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Data Article

# 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

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## ABSTRACT

The data presented in this article are related to the research paper entitled "*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, Volume 284, January 2023, 113336, https://doi.org/10.1016/j.rse.2022.113336).
The data have been acquired with the Mini-EUSO detector, an UV telescope operating in the range 290-430 nm and located inside the International Space Station. The detector was launched in August 2019, and it has started operations from the nadir-facing UV-transparent window in the Russian Zvezda module in October 2019. The data presented here refer to 32 sessions acquired between 2019-11-19 and 2021-05-06. The instrument consists of a Fresnel-lens optical system and a focal surface composed of 36 multi-anode photomultiplier tubes, each with 64 channels, for a total of 2304 channels with single photon counting sensitivity. The telescope, with a square field-of-view of 44°, has a spatial resolution on the Earth surface of 6.3 km and saves triggered transient phenomena with a temporal resolution of 2.5 µs and 320 µs. The telescope also operates in continuous acquisition at a 40.96 ms scale.
In this article, large-area night-time UV maps obtained processing the 40.96 ms data, taking averages over regions of some specific geographical areas (e.g., Europe, North America) and over the entire globe, are presented. Data are binned into 0.1° × 0.1° or 0.05° × 0.05° cells (depending on the scale of the map) over the Earth's surface. Raw data are made available in the form of tables (latitude, longitude, counts) and .kmz files (containing the .png images). These are – to the best of our knowledge – the highest sensitivity data in this wavelength range and can be of use to various disciplines.



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## Specifications Table

| | |
|---|---|
| Subject | Geographical Information System |
| Specific subject area | Near Ultra-Violet night-time emission maps of Earth surface. |
| Type of data | Tables with Raw Data (.txt)<br>Images (.png)<br>KMZ (Keyhole Markup language Zipped) files (.kmz) |
| How the data were acquired | Data were acquired with the Mini-EUSO detector, a telescope with 25 cm diameter lenses and a 48 × 48-pixel focal surface, grouped in 6 × 6 Multi-Anode Photomultiplier Tubes (MAPMT) . Data are read by single photon counting ASICs and sent to a FPGA (Field Programmable Gate Array) board for acquisition and processing. A frame acquired by the telescope has a duration of 2.5 µs.<br>Data are temporary stored by the FPGA in a circular buffer of 128 GTUs and sent to the CPU if the trigger conditions are met. Independently, a 40.96 ms time resolution (produced averaging 128 × 128 frames of 2.5 µs) are saved continuously. In this paper, we present data acquired with the continuous sampling period of 40.96 ms. |
| Data format | Raw<br>Analyzed |
| Description of data collection | Raw data are acquired from the interior of the International Space Station (ISS), looking nadir through a UV-transparent window located in the Zvezda module. They are stored by the CPU on flash USB disks, which are returned to Earth about every 12 months. On ground, data are converted to ROOT (root.cern.ch) format. Only night-time data, with the Sun more than 30° below the horizon, have been employed. |
| Data source location | Mini-EUSO data cover the -51.6º<L<+ 51.6º latitude regions (corresponding to the inclination of the orbit of the ISS). The detector samples a swath of about 300 km size (44° field of view) along the orbit of the ISS). Data are thus limited by the path of the space station. Selected sections refer to North America and Europe/North Africa regions. |
| Data accessibility | Repository name: Mendeley Data<br>Data identification number: 10.17632/57fmn7rh4n.4<br>Direct URL to data: https://data.mendeley.com/datasets/57fmn7rh4n/4 |
| Related research article | M. Casolino, D. Barghini, M. Battisti et al., "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, Volume 284, January 2023, 113336, https://doi.org/10.1016/j.rse.2022.113336). |

## Value of the Data

- These are high resolution (about 6 km) maps of the night-time Earth in the near-UV range. Data in this wavelength range, with a single photoelectron efficiency, were up to now performed with a single pixel photomultiplier [1]. They show the emissions from many different sources of artificial (towns) and natural (airglow, cloud reflection, Moon) origin.
- The data may be of interest to different communities of researchers: a) cosmic ray physicists who want to estimate the exposure and the efficiency of future ultra-high energy experiments in space; b) atmospheric physicists who might study cloud reflection from auroral- and Moon- light; c) biologists who might look for bioluminescence emissions from aquatic organisms; d) environmental scientists who are interested in the light pollution from urban centers, etc...
- As mentioned above, the data can be used to estimate the efficiency of future space station- or satellite-based ultra-high-energy cosmic ray detectors which aim to observe the fluorescence and Cherenkov light emitted by the extensive air showers initiated by the interaction of cosmic rays in the atmosphere [2]. Other possible uses involve the calibration of cloud emission / brightness in the UV range to assess cloud height and structure.

## 1. Objective

In this paper the first observations of night-time Earth in the near UV range performed by Mini-EUSO telescope are made available. Data presented exclude the influence of solar light scattered in the atmosphere, by requiring the position of the Sun to be 30° below the horizon. Global world maps are presented a) without any further cut, b) with the additional requirement of having the Moon below the horizon and c) with no clouds (cloud fraction <1%) in the field of view, in addition to b).

More detailed maps of North America and Europe have been produced according to c).

## 2. Data Description

The entire dataset is hosted on Mendeley data repository [3].

The dataset consists of two folders, “tables” and “figures”. Each of these two folders contains three subfolders: “World map”, “Europe and North Africa Map” and “North America Maps”.

In the folder “figures”, an additional folder named “Figures used in ’Experimental design, materials and methods’ section”, containing the figures used in the following sections, is present.

The folder “figures” includes .kmz (Keyhole Markup language Zipped) format files to visualize the maps in an Earth visualization software such as Google Earth. Kmz files are available for the World map, the Europe and North Africa map and the North America maps published in [3], in figures 18 (World map), 21 (Europe - North Africa) and 21, 23 (North America) respectively.

Files uploaded in the folder “tables” contain the raw data in text format. These are used to produce the corresponding maps of the folder “figures”. Each raw data file is a three-column text table with the following column descriptors: latitude (referred to the bin center), longitude (referred to the bin center) and photoelectron counts/2.5 μs (with 2.5 μs defined as 1 GTU – Gate Time Unit). For the binning description refer to the figure descriptions here below. The number of photoelectrons on each pixel of the focal surface has been normalized with a flat fielding procedure [4]. The conversion to number of photons emitted depends on the nature of the source (see below for the various conversion parameters).

This folder also includes the wavelenght_response.txt text file containing the overall wavelength response of the telescope and the various efficiencies due to the various contributions (MAPMT, BG3 filter on top of each MAPMT, UV-transparent window of the ISS, optics).

## 3. Experimental Design, Materials and Methods

Mini-EUSO is a telescope [5] operating in the near-UV range (290 - 430 nm) from the nadir-facing UV-transparent window in the Zvezda module of the International Space Station (ISS) (Fig. 1). The telescope has a square field of view of 44° × 44° and a focal surface of 48 × 48 pixels, corresponding to a spatial resolution of 6.3 × 6.3 km$^2$ on the ground. The exact size of the pixel depends on the changing altitude of the ISS (taken into account in the map realization).

The optical system consists in two Poly(Methyl Methacrylate) – PMMA Fresnel lenses, each with a diameter of 25 cm. The focal surface is composed by an array of 6 × 6 Hamamatsu Multi-Anode PhotoMultiplier Tubes (MAPMTs), with 8 × 8 pixels each, for a total of 2304 pixels (Fig. 2). The MAPMTs are covered by BG3 UV-bandpass filters (see Fig. 3 for a plot of the overall efficiency of the telescope in function of the wavelength and that of the various components).

The front-end read-out is handled by 36 SPACIROC3 (Spatial Photomultiplier Array Counting Integrated Read-Out Chip [6]) ASIC chips, each capable of handling in parallel the 64 channels of one MAPMT, performing single photon counting of the photoelectron signal generated by incoming UV photons and providing the photoelectron count every 2.5 μs. The dead time is 5 ns for each incident photon and is corrected in the flat fielding phase. Data are sent from the ASICs to a Xilinx Zynq based FPGA board which implements a multi-level triggering [7,8]. Triggered acquisitions are performed on the 2.5 μs and 320 μs time frames, whereas continuous

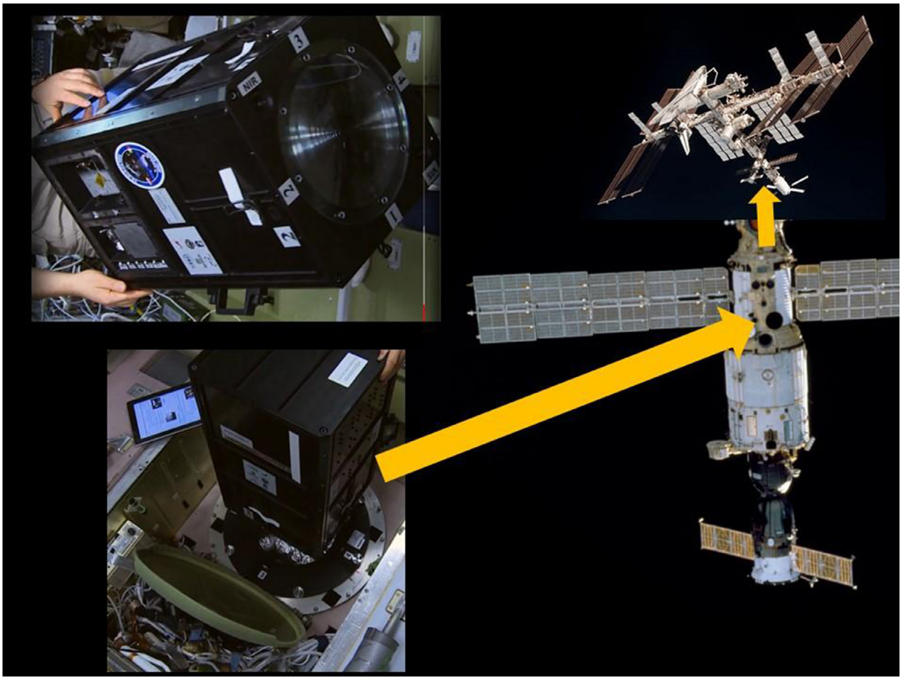

**Fig. 1.** From top-left, in counterclockwise direction: 1. The Mini-EUSO telescope in the Zvezda module of the ISS. 2. The Telescope during its installation on the nadir facing, UV-transparent window of the station. 3. A close up of the Zvezda module, showing the window employed during observations. 4. The position of the Zvezda module in reference to the rest of the station.

(untriggered) acquisition is performed on the sum of 128 × 128=16384 2.5 μs frames resulting in an uninterrupted (except in case of very bright ground lights such as lighting that force the lowering of the high voltage power supply) acquisition with 40.96 ms frames (about 24 Hz).

Raw, binary data are then sent from the FPGA to the CPU, which stores them on USB flash drives.

On ground, data are processed with the ROOT framework. The processing steps include the correction for the dead time (relevant for bright signals), the addition of all ancillary information (e.g., orbit, position, attitude of the station, non-linearities of the lens system) - and the flat fielding procedure. The flat fielding is needed to compensate for the different gain of each pixel of the focal surface. To produce the maps presented here, 40.96 ms frames are then spatially binned in a given location. The night-time maps of the Earth presented here are binned in 0.1° × 0.1° or 0.05° × 0.05° cells over the Earth's surface. These maps show the clear impact of anthropogenic light sources on the night-time UV environment, such as those coming from towns and fishing boats. In the maps presented, the light intensity counts are given in units of photoelectrons/GTU, which means photoelectrons that are read in a time interval of 2.5 μs.

Data are provided in photoelectrons/GTU because the conversion to emitted photons depends on the nature of the observed signal [4]:

### *3.1. Point-Like Sources on the Ground*

Sources with a negligible spatial dimension (such as small villages, single fishing boats, Xenon flashers) are assumed to be point-like sources [4]. Considering an isotropic emission, a ground point source at 395 nm, emitting isotropically on a half sphere and producing $C$ photo-

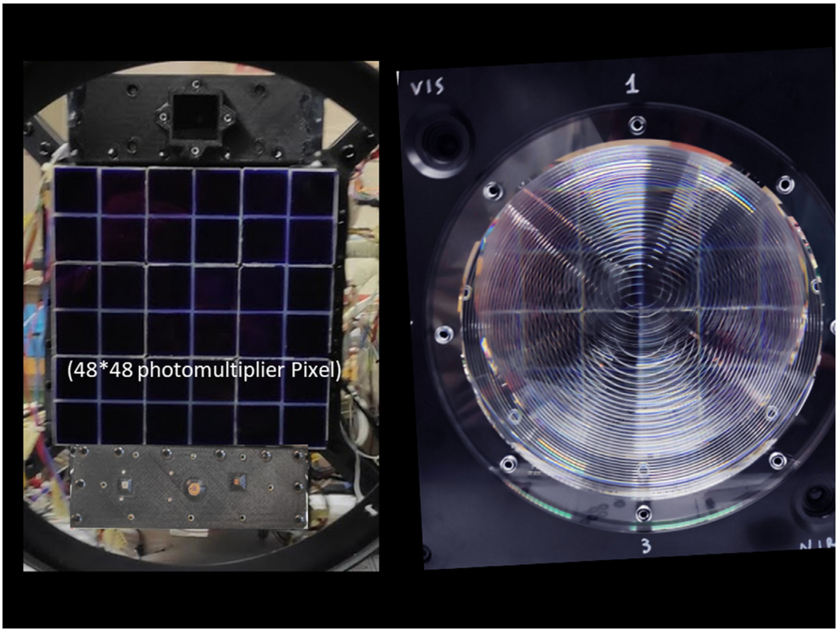


**Fig. 2.** Left: The 48 × 48-pixel focal surface of Mini-EUSO. The 36 64-channel Hamamatsu Multi-Anode Photomultipliers cover an area of 17 × 17 cm$^2$ and are covered by BG3 UV-range filters. Right: The outermost 25 cm diameter Fresnel lens, one of the two that compose the optical system of the telescope.

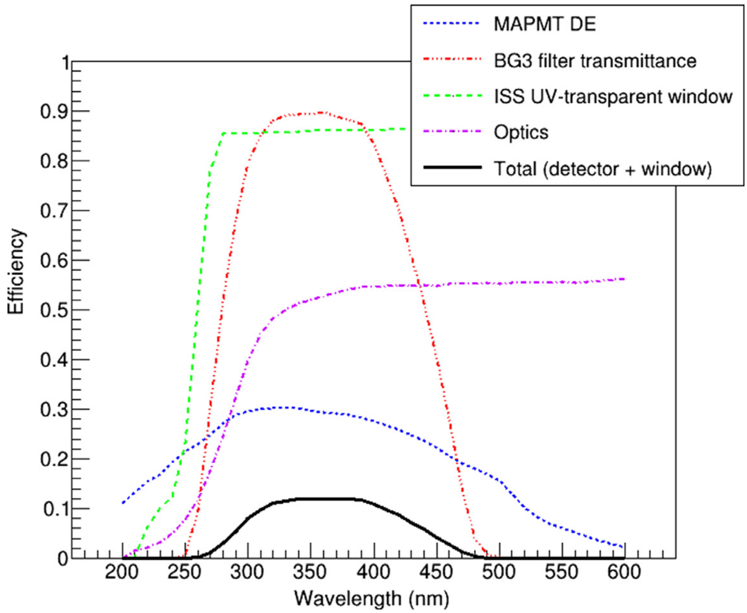


**Fig. 3.** The detection efficiency of Mini-EUSO (black curve) as a function of wavelength. This is the result of the transmittance of the UV-transparent window of the ISS (green curve), the optics (purple curve), the BG3 bandpass filter (red curve) and the MAPMT photon detection efficiency (blue curve) [4]. Efficiency data are in wavelength_response.txt file. Modified from [4].

electron counts/GTU in Mini-EUSO, emits:

$$\Phi(\text{photons/ns}) = C \cdot (1.4 \pm 0.3) \cdot 10^{11}\,\text{ph/ns}$$

The power emitted by this source resulting in 1 photoelectron count detected with the Mini-EUSO instrument (assuming a 400 km altitude of the ISS) is:

$$P(\text{W}) = 70 \pm 15\ \text{W}.$$

This value can be taken as an estimate of the minimum transient point-like source (flashing within a GTU) that could be detected by Mini-EUSO in the absence of background emissions.

### *3.2. Diffuse Sources on the Ground*

If the source has an extension comparable or larger than one pixel of the focal surface ($6.3 \times 6.3$ km$^2$ on the ground for an ISS altitude of 400 km), it can be assumed to be a diffuse source.

This kind of source includes large towns, fleets of fishing boats, and sea bioluminescence. In this case, the light is supposed to be uniformly distributed over a wide area with a flux $\Phi$ (photons/(ns m$^2$ sr)) corresponding to [4]:

$$\Phi(\text{photons/ns}\ \text{m}^2\text{sr}) = C \cdot (550 \pm 100)\text{ph/(ns}\ \text{m}^2\text{sr)}.$$

## Ethics Statements

The work did not involve any human subjects or animal experiments.

## Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## Data Availability

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 +51.6 degrees, acquired on board the International Space Station (Original data) (Mendeley Data).

## CRediT Author Statement

**L. Marcelli:** Writing – original draft, Writing – review & editing, Data curation; **K. Bolmgren:** Formal analysis, Software, Visualization; **D. Barghini:** Methodology; **M. Battisti:** Methodology, Software, Data curation; **C. Blaksley:** Resources; **S. Blin:** Resources; **A. Belov:** Resources; **M. Bertaina:** Conceptualization, Methodology; **M. Bianciotto:** Methodology; **F. Bisconti:** Formal analysis; **G. Cambiè:** Resources; **F. Capel:** Resources; **M. Casolino:** Conceptualization, Writing – original draft, Writing – review & editing; **I. Churilo:** Resources; **M. Crisconio:** Resources; **C. De La Taille:** Resources; **T. Ebisuzaki:** Conceptualization, Resources; **J. Eser:** Software, Visualization; **F. Fenu:** Methodology; **M.A. Franceschi:** Methodology; **C. Fuglesang:** Conceptualization; **A. Golzio:** Formal analysis; **P. Gorodetzky:** Conceptualization; **H. Kasuga:** Methodology; **F. Kajino:** Methodology; **P. Klimov:** Investigation, Conceptualization; **V. Kuznetsov:** Methodology; **M. Manfrin:** Formal analysis, Data curation; **G. Mascetti:** Methodology; **W. Marszal:** Methodology; **H. Miyamoto:** Methodology; **A. Murashov:** Methodology; **T. Napolitano:** Methodology; **H.**

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