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The JEM-EUSO mission

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Abstract

The JEM-EUSO mission aims at studying the origin of the extreme energy cosmic rays (EECRs) beyond the GZK suppression and exploring fundamental physics at these extreme energies, through the observations of the arrival directions and energies of these particles. 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 observing the nighttime earth's atmosphere to detect near UV photons at 330–400 nm (both fluorescent and Cherenkov photons) emitted from the giant air showers produced by EECRs. The high statistics arrival direction map, expected to have at least more than five hundred events at the highest energies, will allow the identification of individual sources of EECRs, and their association with known near astronomical objects, uncovering therefore the origin of the EECRs. This will open the door to ultra-high energy astronomy, leading to an understanding of the acceleration mechanisms and, 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 mechanisms, and will eventually confirm the Greisen–Zatsepin–Kuz'min process validating 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.
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Keywords: Cosmic rays; Neutrino; Lorentz invariance; International Space Station

1. Introduction

The "Extreme Universe Space Observatory - EUSO" is the first mission designed to observe the cosmic-ray air showers from space to explore the Universe through the detection of the extreme energy (at $\sim$E 100 EeV and above) cosmic rays (EECRs) and neutrinos (Takahashi, 2009; Ebisuzaki et al., 2008; Ebisuzaki et al., 2009; Kajino, 2010). JEM-EUSO looks downward from the International Space Station (ISS). The idea of space based observation of EECRs can be traced back to SOCRAS, the Satellite Observatory of Cosmic Ray Showers, proposed by John Linsley in the late 1970's as one of the projects included in the Field Committee Report of NASA "Call for Projects and Ideas in High Energy Astrophysics for the 1980s". The key idea at the base of the SOCRAS concept was very clear: to observe, by means of space-based devices, looking at nadir during night, the fluorescence light produced by an extensive airshower (EAS) proceeding in the atmosphere. Linsley's original concept was based on a 38 m diameter mirror to monitor a circular field of about 100 km in diameter, corresponding to an area of 10^4 km^2 and an air mass of 10^{11} tons, from a circular orbit at about 500–600 km above the surface (Scarsi, 2001). The idea was visionary but unfortunately not feasible with the imaging and space technology of the 80's.

The key breakthrough in the imaging technology was suggested in 1995 by Yoshiyuki Takahashi, who proposed the use of light-weight Fresnel optics to enlarge Field of View to ± 30 degree keeping a reasonable size (Takahashi et al., 1995). This concept evolved into EUSO the Extreme Universe Space Observatory, that, under the leadership of Livio Scarsi (Scarsi et al. 2001), was first proposed as a

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free-flyer, and then selected by the European Space Agency (ESA) as a mission attached to the Columbus module of the International Space Station (ISS) (Parmar et al. 2003). The phase-A study for the feasibility of 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 project never proceeded into phase B. In 2006, the Japanese and U.S. teams redefined the mission as an observatory attached to "KIBO," the Japanese Experiment Module (JEM) of ISS. They renamed the mission JEM-EUSO and started a new phase-A study.

JEM-EUSO is designed to achieve a main scientific objective: to identify the sources of EECRs by arrival direction analysis and to measure the energy spectra from individual sources, with an overwhelmingly high collecting power, that can approach an exposure of 1 million km^2 - sr yr. JEM-EUSO will constrain acceleration or emission mechanisms, and will eventually confirm the Greisen–Zatsepin–Kuz'min process (Greisen 1966; Zatsepin and Kuz'min, 1966) validating Lorentz invariance up to $\gamma \sim 10^{11}$.

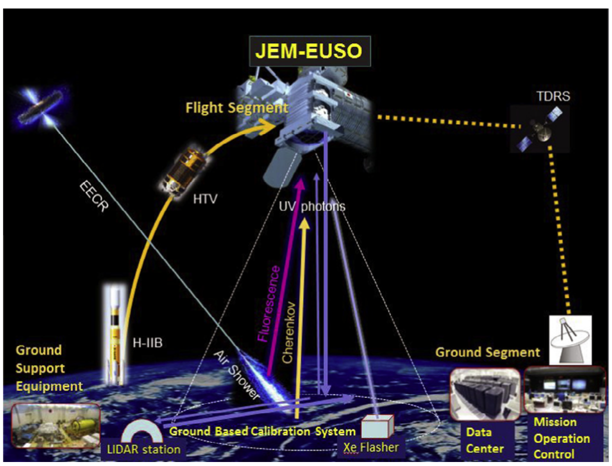

Fig. 1. Principle of the JEM-EUSO telescope to detect Extreme Energy cosmic rays (EECRs). In the present paper, we describe the JEM-EUSO mission in brief. In Section 2, the merits of the space based approach vs. ground-based observations. The science objectives and instruments are described in Sections 3 and 4, respectively.

2. Four merits of looking-down compared with looking-up

The space-based approach, to observe from above looking downward the EAS generated in the earth's atmosphere has four significant merits compared with the conventional looking-up approach from ground: (1) Very large observational area, (2) Fig. 1 Well constrained distances toward showers, (3) Clear and stable atmospheric transmission in the above half troposphere, (4) Uniform Exposure across both north and south skies.

2.1. Very large observational area

The most relevant merit of the space based observation is the very large area that can be monitored from space. In the case of JEM-EUSO, for example, the instantaneous observational area reaches $\sim 2 \times 10^5$ km^2 in nadir mode and $\sim 7 \times 10^5$ km^2 in tilted mode. These are almost two orders of magnitude larger than the largest ground based observatories ($\sim 3 \times 10^3$ km^2 in the case of the Pierre Auger Observatory). Fig. 2 Such a geometrical area could allow us to reach an unprecedented exposure of 10^6 km^2 sr yr (10^6 Linsley), considered critical for astronomy and astrophysics with charged particles and for the detection of neutrinos above 10^{20} eV.

2.2. Well constrained distances toward showers

The distance between the detector and the EAS is well constrained in the case of space-based observations since

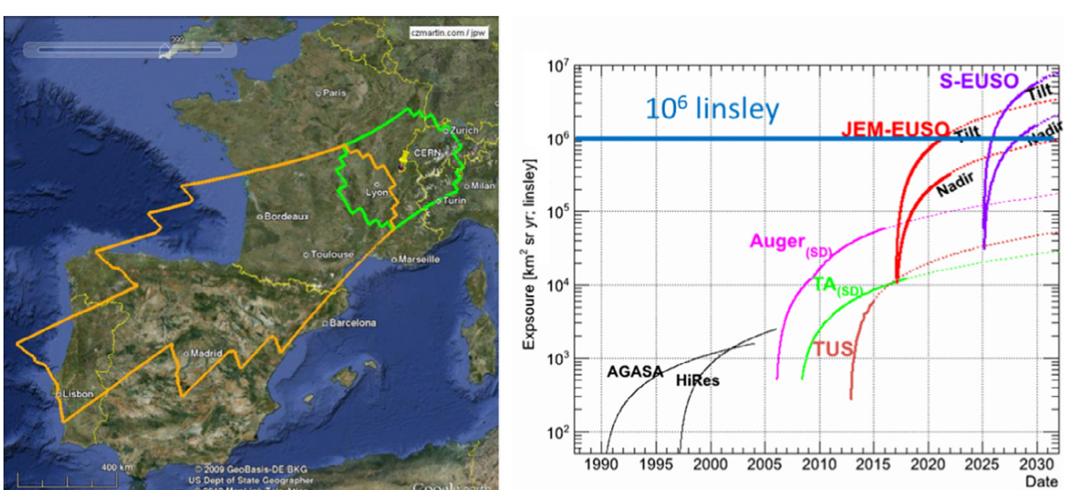

Fig. 2. Left: Footprint of the field of view of the JEM-EUSO telescope, projected to west Europe: Nadir mode (Green) and Tilted mode (Orange); Right: Expected time evolution of the exposure. Space-based missions JEM-EUSO can achieve the critical threshold of 10^6 km^2 sr yr. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

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