Towards the Preliminary Design Review of the Infrared Camera of the JEM-EUSO Space Mission.

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Abstract: An Atmospheric Monitoring System is a key element of a Space-based mission which aims to detect Ultra-High Energy Cosmic Rays (UHECR). The JEM-EUSO Space Mission has a dedicated Atmospheric Monitoring System that plays a fundamental role in our understanding of the atmospheric conditions in the Field of View of the telescope. Our Atmospheric Monitoring System consists of an infrared camera and a LIDAR. The full design, prototyping, construction under space qualification, assembly, integration and verification of the Infrared Camera is under responsibility of the Spanish Consortium within JEM-EUSO. The Infrared Camera Scientific Requirements Review (SRR) was achieved in December 2011 and the System Preliminary Design Review (SPDR) is forseen for 2013. The Infrared Camera of JEM-EUSO will contribute to ensure that the energy of the primary UHECR and the depth of maximum development of the Extensive Air Shower (EAS) are measured with an accuracy better than 30 % and 120 g/cm^2 respectively.

Keywords: JEM-EUSO, UHECR, Space Instrumentation, Fluorescence radiation, Cherenkov radiation, EAS, Atmospheric Monitoring System

1 Introduction

The Extreme Universe Space Observatory on the Japanese Experiment Module (JEM-EUSO) [1],[2] of the International Space Station (ISS) is the first space-based mission worldwide in the field of Ultra High-Energy Cosmic Rays (UHECR) and will provide a real breakthrough toward the understanding of the Extreme Universe at the highest energies never detected from Space so far. JEM-EUSO from Space will pioneer the observation of cosmic rays at the extreme high energy range. Moreover, JEM-EUSO will use our atmosphere as a huge calorimeter to detect the electromagnetic and hadronic components of the Extensive Air Shower (EAS) produced by the primary UHECR.

At the UHECR regime observed by JEM-EUSO, above 10^{19} eV, the existence of clouds will blur the observation of UHECRs [3]. Therefore, the monitoring of the cloud coverage by the JEM-EUSO Atmospheric Monitor System (AMS) ([4],[5],[6]) is crucial to estimate the effective exposure with high accuracy and to calibrate the UHECRs and EHECRs events just above the threshold energy of the telescope. The IR-Camera will be the instrument devoted to detect clouds and determine their top height in the FoV of the JEM-EUSO main instrument. The camera will provide a 2D image of the cloud top temperature, and using this image, with the LIDAR and the global models, the cloud top height under investigation will be achieved with an accuracy better than 500m during the observation period of the JEM-EUSO main instrument. The IR-Camera full design, prototyping, space qualified construction, assembly, verification and integration is under responsibility of the Spanish Consortium involved in JEM-EUSO. The scientific and technical requirements for the IR-Camera are far for being undemanding, and are summarized in Table 1.

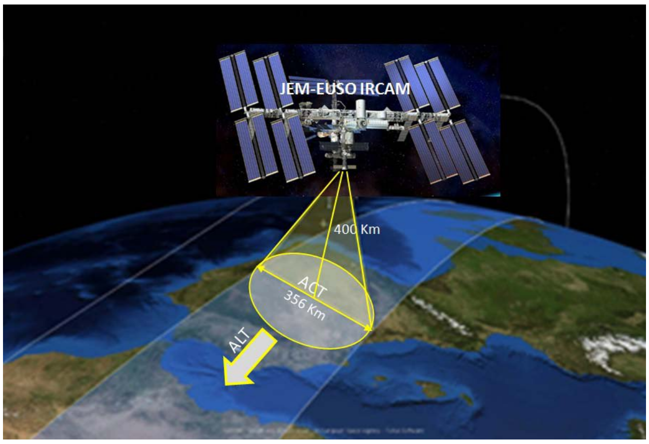

Fig. 1: Schematic view of the IR-Camera observation concept along the International Space Station track.

Moreover, a dedicated End to End (E2E) simulation for the IR-Camera is under development [7]. This work gives us the capabilities to study the impact of several scenarios of the atmosphere, in terms of retrieval temperature accuracy, detector capabilities, calibration procedures and correction factors to be taken into account for the final data products of the AMS system of the JEM-EUSO Space Mission. At this design state of the IR Camera, this E2E similator will give us answers in key points of the design, like the compression algorithms evaluation and estimation of the expected accuracy of the calibration options foreseen [8].

Table 1: Requirements for the IR-Camera of the JEM-EUSO Space Mission.

Parameter	Target value	Comments
Measurement range	220 K - 320 K	Annual variation of cloud temperature plus 20 K margin
Wavelength	10-12 μm	Two atmospheric windows available: 10.3-11.3 μm and 11.5-12.5 μm
FoV	48^o	Same as main instrument
Spatial resolution	0.1^o (Goal) 0.2^o (Threshold)	@FoV center
Absolute temperature accuracy	3 K	500 m in cloud top altitude
Mass	$\leq$ 11 kg	Inc 20% margin.
Dimensions	$400 \times 400 \times 370$	w/o Insulation and mounting bracket.
Power	$\leq$ 15 W	Inc 20% margin.
Lifetime	5 years In-orbit	+2 years On-ground

2 The IR-Camera System Preliminary Design

The IR-Camera [9] is a microbolometer based infrared imaging system aimed to obtain the cloud coverage and cloud top altitude during the observation period of the JEM-EUSO main instrument. Its preliminary design can be divided into three main blocks: the Telescope Assembly, the Electronic Assembly and the Calibration Unit. The main function of the Telescope Assembly is to acquire the infrared radiation by means of an uncooled microbolometer and to convert it into digital counts. A dedicated optical design has been developed as well, with a huge angular field to complain with the wide FoV of the JEM-EUSO main telescope. Meanwhile the Electronic Assembly provides mechanisms to process and transmit the obtained images, the electrical system, the thermal control and to secure the communication with the platform computer. To assure the high demanding accuracy, a dedicated on-board calibration system is foreseen. Moreover, this System Preliminary Design is complemented by a challenging Mechanical and Thermal design to secure that the IR-Camera will be completely isolated.

2.1 The Telescope Assembly; detector and FEE

The IR-Camera Telescope assembly includes the Infrared detector (μBolometer), the FEE (Front End electronic) and the Optical lens assembly (Figure 2).

The infrared detector that has been selected for the JEM-EUSO-IR camera is the UL04171 from the ULIS Company [10]. The UL04171 is an infrared opto-electronic device comprised by a μbolometer Focal Plane Array (FPA); two dimensional detector array made from amorphous Silicon. The working operative temperature is around 30^oC and a dedicated TEC (Thermo-Electrical Cooler) has been implemented to guarantee a very stable temperature. The

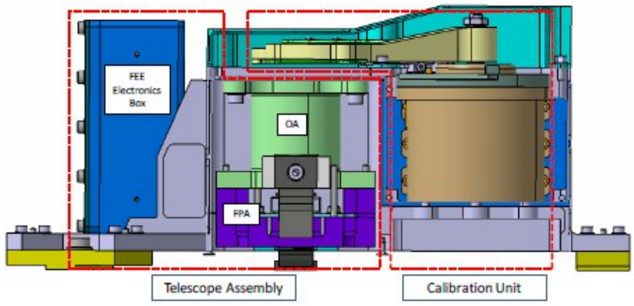

Fig. 2: Illustration of the preliminary design of the infrared camera telescope assembly.

μBolometer is supplied by the manufacturer in a vacuum sealed package with the readout electronics, peltier and temperature sensor integrated. Moreover, a protective window of Germanium glass has been implemented in the optical design.

The FEE (Front End Electronics) manages and drives the μBolometer; It provides the bias and the sequencer and manages the images acquisition modes. The FEE communicates with the ICU and provides it the uncompressed raw images. The core of the FEE shall be a FPGA, VIRTEX family, in charge of implementing the main FEE functions. This includes the control of the UL04171, the generation of all the synchronism including the clocks generation and the interface with the sequencer. The polarization of the detector (bias, gain, offset generation and control) will be also controlled by the FPGA. The data acquisition will be implemented with an Analog Digital Converter (ADC) in each detector output channel previous to the FPGA input. The ADC number of bits will be chosen according to the pixel data resolution required by the IR-Camera.

2.2 The Optical subsystem Preliminary Design

The Optical Assembly is one of the most critical subassemblies of the IR-Camera. For an optimal operation, the design of the Optical subsystem has to fulfill the following technical requirements: To acquire radiation at the mid infrared wavelength band (10-12.5) μm; To guarantee the requested (48^o) FoV; To be very fast in terms of F#; To secure an optimal operative temperature for the ULIS

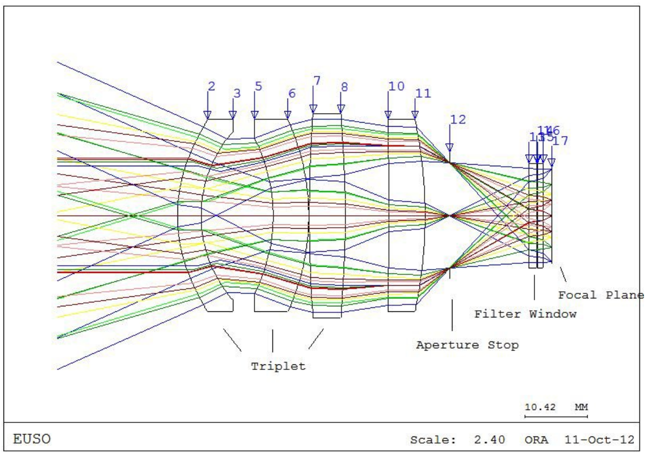

Fig. 3: Schematic illustration of the optic preliminary design of the Infrared Camera.

(29^{o}C) detector, for both, the cold operative case (-15^{o}C) and the hot operative case (15^{o}C); The thermal excursion of the lenses has to be less than 20^{o}C and finally, to keep the Cold Stop temperature 15^{o}C below the ULIS μblometer temperature.

Presently, the optical system design (Figure 3). is a refractive objective based in a triplet with one more lens close to the stop and a window for the filters close to the focal plane. The first surface of the first lens and the second surface of the third lens are aspheric that allow a better quality of the complete system. The aperture stop is situated at 0.40 mm behind the fourth lens, in order to separate the optical system to the detection module. The system, consisting of four lenses, has a focal length of 19.10 mm, and a f-number of 1, and it shall work with a total FoV of 48^o. The overall length between the first surface to the focal plane is 62.30 mm. All the data shown below are related to extreme fields ($\pm$24^o), although better response is obtained for intermediate fields. The full system has been designed only with one optical material, Germanium with a refraction index of 4.003118.

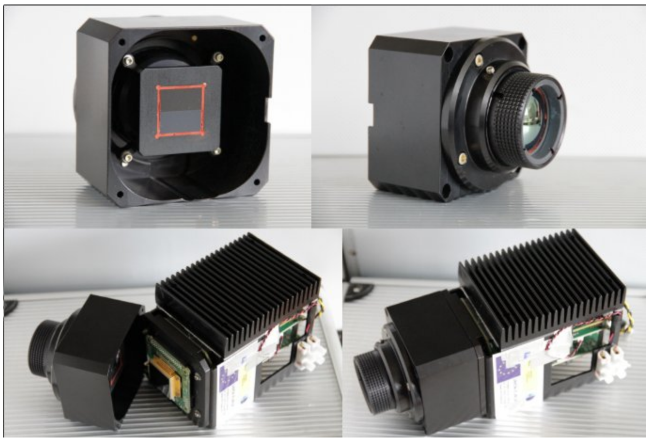

Fig. 4: Breadboard model manufactured at INTA facilities for the Infrared Camera of JEM-EUSO.

A breadboard model (Figure 4) has been manufactured to test the optical performances of the system. The breadboard lenses have been mounted in the same way that will be assembled in the flight model. The tolerances and optomechanical process have been successfully tested and verified at this stage of development.

2.3 The electronic assembly

The Electronic Assembly is composed of two main sections: the Instrument Control Unit (ICU), and the Power Supply Unit (PSU). Both blocks follow cold redundancy architecture and are placed on individual PCBs so that four boards are defined: ICU Main, ICU Redundant, PSU Main, and PSU Redundant. The ICU controls and manages the overall system behavior, including the data management (compression, format), the power drivers and the mechanisms (shutter, blackbodies etc.) controller FPGA. The IR-Camera electronics shall provide mechanisms to process and transmit images obtained from an IR detector controlled by a dedicated FEE board, a Firmware (FW) solution is considered as baseline for this proposal.

Data generated by the FEE is then processed by the Instrument Control Unit (ICU), which is in charge of controlling several aspects of the system management such as the electrical system, the thermal control and the communication with the platform computer. The Power Supply Unit (PSU) receives the main power bus from JEM-EUSO main telescope and it provides the required power regulation to the system and the sub-systems. The actuator will be managed by the ICU, providing control to a stepper motor and acquiring its position by means of micro-switches placed in the stable positions.

2.4 The calibration subsystem

The calibration unit (Figure 5) is dedicated to manage and control the IR calibration operation. This unit has to guarantee a reference internal temperature to ensure the calibration of the data coming out of the FEE. Following the strategy of operational modes, four positions are provided from this unit: Acquire, Shutter (offset correction), Calibration Hot point, and Calibration Cold point.

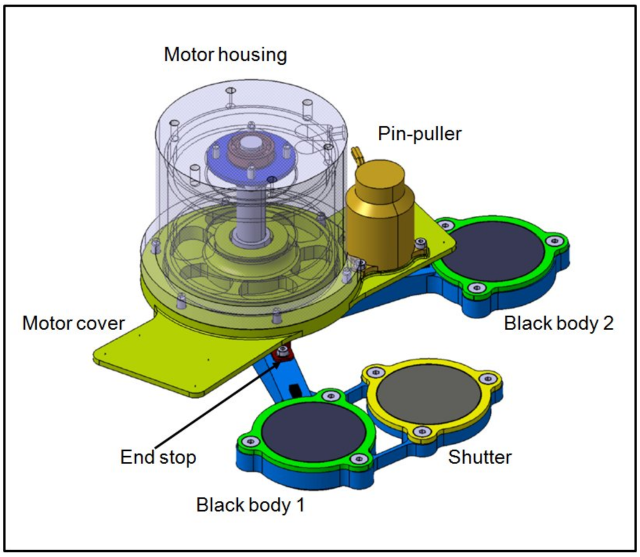

Fig. 5: Ilustration of the calibration subsystem.

The position of shutter will be used to close the optic in the safe and off operation mode. Calibration unit is mainly composed of two Black Bodies with a temperature controlled Shutter, a moving mechanism and the motor, the positioning system and a calibration Thermal control.

2.5 The thermal and mechanical design

The mechanical structure contains and protects the Telescope Assembly and the Calibration Unit. It is attached to the bench of the JEM-EUSO Telescope by means of three flexure-pads. The Main Housing is an aluminium Al6082 monocoque body-shell. It has three different compartments to accommodate the required subsystems and provide overall stiffness and thermal isolation of the Optical Assembly and FPA from the Calibration Unit and the FEE. Stiffeners have been used to optimize the mass of the Main Housing structure. This Housing contains a stiff baseplate, which supports the Calibration Unit and the FEE Electronics Box, both contained in the IF plane to minimize the loads on this plane maintaining a low CoG.

The Lenses Barrel has the mission to enclose and support the lenses, which are positioned with Spacers, and they are bonded with optical adhesive EPO-TEK 301-2. The Cold Stop is a sort of diaphragm between the last lens and the microbolometer. It is necessary for optical purposes, and its temperature must be around 15^{o}C lower than the ULIS temperature. This is achieved by means of a passive thermal control, and two (main and redundant) thermal sensors.

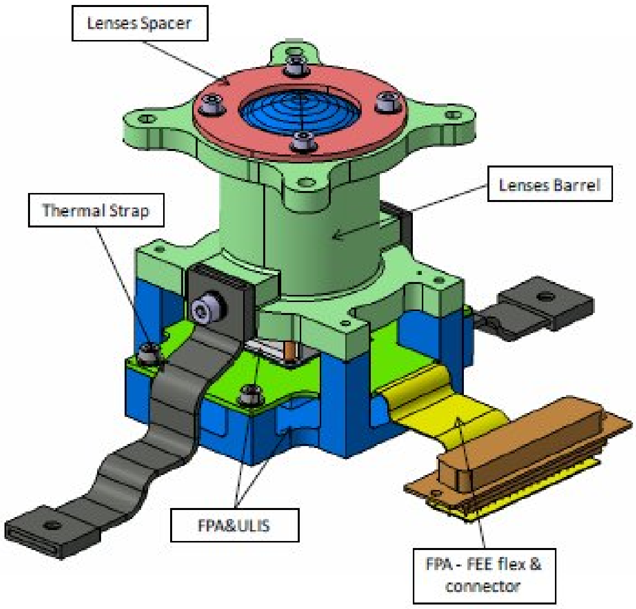

Fig. 6: Optic Assembly where the lenses barrel is shown.

3 Conclusions

Cosmic Rays Physics is one of the Fundamental Physics key issues and an essential branch of Astroparticle Physics. It aims, in an unique way to address many fundamental questions of the extreme and non-thermal Universe in the Astroparticle Physics domain at the highest energies never detected so far. Moreover, UHECR has witnessed a major breakthrough with the Pierre Auger Observatory (PAO) and the Telescope Array (TA) success. The results on UHECR by PAO and TA have pointed out the huge physics potential of this field that can be achieved by an upgrade of the performances of current ground-based instruments and with new space-based missions. To reach the largest exposures, space observatories are likely to be essential. The JEM-EUSO space observatory is aimed to achieve one of our main goals, reach the so called "Particle Astronomy Era".

The IR-Camera onboard JEM-EUSO will consist of a refractive optics made of germanium and an uncooled μbolometer array detector. The FoV of the IR-Camera is 48°, totally matching the FoV of the main JEM-EUSO telescope. The angular resolution, which corresponds to one pixel, is about 0.1°. A temperature-controlled shutter in the camera and blackbodies are used to calibrate background noise and gains of the detector to achieve an absolute temperature accuracy of $\sim$ 3 K. Though the IR-Camera takes images continuously every 17s, in which the ISS moves 1/4 of the FoV of the JEM-EUSO telescope. In this paper an overall description of the present stage of design and development of the IR Camera of JEM-EUSO has been reviewed.

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