



The JEM-EUSO Mission

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Abstract: The JEM-EUSO mission explores the origin of the extreme energy cosmic rays (EECRs) above 100 EeV and explores the limits of the fundamental physics, through the observations of their arrival directions and energies. It is designed to open a new particle astronomy channel. This super-wide-field (60 degrees) telescope with a diameter of about 2.5m looks down from space onto the night sky to detect near UV photons (330-400nm, both fluorescent and Cherenkov photons) emitted from the giant air showers produced by EECRs. The arrival direction map with more than five hundred events will tell us the origin of the EECRs and allow us to identify the nearest EECR sources with known astronomical objects. It will allow them to be examined in other astronomical channels. This is likely to lead to an understanding of the acceleration mechanisms perhaps producing discoveries in astrophysics and/or fundamental physics. The comparison of the energy spectra among the spatially resolved individual sources will help to clarify the acceleration/emission mechanism, and also finally confirm the Greisen-Zatsepin-Kuz'min process for the validation of Lorentz invariance up to $\gamma \sim 10^{11}$. Neutral components (neutrinos and gamma rays) can also be detected as well, if their fluxes are high enough. The JEM-EUSO mission is planned to be launched by a H2B rocket about JFY 2016 and transferred to ISS by H2 Transfer Vehicle (HTV). It will be attached to the Exposed Facility external experiment platform of "KIBO".

Keywords: cosmic rays, neutrino, Lorentz invariance International Space Station.

1 Introduction

The "Extreme Universe Space Observatory - EUSO" is the first space mission devoted to the exploration of the Universe through the detection of the extreme energy ($E > 100$ EeV) cosmic rays (EECRs) and neutrinos [1,2,3,4,5]; it looks downward from the International Space Station (ISS). It was first proposed as a free-flyer, but was selected by the European Space Agency (ESA) as a mission attached to the Columbus module of ISS. The phase-A study for the feasibility of that observatory (hereafter named ESA-EUSO) was successfully completed in July 2004. Nevertheless, because of financial problems in ESA and European countries, together with the logistic uncertainty caused by the Columbia accident, the start of the phase B had been pending. In 2006, Japanese and U.S. teams redefined the mission as an observatory attached to "KIBO," the Japanese Experiment Module (JEM) of ISS. They renamed it JEM-EUSO and started with a renewed phase-A study.

JEM-EUSO is designed to achieve our main scientific objective: astronomy and astrophysics through the particle channel to identify sources by arrival direction analysis and to measure the energy spectra from the indi-

vidual sources, with an overwhelmingly high collecting power comparable to $1 \text{ million km}^2 \text{ sr year}$. It will constrain acceleration or emission mechanisms, and also finally confirm the Greisen-Zatsepin-Kuz'min process [6] for the validation of Lorentz invariance up to $\gamma \sim 10^{11}$.

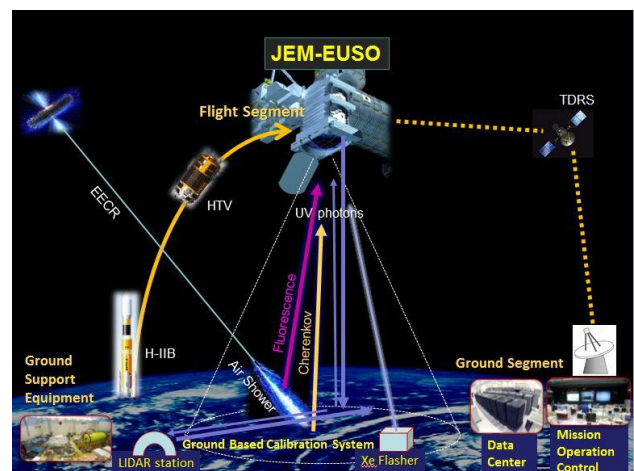


Figure 1. Principle of the JEM-EUSO telescope to detect Extreme Energy cosmic rays (EECRs).

2 Science Objectives

Science objectives of the JEM-EUSO 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 that uses the extreme energy particle channel ($5 \times 10^{19} \text{ eV} < E < 10^{21} \text{ eV}$). JEM-EUSO has the critical exposure comparable to 1 million $\text{km}^2 \cdot \text{sr} \cdot \text{year}$ to observe all the sources at least once inside several hundred Mpc and makes possible the followings:

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

We set five 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 effects at extreme energy
- Global survey of nightglows, plasma discharges, and lightning and meteors

See [7,8,9] for the detailed discussions of scientific objectives. The success criteria of the mission are determined so as to achieve these science objectives (Table 1)

3 Instrument

The JEM-EUSO instrument consists of the main telescope, an atmosphere monitoring system, and a calibration system [10]. The main telescope of the JEM-EUSO mission is an extremely-fast ($\sim \mu\text{s}$) and highly-pixelized ($\sim 3 \times 10^5$ pixels) digital camera with a large diameter (about 2.5m) and a wide-FoV ($\pm 30^\circ$). It works in near-UV wavelength (330-400 nm) with single-photon-counting mode. The telescope consists of four parts: the optics, the focal surface detector and electronics, and the structure. The optics focuses the incident UV photons onto the focal surface with an angular resolution of 0.07 degree [11]. The focal surface detector converts the incident photons to photoelectrons and then to electric pulses [12,13]. The data electronics issues a trigger for air-shower event or other transient event in the atmosphere and send necessary data to the ground for further analysis. Atmosphere Monitoring System (AMS) monitors the earth's atmosphere continuously inside the FoV of the JEM-EUSO telescope [14]. The AMS uses IR camera, Lidar, and the slow data of the main telescope to measure the cloud-top height with accuracy better than 500 m. The calibration system measures the efficiencies of the optics, the focal surface detector, and the data acquisition electronics [15].

4 Observational Merits

In comparison with ground-based observatories, the space-based telescope may provide various merits in observations of EASs induced by EECR. One of substan-

tially differences is that the signals of EAS from higher altitudes are efficiently observed with no or limited attenuation in cloudy cases if either the cloud lies at lower altitudes or optically thin clouds at high altitude. In order to determine the primary energy of EECRs, measurement of shower development including the signature around the maximum of the shower development is needed to be measured.

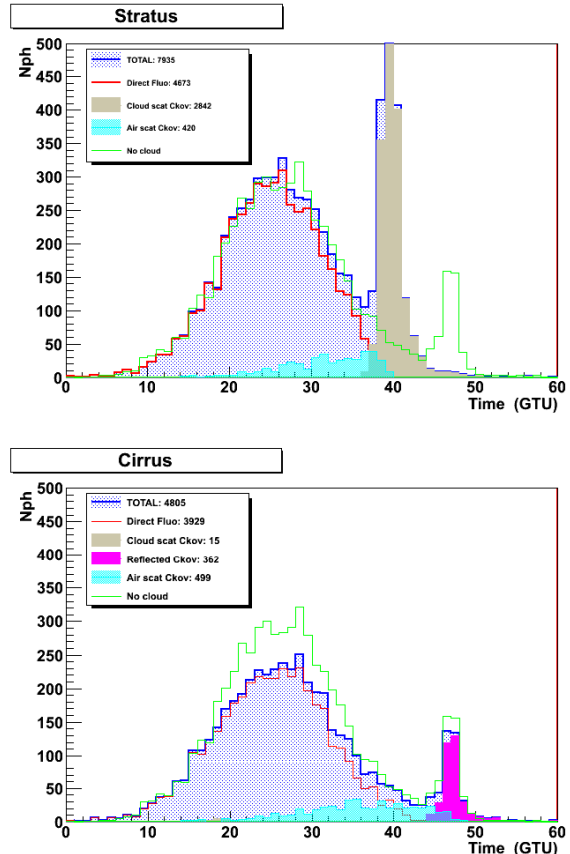


Figure 2. Typical EAS signals in cloudy conditions. Top and bottom panels show the case of the presence of stratus and cirrus. The components of signals are indicated in the legend. The green histogram is the case of EAS signal in clear sky.

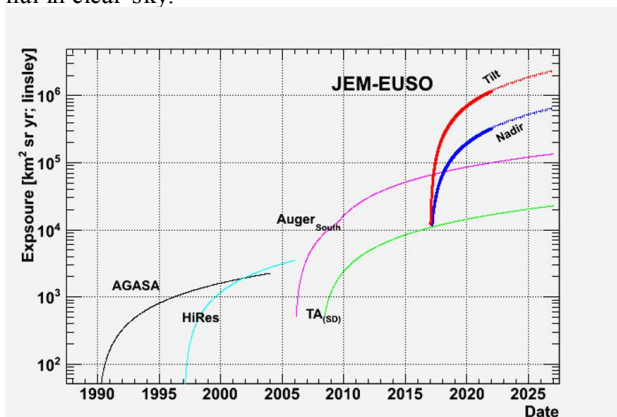


Figure 3 Expected cumulative exposure, in $\text{km}^2 \text{sr yr}$ or linsley units, of JEM-EUSO. The thick blue curve corresponds to pure nadir mode and the thick red curve to pure tilted mode; the actual exposure will depend on the final operating mode adopted and will lay between both curves. For comparison, the evolution of exposure by other retired and running EECR observatories is shown..

Fig. 2 demonstrates the typical EAS with clouds in comparison with one without clouds. In case of optically thick clouds that lie at altitudes lower than the shower maximum, such as stratus, the main part of shower development is well measured to reconstruct the energy deposit in the atmosphere. Moreover, the diffusively reflecting Cherenkov light enhances the total intensity from the shower that helps increasing the efficiency of triggering the shower at nearly threshold energies. In presence of the optically thin clouds that lie at high altitudes, *e.g.* ones categorized as cirrus, most of EAS signals penetrate the layer of the clouds and are attenuated partly and may be recognized as an lower energy event. In such a case, however, the geometry of shower axis is properly determined by the analysis of the angular velocity of the EAS signal.

Figure 3 shows the evolution of the exposures of the past and future missions devoted to research of the extremely high energy cosmic rays. The JEM-EUSO can achieve a more than one order of magnitude larger exposure compared to the Auger experiment of Telescope array experiment.

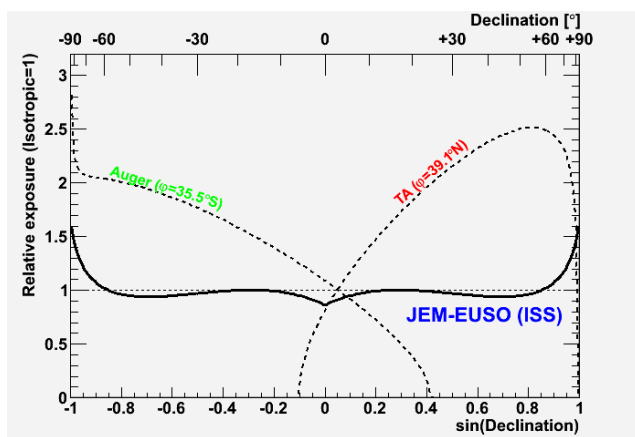


Figure 4. Relative aperture as a function of sine of declination. Dashed curves show the cases of the Auger and Telescope Array experiments for comparison. The pure isotropic exposure to solid angle is defined to 1. The horizontal axis on the top denotes corresponding declination.

Fig. 4 demonstrates the uniformity of exposure expected in the JEM-EUSO mission as a function of sine of declination (solid angle) compared with ones for ground-based experiments (Auger and Telescope Array). In addition to the significant increase of the overall exposure by about one order of magnitude compared with Auger as of today, the orbiting JEM-EUSO telescope will cover the entire Celestial Sphere. Moreover, the cumulative exposure results in high degree of uniformity thanks to inclined ISS orbit. Such an advantage is more pronounced if the EECRs from the single source are observed with angular spread. If it is the case, the gradient of exposure distributions in the Celestial Sphere may sweep over the real signals from the sources.

With wide FOV of JEM-EUSO telescopes observing from the Space, the measurements of the entire profile of the shower development is eased compared with relatively small FOV. In the case of JEM-EUSO, it is more sensitive to showers with larger zenith angles. Such a merit allows the effective measurements of neutrino-induced showers.

5 Conclusion

JEM-EUSO is the science mission looking downward from the ISS to explore the extremes in the Universe and fundamental physics through the detection of the extreme energy $E > 10^{20}$ eV cosmic rays. It is the first instrument that has a full-sky coverage and achieves an exposure comparable to one million $\text{km}^2 \cdot \text{sr} \cdot \text{year}$, the reference value of the exposure to start “astronomy and astrophysics through particle channel.” The JEM-EUSO mission is planned to be launched by a H2B rocket about 2016-2017 and transferred to ISS by H2 transfer vehicle (HTV), and attached to the external experiment platform of “KIBO.”

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