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The JEM-EUSO mission: Context and status

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Abstract. JEM-EUSO, the Extreme Universe Space Observatory, on-board the Japanese Experiment Module of the ISS (International Space Station), is expected, within this decade, to explore the ultra-high energy (UHE) Universe with unprecedentedly large effective area and uniform exposure. In this paper, we summarize the scientific context of the mission and its scientific requirements. We then report: 1) on the status of the instrument, describing the most recent technical developments; and 2) on the mission aspects of the observatory. In addition, we will present the current programmatic status.

1. INTRODUCTION

In any post- Pierre Auger Observatory scenario, observations of Ultra High Energy Cosmic Rays (UHECRS) from space are likely to be essential. Space-based observatories can reach a practical instantaneous geometrical aperture up to $A_{\rm eff} \sim 2.5 \times 10^6\,{\rm km}^2$ sr, which implies a target mass of more than 10^{12} tons. UHECRs space observatories naturally provide a 4π sky coverage, and assuming a duty cycle $\eta \sim 20\%$, the currently expected trigger efficiencies, and an operation time of about five years, they can reach an exposure of $A_{\rm exp} \sim 10^6\,{\rm km}^2$ sr yr. More details are given in [14].

The original idea to observe the fluorescence light ($300 \div 400$ nm) produced by an extended air shower (EAS) proceeding in the atmosphere, by means of space-based devices looking at Nadir nighttime, traces back to 1979, when John Linsley first suggested the “SOCRAS” concept [1]. “SOCRAS” generated the Orbiting Wide-angle Light collector concept (OWL) in the US and the AIRWATCH program in Europe, which after a few years led to the Extreme Universe Space Observatory (EUSO) mission concept.

EUSO [6] was originally submitted to ESA in 2000, in response to the “Call for mission proposals for two flexi-missions (F2 and F3)” issued in 1999. The mission was designed for the ESA’s Columbus module onboard the International Space Station (ISS) and was characterized by an $A_{\rm exp} \sim (1.3 \div 3.2) \times 10^5\,{\rm km}^2$sr yr. The phase A study was successfully completed in 2004. Although EUSO was found technically ready to proceed into phase B, ESA did not continue the mission mainly due to programmatic uncertainties related to the ISS.

In 2004, the EUSO mission concept was reoriented in order to be accommodated on the Exposed facility of the Japanese Experiment module (JEM) of the ISS, also known as KIBO (in English Hope). The development of the JEM-EUSO Instrument is performed by an international Consortium with more than 250 scientists from 13 different countries and is led by the RIKEN institute (Japan).

2. THE SCIENCE OBJECTIVES AND REQUIREMENTS

2.1 The observational technique

The observational technique of JEM-EUSO is shown in Fig. 1. JEM-EUSO is a new type of observatory, based on a UV telescope, which uses the whole Earth as detector. It will observe, from an altitude

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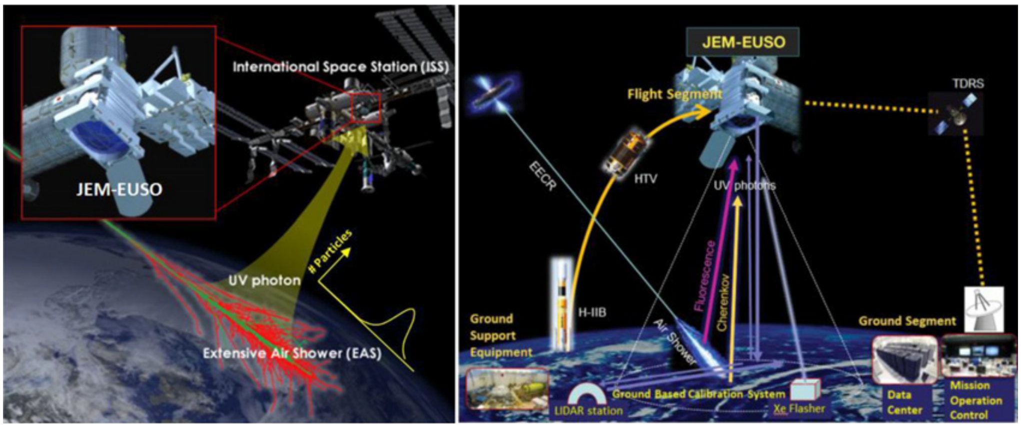

Figure 1. *Left*: simulation of the light profile observed at the entrance pupil and (*Right*) of the observed shower image. Here an event with energy 10^{20} eV and inclination angle of 60° is shown. The dominant light component is due to fluorescence (blue). In green the contribution of scattered Cherenkov light from the primary beam is shown and in red the diffusively reflected Cherenkov light. Time is given in Gate Time Unit (GTU). Each GTU lasts 2.5 μs. The typical duration of the shower is about 150 μs.

of ∼400 km, the fluorescence tracks produced at (330–400) nm by and EAS originated by UHE primaries, which traverse the earth's atmosphere at ultra-relativistic speed. Photons of the Cherenkov beam associated to the EAS diffusively reflected at the ground can also be observed as an evident "Cherenkov mark", if the core of the shower lies within the field of view. The UV telescope records the track of an EAS with a time resolution of 2.5μs and a spatial resolution of about 0.5 km (corresponding to 0.07° in nadir mode) by using a highly pixelized focal surface (3×10^5 pixels) [2, 3]. Detecting the kinematical development of the track, through these time-segmented images, JEM-EUSO will measure the energy, the arrival direction, and the nature of the primary particle. An example of the observed profiles and tracks is shown in Fig. 2.

Because of the ISS orbit, the JEM-EUSO field of view moves in the latitude range ±51° at a speed of ∼7 km/s, and thus the variability of the scene (ocean, land, luminous or dark areas) observed by JEM-EUSO is much higher than that observed by ground-based experiments. In addition, the atmospheric conditions (such as the cloud coverage) observed along the orbit are variable and affect the detection acceptance. For these reasons, an infrared camera and a LIDAR [4] are used to continuously monitor the field of view.

2.2 Science objectives

The main science objective of the JEM-EUSO mission is to perform astronomy and astrophysics through the particle channel. The main science goals are: 1.) The *identification of sources* by high-statistics arrival direction analysis; 2.) The *measurement of the energy spectra* of individual sources (spectral shape, flux, power); 3.) A high statistics measurement *of the trans-GZK spectrum.* The primary goal is therefore to optimize the mission, in order to conduct physics and astrophysics investigation in the energy range $E > 5 \times 10^{19}$ eV.

The exploratory objectives include: 1.) The *discovery of UHE neutrinos* by discriminating weakly interacting event 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 effects [6]; 3.) The *study of the galactic and local extragalactic magnetic fields*, through the analysis of the magnetic point spread function. To reach these objectives, or to put severe limits on the fluxes in case of non-detection, we aim at reaching the highest statistics and, therefore, the largest exposures at extreme

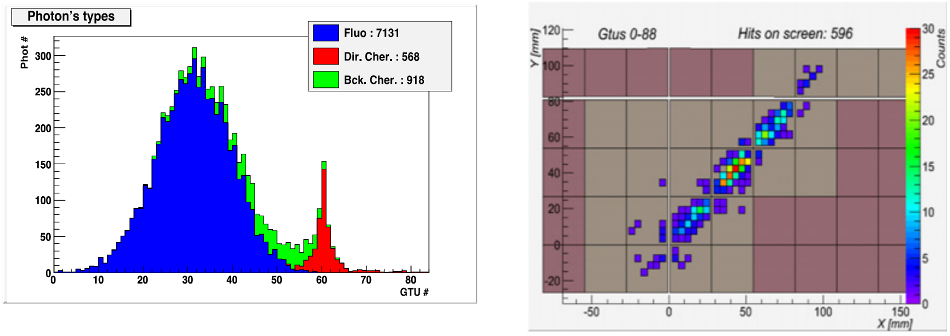

Figure 2. *Left*: simulation of the light profile observed at the entrance pupil and (*Right*) of the observed shower image. Here an event with energy 10^{20} eV and inclination angle of 60° is shown. The dominant light component is due to fluorescence (blue). In green the contribution of scattered Cherenkov light from the primary beam is shown and in red the diffusively reflected Cherenkov light. Time is given in Gate Time Unit (GTU). Each GTU lasts 2.5 μs. The typical duration of the shower is about 150 μs.

energies, that is at $E \approx 10^{20}$ eV. Among the exploratory, objectives several topics of atmospheric science are included. JEM-EUSO will allow a characterization of the nightglow and of the transient luminous events (TLE) in the UV band. It can also detect the slow UV tracks associated to meteors and meteoroids [7].

2.3 Science requirements

From the science objectives, the following scientific requirements have been set: [SR1] *Statistics of several hundreds* events above 7×10^{19} eV, which implies an *Acceptance* $\geq 7 \times 10^5 (\mathrm{h(km)}/400)^2$ km^{2}sr and an *Energy threshold* $\leq 7 \times 10^{19}$ eV; [SR2] *Angular resolution* $\leq 2.5°$ (for a standard shower with $E = 1020$ eV and zenith angle 60°); [SR3] *Energy resolution* $\leq 30\%$ (at $E = 10^{20}$ eV and 60° zenith angle); [SR4] the *EECR primary identification capability* to discriminate between nuclei, gamma ray and neutrinos, implies X_{max} determination error $\leq 120\,(\mathrm{g/cm^2})$ (for $E = 10^{20}$ eV and 60° zenith angle).

End-to-end simulation packages, such as the EUSO Simulation and Analysis Framework (ESAF), are used to evaluate the scientific performances of JEM-EUSO [8]. Details on the expected performances can be found in [14].

3. THE JEM-EUSO MISSION AND INSTRUMENT

3.1 The mission

The main elements of the mission are shown in Table 1. JEM-EUSO will be launched by an H2B rocket and will be conveyed to the ISS by the unmanned resupply spacecraft H-II Transfer Vehicle (HTV). It will be then attached, using the Canadian robotic arm, to one of the ports for non-standard payloads of the Exposure Facility (EF) of the Japanese Experiment Module (JEM). The Instrument will be stored in the HTV, in a folded configuration, and will be deployed after the attachment procedure is successfully completed. Data will be transmitted via TDRS to the Mission Operation Center hosted by JAXA in the Tsukuba Space Center and managed by RIKEN with the support of the whole collaboration. We plan to establish the main JEM-EUSO data center in RIKEN while other data centers will be most likely established in all major participating countries. JEM-EUSO will be operated for three years in Nadir configuration (Nadir mode) to maximize statistics at the lowest energies in order to cross calibrate with the current generation of ground-based detectors. The instrument will be then tilted (about 35°) with respect to Nadir in order to maximize the statistics of events at the highest energies.

Table 1. Parameters of the JEM-EUSO Mission.

Expected launch date	**JFY 2017**
Mission Lifetime	**3+2 years**
Launch Rocket	**H2B**
Transport Vehicle	**HTV**
Accommodation on JEM	**EF#2 (or 9)**
Mass	**1938 kg**
Telemetry and data	**285 kbps (onboard data storage)**
Power	**926 W (op.) 352 W (non op.)**
Height of the Orbit	**400 km**
Inclination of the Orbit	**51.6°**
Operational Temperature	**-10°C–50°C**

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) [9]. 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 have flashers only (GLS-X). Sites will be chosen for their low back-ground light and altitude (above the planetary boundary layer). The main parameter of the mission are summarized in Table 1.

The JEM-EUSO mission is very demanding in terms of ISS resources (mass and power). The mission can be successfully completed if all the major space agencies will take part in this enterprise. This requires complex coordination between JAXA, NASA, ESA and Roscosmos. Such coordination efforts are indeed on-going.

3.2 The Instrument

The key parameters of the mission are summarized in Table 2. JEM-EUSO consists of a main telescope, sensitive to near UV ($330 \div 400$ nm), and an atmosphere monitoring system (AMS). The main telescope is an extremely-fast (of the order of μs) and highly- pixelized (3×10^5 pixels) digital camera with a large-aperture nd wide-Field of View (FoV) operating in single photon counting mode. Two curved, double sided, Fresnel lenses with 2.65 m external diameter, an intermediate curved precision Fresnel lens, and a pupil, are the "baseline" optics of the telescope. The Fresnel lenses provide a large-aperture, wide FoV optics with low mass and high UV light transmittance. The combination of 3 Fresnel lenses allows a full angle FoV of 60° with a resolution of 0.075°, which corresponds to a pixel of about 550 m on earth. The material of the lens is PMMA which has high UV transparency in the wavelength from 330 nm to 400 nm. A precision Fresnel optics based on diffractive optics technology is used to suppress the chromatic aberration. Details of the optics are described in [10]. The focal surface (FS) is spherical with $\sim$2.5 m curvature radius, and 2.3 diameter. The Focal surface is equipped with 5,000 multi-anode photomultiplier tubes (64-pixel MAPMT), with quantum efficiency of about 40%. The FS is organized in 137 Photo-Detector Modules (PDMs), each one consisting of 9 Elementary Cells (ECs). The EC contains 4 MAPMT. Details of the focal surface detector are described in [11]. A protection circuit, which intercepts the photoelectron signal at the initial stage of the dynodes, has been developed to protect MAPMTs from sudden intense illumination such, as lightning. 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

Table 2. Parameters of the JEM-EUSO Instrument.

Field of view	**$\pm 30^\circ$**
Monitored Area	**$> 1.3\times 10^5$ km^2**
Telescope Aperture	**$\geq$2.5 m**
Operational wavelength	**300–400 nm**
Resolution in angle	**0.075°**
Focal Plane Area	**4.5 m^2**
Pixel size	**$<$3 mm**
Number of pixels	**3.2×10^5**
Pixel size on ground	**550 m**
Time resolution	**2.5 μs**
Detection Efficiency	**$\geq$20%**
Dead Time	**$<$3%**

charge integration in a chip with 64 channels [12, 13]. Radiation tolerance of the electronic circuits in space environment is also required. The system is required to have high trigger efficiency and linearity over the 10^{19}–10^{21} eV range.

Power consumption per channel must be less than 2.5 mV to manage 3×10^5 channels within the available budget (1 kW). The anode signals of the MAPMT are digitized and recorded in ring memories a gate time unit (GTU) currently set to 2.5 μs. When a trigger signal is issued the data are read and sent to control boards. The trigger system must acquire EAS events with the highest S/N avoiding fake triggers generated by background. JEM-EUSO uses a hierarchical trigger scheme to reduce data rate from about 10 GB/s/FS down to 297 kb/s, the allowed telemetry rate from ISS to ground operation center.

4. THE CURRENT STATUS

JEM-EUSO is currently completing the preparation of the final documentation of the phase A study (feasibility study and conceptual design) jointly conducted by JAXA and RIKEN. The mission has been found to be technically feasible and no major showstoppers have been identified. However since JEM-EUSO is a complex payload for accommodation on the ISS, the involvement of all major ISS agencies is desirable if not necessary. The mission has been included, after a severe review, and already in 2010 in the ELIPS program of ESA. ESA is also actively acting toward an interagency coordination effort. In 2012 JEM-EUSO has been positively reviewed by the STEC Committee in Russia and submitted officially to ROSCOSMOS for approval. In the US, a renewed team has submitted a proposal in the context of the APRA call, requesting ISS resources (launch mass mainly) to NASA. In parallel to this complex programmatic activity, the development of the engineering models of the optics and of the PDM has continued.

Currently the JEM-EUSO collaboration prepares two small size prototypes of the core detector element to be operated on ground at the Telescope Array site in Utah and to be flown on a balloon platform. The campaign in Utah is expected for November 2012, while the first launch of the balloon is scheduled early 2014. The current foreseen launch date of JEM-EUSO is in the Japanese Fiscal Year 2017.

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