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# The Mini-EUSO telescope on board the International Space Station: Launch and first observations

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**Summary.** — Mini-EUSO is a telescope that observes the Earth from the International Space Station by recording ultraviolet emissions (290–430 nm) of cosmic, atmospheric and terrestrial origin with a field of view of 44° and on different time scales, from a few microseconds upwards. The scientific objectives are manifold and span several fields of research: Ultra-High Energy Cosmic Rays, atmospheric phenomena such as ELVEs, meteors and meteoroids, maps of the Earth night-time ultraviolet emissions and others. In this paper we will describe the instrument, the launching phase and we will discuss some of its first observations.

## 1. – Introduction

Mini-EUSO (Multiwavelength Imaging New Instrument for the Extreme Universe Space Observatory) experiment [1] is part of the JEM-EUSO program, developed by the JEM-EUSO Collaboration to bring to space the observation of Ultra-High Energy Cosmic Rays (UHECRs). Many detectors have been built by the Collaboration up to now: EUSO-TA [2], a ground-based detector placed at the Telescope Array site in Utah (2013-); EUSO-Balloon [3] (2014) and EUSO-SPB1 [4] (Super-Pressure Balloon, 2017), two balloon-borne detectors launched from Canada and New Zealand respectively. A second Super-Pressure Balloon flight, EUSO-SPB2 [5], is planned in 2023.

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

As part of the JEM-EUSO program, Mini-EUSO has been developed to demonstrate the possibility of studying UHECRs from space. Since the small size of the lenses (25 cm in diameter) implies a minimum energy threshold for cosmic rays of $10^{21}$ eV (which have so far not been observed), the collaboration plans to place an upper limit to the flux of particles at this energy. The yearly exposure of about 1000 km$^2$ sr yr makes it unlikely for Mini-EUSO to observe any event at these energies; however, since this is comparable to that of Telescope Array in the north hemisphere, Mini-EUSO can contribute to search for exotic events that would not give a signal in the surface detectors. In addiction, Mini-EUSO is measuring terrestrial and atmospheric UV emissions from Earth orbit providing interesting data for the study of a wide variety of UV phenomena: Transient Luminous Events (TLEs), such as ELVES, meteors and meteroids, strange quark matter, space debris, phytoplankton bioluminescence and others.

## 2. – Mini-EUSO instrument on board the ISS

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

The main telescope optics is composed by two Fresnel lenses (25 cm diameter, PMMA (Polymethyl methacrylate)) focusing 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. Each PMT is powered by a Cockroft-Walton power supply board and presents a BG3 UV filter on the entry window. In addition to the main detector, Mini-EUSO contains two ancillary cameras for complementary measurements in the near infrared (1500–1600 nm) and visible (400–780 nm) ranges, two single pixel UV sensors

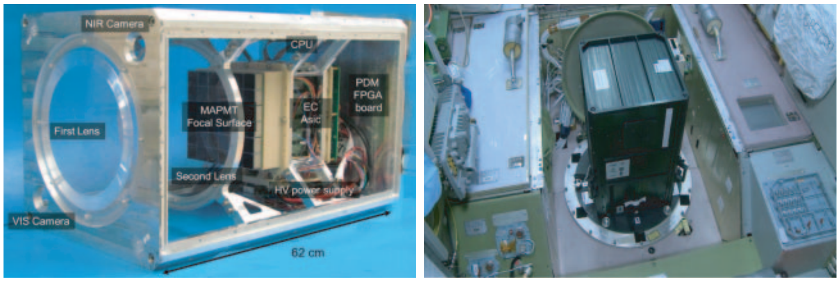


Fig. 1. – Left: Mini-EUSO Engineering model ($37 \times 37 \times 62$ cm$^3$) with focal surface and main elements visible [6]. Right: flight model installed on the UV transparent window of the Zvezda module.

used as switches for day/night transition, a single SiPM and a 64 channel SiPM module. The telescope weighs 35 kg, its power consumption is 60 W and its dimensions are $37 \times 37 \times 62$ cm$^3$ (fig. 1, left).

The detector has been successfully turned on for the first time on October 7, 2019 (fig. 1, right), and, since that date, is switched on about three times a month. For each data session a set of data is sent to ground via ISS telemetry while the full set of data is returned to ground on disk approximately every six months. For a more detailed description of the instrument and launch phase, see [1].

## 3. – First observations

A multi-level trigger system [7] has been implemented in the acquisition logic to optimise the scientific performance of the instrument. This allows the detector to study phenomena of widely varying duration and intensity: ELVEs and UHECR-type events are triggered with a resolution of 2.5 $\mu$s (trigger L1), lightning and other atmospheric events with a resolution of 320 $\mu$s (trigger L2) and there is an additional continuous readout with a resolution of 40.96 ms (data L3) useful for reconstructing meteors and terrestrial UV maps. The complete set of signals recorded by Mini-EUSO is summarised in fig. 2 (left). As an example of the observational capabilities of the instrument, below is an example of reconstruction of a UV map and detection of an ELVE.

*Night-time UV map recostruction*: Mini-EUSO will map the Earth in the near UV range (290–430 nm) with a spatial resolution $\simeq 6.3 \times 6.3$ km$^2$ and a temporal resolution of 2.5 $\mu$s, measuring variations in UV emissions. Earth emissions depend on the visible

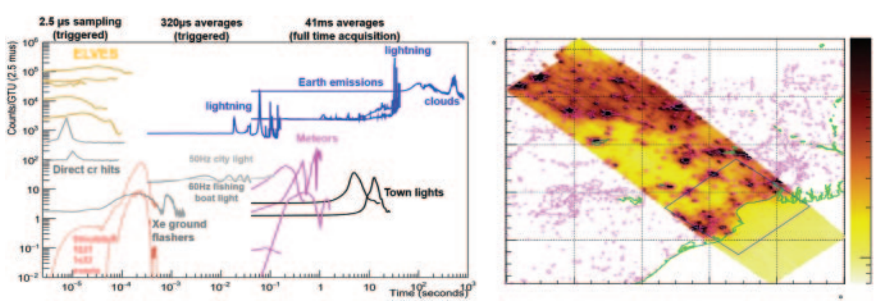


Fig. 2. – Left: temporal profile of various signals observed by Mini-EUSO. Right: map of the east coast of India in the UV range. Ground-water boundary and emissions in the visible range are drawn, the square denotes the size of the field of view of Mini-EUSO.

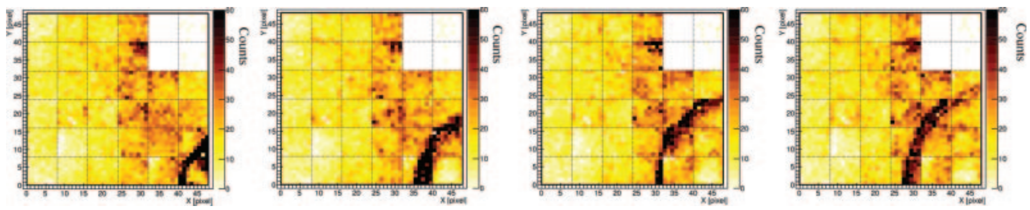

Fig. 3. – Consecutive frames of an ELVE observed by Mini-EUSO. The four top-right MAPMTs are operating at a reduced voltage because previous bright event triggered the safety system.

surface (*e.g.*, land, sea or clouds) and move through the field of view with an apparent velocity close to the orbital velocity of the ISS ($\simeq$7.7 km/s). A given point on the Earth surface is therefore visible for about 42 s ($\simeq$1000 frames in L3 acquisition) while moving across the focal surface; thus it is possible to derive ground maps with high spatial resolution and low statistical fluctuations. A typical map of the Earth UV emissions as reconstructed by Mini-EUSO is shown in fig. 2 (right).

*ELVE detection*: ELVEs are TLEs occurring in the ionosphere and induced by lightning in lower atmophere. They last a few hundred $\mu$s at most. Thanks to the global coverage of its measurements, Mini-EUSO is able to observe these events and study the so-called far-from-thunderstorm transient atmospheric events, observed up to now in a couple of experiments [8,9]. ELVEs are observed as large ring-like ionospheric emissions that appear to expand at superluminal velocity. In fig. 3 are shown consecutive frames of an ELVE entering the field of view.

## 4. – Conclusions

The detector is currently on board the ISS and is making periodic observations of the Earth. Operations are expected to continue for at least three years. Data analysis is underway and confirms that the instrument is working properly and can achieve its stated scientific objectives. Analysis results will be the subject of future publications.

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REFERENCES

[1] Bacholle S. *et al.*, *Astrophys. J. Suppl. Ser.*, **253** (2021) 36.
[2] Abdellaoui G. *et al.*, *Astropart. Phys.*, **102** (2018) 98.
[3] Abdellaoui G. *et al.*, *Astropart. Phys.*, **111** (2019) 54.
[4] Wiencke L., Olinto A. and the JEM-EUSO Collaboration, *International Cosmic Ray Conference*, Vol. **301**, PoS(ICRC2017) p. 1097.
[5] Adams James H. jr., Anchordoqui L. A., Apple J. A. *et al.*, arXiv:1703.04513 (2017).
[6] Belov A., *et al.*, *Aerotec. Missili Spazio*, **99** (2020) 93.
[7] Belov A. *et al.*, *Adv. Space Res.*, **62** (2018) 2966.
[8] Klimov P. *et al.*, *IEEE Geosci. Remote Sens. Lett.*, **15** (2018) 1139.
[9] Aab A. *et al.*, *Earth Space Sci.*, **7** (2020) e2019EA000582.