Beyond TeV: Searching for UHE Neutrinos with PUEO

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The Neutrino Spectrum

UHE neutrinos expected to be produced by CR interactions with the CMB:

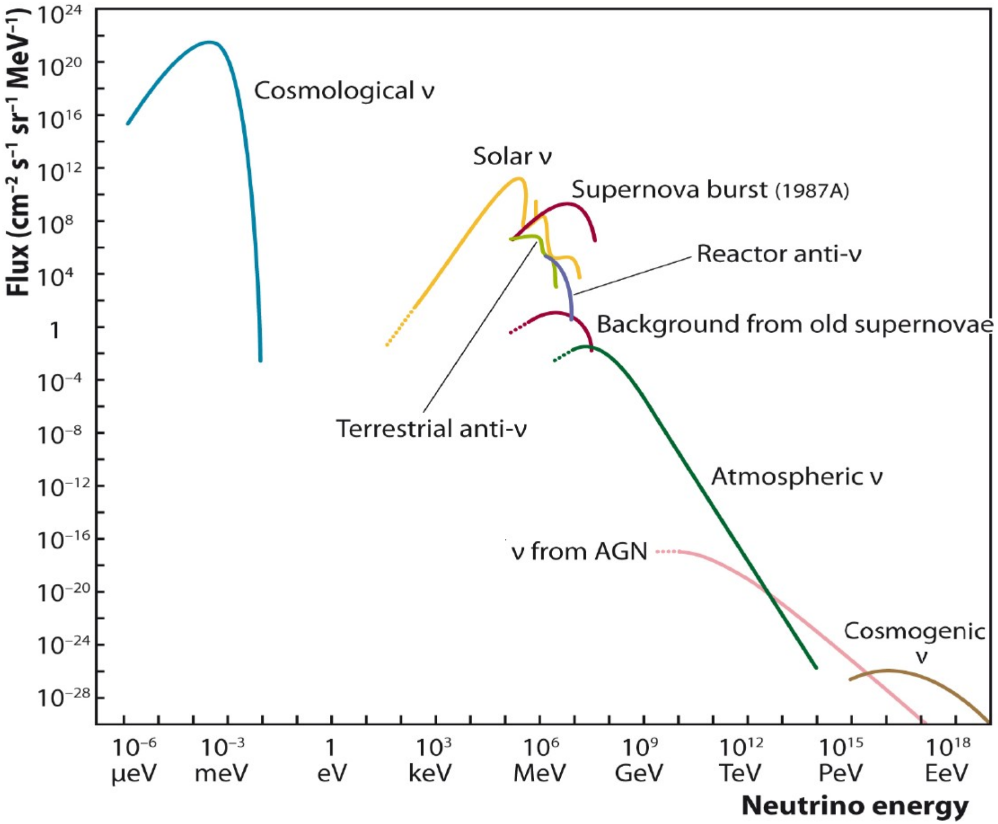
$$p + \gamma \rightarrow \Delta^{+} \rightarrow n + \pi^{+}$$

$$\pi^{+} \rightarrow \mu^{+} + \nu_{\mu}$$

$$\mu^{+} \rightarrow e^{+} + \nu_{e} + \overline{\nu_{\mu}}$$

Problem: The flux is too low to be observed by existing water-cherenkov detectors

We need an efficient way to build large neutrino detectors



The Askaryan Effect

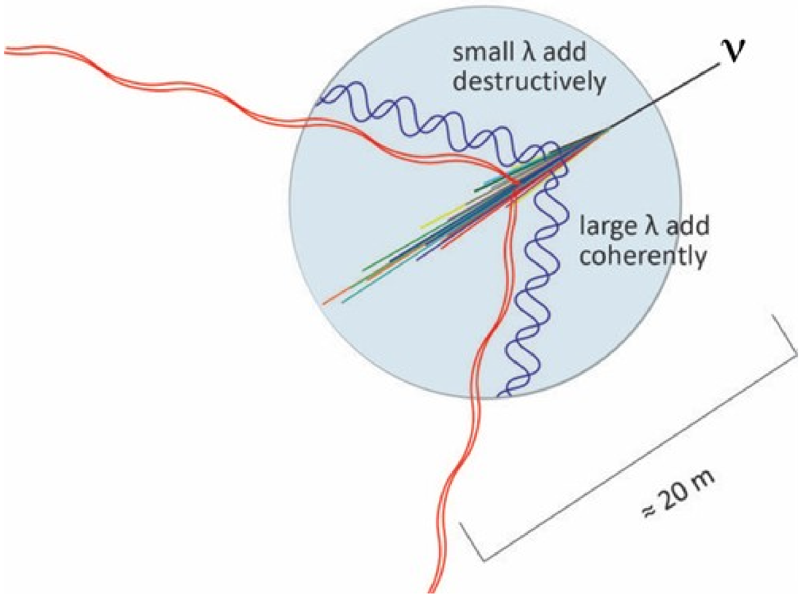
→ Neutrino interactions in the ice will produce a coherent radio wave

→ Attenuation length of radio in ice is ~km

- Compare to ~100m for the optical cherenkov signal

→ Can instrument a large volume of ice with few physical installations

- In-ice (ARA, RNO-G)
- Airborne (ANITA, PUEO)



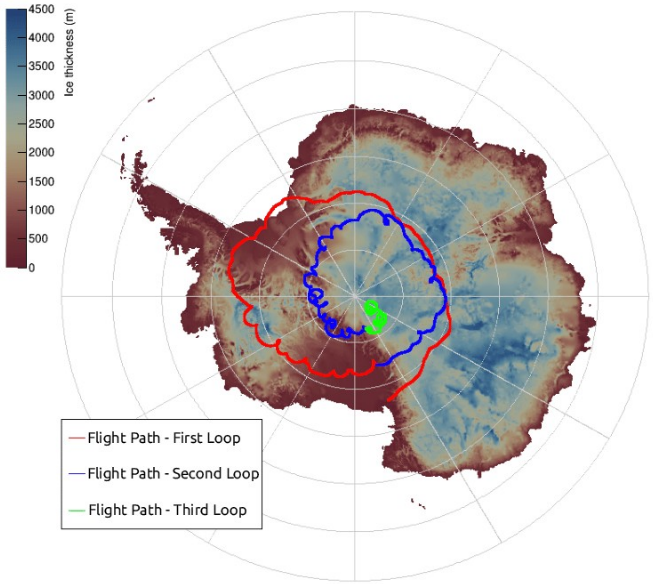
Payload for Ultrahigh Energy Observations

Main instrument with 108 dual-polarization antennas

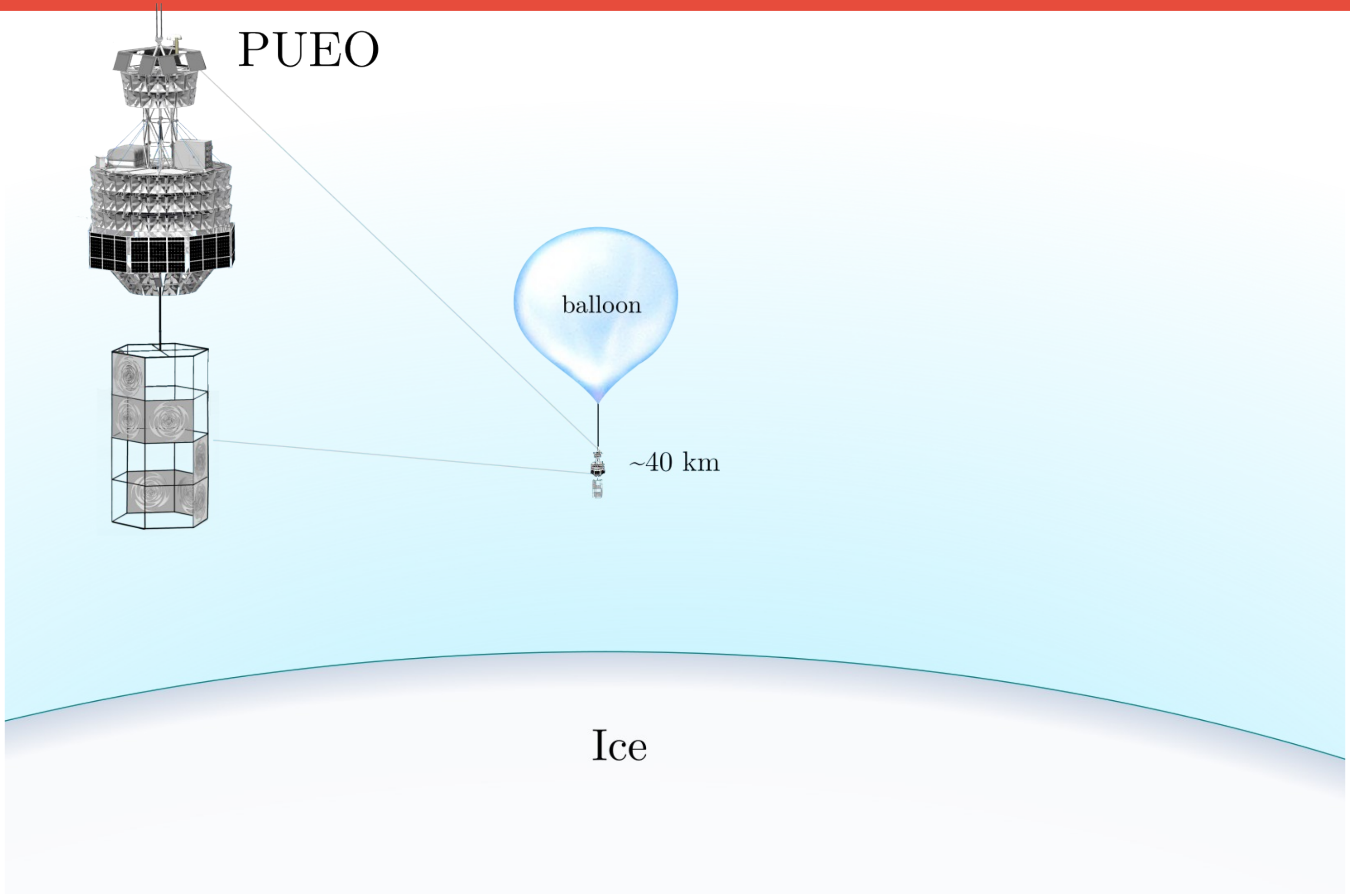
- 300-1200 MHz frequency range
- Look for radio signal from neutrino interactions in antarctic ice
- Lowest 12 antennas tilted downwards an additional 30 degrees to study potential steep events

Low frequency instrument with 8 low-frequency antennas

- 50-300 MHz frequency range
- Deployed below the main instrument
- Enhances sensitivity to air showers and and tau decays



How It Works



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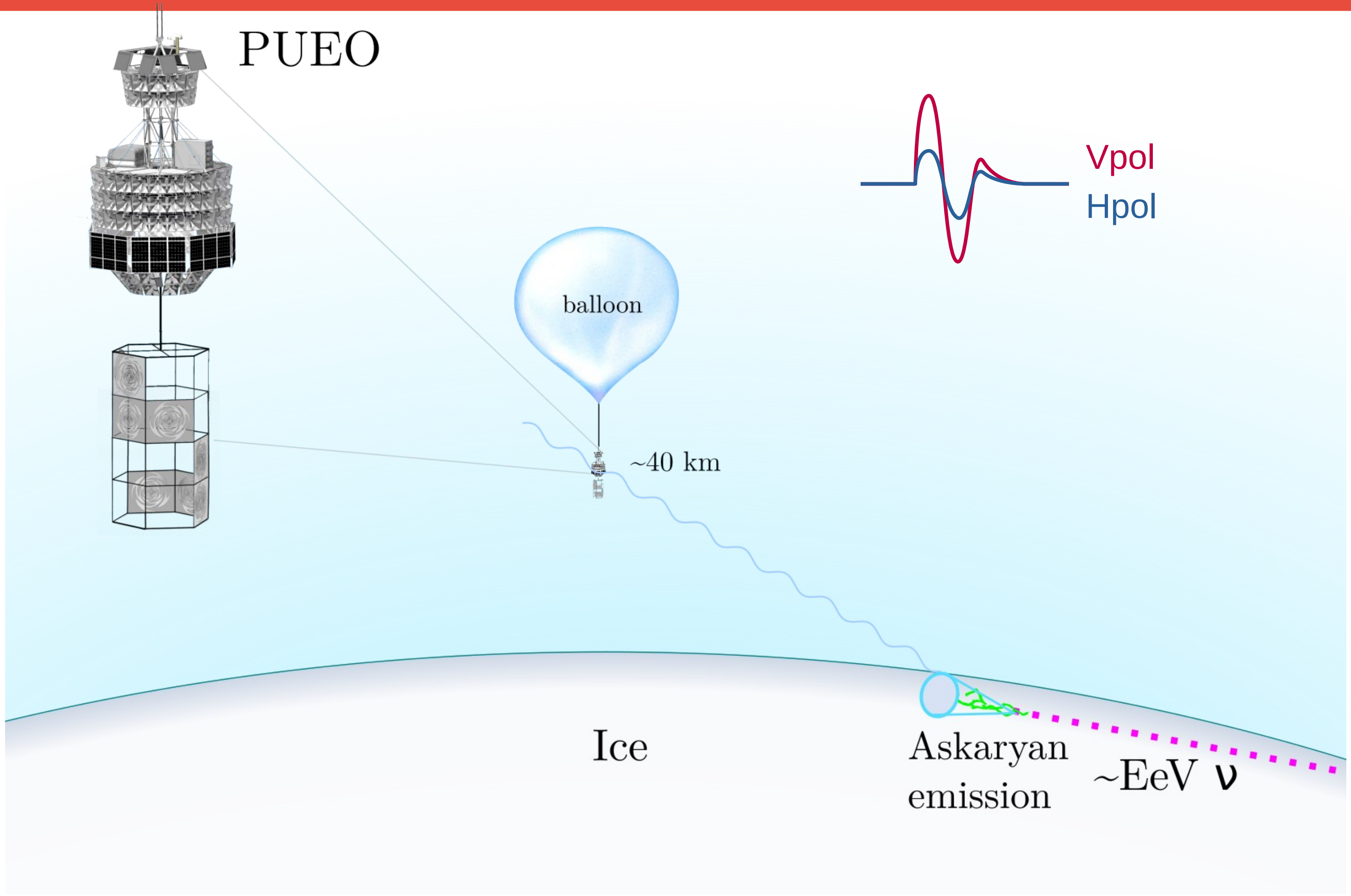

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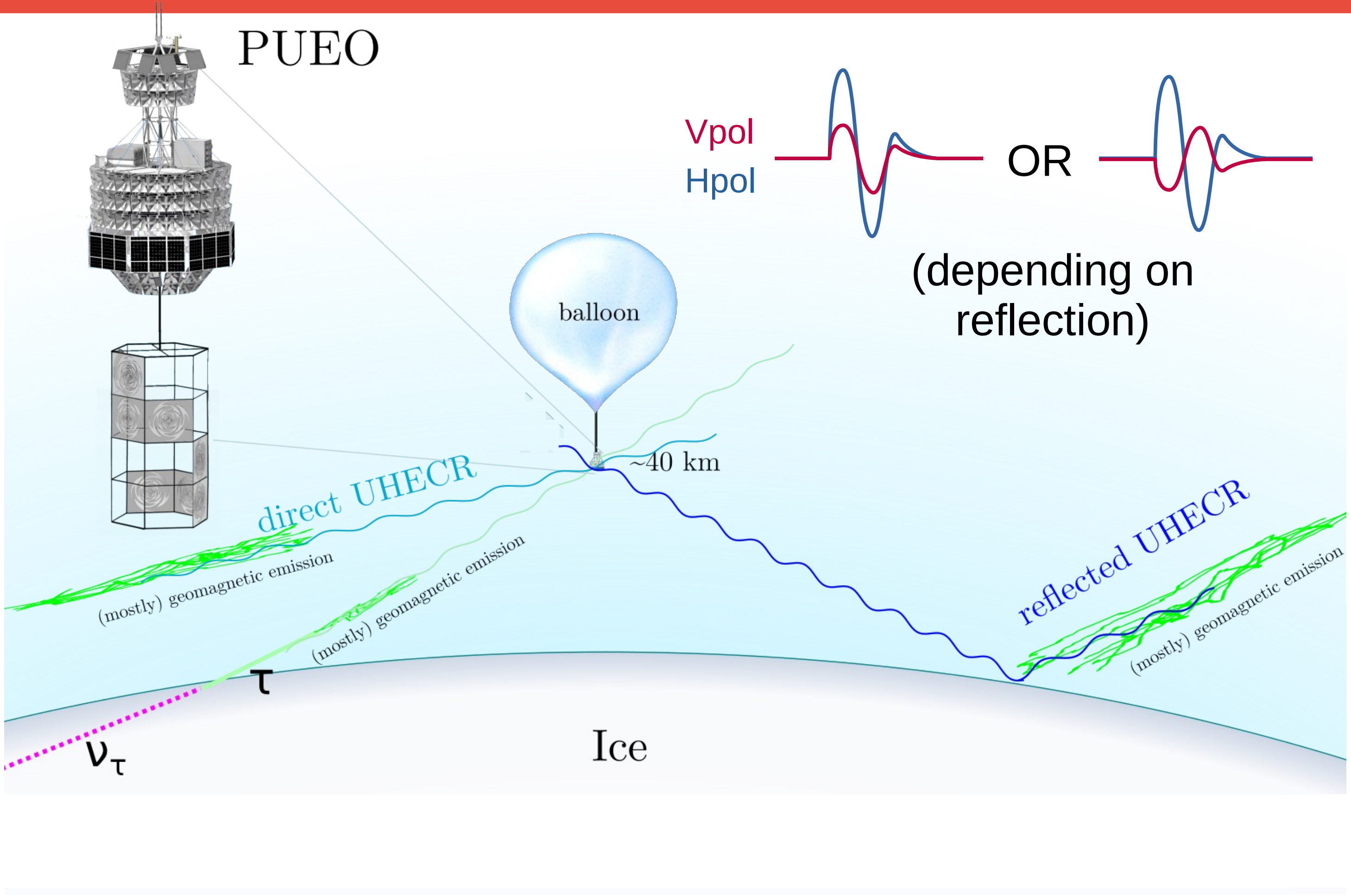
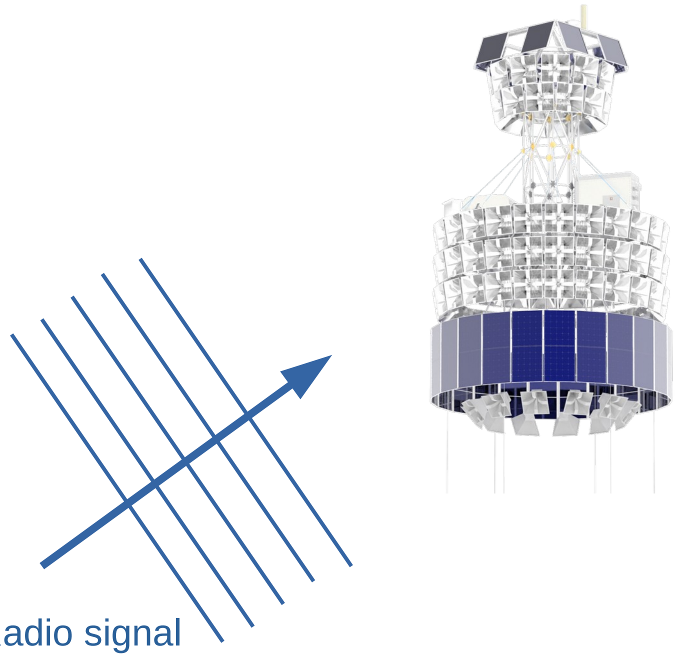
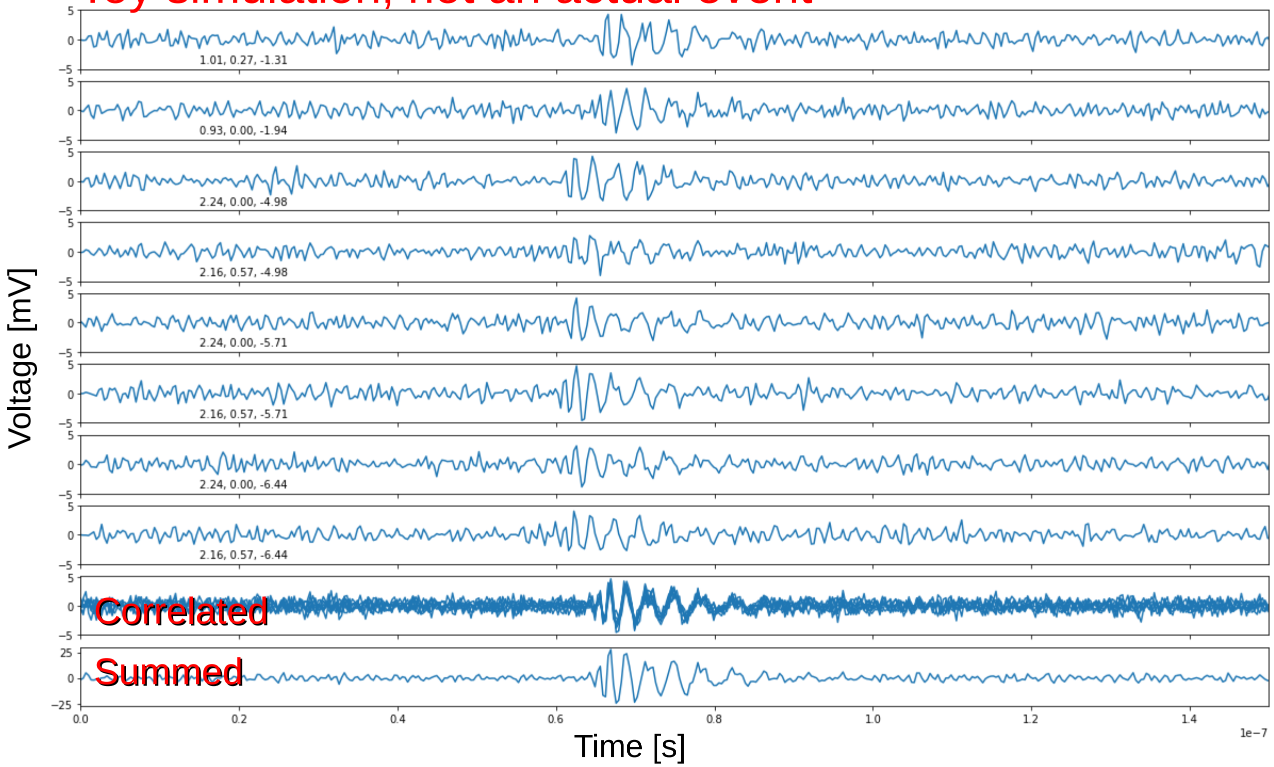

PUEO
Vpol
Hpol
OR
(depending on reflection)
balloon
~40 km
direct UHECR
(mostly) geomagnetic emission
(mostly) geomagnetic emission
reflected UHECR
(mostly) geomagnetic emission
τ
ν_τ
Ice

New Stuff: Phased Array Trigger



Toy simulation, not an actual event



New Stuff: Phased Array Trigger

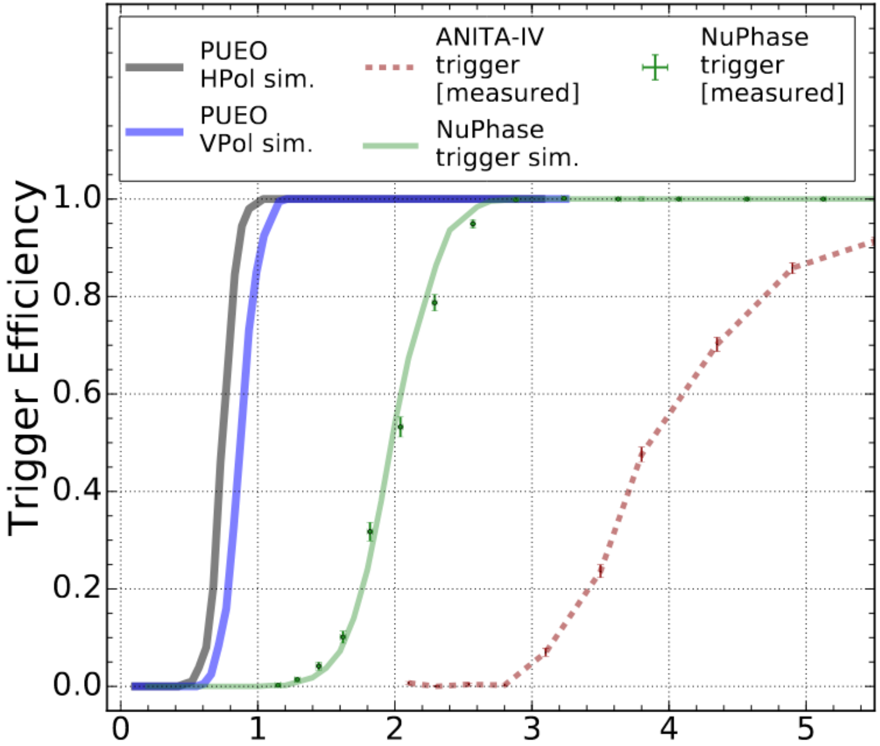
→ Do this all the time in all directions

→ Significantly lowers signal antenna SNR thresholds

→ PUEO will be among the first to implement this concept at the full-detector scale

- Previously demonstrated on ARA (1 station)

- Also planned for other upcoming UHE neutrino detectors (RNO-G, BEACON, etc.)



New Stuff: Low Frequency Instrument

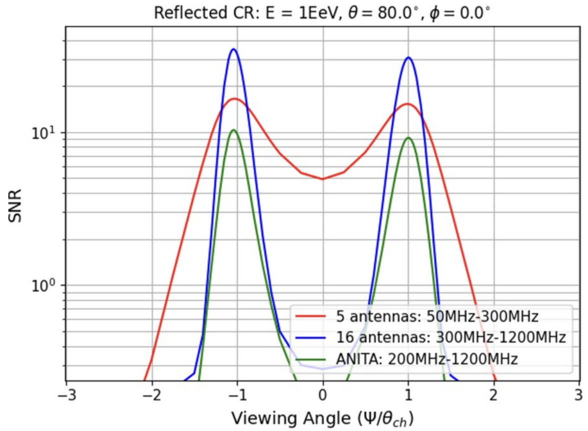
8 antennas deployed below the main instrument

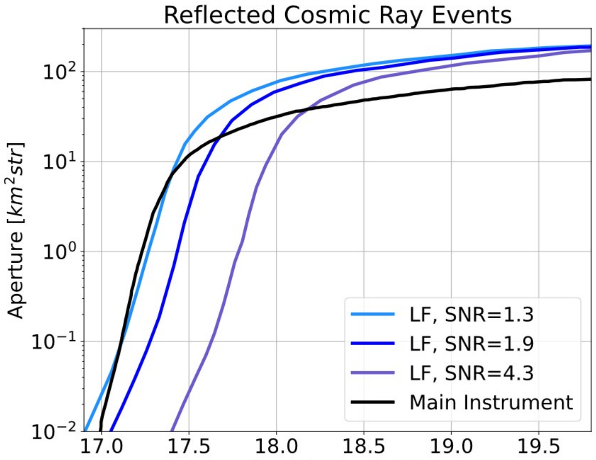
50 MHz to 300 MHz frequency range

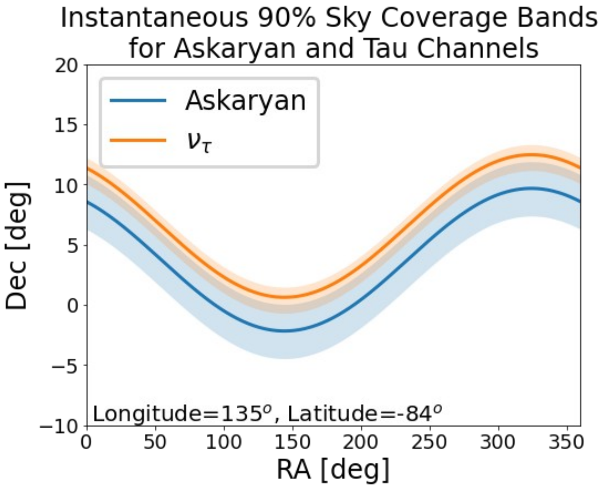
- Broader range of triggerable viewing angles
- Excellent for tau neutrino detections

Independent trigger, but complementary to main instrument

- Coincident triggers can improve sensitivity
- Triggers of one instrument can be used to improve SNR of the other





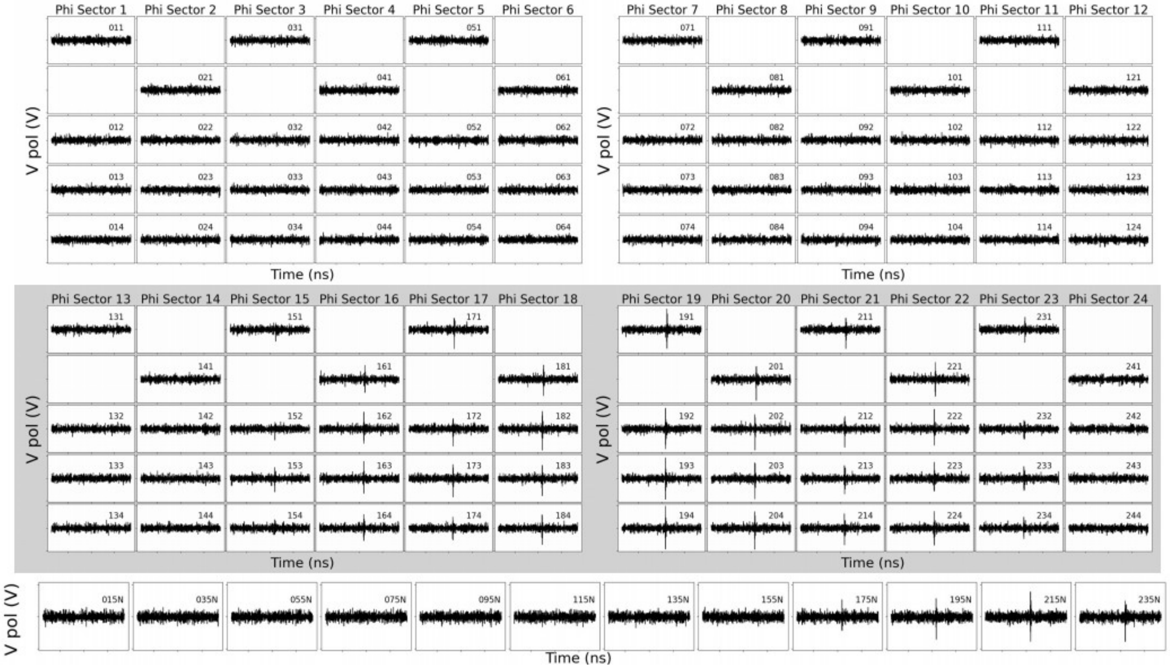


Expected Performance: Diffuse UHE Neutrinos

Updated sensitivity using full detector simulation. Now includes:

- New detector geometry
- New antennas
- New RF amplification chain
- Phased array trigger

Simulated Event : 1E21 eV



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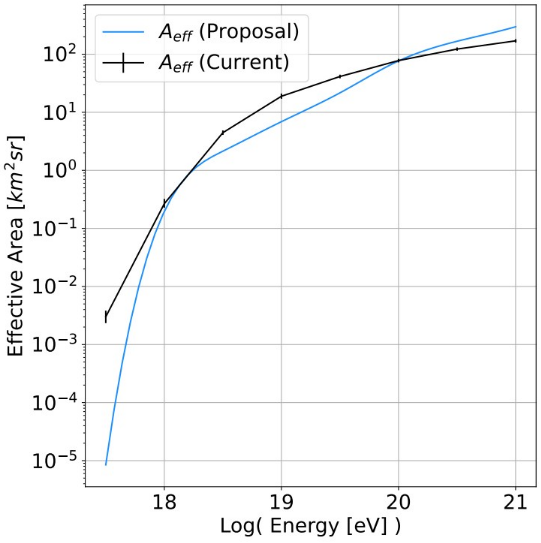
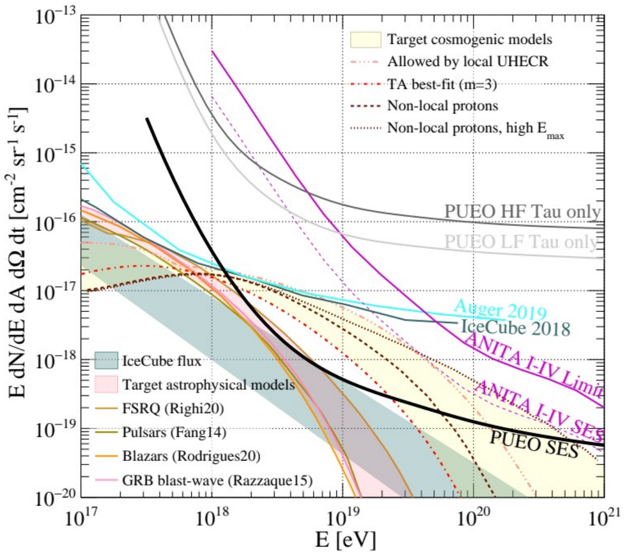
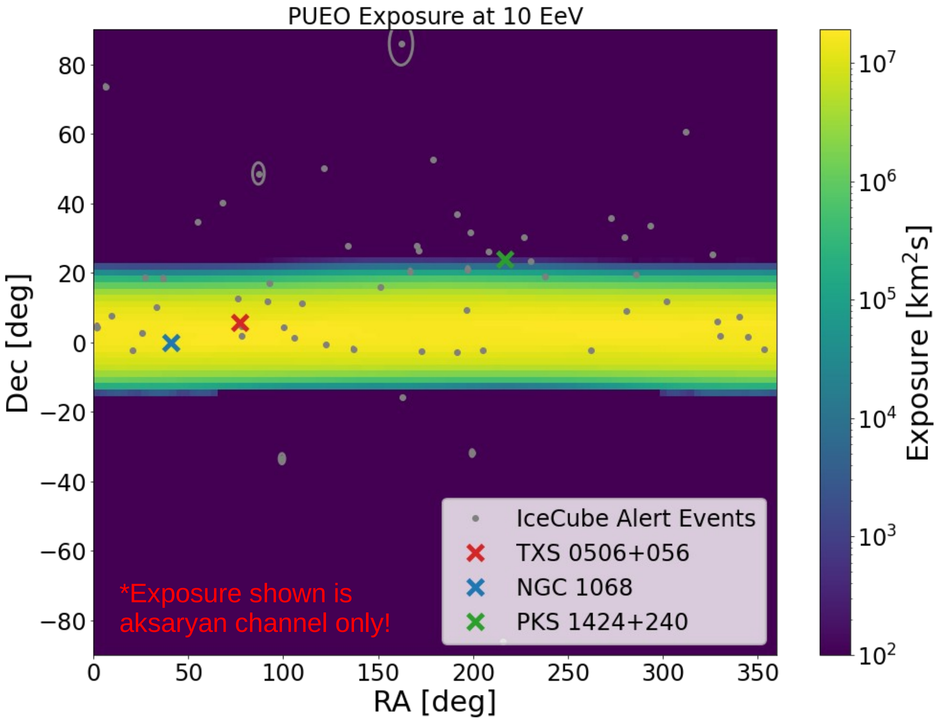
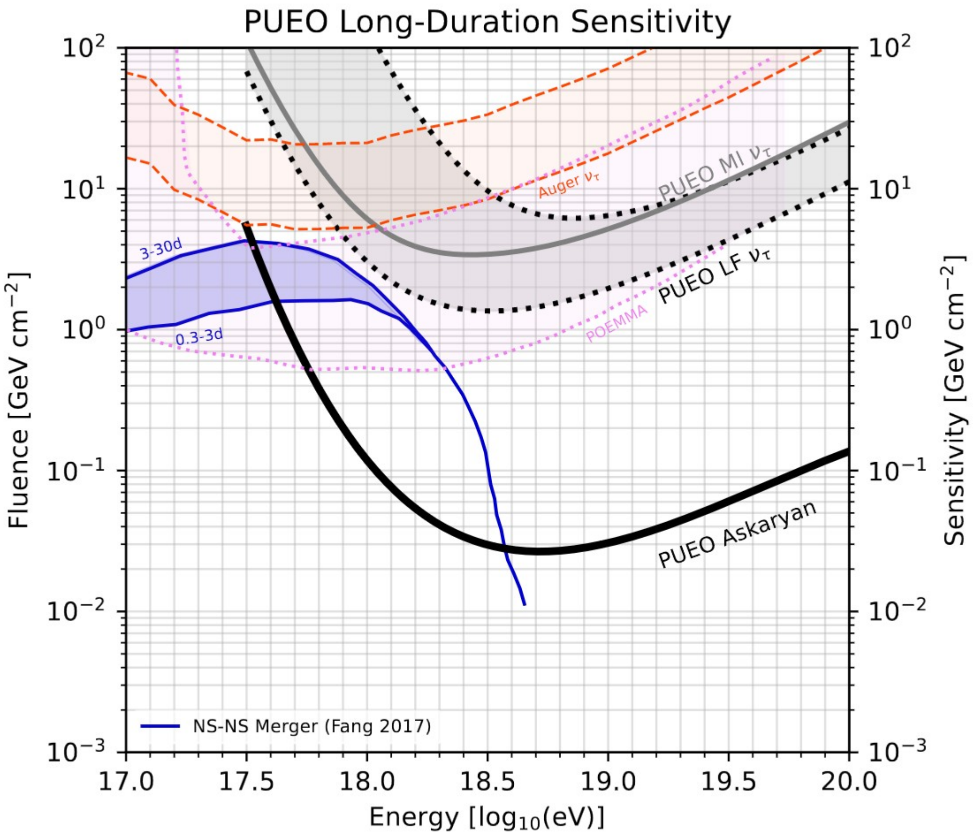
Sensitivity projections have improved since the original proposal!





Expected Performance: Transient Sources





→ Lots of interesting objects within field of view

It’s Happening!

PUEO planned for launch in 2025

- First analysis results expected roughly a year after flight
- Data will be publicly available post-publication

Lots of new things to be excited about:

- Phased array trigger
- LF Instrument
- Additional nadir antennas
- New hardware
- New calibration systems

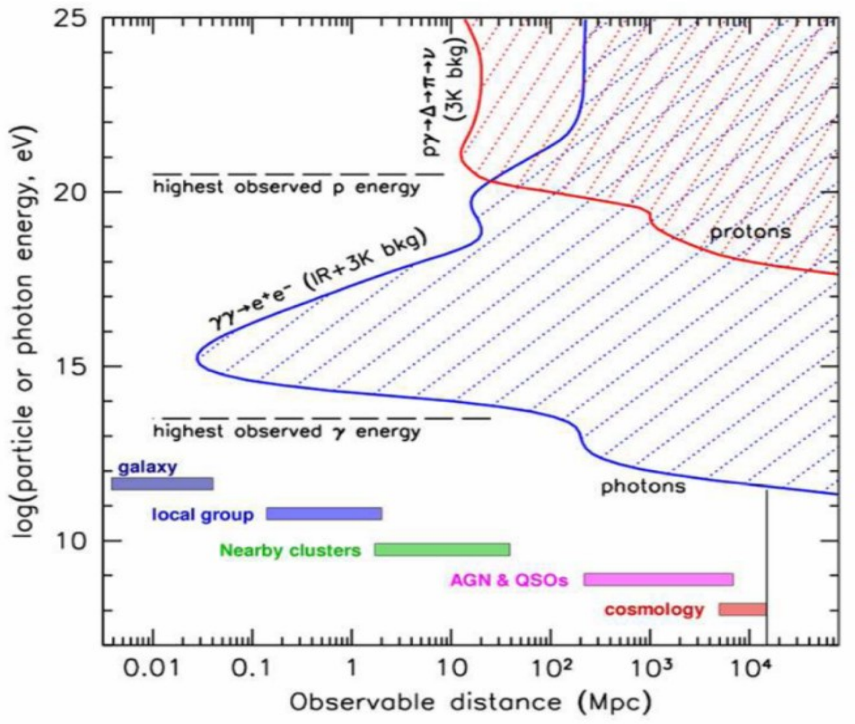
Large instantaneous effective area presents a unique opportunity for UHE astrophysics

Backup Slides

Why Do We Care About Cosmic Rays?

- **Cosmic rays can let us study regions opaque to photons**
  - Energetic sources that are far away
  - Dense regions
- **Can be used to study physics at extreme energies**

- **Problem: Cosmic rays are charged**
  - Arrival direction at Earth does not necessarily correlate to the source direction



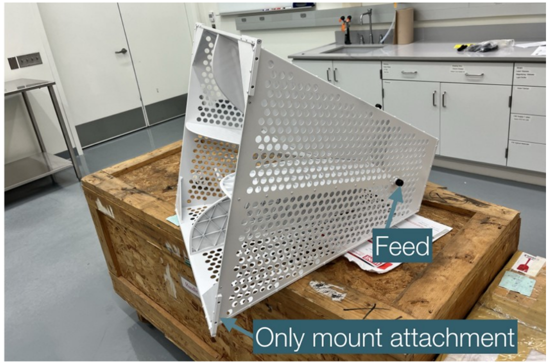
The New Stuff: Antennas

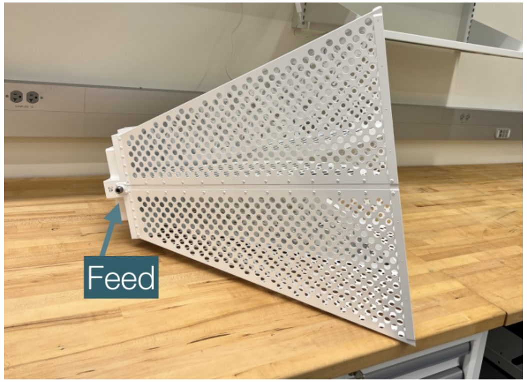
→ New antennas need to be ~30% smaller for the new frequency range

→ Vendor for ANITA antennas effectively no longer exists

→ New antenna production model received and tested!

→ New antenna responses now included in simulation





→ Photos courtesy of Kaeli Hughes and Zach Martin

Airborne Calibration

→ **3 hand-launched payloads**

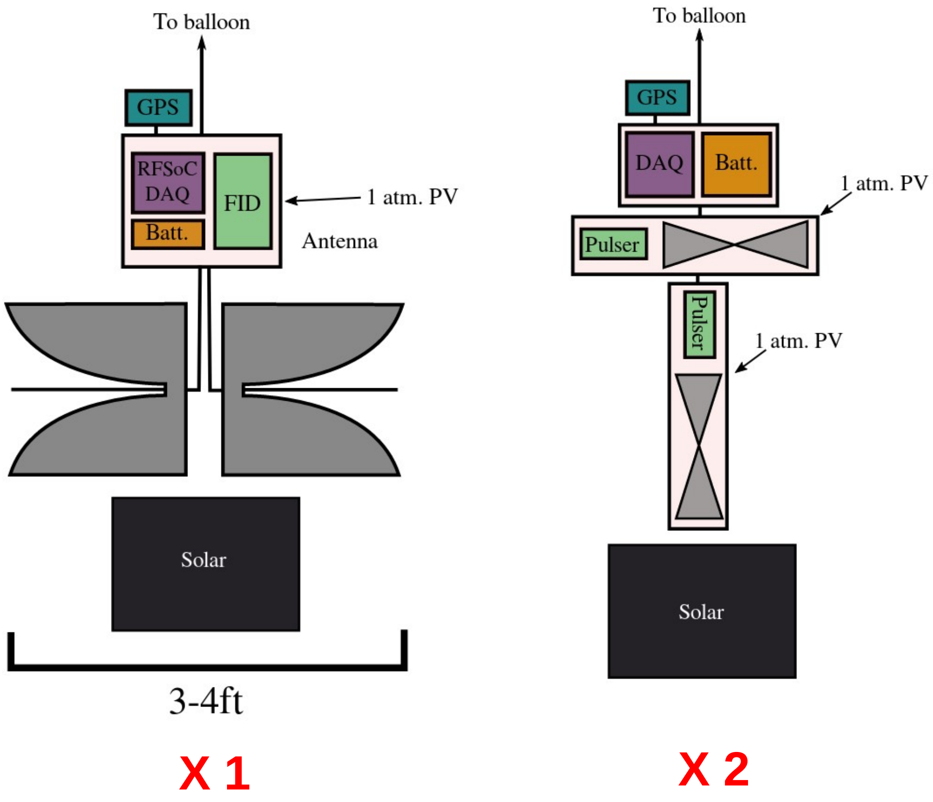
- Ensures at least one payload is near the main PUEO instrument at all times

- Provide regular calibration for the PUEO instrument

- Study the reflection of radio signals off the ice

→ **1 primary payload with fancy, expensive pulser**

→ **2 slimmed down payloads with pulsers built in-house**



Expected Performance

Model	$< N_\nu >$ (30 d)	$< N_\nu >$ (100 d)
Non-local proton cosmogenics	1.8	5.9
Non-local proton cosmogenics (high E_{max})	4.5	15.0
TA best fit [5, 7]	0.9	2.9
Subdominant proton cosmogenics [6]	3.7	12.4
Diffuse FSRQs, max [10]	0.4	1.3
Diffuse Pulsars, max [13]	0.2	0.5
Diffuse AGN [11]	0.2	0.5
Diffuse GRB Blast-waves, max [12]	0.2	0.6
IceCube flux, max, all-flavor, extrapolated [14]	0.5	1.7

Flavor Physics

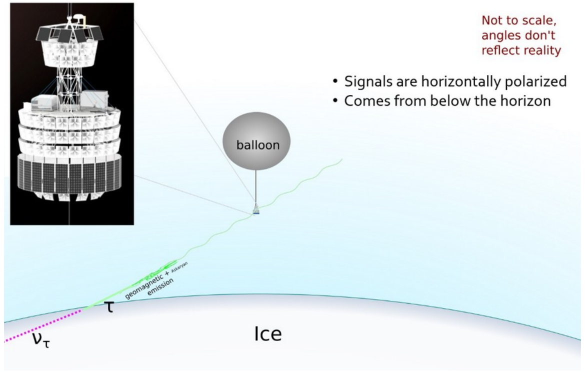
→ Askaryan channel dominated by electron neutrinos at lower energies

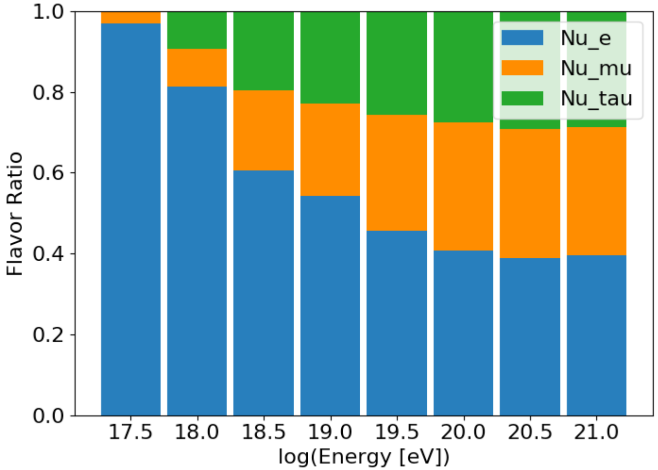
→ Air shower channel dominated by tau neutrinos

→ Measurement of e/τ ratio in new energy regime possible

- Constrains source models (e.g. arXiv: 1902.08630v2)

- Potential tests of fundamental neutrino physics (arXiv: 1001.4878)





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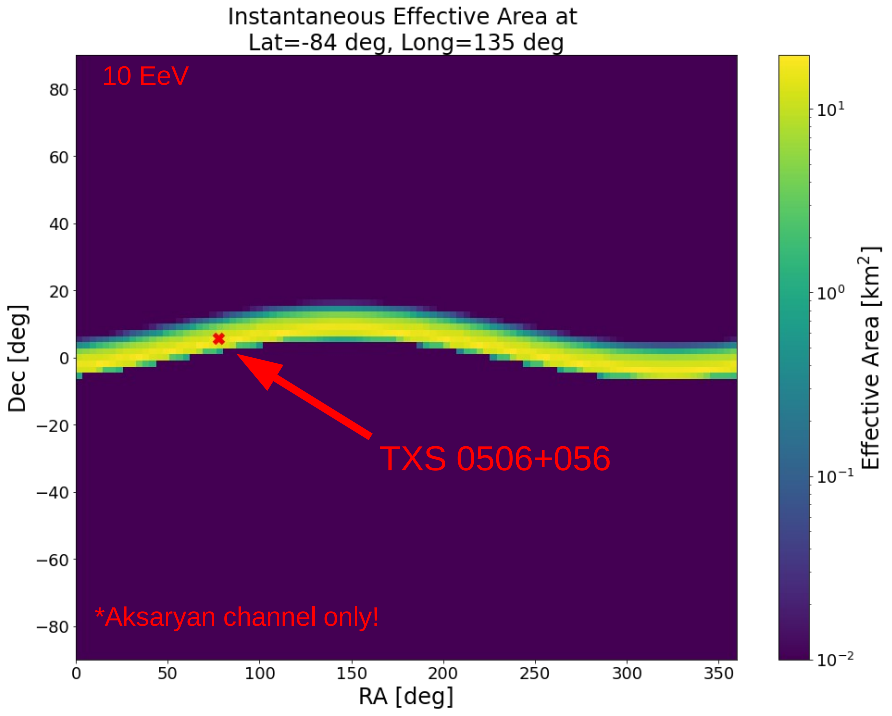

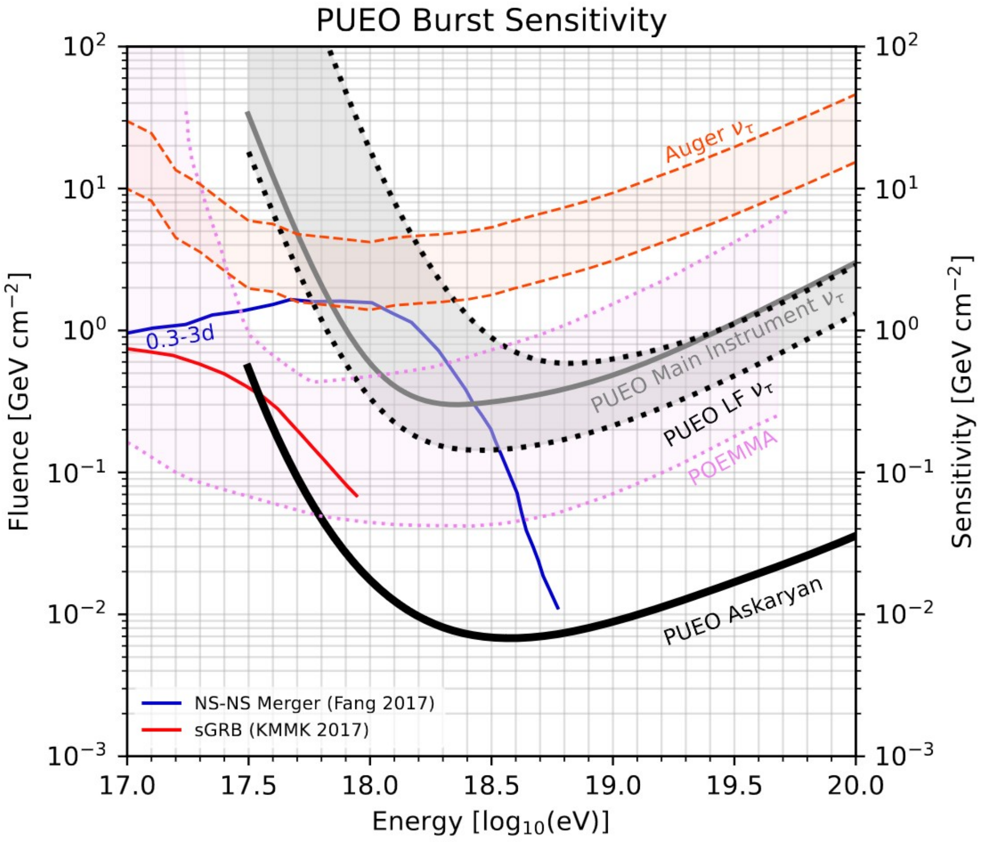

→ **Lots of interesting objects within field of view**