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Science Objectives of the JEM EUSO mission on International Space Station

JEM-EUSO COLLABORATION
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Abstract: JEM-EUSO space observatory is planned with a very large exposure factor which will exceed the critical exposure factor required for observing the most of the sources within the propagational horizon of about one hundred Mpc. The main science objective of JEM-EUSO is the source-identifying astronomy in particle channel with extremey-high-energy particles. Quasi-linear tracking of the source objects through galactic magnetic field should become feasible at energy > 10^{20} eV for all-sky. The individual GZK profile in high statistics experiments should differ from source to source due to different distance unless Lorentz invariance is somehow limited. In addition, JEM-EUSO has three exploratory test observations:

(i). extremely high energy neutrinos beginning at E > 10^{19} eV: neutrinos as being expected to have a slowly increasing cross section in the Standard Model, and in particular, hundreds of times more in the extra-dimension models.

(ii). fundamental physics at extreme Super LHC (Large Hadronic Collider) energies with the hierarchical unified energy much below the GUT scale, and

(iii). global atmospheric observation, including large-scale and local plasma discharges, night-glow, meteoites, and others..

1. Introduction

JEM-EUSO (Extreme Universe Space Observatory on Japanese Experiment Module) uses the whole earth as a detector and can observe extremely high-energy cosmic ray (EHECR) particles with energy above 10^{20}eV and other luminous phenomena in atmosphere. This remote-sensing instrument orbits the earth every ~ 90 minutes on board International Space Station (ISS) at the altitude of ~ 430km (Figure 1) having a wide Field-of-View (±30°) camera with two double sided curved Fresnel lenses. It will record 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)..

JEM-EUSO has two possible modes of operations on board ISS, namely, the nadir and the tilted modes. The latter mode gives up to 5 times larger aperture of the former mode and is specifically considered to observe higher energy regime close to 10^{21} eV.

2. Main Science Objective: Extremely high energy Astronomy in particle channel

Particles with energy above about 7×10^{19} eV are suitable for astronomy in particle channel. They are not deflected more than several degrees by galactic magnetic fields and their propagational horizons do not extend to the whole universe where there are too many background single-event sources that would interfere the extraction of some strong sources. When the statistics above 7×10^{19} eV exceeds thousands, the propagational horizon exceeds the critical value to observe all the sources at least once within a few hundred Mpc when the Greisen-Zatsepin-Kuzmin (GZK) cutoff is at work. Hence, JEM-EUSO may initiate a new astronomy with these particles (7×10^{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 at each multi-event sources;
- clarify the trans-GZK intensity profile [1] of distant sources and make a systematic survey of nearby sources with distinct pile-up below 10^{20} eV for each sources; and
- separate gamma-rays and neutrinos from nucleons and nuclei, which allows testing of the top-down models (Super-Heavy-Particle (SHP) models) that assume long-lived particles produced in the early era of universe.

The EHECR particles can be traced back to the astrophysical origin in the measured arrival direction with accuracy better than a few degrees. AGASA experiments [2] reported small-scale anisotropy (cluster) and some correlation existed in the arrival direction of EHECR 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 (Fig.1) [4]. In a global anisotropy analysis, arrival directions are integrated for spherical harmonics. Such an analysis should reveal the source distributions of EHECRs. 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.

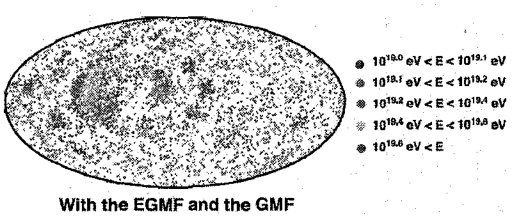

Figure 1. Annisotropy of the bright galaxies [4].

If the EHECRs come from cosmological distances as those of gamma-ray bursts and active galactic nuclei or clusters of galaxies [5], these point sources might indicate global isotropy.

The spectrum region with energy above 10^{20}eV is also a regime where SHP (m ~ $10^{22\text{-}25}$ eV/c^2) is speculated to produce EHECRs without acceleration. SHPs are certainly CDM (Cold Dark Matter) and can be broadly distributed with an enhancement toward the galactic center. It could show small clumps, too, in the outer halo region where these clumps would not be destroyed by the gravitational frictions and tidal effects in the Galaxy. If EHECR 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 galaxy clusters, they may show an enhancement at nearby clusters such as Virgo, Pisces, Peruses, and Heracles [6]. On the other hand, topological defects are expected to extend to the whole universe and do not bear such local characteristics.

Galactic magnetic field is poorly known due to the limited data only from Faraday rotation of polarized radio sources. 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. If there are changes in apparent point-spread-function depending on energy, the galactic magnetic field can be measured [7].

Southern sky experiment has some difficulty to make a comprehensive analysis of the arrival direction due to the very high galactic magnetic fields dominated by the galactic center and galactic plane. If one uses lower energy events, for example, at 4×10^{19} eV, the deflection by magnetic field (~ × 5 higher) is as large as 10 degrees: and is more than enough to erase possible signatures of any small angle anisotropy.

At very high energies, observations from the ground have other problems in the energy region above 5×10^{20}eV, even if a large area for observation becomes possible. An air shower at such high energies in dense atmosphere develops quite differently from the scaled Nishimura-Kamata-Greisen (NKG) lateral-spread function [8] due to the Landau-Pomeranchuk-Migdal (LPM) effect [9]. The lateral distribution method being used for energy determination by ground array experiments might cease to be usable for individual LPM showers due to large fluctuations. JEM-EUSO is relatively free from these problems of the ground-based experiments: in particular, far more immune from uncertainties of the LPM effects for longitudinal calorimetry method of the multi-peaked LPM showers, because it can use a successive shower analysis. Moreover, many showers observable from space develop at high altitudes (above 20km) and at low densities, whose longitudinal shower developments suffer much less LPM uncertainties.

3. Exploratory Objectives

JEM-EUSO has several exploratory objectives in addition to the major science objectives of extremely high-energy astronomy in particle channel.

3.1 Constraint of the extra-dimension theory by extreme energy neutrino

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}: Neutrino events will be recognized as EAS that interacted deep in the atmosphere with nearly horizontal direction (HAS) or as upward-going air showers (UAS) [10]. UAS is produced by the decay of a tau-particle emitted by the interaction in the earth's crust by the interaction of an earth-skimming or earth-penetrating tau-neutrino.

Neutrino-hadron cross-section data at the highest accelerator energy was given by the Electron Positron collider experiments at HERA, $\sigma_{\nu N}^{CC}$ ~2 $\times 10^{-34}$cm^2 at $\sqrt{s}$ =314GeV. According to the standard QCD predictions and cosmogenic GZK neutrino flux calculations, JEM-EUSO is predicted to observe 1-10 neutrino events. Extra-dimensional models [11] predict varieties of cross-sections. The predicted event rate is at least 100 times larger than the Standard QCD rate (Figure 2), and it is testable by JEM-EUSO.

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, dozens of events are expected with the standard QCD cross section. 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. By its three-plus-years of operation of the tiled mode, JEM-EUSO can set an upper-limit of neutrino flux significantly lower than the Waxman-Bahcall limit [12] in the energy range of 10^{20}eV and above (Figure 3).

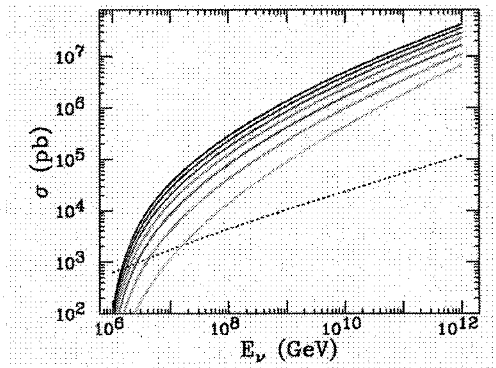

Fig.2 Neutrino cross-sections. Dotted: Standard QCD. Color lines: extra-dimension prediction for Δn = 1 (yellow) to 7 (black).

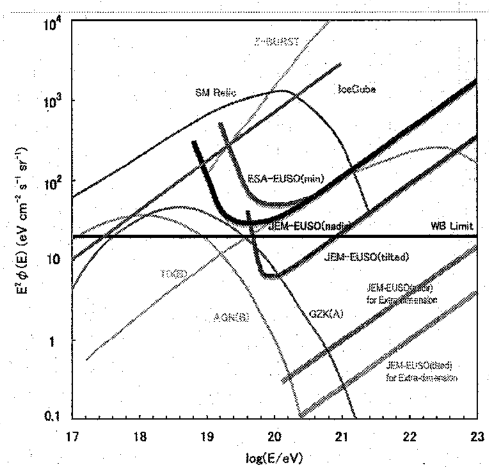

Figure 3 (Preliminary) flux-sensitivity of JEM-EUSO of 1 event/energy-decade/year. An observational efficiency of 25% is assumed. Red Thick Line: EUSO (min); Blue Thick Line: JEM-EUSO Nadir; Green Thick Line: JEM-EUSO-Tilt.

3.2 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. JEM-EUSO can examine the Lorentz Invariance at very high Lorentz factors ($\gamma \sim 10^{11}$). Special relativity has been undoubted at lower energies so that the GZK cutoff is expected to be imminent. In this sense gamma ray mean free path in vacuum is shorter than 100 kpc by interactions with CMB unless strong quantum gravity effect prohibits $\gamma\gamma \to e^+e^-$ process; and hence, no gamma ray events are expected for EHECRs in standard physics. However, if GZK-process itself would not appear as expected, it could imply some limitations of local Lorentz Invariance in the presence of external fields. These EHECRs offer a high-precision experimental testing of the theory of relativity and quantum gravity.

The standard quantum physics also predicts that EAS should suffer a large fluctuation of cascade development because of the Landau-Pomeranchuk-Migdal (LPM) effect. It will become considerable above 5×10^{20} eV for protons and above 5×10^{21}eV from iron nuclei. JEM-EUSO can observe this fluctuation.

3.3. Global Earth Observation

JEM-EUSO is also expected to 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. Gamma rays were also observed associated with lightning [13]. These are explained by streamer discharge [14]. If this is the case, streamer formation must be preceded by the main discharge. Furthermore, some satellites detected several gamma-ray bursts probably associated with lightning from the earth [15]. Such runaway electrons produced by cosmic-rays might be accelerated by the quasi-static electric field of the discharge associated with lightning. JEM-EUSO would keep monitoring both EHECR tracks and runaway phenomena to see whether there is any recognizable relationship. Other exotic atmospheric phenomena such as surface-glow of the earth are also included in the mission studies.

References

[1] V. Berezinsky, M. Kacherlrieb, and A. Vilenkin, *Phys. Rev. Lett.* **79**, 4302, 1997; V. Berezinsky and M. Kachelrieb, *Physical Review D*. **63** 034007, 2001.

[2] Y. Uchihori, et al., *Astropart. Phys.* **13** 151, 2000; N. Hayashida, et al., *Astrophys. J.* **522**, 225, 1999; P/G. Tinyakov and I. Tkachev, *JETP* **74** 445, 2001.

[3] R.U. Abassi, T. Abu-Zayyad, *et al.*, *Astrophys. J.* **623** 164, 2005.

[4] H. Takami, H. Yoshiguchi and K. Sato, *Astrophys. J.* **639** 803, 2006.

[5] S. Inoue, arXiv:astro-ph/0701835, 2007.

[6] G. Medina-Tanco and A. Watson, *Astropart. Phys.* **12**, 25, 1999; G. Medina-Tanco, *arXiv:astro-ph/0607543v1, 2006.*

[7] G. Medina-Tanco, M. Teshima and M. Takeda *Proc. 28-th ICRC Tokyo*, 747, 2003; H. Takami, H. Yoshiguchi and K. Sato, *Astrophys. J.* **639** 803, 2006.

[8] K. Kamata and J. Nishimura *Prog. Theor. Phys.* **Supple 6** 9, 1958; K. Greisen, *Prog. Cosmic Ray Physics III* ed. J G Wilson (North Holland, Amsterdam), 1956.

[9] L.D. Landau and I. J. Pomeranchuk, *Dokl.Akad.Nauk SSSR,* **92** 535, 1935; A.B. Migdal, *Phys. Rev.* **103** 1811, 1956.

[10] S. Palimares-Ruiz, A. Irimia and T.J. Weiler, *Physical Rev. D* **73** 083003 2006.

[11] L.A. Anchordoqui, L.J. Feng, H. Goldberg and A.D. Shapere *Phys. Rev.* **D65** 124027, 2002; L. Anchordoqui, H. Goldberg and P. Nath, *hep-ph/0403115, 2004.*

[12] E. Waxman and J. Bahcall, *Phys. Rev.. D* **59**, 23002, 1999.

[13] V.P. Pasko, and J.J. George, *Journal of Geophysical Research*, **107**, A12, 1458, 2002.

[14] J. Zong, et al., *Photogrammetric engineering & remote sensing*, **68**, 821, 2002.

[15] G.J. Fishman, et al., *Science*, **264**,, 131, 1994.