

Launch and first results of Mini-EUSO telescope: observing UV emissions of cosmic and terrestrial origin from the International Space Station

L. Marcelli

***(INFN, Section of Rome Tor Vergata, Italy)
on behalf of the JEM-EUSO collaboration***



The EUSO program

1. EUSO-TA: Ground detector installed in 2013 at Telescope Array site: currently operational

2. EUSO-BALLOONS:

- 2014, Timmins, Canada
- 2017 NASA Ultra long duration flight. EUSO-SPB

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

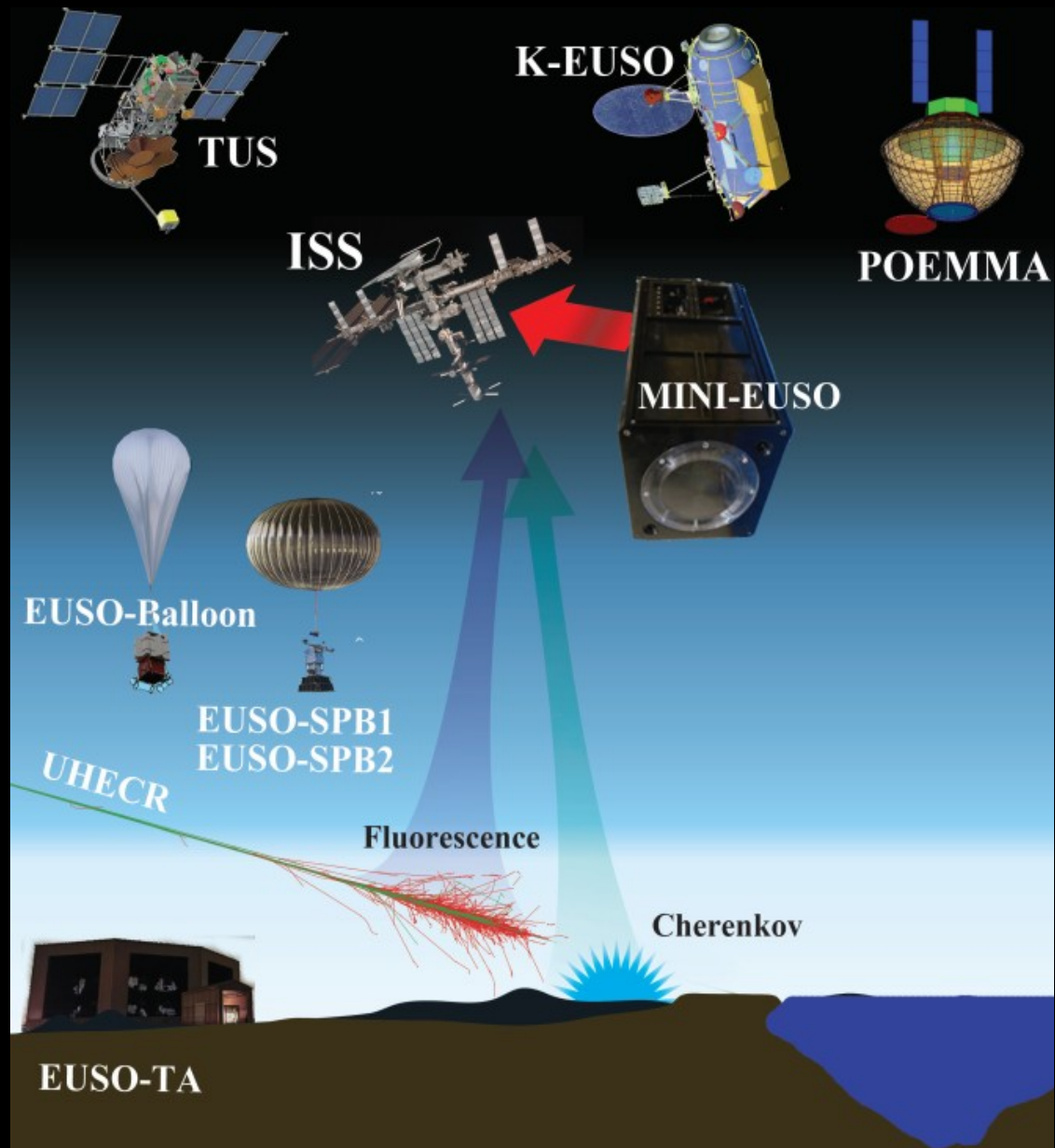
4. Mini-EUSO (2019):

Detector from International Space Station (ISS)
Beyond Mission (L. Parmitano)

5. SPB-2 (NASA) (2023)

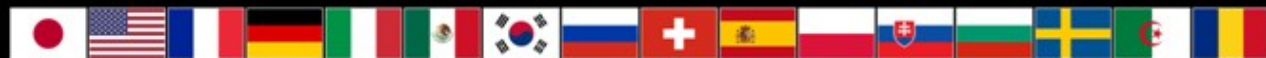
6. K-EUSO (2024): ISS
Phase A, Russian Space Agency

7. POEMMA (2025+):
NASA twin free-Flyer



JEM-EUSO collaboration

16 Countries, 93 Institutes, 351 people



Mini-EUSO / UV-Atmosfera

Multiwavelength Imaging New Instrument for the Extreme Universe Space Observatory

Mini-EUSO telescope on board the ISS

Weight: 35 kg

Power consumption: 60 W

Dimensions: 37x37x62 cm³

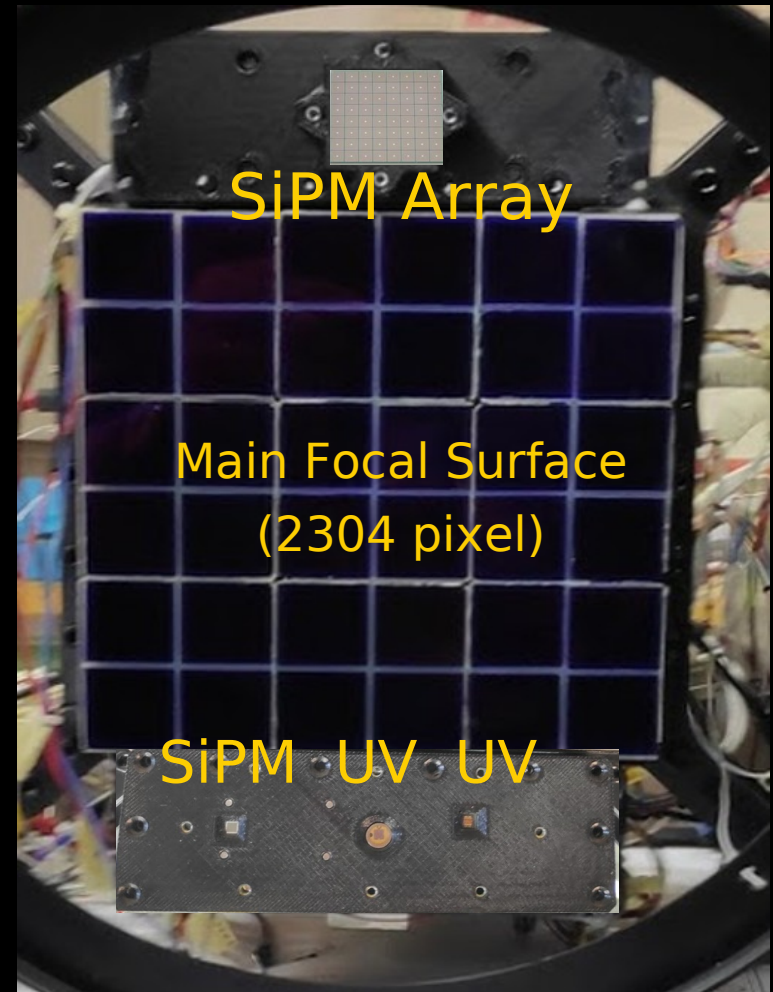
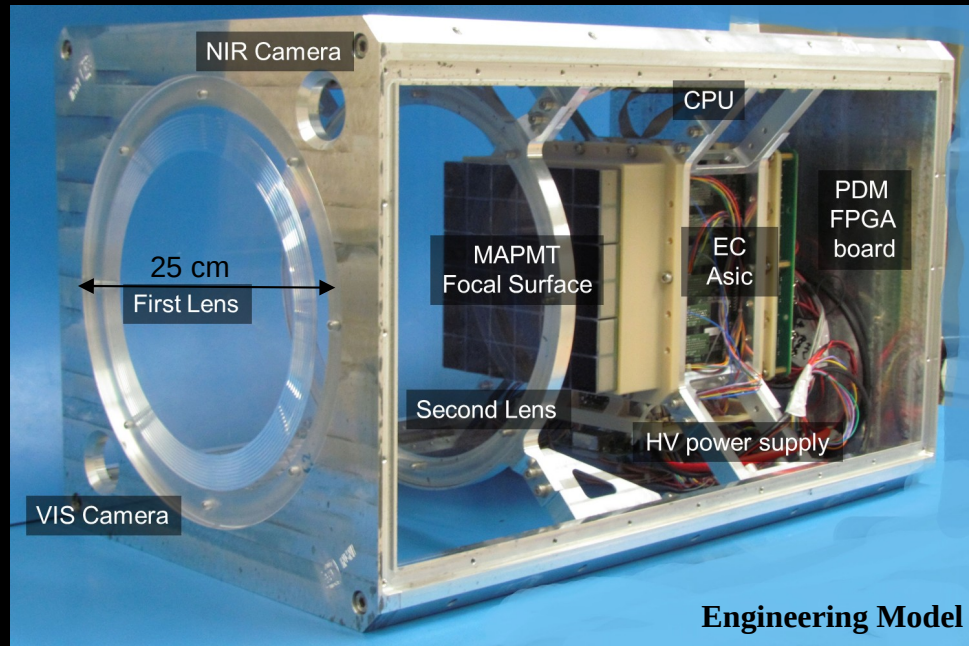


Mini-EUSO / UV-Atmosfera

Multiwavelength Imaging New Instrument for the Extreme Universe Space Observatory

Mini-EUSO main sensors:

- Ultraviolet telescope with Fresnel lenses (48*48 pixels, FoV= 40 deg, $\sim 320 \times 320 \text{ km}^2$, 2.5 μs and above)
- Near Infrared camera (1280*960 pixels, FoV=33.2*24.8 deg, $231 \times 174 \text{ km}^2$, 1s)
- Visible camera (1280*960 pixels, FoV=33.2*24.8 deg, $231 \times 174 \text{ km}^2$, 4s)
- SiPM (8*8 pixels) and UV sensors

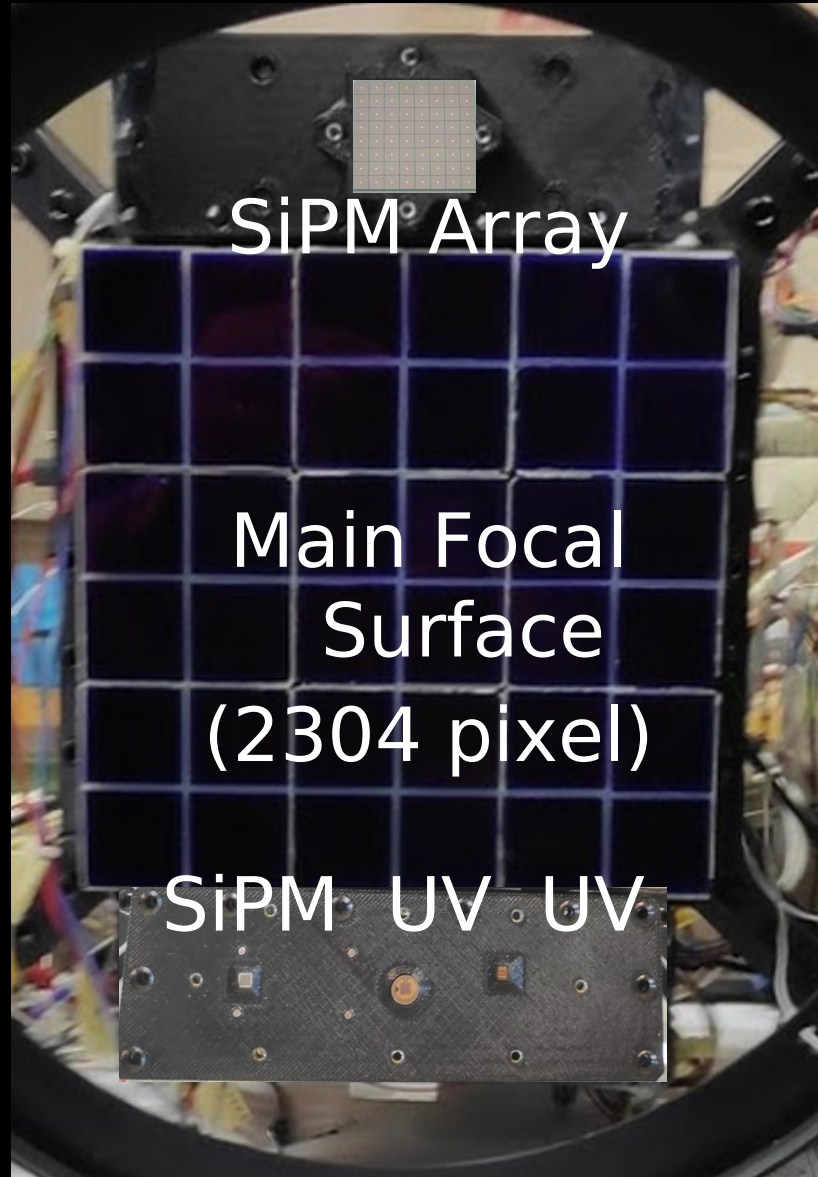


Focal Surface

Silicon Photomultipliers

SiPM Array
Hamamatsu
C14047-3050EA08
8*8 pixel
Imaging system

SiPM single pixel
Hamamatsu
C13365



MAPMTs

Hamamatsu
R11265-M64

UV Light sensors

Hamamatsu
S1226-5BQ log
190-1000nm

Rohm
ML8511 linear
280-400 nm

PDM Data Processing

The PDM, which stands for Photo Detection Module, comprises the chain (showed) of the MAPTM focal surface, 3 SPACIROC3 (Spatial Photomultiplier Array Counting Integrated ReadOutChip) Asic boards, a Xilinx Zynq XC7Z030 system on chip, a PCIe/104 form factor CPU and an ATmega238 rad hard based board for analog sensors such termistors and 64 channels Hamamatsu C13365 Silicon PhotoMultiplier. Incoming photon pulses are pre-amplified and digitized by the Asics at intervals of $2.5\ \mu\text{s}$, referred to as Gate Time Unit or GTU. The Zynq chip, containing a Kintex7 FPGA with an embedded dual core ARM9 CPU processing system, is responsible for data handling and buffering, configuration of SPACIROC3 Asics, triggering, synchronization and interfacing with CPU. The CPU performs the control of the instrument subsystems as well as the data management and storage, housekeeping, switching between operational modes, collecting data from the NIR and VIS cameras and interfacing with the analog board. A multi-level trigger system is implemented in order to maximise the scientific output of the instrument: L1, L2 and L3 respectively of $2.5\ \mu\text{s}$, $320\ \mu\text{s}$ and $40.96\ \text{ms}$.



EC Unit (9 on full FS)



Asic board



Zynq board



PCIe/104 CPU



NIR and VIS camera



SiPM

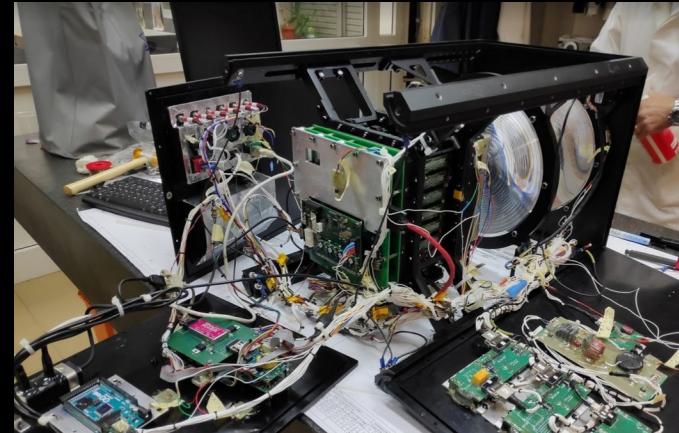
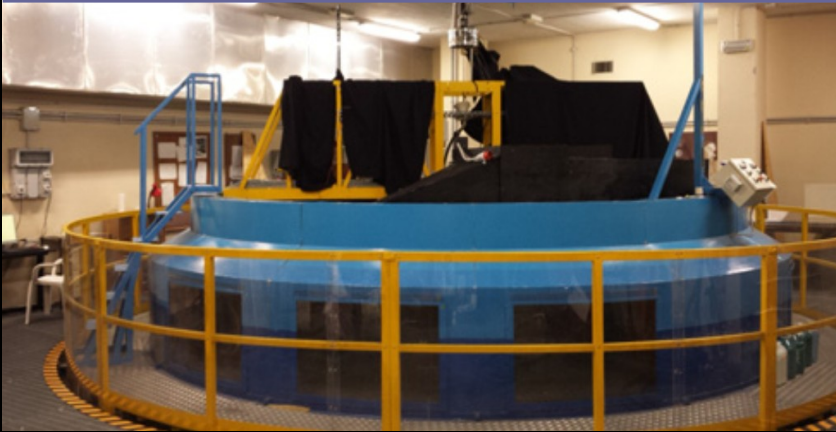
SPACIROC3 Asics
From Omega

Xilinx Zynq XC7Z030
Kintex7 FPGA

Integration and Test of EM and FM

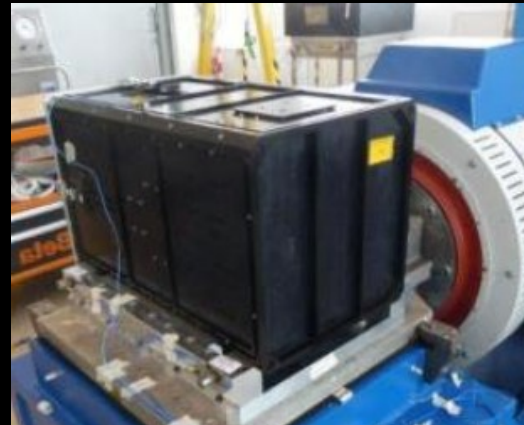
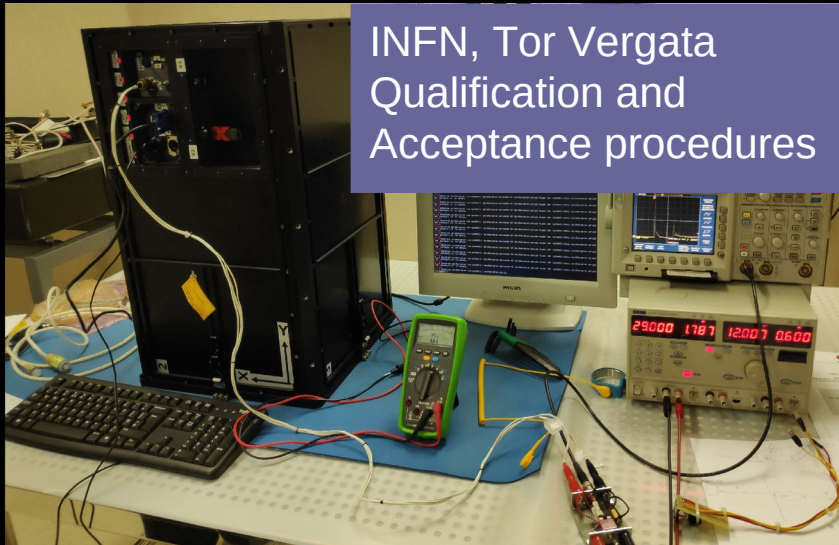
2017-2019

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



INFN, LNF
Mechanics and Integration

INFN, Tor Vergata
Qualification and
Acceptance procedures



MATE Lab
Vibration and shock test



INFN Tor Vergata
Sky tests

Acceptance tests in Baikonur and integration with Soyuz MS-14



Building 254, assembly of Soyuz/Progress

Mini-EUSO Launch -- Soyuz MS-14

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



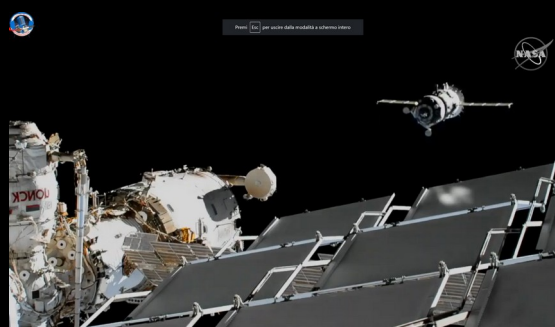
Launch, 22/8/2019



**First docking, 24/8/2019
unsuccessful**



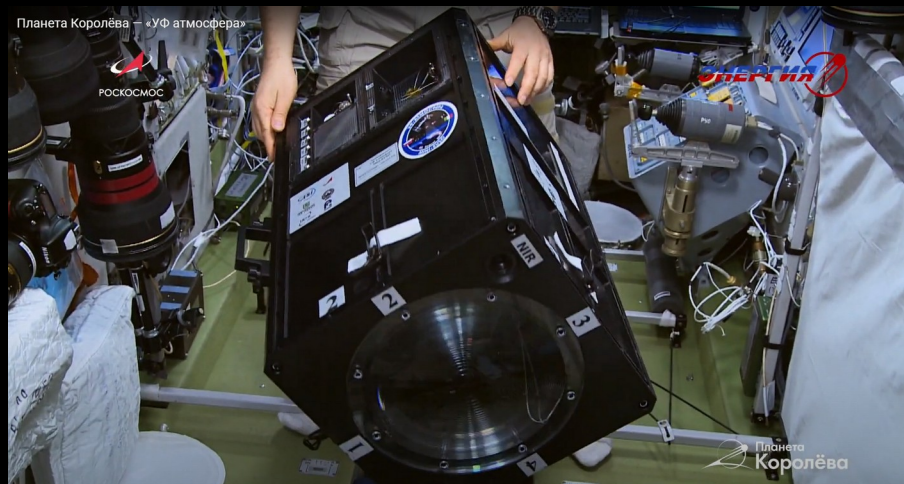
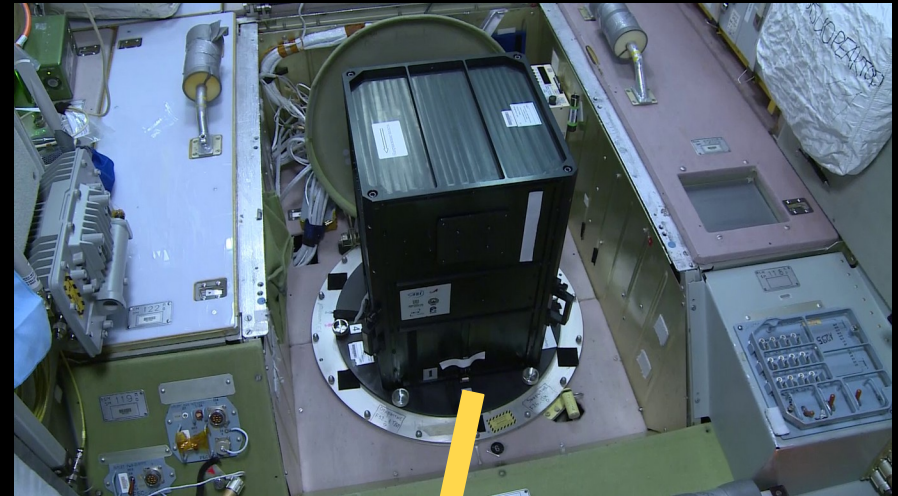
**Relocation of MS-13 from
Zvezda to Poisk**



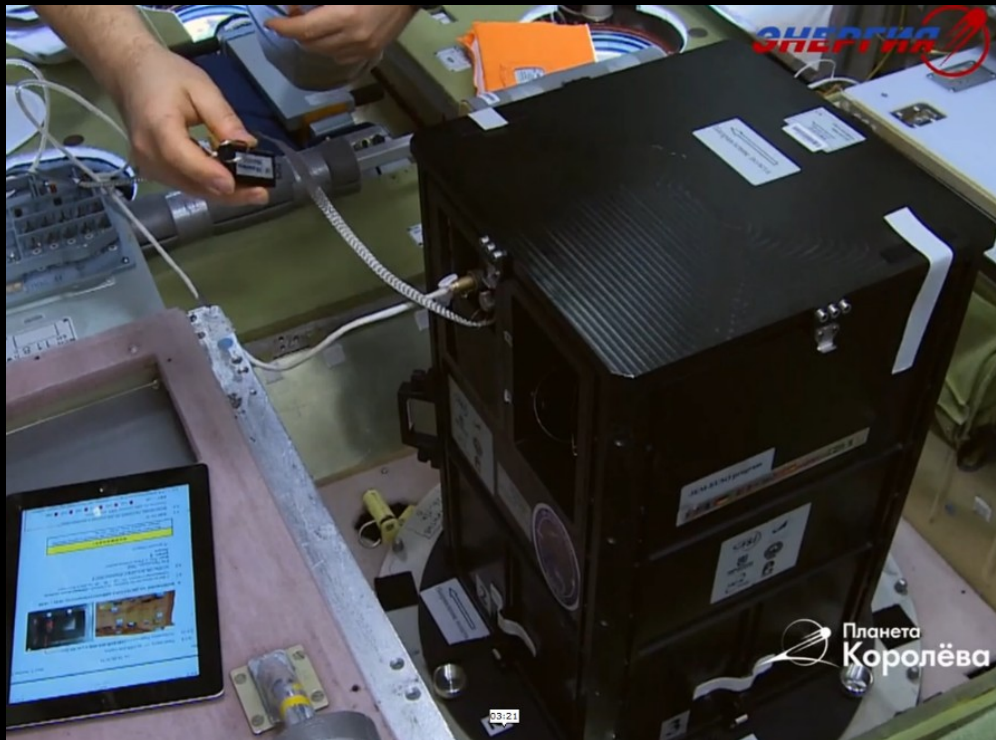
Second docking, 27/8/2019 successful



Mini-EUSO installed on UV transparent window, Zvezda module October 7, 2019



Mini-EUSO in-flight operations



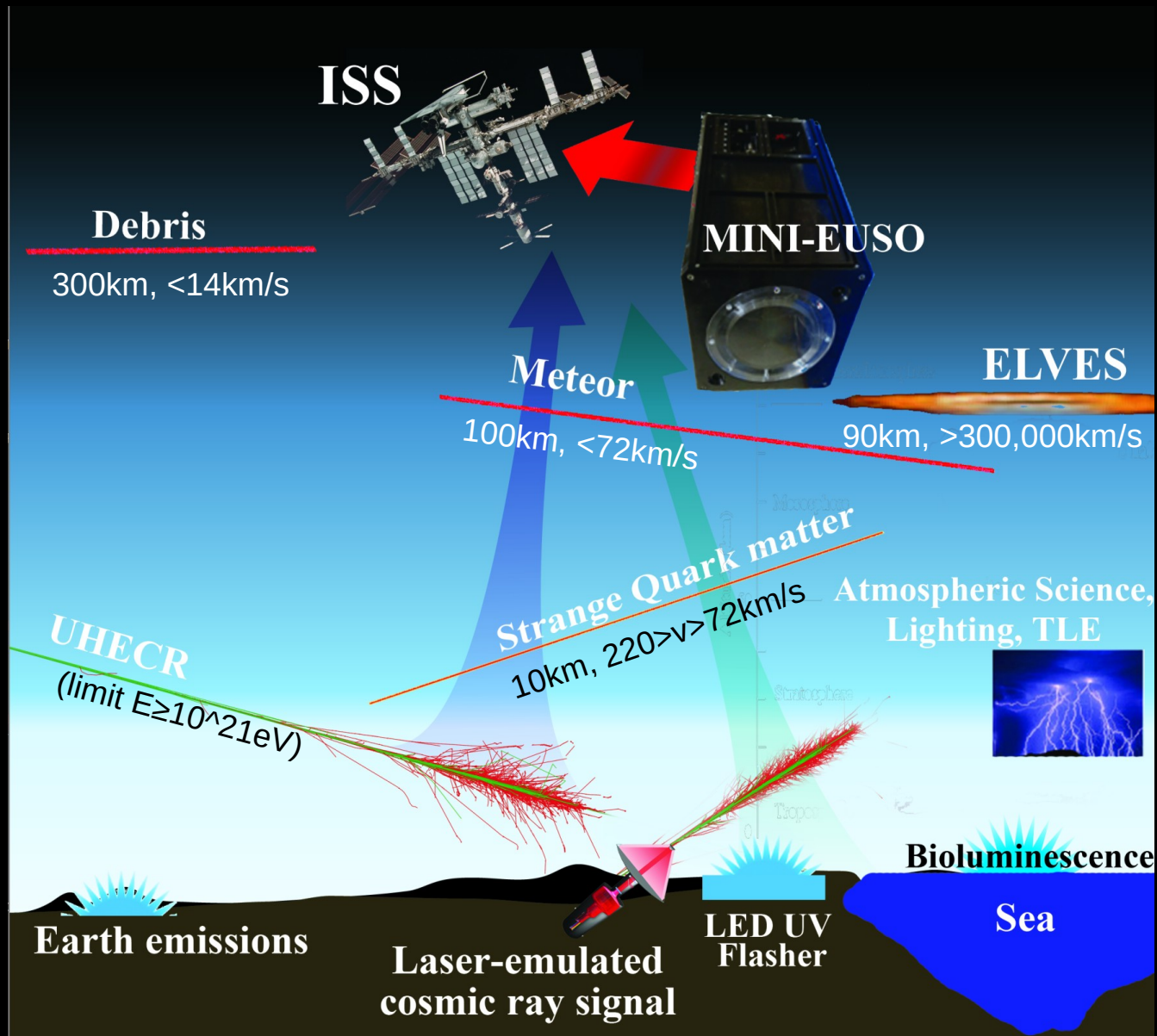
START

- Latch on the UV-transparent window
- Connect 27V power supply
- Connect grounding cable
- Insert empty USB stick
- Turn on switch

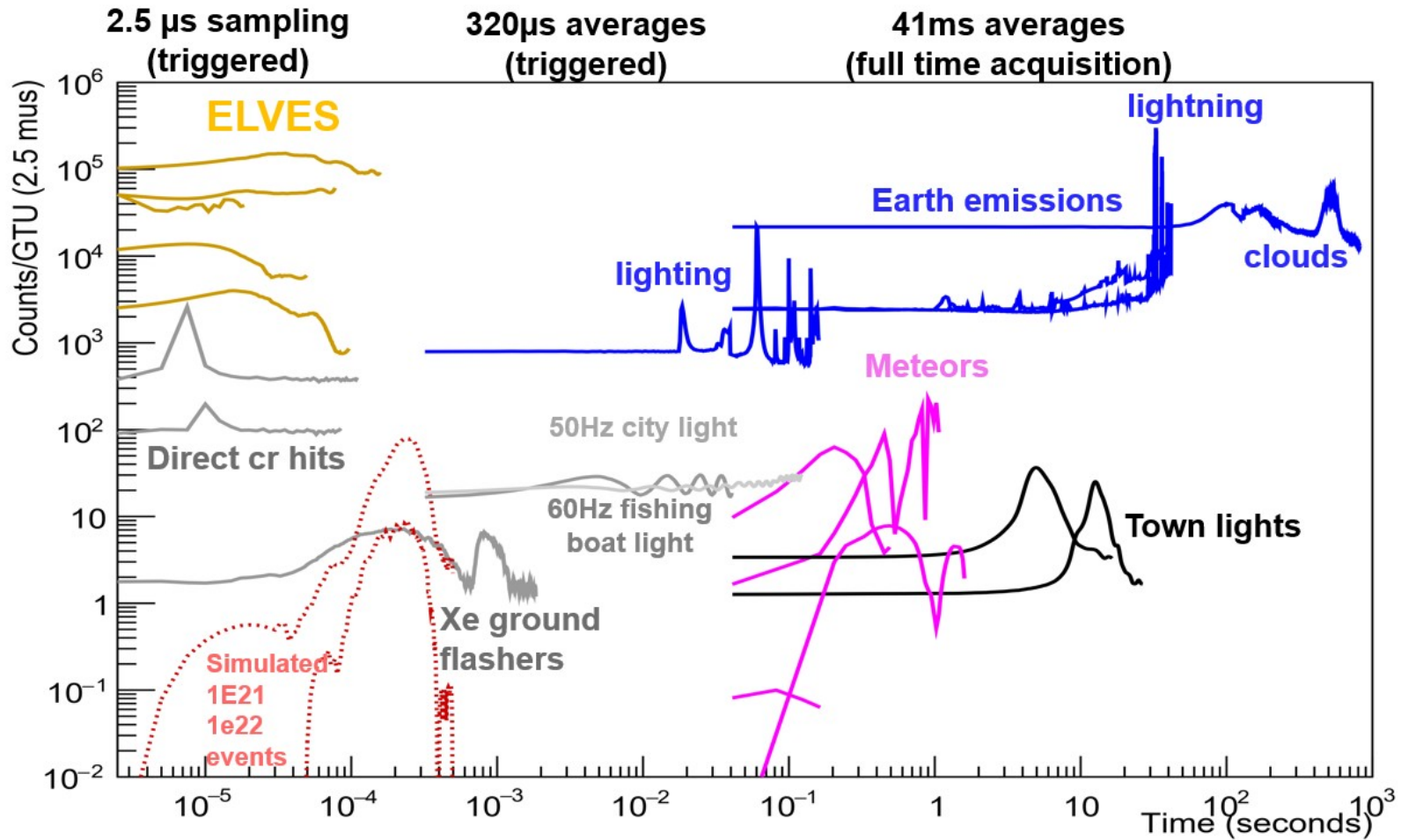
STOP

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

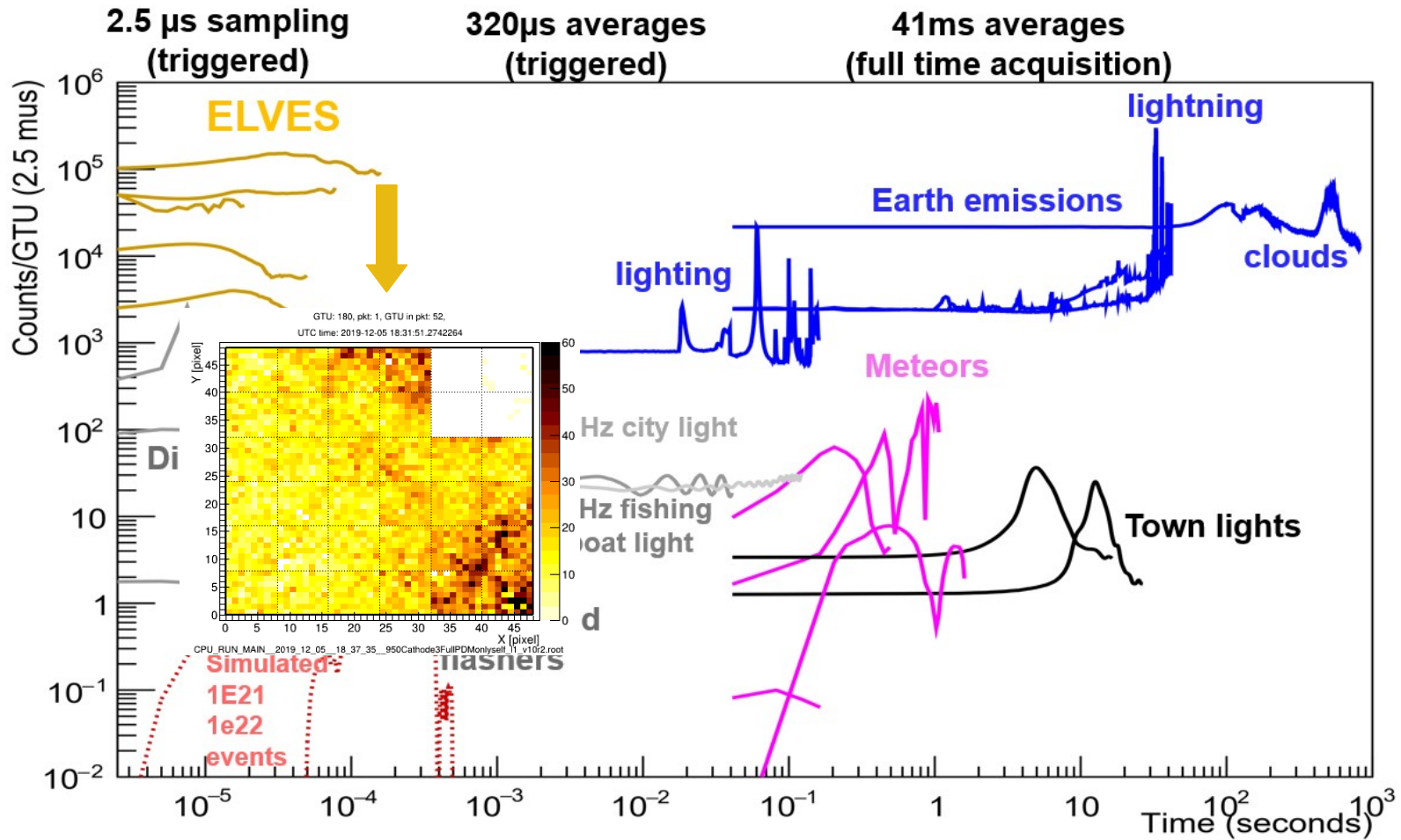
Science Objectives



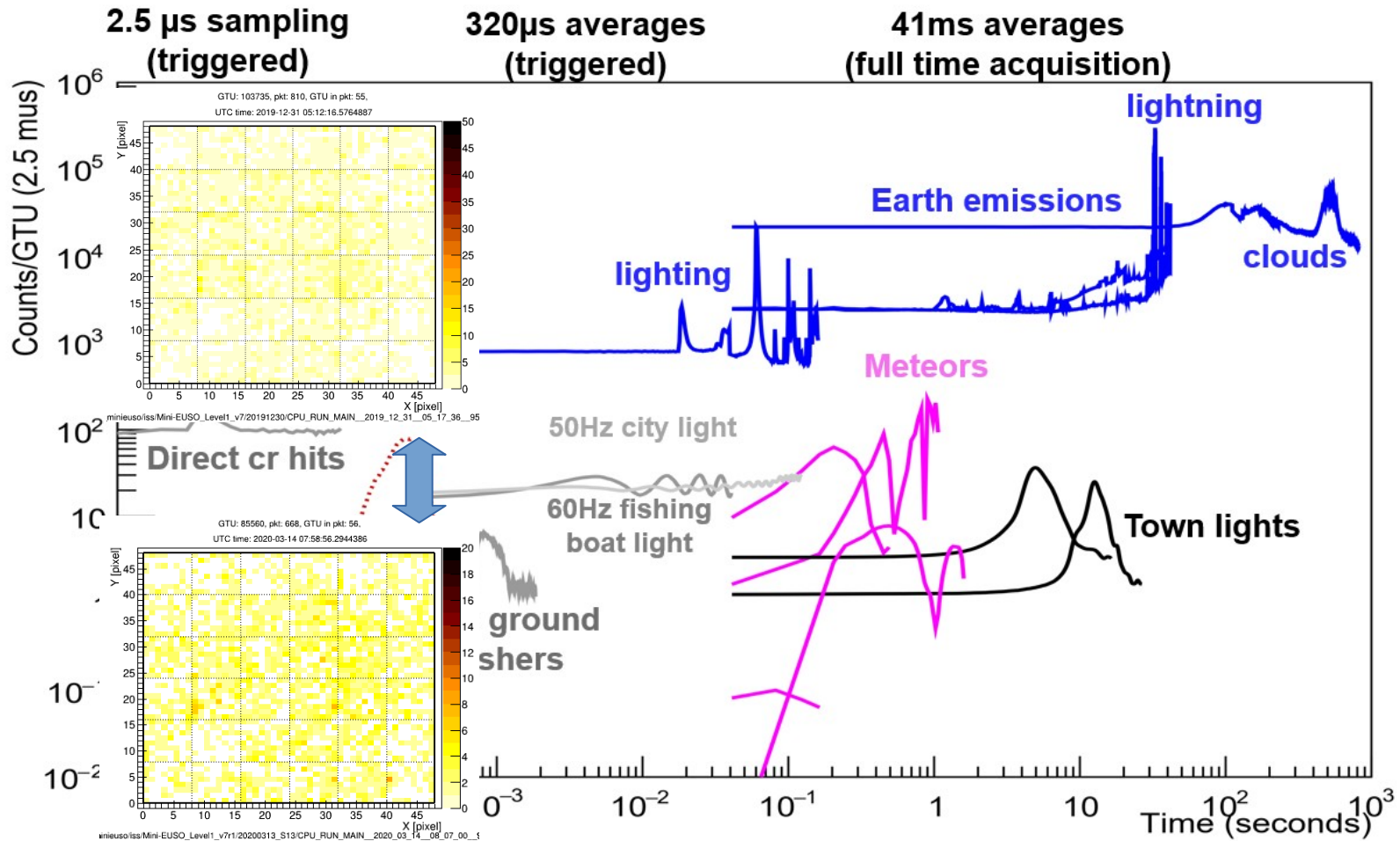
Time profile of various events



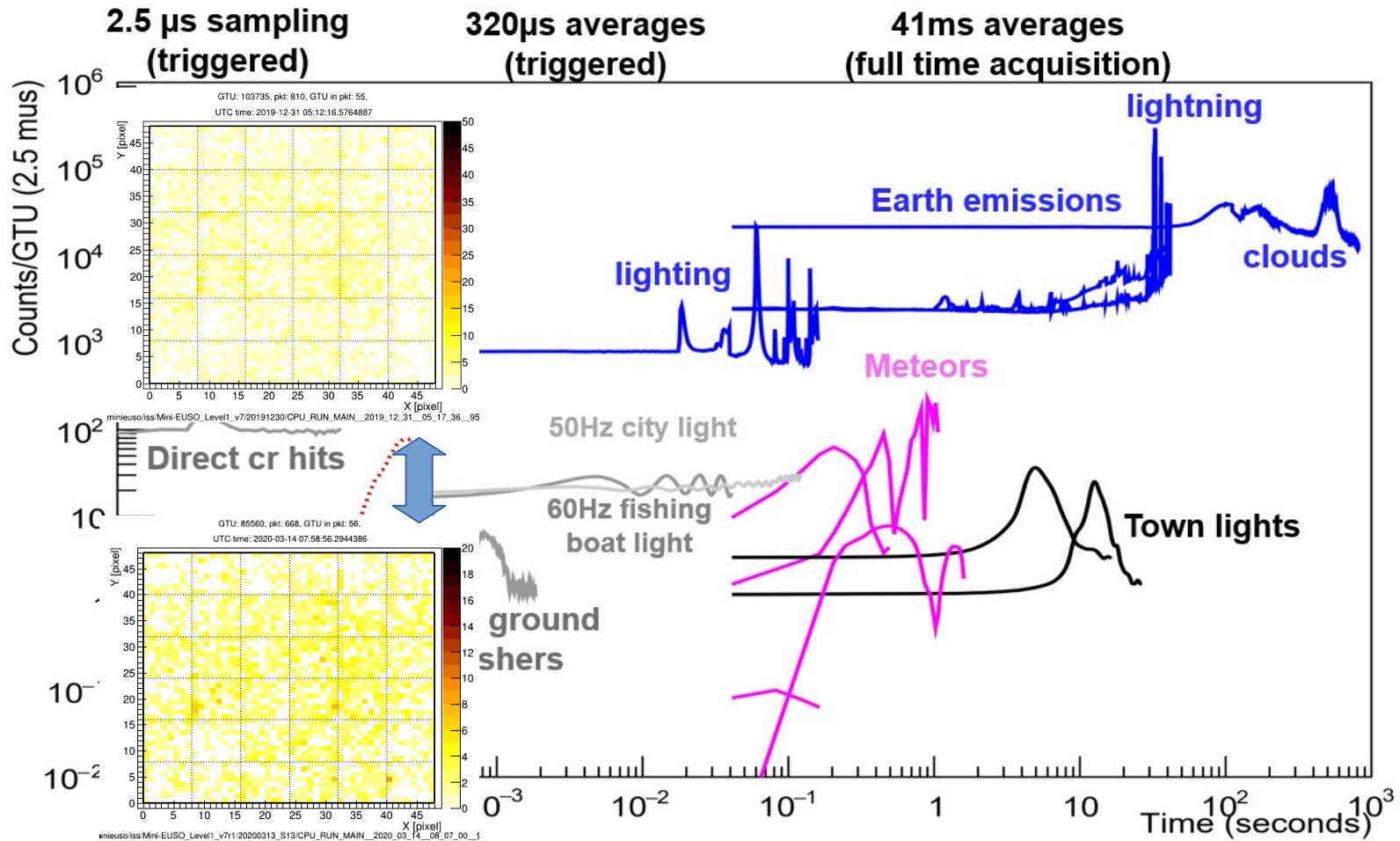
Time profile of various events



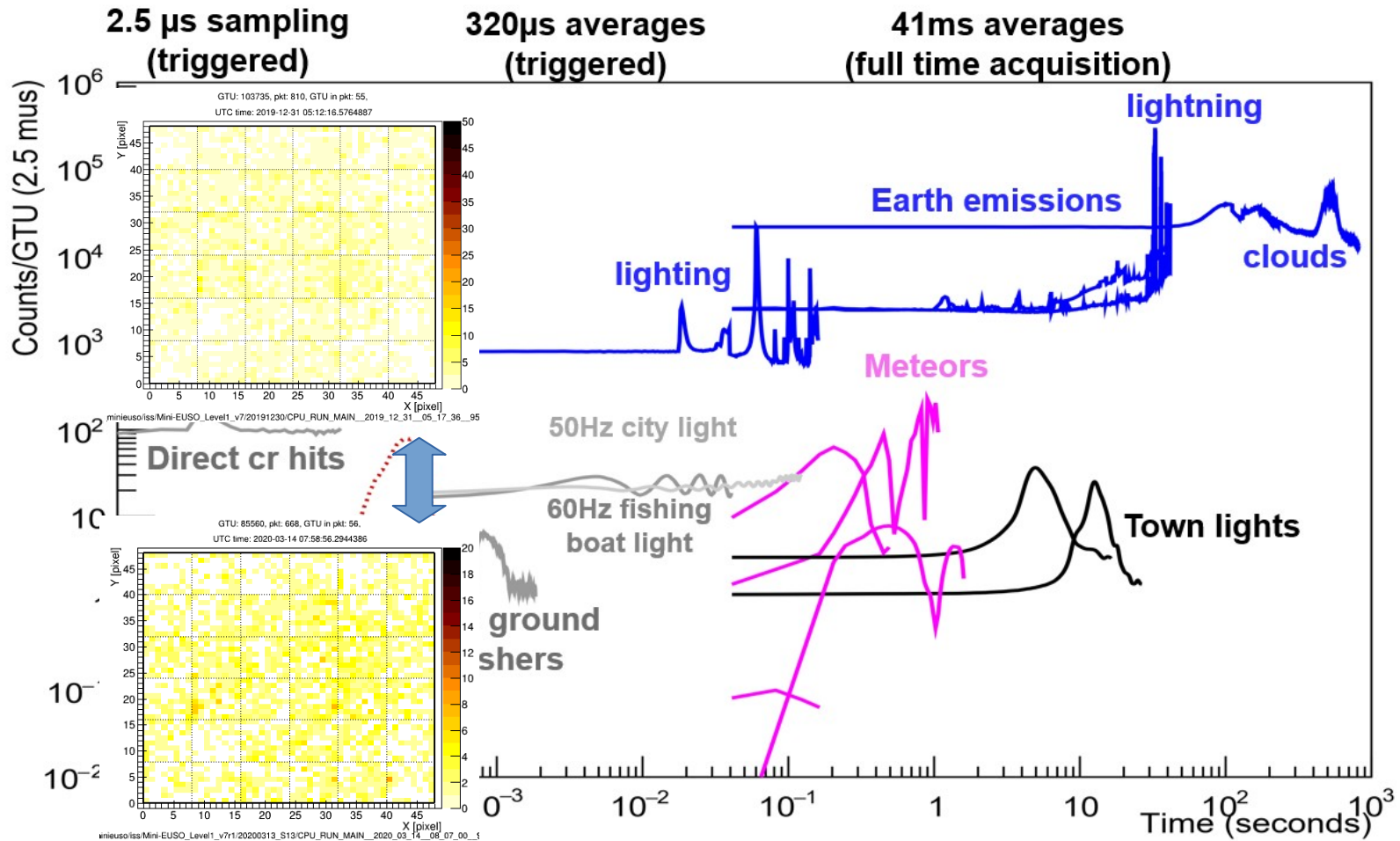
Time profile of various events



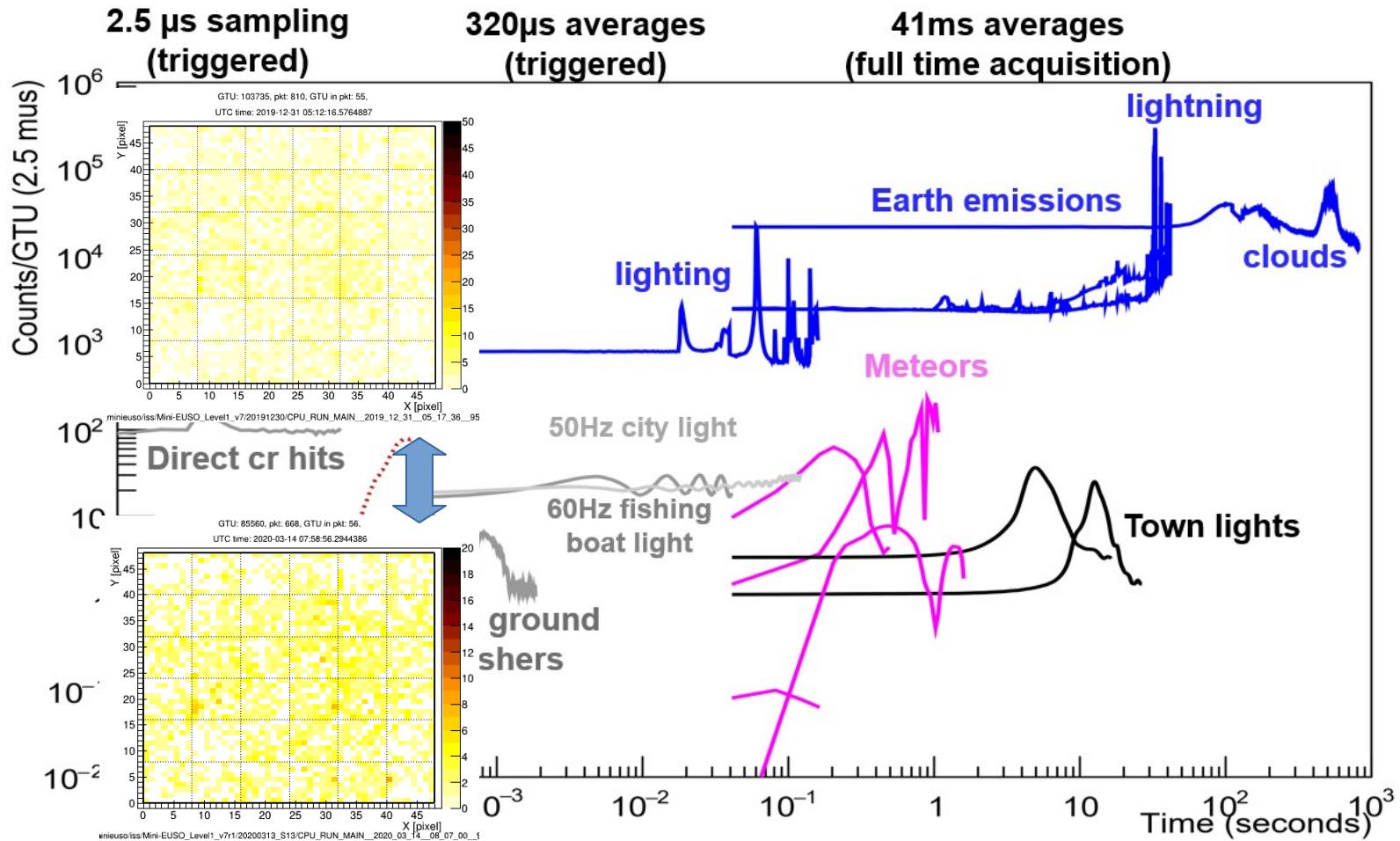
Time profile of various events



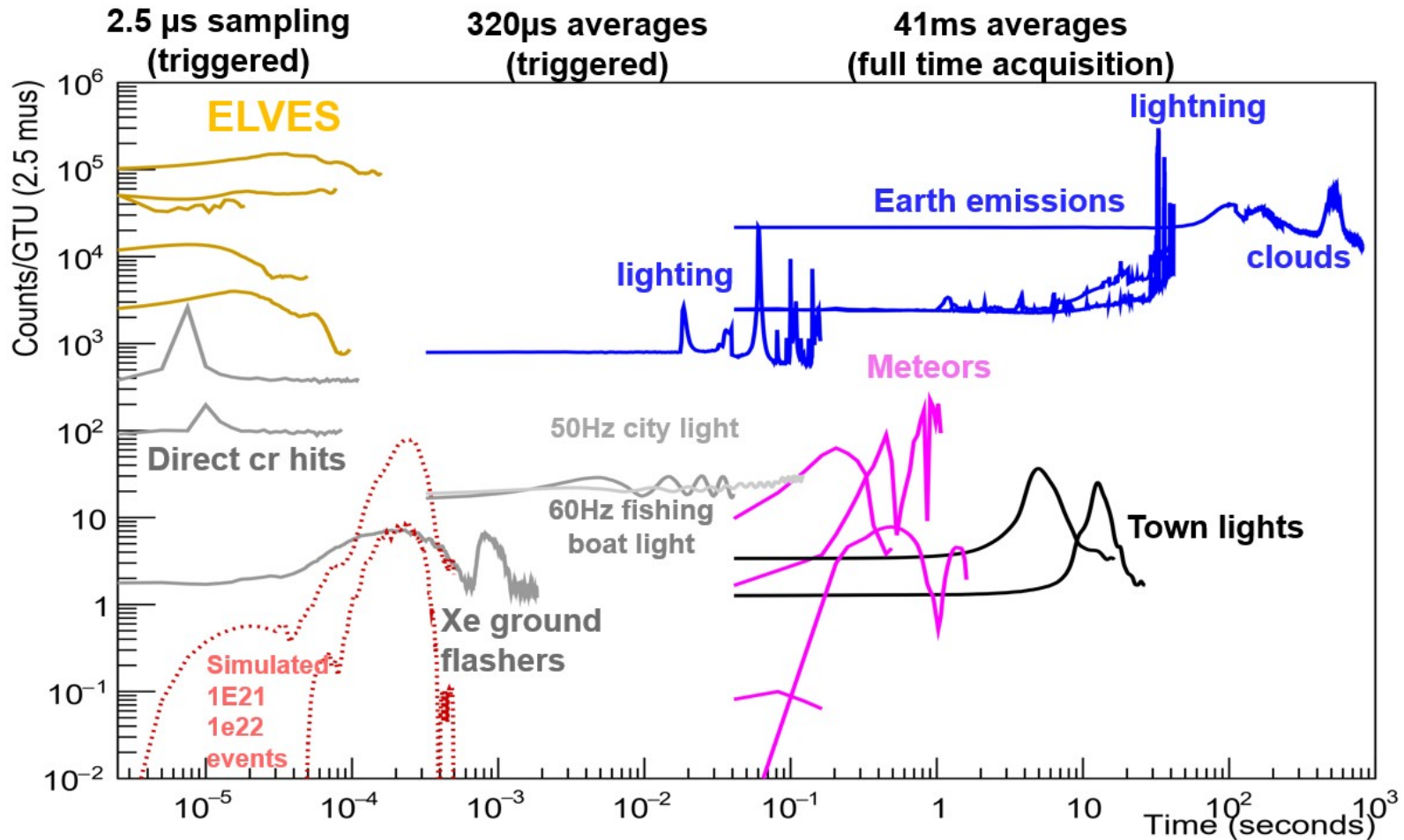
Time profile of various events



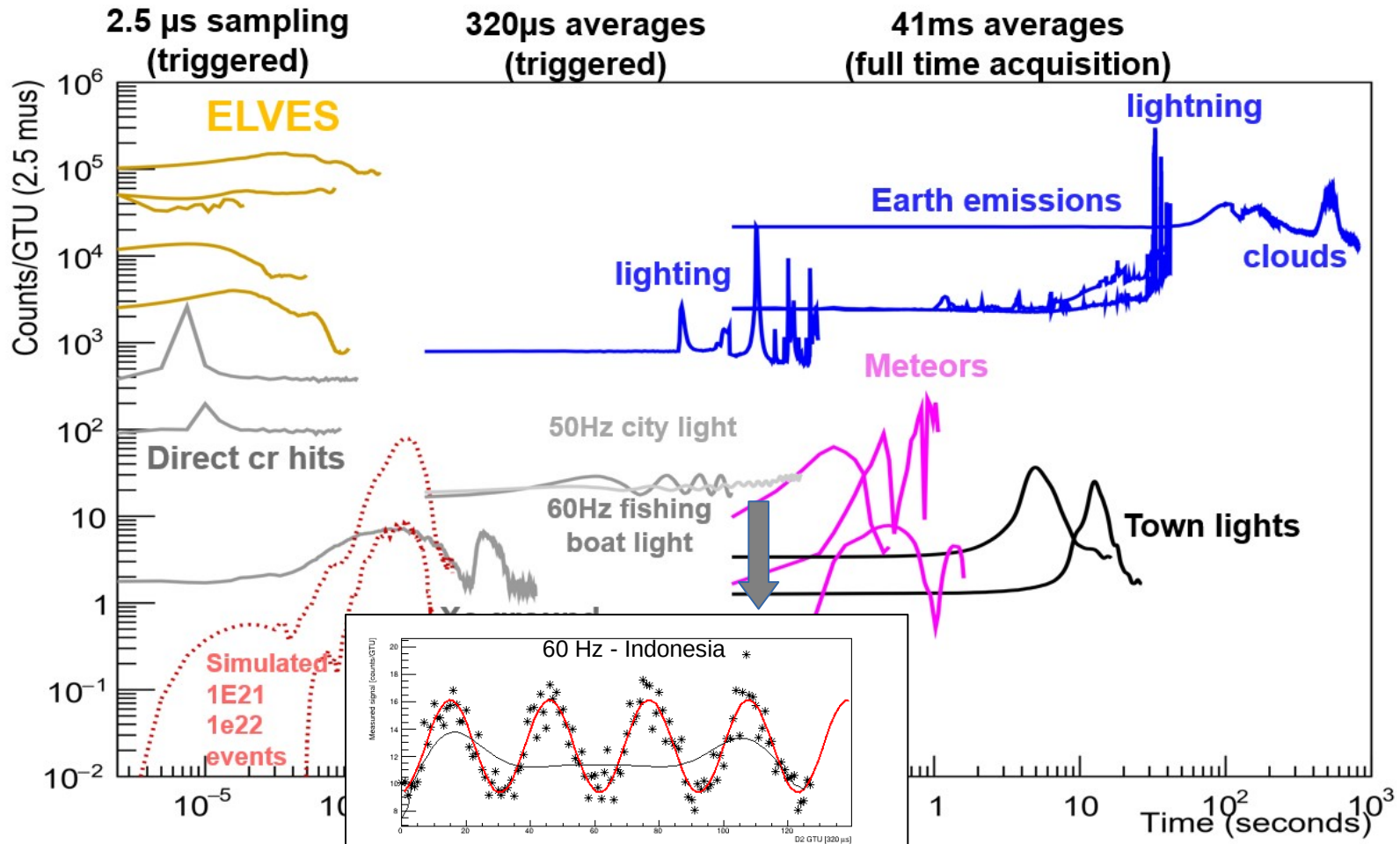
Time profile of various events



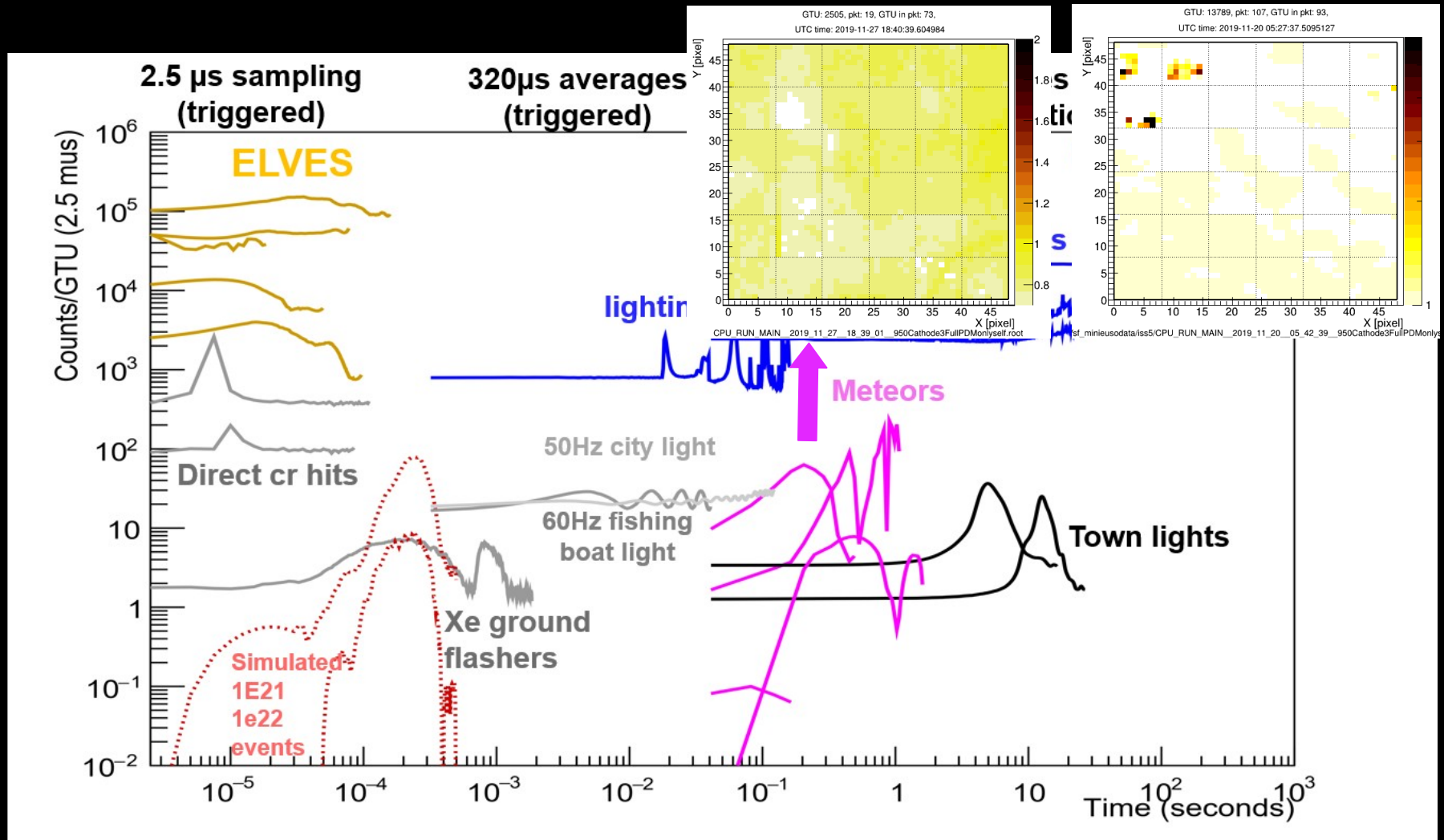
Time profile of various events



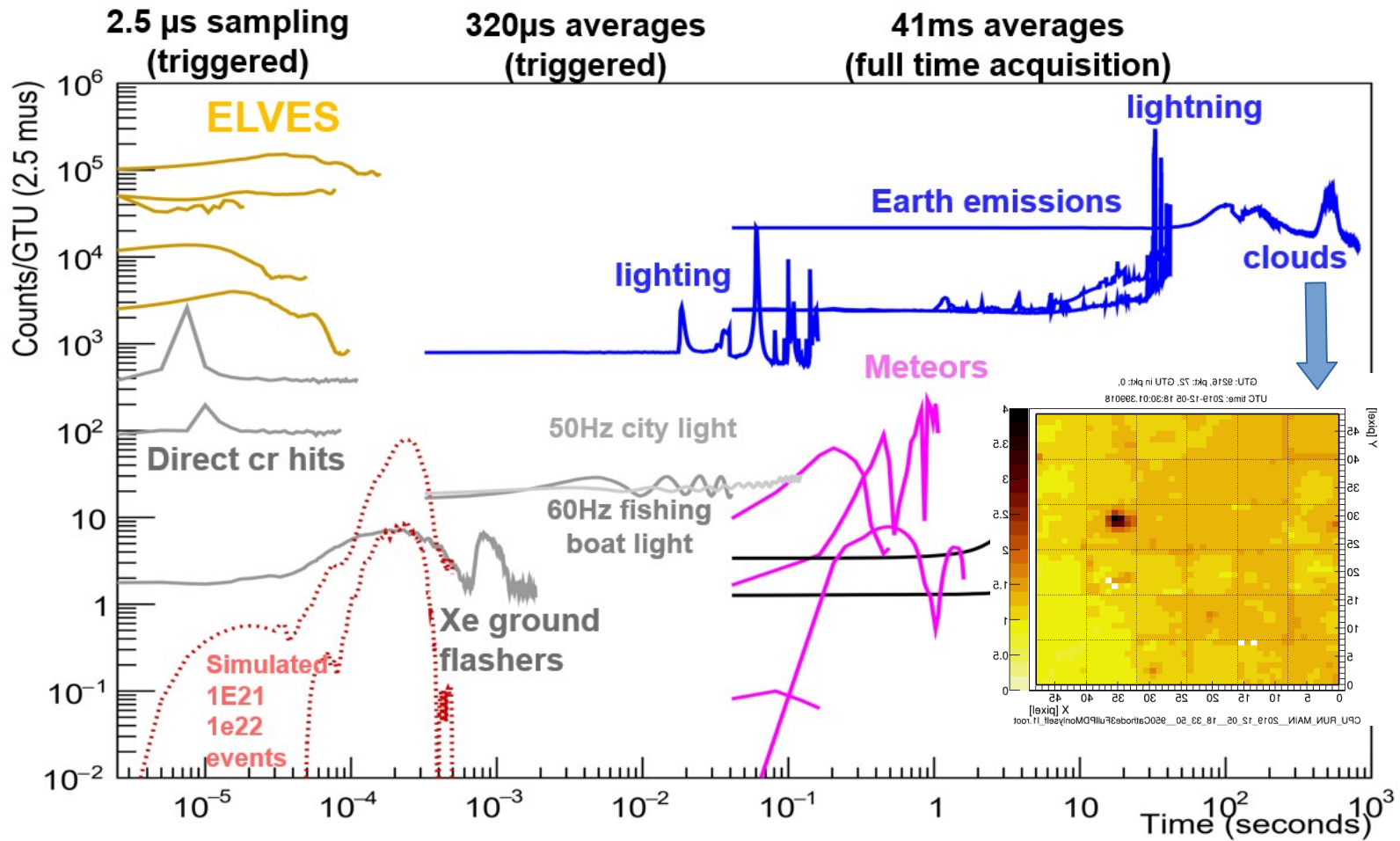
Time profile of various events



Time profile of various events

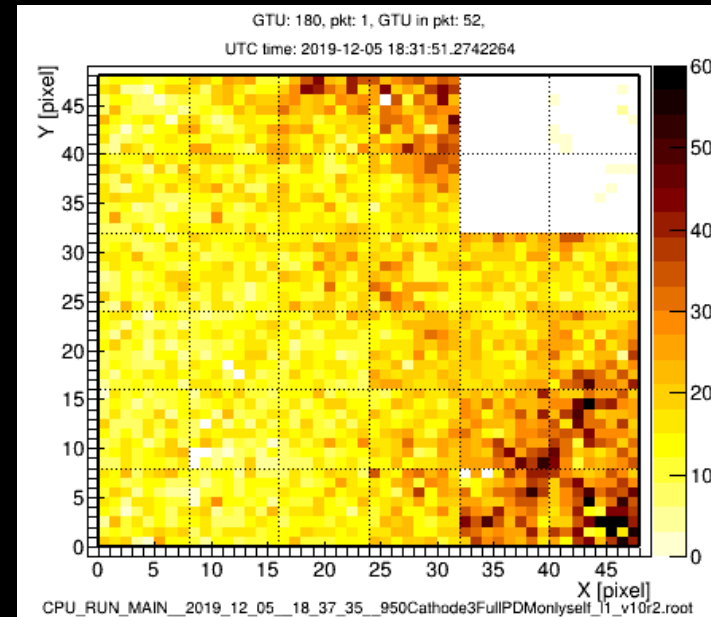
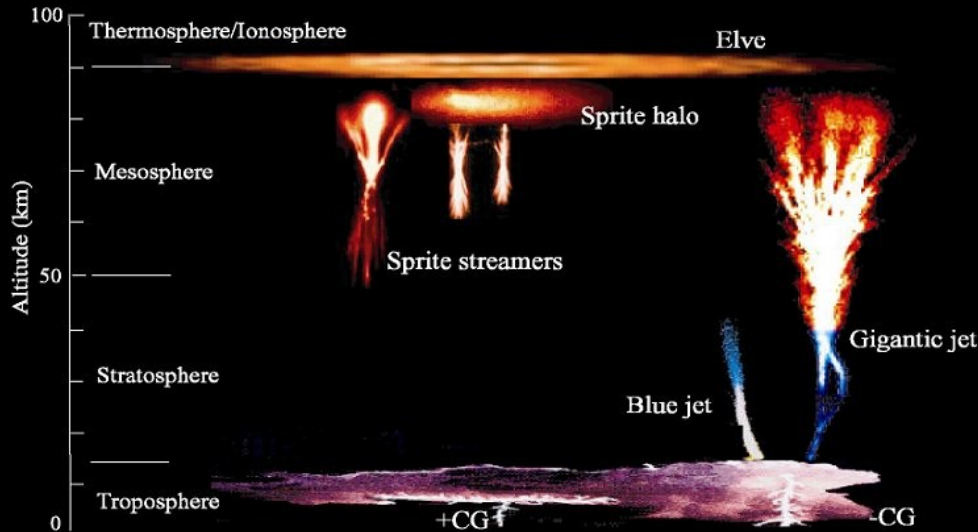


Time profile of various events



ELVES

Sampling: $2.5\mu\text{s}$ GTU



Apparently superluminal rings

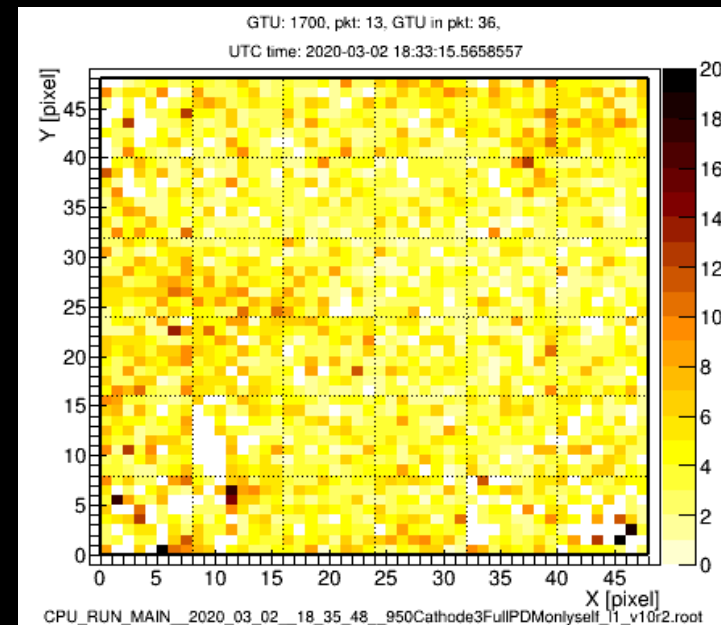
Upper atmospheric lighting releases e.m. wave
which heats the ionosphere
Transient Gamma Flash relationship

Lifetime: About $400\mu\text{s}$

Pixel size:

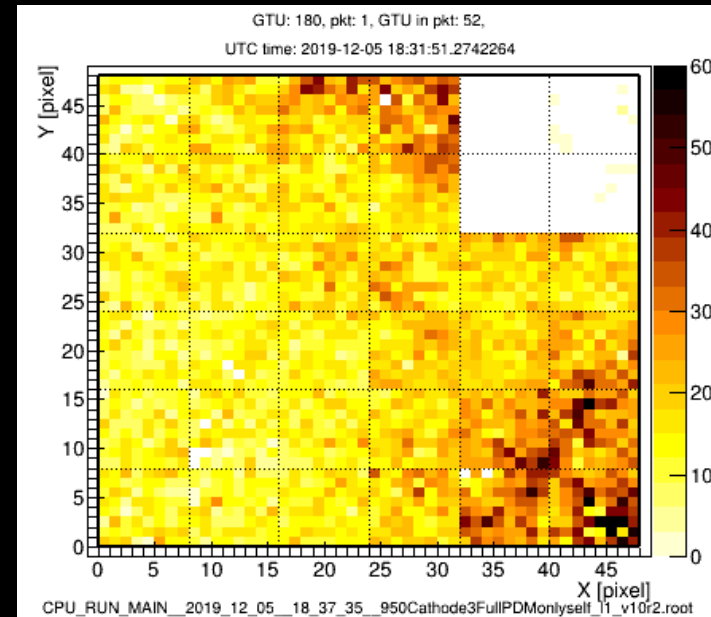
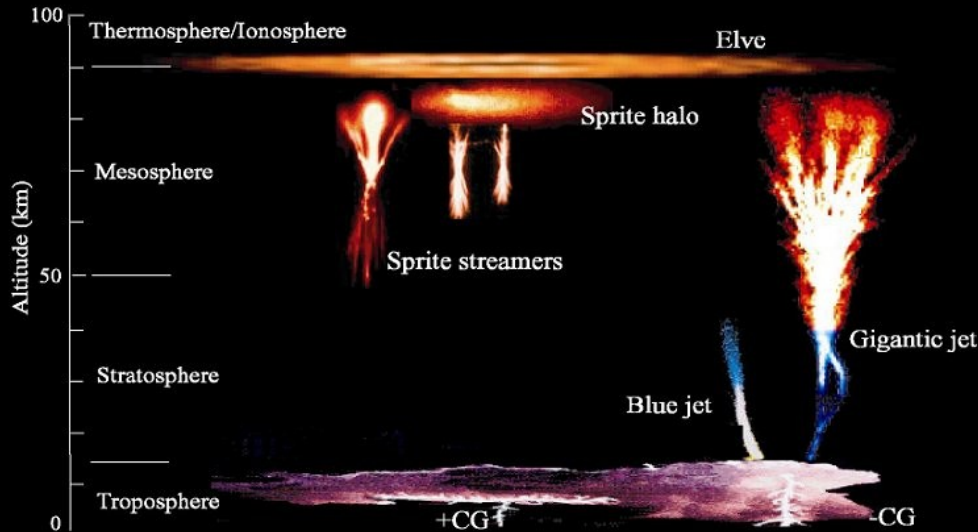
6.6 km on ground

4.9 km at 100 km \rightarrow $240 \times 240 \text{ km}^2$



ELVES

Sampling: $2.5\mu\text{s}$ GTU



Apparently superluminal rings

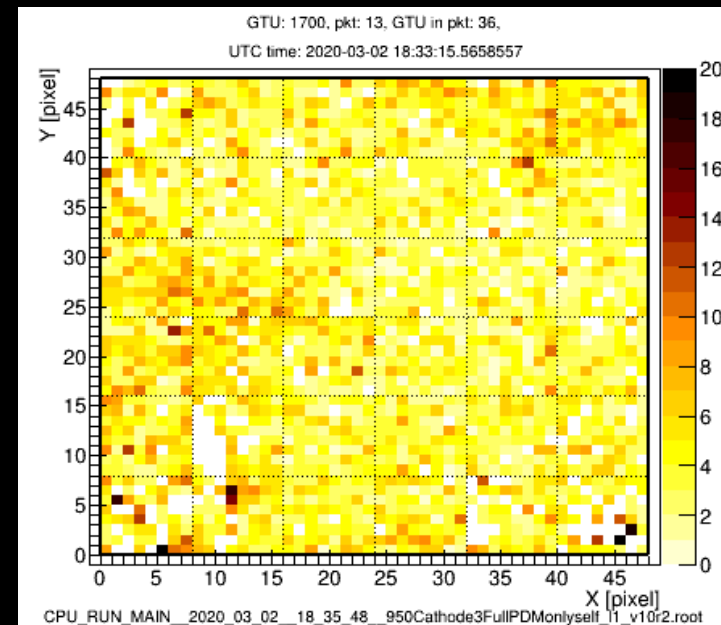
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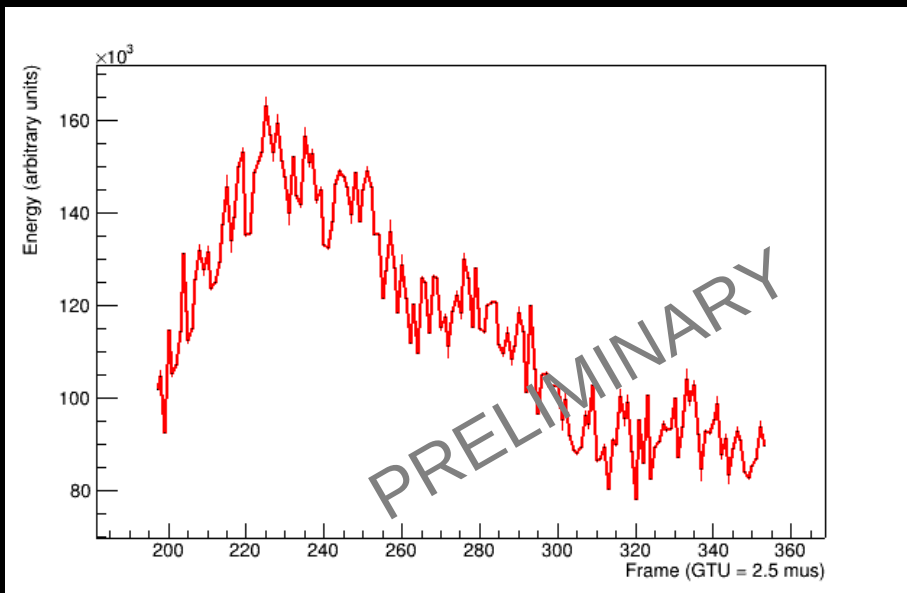
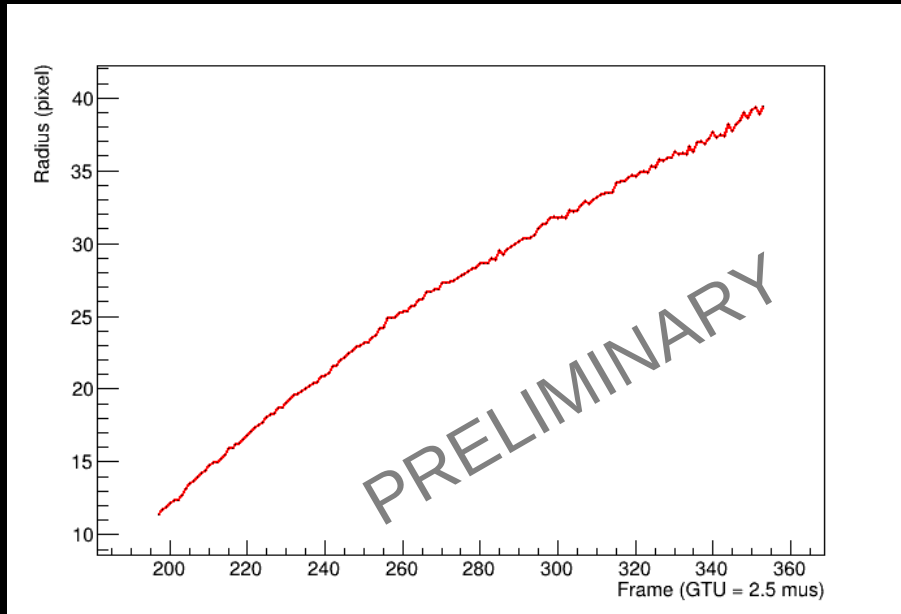
Pixel size:

6.6 km on ground

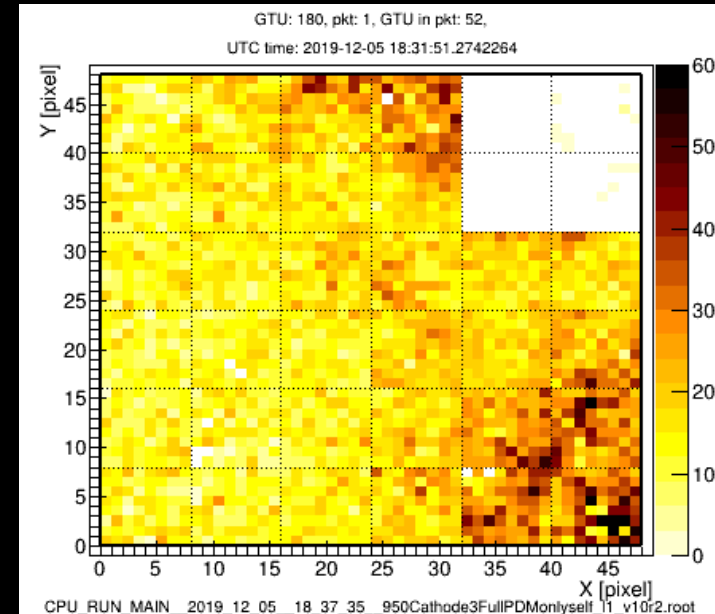
4.9 km at 100 km \rightarrow $240 \times 240 \text{ km}^2$



ELVES



Sampling: $2.5\mu\text{s}$ GTU



Speed $\approx 0.18 \text{ pix/GTU} \approx 338\,400 \text{ km/s}$

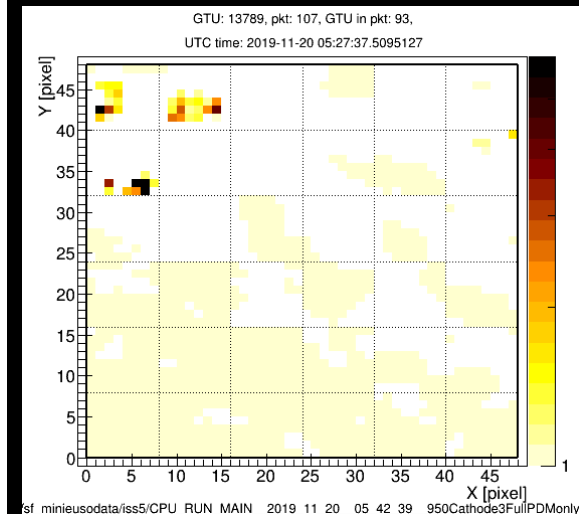
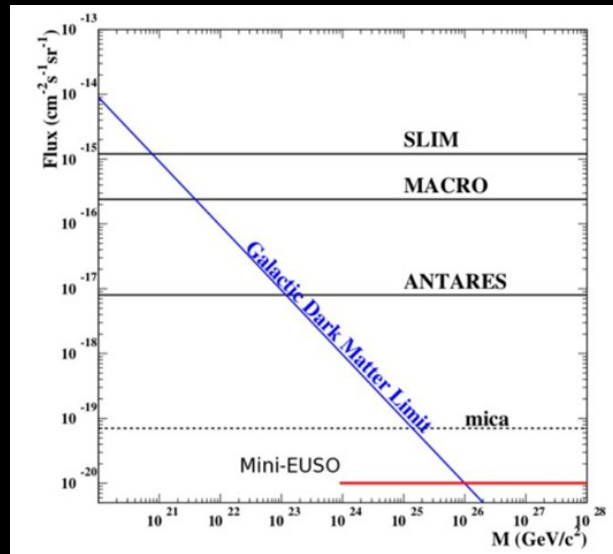
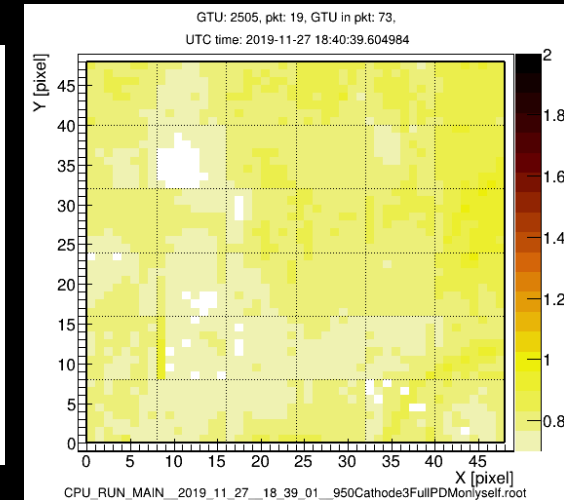
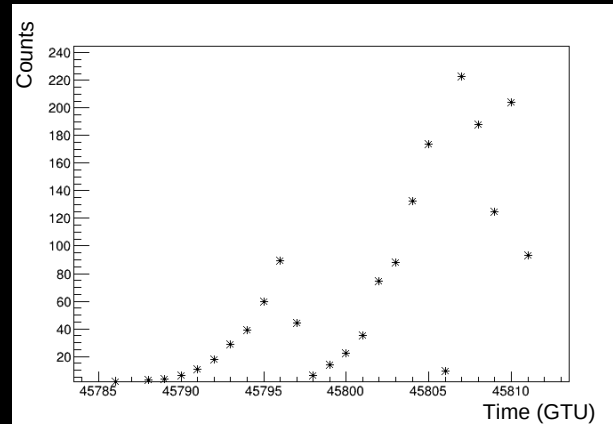
Pixel size:
6.6 km on ground
4.9 km at 100 km

Interstellar Meteors and Search for Strange Quark Matter

Solar system meteors:
 >2000 meteors detected so far
 Near Earth Objects,
 complementary to ground
 arrays (joint observations)
 Maximum speed 72 km/s
 Max. obs. magnitude= 4 - 5

Interstellar meteors:
 $220\text{ km/s} > V > 72\text{ km/s}$
 Relevance for solar system
 formation, Kuiper belt.

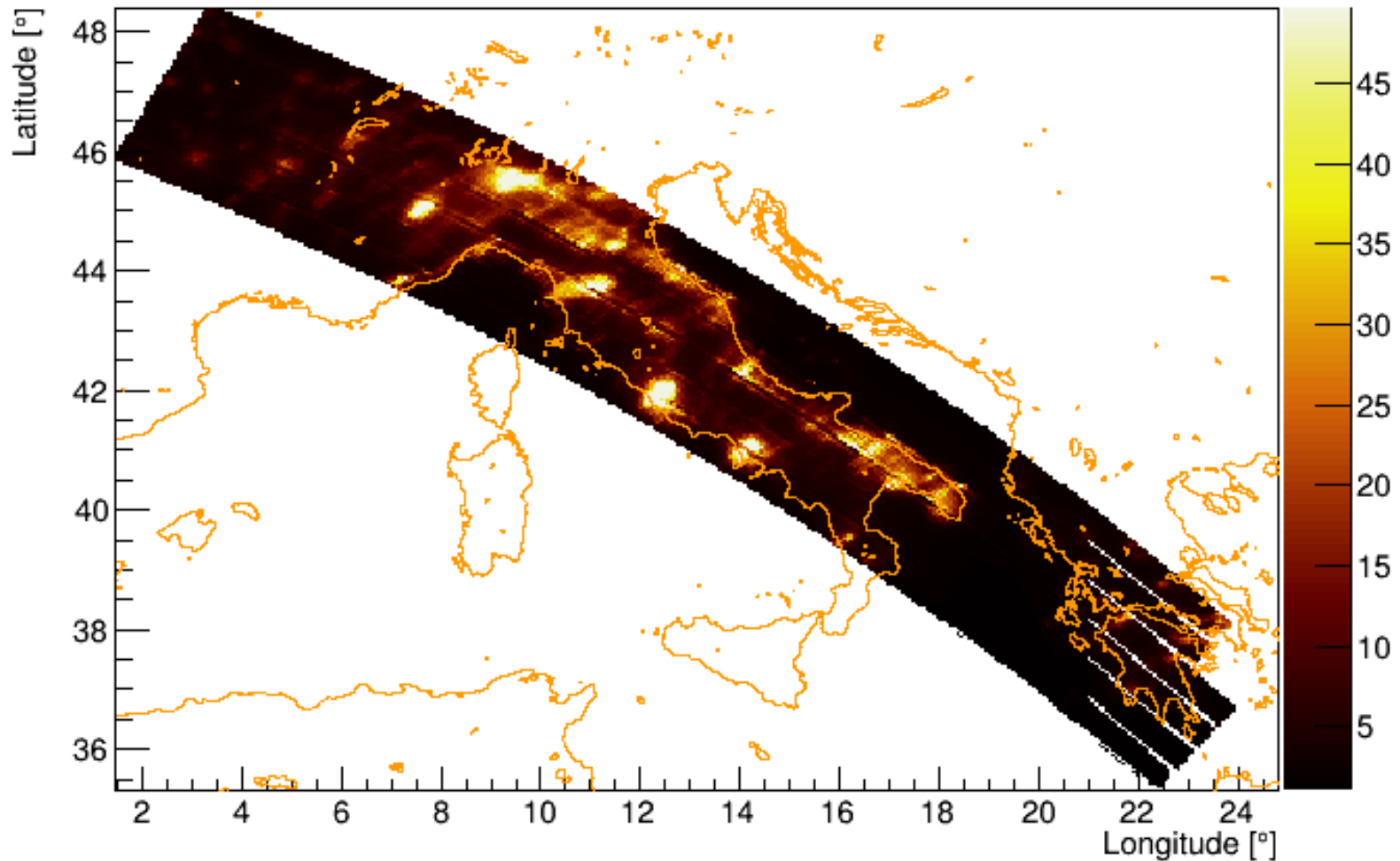
SQM: $220\text{ km/s} > V > 72\text{ km/s}$
 Long continuous track



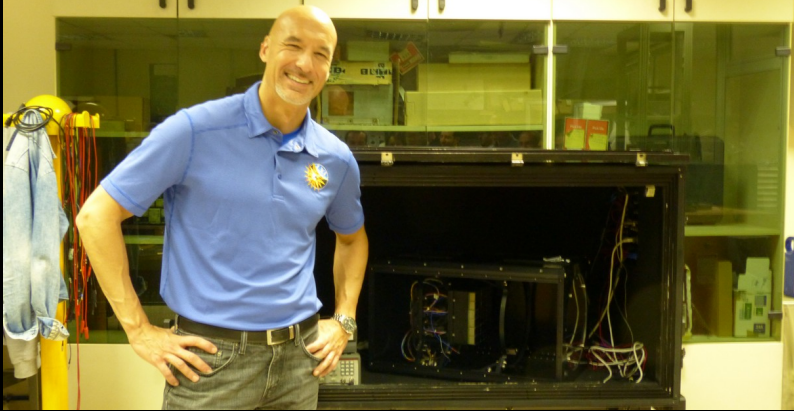
*Meteor studies in the framework of the JEM-EUSO program.
 PLANETARY AND SPACE SCIENCE, 143(SI):245{255, SEP 1 2017.*

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

First UV (300-400 nm) map of Italy from the ISS



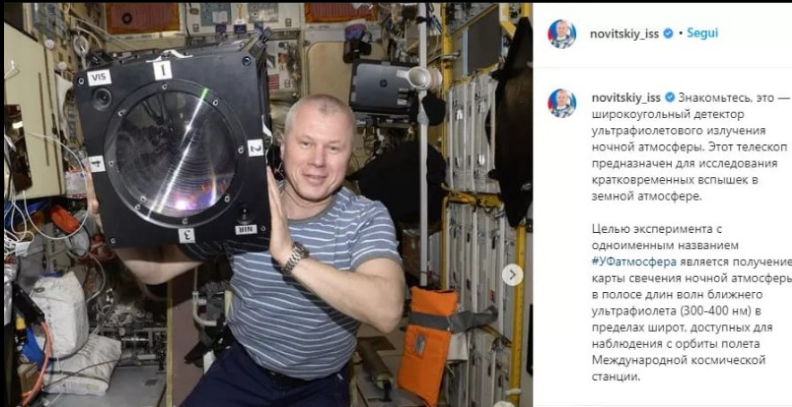
Conclusions



L. Parmitano visits INFN Tor Vergata
FM Mini-EUSO in the black box



L. Parmitano: Outreach video from ISS
<https://www.youtube.com/watch?v=QincAp4V-SM&t=1s>



Twitter from O. Novitskiy



O. Skripochka: Outreach video from ISS
<https://www.youtube.com/watch?v=IXedBGVHc4o&t=62s>

For more technical details...

Poster n. 489

Mini-EUSO telescope on board the International Space Station: in-flight operations and performances

L. Marcelli on behalf of the JEM-EUSO Collaboration
INFN, Strucure of Rome Tor Vergata

Abstract: Mini-EUSO is a high sensitivity imaging telescope that observes the Earth from the ISS in the ultraviolet band (290–430 nm), through the UV-transparent window in the Russian Zvezda module. The instrument, launched in 2019 as part of the Italian "Beyout" mission, has a field of view of 44 degrees, a spatial resolution on the Earth surface of 6.3 km and a temporal resolution of 2.5 microseconds. The telescope detects UV emissions of cosmic, atmospheric and terrestrial origin on different time scales, from a few microseconds upwards. Mini-EUSO main detector optics is composed of two Fresnel lenses focusing light onto an array of 36 Hamamatsu multi-anode photomultiplier tubes, for a total of 2304 pixels. The telescope also contains: two ancillary cameras to complement measurements in the near infrared and visible ranges, an array of Silicon-Photomultipliers and UV sensors to manage night-day transitions. In this work I will describe in-flight operations and performances of the various instruments.

The Roadmap

Mini-EUSO is being developed by the JEM-EUSO Collaboration in the framework of the JEM-EUSO Program. The final goal of the JEM-EUSO program is to send in orbit a new type of observatory to be attached at the International Space Station or orbiting at a free flyer, based on a UV very large telescope, which uses the whole Earth as detector. The JEM-EUSO program is made of different experiments using fluorescence detectors: EUSO-TA, installed at the Telescope Array site in Utah in 2015, is in operation; EUSO-Balloon flew on board a stratospheric balloon in August 2014; EUSO-SPRIS was launched on board a super pressure balloon on April 24th and flew for 13 days. Mini-EUSO has been launched on August 22, 2019 and installed on the UV-transparent window in the Zvezda module of the ISS on October 7. K-EUSO, to be attached outside the ISS, is in phase A. EUSO-SPR2 is in phase of construction for a long duration flight in 2023.

Fig. 1: JEM-EUSO roadmap and detectors.

The Instrument

Mini-EUSO is composed of one JEM-EUSO Photo Detector Module (PDM). It consists of 36 Multi-Anode Photomultiplier Tubes (MAPMTs), 64 pixels each, for a total of 2304 pixels. A system of 2 double-sided Fresnel lenses, 25 cm diameter each, is used to focus light onto the PDM in order to achieve a large field of view (44 degrees) with a relatively light and compact design. The data acquisition system consists of the front-end electronics, the PDM data processing system based on a Xilinx Zynq XC7Z030 on chip and a PCIe104 form factor CPU. In addition to the main detector, Mini-EUSO contains two ancillary cameras for complementary measurements in the near infrared and visible range independently from the PDM. The main task of the cameras is to provide atmospheric monitoring in order to better understand the UV luminosity measurements. Data is stored on board on SSDs which are periodically returned to Earth from the ISS, as it is not possible to telemeter such large amount of data. The complete Mini-EUSO instrument is contained in a box of 37x7x62 cm with a connection to the ISS for power/grounding and the interface to the UV-transparent window, from which Mini-EUSO will observe in a fixed position facing the nadir direction.



Fig. 2: (Left) Engineering model to be accommodated. (Right) Model inside the ISS.

In-flight Operations

In Fig. 3, the cosmonaut O. Novitsky operating on the instrument in order to start a new session of data taking. At the beginning of each session, the cosmonaut have to install the detector on the UV-transparent window, connect the power cable and the ground cable to the control panel of the instrument (Fig. 4), put and latch the USB pen for the storage and switch on the detector, using the devoted switch. Every month, about three data-taking sessions of about 12 hours each are performed. During each session we store 20 GB of data (1 MB/s), an amount of data impossible to down-link through the telemetry channel. However, for each session, the cosmonaut copies a subset of the data on the computer of the ISS to be down-linked to ground via telemetry channel to allow us to check that the instrument is working properly. The complete set of data is instead physically returned to Earth every six months.



Fig. 3: O. Novitsky with Mini-EUSO in the ISS.

START of the session

- Latch on the UV-transparent window
- Connect 2V power supply
- Connect grounding cable
- Insert empty USB stick
- Turn on switch

END of the session

- Turn off switch
- Remove and store USB stick
- Periodically copy of selected files on station computer for later down-link
- Unlatch and store the instrument

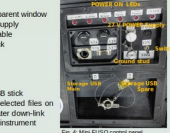


Fig. 4: Mini-EUSO control panel.

Performances

Mini-EUSO was launched on board the Soyuz MS-14 on August 22, 2019. The first installation on the UV-transparent window of the Russian Zvezda module took place a few weeks later, on October 7. Mini-EUSO is capable to make observations at different time scales: the time sampling of 2.5 μ s; then, averaging over 128 GPU, it samples at 320 μ s. And finally it has also continuous acquisition mode, independent from the trigger, on 40.96 ms. Mini-EUSO is capable of addressing a number of different scientific objectives occurring at various time scales, from the very fast events to the slow anthropogenic and natural Earth emissions (see Fig. 9). The detector is designed to operate in night-time conditions.

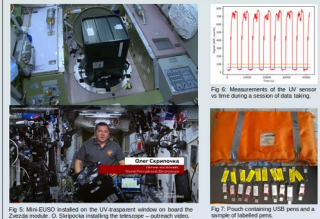


Fig. 5: Mini-EUSO installed on the UV-transparent window on board the Zvezda module. (A) Telemetry receiving the telescope - address cables.

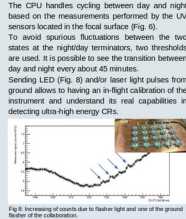


Fig. 6: Mini-EUSO installed on the UV-transparent window on board the Zvezda module. (A) Telemetry receiving the telescope - address cables.

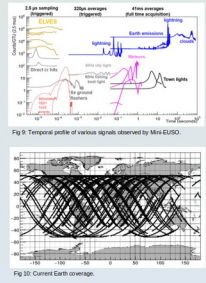


Fig. 7: Temporal profile of various signals observed by Mini-EUSO.

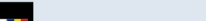


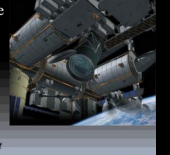
Fig. 8: Current Earth coverage.

Poster n. 532

JEM-EUSO on ISS explores the origin of the highest energy particles in the Universe

Mini-EUSO: a new imaging detector on board the International Space Station to study high atmosphere phenomena and cosmic UV emissions

G. Cambiè, on the behalf of the JEM-EUSO Collaboration
University of Roma 2 Tor Vergata and INFN, Physics Department. giorgio.cambiè@roma2.infn.it



Abstract

Mini-EUSO is a compact telescope (37 x 37 x 62 cm) launched on August 2019 with an unmanned Soyuz spacecraft, currently hosted on board the International Space Station. It is accommodated on the Russian Zvezda module, facing a UV-transparent window in Nadir mode. Mini-EUSO is devoted primarily to study Ultra High Energy Cosmic Rays above 10²¹ eV but also to search for Strange Quark Matter, to observe Transient Luminous Events in upper atmosphere, meteoroids, sea bioluminescence and space debris tracking. Mini-EUSO consists of a main optical system, the Photo Detector Module, sensitive to UV spectrum (300–400 nm) and several ancillary sensors comprising a visible (400–780 nm) and NIR (1500–1600 nm) cameras and a 8 x 8 channels Multi-Pixel Photon Counter Silicon Photomultiplier array which will increase the Technology Readiness Level of this ultraviolet imaging sensor. The main detector has a super-wide field of view (44°) which allows to map an Earth ground area of 263 x 263 km² thanks to the optics which comprises two Poly(methyl methacrylate) Fresnel lenses focusing the radiation onto a 36 Hamamatsu Multi-Anode Photomultiplier Tubes, each of 64 channels for a total of 2304 pixels with a time resolution of 2.5 microseconds. Mini-EUSO belongs to a novel set of missions committed to evaluate, for the first time, the capability of observing Cosmic Rays from a space-based point of view.

Telescope

Mini-EUSO detector is a 37x37x62 cm³ volume body which consists of two main subsystems: Optics and Photo Detector Module. Mini-EUSO optics consists of two double-sided PMMA Fresnel lenses which will focus light onto the focal surface with a large FOV (44°). The full FS consists of an array of 36 Hamamatsu Multi-Anode Photomultiplier Tubes each powered by a Cockcroft-Walton high voltage power supply board placed inside a ceramic pad and present a BG3 UV filter on the entry window.

Together with FS, the signal and data handling electronics form the PDM chain: 3 ASIC boards built on purpose, a Xilinx Zynq XC7Z030 SoC containing a Kintex7 FPGA with an embedded dual core ARM CPU processing system and a PCIe104 form factor CPU. In addition to the main detector, Mini-EUSO contains: two ancillary cameras for complementary measurements in the near infrared and visible range, three single pixel sensor for light and radiation detection and a 64 channels Multi-Pixel Photon Counter SiPM C1363 module provided by Hamamatsu Photonics. An additional Atmel 2560 10-bit microcontroller board is used for ancillary sensor read-out. A three module LVPS (Low Voltage Power Supply) filters and stabilize 27V coming from ISS, providing power for all subsystem and preserving the entire instrumentation from spike or polarization inversion.



Space Qualification Tests

The General Technical Requirements for Experiment, Equipment and Technical Documents on board ISS required several test to be performed on the instrument as: Electro-Magnetic Interference and Conductive (EMC/EMI), vibration and shock; high/low pressure, thermal and humidity functional tests. Mini-EUSO has successfully undergone all of them.

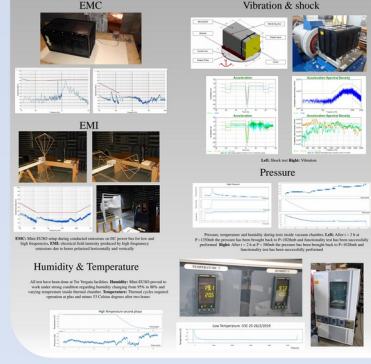


Fig. 2: Space qualification tests results.

Objectives

High resolution UV emission map. Cosmic and terrestrial UV emissions. Mini-EUSO is providing an accurate map covering all of the planet in the latitudinal range covered by the ISS (51.5°N - 51.5°S). **Meteor observation with magnitudes of $M_{\text{eq}} < 5$.** They are detected using off-line trigger algorithms based on photon count and speed. **SQM detection:** Mini-EUSO will be able to set a new upper limit on the detection of Strange Quark Matter which can create a UV signal burning in the atmosphere, that can be discerned from meteor tracks because of the time of flight. **Bioluminescence:** large areas of the ocean surface (up to 16000 km²) sometimes appear to glow during the night for periods of up to several days. The named "Milky sea" condition, is typically attributed to the fluorescence of phytoplankton colonies. **Transient Luminous Events (TLEs)** such as blue jets, sprites and elves events that occur in the upper atmosphere. Mini-EUSO has a dedicated trigger algorithm to capture TLEs and other millisecond scale phenomena. **Space debris observation:** Mini-EUSO will be used as a prototype for the detection of space debris during the twilight periods of observation (when debris are illuminated by the sun, but the instrument is in darkness).

Integration and Characterization

Integration took place at Frascati (INFN), Rome (Univ. of Tor Vergata), Paris (APC), Tokyo (RIKEN), representing part of countries involved in Mini-EUSO project and development.

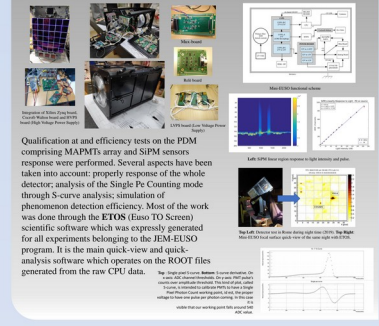


Fig. 3: Integration and characterization tests results.

Launch & Accomodation

Mini-EUSO was launched on 22 August 2019 with the unmanned Soyuz MS-14 spacecraft (with robot Fedor). Currently, it is hosted on board the International Space Station, properly on the Russian Zvezda module, facing a UV-transparent window in Nadir mode.



Fig. 4: Mini-EUSO installed on the UV-transparent window on board the Zvezda module.

JEM-EUSO collaboration 16 Countries, 93 Institutions, 351 people

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