The Beautiful Success of EUSO-Balloon

The JEM-EUSO Collaboration

August, 24th 2014, 8:53 pm. As the sun sets and the sky lights up in changing hues of ochre and rose, a stratospheric balloon suddenly takes off and rises at impressive speed above Timmins, Ontario (Canada). A payload of about 450 kg is following a hundred meters below. Its name is EUSO-Balloon, a mission approved and funded by the French space agency, CNES, and also supported by national agencies and space agencies of the countries directly participating to the hardware (France, Germany, Italy, Japan, Korea, Mexico, Poland, Spain, USA).

It is the result of over two years of development by a large team of cosmic-ray physicists and engineers within the international JEM-EUSO collaboration. The instrument itself is a relatively small UV telescope, made of two square Fresnel lenses with a side of 1 meter covering a field of view of ±5 degrees, and a focal surface accommodating 36 multi-anode photomultiplier tubes containing 64 pixels each, equipped with electronics to measure the UV flux in the single photon counting mode, for the highest sensitivity, with a gate time of 2.5 μs. Besides the main instrument, a stand-alone and waterproof infrared camera is on board, to take pictures of the whole field of view and infer the cloud top height from the temperature of the clouds below.

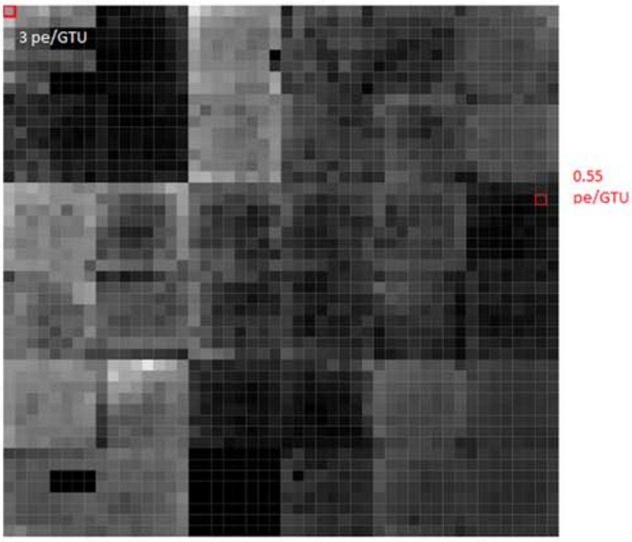
The mission of EUSO-Balloon was to prove the concept of cosmic-ray-induced air shower detection from space, and to measure the UV background coming from the Earth as weel as its variability, for the first time with a focusing instrument and a small pixel size.

The so-called ultra-high-energy cosmic rays (UHECRs) are the highest energy particles known in the universe, with macroscopic energies reaching several tens of Joules! Their very existence is a wonder of Nature and a challenge to astrophysicists, who have been trying for decades to understand their origin and identify their sources. The hope of astroparticle physicists is also to use these UHECRs to obtain new information or derive new constraints about high-energy physics, at much higher energy than can be accessed in man-made accelerators, and eventually to use them as new messengers from the high-energy universe, complementary to photons, in a multi-messenger strategy.

However, in additional to being extremely energetic, the UHECRs are also extremely rare: their flux above 1020 eV is on the order of 1 particle per square meter per… billion year! For this reason, their study requires the development of very large detectors, measured in thousands of square meters! This also implies that the UHECRs are not detected directly, but through the extensive air showers that they generate in the atmosphere, containing up to several hundreds of billions of secondary particles. As these particles cross the atmosphere, they excite molecules, notably dinitrogen molecules, which then de-excite by emitting fluorescence light, mostly in the form of UV lines.

The observation of this fluorescence light by ground-based UV telescopes is a very mature technique. It has been applied on the ground since more than two decades, first by the Fly's Eye collaboration, and then by the HiRes, Pierre Auger and Telescope Array collaborations. The largest area covered to date is ~3000 km2 in the Southern hemisphere, at the Pierre Auger Observatory, and ~700 km2 in the Northern hemisphere, at the Telescope Array site. This appeared not to be enough to identify the UHECR sources, and it is widely believed that gaining one order of magnitude in exposure would lead to very important progress in the field, answering key questions about the existence of small-scale anisotropies in the UHECR arrival directions and about the interest of pursuing further the on-going quest.

A wide community of researchers believe that such a decisive increase in exposure can realistically be achieved only by transposing the fluorescence technique of detection into space. A space-based instrument would also offer the advantage of allowing an almost uniform full-sky coverage, and thus avoid the problems associated with mixing data sets from different instruments or techniques.
The idea has been around since decades, but it is only more recently that a dedicated mission with high-enough performances became technically and strategically attractive. Such a project was embraced by the international JEM-EUSO collaboration, gathering 14 countries over 4 continents. EUSO-Balloon has been conceived and developed as a technological and scientific pathfinder to JEM-EUSO. It involves notably the first implementation of the JEM-EUSO Fresnel optics concept, an innovative Cockcroft-Walton power supply with automatic switches of the PMTs' collection efficiency to allow continuous data taking even in the presence of large variations of the background, as well as dedicated electronics with SPACIROC ASICs and adapted FPGA and complete data processing system. A prototype of the JEM-EUSO infrared camera was also developed and imple mented. Therefore, the success of last month's one-night flight is an important achievement for the development of UHECR studies from space.
The flight itself, jointly operated in Timmins by CNES and the Canadian Space Agency, has been particularly smooth and interesting from the scientific point of view, since different types of grounds could be overflown, as well as regions with and without clouds of different types. This will allow the comparative study of the UV background in different conditions, which was one of the complementary goals of the mission. From the technical point of view, all the subsystems of EUSO-Balloon behaved in flight according to their nominal requirements, and the proof of concept seems to be fully validated. As an additional source of satisfaction, the good behaviour of the instrument could be assessed during the flight itself, thanks to the sample data sent by telemetry, which correspond to about 1% of the total data collected. These data, quickly analysed during the flight, were sufficient to show the changing light level on each pixel, as well as the light of a calibrated UV flasher and the track of a laser shot emitted from a helicopter, which flew under the balloon for about two hours, as a coordinated contribution of NASA to the campaign.



Of course, such happy news are just a few preliminary insights into the wealth of data which now remain to be processed and analysed. Two weeks after the flight, another phase of work is now starting within the EUSO-Balloon and JEM-EUSO collaborations, which expect to present and publish their first results in 2015.
Finally, as an icing on the cake, a bad trick of destiny turned out an interesting fortune: while it was intended to land safely on the ground, EUSO-Balloon ended its flight in the middle of a lake! Fortunately, such an eventuality had been considered and floaters had been added to a specially designed waterproof gondola. As a matter of fact, all the electronics (and the hard disks containing the data!) were found totally dry, ready for a second flight! This is how the EUSO-Balloon flight eventually allowed CNES to demonstrate the water recovery of a balloon-borne scientific pay load! This is also interesting for the JEM-EUSO collaboration, since it opens in principle the possibility of a longer flight over a sea or ocean, where a different type of UV background could be measured (corresponding to a different albedo), and where the fluorescence light of actual cosmic-ray showers could be detected from above for the very first time!