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

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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 "Beyond" 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 as 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 2013, is in operation; EUSO-Balloon flew on board a stratospheric balloon in August 2014; EUSO-SPB 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-trasparent window in the Zvezda module of the ISS on October 7.
K-EUSO, to be attached outside the ISS, is in phase A.
EUSO-SPB2 is in phase of construction for a long duration flight in 2023.

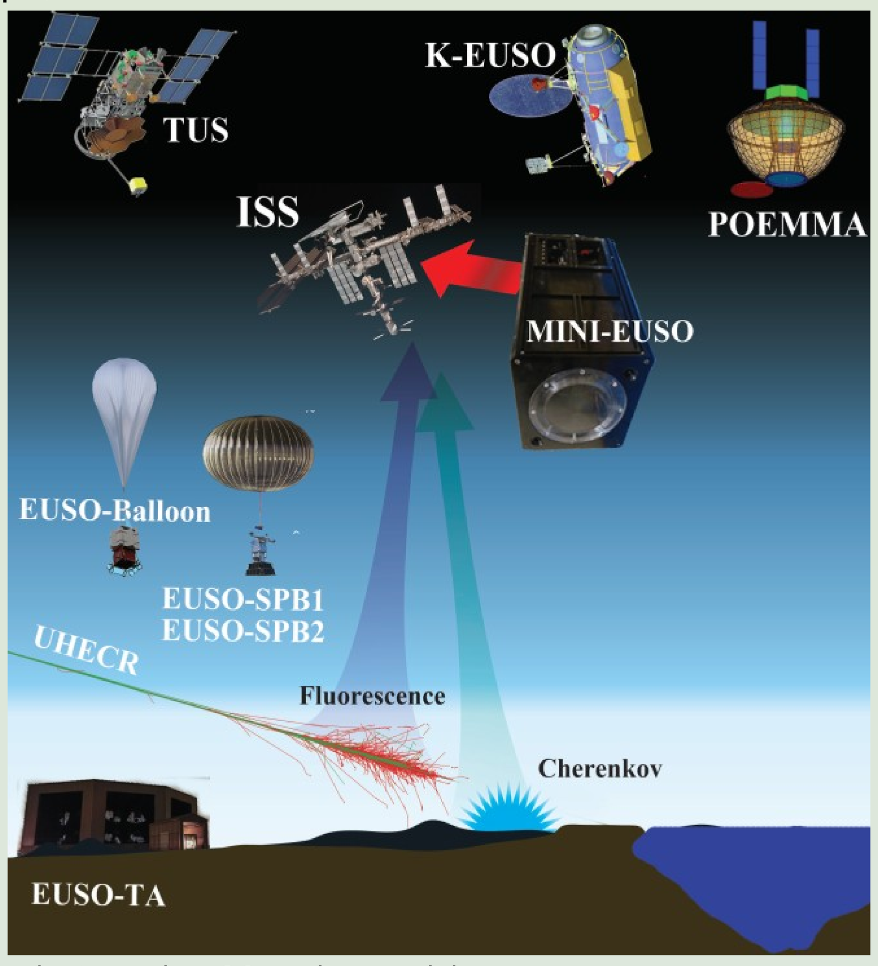

Fig. 1: JEMi-EUSO roadmap and detectors.

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 PCIe/104 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 37x37x62 cm^3 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.

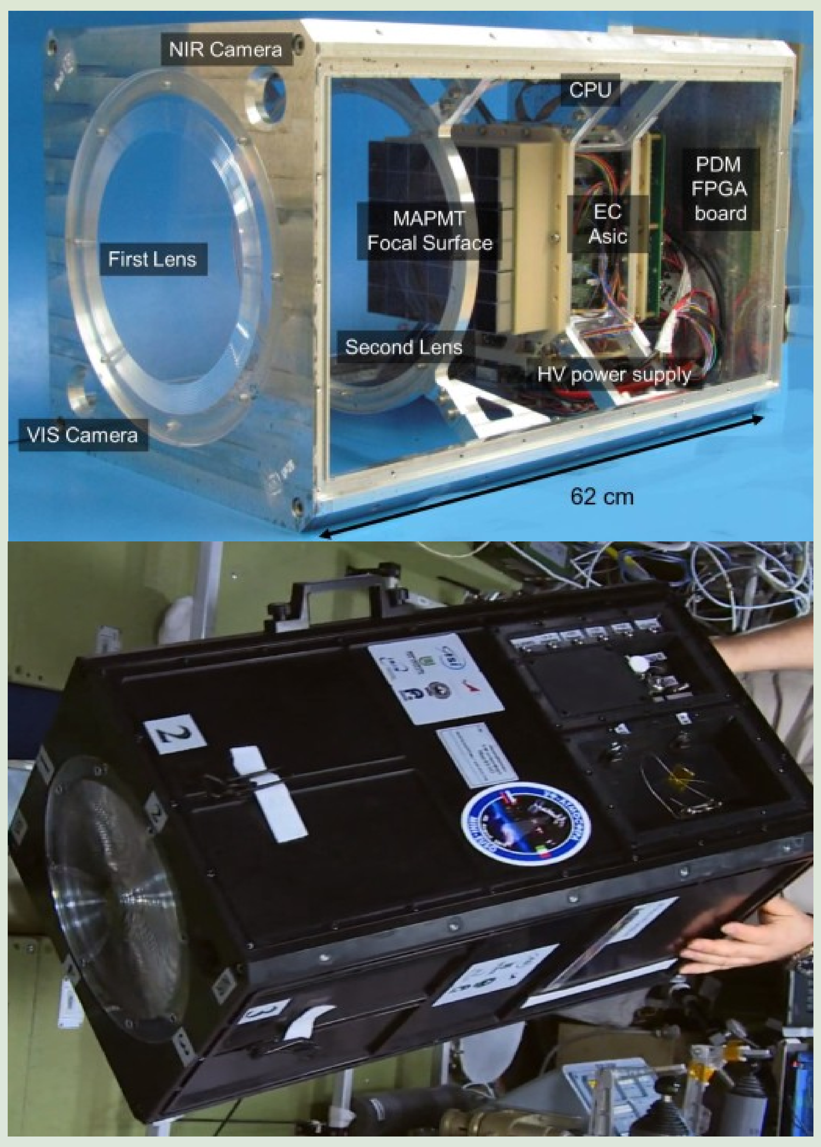

Fig 2: Up: Engineering model to be assembled. Down: Flight model inside the ISS.

In-flight Operations

In Fig. 3, the cosmonaut O. Novitskiy 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-trasparent 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 trough 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/twelve months.

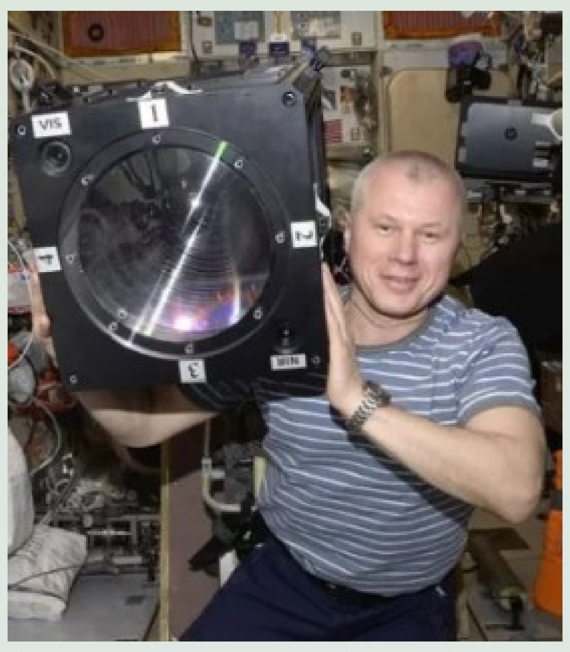

Fig. 3: O. Novitskiy and Mini-EUSO in the ISS.

START of the session
- Latch on the UV-trasparent window
- Connect 27V 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

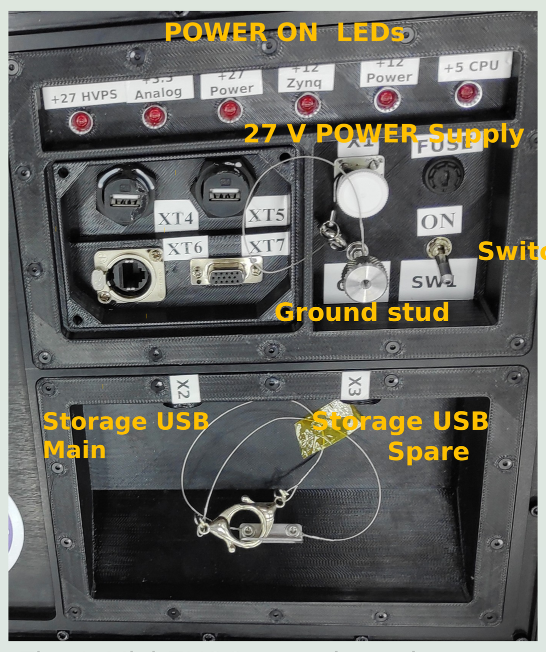

Fig. 4: Mini-EUSO control panel.

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 instrument has a time sampling of 2.5 μs; then, averaging over 128 GTU, it samples at 320 μs. And finally it has also a 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 elves to the slow anthropocentric 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-trasparent window of the Zvezda module. O. Skripocka installing the telescope – outreach video.

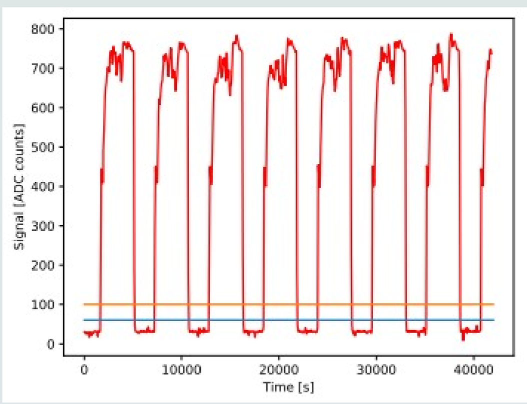

Fig 6: Measurements of the UV sensor vs time during a session of data taking.

Fig 7: Pouch containing USB pens and a sample of labelled pens.

The CPU handles cycling between day and night based on the measurements performed by the UV sensors located in the focal surface (Fig. 6).
To avoid spurious fluctuations between the two states at the night/day terminators, two thresholds are used. It is possible to see the transition between day and night every about 45 minutes.
Sending LED (Fig. 8) and/or laser light pulses from ground allows to having an in-flight calibration of the instrument and understand its real capabilities in detecting ultra-high energy CRs.

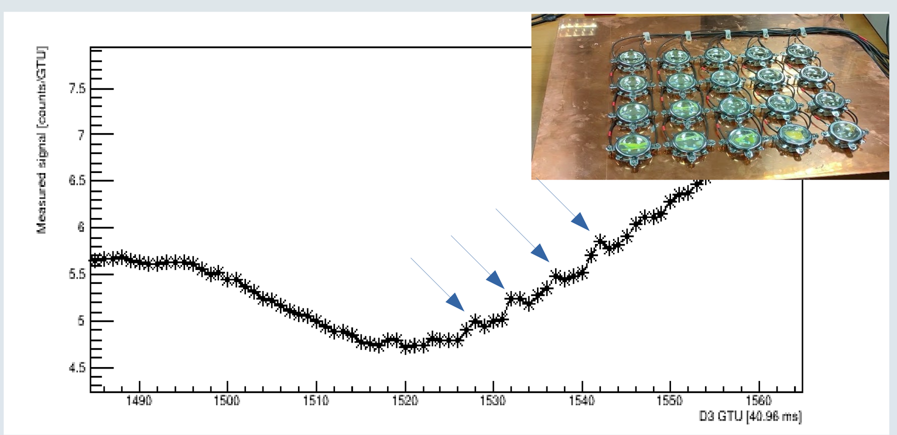

Fig 8: Increasing of counts due to flasher light and one of the ground flasher of the collaboration.

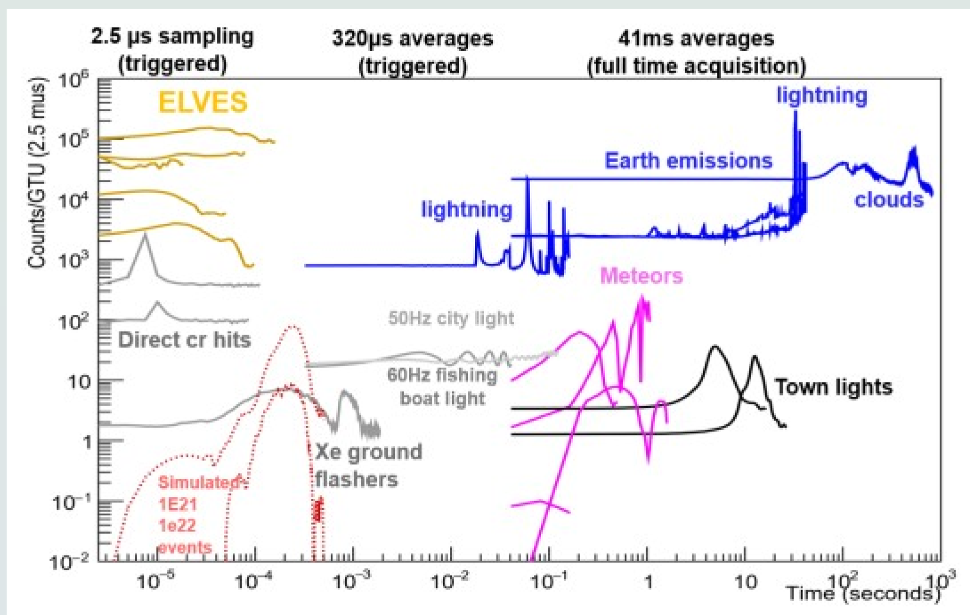

Fig 9: Temporal profile of various signals observed by Mini-EUSO.

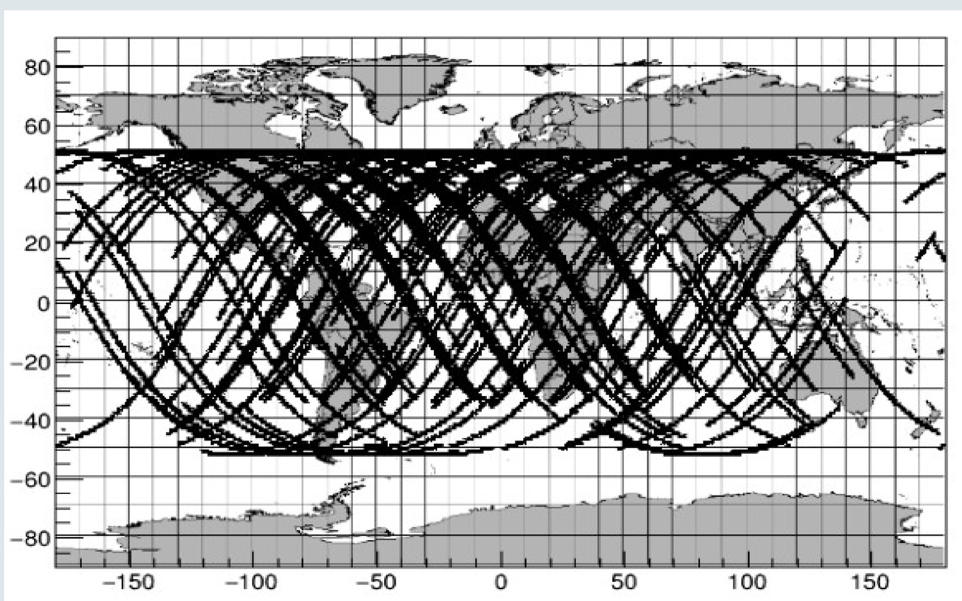

Fig 10: Current Earth coverage.

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