Status of the JEM-EUSO Mission

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Abstract: The Extreme Universe Space Observatory, on-board the Japanese Experimental Module of the ISS (JEM-EUSO), mainly aims at unveiling the origin of the ultra high energy cosmic rays (UHECRs), beyond the suppression due to the Greisen-Zatsepin-Kuz'min effect. JEM-EUSO will also explore fundamental physics at these extreme energies. Designed to measure the arrival directions, the energies, and possibly, the nature of these particles, JEM-EUSO consists of a wide-field of view (60 degrees) telescope, with a diameter of about 2.5m, which points to Nadir from space to detect, during night-time, the UV (290-430 nm) tracks generated by extensive air showers propagating in the earth's atmosphere. The high statistics arrival direction map will allow anisotropy studies and, most likely, the identification of individual sources of UHECRs and their association with known nearby astronomical objects. This will shine new light on the understanding of the acceleration mechanisms and, perhaps, will produce new discoveries in astrophysics and/or fundamental physics. The comparison of the energy spectra among the spatially resolved individual sources will eventually confirm the Greisen-Zatsepin-Kuz'min process, validating Lorentz invariance up to $\gamma \sim 10^{11}$. In this paper, we will present the current status of the mission, reporting on the most recent technical developments, mission, and programmatic aspects of this challenging space-based observatory.

Keywords: JEM-EUSO, UHECR, EECR, Space-Approach

1 Introduction

The Extreme Universe Space Observatory, on-board the Japanese Experiment Module (JEM-EUSO) of the ISS [1, 2], is a space based mission which aims at studying ultra-high-energy cosmic rays (UHECRs) of the highest energy. These are cosmic particles with energy $E \geq 5 \times 10^{19}$ eV, above the threshold of the Greisen-Zatsepin-Kuz'min suppression of the cosmic ray spectrum [4]. Building on the heritage of the Pierre Auger and Telescope Array observatories, JEM-EUSO focuses its science case on the most energetic of those events, at $E \sim 10^{20}$ eV, often referred to as extreme energy cosmic rays (EECRs).

JEM-EUSO is designed to monitor from space, looking towards nadir during night-time, the earth's atmosphere to detect the UV (290-430 nm) tracks generated by the gigantic extensive air showers (EAS) propagating through the atmosphere. By imaging, with a time resolution of the order of μs, the fluorescence and Cherenkov photons of the EAS, the energy, arrival direction and nature of the primary UHECR particle will be reconstructed.

Placed at an altitude of $H \sim 400$ km from the earths surface, JEM-EUSO orbits the earth, with a speed of ~ 7 km s^{-1}, every ~ 90 min. with the inclination of the ISS $\pm 51.6°$. JEM-EUSO can be operated pointing to nadir ("nadir mode"), or slightly tilted ("tilted mode"). JEM-EUSO can reach an instantaneous aperture of about $6-7 \times 10^5$ km^2 sr [3], beyond the practical limit of any ground-based UHE observatory. An extended study on the expected exposures, obtained taking into account the duty cycle, the cloud coverage of the observed scene, and the trigger efficiencies, is reported in [5]. An updated study on the expected performance is given in [6]. JEM-EUSO is expected to reach in nadir mode, at $E \sim 10^{20}$ eV, an annual exposure about 9 times the one of the Pierre Auger Observatory. Operating in tilted mode, it will reach an annual exposure of about 20 times larger than the one of the Pierre Auger Observatory.

During the lifetime of the mission, JEM-EUSO is expected to observe several hundreds of UHECR events with energies exceeding 5×10^{19} eV, and a few hundreds at 10^{20} eV and above.

In addition to the very large area monitored by space-based UHE observatories, other advantages are the well constrained distances toward showers, the clear and stable atmospheric transmission in the above half of the troposphere, the uniform exposure across both north and south skies. All of these aspects are discussed in detail in [5].

2 Science objectives and requirements

The science objectives of the mission are divided into one main objective and five exploratory objectives. The main objective of JEM-EUSO is to initiate a new field of astronomy using the extreme energy particle channel, being the first instrument to explore, with high statistics, the energy decade around and beyond 10^{20} eV. At these extreme energies, due to attenuation effects, only a handful of sources must dominate the EECR flux. The main science goals are therefore: 1) The study of the anisotropies of the EE sky; 2) The identification of sources by high-statistics arrival direction analysis and possibly the measurement of the energy spectra in a few sources sources with high event multiplicity; 4) A high statistics measurement of the trans-GZK spectrum.

Besides the prime science objectives, we set five exploratory objectives to which the instrument can contribute, depending on the actual nature of the extreme energy cosmic ray flux: 1.) The study of the UHE neutrino component, by discriminating weakly interacting events via the position of the first interaction point and of the shower maximum; 2) The discovery of UHE Gamma-rays, whose shower maximum is strongly affected by geomagnetic and LPM effect; 3.) The study of the galactic and local extragalactic magnetic fields, through the analysis of the magnetic point spread function. The science capability of the mission is discussed in detail in [7].

Among the exploratory objectives, several topics of atmospheric science are included. JEM-EUSO will allow a characterization of the night-glow and of the transient luminous events (TLE) in the UV band. It can also detect the slow UV tracks associated to meteors and meteoroids.

One of the key requirements of the mission is certainly the validation of the observational technique in space operation condition. A proper operation of the main telescope, of the AMS, the measurement of the background and its variability, the determination of the duty cycle, the identification of the atmospheric scene, which is essential to correctly estimate the exposure, are the key requirements to be reached during the first phase of the mission.

We then aim at a stringent comparison of the energy spectrum with the one measured by the current generation of UHCR observatories around and above 5×10^{19} eV, which implies a comparable annual exposure at lower energies. Since the key goal of the mission is to explore the highest energies, one of the key requirements of JEM-EUSO is to reach an annual exposure of approximately one order of magnitude larger than the one of the ground based observatory at EECRs.

More specifically, from the science objectives, the following scientific requirements have been set: *Statistics of a few hundreds events* above $E > 7 \times 10^{19}$ eV, which implies an exposure (in three years) of $\geq 10^5$ km^2 sr yr; *Angular resolution* $\leq 3°$ at $E > 8 \times 10^{19}$ eV (expressed in terms ofγ_{68}); *Energy resolution* (expressed in terms of the 68% of the distribution) $\leq 30\%$ for $E > 8 \times 10^{19}$ eV (goal: for $E > 6 \times 10^{19}$); capability to discriminate between nuclei, gamma ray and neutrinos, which implies *Xmax determination error* ≤ 120 (g/cm^2) $E = 10^{20}$ eV and zenith angle 60 degrees); *full-sky observation* with $< 30\%$ (goal 15%) non uniformity among hemispheres. We eventually aim at measuring the timing properties of luminous atmospheric events with ms resolution.

The requirements are currently being validated with end-to-end simulations based on the EUSO Simulation and analysis framework (ESAF) and with the recently developed EUSO-offline framework. More details are found in [8, 9].

3 The JEM-EUSO instrument

JEM-EUSO consists of a main telescope, sensitive to near UV, and of an atmosphere monitoring system (AMS). The main telescope is a fast (of the order of μs) and highly- pixelized 3×10^5 pixels) digital camera with a large-aperture wide-Field of View (FoV, $2 \times 30°$) normally operating in *single photon counting* mode but capable of switching to *charge integration* mode in case of strong illumination.

The current baseline optics consist of two curved, double sided, Fresnel lenses with 2.65 m external diameter, and of an intermediate curved precision Fresnel lens. The precision Fresnel lens, takes an advantage based on state of the art diffractive optics technology, and is used to reduce chromatic aberration. The combination of 3 Fresnel lenses allows a full angle FoV of 60 degrees with a resolution of 0.075 degrees, corresponding to a pixel of about 550 m on earth. PMMA, which has high UV transparency in the wavelength from 330nm to 430nm, and CYTOP are candidate materials. Details of the optics are described in [10, 11]. The focal surface (FS) is, in the current baseline, spherical with ∼2.5 m curvature radius, and 2.3 m diameter. A bread-board model has been already manufactured and tested at the MSFC of NASA in Huntsville (see figure 1)

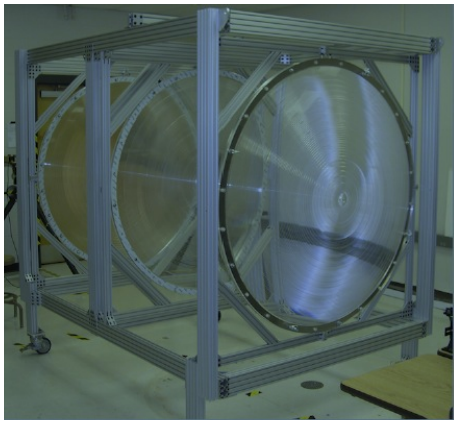

Fig. 1: The Bread-board model of the JEM-EUSO optics tested at MSFC, NASA, Huntsville. The diameter is 1.5 m.

The Focal surface is organized in 137 Photodetector modules (PDMs), each one consisting of 9 Elementary cells (ECs). Each EC contains 4 multi-anode photomultiplier tubes (64-pixel MAPMT), with a quantum efficiency of about 40 %. More than 5,000 MAPMTs are, therefore, integrated in the focal surface. The electronics record the signals generated by the UV photons of the EAS in the FS, providing a kinematic reproduction of each track. A new type of front-end ASIC has been developed, which has both functions of single photon counting and charge integration in a chip with 64 channels [12]. Radiation tolerance of the electronic circuits in space environment is also required.

The first prototype of the JEM-EUSO PDM, that will used for the TA-EUSO experiment, has been recently integrated in Wako (Japan) at RIKEN [13] (see figure 2).

The system is required to have high trigger efficiency and linearity over the $10^{19} - 10^{21}$ eV range. A trigger logic based on two levels has been implemented. The logic seeks pattern features close to those of signal tracks we would expect from a moving EAS. When a trigger is issued, the time frame of 128 GTU (gate time units, 2.5 μs) is saved to disc or transferred by the telemetry.

The AMS monitors the atmospheric scene of the FoV of the UV telescope [14]. It consists of an IR camera, a Lidar, and the slow data of the main telescope to measure the cloud-top height with an accuracy better than 500 m. The calibration system monitors the efficiencies of the optics, the focal surface detector, and the data acquisition electronics.

Calibration of the instrument will be possible by built-in LEDs and additional xenon flashers from ground.

4 The Mission

The main elements of the mission are shown in 3.

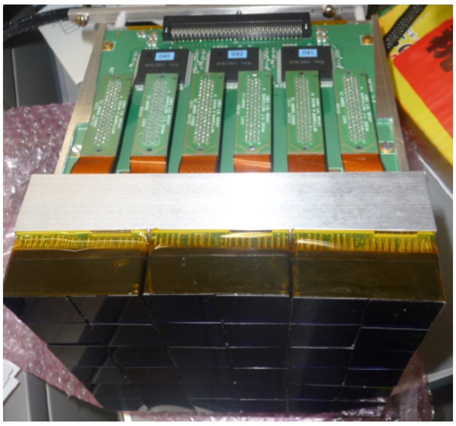

Fig. 2: The first prototype of the JEM-EUSO PDM, already integrated in RIKEN. It will be tested as the focal surface of the TA-EUSO experiment, to be deployed at the TA site in UTAH in summer 2013.

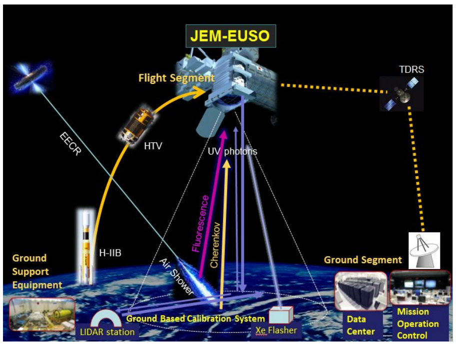

Fig. 3: The main elements of the mission are summarized in the figure.

According to the current baseline, JEM-EUSO shall be launched by an H2B rocket and will be conveyed to the ISS by the the unmanned resupply spacecraft H-II Transfer Vehicle (HTV). It will then be attached, using the Canadian robotic arm, to one of the ports (baseline is port 9) for non-standard payloads of the Exposure Facility (EF) of the JEM. Such a scenario was successfully studied during the phase A study of the mission performed under the leadership of JAXA. During launch and transportation, the instrument will be stored in a folded configuration, and will be deployed after the attachment procedure is successfully completed. The telescope structure and the deployment system are currently studied at the Skobeltsyn Institute of Nuclear Physics in Moscow. Three mechanical concepts for the extension mechanism have been developed. The so-called "Pyramid" variant is shown in figure 4.

In alternative to the H2B-HTV scenario, the possibility of using the SpaceX Dragon spacecraft is under consideration as an option for the transfer vehicle. The accommodation of JEM-EUSO in the trunk section of the SpaceX Dragon Spacecraft will require an optimization of the instrument baseline and slight modification will be necessary [15]. In particular, through a careful study of the system, we are confidently reducing the weight of the instrument towards the 1.1-1.2 ton goal (including margins). These modifications will not impact the science performance of the mission. SpaceX began regular missions to deliver cargo to the International Space Station (ISS) in October 2012.

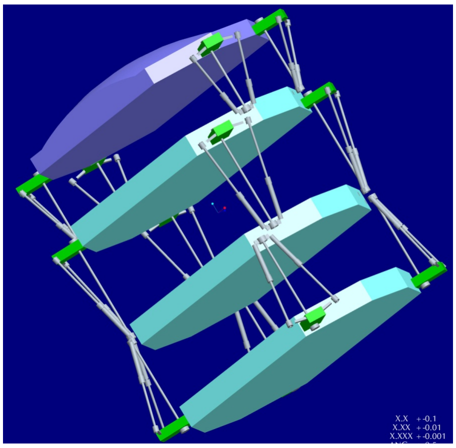

Fig. 4: The Pyramid variant of the extension mechanism. Displacement screws move the lenses. The pyramidal structures provides the necessary strength and stiffness.

Data will be transmitted to the Mission Operation Center hosted by JAXA in the Tsukuba Space Center and managed by RIKEN with the support of the whole collaboration, via TDRS. We plan to establish several data centers in all major participating countries.

According to the current plans, JEM-EUSO will be operated for three years in Nadir configuration (Nadir mode) to maximize statistics of events at the lowest energies in order to cross calibrate with the current generation of ground-based detectors. The instrument will then be tilted (about 35 degrees) with respect to Nadir, to maximize the statistics of events at the highest energies.

During flight, JEM-EUSO will be calibrated, in addition to the on-board calibration system, using a ground-based Global Light System (GLS). The GLS is a worldwide network that combines ground-based Xenon flash lamps and steered UV lasers, which will generate benchmark optical signatures in the atmosphere with similar characteristics to the optical signals of cosmic ray EAS and with known energy, time, and direction (lasers). There will be 12 ground based units strategically placed at sites around the world. Six locations will have flashers and a steerable and remotely operated laser (GLS-XL), and 6 will only have flashers (GLS-X). Sites will be chosen for their low background light and altitude (above the planetary boundary layer) [16].

5 Status

The payload of the mission is currently being studied by an international collaboration, which includes more than 70 scientific institutions from 13 different countries and is led by RIKEN. Given the complexity of the mission, the participation of the major agencies involved with the ISS is essential.

In 2010, JEM-EUSO has been included as a study in the ELIPS program of ESA. NASA is supporting the activities of the US team in the framework of APRA funds. The mission has been approved by the Tsiinimash Institute in Russia and has been submitted to ROSCOSMOS for implementation. Major funding agencies in Europe, Korea, and Mexico have been active in supporting the R&D and the development of prototypes.

Once completed, the payload will be delivered to JAXA. In the present scheme, JAXA is responsible, in coordination with the agencies playing a major role in the ISS, NASA, ESA and ROSCOSMOS, of the key aspects of the mission.

6 Status

While the studies for the main mission are actively continuing, the JEM-EUSO collaboration is developing and implementing two pathfinder experiments: the EUSO-TA and the EUSO-Balloon. The aim of the EUSO-TA project is to install a reduced prototype of the UV telescope in theTelescope Array (TA) site in Black Rock Mesa, Utah, US. EUSO-TA will perform observations of ultraviolet light generated by cosmic ray showers and artificial sources. The detector consists of one PDM and the telescope is housed in a shed located in front of one of the fluorescence detectors of the Telescope Array collaboration, pointing in the direction of the ELF (Electron Light Source) and CLF (Central Laser Facility). EUSO-TA will be installed and start operations in summer 2013. Details can be found in [13].

The EUSO-Balloon mission is a pathfinder mission of JEM-EUSO and consists of a series of stratospheric balloon flights starting in 2014, and performed by the French Space Agency CNES. The payload of the EUSOBALLOON consists of a scaled version of the telescope and is developed by the JEM-EUSO consortium as a demonstrator for the technologies and methods featured in the forthcoming space instrument. With its Fresnel Optics and PDM, the instrument monitors a $12^\circ \times 12^\circ$ field of view in a wavelength range between 290 and 430 nm, at a rate of 400,000 frames/sec. Details can be seen in [17].

7 Conclusions

JEM-EUSO is an ISS space-mission designed to to explore the extreme energies of our universe and its fundamental physics through the detection of UHECRs with high statistics. It is the first observatory with full-sky coverage and can achieve, depending on the mission lifetime, an exposure comparable close to 10^6km^2 sr year. JEM-EUSO is currently designed to meet a launch date in 2017. A pathfinder for future missions, JEM-EUSO will pave the way to even larger space-based observatories, that will definitely explore the extremes of the Universe [18].

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