POEMMA-Balloon with Radio (PBR): A balloon born Multi-Messenger Multi-Detector Observatory

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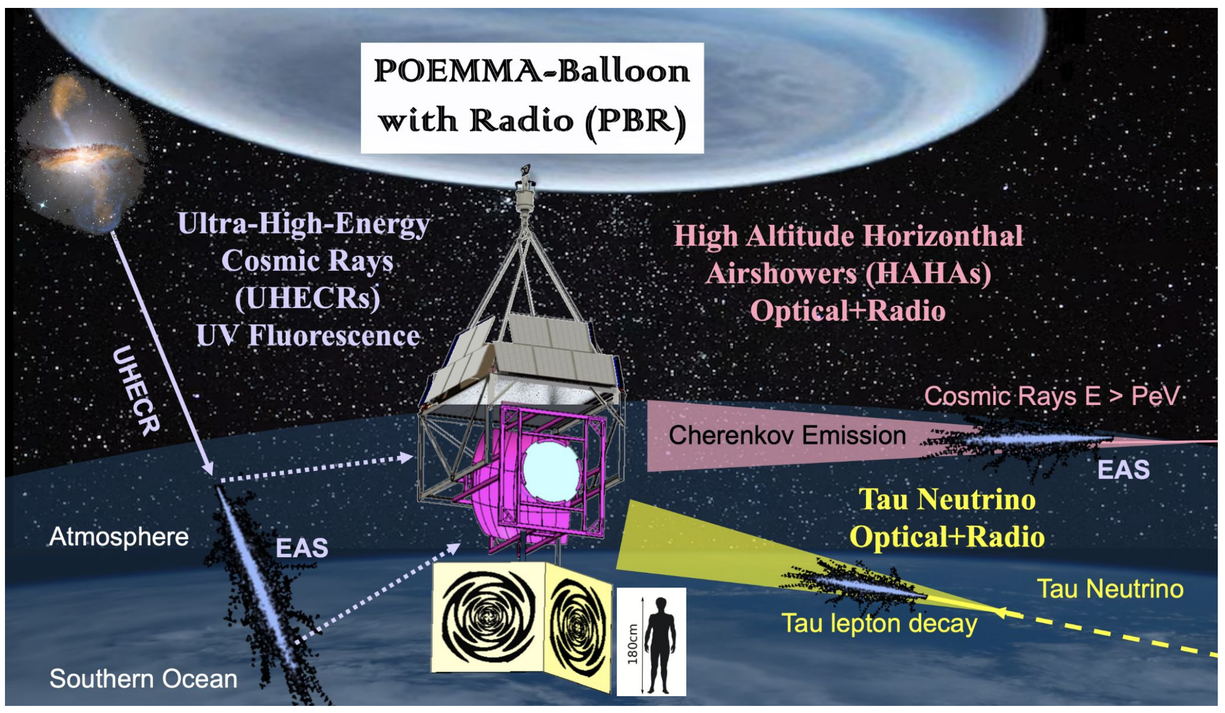
The Probe Of Extreme Multi-Messenger Astrophysics (POEMMA) is a proposed dual-satellite mission to observe Ultra-High-Energy Cosmic Rays (UHECRs) increase the statistics at the highest energies and Very-High-Energy Neutrinos (VHENs) following multi-messenger alerts of astrophysical transient events, such as gamma-ray bursts and gravitational wave events, throughout the universe.

POEMMA-Balloon with radio (PBR) is a small-scale version of the POEMMA design, adapted to be flown as a payload on one of NASA's suborbital Super Pressure Balloons (**SPBs**) circling over the Southern Ocean.

The PBR instrument consists of a 1.1 m aperture Schmidt telescope with two cameras in its focal surface: a Fluorescence Camera (FC) and a Cherenkov Camera (CC). In addition, PBR has a Radio Instrument (RI) optimized for the detection of EASs (covering the 50-550 Mhz range).

PBR targets a launch in 2027 as a payload of an ultra-long duration balloon flight with a duration of up to 100 days.



PBR sketch along its scientific goals featuring three different detector, a Fluorescence Camera (FC) based on Multi-Anode Photomultipliers (MAPMTs), a Cherenkov Camera (CC) based on Silicon Photomultiplier (SiPM) and a Radio Instrument (RI) based on two low frequency antennas covering the 50-550 Mhz range .

PBR Science:

Open Questions:

1) What is the origin of ultra-high-energy cosmic rays (UHECRs)?
2) How do Extensive Air-Showers (EASs) develop at high altitudes? What is the cosmic ray composition around PeV energies?
3) What are the sources of astrophysical neutrinos?

Scientific Goals (SGs):

SG1) Observe, for the first time, the fluorescence emission of EASs produced by UHECRs from sub-orbital altitudes.

SG2) Observe a large number of high-altitude horizontal air-showers (HAHAs) with energy around the cosmic ray knee (PeV). Observe, for the first time, the simultaneous optical Cherenkov and radio emission of EASs above the ground.

SG3) Search for astrophysical neutrinos from a Target-of-Opportunity (ToO) following multi-messenger events (gamma-ray bursts, tidal disruption events, binary coalescence of compact objects).

PBR Instrument:

Rotation system

Freely rotating for **360° in azimuth.**
Tilting **from nadir to 10° above horizontal.**

Optical system

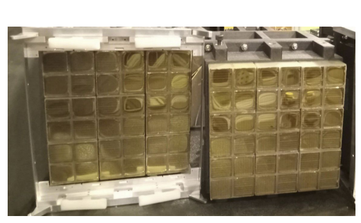
Schmidt optics design, common to the FC and the CC, 1.1 m entrance pupil. Bi-focalizer in front of the CC.

Infrared camera

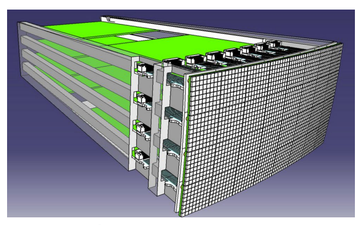
Observations at 8, 10 and 12 microns. Quantifying **cloud coverage** (temperature, density and cloud-top height).

X-ray, γ-ray and charged particle detectors

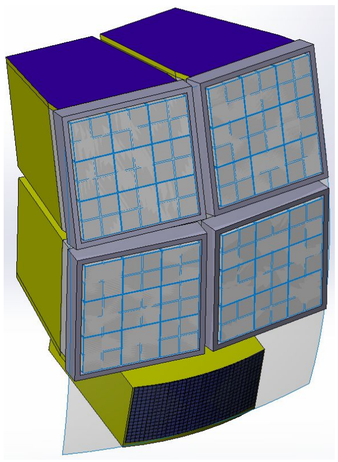
Probing synchrotron and bremsstrahlung emissions from e^+ e^- produced in the early stage of HAHAs.



Two of the PDMs used in EUSO-SPB2 flight.



CAD view of the CC



Fluorescence Camera (FC)

- **4 PDMs** = 4×36 MAPMTs **= 9216 pixels [24°x24° FoV]**
- **Single photon counting,** peak sensitivity ~**300-400 nm**
- Time resolution **1.05 μs** (double pulse resolution ~5-10 ns)

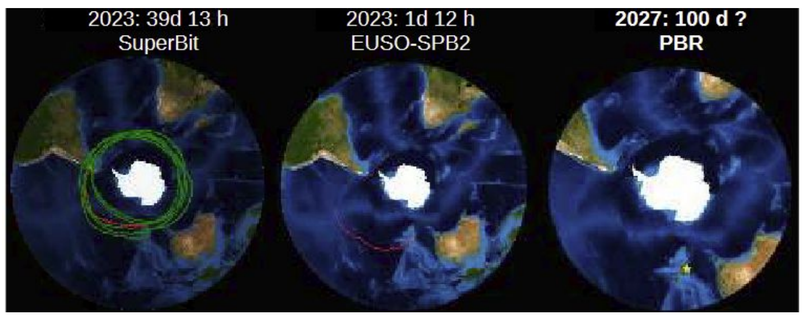
Cherenkov Camera (CC)

- **2048 px** (SiPMs, Hamamatsu S13361-3050 series) **[12°x6° FoV]**
- **Dedicated ASIC** (MIZAR [under development] /RADIOROC)
- **10ns** integration time, **320-900 nm** detection window
- Self trigger based on bi-focalized signal (high rejection power for charged particles)

Radio Instrument (RI)

- Two 2x2 m^2 dual-polarize sinuous antennas, based on PUEO-LF instrument
- Frequency range: 50-500MHz, 60° x 60° FoV overlapping with CC
- Energy threshold 10^{18}eV - external trigger from CC

PBR Operation and goals

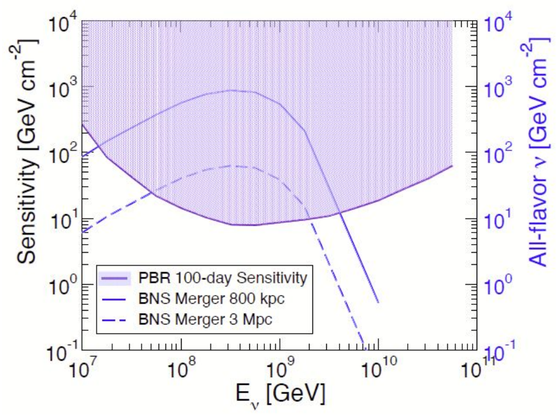


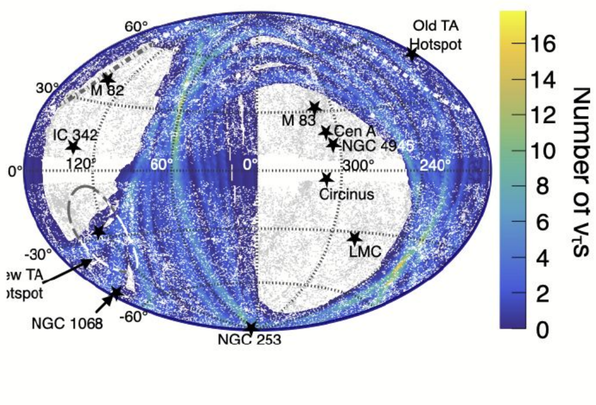
The two latest Super Pressure Balloons (SPBs) flights, starting from Wanaka, New Zealand.

SPBs are launched from New Zealand, aiming for a 100-day flight around the South Pole. For PBR this translates into up to 500 hours of operation, assuming a 20% duty cycle (Sun, Moon, clouds).

Neutrino search from Targets of Opportunity

AKA: Observe high-energy neutrinos from transient sources (supernovae, binary neutron star mergers, tidal disruption events, blazar flares, and gamma-ray bursts).
Observed **in tilted mode by the CC** looking **below the limb.**

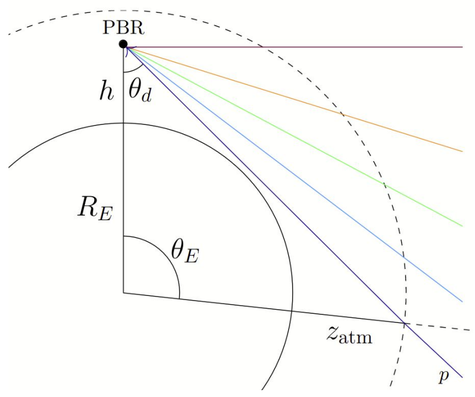


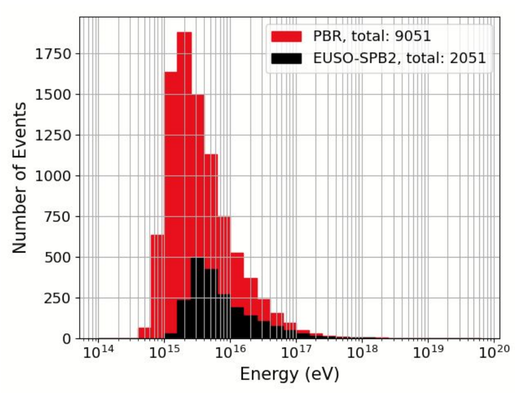


Plot assuming a 100-day flight in case of a BNS merger at 3 Mpc. PBR can achieve large sensitivity to neutrinos from nearby sources in large portion of the sky.

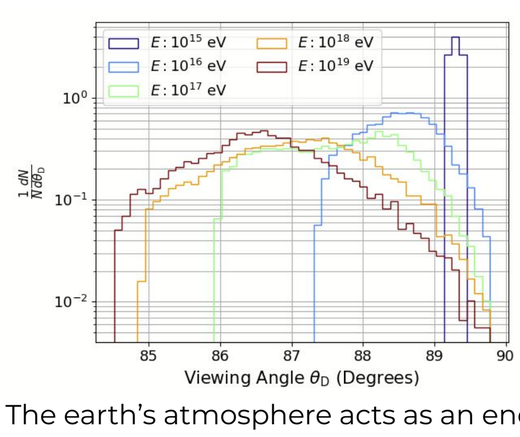
High-Altitude Horizontal Air-showers (HAHAs)

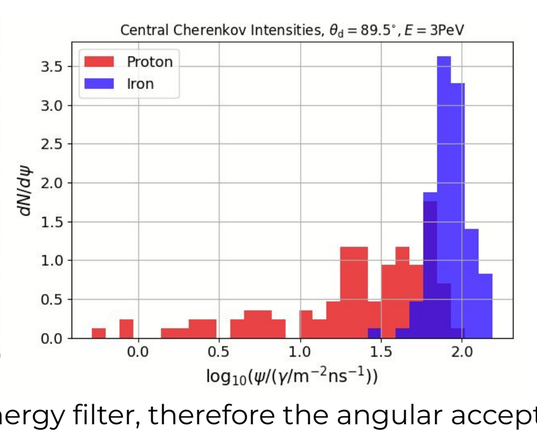
AKA: EASs induced by cosmic rays that skim the Earth's atmosphere and traverse the telescope FoV, never intersecting the ground.
Observed **in tilted mode by the CC (main), RI, X and γ-ray**, looking **above the limb.**





PBR will observe HAHAs ranging from Earth's horizon (84.2°) to horizontal, at a rate of ~65/live hour, increasing the detected events by a factor of 4 from EUSO-SPB2.





The earth's atmosphere acts as an energy filter, therefore the angular acceptance is energy dependant. PBR will also provide chemical identification on a statistical basis around the cosmic ray knee energy.