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THE JEM-EUSO MISSION

Mario Bertaina[a,b], Toshikazu Ebisuzaki[c], Piero Galeotti[a,b,*], Fumiyoshi Kajino[d], on behalf of the JEM EUSO Collaboration

[a] *Department of Physics, University of Torino, Torino, Italy*
[b] *National Institute of Nuclear Physics (INFN), Sez. di Torino, Italy*
[c] *RIKEN Advance Science Institute, Tokyo, Japan*
[d] *Department of Physics, Konan University, Kobe, Japan*
[*] corresponding author: piero.galeotti@unito.it

Abstract. The JEM-EUSO mission explores the origin of extreme energy cosmic rays (EECRs) above 50 EeV and explores the limits of fundamental physics, through 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 2.5 m looks down from space onto the night sky to detect near UV photons (330 ÷ 400 nm, 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 will 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 to 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, if their fluxes are high enough. The JEM-EUSO mission is planned to be launched by a H2B rocket in about 2017 and transferred to ISS by the 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 exploring the Universe through the detection of the extreme energy ($E > 50$ EeV) cosmic rays (EECRs) and neutrinos [1–5]; 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 this observatory (which we will refer to here as ESA-EUSO) was successfully completed in July 2004. However, because of financial problems at ESA and in the European countries, together with the logistic uncertainty caused by the Columbia accident, the start of phase B was put back. 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 individual sources, with an overwhelmingly high exposure, approaching $1 \times 10^6\,\mathrm{km^2\,sr\,yr}$ at energies above 300 EeV (see Fig. 3). This will allow the exploration of an energy region beyond any other previous or planned experiment (in the case of space-based telescopes, the observation area of the Earth's surface is essentially determined by the projection of the field of view of the optics). It will constrain the acceleration or emission mechanisms, and will also finally confirm the Greisen–Zatsepin–Kuz'min process [6] for the validation of Lorentz invariance up to $\gamma \sim 10^{11}$.

2. Scientific objectives

The scientific 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 ($5 \times 10^{19}\,\mathrm{eV} < E < 10^{21}\,\mathrm{eV}$).

JEM-EUSO has the critical exposure ($(0.1 \div 1 \times 10^6)\,\mathrm{km^2\,sr\,yr}$ depending on energy) to observe all the sources at least once inside several hundred Mpc, and makes possible the following:

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

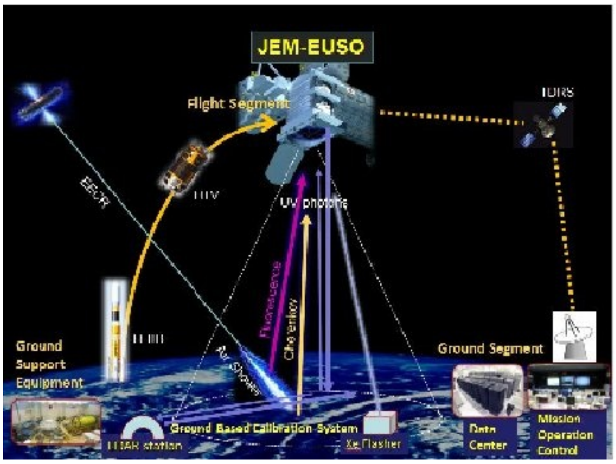

FIGURE 1. Principle of the JEM-EUSO telescope for detecting extreme energy cosmic rays.

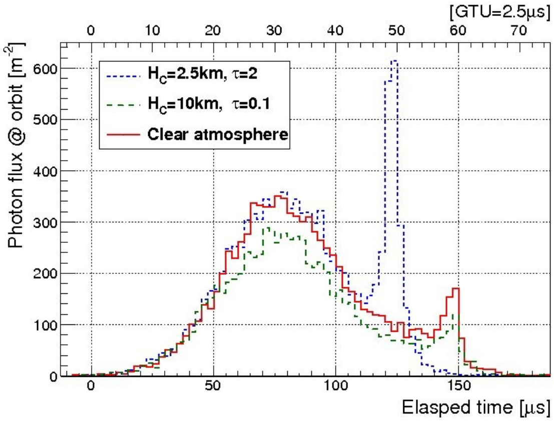

FIGURE 2. Arrival time distribution of photons at the telescope per m^2 from an EAS of $E = 10^{20}$ eV and $\Theta = 60°$ with various cloud conditions. Dashed and dotted lines correspond to the case of cirrus-like and stratus-like test clouds, along with a solid line for the clear atmosphere case. The peak at ~ 150 µs in a clear atmosphere and cirrus-like cloud is due to the Cherenkov light reflected from the ground, and it is fainter for cirrus. In case of stratus-like clouds, such reflection occurs at cloud-top; this peak is therefore closer to the fluorescence shower maximum.

We have set five exploratory objectives:

- Detection of extreme energy gamma rays.
- Detection of extreme energy neutrinos.
- A study of the Galactic magnetic field.
- Verification of relativity and quantum gravity effects at extreme energies.
- A global survey of nightglows, plasma discharges, and lightning and meteors.

See [7–9] for detailed discussions of the scientific objectives. The criteria for the success of the mission involve achieving these scientific objectives.

3. INSTRUMENT

The JEM-EUSO instrument consists of the main telescope, the atmosphere monitoring system, and the calibration system [10]. The main telescope of the JEM-EUSO mission is an extremely-fast ($\sim$ µs) and highly-pixelized ($\sim 3 \times 10^5$ pixels) digital camera with a large diameter (about 2.5 m) and a wide-FoV (±30°). 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 on to 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 an air-shower event or an other transient event in the atmosphere, and sends necessary data to the ground for further analysis. The atmosphere Monitoring System (AMS) monitors the earth's atmosphere continuously inside the FoV of the JEM-EUSO telescope [14]. AMS uses an 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 MERIT

In comparison with ground-based observatories, the space-based telescope may provide various merits in observations of EASs induced by EECR. One of the substantial differences is that the signals of EAS from higher altitudes are efficiently observed with no attenuation or with limited attenuation in cloudy cases, either if the cloud lies at lower altitudes or if optically thin clouds lie at high altitude. In order to determine the primary energy of EECRs, it is necessary to measure the shower development, including the signature around the maximum of the shower development.

Figure 2 compares the behavior of typical EAS developping inside clouds and without clouds. In the case of optically thick clouds that lie at altitudes lower than the shower maximum, e.g. stratus, the main part of the shower development is well measured and this allows the energy deposit in the atmosphere to be reconstructed. Moreover, the diffusively reflecting Cherenkov light enhances the total intensity from the shower, which helps to increase the efficiency of triggering the showers at nearly threshold energies. In the presence of the optically thin clouds that lie at high altitudes, e.g. those categorized as cirrus, most EAS signals penetrate the layer of the clouds and are attenuated partly and may be recognized as a lower energy event. In such a case, however, the geometry of the 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 on the extremely high energy cosmic rays. At the highest energies, JEM-EUSO can achieve more than one

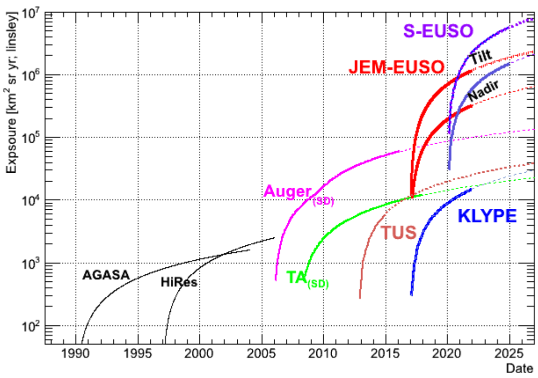

Figure 3. Expected highest cumulative exposure, in km^2 sr yr or Linsley units, of JEM-EUSO. The two thick red curves correspond to pure nadir mode and pure tilted mode; the actual exposure will depend on the final operating mode adopted and will lie between the two curves. For comparison, the evolution of exposure by other retired, running and proposed EECR observatories is shown.

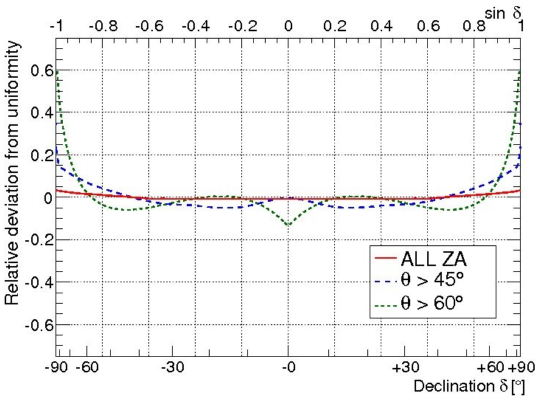

Figure 4. Relative deviation from uniformity of the aperture as a function of the sine of declination. Dashed curves show the cases for a selection of events with different zenith angle. The pure isotropic exposure to the solid angle is defined as 0. The horizontal axis on the bottom denotes the corresponding declination.

order of magnitude larger exposure than the Auger experiment or the Telescope array experiment.

Figure 4 demonstrates the uniformity of exposure expected in the JEM-EUSO mission as a function of the sine of declination (solid angle). This is not the case for ground-based experiments, such as Auger and Telescope Array. In addition to the significant increase in 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 a high degree of uniformity, thanks to the inclined ISS orbit. This advantage is more pronounced if the EECRs from the single source are observed with angular spread. If this is the case, the gradient of exposure distributions in the Celestial Sphere may sweet over the real signals from the sources.

With the wide FoV of JEM-EUSO telescopes observing from Space, the measurements of the entire profile of the shower development is simpler than with ground-based experiments with relatively small FoV. JEM-EUSO will survey an atmospheric mass on the Earth in excess of 10^{12} tons, and will be more sensitive to showers with larger zenith angles. This property allows effective measurements of neutrino-induced showers.

5. Conclusions

JEM-EUSO is a scientific mission looking downward from ISS to explore the extremes in the Universe and fundamental physics through the detection of extreme energy ($E > 5 \times 10^{19}$ eV) cosmic rays. It is the first instrument that has full-sky coverage and achieves exposure comparable to one million km^2 sr yr. The JEM-EUSO mission is planned to be launched by an H2B rocket in about 2017. It will be transferred to ISS by the H2 transfer vehicle (HTV), and attached to the external experiment platform of KIBO.

Acknowledgements

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