POEMMA-Balloon with Radio:
a balloon-borne Multi-Messenger Observatory

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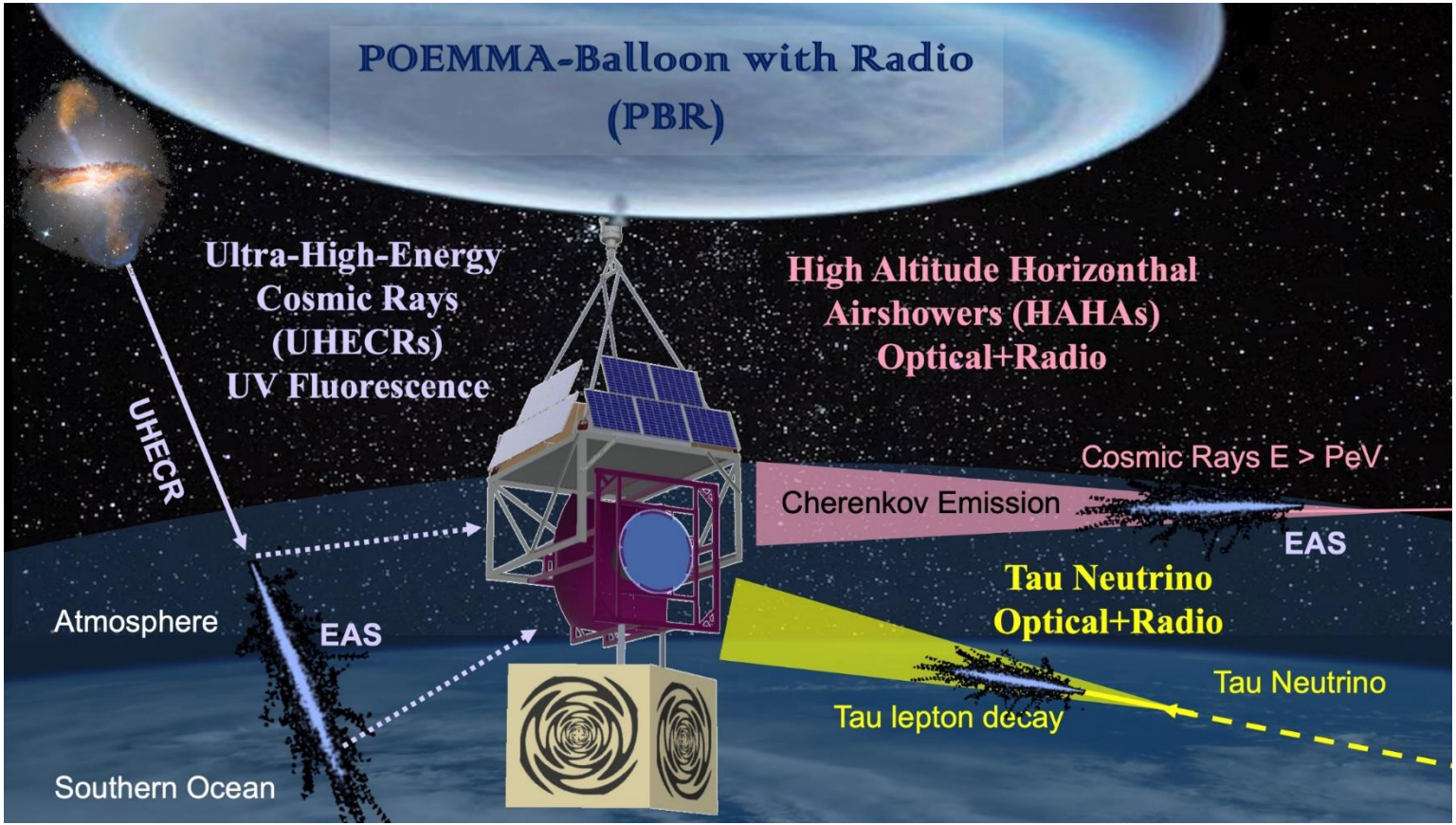
Goals


POEMMA-Balloon with Radio
(PBR)
Ultra-High-Energy
Cosmic Rays
(UHECRs)
UV Fluorescence
UHECR
High Altitude Horizonthal
Airshowers (HAHAs)
Optical+Radio
Cosmic Rays E > PeV
Cherenkov Emission
EAS
Tau Neutrino
Optical+Radio
Tau Neutrino
Tau lepton decay
Atmosphere
EAS
Southern Ocean

Timeline and developments

EUSO-Balloon

2014 Timmins

EUSO-SPB1

2017 Wanaka

EUSO-SPB2

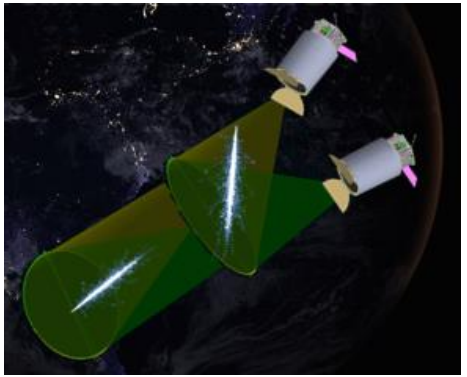
2023 Wanaka

POEMMA Balloon with Radio

50+ members, 22 institutions, 8 countries

2027 Wanaka

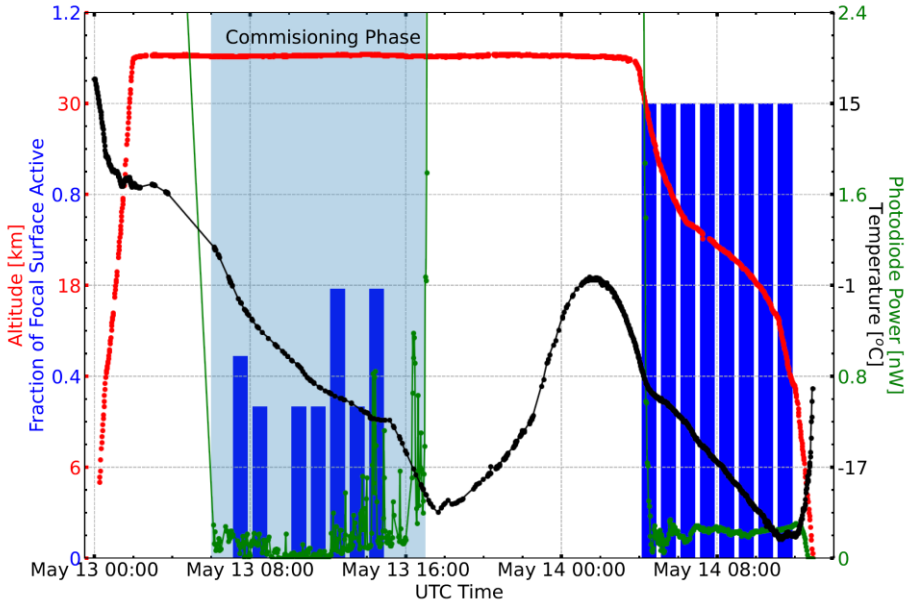
POEMMA



203* Earth Orbit

EUSO-SPB2

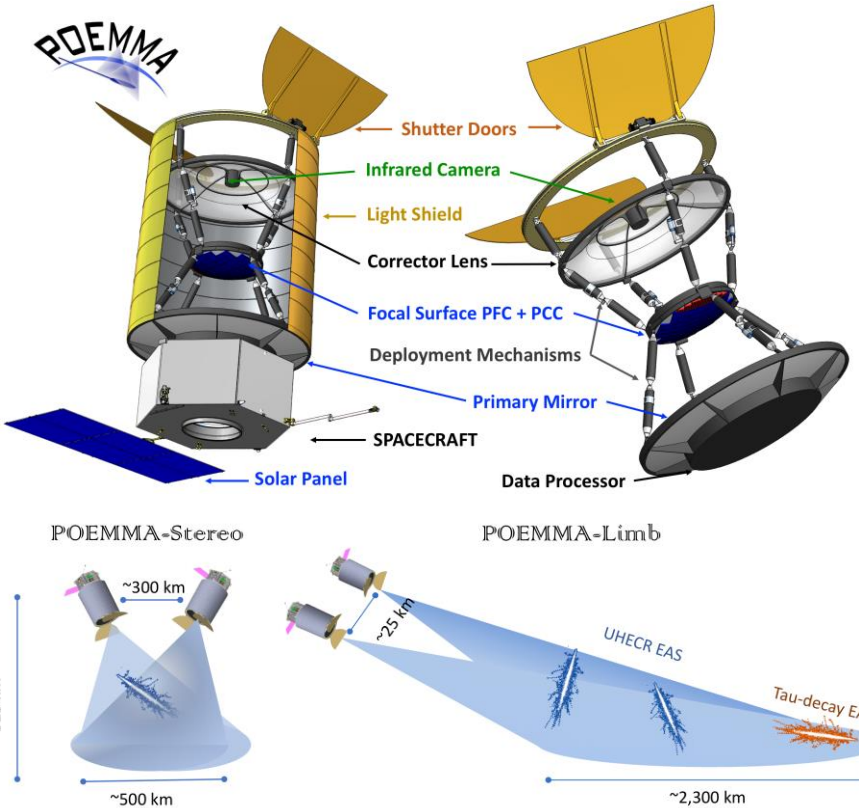
- Flight terminated after 1.5 days due to a leak in the balloon
- Instruments worked as expected, but not enough time to accomplish main science goals



Scientific instruments:

- Two 1m-diameter telescopes (fluorescence and Cherenkov)
- Infrared camera

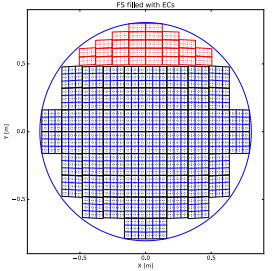
POEMMA: Probe Of Extreme Multi-Messenger Astrophysics



Conceptual design for a NASA Astrophysics Probe-class mission 1

- 2 satellites flying in formation in Low Earth Orbit
- Large FoV (45° × 45°), 4 meter Schmidt optics, hybrid focal surface for fluorescence and Cherenkov observations

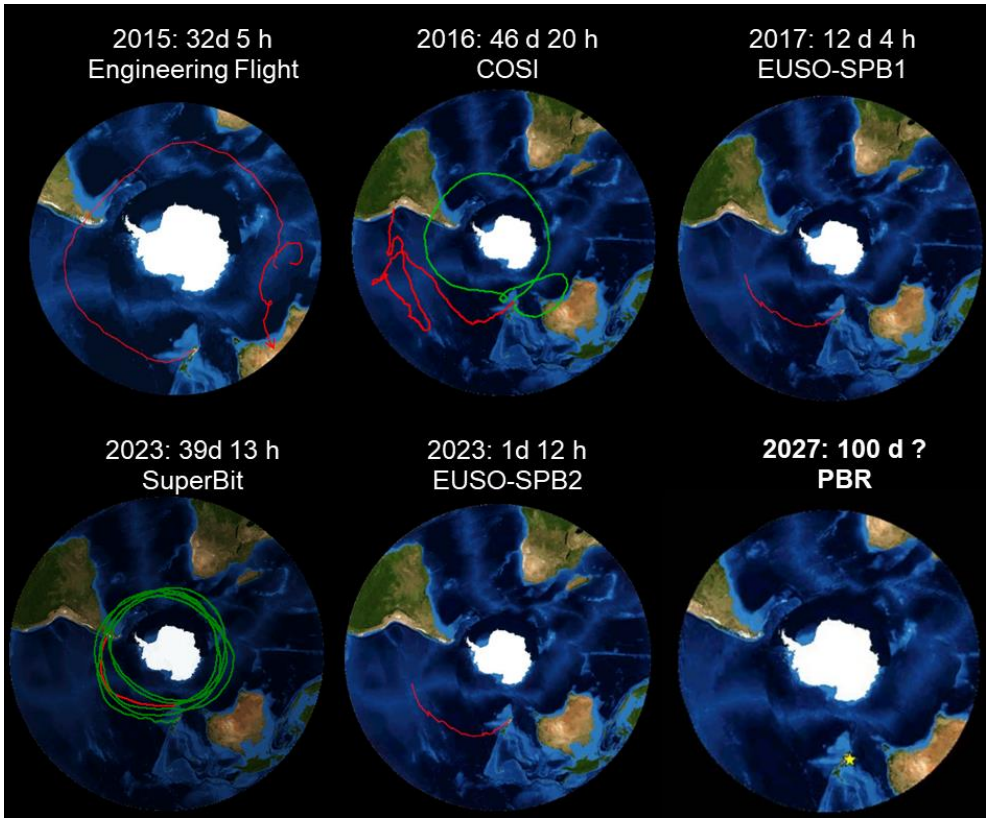
UV Fluorescence detection with MAPMTs 1µs sampling



Cherenkov detection with SiPMs 10 ns sampling

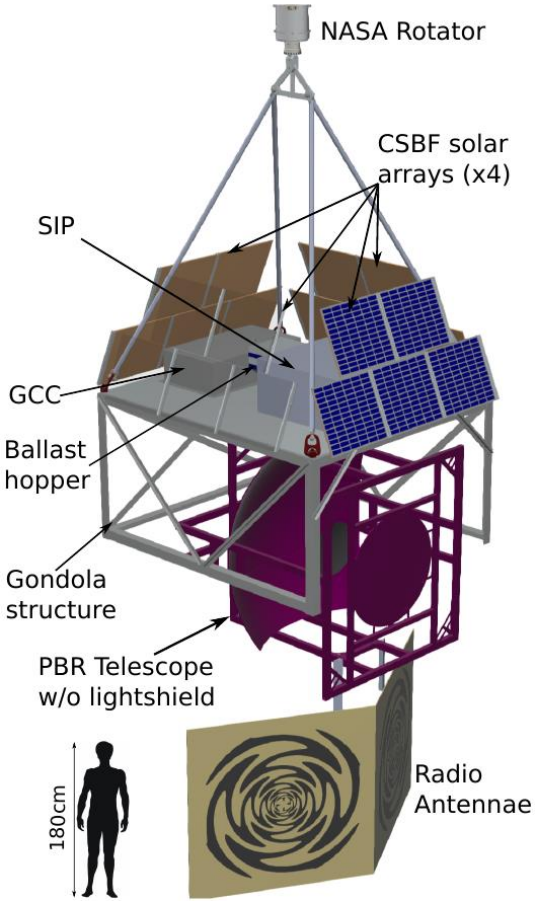
- 2 observation modes:
  - Stereo optimized for UHECRs
  - Limb optimized for astrophysical ν_τ

The PBR mission



- Planned launch for spring 2027 from Wanaka, NZ on a Super Pressure Balloon
- Floating altitude 33 km
- Mid-latitude flights with dark periods of observations and sunlight for battery charging
- Up to 100-day flight
- 500 hours of operation (~20% duty cycle)
- Min 14 days (70 h)
- 1500 kg of scientific payload

The payload: a multi-detector approach



Scientific payload:

- 1.1m-diameter Schmidt optic telescope with hybrid focal surface
- Low frequency Radio Instrument
- X-ray/Gamma/Particle detectors
- InfraRed Camera to measure cloud coverage within the telescope's FoV

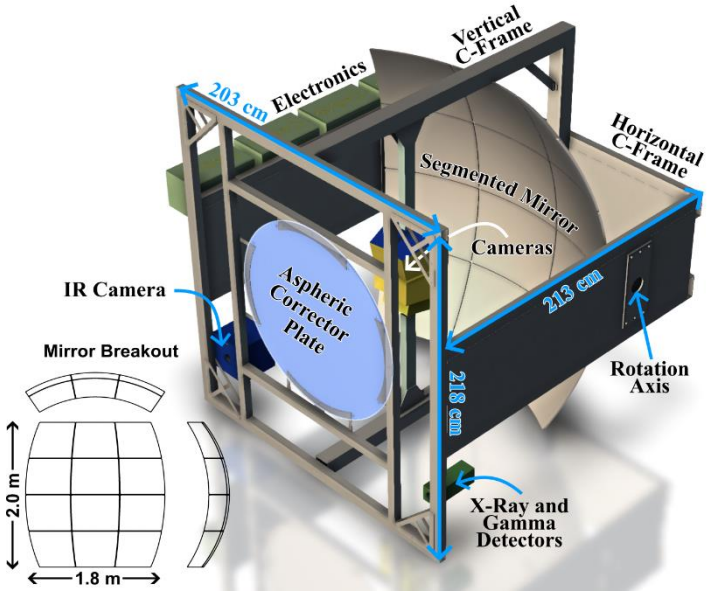
Pointing:

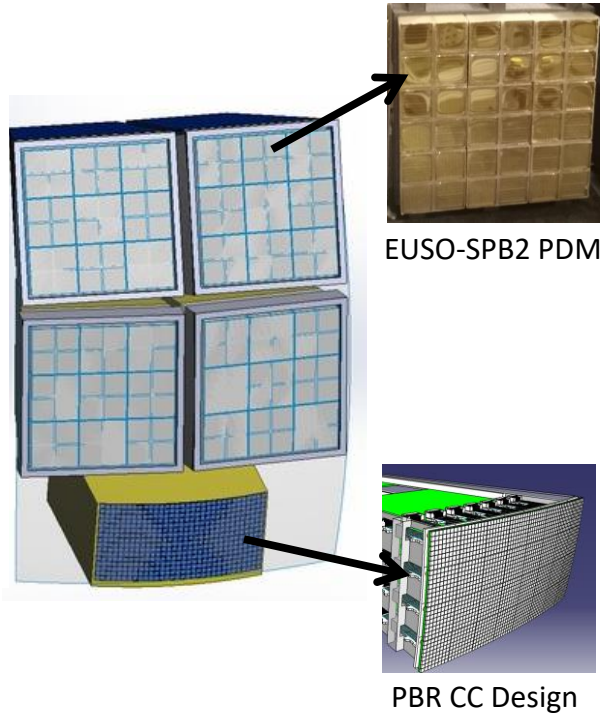
- 360 deg in azimuth via NASA rotator
- From -90° (nadir) to +13° above horizon in zenith

Long Duration Balloon equipment:

- Telemetry (including StarLink)
- Solar power system

The hybrid telescope





EUSO-SPB2 PDM

PBR CC Design

Fluorescence Camera (FC)

4 Photo Detection Modules (R11265 MAPMT): **9216** px

- 24° × 24° FoV
- 290 ÷ 430 nm detection window (BG3 filter)
- Integration time of 1 µs

Cherenkov Camera (CC)

4 rows of SiPM matrices (S13361-3050NE-08): **2048** px

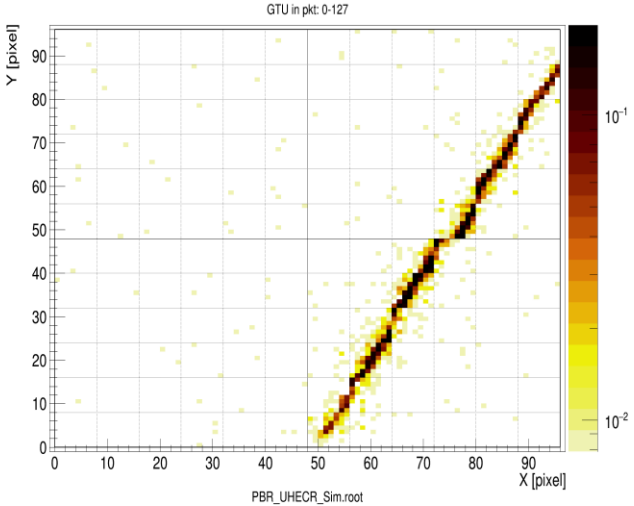
- 12° × 6° FoV
- Bi-focal for bg reduction
- 320 ÷ 900 nm detection window
- Integration time of 10 ns

The Fluorescence Camera

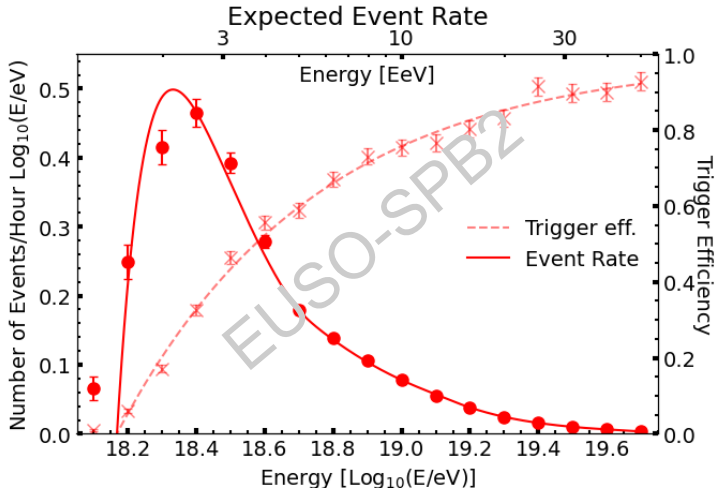
- Observe UHECRs via fluorescence from above

Tilting the telescope:

- Observe High Altitude Horizontal Air showers that are not visible from ground
- Measure the evolution of UV airglow with zenith angle
- Star observation for calibration

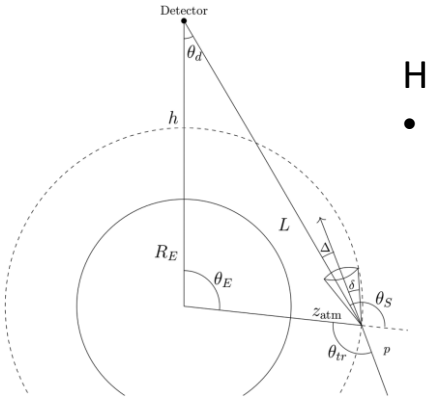


20 EeV, 57° zenith angle, pointing nadir



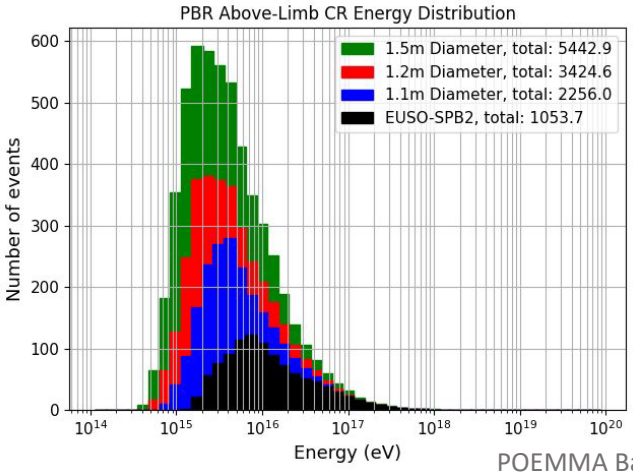
- Increase in FoV by 25% and 16% more light collection compared to EUSO-SPB2
- Threshold $\gtrsim$ EeV
- Peak sensitivity of 4 EeV

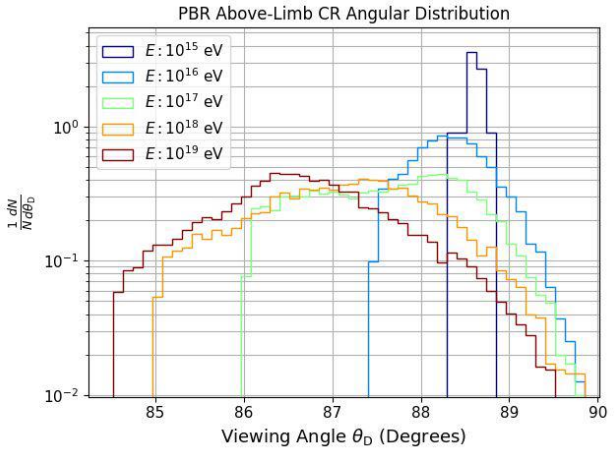
The Cherenkov Camera: above limb



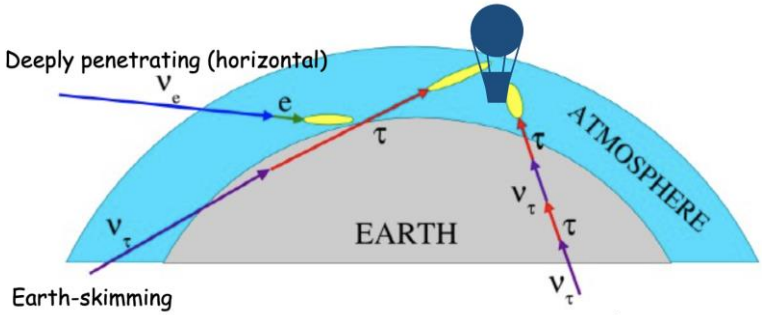
HAHA guaranteed signal with significant statistics (similar signature to ν event)

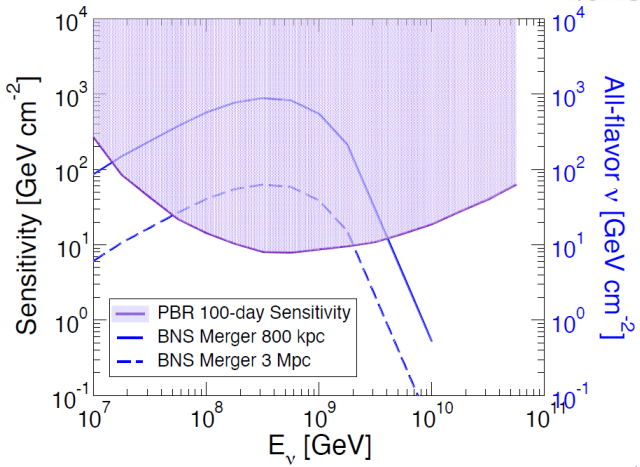
- Simulation study using EASCherSim*
  - **~60+ events/h**
  - Energy threshold ≈ 400 TeV
  - Maximum sensitivity ≈ 2 PeV
  - Energy-dependent angular acceptance: geometric energy filter





The Cherenkov Camera: below the limb

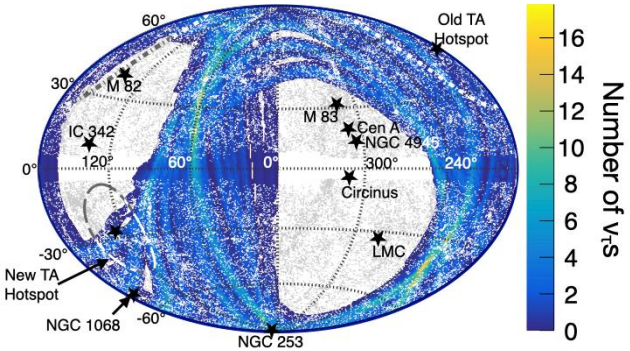




Per decade all-flavor sensitivity

PBR has very limited sensitivity to diffuse neutrino flux, but can observe transients by pointing

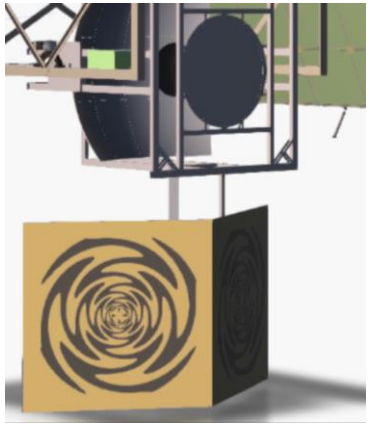
- Target of Opportunity: galactic SN, BNS/BH/NS merger, flaring Blazar/AGN, GRB…
- Steady sources (e.g. TA hotspots)

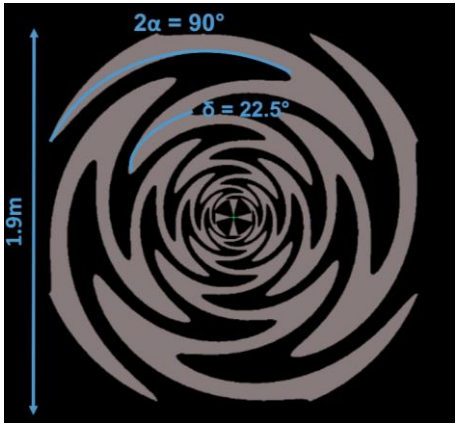


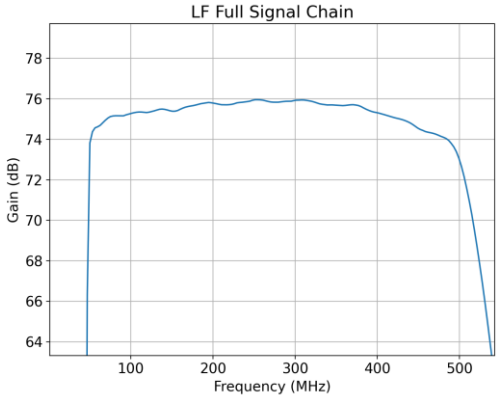
ToO: Acceptance Sky Map (100-day Flight)

- Models are fluences (integrated over time)
- Accounting for Sun/Moon effect and balloon trajectory

The Radio Instrument



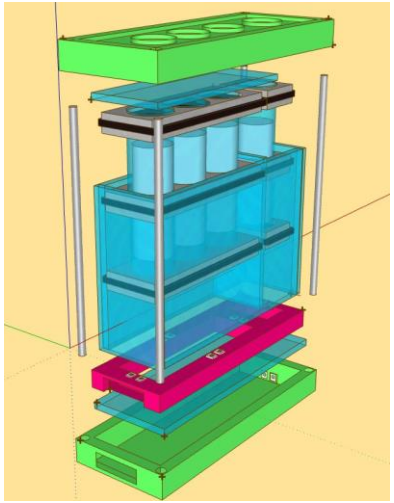




Two 2×2 m dual-polarize sinuous antennas canted at 120° from each other

- Based on PUEO Low Frequency instrument design
- 50 ÷ 500 MHz frequency range
- 60° × 120° FoV overlapping with the CC
- Expected energy threshold E > 10^{18} eV
- Self-triggering during the day
- Triggers from the CC during the night
- Radio spectrum contains information about distance from the shower axis
- Combining with CC measurements leads to a better constraint on the shower energy and direction (azimuth)

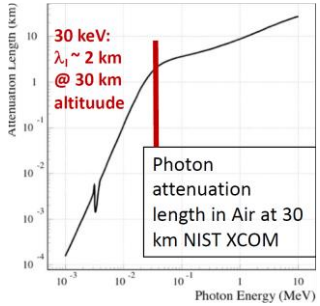
X, gamma and charged particle detectors

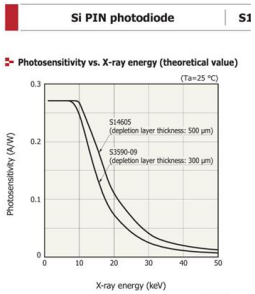


25.4B25.4/SIP-E3-Cs-T-X

CsI(Tl) scintillation detector with SIPM readout and built-in preamplifier / bias generator and temperature sensor

- X-ray (10 ÷ 300 keV): there is significant geometry factor for the PBR instruments to be within the EAS cascade development: unique shower measurements

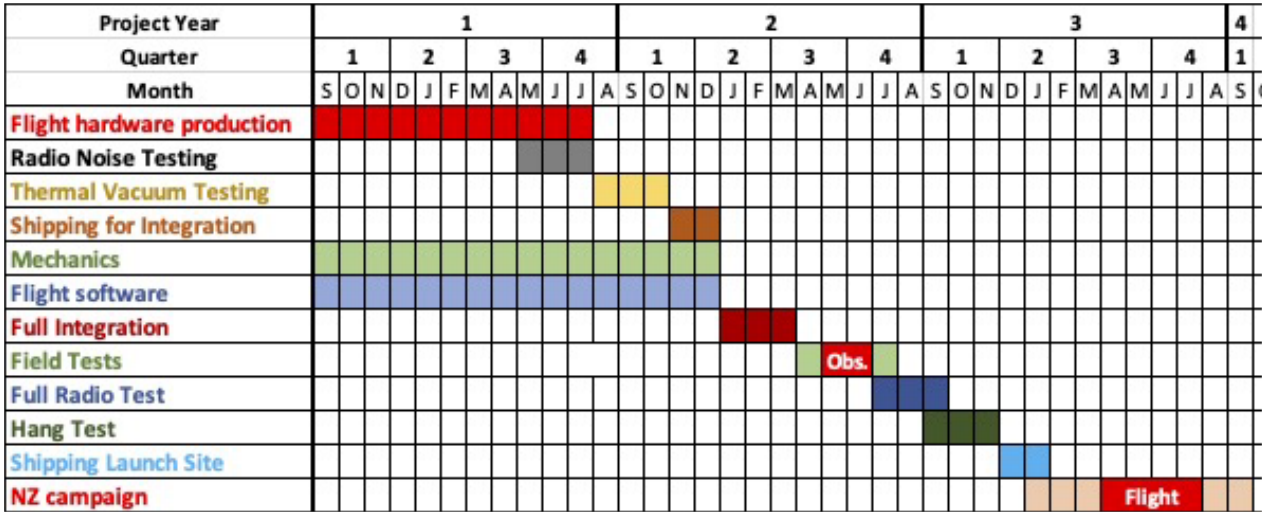




- 2 gamma detectors (0,1 ÷ 4 MeV): TLEs, ToO, GRBs...
- Charged particles: particle correlation for CC and FC (part of EAS, ToO), charged count (Galactic, SPEs), bkg

Current status and schedule

- APRA proposal accepted and funded
- Design well underway
- Procurement of components and prototyping has begun
- 2027 flight application submitted



Proposed schedule to begin September 2024

Summary and outlook

POEMMA Balloon with Radio is the **successor** of the EUSO-SPB2 mission and an advanced **precursor** of the dual satellite mission **POEMMA**

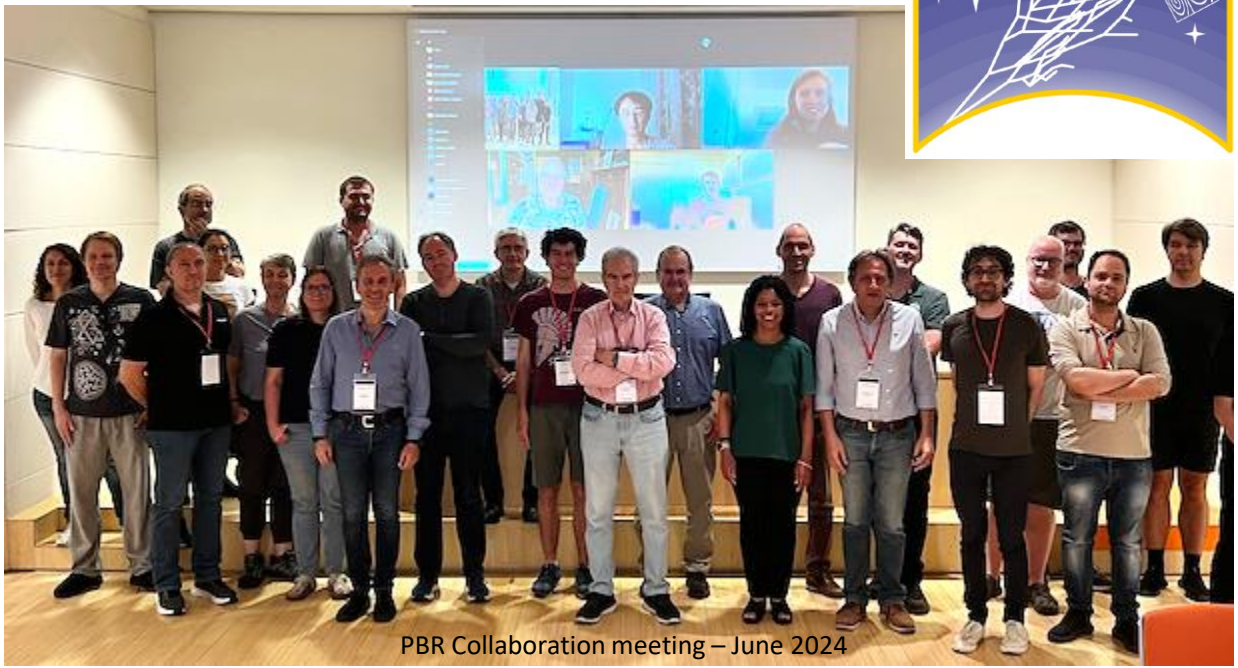
Preparation has started for a launch from Wanaka, NZ in Spring of 2027

Goals:

- UHECR observation from above
- Observation of High-Altitude Horizontal Air-shower (HAHAs)
- Neutrino search from Target of Opportunity
- First combined observation of optical Cherenkov and radio signal
- Raise TRL for POEMMA (first hybrid focal surface)

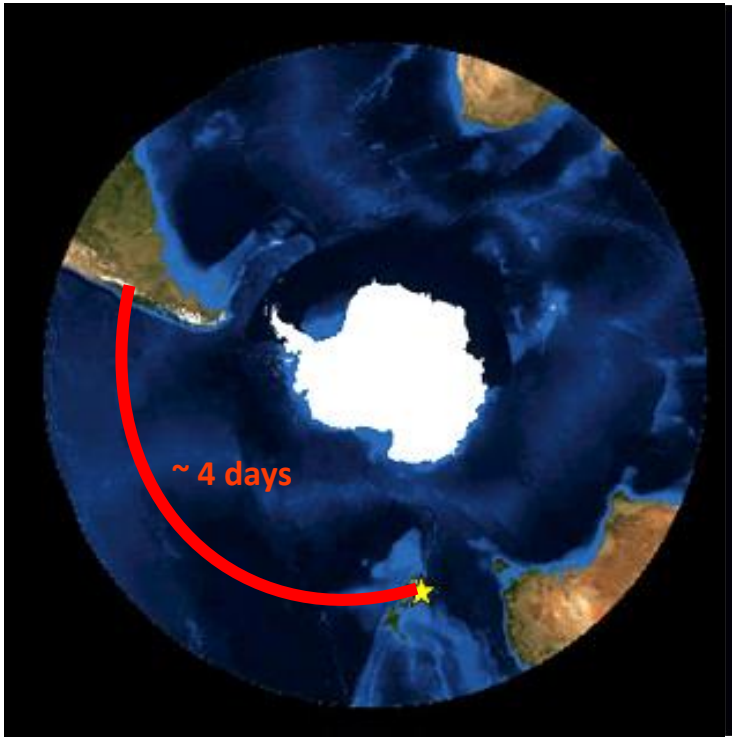
Thank you!

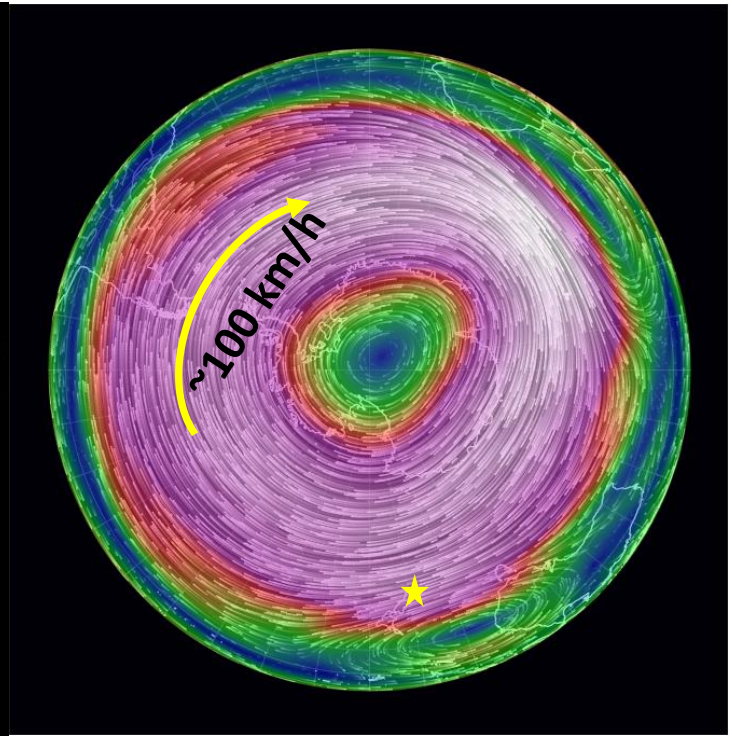
(and stay tuned)



PBR Collaboration meeting – June 2024

Why New Zealand?





Cameron Beccario

Wanaka, New Zealand

air flow at ~30 km June 9th 2017

https://earth.nullschool.net/#current/wind/isobaric/10hPa/orthographic=180,-90,300

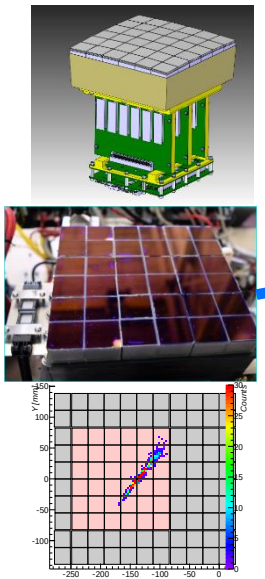
The POEMMA instrument

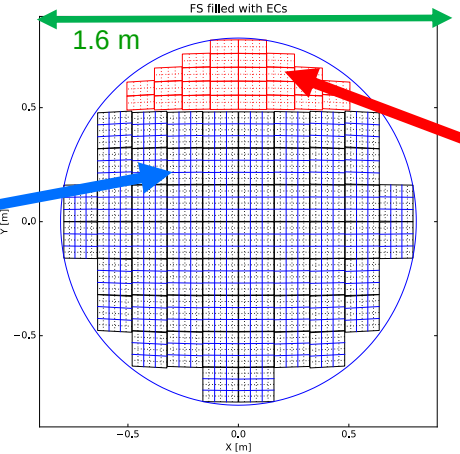
Two **4 meter** F/0.64 Schmidt telescopes with **45°FoV**

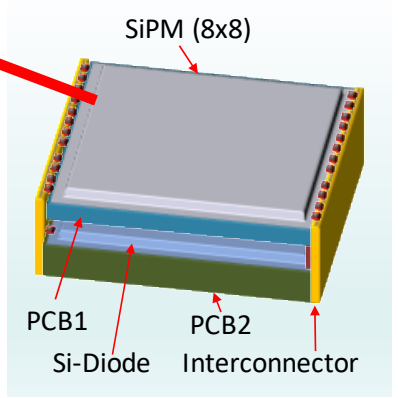
3 mm linear pixel size: 0.084° FoV

~ 150k pixels

UV Fluorescence detection with MAPMTs 1µs sampling







Cherenkov detection with SiPMs 10 ns sampling

60 Photo Detector Modules (PDMs) = 138,240 pixels

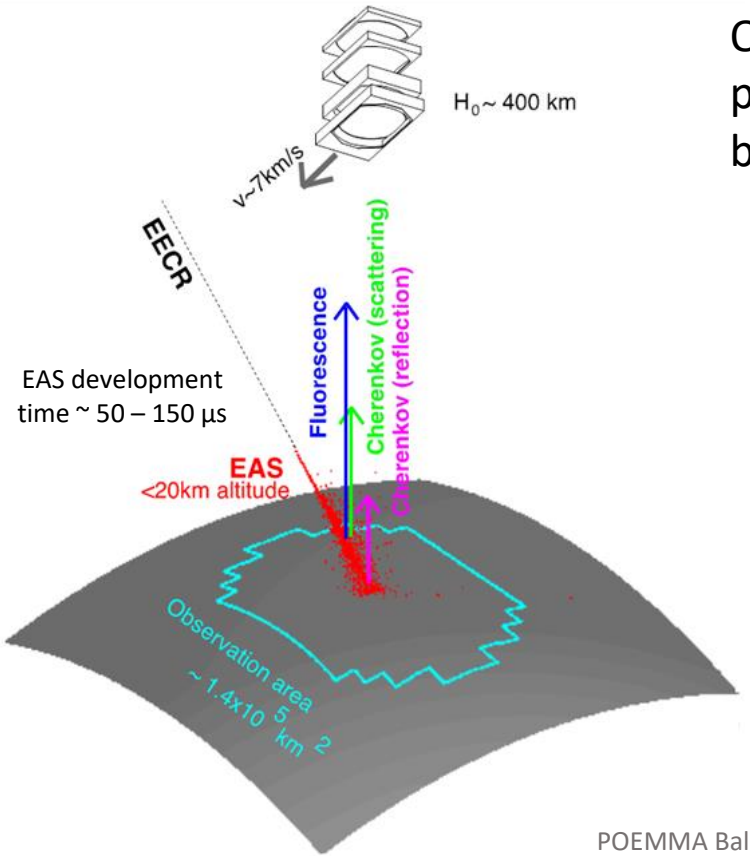
64 channels Multi-Anode PMT with BG3 filters

1 PDM = 36 MAPMTs = 2,304 pixels

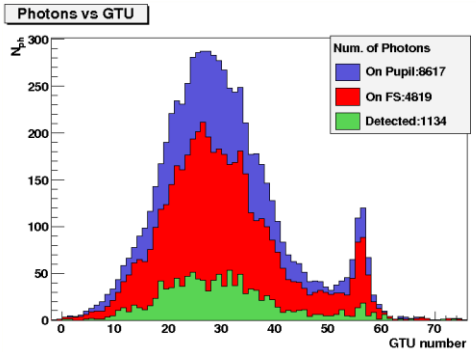
28 SiPM Focal Surface Units (FSUs) =14,336 pixels

1 FSU= 32 × 4 × 4 = 512 pixels

JEM-EUSO observational strategy



Observe from space fluorescence and Cherenkov UV photons generated by Extensive Air Showers created by EECR

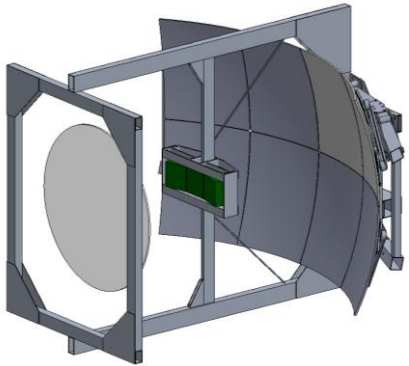


Main advantages:

1. The target volume is far greater than possible from the ground
2. Full sky coverage

First idea: J. Linsley, late ’70s

EUSO-SPB2 Fluorescence Telescope

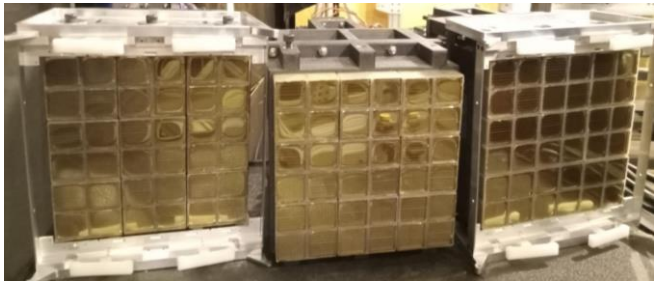


Modified Schmidt optics

FoV: 3×(12°×12°) ~36 km^2 on ground
Common focus mirror
Corrector Plate: 1 m^2
Pixel size: ~3 × 3 mm^2

Camera

MAPMT w/ single photoelectron counting
1 μs time bins, 1 “video clip” = 128 time bins
~15 watts



Energy Threshold	~ 5 × 10^{18} eV
Wavelength Sensitivity	UV 300 - 420 nm (BG3 filter)
Pointing (zenith angle)	Down (nadir)
Number of Pixels	3 × 2304 = 6912 (3 PDM)
Payload Mass (kg)	545

Data Processor

Readout performed by one ASIC per MAPMT + multiple trigger levels to filter out noise and identify events of interest

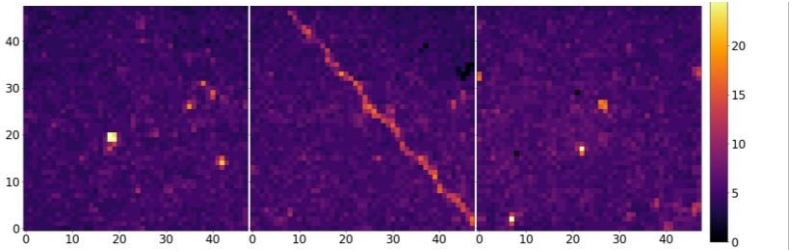
EUSO-SPB2 FT performance

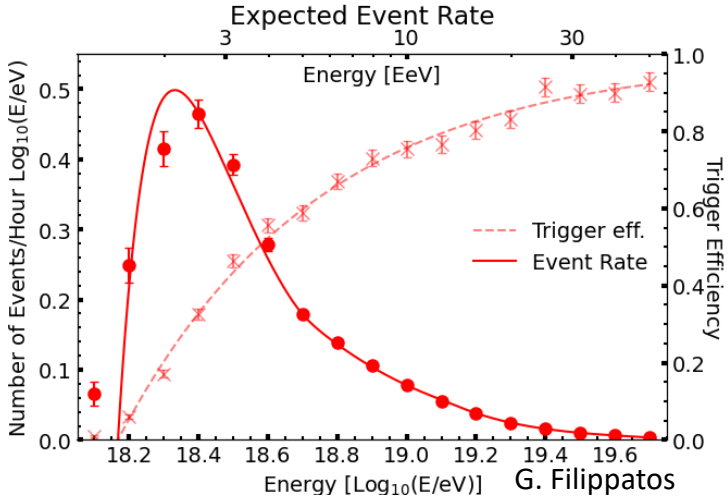
Extensive simulation study

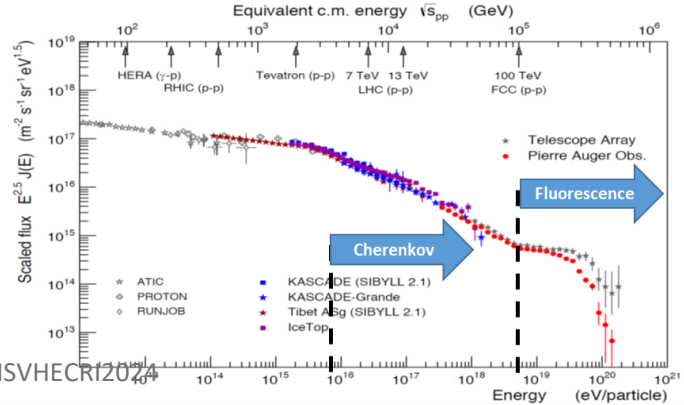
- Energy threshold: ~2 EeV with peak sensitivity at 4 EeV
- **0.12 events per hour,** <10% are reconstructable: geometry, longitudinal profile contains Xmax
- On board pre-selection using Neural Network (~90% accuracy)

Field tested in Aug 2022 with 10^4 laser shots and LED evts

- Full end-to-end calibration
- Hours of CR observation



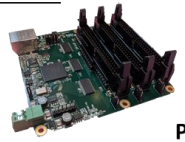




EUSO-SPB2 Cherenkov telescope

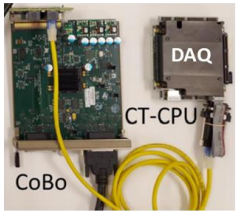
Read-out Electronics

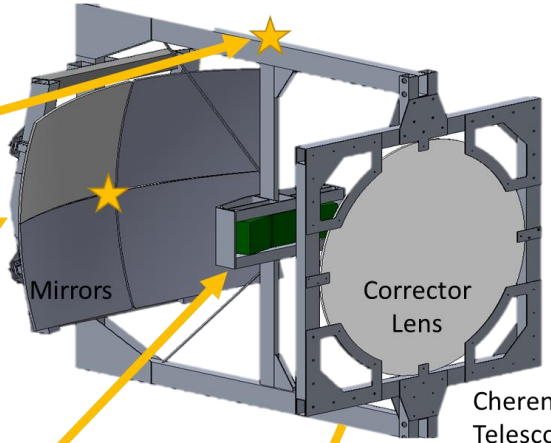
Trigger Board



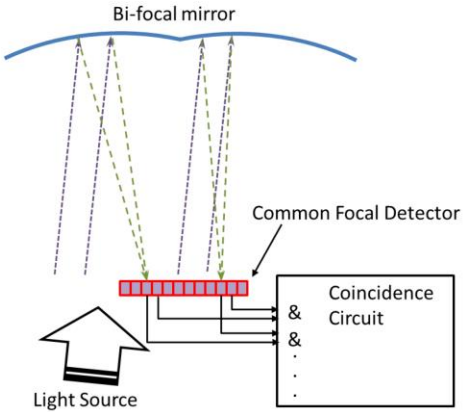
Digitizer Board

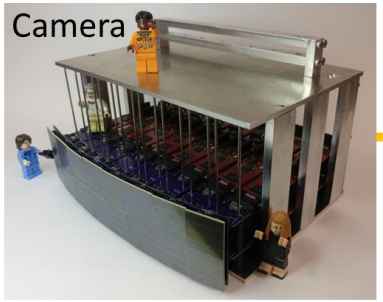
Power Module

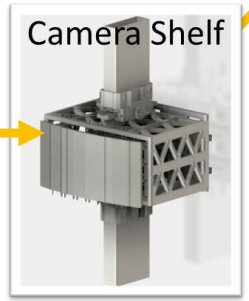


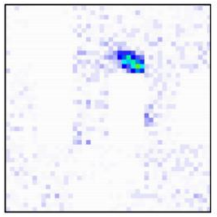


Cherenkov Telescope

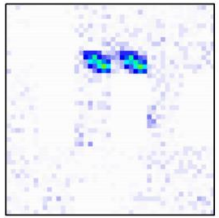








Charged particle hitting camera



Light pulse from outside the telescope

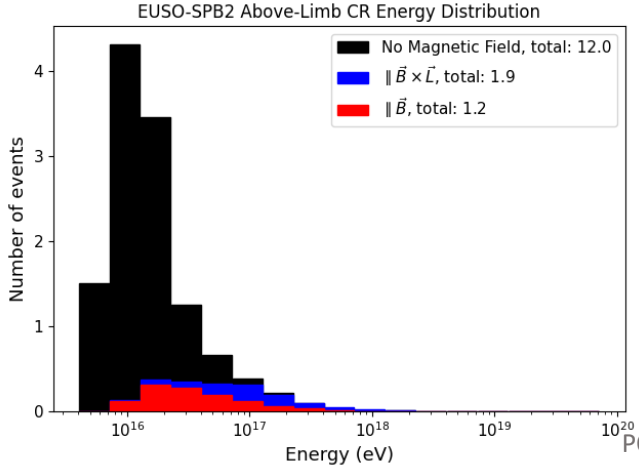
EUSO-SPB2 CT performance

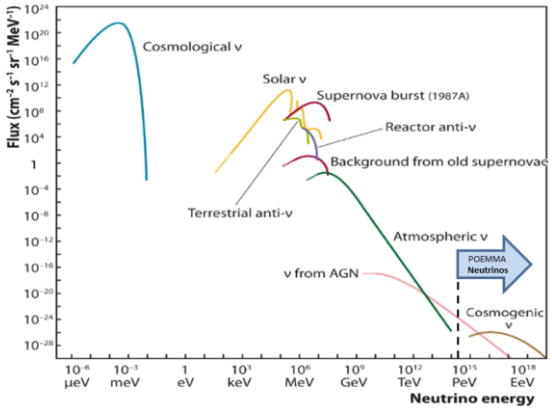
Above the limb

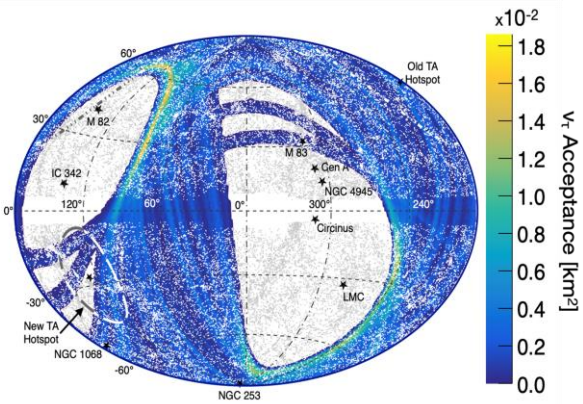
- Simulation study using EASCherSim
- Low energy threshold of 10 PeV
- Angular acceptance is energy dependent
  - Geometric energy filter

Below the limb

- Not sensitive to the diffuse neutrino flux, but can observe transients by pointing
  - Galactic and extragalactic supernovae
  - BNS/BH-NS merger, nearby TDE
  - Flaring Blazar/AGN
  - GRBs
  - Steady sources (e.g. TA hotspot)







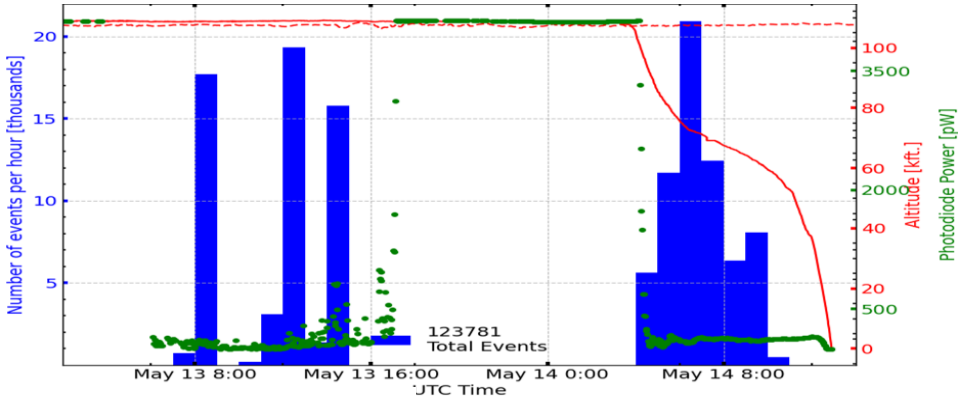
ToO: Acceptance Sky Map (100-day Flight)

EUSO-SPB2 data collected & example events (FT)

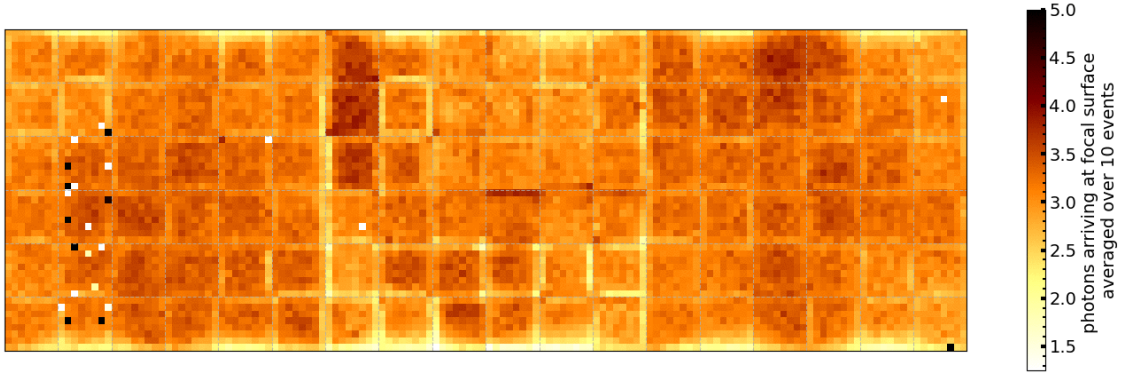
Operated for 2 nights :

- May 13th : 7 hours commissioning
- May 14° : learned of bad leak in balloon
  5 hours (downloaded data)

➢ More than 120000 triggers recorded and downloaded (thanks to StarLink)



Event #11877 - #11887 ; UTC Time 14 May 2023 06:20:05

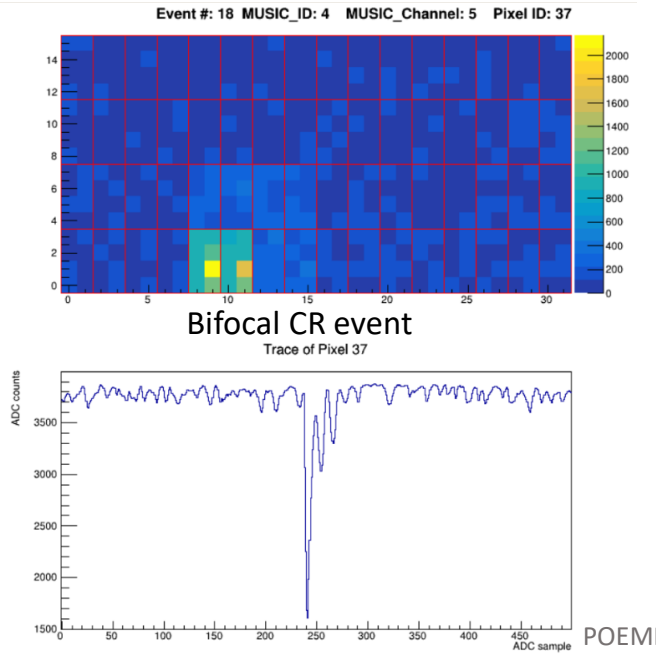


FT performed well
but no UHECR found

EUSO-SPB2 data collected & example events (CT)

Operated for 2 nights (first night mainly commissioning):

- Several upward-going EAS caused by PeV Cosmic Rays recorded + Night Sky Background observations
- No ToO follow up due to time



Bifocal CR event

01 10GB of Raw data
Raw/CoBo files: 31,269 Bifocal, 832 HLED

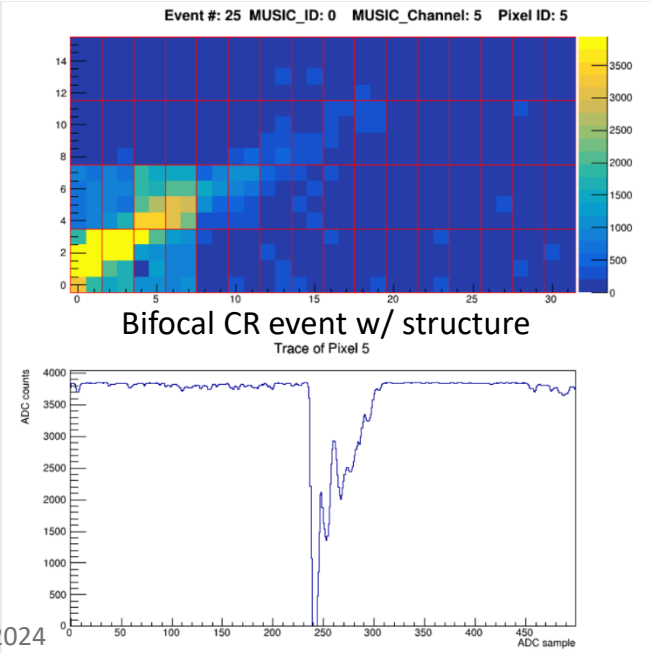
02 Processed Files:

a Gold Plated, Bifocal Events: 1,463

b Gold Plated, HLED Events: 11,693

c Vanilla Events: 534 HLED, 21,956 Bifocal

d Everything Else: 91 HLED, 32,741 Bifocal



Bifocal CR event w/ structure

Collaboration

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SK	SAS	S. Mackovjak

PRELIMINARY

51 members, 22 institutions, 8 countries