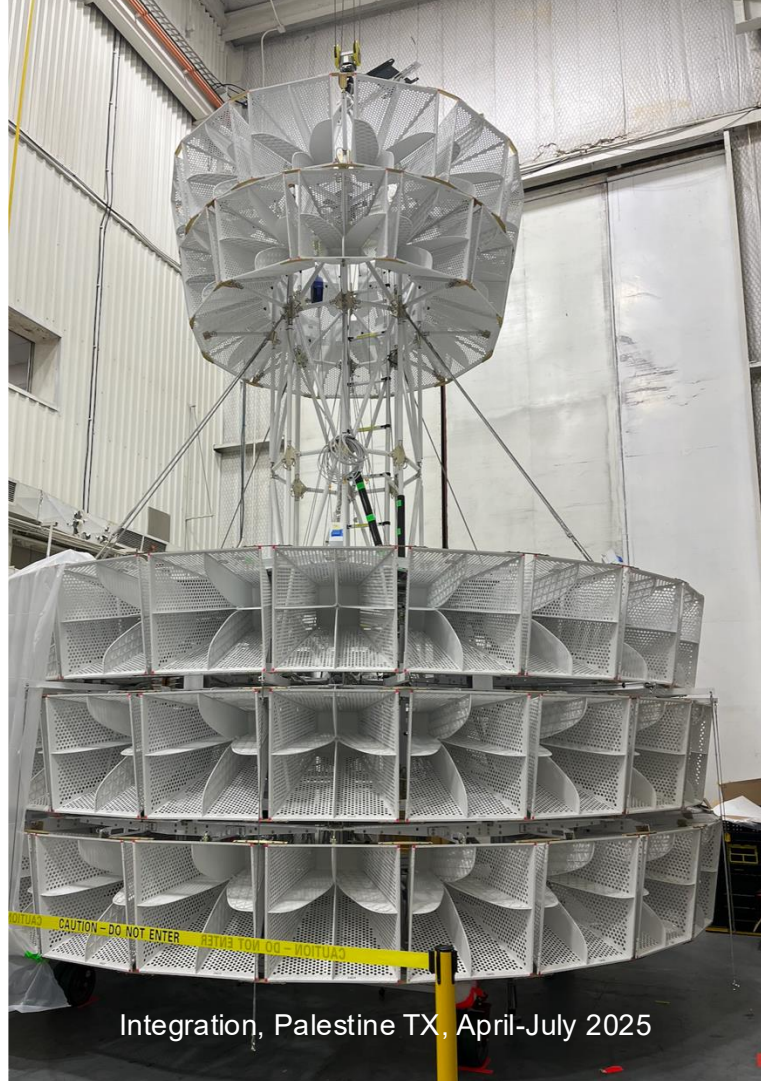
# Deployable Systems: Maximizing science on a constrained platform

- 





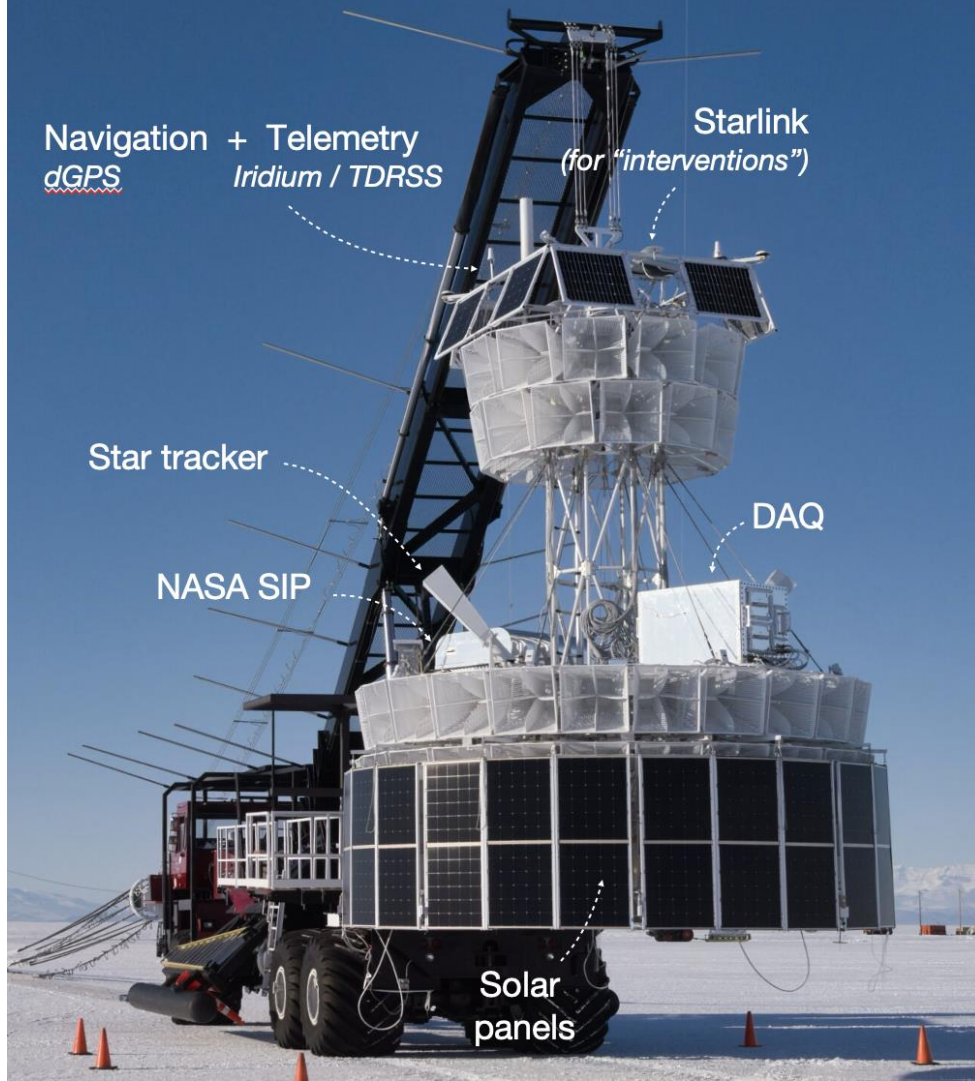
First assembly, Chicago, Jan-April 2025



Integration, Palestine TX, April-July 2025



Final Integration and Launch, McMurdo,  
November- December 2025



Arrival at LDB: November 15

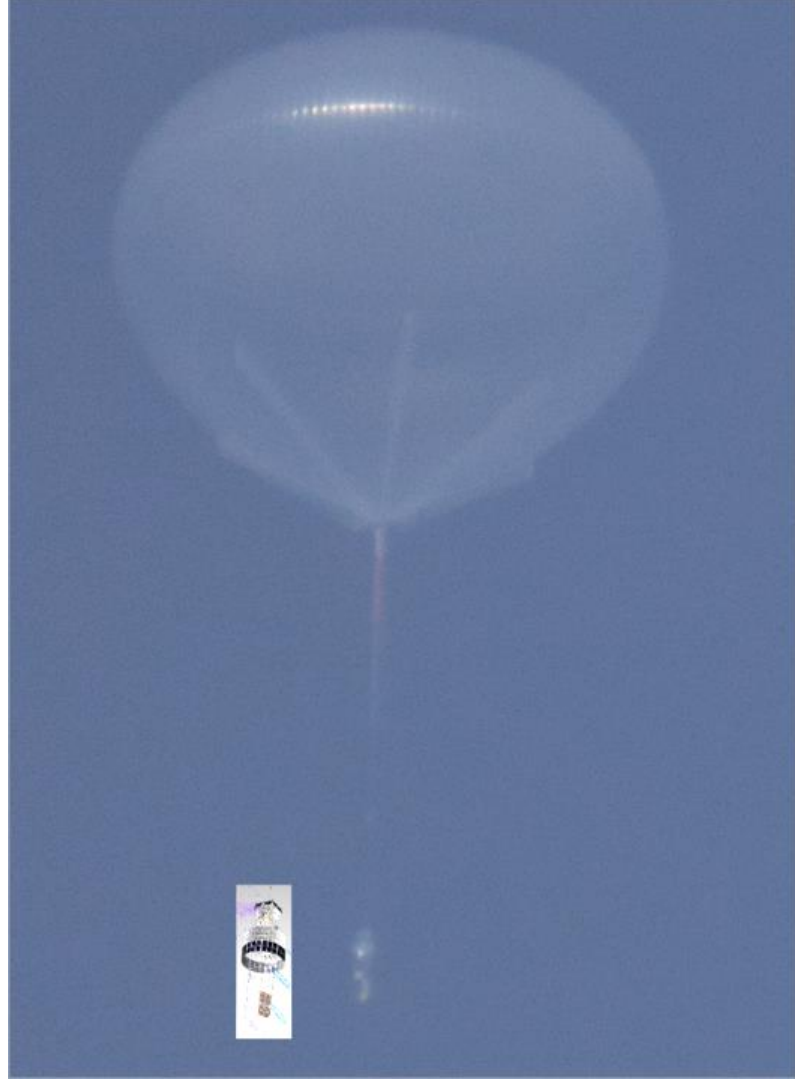
A Sleepless PI: December 1-4

Compatibility/Hang Test: December 8

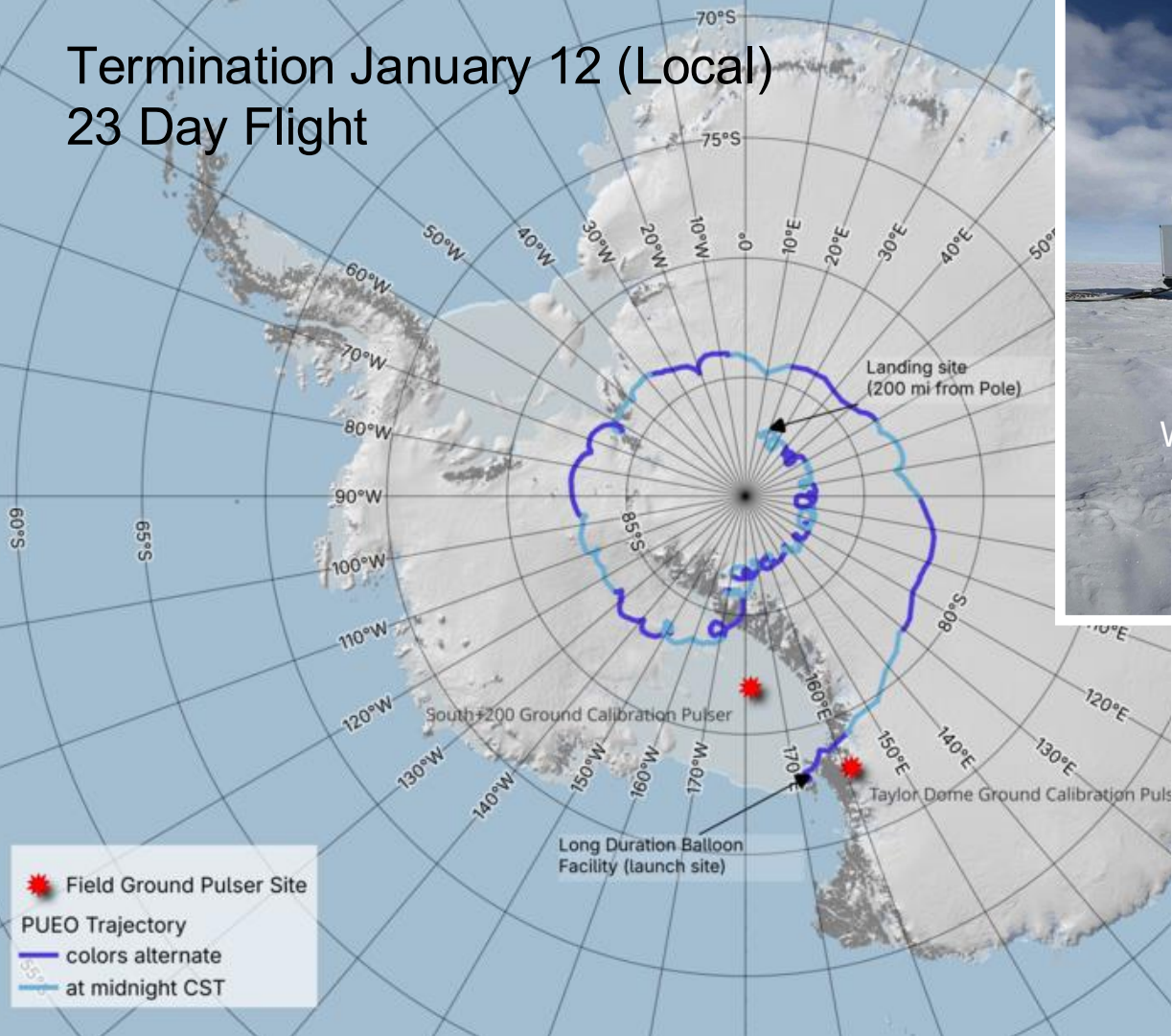
Flight Readiness Review: December 11

Launch: December 20, 2025 (Local)

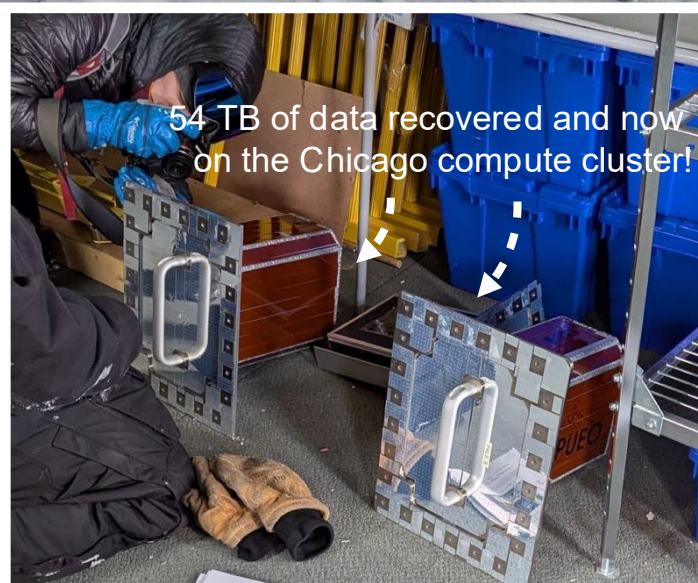




# Termination January 12 (Local) 23 Day Flight

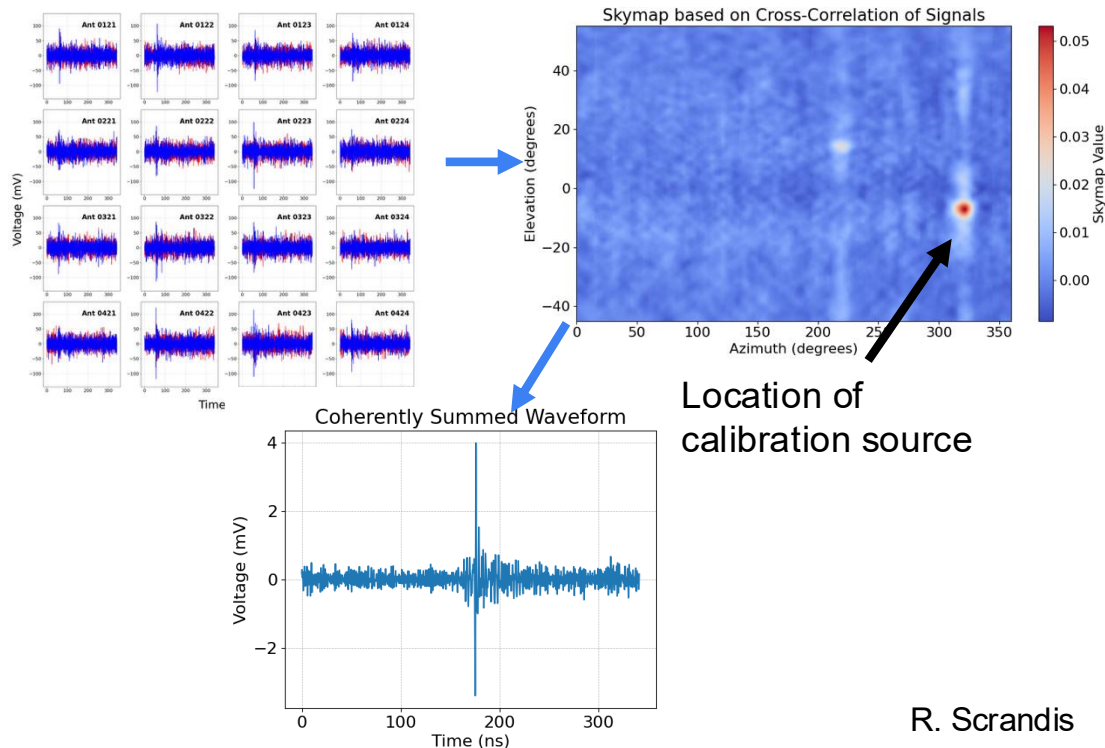


Landing site  
Jan. 14



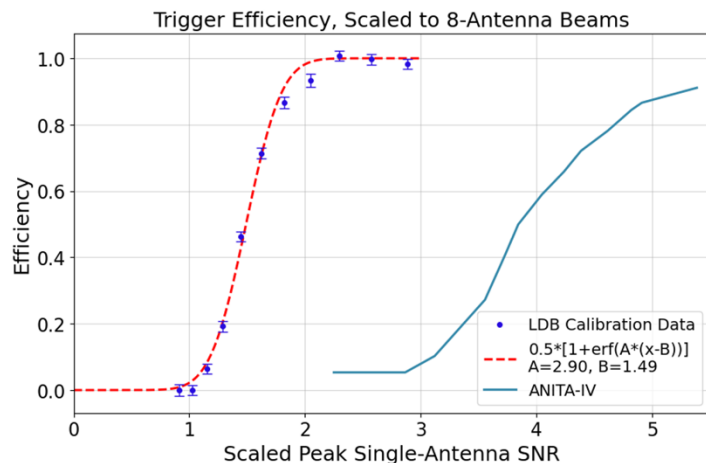
# A Look At the Flight Performance

## Calibration Event from the Ground



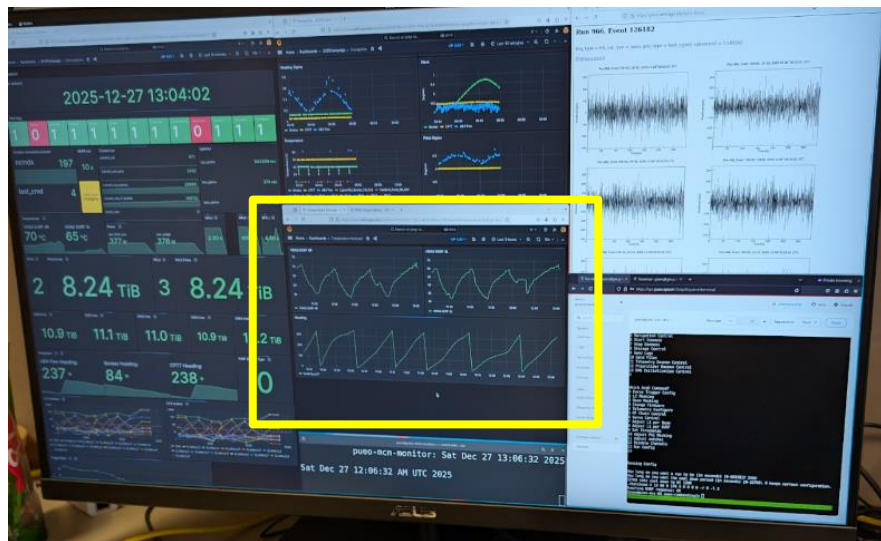
R. Scrandis

## Trigger Efficiency



L. Beaufore

# A Look At the Flight Performance



1) Due to thermal issues, we ended up with a 55% total livetime. We expected ~90% (from launch to termination)



2) Despite our upgraded navigation system, we will end up with worse resolution in heading than we hoped (comparable to ANITA, but not significantly better as hoped)

# GRAND: Giant Radio Array for Neutrino Detection



GRANDProto300 & other prototypes: **experimental setup**

Deployment of 13 antennas in Gansu (China)  
65 in 2025 and 200 more later

Deployed Feb 2023

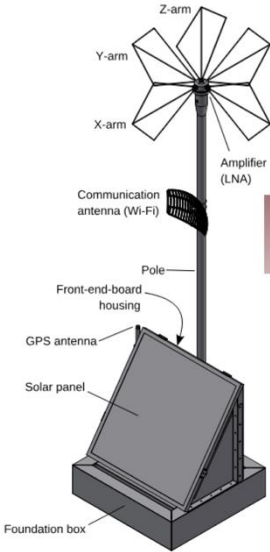
Deployment of 10 antennas on the Auger site  
in Malargüe, Argentina (cross-calibration)

Deployed Aug 2023

Deployment of 4 antennas in Nançay radio  
observatory (France) for trigger test (LPNHE)

Deployed Oct 2022

Full GRAND: 200,000 antennas, on a plateau, looking for skimming air showers induced by tau neutrino interactions in the Earth



**GRAND Coll. ICRC 2025**

**GRAND Coll. Moriond 2025 (Ferrière, Guelfand, Lavoisier)**

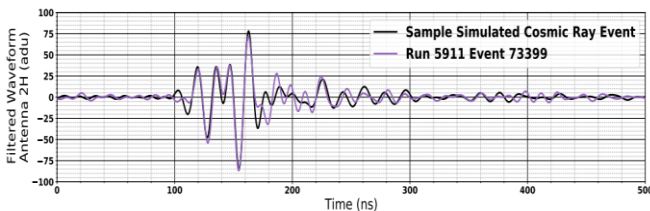
# BEACON: The Beamforming Elevated Array for Cosmic Neutrinos



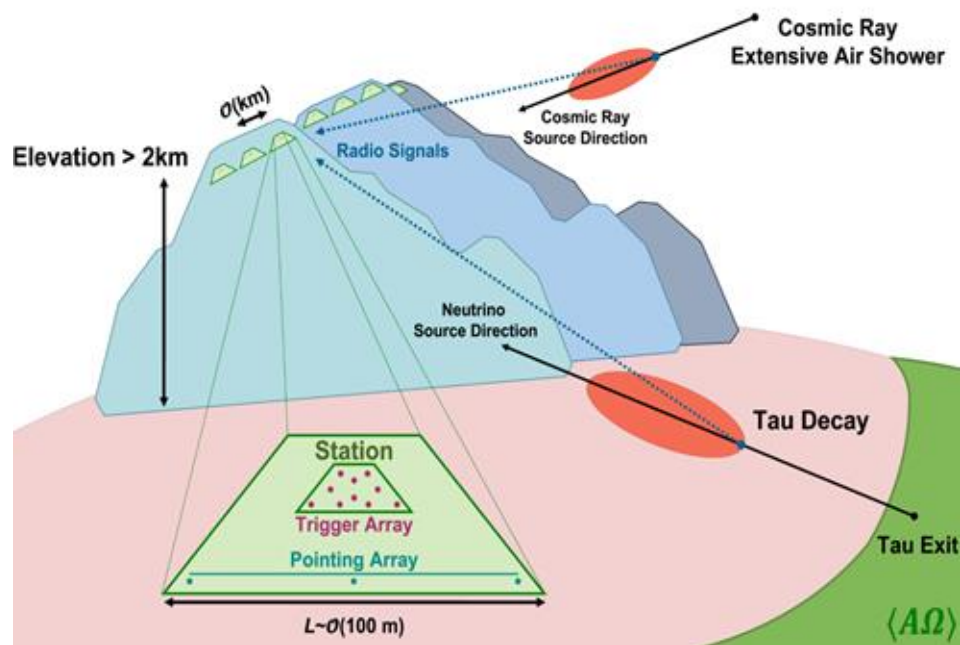
Concept:  $\mathcal{O}(1000)$  antennas, in beamforming stations on high mountaintops, designed to detect the radio emission of upgoing air showers created by earth-skimming  $\nu_\tau$ . Being on a mountain helps.



Cosmic-ray candidates event identified with prototype



S. Wissel et al. JCAP11(2020)065, D. Southall et al NIM-A 2022



See Zack Martin Talk

# HERON: Hybrid Elevated Radio Observatory for Neutrinos

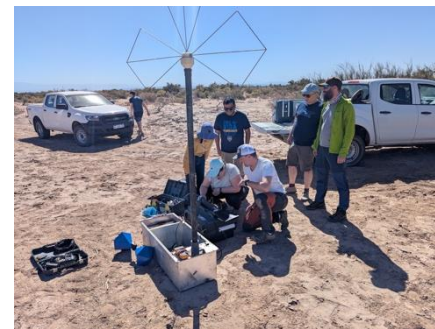


## HERON=BEACON+GRAND

- 24 compact beamforming stations, of 24 antennas each, are embedded within a large sparse array of 360 standalone antennas
- Elevated 1-2 km above a valley floor
- Each beamforming station triggers the 15 nearest standalone antennas
- Sparse array provides offline event reconstruction and background rejection, and a separate veto trigger.

Site: San Juan Province, Argentina.

Full construction (936 antennas) was funded recently by an ERC grant; plan is to construct and calibrate the full array in the coming 5 years.



# Summary

New results in the last year include the first detection of Askaryan emission from ultra-high energy particles in dense media, and new world's best constraints on the neutrino flux at the highest energies.

New, science-scale (not prototypes!) experiments are being constructed and are operating (e.g. RNO-G and HERON).

PUEO launched this year, and results will come in the next year. First results from RNO-G, and then from HERON will follow.

IceCube-Gen2-Radio would be a major advancement for radio detection of UHE neutrinos, and the hardware has made major advancements, is scalable, and will be ready.

