Sub-Orbital Multi-Messenger Multi-Detector: The Case of POEMMA-Balloon with Radio (PBR)

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Mission Overview and Science Goals

The **Probe of Extreme Multi-Messenger Astronomy on a Balloon with Radio (PBR)** is a planned NASA Super Pressure Balloon mission, conceived as the successor of EUSO-SPB2 and as a prototype for the **future space-based POEMMA mission**, with an Ultra-Long Duration Balloon launch from Wanaka, New Zealand, targeted for 2027.

PBR will carry a **multi-instrument** payload including a **Fluorescence Camera** and a **Cherenkov Camera** sharing a common focal plane, augmented by a **low-frequency radio instrument**, infrared camera, **gamma-ray/X-ray detector**. This unique configuration enables the observation of extensive air showers (EAS) developing high in the atmosphere **through four complementary detection channels**, producing an unprecedented multi-messenger dataset. The primary science objectives include the **first observations of ultra-high-energy cosmic rays from above** via fluorescence light, detailed measurements of **high-altitude horizontal air showers across varying slant depths**, and searches for **Earth-skimming PeV tau neutrinos**, whose atmospheric decay showers can be detected by PBR. The payload is mounted on a Schmidt optical telescope with azimuthal rotation of 360° and elevation control from nadir to 13° above the horizon, representing a significant step toward a future space-based observatory.

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**

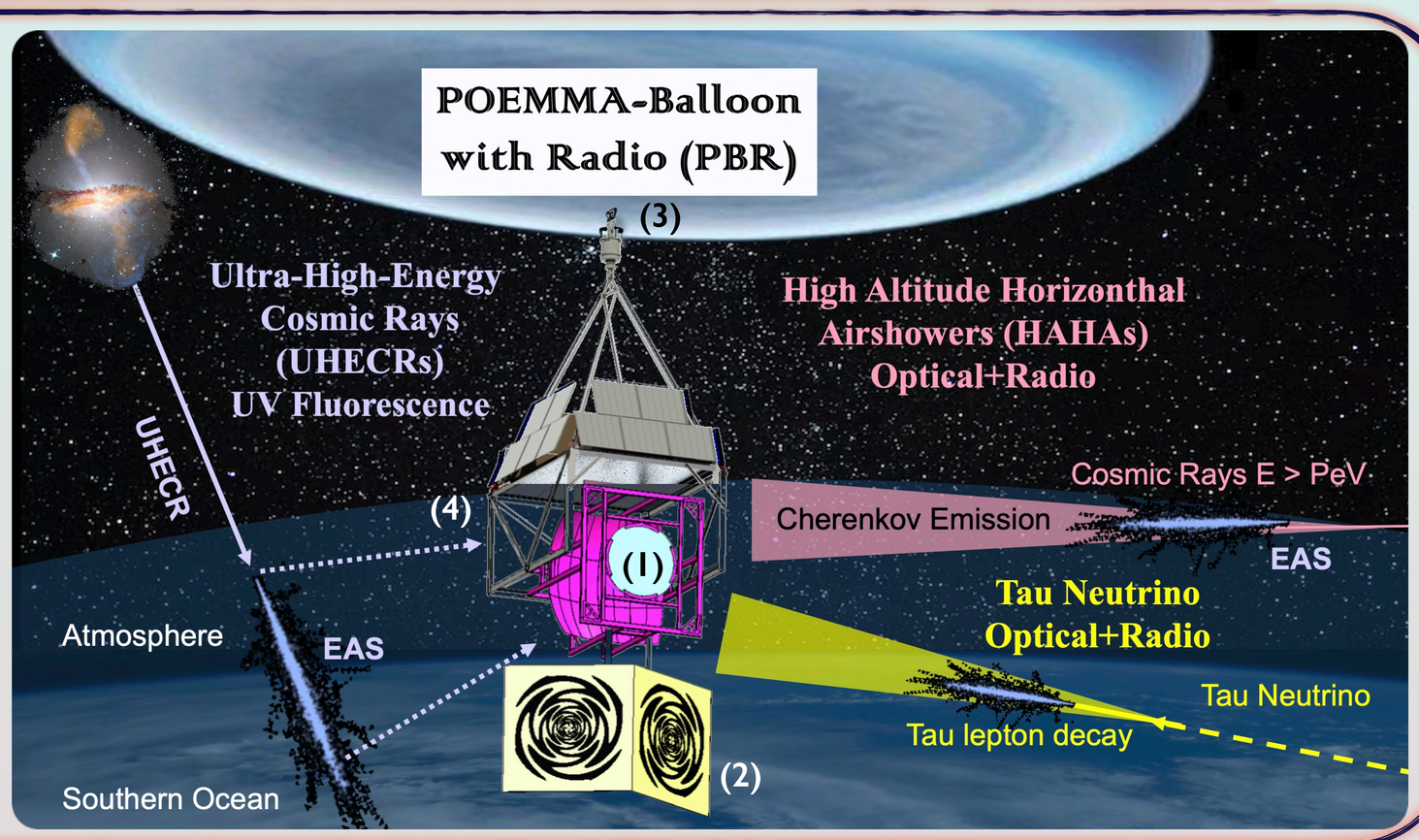
(2) **Low frequency radio instrument**

(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



Radio Instrument

Based on PUEO LF design and used to characterize cosmic ray air-showers and tau lepton decay induced air-showers.

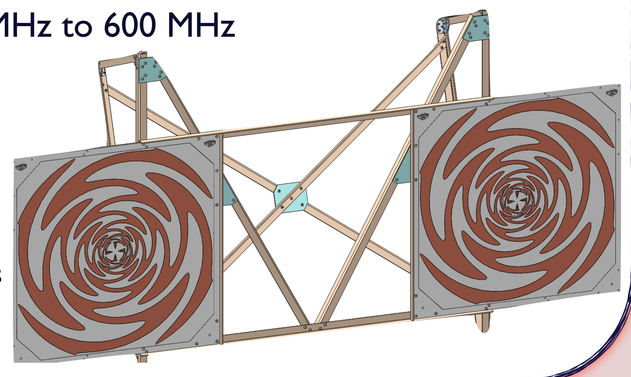
- 2 m wide, dual polarized sinuous antennas

- broadband 5 dBi gain from 60 MHz to 600 MHz

- Field of view of 60°x120°

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

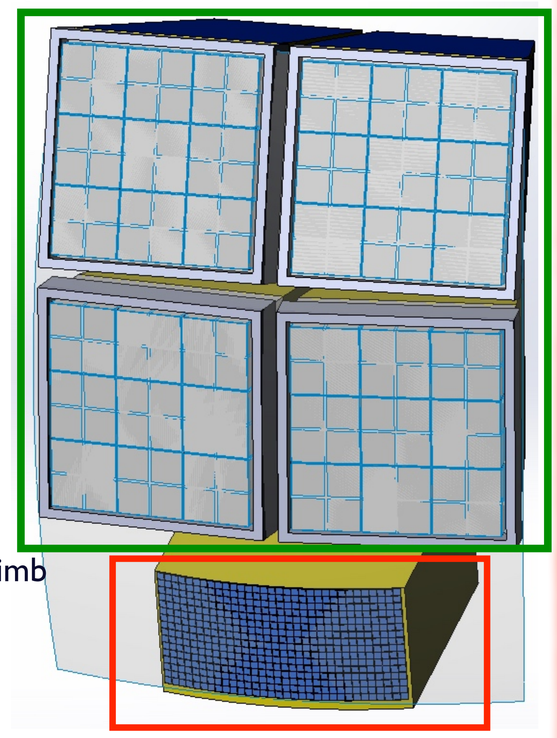
Simulation and performance estimates currently under production via RASPASS and CORSIKA/COREAS



Combined Focal Surface

Fluorescence Camera (FC)

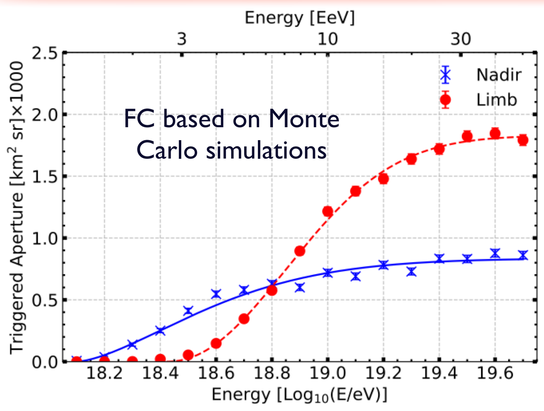
- UV fluorescence detection of **UHECR-induced EAS (≳ EeV)**
- Largest FC FoV flown at high altitude: **25° × 25°**
- **4 PDMs** (EUSO-SPB2 heritage)
  - 48 × 48 pixels per PDM
  - **36 MAPMTs per PDM**
- **9,216 total pixels**, pixel size **3 × 3 mm²**
- Narrow-band UV filter + field-flattening lens
- Readout: **SPACIROC3**, **10 ns** double-pulse resolution



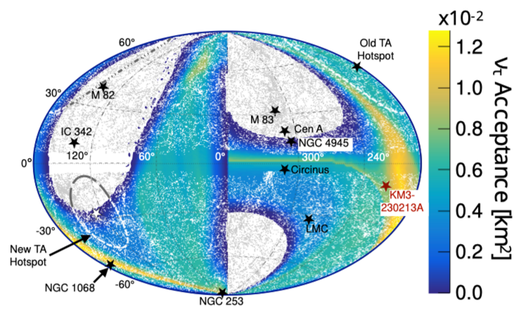
Cherenkov Camera (CC)

- Cherenkov detection of **above-the-limb CRs (≳ 500 TeV)**
- Search for **Earth-skimming neutrinos** below the limb
- **4 × 8 SiPM arrays**
  - 8 × 8 channels per SiPM
- **2,048 total pixels**, pixel size **3 × 3 mm²**
- Sampling time: **5 ns**
- FoV: **12° × 6°**
- SiPM model: **Hamamatsu S13361-3050** (320–900 nm)
  - Integrated optical splitter for dual-spot imaging

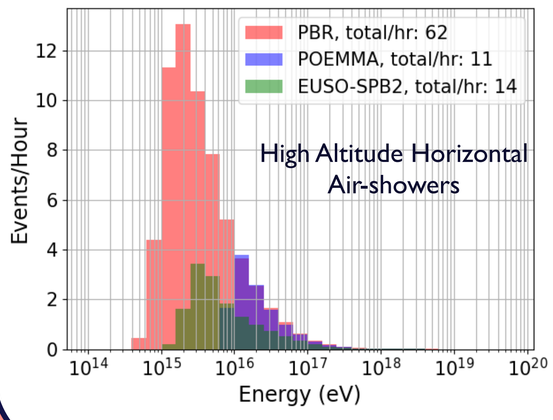
PBR performances

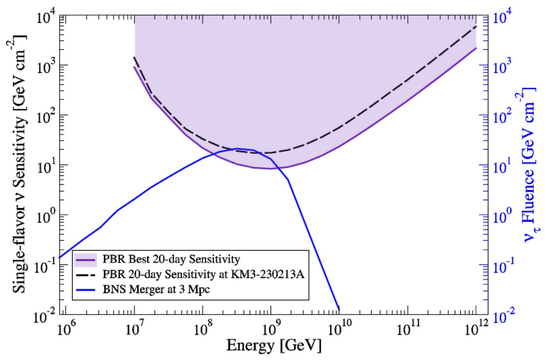


Neutrino search from Targets of Opportunity



ν_τ acceptance assuming a BNS merger model at 3 Mpc distance in galactic coordinates for a mission lasting 50 days





The single-flavor sensitivity range for PBR for a 20-day flight launched in early April 2027

Gamma-ray / X-ray detector

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

On the front of the telescope it will point in the direction of the CC and FC.
It will have coincidence measurements with CC and radio instrument
Simulation and performance estimates currently under production see [9].

[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
[4] "POEMMA-Balloon with Radio: A multi-messenger, multi-detector balloon payload", PBR Collaboration arXiv:2601.19997v1
[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"
[9] "X-rays Emission: a novel tool to detect Extensive Air Showers", R. Torres et al., arXiv:2511.0162

Software and Tools
- The CURVED version of the air shower simulation program CORSIKA, D. Heck et al.
- EasCherSim https://pypi.org/project/easchersim/
- GEANT4 collaboration, GEANT4 - A Simulation Toolkit, Nucl. Instrum. Meth. A 506 (2003) 250
- Radio Emission from Atmosphere-Skimming Cosmic Ray Showers in High-Altitude Balloon-Borne Experiments, M. Tueros et al., arXiv:2409.13141

References