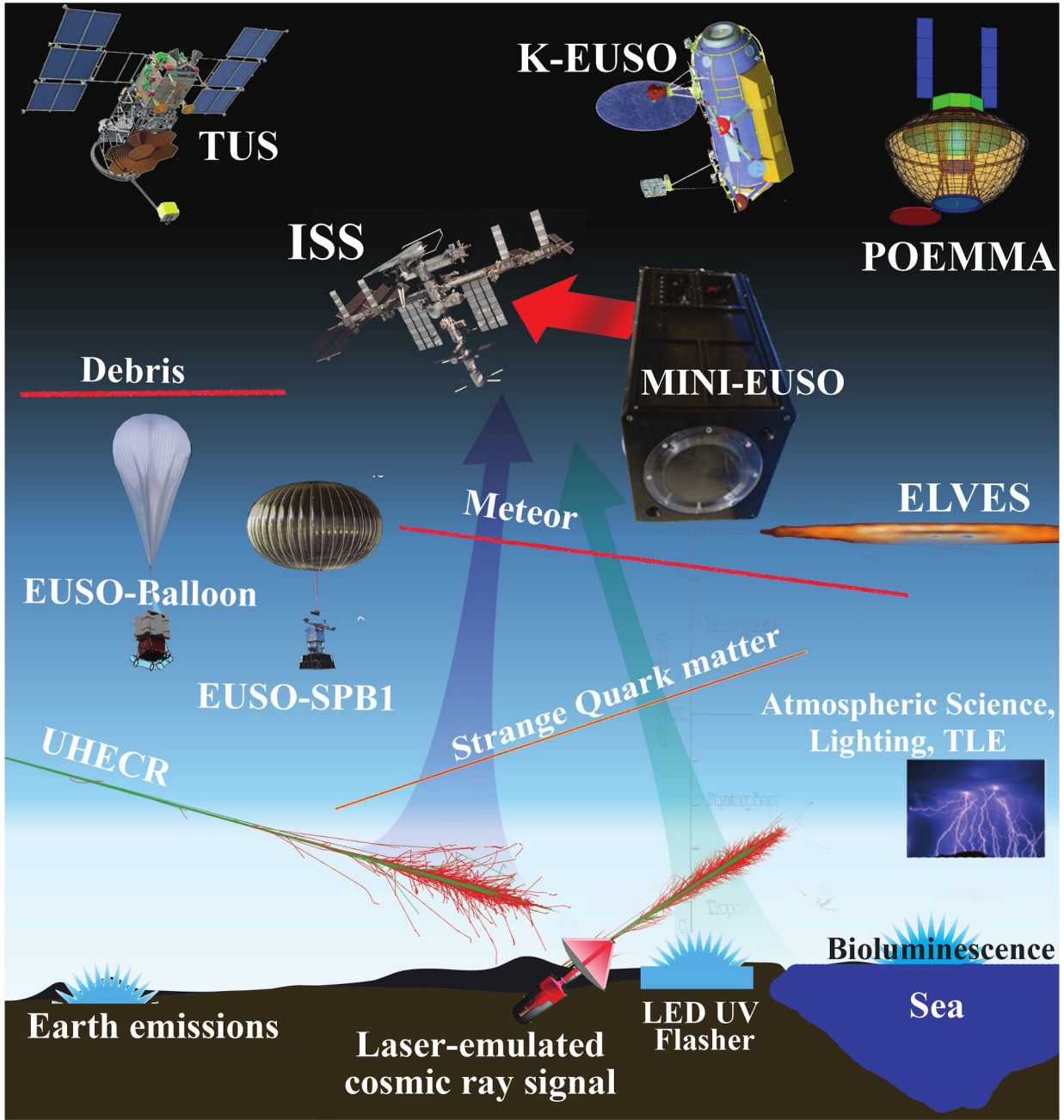
Joint Experiment Missions-
Extreme Universe Space Observatory

The Mini-EUSO telescope on board the International Space Station: first results in view of UHECR measurements from space

M. Bertaina – Univ. & INFN Torino
for the JEM-EUSO Collaboration
27th ECRS, Nijmegen

The JEM-EUSO program

1. EUSO-TA: Ground detector installed in 2013 at Telescope Array site, Utah, USA
2. EUSO Balloon (2014): Timmins, Canada, 1-night flight
3. EUSO SPB1 (2016): NASA ultra long duration flight from Wanaka, New Zealand
4. TUS (2016): free-flyer on Lomonosov Satellite
5. **Mini-EUSO (2019): Detector from International Space Station (ISS): 40 kg total, currently working**
6. EUSO SPB2 (2023): second Super Pressure Balloon flight from Wanaka, New Zealand
7. K-EUSO (2025+): ISS. Approved by Russian Space Agency
8. POEMMA (2029+): NASA twin free-Flyer



Snowmass 2021: https://arxiv.org/pdf/2205.05845

Submitted to the US Community Study
on the Future of Particle Physics (Snowmass 2021)

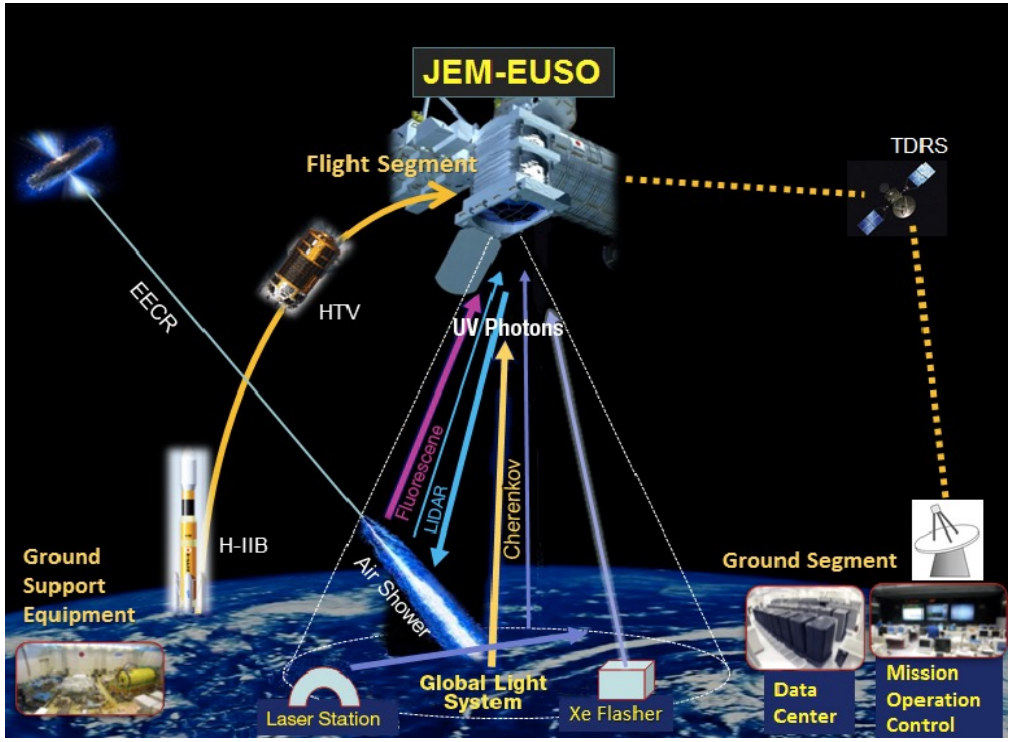
arXiv:2205.05845v2 [astro-ph.HE] 16 May 2022

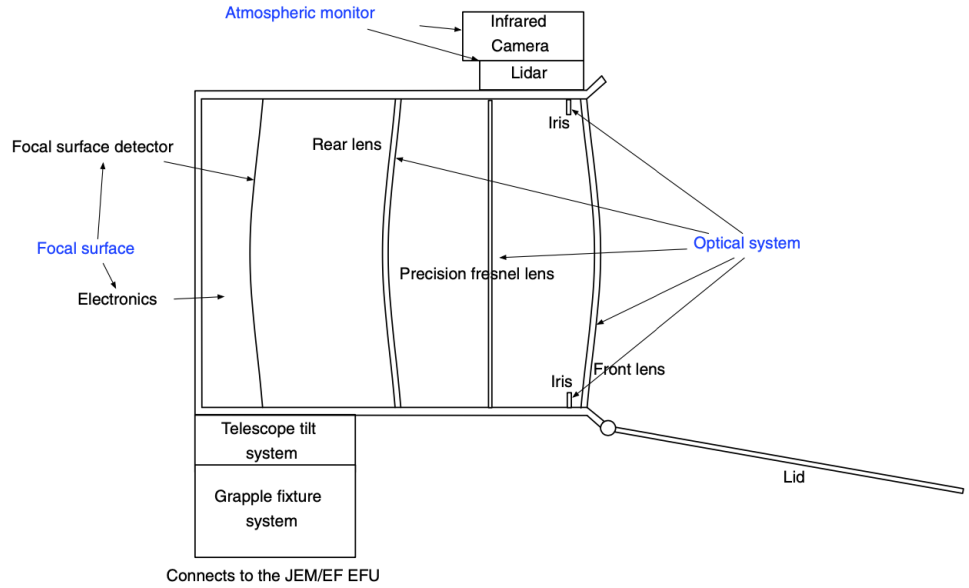
Ultra-High-Energy Cosmic Rays

The Intersection of the Cosmic and Energy Frontiers

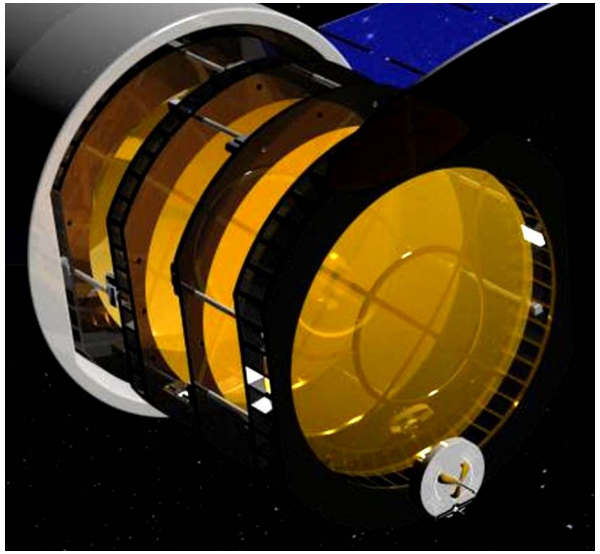
Abstract: The present white paper is submitted as part of the "Snowmass" process to help inform the long-term plans of the United States Department of Energy and the National Science Foundation for high-energy physics. It summarizes the science questions driving the Ultra-High-Energy Cosmic-Ray (UHECR) community and provides recommendations on the strategy to answer them in the next two decades.

JEM-EUSO



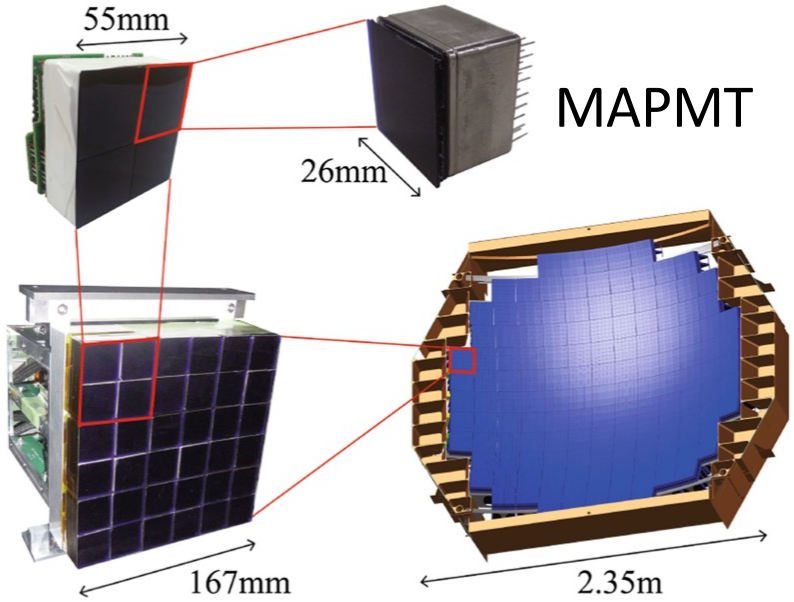


HTV configuration



Dragon configuration

EC



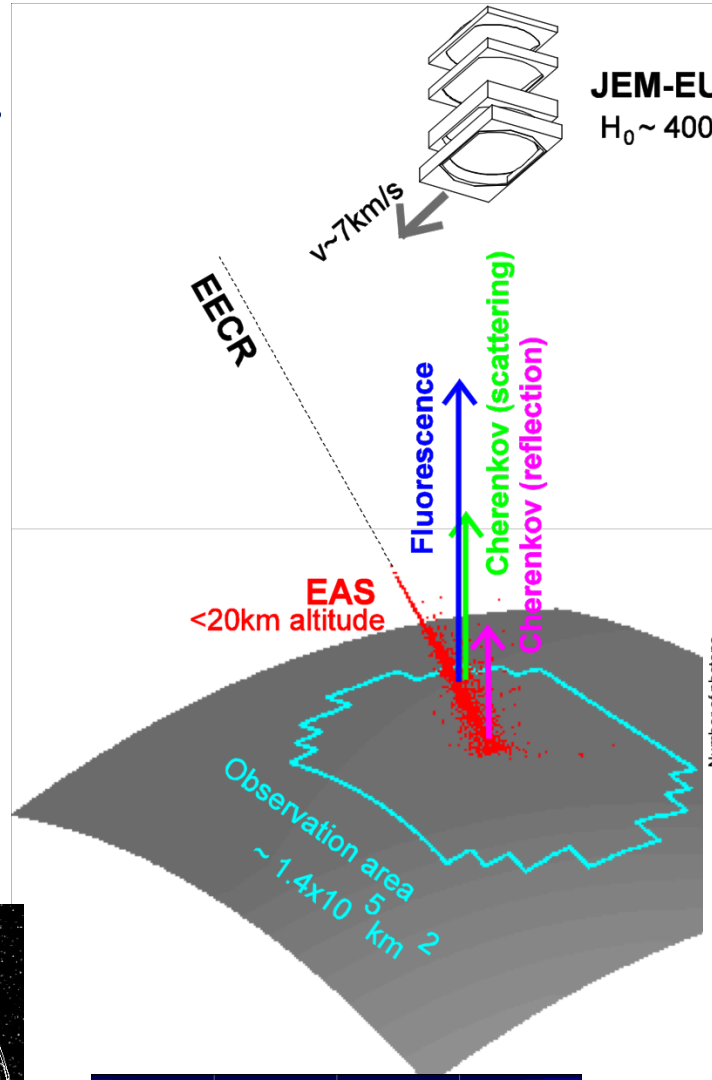
MAPMT

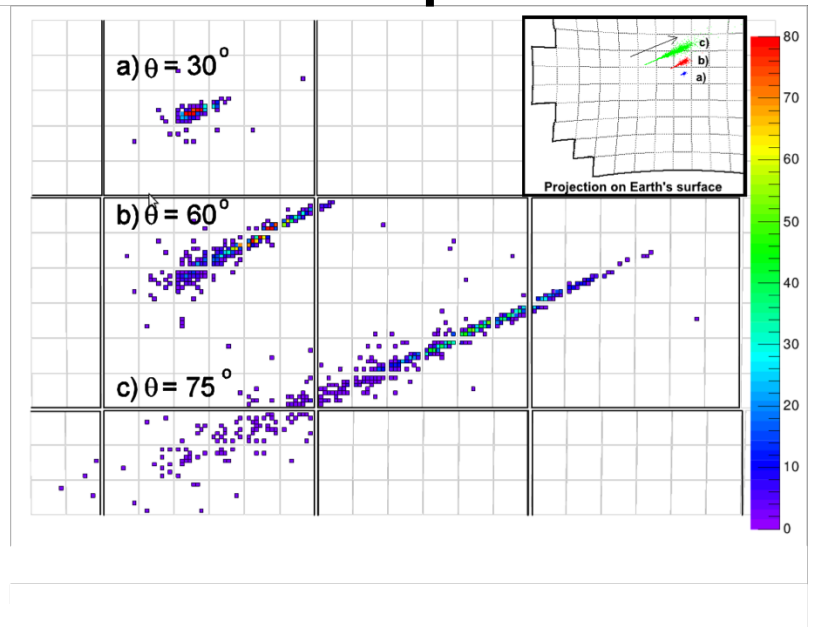
PDM

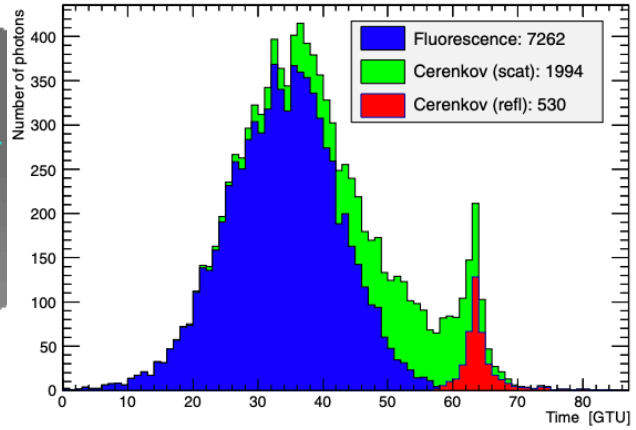
FOCAL SURFACE

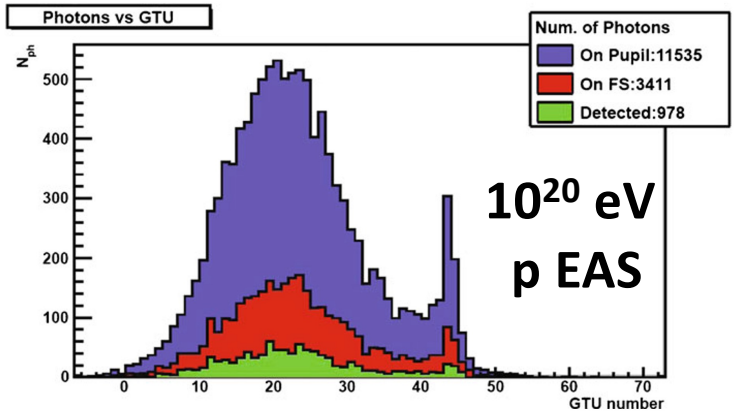
JEM-EUSO Observation Principle

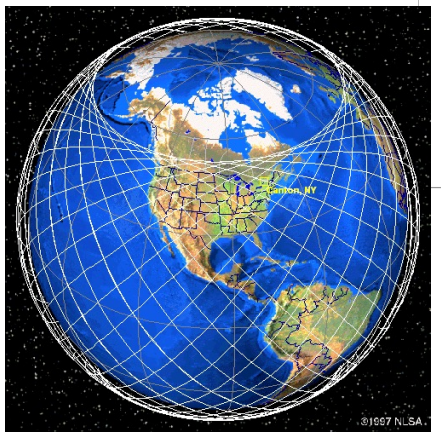
JEM-EUSO Coll. Astrop. Phys. 44 (2013) 76

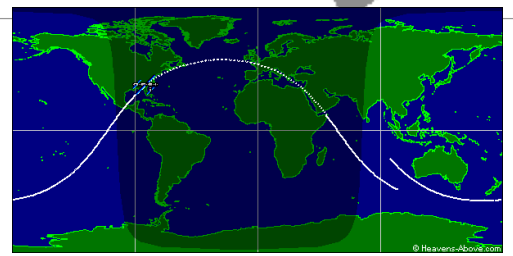












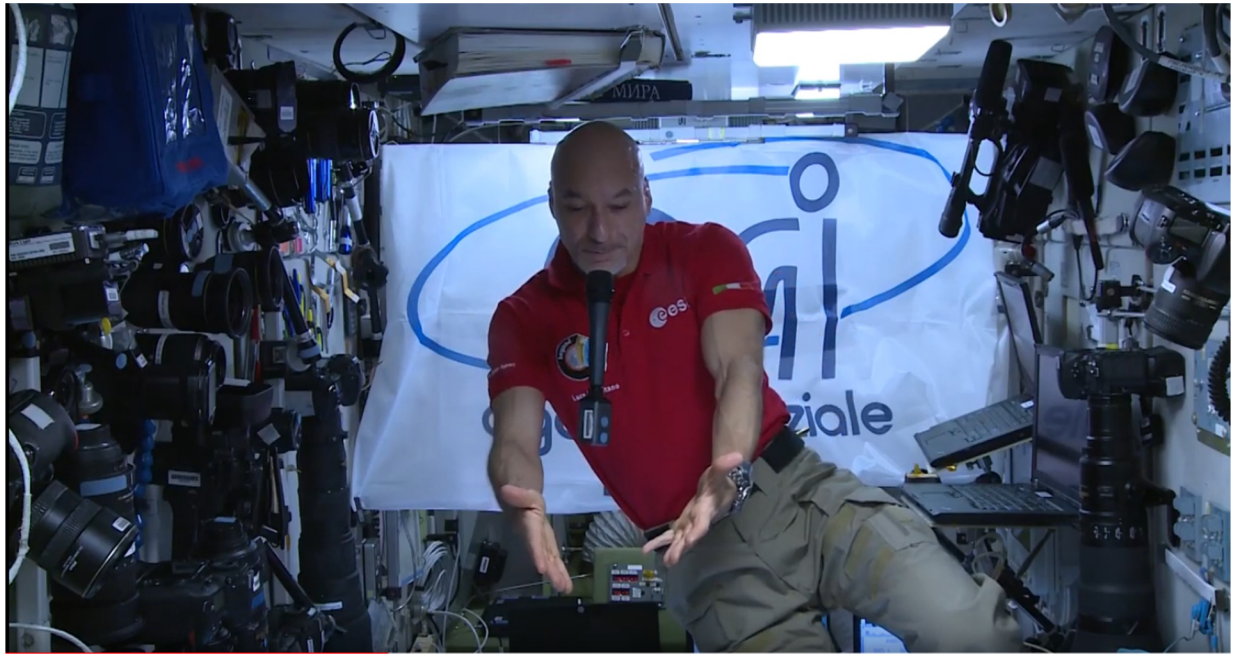
Δt ~ 50 - 150 μs

Δt ~ 20 - 60 GTUs

(1 GTU = 2.5 μs)

Mini-EUSO onboard the ISS with Luca Parmitano

Luca Parmitano in Roma Tor Vergata with Mini-EUSO

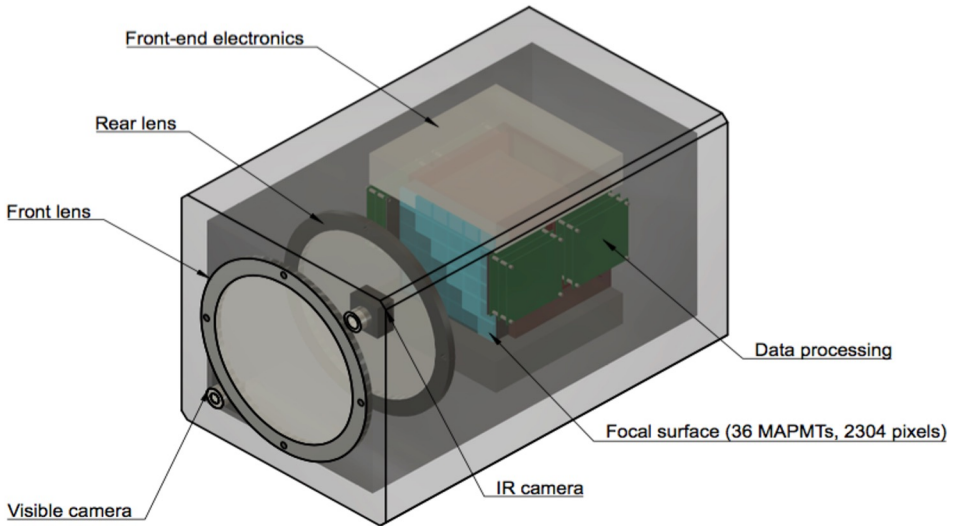


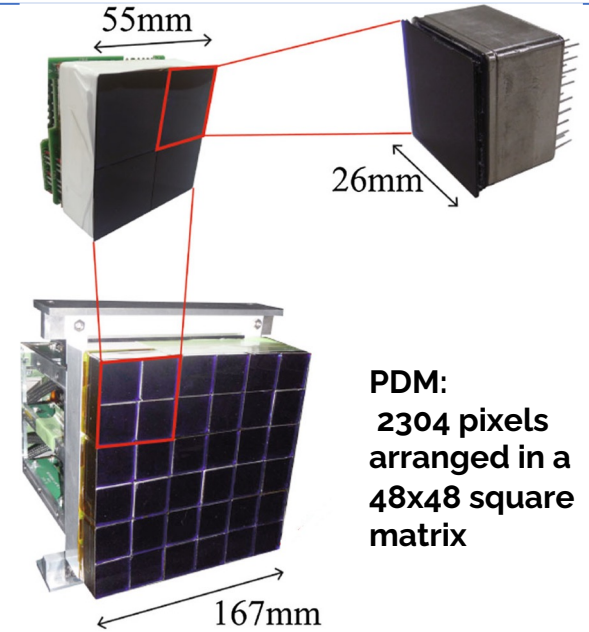
Luca Parmitano in the Zvezda Module on the ISS with Mini-EUSO
Video from *www.youtube.com/watch?v=QincAp4V-SM&t=1s*

ISS commander Luca Parmitano operated the first switch on of Mini-EUSO on 7th October 2019, as part of the scientific objectives of Mission Beyond

Mini-EUSO (Multiwavelength Imaging New Instrument for the Extreme Universe Space Observatory)

- Compact detector (37 × 37 × 62 cm^3)
- 48x48 pixels, single photon counting
- UV wavelength (300-400 nm)
- Optical system: two Fresnel lenses, 25 cm diameter
- Large FOV (±21°). Pixel size at sea level ~6.3km
- **Three different timescales**:
  - D1: 2.5 μs - EECRs and fast events (elves) - dedicated trigger logic (L1 trigger)
  - D2: 320 μs - atmospheric events - dedicated trigger logic (L2 trigger)
  - D3: 40.96 ms - slow events and UV maps - continuous data taking
- Ancillary cameras





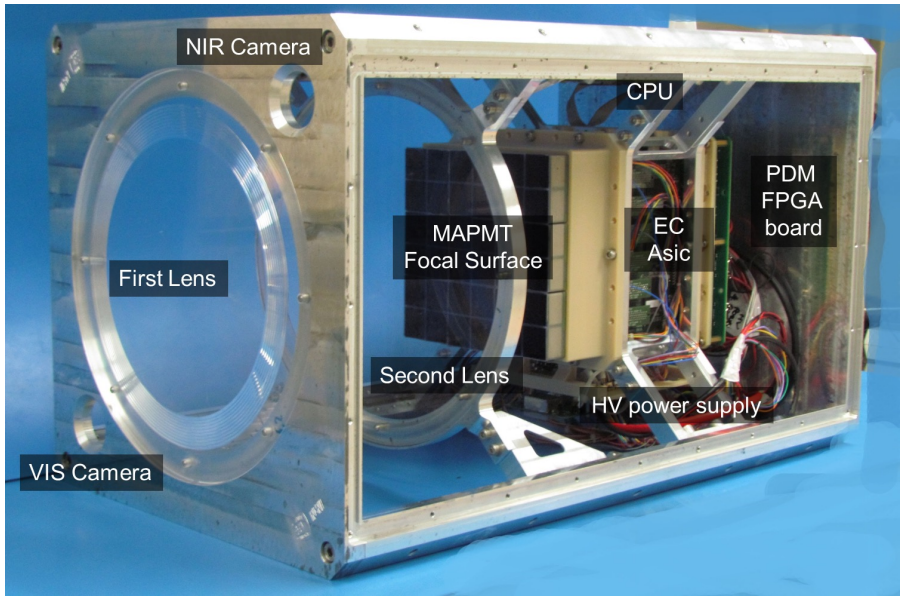
PDM:
2304 pixels arranged in a 48x48 square matrix

TopLeft: Simplified diagram of Mini-EUSO

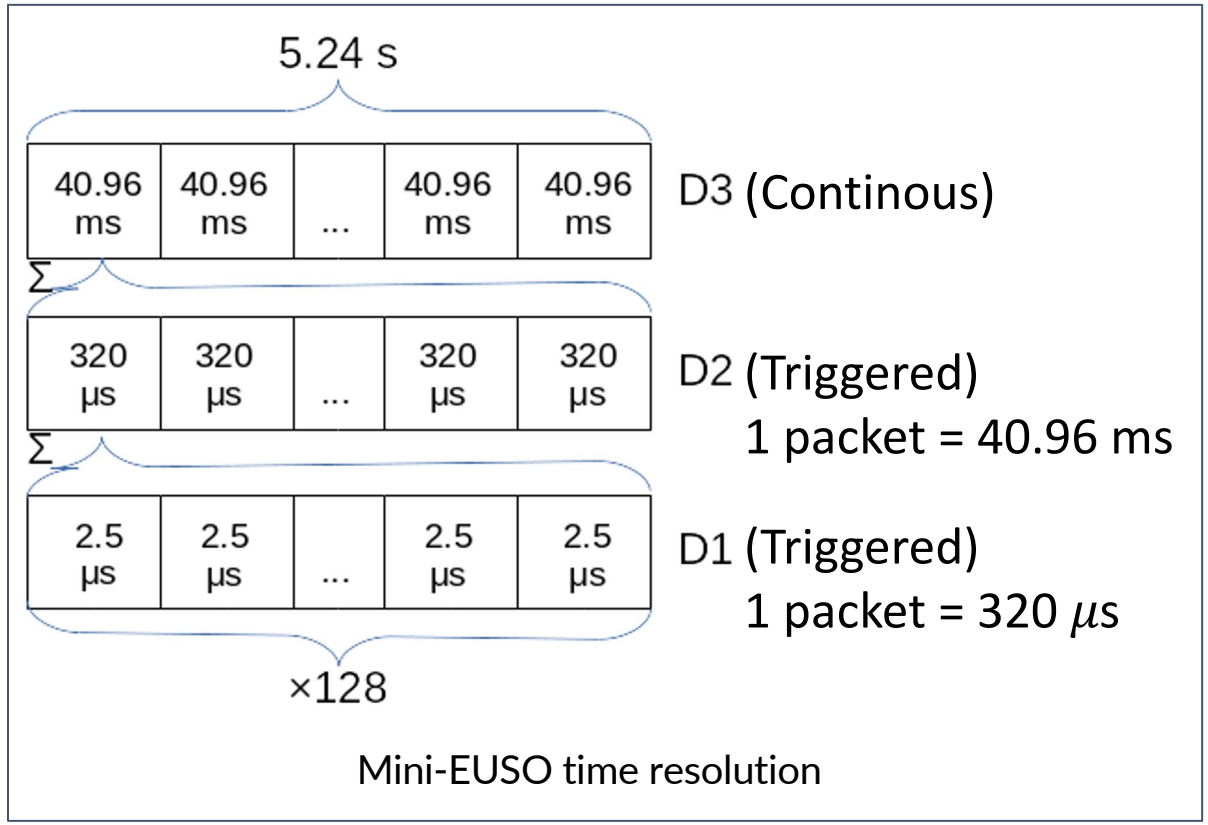
TopRight: Mini-EUSO focal surface

Bottom: Mini-EUSO installed onboard the ISS (ZVEZDA module) during a data-taking session

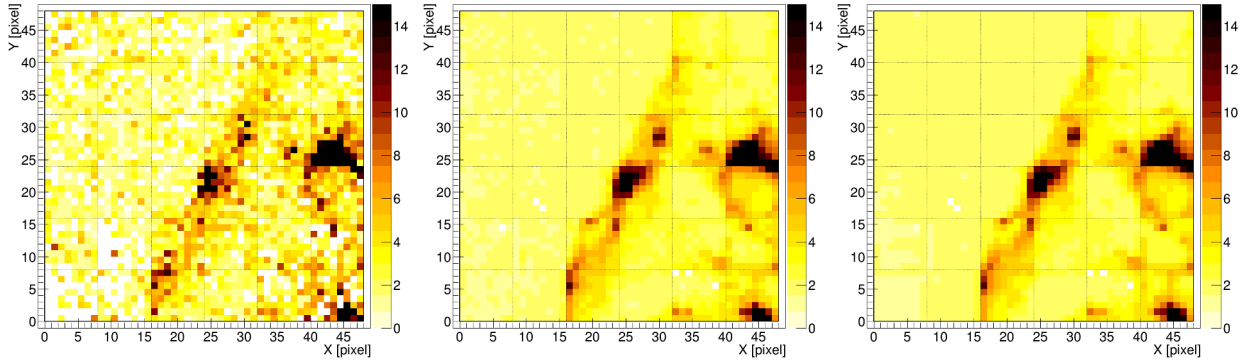
Data acquisition system



Views of the Indian coast



counts/GTU



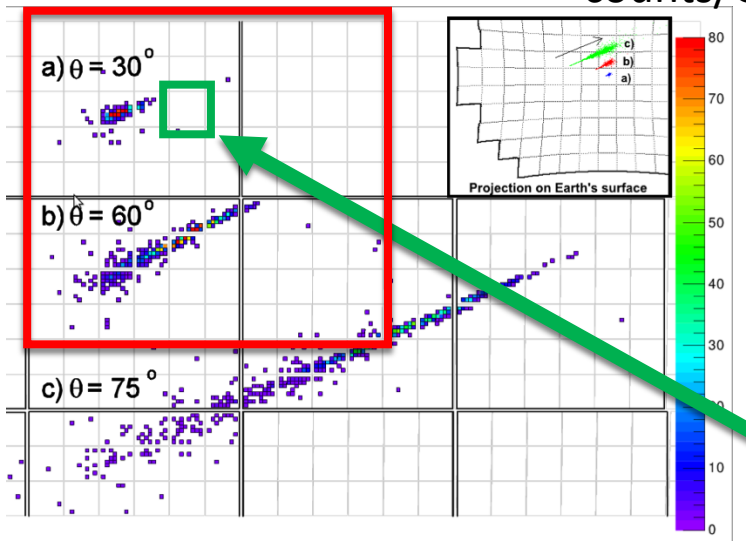
D1 D2 D3

JEM-EUSO & Mini-EUSO

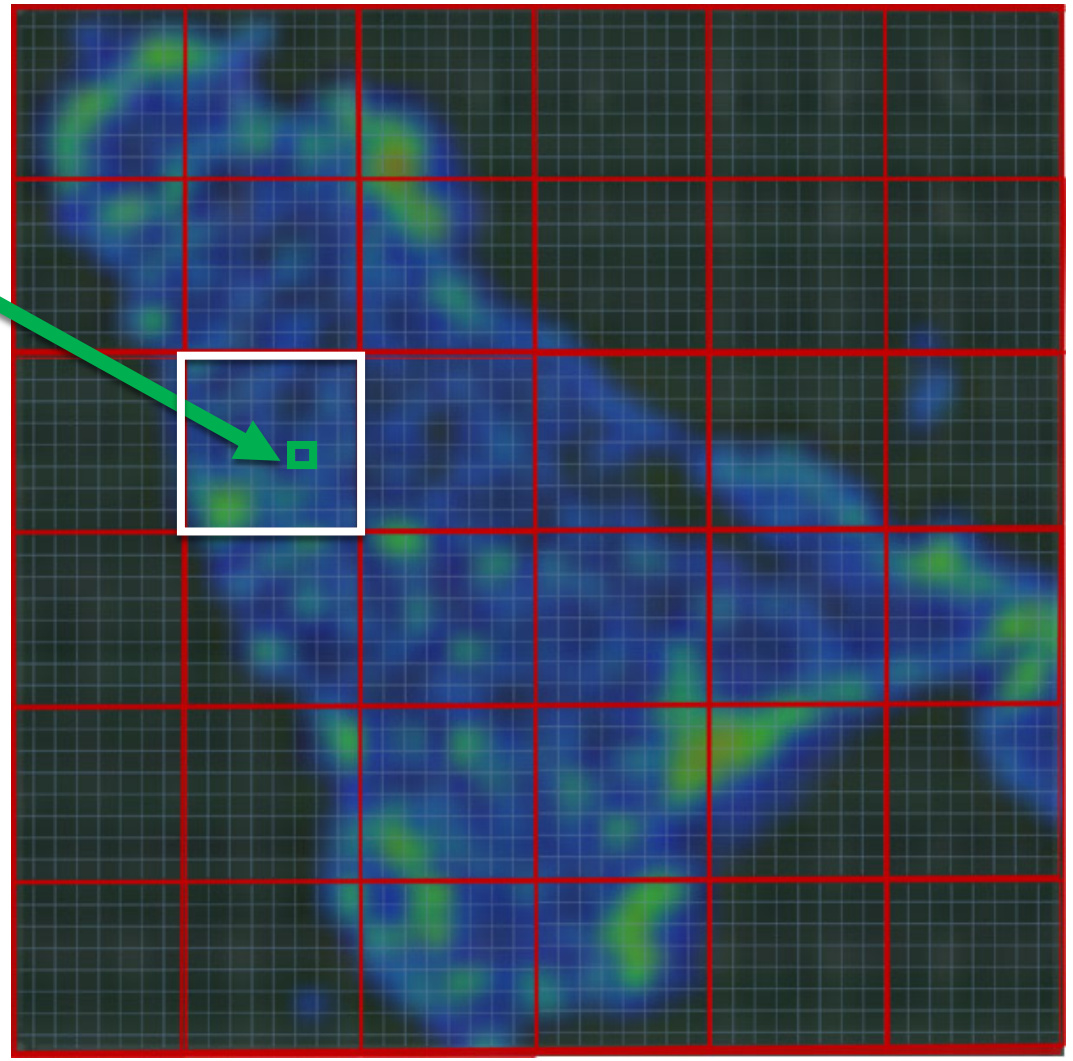
FoV

counts/GTU

JEM-EUSO



Mini-EUSO



Simulation pre-flight

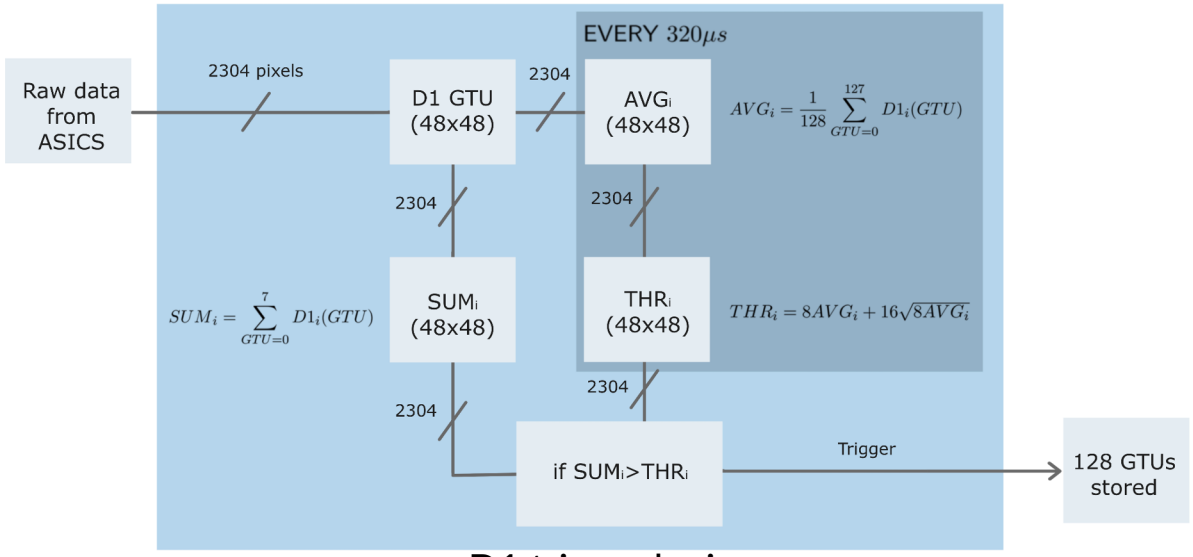
Comparison @ order of magnitude level

	Mini-EUSO	JEM-EUSO
	~1 pixel	~ 1 MAPMT
	~1 PMT	~ 3 PDM
Spatial resolution	**~6.3 km**	**~0.55 km**
Optics aperture	**~0.05 m²**	**~4.5 m²**

Similar counts/pixel from diffuse light in JEM-EUSO & Mini-EUSO

x100 light in JEM-EUSO from point-like sources

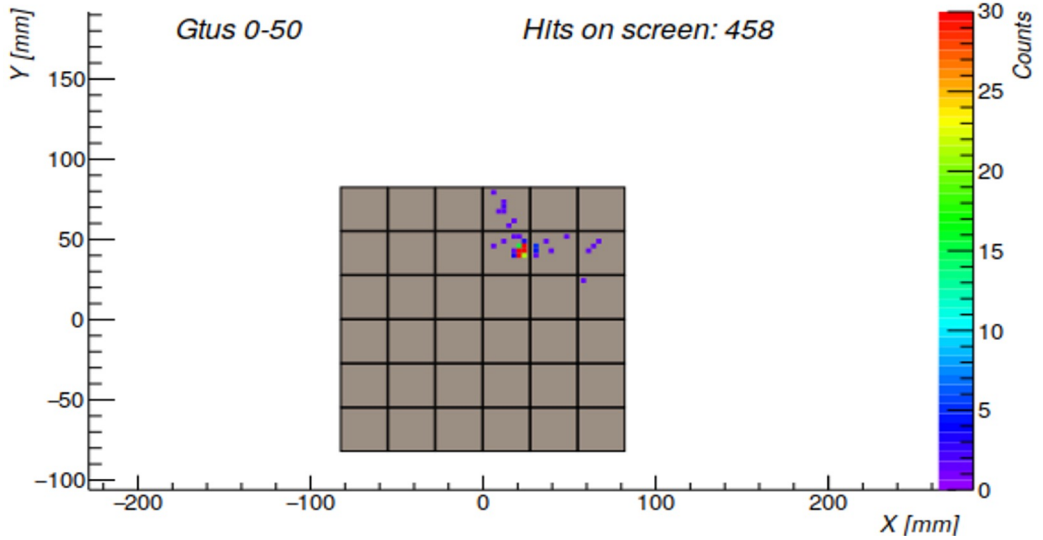
D1 trigger logic



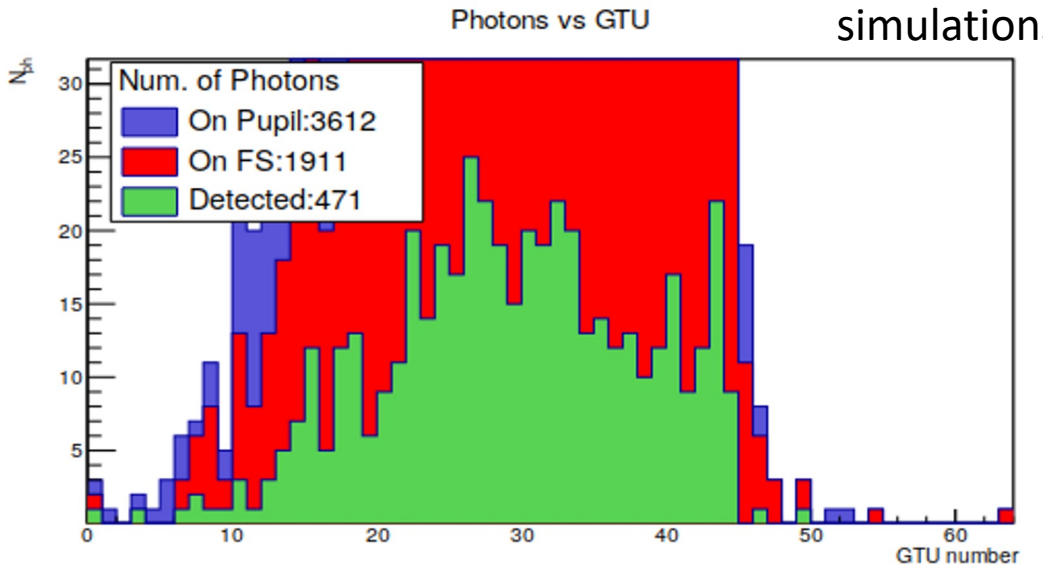
D1 trigger logic

- Each pixel is independent
  - Each pixel has its own threshold
  - A pixel over threshold is enough to issue a trigger
- The thresholds are updated every 128 D1 GTUs (320 μs)
  - Thresholds are set 16**σ** above the average value of the pixel (background)
- The logic looks for an excess of signal over 8 consecutive GTUs in the same pixel

Proton E = 5x10^{21} eV, 50°

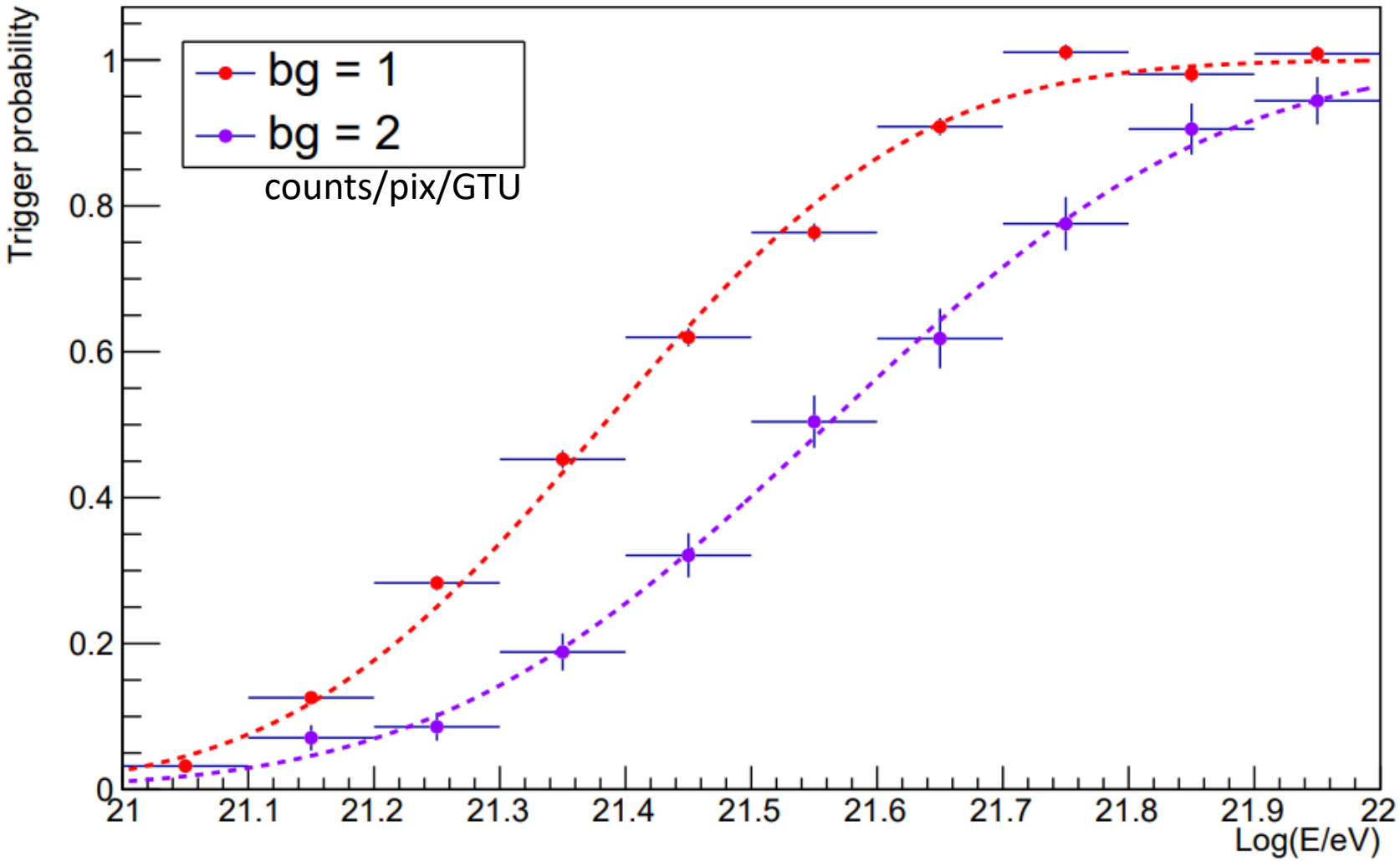


ESAF simulations



10

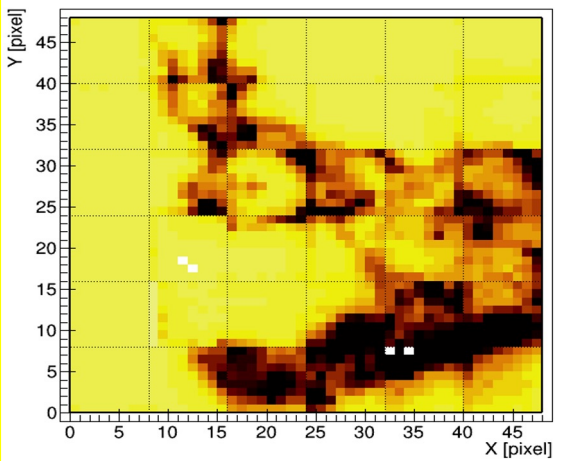
Mini-EUSO EAS trigger probability



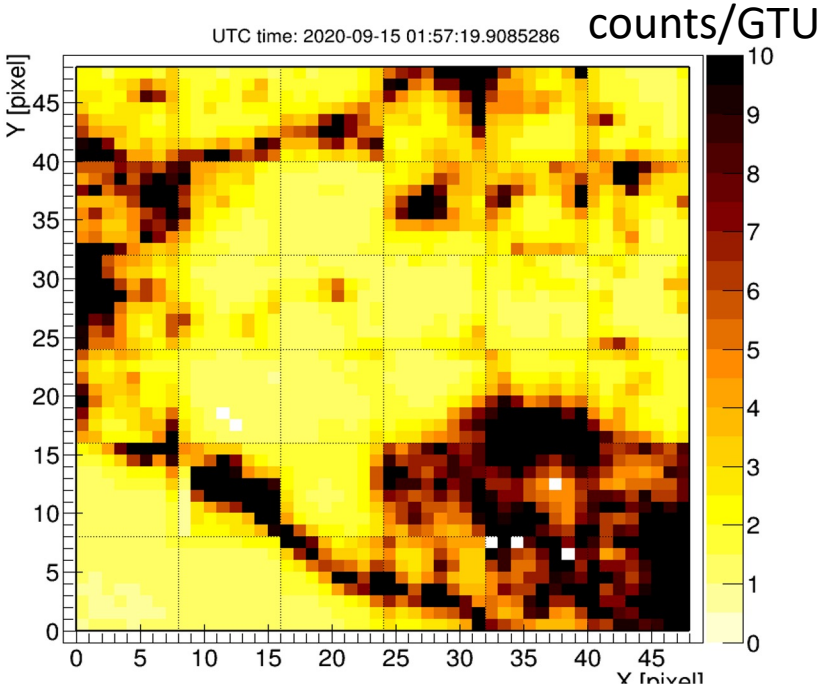
Obtained using ESAF simulations

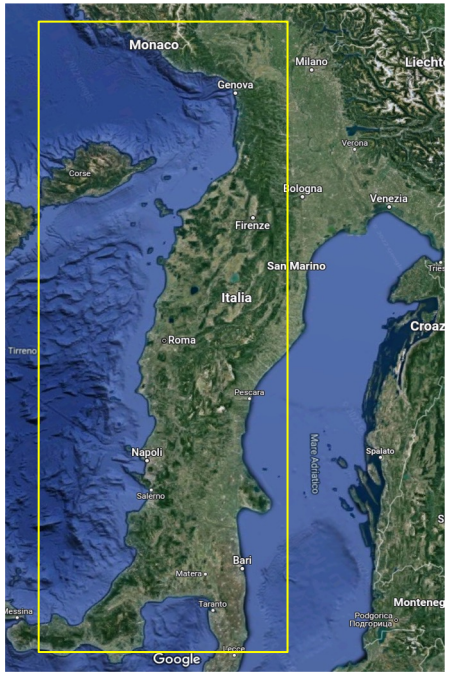
Proton EASs

Diffused sources in Mini-EUSO

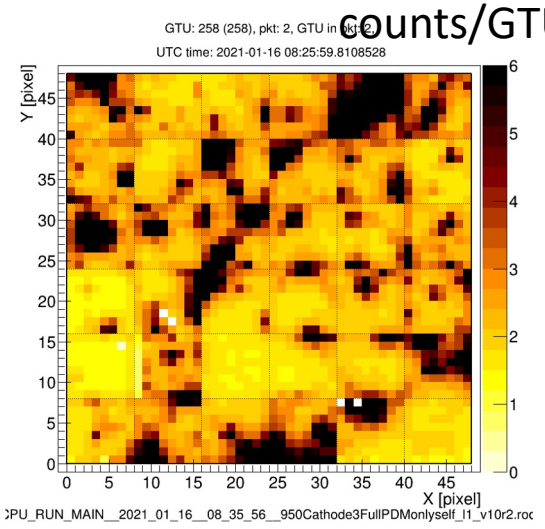


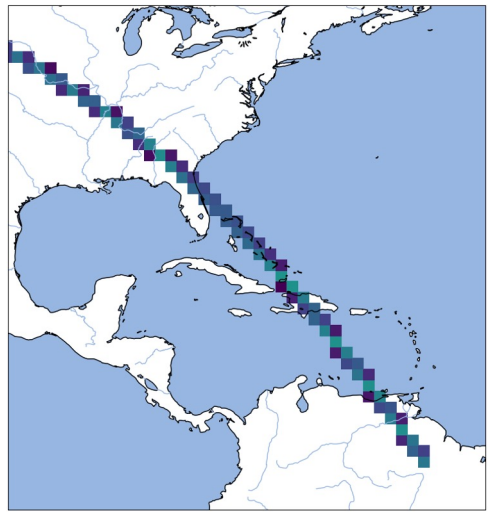
Southern Italy





Italy view from North to South



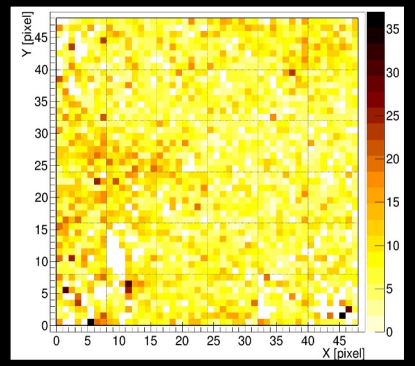


Florida and Haiti/Dominican Republic

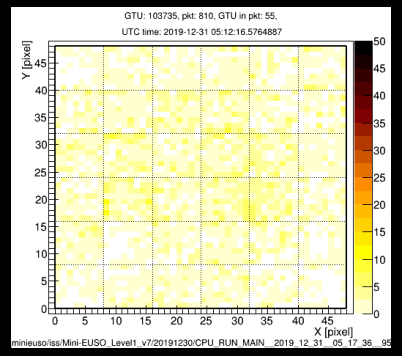
S. Bacholle et al. ApJS Vol. 253 (2021) 36

Mini-EUSO events zoo

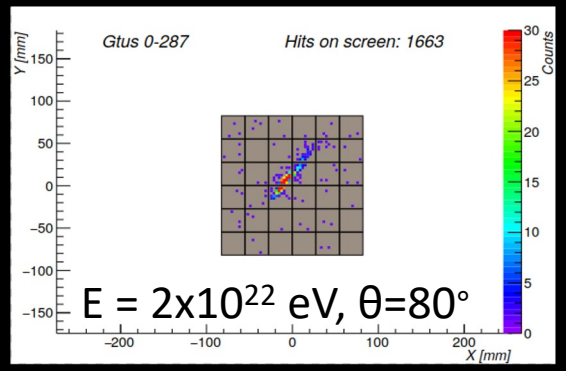
TLEs

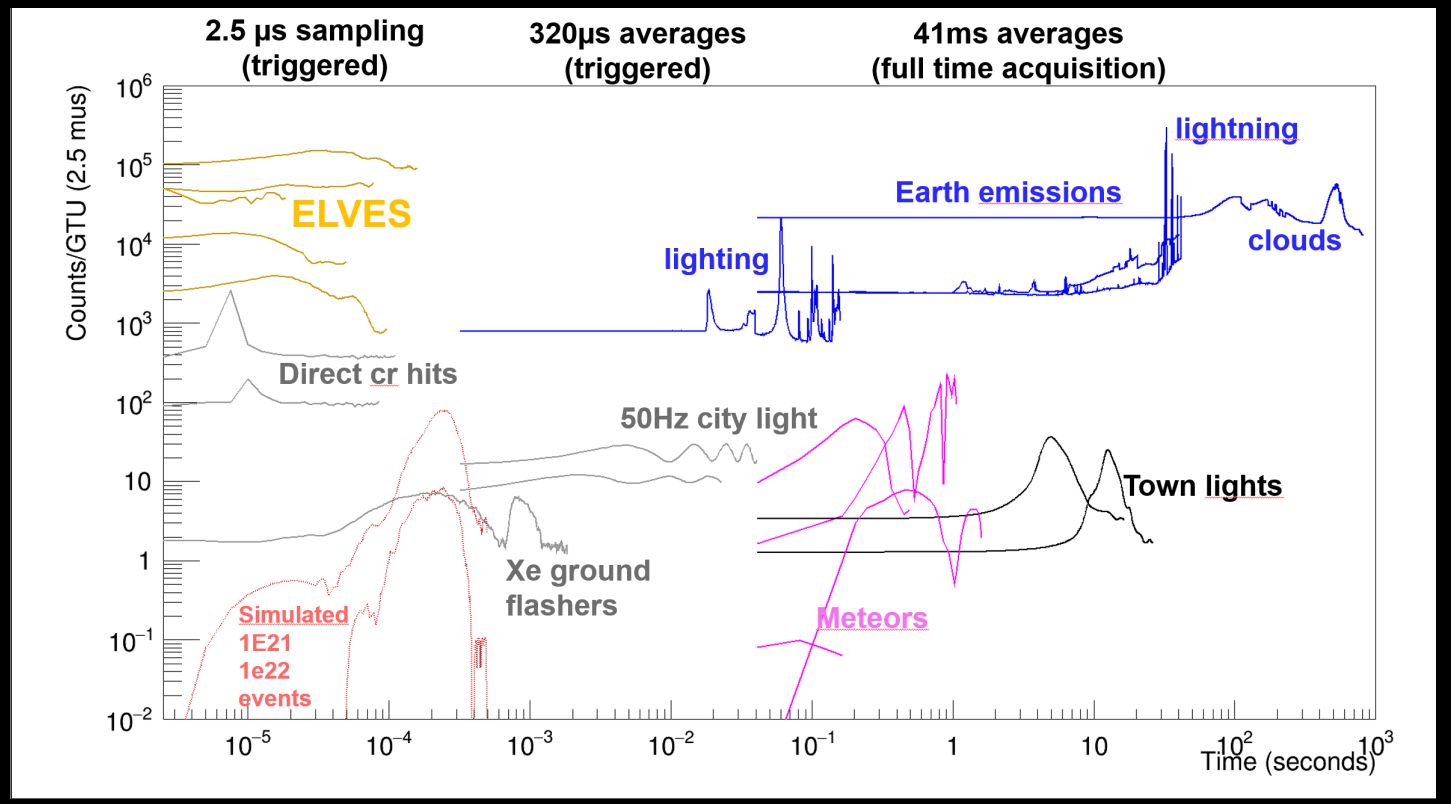


Direct CR

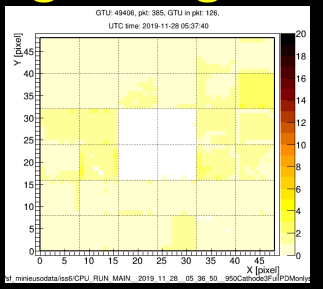


Simulated EAS

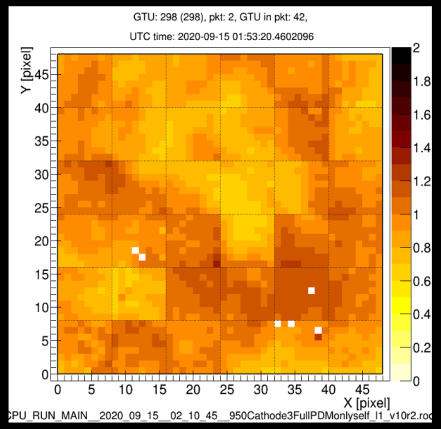




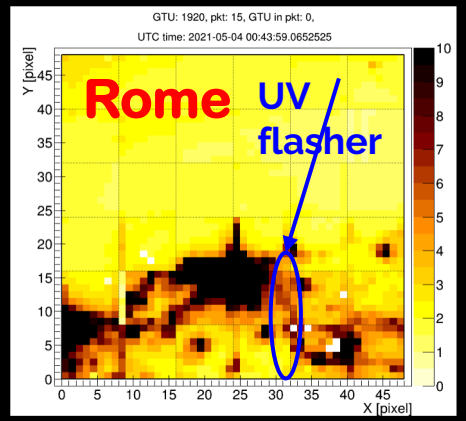
lightning



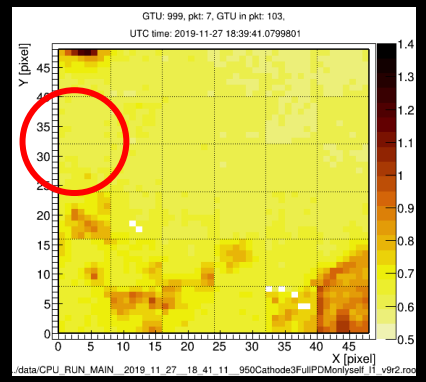
clouds



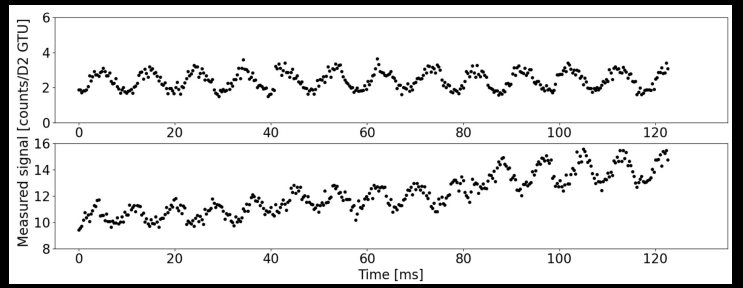
Artificial sources



meteors

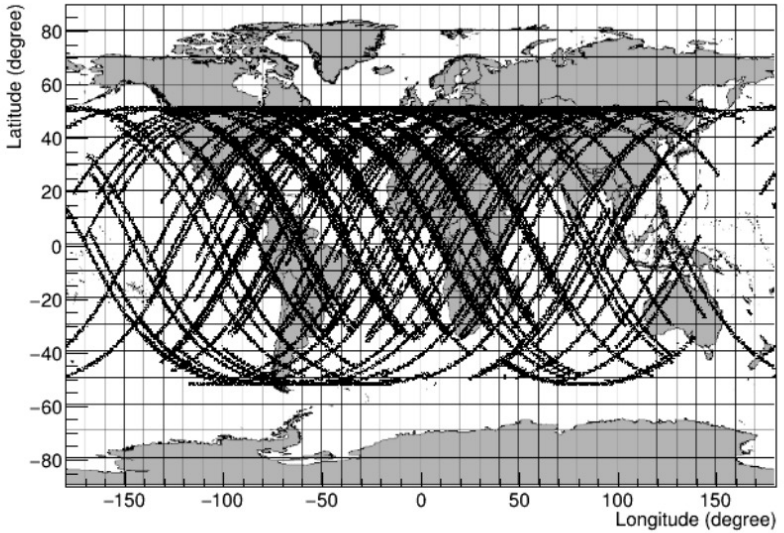


Artificial sources (50-60 Hz oscillations)



UV maps - Europe and Mediterranean area

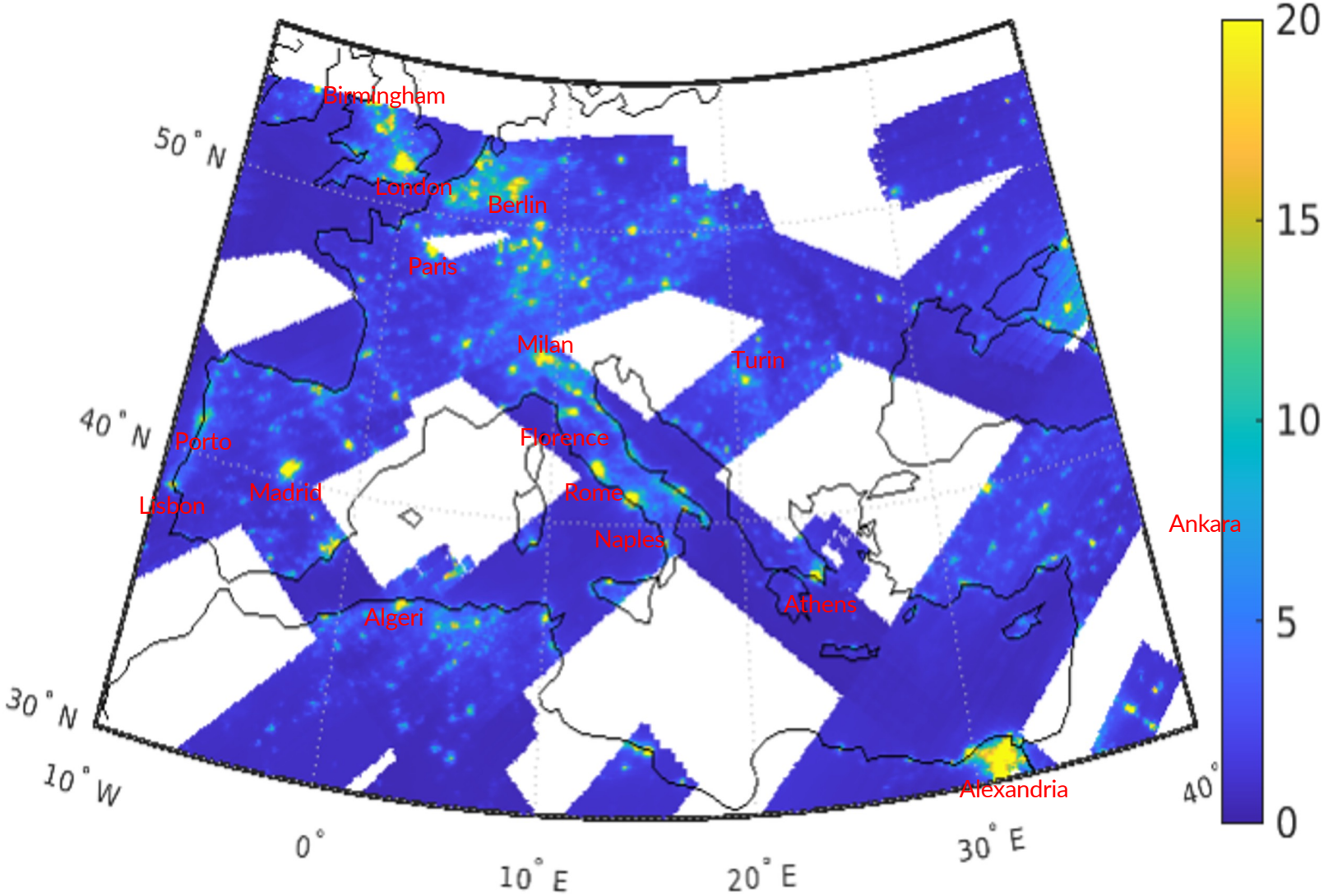
Data transfer and Earth Coverage (up to Nov 2021)



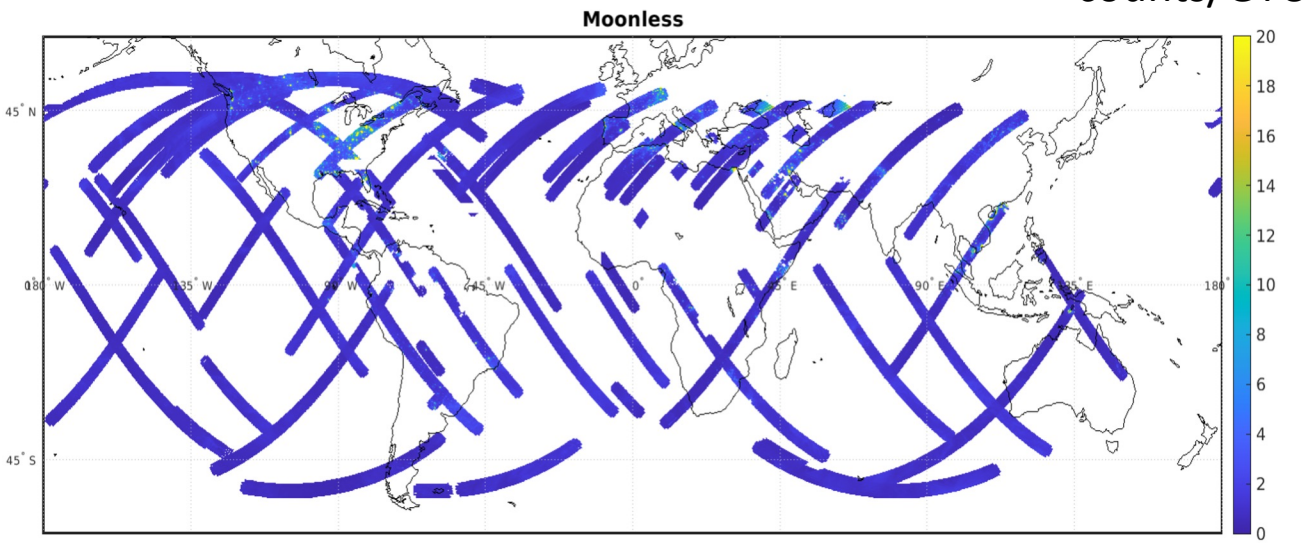
Data from sessions 4-41

>120 crew hours

56 sessions: > 200 hours (live time)



UV maps

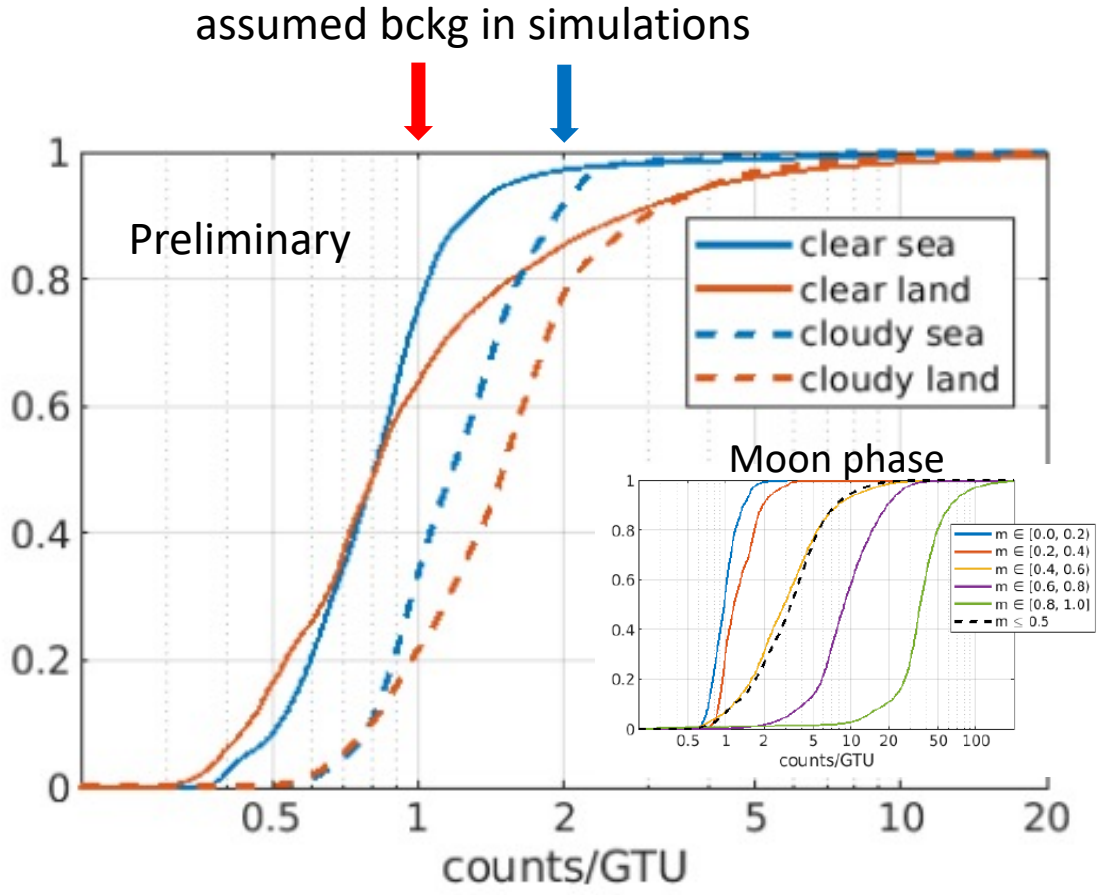


UV maps considering only data taken during moonless nights

In JEM-EUSO typically assumed:
- UV background light ~1 count/pix/GTU &
- ~10% inefficiency due to anthropogenic light
- Clouds increase background x2
- Factor x30 between New and Full Moon

J.H. Adams et al. Astrop. Phys. 44 (2013) 76

Consistent numbers in Mini-EUSO:
- ~80% background < 1 count/pix/GTU
- Clouds shift count rate < x2
- for city lights: 30%(continents) x 35% (>1 ct/pix/GTU) = 10.5%



Cumulative distributions of the emissions of land and sea regions in cloudless/cloudy moonless conditions.

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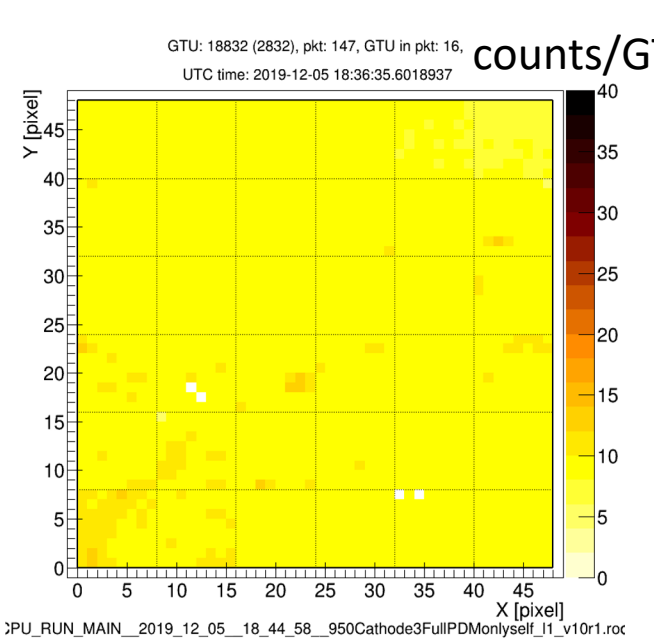
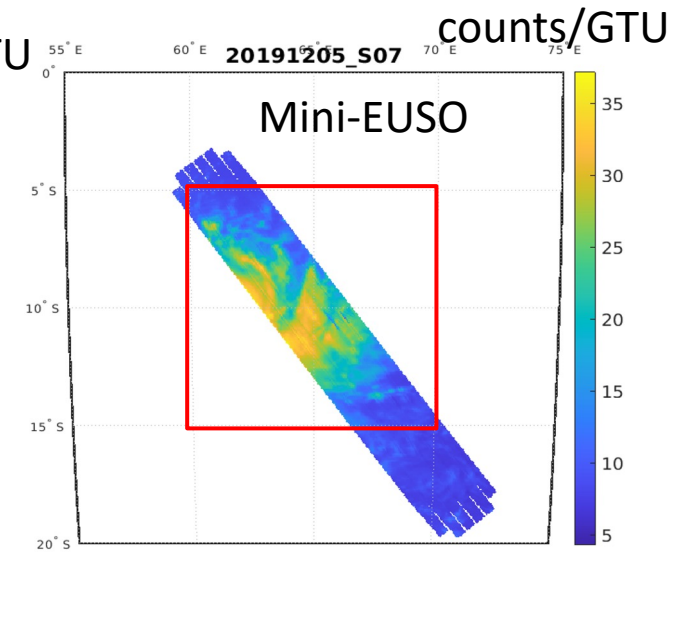
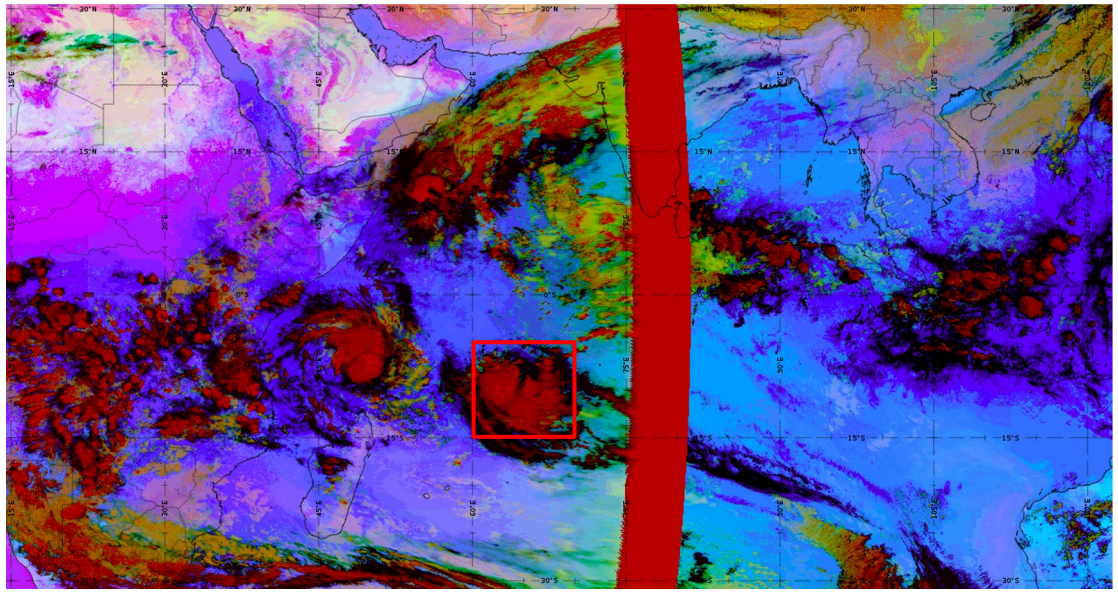
From literature UV background (300 – 400 nm):
300 – 1000 ph/m^2/ns/sr

If 1 count/pix/gtu → 500 ph/m^2/ns/sr
consistent with Mini-EUSO observations (TBC)

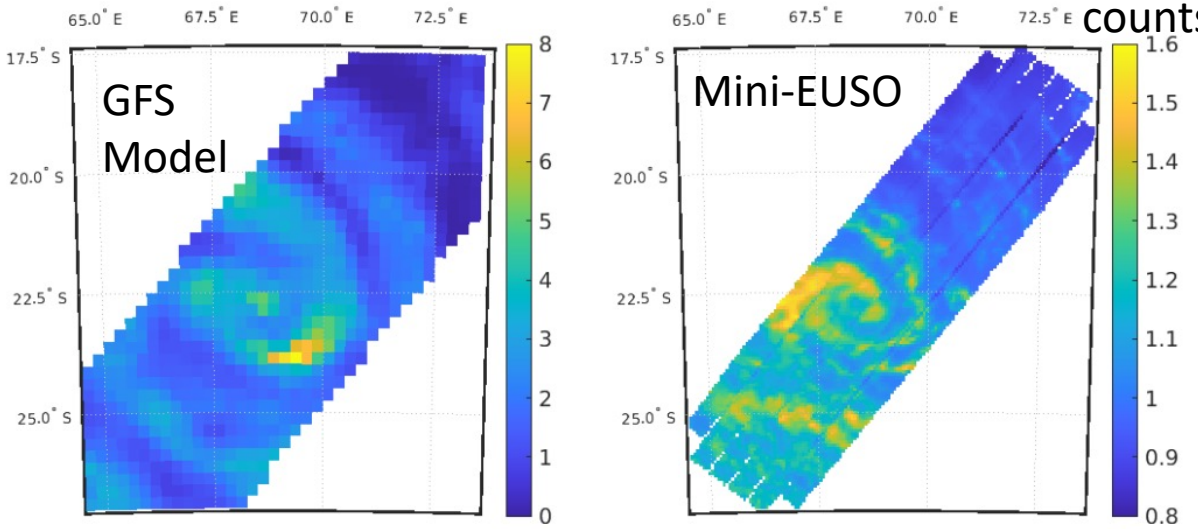
Cloud monitoring → Important for exposure estimation



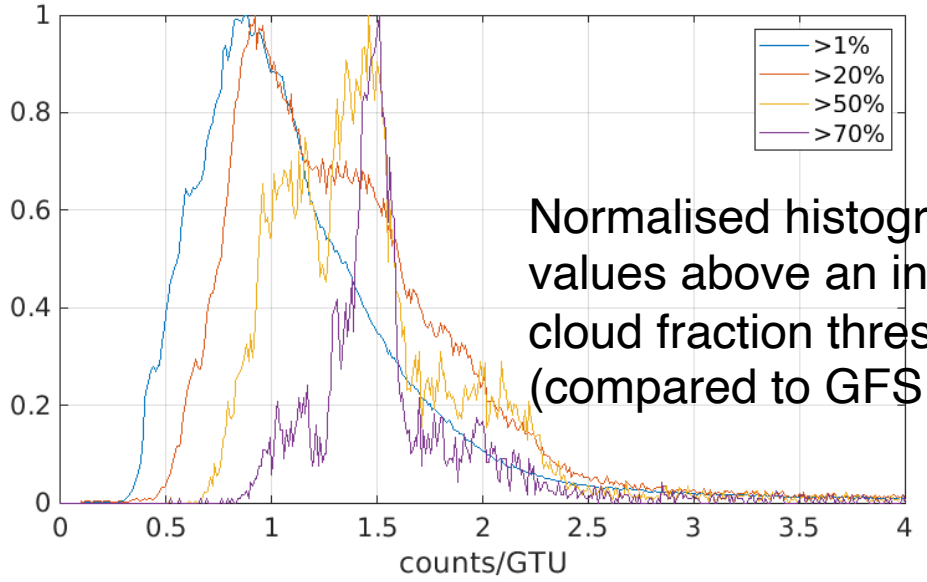




Circular cloud event over the Indian Ocean. Satellite data from *Himawari* satellites.

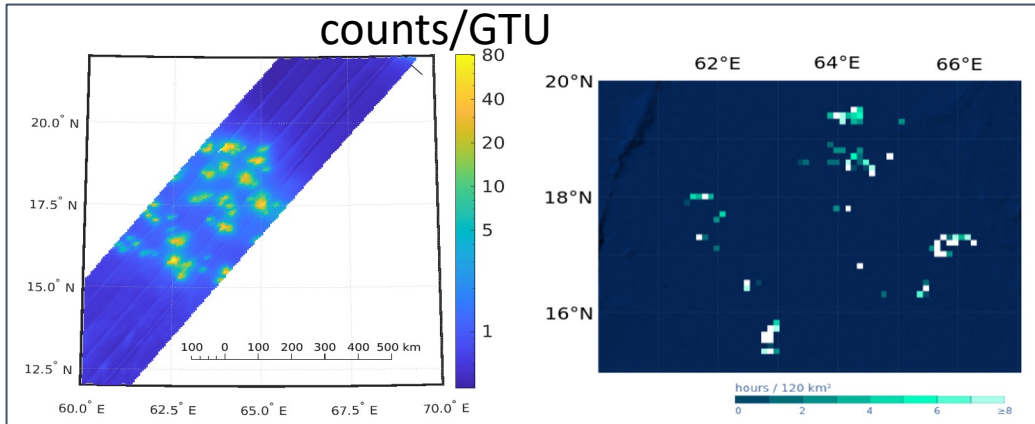


Cyclon near Mauritius Islands.

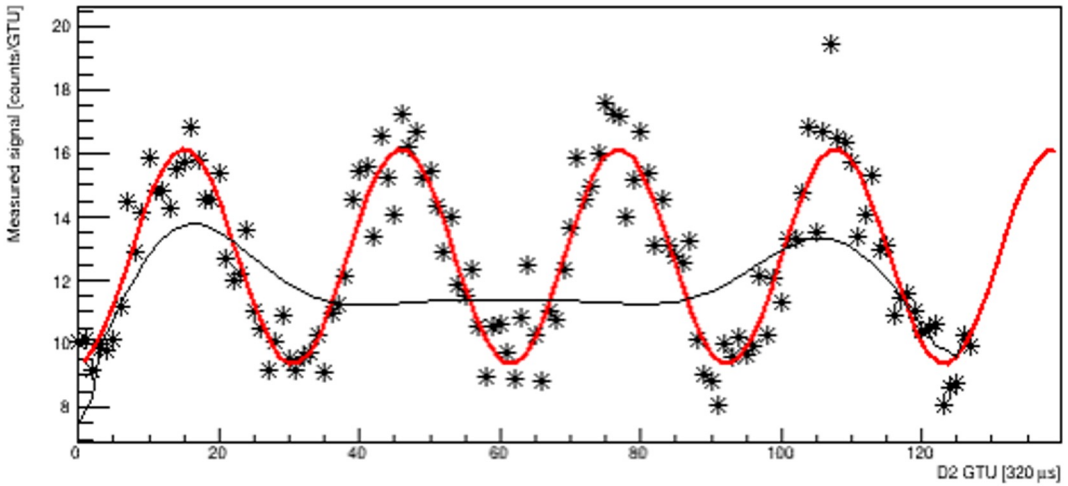


Normalised histograms for values above an increasing cloud fraction threshold (compared to GFS model)

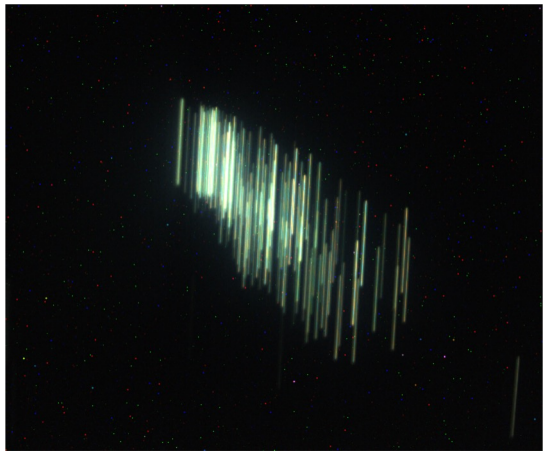
Fishing boats and AC modulation



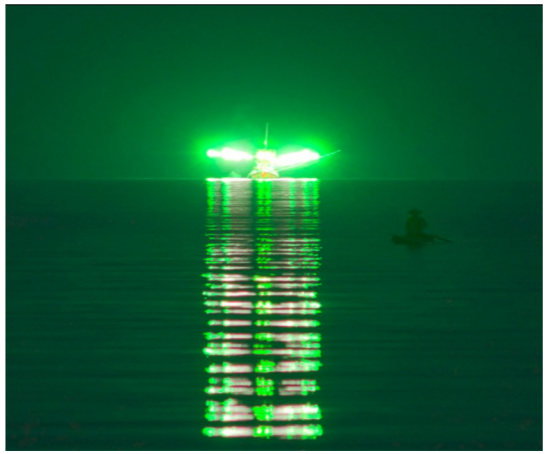
Fishing boats in the Arabian sea. Left: Mini-EUSO data. Right: Data from the Global Fishing Watch [https://globalfishingwatch.org]



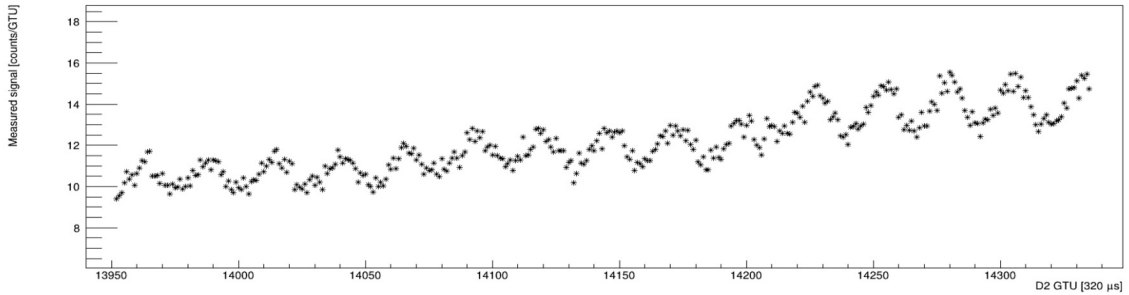
50 Hz modulation over an Indonesian city



Mini-EUSO visible camera off the coast of Argentina



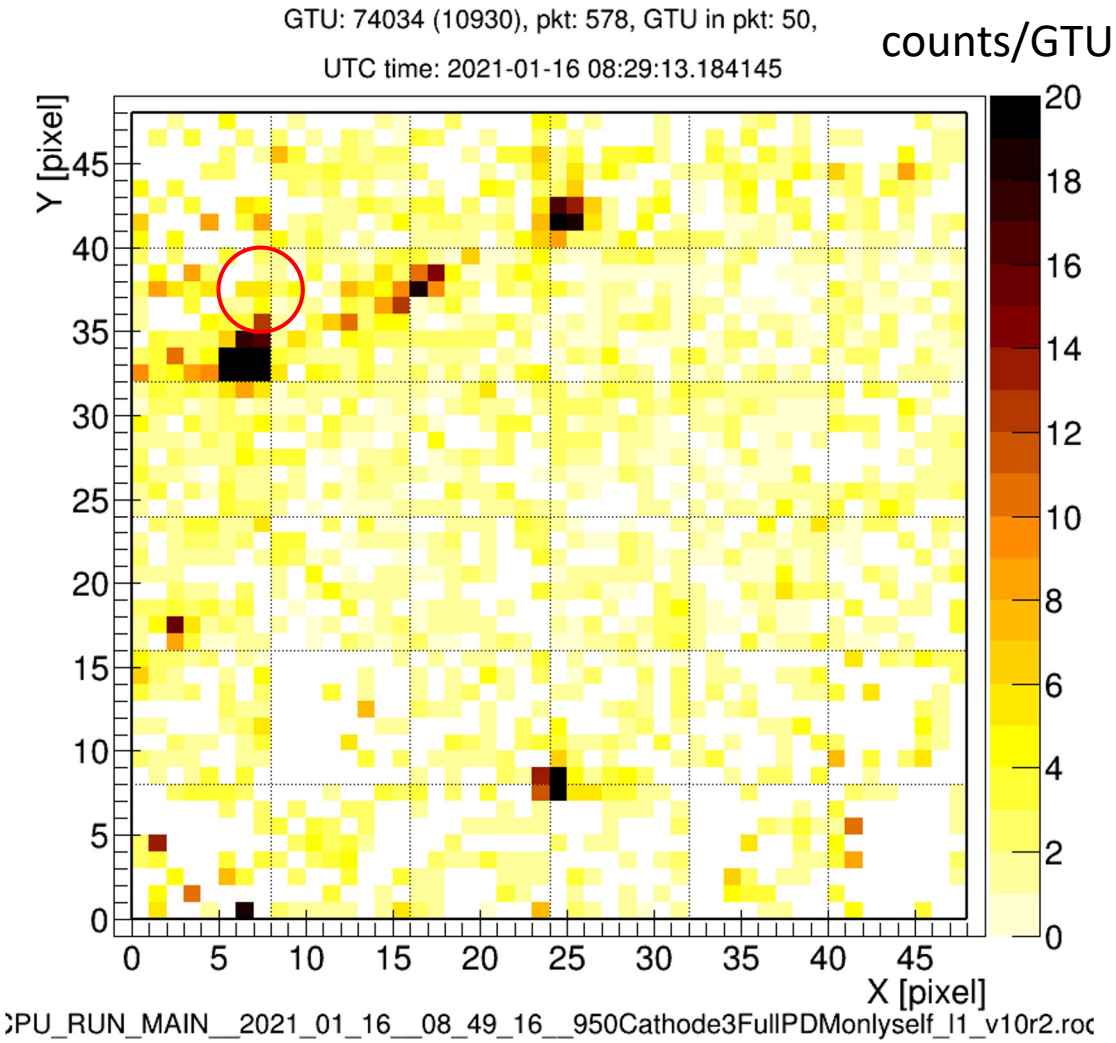
Squid fishermen use bright lights to draw fish and squid toward the sea surface at night. (©2012 Jay Lawler)

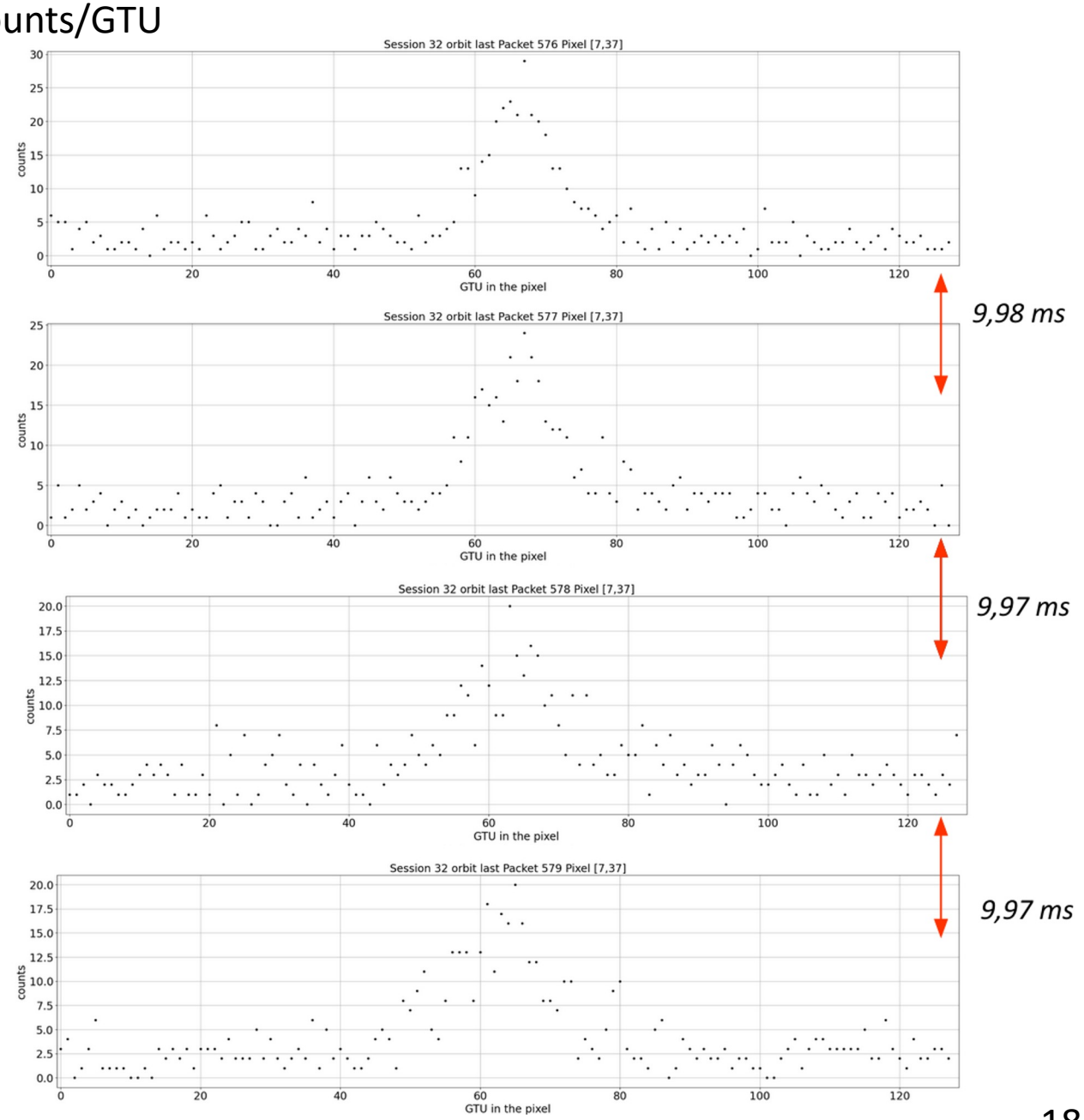


60 Hz modulation produced by the fishing boats off the coast of Argentina

Repeated ground flashers

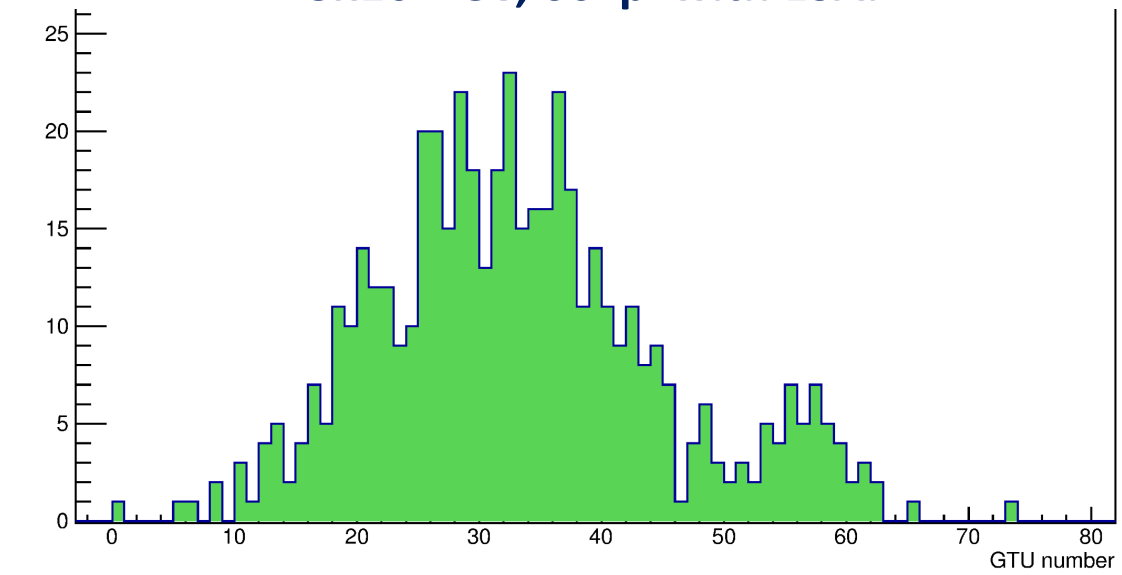
Michigan, US





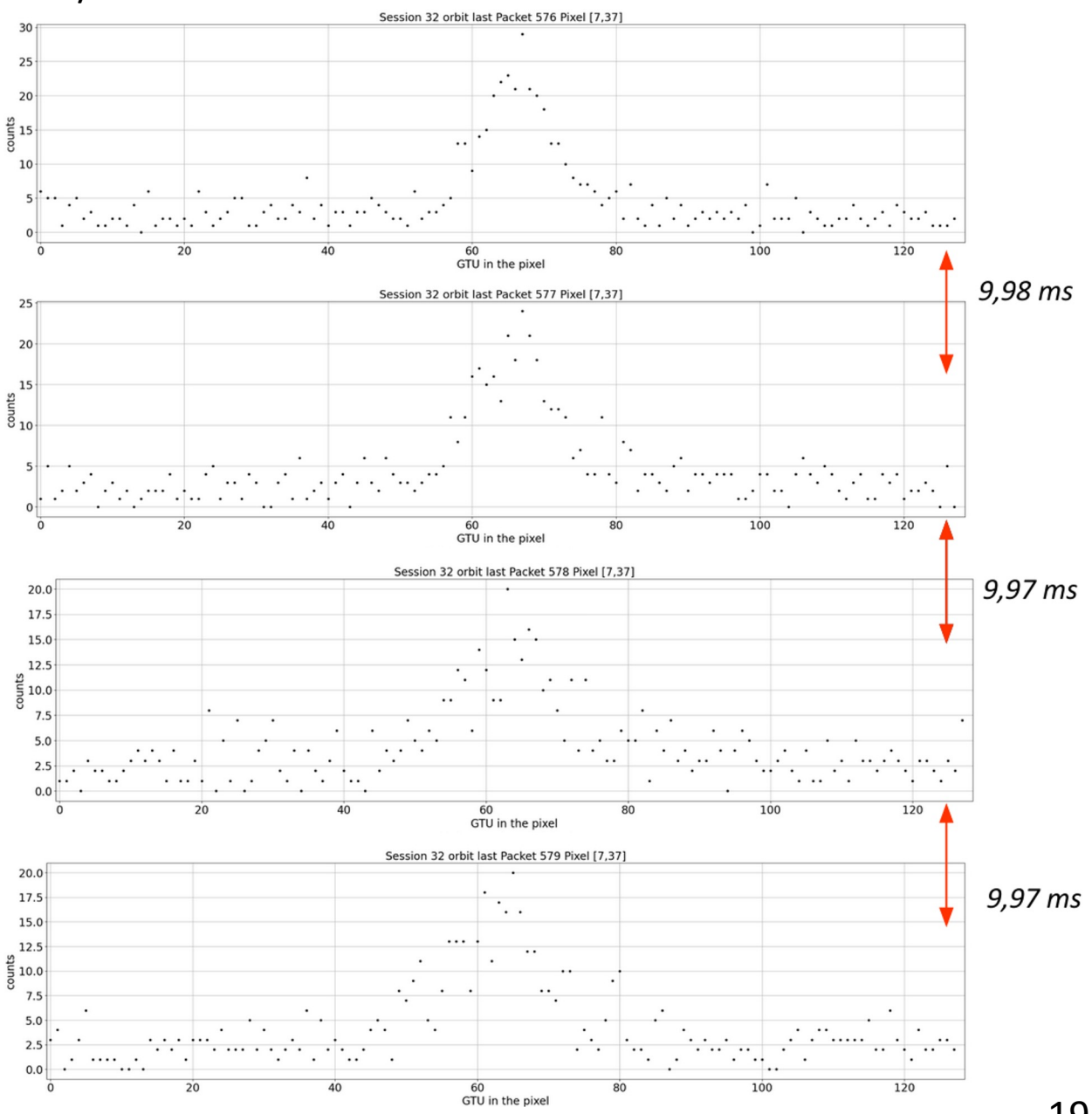
UHECRs in JEM-EUSO & ground flashers in Mini-EUSO

JEM-EUSO
$5x10^{19}$ eV, 60° p with ESAF



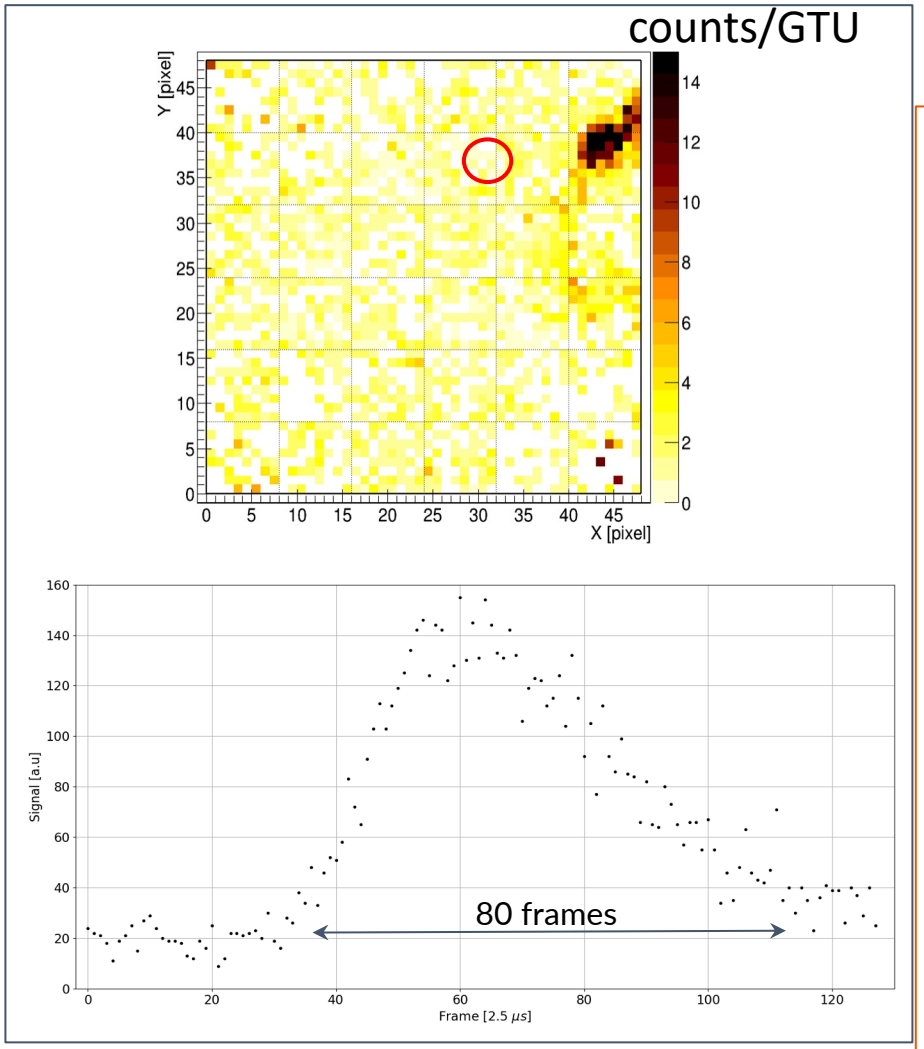
Proof of the detection principle of UHECRs from space with signals in Mini-EUSO similar to those expected in JEM-EUSO

Mini-EUSO ground flashers



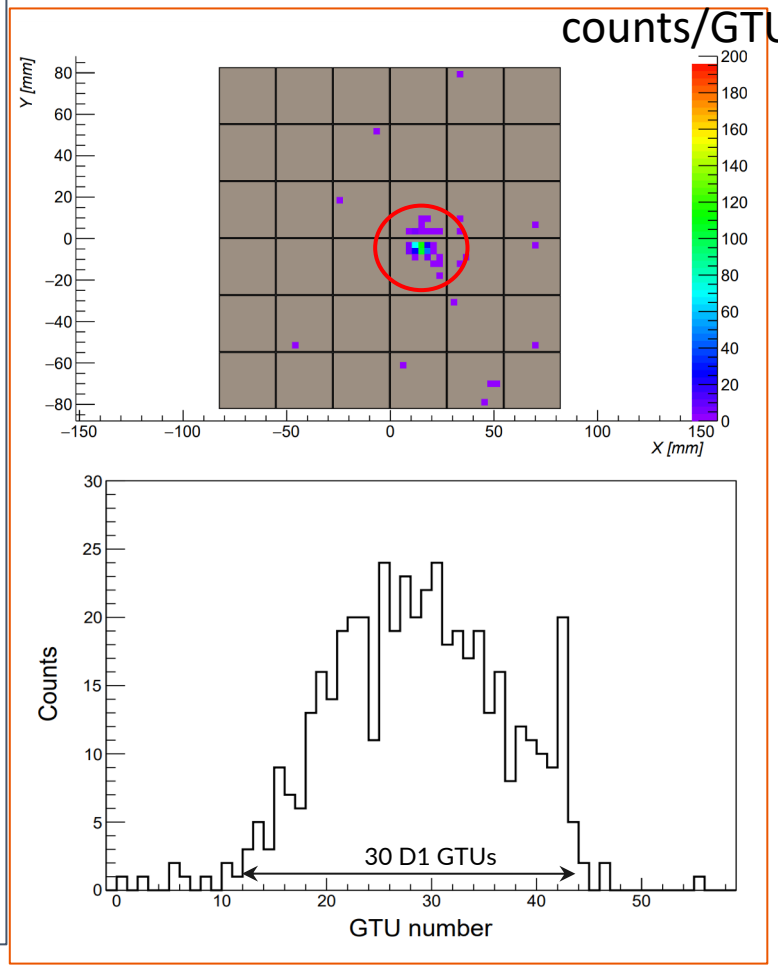
Mini-EUSO – non repetitive ‘EAS-like’ signal

Mini-EUSO data

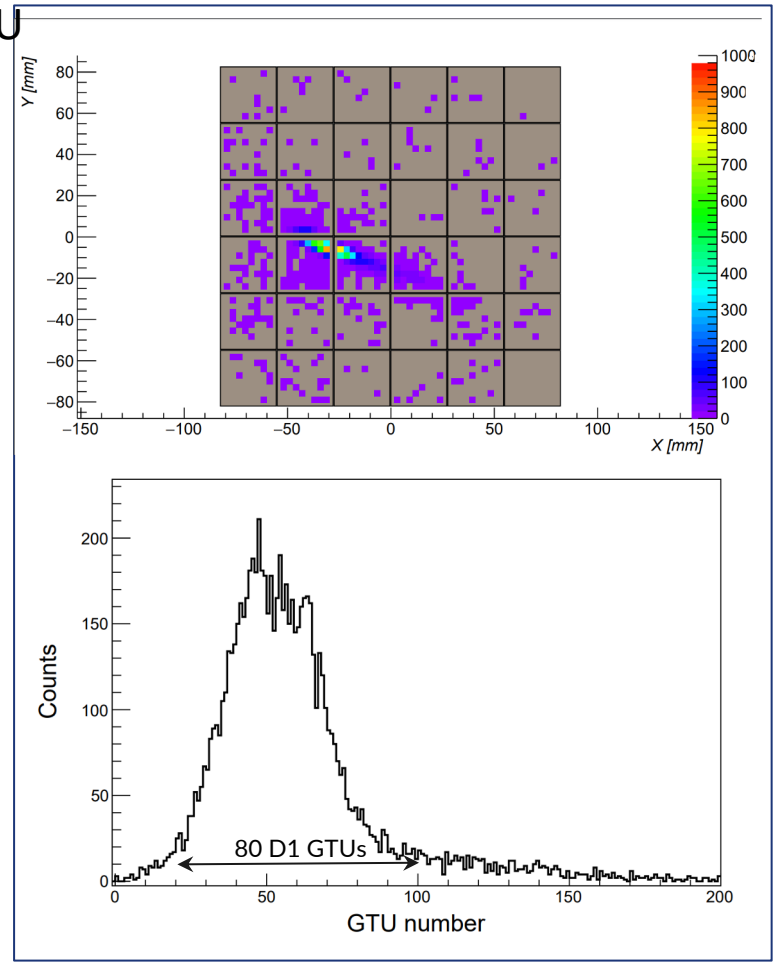


Focal plane view and lightcurve of the detected signal

ESAF p, E = 5x10²¹ eV Zenith = 50°

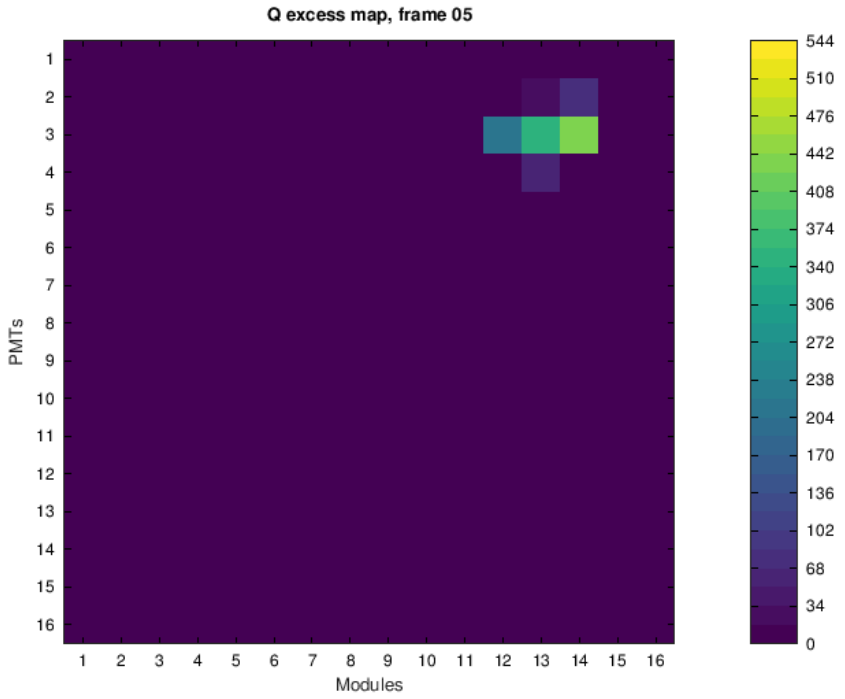


ESAF p, E = 2x10²² eV Zenith = 80°



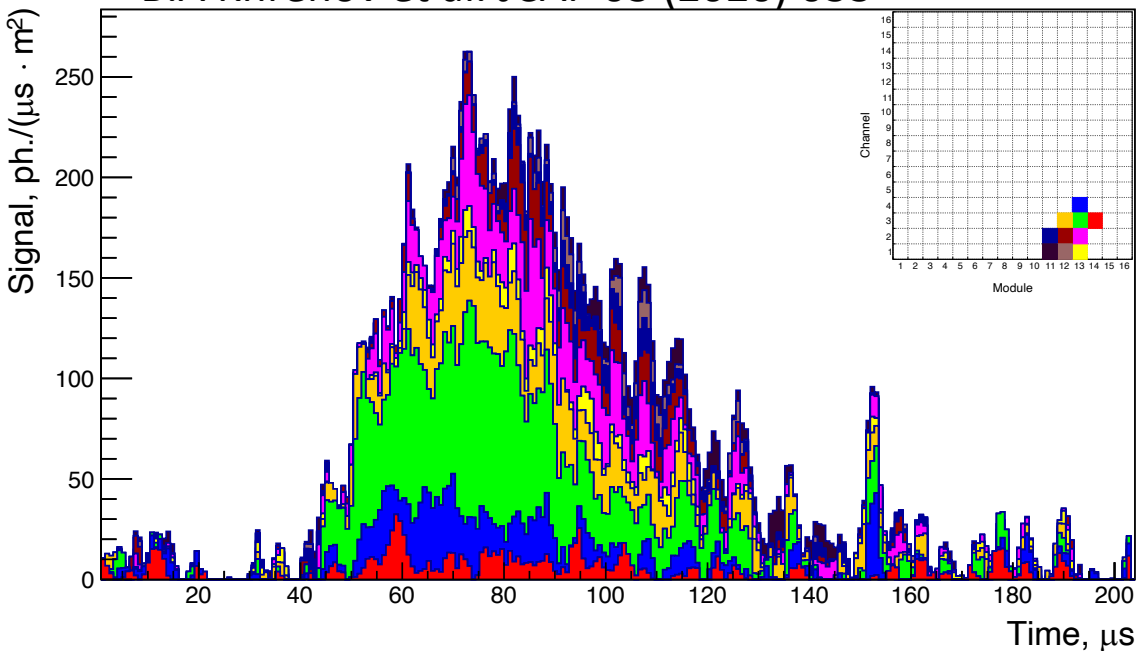
Cosmic ray simulations. Top: focal plane view. Bottom: lightcurves. Left: Zenith angle = 50°. Right: Zenith angle = 80°

TUS & Mini-EUSO

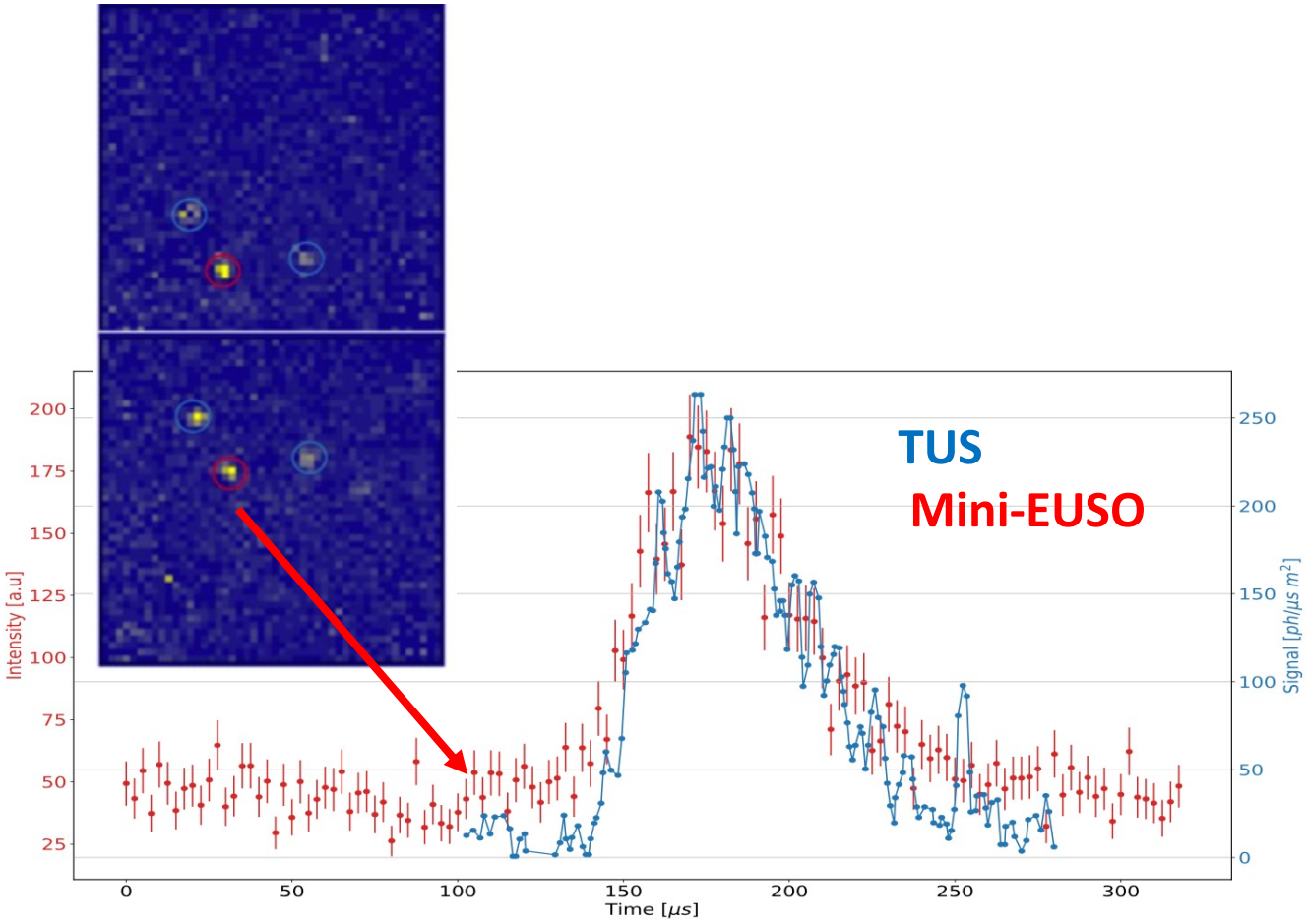


TUS Minnesota event

B.A Khrenov et al. JCAP 03 (2020) 033

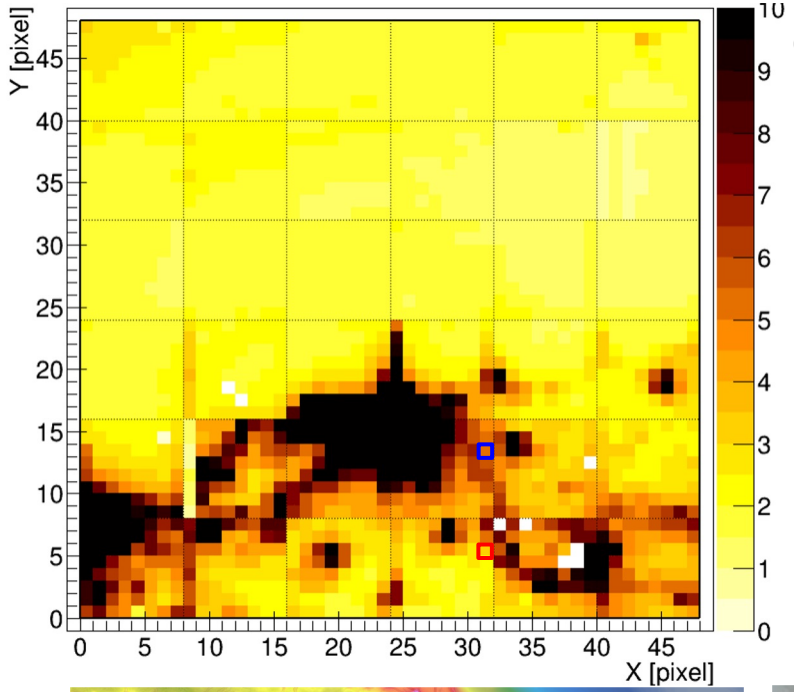


Mini-EUSO sees ground flashers with signal in shape similar to the TUS Minnesota event. However, in TUS event an apparent movement is visible while in Mini-EUSO the signal is static.



Mini-EUSO end-to-end calibration

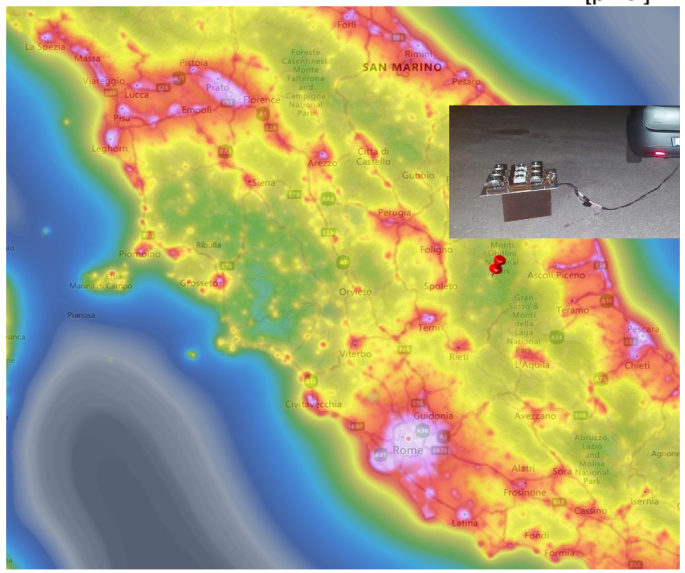
PRELIMINARY

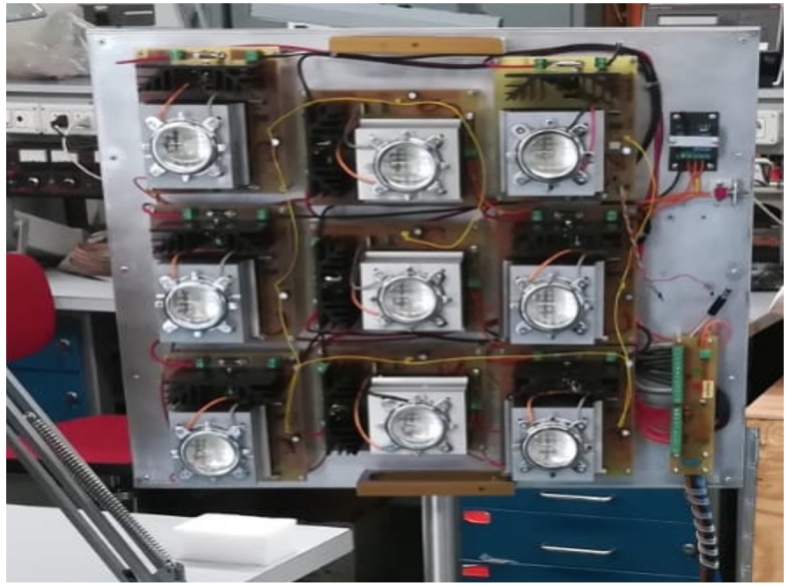


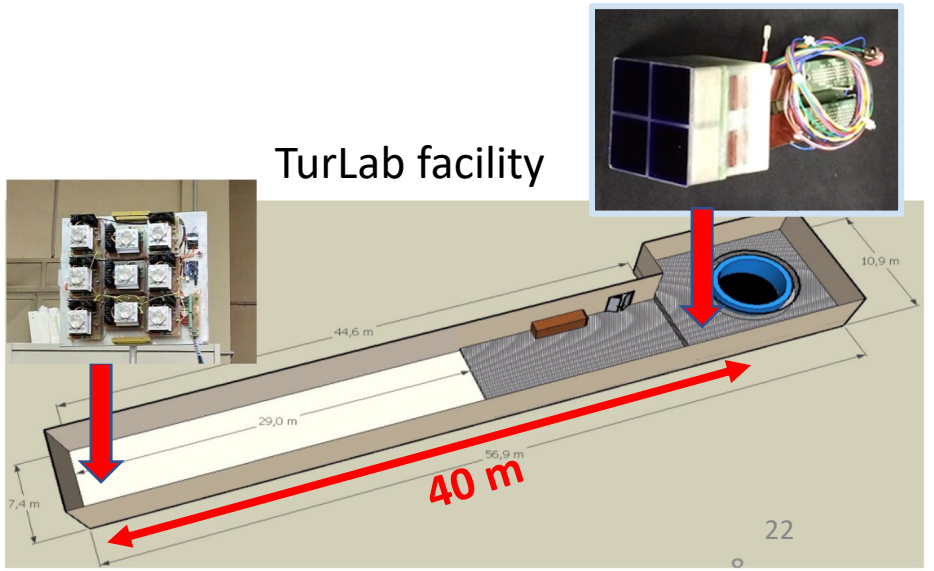
$$Eff_{ME} = \frac{n_{phe}^{detected}}{n_{photons}^{window}} = \frac{9.7}{120.4} = (8.0 \pm 1.5)\%$$

$$Eff_{ME} = \frac{n_{phe}^{detected}}{n_{photons}^{window}} = \frac{8.3}{139.3} = (6.0 \pm 1.1)\%$$

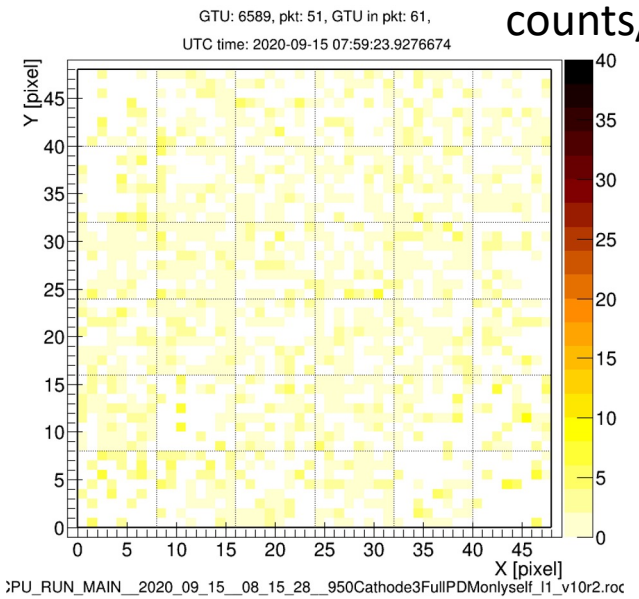
$$n_{photons}^{window} = n_{photons}^{TurLab} \times Angular_{lens} \times Abs_{atm} \times \frac{Area(ME)}{Area(To\text{-}EC)} \times \left(\frac{Distance(To\text{-}EC)}{Distance(ME)}\right)^2 \times cos(\theta)$$

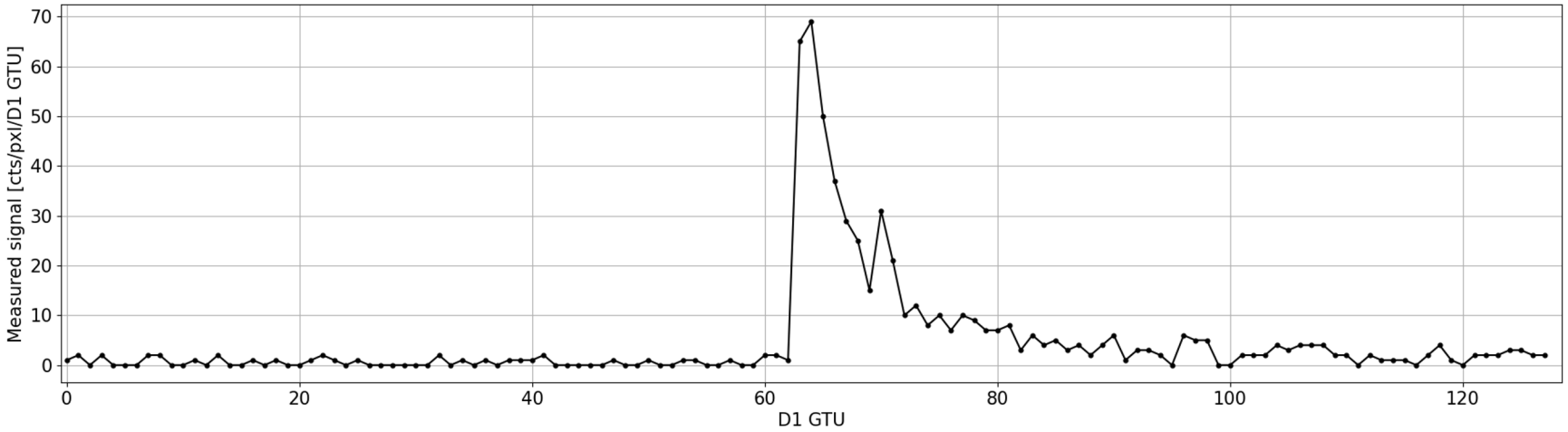




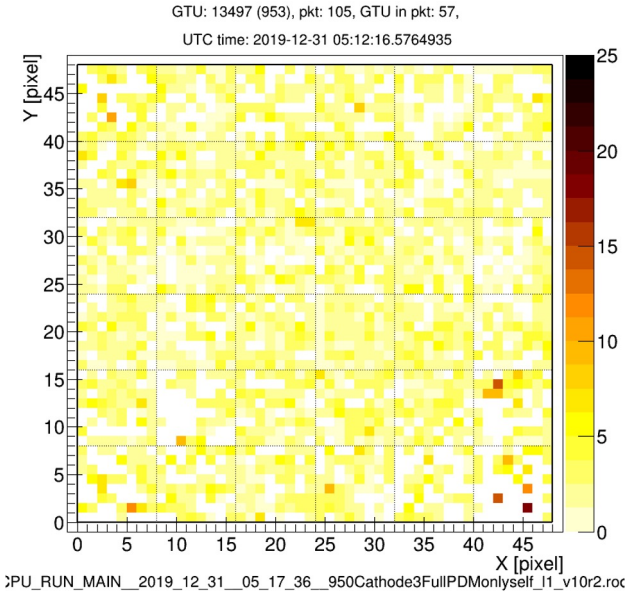


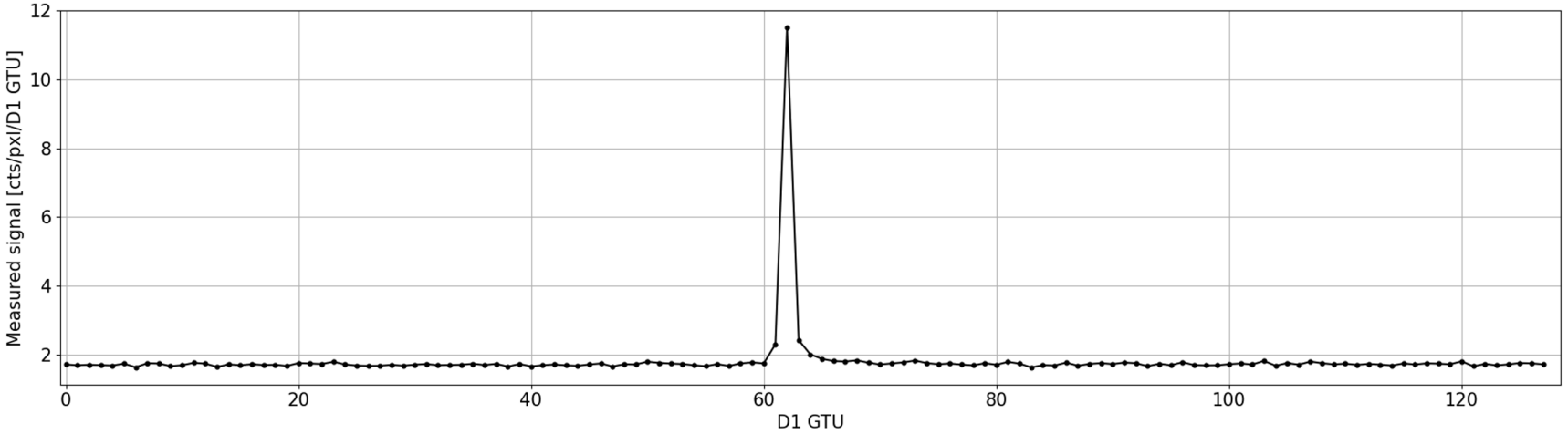
Direct cosmic ray hits





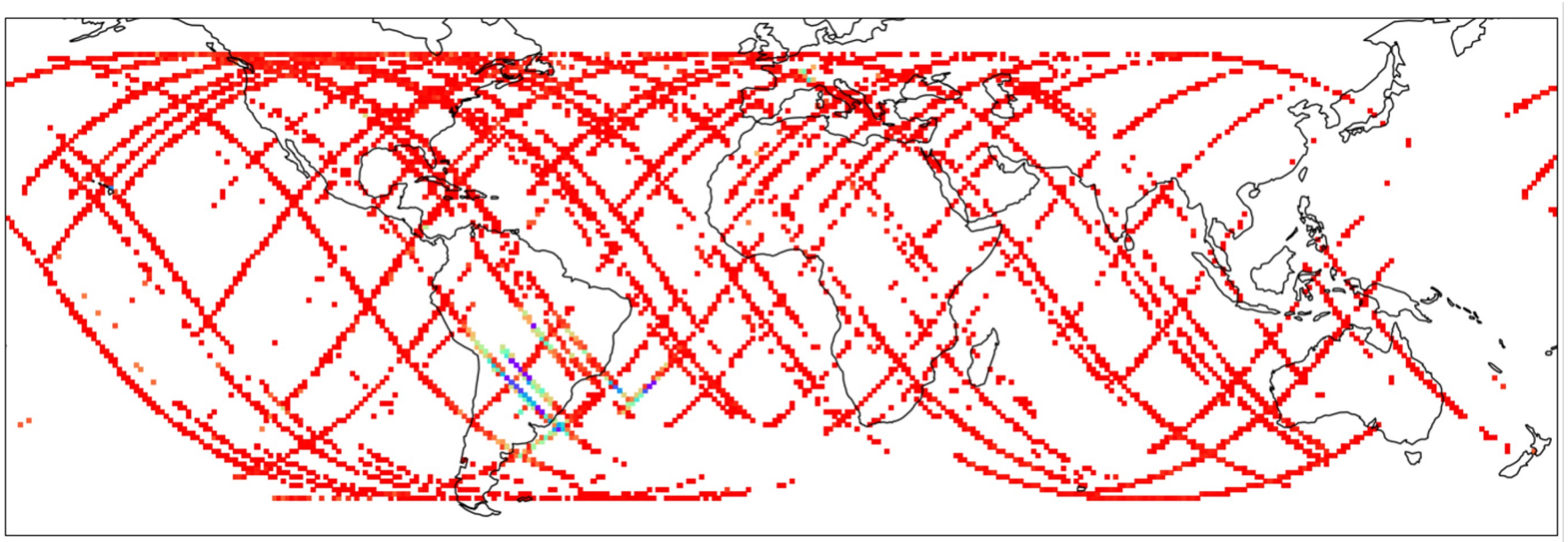
Single pixel lightcurve

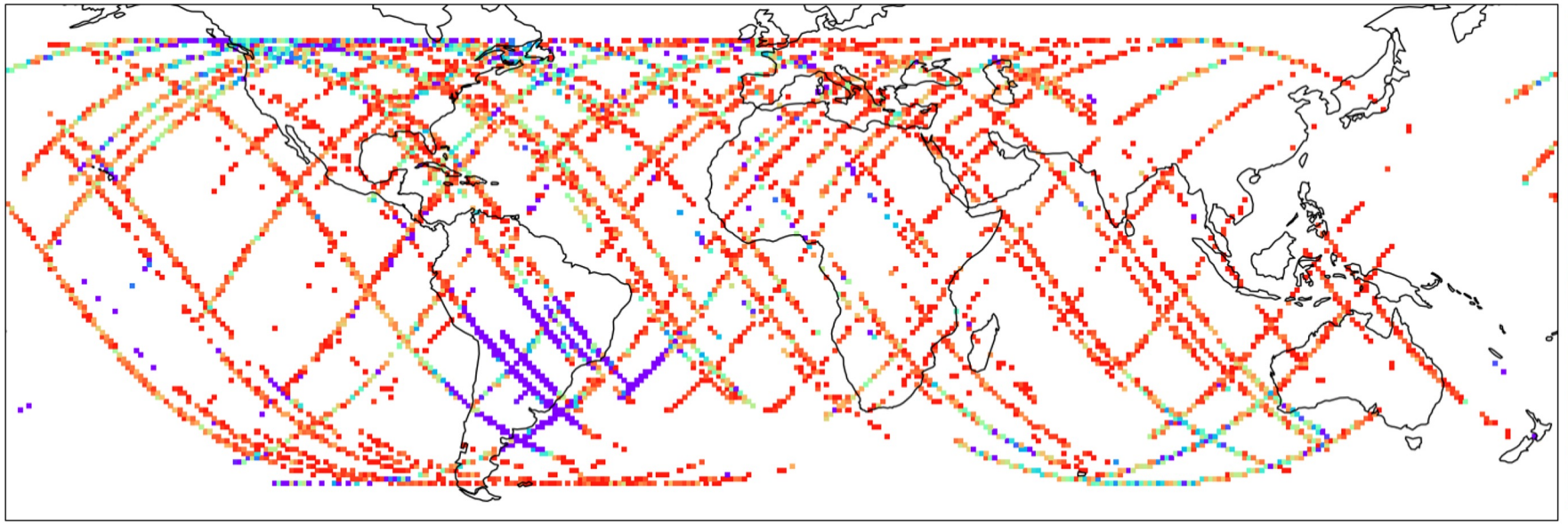




Lightcurved averaged over the entire PDM

Direct cosmic ray hits distribution

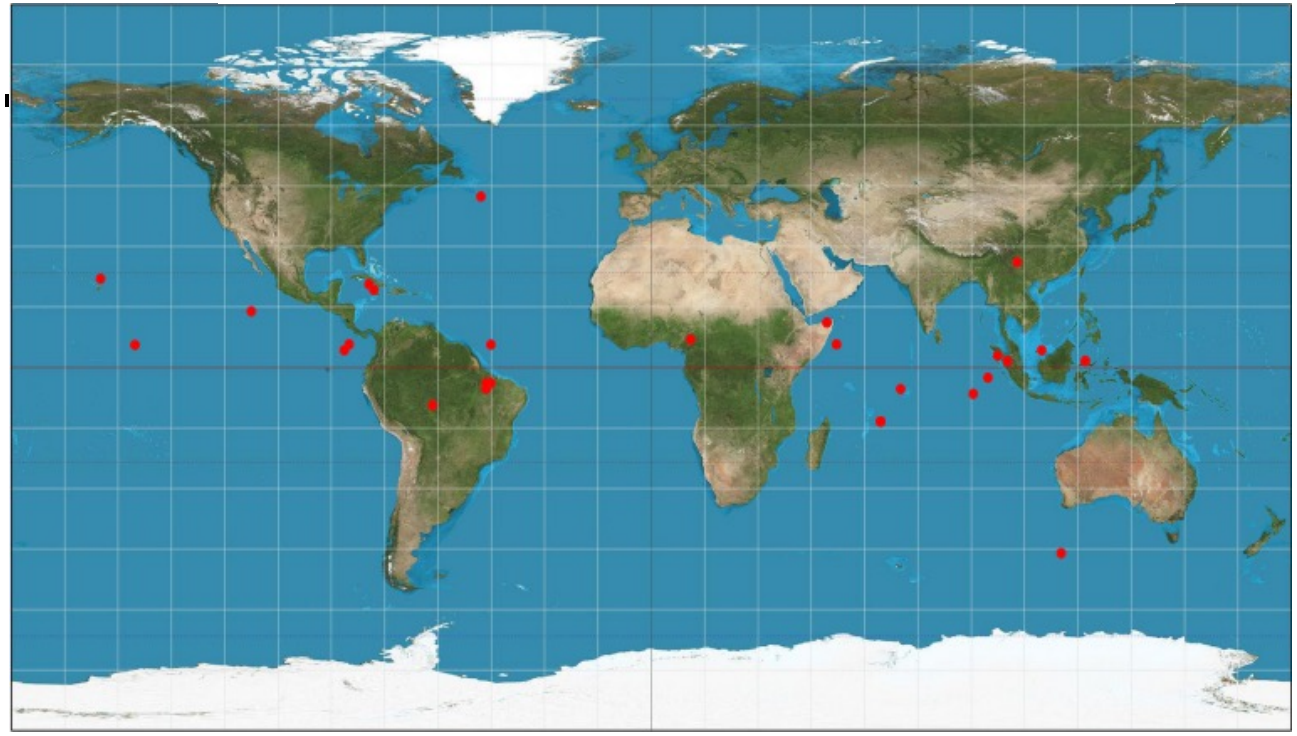


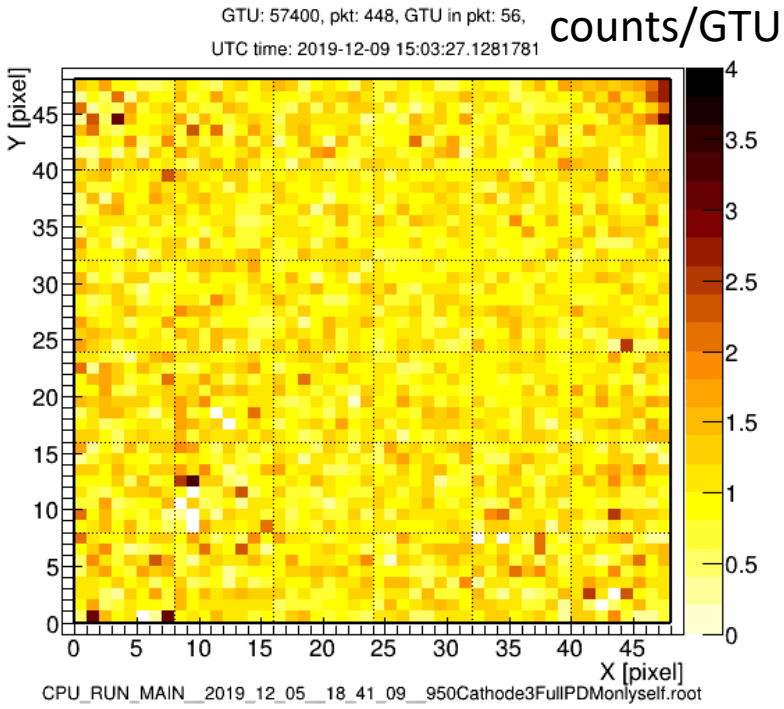


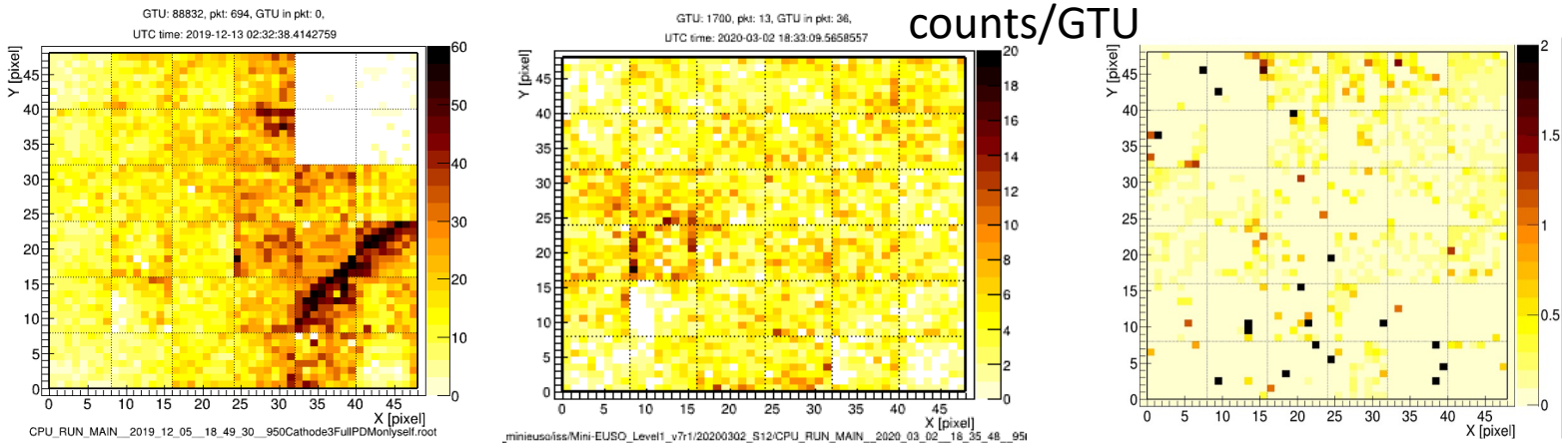
Map of the fraction of the **direct cosmic ray flux** as measured by Mini-EUSO. The globe has been divided into a 1° × 1° grid, the color representing the relative rate of direct cosmic rays detected by the instrument. The areas of higher trigger density correspond to the **South Atlantic Anomaly** (inner Van Allen belt) and the high latitude region over Canada and the south Pacific (**outer radiation belt)**. The map shows a correlation between the region where Mini-EUSO detects a higher rate of direct cosmic rays and the region with a higher level of radiation produced by low energy cosmic rays.

Mini-EUSO - other events in the µs timescale (Elves)

26 ELVES detected, max duration: 400 µs



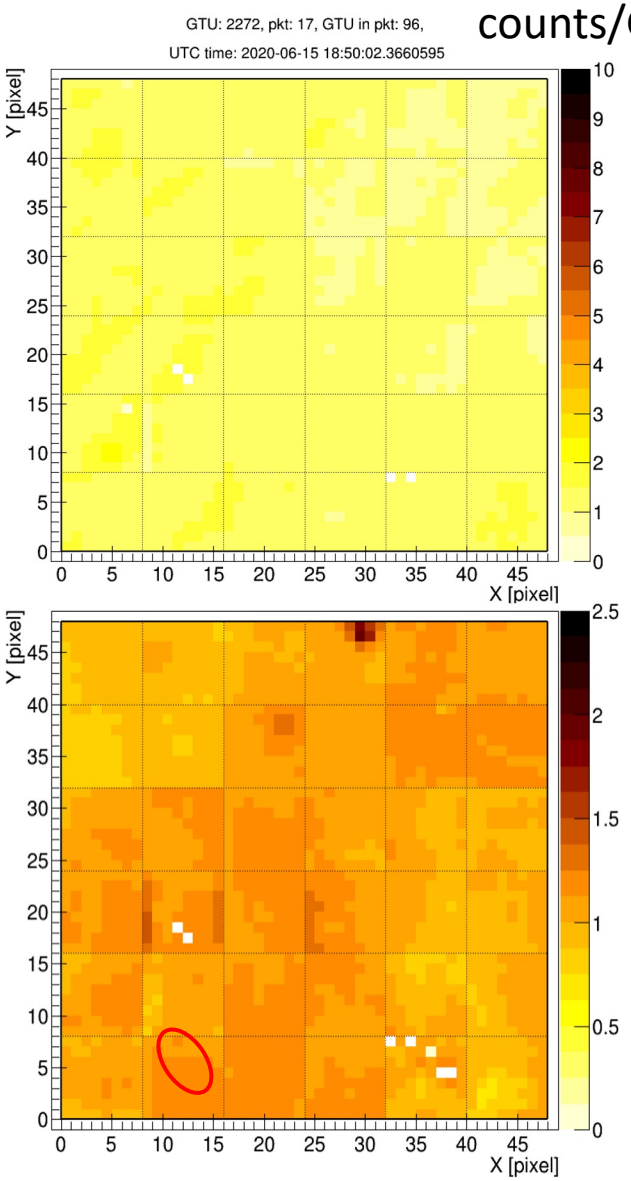




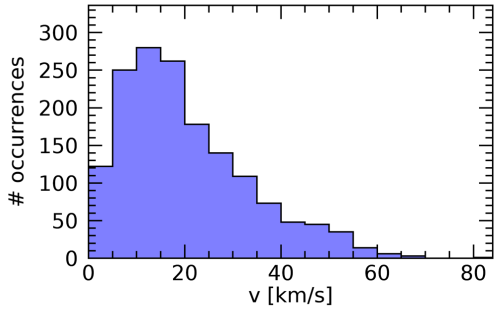
Top: picture of an elve taken with a commercial camera.
Bottom: Elves seen by Mini-EUSO

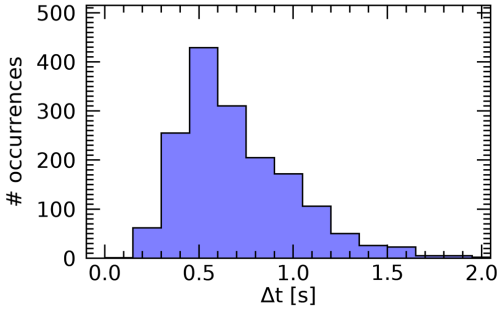
Meteors

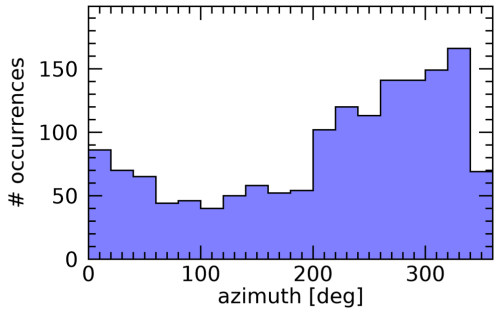
Over 2000 meteors in a subsample of 9 fully analyzed sessions (~ x10 in full data set)

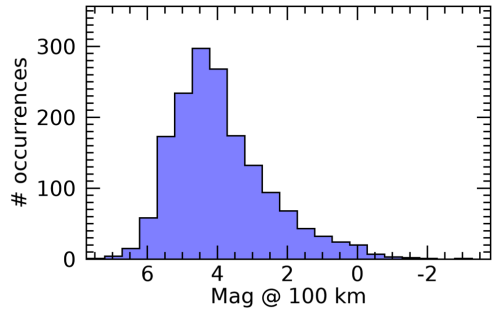


A bright and a dim meteor detected by Mini-EUSO



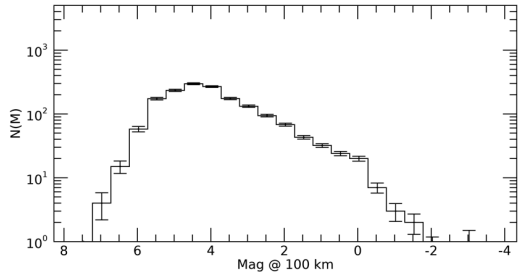


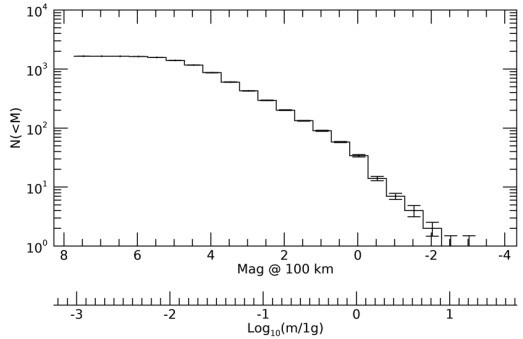




Velocity, duration, azimuth and magnitude distributions of meteors detected by Mini-EUSO

Distribution of the meteor's magnitude and estimated mass

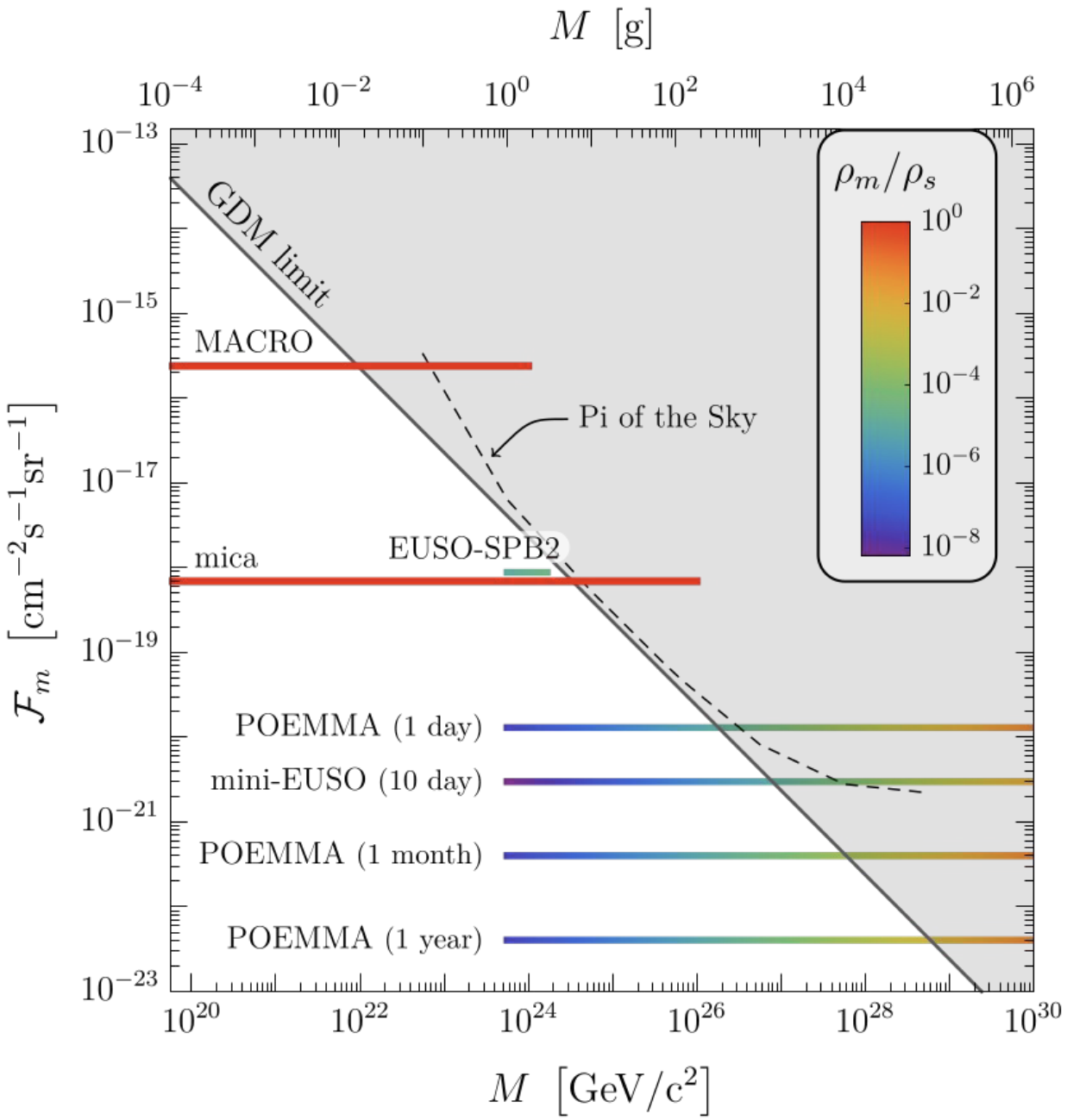




MACROscopic dark matter

"As a complementary effort, experiments with sufficient exposure (> 5 x 10^5 km^2 sr yr) are needed to search for Lorentz-invariance violation (LIV), SHDM, and other BSM physics at the Cosmic and Energy Frontiers, and to identify UHECR sources at the highest energies." from SNOWMASS 2021

MACRO candidates in Mini-EUSO searched as fast moving `meteors'



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CONCLUSIONS

- Mini-EUSO on ISS for almost three years.
- Mini-EUSO observes events of different nature showing the broader impact of an UHECR detector in space.
- It proves that it is possible – with larger detectors – to perform UHECR observation from space.
- Preliminary results indicate that measurements are in agreement with predictions from simulations.

THANK YOU

backup