An End to End Simulation code for the IR-Camera of the JEM-EUSO Space Observatory.

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Abstract: The Extreme Universe Space Observatory on the Japanese Experiment Module (JEM-EUSO) of the International Space Station (ISS) is the first space-based mission worldwide in the field of Ultra High-Energy Cosmic Rays (UHECR). JEM-EUSO will use our atmosphere as a huge calorimeter, to detect the electromagnetic components of the Extensive Air Shower (EAS). Therefore, the atmosphere must be calibrated and has to be considered as input for the analysis of the fluorescence signals. The JEM-EUSO space observatory is implementing an Atmospheric Monitoring System (AMS), to gather data of the atmosphere status during the UHECR observation period, it will include an IR-Camera and a LIDAR. The AMS IR-Camera is an infrared imaging system aimed to detect the presence of clouds. Our paper is focused on the End to End (E2E) simulation developed for the IR-Camera of the JEM-EUSO Space Mission. This work gives us the capabilities to study the impact of several scenarios of the atmosphere, in terms of retrieval temperature accuracy, detection 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.

Keywords: JEM-EUSO, UHECR, space instrument, IR-Camera, simulation

1 Introduction

The JEM-EUSO space observatory is foreseen to be launched and attached to the Japanese module of the International Space Station (ISS) in 2017 [1], [2]. It aims to observe UV photon tracks produced by Ultra High Energy Cosmic Rays (UHECR) developing in the atmosphere and producing Extensive Air Showers (EAS). However the atmospheric clouds blurs the UV radiation produced by the EAS [3].

In order to monitor the atmosphere, and more important to obtain the cloud coverage in the JEM-EUSO FoV an Atmospheric Monitoring System (AMS) will be included in the telescope [4]. The AMS consists of a LIDAR, an infrared (IR) camera and global atmospheric models will be used as well. The LIDAR will measure the optical depth profiles of the atmosphere in selected directions. The IR-Camera will provide the cloud coverage and the cloud top height [5]. The global atmospheric models will be used to retrieve the atmospheric parameters (temperature, pressure and humidity vertical profiles) in the monitored region [6].

In this publication we disclose the status of the IR-Camera End to End (E2E) simulation fully developed for the IR-Camera of the JEM-EUSO Space Mission. This work gives us the capabilities to study the impact of several scenarios of the atmosphere, in terms of retrieval temperature accuracy, detection capabilities, calibration procedures, and correction factors to be taken into account for the final data products of the AM system of the JEM-EUSO Space Mission.

At this design stage of the IR-Camera prototype, this E2E simulation is giving us some answers in key points of the design, like the compression algorithms evaluation presented here.

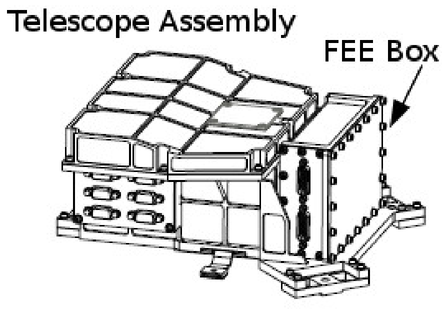

Figure 1: IR-Camera Telescope Assembly Illustration.

2 The IR-Camera Preliminary Design

The Atmospheric Monitoring System (AMS) IR-Camera [7] 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. The scientific and technical requirements for the IR-Camera are far for being undemanding, and are summarized in Table 1. Its preliminary design [8] can be divided into three main blocks: the Telescope Assembly, the Electronic Assembly, and the Calibration Unit.

The Telescope Assembly (Figure 1) has to acquire the infrared radiation by means of an uncooled microbolometer and to convert it into digital counts. The IR-Camera Telescope assembly encompass the Infrared detector (μBolometer), the FEE (Front End electronic) and the Optical lens assembly. The infrared detector that has been selected for the JEM-EUSO IR-Camera is the UL04171 from the ULIS Company [9]. The UL04171 is an infrared opto-electronic device comprised by a μbolometer Focal Plane Array (FPA). The FEE (Front End Electronic) manages and drives the μBolometer; It provides the bias and the sequencer and manages the images acquisition modes.

Presently, the optical system design 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 0.40mm 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 19.10mm, and a f# 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 62.30mm.

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. The Electronic Assembly is composed of two main sections: the Instrument Control Unit (ICU), and the Power Supply Unit (PSU). 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. A dedicated on-board calibration system is foreseen [7],[8]. The calibration mechanism consists of a stepper motor governing the blackbodies and shutter.

3 IR-Camera Prototype Tests

The main aim of these tests is to characterize the microbolometer detector to be used in the JEM-EUSO IR-Camera. This work made in the Astrophysics Institute of the Canary Islands (Instituto de Astrofisica de Canarias, IAC, Tenerife) has provided very useful information of the detector performances to be implemented in the IR-Camera.

In order to acquire data and images from this FPA, a electronics prototype module developed by INO (Canada) has been used [10]. This electronics core is known as IRXCAM-640. Although the chip architecture exploits a TEC less operation, the already integrated TEC and the control loop allow us 10 mK stability in temperature, keeping very low Noise Equivalent Temperature Difference (NETD) values. For the camera optics we decided to use a commercial unit, the Surnia lenses from Janos [11], capable to measure in the 7-14 μm region. The main characteristics of this optics are: focal length = 25 mm and f#=0.86, with a circular FoV of 45^o. Wavelength is limited in the 7 to 14μm range.

The used infrared radiation source was a Black Body (model DCN-1000-L3) from HGH Systems Infrarouges (France) [12], with an emissive area equal to 75x75 mm and an absolute temperature range from -40^{o}C to 150^{o}C. The thermal uniformity is better than 0.01^{o}C with an stability of 0.002^{o}C. To complete the testing procedure a control system was built as well. The system consists of: (a) 8 Pt-100 temperature sensors placed everywhere, (b) a commercial Lakeshore-218 8-channel temperature monitor and (c) a Proportional Integral Derivative (PID) control loop handled by a Lakeshore-331 temperature controller to keep the optics case in the 10 mK environment. The entire device has been synchronized and controlled by a friendly user-interface developed under NI-Labview, using a PC-platform. Most typical tests, as linearity, temperature stability, non-uniformity calibration or NETD, were fully automatized for these purposes.

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	≤ 11 kg	Inc 20% margin.
Dimensions	$400 \times 400 \times 370$	w/o Insulation and mounting bracket.
Power	≤ 15 W	Inc 20% margin.
Lifetime	5 years On-orbit	+2 years On-ground

4 The End to End Simulation code.

An End to End (E2E) dedicated simulation of the infrared camera will give us simulated infrared images of those we expect to obtain with the instrument. It provides us with the capabilities to study the impact of several scenarios of the atmosphere, in terms of retrieval temperature accuracy, to analyze the detection capabilities, calibration procedures, and correction factor to be taken into account for the final data products of the AMS system of the JEM-EUSO Space Mission. At this design stage of the IR-Camera prototype, this E2E simulation will give some answers in key points of the design, like the compression algorithms evaluation, and an estimation of the expected accuracy of various calibration options.

The simulation is a complex software, written in C++, and divided into several stages [13]. It starts with the simulation of the IR scenario with atmospheric simulation software, like the Satellite Data Simulator Unit (SDSU) [14]. Instead of the simulator we can use real satellite IR images, taken by missions like MODIS [15] or CALIPSO

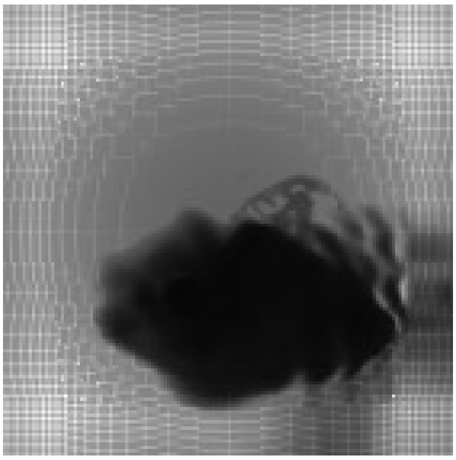

Figure 2: Grayscale image of a cloud brightness temperature simulated in SDSU + IR-Camera E2E. The white lines are produced by the non-continuous barrel distortion simulation.

[16]. After the input scene is read by the simulator, an optics elements simulation takes place. Starting from the simulation of the diffraction, distortion and efficiency of the optics module, using the evaluated optics design with software Code-V [17]. The image is first blurred with the PSF (Point Spread Function) calculated for several regions of the optics. Then each pixel of the FoV image is transported to the position inside a distorted image, using a transport matrix calculated with the distortion data. Similar to the optics, the filters spectrum function made by the manufacturer is taken into account, and produces a 2-bands image which is later processed by the detector module.

To create a model of a detector, we used results of the test described in section 3. Therefore, we can translate the input values to analog voltage values that should be similar to the detector response. Moreover, we can apply the ADC (Analog to Digital Conversion) of 12bits, and its corresponding change to 10bits. As a last step, in the instrument simulation, we have compressed the image, using HP (Hewlet Packard) code LOCO-I/JPEG-LS algorithm [18] with nearly loss-less code. In Figure 2 a simulated IR image is shown as an example.

In addition the simulation should include, at least, some on ground processing steps. Therefore, we have to perform decompression, implementation of calibration curves to convert digital values into temperature values, and background and noise reduction using feedback from housekeeping data. A data analysis module is foreseen to take the data from simulator, and real data from the IR-Camera to perform the analysis tasks with the algorithms for data retrieval. The output from this analysis module will be used as an input in the official codes for the performance analysis, and event reconstruction of the main telescope. A diagram of the simulation path explained before is shown in Figure 3.

5 Compression Algorithm evaluation

One of the key points to estimate the data rate bandwidth for the infrared camera requirements is the capability to compress the images to be sent. The evaluation of the impact of these algorithms is crucial to assure that the scientific data

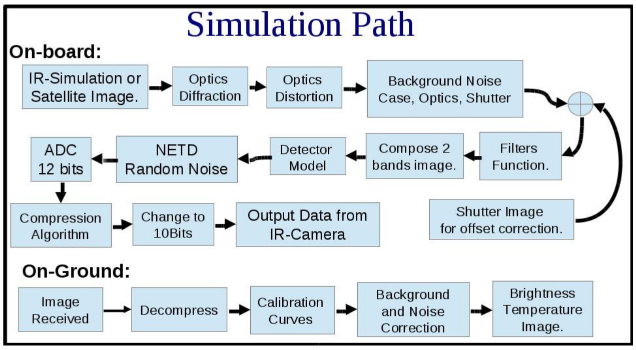

Figure 3: Block diagram of the simulation for the IR-Camera End to End simulation.

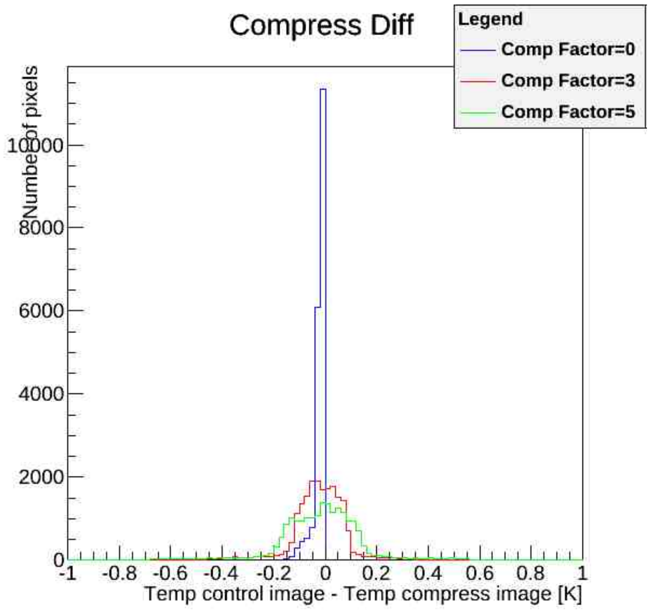

Figure 4: Histogram with the pixel by pixel value comparison between the control image and the compressed-decompressed image.

will not be compromised by the compression. To perform this trade off, we have used the simulator being developed for the instrument, and some test images created with SDSU. The compression algorithm under study is the HP Labs LOCO-I/JPEG-LS [4]. The procedure is very simple, we have used the simulated images of SDSU to create a control output image, and test these images with different compression factors to evaluate the compression ratio, and the impact on the data decompressed when compared to the control images. Figure 3 shows the simulation path followed by the test and control images.

For this first study we have evaluated compression factors of 0 (near-lossless), 3 and 5. Differences in the images cannot be appreciated by human eyes, therefore we have compared the values of each pixel of the test image, with the related pixel of the control image, and plot an histogram to evaluate the differences of the values. Results are presented in Table 2. The Output from pixels values comparison of test images with the control image are presented in Figure 4 for the compression factor of 0 (nearly loss-less), 3 and 5.

Table 2: Analysis of one compression image.

Comp Factor	0	3	5
In [kbits]	235.2	235.2	235.2
Out [kbits]	65.232	34.788	29.288
Comp Ratio	3.6	6.76	7.92
Typ Dispersion [^oK]	≈0.10	≈0.15	≈0.2
Max Dispersion [^oK]	0.15	0.63	0.9

6 Conclusions

At the UHECR regime observed by JEM-EUSO, above 10^{19} eV, the existence of clouds will blur the observation of UHECRs. Therefore, the monitoring of the cloud coverage by the JEM-EUSO Atmospheric Monitor System (AMS) 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 AMS IR-Camera of JEM-EUSO is an infrared imaging system aimed to detect the presence of clouds in the FoV of the JEM-EUSO main telescope and to obtain the cloud coverage and cloud top altitude during the observation period of the JEM-EUSO main instrument. Its full design, prototyping, space qualified construction, assembly, verification and integration is under responsability of the Spanish Consortium involved in JEM-EUSO. The observed radiation is basically related to the target temperature and emissivity and it can be used to get an estimate of the clouds top height.

The development of the E2E simulation is an undergoing work, making the model more accurate, and covering each area of the infrared camera design deeply. The prototype test has given us the opportunity to acquire the knowledge to build the detector model. Moreover, the optics, designed by the INTA and characterized with CODE-V have been simulated with our code as well.

Our next objective is to try to address the impact of several design characteristics to have a very detailed study of the detection error, and to provide a plattform for the IR-Camera design engineers to test the changes neccesary in each step of the infrared camera development process. Moreover, from the compression algorithm trade off, we can conclude that the HP-LOCO algorithm is suitable for our IR-Camera and, a compression ratio of 3 is required to ensure a feasibly quality images with minor losses.

Acknowledgment: The Spanish Consortium involved in the JEM-EUSO Space Mission is funded by MICINN & MINECO under projects AYA2009- 06037-E/ESP, AYA-ESP 2010-19082, AYA-ESP 2011-29489-C03- 01, AYA-ESP 2011-29489-C03-02, AYA-ESP 2012-39115-C03-01, AYA-ESP 2012-39115-C03-03, CSD2009-00064 (Consolider MULTIDARK) and by Comunidad de Madrid (CAM) under project S2009/ESP-1496. This work was partially supported by Basic Science Interdisciplinary Research Projects of RIKEN and JSPS KAKENHI Grant (22340063, 23340081, and 24244042), by the Italian Ministry of Foreign Affairs, General Direction for the Cultural Promotion and Cooperation, by the 'Helmholtz Alliance for Astroparticle Physics HAP' funded by the Initiative and Networking Fund of the Helmholtz Association, Germany, and by Slovak Academy of Sciences MVTS JEM-EUSO as well as VEGA grant agency project 2/0081/10. The calculations were performed by using the RIKEN Integrated Cluster of Clusters (RICC) facility. J.A. Morales de los Rios wants to acknowledge the financial support from the UAH-FPI grant, and the RIKEN-IPA program.

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