Results of the first EUSO-Balloon flight

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Abstract. EUSO-Balloon, a balloon-borne diffractive fluorescence telescope, was launched by the French Space Agency CNES from the Timmins base in Ontario (Canada) on August 25th in 2014. After reaching the floating altitude of about 38 km, EUSO-Balloon imaged the UV background for more than 5 hours before descending to ground using the key technologies of JEM-EUSO. A detailed and precise measurement of the UV background in different atmospheric and ground conditions was achieved. The instrument proved the capability of detecting Extensive Air Showers (EAS) by observing laser tracks with similar characteristics. This contribution will summarise the first results obtained concerning all the topics described above.

1. Introduction
The EUSO-Balloon experiment is a pathfinder mission for JEM-EUSO [1]. The main objectives are to perform: a) a full scale end-to-end test of all the key technologies and instrumentation of JEM-EUSO; b) a detailed and precise measurement of the UV background in different atmospheric and ground conditions; c) a first measurement of air shower tracks from the edge of space. For the first flight, EUSO-Balloon was launched by CNES from the Timmins base in Canada on August 25th, a moonless night in 2014 [2]. After reaching the floating altitude of \( \sim 38 \text{ km} \), EUSO-Balloon imaged the UV background in the wavelength range of 290 - 430 nm for more than 5 hours before descending to ground. The main part of the telescope consists of two 1 m\(^2\) sized Fresnel lenses and a focal surface (FS) filled with 36 Multi-Anode Photomultiplier Tubes (MAPMT, Hamamatsu R11265-103-M64) forming 9 Elementary Cell units (EC unit), each of which consist of 4 MAPMTs with three layers of PCB, and front-end electronics (FEE) consisting of 36 SPACIROC1 readout ASIC chips [3]. The spatial and temporal resolution of the detector were \( \sim 130 \text{ m} \) and 2.5 \( \mu \text{s} \) determined by so called Gate Time Unit (GTU) respectively. The full field of view (FoV) in nadir mode was about 11°. The UV data was complemented by infrared (IR) images taken by a stand-alone bi-spectral IR camera on-board EUSO-Balloon [4]. Fig.1 shows the flight trajectory of EUSO-Balloon. EUSO-Balloon flew over a variety of ground surfaces including different types of soil and vegetation, wetlands, open water, urban and industrial areas to characterise the background intensity in several conditions. EUSO-Balloon also crossed areas characterised by scattered and broken clouds at low altitudes (around 700 - 800 hPa) and thick ice clouds at higher altitudes (around 200 - 300 hPa). All these variety of situations turned out to be an ideal case to test the conditions that JEM-EUSO is expected to view during its operation on the ISS orbit. A calibrated light source system consisting of a pulsed UV laser and two UV flashers (LED and Xe) on-board a Bell 212 helicopter flew below EUSO-Balloon for more than 2 hours between 03:31 and 05:52 UT to calibrate and reproduce air shower tracks artificially. The wavelength of these light sources were chosen to reflect the fluorescence emission of electrons in the air. The nominal laser energy was equivalent to the...
Figure 1. EUSO-Balloon flight trajectory on Aug 25, 2014 UT. The flight started from Timmins airport and ended in a tiny lake on the left part of the image. Balloon elevation during the flight is indicated in the legend. EUSO-Balloon imaged mostly urban areas in the first part while it flew over mostly forests and lakes for the second part of the flight.

light emitted by a 100 EeV EAS. The light sources were fired \(\sim 150,000\) times with two energy settings (see [5, 6] for details). The laser energy was changed every two minutes between 15 mJ and 10 mJ, fired at a rate of 19 Hz to guarantee random coincidences with the balloon readout (20 Hz). An example of such events is shown in Fig.2. The left panel shows the integrated counts in a packet (128 GTUs) which includes all the light sequence. The LED and Xe-flasher signals can be seen at around a pixel\((X,Y=5,25)\). The right plot shows the evolution of the signal in a box of \(3 \times 3\) pixels around the pixel\((X,Y=5,25)\) in the packet. The LED light appears between GTU 19 - 31, followed by the laser shot at GTU 55 - 56 and by the Xe-flasher between GTU 58 - 65. An afterpulse from the Xe-flasher occurs between GTU 70 - 73.

Figure 2. Left: Image of helicopter event; counts of each pixels integrated for the entire packet (128 GTUs). UV-LED and Xe-flasher signals can been seen at around the pixel\((X,Y=5,25)\). Right: Evolution of summed counts in \(3 \times 3\) pixel-box around \((X,Y=5,25)\) in the packet.

EUSO-Balloon recorded and stored nearly 260,000 packets, corresponding to \(\sim 33\) million frames in total, on the two redundant hard-drives on-board. Currently the analysis is ongoing to infer the different information: study of the performance of different parts of the detector; the detector response to the UV flasher and laser events; UV radiation from the atmospheric air and ground in various conditions such as clear and cloudy atmosphere, grass, forests, lakes and city lights.

2. Technological Aspects
The main objective of the first flight was to demonstrate a full scale end-to-end test of all the key technologies and instrumentation of JEM-EUSO detector. The acquisition system performed well with an integrated data taking time of 15,300 s of the total flight time of 18,900 s (\(~81\%)\).
The trigger was provided externally by CPU at a rate of ∼20 Hz. For a total of 258,592 events (∼83 s) were recorded, each of which is composed by 128 frames (2.5 µs for each). Such events are distributed uniformly along the flight, which allows a detailed temporal resolution of the light intensity on the various locations. Various configurations of the preamp gain and thresholds on the photon counting were applied and tested during the flight. The FS detectors and FEE behaved rather well. We had a failure of one EC unit and one ASIC. In total, 5 over 36 MAPMTs were not available for the data analysis. A detailed calibration of the 36 MAPMTs (2,304 pixels in total) was performed before and repeated after the flight [7]. About 25% of the active pixels were selected based on the performance for an accurate measurement of the UV background intensity. The global efficiency and point spread function (PSF) of the optics were calibrated before and after the flight at IRAP Toulouse. The PSF was verified during the flight using LED and flasher images. The IR camera recorded about 350 images during the flight to obtain the Cloud Top Height (CTH) and cloud coverage in the FoV with two Long Wave InfraRed (LWIR) bands centred at 10.8 µm and at 12 µm. The performance is under evaluation and the calibrated data will be used to calculate the CTH of all the clouds in the camera FoV.

3. UV background measurement

![Image](image1.png)

**Figure 3.** Top: Relative UV intensity map in logarithmic scale with relative values to the mean of UV background intensity over reference area “A”. Bright areas with high intensity represent artificial light in Timmins and neighbourhoods, mines and airport. Red and light blue areas are related to cloud coverage. Dark blue areas indicate the lowest values of UV background. Bottom: IR radiation map in arbitrary units, relative to the mean of IR radiation over reference area “A”. Values were changing in time due to movement of clouds and motion of EUSO-Balloon.

The main scientific objective of the EUSO-Balloon flight is the absolute measurement of the UV background intensity. This is relevant to JEM-EUSO as it is one of the key parameters to estimate the exposure curve as a function of energy [8]. EUSO-Balloon uses an optical refractive system with very fine spatial and temporal resolutions, which allows a much better determination of the space and time variations of the UV intensity than the measurements performed in the past by BaBy [9], NIGHTGLOW [10] and Sakaki et al. [11]. A detailed description of the analysis and results to infer the UV background intensity of EUSO-Balloon is reported in [12]. The conversion of digital counts of the pixels to UV intensity has to take into account many aspects such as entrance aperture of the optics and its throughput, MAPMT
detection and filter efficiencies, pixel FoV and GTU duration, and many of such parameters are wavelength dependent. An accurate determination of all these parameters is currently ongoing and, therefore, the results obtained so far have to be considered preliminary. 

The top panel of Fig.3 shows a map of relative UV background intensity in logarithmic scale. The bright areas with high intensities represent artificial light in the city of Timmins and its neighbourhoods, mines and airport. The red and light blue areas are related to cloud coverage (see the bottom panel of Fig.3). The dark blue areas indicate the lowest values of UV background. Analysis of the clear sky region showed that there are no significant variations in the UV background intensity from different ground surfaces such as forests and lakes. In a pixel, the intensities of UV emission from such different surfaces are the same within measurement uncertainties. As a whole, there is an anti-correlation between the UV flux from a given direction and the IR radiation from the same direction in presence of clouds, where the UV intensity can rise up to by a factor of two, while this effect is not present in the case of clear sky conditions. Qualitative explanation for the anti-correlation is that clouds with higher optical depth are more efficient in scattering the UV radiation and producing an albedo which increases the overall intensity of the UV background in the cloudy pixels. UV radiation is absorbed in the atmosphere and higher altitude clouds have higher albedo (at equal optical depth). Higher clouds are also colder and produce low IR radiation. In general, the combination of the measurement of IR emission and UV albedo of the clouds provides a tool for characterisation of the clouds, which should improve the quality of reconstruction of EAS occurring in the cloudy sky. In presence of urban areas, the UV light intensity rises even higher than 10 times compared to green areas. Such a relative behaviour is essentially in agreement with measurements performed by BaBy.

4. Helicopter events, IR data and other analysis

The helicopter events revealed to be extremely useful to understand the performance of the system (optics, photodetector and FEE) and the capability of EUSO-Balloon to detect and reconstruct EAS-like events. The EUSO-Balloon configuration has been implemented inside the JEM-EUSO OffLine package. Laser tracks are used to test the reconstruction algorithms. The analysis currently in use is based on the geometry of triggered pixels to constrain the evolution of an event on the so called Shower Detector Plane (SDP). The shower geometry is firstly guessed by the pointing direction of selected pixels, then differences between an expected and the observed time for the signals going through the pixels are compared to constrain further the geometry. In this way, the distance of closest approach ($R_p$) and the angle from horizontal to $R_p$ ($\Psi_0$) are determined to provide information on the shower axis. The geometry is then defined better using the known position of the helicopter. The timing fit of a typical laser event (left) and the reconstruction of directions of the laser shots (right) are shown in Fig.4 (See [5] for details). Note that the readout period of 2.5 $\mu$s is optimised for JEM-EUSO for the detection of EAS at $\sim$400 km distance instead of $\sim$35 km as in the case of EUSO-Balloon. The fact that EAS-like

![Figure 4.](image-url)
tracks can be reconstructed also in EUSO-Balloon is quite promising in view of JEM-EUSO. Performance of the First Level (L1) Trigger of JEM-EUSO [13] is tested offline analysing the EUSO-Balloon data. Around 300 laser tracks were detected. The system showed to be flexible enough to adapt its response to the very variable background conditions during the night. The trigger rate on UV background, clouds, cities and so on satisfies the JEM-EUSO requirements. No EAS event is recognised so far among the triggers, which is however expected as the data acquisition was based on a synchronised clock. The analysis of IR images taken during the flasher events is also ongoing. The optical depth of clouds is inferred by comparing the flasher luminosities with the signal recorded by EUSO-Balloon, in clear and not clear conditions.

5. Conclusions and Perspectives
The EUSO-Balloon flight in 2014 was successful. A full scale end-to-end test of key technologies and instruments of JEM-EUSO detector was performed. We achieved a detailed and precise measurement of UV background in various atmospheric and ground conditions. The analysis is in progress to provide the absolute intensities. The detection of laser events proved the feasibility of the observation of EAS-like events. The EUSO-Balloon is currently being refurbished for the second flight of much longer duration [14]. In parallel, a prototype of JEM-EUSO is being developed to measure the UV background and atmospheric phenomena from ISS altitude [15].

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