EUSO-Super Pressure Balloon flight: results from the first flight and perspectives for SPB2

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1 Introduction

The aim of the JEM-EUSO program is the study of Ultra High Energy Cosmic rays (UHECR) from space observing the UV light emitted by Nitrogen molecules that have been excited by Extensive Air Showers propagating in the Earth's atmosphere. A space based detector for UHECR research has the advantage of a much larger exposure, a uniform coverage of the celestial sphere and the observation of Earth's atmosphere at a relatively constant thickness. First observations from space would be complementary to those on ground, which have the advantage of using hybrid detection techniques, higher sampling rate and a finer measurement of the shower development thanks to the higher mass and power available. UHECR space missions can potentially reach exposures several orders of magnitude higher than those of ground based observatories – for example in a geostationary orbit satellite – allowing to study in detail the cosmic ray origin and nature at the highest energy.

The design of a space-based telescope for UHECR meeting the strong constraints of power, mass, size and bandwidth required by space detectors, has prompted the development of a number of new technologies from optics to sensors, front-end and read-out electronics.

In this work we focus on the balloon-borne detectors that employ the principles of observation and technologies which will be used in the large exposure EUSO mission, namely: a) EUSO-BALLOON, a stratospheric flight successfully carried in 2014 from Timmins (CA); b) EUSO-SPB, a NASA Ultra long Duration Balloon flight, launched from New Zealand (2017); c) EUSO-SPB2 a new Superpressure Ballon Flight expected to fly in 2021. All steps are summarized in Figure 1.

2 The EUSO balloon flights

2.1 EUSO-BALLOON

The EUSO-BALLOON flight took place in August 2014 from Timmins, Canada[1]. The CNES (French Space Agency) balloon carried an instrument similar to EUSO-TA, pointed towards nadir from a float altitude of about 40 km. The objective of EUSO-BALLOON was to perform a full end-to-end test of all the main subsystems in a near space environment. In this way it was possible to test the key technologies and methods featured in its future space mission and raise their Technological Readiness Level (TRL).

The total mass of the payload was about 320 kg. The optical bench contained two Fresnel lenses made from 8 mm thick PMMA with a front surface of 100×100 cm each. The instrument booth was made as a watertight capsule using front Fresnel lens as a porthole[1]. Besides the PDM and associated electronics, similar to the ones developed for the main mission, the instrument booth housed the telemetry system (SIREN), CNES specific instrumentation (ICDV, Hub), and two battery-packs of 28 V – same voltage that will be used on ISS for JEM-EUSO. Ancillary payloads included an infra-red camera, a visible light camera and a Geiger particle counter. During the flight we were able to observe the Earth's albedo from different ground types (forest, town, lakes), as is shown in Figure 2 (left). Furthermore, a NASA-funded helicopter

[1] This protected the electronics in the water landing, with the payload being successfully recovered.

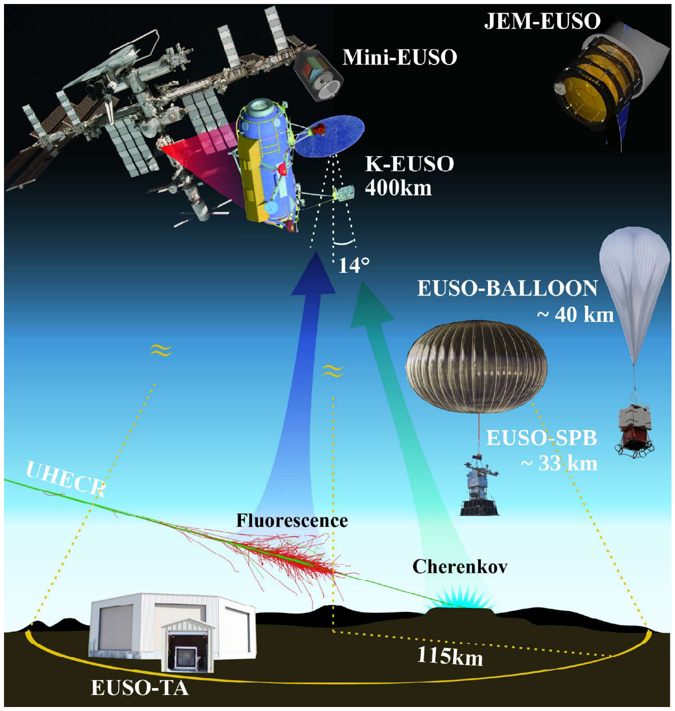

Figure 1: The detectors of the JEM-EUSO program: a) EUSO-TA: Ground detector installed in 2013 at Telescope Array site. b) EUSO-BALLOON: First balloon flight from Canada, August 2014; EUSO-SPB - Long duration NASA flight. SPB-1, New Zealand, 2017, SPB-2 New Zealand 2021; c) MINI-EUSO, Earth observation telescope to be installed inside the International Space Station in 2018; d) K-EUSO (2022): Reflector telescope to be installed on Russian section of International Space Station (ISS). e) Large size telescope (JEM-EUSO / POEMMA > 2028).

was following the balloon trajectory, generating artificial light using Xenon lamps, and mimicking an EAS using a laser beam. Both the Xenon flashes and the laser shots were successfully detected by the apparatus (Figure 2, right). All system worked correctly and according to specifications. The PDM was functioning for the whole time, and the high voltage power supply was stable and operated with no trouble in the residual atmosphere of 40 km altitude.

2.2 EUSO-SPB

In 2017 EUSO-SPB flew from New Zealand for a long duration flight (Figure 3, 4) of 12 days. This flight employed NASA's new Super Pressure Balloon (SPB) technology which is based on a sealed balloon to achieve circum-Antarctic flights with a duration of more than a month. The first technological test flight was successfully performed by NASA in 2015. The EUSO-SPB includes a new set of lenses with improved parameters and a new PDM with higher gain PMTs . Use of a new ASIC chip – SPACIROC 3 – increases the saturation level from ~ 30 to more then 150 photoelectrons. The experiment houses also two auxiliary devices – an infra-red camera and a silicon photomultiplier based detector with 256 pixels.

The long duration flight was devoted to detect several EASs by looking downward from the altitude of about 33 km. Its low elevation compared to JEM-EUSO (33 km vs 400 km), and the lens size cause the balloon energy threshold for shower detection to be about 3×10^{18} eV. The field of view of about $11^\circ \times 11^\circ$ results in $\sim 7 \times 7$ km instantaneous aperture on the ground and a spatial resolution better than 150 m.

EUSO-SPB optics and electronics have been extensively tested on-ground, including measurements performed in TA site in Utah, along EUSO-TA. Observations of stars and lasers has been performed, as well as absolute calibration. The detector passed two hang and compatibility tests required by NASA. The detector flew for 12 days in April 2017[2], see Figure 5 for a plot of its trajectory.

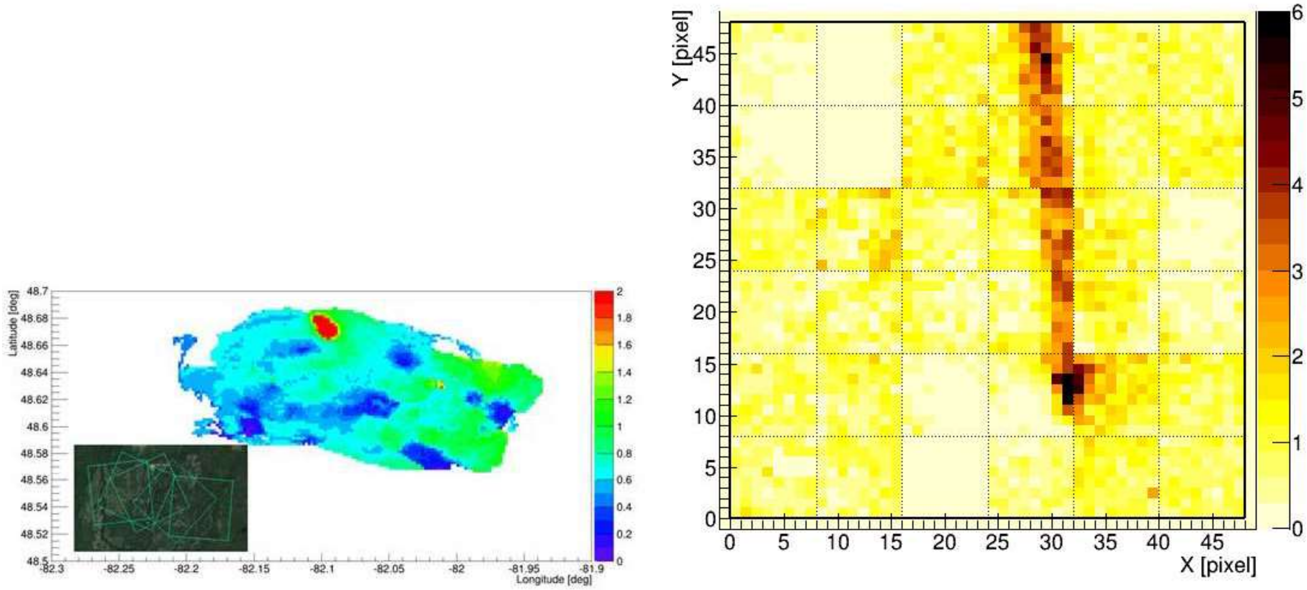

Figure 2: Left: UV background map (arbitrary units) in the region of Timmins. The red spot on top is the light from a mine. Right: experimental data registered by the EUSO-BALLOON of a laser shot from an helicopter flying below the gondola. The picture is a sum of 9 frames (22.5 μs total time) during which the signal was moving from bottom to the top. Colour scale shows detector counts.

Figure 3: Left: The EUSO-SPB payload in the flight configuration during standalone hang tests in Palestine, Texas. Top right: the electronics with the PDM focal surface in the centre. Bottom right: the Fresnel lens optics.

3 EUSO-SPB2

Balloon flights within JEM-EUSO framework will continue with EUSO-SPB2 [3], a long duration, super pressure balloon of NASA. The payload will be equipped with 3 telescopes. One telescope will be devoted to UHECR measurements using the fluorescence technique. The FS will be equipped with 3 PDMs to increase the UHECR statistics. Optics with more throughput (Schmidt camera) and a reduced GTU (1 μs) will lower the energy threshold of the instrument. The FS of the other two telescopes will be based on silicon

Figure 4: The EUSO-SPB payload (left) moments before launch from New Zealand.

photomultipliers and a dedicated electronics to detect the Cherenkov emission in air by UHECR-generated EASs. In perspective they will test the capability to detect EAS generated by ν_τ interacting in the Earth crust. For this observation the detector will be pointing slightly below the limb. EUSO-SPB2 is expected to fly by 2021 from Wanaka, New Zealand on a NASA Super Pressure Balloon.

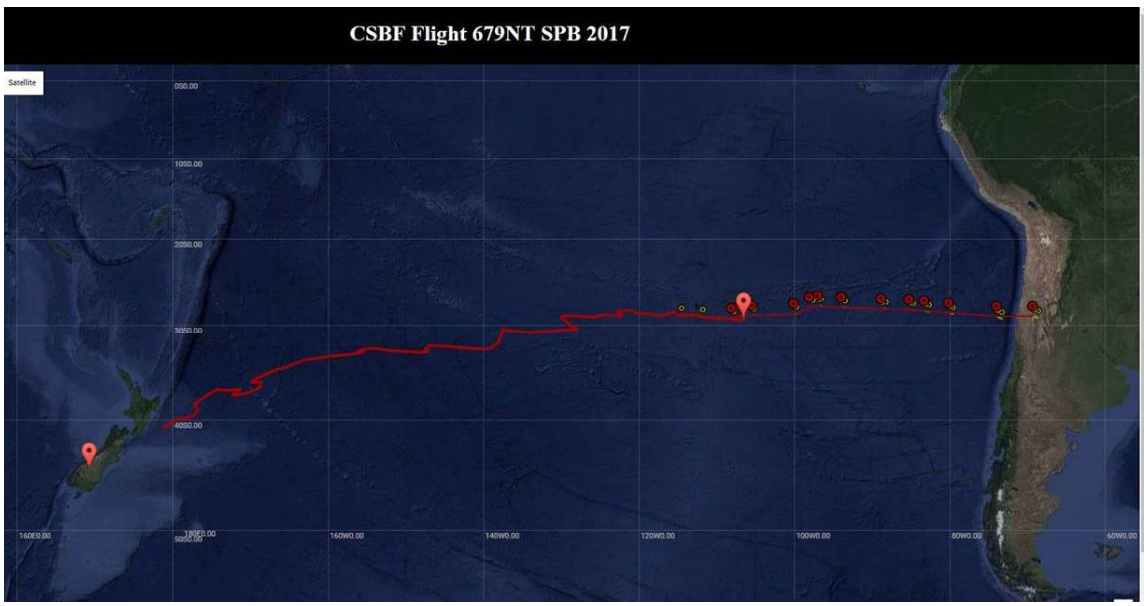

Figure 5: Trajectory of EUSO-SPB detector after its launch from New Zealand.

Acknowledgments

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