Proceedings of the 30th International Cosmic Ray Conference
Rogelio Caballero, Juan Carlos D'Olivo, Gustavo Medina-Tanco,
Lukas Nellen, Federico A. Sánchez, José F. Valdés-Galicia (eds.)
Universidad Nacional Autónoma de México,
Mexico City, Mexico, 2008
Vol. 5 (HE part 2), pages 1045–1048

30TH INTERNATIONAL COSMIC RAY CONFERENCE

ICRC'07
Mérida, México

The JEM-EUSO Mission

THE JEM-EUSO COLLABORATION
T. Ebisuzakiebisu@postman.riken.jp

Abstract: JEM-EUSO is a science mission to explore extremes of the Universe. It will observe 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 nature can 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 by HTV (H2 Transfer Vehicle) and will be attached to the Japanese Experiment Module/ Exposure Facility (JEM/EF) of International Space Station. JAXA has selected JEM-EUSO as 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.

Mission Overview

EUSO (Extreme Universe Space Observatory)[1] , presently JEM-EUSO, 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. A super wide-field telescope and fine-pixel sensors in space can detect fluorescent tracks of particles with energy above 10^{20}eV. Such a remote-sensing instrument will orbit the earth every ~ 90 minutes on board International Space Station (ISS) at the altitude of ~ 430 km (Figure 1). JEM-EUSO will capture 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 spatial images allow determining the energies and directions of the primary particles. The incoming direction of the extreme energy particles will be reconstructed with accuracy better than several degrees.

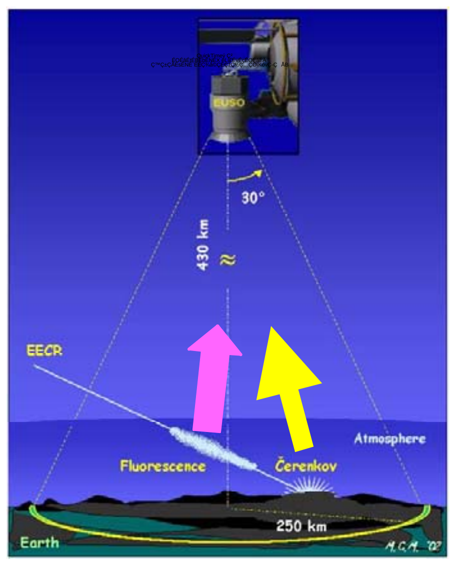

Figure 1: JEM-EUSO telescope

The JEM-EUSO aperture for the ground area is a circle of 250 km radius and its atmospheric volume above it with a 60-degree field-of-view is about 1 tera-ton, or more for the tilted view of the observation (Figure 2). 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).

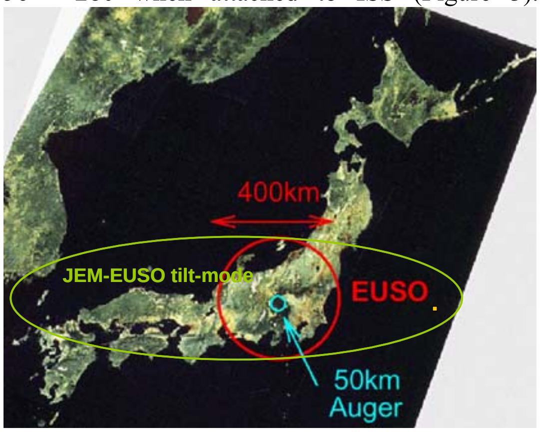

Figure 2: Observational Aperture of JEM-EUSO

Vertical Mode Tilted Mode

Figure 3: JEM-EUSO attached to ISS

Parameters of Instruments

- Field of View: ±30°
- Aperture Diameter: 2.5m
- Optical bandwidth: 330–400nm
- Angular Resolution: 0.1°
- Pixel Size: 4.5mm
- Number of Pixels: $\sim 2.0 \times 10^5$
- Pixel Size at the ground: 750m
- Duty Cycle: ~20%
- Observational Area: 1.9×10^5 km^2

Parameters of Mission

- Time of launch: 2013
- Operation Period: 5years
- Launching Rocket : H2B
- Transportation to ISS: Unpressurized Carrier of H2 Transfer vehicle called HTV
- Site to Attach: Japanese Experiment Module/ Exposure Facility #2 of ISS
- Mass budget: 1880 kg
- Power budget:
  - 1031W(operative),
  - 344 W (non-operative)
- Data Transfer Rate: 360 kpbs
- Height of the Orbit: ~430km
- Inclination of the Orbit: 51.6°

Observational Method

An extreme energy particle collides with an nucleus in the atmosphere and produces many secondary particles. These secondary particles make still many particles to form an extensive air shower: the cascade of relativistic particles. At its maximum, the number of the particles (mostly electrons, positron, and photons) reaches the shower maxim of about 10^{11}. The charged particles in EAS excite the nitrogen molecules to emit near UV photons. They also produce directional Cerenkov light in the cone of 1.3 degree in the observational wavelength 300nm-400nm. They move at the speed of light in the atmosphere and would hit the clouds (or grounds) with high reflectivity of 80-90% on clouds and low reflectivity of ~8% on grounds.

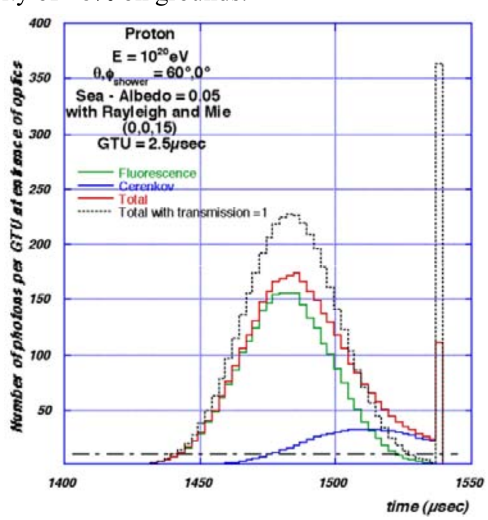

Figure 4: Space-time transition curves.

If one looks at an EAS from space, one can see it as a bright spot moving at the speed of light.

When it meets the ground or cloud, the Cerenkov light is reflected and can be observed as a strong Cerenkov mark as shown in Figure 4 for a typical EAS event (proton with energy10^{20}eV).

The ISS covers the whole earth surface in the latitude range ±51° with a track at the earth surface moving at a speed of ~7km/s. The instantaneous aperture of JEM-EUSO is 200 thousand km^2 in one shot and watches 10^{12} tons of transparent atmosphere for neutrino interactions.

Observation from space is advantageous compared with that from ground in the following three points.

- Observation from space is free from the proximity trouble of the ground based observation. Distance of the EAS from the instrument is effectively fixed at about 430 km, so that the uncertainty of the brightness-luminosity relationship of the observed fluorescence signal is less than 0.2%, far smaller than that of the fluorescence method on ground. The events with a larger number of photons are certainly higher energy events. In this sense, systematic error is much smaller, by nature, than the ground observations.
- The effective thickness of the atmosphere for shower development is less than 10 km and overlaying atmosphere is negligibly small as viewed from space. JEM-EUSO observes EAS through thin clean upper atmosphere, while ground fluorescence method observes through thick dirty atmosphere near ground. Therefore, the correction by atmospheric absorption is not so large for observation from space (50% at most) and systematic error is relatively small in space based observation.
- Clouds prevent fluorescence observation from grounds, while helping observation from space due to the clear reflection signals of Cherenkov lights. Simulations with various clouds show that the effective duty cycle is barely reduced by the existence of clouds.

Main Science Objective: Astronomy in 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 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 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 directions with accuracy better than a few degrees. AGASA experiments [2] reported small-scale anisotropy (cluster) and some correlation existed in the arrival direction of extreme energy particles with AGNs/Blazars. Hi-Res [3] 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.

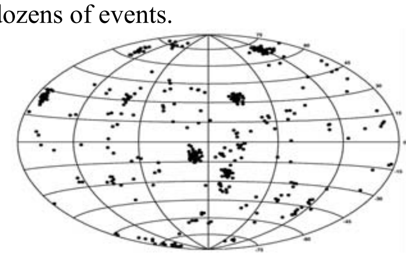

Figure 5: Arrival direction map expected for JEM-EUSO.

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.

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 within their propagation horizons. Changes in apparent point-spread-function depending on energy, magnitude and direction, and they can help determining the galactic magnetic field.

The JEM-EUSO mission includes additional observational objectives as exploratory testing subjects. More details are described in the accompanying paper, “Science Objectives of the JEM EUSO mission on International Space Station” [4].

- **Exploratory Objective 1: Detection of Extreme Energy Neutrino and Constraints to the Extra-dimension Theory.**

The GZK origin of EHE neutrinos has been discussed in the past ESA Phase-A study, for which JEM-EUSO could expect only a handful of events. However, these expectation can be $O(10^2)$ higher than those expectation if extra-dimensional theories are valid.

- **Exploratory Objective 2: Exploration of Super-LHC Physics.**

This study includes possible effects of quantum gravity for gamma ray propagation, and tests of the local Lorentz Invariance extended in the cosmological setting for EHECRs and EHE neutrinos.

- **Exploratory Objective 3: Global Earth Observation (shown below in Figure 6).**

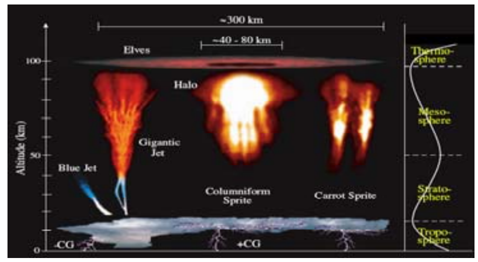

Figure 6: Various transient luminous events associated with atmospheric plasma discharge

Summary

In May 2007, JAXA has selected JEM-EUSO as one of the mission candidates of the second phase utilization of JEM/EF for launch in early 2010s. The mission duration being proposed and accepted is five years, and could be longer if ISS remains feasible after 2018.

One year-long phase-A study began from June 2007 under JAXA as its collaboration with the JEM-EUSO team. Technical details will be elaborated during this period for using HTV and JEM/EF. The versatile performances of JEM-EUSO for several years to a decade is expected to help observational studies of extremely high energy universe, possibly mapping out the astronomical sources of EHECRs and exploring fundamental physics beyond the LHC energies as well.

References

[1] L. Scarsi, in Extremely High-Energy Cosmic Ray, Proceedings of the International Workshop November 5-6, 2002, ed. M. Teshima and T. Ebisuzaki, Universal Academy Press, Inc., Tokyo, Japan.
[2] Y. Uchihori et al., Astropart. Phys., 13, 151, 2000; Hayashida N. et al, Astrophys. J., 522, 225, 1999.
[3] R.U. Abassi et al., Astrophys. J., 623, 164, 2005.
[4] JEM-EUSO Collaboration, 2007, this Conference.