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The JEM-EUSO Mission

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Abstract: JEM-EUSO is a science mission to explore extremes of the Universe. It observes the dark-side of the Earth and detects UV photons emitted from the extensive air shower caused by an extreme energy particle (about 10^{20} eV). Such a particle arrives almost straightly through our Milky Way Galaxy and is expected to allow us to trace the source location by its arrival direction. This will open the door to the new astronomy with charged particles. In its five years operation including the tilted mode, JEM-EUSO will detect at least 1,000 events with $E>7\times10^{19}$ eV and determine the energy spectrum of trans-GZK region with a statistical accuracy of several percent. JEM-EUSO is planned to be transported with HTV (H2 Transfer Vehicle) and attached to the Japanese Experiment Module/ Exposure Facility (JEM/EF) of International Space Station. JAXA has selected JEM-EUSO for one of the mission candidates of the second phase utilization of JEM/EF for the launch of early 2010s. One year-long phase-A study will be carried out under JAXA.

1. Mission Overview

JEM-EUSO (Extreme Universe Space Observatory on Japanese Experiment Module) is a new type of observatory that uses the whole earth as a detector including the International Space Station (ISS) where a remote sensor is located. It observes transient luminous phenomena taking place in the earth's atmosphere caused by particles and waves coming from space. The sensor is a super wide-field telescope that detects extreme energy particles with energy above 10^{20}eV. This remote-sensing instrument orbits the earth every ~ 90 minutes on board International Space Station (ISS) at the altitude of ~ 430 km (Figure 1). An extreme energy particle collides with a nucleus in the earth's atmosphere and produces an Extensive Air Shower (EAS) that consists of numerous electrons, positrons, and photons. JEM-EUSO captures the moving track of the fluorescent UV photons and reproduces the development of EAS.

The JEM-EUSO telescope has a super-wide Field-of-View (±30°) with two double sided curved Fresnel lenses and records the track of an EAS with a time resolution of 2.5μs and a spatial resolution of about 0.75 km (corresponding to 0.1 degrees). These time-segmented images allow determining the energies and directions of the primary particles.

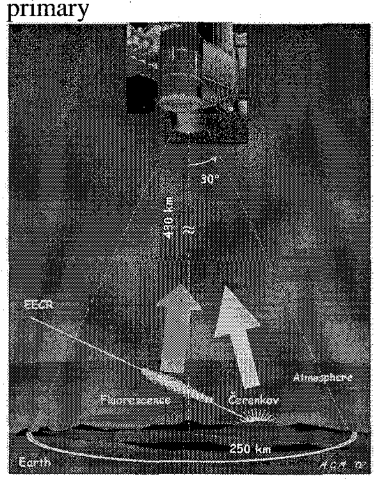

Figure 1 JEM-EUSO telescope

JEM-EUSO instrument can reconstruct the incoming direction of the extreme energy particles with accuracy better than several degrees. Its observational aperture of the ground area is a circle with 250 km radius and its atmospheric volume above it with a 60-degree field-of-view is about 1 tera-ton or more. The target volume for upward neutrino events exceeds 10 tera-tons. The instantaneous aperture of JEM-EUSO is larger than the Pierre Auger Observatory by a factor of 56 - 280 when attached to ISS (Figure 3).

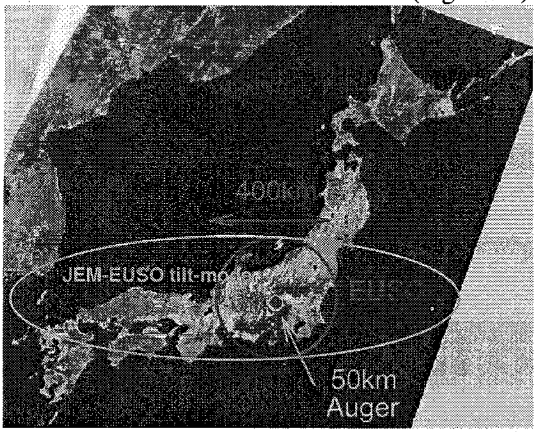

Figure 2 Observational Aperture of JEM-EUSO

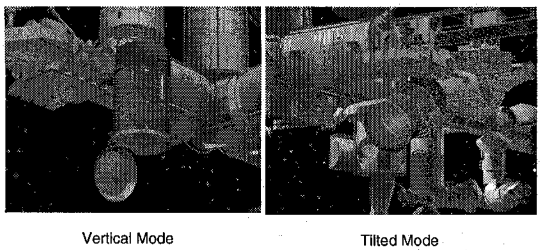

Figure 3 JEM-EUSO attached to ISS

2. Science Objectives

2.1. Main Objective: Straight Line Astronomy by Particle Chanel at Energy >10^{20}eV

JEM-EUSO is designed to detect more than 1,000 events with energy higher than 7×10^{19}eV in a few years of operation. This number of events exceeds the critical value to observe all the sources at least once within several hundred Mpc even when the Greisen-Zatsepin-Kuz'min (GZK) cutoff [1] is at work. Hence, JEM-EUSO may initiate a new astronomy with these charged particles (10^{19}eV<E<10^{21}eV). This experiment can

- possibly identify the particle and energy sources using the arrival direction, and study acceleration mechanisms with the observed events;
- clarify the trans-GZK intensity profile [2] of distant sources and make a systematic survey of nearby sources; and
- separate gamma rays and neutrinos from nucleons and nuclei, which allows testing of the Super-Heavy-Particle (SHP) models that assume long-lived particles produced in the early era of the universe.
- The extreme energy particles can be traced back to the origin in the measured arrival direction with accuracy better than a few degrees. AGASA experiments [3] reported small-scale anisotropy (cluster) and some correlation existed in the arrival direction of extreme energy particles with AGNs/Blazars. Hi-Res [4] also indicated such a point-source correlation with AGNs. If they come from isotropically-distributed point sources in three-dimensional space, several dozen clusters would be found with the statistics expected for JEM-EUSO. Nearby point sources can bear several dozens of events.

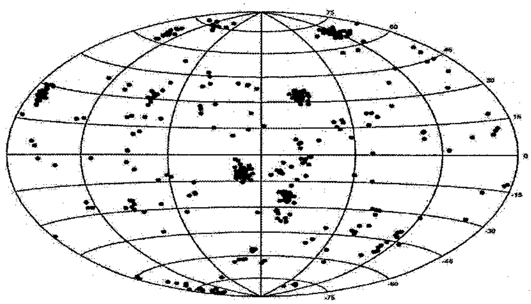

Figure 4 Arrival direction expected from JEM-EUSO

In a global anisotropy analysis, arrival directions are integrated for spherical harmonics. Such an analysis should reveal the source distributions of Extreme energy particles. For the best analysis, the exposure must be uniform over all sky. ISS has an inclination of 51.6 degree, and JEM-EUSO on it can observe both north and south sky equally and would offer a nearly uniform exposure for all sky. If the extreme energy particles come from cosmological distances as those of gamma-ray bursts and active galactic nuclei, these point sources might indicate global isotropy. Decay or annihilation of a super-heavy particle (SHP; m ~ $10^{22\text{-}25}$ eV/c^2) can also produce extreme energy particles. If extreme energy particle source is such a SHP dark matter, it could be concentrated in our Milky Way Galaxy and might show an enhancement in the direction of Sagittarius, too. If they belong to clusters of galaxies, they may show the enhancement at nearby clusters [5].

When the point sources are seen for events above 10^{20}eV, other member events of these sources at different energies could also be identified. Changes in apparent point-spread-function depending on energy, magnitude and direction, and they can help determining the galactic magnetic field [6].

2.2. Exploratory Objectives

2.2.1. Detection of extreme energy neutrino can constrain the extra-dimension theory

Cosmogenic neutrinos may steadily be produced in universe in the GZK process in which an extreme energy proton looses its energy through the collisions with 2.7K microwave backgrounds. Many authors already pointed out the possibility that they are also produced during acceleration at high-energy objects such as AGNs or gamma-ray bursts.

Neutrino-hadron cross-section data at the highest accelerator energy was given by the Electron Positron collider experiments at HERA at the center of mass energy of 314 Gev, which corresponds to 52 TeV of such fixed target collision as that of cosmic-ray experiments. According to the standard QCD predictions and cosmogenic GZK neutrino flux calculations, JEM-EUSO is predicted to observe 1-10 neutrino events [7]. Extra-dimensional models [8] predict varieties of cross-sections. The predicted event rate is at least 100 times larger than the Standard QCD rate, and it is testable by JEM-EUSO.

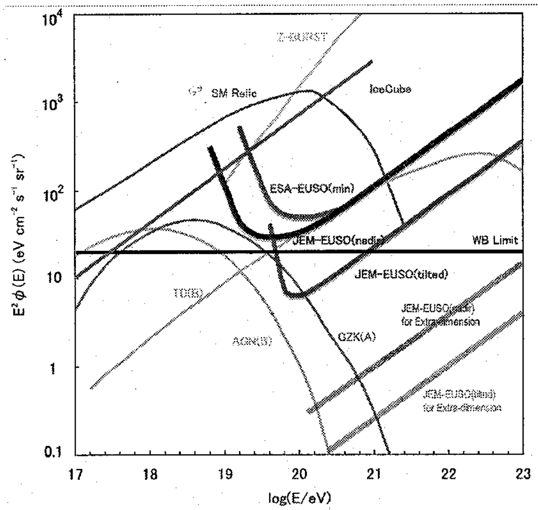

Figure 4 The flux-sensitivity of JEM-EUSO of 1 event/energy-decade/year; an observational efficiency of 25% is assumed. Red Thick Line: ESA-EUSO (min); Blue Thick Line: JEM-EUSO Nadir; Green Thick Line: JEM-EUSO-Tilt. As for Ice cube (Pink line), a few events/energy-decade/10years is assumed. Black Line denotes the Waxman-Bahcall limit.

Neutrino events can clearly be distinguished by JEM-EUSO from those of gamma-ray, protons and nuclei in terms of the shower maximum X_{max} [9].

By its three-years of operation of the tiled mode, JEM-EUSO can set an upper-limit of neutrino flux significantly lower than the Waxman-Bahcall limit [10] in the energy range of 10^{20}eV and above. Cosmogenic neutrinos are expected to be observed at least for a few events in JEM-EUSO. If top-down scenario for super-GZK particles (blue and green lines) is the valid case, at least several events are expected in a year. On the other hand, if JEM-EUSO does not observe significant neutrino events exceeding a few events, it would exclude most of the top-down models, as well as the extra-dimensional models.

2.2.2. Super-LHC Physics

The center of mass energy of an extreme energy particle and a target nucleus interaction in the atmosphere exceeds the energy reachable by Large Hadron Collider (LHC) more than three orders of magnitudes. In this extreme energy frontier, many new physics that may change around the trans-GZK energies have been proposed and seriously discussed. For example, JEM-EUSO can examine the Lorentz Invariance at very high Lorentz factors ($\gamma \sim 10^{11}$). If GZK-process itself would not appear as expected [11], it could imply some limitations of local Lorentz Invariance in the presence of external fields. The standard quantum physics also predicts that EAS suffers large fluctuations of cascading from Landau-Pomeranchuk-Migdal (LPM) effect [12]. It becomes considerable from 5×10^{20} eV for protons and from 5×10^{21}eV from iron nuclei. JEM-EUSO can observe this fluctuation with a high statistics.

2.2.3. *Global Earth Observation*

JEM-EUSO will also observe atmospheric luminous phenomena such as lightning, nightglow, and meteors. In the upper atmosphere of the thunderstorm, many luminous transient events have been observed, such as, sprite, blue jet, and elves. These are believed to be a secondary discharge caused by the electric field from the redistribution of electric charge of the lightning [14]. Gamma rays were also observed associated with lightning [15]. Runaway electrons produced by cosmic-rays might be accelerated by the quasi-static electric field of the discharge associated with lightning.

3. Conclusions

JAXA has selected JEM-EUSO for one of the mission candidates of the second phase utilization of JEM/EF for the launch of early 2010s. One year-long phase-A study will be carried out under JAXA. Its expected versatile performances on orbit for several years to a decade will be helpful in observing extremely high energy universe and exploring fundamental physics beyond the LHC energies

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