PNHE 2023

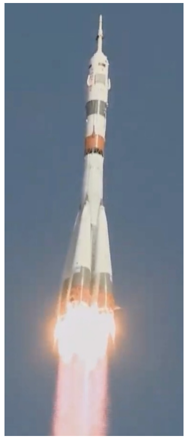
– IAP, 6th of September 2023 –

JEM-EUSO : la voie spatiale pour les UHECRs

Étienne Parizot
(APC, Université de Paris)

EUSO-Balloon

EUSO-TA (1, 2 & 3)



MINI-EUSO

EUSO-SPB1

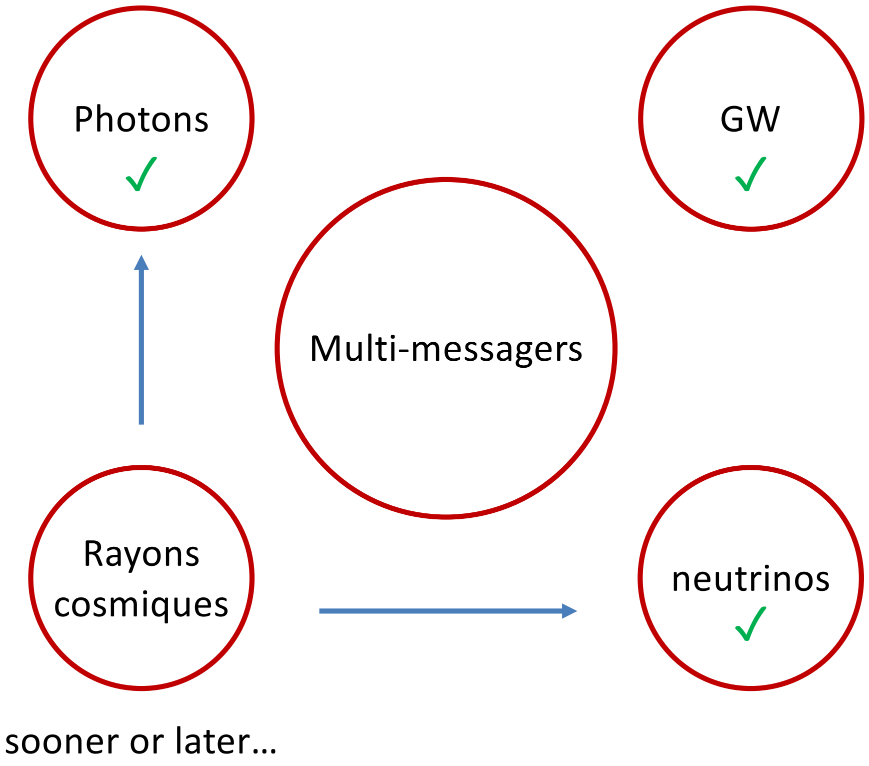
EUSO-SPB2

Context: the multi-messenger strategy

- 4 complementary pillars:

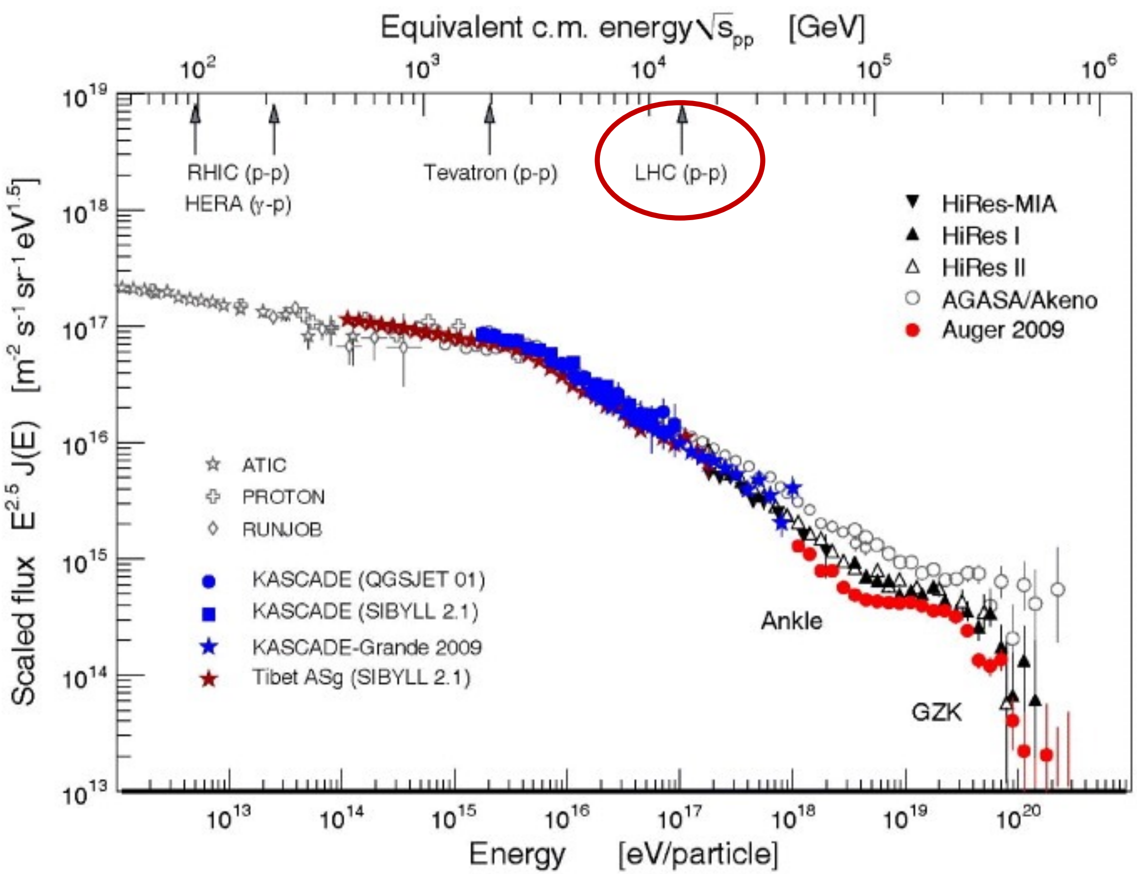
- Origin to 18th century: visible astronomy (positions & magnitudes)
- 19th century: Spectroscopy revolution
- 20th century: Multi-wavelengths revolution
- 21th century: Multi-messenger revolution

- Focus of important international efforts

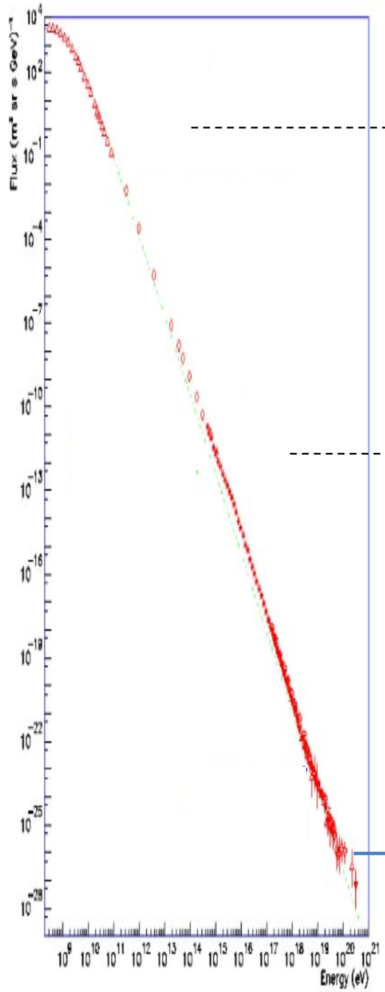


Ultra-High-Energy Cosmic Rays (UHECRs)

★ Astroparticle Physics : High energy physics and astrophysics



UHECR : most energetic particles known in the universe



1 particle per m^2 per second

1 particle per m^2 per year

1 particle per m^2 per billion years !

Important results*

Auger: 3000 km^2
+ upgrade (muon detectors)

NB: GZK effect = interaction of the UHECRs with the ambient photons!

GZK-like attenuation: established!

Composition getting heavier above a few EeV

Departure from isotropy (first order: dipole) at ”low" energies (≥8 EeV, 6%, 6σ)

Correlation with matter (but not discriminating) at intermediate energies (> 3 σ)
(and "anisotropic fraction" ~10%)

Warm spot at intermediate angular scales at the highest energies
(between 2.3 and 3.9 σ)

Shower physics: "muon excess" (indirect)

Composition anisotropy: TBC

Telescope Array:
700 km^2 –> 2800 km^2

GZK-like attenuation: established!

Warm spot at intermediate angular scales at the highest energies (3.4 σ)

Declination-dependent energy spectrum (4.3 σ)

However, no clear progress regarding sources and acceleration mechanisms
+ partially confused observational situation…

*not updated for possible new results presented at the ICRC 2023

UHECR: state of the art

– Regarding astrophysics => we do not know what the sources are!

– Regarding Physics: => we do not know what the acceleration mechanisms are!

=> we do not fully understand the physics of the showers!

– Regarding observations:

=> remarkable progress has been accomplished with the current generation of observatories

NB: current data provide explanation for their shortfall!

=> Now, a new generation is needed:

- larger statistics (as much as possible)
- full sky coverage (as uniformly as possible)
- complementarity between low energies (10^{18}–10^{19} eV) and high energies (10^{20} eV)
- complementarity between precision and statistic
- complementarity between ground-based and space-based instruments

Key white paper in the domain: 2023 state-of-the-art and perspective. TO BE READ!

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Contents lists available at ScienceDirect

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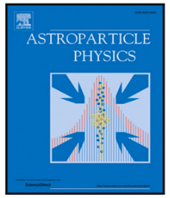
journal homepage: www.elsevier.com/locate/astropartphys



Review

Ultra high energy cosmic rays
The intersection of the Cosmic and Energy Frontiers☆

A. Coleman [1,a], J. Eser [2,a], E. Mayotte [3,a], F. Sarazin [3,a,*], F.G. Schröder [1,4,a,*], D. Soldin [1,5,a],

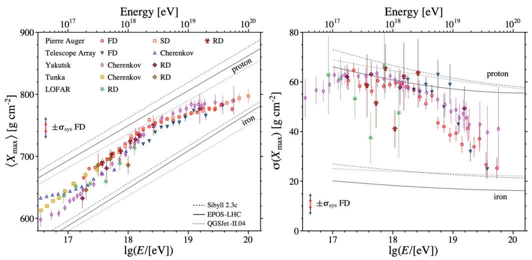
- The next-generation experiments (GCOS, GRAND, and POEMMA) will provide complementary information needed to meet the goals of the UHECR community in the next two decades. They should proceed through their respective next stages of planning and prototyping.

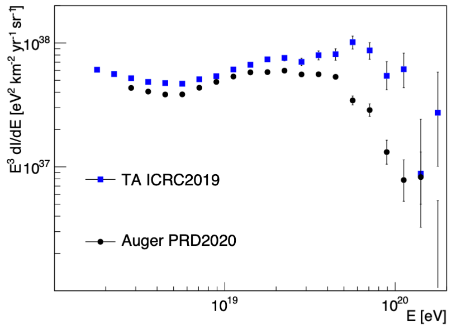
- Full-sky coverage with low cross-hemisphere systematic uncertainties is critical for astrophysical studies. To this end, next generation experiments should be space-based or multi-site.

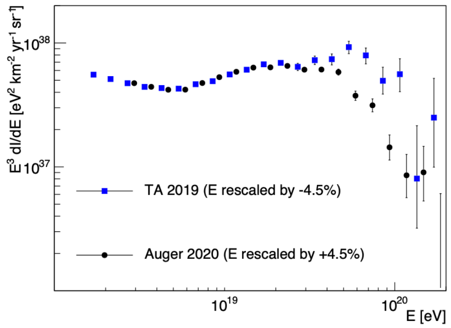
Why go to space for UHECR studies?

★ Full sky!

- ✧ Draw the first full-sky map in UHECRs with a single instrument!
- ✧ Solve tensions and potential discrepancies







- ✧ Study anisotropies with increased power: important focus!
- ✧ All sky <u>with one single instrument</u>: nearly uniform exposure, same performances, same systematics

★ Exposure!

- ✧ Auger and TA are doing miracles, but there is a limit to the area over which one can deploy and maintain UHECR detectors
- ✧ Huge instantaneous aperture, <u>with one single instrument</u>
- ✧ Considerable increase in fluorescence aperture

Why go to space for UHECR studies?

★ Additional physics and science objectives from space

- Atmospheric physics
- TLEs, elves
- Meteors
- Nuclearites, SQM
- Ionosphere (tsunamis…)
- Bioluminescence
- etc.

★ Additional cosmic-ray physics!

- High-altitude showers — shower development in low density medium! (=> addressing the muon problem?)
- composition at higher energy from X_{max} (NB: 1 x Auger = 10 x Auger FD)
- Earth skimming (neutrinos, anitons?, multi-messenger targets of opportunity?)
- Cherenkov detection => down to much lower energies

The JEM-EUSO Collaboration

JEM-EUSO
Joint Exploratory Missions
Extreme Universe
Space Observatory

Joint **E**xploratory **M**issions
towards an **E**xtreme **U**niverse **S**pace **O**bservatory

10 countries, 160 members

Supported by space agencies and national institutes

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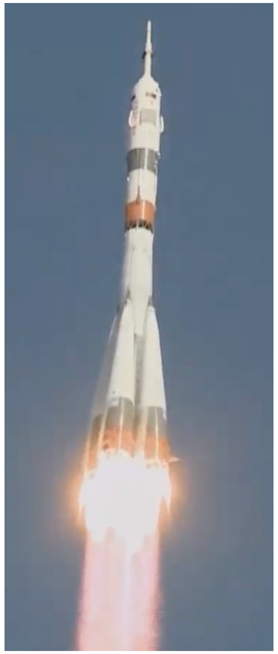
EUSO BALLOON	EUSO TA	EUSO SPB1	MINI EUSO	EUSO SPB2
2014	2014–202x	2017	2019	2023

The JEM-EUSO Program

EUSO-Balloon (2014)

EUSO-TA (1, 2 & 3): since 2014

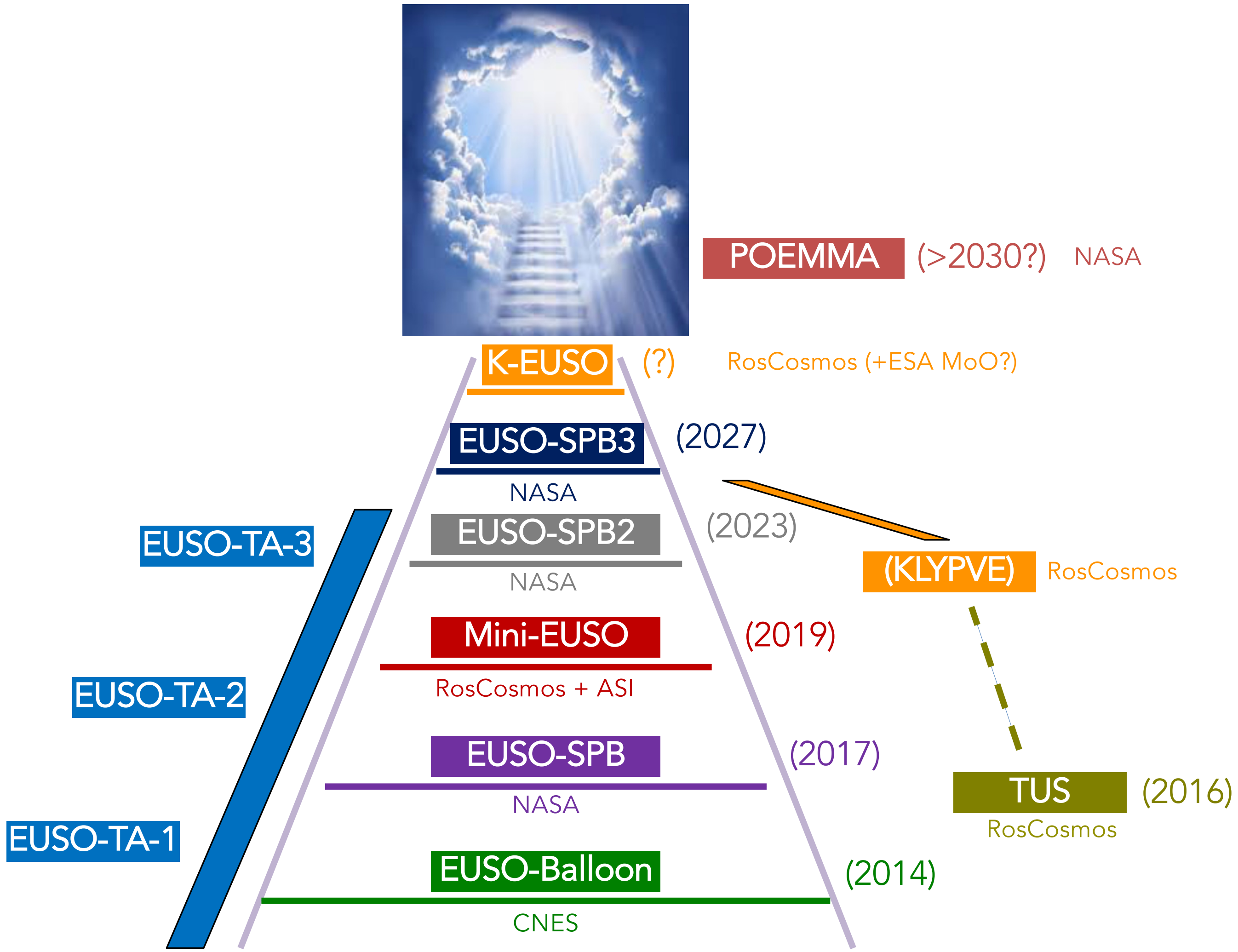


MINI-EUSO (since 2019)

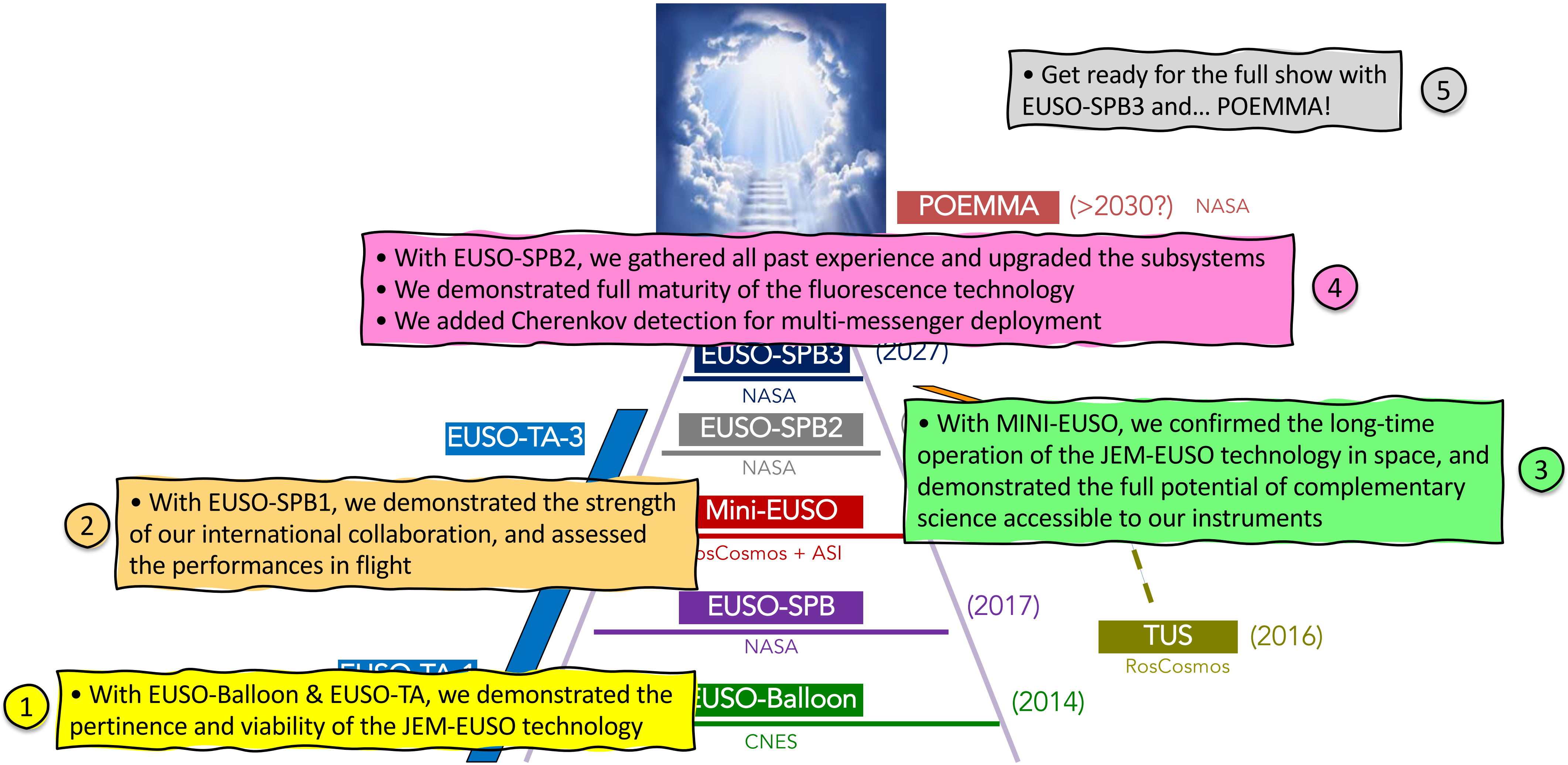
EUSO-SPB1 (2017)

EUSO-SPB2 (2023)

Stairway to heaven!



Stairway to heaven!



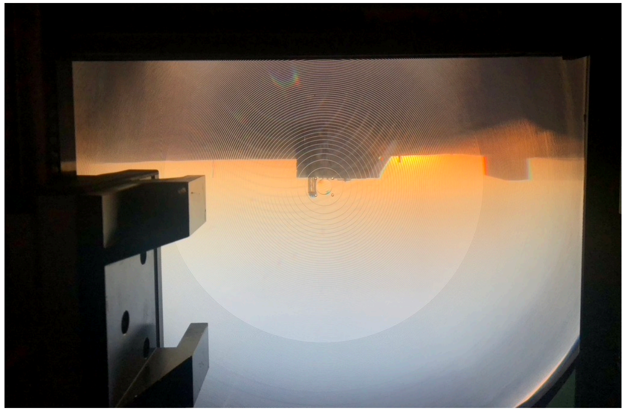
The JEM-EUSO instrumentation

NB: operating from space

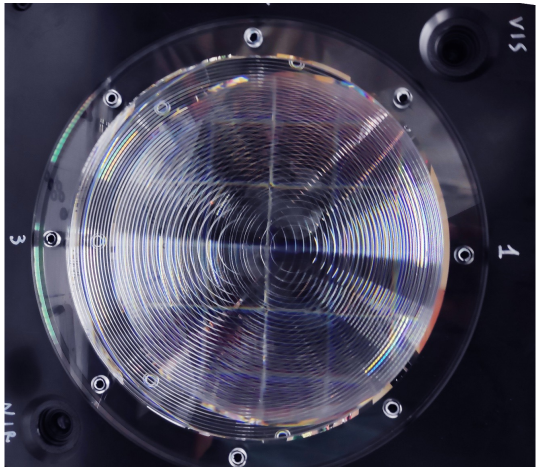
Larger distance => larger exposure
but also fewer photons => higher E threshold
=> requires large collection area

Optics:

=> large Fresnel lenses (Japan)
=> large mirror (Schmidt)
(Czech Rep.)



Looking through EUSO-TA optics

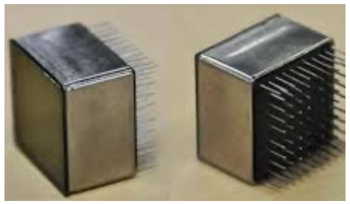


MINI-EUSO Fresnel optics

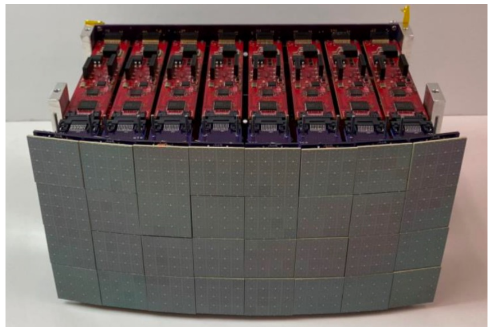
EUSO-SPB2 mirrors

Photosensors:

=> MAPMT (Hamamatsu, Japan)
(Fluorescence telescope)
=> SiPM (Hamamatsu, USA)
(Cherenkov telescope)



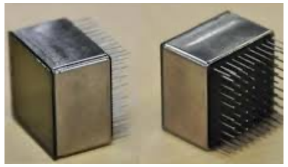
MAPMT 64 pixels

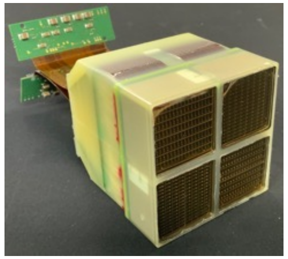


Cherenkov camera of EUSO-SPB2 (USA)

The JEM-EUSO instrumentation

Detection units: (France)

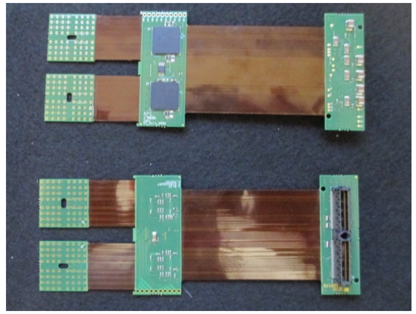




3rd generation "elementary cells"

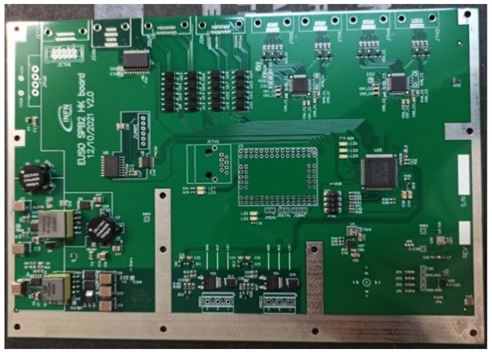
Electronics: => Dedicated ASIC (France)

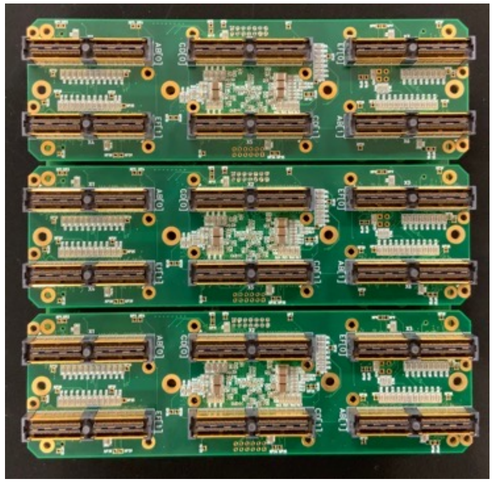
=> Dedicated HVPS (Poland)



Data acquisition: => FPGA, Zynq (Russia)

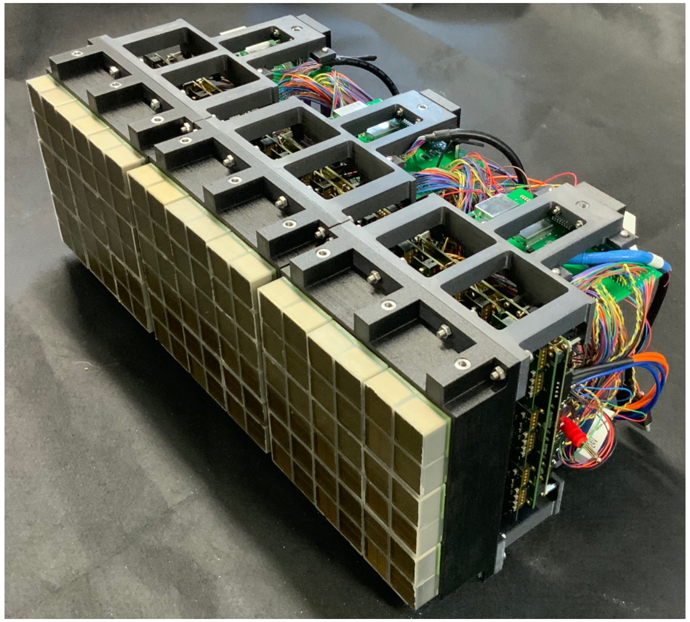
Data processing and control: (Italy)

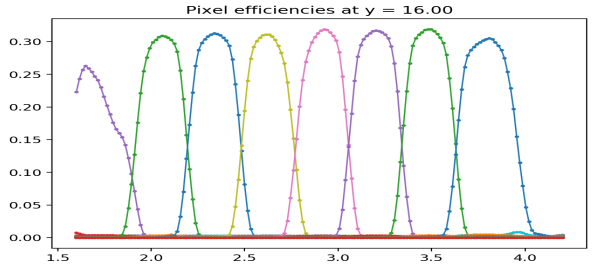


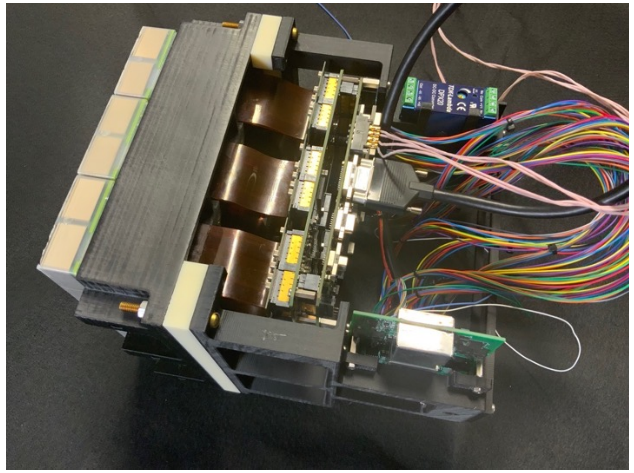


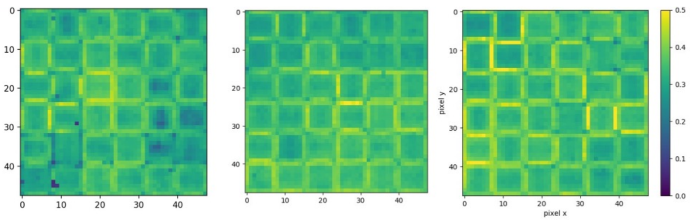
The JEM-EUSO instrumentation

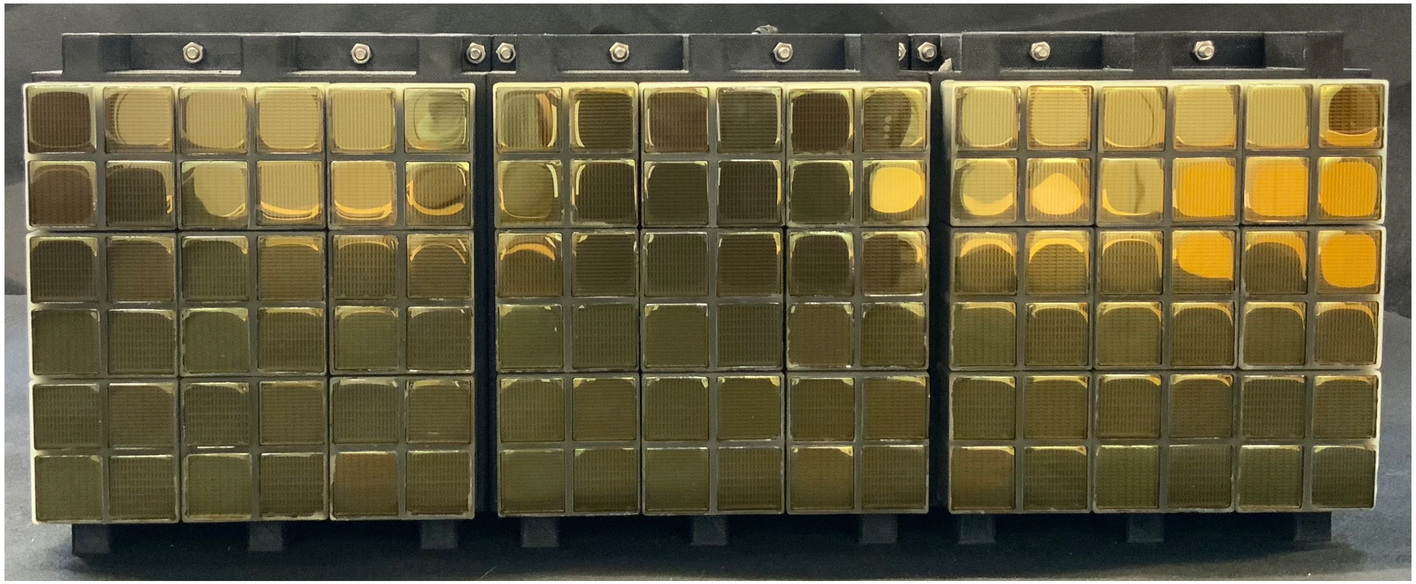
Assembled photodetection modules:











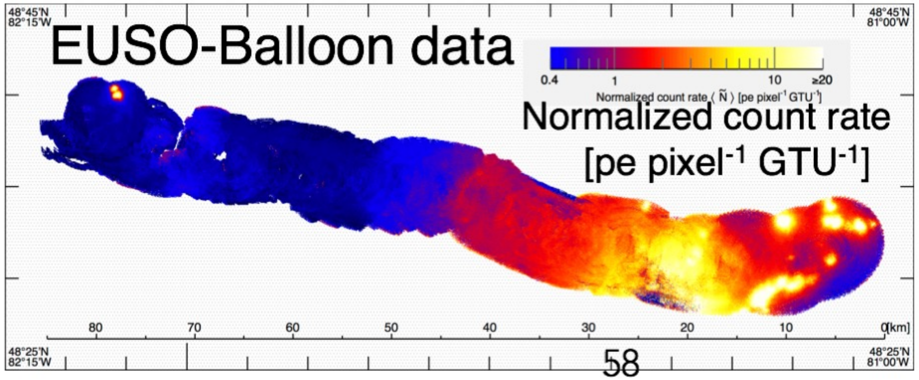
The three photodetection modules of EUSO-SPB2

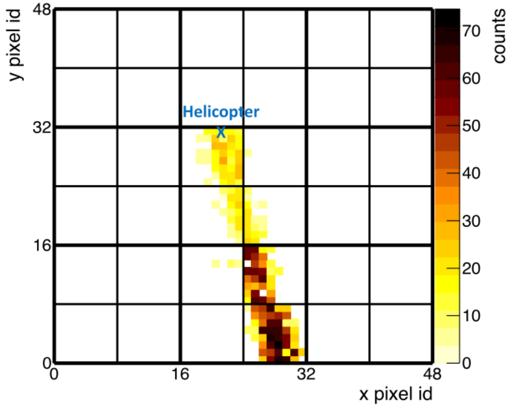
(6912 pixels with single photon sensitivity and 1 μs resolution)

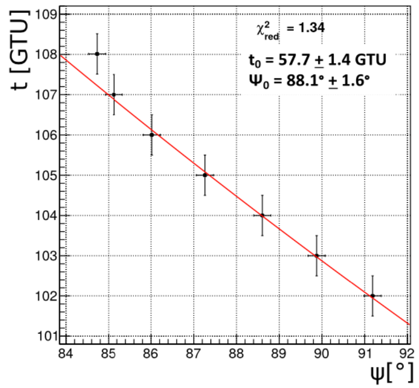
EUSO-BALLOON:

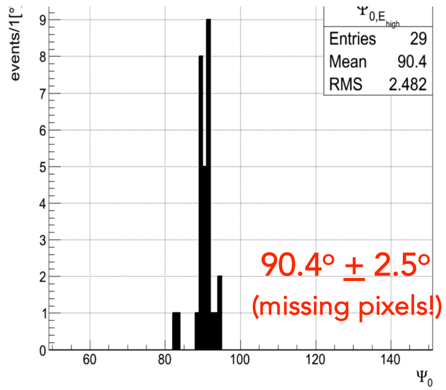
CNES mission, 2014

1 night flight with 1 PDM







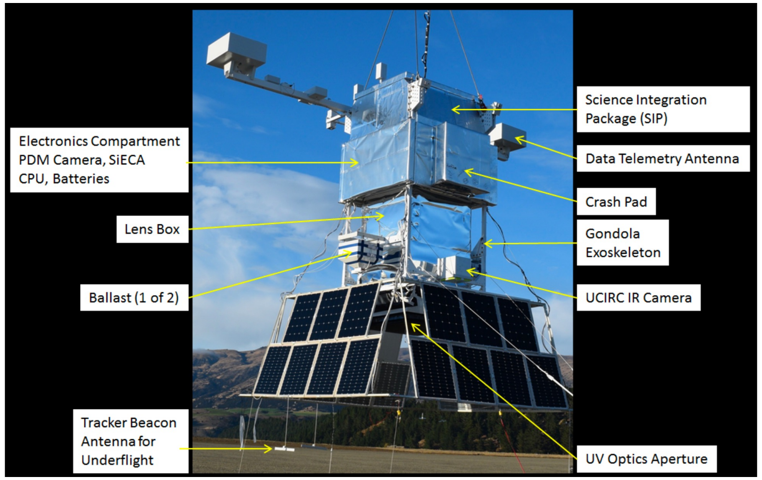


Main innovations:
- front-end electronics (SPACIROC 1)
- HVPS (low consumption + switch)
- Efficient data processing
- Operation at 3 mbar

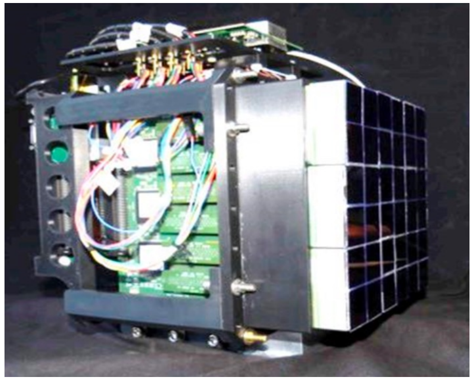
Main teachings:
- UV emissivity w/ or w/o cloud
- UV / IR anti-correlation (expected)
- Laser events reconstruction
- Serendipitous flash source detection

EUSO-SPB: (super pressure balloon)

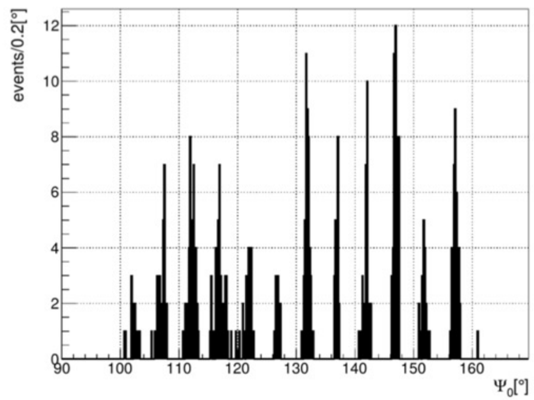
NASA mission, 2017



<u>Main improvements</u>:
- Upgraded electronics: SPACIROC 3
- 2nd generation of the detection unit
- Complete autonomous scheme with trigger
- Solar panels for long duration flight
- Optics performance + stability



Photodetection module

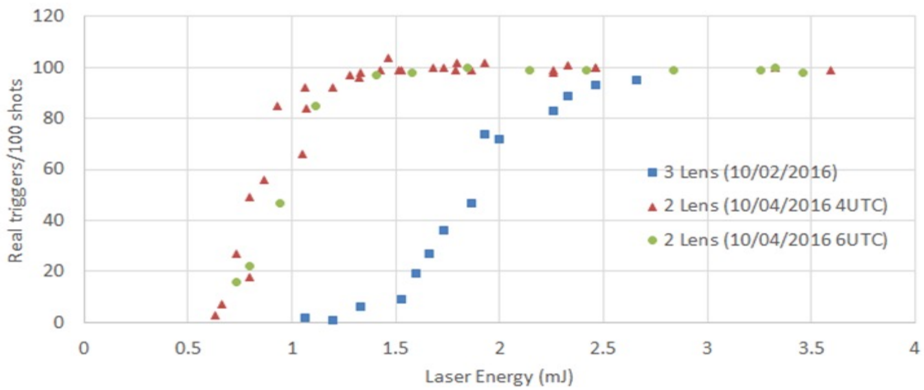


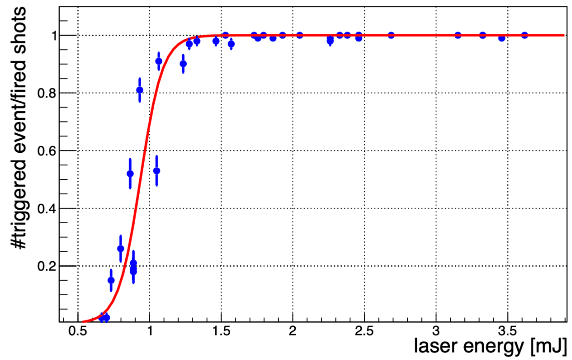
Angular resolution better than 1°

EUSO-SPB:

Energy threshold	≈3 EeV
Trigger aperture	≈20 km^{2}sr @ 5 EeV
	≈200 km^{2}sr @ 10 EeV
Telescope optics	2×1 m^2 Fresnel lenses
Field of view	11.1°×11.1°
Pixel field of view	0.2°×0.2°
Pixel ground footprint	120 m×120 m
Number of pixels	2304 (48×48)
MAPMT	R11265-113-M64-MOD2
UV transmitting filter	BG-3, 2 mm thick
Read out	DC coupled
Time bin duration	2.5 μs integration
Balloon	18×10^6 ft^3 (0.5×10^6 m^3)
Nominal float height	33.5 km (110000 ft)
Telemetry (data)	2×≈ 75 kbits/s
Telemetry (comms)	≈1.2 kbits/s (255 bit bursts)
Power consumption	40 W (day) 70 W (night)
Batteries	10 each 42 A·h
Solar panels	3×100 W on all 4 sides
Detector weight	1223 kg (2250 lbs)
Releasable ballast	545 kg (1200 lbs)
Total weight	2500 kg (5500 lbs)
Flight start	April 24 23:51 UTC 2017
Flight end	May 6 3:40 UTC 2017
Flight duration	12 days 4 hours

Energy-equivalent threshold measurement

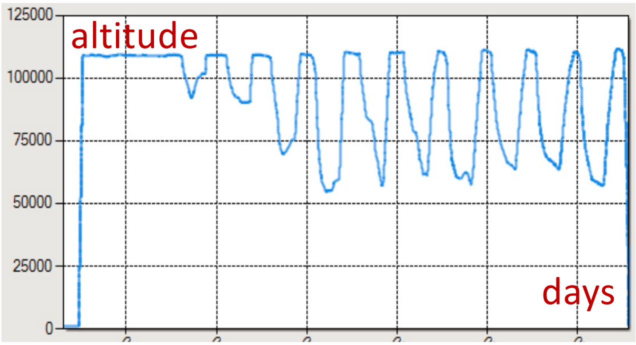


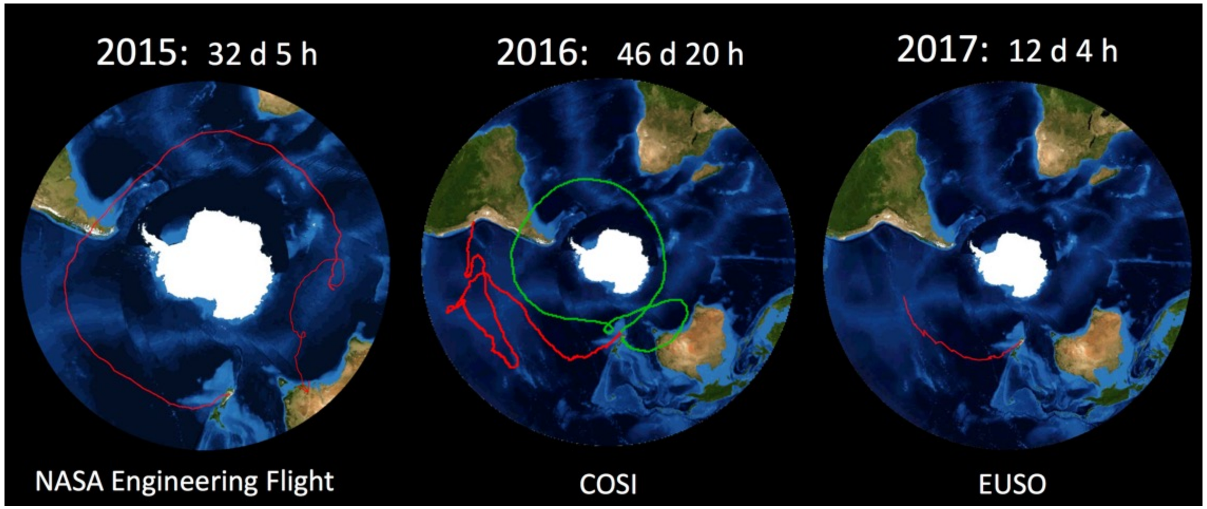


E_{th} ~ 3 EeV

=> 1–2 showers/month expected

Successful launch (April 2017) But… leaking balloon!





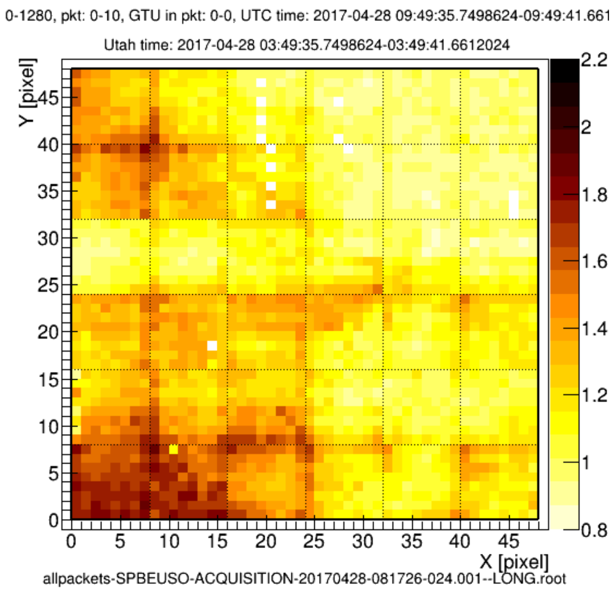
EUSO-SPB:

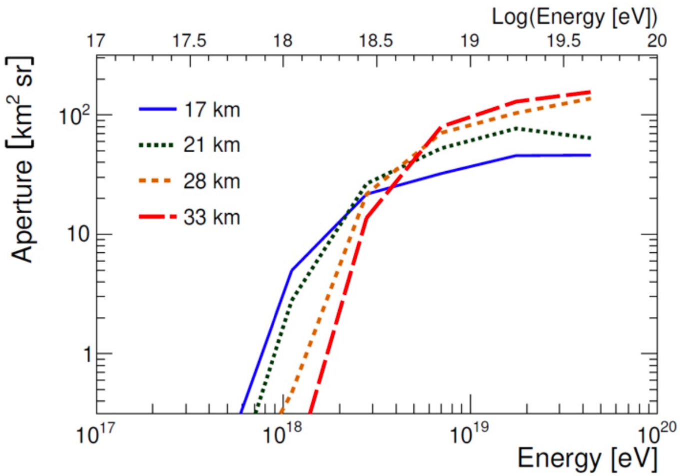
Nominally working instrument!

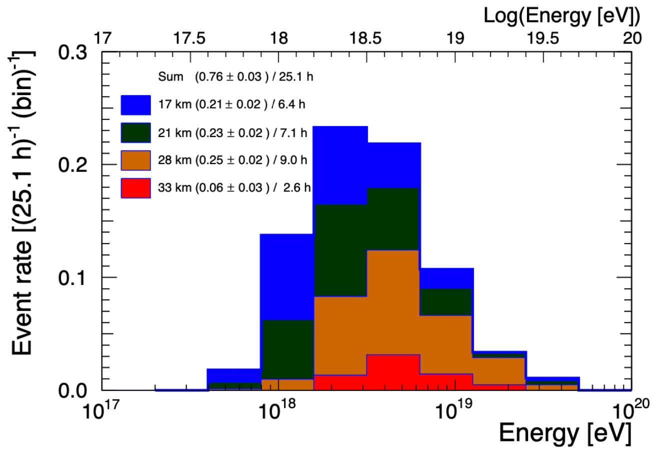
Photometric stability: ±5%

25.1 hours of downloaded data

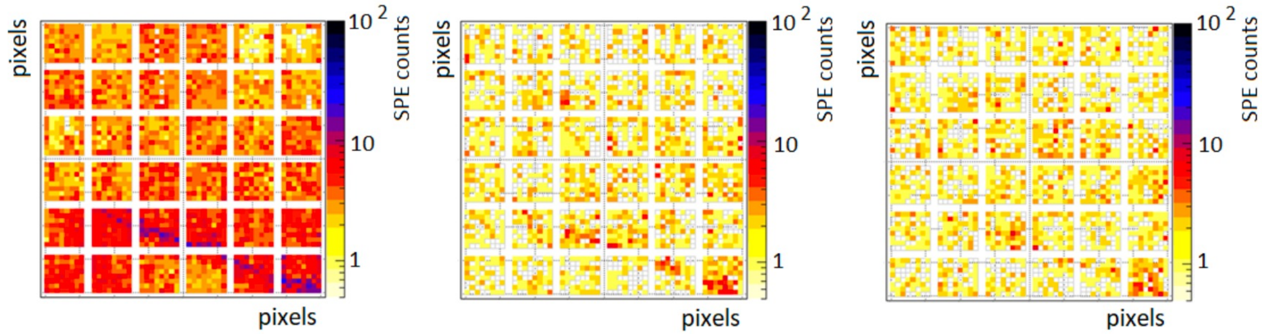
Clouds across the field of view







0.7 ± 0.03 events for the 25.1 hours => reduced to 0.4 event (clouds)



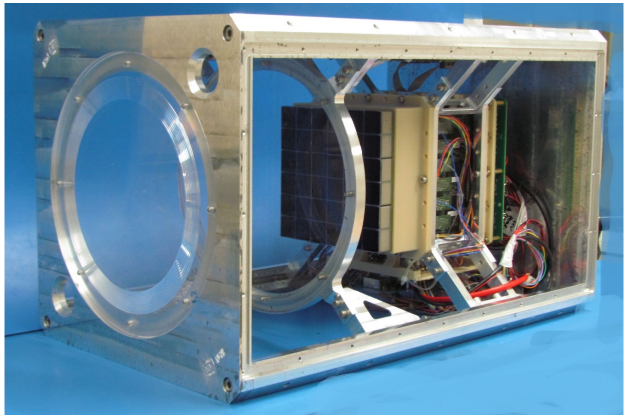
Direct cosmic-ray hit: 3 consecutive frames (2.5 µs)

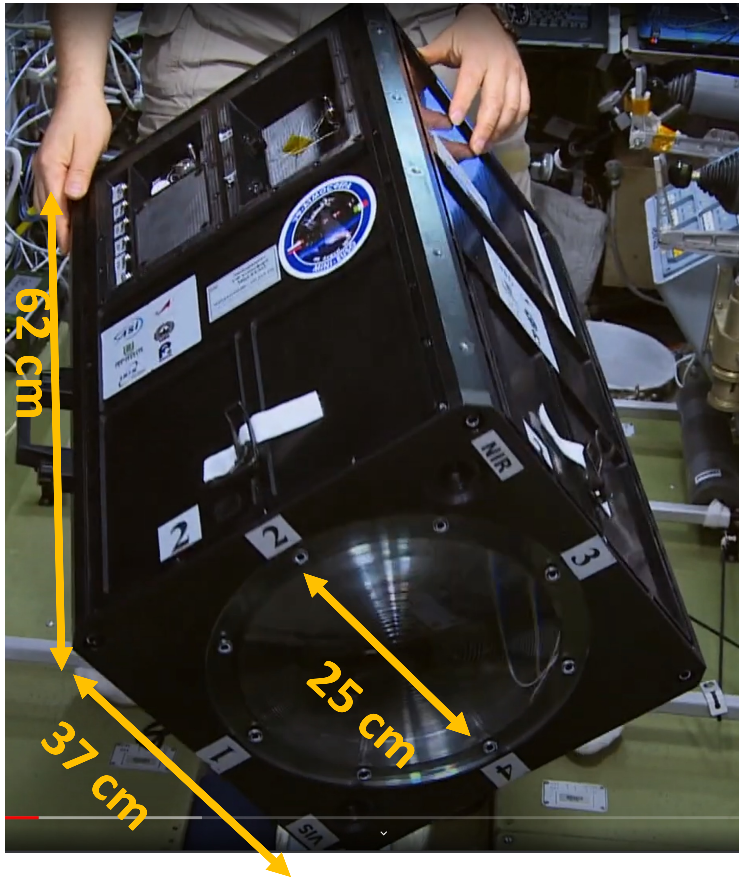
NB: 5 µs persistence of the track

=> useful classification of ≠ types of direct CR hits

MINI-EUSO:

ASI & ROSCOSMOS mission, in the ISS since 2019





Weightlessness is real!

MINI-EUSO:

Major asset: 3 timescales operating in parallel!

Level 1: Basic time resolution: 2.5 μs

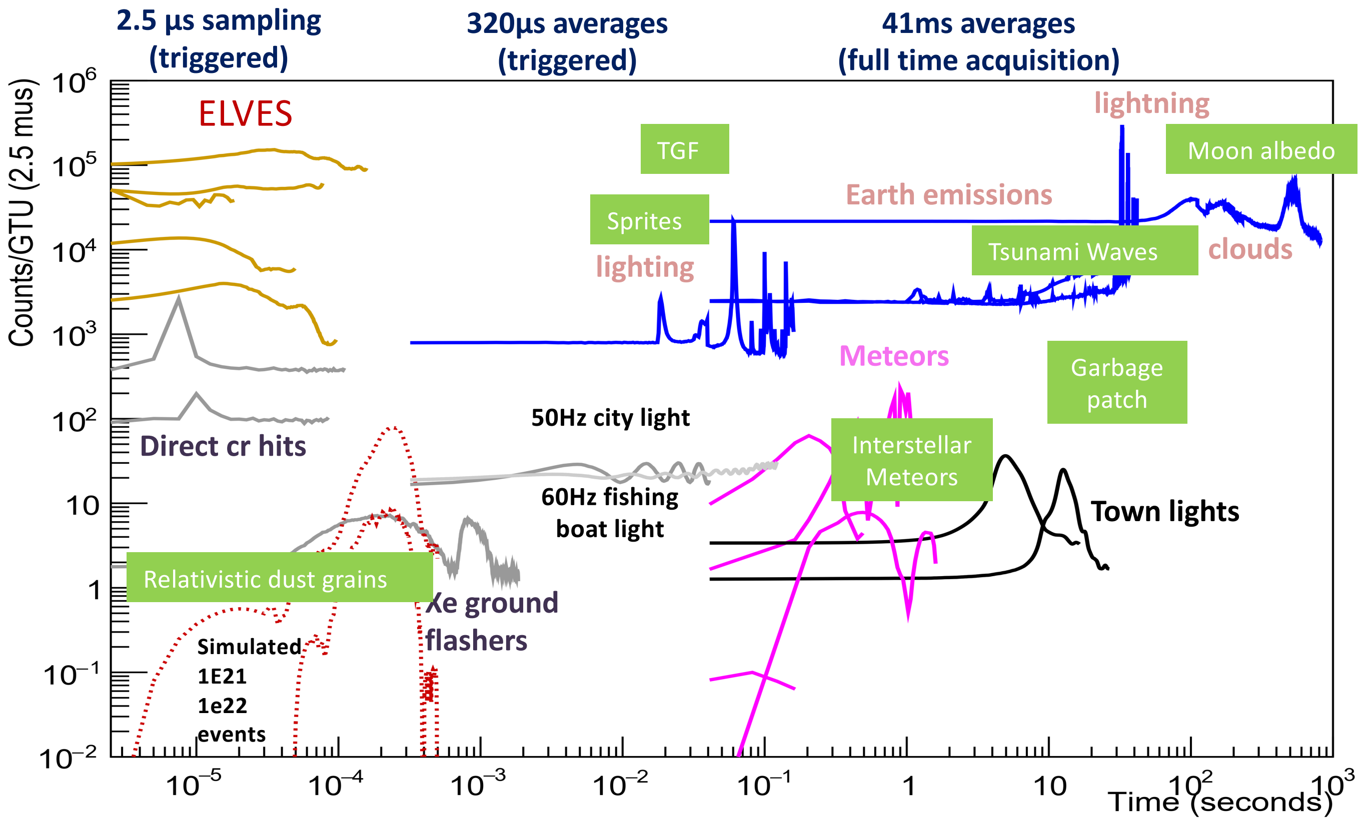
- Cosmic-rays
- Elves
- Relativistic grains?
- Artificial flashers

Level 2: 128 x 2.5 μs = 320 μs

- Some TLEs
- Cities
- Anthropogenic activity

Level 3: 128 x 320 μs = 40.96 ms

- Lightning
- Clouds
- Ionospheric waves (tsunami)
- Natural and non natural emissions

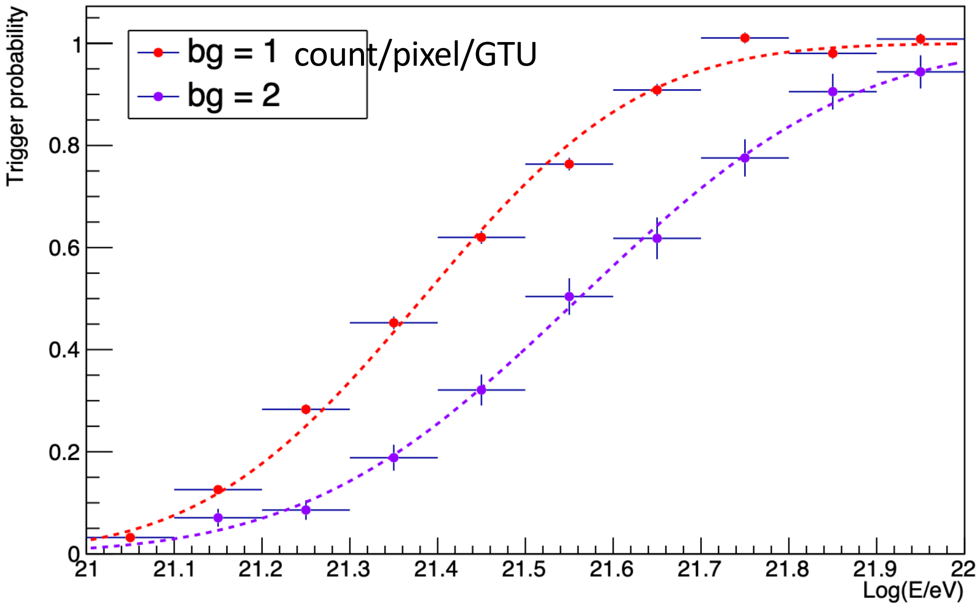


+ unknown emissions!

MINI-EUSO:

End-to-end calibration with ground flashers!

- UHECRs None of course: high energy threshold ($\sim 3\ 10^{21}$ eV)



<u>We have learned a lot about:</u>

- the performance of our technology
- the background for UHECR detection
- the diversity and importance of complementary objectives

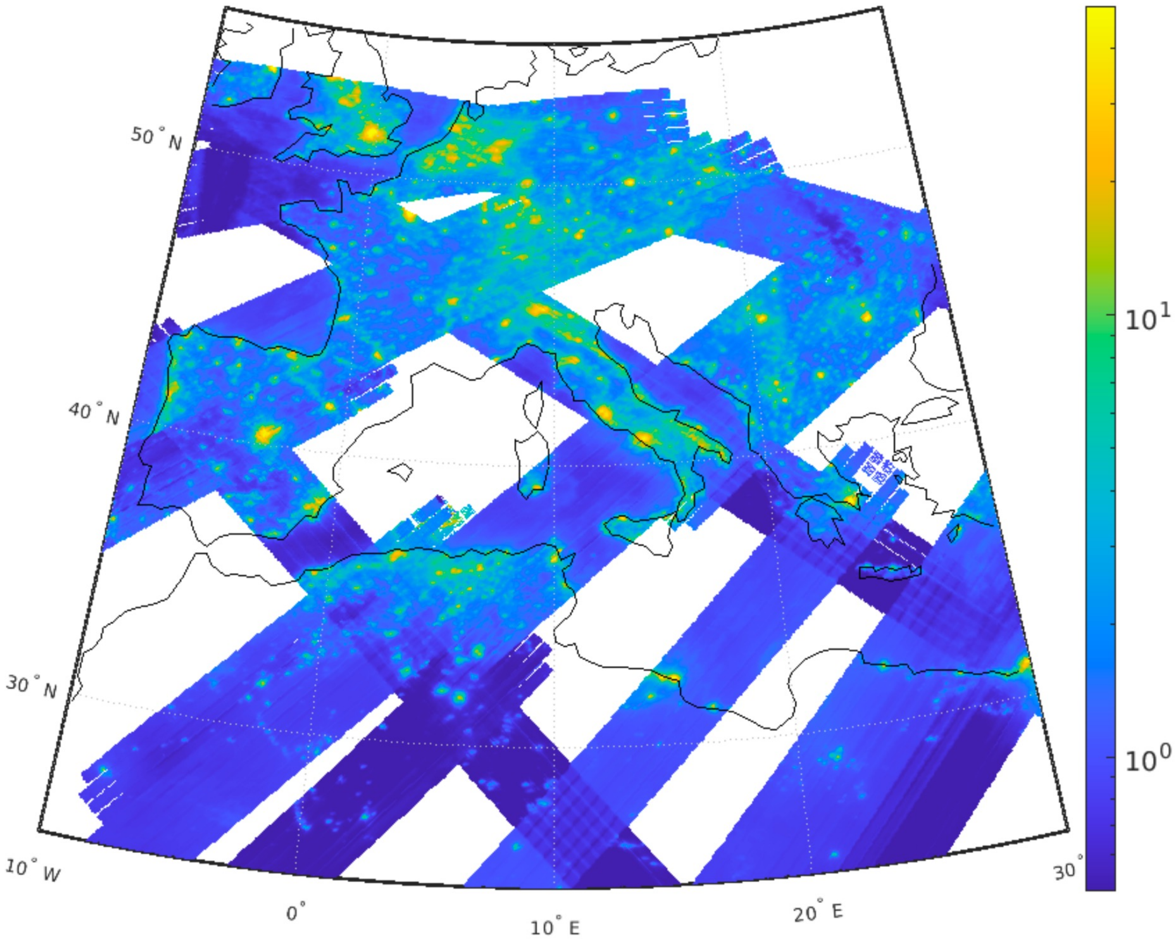
- NB: ~80 sessions so far! ∼250 hours of data

Very precious crew time + very efficient contribution of cosmonauts!

MINI-EUSO:

Mapping the Earth in the UV… for the first time!!!

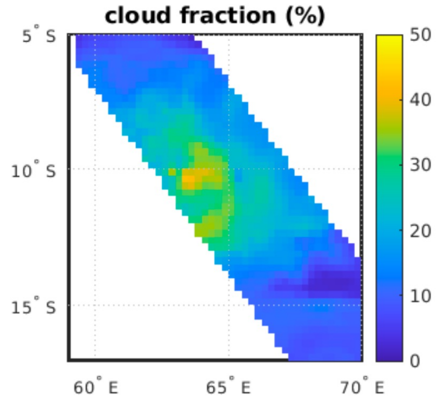
(MINI-EUSO pixel size: 6.1 km)

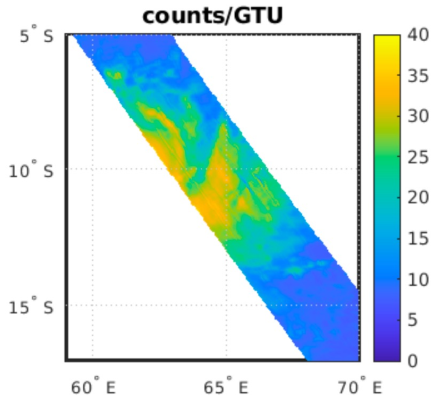


=> new Google map!

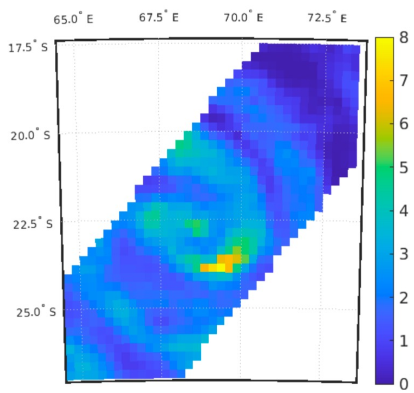
MINI-EUSO:

Clouds, etc.

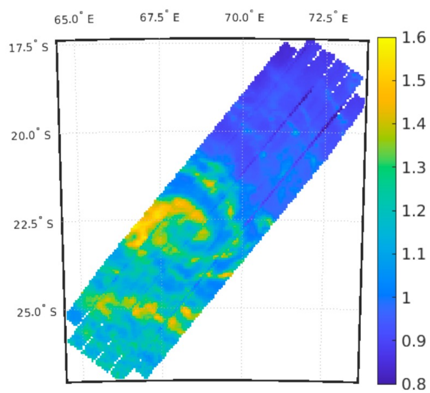




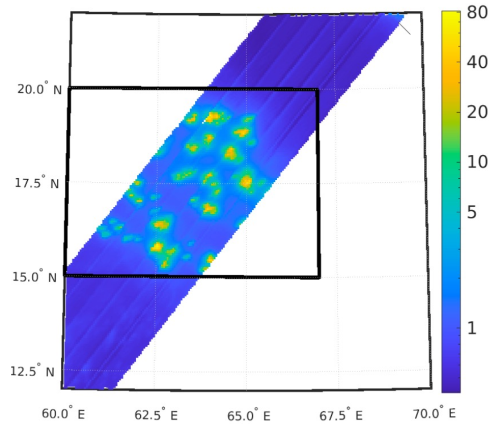
GFS (Global Forecast System)



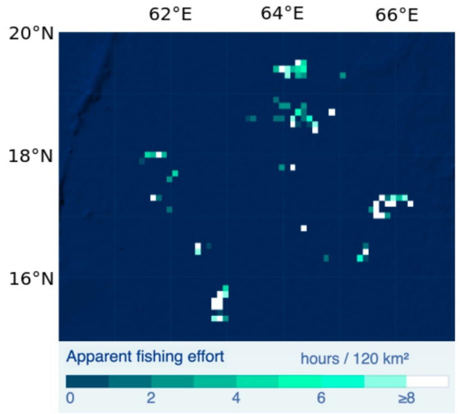
MINI-EUSO



Human activities…



MINI-EUSO: fishing boats!



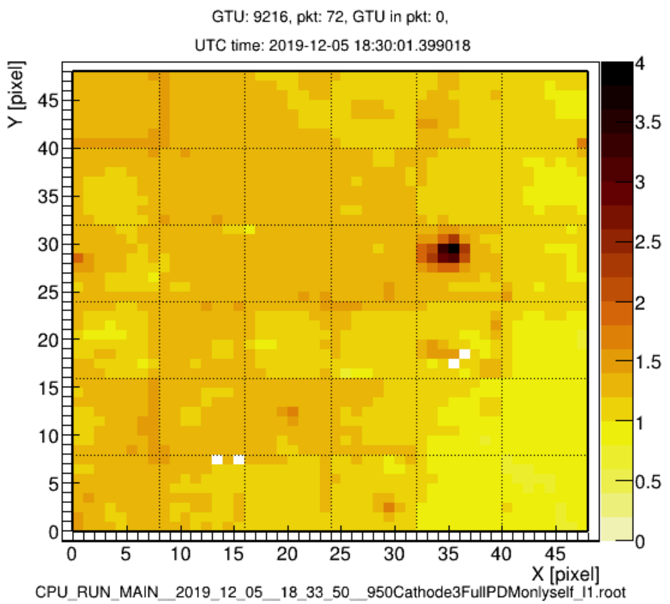
map of apparent fishing activity from the Global Fishing Watch

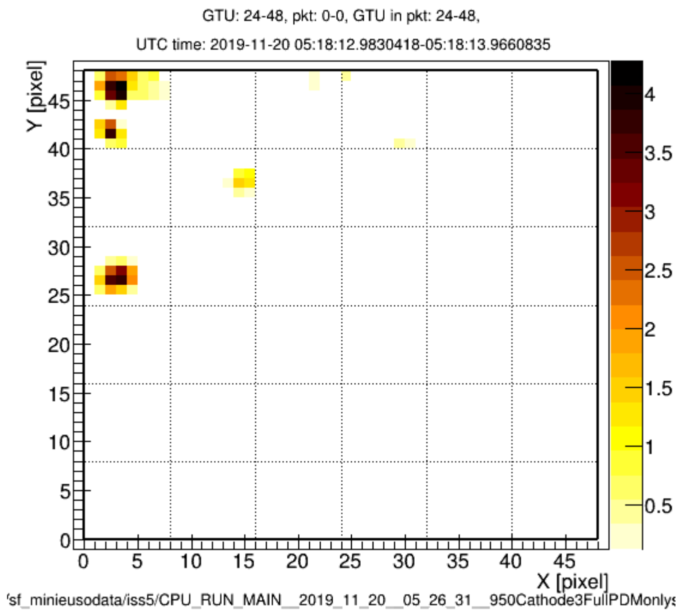
MINI-EUSO:

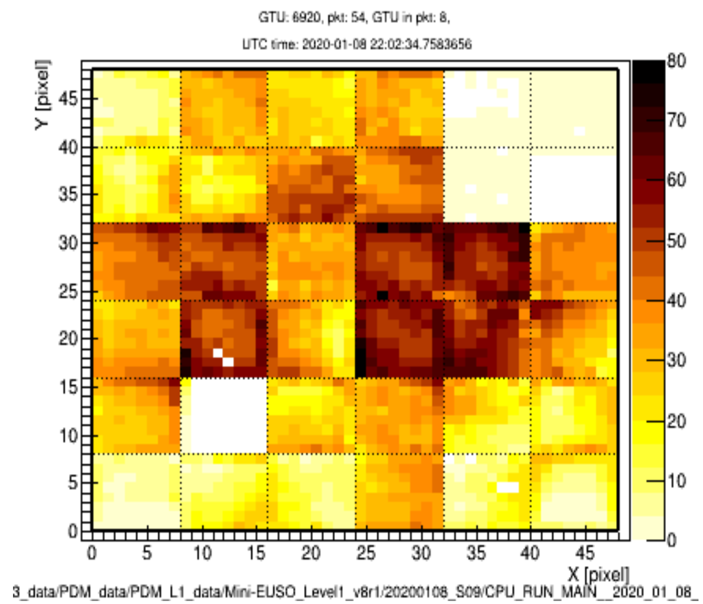
Clouds, etc.

Ground emissions (cities…)

Moon reflection!







(ISS orbital velocity: ~ 7 km/s)

(static!)

+ large number of meteors (>1000)

Visible down to magnitude 6.5 (~ 3 mg)

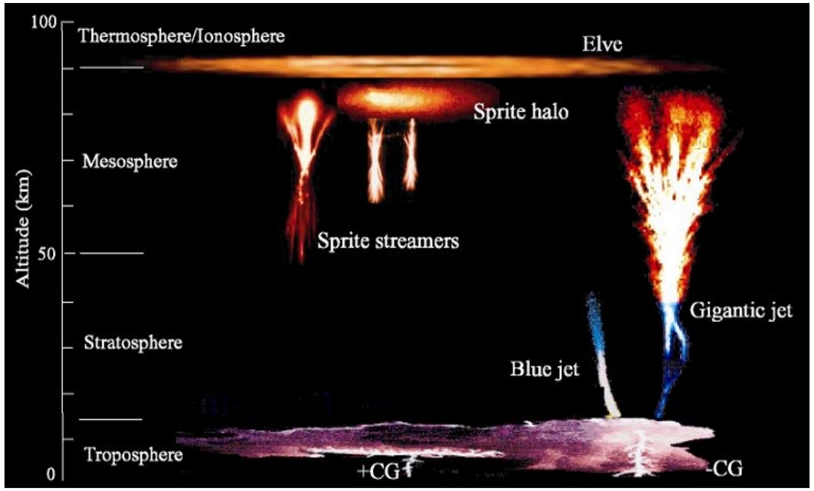
(fully efficient above magnitude 5, i.e. ~ 10 mg)

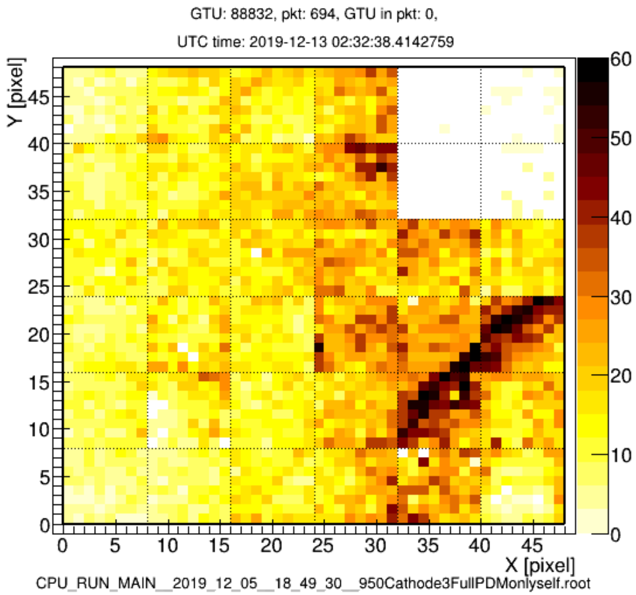
MINI-EUSO:

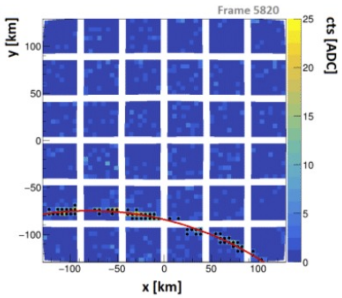
- Elves

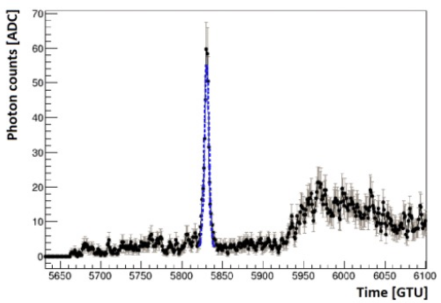
MINI-EUSO offers unprecedented precision and imaging capability

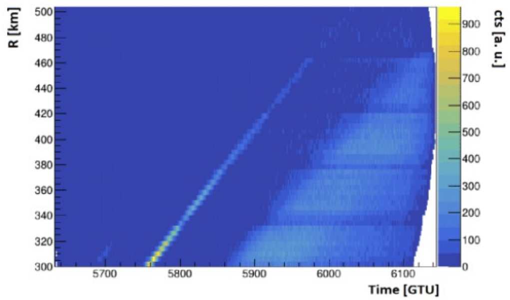
=> new physics discoveries!

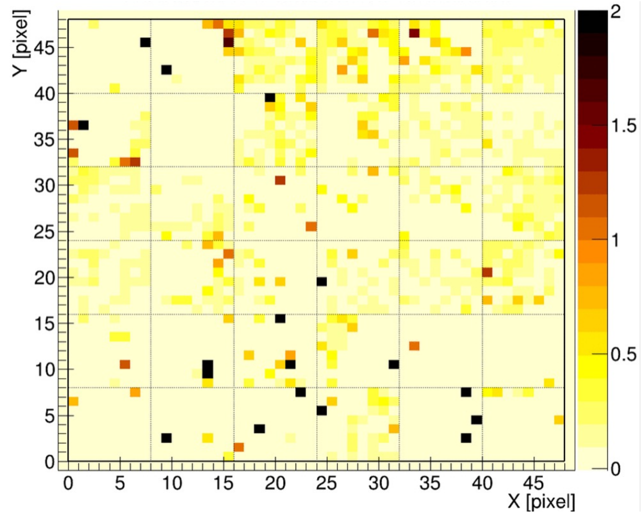












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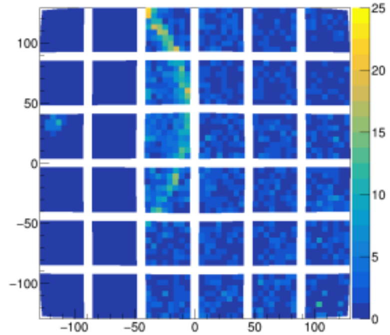
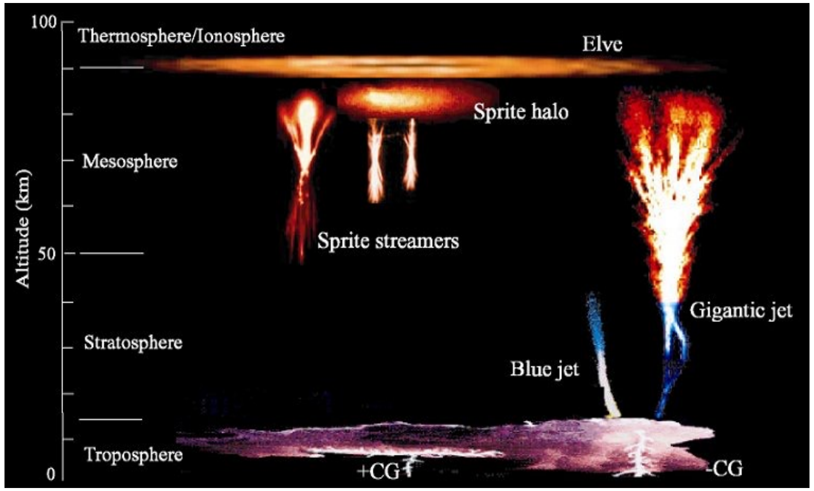
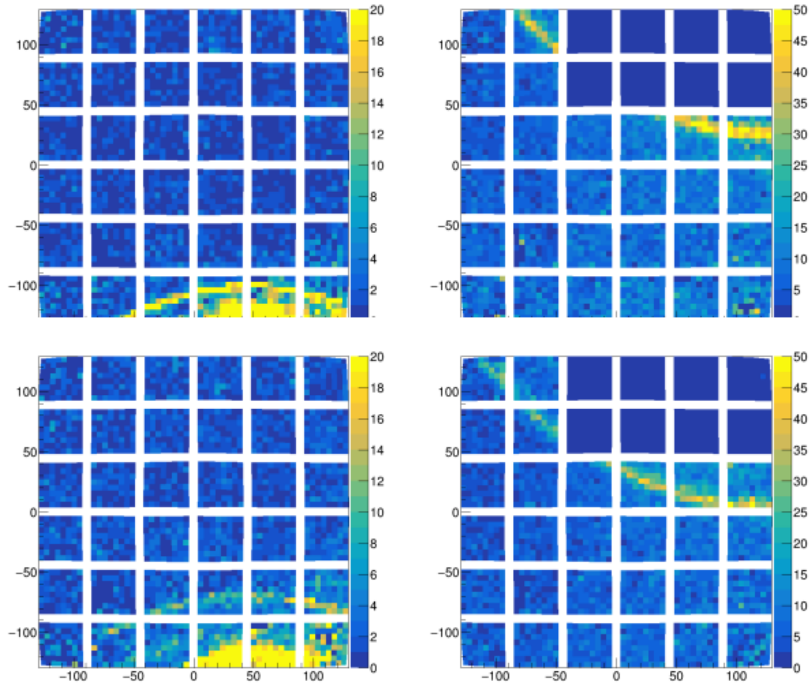
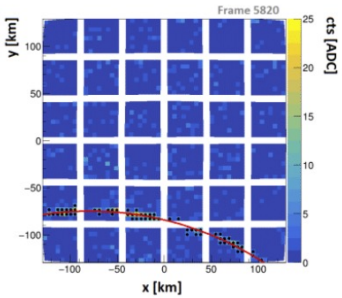
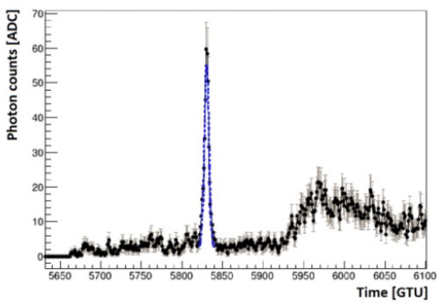
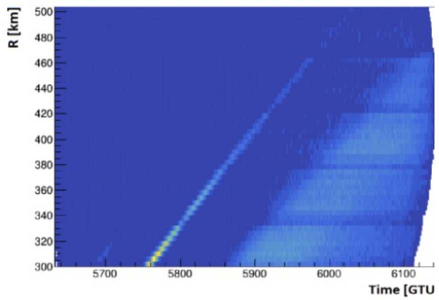












EUSO-SPB2:

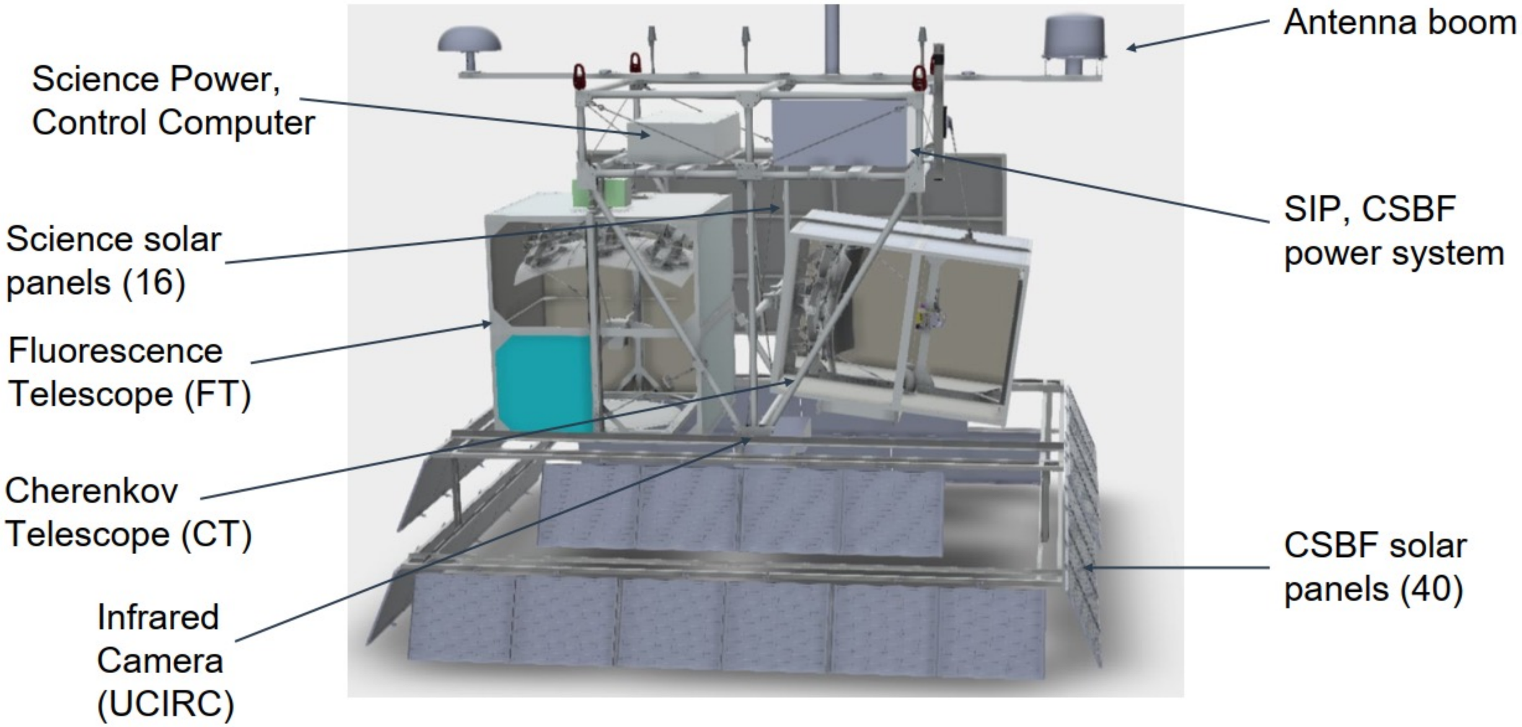
NASA mission on a super pressure balloon => long duration

Pathfinder to POEMMA

Two telescopes in one mission:

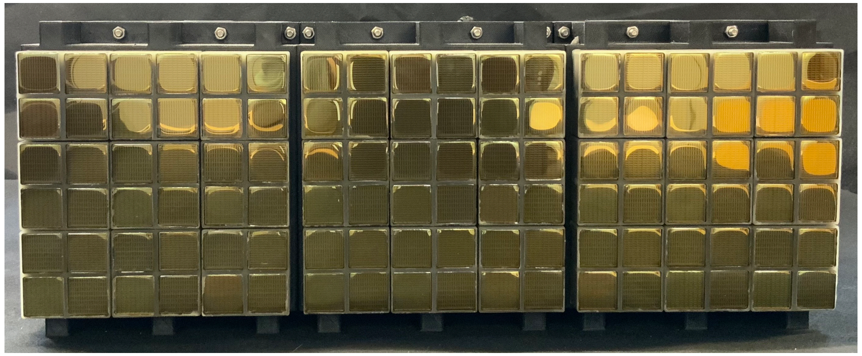
Fluorescence telescope: pointing to nadir

Cherenkov telescope: pointing to the limb (upward going neutrinos + CR direct Cherenkov)

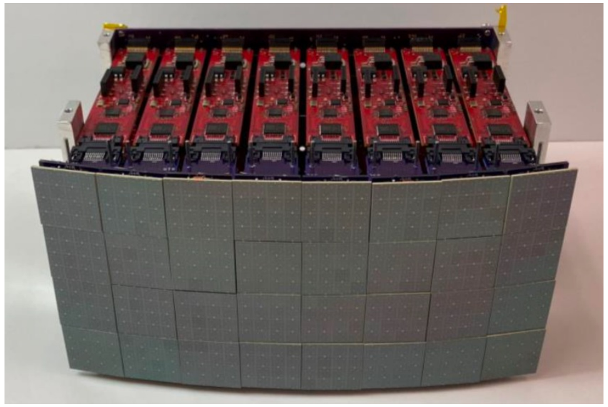


EUSO-SPB2:

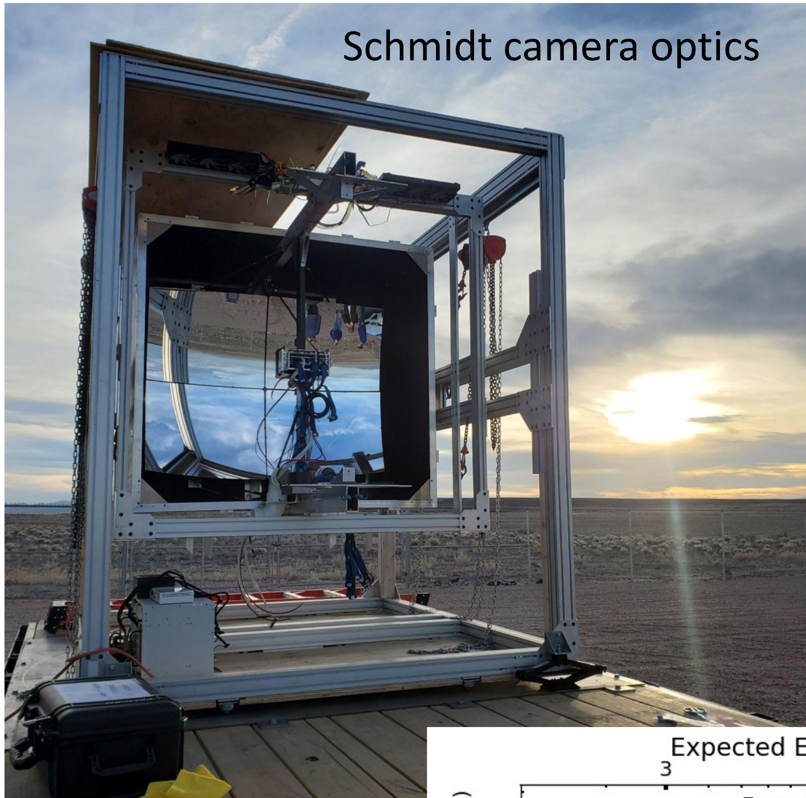
Fluorescence telescope focal surface



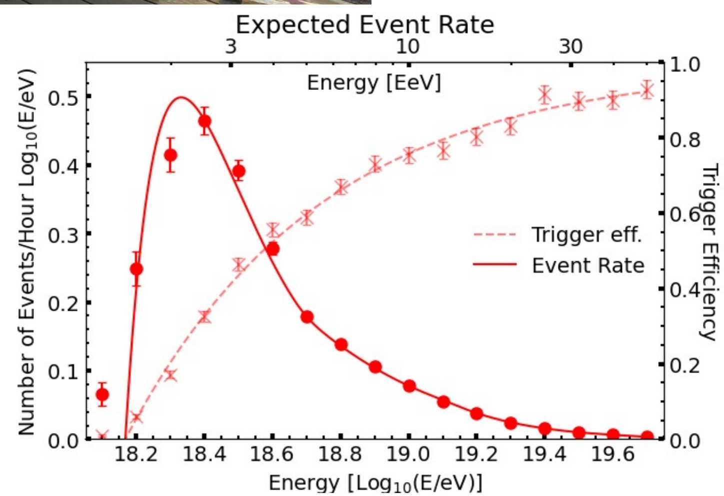
Cherenkov telescope focal surface



Schmidt camera optics



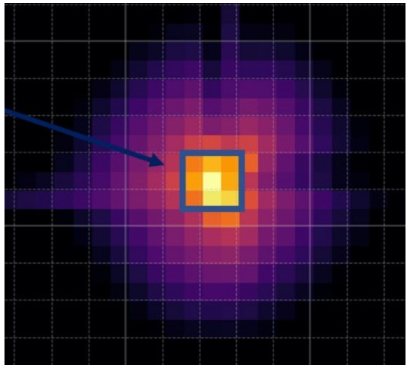
First CR events seen from above (in fluorescence) expected

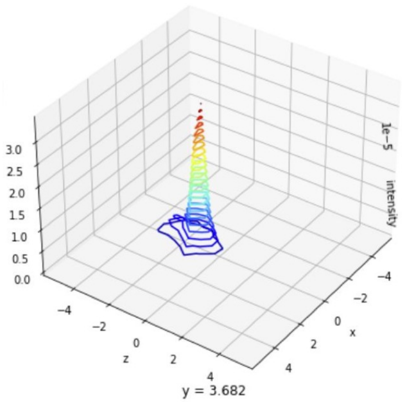


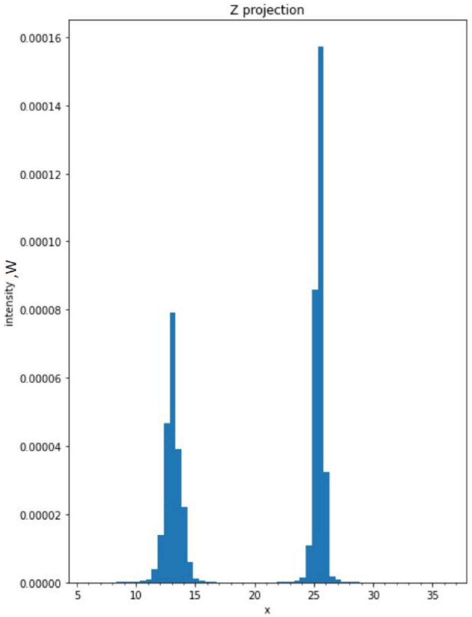
EUSO-SPB2:

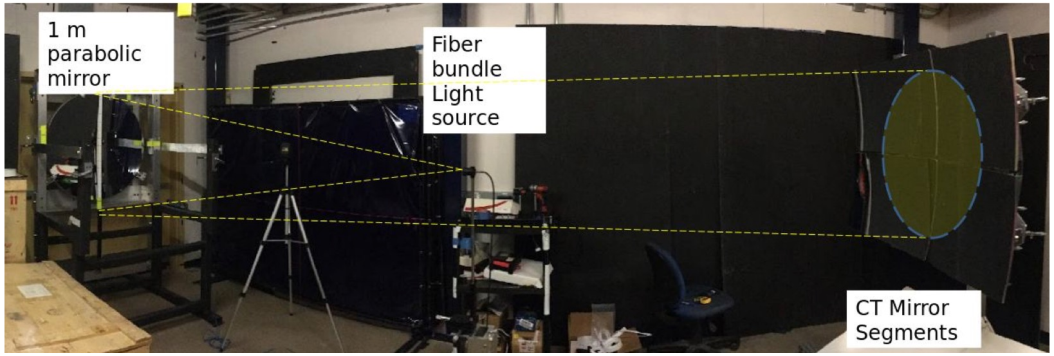
PSF: optics measurements in lab

95% of the energy with r = 1.8 mm (CT), 2.1 mm (FT)









EUSO-SPB2:

THANKS A LOT to Telescope Array people!!!

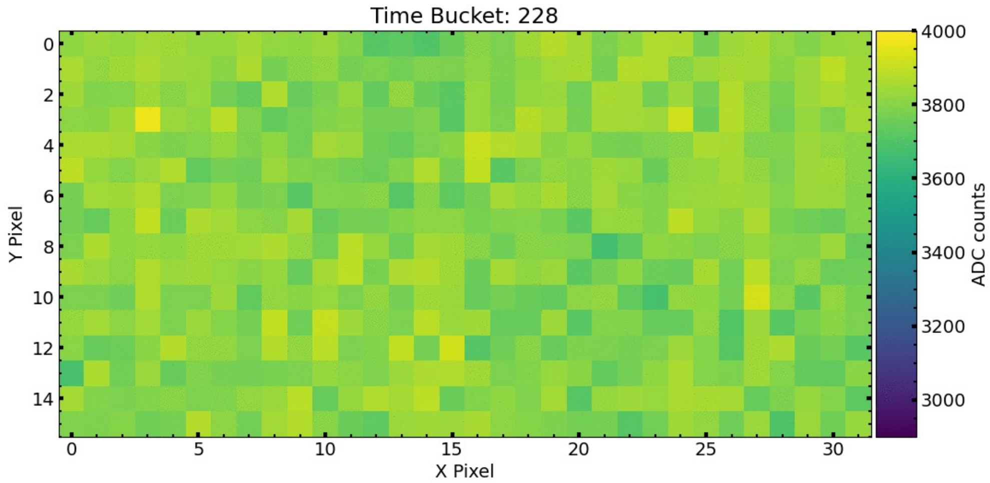
Field test of the Cherenkov telescope (March 2022)

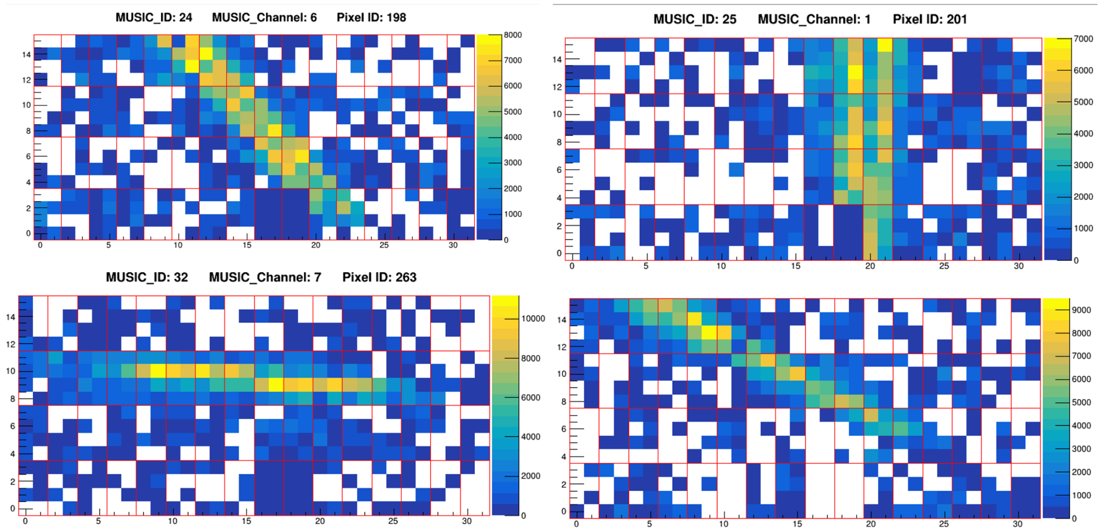
Cherenkov Telescope

Laser System

EUSO-SPB2:

Field test of the Cherenkov telescope (March 2022)



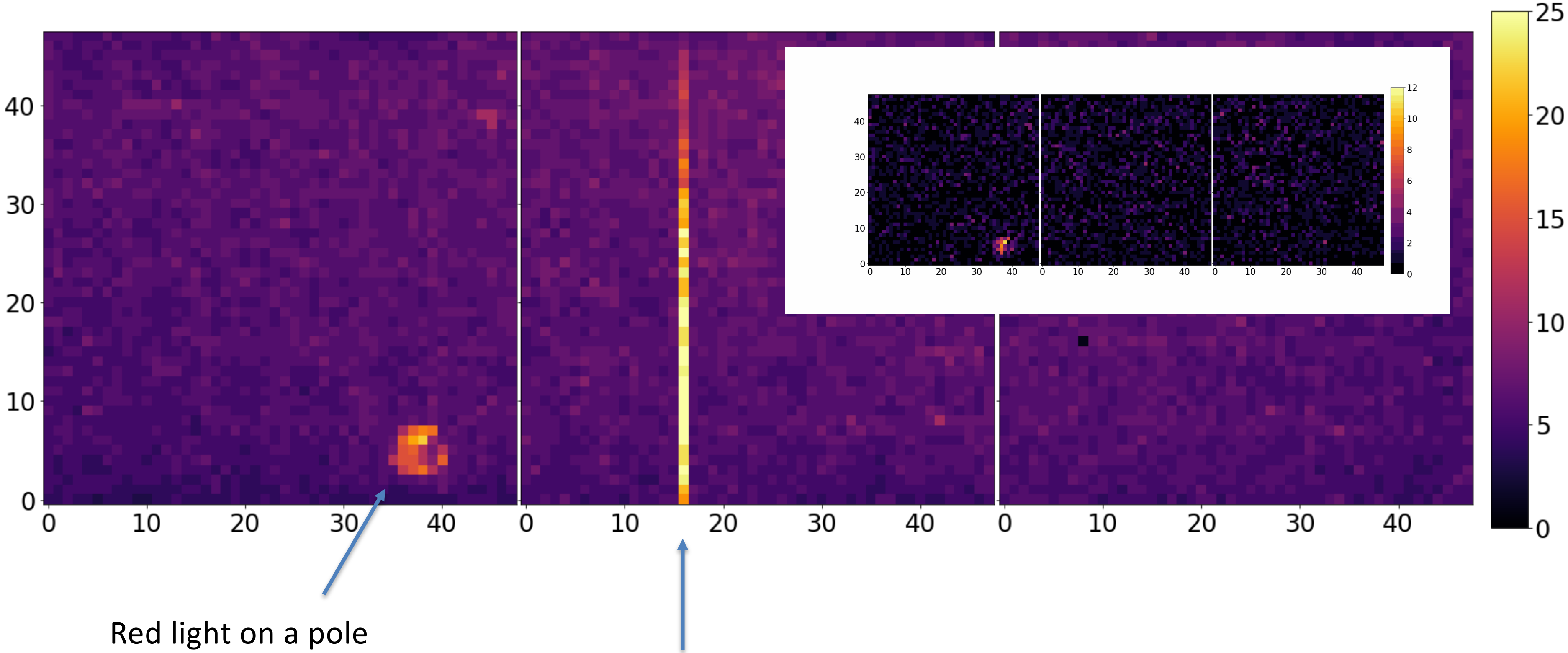


Bi-focal mirror in action!

EUSO-SPB2:

Field test of the Fluorescence telescope (August 2022)

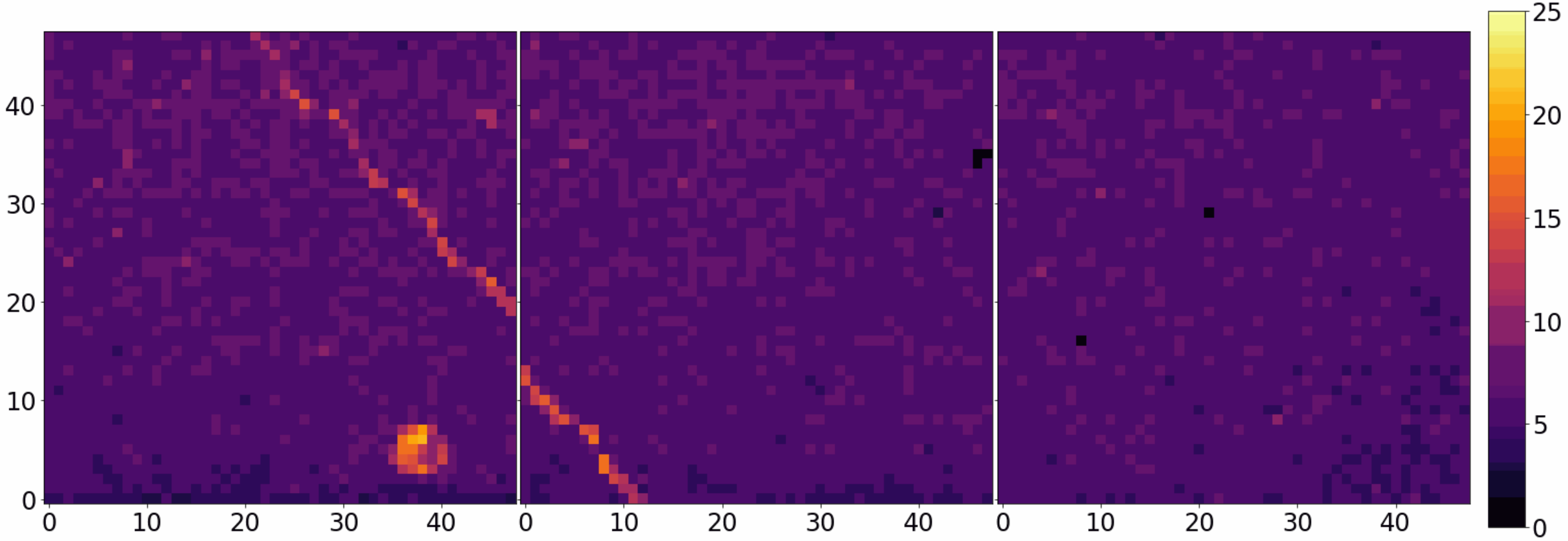
Laser sweep in the field of you: Ready for the show?



Red light on a pole in the field of view

Beautifully focused, vertical laser track! (within 1 pixel!)

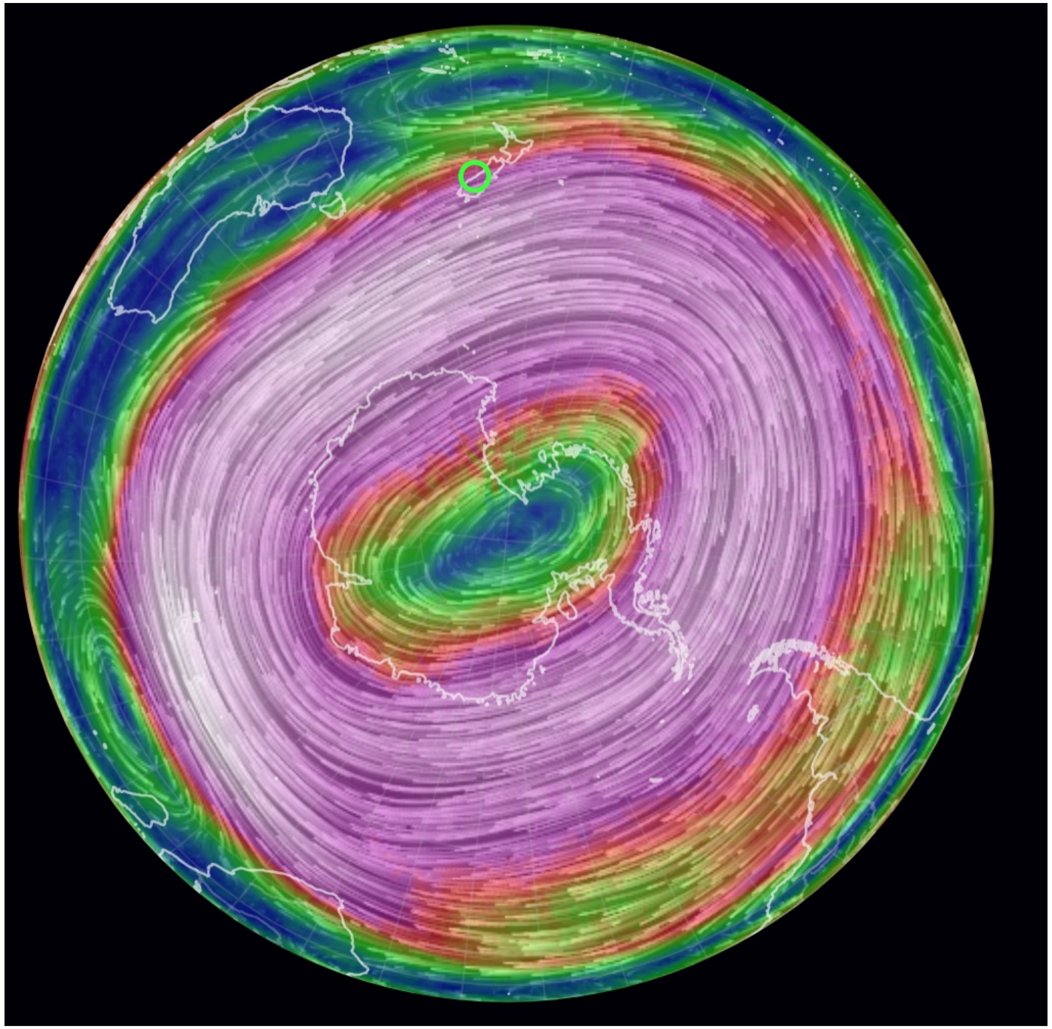
ENJOY!



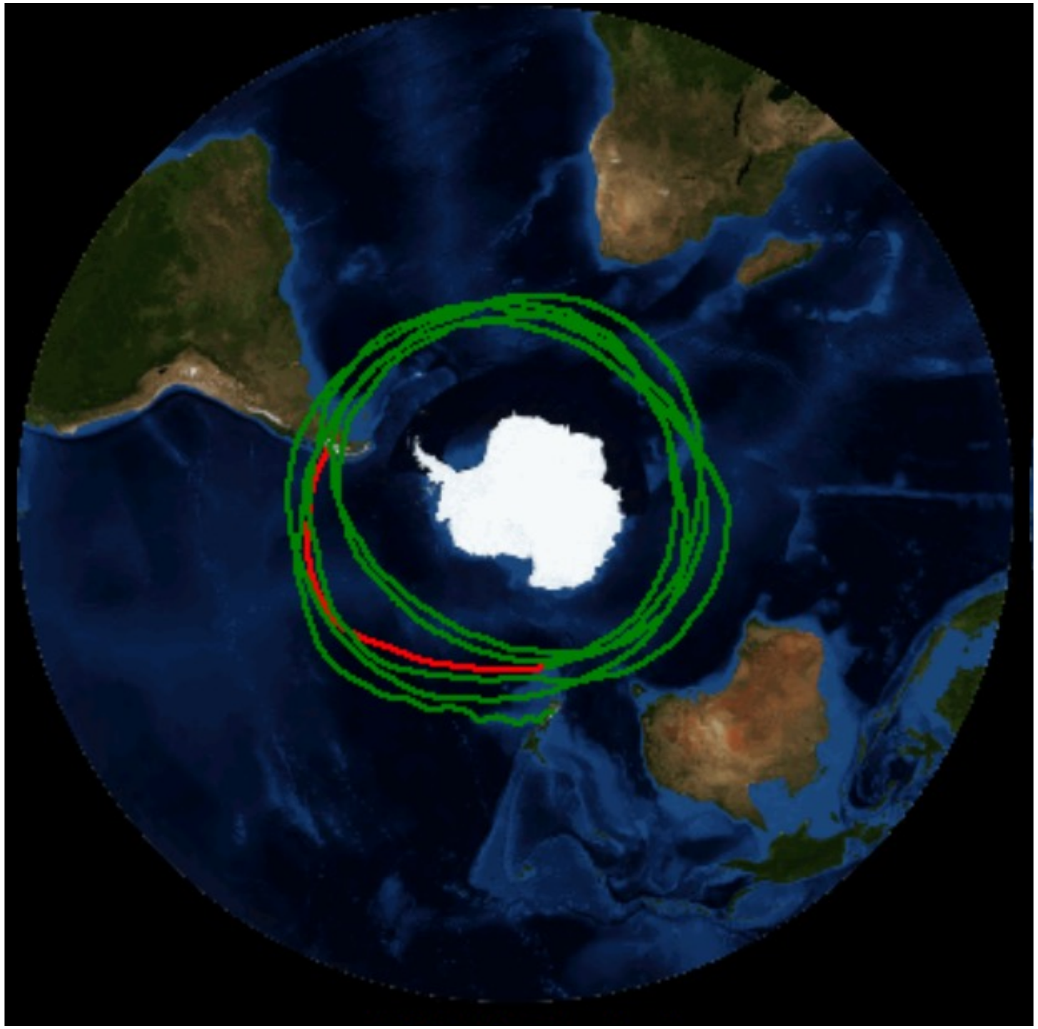

Wanaka NZ
13 MAY, 2023 00:01:37
COLUMBIA SCIENTIFIC
BALLOON FACILITY

13 mai 2023:

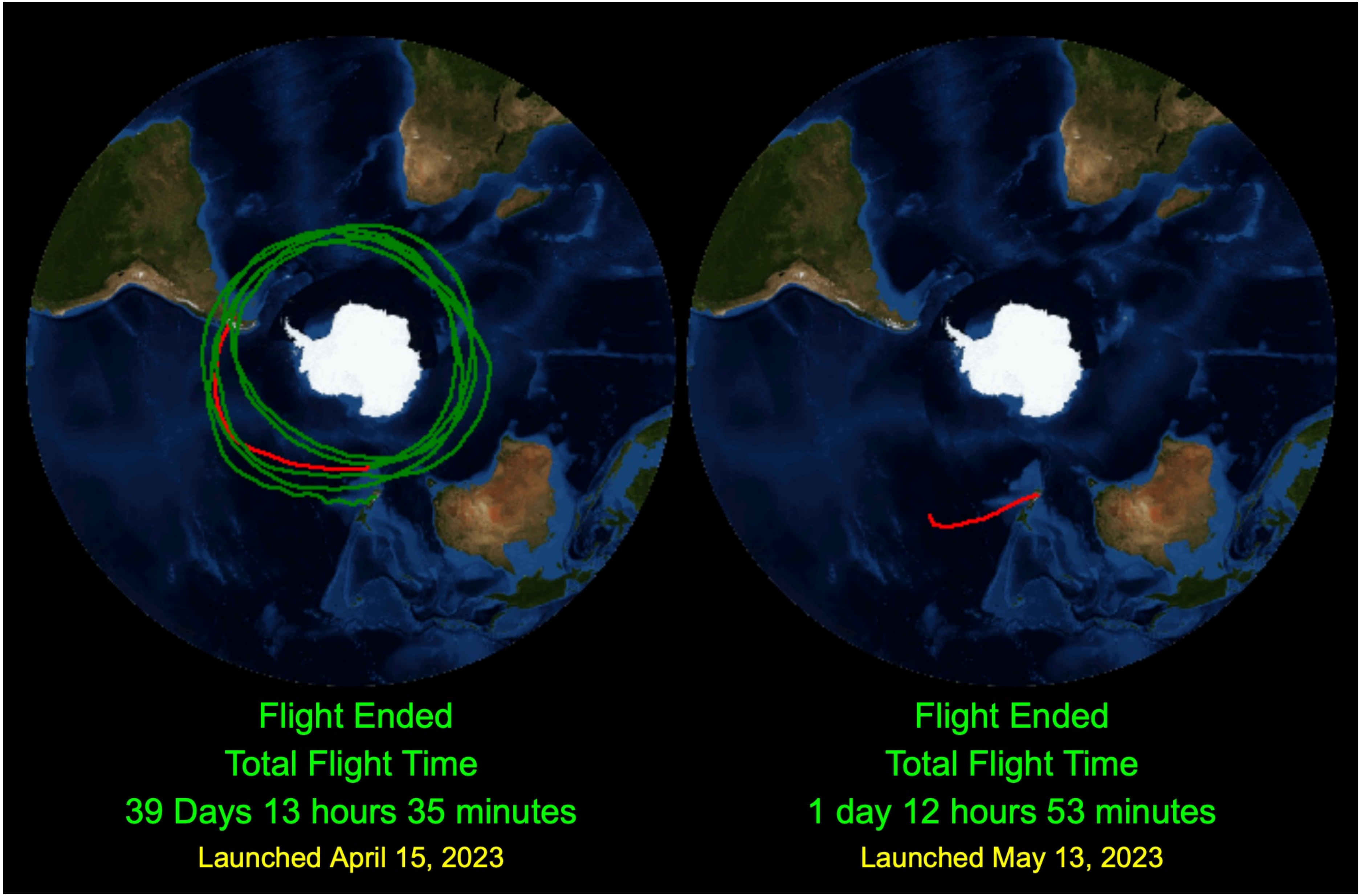
Stratospheric winds



Perfect flight of SuperBit



Launched on April 15th, 2023


Flight Ended
Total Flight Time
39 Days 13 hours 35 minutes
Launched April 15, 2023
Flight Ended
Total Flight Time
1 day 12 hours 53 minutes
Launched May 13, 2023

Super Pressure Balloon

NASA Super Pressure Balloon Mission Terminated Due to Anomaly

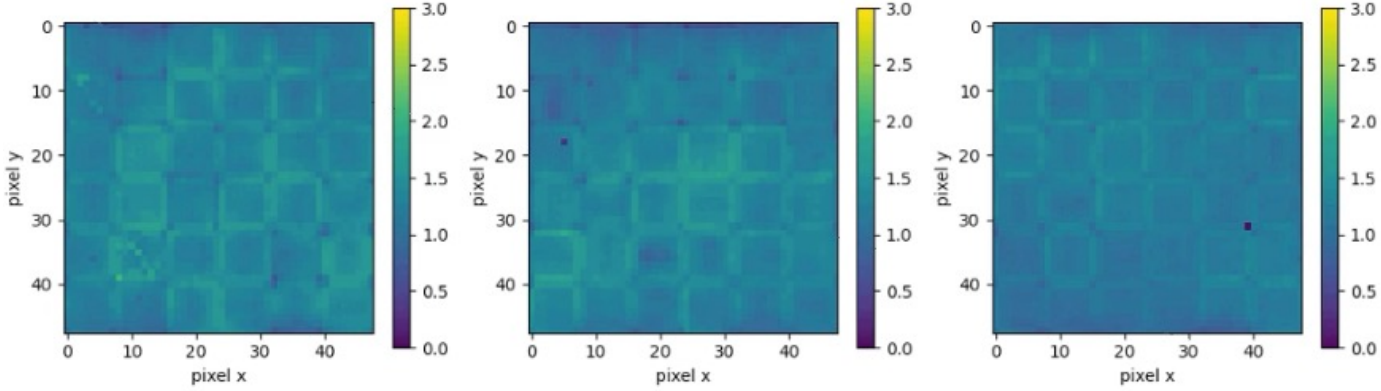
Jamie Adkins

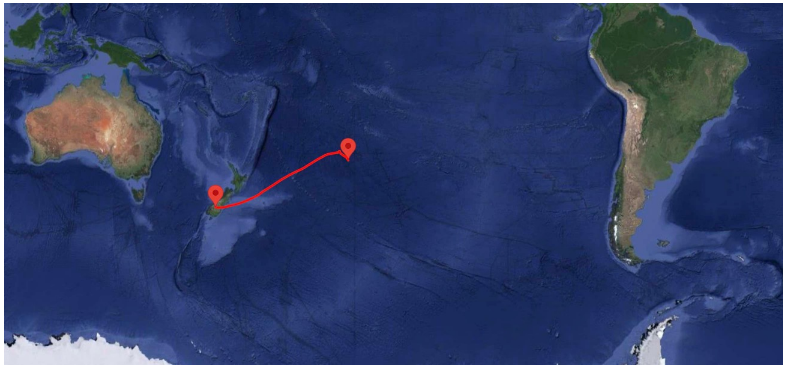
May 14, 2023

2023 Campaign, EUSO

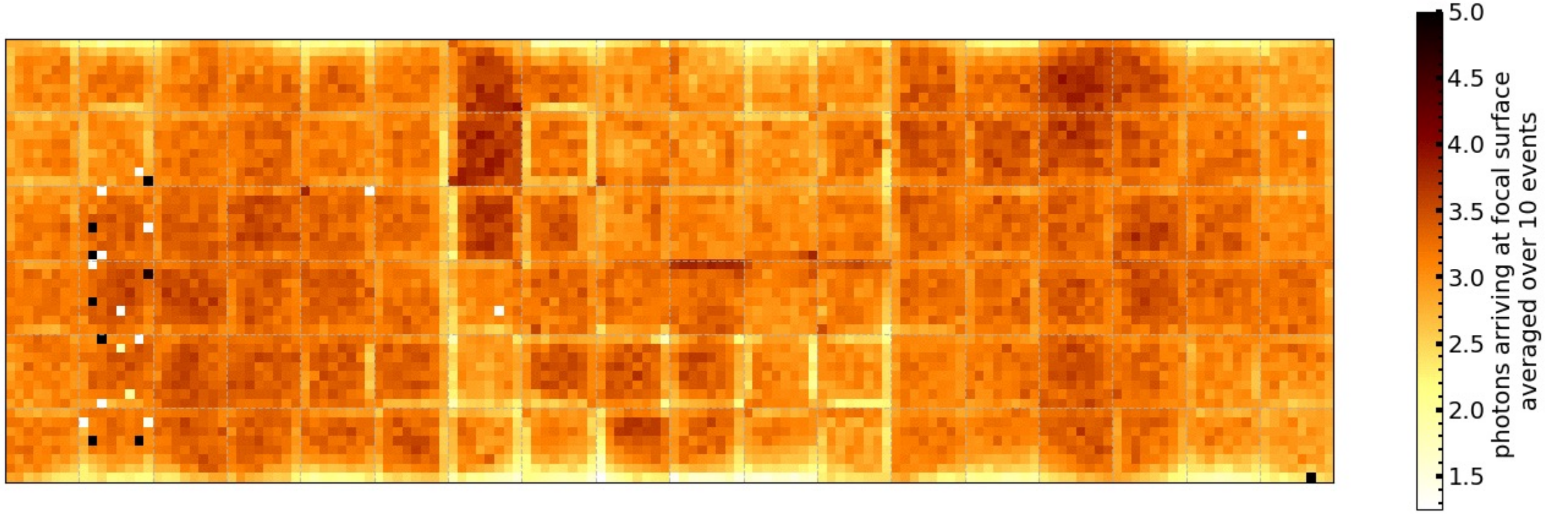
The EUSO-2 mission being prepared for launch on a super pressure balloon from New Zealand. Credits: NASA/Bill Rodman

Very disappointing: it was working so well!!!

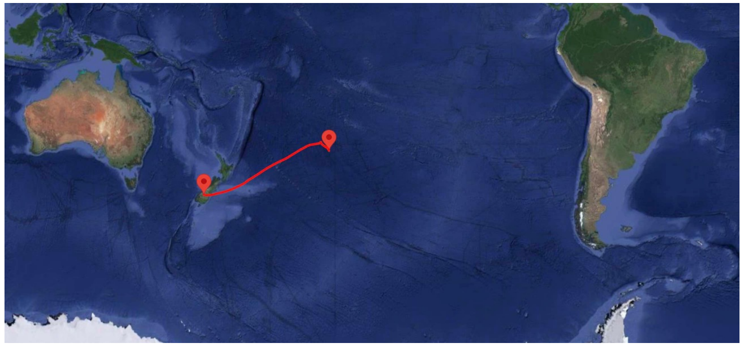




Event #11877 - #11887 ; UTC Time 14 May 2023 06:20:05



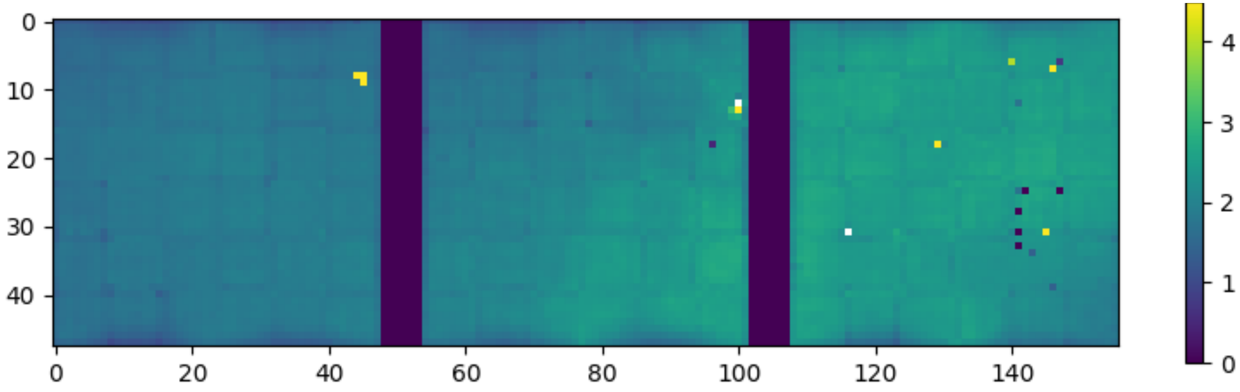
Very disappointing, but…



- We demonstrated complete full maturity of the technology for the fluorescence telescope.

- We observed CR showers with the Cherenkov telescope, for the first time in flight!

- We demonstrated nominal operation in flight of all and every subsystems.
(Hardware, firmware, triggers, data prioritization, telemetry…)



- We collected data from 123 781 triggered events (thanks to StarLink!)

- We measured ocean and cloud UV emissivity for different of moon elevations: which is relevant to estimate the exposure of future missions

- We assessed earth-skimming neutrino shower detection potential, by measuring UV emissivity towards the limb

- And… NASA offered a new flight! => EUSO-SPB3/PBR

EUSO-SPB3 will be POEMMA-Balloon with Radio (PBR)

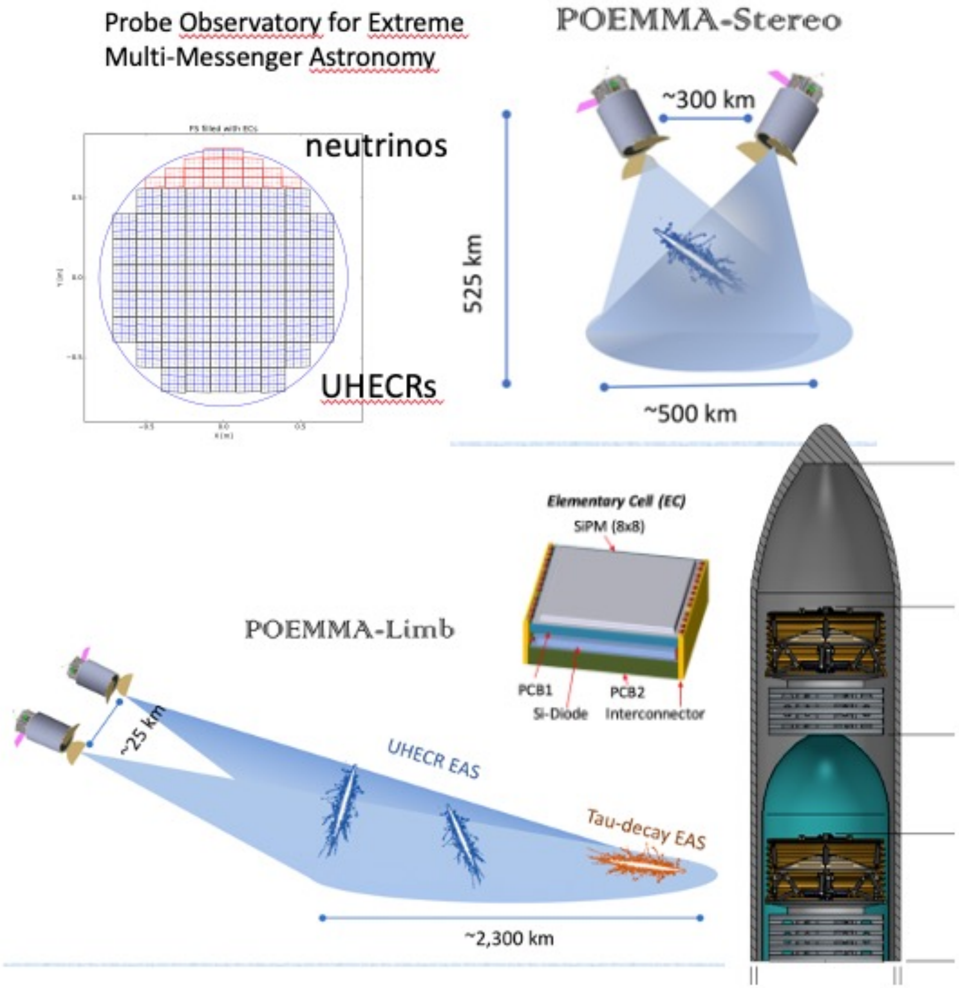
• Both Fluorescence camera and Cherenkov camera at the focal surface of the same telescope (with Schmidt design)

• Conceived as a complete (apart from stereo) and final pathfinder before POEMMA

• Tiltable telescope, from nadir to horizontal

• Addition of Radio detection of the showers, using the PUEO design (new generation ANITA mission)

• Ancillary devices: IR camera, X-ray detector, gamma-ray detector, SQM-ISS prototype



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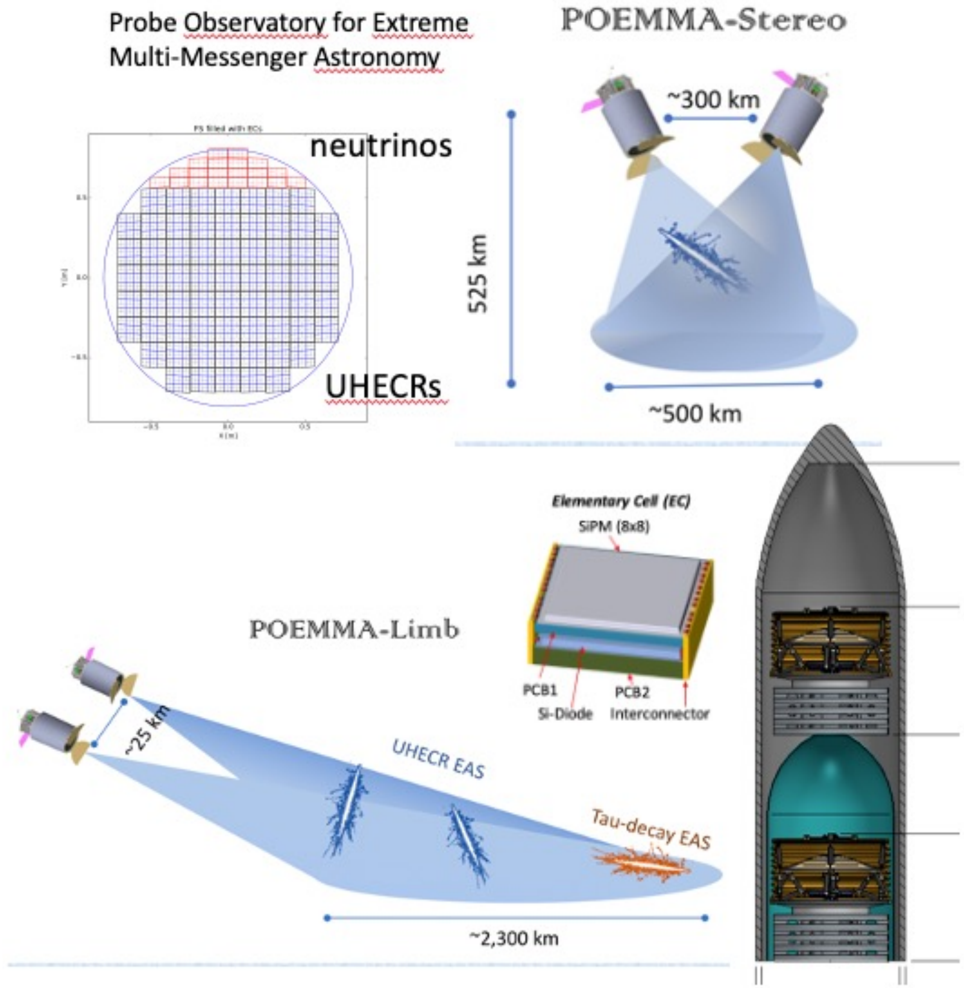

STAY TUNED: WE WILL BE BACK!

For good!