Proc. 10th Int. Workshop on Very High Energy Particle Astronomy in 2019 (VHEPA2019)
JPS Conf. Proc. **39**, 011005 (2023)
https://doi.org/10.7566/JPSCP.39.011005

Overview of the POEMMA mission and the JEM-EUSO sub-missions

Y. Takizawa[1*] for the JEM-EUSO collaboration

[1*]*RIKEN, Saitama 351-0198, Japan*

**E-mail: takky@riken.jp*
(Received November 8, 2019)

The main goal of the JEM-EUSO group is to solve the mystery of the origin of Ultra-High Energy Cosmic Rays utilizing space-based missions. The JEM-EUSO group promotes many kinds of missions from the ground, stratospheric balloons, and space, such as EUSO-TA, EUSO-Balloon, EUSO-SPB1, EUSO-SPB2, Mini-EUSO, K-EUSO, and POEMMA. This paper describes the current status of these missions.

KEYWORDS: UHECRs, Neutrinos, EUSO, EUSO-TA, EUSO-Balloon, EUSO-SPB1, EUSO-SPB2, Mini-EUSO, K-EUSO, POEMMA

1. The JEM-EUSO program

The origin and acceleration mechanisms of Ultra-High Energy Cosmic Rays (UHECRs) are one of the mysteries in astroparticle physics. The main aim of the JEM-EUSO group is to solve this mystery by utilizing space-based missions. Recently, the JEM-EUSO group has promoted many kinds of missions from the ground, from stratospheric balloons and space (Fig. 1). Therefore, “JEM-EUSO” is redefined as the Joint Experiment Missions for Extreme Universe Space Observatory. JEM-EUSO means “the Extreme Universe Space Observatory on the Japanese Experiment Module of ISS” and all missions use EUSO technologies. Our key technologies are super-wide-field optics and an extensive array of sensors with high spatial resolution and high speed to detect UV fluorescence photons from air showers by UHECRs in the night atmosphere. This paper describes the current status of all missions (EUSO-TA, EUSO-Balloon, EUSO-SPB1, EUSO-SPB2, Mini-EUSO, K-EUSO, and POEMMA).

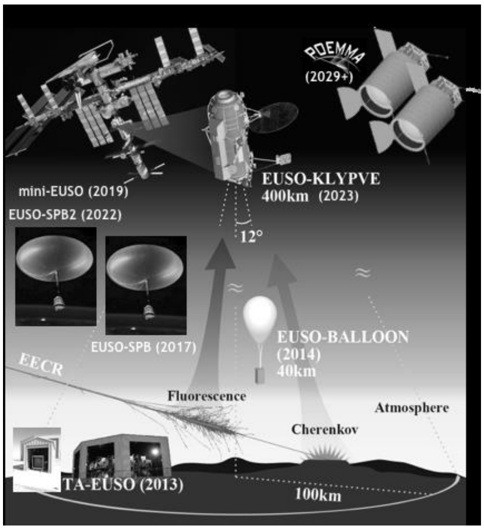

Fig. 1. The JEM-EUSO program

2. The JEM-EUSO missions

2.1 EUSO-TA

EUSO-TA is a telescope on the ground with a 1 m^2 squared aperture (Fig. 2). It is installed at Black Rock Mesa, Utah, USA, in front of a fluorescence detector (FD) of the Telescope Array (TA) experiment. The location can observe artificial lights from the TA's Central Laser Facility (CLF) and the Electron Light Source (ELS). EUSO-TA experiment is a good test bench to observe artificial light and cosmic ray events and to test our technology, such as optics components, detectors, and calibration systems for future space-based missions. The two Fresnel lenses are fabricated from UV-transmitting polymethyl-methacrylate (PMMA). The lenses focus on the 170 mm×170 mm Photo Detector Module (PDM). The PDM has 6×6 Multi-Anode Photomultiplier Tubes (MAPMTs), each containing 64 pixels. The total pixel number of PDM is 2304. The nominal high voltage of the MAPMTs is 1000 V. The time resolution is 2.3 usec, called the Gate Time Unit (GTU). PDM has a ring buffer memory of 128 GTUs. The EUSO-TA optics and the telescope frame were installed in March 2013. A PDM was installed at the end of FY 2015. In the first step, EUSO-TA observed stars to confirm the point spread function (PSF) and the field of view (FOV). The PSF is 2.62 pixels (FWHM), and The FOV is 10.6° ±0.3°. They meet the design requirement for observing UHRCR showers. EUSO-TA run five observational campaigns, four in 2015 and one in 2016. More than 136 hours of observation were performed using TA FD external trigger of UHCER events. Nine UHECR events have been identified. Their distances from the detector vary between 0.8 and 9 km, while the energy is between $10^{17.7}$ – $10^{18.8}$ eV, according to TA observation. EUSO-TA observed several "slow" events, such as stars, meteors, and planes. More detailed description of EUSO-TA can be found in the ICRC paper of Lech Piotrowski et al. [1].

Fig. 2. EUSO-TA photo in front of Telescope Array Florescence detector at Black Rock Mesa.

2.2 EUSO-Balloon

EUSO-Balloon is the first Balloon flight mission of the JEM-EUSO group led by the French EUSO team by using the same type of EUSO-TA optics and PDM (Fig. 3). EUSO-Balloon observes nadir direction from 38 km altitude. The main aims are to confirm the UV background level and to detect tracks of UV light by using a UV laser and UV flashers (LED and Xe lamps) on board a helicopter that flew and followed the balloon for over two hours at an altitude of 3 km. On August 25, 2014, on a moonless night, EUSO-Balloon was launched from Timmins Stratospheric Balloon Base (Ontario, Canada) by the balloon division of the French Space Agency CNES. The total observation time was 8 hours during the entire astronomical night. The UV background was observed from various ground features and the detection of hundreds of laser tracks shot from the helicopter to confirm the ability to detect Extensive Air Showers from above. More detail about EUSO-balloon is described in the ICRC paper of the JEM-EUSO Collaboration [2].

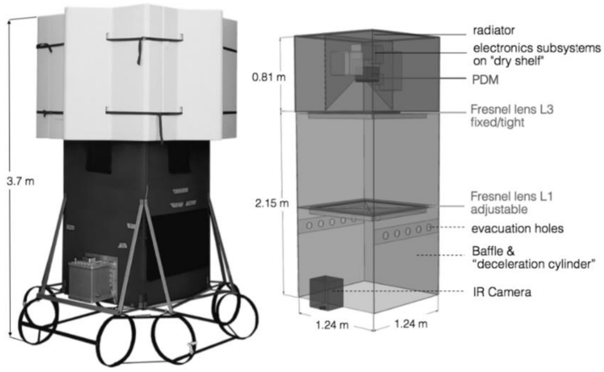

Fig. 3. The EUSO-Balloon instrument [2].

2.3 EUSO-SPB1

The Extreme Universe Space Observatory on a Super Pressure Balloon (EUSO-SPB1) mission is another balloon flight mission using the same type of EUSO-TA optics and PDM led by the USA EUSO team as a mission of opportunity on a NASA SPB (Fig. 4). The EUSO-SPB1 observes UV light emitted by extensive air showers above the energy threshold of $3\text{x}10^{18}$eV. The EUSO-SPB1 was launched at 23:30 UTC on 24th April 2017 from Wanaka, New Zealand. This flight was the 3rd Super Pressure Balloon test flight. A goal of the NASA SPB test is to reach a flight duration of 100 days. However, the EUSO-SPB1 flight was 12 days over the Pacific Ocean due to developing a leak that took over 27 hours of data. Because the mission was early terminated after the balloon developed a leak and could not keep altitude. Any cosmic ray candidates could not be found. This result is in agreement with a simulation study performed after the flight. The EUSO-SPB2 is planned to launch as a follow-up mission of SPB1 in 2022. Further results about EUSO-SPB1 can be found in the ICRC paper of the J. Eser et al. [3].

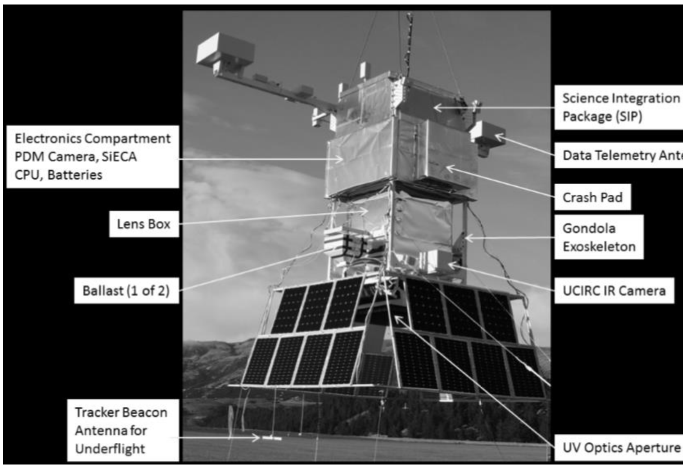

Fig. 4. The EUSO-SPB1 instrument [3].

2.4 EUSO-SPB2

The Extreme Universe Space Observatory on a Super Pressure Balloon II Mission (EUSO-SPB2) is a pathfinder for a next-generation space observatory of "the Probe Of Extreme Multi-Messenger Astrophysics (POEMMA)" for multi-messenger astrophysics. Furthermore, the R&D of the EUSO-SPB2 will be applied to the Klypve-Extreme Universe Space Observatory (K-EUSO) mission (Fig. 5) which is described in the later section. The EUSO-SPB2 optics is a ~1/11 scaled-down version of the POEMMA Schmidt-based optics. EUSO-SPB2 will accommodate two 1 m diameter aperture telescopes, one to detect UV fluorescence photons from UHECR showers and the other to detect Cherenkov photons (UV/VIS) from PeV cosmic ray showers. The optical background will be investigated for ντ detection in the earth's limb from 33 km altitude. The launch date is planned for 2022. Photodetectors are PDM for UHECRs and SiPMs for Cherenkov emissions, like POEMMA. The estimated event rate will be 0.2/hour with a trigger threshold of about 1 EeV in the nadir observation with the fluorescence telescope. When the telescope is pointed toward 30° below the horizon, the estimated event rate will be 0.09/hour with 10 EeV threshold. More details about EUSO-SPB2 are described in the ICRC paper of L. Wiencke et al. [4].

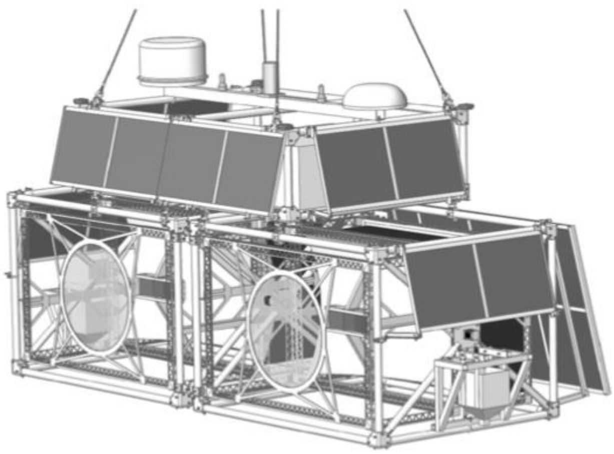

Fig. 5. Preliminary design of the EUSO-SPB2 [4].

2.5 Mini-EUSO

Mini-EUSO (UV-Atmosphere in Russian program) telescope is installed on a nadir-facing UV transparent window inside the Russian Zvezda module of ISS (Fig. 5). Mini-EUSO will observe the night atmosphere in the UV range (300 - 400 nm) to study many kinds of atmospheric events such as not only UV background for future space-based EUSO mission but also Transient Luminous Events (TLEs), meteors and marine bioluminescence. Furthermore, searching for UHECRs above 10^{21} eV and Strange Quark Matter (SQM) has challenging objectives. Mini-EUSO telescope has a large field of view (44°) using two double-sided Fresnel lenses. The light is focused onto a PDM, the same as EUSO-SPB1. In addition, Mini-EUSO has two supplementary cameras for complementary measurements in the near-infrared (1500 - 1600 nm) and visible (400 - 780 nm) range and an 8×8 SiPMs imaging array. Mini-EUSO was launched from the Baikonur Cosmodrome (Kazakhstan) on 22nd August 2019. Mini-EUSO was installed on the UV-transparent window of the Zvezda module and got the first light on 7th October 2019. We confirmed that the Mini-EUSO system is working perfectly. The Mini-EUSO will observe for three years or more. More details are described in the ICRC paper of M. Casolino et al. [5].

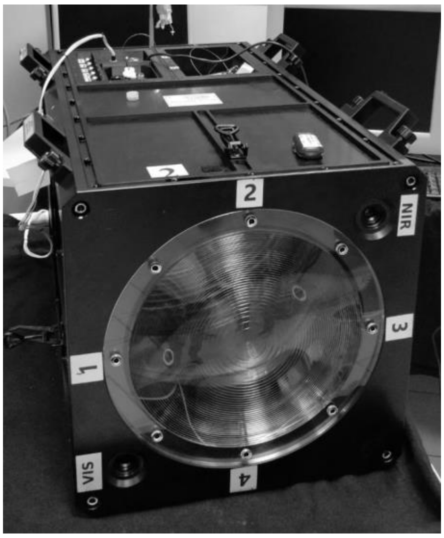

Fig. 6. Left: The Mini-EUSO instrument [5] and Right: The Mini-EUSO was launched from the Baikonur Cosmodrome.

2.6 K-EUSO

Klypve-EUSO (K-EUSO) will be the first full-scale telescope from space for UHECR studies (Fig. 6). The original KLYPVE mission in Russia was based on technologies of Tatiana-1, Tatiana-2, and TUS. The KLYPVE, named after the Russian word "ultra-high energy cosmic rays," was selected by the Space Program of the Russian Federation. K-EUSO is an upgraded telescope of KLYPVE that uses EUSO technologies such as large plastic lenses and PDMs. The optical design has been changed from a prime focus reflecting optics design to a Schmidt optics design to get good PSF, smaller than 2.88 × 2.88 mm, and a large field of view, 40° full-FOV, simultaneously.

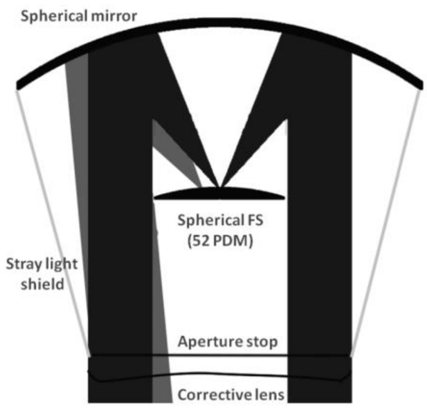

Fig. 7. Schematic view of the K-EUSO Schmidt optics [6].

The purpose of K-EUSO is to observe UHECRs from space with a large aperture area and to study of the anisotropy in the arrival direction of UHECRs on the celestial sphere. Furthermore, K-EUSO will observe intrinsic phenomena to the Earth's atmosphere or induced by the meteoroids incoming from space and search for strange quark matter. K-EUSO will be attached to the Russian MRM-1 module onboard ISS. It will detect UHECRs above 2×10^{19} eV with about four times larger annual exposure than that of the Pierre Auger Observatory., Thanks to the orbit of ISS, the exposure will be flat over the whole sky. Phase A study in Russia, including the launch and accommodation on the ISS, was finished successfully in June 2019. K-EUSO is planned to launch in 2023 or later and operate for two years (minimum) and more than six years if the ISS program is extended. More details about K-EUSO are described in the ICRC paper of M. Casolino et al. [6].)

2.7 POEMMA

The Probe Of Extreme Multi-Messenger Astrophysics (POEMMA, Fig. 8) is designed to observe cosmic neutrinos above 20 PeV and UHECRs above 20 EeV over the whole sky. The POEMMA will make a loose formation flight of two satellites for the stereo observation. Each telescope has a 3.3-meter aperture full-FOV (45°) Schmidt optics with a 4 m primary mirror. The hybrid focal surface includes a fast (1 μs) UV camera for fluorescence observations and an ultrafast (10 ns) optical camera for Cherenkov observations. POEMMA will open new multi-messenger windows to the universe's most energetic events to study new astrophysics and particle physics. The main goals are to discover the origins of cosmic rays with energies above 10^{18} eV and to observe cosmic neutrinos with energies above 20 PeV, including the full-sky coverage of the celestial sphere. POEMMA has different observation modes: a stereo fluorescence observation mode close to the nadir for UHECR observations and Earth-limb viewing mode for Cherenkov observation to search for optical Cherenkov signals of upward-moving EASs generated by τ-lepton decays produced by ν_τ. The limb observing mode can observe neutrinos and UHECRs due to the POEMMA focal surface hybrid design (PDMs and SiPMs array). POEMMA will observe UHECRs with about ten times larger annual exposure than ground fluorescence telescopes. The launch date will be 2029 or later if POEMMA is selected. More details about POEMMA are described in the ICRC paper of the A. Olinto et al. [7].

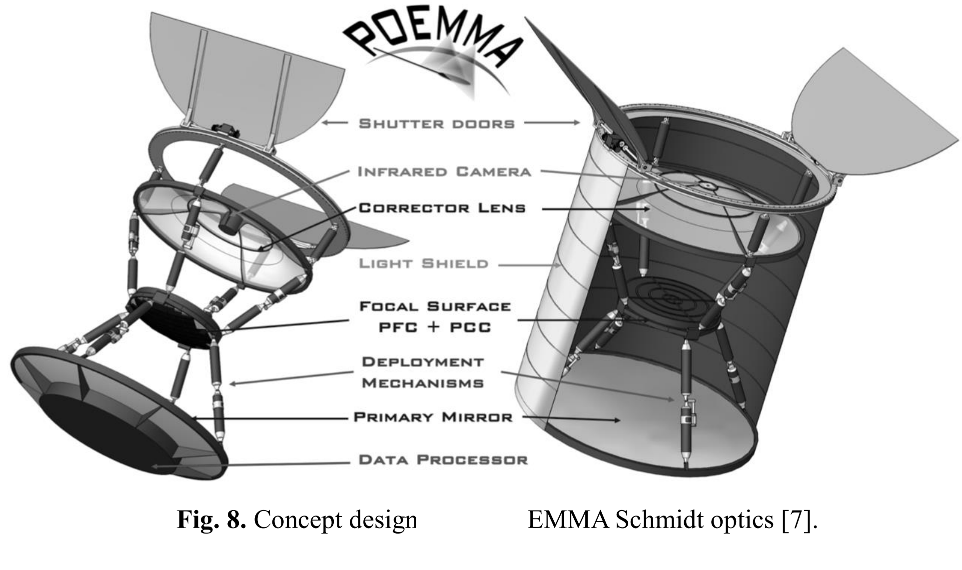

Fig. 8. Concept design EMMA Schmidt optics [7].

3. Conclusion

We have developed several optics and photodetector modules of 36 MAPMTs through sub-missions such as EUSO-TA, EUSO-Balloon, EUSO-SPB1, EUSO-SPB2, Mini-EUSO to reach high technology readiness level for the space missions. These technologies provide full-scale space missions such as K-EUSO and POEMMA.

References

[1] Lech Wiktor Piotrowski for the JEM-EUSO collaboration: proceedings of the ICRC 2019, 388, (2019).
[2] The JEM-EUSO Collaboration: proceedings of ICRC 2015, 322, (2019).
[3] J. Eser, A. Olinto, L. Wiencke et al: proceedings of ICRC 2019, 247, (2019).
[4] L. Wiencke and A. Olinto: proceedings of ICRC 2019, 466, (2019).
[5] M. Casolino et al.: proceedings of ICRC 2019, 212, (2019).
[6] M. Casolino et al.: proceedings of ICRC 2017, 368, (2017).
[7] Angela V. Olinto et al.: proceedings of ICRC 2019, 378, (2019)