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The JEM-EUSO mission to explore the extreme Universe

Fumiyoshi Kajino *

Department of Physics, Konan University, Okamoto 8-9-1, Higashinada, Kobe, Hyogo 658-8501, Japan

For the JEM-EUSO collaboration

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ABSTRACT

Accommodated on the Japanese Experiment Module (JEM) of the International Space Station (ISS), the Extreme Universe Space Observatory JEM-EUSO will utilize the Earth's atmosphere as a giant detector of the extreme energy cosmic rays; the most energetic particles coming from the Universe. Looking downward the Earth from Space, JEM-EUSO will detect such particles by observing the fluorescence and Cherenkov photons produced during their pass in the atmosphere. The main objective of JEM-EUSO is doing astronomy and astrophysics through the particle channel with extreme energies above several times 10^{19} eV with a significant statistics beyond the Greisen–Zatsepin–Kuzmin (GZK) cut-off. Moreover, JEM-EUSO could observe extremely high energy neutrinos. JEM-EUSO has been designed to operate for more than 3 years onboard the ISS orbiting around the Earth every 90 min at an altitude of about 400 km. JAXA has selected JEM-EUSO as one of the mission candidates of the second phase utilization of JEM/EF for the launch in mid 2010s.

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1. Mission overview

Extreme Universe Space Observatory on Japanese Experiment Module (JEM-EUSO) [1] is a new type of high-energy astronomical observatory which utilizes the Earth and its atmosphere as a "detector" with a remote sensing telescope on board the Exposed Facility (EF) of the International Space Station (ISS). The telescope observes very faint transient luminous phenomena taking place in the dark Earth's atmosphere caused by particles and waves coming from outer space. The telescope has a super wide field-of-view (FoV) of 60° and observes the area of the Earth's surface with 1.9×10^5 km^2 or more at a time. This telescope orbits around the Earth every $\sim$90 min on board the ISS at an altitude of $\sim$400 km. An extremely energetic cosmic ray (EECR) coming from the Universe collides with a nucleus in the atmosphere and produces an extensive air shower (EAS) which consists of numerous electrons, positrons, photons and other particles. JEM-EUSO captures the moving track of the fluorescent and Cherenkov ultraviolet (UV) photons, as sketched in Fig. 1, and reproduces the calorimetric development of the EAS.

Scientific objectives of the JEM-EUSO mission consist of the followings items:

Main objectives:

Astronomy and astrophysics through particle channel with extreme energies $>10^{20}$ eV.

- Identification of sources by the high-statistics arrival direction analysis.
- Measurement of the energy spectra from individual sources to constrain acceleration or emission mechanisms.

Exploratory objectives:

- Detection of extreme energy gamma rays.
- Detection of extreme energy neutrinos.
- Study of the Galactic magnetic field.
- Verification of the relativity and the quantum gravity effect in extreme energy.
- Study of nightglows, plasma discharges and lightning.

Main mission parameters of JEM-EUSO are summarized in Table 1.

2. Instrument

The first EUSO observatory was originally selected by the European Space Agency (ESA) as a mission to be attached to the European Columbus module of the ISS. The ESA-EUSO phase-A study was successfully completed in July 2004 [2]. In 2006, the mission was redefined as an observatory to be attached to the Japanese Experiment Module/Exposure Facility (JEM/EF) of the ISS. Thereafter, the mission was renamed as JEM-EUSO.

* Tel.: +81 78 435 2487; fax: +81 78 452 9502.
E-mail address: kajino@konan-u.ac.jp

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The JEM-EUSO instrument basically consists of an EECR telescope assisted by an atmosphere monitoring device and controlled by a calibration system.

The JEM-EUSO telescope is an extremely fast, highly pixelized, large-aperture and large-FoV digital camera, working in near-UV wavelength range (330–400 nm) with single photon counting capability. The main components of the telescope are the collecting optics, the focal surface detector, the electronics and the structure, as shown in Fig. 2. The optics system is composed of two Fresnel lenses and one diffractive precision lens. With an aperture of $\pm 30^\circ$ FoV, the optics focuses the incident UV light onto the front lens toward the focal surface with a spatial resolution of 0.1°. The focal surface detector is composed by a grid of ~6000 multi-anode photomultipliers (MAPMT) which convert the energy of the incoming photons into electric pulses with duration of ~10 ns [3,4]. The electronics counts-up the number of the electric pulses in time period of 2.5 μs and records them to the memory. When a signal pattern coming from EECR events is found, the electronics issues a trigger signal and transmits all the useful data to the ground operation centre.

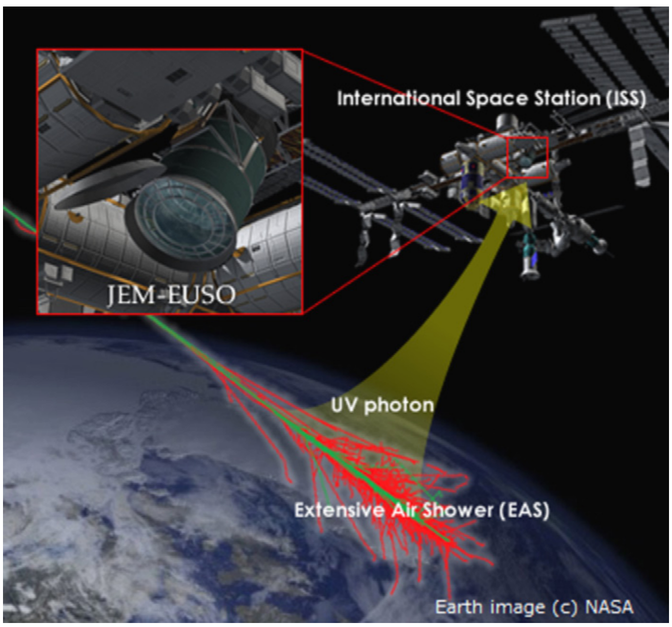

Fig. 1. Artistic view of the JEM-EUSO telescope accommodated on the ISS.

Table 1
Main mission parameters of JEM-EUSO.

Time of launch	mid 2010s
Operation period	3 years (+2 years)
Mass	1983 kg
Power	926 W (operative)
Data transfer rate	285 kbps
Height of the orbit	~400 km
Inclination of the orbit	51.64°

The atmospheric monitoring device consists of an infrared (IR) camera and a Lidar (LIght Detection and Ranging) with UV laser to observe the conditions of the atmosphere in the FoV of the EECR telescope, with the objective of determining effective observation time, and of increasing the reliability of the events around the energy threshold.

The role of the Lidar is the following: to observe the condition of clouds in several points of the telescope FoV, and to calibrate with high accuracy the transformation table between altitude of cloud tops and their temperature, obtained by the analysis of the IR camera images. Using the wavelength of the laser (355 nm) in the range of interest for JEM-EUSO, the focal surface detector of the EECR telescope will be used as Lidar receiver unit.

Gain and detection efficiency of the JEM-EUSO detector will be calibrated through instrumentation both onboard and on the ground. The onboard calibration system of JEM-EUSO is composed of a set of LEDs with different wavelengths installed in the telescope.

Moreover, Xenon flasher lamps will be installed in a dozen of sites on the ground. When JEM-EUSO passes over them, once a day or so, it will detect such lights and measure the total atmospheric UV absorption and, therefore, calibrate the device. In order to estimate the systematic error in the energy and arrival direction of the primary cosmic rays, JEM-EUSO telescope observes the UV laser from the ground as the simulated EAS. This observation also allows us to estimate the transmittance of the atmosphere as a function of the altitude.

The main instrumental parameters of JEM-EUSO are summarized in Table 2.

3. Expected performance

JEM-EUSO observes air fluorescence light from EAS in a background light emitted from ground and airglow sources. Therefore, optimized triggering method will be required to

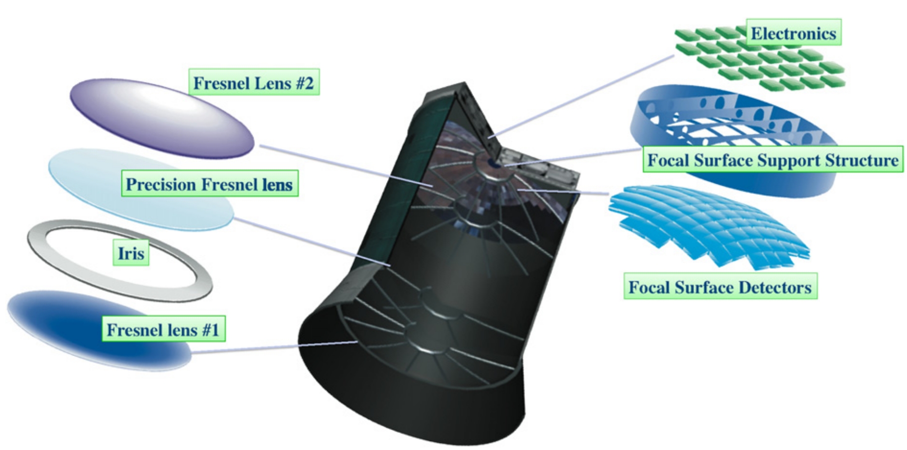

Fig. 2. Schematic view of the JEM-EUSO telescope.

Table 2
Main instrumental parameters of JEM-EUSO.

Field of view	$\pm 30^\circ$
Observational area	$> 1.9 \times 10^5$ km^2
Optical bandwidth	$330 \div 400$ nm
Focal surface area	4.5 m^2
Number of pixels	$\sim 2.0 \times 10^5$
Pixel size	4.5 mm
Pixel size at ground	750 m
Spatial resolution	0.1°
Event time sampling	≤ 2.5 μs
Duty cycle	$\sim 20\%$

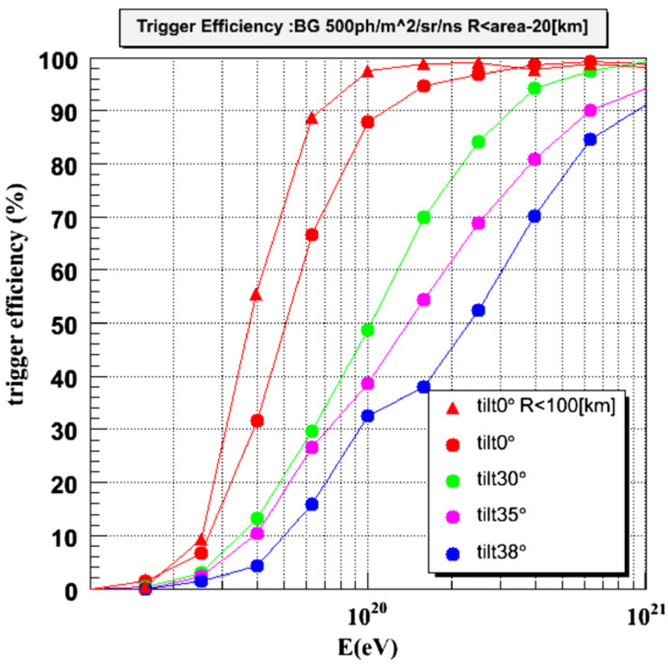

Fig. 3. Trigger efficiency as a function of energy for various tilt angles of the JEM-EUSO telescope.

acquire the EAS events efficiently with good signal-to-noise ratio avoiding fake triggers.

Fig. 3 shows the trigger efficiency as a function of energy of the JEM-EUSO telescope with an assumption of background light intensity of 500 photons/(m^2 sr ns) for various tilt angles. The "track trigger method" has been applied to the individual time profile of photo-electrons from the MAPMT.

The trigger efficiency at 10^{20} eV is 88% for nadir mode observation, and EAS threshold energy is estimated to be 5.0×10^{19} eV at 50% detection efficiency level. The trigger efficiency for the EAS within a radius of 100 km well inside the FoV shows that the threshold energy becomes about 4×10^{19} eV because of the better performance of optical system and smaller impact parameters.

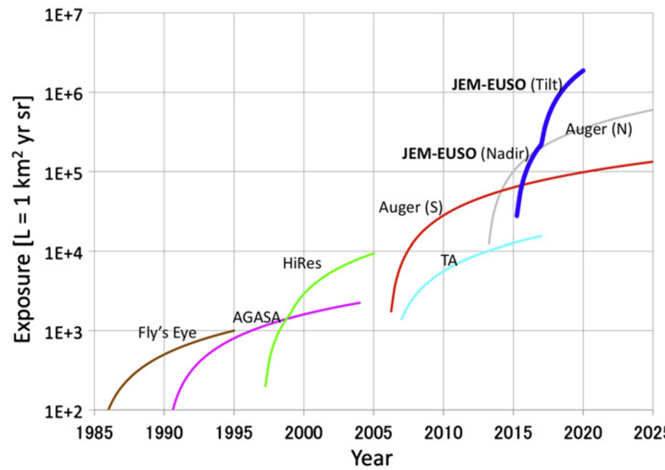

Fig. 4. Expected cumulative exposure of JEM-EUSO in Linsley unit (1 Linsley=1 km^2 sr year). Evolution of exposure by other retired and running EECR observatories is also shown for comparison.

The threshold energy increases as the tilt angle increases due to the increase of the distance from the EAS to JEM-EUSO.

Effective acceptance of the tilt mode observation with 38° has been calculated to be 1.8 times and 2.4 times larger at 10^{20} and $10^{20.5}$ eV, respectively, than that of the nadir mode observation with 0°.

Angular resolution of the EECR arrival directions observed by JEM-EUSO is obtained by the simulation to be well less than 2.5° for energies $10^{19.5}$–10^{21} eV and for incident zenith angles 30–70° for nadir mode observation. The resolution becomes worse as the incident zenith angle becomes smaller for the angles 0–30°, because length of the EAS becomes shorter.

Energy resolution of the EECR events is obtained to be well less than 30% for various energies and zenith angles mentioned above.

To determine the depth of the shower maximum measured from the top of the atmosphere, $X_{\max}$, is important to determine the composition of the EECR. Obtained $X_{\max}$ resolution is roughly 60 g/cm^2 for various energies and zenith angles.

Expected cumulative exposure of JEM-EUSO with other experiments for comparison is shown in Fig. 4. JEM-EUSO will be able to reach 1 M Linsley at which roughly 1000 EECR events are detected. EECR origins may be specified by clusters of events and energy spectra of the clusters from such large number of events [5]. Therefore, we expect astronomy and astrophysics by EECR will really open in 5 years of operation of JEM-EUSO.

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