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The Spanish Infrared Camera onboard the EUSO-BALLOON (CNES) flight on August 24, 2014

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The EUSO-Balloon (CNES) campaign was held during Summer 2014 with a launch on August 24. In the gondola, next to the Photo Detector Module (PDM), a completely isolated Infrared camera was allocated. Also, a helicopter which shooted flashers flew below the balloon. We have retrieved the Cloud Top Height (CTH) with the IR camera, and also the optical depth of the non-clear atmosphere have been inferred with two approaches: The first one is with the comparison of the brightness temperature of the cloud and the real temperature obtained after the pertinent corrections. The second one is by measuring the detected signal from the helicopter flashers by the IR Camera, considering the energy of the flashers and the location of the helicopter.

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1. Introduction

JEM-EUSO (Extreme Universe Space Observatory on Japanese Experiment Module) is a novel space-based experiment that will be launched in 2019. Its aim is to observe EAS (Extensive Air Showers) produced by UHECRs (Ultra High Energy Cosmic Rays) and EECRs (Extremely High Energy Cosmic Rays) in an energy range between $10^{19.5}$ eV and 10^{21} eV [1]. Observing from space (this is, with a larger observation area), a larger exposure is achievable [2]. And this is required, due to the small UHECRs flux. The arrival direction map will provide us information on the origin of the UHECRs, probably allowing us to identify the nearest UHECR sources with known astronomical objects. This will allow us to understand their acceleration mechanisms. Moreover, it will help to clarify the acceleration and emission mechanisms, and to confirm the Greisen-Zatsepin-Kuz'min suppression. JEM-EUSO will use the atmosphere as a detector [3]. Therefore, information about properties of the Earth's atmosphere and presence of clouds is highly needed [4]. The telescope includes an Atmospheric Monitoring system (AMS) which provides information on the clouds and aerosol distribution, as well as their optical properties within the telescope Field of View (FoV) [5, 6]. The AMS will consist of an infrared camera (IR), and a LIght Detection And Ranging device (LIDAR).

There are three JEM-EUSO pathfinders at different stages (either functioning or under construction): EUSO-Balloon, EUSO-TA and Mini-EUSO. The objectives of these pathfinder missions are: to perform a full scale end-to-end test of the JEM-EUSO concept and key technologies, to test the electronic components in stratospheric conditions, and to measure the UV background at high altitudes.

2. EUSO-Balloon

EUSO-Balloon is a balloon-borne experiment developed by the JEM-EUSO consortium [7]. Its aim is to test the technologies and methods used in the forthcoming main experiment, through a series of stratospheric balloon flights that have already started in August, 2014. EUSO-Balloon, as the main mission, is an imaging UV telescope. It points towards the nadir from an altitude of about 40 km. It is equipped with one Photo Detector Module (PDM) identical to one of the JEM-EUSO instrument, and three Fresnel lenses which are prototypes of those which will be installed in JEM-EUSO. The instrument will cover a Field of View of $12^\circ \times 12^\circ$ in a wavelength range between 290 and 430 nm. The EUSO-Balloon, as well as the main mission, will have an Infrared Camera to analyze the atmospheric properties along the Balloon flight.

The objectives of the IR camera are:

- To validate the JEM-EUSO IR camera mission concept
- To obtain real data with microbolometer detector (used in JEM-EUSO IR camera).
- To assess the wavelength bands and filters selection.
- To validate and optimize the retrieval algorithms.
- To validate and optimize stereo vision technique.

- To validate and assess part of calibration strategy .
- To validate and optimize temperature retrieval algorithms.

3. EUSO-Balloon IR Camera Design

The IR Camera is a stand-alone subsystem within the balloon, which provides images centered at 10.8 μm and 12 μm (medium infrared), thanks to a ULIS UL 04171 microbolometer and two filters centered in that wavelengths with 0.85 μm of bandwidth. The imaging system is exactly as the JEM-EUSO IR Camera in its BreadBoard Model.

The camera module is the IRXCAM-640 developed to handle the microbolometer ULIS UL-04-17-1 [8]. It incorporates a shutter control. The electronics show a very weak level of noise, which is lower than the noise level of the detector. The IRXCAM-640 software controls the detector, calibrates and characterizes the IR-camera. However, this software is only used to center the target in the FoV. Therefore, a specific software has been developed to control the IRXCAM-640.

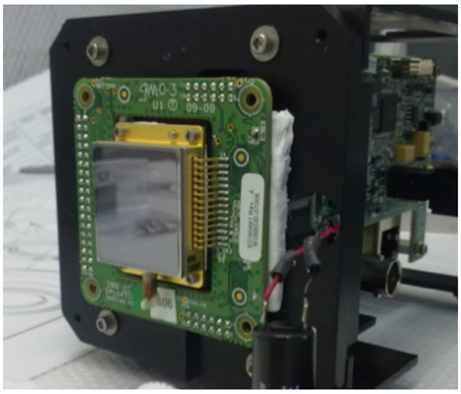

Figure 1: ULIS UL-04-17-1 microbolometer.

The ULIS detector is an infrared opto-electronic device sensitive to radiation in the long wave spectral range. It includes a microbolometer Focal Plane Array (FPA) comprised of a 640 $\times$ 480 pixels. The pixel pitch is 25 μm by 25 μm, being the image size is 16 mm by 12 mm. This detector array, made from silicon resistive bolometer microbridges, is connected to a silicon ReadOut Integrated Circuit (ROIC). It also includes a Thermo Electric Cooler (TEC), which is controlled by the IRXCAM-640. The detector has several internal parameters that need to be configured by the user, according to the measurement range, environment, and camera configuration. These parameters are optimized to obtain the lowest Noise Equivalent Temperature Difference (NETD) possible. Although the microbolometer could operate without TEC and improve the system efficiency (lowest power consumption), for applications which require an accurate FPA thermal stability (our case), the module provides the Focal Plane Array (FPA) temperature value that can be used to control the TEC already integrated into the FPA package. The accuracy of the temperature sensor is 10mK [9].

For the camera optics we decided to acquire a SURNIA Lenses equipment from the company Janos Technology. Due to its very fast F#, the maximum amount of energy will reach our focal

Table 1: Technical specifications of the camera module IRXCAM-640.

	IRXCAM-640
Sensor	640 × 480 pixels ULIS UL 04 17 1 uncooled microbolometer
Power supply	9-12 V DC
Dimensions	65 mm (H) 59 mm (W) 125 mm (L)
Weight	250 g
Temperature	Operating: -30 to 55°C Storage: -40 to 80°C

Table 2: Technical specifications of the μbolometer UL 04 17 1.

	UL 04 17 1
Pixel-pitch	25 μm
Dimensions	7.7 mm (H) 32 mm (W) 23.5 mm (L)
Weight	<25 g
Power comsumption	<300 mW (without TEC)
NETD	<120 mK

plane. Although it is designed for camera systems with a stop, and longer back working distance (common for cooled systems or detectors requiring a radiation shield), it can be adapted to most longwave infrared (LWIR) cameras. Moreover, the IRXCAM-640 manufacturer has provided us the mechanical mount to adapt these lenses to the device.

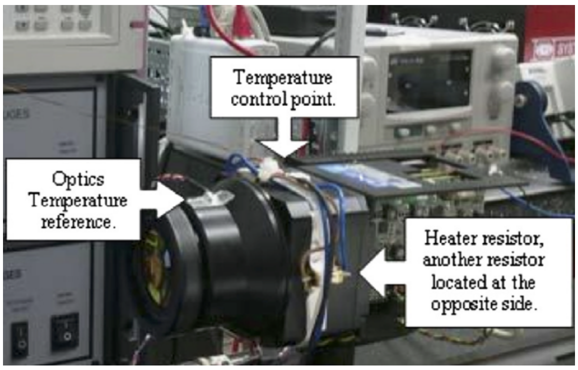

Figure 2: Scheme of the IRXCAM-640 camera module and SURNIA optics.

The filters defines two bands. The first band covers from 10.375 μm to 11.225 μm, while the

Table 3: Main characteristics of the SURNIA optics.

Parameter	Value
Image diagonal	21 mm
Stop size	26.4 mm
Stop position	22.9 mm
Back Working Distance (BWD)	35.6 mm
Flange to Focal Plane (FP)	39.4 mm
Focal length	25 mm
F#	0.86
Wavelength	7-14 μs
Circular FoV	45°
Transmission (typical)	95%
Weight	400 g
Min. Obj. Distance	200 mm
Mount type	Threaded Mount
Focus type	Manual Focus

second band covers from 11.575 μm to 12.425 μm [10]. In terms of the FPA position, the first filter, which defines the first band, is located in the X axis from the pixel 1 to the pixel 320. The second filter, which defines the second band, is located from the pixel 321 to the pixel 640. Both filters covers the area located from pixel 1 to 480 in the Y axis.

The system's FoV is 45°, enough to cover the area studied by the UV PDM of the EUSO-Balloon, which is 12° [11]. All the data taken by the IR camera, the temperature, humidity and pressure, is stored redundantly in two Solid State Devices (SSD). The whole IR camera system is placed inside an aluminium box, filled with nitrogen at a pressure of 1.5 bars, and covered by a styrofoam layer.

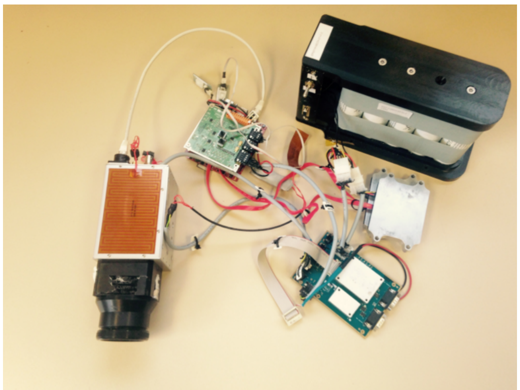

Figure 3: Some IR camera devices (current converter, SSD, IR camera module and the electronic).

The power supply of the camera consists of two rows of 5 cells. Every row has the dimensions: 208 mm × 141 mm × 84 mm. Each cell weights 300 g. The total capacity of the battery block is

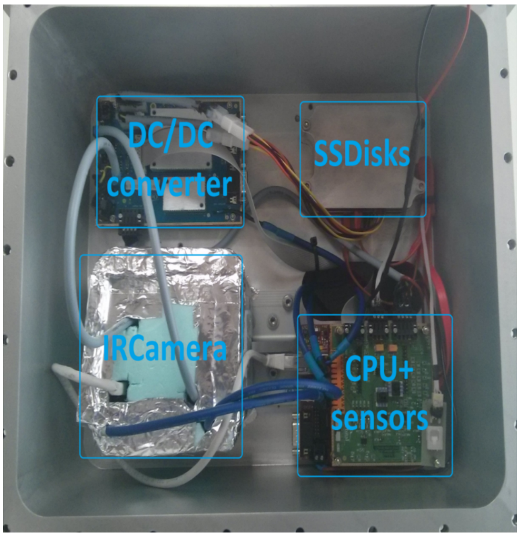

Figure 4: The battery pack together with all the IR camera devices.

18 amp $\times$ hour, and gives an output voltage of 28V DC.

Table 4: Power budget for all the IR camera instruments.

	Power (W)	Current (A)	Voltage (V)
CPU & sensors	4	0.15	5
IRcamera	4.8	0.4	12
Heaters (2 $\times$ 4W)	8	0.67	12
DC-DC (12V)	1.8	0.15	12
DC-DC (5V)	0.75	0.15	5
Total	19.35	-	-

4. EUSO-Balloon IR Camera Data

The EUSO-Balloon IR Camera took one picture every 80 seconds during the balloon flight held in August, 2014, over Timmins (Canada). It was functioning for around 17 hours, and therefore, took an overall of 753 photos. Although the EUSO-Balloon splashed down on a lake, the IR camera is water-proof, so all the data could be recovered. Due to the perfect isolation, the device is still perfectly working and the internal pressure only decreased to 1.3 bars. Moreover, after the flight the battery pack was still half charged.

Regarding the images, seven out of the 17 hours, the camera was functioning under water. Then, around 400 photos must be discarded from our analysis. If we take into account that the EUSO-Balloon conditions were not completely stable during the take off and landing, and we only consider for our study the photos taken during the proper flight (from around 03:30 to 8:20 UTC),

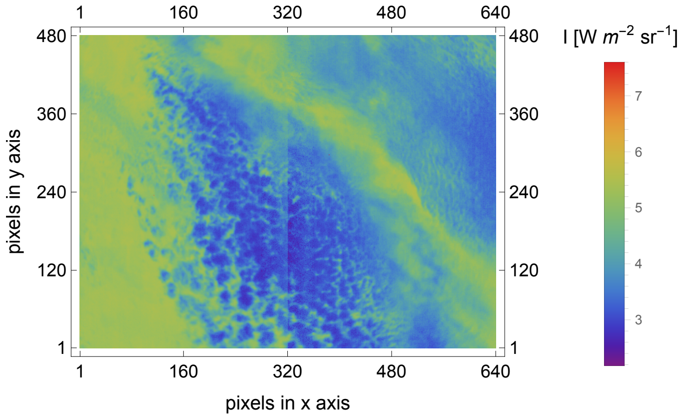

Figure 5: Image taken by the IR camera during the balloon flight.

220 photos need to be analyzed. Figure 5 is an example of the irradiance gotten from the IR camera data in one shot.

Once the analysis of the images is completed and brightness temperature is retrieved of IR-Camera, the Cloud Top Height (CTH) is established using a Weather Research and Forecasting model [12]. Vertical profiles of temperature and humidity are obtained for different locations and at different times covering the whole of EUSO-Balloon track. Thus, an algorithm is built obtaining the cloud top height in each pixel of IR-Camera [13]. To assess the fit of the model firstly we have compared the vertical profiles of the WRF with adjacent radiosondes and subsequently, CTH retrieved by the algorithm is compared with those provided by other satellites flying over EUSO-Balloon track. Also, some information related to the atmospheric optical depth can be obtained with the IR camera data [14].

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