The JEM-EUSO Mission

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***Abstract*. JEM-EUSO (Extreme Universe Space Observatory on-board Japanese Experiment Module of ISS) is the science mission which observes the particles with extreme energies around 10^{20} eV. The observation of the particles will be performed by the detection of the optical signals, time and space-resolved, following the traces of the particles in Earth's atmosphere. It is the direct successor of the EUSO mission, which had been selected in the year 2000 by European Space Agency (ESA), but was postponed after its successful completion of the phase-A study.**

JEM-EUSO is designed to detect more than 1,000 events above 7×10^{19} eV during its five years' operation. This overwhelmingly high statistics permits us to achieve our main scientific objective: astronomy and astrophysics through the particle channel with extreme energies to identify sources by arrival direction analysis, and to measure the energy spectra from the individual sources, which will constrain acceleration or emission mechanism.

JEM-EUSO was selected as one of the mission candidates of the second phase utilization of JEM/EF. The phase-A (feasibility study and conceptual design) study has been conducted by RIKEN and JAXA, in cooperation with an international team of scientists from twelve countries, Japan, USA, France, Italy, Germany, Switzerland, Russia, Republic of Korea, Mexico, Spain, Poland, and Slovakia, aiming at the launch in 2013-2015 time-frame. It is designed to be transferred to ISS by HTV (H2 Transfer Vehicle).

***Keywords*: EECRs, International Space Station, GZK, and Lorentz invariance**

I. 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 $>$ 10^{20} eV) cosmic rays (EECRs) and neutrinos[1]; it will do astronomy looking downward from the International Space Station, ISS, using Earth's atmosphere as a giant detector.

Firstly proposed as a free-flyer, the observatory was selected by the European Space Agency (ESA) as a mission attached to the Columbus module of the 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, the green-light to start the ESA-EUSO phase-B had been pending for a long time.

In 2006, Japanese and U.S. teams redefined the mission as an observatory attached to the Japanese Experiment Module/Exposure Facility (JEM/EF) of the International Space Station. They renamed it JEM-EUSO and started with a renewed two-year-long phase-A study, targeting the launch of 2013-2015 in the framework of the second phase of JEM/EF utilization.

JEM-EUSO is designed to detect more than 1,000 events above 7×10^{19} eV during its five years' operation. This overwhelmingly high statistics permit us to achieve our main scientific objective: astronomy and astrophysics through the particle channel with extreme energy particles to identify sources by arrival direction analysis and to measure the energy spectra from the individual sources, which will constrain acceleration or emission mechanism.

TABLE I
PARAMETERS OF THE MISSION

Time of launch	2013-2015
Operation period	3 years (+ 2 years)
Launching rocket	H2B
Transportation to ISS	Non-pressurized carrier of H2 Transfer Vehicle (HTV)
Site to attach	Japanese Exposure Module (JEM)/ Exposure Facility# 2
Mass	1983 kg
Power	926 W (operative) 352 W (non-operative)
Data transfer rate	285 kbps
Orbit height	$\sim$ 400 km
Inclination	51.64°

II. INSTRUMENT

The JEM-EUSO mission uses a super-wide-field (almost $\pm$ 30 degrees) telescope with the effective diameter of about 2.5 meters to collect UV photons with the wavelengths of 330-400nm. It has three double-sided curved Fresnel lenses made of plastic material, an iris, and a focal surface assembly, which is composed of photo-detectors, electronics, and a support structure (figure 1). Kajino *et al.* (2009) gives the descriptions of the JEM-EUSO instrument [2].
The telescope was cut in its side to 1.9 m to meet the requirement of the inner envelope of the un-pressurized carrier of H2 transfer vehicle (HTV). It is shrunk by a factor of about 2.5 along the optical axis in the stow configuration and is extended to the observational configuration in the orbit. The telescope observes the nadir direction in the first two years (nadir mode), and then the tilted direction (by 30-38 degrees; tilt mode) in later phases to increase the exposure to detect events higher than 10^{20} eV (see figure 2). Table II compares the cumulative exposures of the JEM-EUSO mission with those of other experiments.

III. SCIENCE OBJECTIVES

Science objectives of the JEM-EUSO mission are divided into one main objective and five exploratory objectives:

- **Main Objective: Astronomy and astrophysics through particle channel with extreme energies $> \mathbf{10^{20}eV}$**
  – Identification of sources by the high-statistics arrival direction analysis
  – Measurement of the energy spectra from individual sources to constrain acceleration or emission mechanism
- **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 at extreme energy
  – Global survey of nightglows, plasma discharges, and lightning

As shown in figure 3, the JEM-EUSO mission is the first instrument that achieves one million Linsley (1 Linsley = 1 $\mathrm{km}^2 \cdot \mathrm{sr} \cdot$ year), which is the critical value of the exposure to start "astronomy and astrophysics through particle channel" with overwhelmingly higher statistics compared with other experiments: it can detect more than 1000 events with the energy higher than 7×10^{19} eV.
JEM-EUSO, which has an almost uniform full-sky coverage by means of a single instrument on-board the ISS, will be the first and only instrument studying all the EECR sources within the GZK horizon that contribute to the highest energy particles reaching the Earth. Arrival direction analysis in both large and small scales is much easier in the case of JEM-EUSO than those of the observatories on the ground, where only a half hemisphere of the sky can be observed.
Figure 4 shows the direction distribution simulated with the assumption that EECRs are emitted from the several dozen point sources [5]. Point sources are clearly recognized as clusters of several dozen events; in case of persistent or recurrent sources, they could hopefully be identified as known celestial objects, such as active galactic nuclei. Once they are identified, then we can use a huge amount of information (such as the distances to the sources) accumulated by the astronomical observations with many wavelengths (from radio-waves to gamma-rays). The existence of the GZK mechanism [8] and the Lorentz invariance at $\gamma \sim 10^{11}$ will be firmly established and studied directly only when we confirm a strong dependence of the GZK features upon the distances to the sources [9], as shown in figure 5 [3]. Detailed discussions including the exploratory objectives are given by Medina-Tanco *et al.* [4]. The detections of gamma rays and neutrinos are discussed in Supanistky *et al.* [11], [12].

IV. PHASE-A STUDY

The JEM-EUSO mission was selected as one of the mission candidates of the second phase utilization of JEM/EF. The phase-A (feasibility study and conceptual design) study has been conducted by RIKEN and JAXA in cooperation with an international team of scientists from twelve countries: Japan, USA, France, Italy, Germany, Switzerland, Russia, Republic of Korea, Mexico, Spain, Poland, and Slovakia. Some of the outcomes of the phase-A study are reported in this conference: test manufacturing of 1.5 meter lens set [10], design and performance estimation of the optics [13], design of the focal surface detectors [14], manufacturing and testing of the front-end ASIC [15], design of the trigger

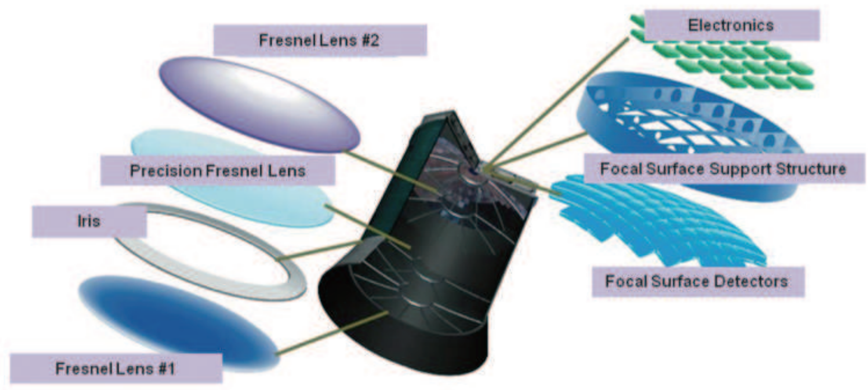

Fig. 1. Schematic view of the JEM-EUSO telescope.

TABLE II
COMPARISON OF THE EXPECTED CUMULATIVE EXPOSURES

Experiment	Geometrical Acceptance (km^2sr)	Operational year	period (years)	Observational Efficiency (%)	Cumulative Exposure (1,000 km^2sr year)	relative Exposure to AGASA
AGASA [26]	160	1990-2004	14	100	1.8	1
HiRes [27]						
-I	8,000	1997-2005	8	10	6.4	3.6
-II	5,000	1999-2004	4	10	2.0	1.1
Auger						
South SD	7,000	2006-2017	12	100	84	47
North SD	50,000	2013-2017	5	100	250	140
Telescope Array						
SD	1,400	2007-2017	11	100	14	7.8
FD	6,700		11	10	7	3.9
JEM-EUSO						
Nadir	580,000	2013-2014	2	19¶	220†	120
Tilt(38°)	2,900,000	2015-2017	3	19¶	830‡	460
Total					1,050	580

¶The areas covered by clouds are not taken into account in the observational effciency of JEM-EUSO. Note that a significant fraction of the air showers reach their maxima above the clouds and can be reconstructed even in the cloud covered areas. If we take into account these showers, the exposures of JEM-EUSO will increase significantly.
†trigger efficiency = 100% for E> 10^{20}eV
‡trigger efficiency = 50% for E> 10^{20}eV

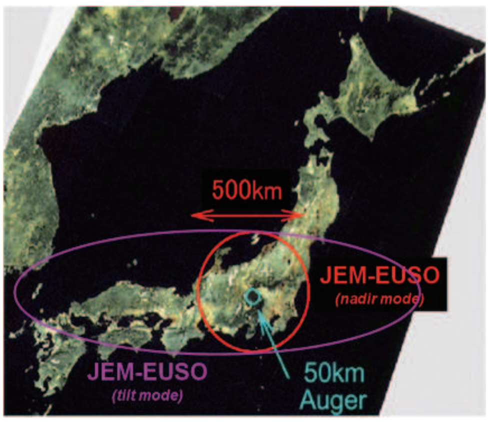

Fig. 2. Area observed by the JEM-EUSO telescope in one shot under "nadir" and "tilt" observation modes.

system [16], design of the data acquisition system [17], performance estimation by the End-to-End simulations [18], [19], [20], [21], the atmosphereic monitor system [22], [23], development of SiPM detector [24], and the pathfinder mission, TUS [25].
The review of later phases is scheduled in August 2009 by JAXA.

V. 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 more than one million Linsley (1 Linsley = 1 $km^2 \cdot sr \cdot$ year), the critical value of the exposure to start "astronomy and astrophysics through particle channel."

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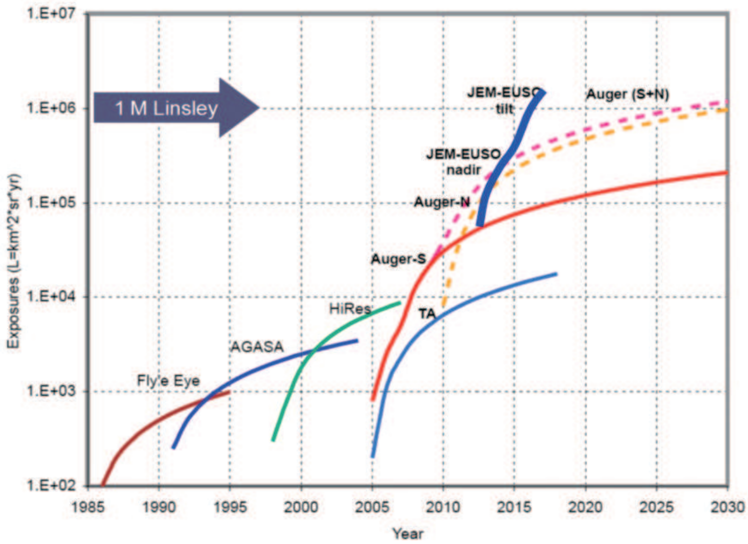

Fig. 3. Expected cumulative exposure, in Linsley units, of JEM-EUSO. For comparison, the evolution of exposures of other retired and running EECR observatories are shown (1 Linsley = 1 km^2 $\cdot$ sr$\cdot$ year).

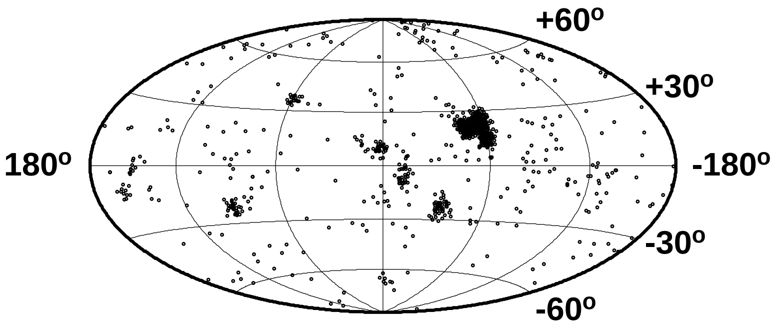

Fig. 4. Numerically simulated arrival direction distribution of EECRs for $E > 7 \times 10^{19}$ eV (1000 events), if AGNs are the sources of EECRs[5]. Here, we assume that 34 AGNs are sources of EECRs and their particle luminosities are proportional to X-ray luminosities observed by INTEGRAL[7]. Galactic and intergalactic magnetic fields are taken into account. The later is normalised to 0.4 μ Gauss at Virgo cluster. We use a galactic magnetic field model with spirals and a dipole structure proposed in [6]

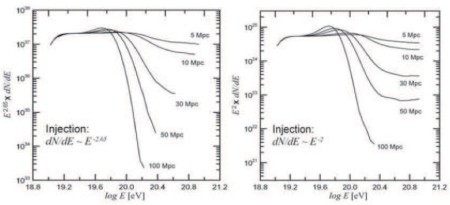

Fig. 5. GZK features for the intrinsic spectral index = -2[4].

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