The Mini-EUSO telescope on board the ISS: 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 ESA mission Beyond, has a field of view of 44°, 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 we will describe the in-flight operations and performances of the various instruments in the first months after launch.

1. Introduction

The Mini-EUSO (Multiwavelength Imaging New Instrument for the Extreme Universe Space Observatory) experiment is part of the JEM-EUSO program [1], developed by the JEM-EUSO Collaboration and devoted to the goal of observation of Ultra-High Energy Cosmic Rays (UHECR) from space. The collaboration has already carried out several successful missions: from ground (EUSO-TA [2], 2013-) and on stratospheric balloons (EUSO-Balloon [3] (2014) and EUSO-SPB1 [4] (Super-Pressure Balloon, 2017)). A second Super-Pressure Balloon flight, EUSO-SPB2 [5], is planned in 2023. A big step forward was made in 2019 with the Mini-EUSO instrument [6, 7]: Mini-EUSO is the first detector placed in space to employ this technology.

The Mini-EUSO telescope was designed to be hosted on board the International Space Station (ISS) on the UV-transparent window located in the Russian Zvezda module. The instrument has been launched on August 22, 2019, from Baikonur and is at present on board the ISS.

Mini-EUSO is currently monitoring terrestrial and atmospheric UV emissions from Earth orbit and provides exciting data for studying a wide variety of UV phenomena: Transient Luminous Events (TLEs) such as ELVES, meteors and meteroids, strange quark matter, space debris, marine phytoplankton bioluminescence and others. It can also observe UHECRs above 10^{21} eV (thus placing a limit on the flux since they have not been observed so far) and artificially generated LED and/or laser shoters from ground (useful for calibrating the detector as well as understanding the instrument's capabilities in UHECR detection).

2. Mini-EUSO Instrument on board the ISS

Mini-EUSO is a UV telescope (range: $290 \div 430$ nm) that observes the Earth with a temporal resolution of 2.5 μs and a spatial resolution of about 6.3 km on ground, corresponding to a field of view of 44°.

The optics of the main telescope is composed by two Fresnel lenses (25 cm diameter, PMMA (Polymethyl methacrylate)) that focus the light onto a Photo Detector Module (PDM) composed of an array of 36 Hamamatsu multi-anode PMTs, each of 64 channels for a total of 2304 pixels. In addition to the main detector, Mini-EUSO contains two ancillary cameras in visible ($400 \div 780$ nm) and the near infrared ($1500 \div 1600$ nm) ranges to complement the UV measurements, two single pixel UV sensors used to manage the day/night transition, a single SiPM and a 64 channel SiPM module. The telescope has a power consumption of 60 W, it weighs 35 kg and its dimensions are $37 \times 37 \times 62$ cm^3 (Figure 1).

The detector was successfully switched on for the first time on 2019, October 7^{th} (Figure 2), and is turned on about three times a month.

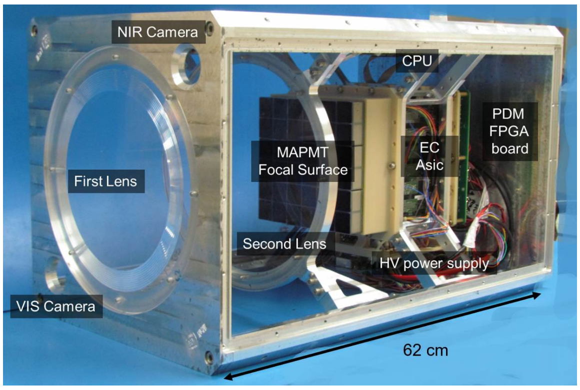

Figure 1. Mini-EUSO Engineering model (37x37x62 cm^3) with focal surface and main elements visible [8].

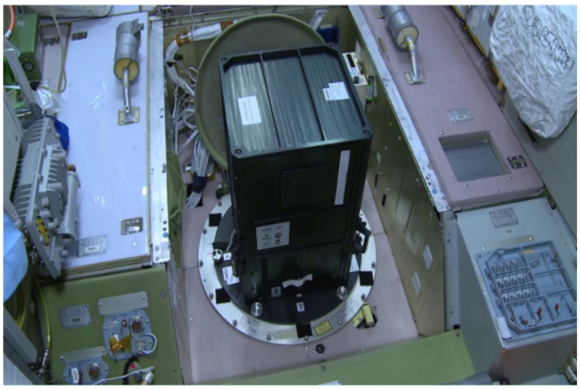

Figure 2. Flight model installed inside the ISS on the UV transparent window of the Zvezda module.

3. In-flight operations

At the beginning of each session, the cosmonaut has to take the detector from the storage, remove the lens cover and install the instrument on the UV transparent window of the Zvezda module. Then he has to connect the power and ground cables, put and latch the SSD card on the USB port of the control panel and, finally, switch on the detector. There are no other connection with the ISS, the time is kept internally with a Real Time Clock. The daily drift of the clock is regularly checked with the data taken on board.

At each startup, the system checks if there are specific operating parameters on the SSD card that override the existing ones. The initialization program also checks whether software and/or firmware updates are present in the SSD and, if so, uses them. This flexible approach allows continuous improvement of operations and acquisition.

At the end of each session the cosmonaut stores the detector and the SSD card. The log file and some data files are transferred to ground by the ISS telemetry channel for analysis and verification of the correct operating of the system. The SSD cards are stored inside a pouch (see Figure 3); every 6-12 months the pouch with used SSD cards comes back to Earth and another pouch with new SSD cards is sent to the station.

As previously reported, the instrument is studied to operate in night conditions. The CPU manages the transitions from day to night, and viceversa, on the basis of the measurements performed by the UV sensors located on the focal surface (for redundancy reasons all three sensors, two photodiodes and one SiPM, can be used). Figure 4 represents the light measured by the UV sensor as a function of time during a session of data acquisition. Two thresholds are used for determining the passage from day to night (60 ADC counts, blue line) and vice versa (100 ADC counts, orange line) to avoid fluctuations on the day-night terminator line. It is possible to see the transition between day and night approximately every 45 minutes[1].

Figure 3. Pouch and USB pens ready to be sent on the ISS.

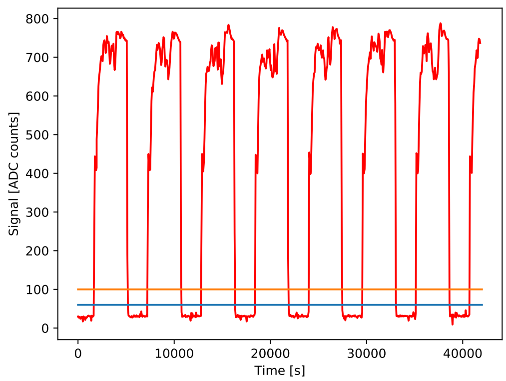

Figure 4. Plot of the measurements of the UV sensor as a function of time.

4. Mini-EUSO perfomances

Mini-EUSO raw data (.dat format) are processed and analyzed with the ROOT (Brun & Rademakers 1997) framework producing Level0 files. Thereafter, for each Level0 file, a Level1 file is produced mainly including the correction of the time drift and the orbital information.

Figures 5 and 6 represent the Earth coverage of data contained in the set of SSD cards of the first pouch returned to Earth, corresponding to the period October 2019 - March 2020 (14 sessions of data taking performed), and in the subset of files downlinked via telemetry channel from April 2020 to now (27 sessions of data taking performed, 10% of data downlinked)

[1] The period of illumination is determined by the β angle of the ISS, the angle between the ISS orbital plane and the Sun-Earth vector: when β is close to 90^o the station is almost always illuminated by the Sun and the duration of nights is very short, when β=0 the local night duration is the longest.

respectively. In Figure 5 data are acquired during the winter time for the Northern hemisphere and a worst coverage of the southern hemisphere is visible. In Figure 6, although this is only a subsetof the data, it is possible to see that they cover a whole year and are therefore uniformly distributed over the Earth's surface.

For a complete review of the first scientific results, see [6].

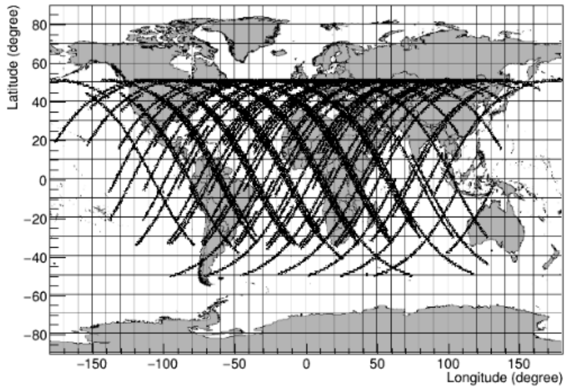

Figure 5. Earth coverage of the data contained in the set of SSD cards of the first pouch returned to Earth: 14 sessions acquired during the winter time for the Northern hemisphere.

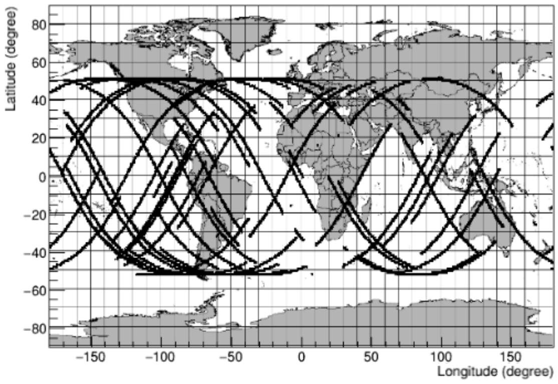

Figure 6. Earth coverage of the data in the subset of files downlinked via telemetry channel from April 2020 to now (27 sessions of data taking performed, 10% of data downlinked).

5. Conclusions

Mini-EUSO is presently on board the ISS and is performing periodic observations of the Earth. It is planned that operations will continue for at least three years. The on-going data analysis confirms that the instrument is functioning properly and can accomplish its stated scientific objectives.

The scientific results of the data analysis will be the subject of future publications.

Acknowledgments

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