The Payload for Ultrahigh Energy Observations (PUEO)

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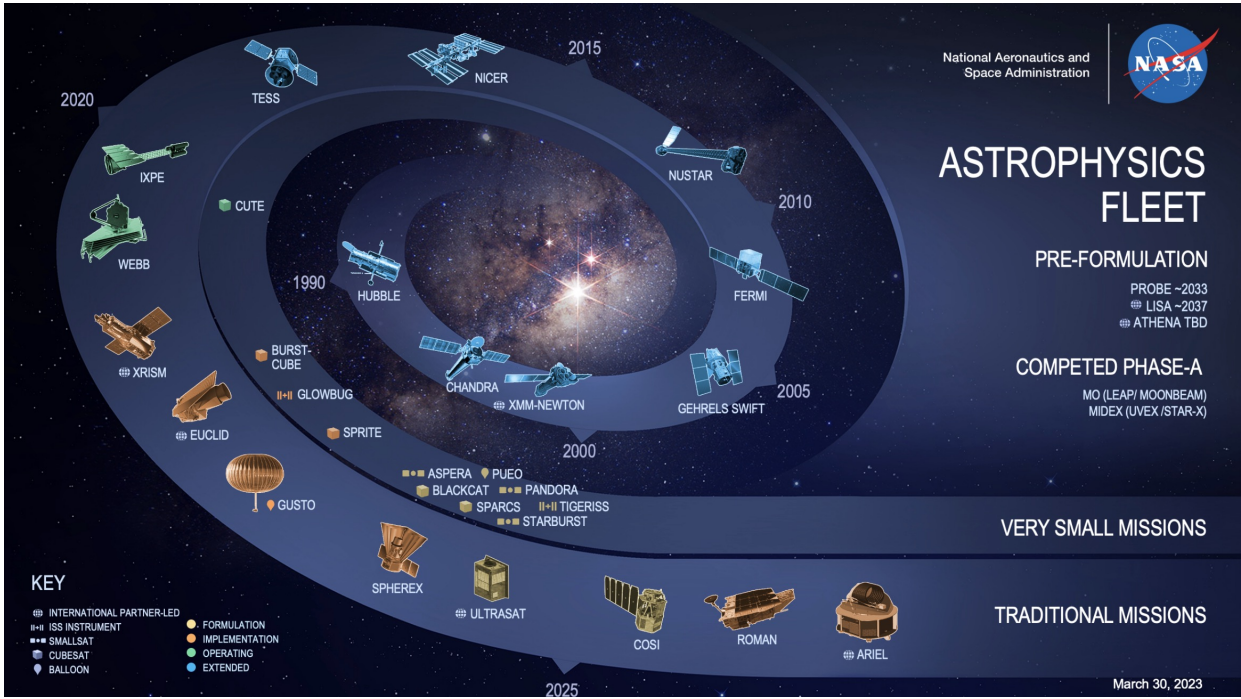

The PUEO Team

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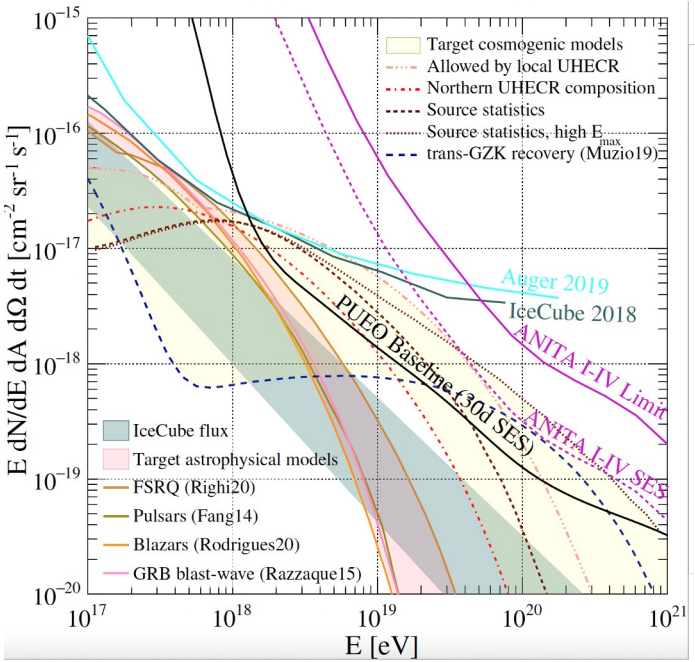
The PUEO Mission

PUEO is part of the inaugural class of Astrophysics Pioneers Missions (cost cap $20M, 5-year missions), and the only Pioneers balloon so far

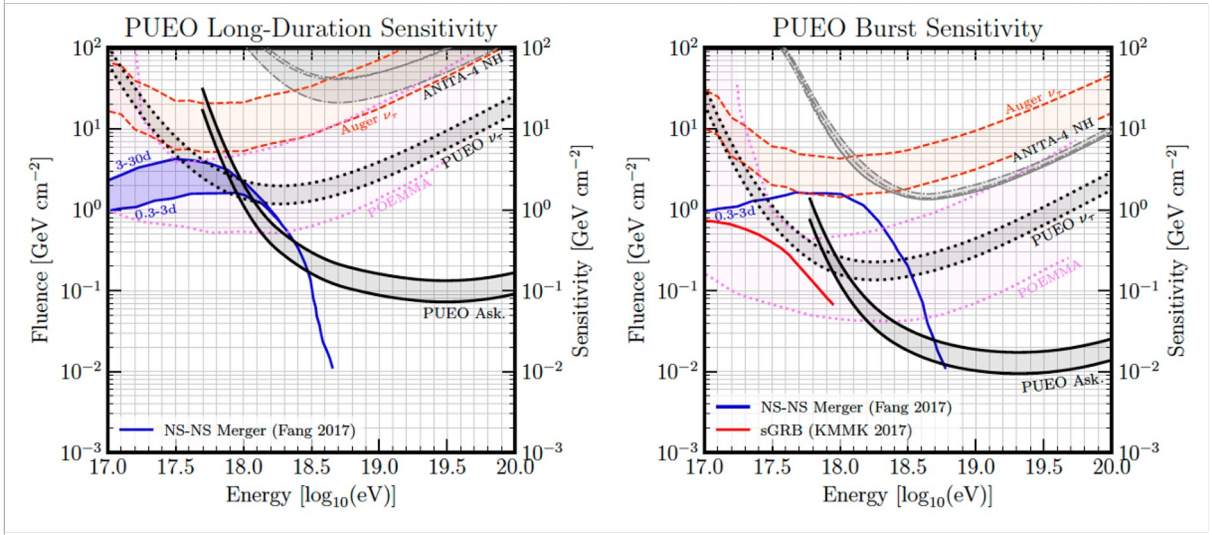
- Project start in February 2021
- Antarctic LDB Mission
- Flight planned for the 2025-26 Austral summer.

Science Reach of PUEO

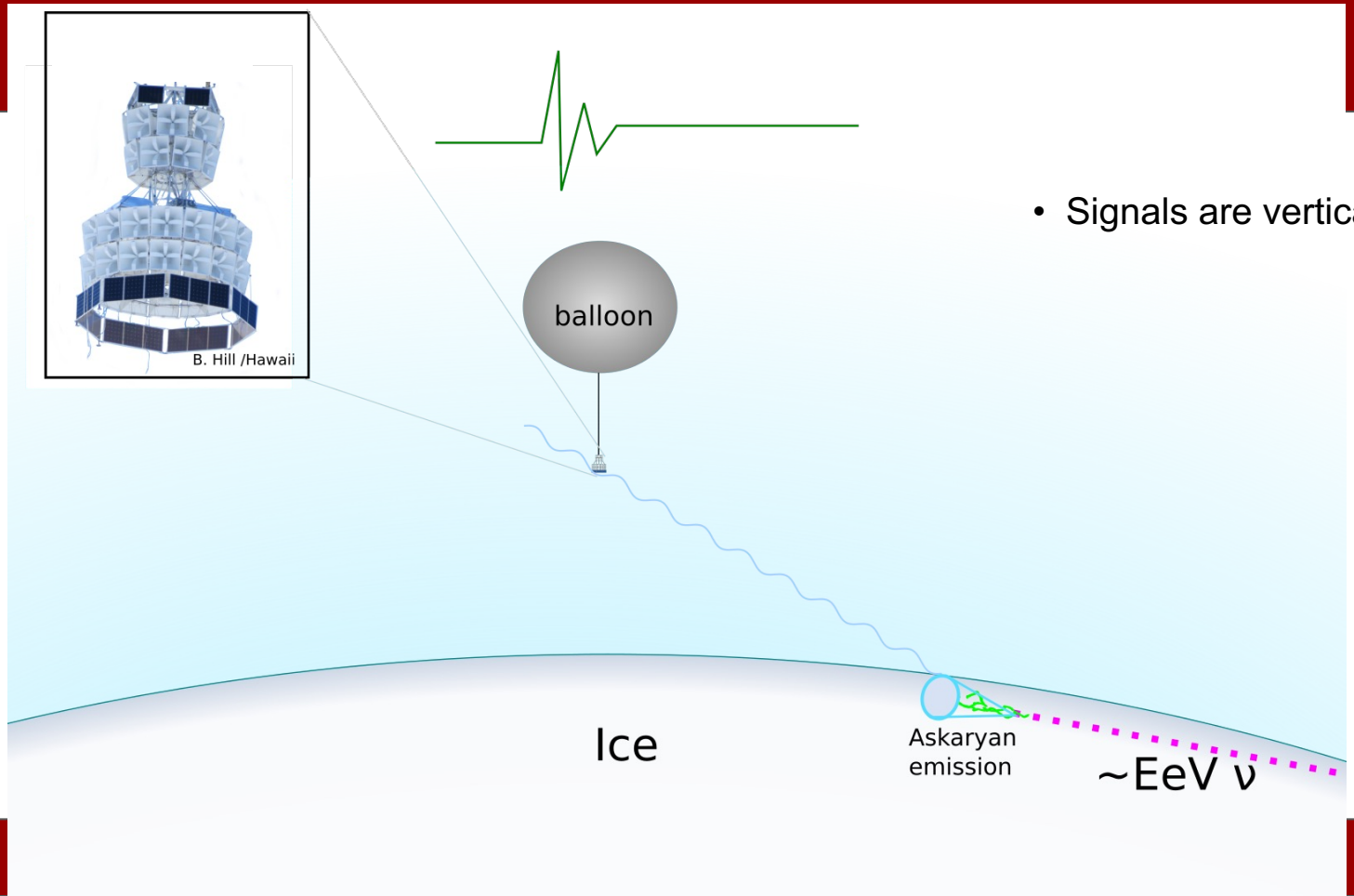
Diffuse Flux Sensitivity of PUEO



Transient Sensitivity, Long (Length of Flight) and Short (1000s)

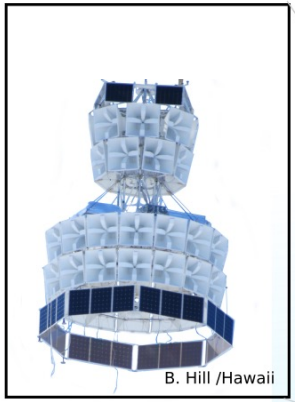


1) Neutrino-Induced Askaryan Emission in Ice



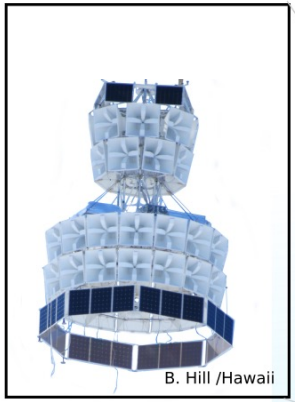
- Signals are vertically polarized

2) Radio Emission from Tau-Neutrino-Induced Air Showers



- Signals are horizontally polarized
- Comes from below the horizon

3) Radio Emission from Cosmic-Ray-Induced Air Showers



- Signals are horizontally polarized
- Polarity of reflected (below-horizon) signal is inverted compared to direct (above-horizon) signal and tau neutrino (below-horizon) signal

The PUEO Payload

- 192-RF-Channel Main Instrument.
- 16-antenna, dual-polarization beamforming trigger
- 16-RF-Channel Low Frequency Instrument
- Triply redundant 128 TB onboard data storage
- Command and control, data transfer to the ground
- Suite of navigation instruments: heading, pitch, roll, location
- Housekeeping/environment sensor system
- In-flight calibration from the ground and from a suite of hand-launched HiCal payloads

Why is PUEO So Much More Sensitive than ANITA (Ideas to be carried forward in GRAND/BEACON designs?)

More than an order-of-magnitude sensitivity increase enabled by:

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

Other features that improve performance

- Real-time digital filtering
- Improved pointing resolution
- Low frequency instrument (important for air shower events)

ANITA-III

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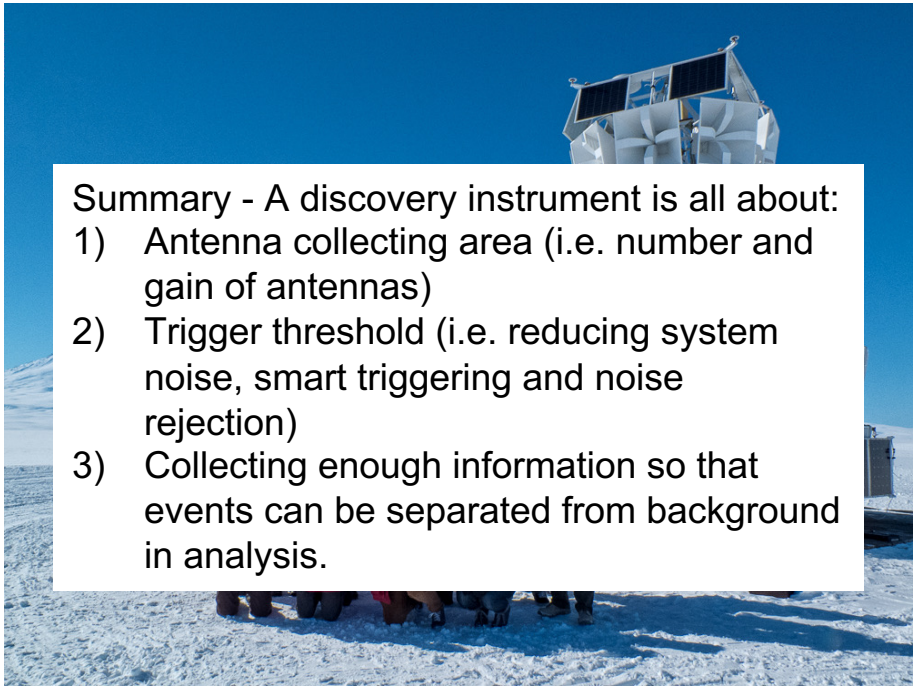
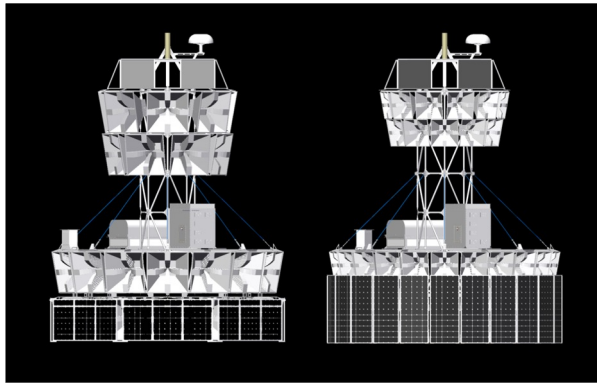


Summary - A discovery instrument is all about:

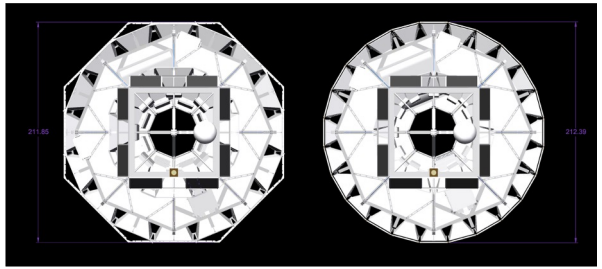
1) Antenna collecting area (i.e. number and gain of antennas)
2) Trigger threshold (i.e. reducing system noise, smart triggering and noise rejection)
3) Collecting enough information so that events can be separated from background in analysis.

ANITA-III

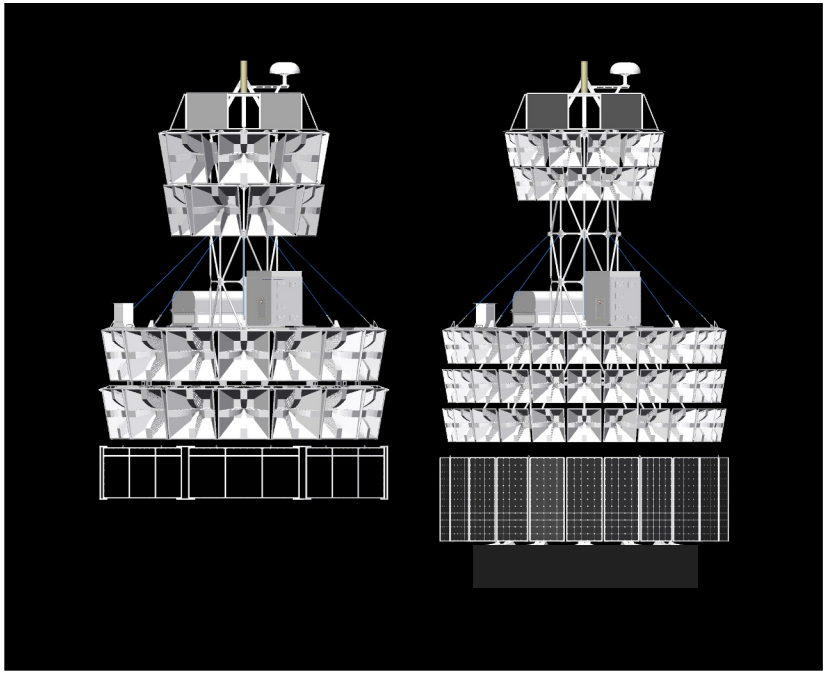
PUEO vs ANITA



ANITA PUEO



- 2/3x scaled antennas
- Nearly identical footprint
- Identical launch configuration

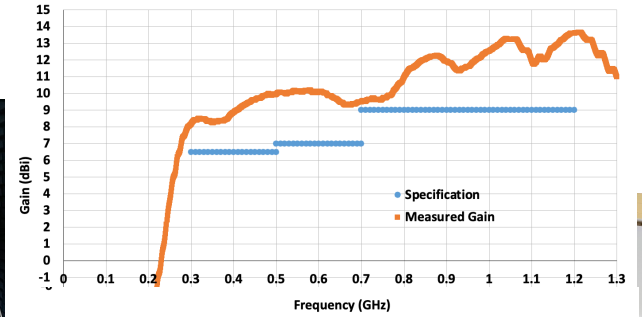


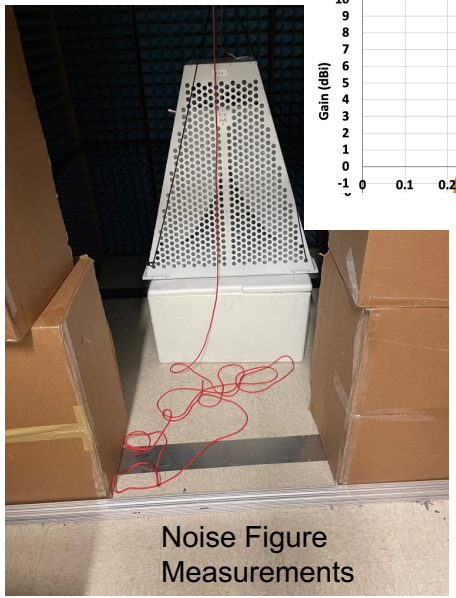
ANITA PUEO

Always Work Hard for Better Antennas.

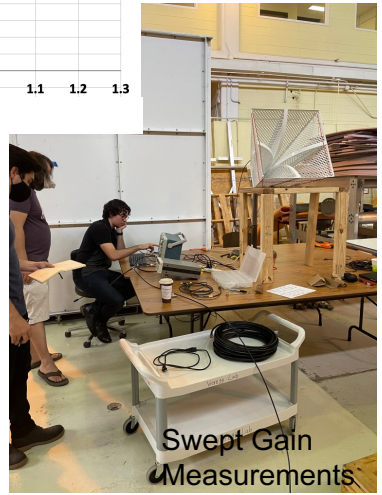
- 96 Quad-ridged horn antennas, 300-1200MHz
- Vendor selected: Toyon Antennas (these antennas are significantly better (i.e. higher gain while still meeting the bandwidth, size, and weight requirements) than the antennas we used on ANITA

Boresight Swept Gain from Company Measurements



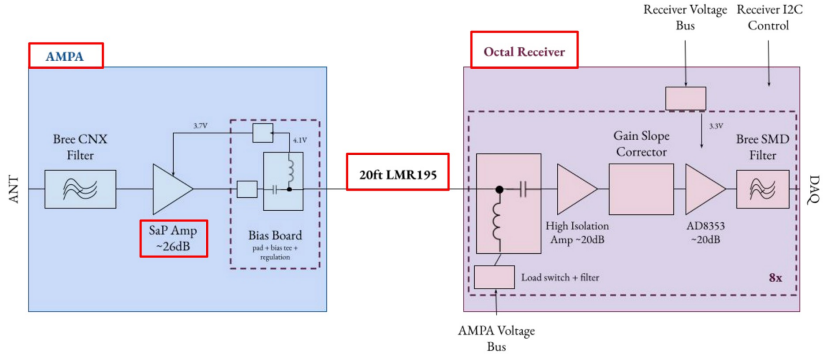


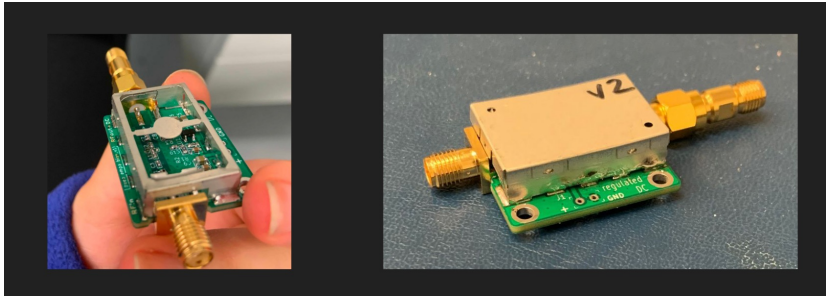
Noise Figure Measurements



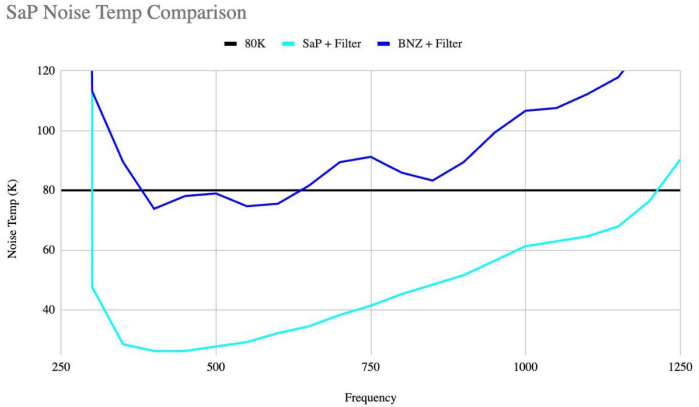
Swept Gain Measurements

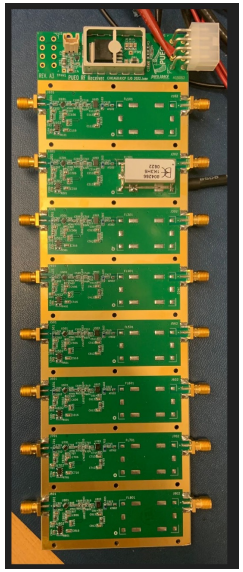
Always Work Hard for a Better RF Front-End.





Switching to a new LNA: ~20% more neutrinos over design sensitivity

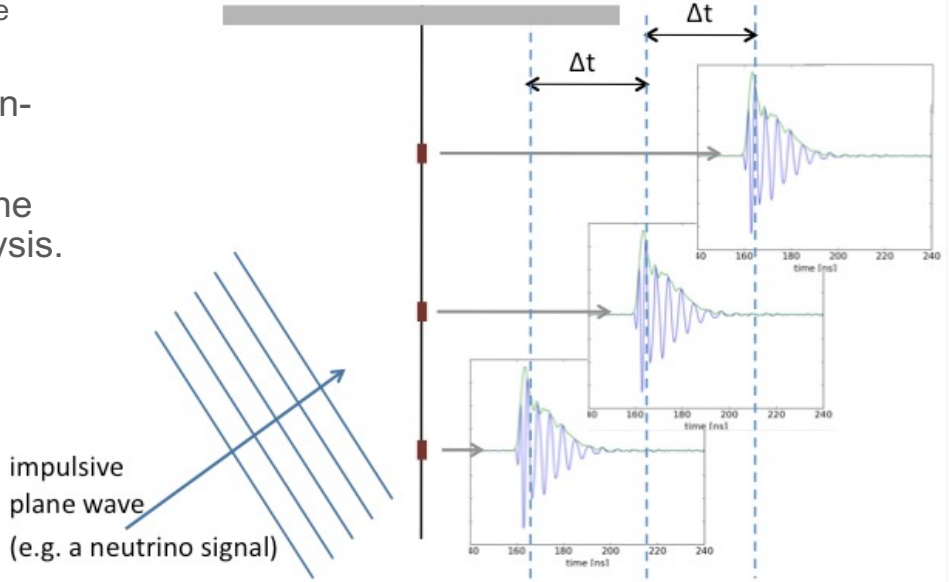




Always Work Hard for a Better Trigger Threshold.

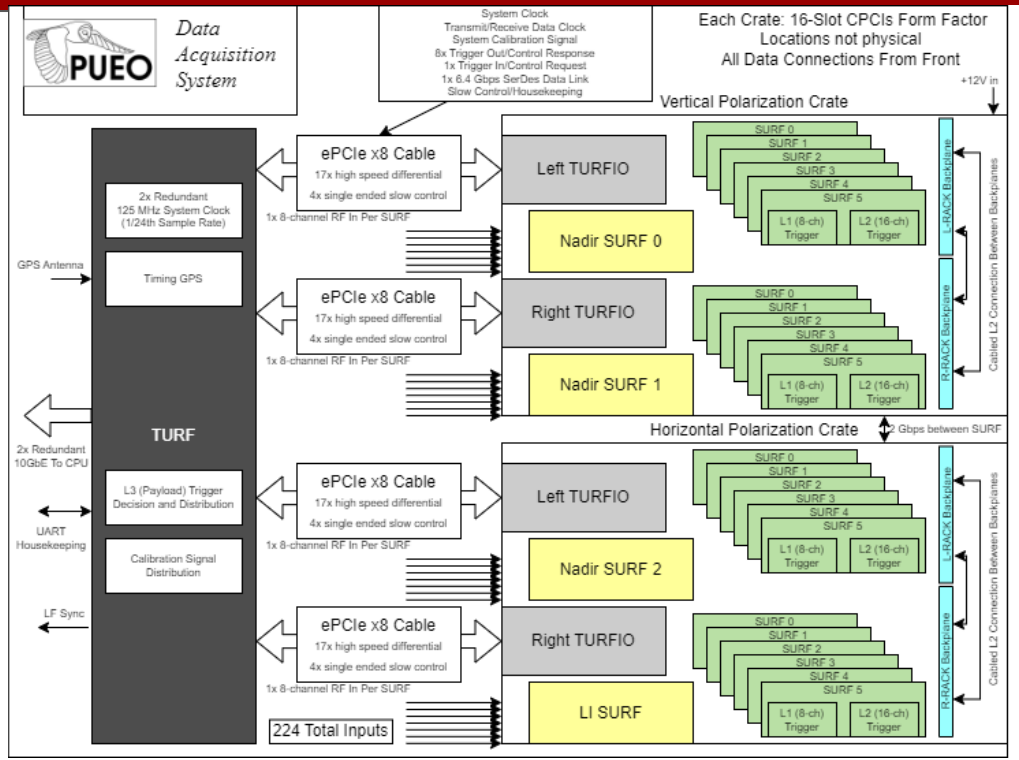
- PUEO incorporates an interferometric phased array trigger
  - Builds on successful demonstration on ARA at the South Pole
  - RNO-G also incorporates this type of trigger
- PUEO uses an RFSoC-based design in a conduction-cooled crate.
- Optimized trigger band: optimal trigger band is not the same as the optimal band to record signals for analysis.

3 Antenna Example, Side View



The PUEO DAQ System

- 212 RF input channels total, including 16 Low-Frequency (LF) instrument channels
  - 300-1000 MHz 3 dB bandwidthTrigger-level effective gain of 20 dBi required to achieve design sensitivity (antennas are ~8 dBi)
  - 3-stage beamforming trigger
    - L1: 8 beamformed channels (1 SURF)
    - L2: 16 beamformed channels (neighbors)
    - L3: full payload (combine/reduce L2s)
- Real-time CW interference rejection
  - Dynamically notch
- 100+ Hz event (1024 samples) rate
- Slow housekeeping/monitoring



Launch Envelope & Deployable Systems

A Fixed Launch Envelope

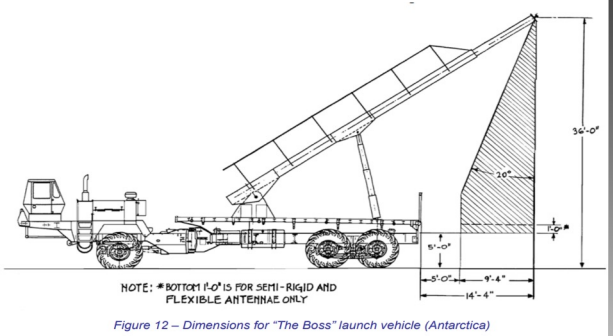
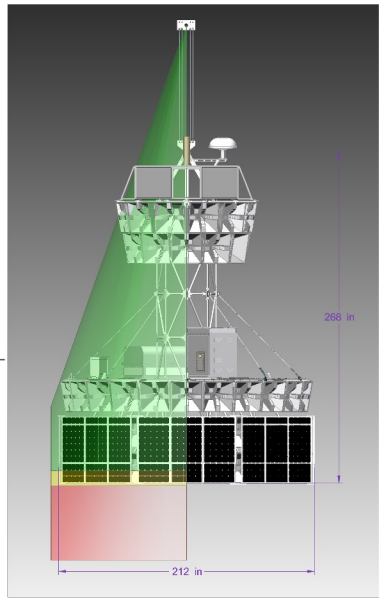
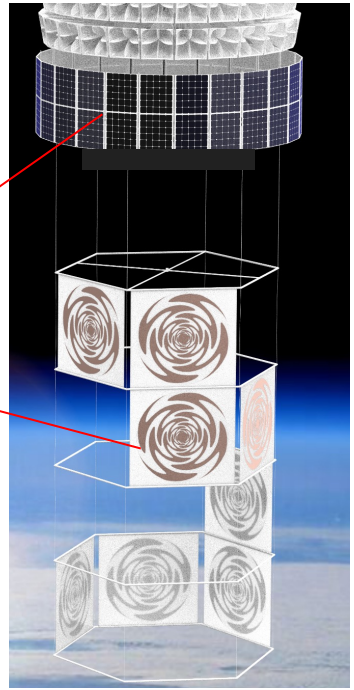


Figure 12 – Dimensions for "The Boss" launch vehicle (Antarctica)

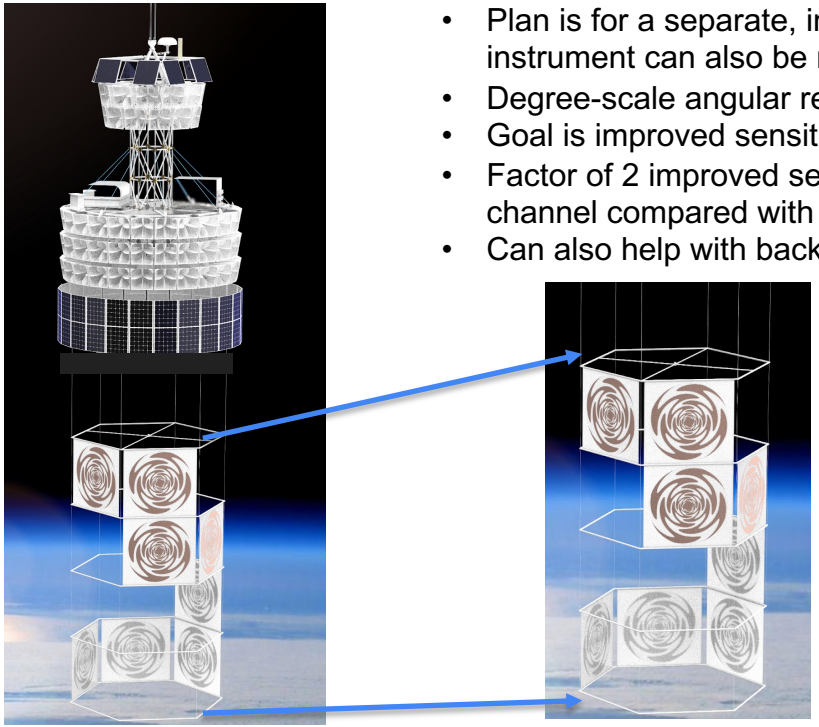


Deployable Systems: Maximizing science on a constrained platform

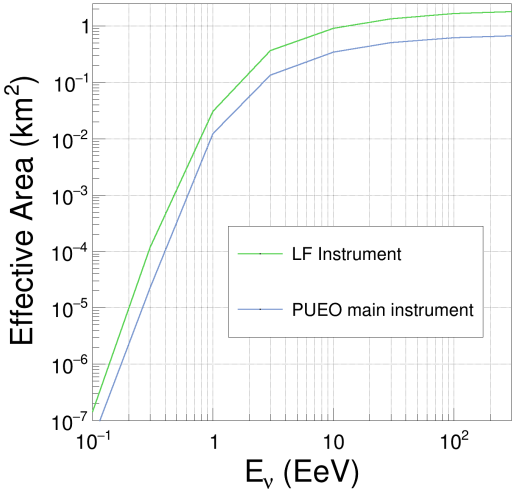
1. Science PV Array
2. LF Sinuous Antenna Array



Low Frequency Instrument Performance



- Plan is for a separate, independent trigger for the LF instrument. The LF instrument can also be recorded when the Main Instrument triggers.
- Degree-scale angular resolution expected
- Goal is improved sensitivity to air shower events.
- Factor of 2 improved sensitivity (effective area) in the tau neutrino air shower channel compared with Main Instrument
- Can also help with background rejection



Low-Frequency Antennas

Dual-polarized sinuous antennas, 50-300 MHz.

LF Instrument Deployment Testing

PUEO Outlook

- Planned Launch in December 2025
- PUEO opens up discovery space for ultra-high energy neutrinos that is not possible any other way: more than order of magnitude improvement over current best sensitivity
- This new mission is only enabled because of the Pioneers program