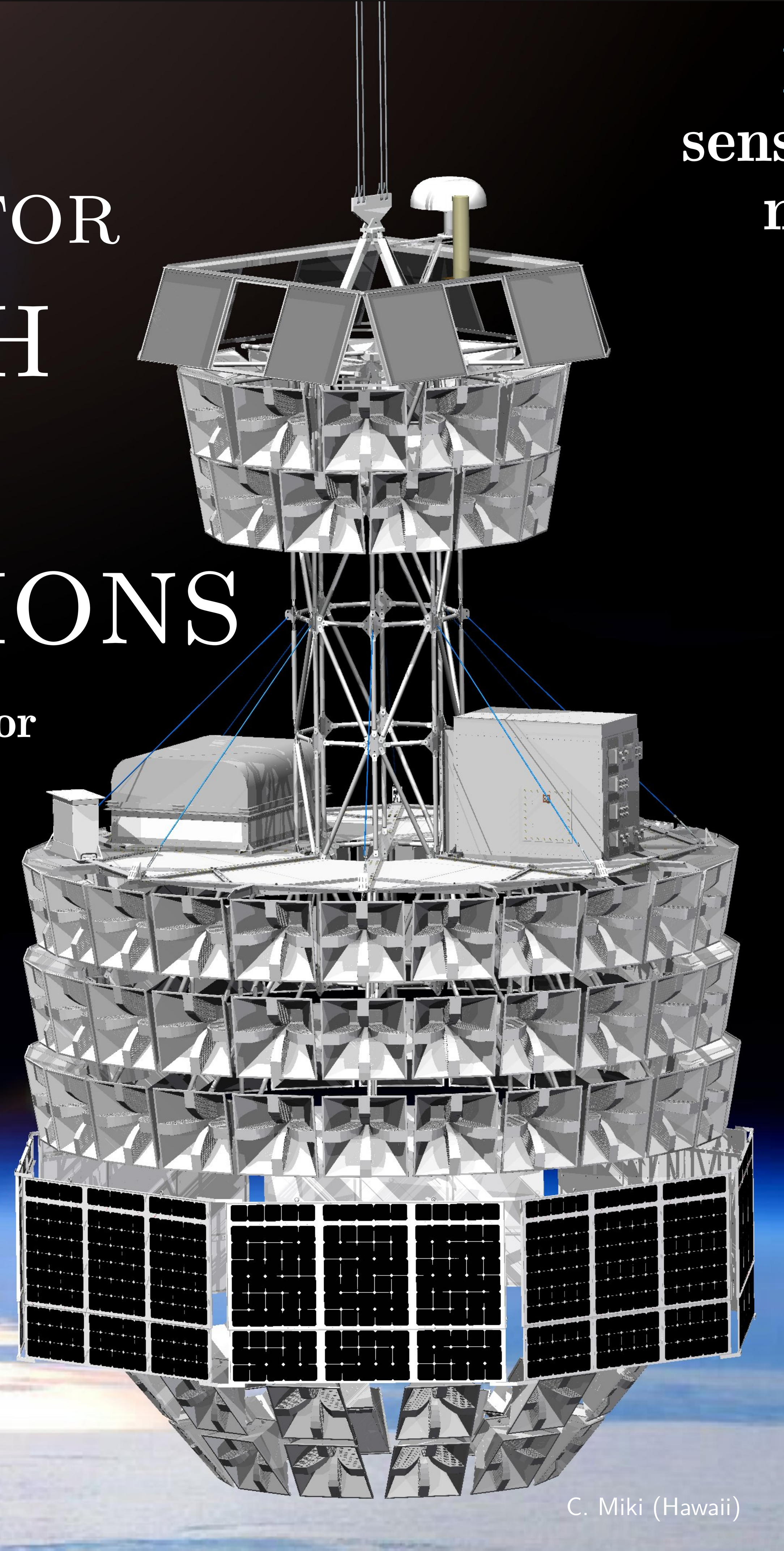
The Payload for Ultrahigh Energy Observations

Cosmin Deaconu (UChicago) for the PUEO Collaboration
cozzyd@kicp.uchicago.edu



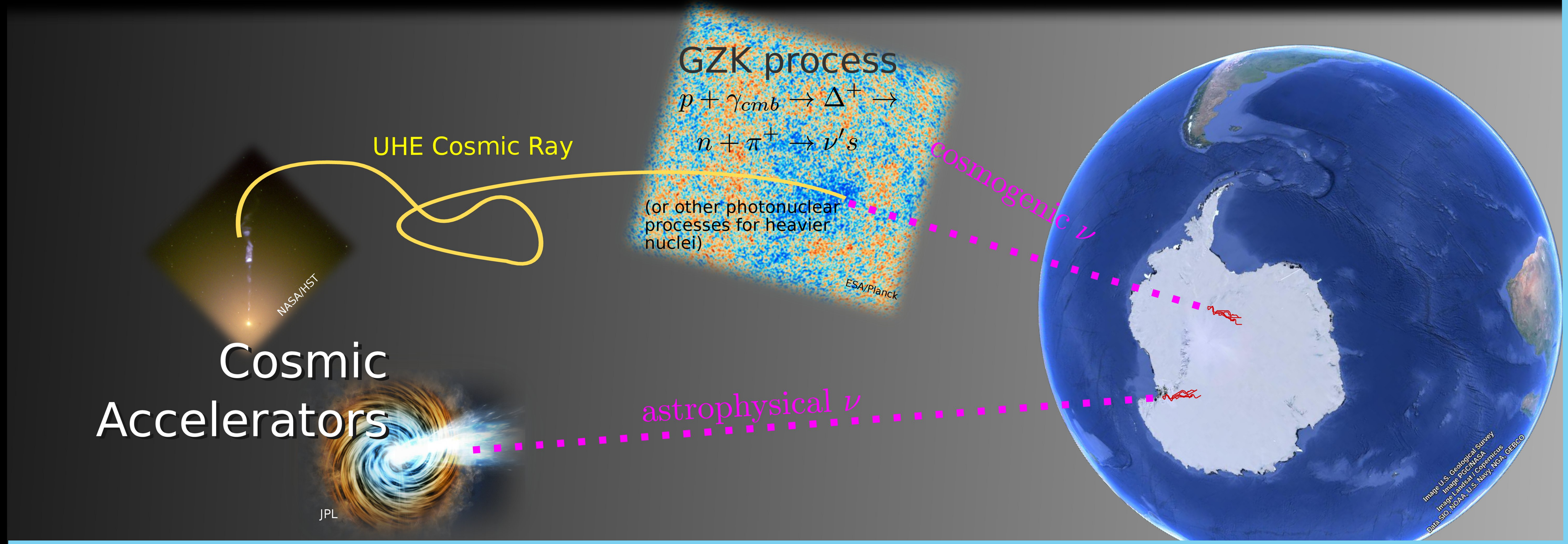
PUEO will have leading sensitivity to ultra-high energy neutrinos above 10 EeV

Science Goals

The Payload for Ultrahigh Energy Observations (PUEO) is a proposed long-duration balloon mission with a primary goal of detecting ultra-high-energy (UHE) neutrinos (>10 EeV). Such energetic neutrinos have not been detected yet, but can be produced in photonuclear processes, either during propagation of UHE cosmic rays or within cosmic accelerators.

Unlike other particles, UHE neutrinos can travel cosmological distances, and therefore have the ability to probe the UHE universe far away from our local neighborhood. PUEO will also have a large instantaneous exposure well-suited to detecting potential UHE transients.

PUEO is an evolution of the successful Antarctic Impulse Transient Antenna (ANITA) program [1]. In addition to probing new regions of neutrino parameter space, PUEO is also sensitive to extensive air showers from cosmic rays as well as a wide range of exotic particles and can also study Antarctic ice properties.

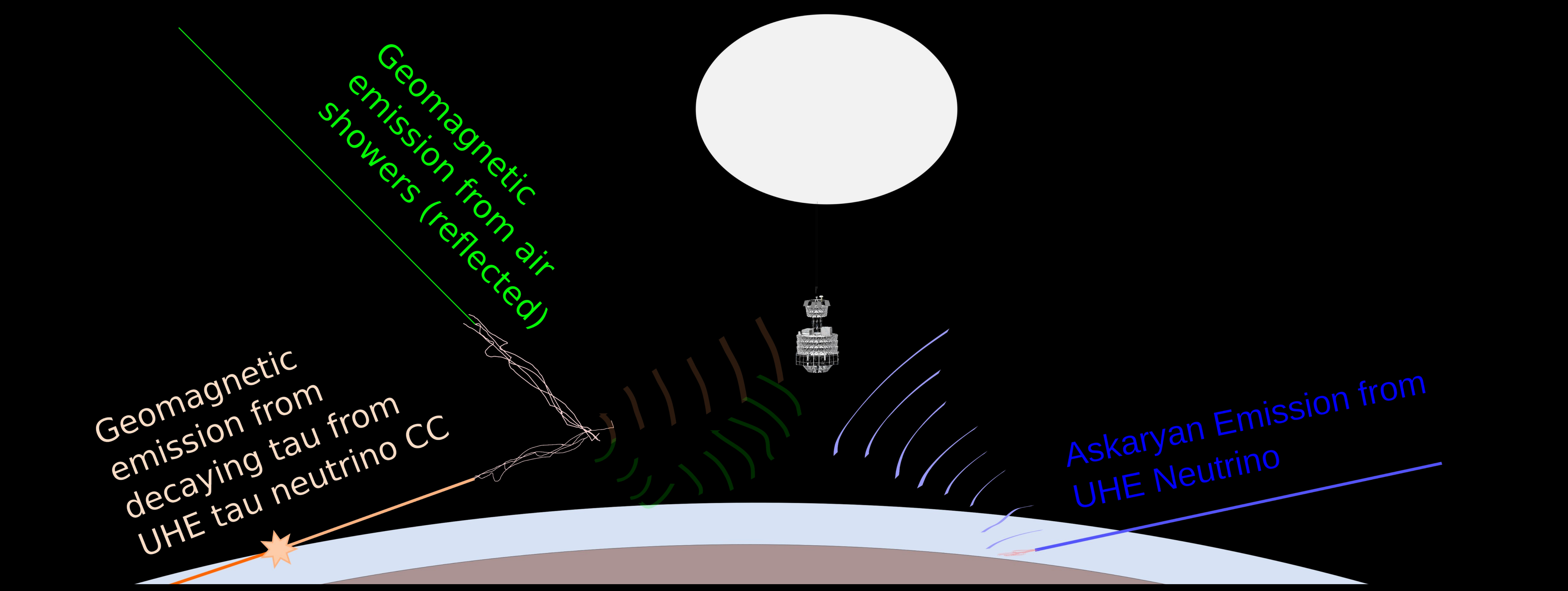


Detection Principle

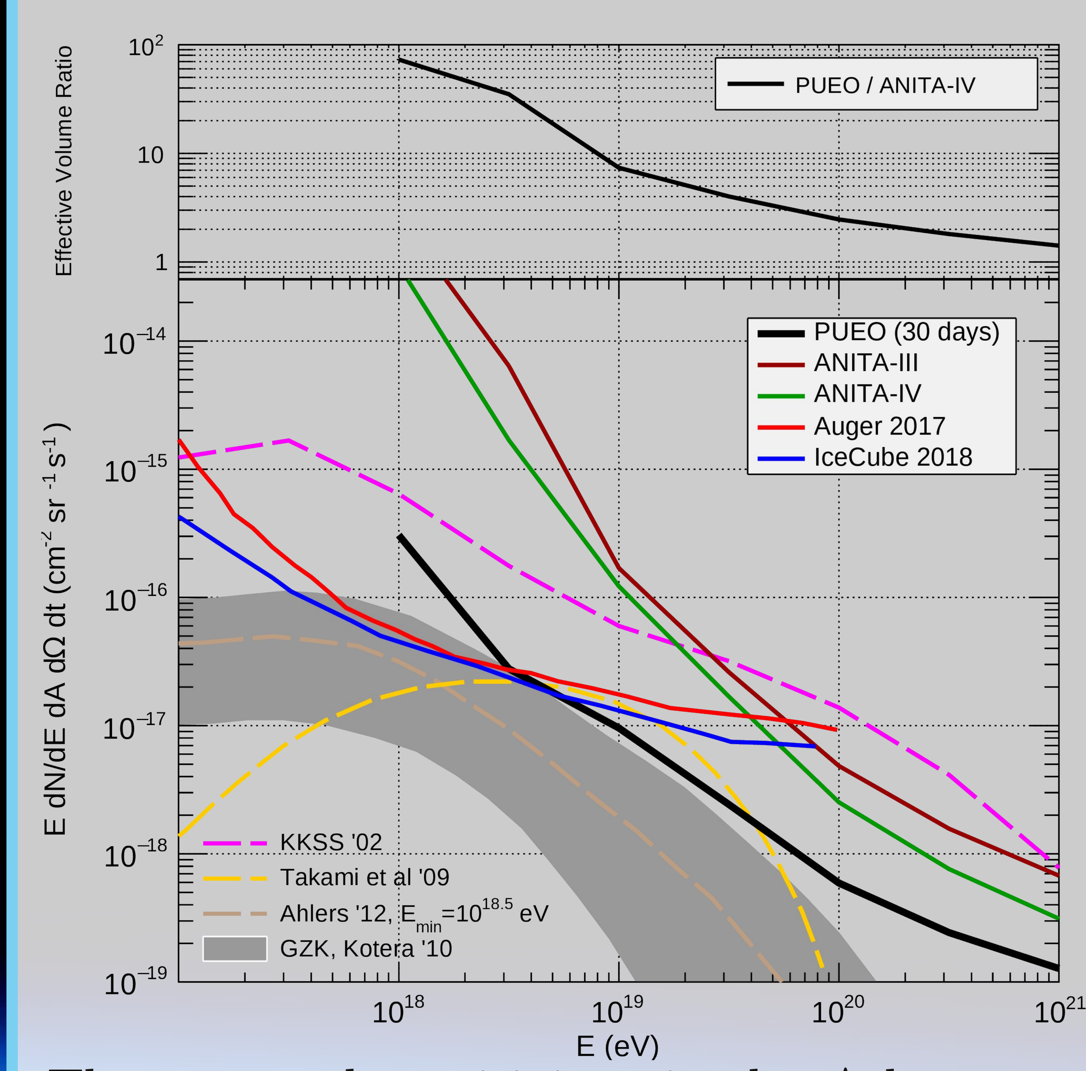
PUEO will fly 40 km above Antarctica to detect the impulsive Askaryan radio emission from UHE neutrinos interacting in the ice. The induced particle cascades in dense dielectric media like Antarctic ice develop a negative charge excess due to the bound electrons present, leading to coherent emission at radio wavelengths. Antarctic ice has a typical radio attenuation length of a kilometer, providing high-altitude payloads with an immense instantaneous detection volume on the order of a million km^3.

PUEO can also detect extensive air showers (EAS) [2], where Earth's magnetic field separates charges to induce impulsive radio emission. EAS emission is mostly horizontally-polarized due to the magnetic field direction, while Askaryan emission as viewed from above is typically vertically-polarized due to shower geometry and transmission at the ice-air interface. As EAS emission is forward-beamed, cosmic rays may be detected in two geometries: a "reflected" geometry, which has a phase flip from the ice, or a "direct" geometry where air showers miss the Earth entirely.

Tau neutrinos interacting in ice may also produce EAS via atmospheric decay of the outgoing tau. This would appear as an EAS from the ground with no phase flip. This channel adds substantial neutrino sensitivity to PUEO at lower energies. ANITA has detected events consistent with upward EASs [2], but due to the apparent angles, interpretation as tau neutrinos is in tension with other data [3], leading to various other explanations [4].



Sensitivity



The expected sensitivity via the Askaryan channel of PUEO compared to the most recent ANITA flights [1,5] and IceCube, as well as some predictions of neutrino flux. PUEO's lower trigger threshold results in a substantial improvement especially at low energies.

PUEO Design

PUEO is designed to detect and reconstruct the direction and polarization of broadband impulsive radio emission. PUEO's current design consists of 120 dual-polarized quad-ridge horn antennas in an azimuthal arrangement with a band of 300-1200 MHz.

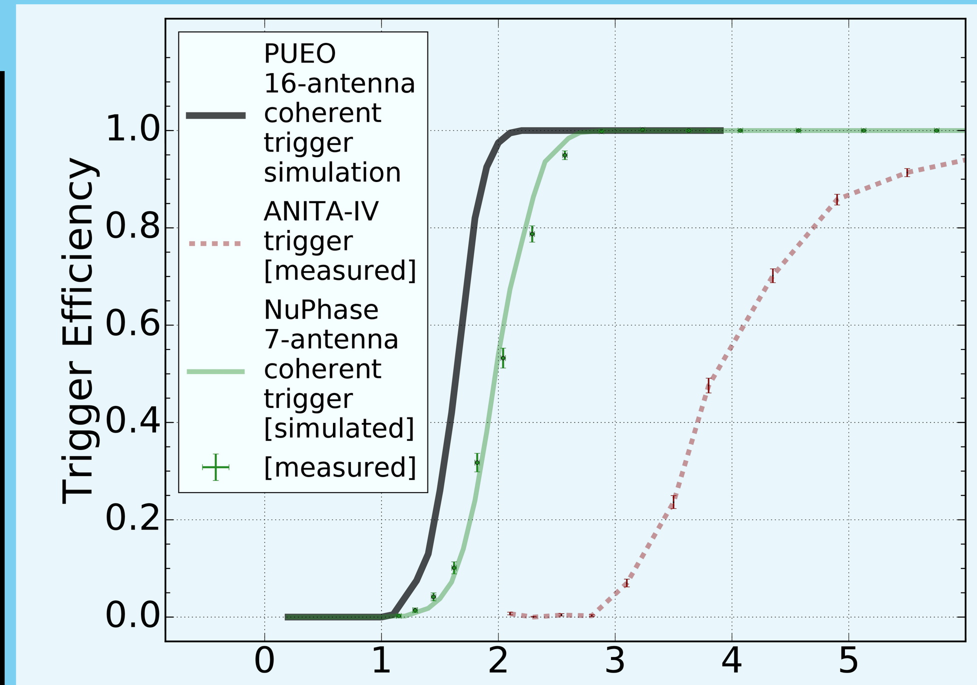
96 antennas take part in the main trigger, where signals from 16 adjacent antennas are digitally summed with time delays corresponding to various incoming plane-wave hypotheses ("beams") before being compared to a threshold. This allows triggering on very small signals without incurring an overwhelming rate of triggers from thermal noise. This beamforming trigger technique has been demonstrated by the NuPhase instrument at the South Pole [6] and is the major reason for the improvement in PUEO over ANITA.

PUEO will also have a dedicated array of antennas that are tilted further down, providing additional angular coverage for steep events. These antennas will drop down after launch to stay within the envelope imposed by the launch vehicle.

Compared to ANITA, PUEO has a higher high-pass, allowing smaller antennas so that more can be fit. PUEO will also have higher-fidelity digitizers and a signal chain with lower noise figure. PUEO will have an improved measurement of orientation by using an inertial measurement unit.

Key PUEO upgrades compared to ANITA

* Lower trigger threshold, from new trigger and more antennas
* Improved digitizers, RF chain
* Improved pointing resolution
* Steeply-canted nadir antennas



The trigger efficiency vs. amplitude signal-to-noise ratio (SNR) for PUEO, compared to ANITA-IV and the NuPhase prototype at the South Pole.

References

[1] Phys.Rev.D 99 (2019), 122001
[2] Phys.Rev.Lett. 121 (2018), 161102
[3] Phys. Rev. D 99 (2019), 063011
[4] PoS ICRC2019 (2020), 884
[5] Phys. Rev. D 98 (2018), 022001
[6] NIM A 930 (2019) 112-125