EUSO-SPB2 and Mini-EUSO

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EUSO-SPB2 and Mini-EUSO are part of the JEM-EUSO [1] International Program (Joint Experiment Missions for Extreme Universe Space Observatory), a mission concept devoted to the observation and study from space of the cosmic rays at the highest energies (UHECRs, Ultra High Energy Cosmic Rays) above $10^{19} eV$. The main scientific objectives, the instrumentation and the observational principle of JEM-EUSO have been described in detail in previous reports.

EUSO-SPB2

EUSO-SPB2 (Super Pressure Balloon 2) has been designed for a long duration balloon flight as a follow-up of previous balloon flights (EUSO-Balloon in 2014 and EUSO-SPB1 in 2017) performed by the JEM-EUSO Collaboration. This is a second generation stratospheric balloon instrument for the detection of Ultra High Energy Cosmic Rays (UHECRs) via the fluorescence technique and of Ultra High Energy (UHE) neutrinos via Cherenkov emission. EUSO-SPB2 is also conceived as a pathfinder mission for instruments like the proposed space mission Probe Of Extreme Multi-Messenger Astrophysics (POEMMA) [2]. The purpose of such a space-based observatory is to measure UHECRs and UHE neutrinos with high statistics and uniform exposure. EUSO-SPB2 is designed with two mirror Schmidt telescopes, each optimized for their respective observational goals. A scheme of the layout of the instrument, together with the fully assembled instrument is given in Fig.1.

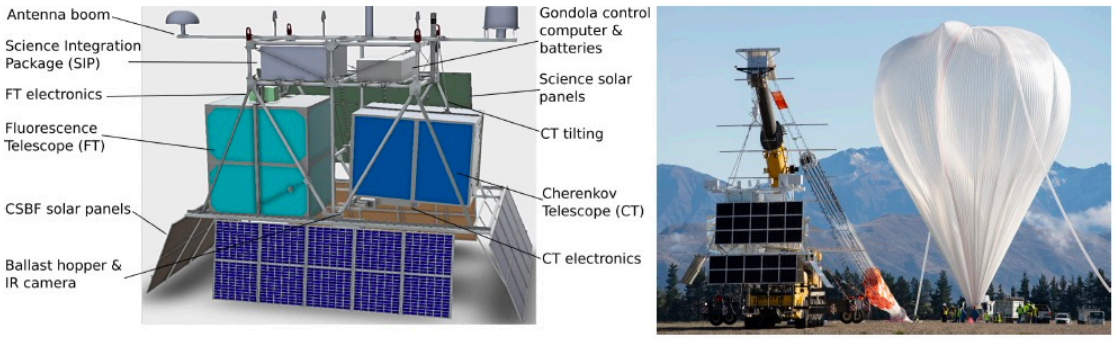

Figure 1: *A labeled sketch of EUSO-SPB2 (left) and a picture of the fully assembled instrument before launch (right). The sketch shows the two telescopes (FT and CT) and the associated electronic boxes, as well as the long-duration balloon flight gear, such as solar panels and telemetry antennas. The picture shows the instrument hanging from the launch vehicle.*

The Fluorescence Telescope (FT) looks at the nadir to measure the fluorescence emission from UHECRs, while the Cherenkov Telescope (CT) is optimised for fast signals (10 ns) and points near

the Earth 's limb. This allows for the measurement of Cherenkov light from Extensive Air Showers caused by Earth skimming UHE neutrinos if pointed slightly below the limb or from UHECRs if observing slightly above.

EUSO-SPB2 was successfully launched on May 13th, 2023 from Wanaka, New Zealand. However, the balloon developed a hole in the envelope and was prematurely terminated over the Pacific Ocean after only about 37 hours of flight. Despite this very short flight, all instruments worked as expected based on extensive simulations and rigorous laboratory and field tests. Around 56GB of data have been downloaded, which included more than 120,000 FT events and more than 32,000 bifocal CT triggers. Full data analysis is in progress, and first, preliminary results - together with the main performance of the detectors - have been presented at the International Cosmic Ray Conference, (ICRC) Nagoya 2023 [3].

The Flight data comprises camera performance data, night sky background images, and bifocal events collected during two nights of observation. The first night was mainly used for commissioning the instrument, which performed as expected at suborbital space for the first time. This demonstrates its potential for future space missions such as POEMMA.

Some of the more than 32,000 events triggered by the bifocal trigger were manually scanned to identify their possible origins. These bifocal events could be examples of extensive air showers (EASs) induced by cosmic rays or neutrinos, direct hits, or accidental triggers caused by background fluctuations. For about 45 minutes, the telescope was pointed above the Earth 's limb to search for cosmic rays and found several candidates, one of which is shown in Fig.2. The left panel shows one frame of the entire camera, clearly demonstrating the bifocal alignment, while the right panel shows the signal trace of one of the pixels, emphasizing the signal strength of such an event. For the rest of the time, the telescope was pointed below the limb to search for Earth-skimming VHE-neutrinos, but no candidates were found. This is consistent with the limited observation time and the lack of astrophysical alerts to follow up on. Data will be analysed more thoroughly in the future to characterize the night sky background and classify all triggered events. Some events were also noticed that did not show bifocal topologies, which may be explained by direct cosmic ray hits.

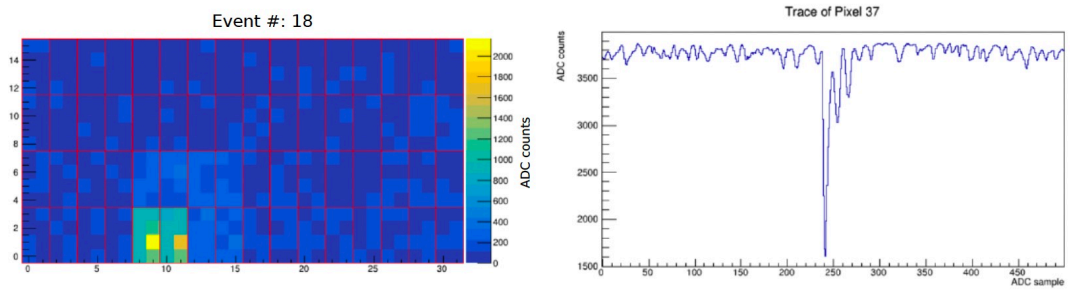

Figure 2: *An example of a cosmic ray event above the limb observed on May 14th, 2023. The left panel shows a single frame of the entire camera, where color represents the ADC counts. The right panel displays a time trace of the pixel with the highest signal, indicating the intensity of the Cherenkov radiation from the cosmic ray event.*

Encouraged by the instruments ' performance, the Collaboration started planning a new pathfinder balloon mission called POEMMA-Balloon with Radio (PBR). This mission will be designed with all the experience of EUSO-SPB2 in mind but with some significant changes and upgrades. The main change is to combine both telescopes into one with a hybrid focal surface similar to the original POEMMA design and to increase the light collection area by a factor of 1.2

to 1.5. In addition to the optical telescope, the PBR design will include a radio detector for the detection of upward-going EAS from cosmic rays and neutrinos to explore the synergy between the optical Cherenkov measurement and the radio detection of such events. The project is in the early design phase but has a target launch date of Spring 2027.

EUSO-SPB2 in Italy was approved - under the name SPB2 - in 2019 by the "Commissione Scientifica Nazionale II of INFN [4)] and, in 2020, by the Italian Space Agency, ASI. An agreement for EUSO-SPB2 between ASI and INFN (Convenzione Quadro ASI-INFN-2021-8-Q.0) was established in 2021. The Italian group (Bari, Catania, LNF, Napoli, Roma 2 Tor Vergata, Torino) had the full responsibility of the development of the Data Processor (DP) and CPU of the Fluorescence Telescope (FT) and of the overall Data system architecture and trigger algorithms of both telescopes. Within the PBR project, approved by INFN Commission and pending approval by ASI, new groups entered the Italian collaboration, namely Trento, Lecce and the Gran Sasso Science Institute (GSSI). In respect to SPB2, besides the above mentioned responsibilities, Italy will manage the design and construction of the entire Cherenkov camera. A program on R&D of Silicon Photomultipliers (SiPMs) for space is also carried out by the Italian group. Within this task, the LNF group is working in collaboration with the Roma 2 - Tor Vergata group on the development of different SiPMs configurations. It is also involved in the management and coordination of the Italian Collaboration (Country representative) and in the activities of the Speaker's Office (publications, conferences etc.).

During the first part of the year 2023 members of the Italian group have been involved in the balloon flight campaign in New Zealand. After the flight, the work has been mainly focused on data analysis and on the preparation of the tasks related to the PBR new mission.

Mini-EUSO

Mini-EUSO, approved by the Russian Space Agency Roscosmos (under the name "UV-Atmosphere") and by the Italian Space Agency, ASI, has been conceived to study and measure the UV emissions from Earth and to perform studies of atmospheric phenomena, observation of meteors, strange quark matter search and space debris tracking. Launched in August 2019 and installed onboard the Russian Module of the International Space Station (ISS), its main goal is to map the Earth in the UV spectrum from space. The instrument and its functionalities have been described in previous LNF Reports.

Mini-EUSO (Fig.3) is in operation and taking data since October 2019. Several astronauts, including the Italian ESA astronaut Luca Parmitano during the mission "Beyond", have operated the instrument in successive observation sessions. Part of the data is directly transmitted to ground by telemetry, while a larger set of data (stored on 512 GB USB SSD - Solid State Disks) is physically brought to Earth during some of the astronauts' returning missions. The results so far obtained have shown the good performance of the instrument and its potentialities in fulfilling the scientific objectives [5)]. In particular, several ELVES (Emission of Light and Very low frequency perturbations due to Electromagnetic pulse Sources), a particular class of lightnings, and meteors have been observed, together with other atmospheric phenomena like the TLE's (Transient Luminous Events). Space debris tracking is also in the reach of the observation program. Several UV maps of Earth have been achieved (see References) and further, more detailed processing of images is in progress, with the implementation of the analysis techniques through machine learning methods [6) 7)].

In the preparation of the mission and of the flight instrument, the LNF group has played a key role, through the Mechanical Design and Construction Service (SPCM), responsible of the design, test, prototyping and production of all the mechanical structures and containers and of the overall Focal Surface of the Engineering/Qualification and Flight Model of Mini-EUSO. So far,

including year 2023, more than 100 (not consecutive) sessions of data taking (both engineering and science) have been performed. The LNF group has continued its activity into the quicklook control of the mission and the analysis work in collaboration with the group of Roma 2 Tor Vergata.

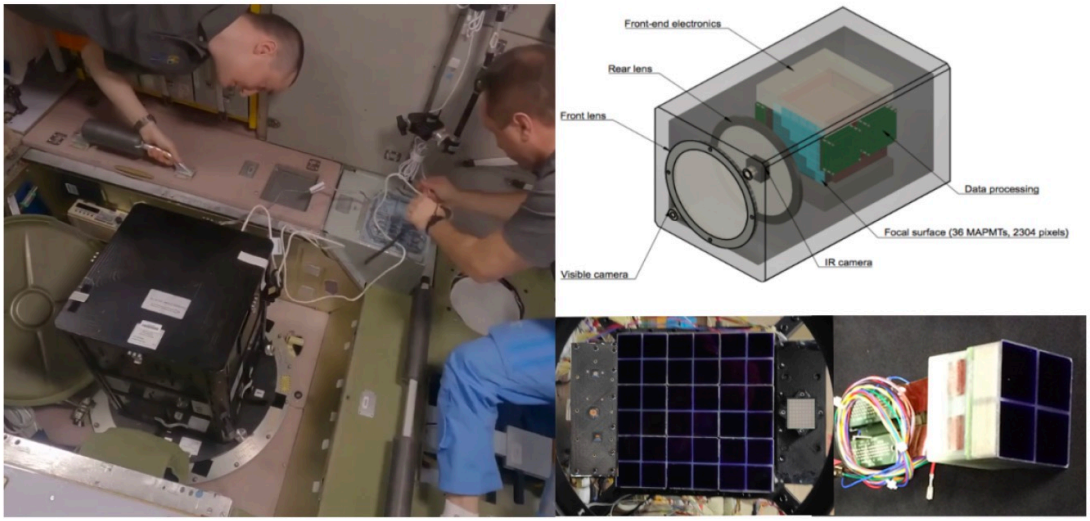

Figure 3: ***Left****: Mini-EUSO installed inside the ISS on the nadir-facing UV transparent window of the Zvezda module by two cosmonauts.* ***Right-top****: schematic view of the instrument.* ***Right-bottom****: the focal plane composed of a* 6×6 *array of Multi-anode Photomultiplier Tubes (MAPMT's) and a close-up of a single* $2x2$ *module.*

References

1. JEM-EUSO Official web site: https://www.jemeuso.org

2. A. Olinto et al. (POEMMA Collaboration): *The POEMMA (Probe of Extreme Multi-Messenger Astrophysics) observatory*; Journal of Cosmology and Astroparticle Physics (JCAP) **06** (2021) 007

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4. Gruppo Italiano SPB2, "Proposta alla Commissione Scientifica Nazionale II INFN di partecipazione italiana alla missione NASA SPB2 (Super Pressure Balloon 2)", Documenti della CSNII, Riunione del 16-20/9/2019

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