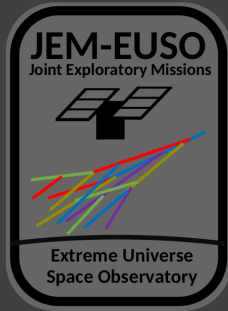


# Status of the JEM-EUSO Collaboration: Ground, Balloon and Space-Based Observations of UHECRs and Related Phenomena



**Zbigniew Plebaniak**

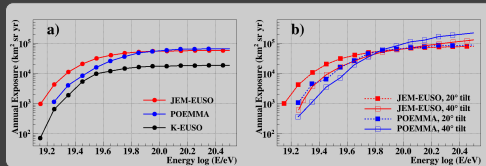
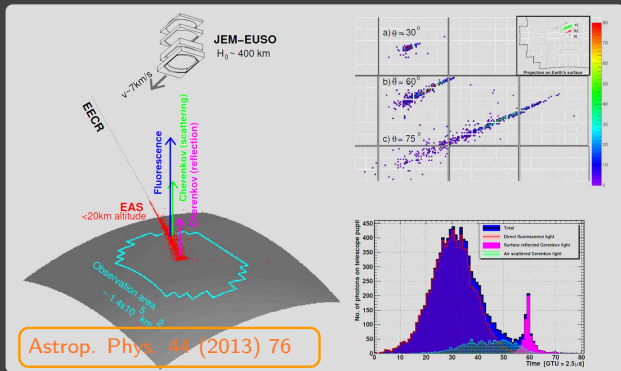
**The JEM-EUSO Collaboration**

Physics Department  
University of Rome & INFN, Tor Vergata

PAiP-2025 — Particle Astrophysics in Poland, February 21st 2025, Warsaw, Poland

# The JEM-EUSO observation principle

- ➔ Observations of the EAS from space in UV
- ➔ around 10 times higher exposure than for ground observatories
- ➔ angular resolution:  $3 - 8^\circ$
- ➔  $X_{max}$  resolution:  $50 - 100 \text{ g cm}^{-2}$
- ➔ energy resolution:  $15 - 30\%$
- ➔ energy threshold:  $>7 \cdot 10^{19} \text{ eV}$ 
  - ➔  $> 1000$  events expected during 3 years of mission





# The JEM-EUSO Scientific Program

## Joint Exploratory Missions for an Extreme Universe Space Observatory

EUSO-TA (2013 - now, ground)

EUSO-Balloon (2014, balloon)

TUS (2016, satellite\*)

EUSO-SPB1 (2017, balloon)

Mini-EUSO (2019 - now, space)

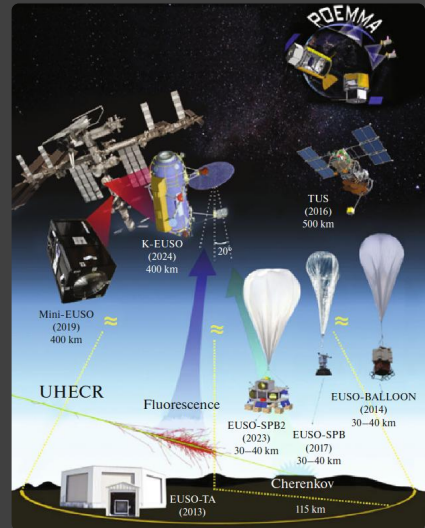
EUSO-SPB2 (2016, balloon)

POEMMA Balloon with Radio (Planned - 2027, balloon)

K-EUSO (Planned - on hold, ISS)

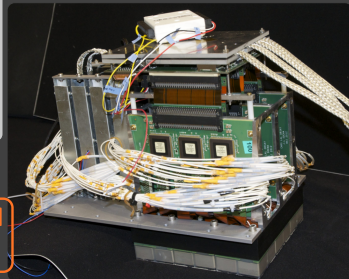
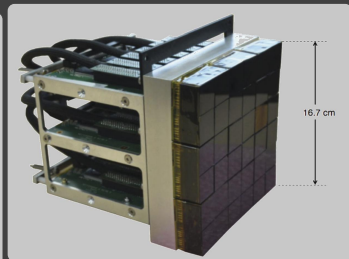
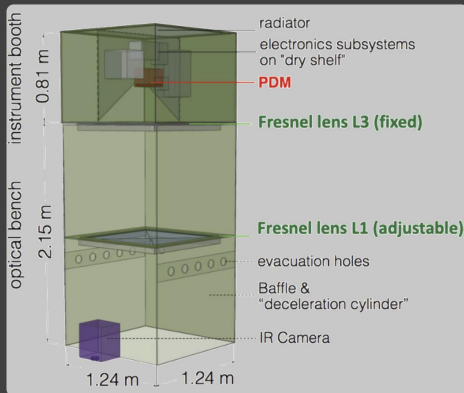
POEMMA (Planned - 2030, satellite)

Since 2004 - 16 countries,  $\sim 100$  institutions  
and 6 space agencies



# EUSO-Balloon - 2014 - CNES - The JEM-EUSO pathfinder

- ➔ Spectral range: 290-430nm
- ➔ FoV:  $\sim 10^\circ$  ( $0.21^\circ$  / pix)
- ➔ Pupil area:  $0.91\text{m}^2$
- ➔ Optical system: two Fresnel lenses
- ➔ FS: 2304 (48x48) pixels
- ➔ single photon counting mode with  $2.5 \mu\text{s}$  time resolution (GTU)
- ➔ Double pulse resolution:  $\sim 10\text{ns}$

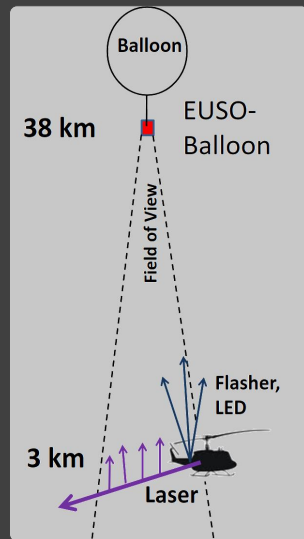
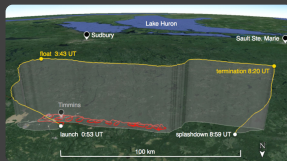


Space Sci Rev 218, 3 (2022)

The HVPS system fully designed and produced in Poland

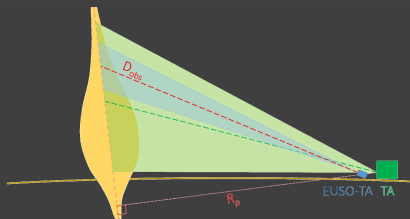
# EUSO-Balloon, 2014 - first flight

The very first detection of ultra fast UV trackt "from above"  
August 25, 2014, EUSO-Balloon

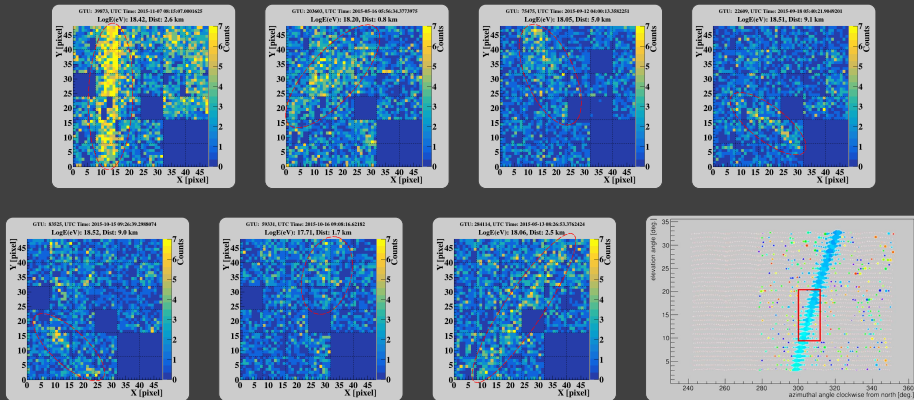


# EUSO-TA - 2013 - now - cooperation with Telescope Array

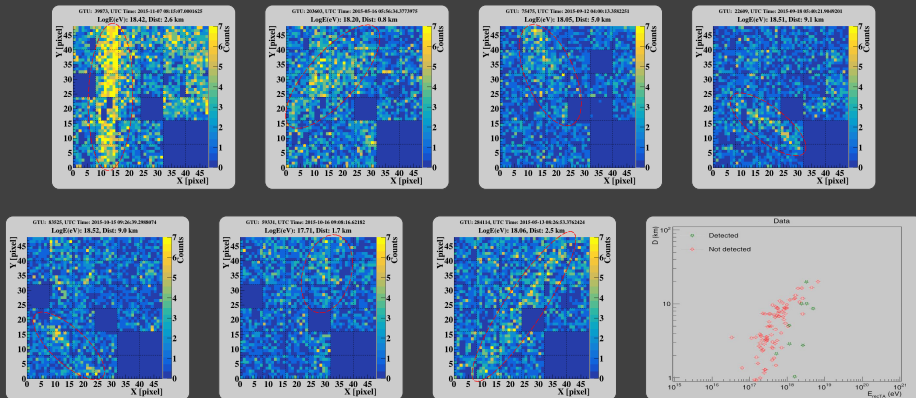
- EUSO-TA telescope is located in front of TAFD-BRM station, Utah, USA
  - powered and triggered by TA station
  - desert and dark sky, good conditions for testing UV detectors probing atmospheric transmission etc.
  - Central Laser Facility and Electron Light Source in FoV



## EUSO-TA results - detected UHECR events

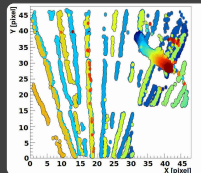


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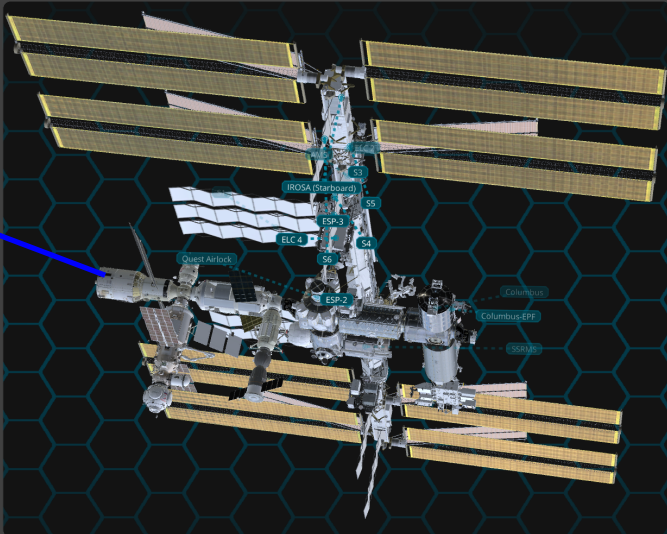
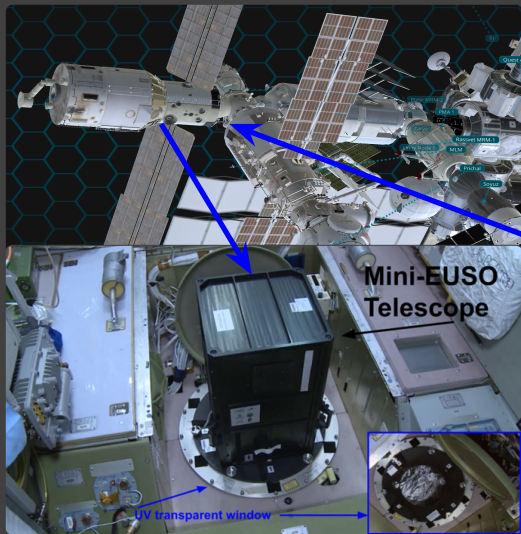


# EUSO-TA - calibration with UV lasers and stars

- Central Laser Facility
  - Vertically emitted UV signals at the distance of 21 km
  - energy range 4-6mJ (2.2mJ corresponds to  $10^{19}$  eV shower)
- Global Laser System (GLS)
  - The prototype of laser station on mobile to test response of EUSO detectors
  - Pulses generated as equivalent of EAS signals at  $10^{19}$  -  $10^{21}$  eV
  - Automatic changing of pointing direction allowing for swipes through the field of view



# Mini-EUSO - 2019 - now - The first EUSO telescope in space



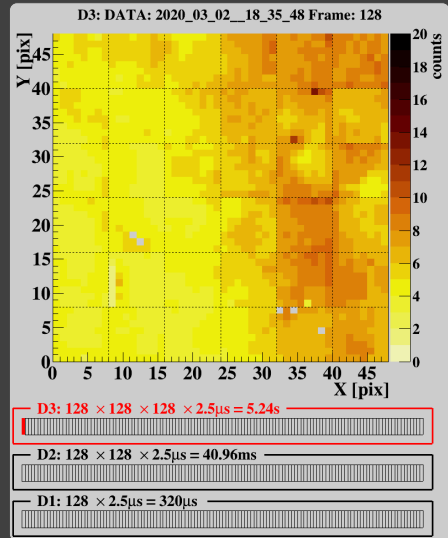


# Mini-EUSO data acquisition

Mini-EUSO is taking data by counting photoelectrons in the UV range during observations of the Earth's atmosphere in nadir. The detector efficiency is about 6%.

The counts are summarized in 2.5 microsecond GTUs in a matrix of 48x48 pixels and saved in packets of 128 frames. Data are stored in three modes:

Pixel signal is integrated over 8 consecutive GTUs and compared with the background level, determined by averaging over 128 GTUs, to look for an excess. If the signal is  $8\sigma$  above background, the event is triggered, the whole focal surface is read out, and a packet of 128 GTUs is stored, centered on the trigger.



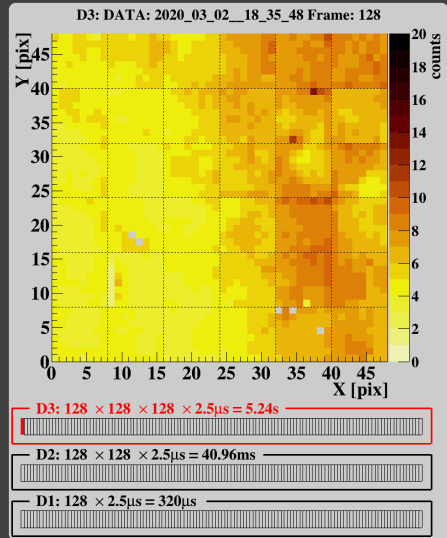
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- continuously when the detector is on. Counts are summarized over >16k GTUs (40.96 ms).
- D2 - triggered on data with counts integrated over 128 GTUs (320  $\mu$ s). 4 D2 packets can be stored during 1 D3 period.
- D1 - triggered on data with counts integrated over a single GTU (2.5  $\mu$ s). 4 D1 packets can be stored during 1 D3 period.

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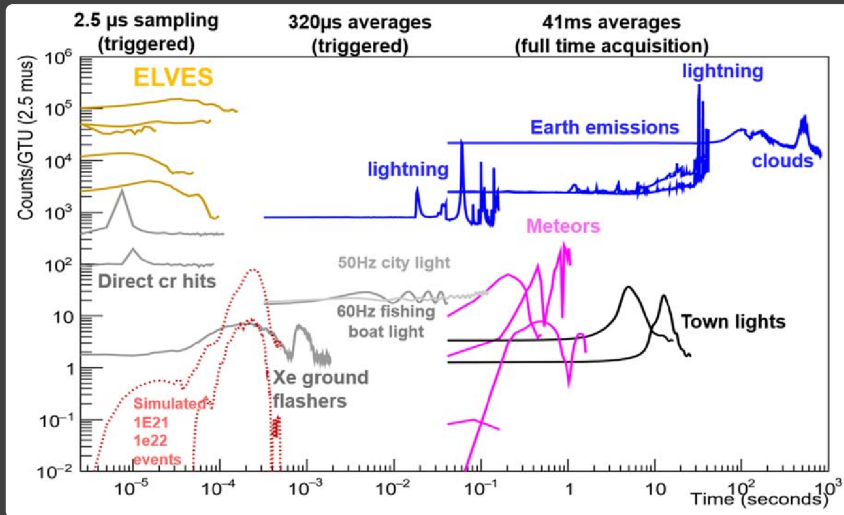
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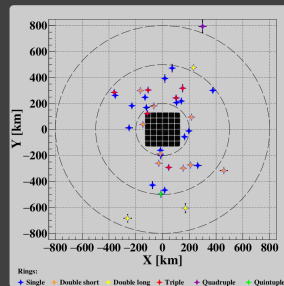
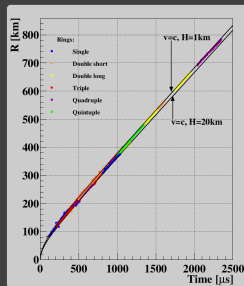
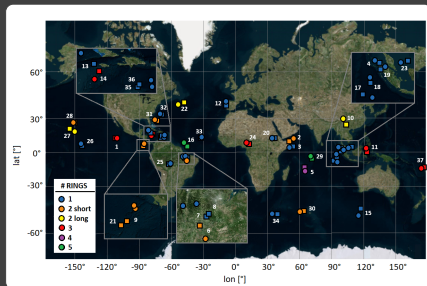
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## Mini-EUSO - all types of measured signals

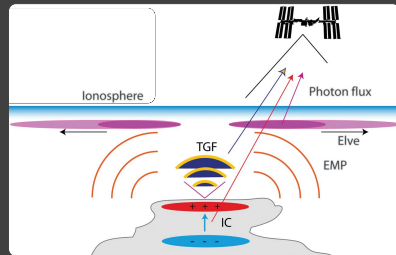


# Mini-EUSO - detection of the ELVES from space



Emission of **L**ight and **V**ery low frequency perturbations due to **E**lectromagnetic pulse **S**ources

37 ELVES events have been detected and analyzed in the first 160 hours of Mini-EUSO data

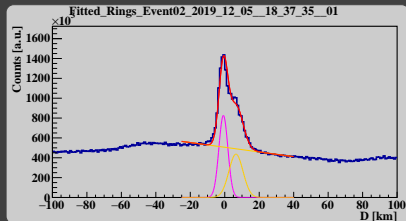
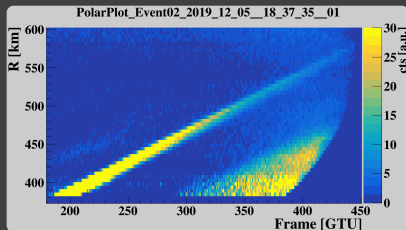




# Double-ringed ELVES with short delay and dynamic halo

## EVENT 2 - 2019-12-05 18:37:35

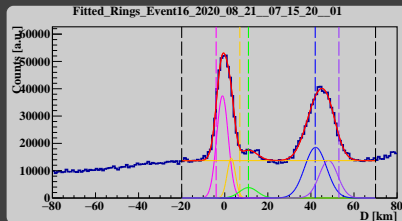
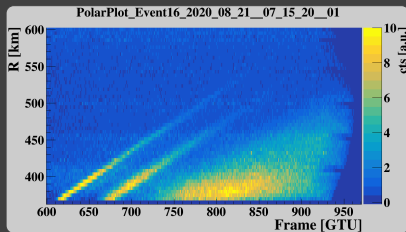
A double-ringed event with inner-peak delay of about  $25 \mu\text{s}$  and ring widths up to  $\sim 7\text{km}$ . Event observed at  $>550\text{km}$  distance. The short interval multi-rings ELVES are so close one another, the inter-ring emission does not return to background values. There are 5 more events of this class.



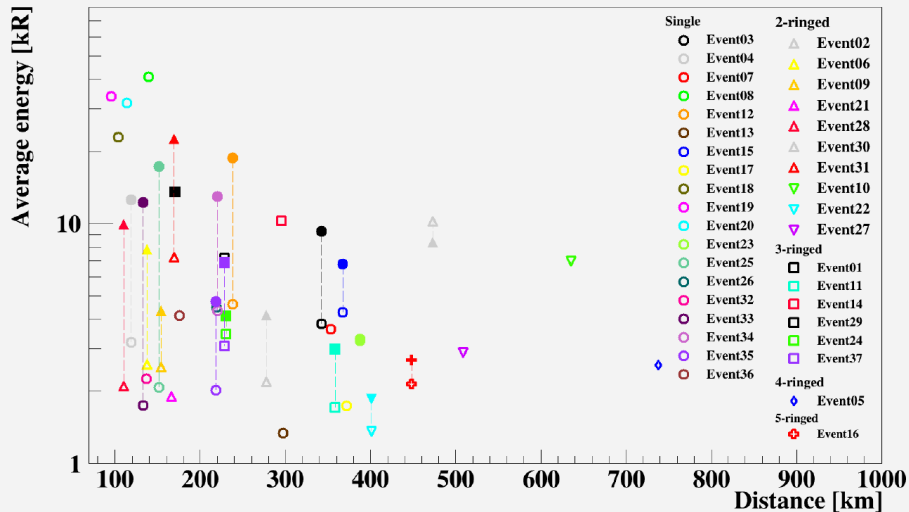
# Five-ringed ELVES with dynamic halo

## EVENT 16 - 2020-08-21 07:15:20

A five-ringed event composed of three main peaks with the weakest in the center. Both of the two brightest rings show two short delay events with delays of 15 and 19  $\mu\text{s}$ . The duration of the whole ELVES event is reaching 160  $\mu\text{s}$ . The dynamic halo is delayed by  $\sim 250\mu\text{s}$ .



## Mini-EUSO - ELVES - average intensity

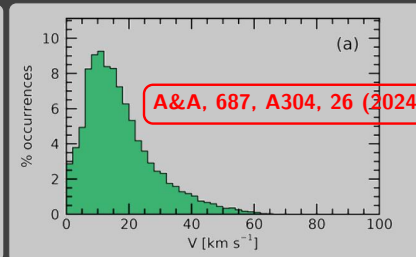
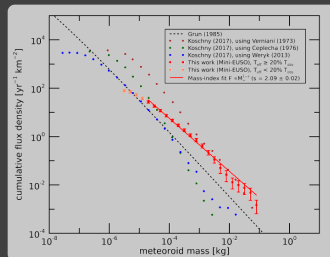
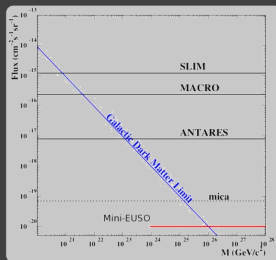
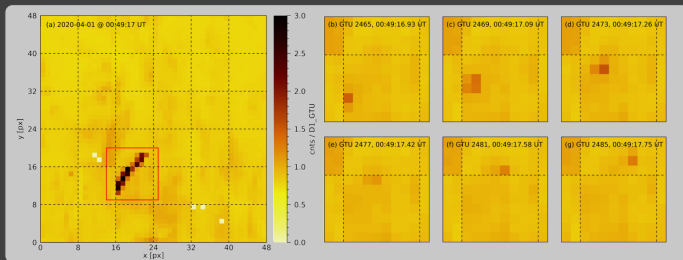


# Mini-EUSO - UV maps of the Earth

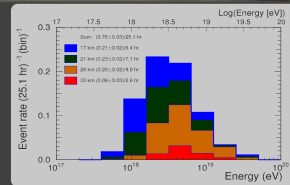
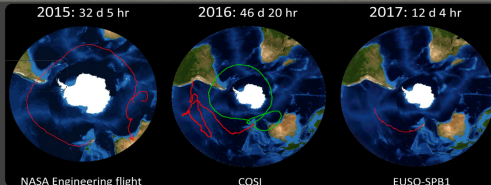
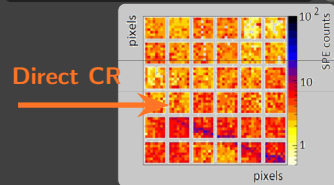
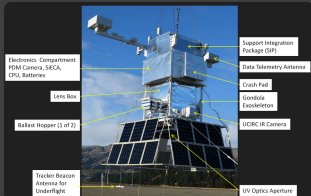
Observation of night-time emissions of the Earth in the near UV range from the International Space Station with the Mini-EUSO detector, Remote Sensing of Environment 284 (2023) 113336  
Mendeley database: <https://data.mendeley.com/datasets/57fmn7rh4n/4> Data in Brief 48 (2023) 109105

# Mini-EUSO - meteors from space

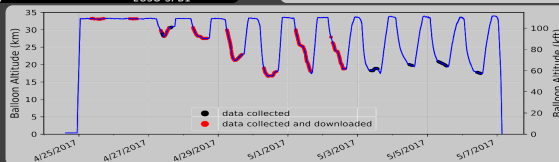
- ➔ 24 000 meteor events from 40 Mini-EUSO sessions ( $\sim 6$  days)
- ➔ mass range:  $10^{-5} - 10^{-1}$  kg,  $\text{mag} < +6$
- ➔ mass index  $s = 2.09 \pm 0.02$  for  $M_{inf}^{1-s}$
- ➔ three events with velocity  $> 85$  km s, no SQM candidates



## EUSO-SPB1 - 2017 (April 24 23:51 UT) - NASA



The primary scientific goal was to make the first observations of ultra-high-energy cosmic-ray EAS by looking down on the atmosphere with an ultraviolet (UV) fluorescence telescope from suborbital altitude (33 km) - failed

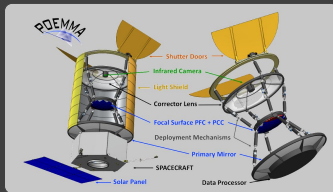


# Probe Of Extreme Multi-Messenger Astrophysics (POEMMA)

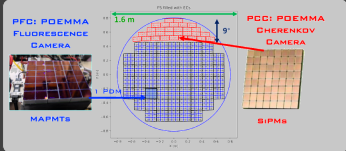
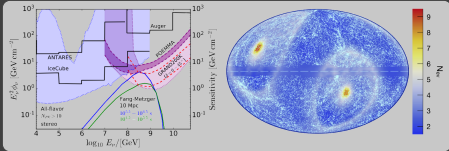
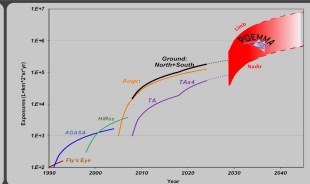
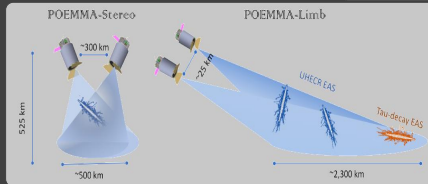
## The main scientific objectives:

- ➔ Discover the nature and origin of the highest-energy particles in the universe
- ➔ Discover neutrino emission above 20 PeV associated with extreme astrophysical transients
- ➔ Probe particle interactions at extreme energies
- ➔ Observe TLEs
- ➔ Observe meteors
- ➔ Search for exotic particles

## NASA probe-class mission selected for validation



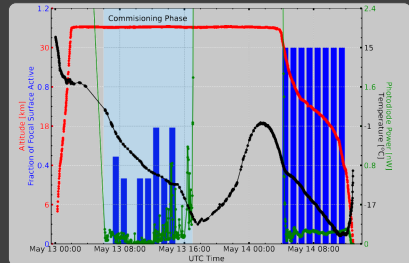
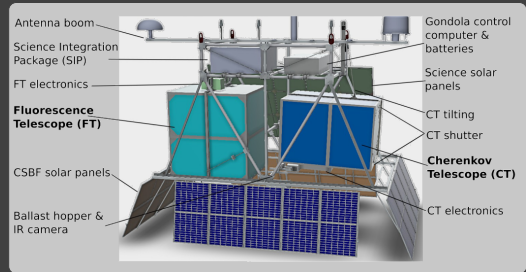
Telescope:	Instrument	Spacecraft
Optics	Schmidt 45° full FoV	Slow rate 90° in 8 min
	Primary Mirror 4 m diam.	Pointing Res. 0.1°
	Corrector Lens 3.3 m diam.	Pointing Know. 0.01°
	Focal Surface 1.6 m diam.	Clock synch. 10 ns
	Pixel Size 3 × 3 mm <sup>2</sup>	Data Storage 7 days
	Pixel FoV 0.084°	Communication S-band
PFC	MAPMT (1μs)	Wet Mass 3,450 kg
PCC	SiPM (20 ns)	Power (w/cont) 550 W
Observatory	Each Telescope	Mission (2 Telescopes)
	Mass 1,550 kg	Lifetime 3 year (5 year goal)
	Power (w/cont) 700 W	Orbit 525 km, 28.5° Inc
	Data < 1 GB/day	Orbit Period 95 min
		Telescope Sep. ~25 - 1000 km



JCAP 06 (2021) 007

# EUSO-SPB2 - 2023 (May 13th) - NASA

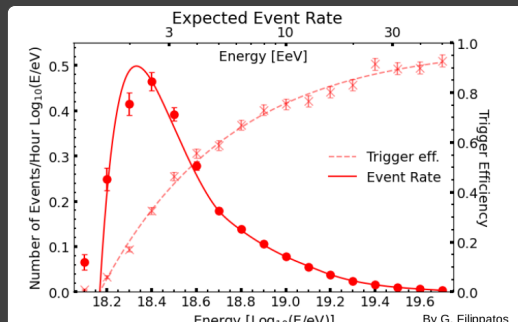
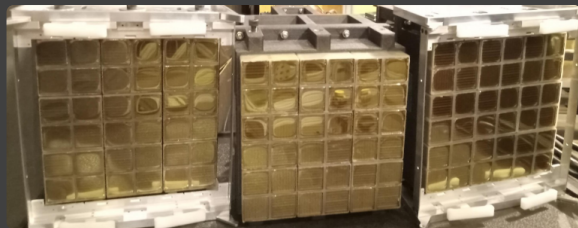
- ➔ Expected flight time: 100 days
- ➔ Real flight time: 37 hours
- ➔ Weight:  $\sim 1.5$  t
- ➔ Cherenkov Telescope
- ➔ Fluorescence Telescope (3xPDM)
- ➔ Optics: 2x Schmidt optics
- ➔ IR camera
- ➔ altitude: 33km
- ➔ Target of Opportunity  
(rotator, cherenkov camera)





# EUSO-SPB2 - Fluorescence camera

- ➔ Pixels: 6912
- ➔ Integration time:  $1\mu\text{s}$
- ➔ Detection window: 290-430 nm
- ➔ FoV:  $12^\circ \times 36^\circ$
- ➔ Pointing: nadir
- ➔ Energy threshold:  $2\text{EeV}$   
(peak sensitivity at  $4\text{EeV}$ )
- ➔ Expected event rate: 0.12 per hour
- ➔ No detected events

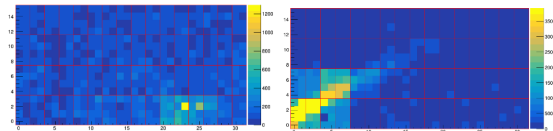


**Astropart, Phys., 165, 103046, (2025)**

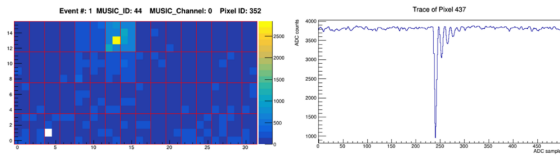
# EUSO-SPB2 - Cherenkov camera

- ➔ Pixels: 512 (SiPM)
- ➔ Integration time: 10ns
- ➔ Detection window: 200-800nm
- ➔ FoV:  $6.4^\circ \times 12.8^\circ$
- ➔ Bi-focal optics
- ➔ Pointing:  $2.5^\circ$  to  $-13.1^\circ$
- ➔ Above the limb threshold: 10PeV
- ➔ Below the limb: ToO, no events

[arXiv:2308.15628](https://arxiv.org/abs/2308.15628)



**Figure 7:** Candidates for Cosmic ray induced air shower events, Left: BiFocal, Right: Cherenkov cone. Both images were taken as the focal plane was pointed at the limb, therefore the top half of the display is below the Earth's limb while the bottom half is above, the image is flipped due to optics.

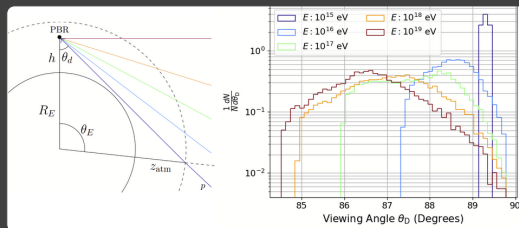
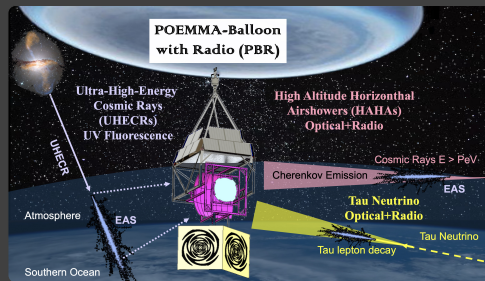


**Figure 8:** Possible direct cosmic-ray hit

# Poemma Balloon with Radio (PBR) - planned for 2027

- ➔ Fluorescence Telescope (4xPDM)  
the polish group already provided HVPS modules
- ➔ Expected flight time: 100 days
- ➔ FT: 4xPDM, 9216 pix
- ➔ CT: 2048 pix
- ➔ Radio: 50-500MHz, 60x60 deg,  $E > 10^{18}$  eV
- ➔ HAHA:  $> 0.4$  PeV, 60 events per hour
- ➔ Target of Opportunity

**NIMA 1069, 169819 (2024)**



# Polish group in JEM-EUSO - 2025

## Polish institutions involved in JEM-EUSO in 2025:

- ➔ University of Warsaw (1)
- ➔ Stefan Batory Academy of Applied Sciences, Skierniewice (1)
- ➔ National Centre for Nuclear Research, Warsaw (2)
- ➔ University of Lodz (1)
- ➔ no affiliation (1)

**Currently no financial support**



# Thank You for Your Attention