UHECR 2022

– L'Aquila, 7th of October 2022 –

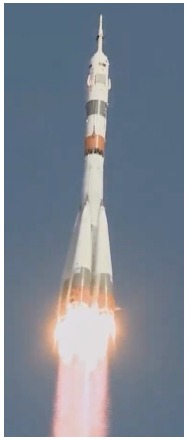
"Space poetry"!

The JEM-EUSO program for UHECR studies from space

Étienne Parizot, for the JEM-EUSO Collaboration
(APC, Université de Paris)

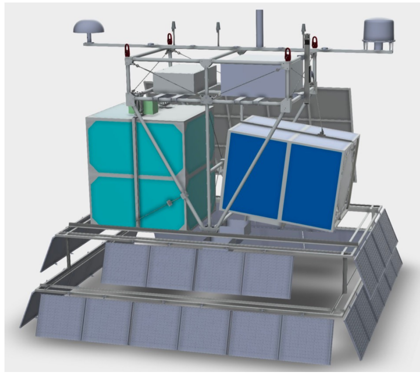
EUSO-Balloon

EUSO-TA (1, 2 & 3)



MINI-EUSO

EUSO-SPB1



EUSO-SPB2

The JEM-EUSO Collaboration

Joint Experiment Mission – Extreme Universe Space Observatory

16 countries, 300 physicists and engineers

Supported by space agencies and national institutes

…

See also:

Talk by Marco Casolino on the MINI-EUSO mission and results

Talk by Mario Bertaina on the implications of the measurements of the MINI-EUSO and EUSO balloon missions for a major JEM-EUSO-like space mission

Talk by Austin Cummings on the EUSO-SPB2 mission

Talk by John Krizmanic on the POEMMA mission

Poster presented by Hiroko Miyamoto on the end-to-end calibration of MINI-EUSO

Poster presented by Daniil Trofimov on the absolute calibration of EUSO Photo-Detector Modules, with subpixel resolution

Important results

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

Auger: 3000 km^2
–> upgrade (muon detectors)

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…

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!

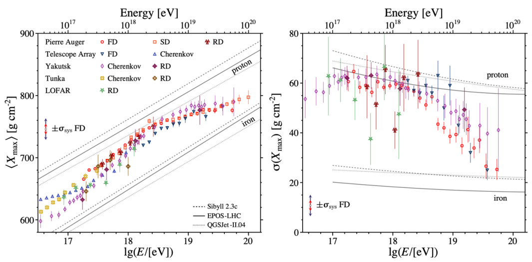
=> Now, a new generation is needed:

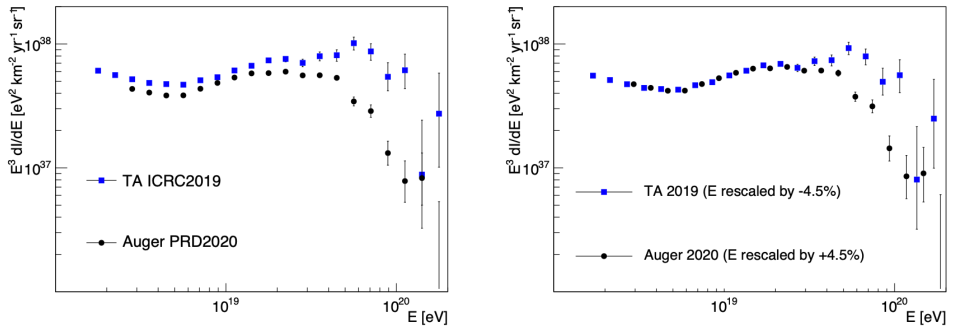
- larger statistics (as much as possible)
- full sky coverage (as uniformly as possible)
- complementarity between low energies (10^{18}–10^{19} eV) and high energies (10^{20} eV)
- complementarity between precision and statistic
- complementarity between ground-based and space-based instruments

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.

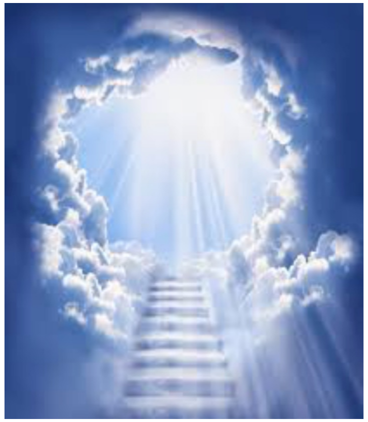
★ Additional cosmic-ray physics!

- 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 Program: a stairway to heaven!

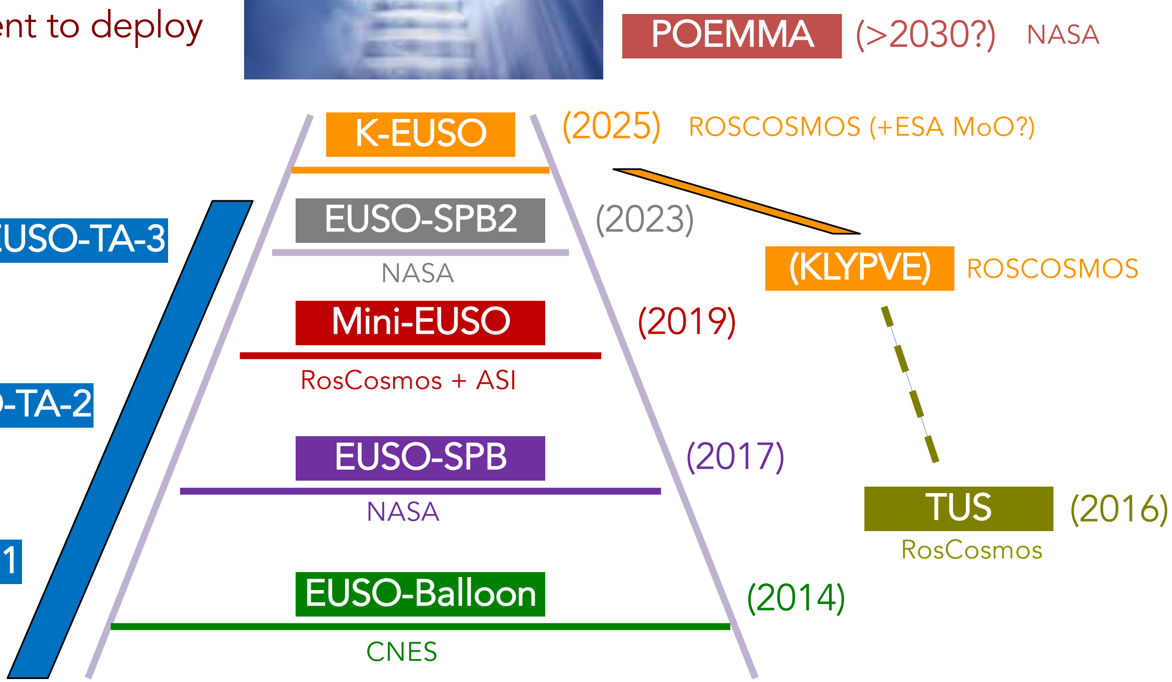
Towards UHECR and high-energy neutrino detection from space

- Unprecedented aperture
- Only one instrument to deploy
- Full-sky coverage



Research program and instruments funded by the main space agencies and national institutions

16 countries
300 physicists+engineers



The JEM-EUSO instrumentation

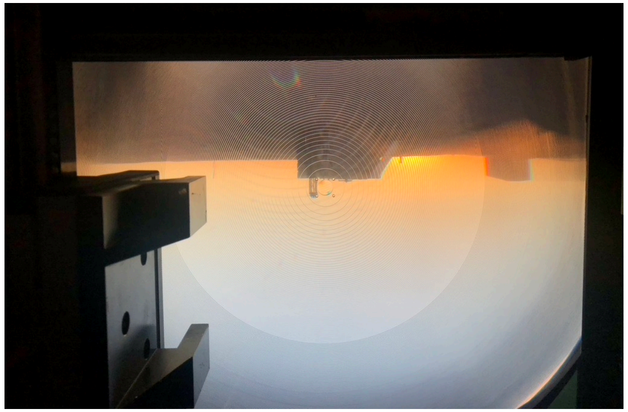
NB: operating from space

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

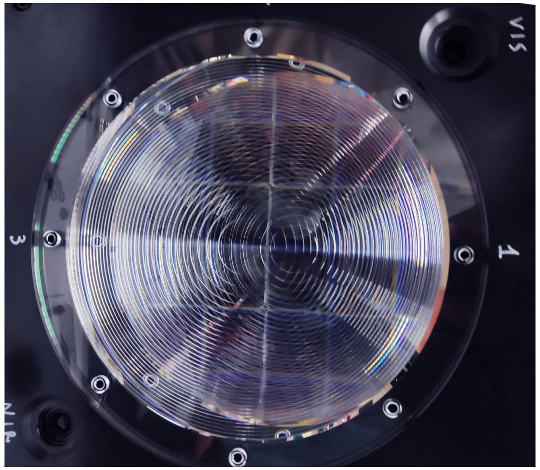
Optics:

=> large Fresnel lenses (Japan)

=> large mirror (Schmidt)
(Czech Rep.)



Looking through EUSO-TA optics



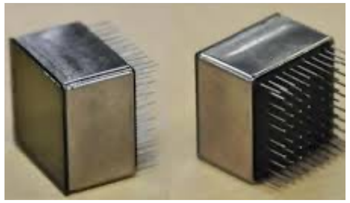
MINI-EUSO Fresnel optics

EUSO-SPB2 mirrors

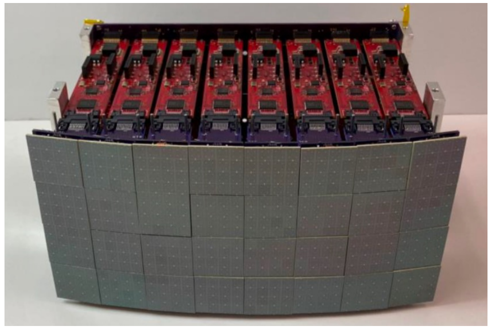
Photosensors:

=> MAPMT (Hamamatsu, Japan)
(Fluorescence telescope)

=> SiPM (Hamamatsu, USA)
(Cherenkov telescope)



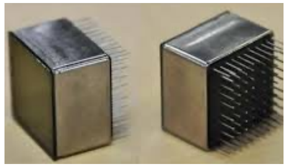
MAPMT 64 pixels

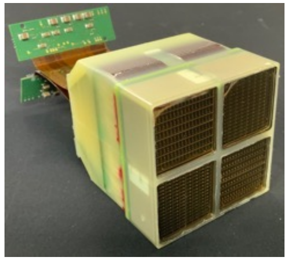


Cherenkov camera of EUSO-SPB2 (USA)

The JEM-EUSO instrumentation

Detection units: (France)

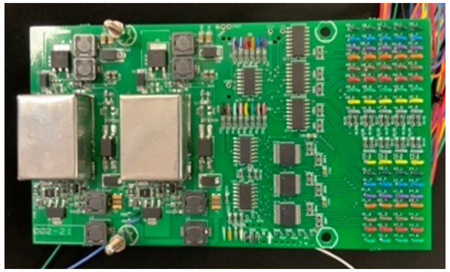


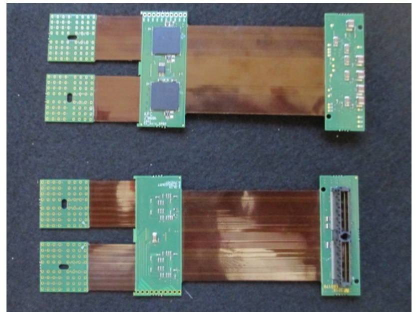


3rd generation "elementary cells"

Electronics: => Dedicated ASIC (France)

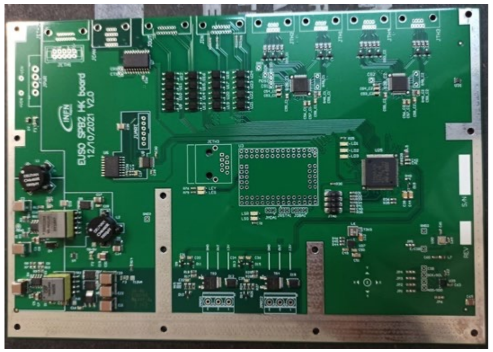
=> Dedicated HVPS (Poland)

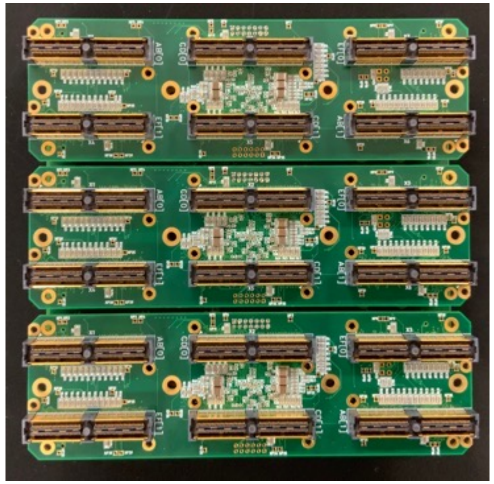




Data acquisition: => FPGA, Zynq (Russia)

Data processing and control: (Italy)

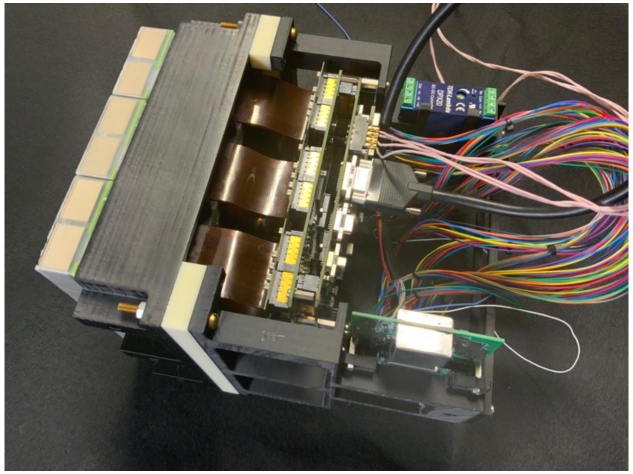


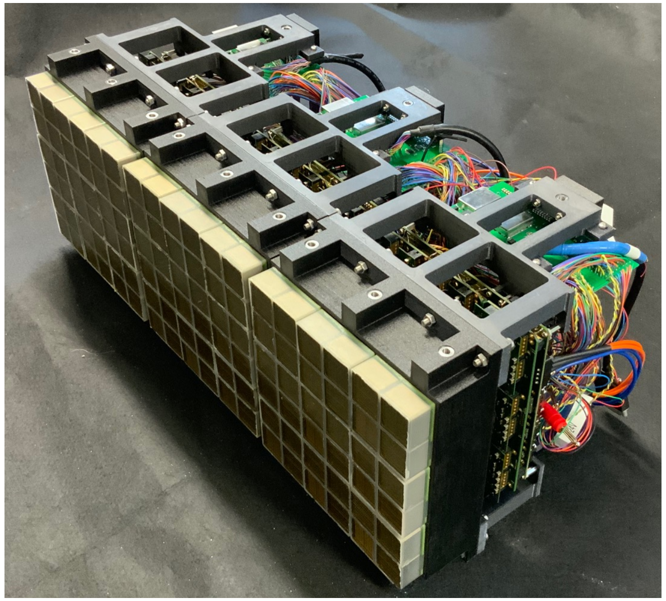


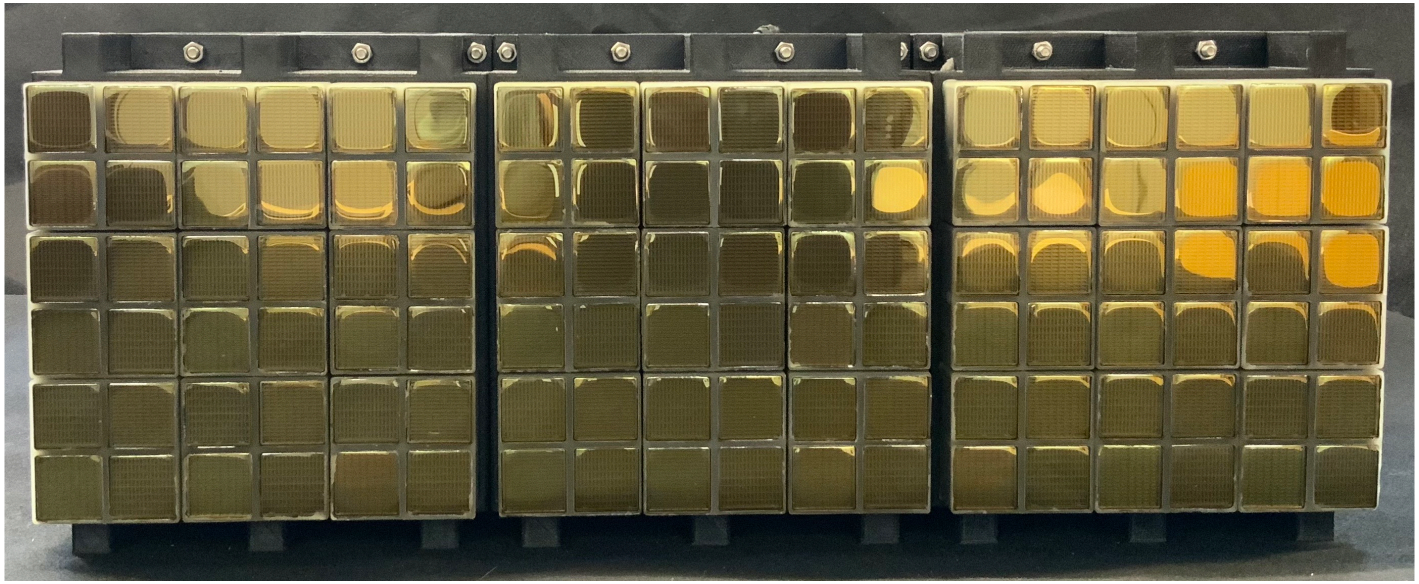
The JEM-EUSO instrumentation

Assembled photodetection modules:

(France, Poland, Italy, Russia)







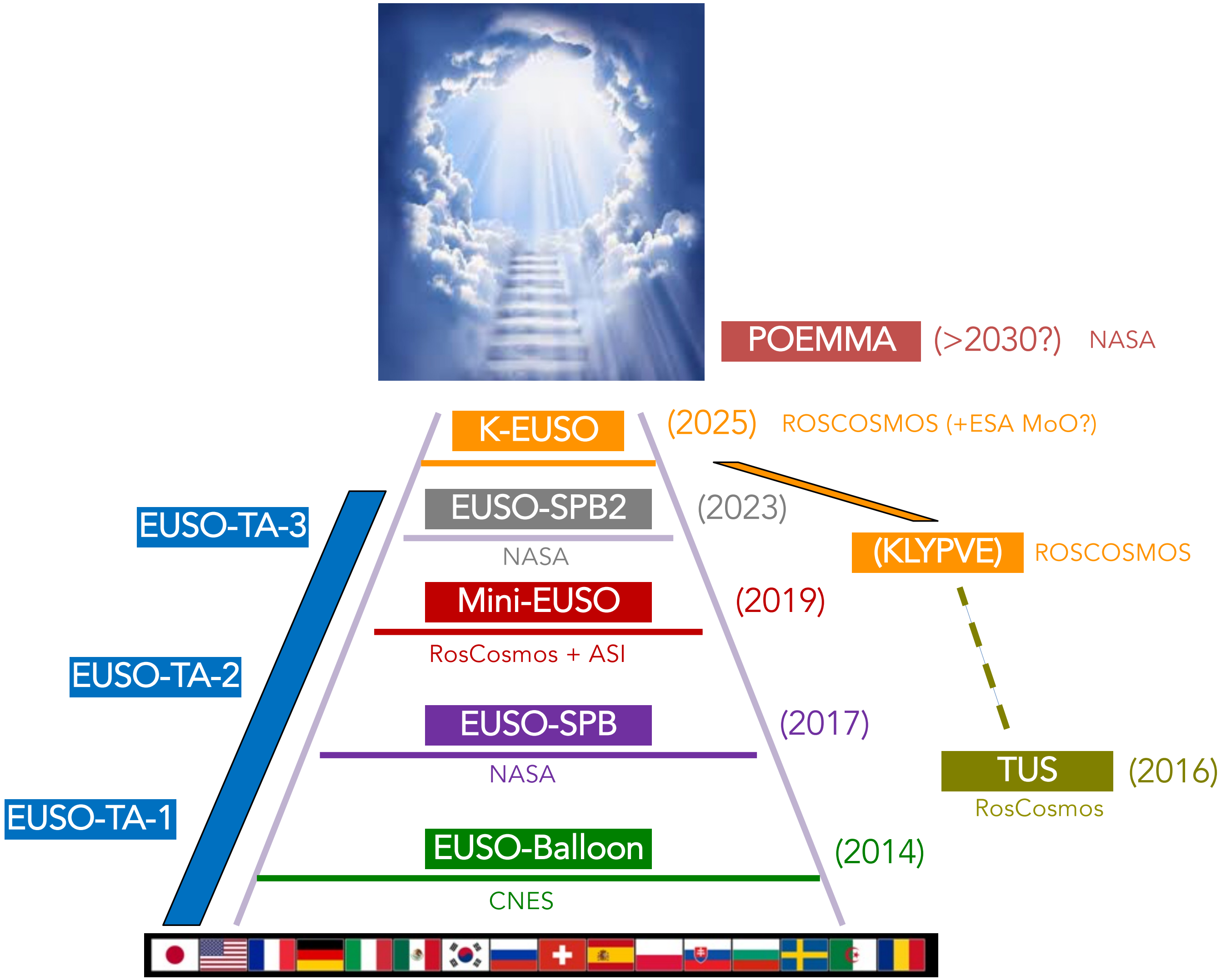
+ simulation tools and analysis

(all countries)

The three photodetection modules of EUSO-SPB2

6912 pixels with single photon sensitivity and 1 μs resolution

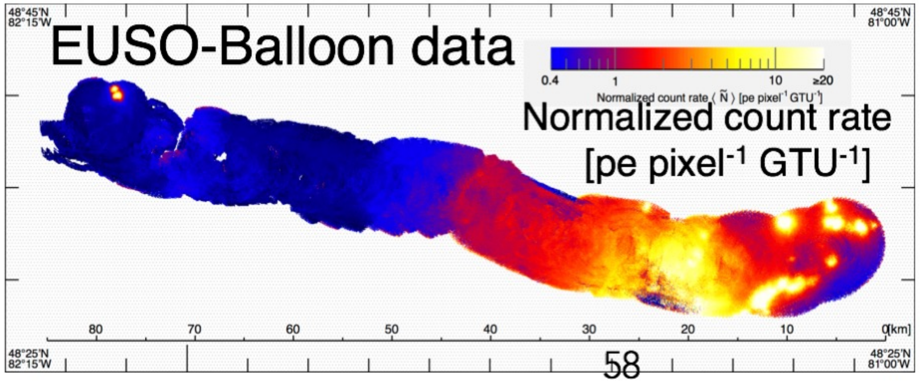
Stairway to heaven!

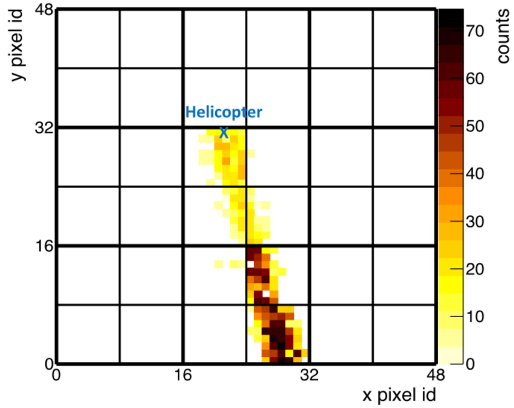


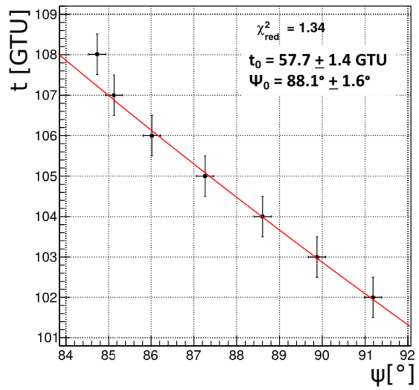
EUSO-BALLOON:

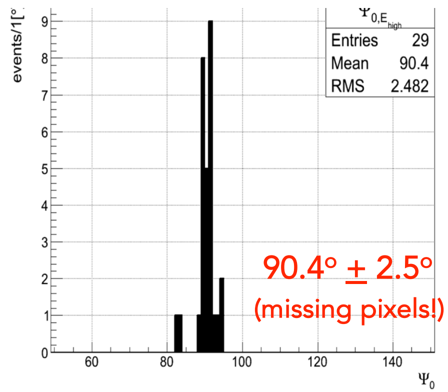
CNES mission, 2014

1 night flight with 1 PDM







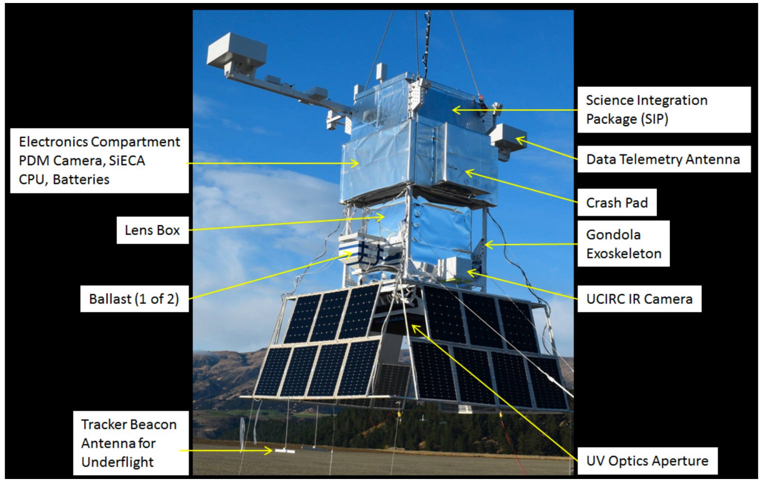


<u>Main innovations</u>:
- front-end electronics (SPACIROC 1)
- HVPS (low consumption + switch)
- Efficient data processing
- Operation at 3 mbar

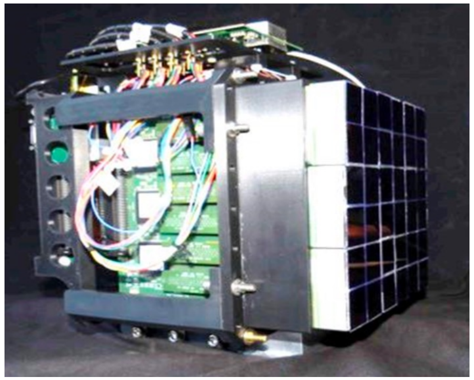
<u>Main teachings</u>:
- UV emissivity w/ or w/o cloud
- UV / IR anti-correlation (expected)
- Laser events reconstruction
- Serendipitous flash source detection

EUSO-SPB: (super pressure balloon)

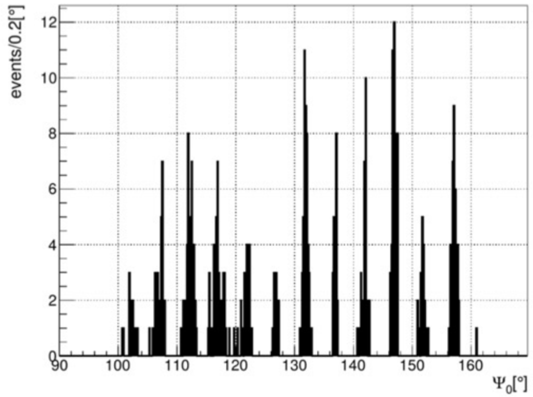
NASA mission, 2017



Main improvements:
- 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

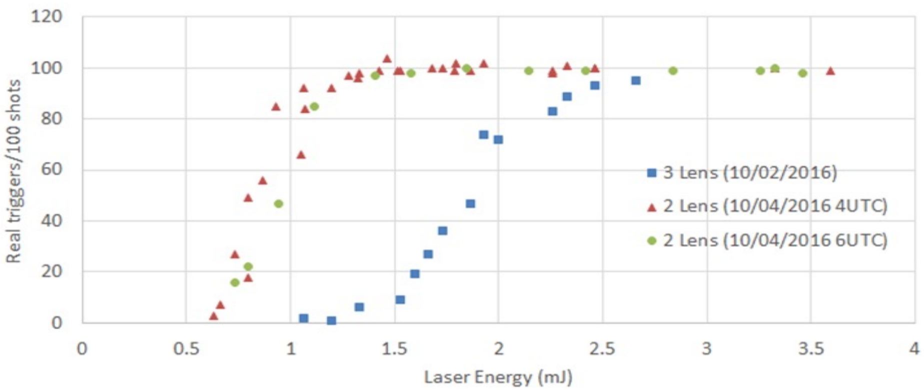


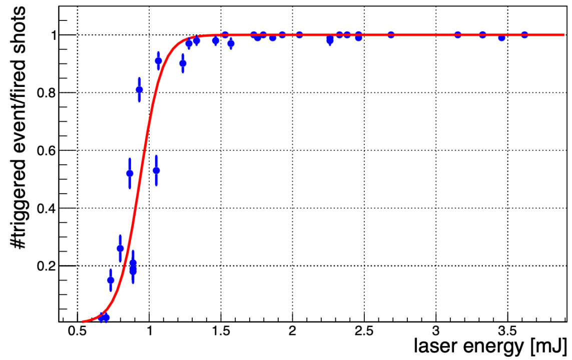
Angular resolution better than 1°

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



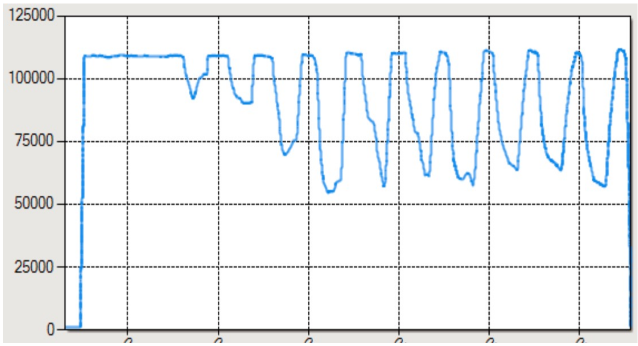


E_{th} ~ 3 EeV

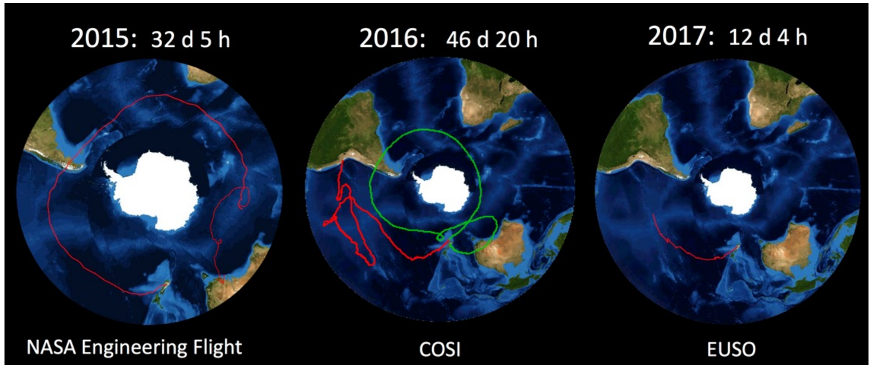
=> 1–2 showers/month expected

Successful launch (April 2017)   But…   leaking balloon!

altitude



days



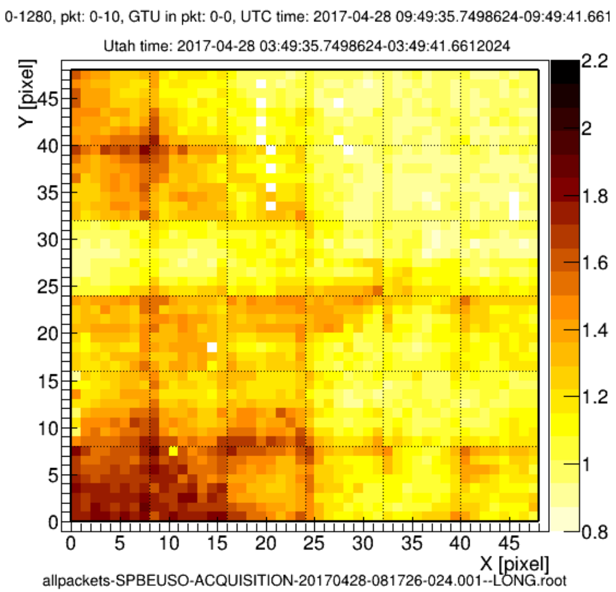
EUSO-SPB:

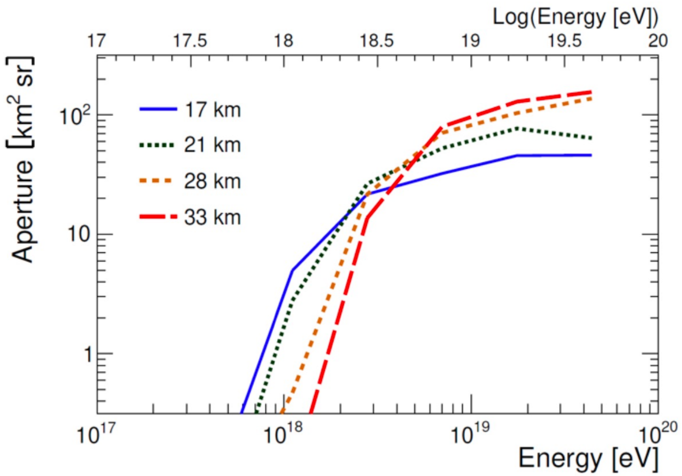
Nominally working instrument!

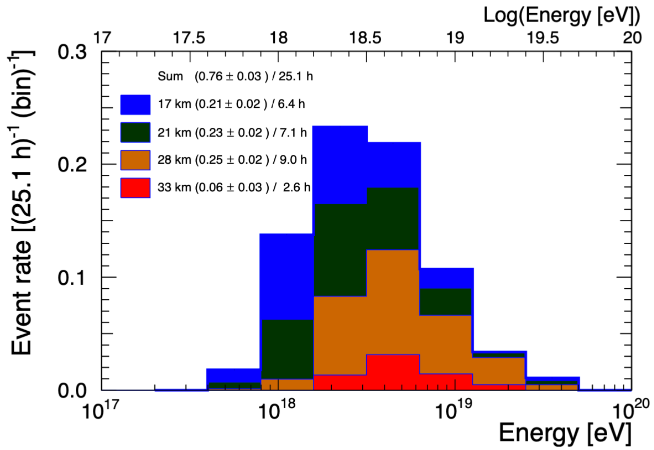
Photometric stability: ±5%

25.1 hours of downloaded data

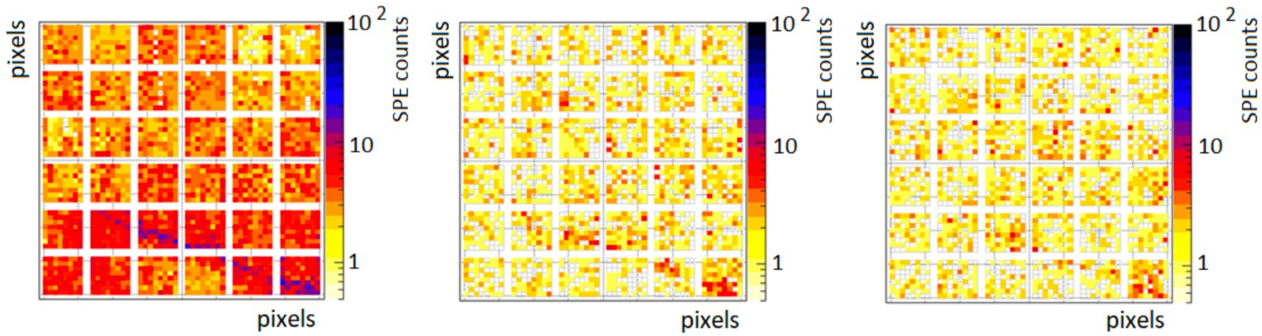
Clouds across the field of view







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



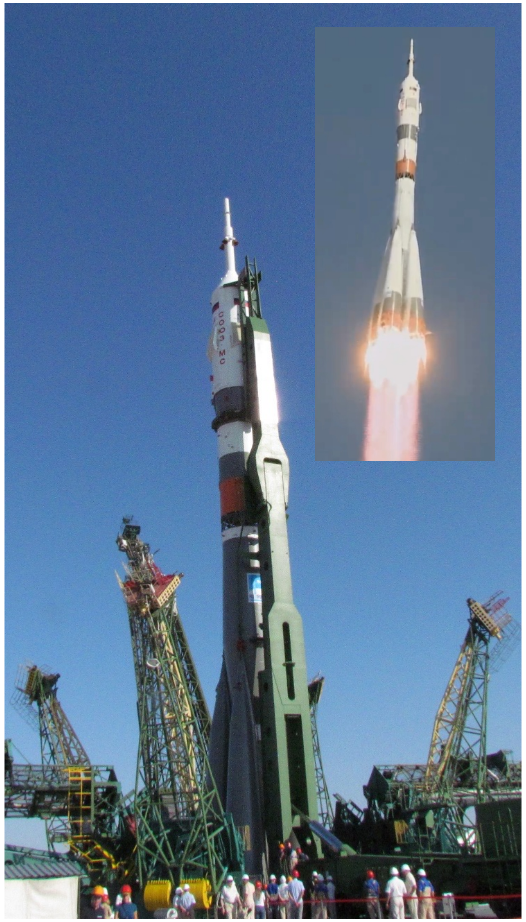
Direct cosmic-ray hit: 3 consecutive frames (2.5 µs)

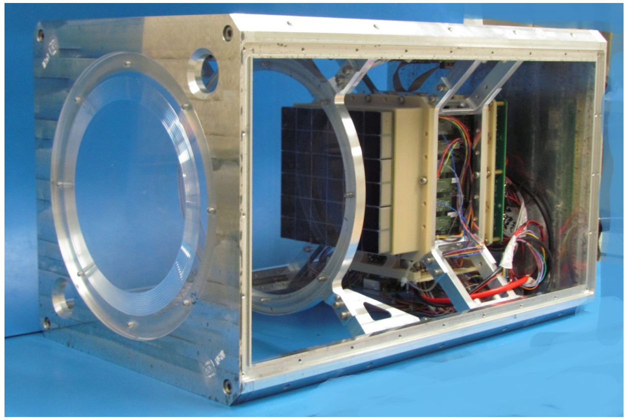
NB: 5 µs persistence of the track

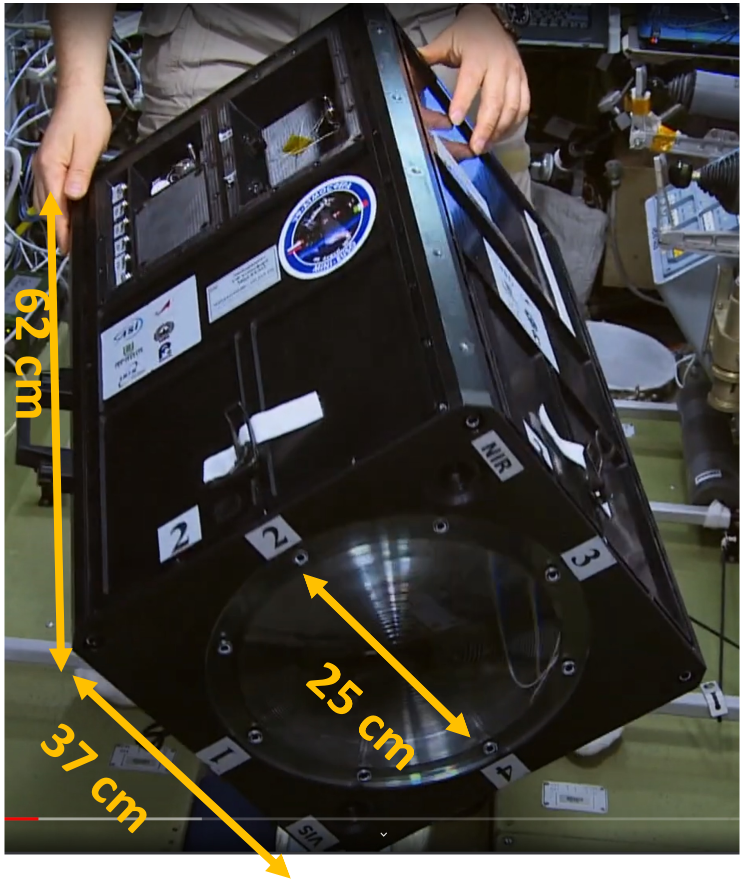
=> useful classification of ≠ types of direct CR hits

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

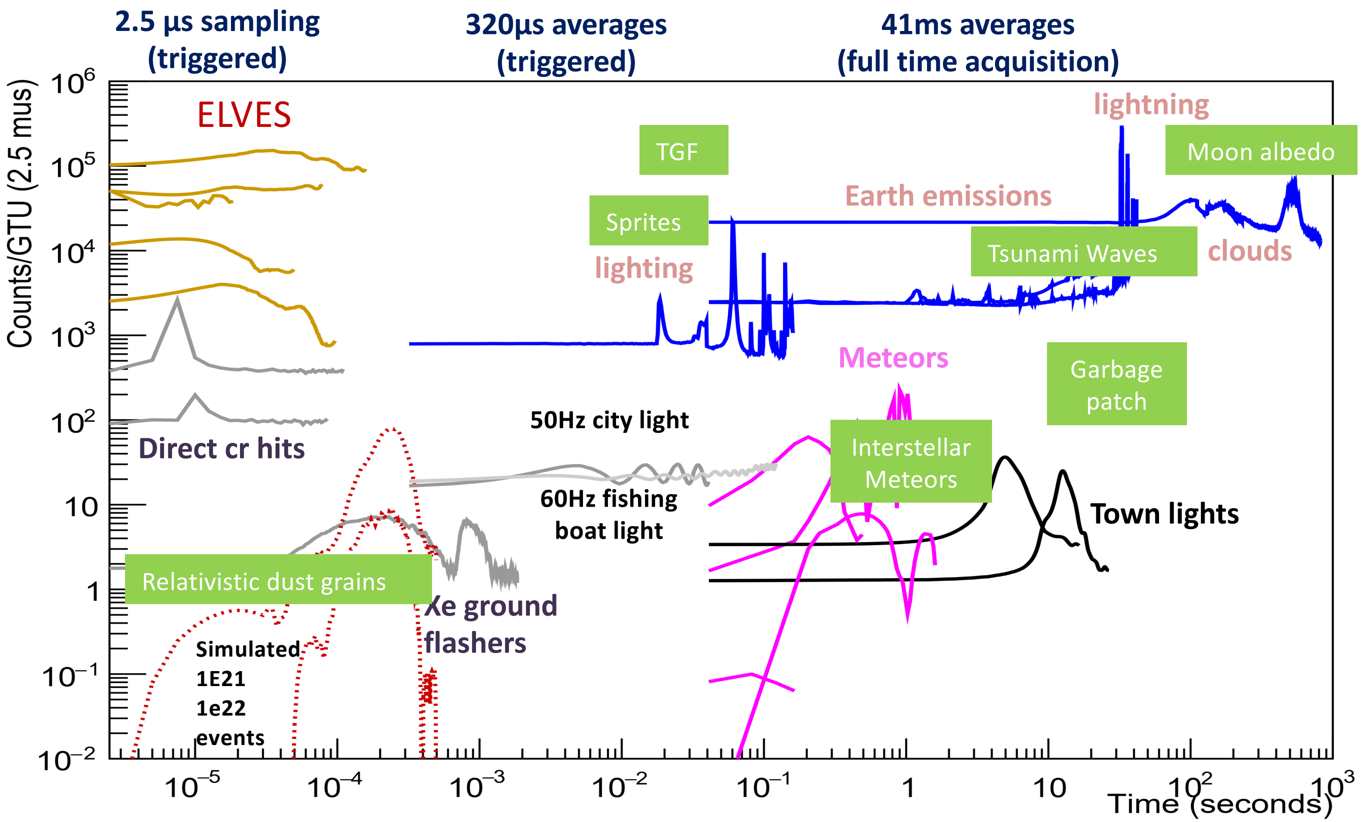
- Cosmic-rays
- Elves
- Relativistic grains?
- Artificial flashers

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

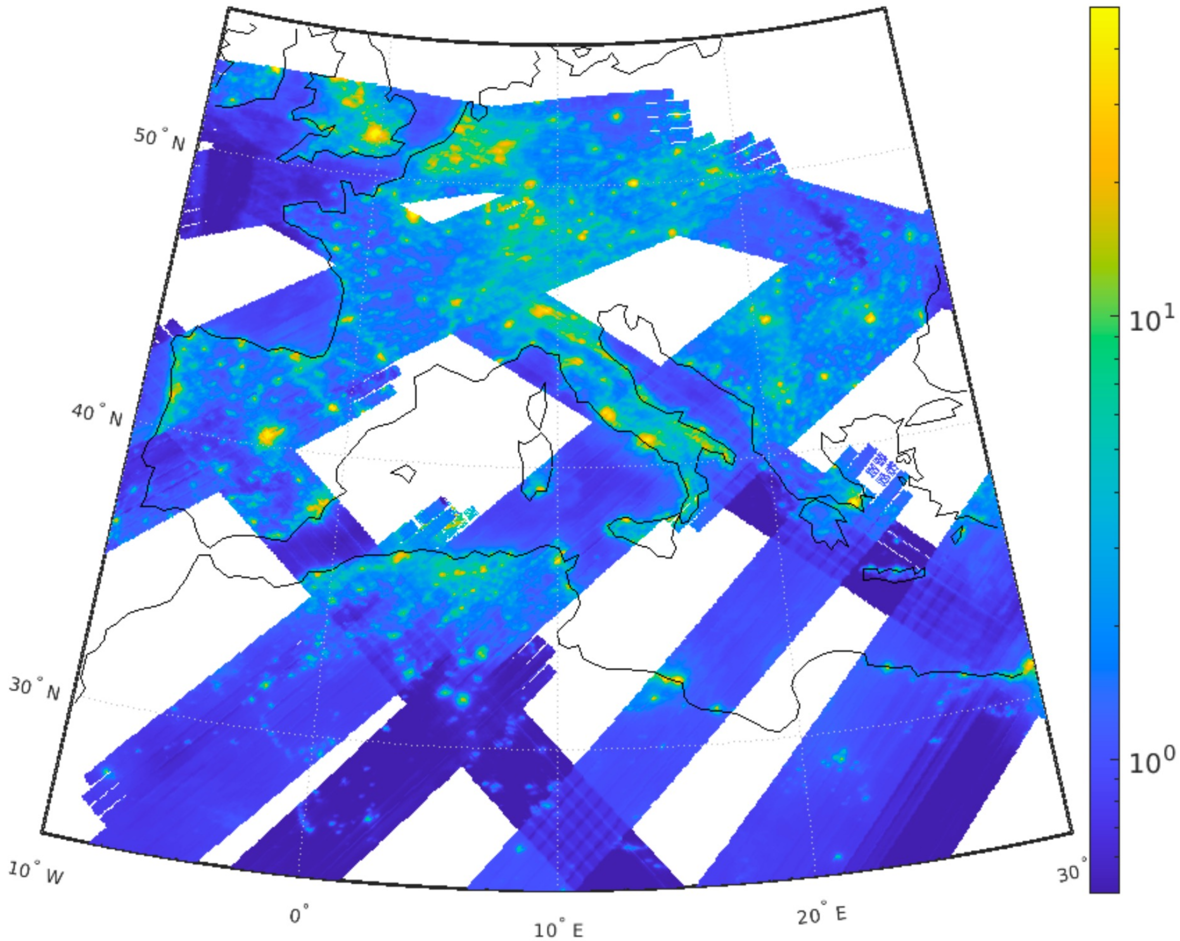


+ unknown emissions!

MINI-EUSO:

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

(MINI-EUSO pixel size: 6.1 km)



=> new Google map!

MINI-EUSO:

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

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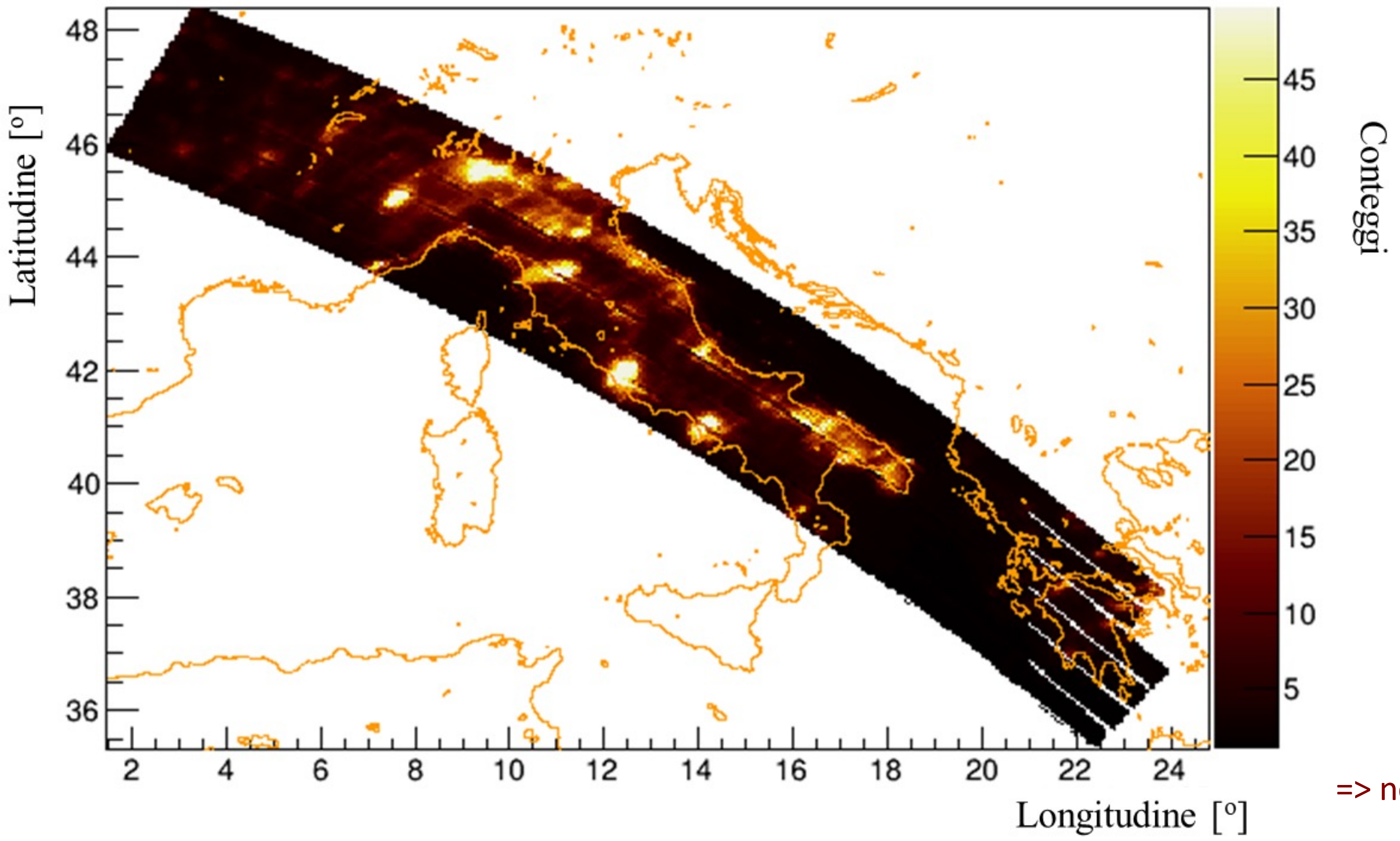
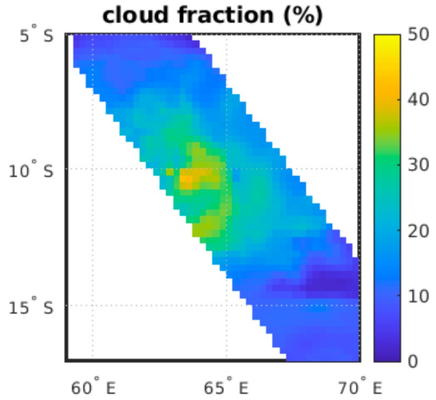
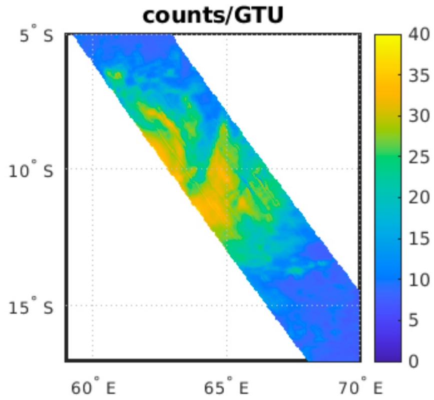


=> new Google map!

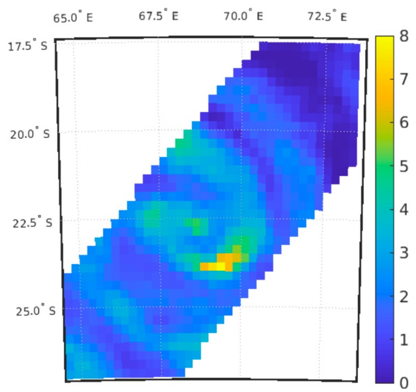
MINI-EUSO:

Clouds, etc.

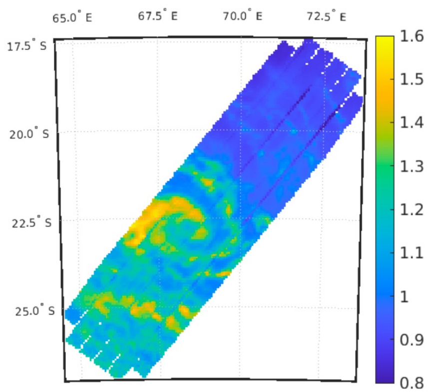




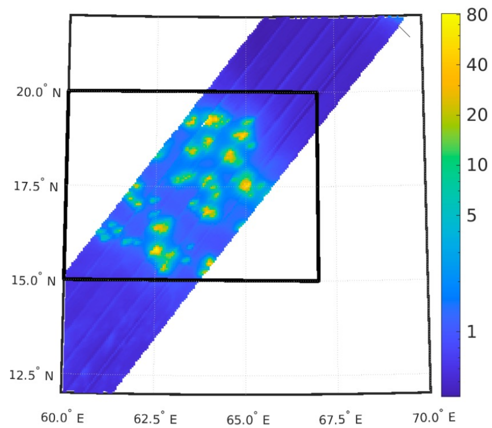
GFS (Global Forecast System)



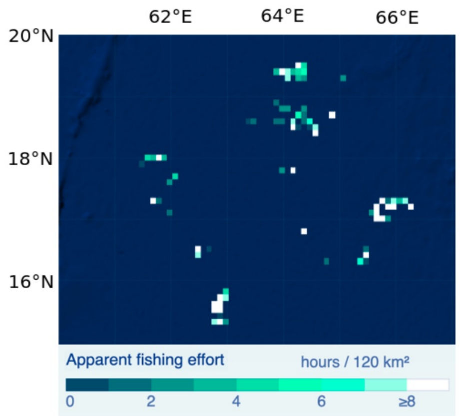
MINI-EUSO



Human activities...



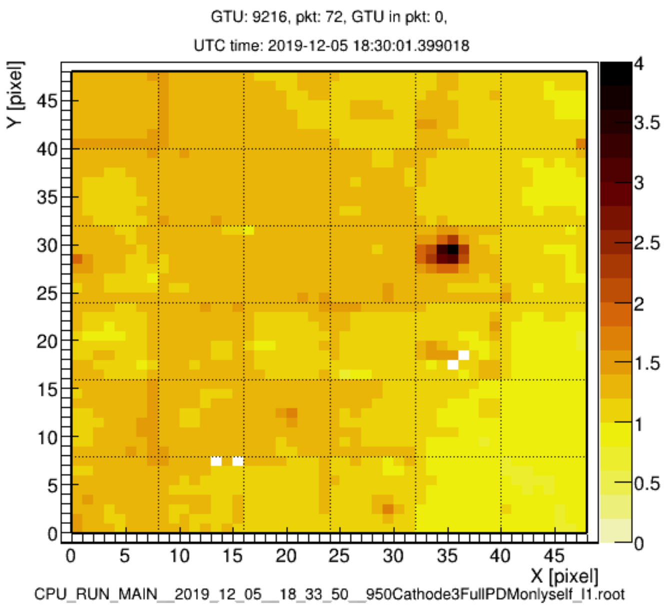
MINI-EUSO: fishing boats!



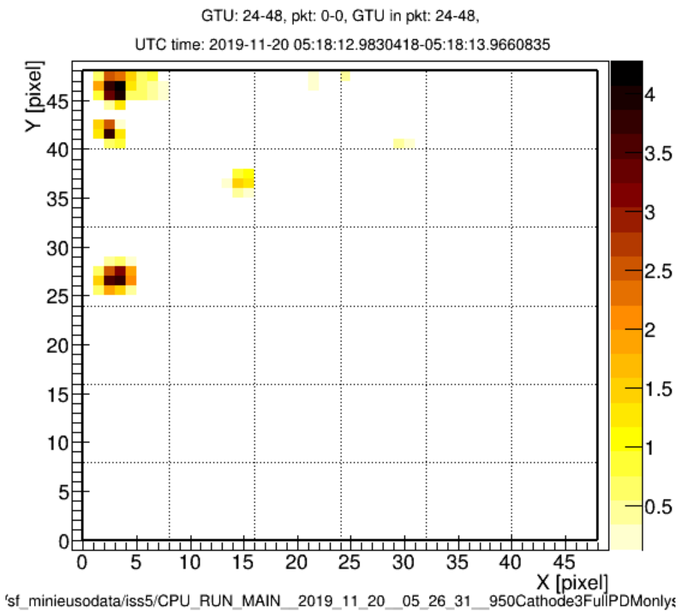
map of apparent fishing activity from the Global Fishing Watch

MINI-EUSO:

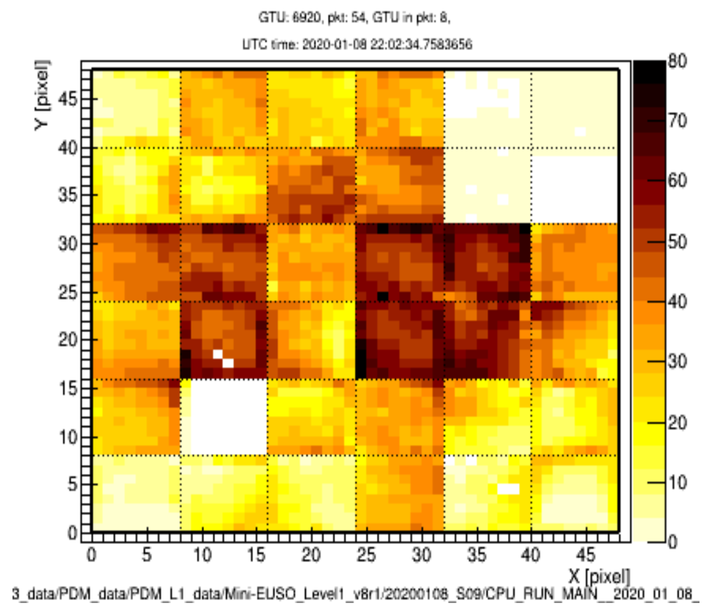
Clouds, etc.



Ground emissions (cities…)



Moon reflection!



(ISS orbital velocity: ~ 7 km/s)

(static!)

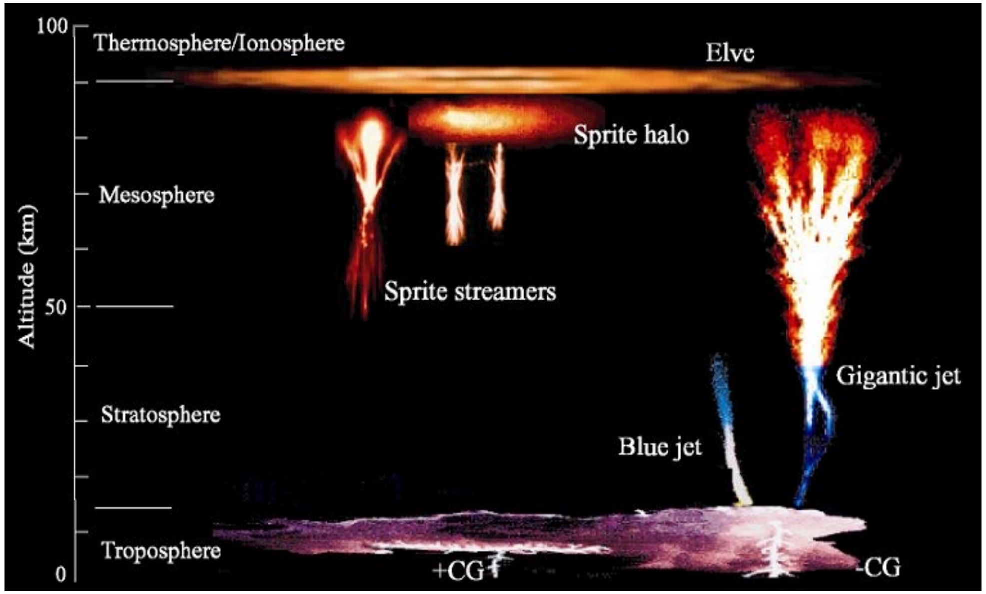
+ large number of meteors (>1000)

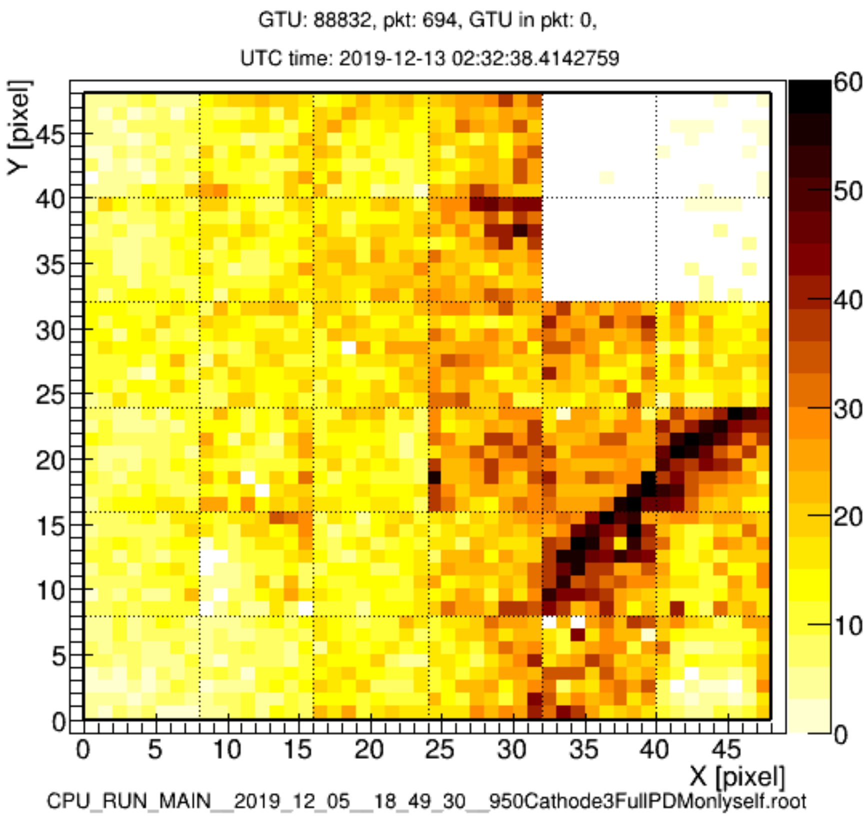
Visible down to magnitude 6.5 (~ 3 mg)

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

MINI-EUSO:

- Elves





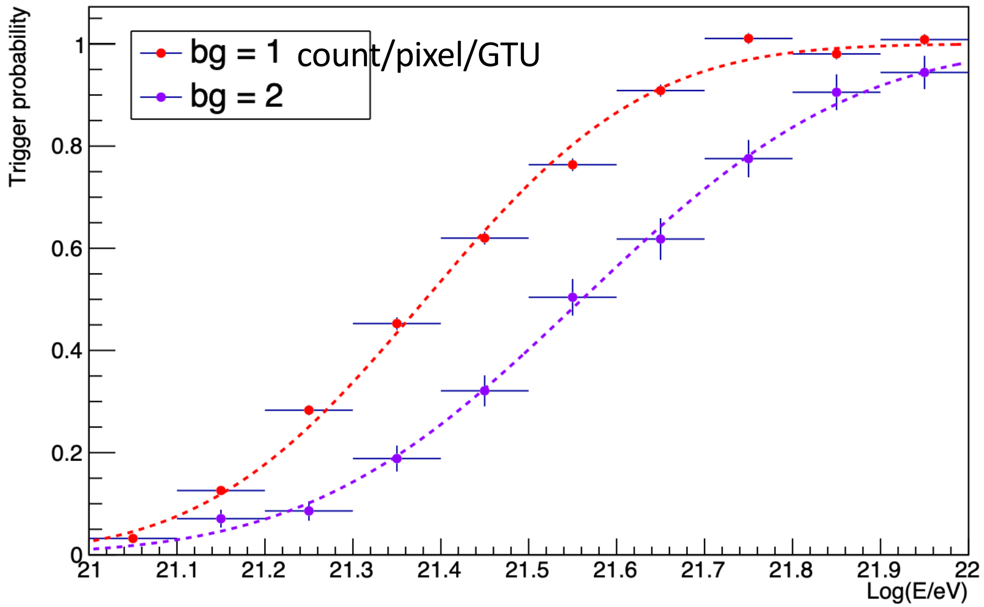
MINI-EUSO offers unprecedented precision and imaging capability

=> new physics discoveries!

MINI-EUSO:

End-to-end calibration with ground flashers! (H. Miyamoto, M. Battisti, M. Bertaina)

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



We have learned a lot about:
- the performance of our technology
- the background for UHECR detection
- the diversity and importance of complementary objectives

- NB: 63 sessions so far! ~200 hours of data

Very precious crew time + very efficient contribution of cosmonauts!

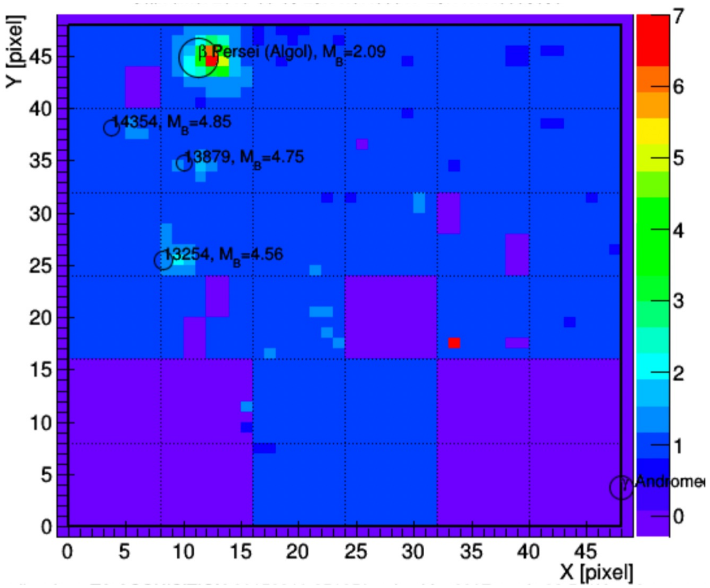
21 new sessions programed from Sept. 30th, 2022 to March 23rd, 2023

EUSO-TA-1:

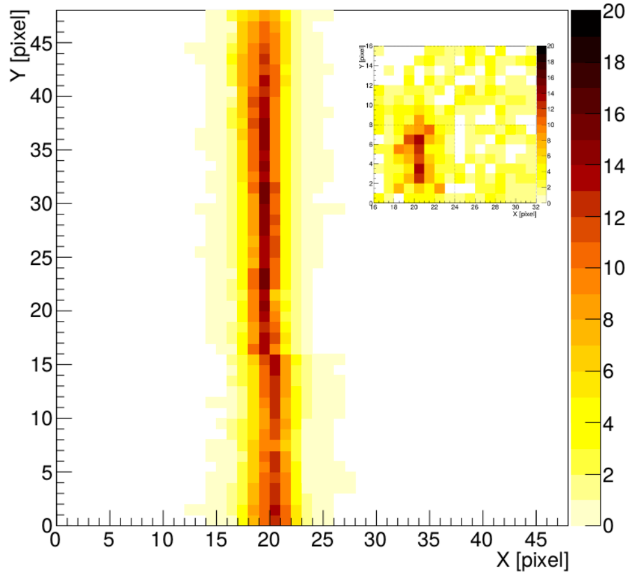
1) A ground-based facility for the development and characterisation of the JEM-EUSO technology

2) A scientific instrument on its own right! (EUSO-TA-1 and EUSO-TA-2)

Check optics and photodetection performances



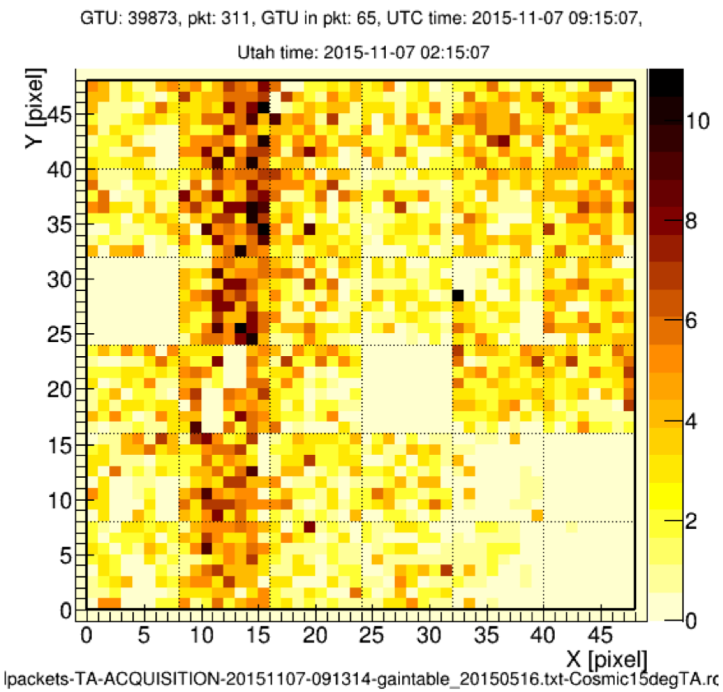
Identified stars



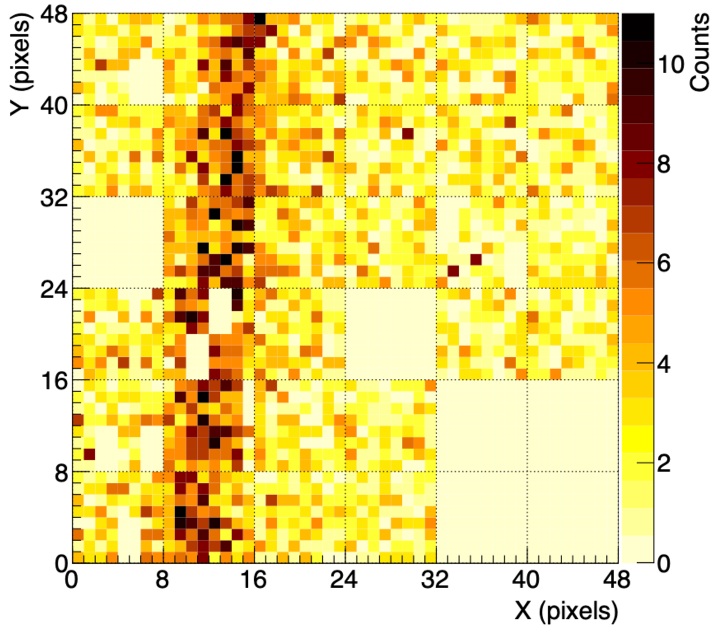
Laser track (21 km)

EUSO-TA:

Towards a measurement of the transverse structure of the fluorescence signal



Data



Simulation

(offline)

TA trigger and reconstruction: energy: $10^{18.4}$ eV

distance: 2.6 km

EUSO-SPB2:

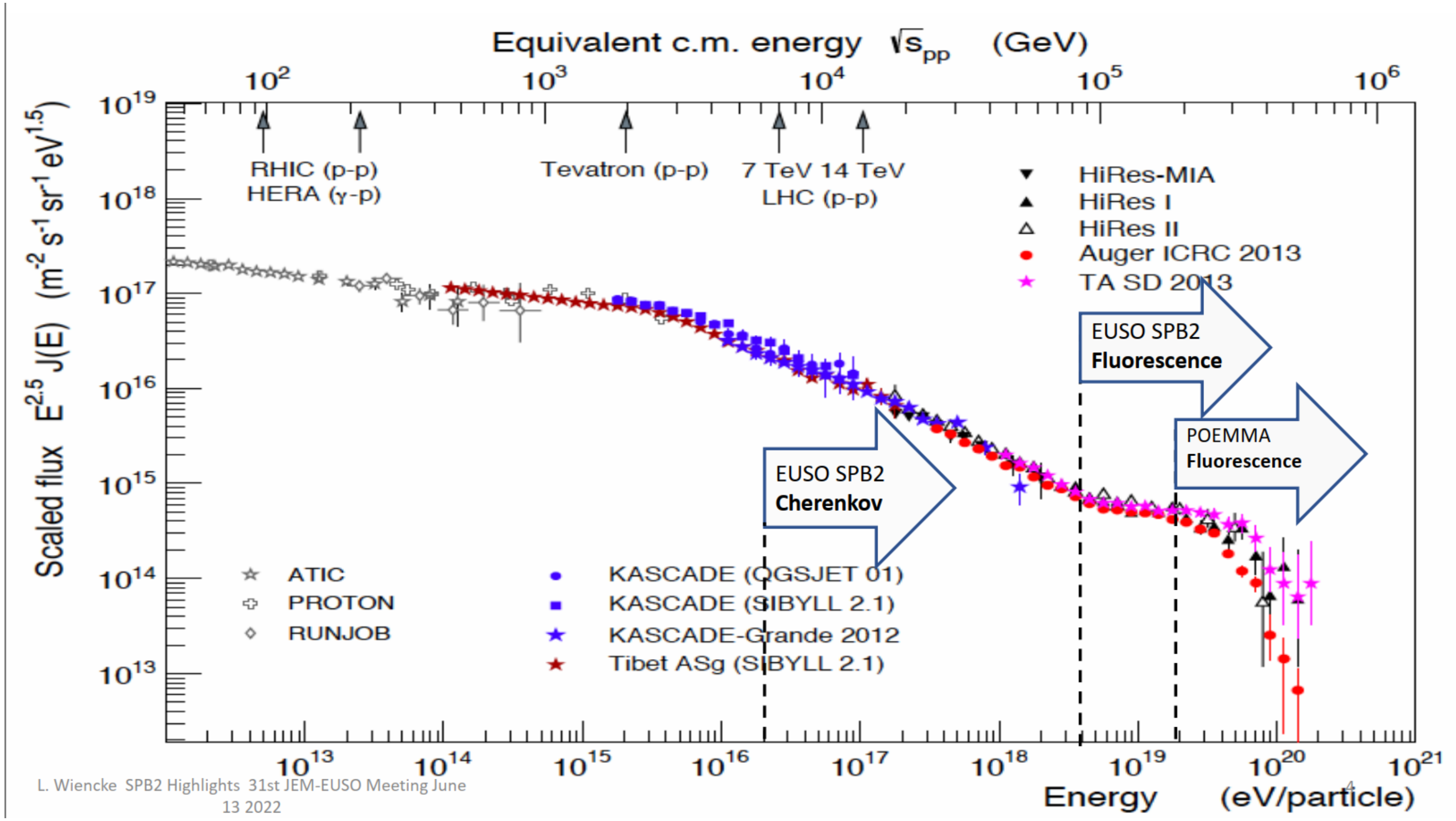
NASA mission on a super pressure balloon => long duration

Major mission to come!
Pathfinder to POEMMA

Two instruments in one:

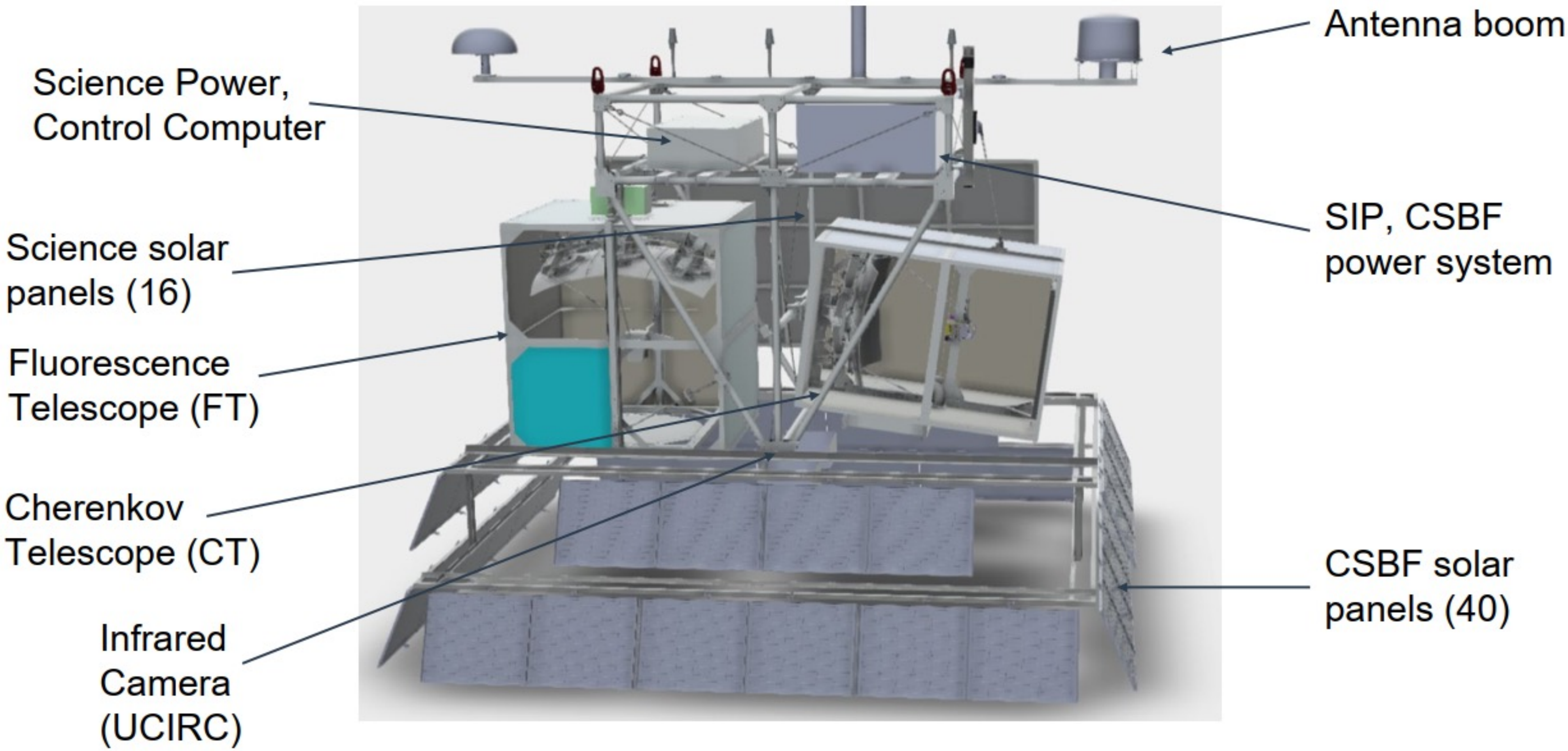
Fluorescence telescope: pointing to nadir

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



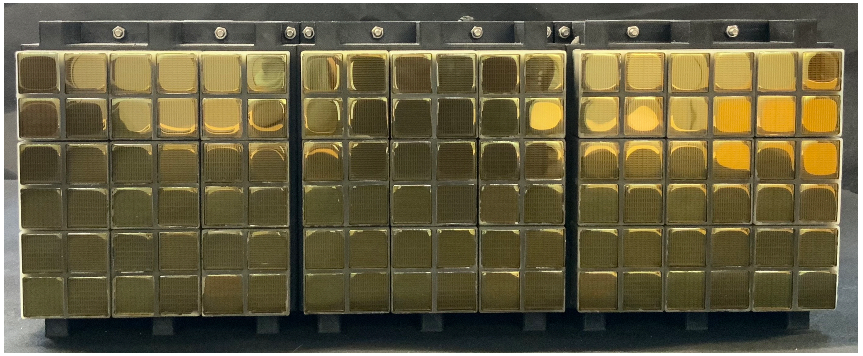
L. Wiencke SPB2 Highlights 31st JEM-EUSO Meeting June 13 2022

EUSO-SPB2: Major mission to come!

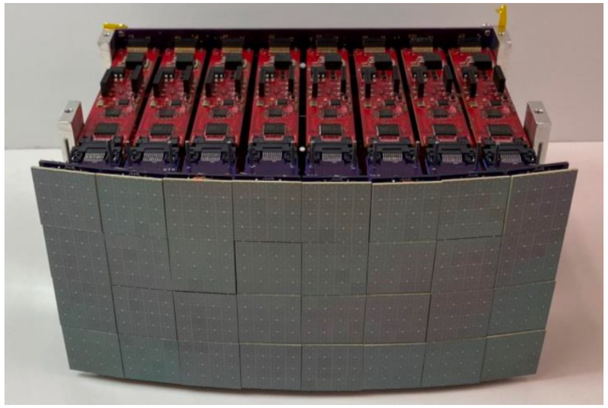


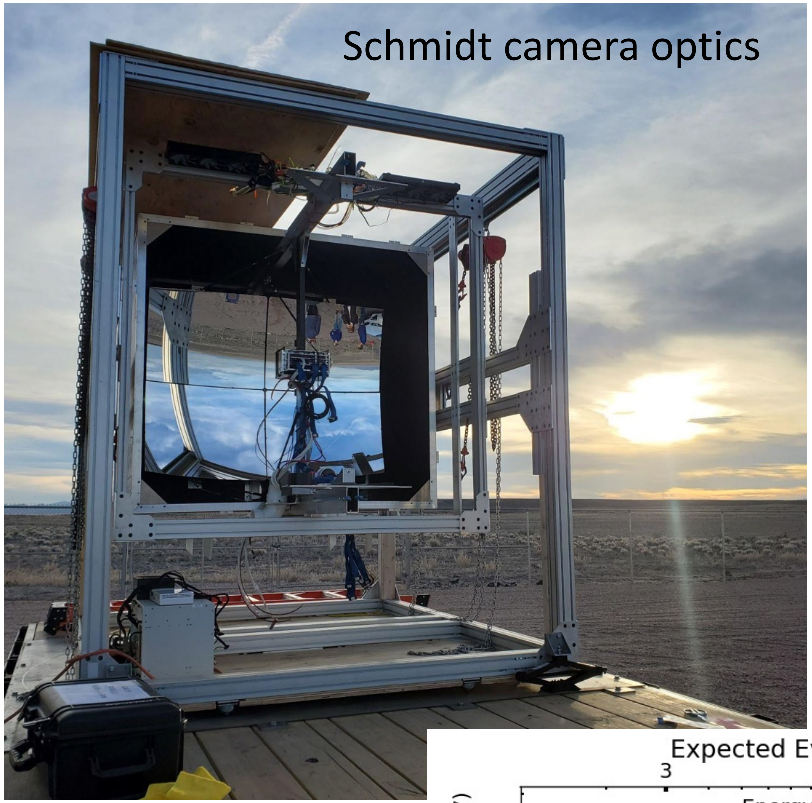
EUSO-SPB2: Major mission to come!

Fluorescence telescope focal surface

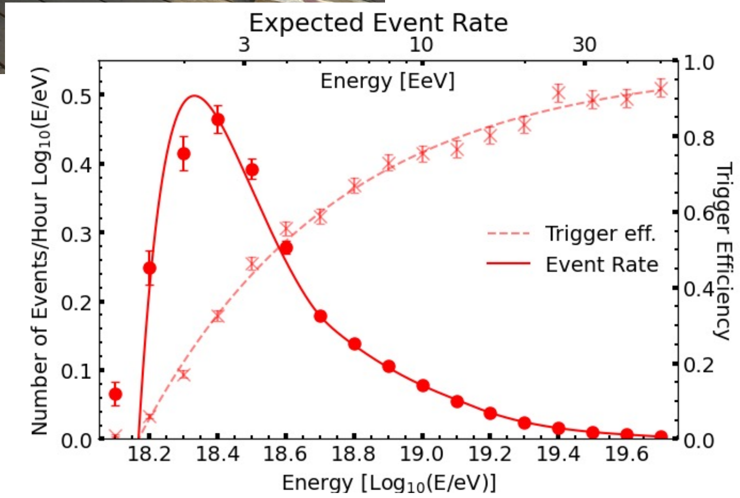


Cherenkov telescope focal surface





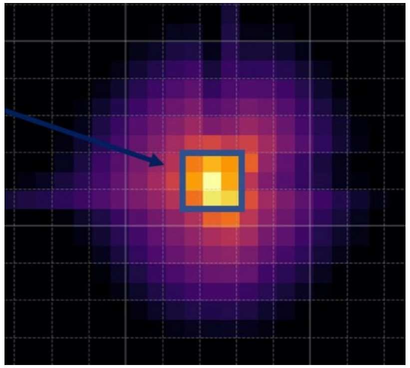
First CR events seen from above (in fluorescence) expected

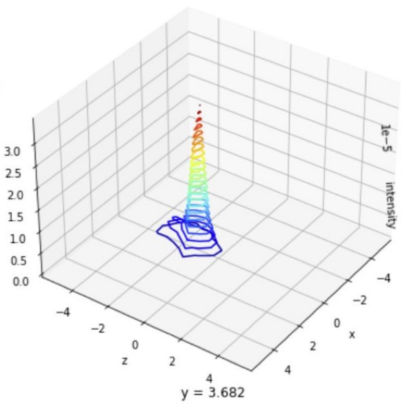


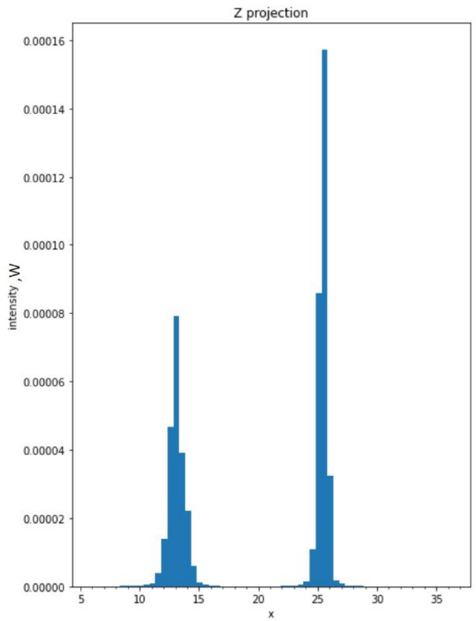
EUSO-SPB2:

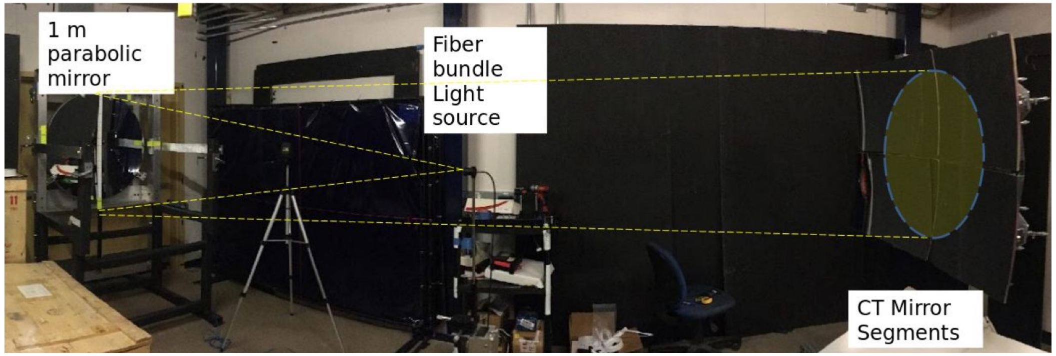
PSF: optics measurements in lab

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





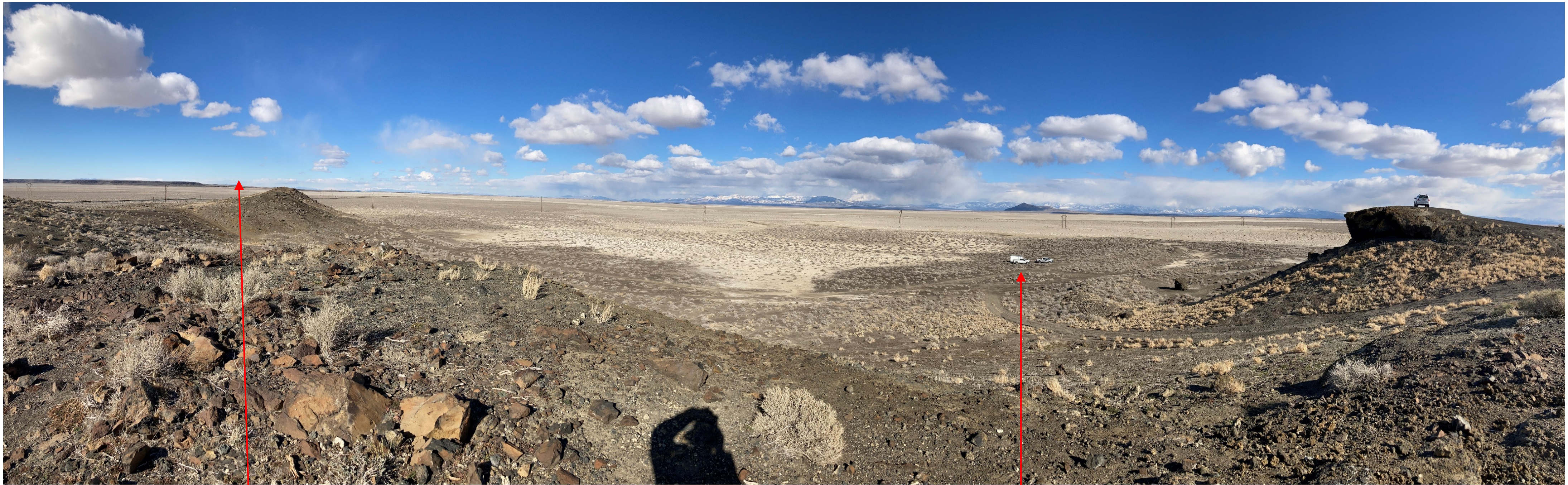




EUSO-SPB2:

THANKS A LOT to Telescope Array people!!!

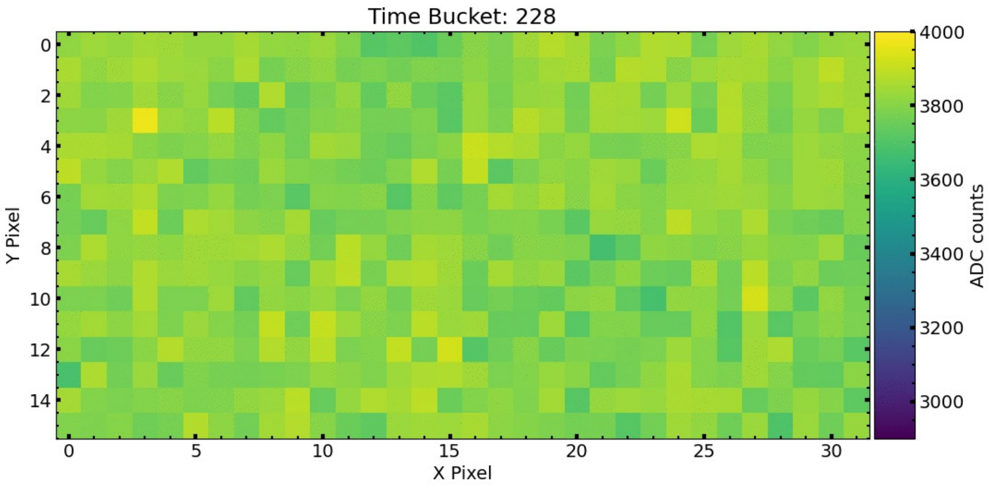
Field test of the Cherenkov telescope (March 2022)

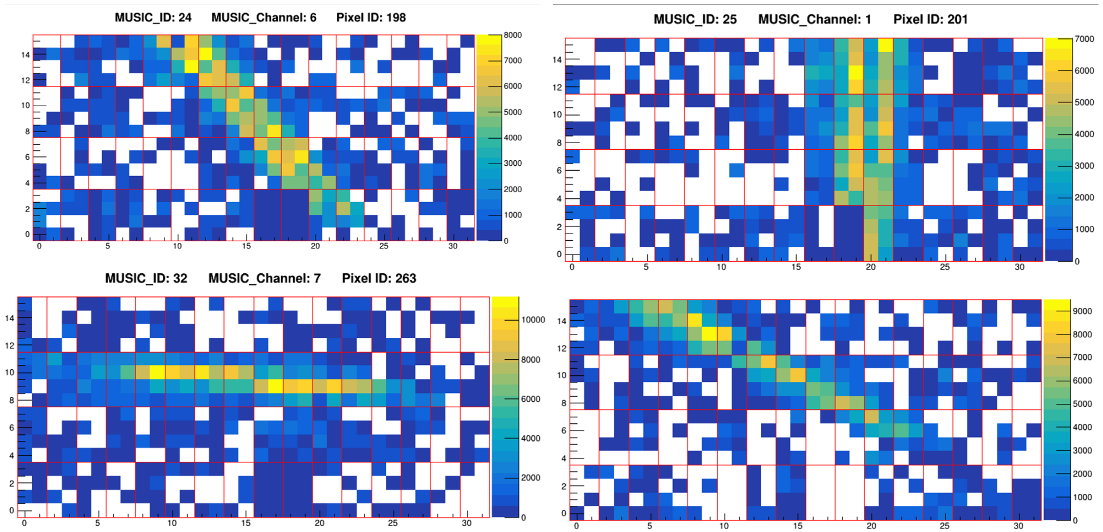


EUSO-SPB2:

THANKS A LOT to Telescope Array people!!!

Field test of the Cherenkov telescope (March 2022)



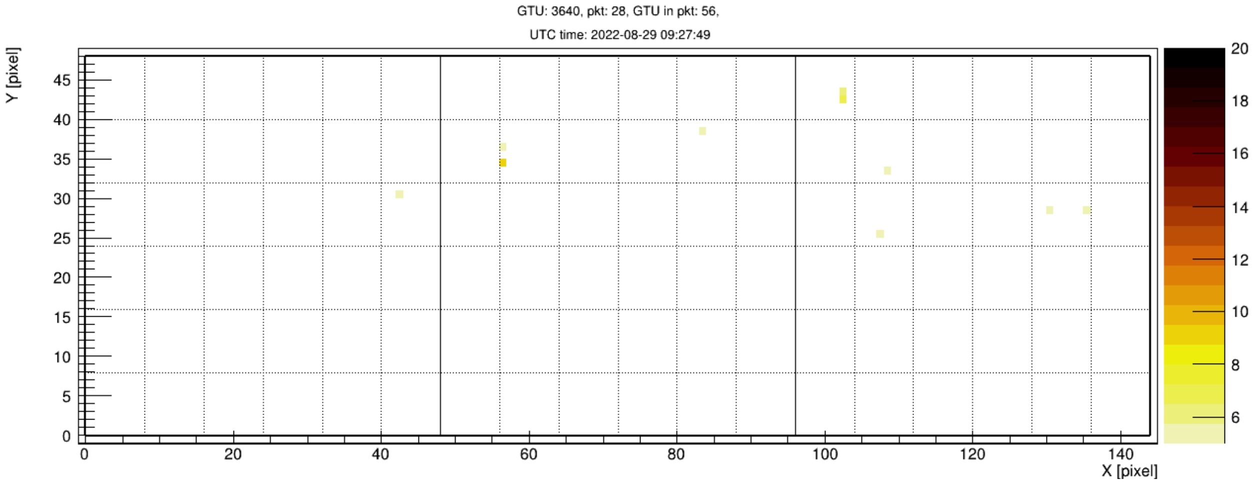


Bi-focal mirror in action!

EUSO-SPB2:

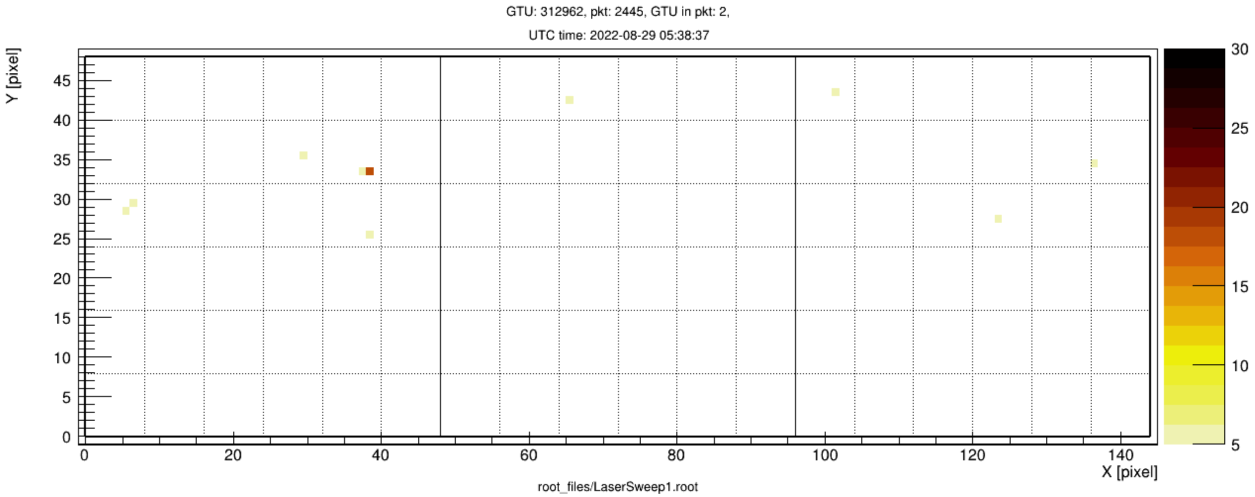
THANKS A LOT to Telescope Array AGAIN!!!

Field test of the Fluorescence telescope (August 2022)



Laser signal within 1 pixel

+ special thanks to George Fillipatos, Viktoria Kungel and Tobias Heibges

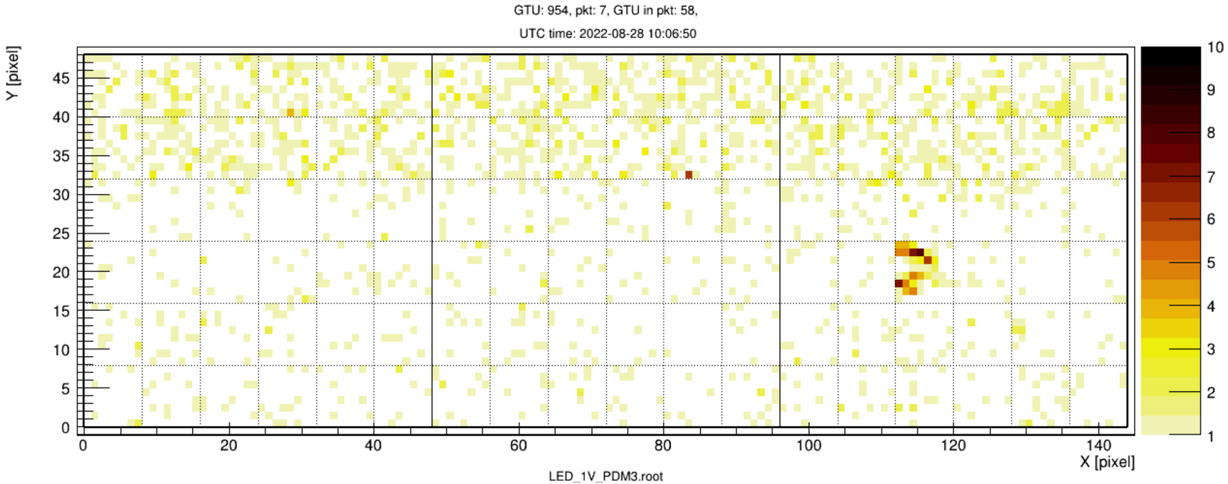


Inclined laser shot: crossing all 3 photodetection modules

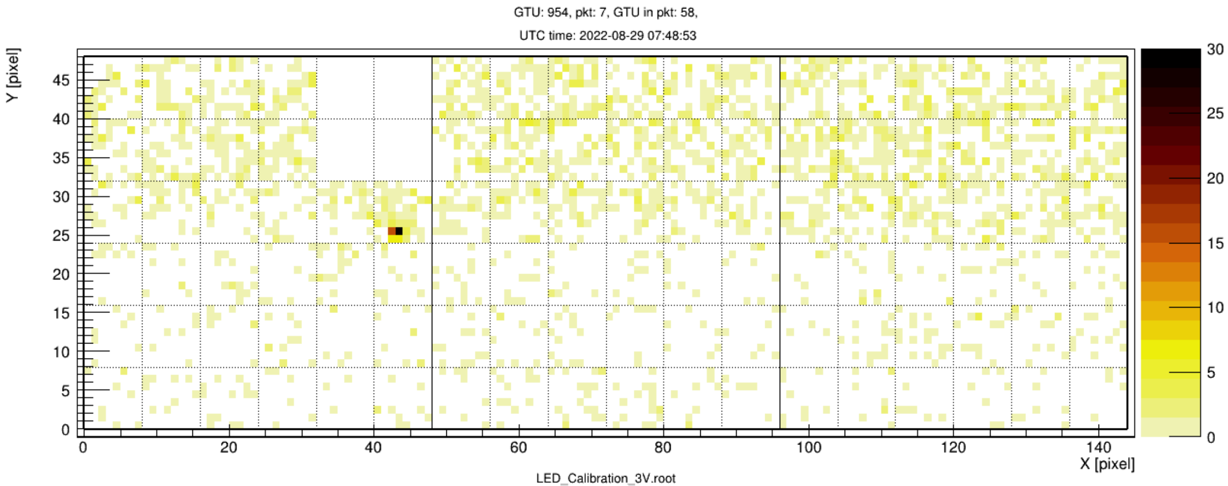
EUSO-SPB2:

Field test of the Fluorescence telescope (August 2022)

Calibrated LED flashes: near field



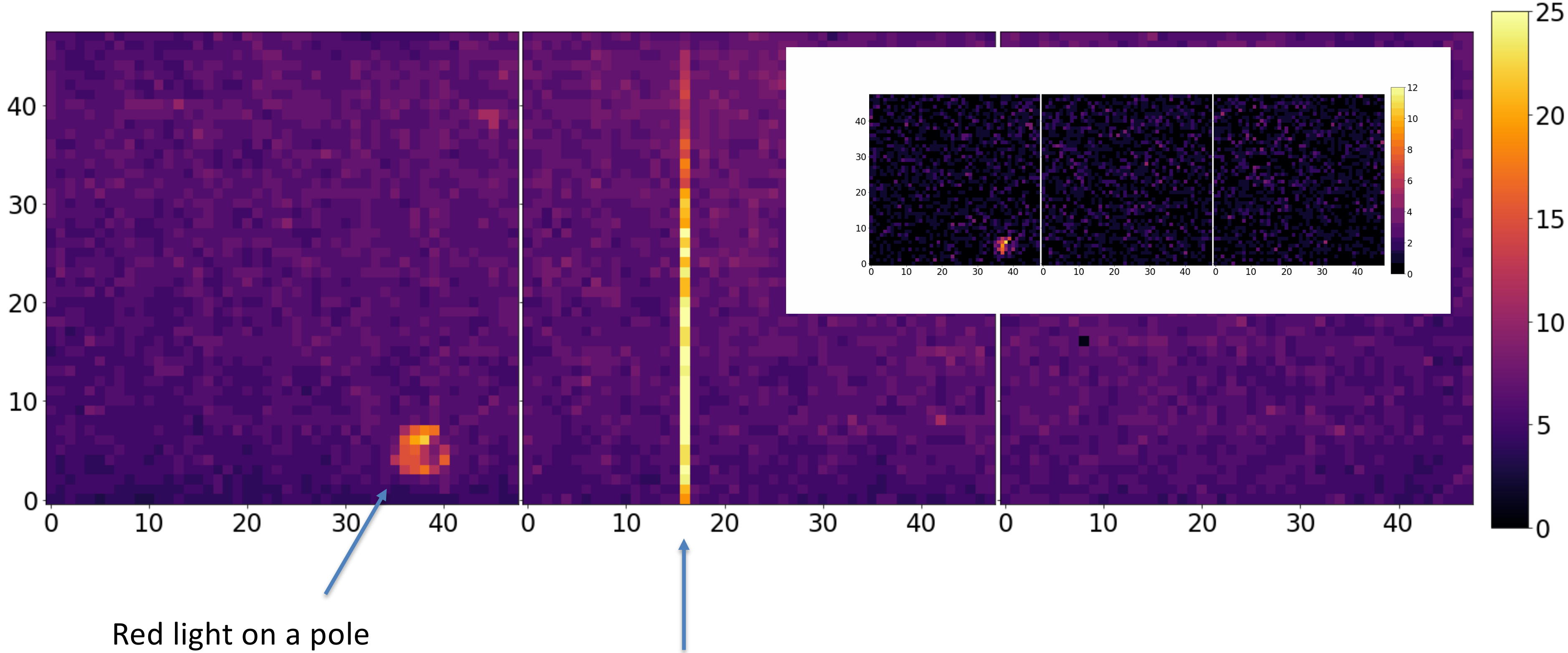
Calibrated LED flashes: far field



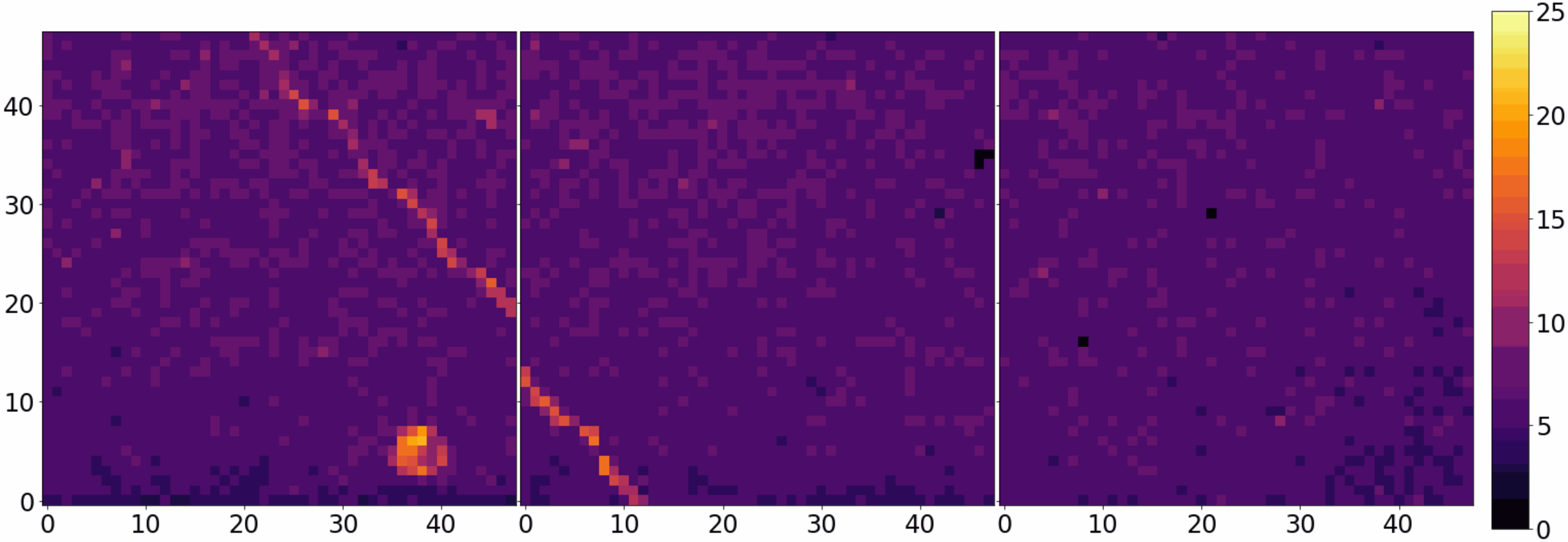
EUSO-SPB2:

Field test of the Fluorescence telescope (August 2022)

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



ENJOY!



Summary: we are ready!

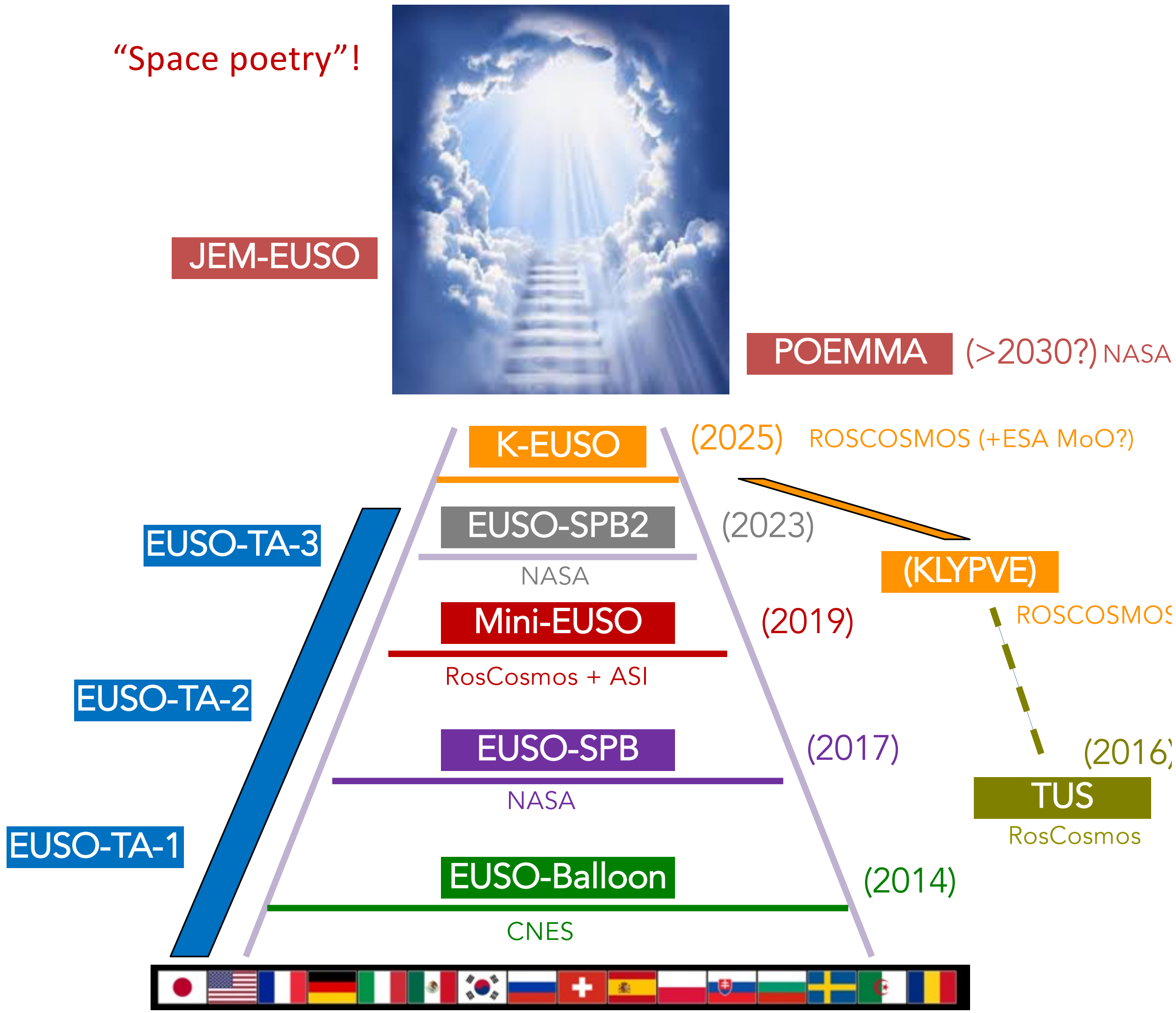
- With EUSO-Balloon, EUSO-TA, we have demonstrated the relevance of the JEM-EUSO technology

- With EUSO-SPB1, we have demonstrated the strength of our international collaboration, and assessed the performances in flight

- With MINI-EUSO, we have confirmed the long-time operation of the JEM-EUSO technology in space, and demonstrated the full potential of complementary science accessible to our instruments

- With EUSO-SPB2, we gathered all the past experience and upgraded the subsystems + we added Cherenkov detection for multi-messenger deployment.

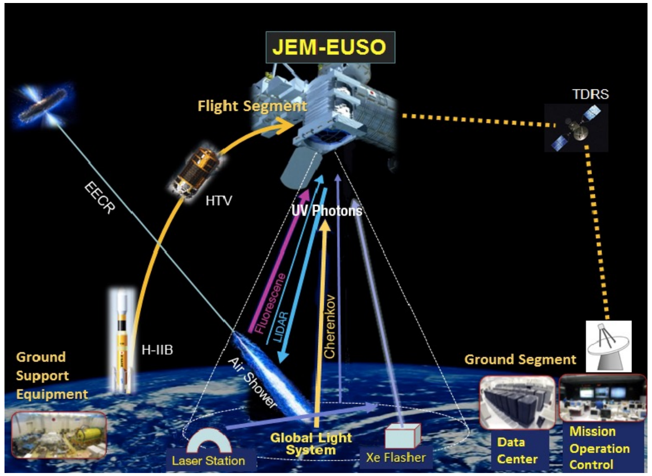
- EUSO-SPB2 ***will*** detect HECR showers!

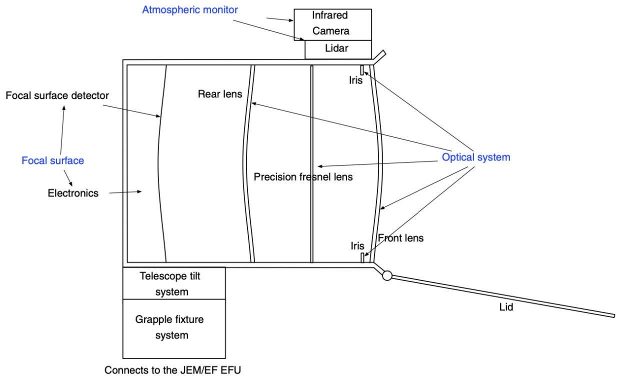


=> After 10 years of intense work, our collaboration appears mature and ready for full-scale UHECR observations from space!

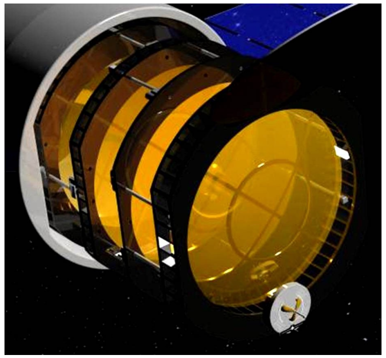
What’s next?

JEM-EUSO





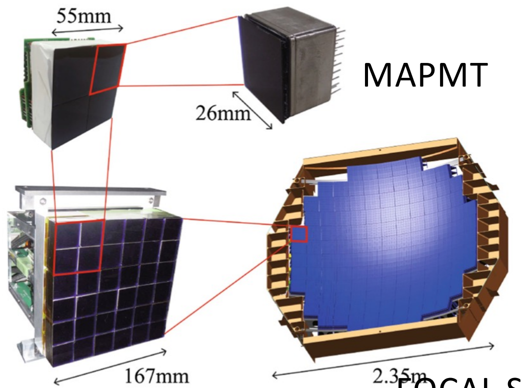
HTV configuration



Dragon configuration

EC

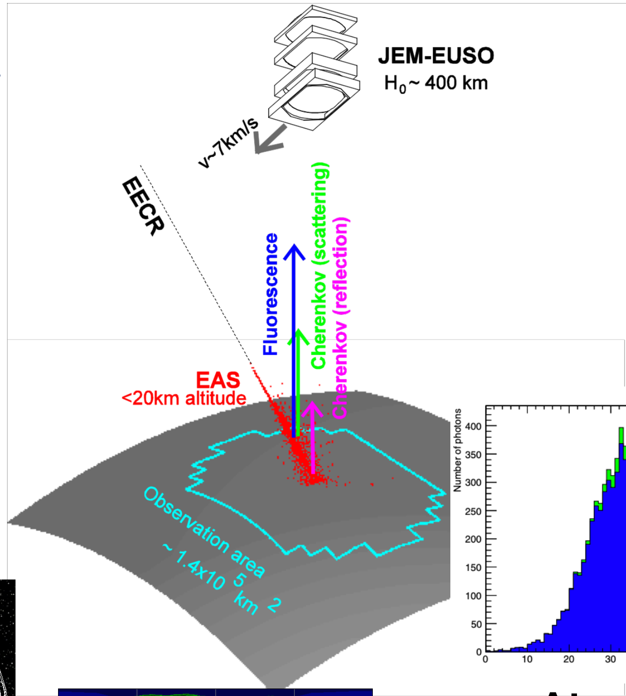
MAPMT

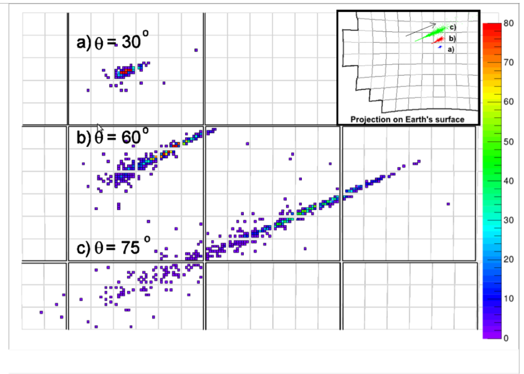


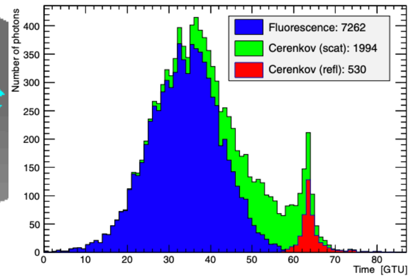
PDM

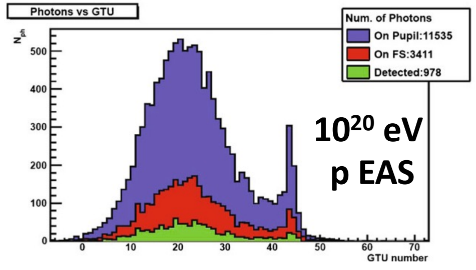
FOCAL SURFACE

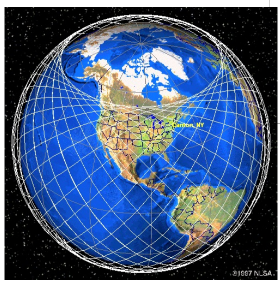
JEM-EUSO Coll.
Astrop. Phys.
44 (2013) 76

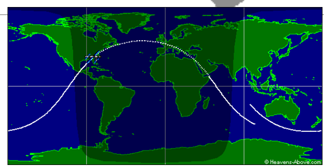










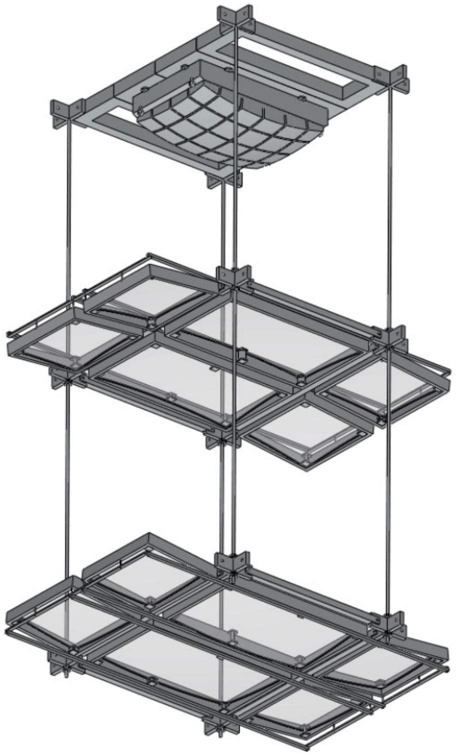


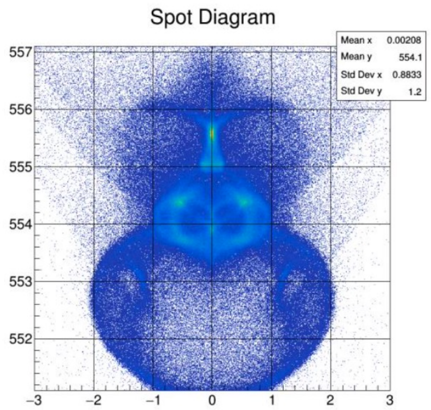
Δt ~ 50 - 150 μs

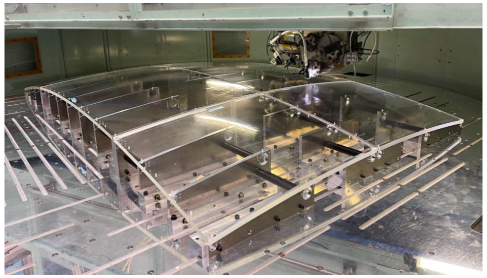
Δt ~ 20 - 60 GTUs

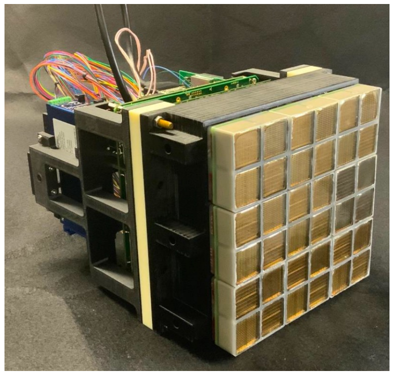
(1 GTU = 2.5 μs)

K-EUSO-like future…







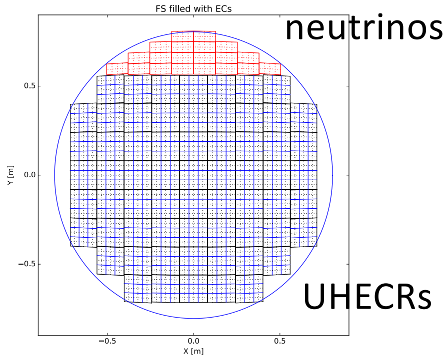


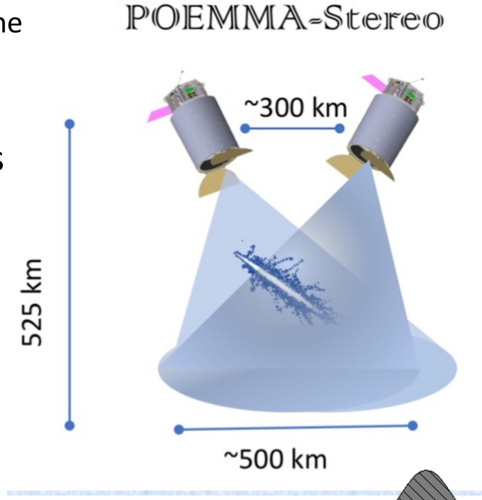
Ready (partly produced!)
Short time
Very relevant

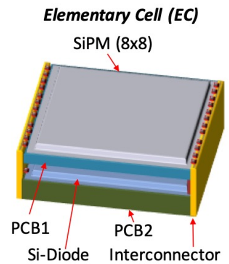
(But on hold… ☹)

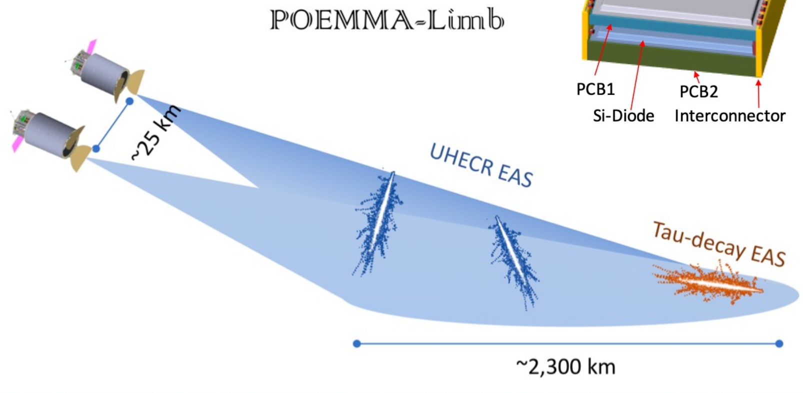
POEMMA-like future…

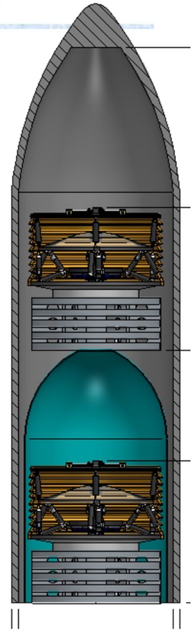
Probe Observatory for Extreme
Multi-Messenger Astronomy












Only the future knows the future.
Stay tuned...
Grazie mille!