

The JEM-EUSO mission

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Abstract. The Extreme Universe Space Observatory on Japanese Experiment Module (JEM-EUSO) is a science mission planned to be launched in 2017 to the International Space Station (ISS) to investigate the nature and origin of Extreme Energy Cosmic Rays (EECR) beyond energy 3×10^{19} eV. JEM-EUSO is a wide-angle telescope (60 degrees full field of view) and consists of high-transmittance Fresnel lenses 2.5 m in diameter, an advanced photo-sensitive detector at the focal surface and a suitable electronics. An infrared camera and a LIDAR system will also be used to monitor the Earth's atmosphere and provide significant information on cloud coverage. The present status of advancement of the mission is reported.

1. Introduction

JEM-EUSO is the first space mission devoted to the exploration of the Universe through the detection of Ultra High Energy Cosmic Rays (UHECR) and neutrinos with energy $E > 100$ EeV [1]. It is intended to address basic problems of fundamental physics and high energy astrophysics by investigating the nature and origin of UHECR. The corresponding jump in statistics due to the by-far larger exposure than presently ground-based running experiments, will clarify the origin (sources) of UHECR and, possibly, the particles mechanisms operating at energies well beyond those achievable by man-made accelerators. Furthermore, the spectrum of scientific goals of JEM-EUSO includes also as explorative objectives the detection of high energy gamma rays and neutrinos, the study of cosmic magnetic fields, and testing relativity and quantum gravity effects at extreme energies. In parallel, along the mission, JEM-EUSO will systematically survey atmospheric phenomena over the Earth Surface.

In the JEM-EUSO concept, the Earth's atmosphere is a giant detector. UHECRs collide with atmospheric nuclei and produce Extended Air Showers (EAS). JEM-EUSO observes the fluorescence light emitted by the nitrogen molecules excited by the EAS charged particles and the reflected signal at ground of the Cherenkov emission associated with the shower development. Viewing from the ISS orbit, the $\pm 30^\circ$ Field-of-View (FoV) of the telescope corresponds to an observational area at ground larger than 1.9×10^5 km².

The threshold energy of the detector is around 3×10^{19} eV. Increase in exposure and energy threshold is realized by inclining the telescope from nadir to tilted mode, to extend the range of observation up to 10^{21} eV.

JEM-EUSO is foreseen to be launched in 2017 by a JAXA H2B rocket and conveyed by an H-II Transfer Vehicle on ISS and attached to the Exposure Facility of JEM.

2. The main scientific objectives

Cosmic Radiation can be considered as the particle channel complementing the electromagnetic one of conventional astronomy. Given current uncertainties [2, 3], the expected number of events that will be detected by JEM-EUSO in 3 years mission (nadir mode) will be between 500 and 800 with energy above 5×10^{19} eV. Such a number of events makes possible the following physics targets: a) identification of sources by high-statistics arrival direction analysis; b) measurement of the energy spectra from individual sources to constrain acceleration or emission mechanisms.

The photo-pion production of UHE proton interaction with the Cosmic Microwave Background (CMB) strongly suppresses the UHECR spectrum above $\sim 4 \times 10^{19}$ eV (the GZK-cutoff [4]) effectively setting a horizon at nominally ~ 100 Mpc. The same applies for nuclei due to photo-disintegration. The result is that that UHECR sample the very local Universe, where the Large Scale Mass Distribution (LSMD) is inhomogeneous, therefore, the source distribution should emerge from the UHECR flux and arrival direction. Such an analysis is being attempted by current operating observatories, however, the results are still uncertain. JEM-EUSO has the great advantage of significantly increase the exposure with a very low declination dependence, which is a combination of two essential parameters to significantly improve this kind of analysis.

If several sources are found with at least a dozen of observed events, the observed differences in spectral features among those sources, combined with a multi-wavelength approach, will provide direct clues on the identity of the sources and the acceleration mechanisms involved. In fact, the spectrum of a source located around 5 Mpc should manifest a very low GZK cut-off effect, while a similar source around 50 Mpc should show a much steeper energy spectrum [5].

The pattern of the energy dependent distortions of the sources point spread functions as a result of the Galactic Magnetic Field, over the celestial sphere can be used to infer the large scale structure of the Galactic Magnetic Field itself.

3. The JEM-EUSO telescope

The JEM-EUSO telescope [6] is an extremely-fast, highly-pixelized, large-aperture and large-FoV digital camera, working in near-UV wavelength range (300-400 nm) with single photon counting capability. The telescope mainly consists of four parts: collecting optics [7], focal surface detector (FS) [8], electronics [9] and structure [10] as shown in Fig.1.

The optics is composed of two curved double sided Fresnel lenses with 2.65 m external diameter, a precision middle lens and a pupil. The UV photons are focused onto the FS with an angular resolution of $\sim 0.07^\circ$. The FS detector (covered by ~ 5000 multi-anode photomultipliers) converts the incident photons to electric pulses, which are counted by the electronics in 2.5 μ s Gate Time Units (GTU). When a signal pattern of an EAS is found, the trigger [11] is issued and the intensity of the signal in the triggered and surrounding pixels is sent to the ground operation center. The list of the main parameters of JEM-EUSO telescope is reported in table 1.

The intensity of the fluorescence and Cherenkov light from EAS depends on the transparency of the atmosphere, the cloud coverage and the height of cloud tops. For these reasons, JEM-EUSO will also include an Atmospheric Monitoring (AM) system [12] to estimate as precisely as possible the sky conditions and the effective observing time with high accuracy. AM will consist of an infrared camera and a LIDAR system integrated by the slow mode trigger of the telescope itself.

4. The observational technique

The main advantages of JEM-EUSO compared to any existing or planned ground-based experiment are the significant increase of aperture and the full-sky coverage with an almost uniform exposure. Moreover, as the EAS maximum develops for most zenith angles at altitudes higher than 3-5 km from ground, the measurements will be possible even in cloudy sky conditions.

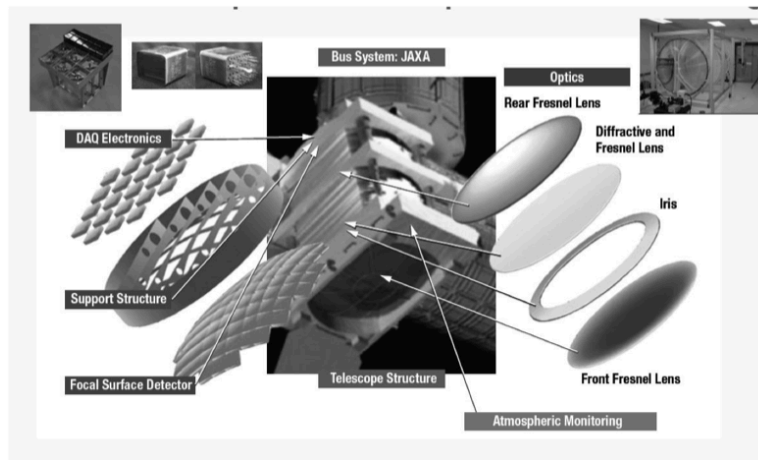


Figure 1. Sketch of the main parts of the JEM-EUSO telescope.

Table 1. Parameters of JEM-EUSO telescope.

Field of View	$\pm 30^\circ$
Observational area	$> 1.9 \times 10^5 \text{ km}^2$
Optical bandwidth	$330 \div 400 \text{ nm}$
Focal Surface Area	4.5 m^2
Number of pixels	3.2×10^5
Pixel size	2.9 mm
Pixel size at ground	$\sim 550 \text{ mm}$
Spatial resolution	0.07°
Event time sampling	$2.5 \mu\text{s}$
Duty cycle \times cloud impact	$\sim 14\%$

Compared to ground-based detectors, the duty cycle will be, therefore, mostly limited by the moon phase, while the cloud impact will be less important than for ground-based observations.

One of the key elements to estimate the performance of JEM-EUSO is the evaluation of its exposure. This can be factorized into three main contributions: the trigger aperture, the observational duty cycle and the cloud impact. The observational duty cycle, meant as the fraction of time in which EAS observation is not hampered by the brightness of the sky, has been evaluated by analyzing the measurements of the Russian satellite Tatiana and rescaling them to the ISS orbit [13] and it accounts for $\sim 20\%$.

The peculiarity of the observation from space is the possibility of observing CRs also in some cloudy conditions (i.e. if the shower maximum is above the cloud top), which is typically not the case for ground-based telescopes. Studies and simulations on cloud distributions and evaluation of cloud impact have been carried out [14], [15]. The result indicates that the average fraction of the observational time where the measurement will not be hampered by atmospheric factors is $\sim 70\%$. This number, convoluted with the 20% duty cycle observational time, provides a final 14% multiplication factor to be applied to the aperture to determine the exposure.

Fig.2 shows the full aperture, and annual exposure of JEM-EUSO in nadir mode for the full FoV of the detector together with different quality cuts [16]: 80-90% aperture is already reached

at energies $\sim 2\text{--}3 \times 10^{19}$ eV when the foot print of the shower is located in the central part of the FoV ($R < 125$ km from nadir) and with zenith angles $\theta > 60^\circ$, and it slightly increases at $\sim 5 \times 10^{19}$ eV if the entire FoV is considered. In the most stringent conditions JEM-EUSO has

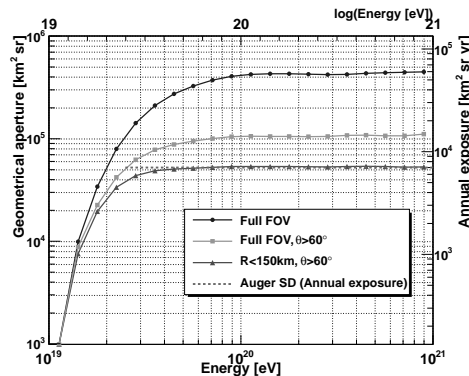


Figure 2. Aperture and annual exposure of JEM-EUSO for different quality cuts.

an annual exposure equivalent to Auger (~ 7000 km² sr yr) while it reaches ~ 60000 km² sr yr at 10^{20} eV, 9 times Auger equivalent.

5. Planned work

Besides simulations and performance studies, several technological prototypes of the optical system, of the mechanical support structures and of the front-end electronics and data acquisition have been developed and are in progress. In the forthcoming two years a couple of tests on a scaled prototype of the telescope made by a system of Fresnel lenses and one single PDM (Photo Detector Module) fully equipped unit are being planned. The first one will be performed at the Telescope Array site in Utah where such a prototype will be deployed for calibration purposes. Then, a similar one will fly on stratospheric balloons (managed by CNES, France) for engineering purposes such as the verification of the trigger electronics and the measurement of the nightglow background in conditions as close as possible to what is expected from ISS, and possibly to observe the first EAS from space.

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