Results and performance of the Mini-EUSO telescope on board the ISS

L. Marcelli

(INFN, Structure of Rome Tor Vergata, Italy)

Vulcano Workshop 2024 – Ischia, May 27-31, 2024

The JEM-EUSO program

1. **EUSO-TA (2013-):** Ground detector installed at Telescope Array site

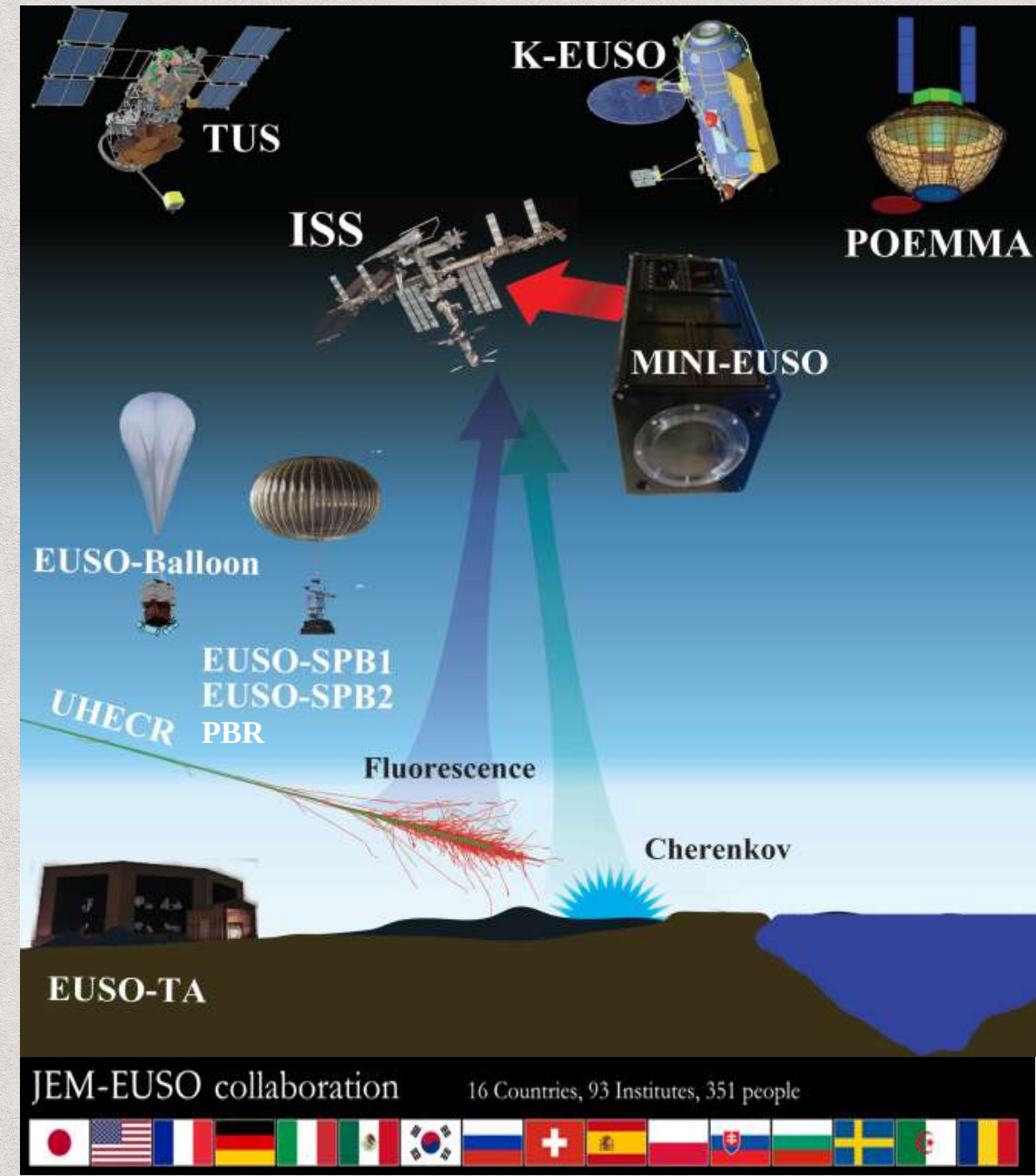
2. **EUSO-BALLOONS (2014-2027):**
- 2014: EUSO-Balloon Timmins, Canada
- 2017: EUSO-SPB, NASA, Ultra long duration flight
- 2023: EUSO-SPB2, NASA, Ultra long duration flight
- 2027: PBR, NASA, Ultra long duration flight

3. **TUS (2016):** free-flyer on Lomonosov Russian Satellite

4. **Mini-EUSO (2019):** ISS, Beyond Mission (L. Parmitano)

5. **K-EUSO (2028+):** ISS, Phase A, Russian Space Agency

6. **POEMMA (2030+):** NASA twin free-flyer



Mini-EUSO / UV-Atmosfera

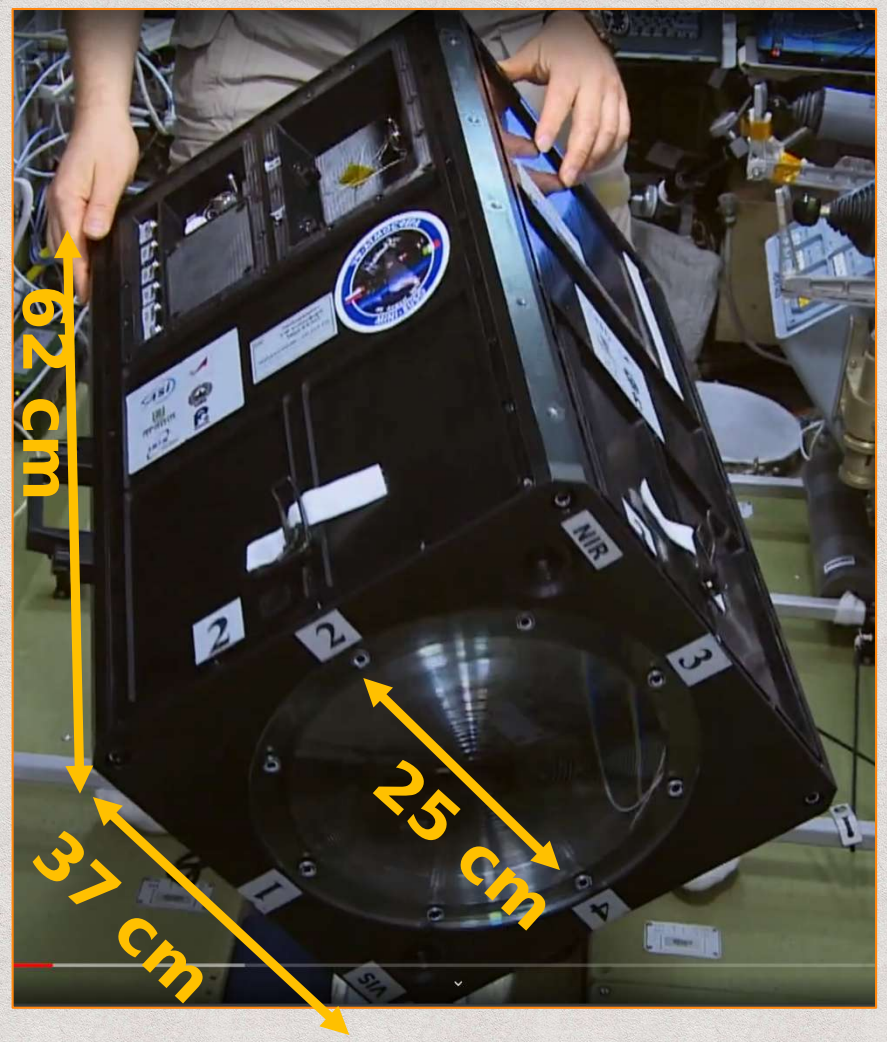
Multiwavelength Imaging New Instrument for the Extreme Universe Space Observatory

Installed on a UV-transparent window on board the ISS

Weight: 35 kg

Power consumption: 60 W

Dimensions: 37x37x62 cm^3



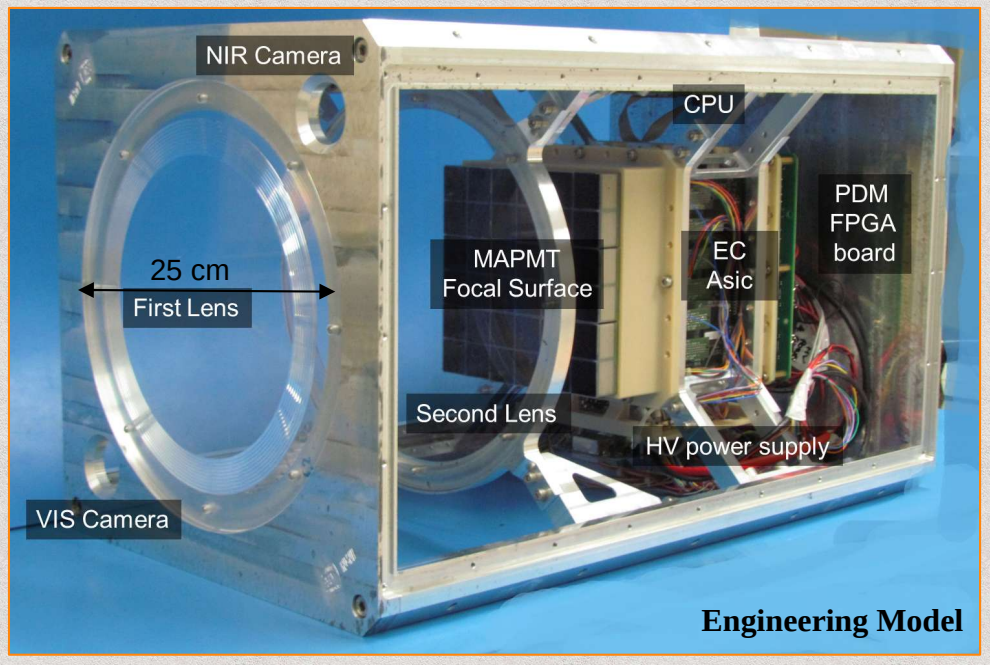
Mini-EUSO Mission to Study Earth UV Emissions on board the ISS
S. Bacholle et al., The Astrophysical Journal Supplement Series, 253:36, 2021

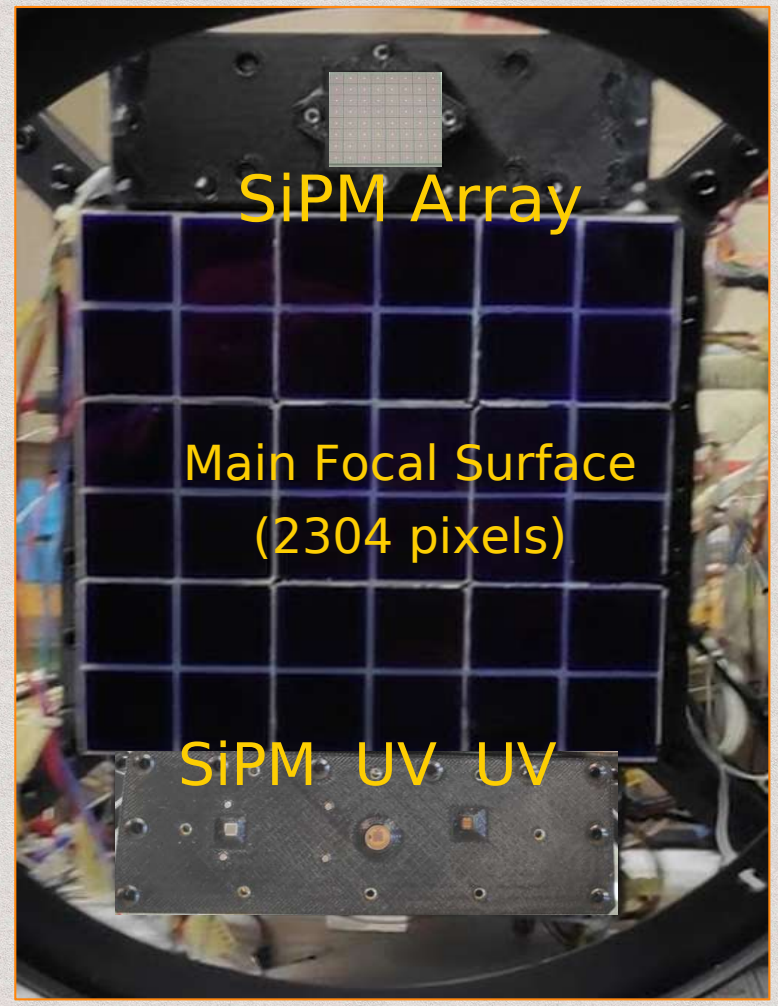
Mini-EUSO / UV-Atmosfera

Multiwavelength Imaging New Instrument for the Extreme Universe Space Observatory

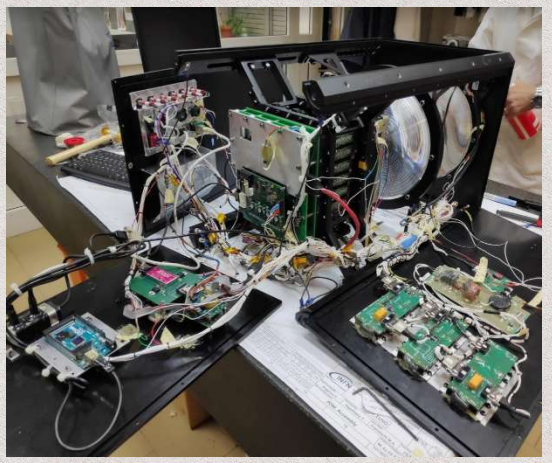
Mini-EUSO main sensors:

- Ultraviolet telescope with Fresnel lenses (48x48 pixels, FoV= 44 deg, ~320x320 km^2, 2.5 μs and above)
- Near Infrared camera (1280x960 pixels, FoV=33.2x24.8 deg, 231x174 km^2, 1s)
- Visible camera (1280x960 pixels, FoV=33.2x24.8 deg, 231x174 km^2, 4s)
- SiPM matrix (8x8 pixels) and UV sensors



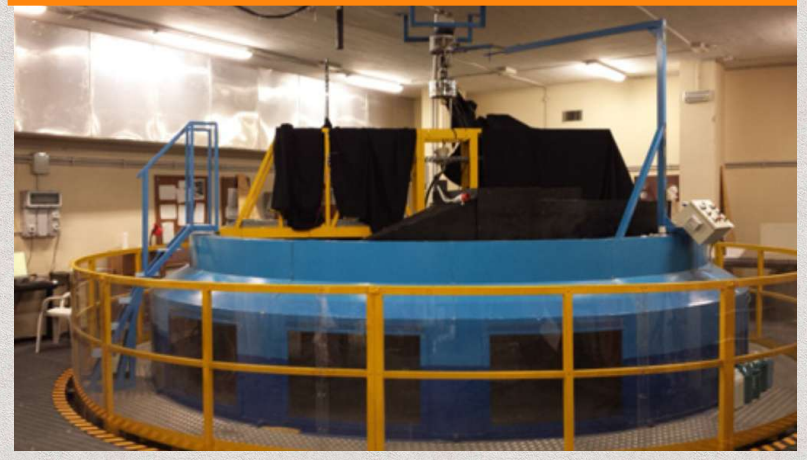


Integration and Test of EM and FM
2017-2019



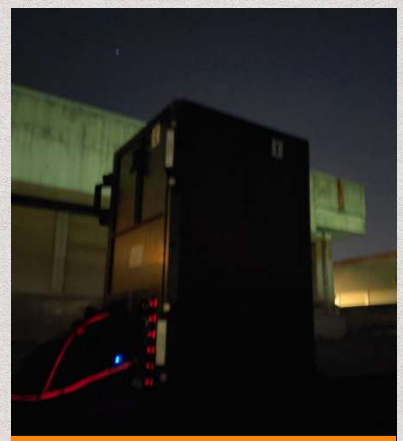
INFN, Tor Vergata & LNF
Mechanics and Integration

TUR-LAB, Univ and INFN Torino
Test on EM and emulation of ISS

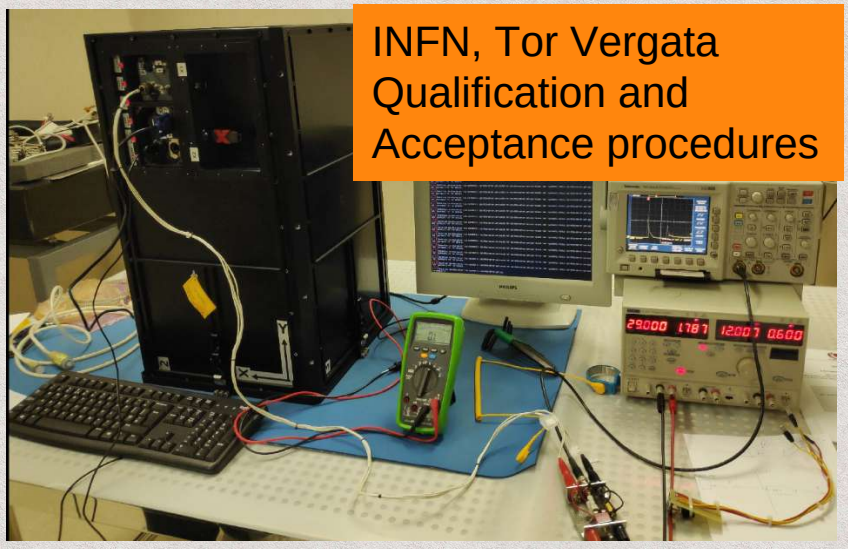


GSD Laboratory
EMI/EMC Tests

MATE Laboratory
Vibration and shock tests



INFN Tor Vergata
Sky tests



INFN, Tor Vergata
Qualification and
Acceptance procedures

Acceptance tests in Baikonur and integration with Soyuz MS-14

Building 254, assembly of Soyuz/Progress

Roll-out of Soyuz MS-14, 19/8/2019

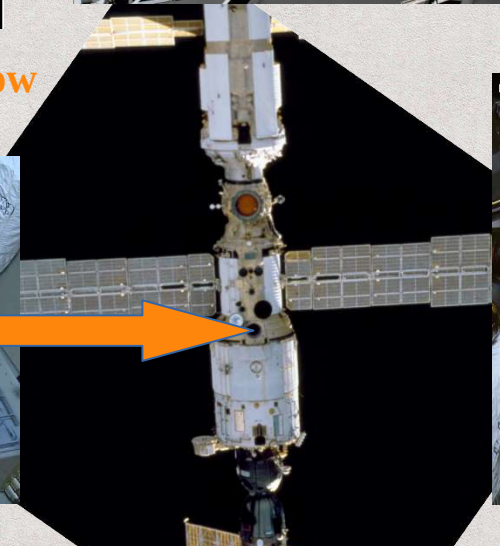
Launch, 22/8/2019

First docking, 24/8/2019 unsuccessful

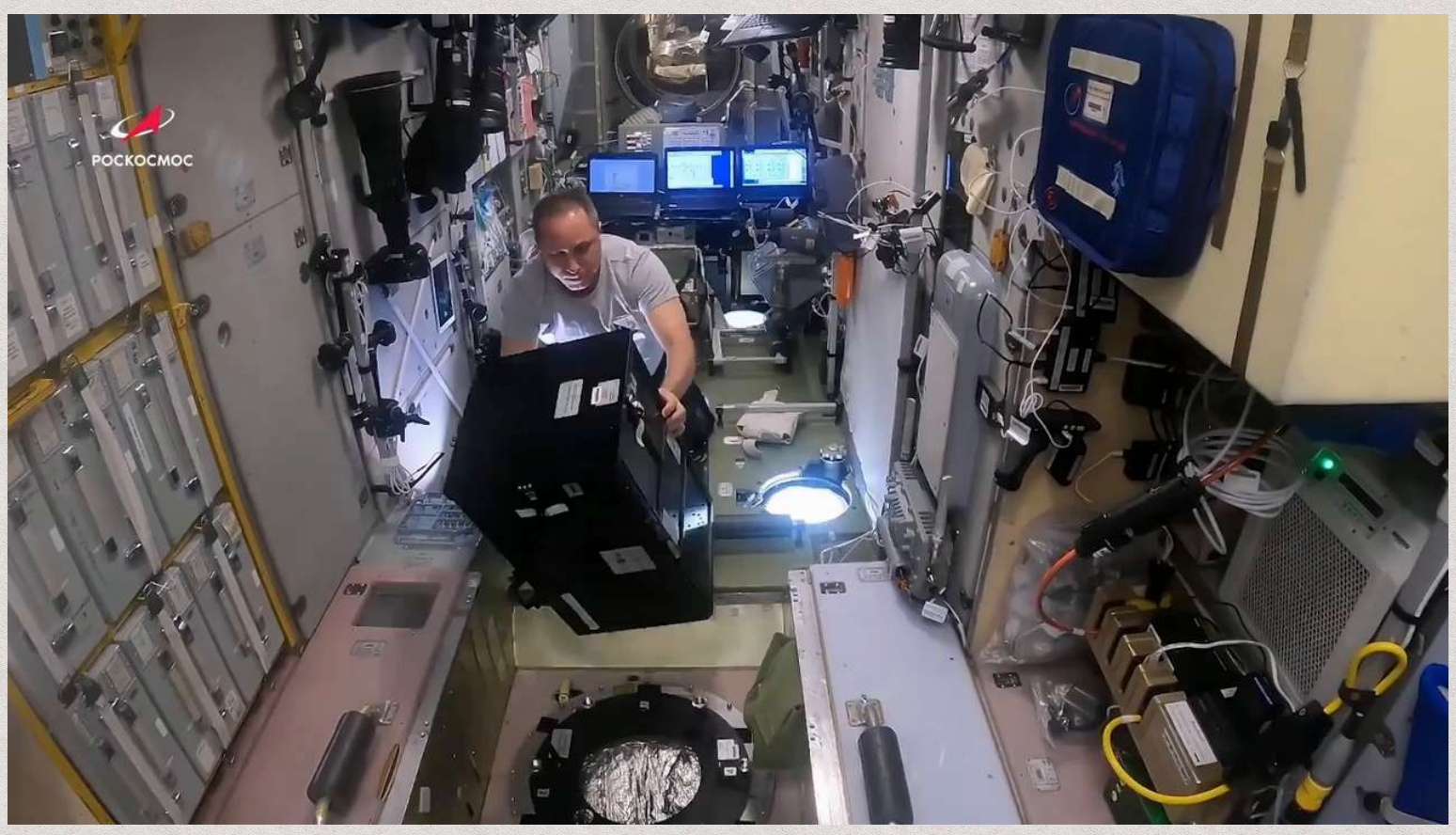
Relocation of MS-13 from Zvezda to Poisk

Second docking, 27/8/2019 successful

Installation - UV transparent window Zvezda module, 07/10/2019



Mini-EUSO in-flight operations



START OF SESSION
- Latch on the UV-trasparent window
- Connect 27V power supply cable
- Connect grounding cable
- Insert and latch the USB stick
- Turn on the switch

END OF SESSION
- Turn off the switch
- Remove and store USB stick
- Periodically copy of selectet files
  on station computer for later downlink
- Unlatch and store the instrument

Mini-EUSO in-flight operations

Launch: August 2019

Pouch003: sessions 1-14
Returned in April 2020

Pouch004: sessions 15-44
Returned in October 2021

Pouch003_v2: sessions 45-(?)
Currently in use

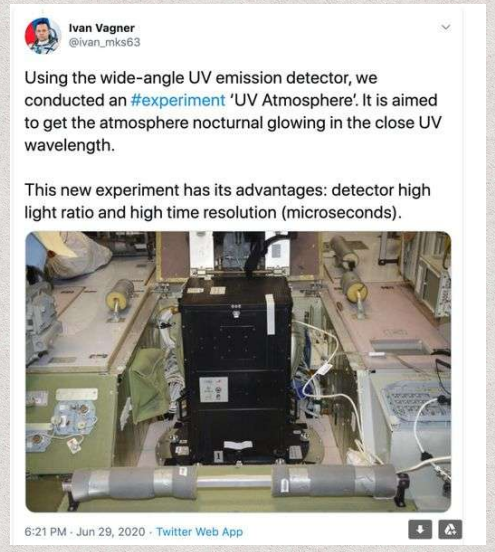
Pouch004_v2:
Ready to be launched!

~3 sessions/month
~12 hours/session

~20 GB stored each session
(data subset downlinked
via telemetry channel)

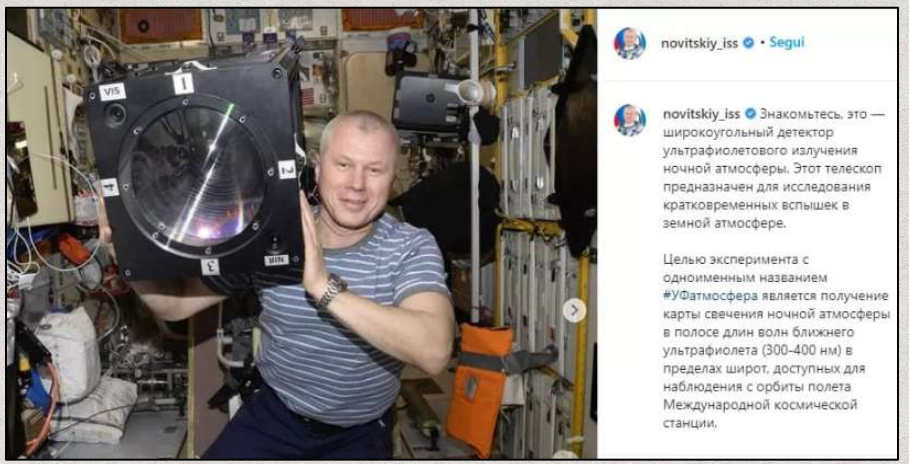
Mini-EUSO on the ISS

Sergei Kud-Sverchkov



Twitter from I. Vagner

Oleg Artemyev



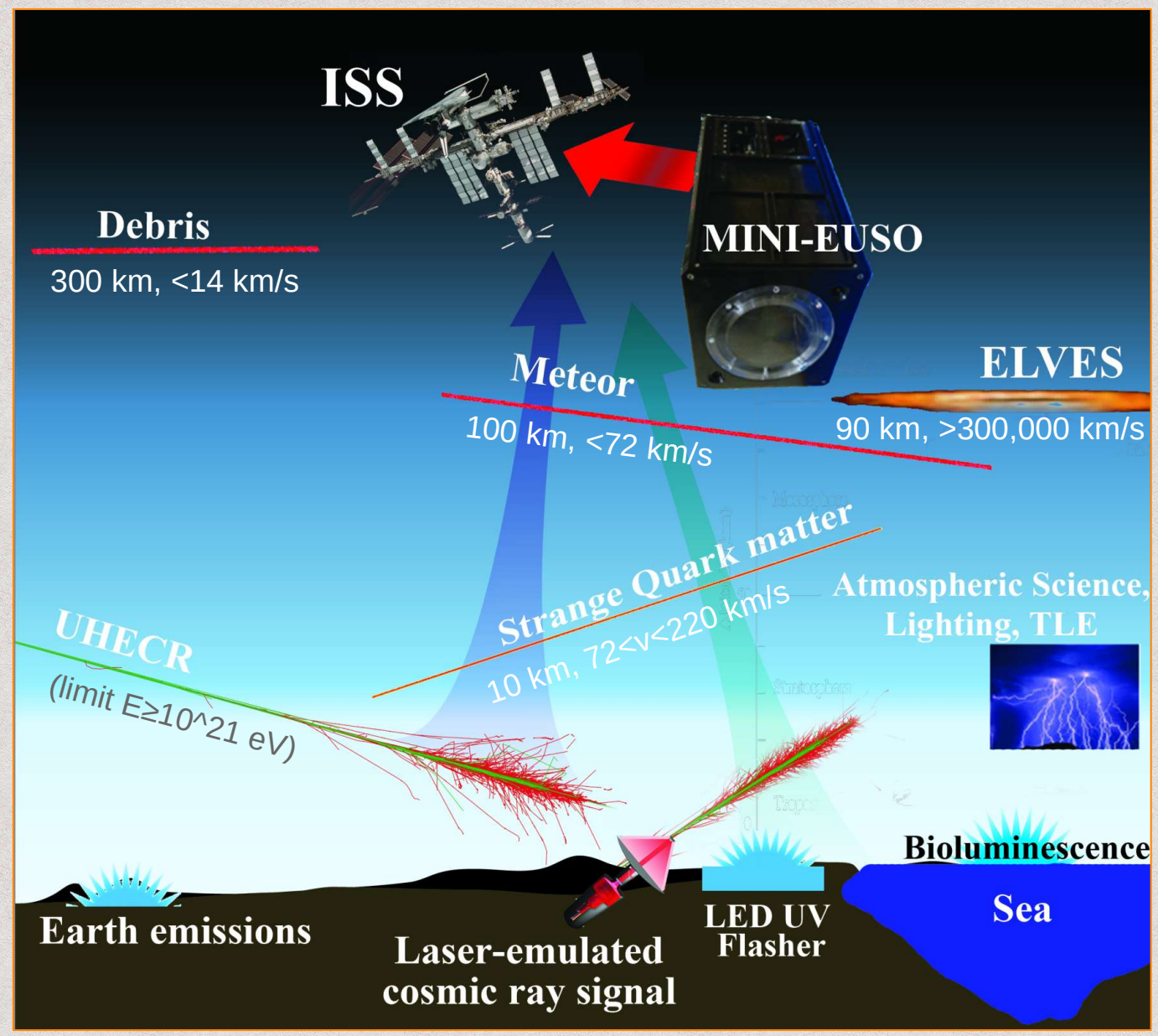
Twitter from O. Novitskiy

O. Skripocka: outreach video from ISS
https://www.youtube.com/watch v=lXedBGVHc4o&t=62s

116 sessions performed

>200 crew hours

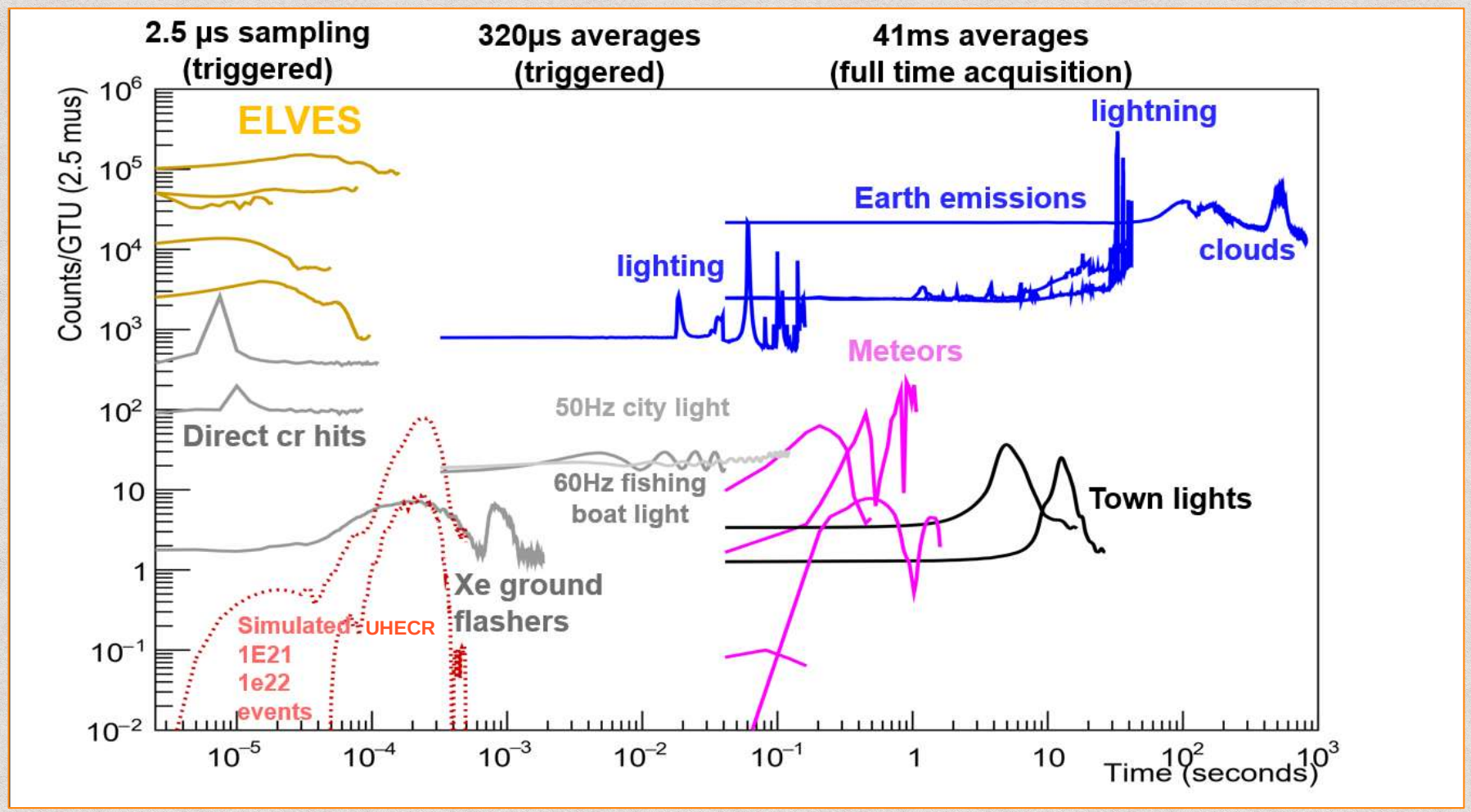
Science Objectives



Time profile of various events

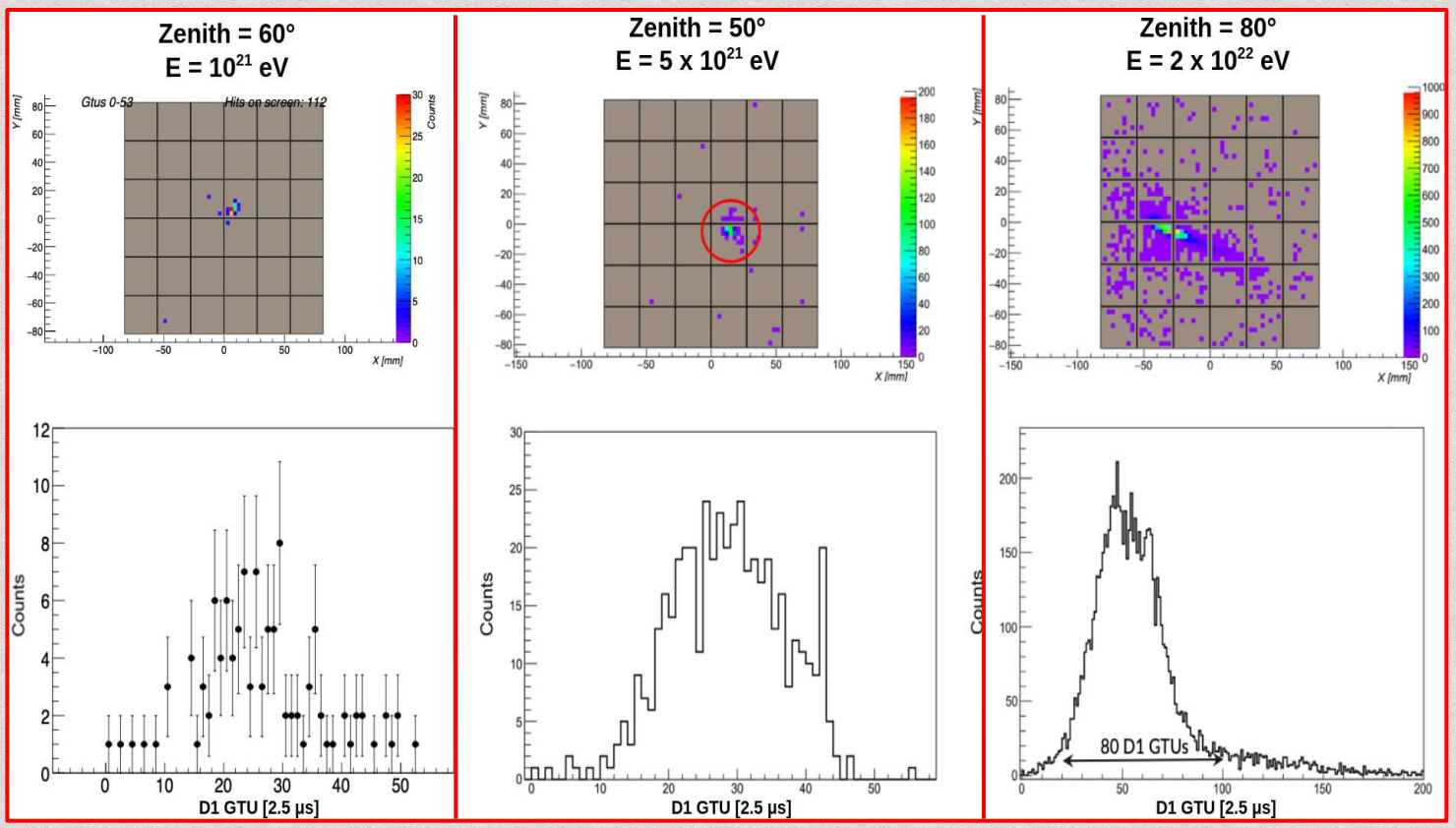
2.5 µs X 128 320 µs X 128

D1 acq. mode → D2 acq. mode → D3 acq. Mode



UHECR: simulated EAS

MC SIMULATIONS



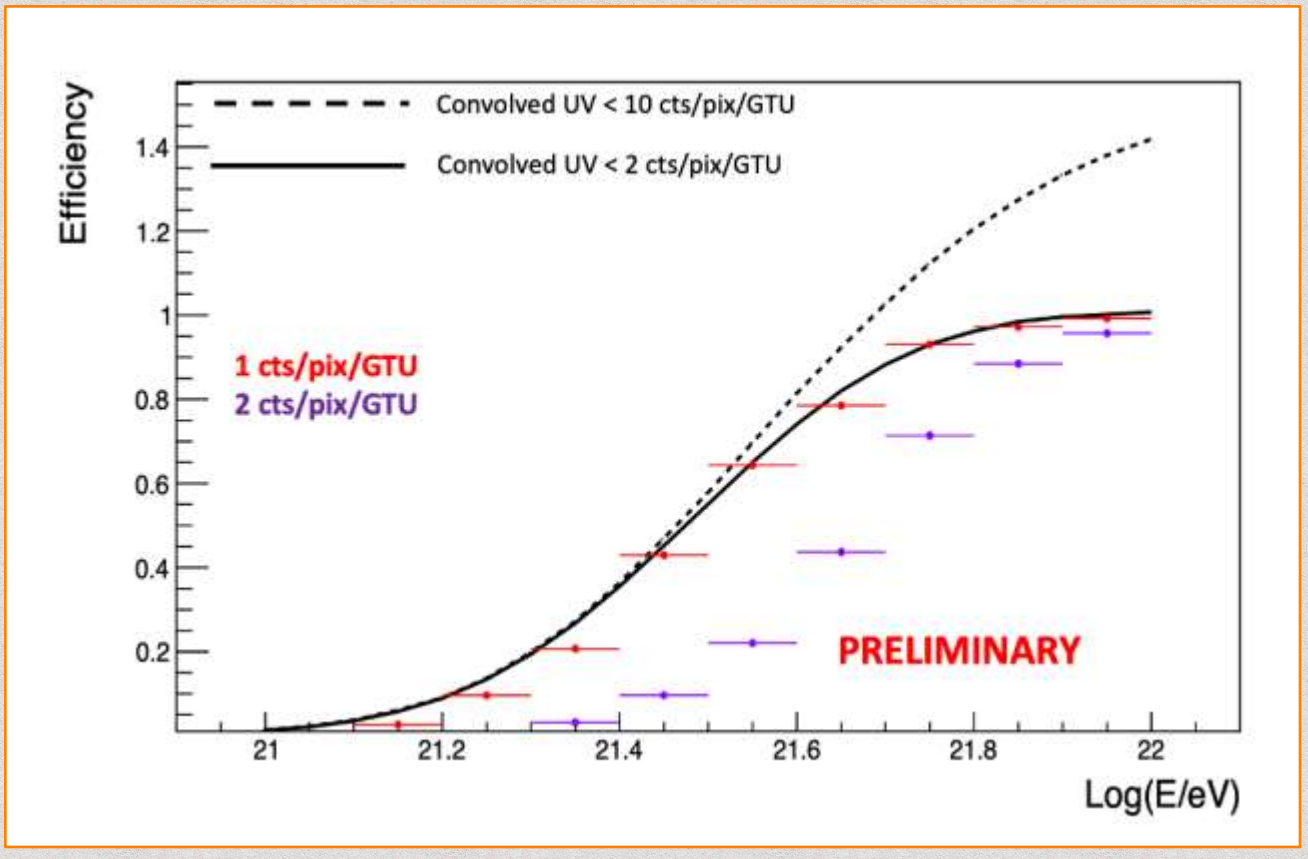
Simulation of Extensive Air Shower (EAS) events produced by primary protons

EAS events in data:

- lightcurves show a bi-gaussian shape (fast rising, slow decay)
- Event duration: < 80 D1-GTU ~ 200 µs
- footprints show a compact shape of no more than 20 pixels

Developments and results in the context of the JEM-EUSO program obtained with the ESAF simulation and analysis framework S. Abe et al., Eur. Phys. J. C 83, 1028 (2023).

UHECR detection efficiency



Detection thresholds (trigger efficiency = 50%): 3-5 x 10^{21} eV
→ in agreement with results from pure simulation

Implications of Mini-EUSO measurements for a space-based observation of UHECRs
M. Bertaina et al., EPJ Web of Conferences 283 , 06008 (2023).

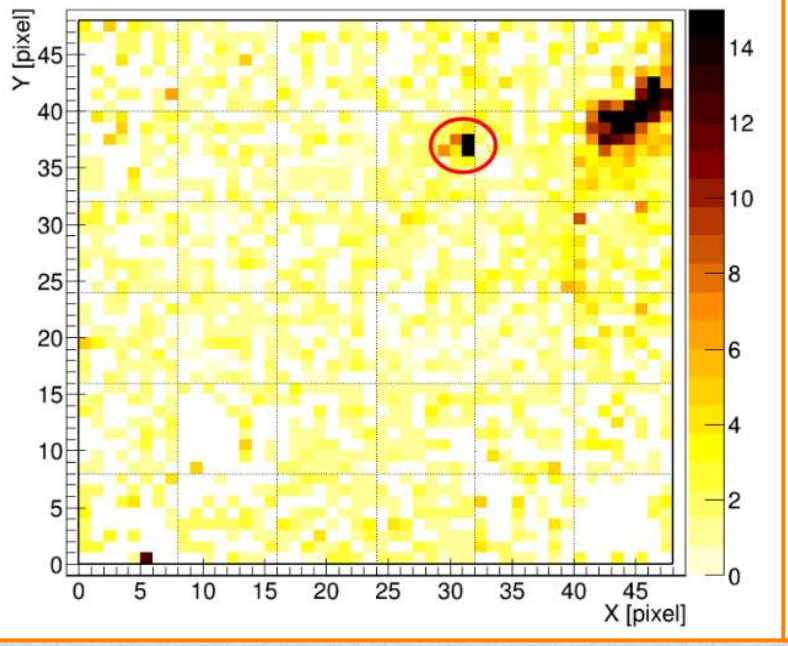
EAS-like (SLT) events

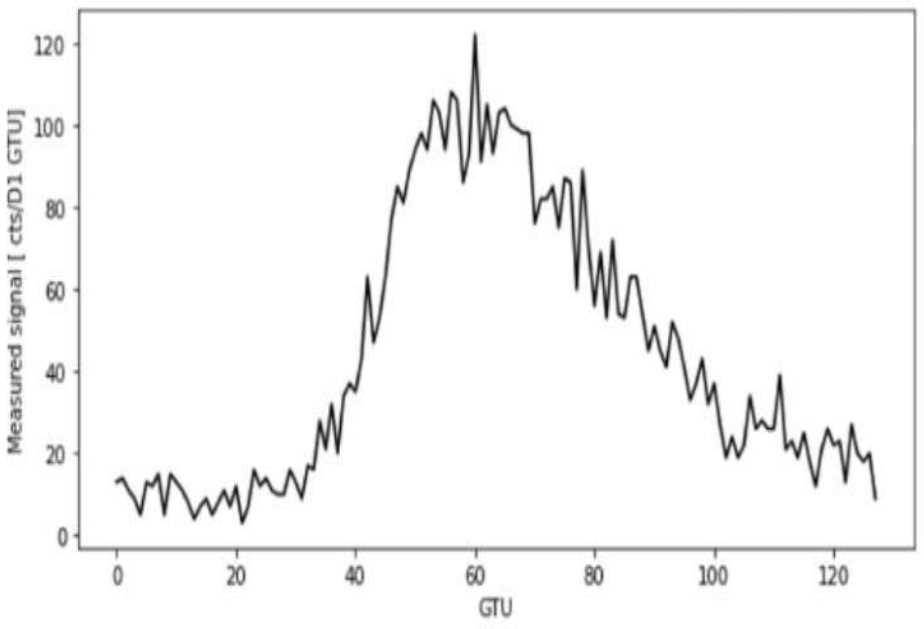
14 Short Light Transient (SLT) events found, two different types:

- ✓ single events (8/14)
- ✓ precursors of an atmospheric event (6/14)

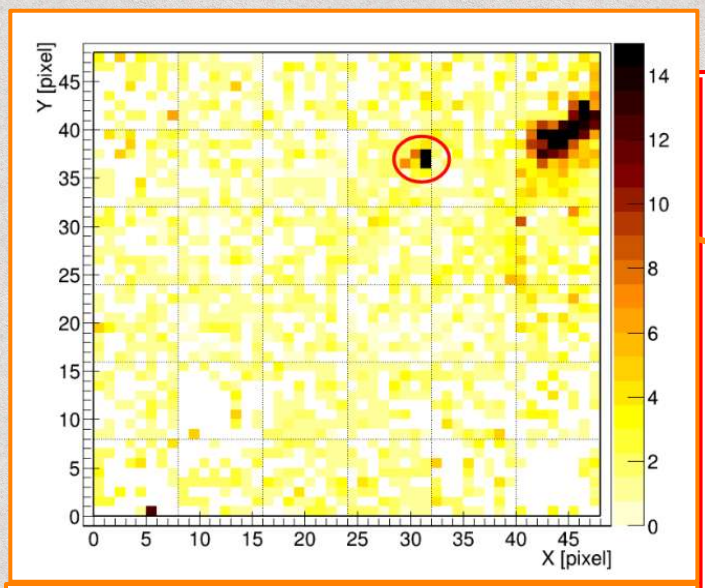
Origin probably linked to thunderstorm activity or TLEs in the atmosphere.

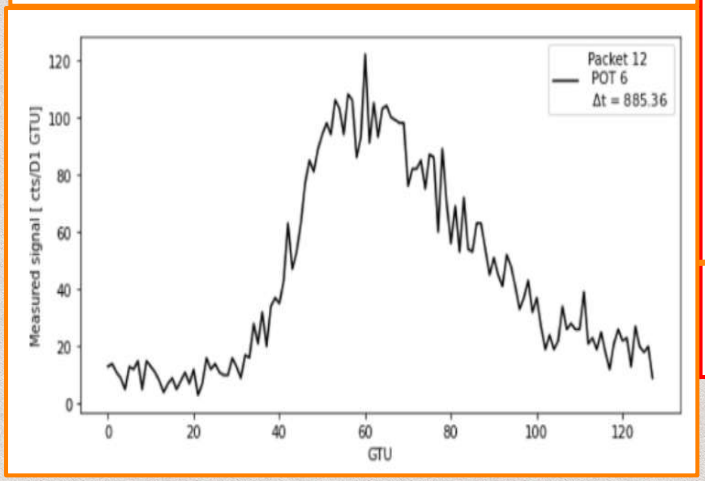
Cosmic origin can be excluded by a comparison of the focal plane footprint and the lightcurve duration with simulations.



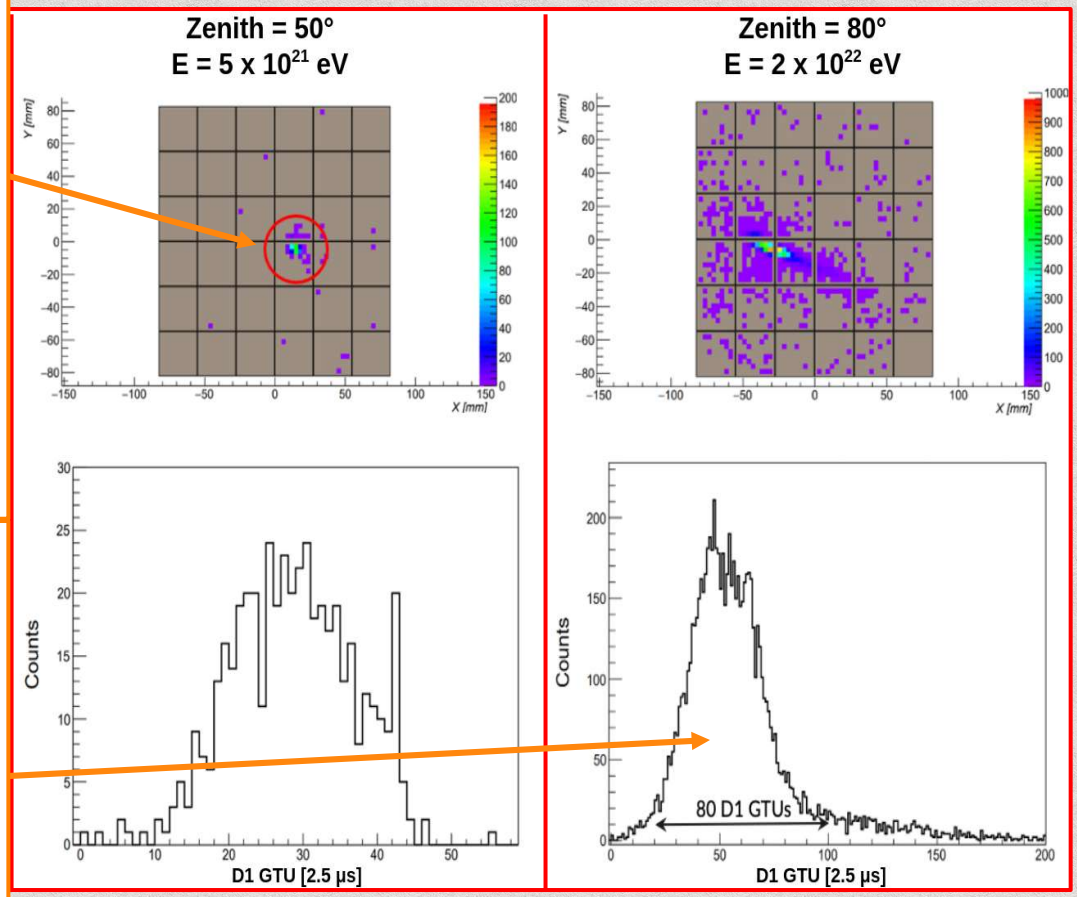


EAS-like (SLT) events



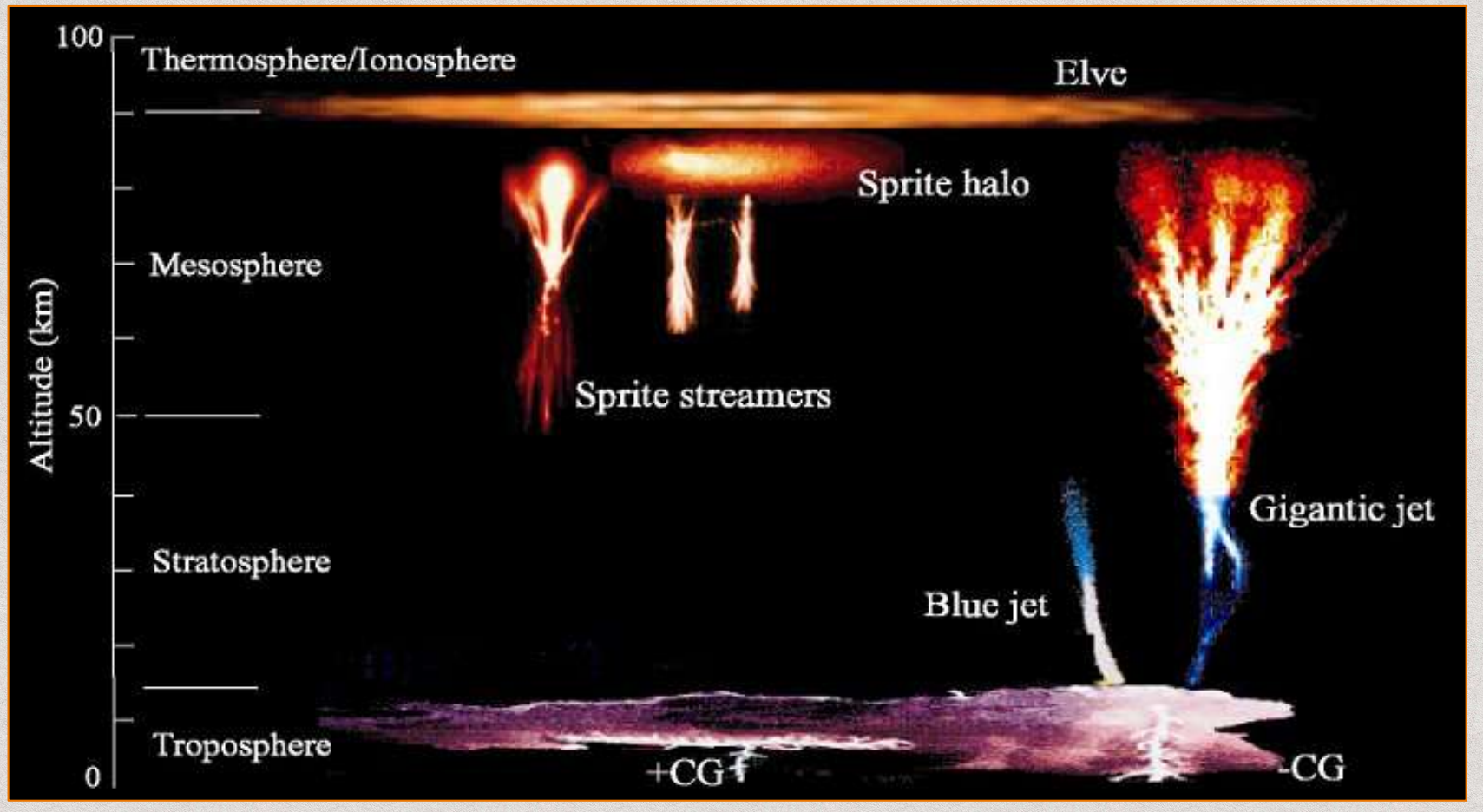


Mini-EUSO Data



MC SIMULATIONS

ELVES

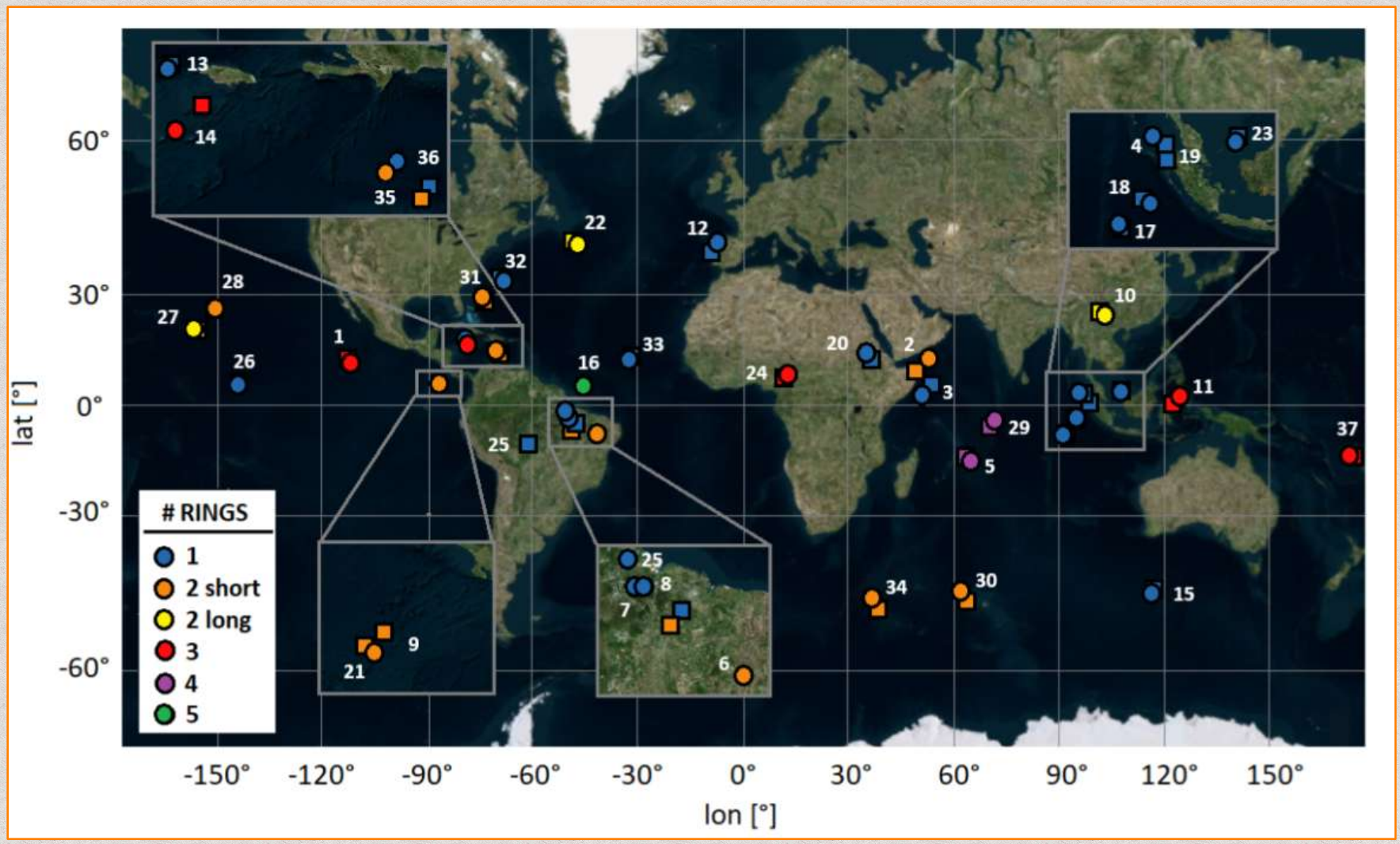


Fast-expanding rings at the height of the ionosphere

Upper atmospheric lighting releases e.m. wave which heats the ionosphere

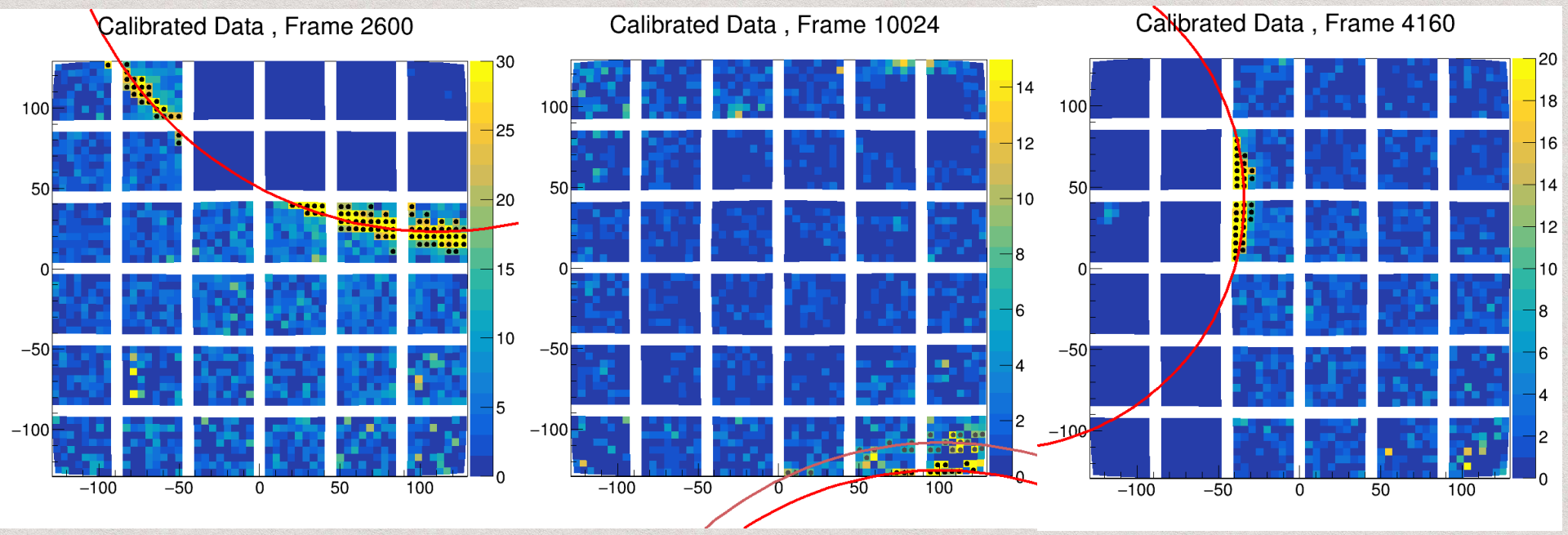
ELVES

37 ELVES detected so far (less than half dataset received)
mostly in the equatorial region



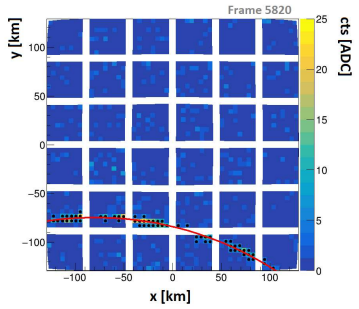
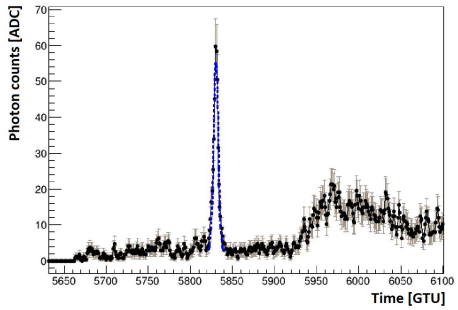
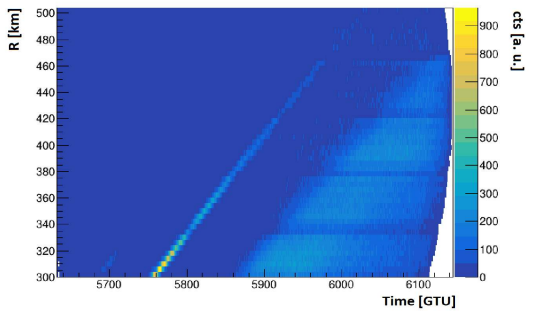
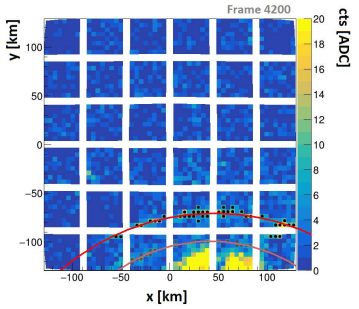
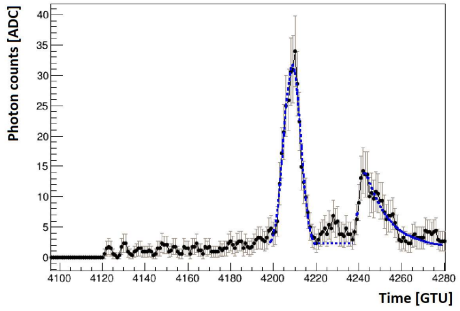
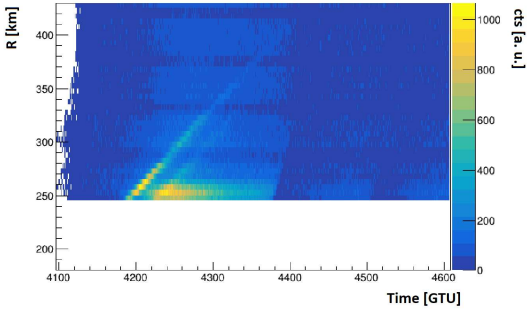
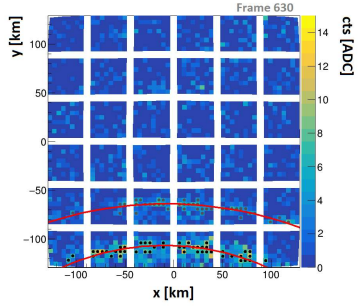
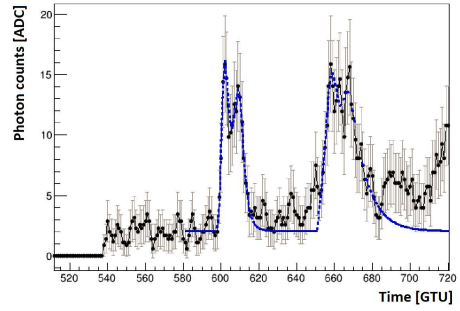
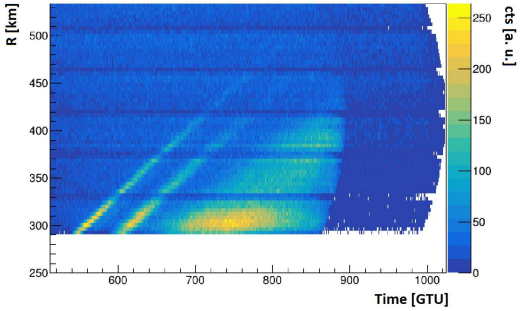
ELVES

Time sampling: 2.5 µs
Pixel size: 5x5 km^2 (@ 90 km)
Elve lifetime: about 400µs



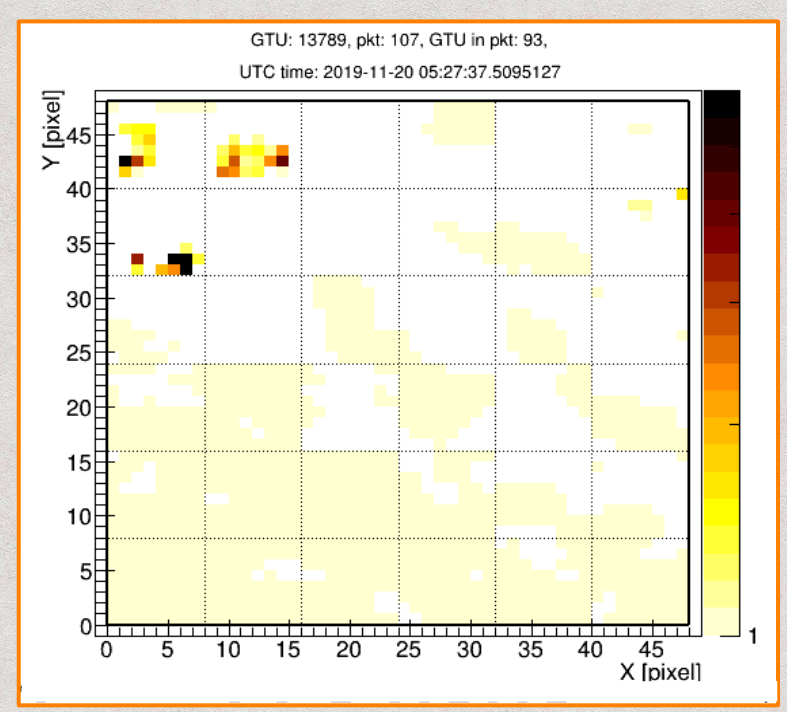
Tracking fitting algorithm -> ELVES centre

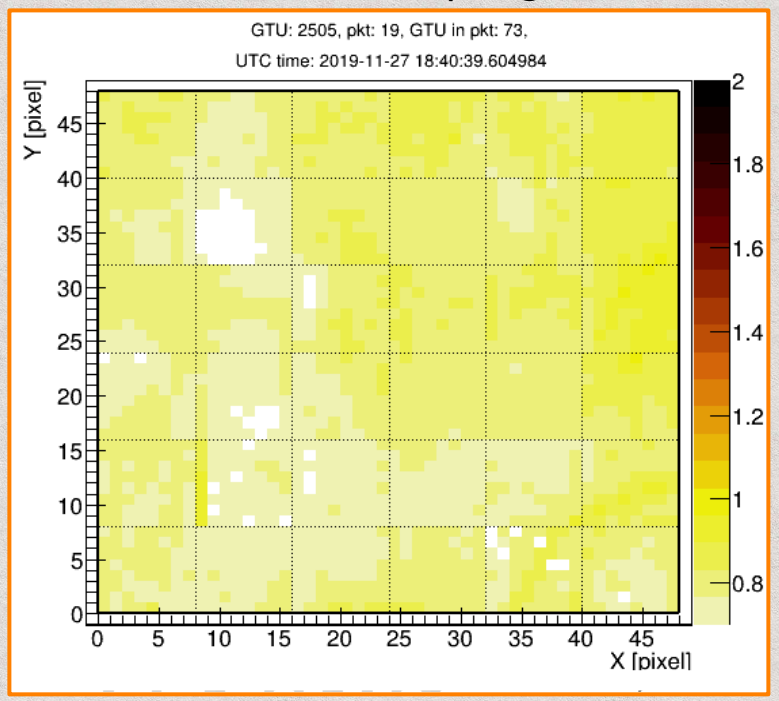
ELVES

	SINGLE FRAME — circle fit	SINGLE PIXEL SIGNAL — fit exGauss	POLAR PLOT
24/09/2020			
25/09/2020			
21/08/2020			

Meteors

Time sampling: 40.96 ms





Mini-EUSO detected meteors: 24k
(less than half dataset received)

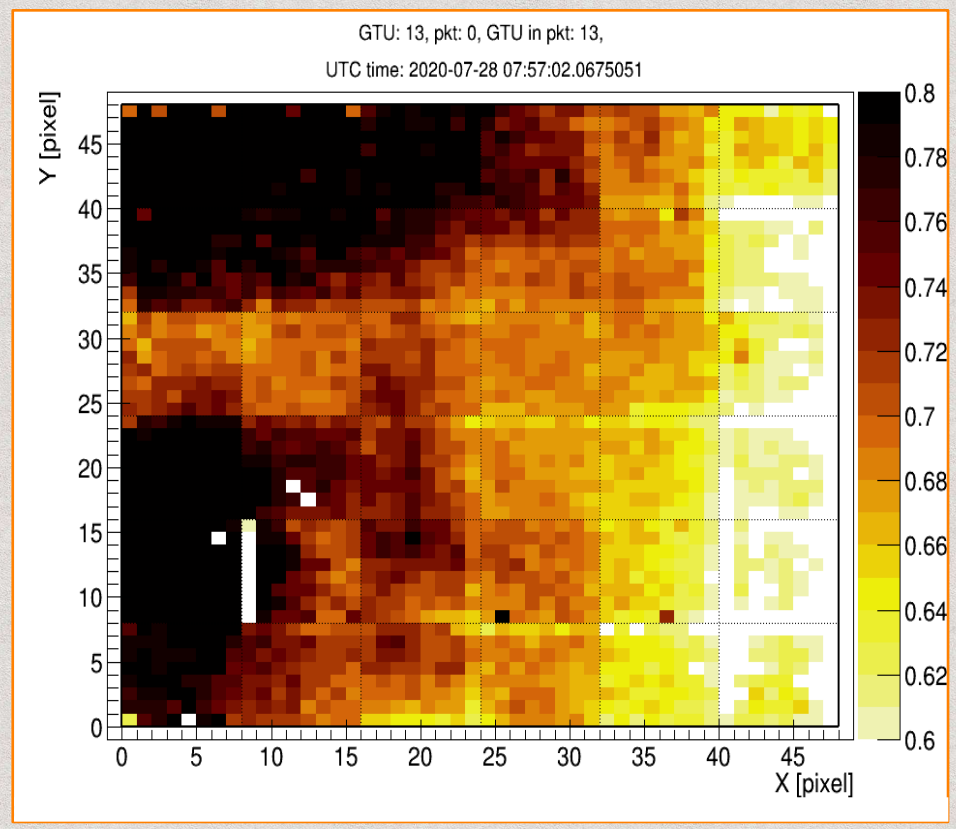
First systematic survey of meteors from space

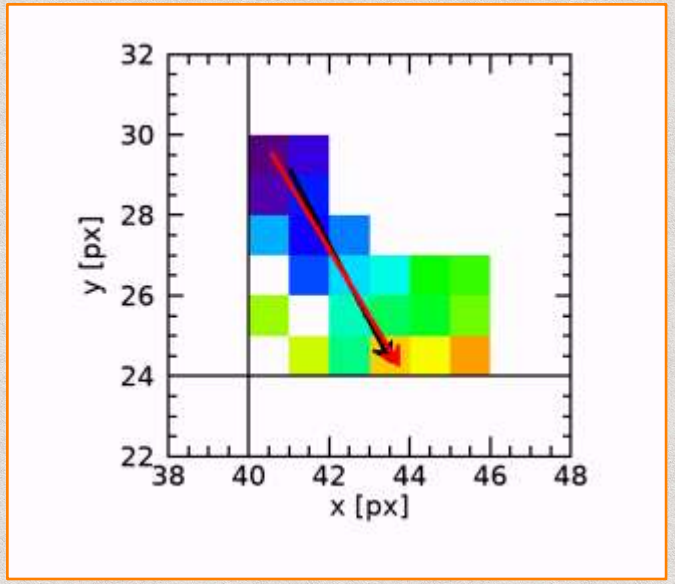
rate ~ 3 meteors/min
70% over ocean, 30% over land

Observation of meteors from space with the Mini--EUSO detector on board the International Space Station
D. Barghini et al., In press in "Astronomy & Astrophysics", section "Planets and planetary systems"

Meteor tracking algorithm

From D. Barghini





Meteor tracking algorithm

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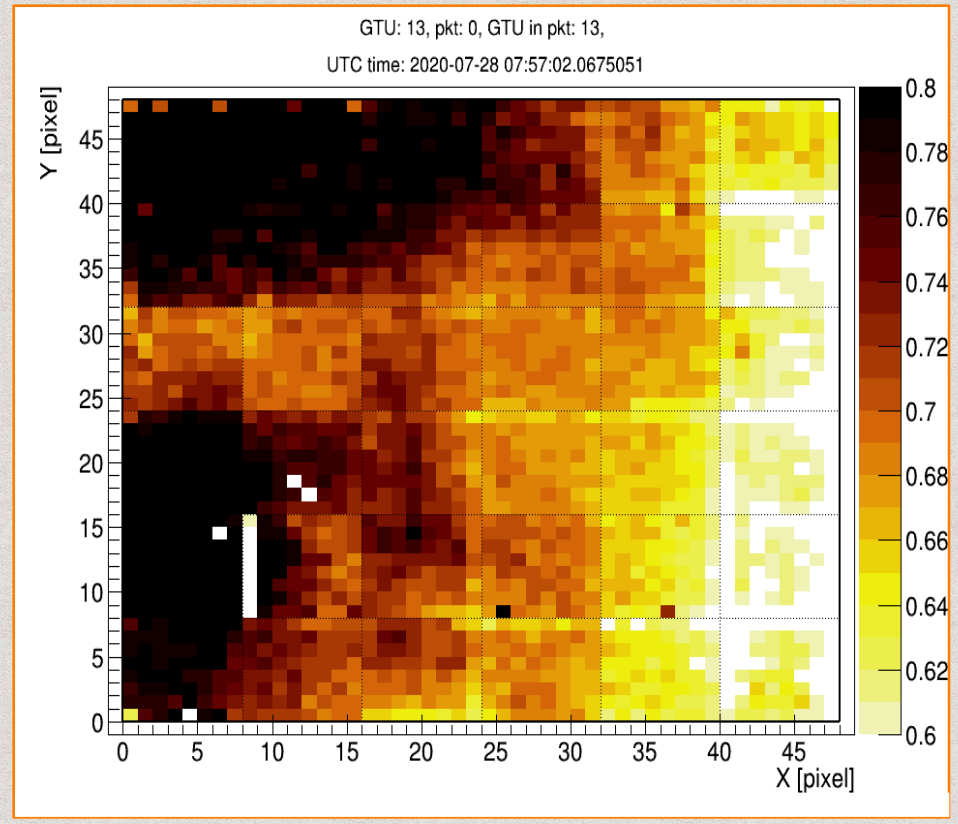
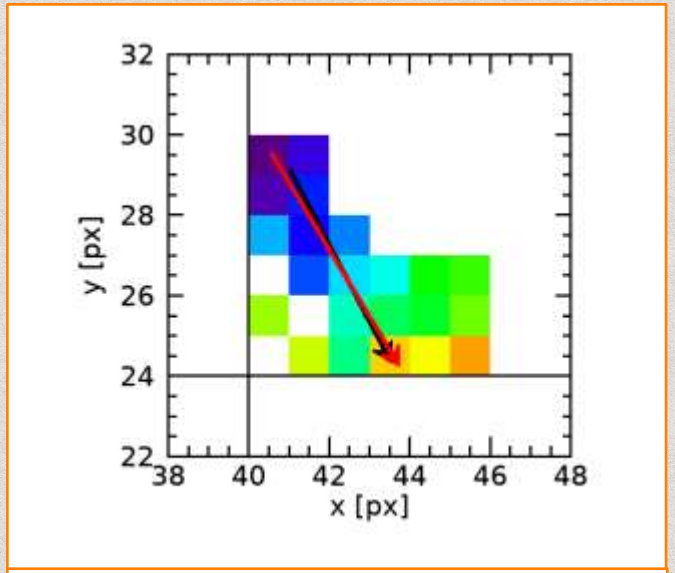
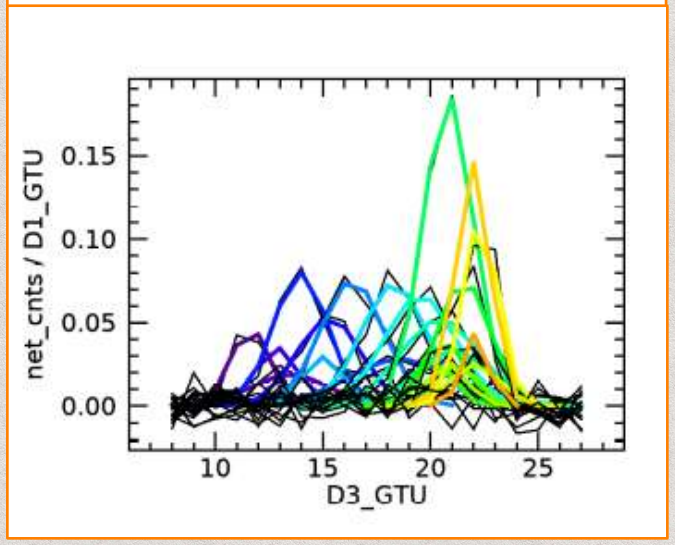
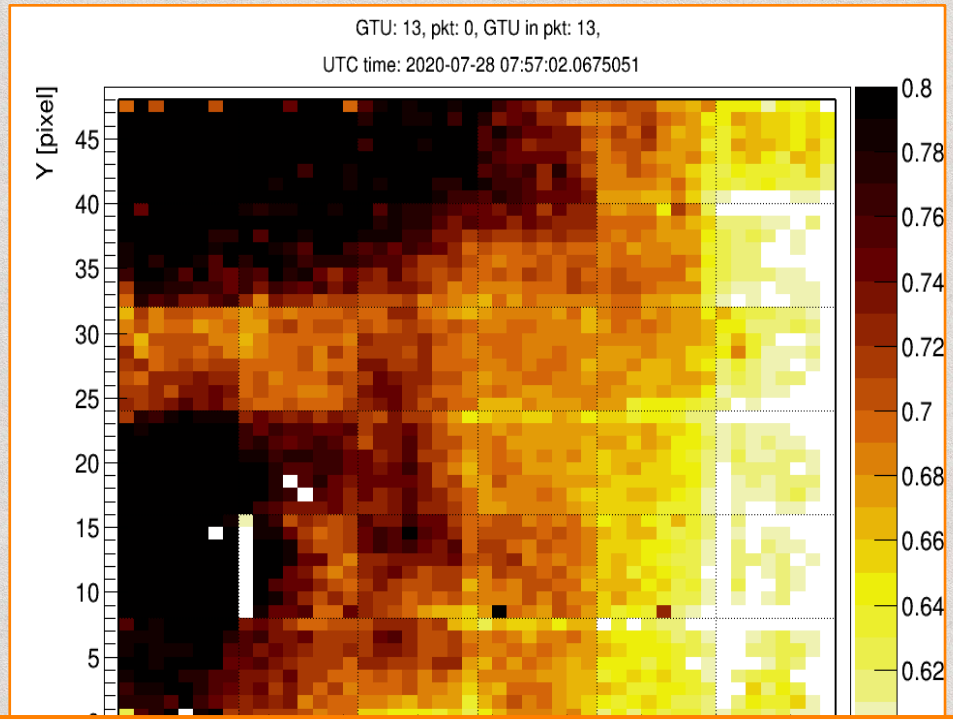


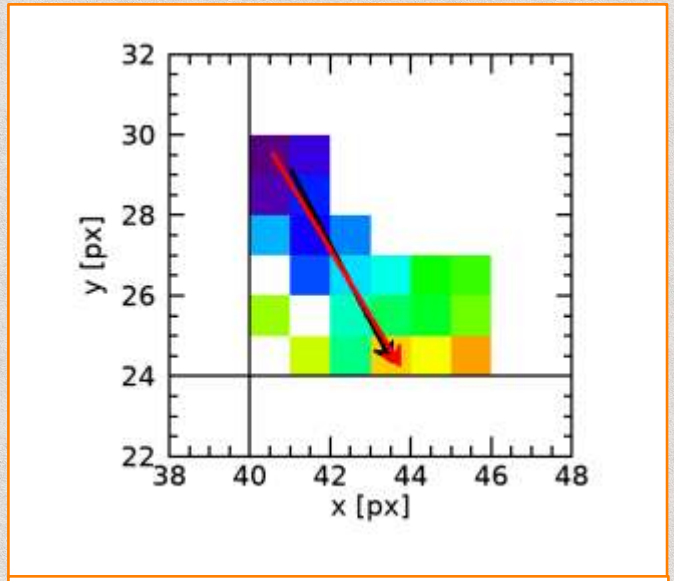


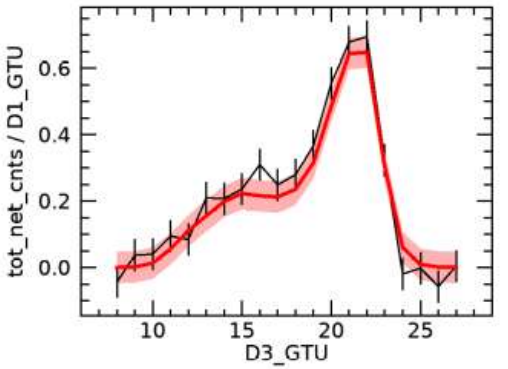


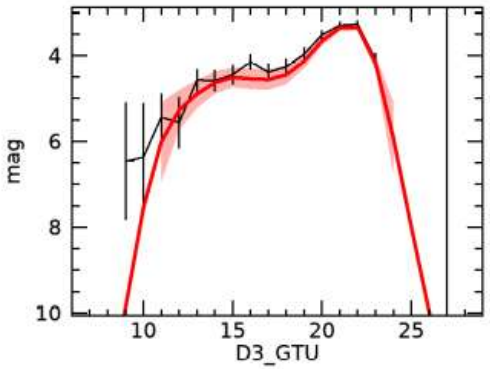
Meteor tracking algorithm

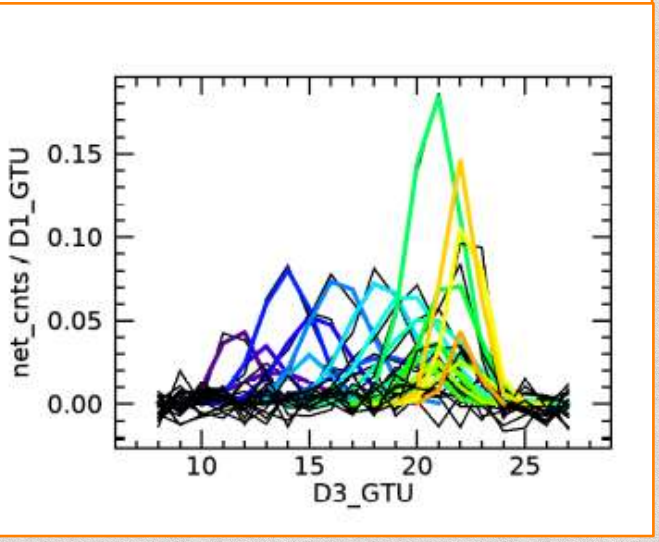
From D. Barghini



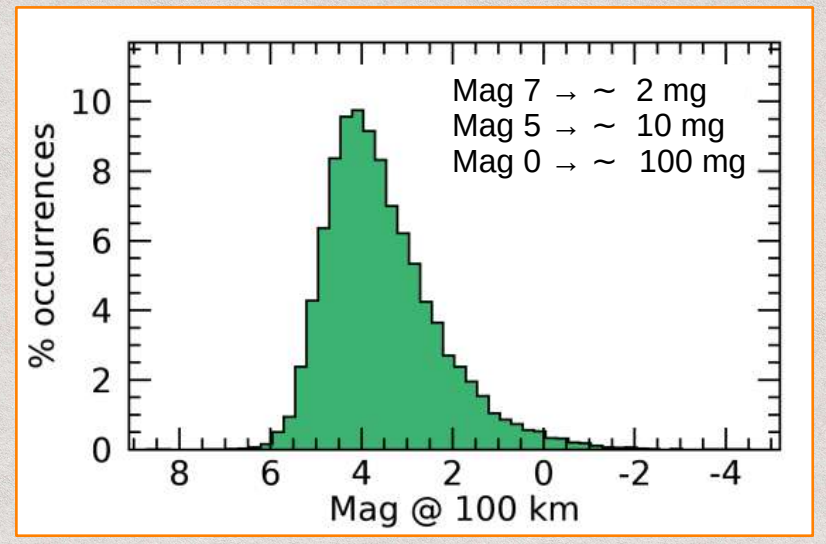


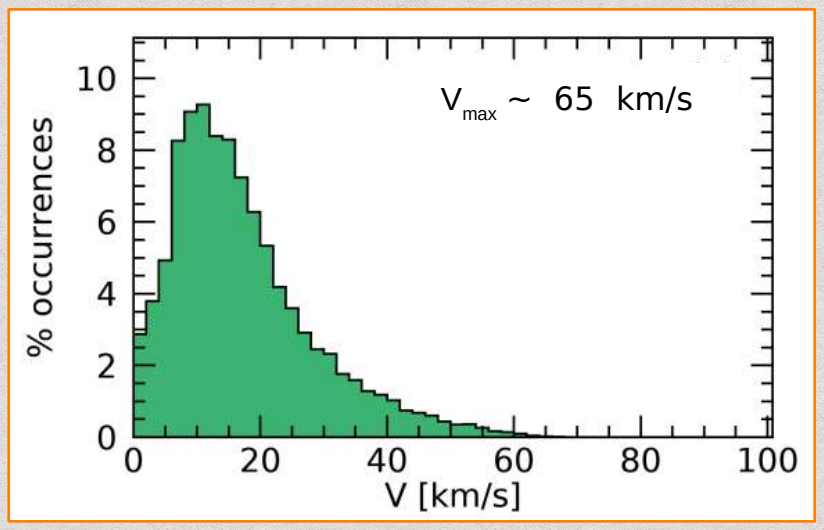


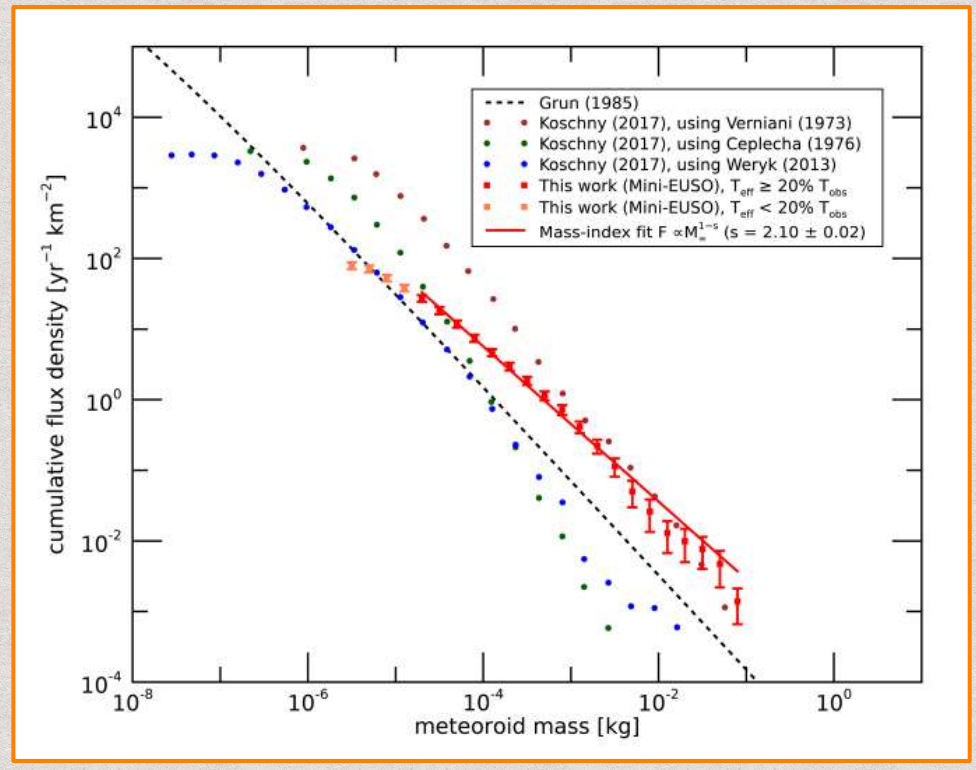




Meteors

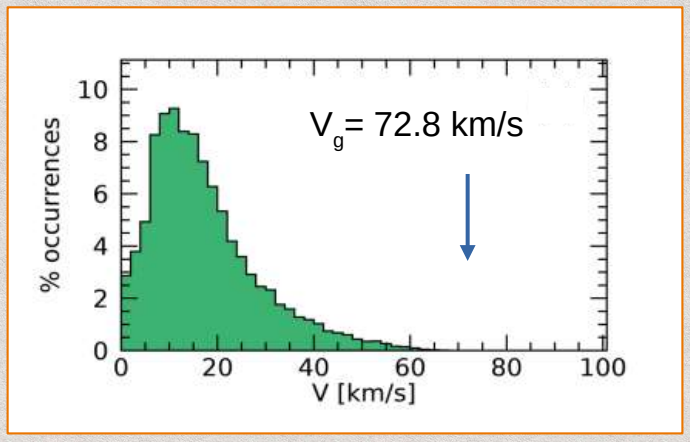






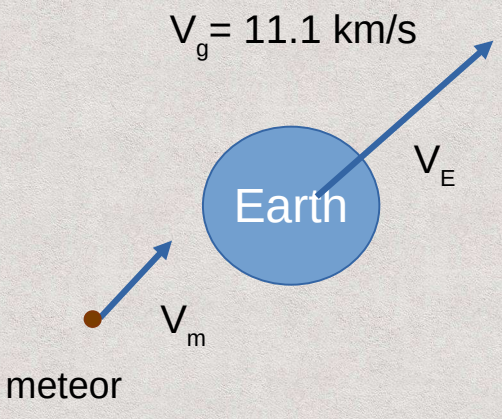
Observation of meteors from space with the Mini--EUSO detector on board the International Space Station
D. Barghini et al., In press in "Astronomy & Astrophysics", section "Planets and planetary systems"

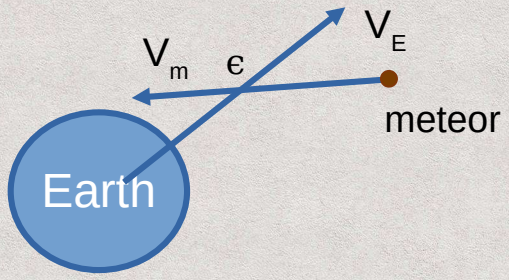
Search for Interstellar meteors

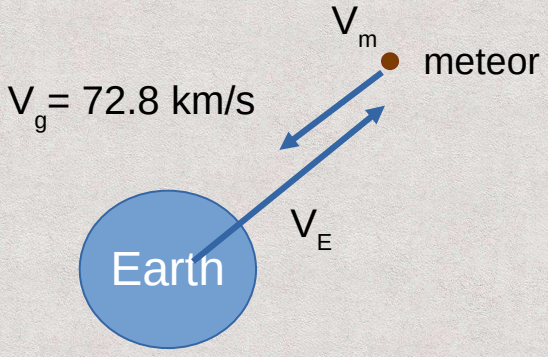


Solar system meteors:

$11.1 \text{ km/s} < v_g < 72.8 \text{ km/s}$

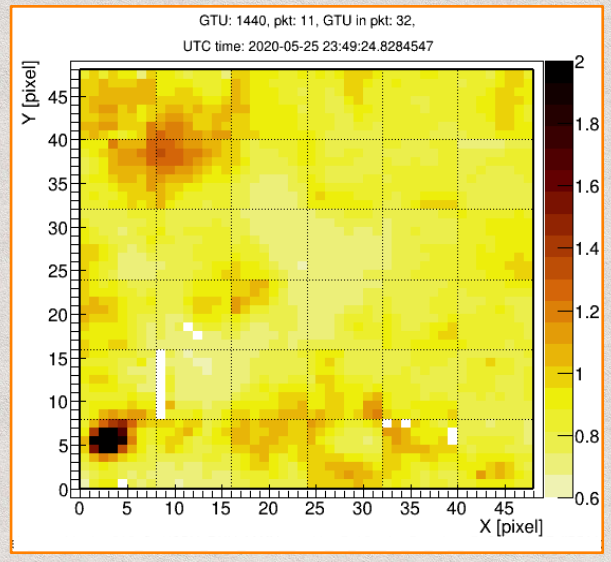




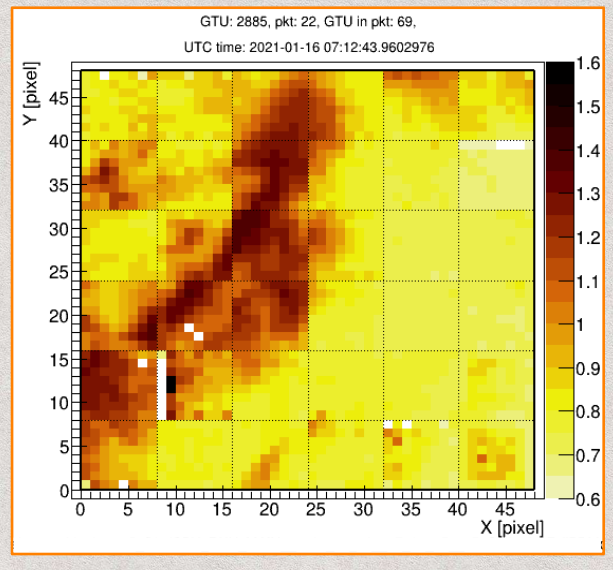


Interstellar meteors: meteor with a speed above solar system allowed speed

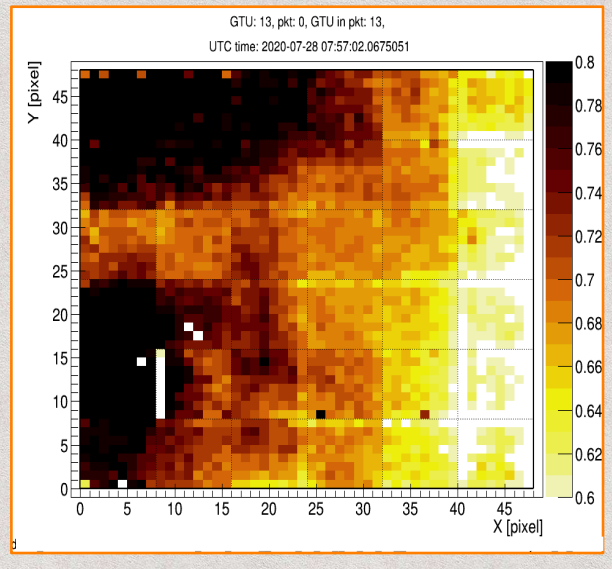
Interstellar meteors: three candidates



V_{hor} = 33 ± 2 km/s
M= 2.7 ± 0.1
N_{pix} = 9
ΔT = 0.70 s



V_{hor} = 42 ± 4 km/s
M= 3.3 ± 0.1
N_{pix} = 22
ΔT = 0.82 s

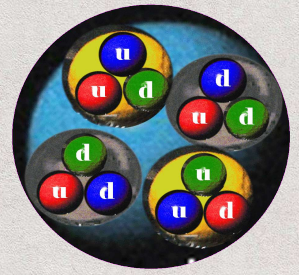


V_{hor} = 37 ± 3 km/s
M= 2.9 ± 0.1
N_{pix} = 10
ΔT = 0.78 s

Event Selection: - robust track reconstruction (n. pixel, magnitude, ...)
- correct estimation of uncertainty on velocity measurement (trajectory inclination missing)

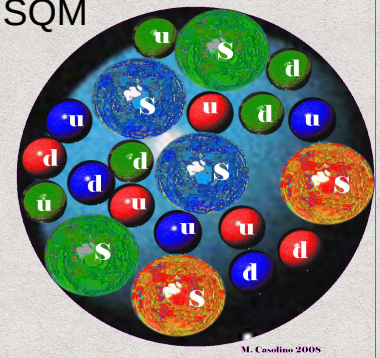
Search for Strange Quark Matter

Ordinary matter



Z=2 A=4 (4He)
Z/A=0.5

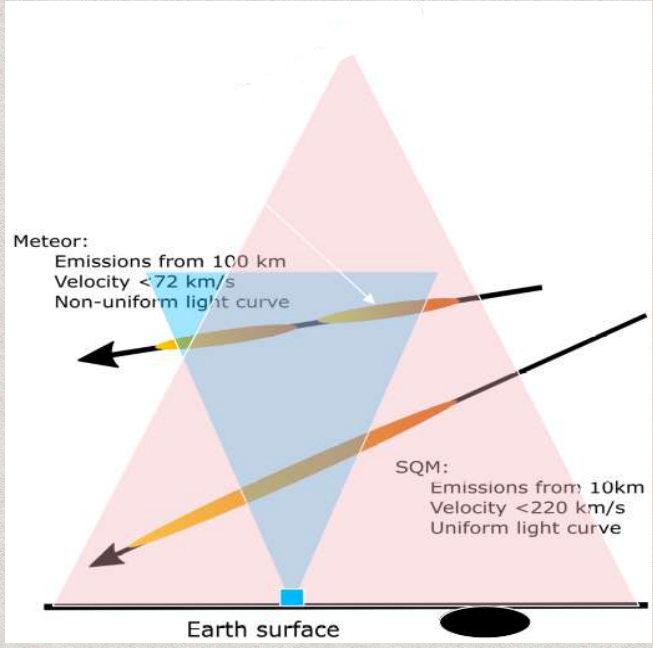
SQM

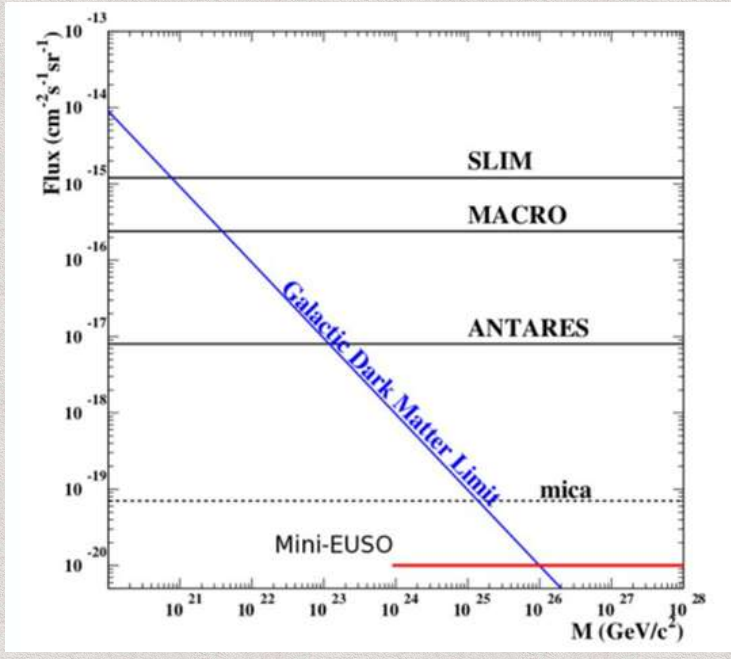


Z=2 A=/ Z/A=0.286

Roughly equal numbers of u,d,s quarks in a single 'bag' of cold hadronic matter:

- u,d,s quark matter might be stable
- Not limited in A: A=100, 1000….
- Z is almost zero due to cancellation of quark charge
- Could account for a (small) part of DM
- Also candidate of UHECR





Meteor studies in the framework of the JEM-EUSO program. PLANETARY AND SPACE SCIENCE, 143(SI):245-255, 2017.

JEM-EUSO: Meteor and nuclearite observations. Experimental Astronomy, 40:253- 279, 2015.

Night-time Earth Emissions

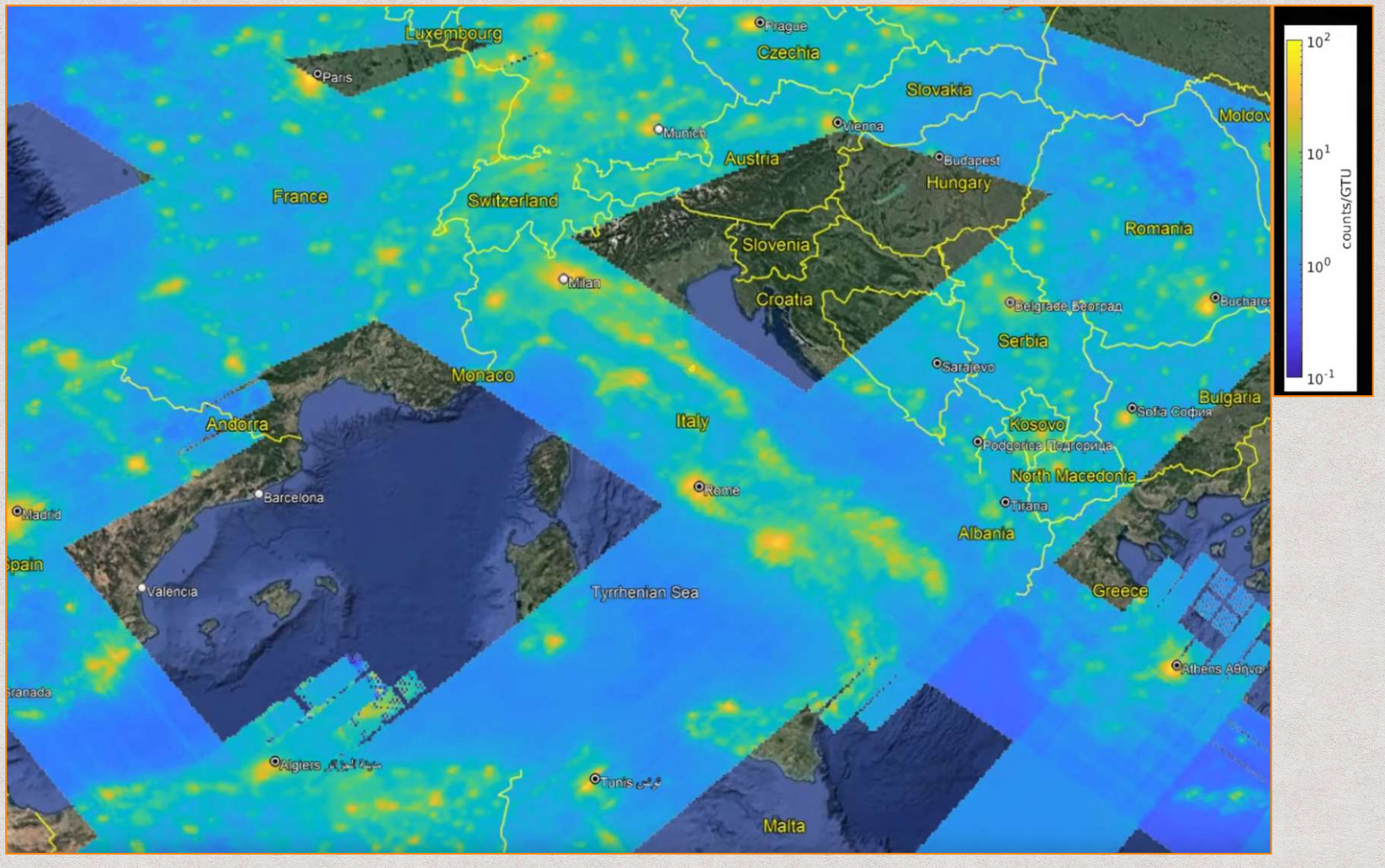
Time sampling: 40.96 ms

Pixel size: 6 x 6 km^2

Mendeley database: https://data.mendeley.com/datasets/57fmn7rh4n/4

Youtube video: https://youtu.be/X_QATIf38Og

Night-time Earth Emissions

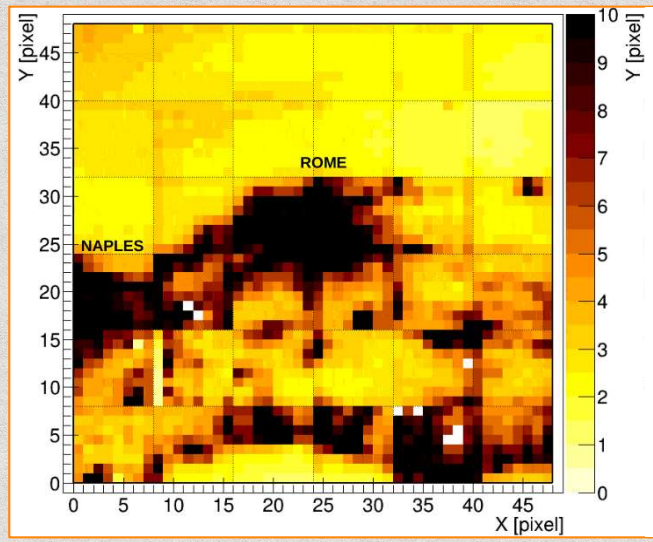


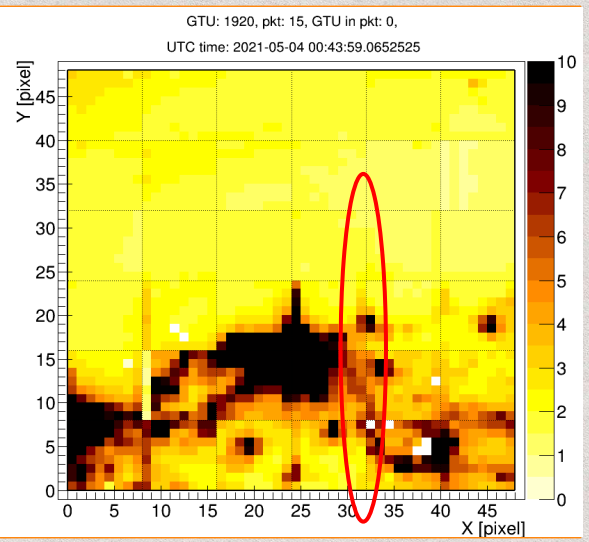
Observation of night-time emissions of the Earth in the near UV range from the International Space Station with the Mini-EUSO detector
M. Casolino et al., Remote Sensing of Environment 284 (2023) 113336

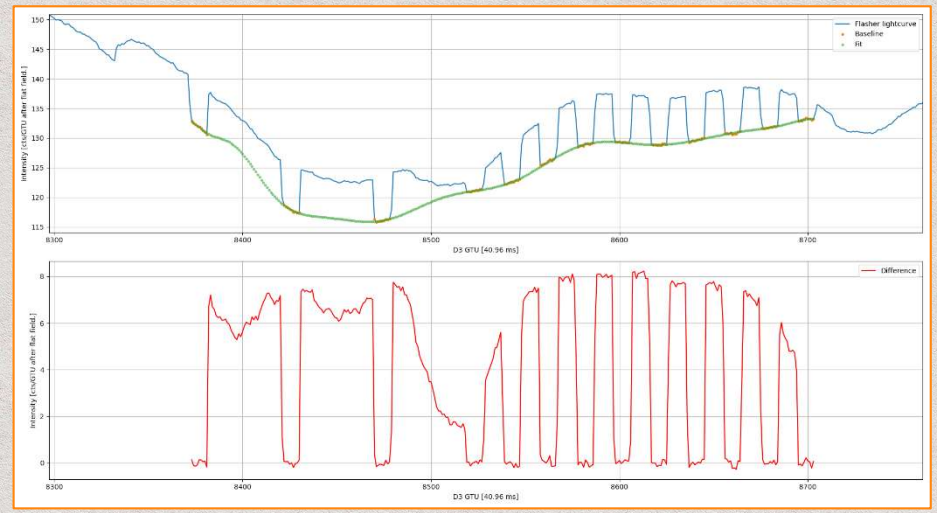
Dataset of night-time emissions of the Earth in the near UV range (290-430 nm), with 6.3 km resolution in the latitude range -51.6<L<+51.6 degrees, acquired on board the International Space Station with the Mini-EUSO detector
L. Marcelli et al., Data in Brief 48 (2023) 109105

End-to-end in-flight Calibration with ground UV flashers

- 2kW pulsed UV LED arrays
- Calibration from ground
- Shoot when in field of view
- Pulsed and coded shots
- Many flasher campaigns performed from Italy and France
- Partial results published, waiting for new data







An end-to-end in-flight calibration of Mini-EUSO detector
H. Miyamoto, EPJ Web of Conference 283, 06017 (2023)

Conclusions

After 116 sessions (**more than 4 years in space**) Mini-EUSO works nominally

Mini-EUSO is a multisciplinary experiment (ELVES, UV Earth maps, SQM...)

UHECR detection efficiency estimation validated for future missions

Mini-EUSO (+ SPB2) results pave the way for UHECR detection from space

Selected publications

Mini-EUSO on Board the International Space Station: Mission Status and Results
Instruments 2024, 8 (1), 2024.

Dataset of night-time emissions of the earth in the near uv range (290-430 nm), with 6.3 km resolution in the latitude range -51.6<L<+51.6 degrees, acquired on board the international space station with the mini-euso detector
Data in Brief, 48, 2023.

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.

Neural Network Based Approach to Recognition of Meteor Tracks in the Mini-EUSO Telescope Data
Algorithms, 16(9), 448, 2023.

Onboard performance of the level 1 trigger of the mini-euso telescope
Advances in Space Research, 70(9):2750–2766, 2022.

Pre-flight qualification tests of the mini-euso telescope engineering model
Experimental Astronomy, 53(1):133–158, 2022.

Mini-EUSO Mission to Study Earth UV Emissions on board the ISS
The Astrophysical Journal Supplement Series, 253, 2 , 36, 2021.

Secondary cameras onboard the Mini-EUSO experiment: Control software and calibration
Advances in Space Research, 64(5):1188-1198, 2019.

Mini-EUSO data acquisition and control software
Journal of Astronomical Telescopes Instruments and Systems, 5(4), 2019.

Mini-EUSO: A high resolution detector for the study of terrestrial and cosmic UV emission from the International Space Station
Advances in Space Research, 62(10):2954-2965, 2018.

The integration and testing of the Mini-EUSO multi-level trigger system
Advances in Space Research, 62(10), 2966-2976 , 2018.