POEMMA-Balloon with Radio Overview

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Mission Overview

The Probe of Extreme Multi-Messenger Astronomy (POEMMA) on a Balloon with Radio (PBR) is a planned NASA Super Pressure Balloon instrument designed as a successor mission of EUSO-SPB2 [2] and a prototype for a space-based POEMMA mission [1] targeting ULDB launch from Wanaka NZ in 2027.

PBR will fly a variety of detectors, including a Fluorescence Camera and a Cherenkov Camera. These cameras will have a shared focal plane similar to the design of POEMMA and will be augmented with a Radio Instrument, Infrared Camera, Gamma-ray/x-ray, and particle detector. The detectors combined give PBR the unique ability to measure EAS developing high in the atmosphere using four different channels. This will lead to a unique dataset that can improve our understanding of EAS by leveraging the other observation channels.

Primary Science Objectives

1. Make the first observations of Ultra-High-Energy Cosmic Rays (UHECR) from above using fluorescence light measurements. To detect UHECRs, PBR searches for fluorescence light emmisions of extensive airshowers using the Fluorescence Camera

2. Measure high-altitude horizontal air-showers (HAHAs). The changing atmospheric density allows PBR to observe EAS and scan at many slant depths and probe the airshower development at various stages depending on the viewing angle.

3. Search for Earth-skimming astrophysical neutrinos with PeV energies diffuse or from point sources. When a tau-neutrino interacts inside the Earth, it can produce a tau lepton, which has a chance to exit the Earth. When the tau-lepton decays in the atmosphere, it can create an extensive airshower observable by PBR [8].

Payload Description

This setup allows for additional science cases and is a significant step towards space-based satellite configuration.

(1) Schmidt Optical Telescope with a Flourescence Camera (FC) and Cherenkov Camera (CC) on a combined focal surface as well as housing a Gamma Ray/X-ray detector and Infrared Camera.

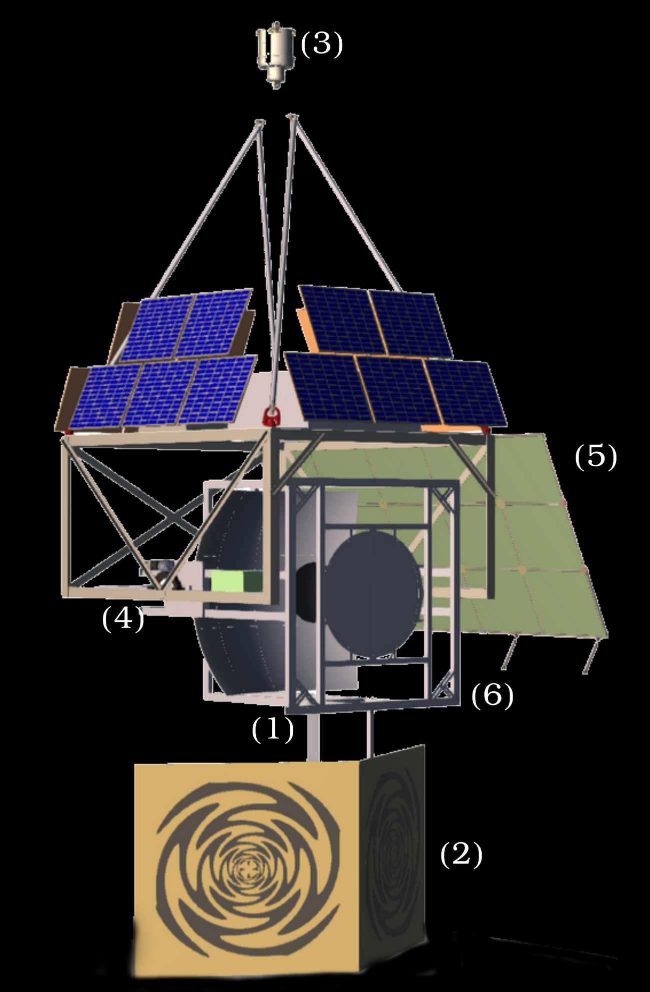
(2) Low frequency radio instrument.

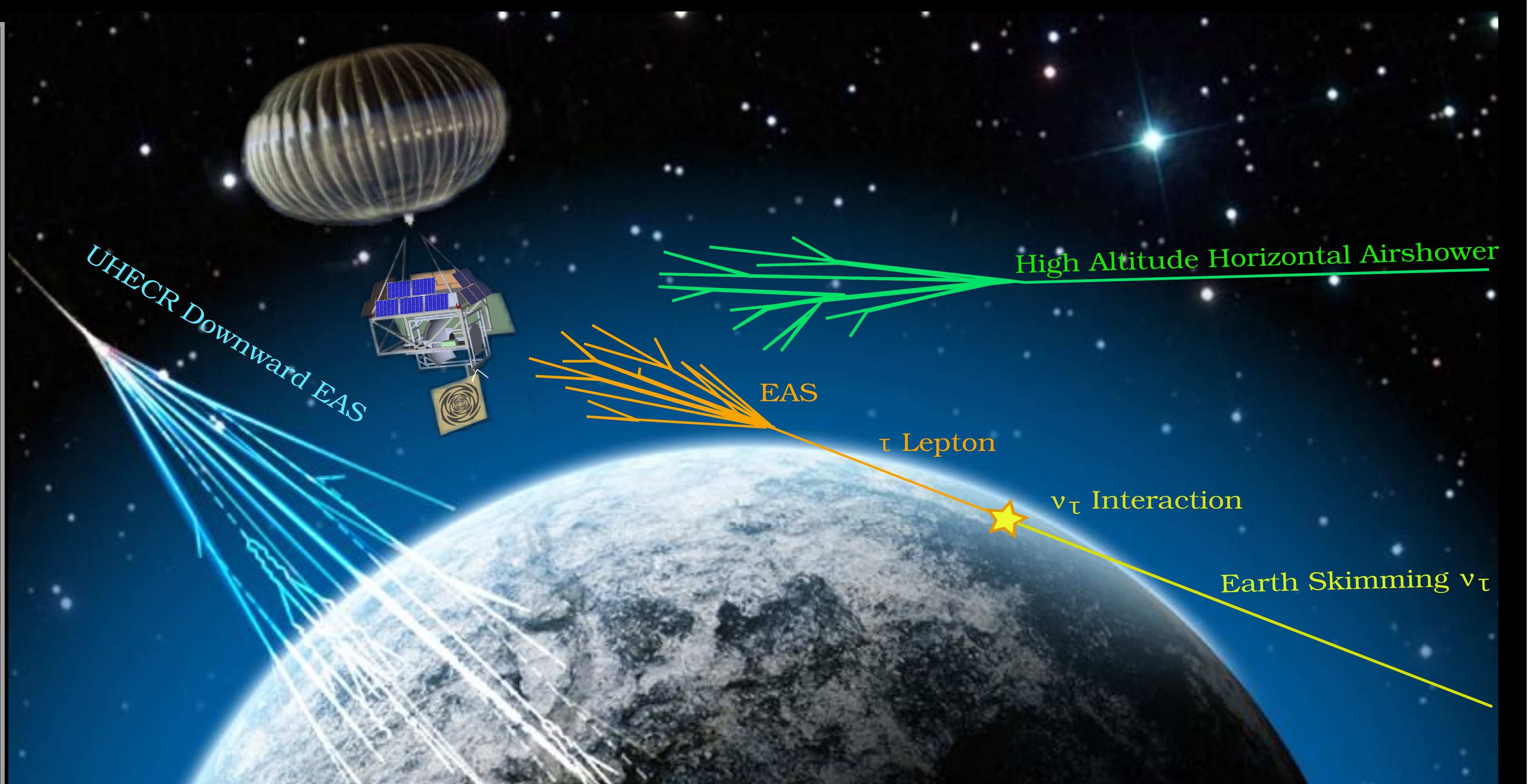
(3) NASA Rotation system: rotates in azimuth 360°

(4) Telescope rotation system: Nadir to +13° above horizon.

(5) 15 panel science solar array for recharging the battery system.

(6) Aspheric Corrector Plate to address spherical aberration





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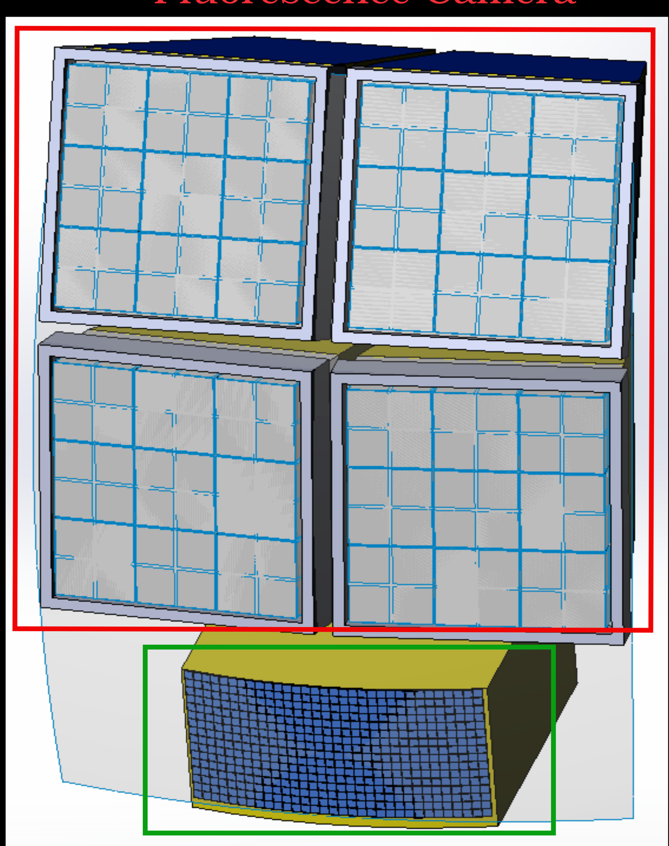
Fluorescence Camera

Fluorescence Camera



Cherenkov Camera

Measures UV fluorescence light emission of UHECR induced air-showers of ≳ EeV range energies [3] with largest FC field of view flown in a high-altitude mission with an FoV of 25° (h) x 25° (v).

- 4 Photo-Detection Modules (PDMs) based on EUSO-SPB2 [3]with 48 x 48 pixels per PDM and
- 36 MAPMTs per PDM [3] giving 9216 total pixels. The pixel size is 3x3 mm².
- narrow band UV light filter to keep background light from reaching the focal surface, as well as a field flattening lens that maps the spherical focal surfaceto a flat camera.
- Managed by SPACIROC3 including a double pulse resolution of 10 ns.

Cherenkov Camera

Measures Cherenkov light produced by above-the-limb cosmic rays with energies of ≳ 500 TeV and searches for Earth-skimming neutrino signatures below the limb.

- 4 rows of 8 Silicon Photo-Multiplier (SiPM) arrays
- 8x8 channels per SiPM with 3x3 mm² pixel size, totaling 2048 pixels.
- Sampling frequency of 5 ns.
- Field of view: 12° (h) x 6° (v)

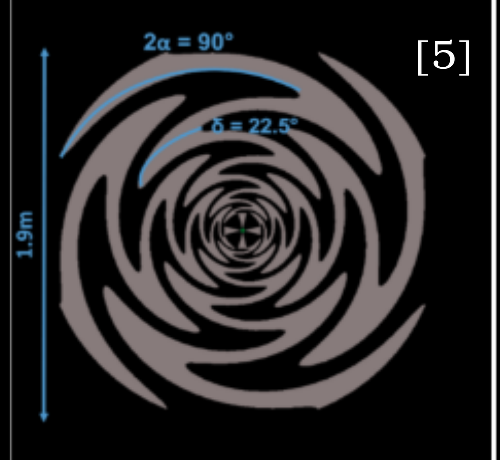
The chosen model for the SiPM array is the Hamamatsu S13361-3050, which operates in a wavelength range of 320-900 nm and includes optical piece that splits the light into two distinct spots for the CC.

Radio Instrument

Based on PUEO LF design [5] and used to characterize cosmic ray airshowers and tau lepton decay induced airshowers [5].

- 2 m wide, dual polarizd sinuous antennas
- broadband 5 dBi gain from 50 MHz to 500 MHz [5,
- Field of View of 60° × 120°

Will be triggered by CC which gives the opportunity for hybrid measurements.



Gamma-ray/X-ray

Used to search for
- TLEs
- TGFs,
- ToO events,
- GRB

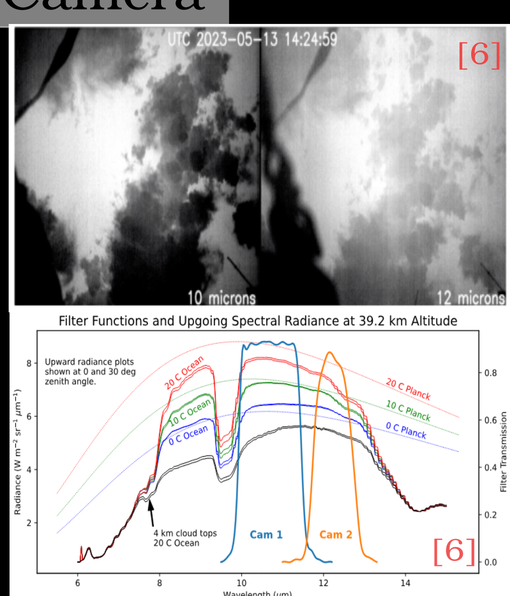
Will be mounted on the front of the telecope and point in the direction of the CC and FC.

Will have coincendence measurements with CC and radio insturment

Infrared Camera

Used for cloud obersvations and allows for better reconstruction of events [6]. Can affect the visibility and exposure toward EAS observations.

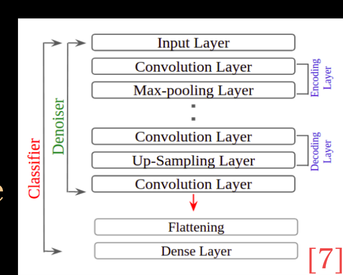
Includes 4 cameras:
8.5 microns,
10.5 microns,
12.5 microns
Full Band (8-13 microns)



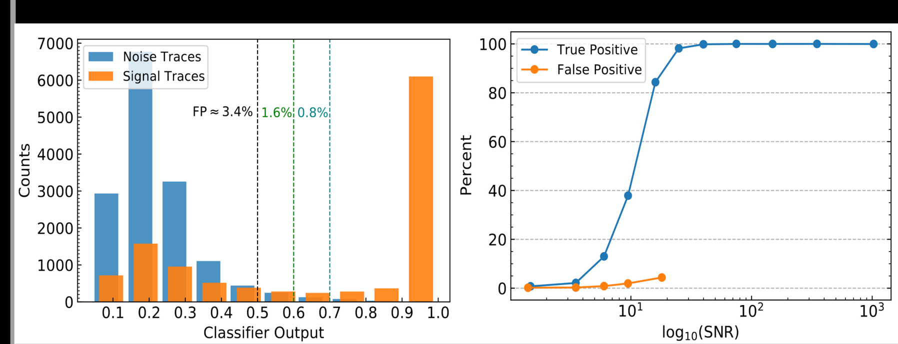
Machine Learning Studies

ML with Radio

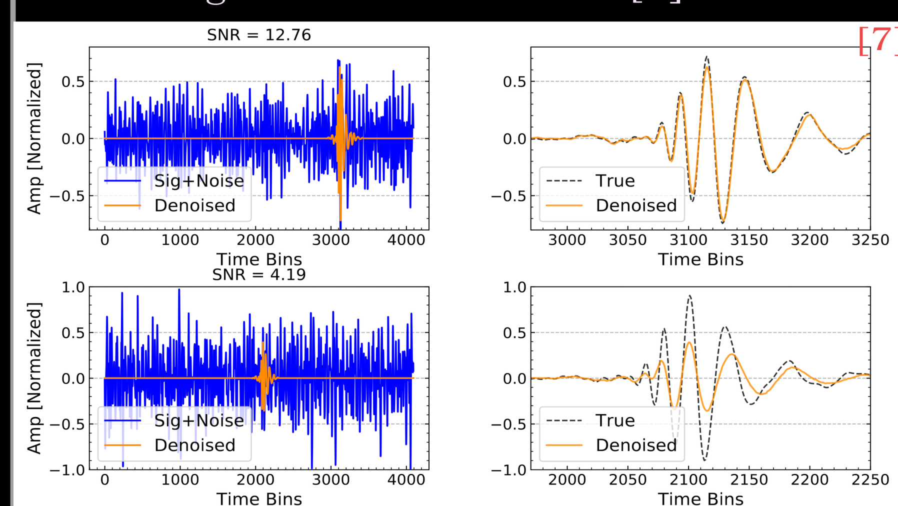
Due to a typically small signal to noise ratio (SNR) Machine Learning methods are necessary to help identify EAS radio signals and remove noise to enhance CR detection [7].



A classifier is used to identify EAS signals from background gives an output value of [0,1]:



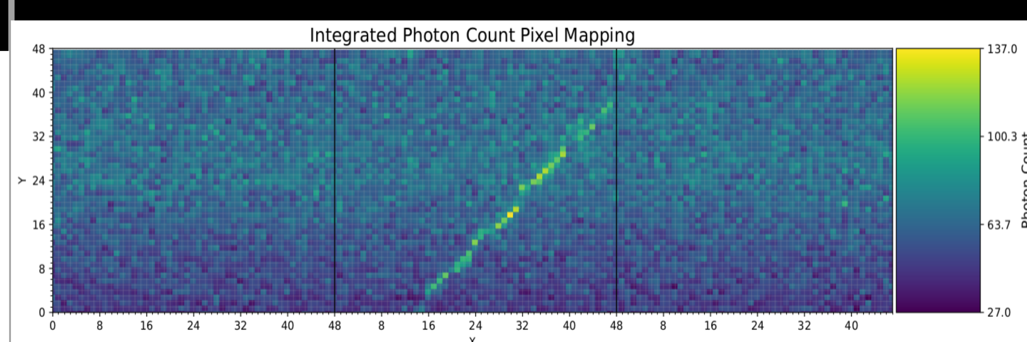
A denoiser is used to unmask the EAS signal from background as shown below [7]



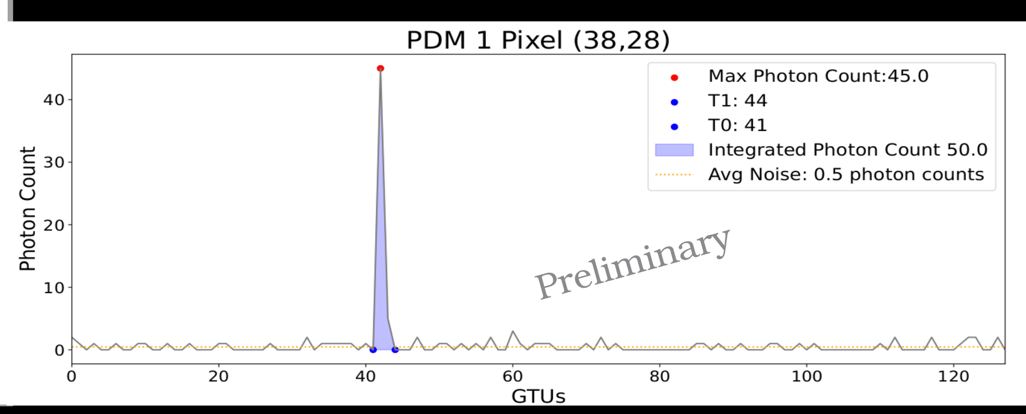
Preliminary ML work for EAS reconstruction

ML for FC and CC to identify possible events and improve reconstructon of zenith, azimuth, energy and possibly Xmax.

Because of a lower signal to noise ratio and more difficult to reconstruct traces than what is seen on the ground for comparible energies, ML is vital for better reconstruction and lowering detection thresholds.



For a complete picture, an event requires a 4-D CNN (timing, pixel location x and y, and photon count) which is very ineníficient. Can collapse into a 3-D CNN through pre-processing algorithms:



Machine learning techniques utilized with the PBR mission aim at lowering detection thresholds and increase the accuracy of reconstructing events.

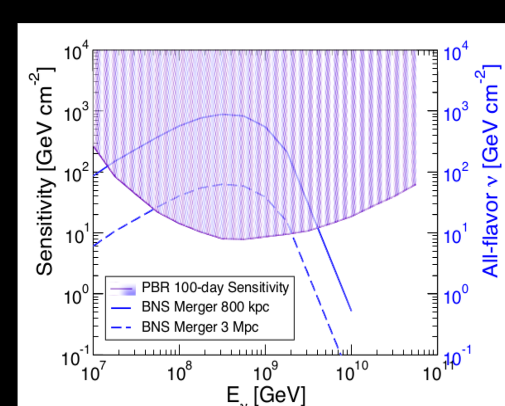
Target of Opportunity

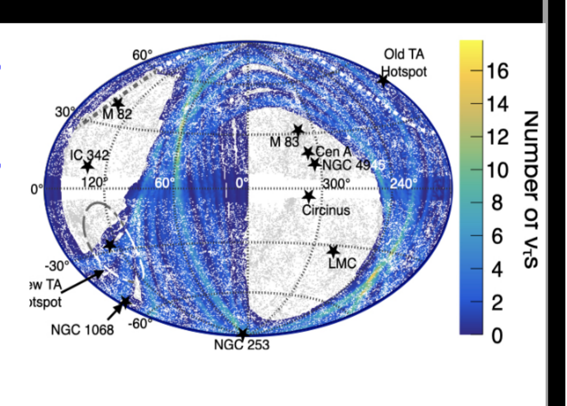
Methodology used to search for Earth-skimming neutrinos in coincidence with observed transient events such as BNS, AGNs, GRBs, IceCube Events and known UHECR souces [8].

Will allow PBR to utilize the whole size of the shower footprint as an effective area if the source crosses through the field of view of PBR.[8]

Predicted sensitivity is expected to achieve instantaneous single source sensitivities able to probe predicted model fluxes at energies above ~ 10 PeV [8].

The ToO program has been developed for EUSO-SPB2 [8] and software to collect alerts from standard alert networks such as GCN, TNS, or Atels, and can be used to schedule observations during flight with plans to refine this system for the flight of PBR.





References:

[1] "POEMMA (Probe Of Extreme Multi-Messenger Astrophysics) Roadmap Update", A. Olinto, 2023,"10.22323/1.444.1159"
[2] "Overview and First Results of EUSO-SPB2", J. Eser et al., 2023, ICRC PoS "10.22323/1.444.0397"
[3] "EUSO-SPB2 Fluorescence Telescope in-flight performance and preliminary results", G. Filippatos, 2023, ICRC PoS arXiv:2308.13477
[5] "The Payload for Ultrahigh Energy Observations (PUEO)", A. Cummings, 2022, ARENA PoS, "10.22323/1.424.0004"
[6] "Infrared Cloud Monitoring with UCIRC2", R. Diesing, 2023, ICRC PoS"10.22323/1.444.0450"
[7] "Classification and Denoising of Cosmic-Ray Radio Signals using Deep Learning", A. Rehman et al., 2021, PoS ICRC2021 417 (2021)
[8] "Overview of the EUSO-SPB2 Target of Opportunity program using the Cherenkov Telescope", T. Heibges et al., 2023, ICRC PoS "10.22323/1.444.1134",