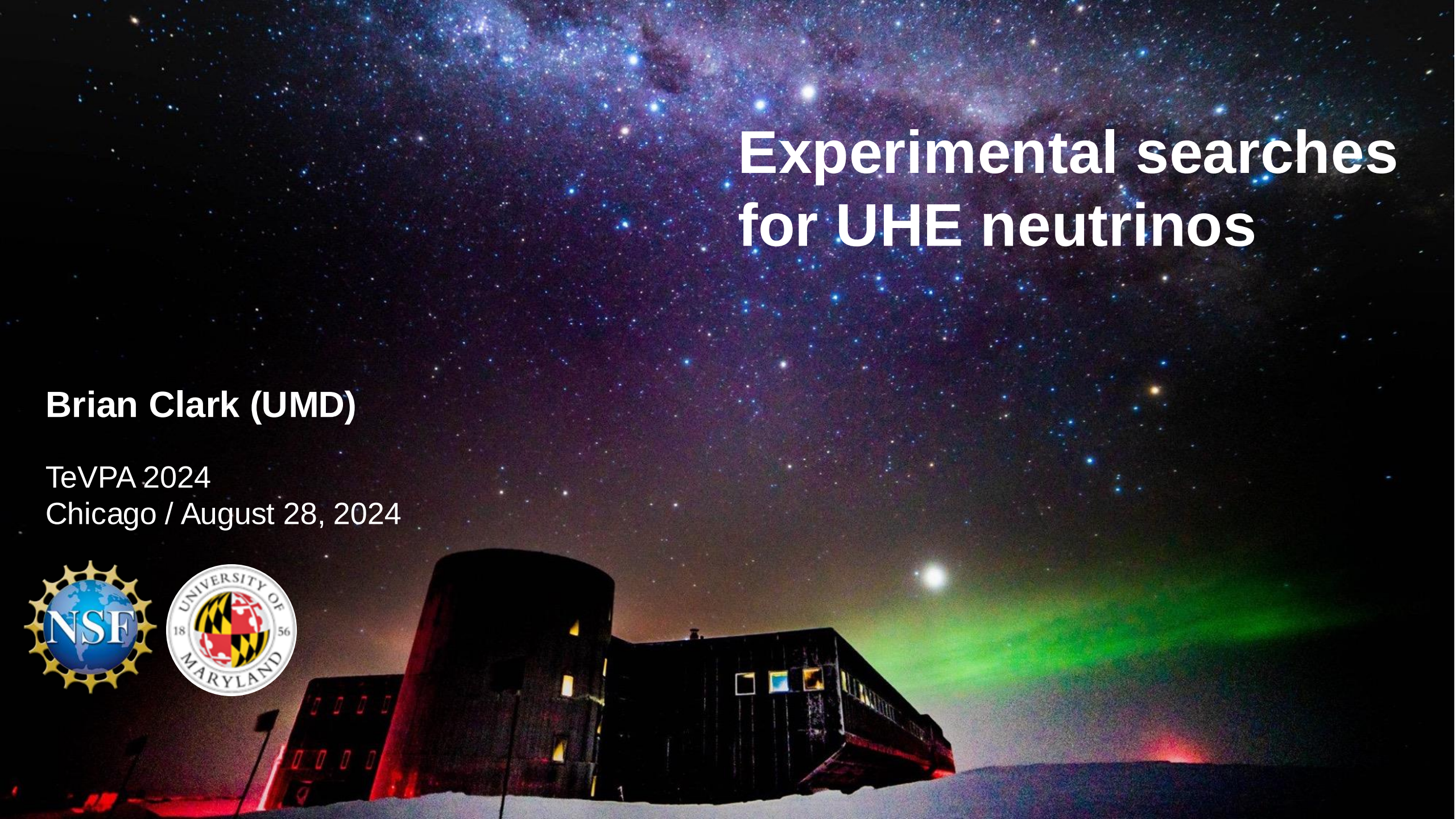
# Experimental searches for UHE neutrinos

**Brian Clark (UMD)**

TeVPA 2024
Chicago / August 28, 2024



# Why Study Neutrinos?

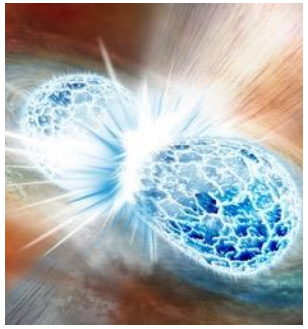
## Origin of UHE Cosmic Particles

The universe creates extraordinarily energetic particles (protons, neutrons, etc.)

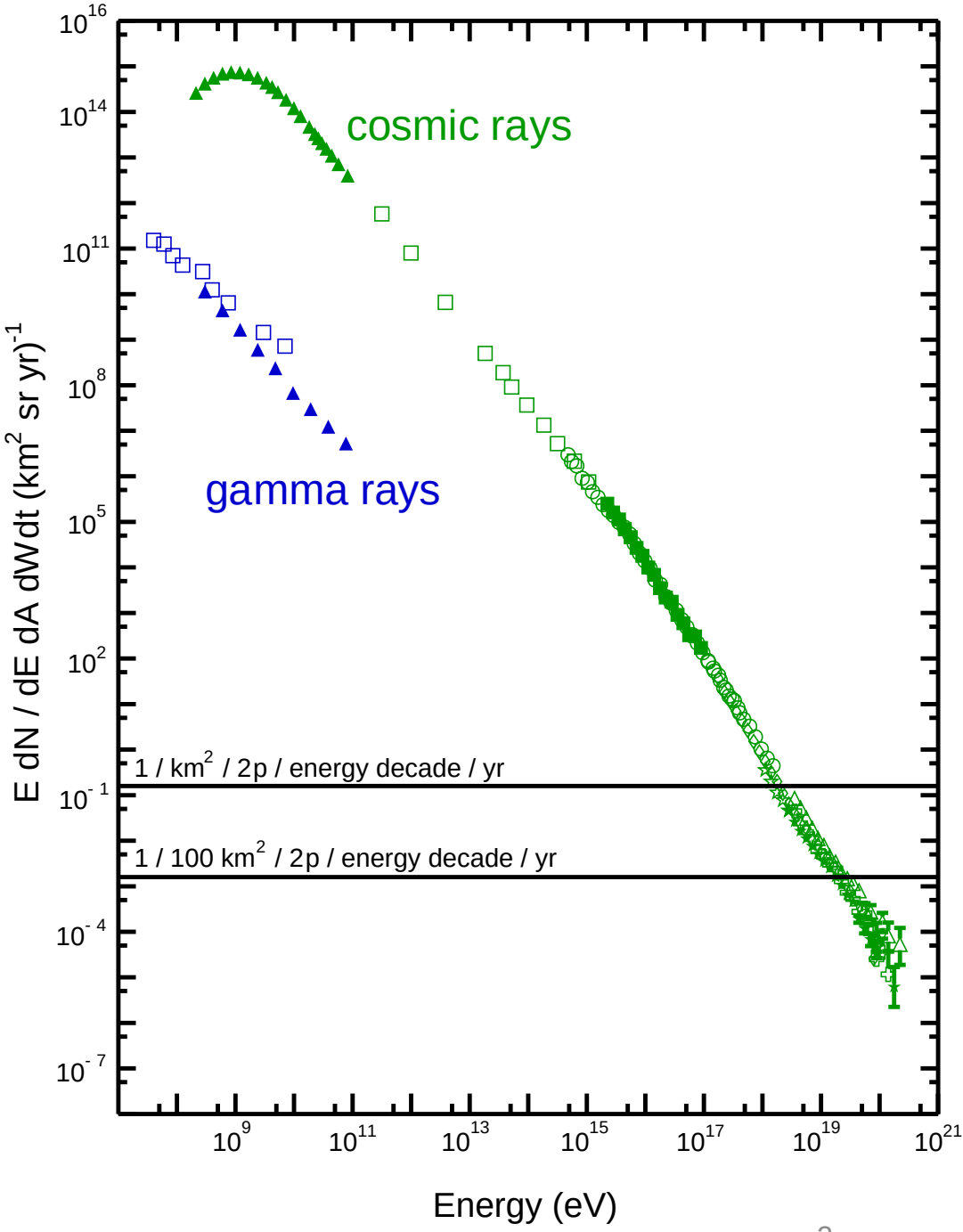
**Where** are they accelerated?

**How** are they accelerated to such tremendous energies?

AGN?



Mergers?



# Observational Challenges

Cosmic rays

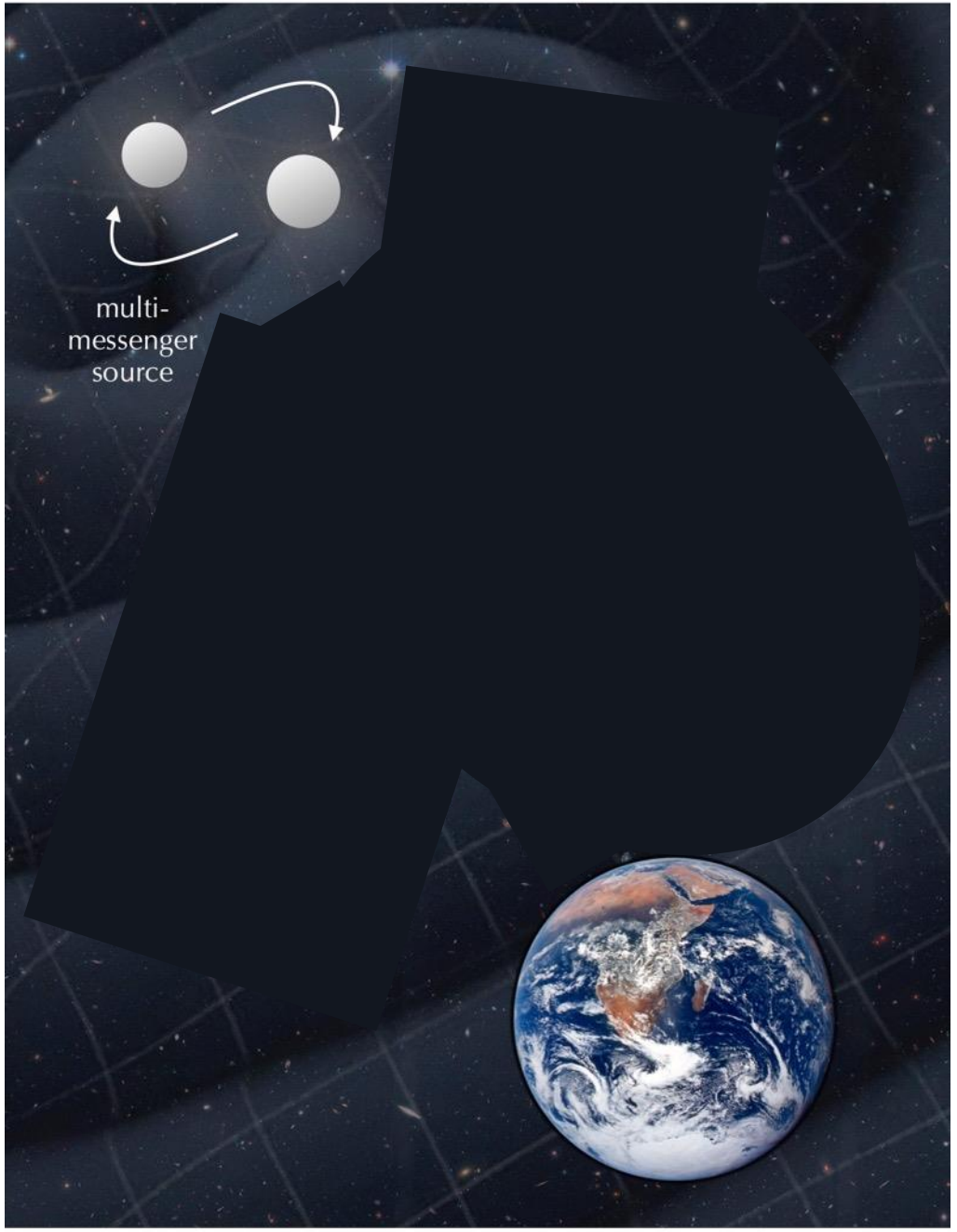
- Bent by magnetic fields
- Do not escape dense environments

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

- 100 MPc horizon above $10^{19.5}$ eV (GZK interaction)

Gamma rays: absorbed by CMB, EBL, dust

We need a new messenger!

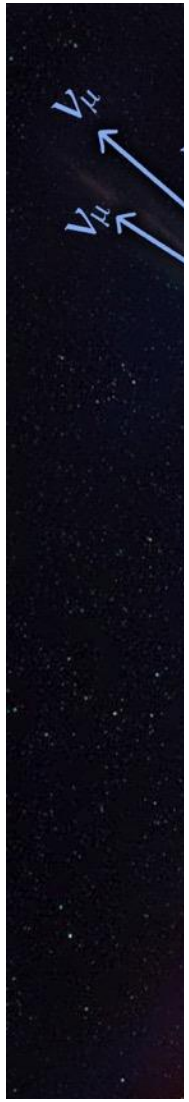


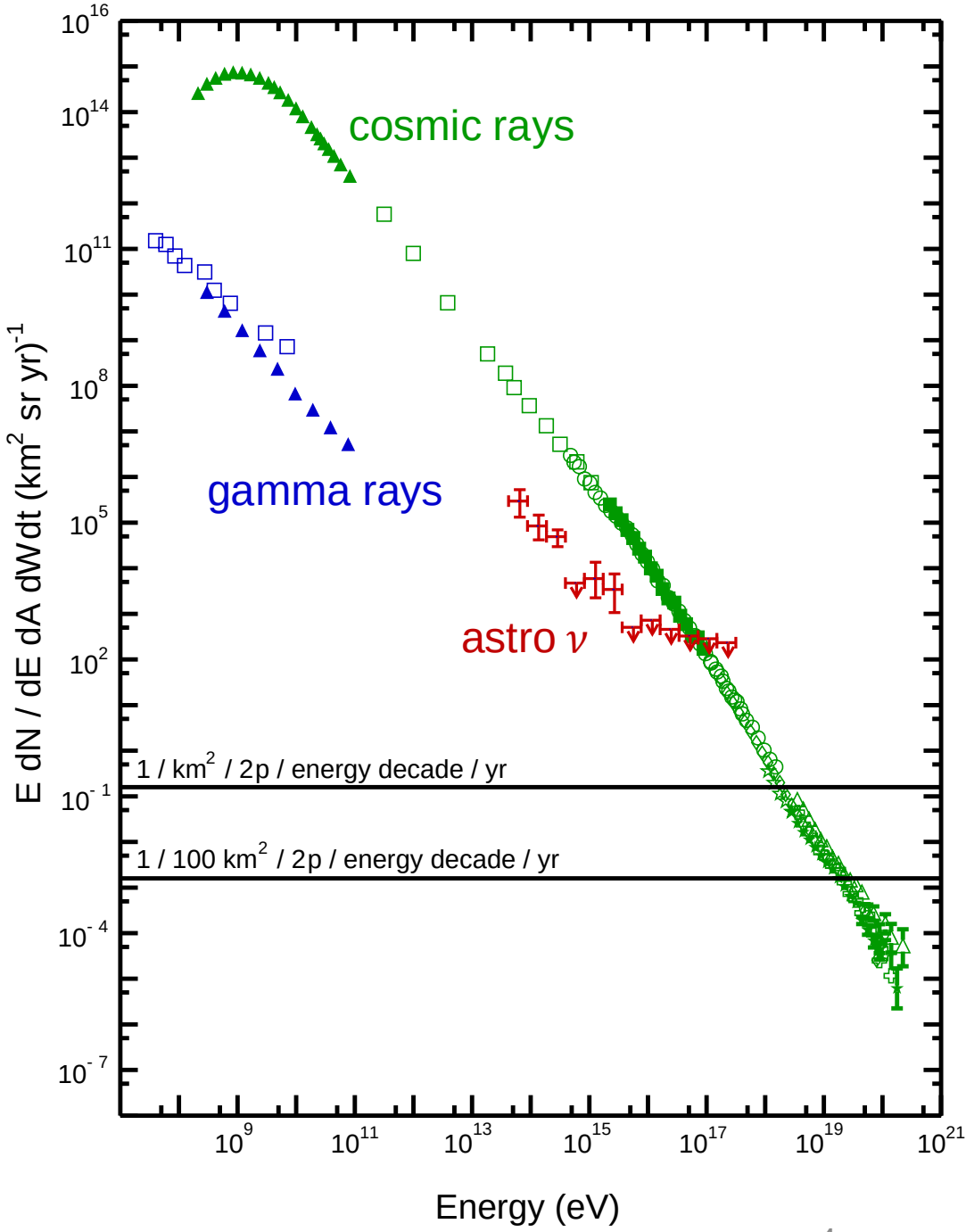
# Astrophysical Neutrinos

Neutrinos born in (or near) the cosmic ray accelerators

Unambiguous proof of hadronic acceleration

Detected in 2012!



# Cosmogenic Neutrinos

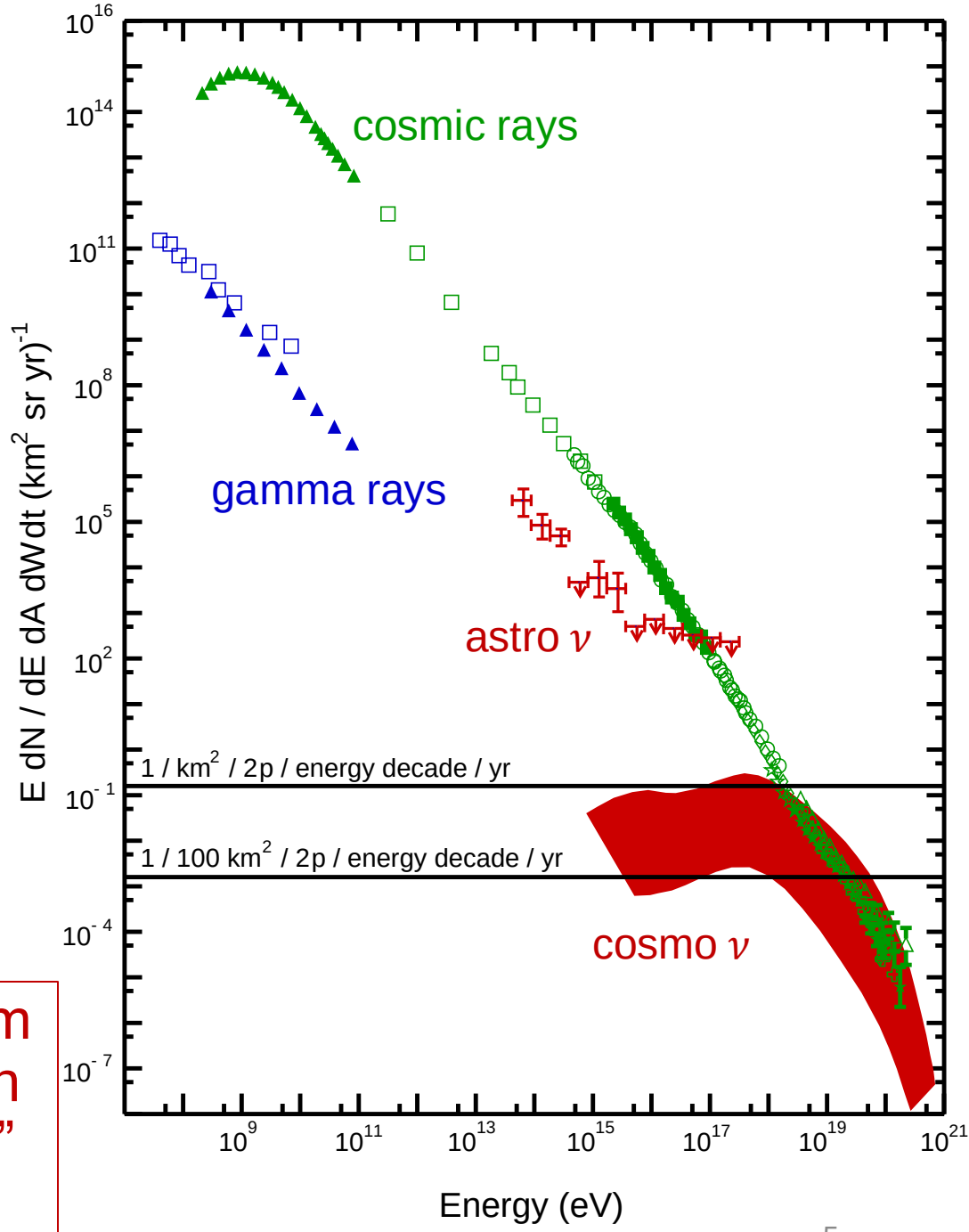
Pions from the GZK interaction further decay

$$p + \gamma_{CMB/EBL} \rightarrow n + \pi^+$$
$$\hookrightarrow \mu^+ + \nu_\mu$$
$$\hookrightarrow e^+ + \nu_e + \bar{\nu}_\mu$$

Undetected. But! Shape encodes important astrophysics:

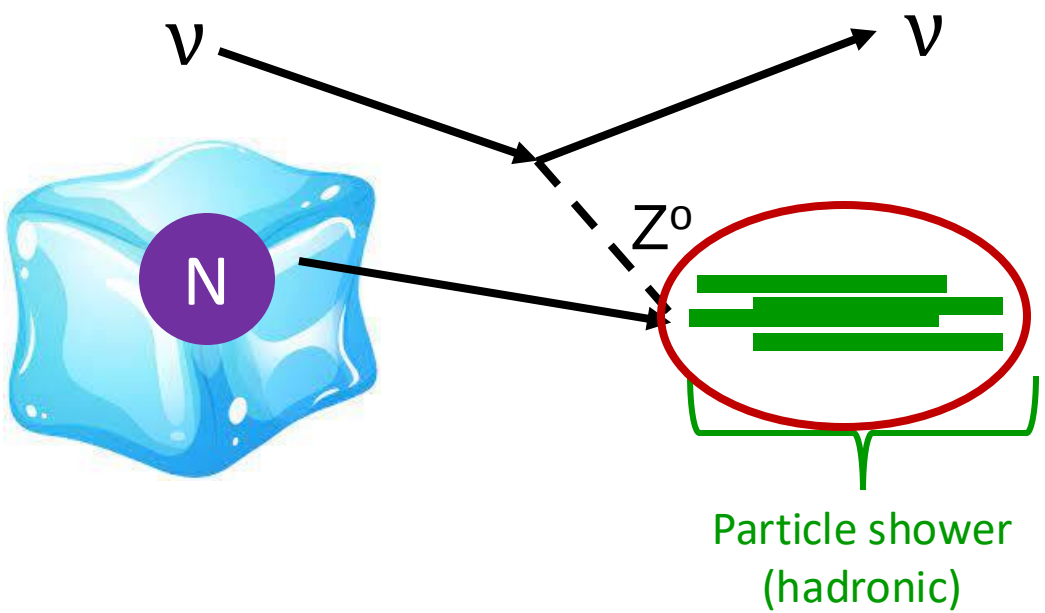
- Maximum accelerating energy
- Source redshift evolution
- Cosmic ray composition

By “UHE”, I am going to mean “$E_\nu > 10\ PeV$”

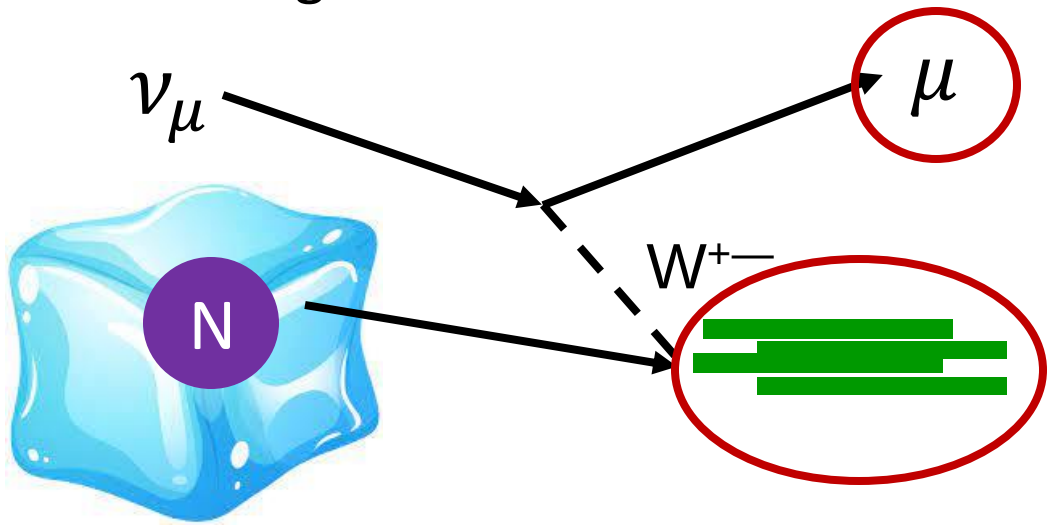


# How to Observe a Neutrino

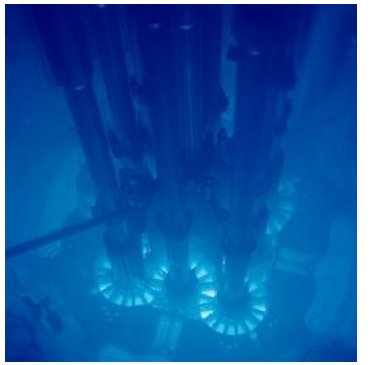
"Neutral Current" Interaction




"Charged Current" Interaction




The byproducts are charged and moving faster than light in ice. Emit Cherenkov radiation.



# Radio Cherenkov Effect

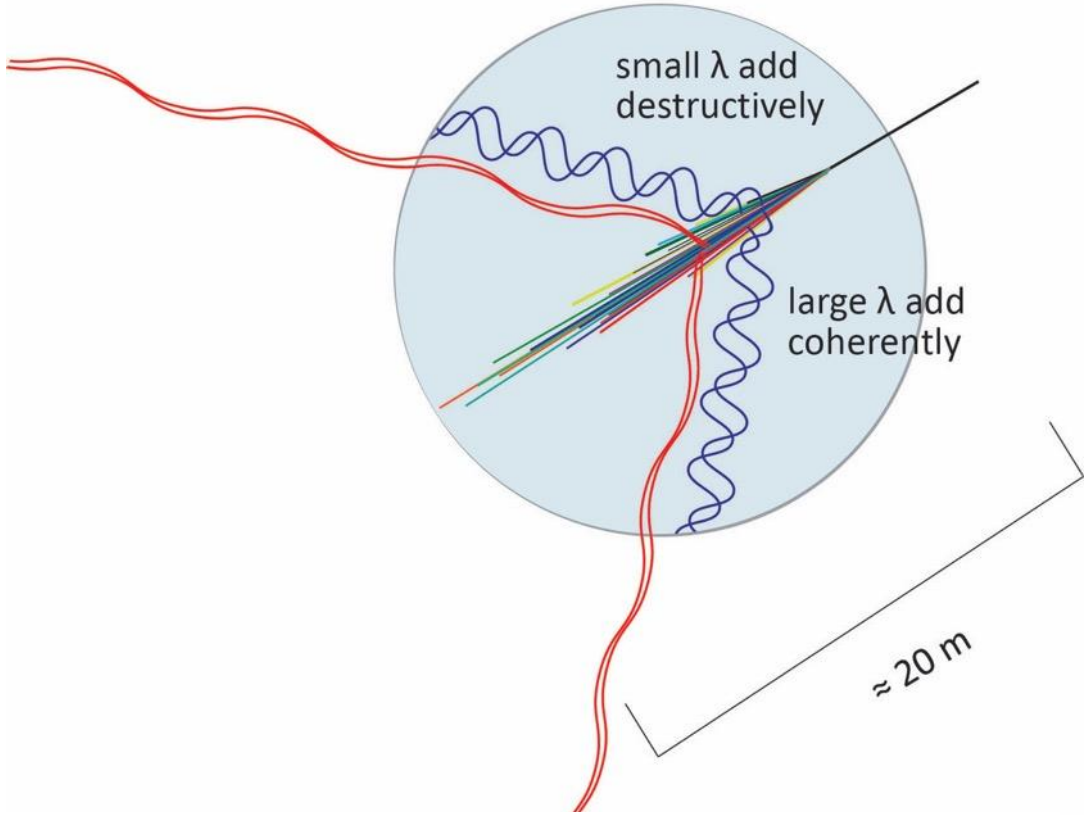
## "Askaryan Emission"

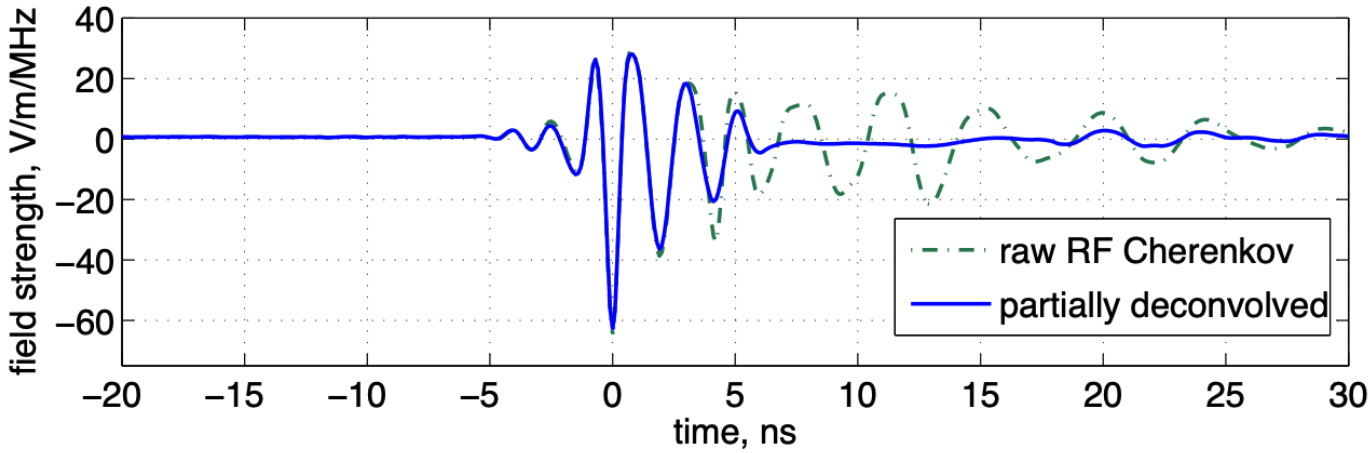
The shower becomes net *negatively* charged

Wavelengths the size of the shower add *coherently*

10cm transverse size →

200 MHz-1.2GHz broadband radio pulse

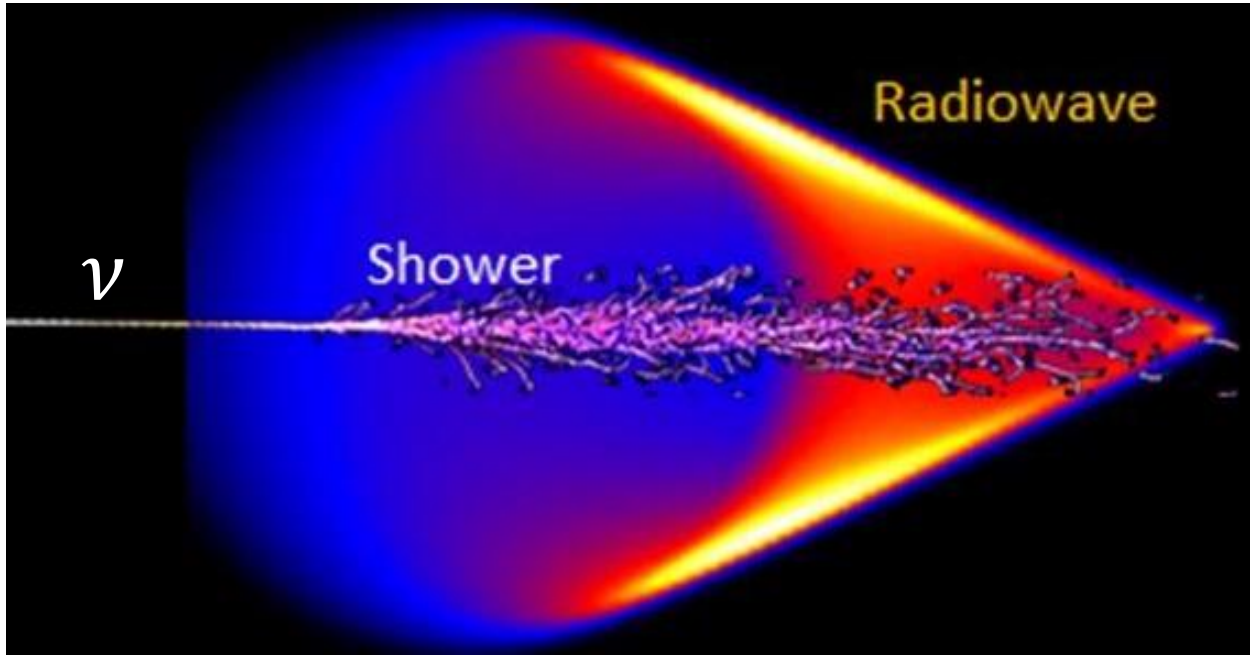



ANITA PRL 99, 171101 (2007)

# Signature of a neutrino interaction

Flash of blue/UV light, and a pulse of radio waves



# The Need

Extremely large volume
(1 to $10^3$ $km^3$)

of

Transparent medium

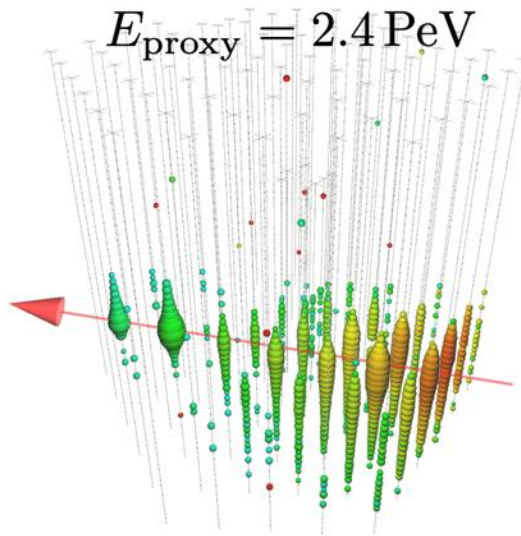


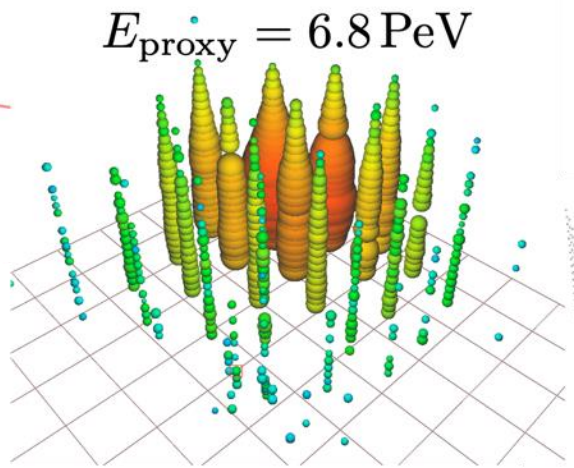
# IceCube as a UHE detector

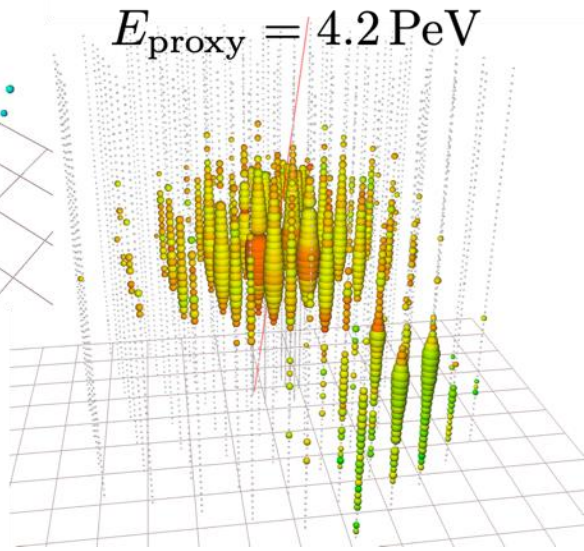
Can use the IceCube detector to look for very high energy events

Latest analysis, using 12.6 yrs of data (2010-23), finds three events at PeV scale

Consistent with flux of astrophysical neutrinos



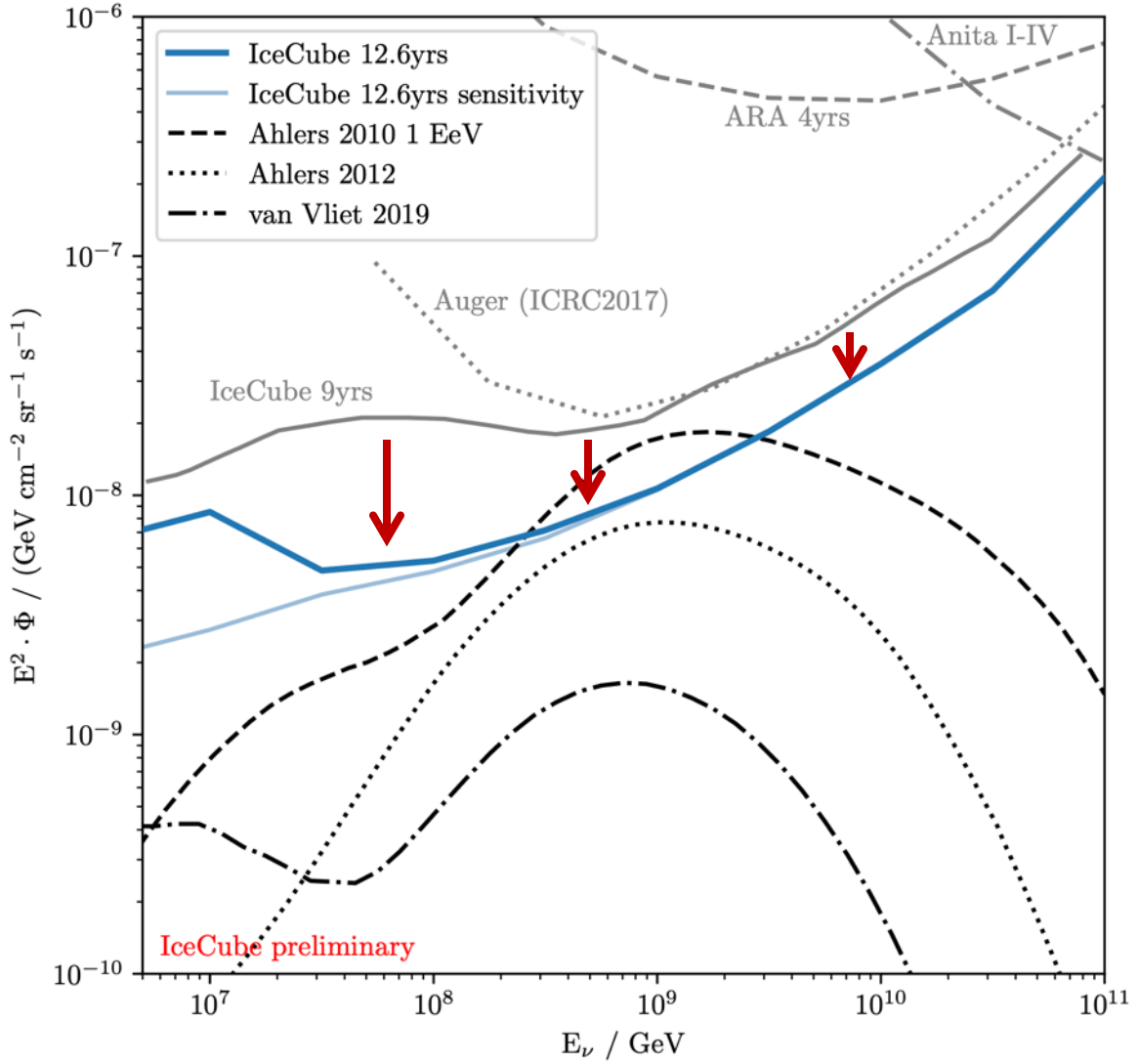



# Latest EHE Results from IceCube

New world leading limit on flux of EHE neutrinos

$$E^2\Phi \cong 10^{-8} GeV\ cm^2 s^{-1} sr^{-1}$$

Improved by almost factor 2 @ 1 EeV!

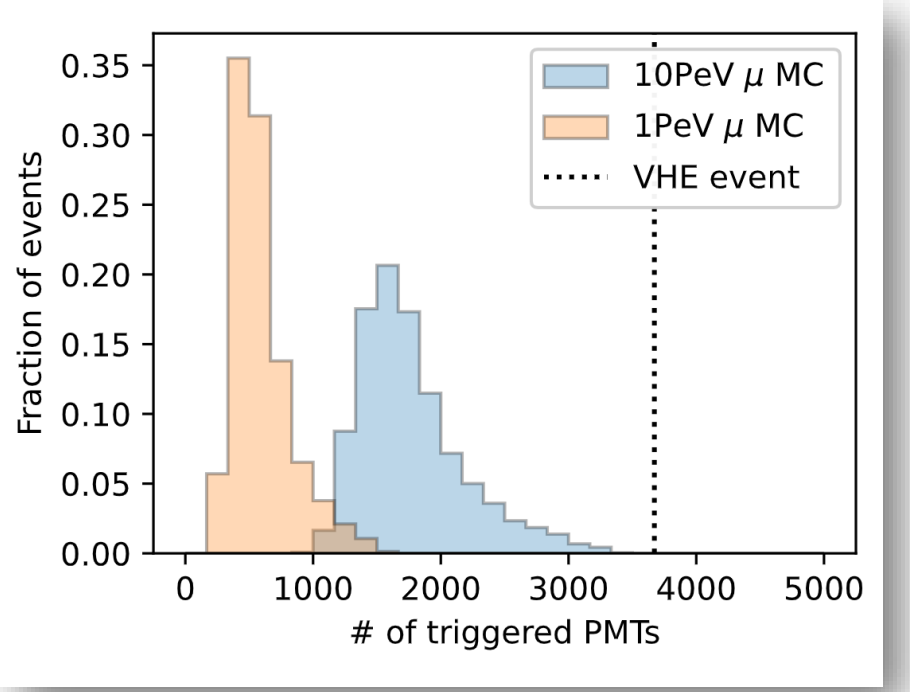


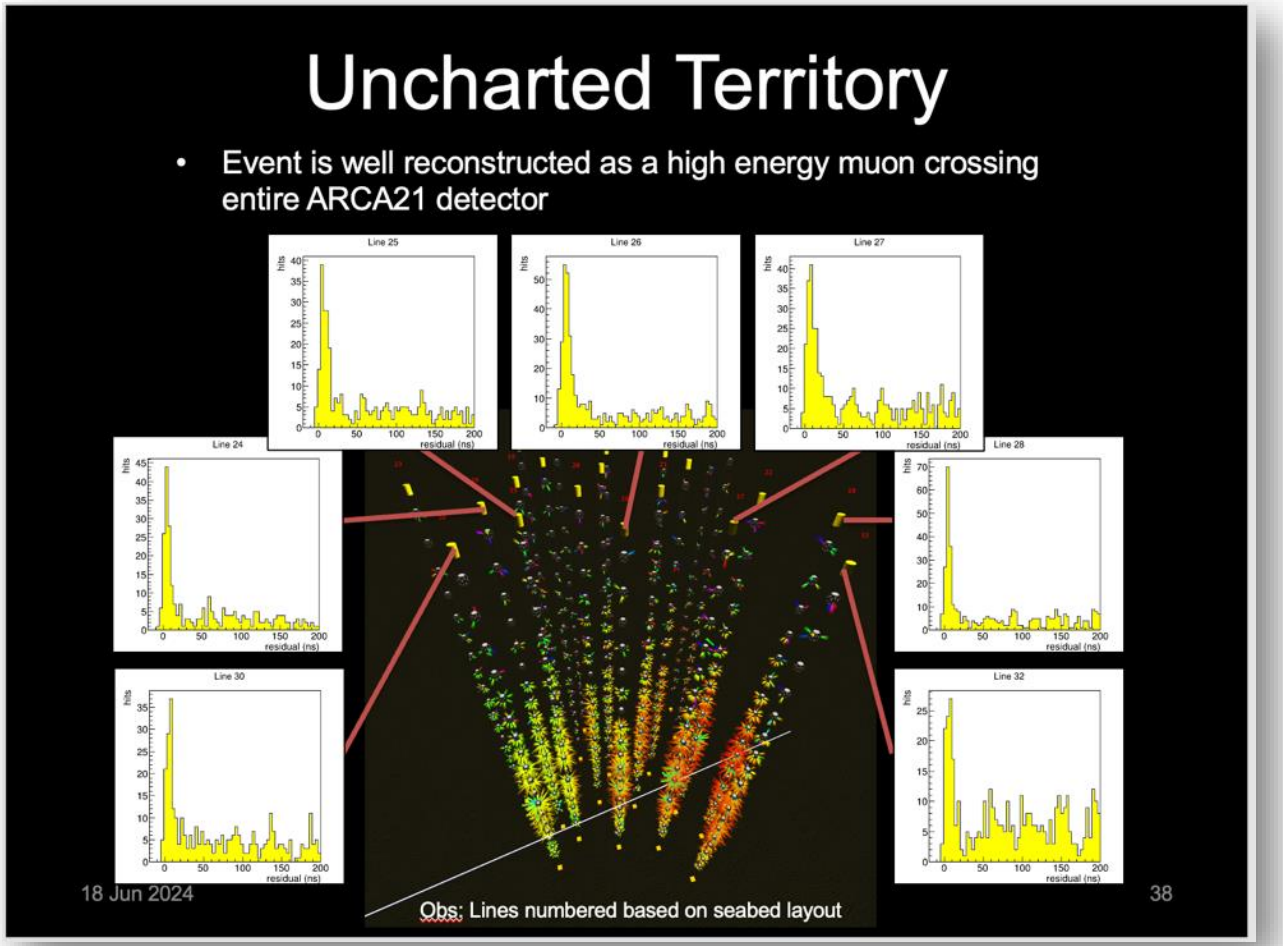

M. Meier, B. Clark
Moriond VHEPU 2024

# An exciting hint from KM3NeT

KM3NeT (ARCA21) observes very bright track

Brightness hints at few x 10 PeV!




J. Coelho, Neutrino 2024,
M. Circella (this conference)

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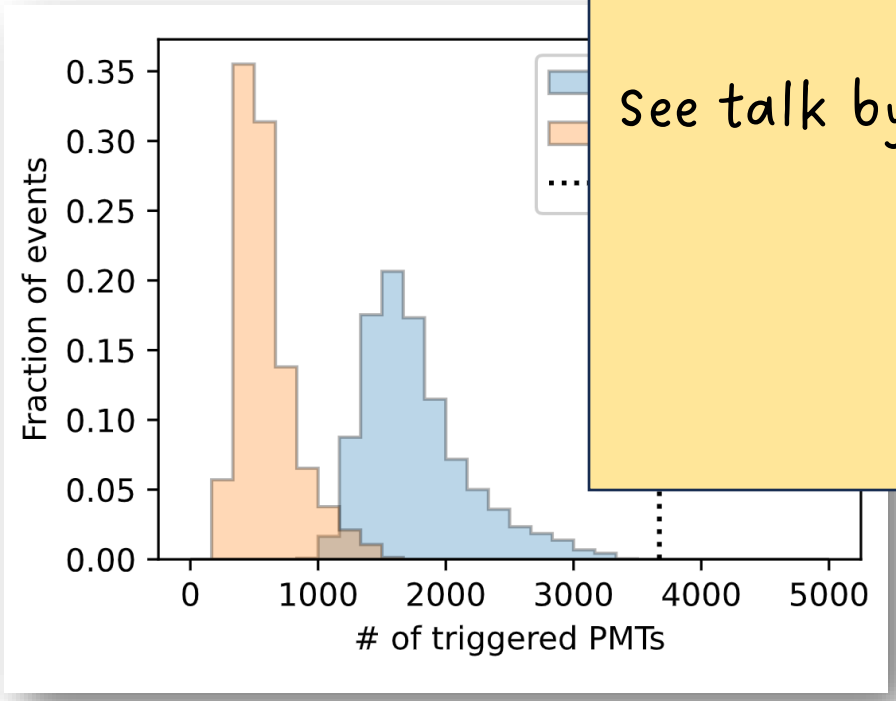
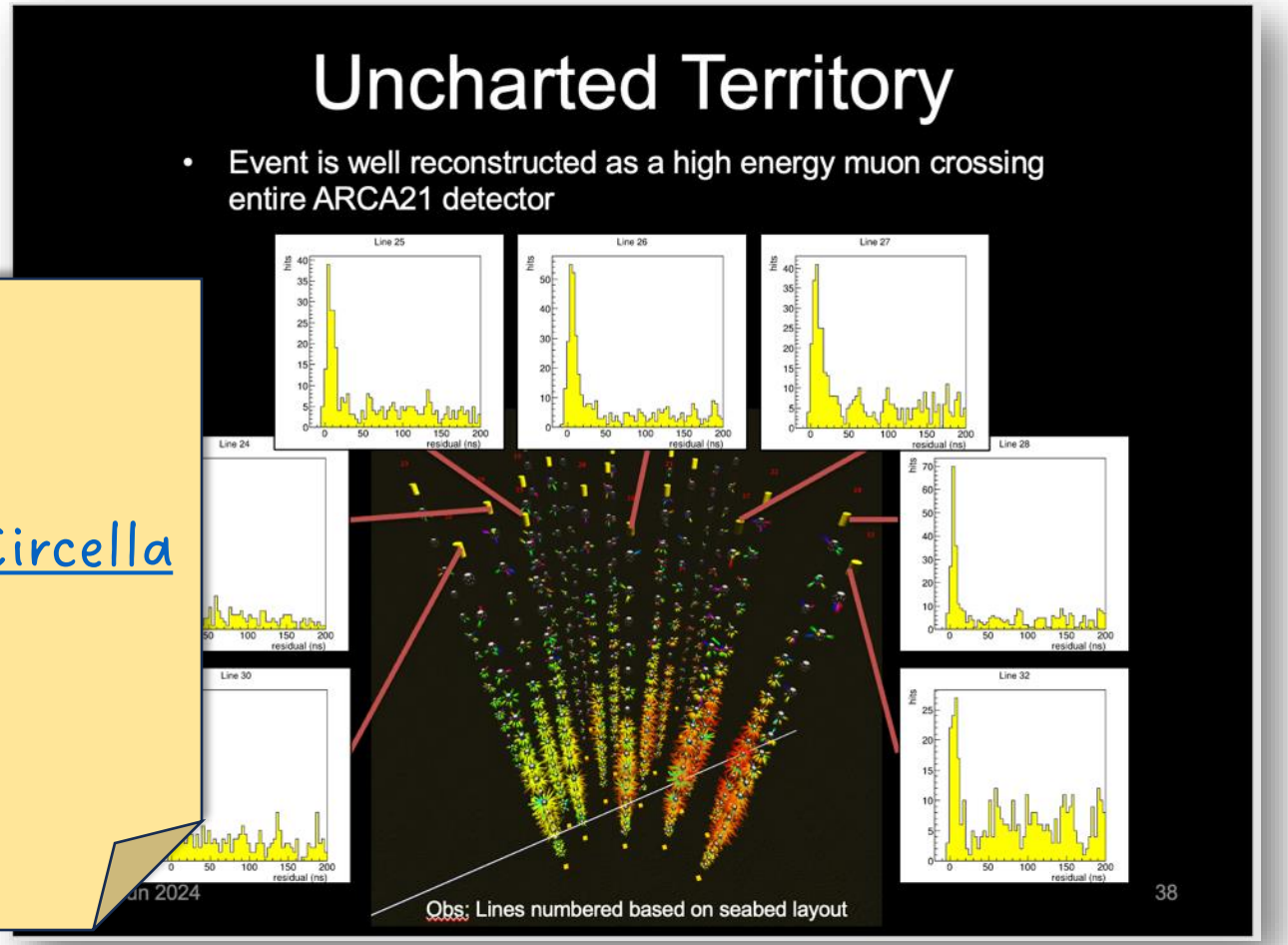


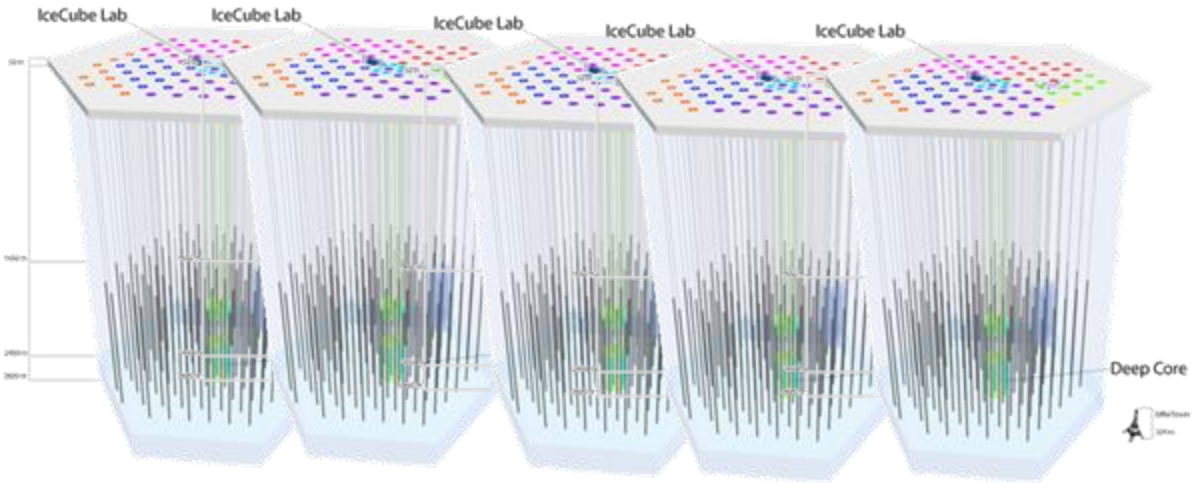

See talk by M. Circella




J. Coelho, Neutrino 2024

# Going Bigger

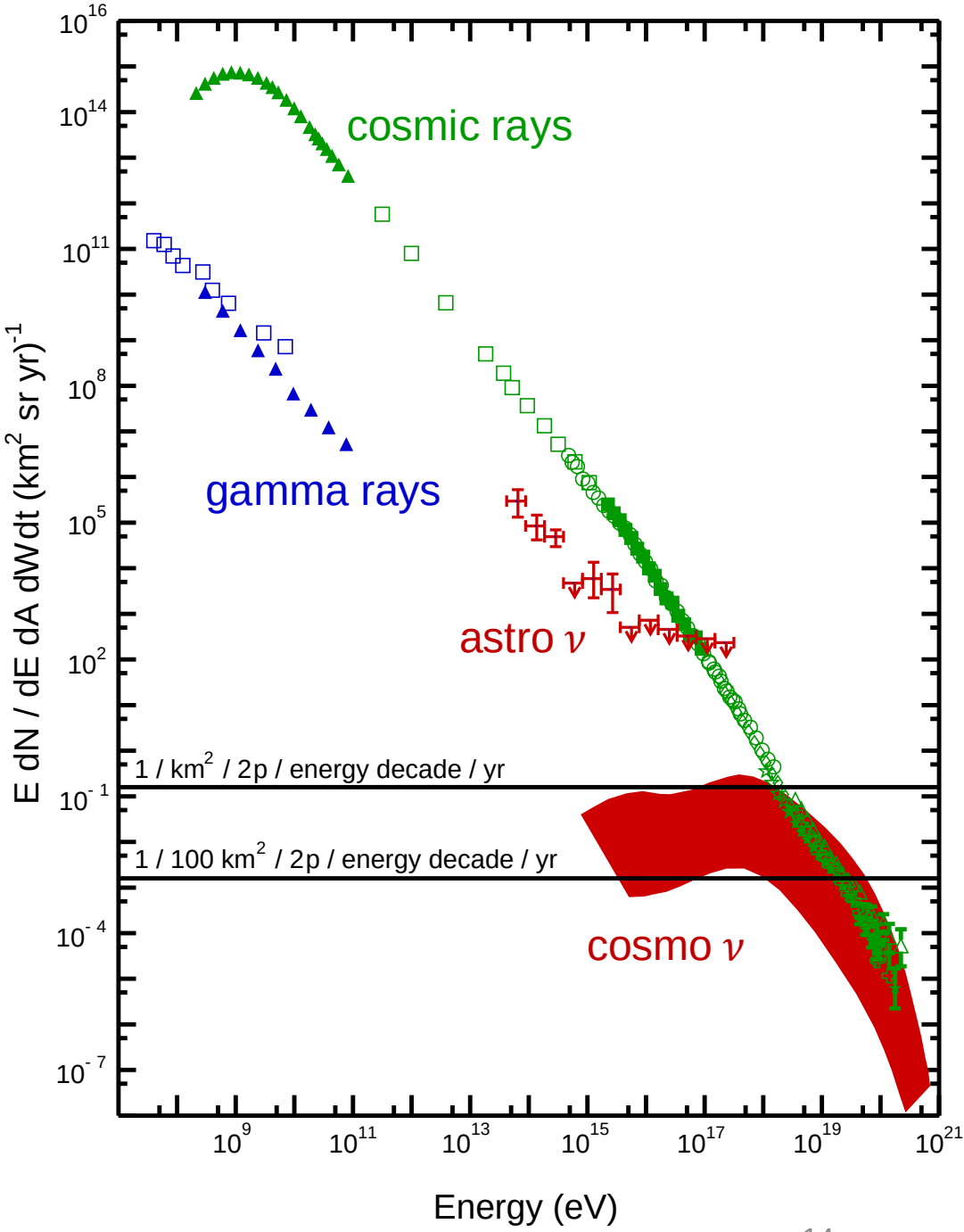
But we cannot build 100x IceCube…



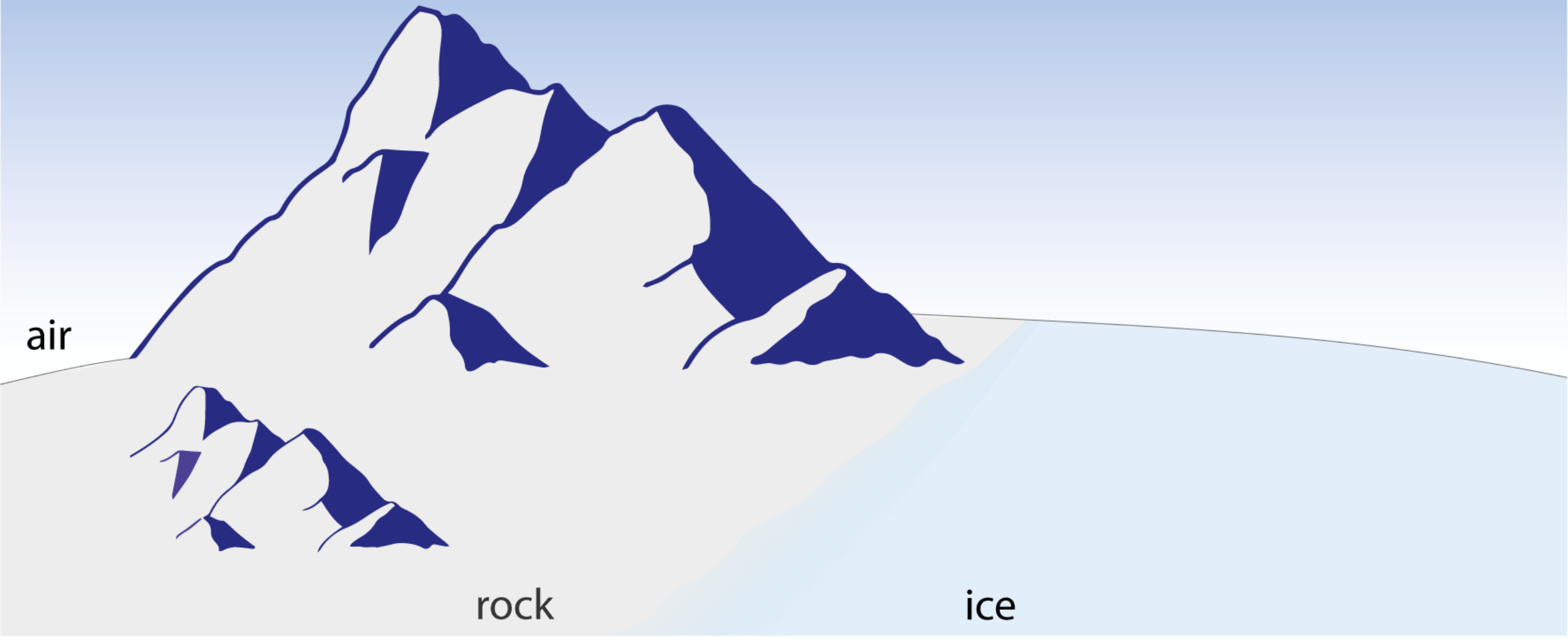

…

Switch to the radio technique

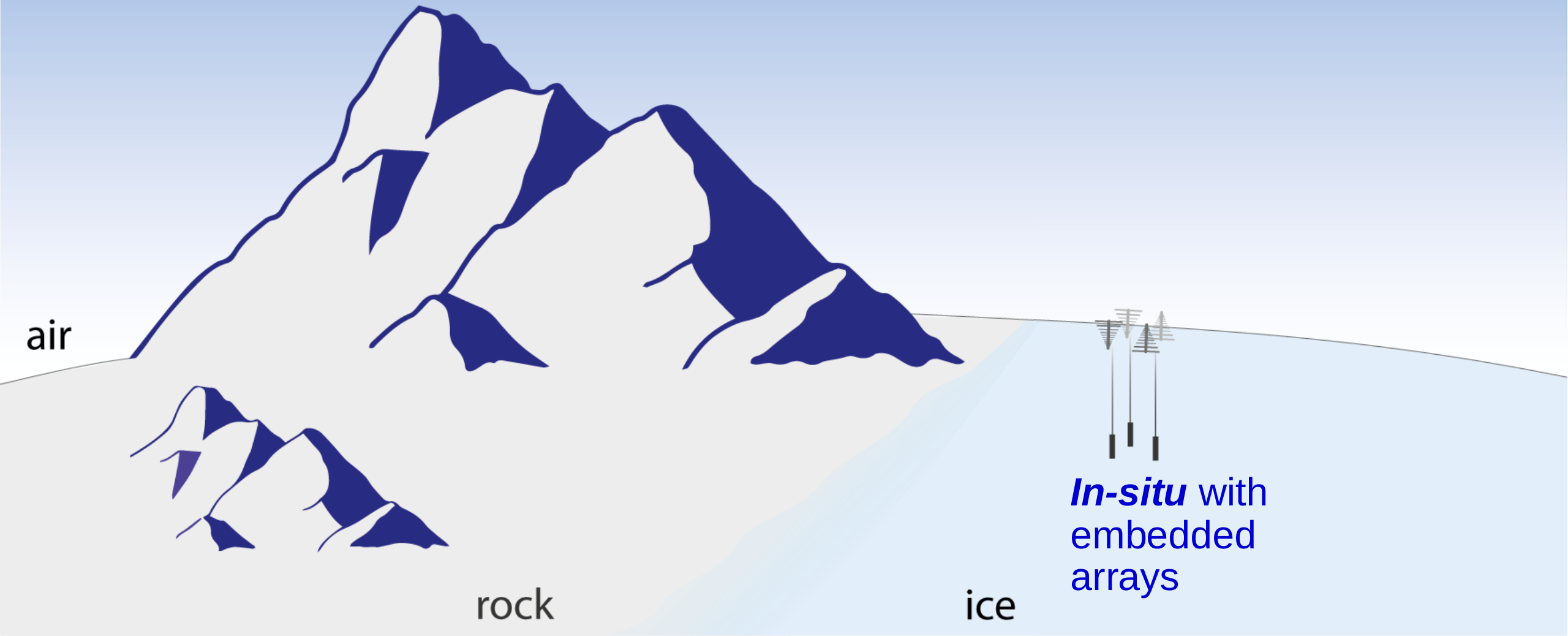
Attenuation length: ~1km



# UHE Neutrino Detection Landscape



# Two basic approaches




***In-situ*** with embedded arrays

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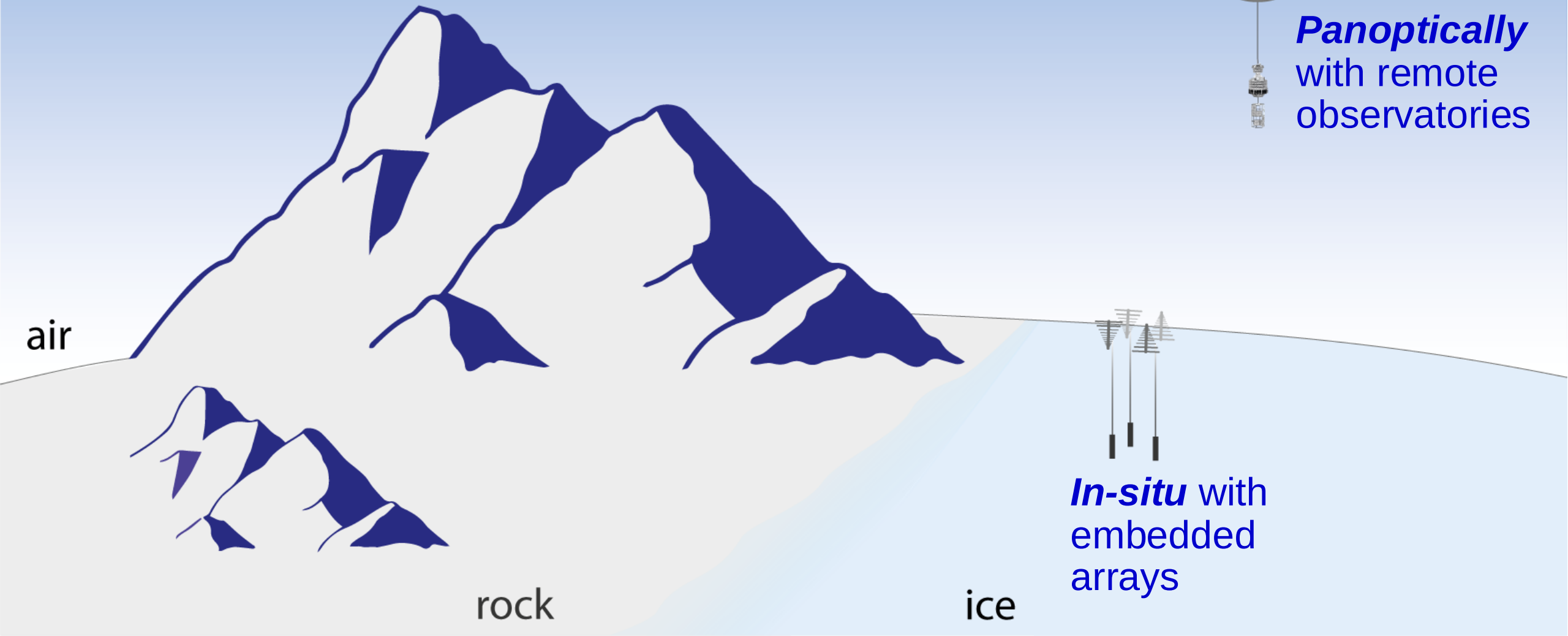


***Panoptically*** with remote observatories

***In-situ*** with embedded arrays

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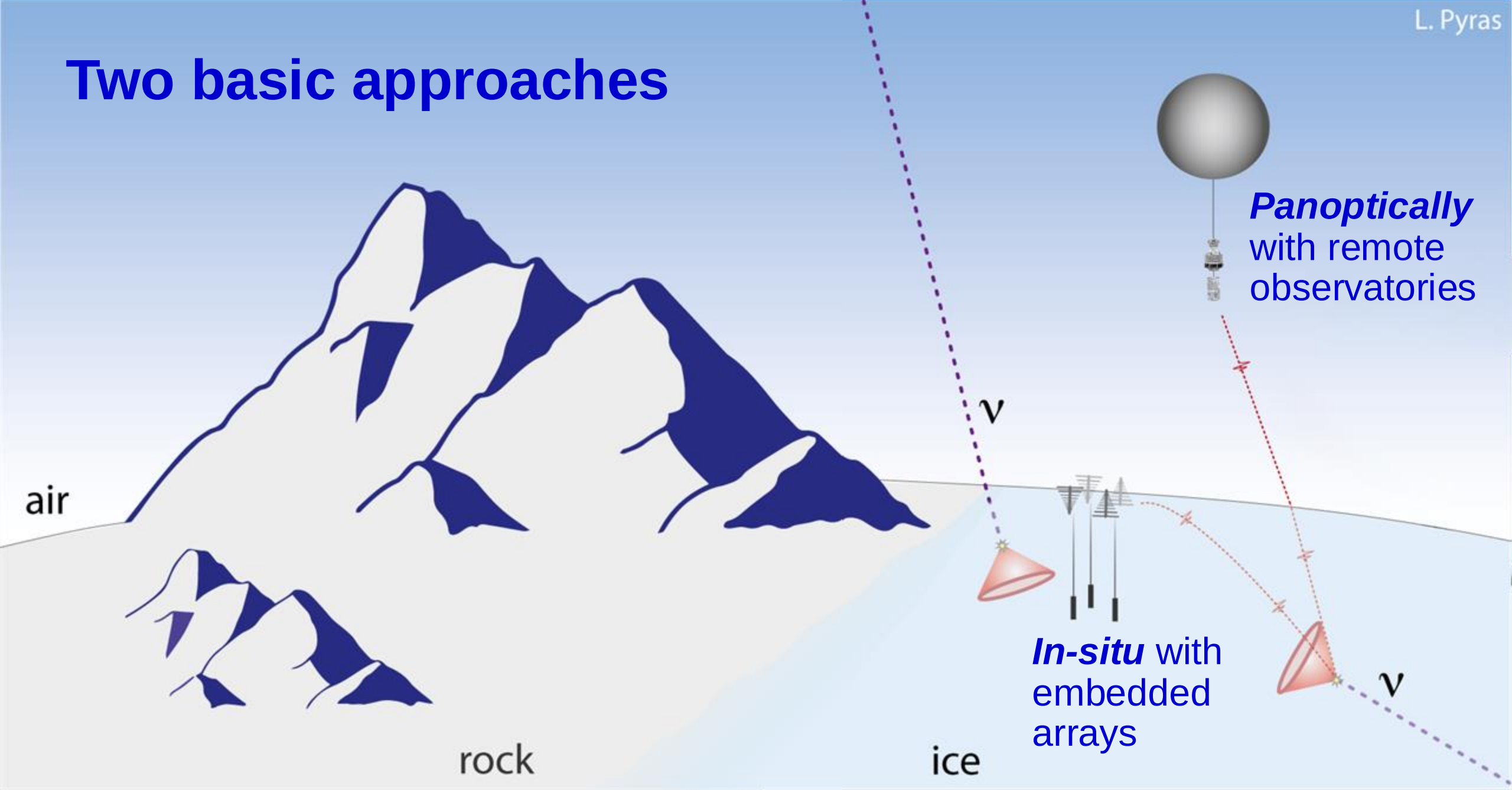


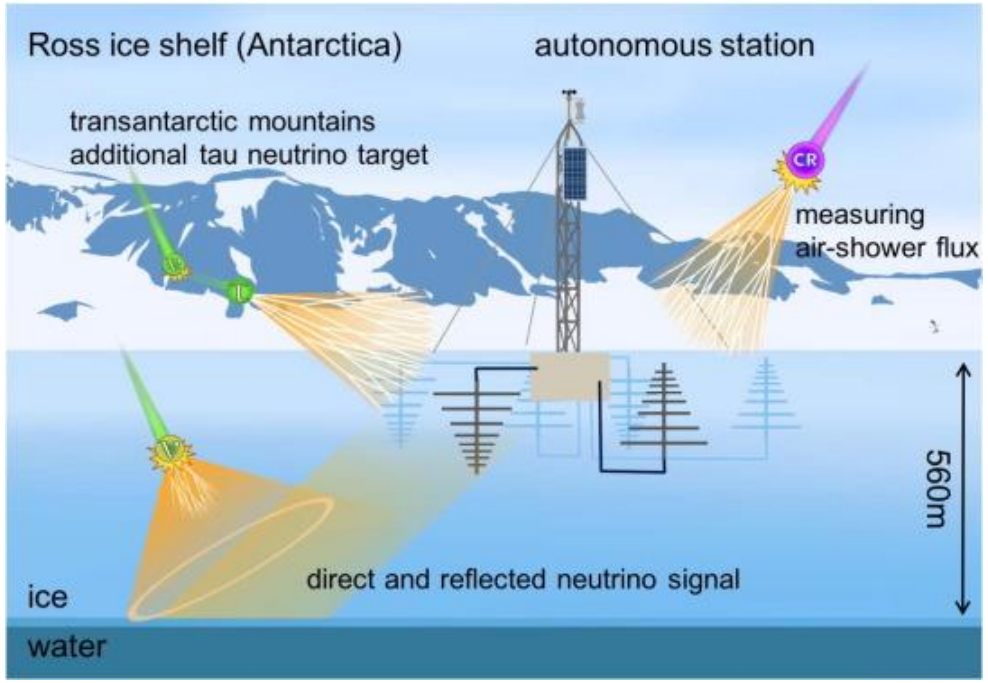

***Panoptically*** with remote observatories

***In-situ*** with embedded arrays

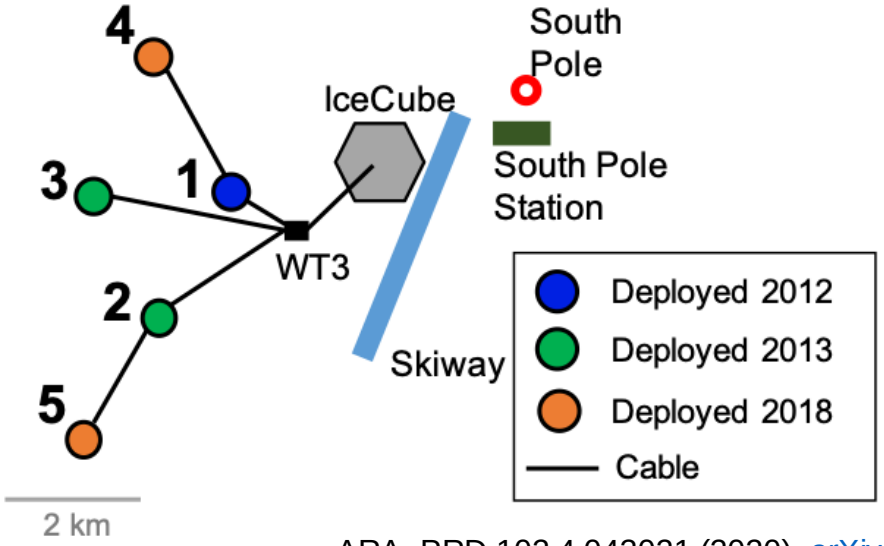
# ARA and ARIANNA

Complimentary experiments leveraging the *in-situ* approach

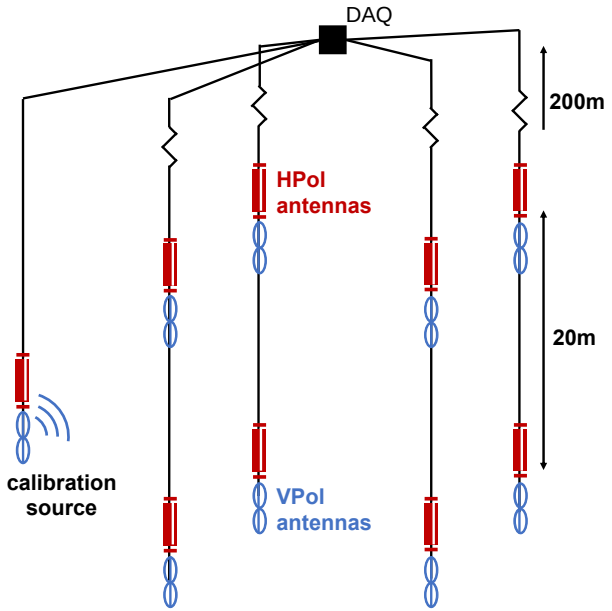
## ARIANNA (ran 2011-2020 @ Moore's Bay)

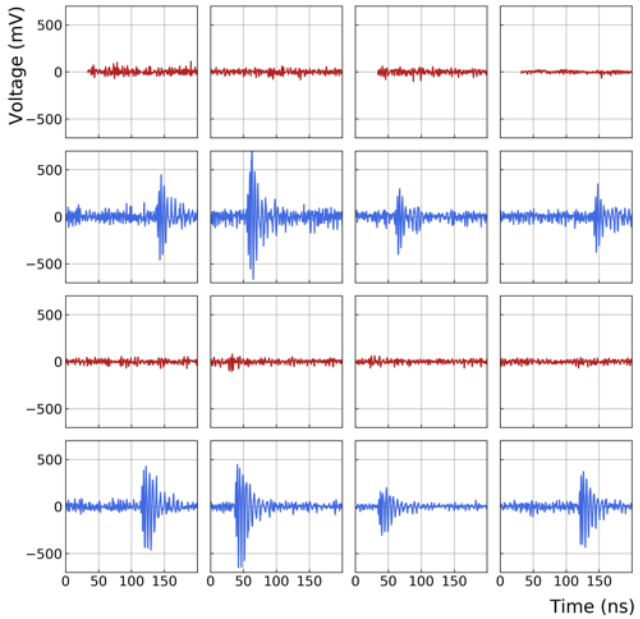



## ARA (running @ SP)




ARA, PRD 102 4 043021 (2020), arXiv 1912.00987



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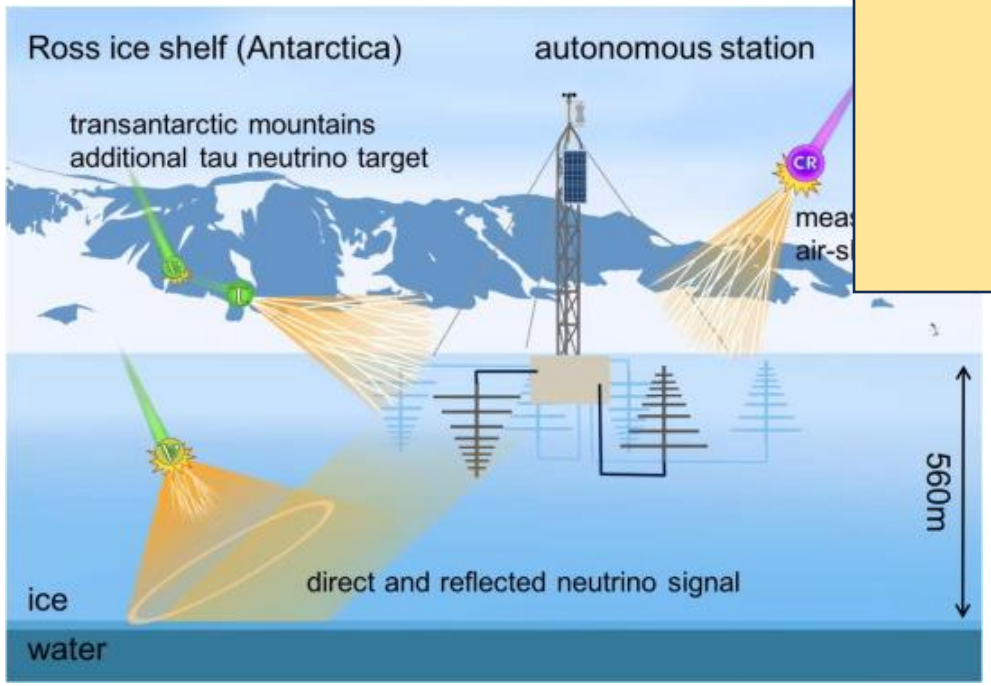


See talks by A. Gomez, M. Muzio, K. Couberly, P. Dasgupta

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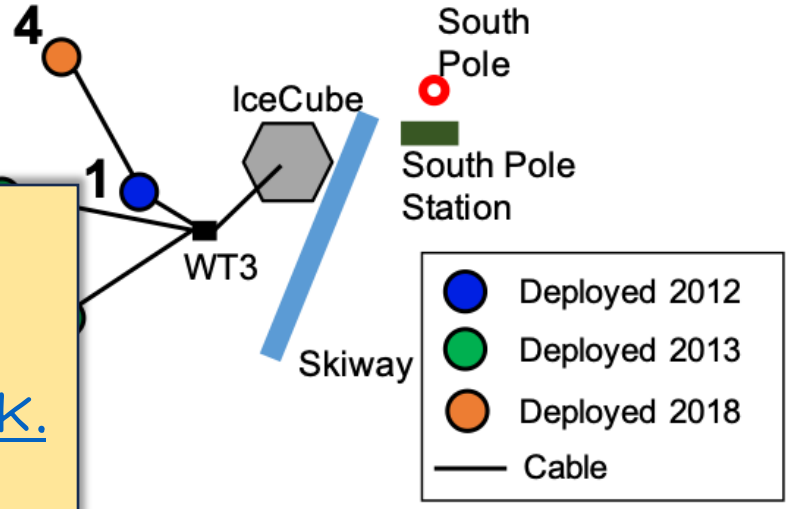


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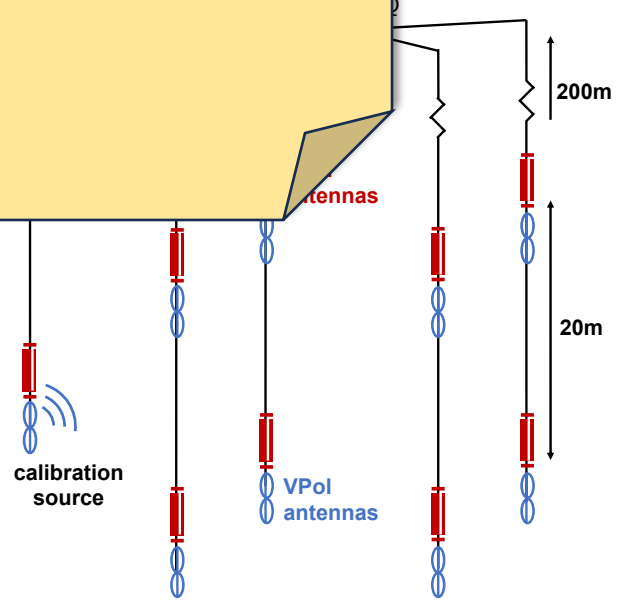
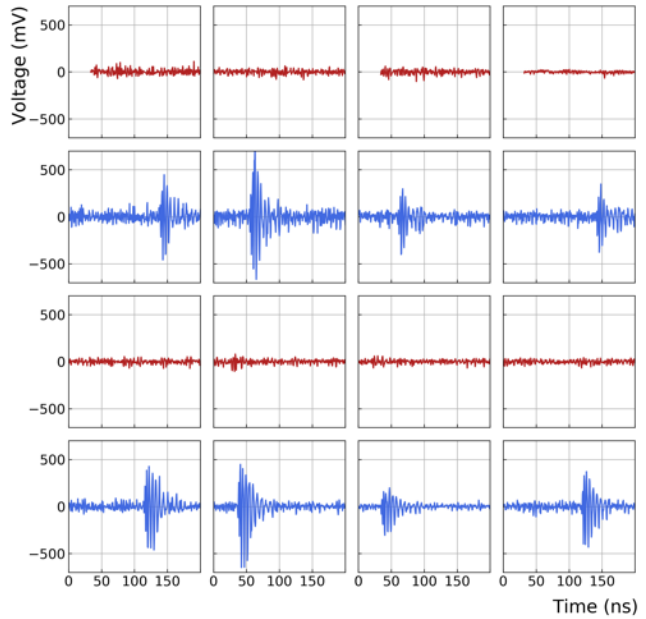
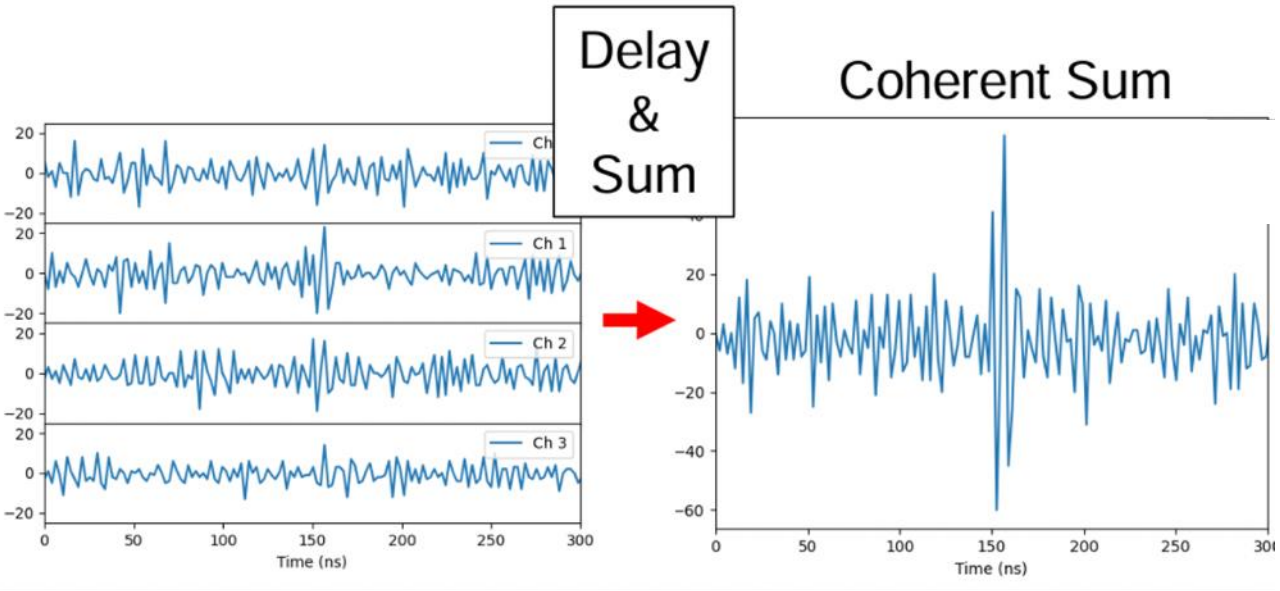


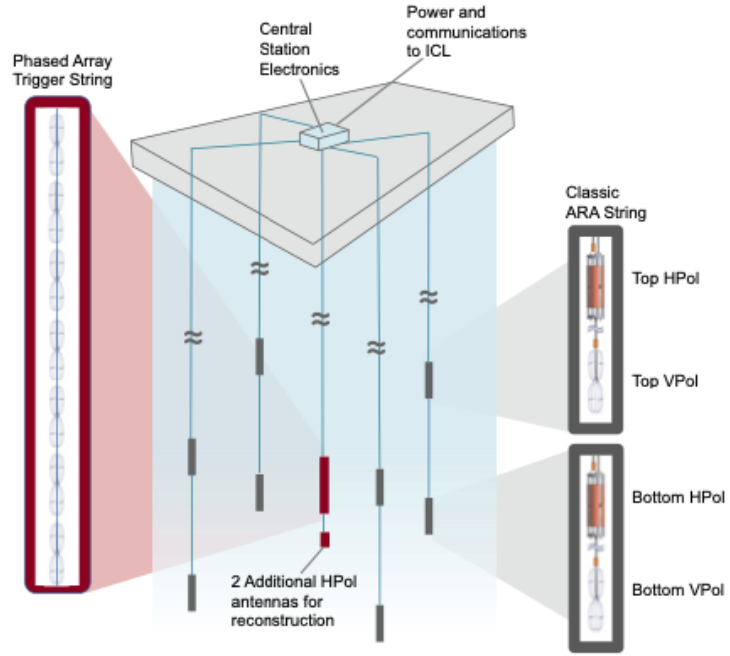



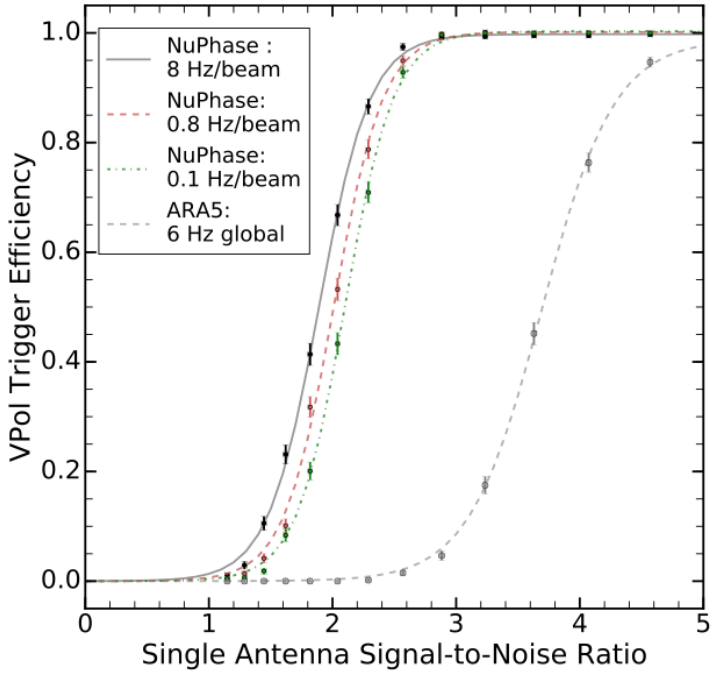
# Phased Array

Latest ARA station has threshold-lowering phased array trigger – beamform on FPGA to lower thresholds

2x more effective volume at trigger level at 10 PeV!



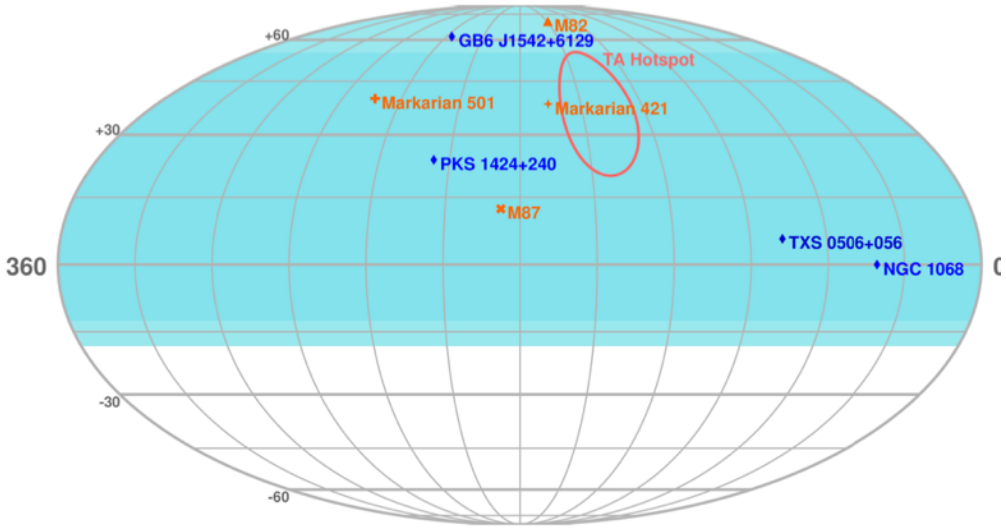

ARA, NimA 2019.01.067,
arXiv 1809.04573

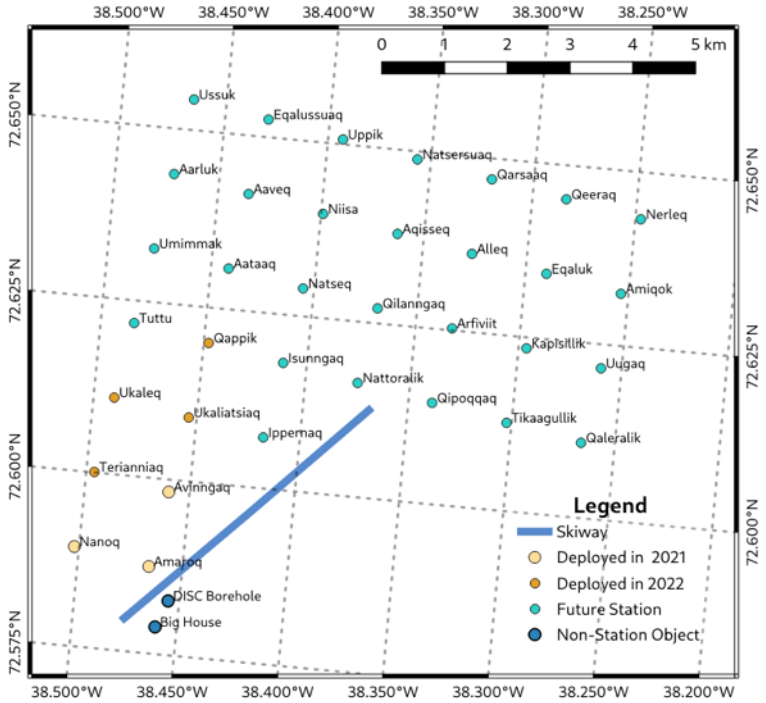
# RNO-G

## Radio Neutrino Observatory – Greenland

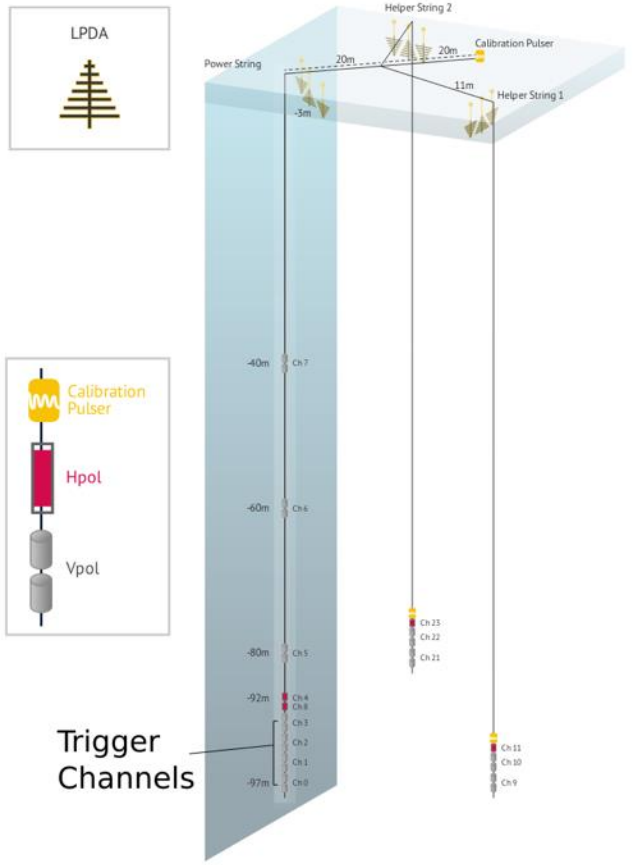
Deployment under since 2021,
goal of 35 stations -- 8 so far!

First UHE observatory in the
northern hemisphere




RNO-G, JINST 16 P03025 (2021)
arXiv 2010.2279




Combines strength of deep (ARA, RICE) and shallow (ARIANNA) technology, including phased array

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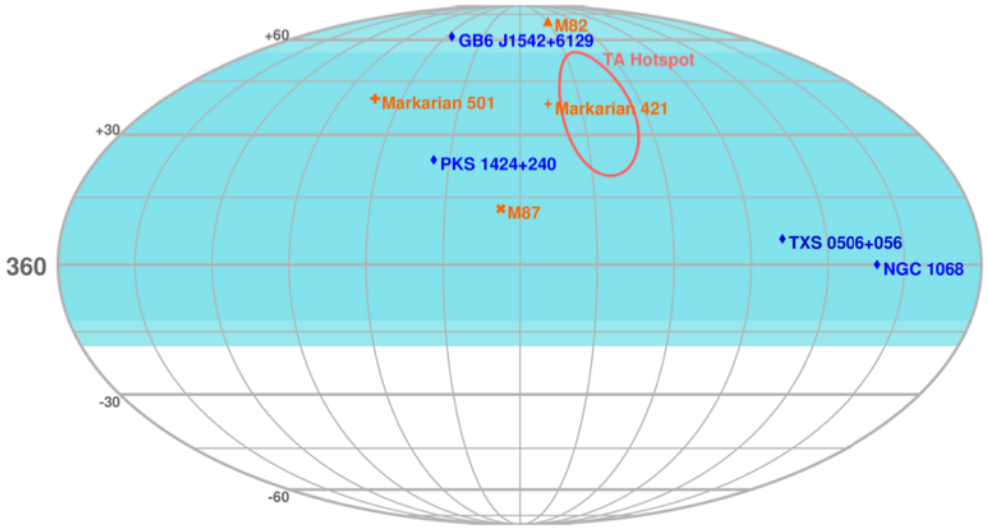
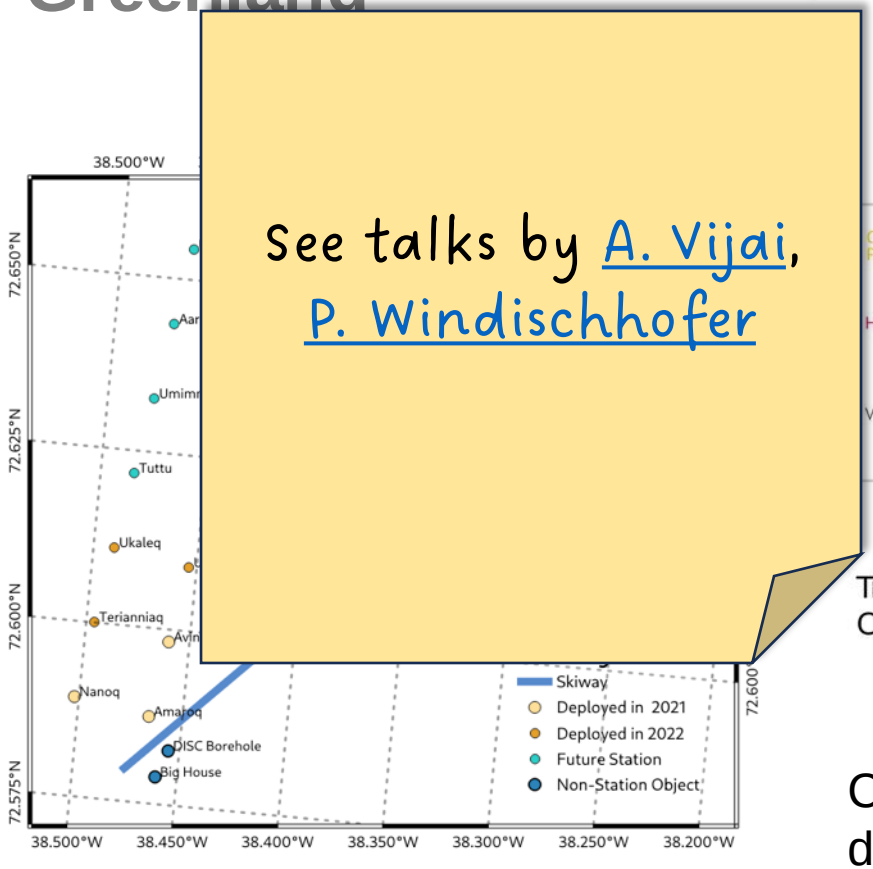
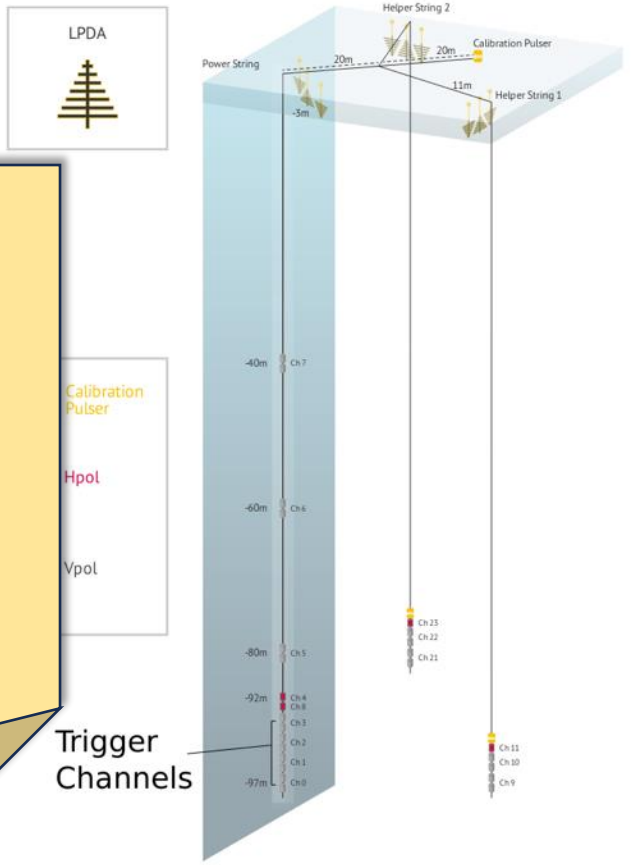



See talks by A. Vijai, P. Windischhofer




RNO-G, JINST 16 P03025 (2021)
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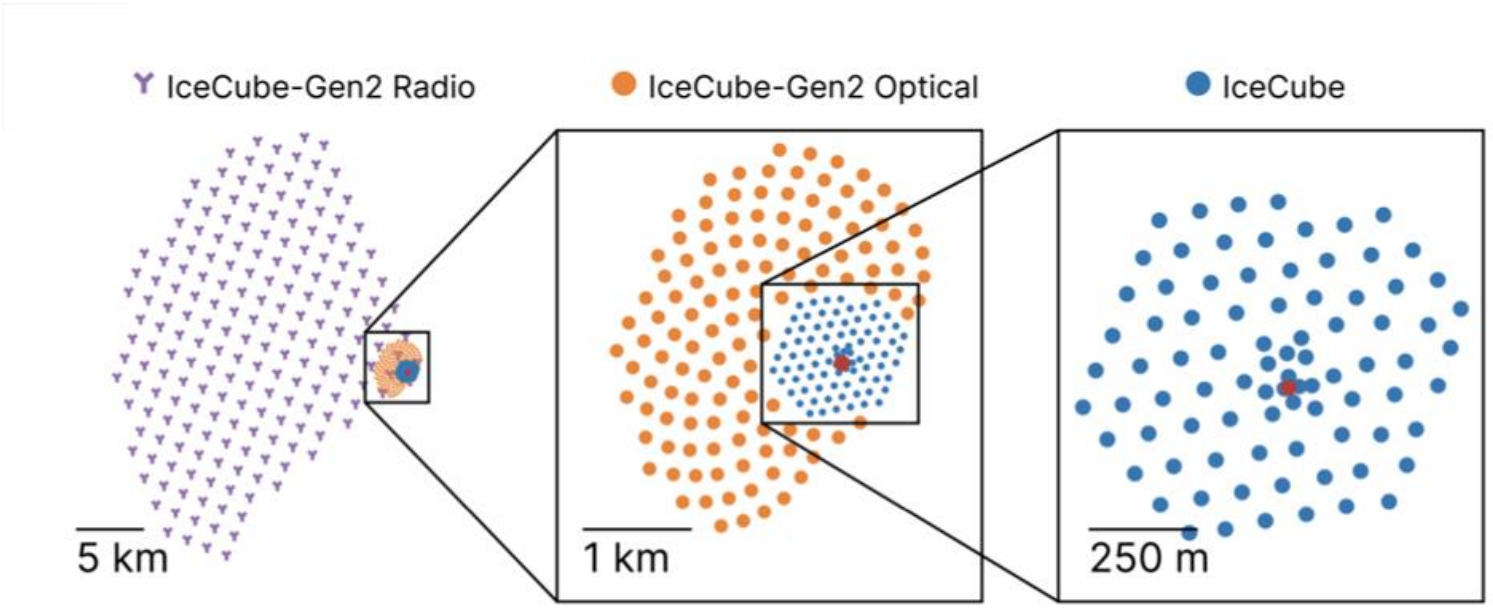
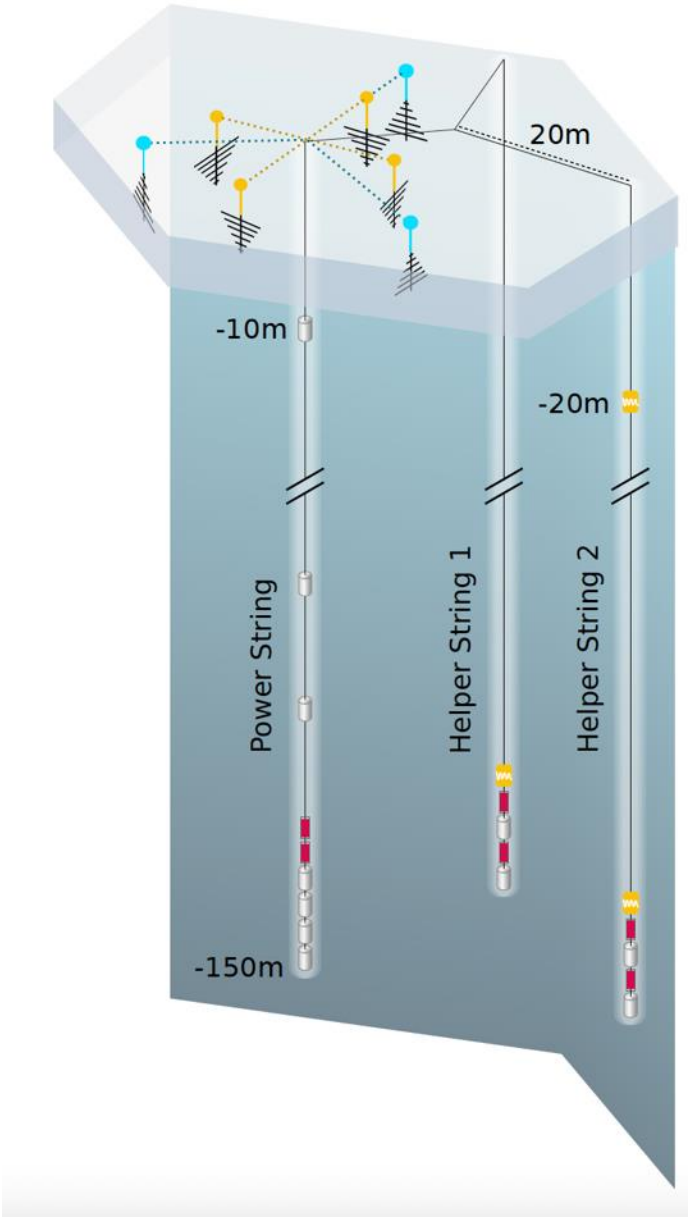
# IceCube Gen2

500 km$^2$ radio array,

with both shallow and deep component



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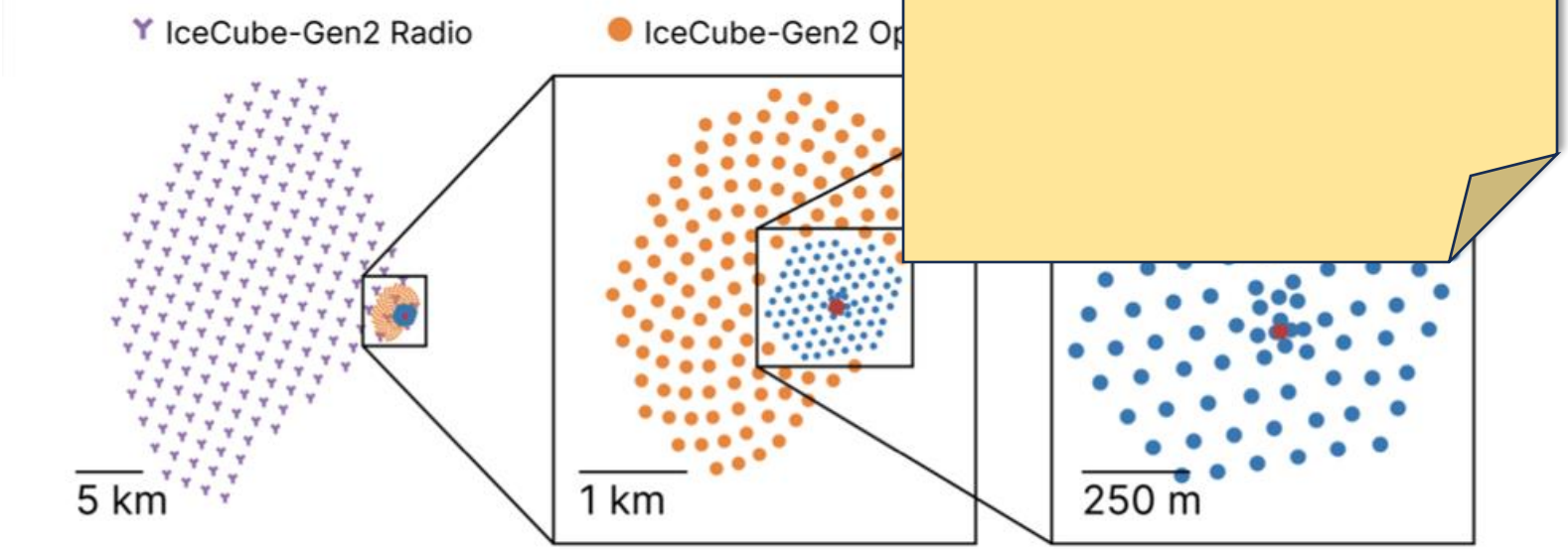
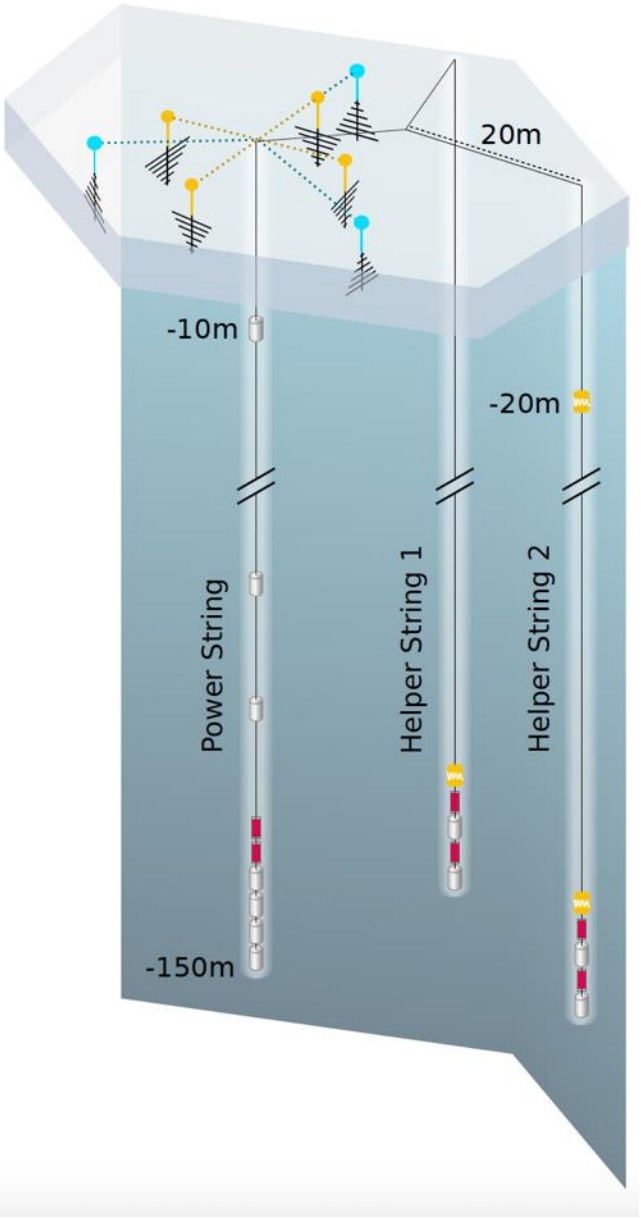
See talk by A. Karle



# ANITA

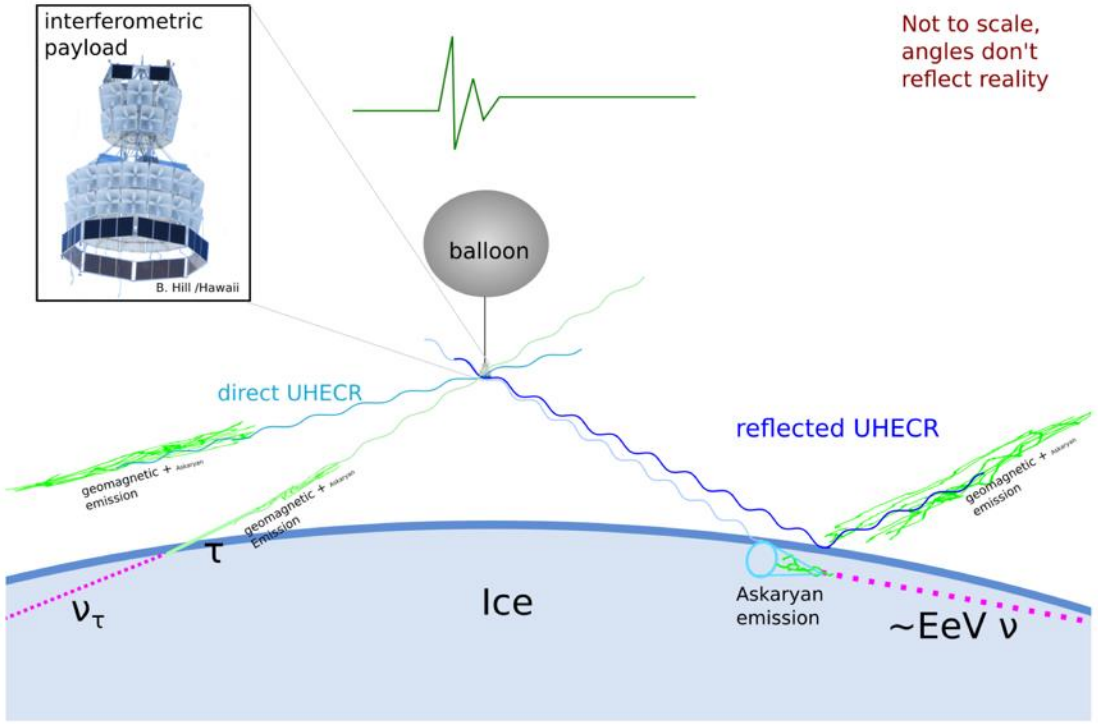
## Antarctic Impulsive Transient Antenna

Array of horn antennas suspended from NASA Long Duration Balloon (LDB)

Four flights 2006-2016

- Askaryan (neutrino) channel: no excess above background
- ~100 UHECR seen

Demonstrates the feasibility of the panoptic method



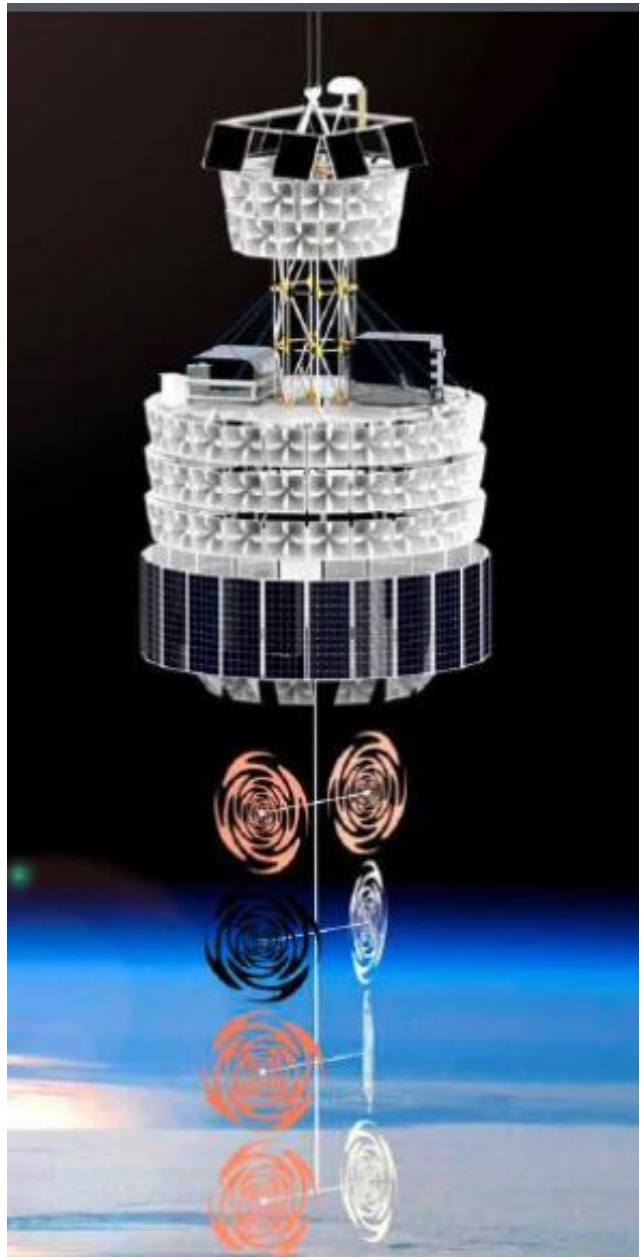
# PUEO

## Payload for Ultra High Energy Observations

Successor to ANITA experiment—array of horns, with phased trigger, to fly on an LDB

>10x more sensitive than ANITA, especially good for transients, point sources, MMA

Funded through the NASA Pioneer Program, flight in 2025-26 season!



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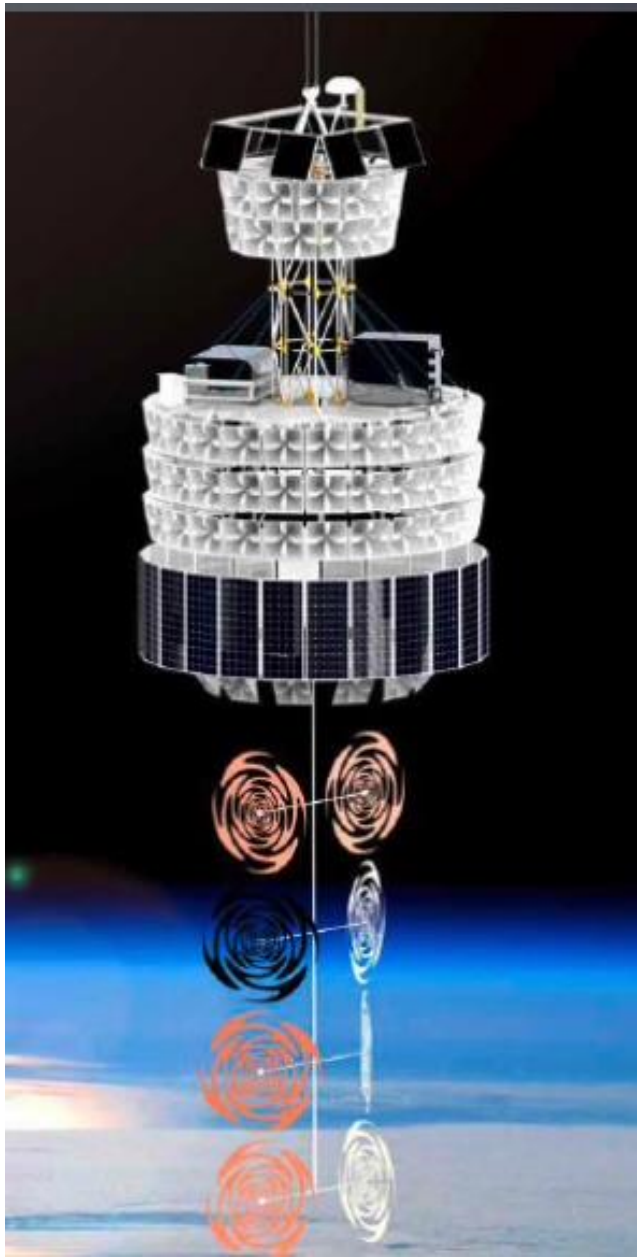
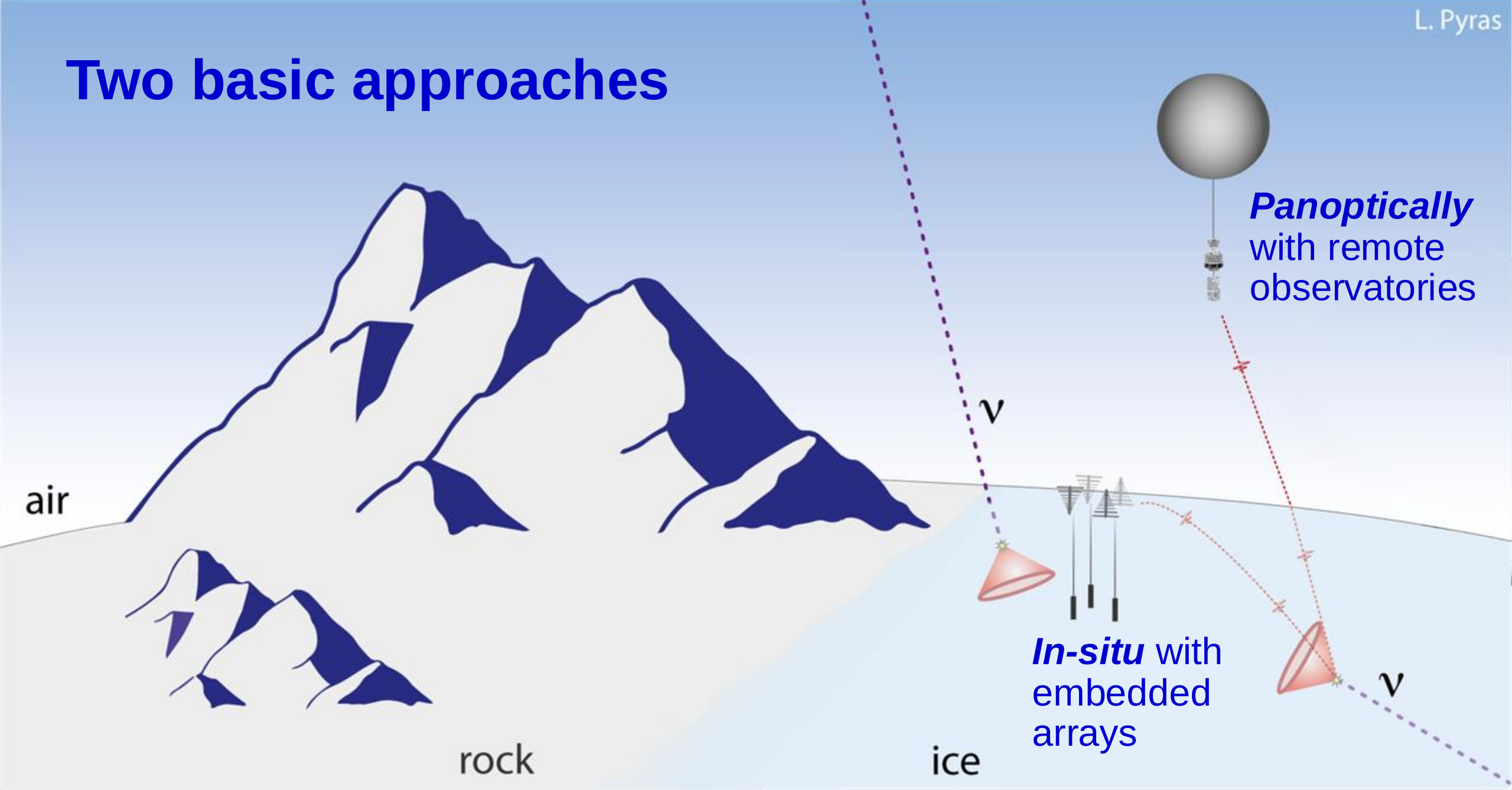
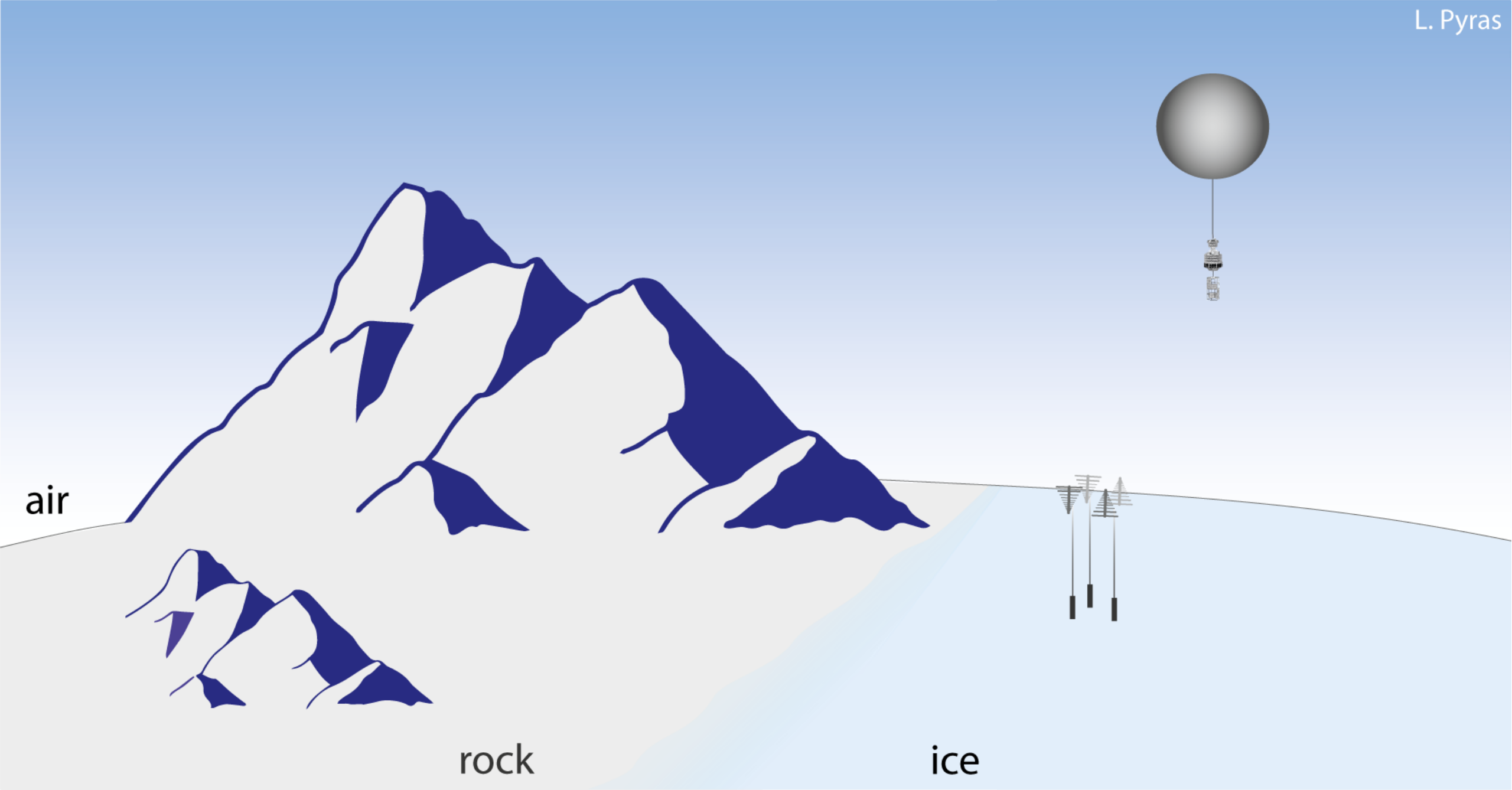
Funded through the NASA Pioneer Program, flight in 2025-26 season!

See talks by R. Scrandis, L. Beaufore, A. Cummings

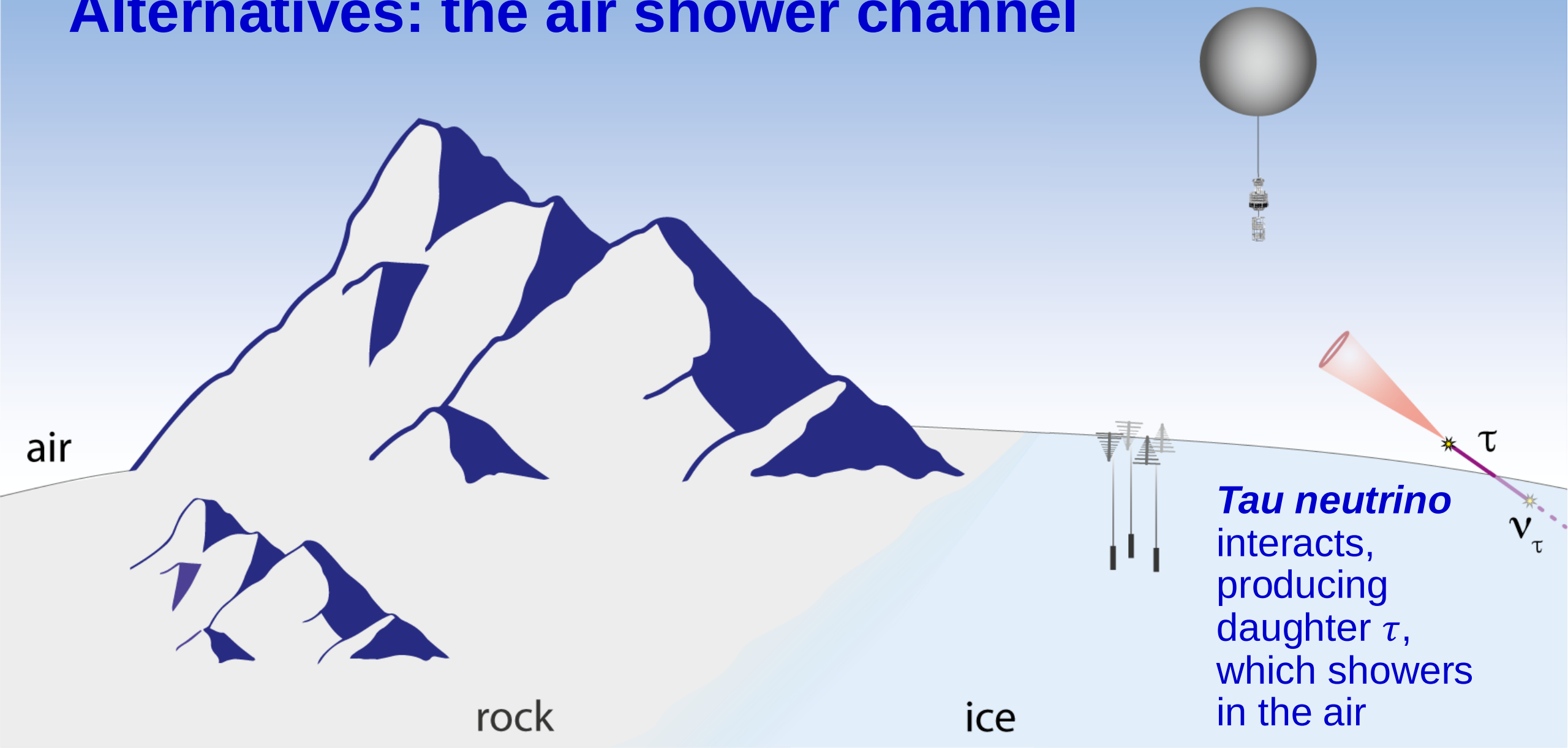


# Two basic approaches




L. Pyras
air
rock
ice

# Alternatives: the air shower channel




***Tau neutrino*** interacts, producing daughter $\tau$, which showers in the air

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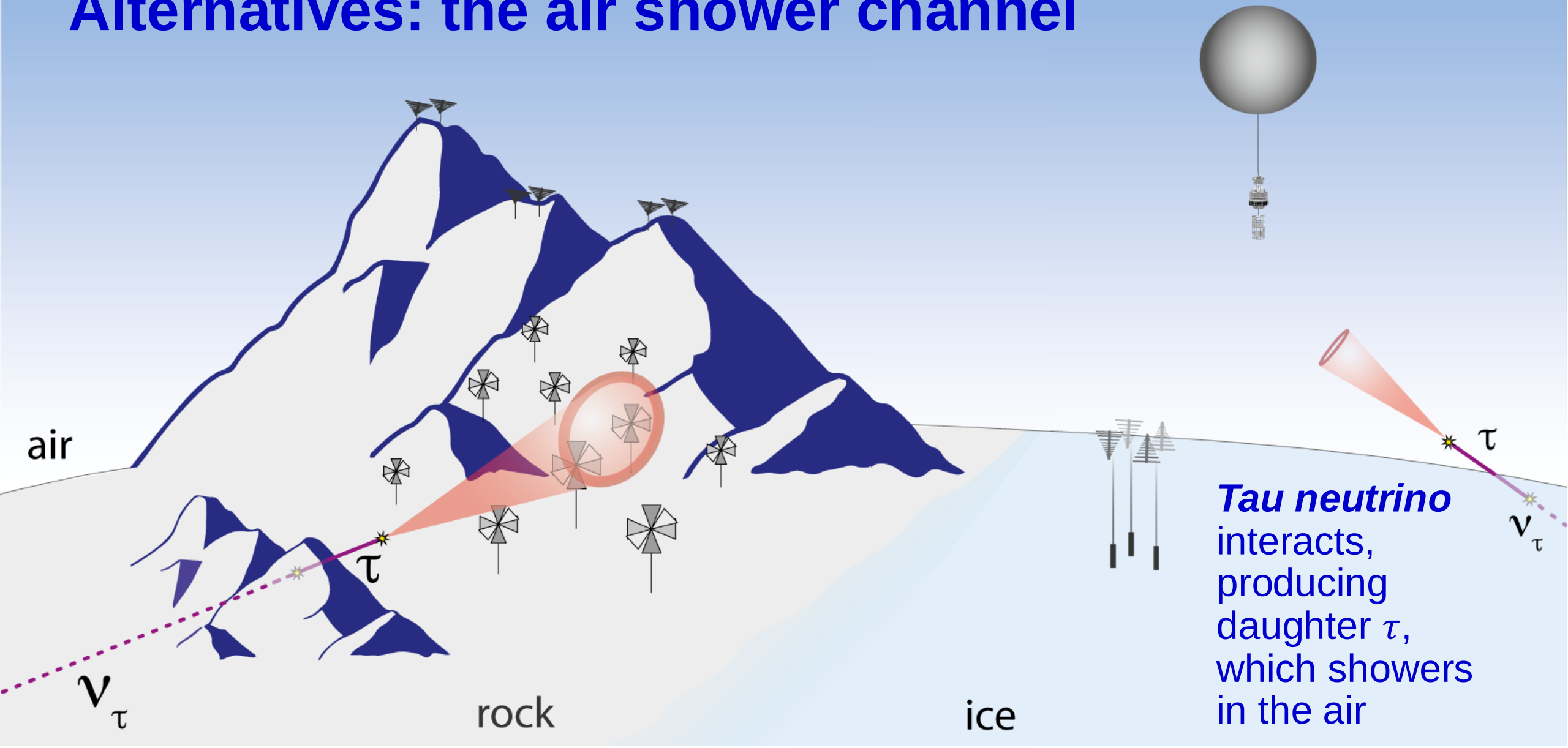
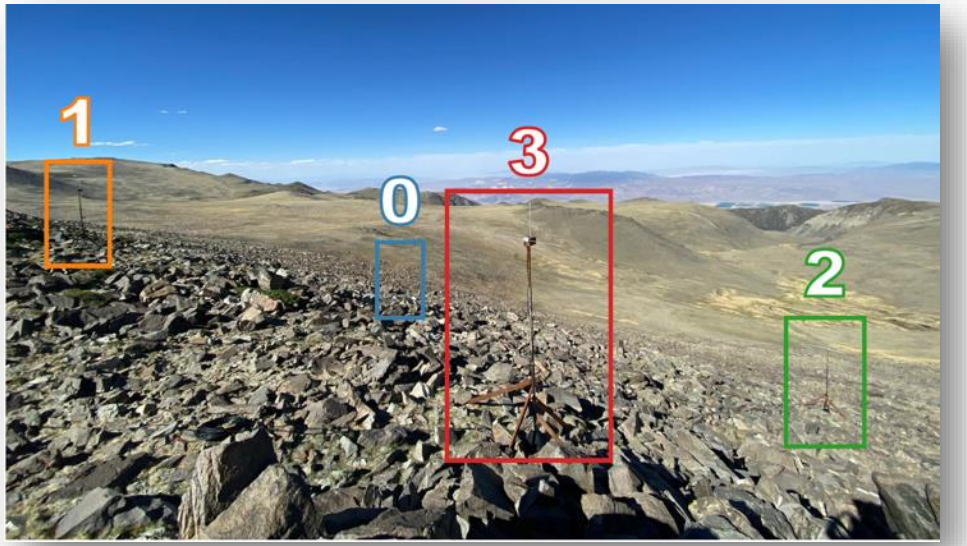


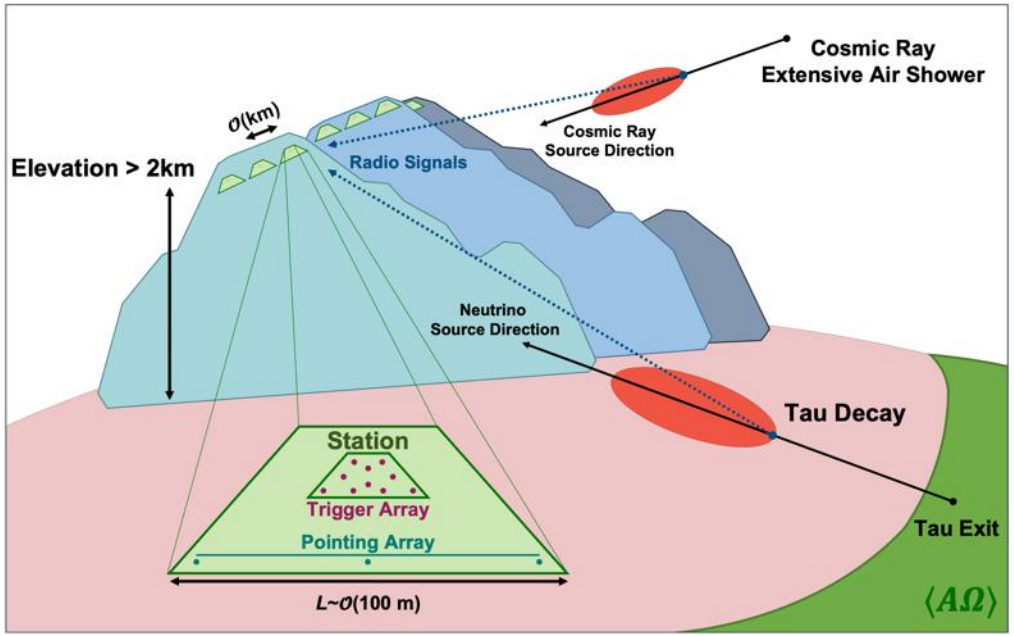

***Tau neutrino*** interacts, producing daughter $\tau$, which showers in the air

# BEACON, GRAND

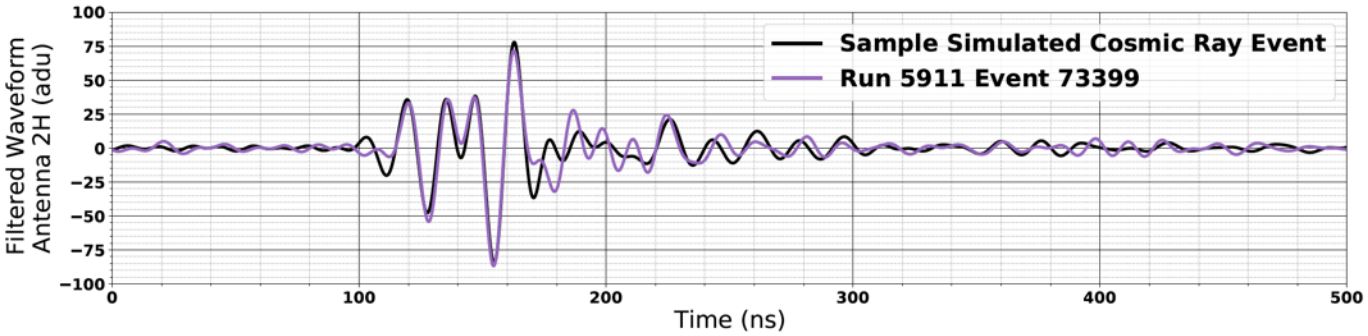
One option is detection with the radio mechanism




BEACON Prototype – White Mountain, CA NimA Vol 1048 (2023), 167889, [arXiv 2206.09660]



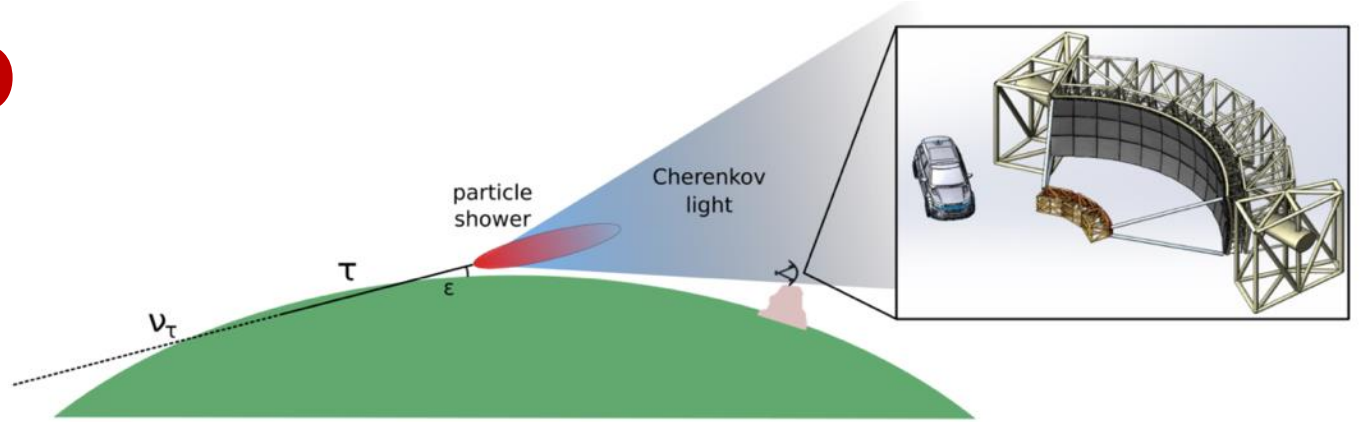

GRANDProto13–Ghobi Desert (Dunhuang, China)
P-X. Ma ICRC 2023 [arxiv 2307.12769]

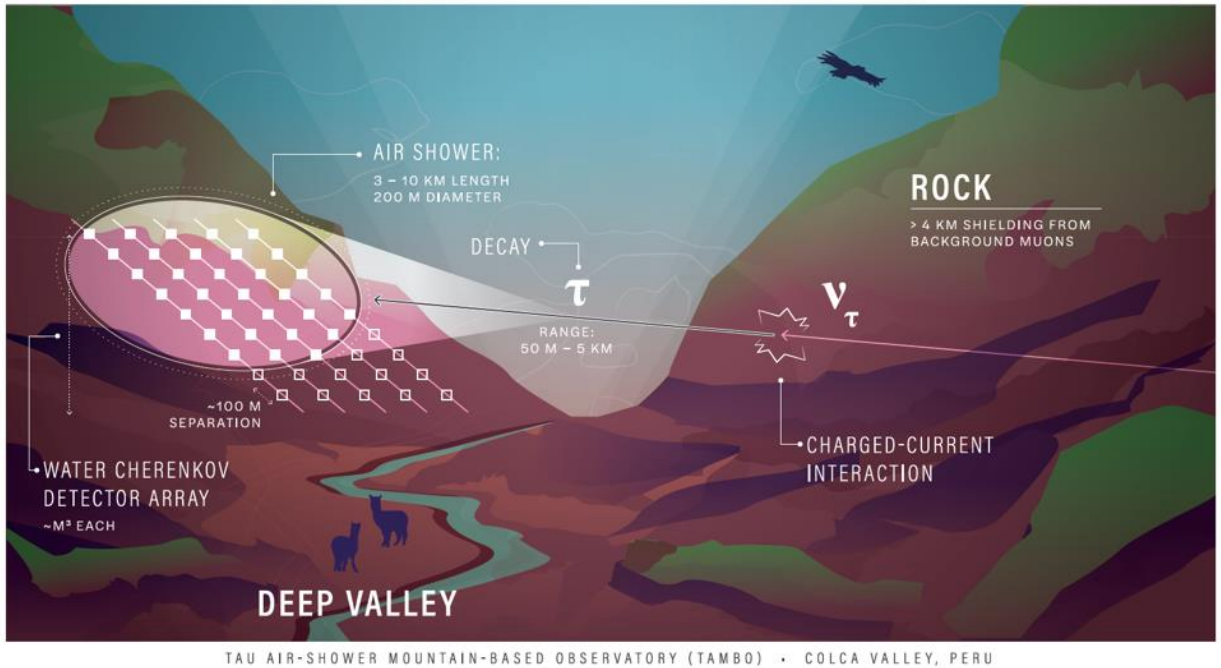



Arrays see cosmic rays, planes – lots of work ongoing to understand backgrounds!

# TRINITY, TAMBO, EUSO

An alternative relies on traditional tanks and Cherenkov telescopes




Trinity Demonstrator – Frisco Peak, Utah

Some concepts even space born (e.g. EUSO, POEMMA)

# TRINITY, TAMBO, EUSO

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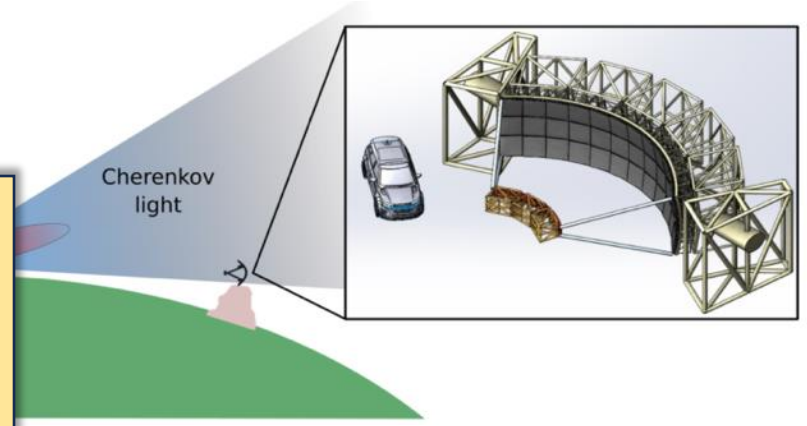
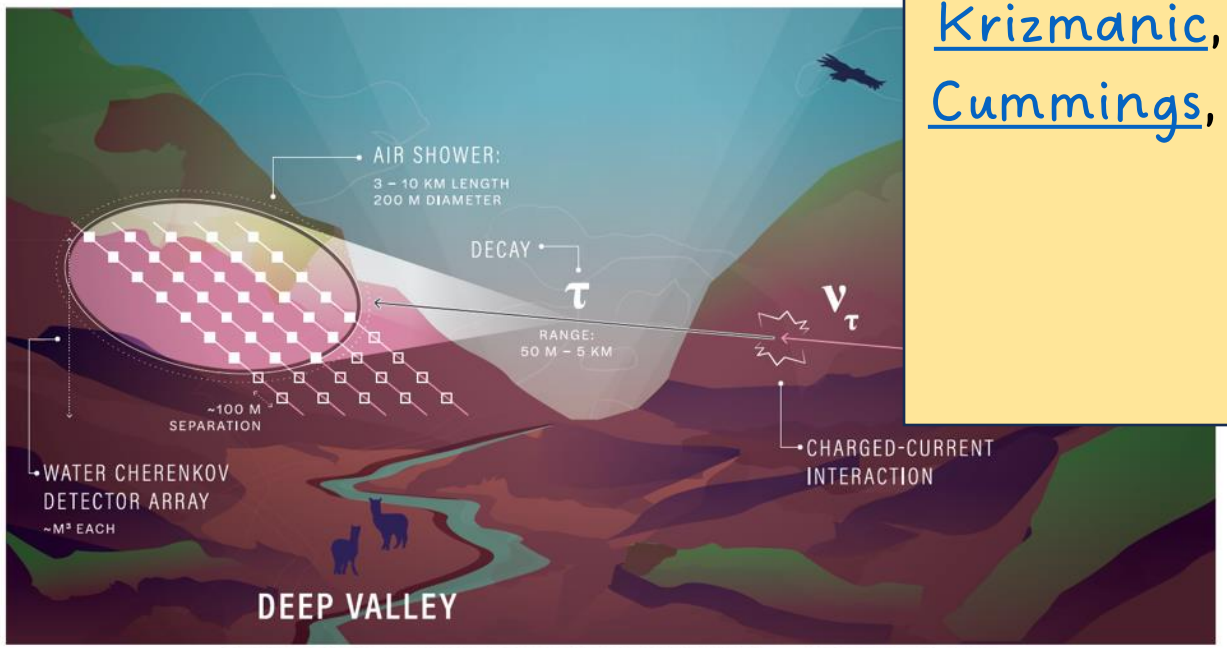



See talks by J. Krizmanic, T. Venters, A. Cummings, W. Thompson



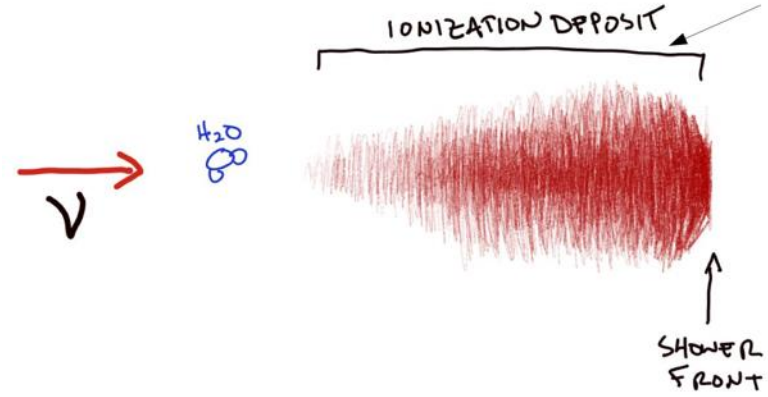

TAU AIR-SHOWER MOUNTAIN-BASED OBSERVATORY (TAMBO) · COLCA VALLEY, PERU

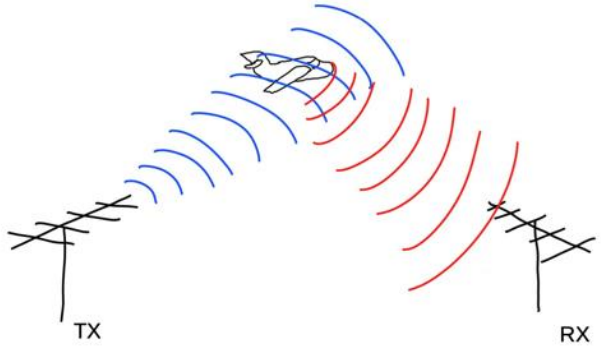
inity
or –
eak,
Utah

Some concepts even space born (e.g. EUSO, POEMMA)

# RET

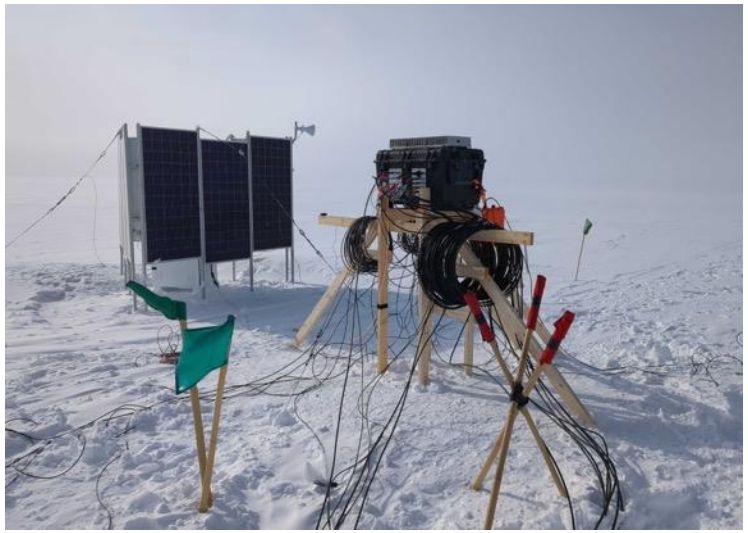
## Radar Echo Telescope



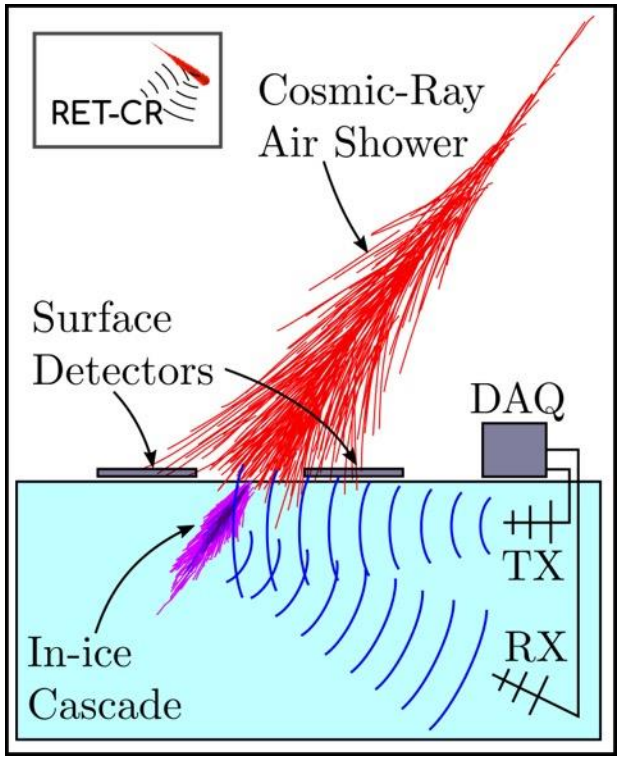




"Active" experiment – try to detect radar reflection from ionization deposition

Cosmic ray demonstrator (RET-CR) deployed & run in Greenland this year – data analysis to begin!



Courtesy of Steven Prohira



# RET

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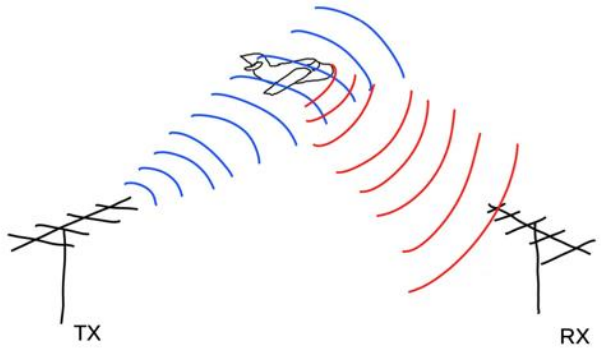
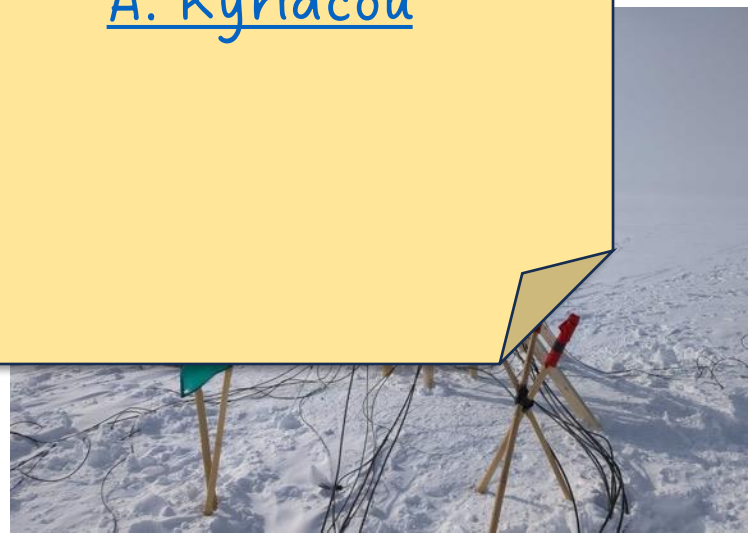
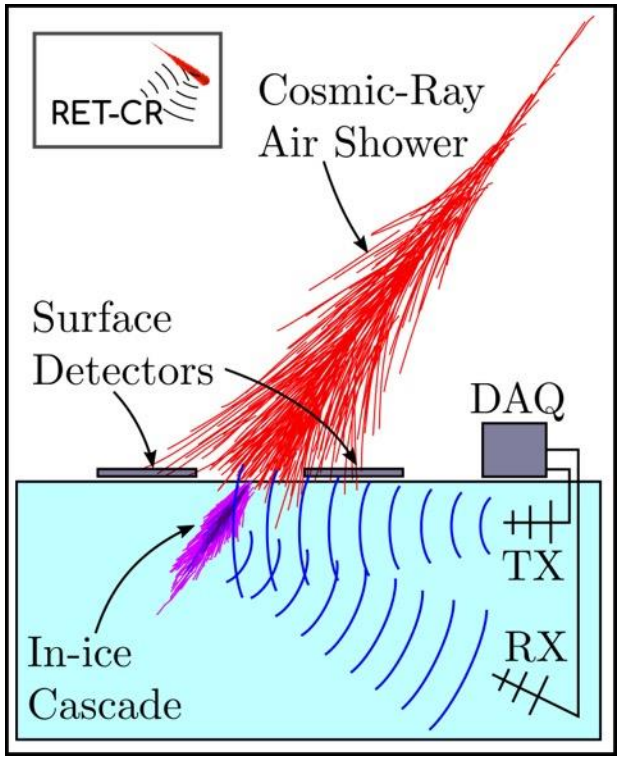



See talks by D. Frikken, A. Kyriacou

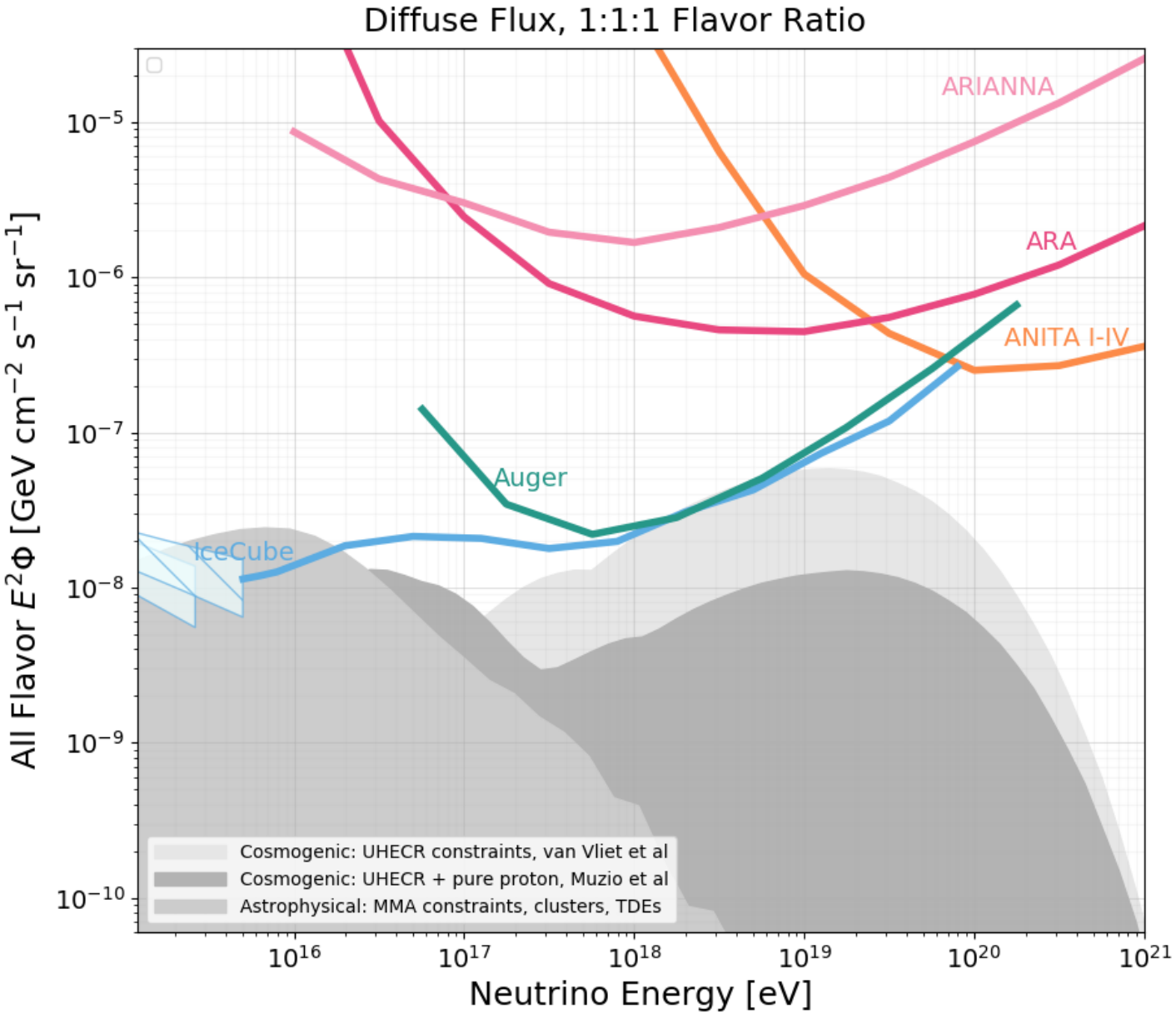


Courtesy of Steven Prohira



# The Status Quo

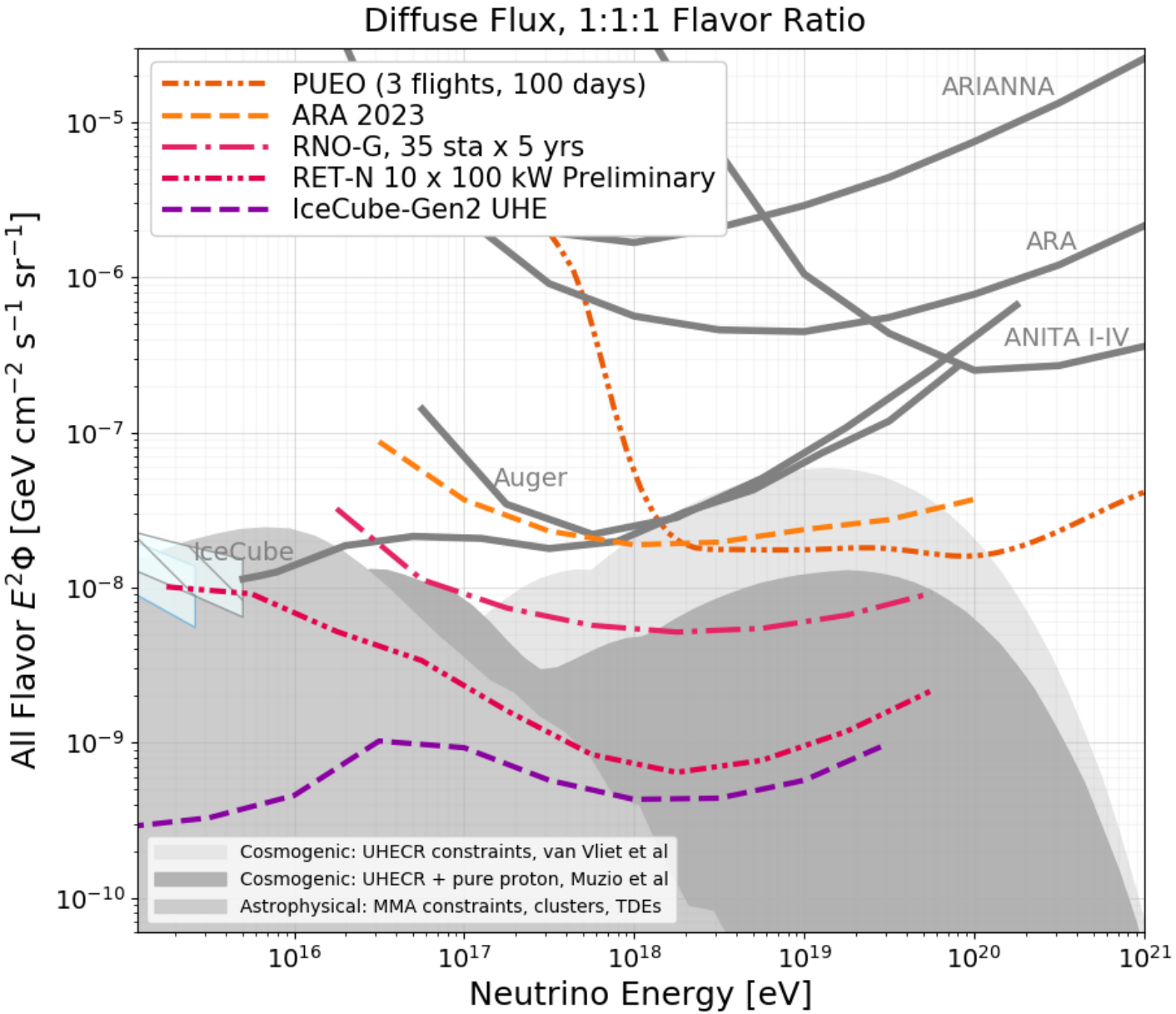
Series of experiments have demonstrated the feasibility and scalability of UHE technology



# The (near🤞) Future

Series of experiments have demonstrated the feasibility and scalability of UHE technology

Future projects chart steady progress in opening this discovery space

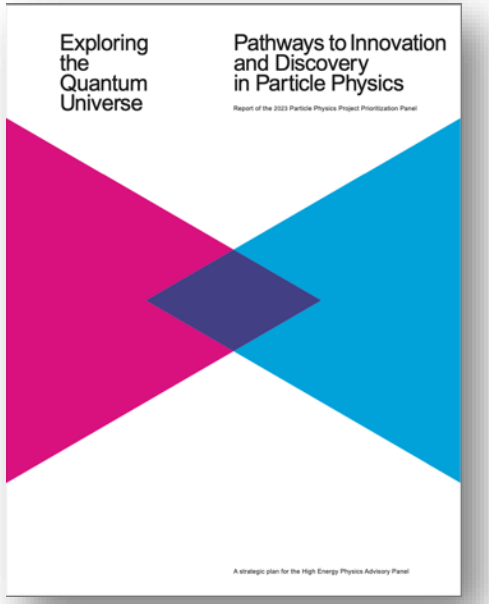


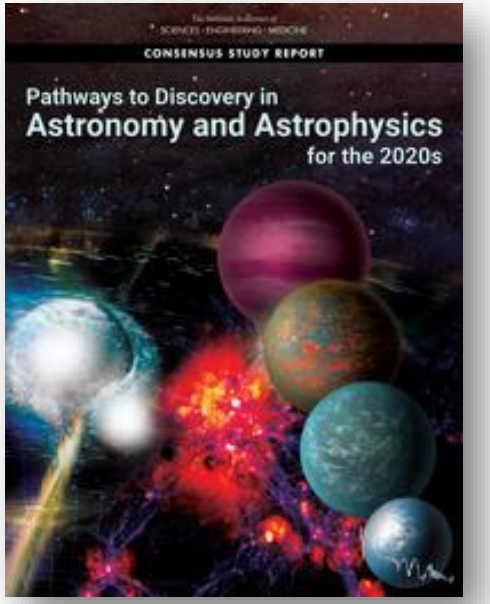
# Conclusions

Neutrinos are unique messengers to the cosmos – we really want, and need, to see $\mathcal{O}(100)$ PeV events!

Recommended as science priority by P5 and Astro2020

Extremely active field – lots of ideas on how to achieve the necessary effective volume (ice, mountains, …)




The presenter acknowledges support from the NSF through awards PHY-2310125 and PHY-2411849.

# Thank You!

*Questions?*

***”Where the telescope ends, the microscope begins. Which of the two has the grander view?”***

**—Victor Hugo**