

JEM EUSO mission on International Space Station

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Abstract. The **Extreme-Universe Space Observatory (EUSO)** on Japanese Experiment Module (JEM) is a mission on ISS [1], led by Japan Aerospace Exploration Agency (JAXA) to investigate the nature and origin of extremely-high-energy cosmic rays (EHECRs). This is the sole window on the extreme-energy universe. JAXA has selected JEM-EUSO for study as one of two international mission candidates for installation on the JEM Exposure Facility by 2013. JEM-EUSO (hereafter, EUSO) is designated to pioneer measurements of EHECR-induced extensive air showers (EAS) from space. As the detector, it uses the whole earth, observing from the International Space Station (ISS) where a remote sensor is located. The signal is fluorescent and Cherenkov light from the Extensive Air Showers (EAS).

1. Extreme-Energy Astronomy - Astrophysics, Cosmology, and Fundamental Physics Quests at the highest energies

The flux of EHECR protons at energies above $\sim 7 \times 10^{19}$ eV reaching earth from distances exceeding 200 Mpc is so suppressed by the Greisen-Zatsepin-Kuzmin (GZK) effect [1] that we expect to find the dominant sources only nearby (< 90 Mpc at 10^{20} eV). Because these EHECRs will not be much deflected by extra-galactic and galactic magnetic fields (**Fig.1**), charged-particle astronomy is possible above these high energies. The goals of EUSO, having the instantaneous aperture of 0.6 - 3 million $\text{km}^2 \text{sr}$, are set as follows:

- Collect a large sample of EHECRs (several x 1000 above 7×10^{19} eV) extending to 10^{21} eV and beyond; measure their energies, directions, and particle species; and determine their nature and origins.
- Make astronomical source observations at extreme energies using charged particles (and neutrinos and/or gamma rays, if detected) initiating comprehensive studies of the individual astronomical sources of cosmic ray particles at these extreme energies.

2. Outstanding Problems and Opportunities

2.1 Acceleration mechanism, probing by GZK and super-GZK Particles:

No known models for astrophysical objects accelerate particles beyond 10^{21} eV (ZeV). Even if $\sim \text{ZeV}$ energies are achievable, it is unclear how the accelerated particles in the shock regions can emerge from the ambient dense radiation fields without significant energy loss. In addition, most of the candidate sources, radio galaxies and AGN, are at distances well beyond the GZK horizon, and so their cosmic ray fluxes suffer photo-pion losses on the CMB. Thus, the mystery of acceleration dynamics that deliver observed EHECRs persists.

2.2 Relatively nearby sources help exploring the acceleration mechanisms

Close sources may deliver multiple events to EUSO's large aperture, as the simulation in **Fig. 1** shows. Dozens of events per single source are possible, sufficient for definitive source identification. These events will also allow an inference of the energy spectrum and its end point, from which we may learn the nature of the hitherto unknown acceleration mechanism, as well as the type of the sources.

A rather different picture emerges if there are no identifiable strong astronomical EHE sources within 50 Mpc. Then, event-clustering about the rare, nearby sources (as suggested in the simulations in **Fig.1**) would not be seen, and the more or less isotropic EHECRs must come from distant sources. Among the known particles, only neutrinos can propagate unimpeded to Earth from distant acceleration sites at super-GZK energies. One possibility for observable fluxes from distant sources is the Z-burst mechanism [2]. In this mechanism, neutrinos from distant sources annihilate on the cosmic neutrino background (CNB) to produce very boosted Z bosons. Those annihilations occurring within the GZK-horizon produce, via Z-decay, cosmic-rays which may arrive at Earth. Since the Z-bursts result from a resonant process, the incident neutrino energy is well-defined, $E_{\nu}^R = M_Z^2/2m_n = 4$ (eV/ m_n) ZeV. If this flux is nonzero, Z-bursts must occur. Observations of Z-burst events could allow us to make the first direct measurement of the CNB density, liberated only a second after the Big Bang, earlier by 400,000 years than liberation of the CMB in the hydrogen recombination era.

There is another speculative class of super-GZK sources which do not require acceleration at all: The so-called top-down models, in which EHECRs are produced in the decay or annihilation of supermassive particles (SMPs) or topological defects (TDs), or SUSY or Extra-dimensional dark matter. These dark and heavy relics may have been produced in the hot-phase early-universe (sometimes via a symmetry-breaking phase-transition, sometimes at the termination of the inflationary epoch of the very early universe). The recent Auger limit on the primary photon fraction sets a severe upper-bound on the local SMP contribution, but not on TDs.

2.3 Neutrino Astronomy

Detection of astrophysical neutrinos demands an extraordinarily large volume because of the small cross section. The neutrino-nucleon cross section increases indefinitely with energy in the Standard Model (SM) of electroweak and quantum chromodynamics (QCD), $\sigma_{\nu N} \propto E_{LAB}^{0.4 \pm 0.1}$ above 10 TeV, yielding an ~ 0.1 microbarn at 10^{20} eV. This extrapolated cross section however is uncertain; we expect it to be large enough for cosmic neutrinos to produce observable numbers of showers in the $\sim 10^{13}$ tons of atmosphere and earth-crust within the field of view of EUSO.

2.3.1. Horizontal Neutrino Showers (HNS) and Upward neutrino showers (UNS)

HNS can constrain topological defects, mirror matter, and the extra-dimension or low-scale unification theory. Neutrino-hadron cross-section data at the highest accelerator energy was given by the Electron Proton collider HERA experiment, $\sigma_{\nu N} \sim 2 \times 10^{-34} \text{cm}^2$ at $\sqrt{s} = 314$ GeV. Extra-dimensional models [3] predict a host of larger cross-sections, of which some are 10-100 times larger than what QCD suggest. According to the standard QCD prediction and cosmogenic neutrino flux calculations, EUSO is predicted to observe 1-10 neutrino events per year, while with extra-dimension, hundreds of events could be observed. If the top-down scenario for super-GZK particles (purple and green lines) is valid, an addition of at least several to hundreds of events per year are also expected. If only a few neutrino events are seen, it would clearly exclude most of the top-down models, as well as the extra-dimensional models.

The idea of UNS for Earth-crust events is that some neutrinos interact near the Earth's surface after skimming through the Earth. While electrons and muons are absorbed by the Earth, sometimes a tau (from ν_{τ} interactions) will emerge from the Earth and decay to produce a shower which fully develops in earth's atmosphere. It is predicted that such neutrino events through oceans are enhanced $\times 10$

relative to land, thereby favoring space-based observations. Such a measurement would establish the value of this cross section at high energies independent of the neutrino flux [4]. The expected number of events should be enhanced by a factor of ~ 10 depending on energy due to the Landau-Pomeranchuk-Migdal (LPM) effect [5] in the Earth's crust.

From the predicted flux of GZK cosmogenic neutrinos alone, the EUSO mission is expected to observe a few or more events in the Earth's atmosphere and crust. If some more speculative predictions are correct, even more neutrino events will be observed.

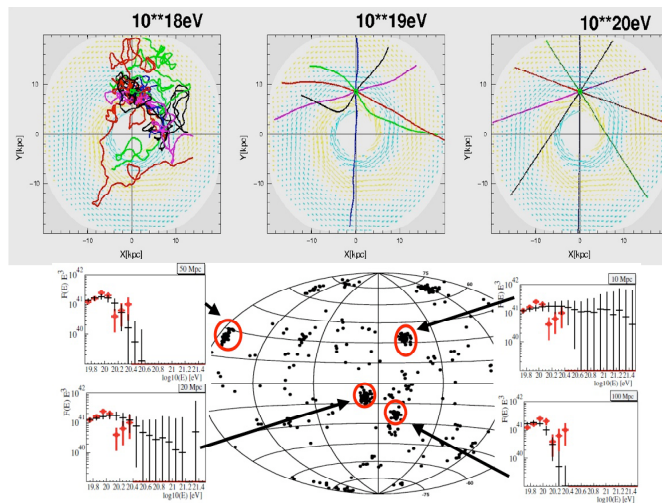


Fig. 1 Magnetic deflections and the source tracing at EHE.

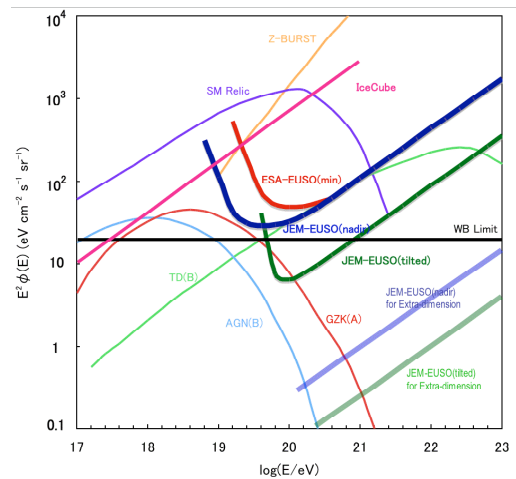


Fig. 2. Observable neutrinos

Fig. 2 shows neutrino fluxes from various models and the sensitivity of EUSO for detecting 1 event/energy-decade/year. An observational efficiency of 25% is assumed. Red Thick Line represents EUSO of previous ESA-Phase-A design; Blue Thick Line: EUSO Nadir; Green Thick Line: EUSO-Tilt. As for Ice cube (Pink line), a few events/energy-decade/10years is assumed. Black Line denotes Waxman-Bahcall limit EUSO sensitivity lines at the lower right part of the graph correspond to the high-cross-section case of the extra-dimension models.

3.4. High-Energy Gamma Rays and Quantum Gravity

The gamma ray window of the known universe is closed in the $10^{13} - 10^{20}$ eV energy interval because they are attenuated by pair production on infrared, microwave, and radio backgrounds, therefore, no gammas from distant sources are expected. However, once one optical length for photons exceeds the GZK length above 10^{20} eV the recovery of the transparency in gamma-ray channel is guaranteed. It has been conjectured further that quantum gravity effects [6] may make the universe far more transparent to such gamma rays. EUSO observations of extremely high energy (EHE) gamma rays originating from distant sources could become an evidence for this effect. EUSO could observe this effect by a time delay between a GRB or AGN flares and the arrival of the high-energy gamma rays from them.

References

- [1] Greisen K.: *Phys. Rev Lett.*, Vol. 16, p. 748, 1966; Zatsepin G.T. and Kuzmin V.A.: *Pis'ma Zh. Eksp. Teor. Fiz.*, Vol. 4, p. 78, 1966.
- [2] Weiler, T.: *Phys. Rev. Lett.*, 49, 234, 1982; Weiler, T.: *Astropart. Phys.*, 11, 303, 1999.
- [3] Anchordoqui L A, Feng L J, Goldberg H, and Shapere A D, *Phys. Rev.* **D65** 124027 (2002).
- [4] Palomares-Ruiz S.; Irimia A; and Weiler T. J.: *Phys. Rev. D* **73**, 083003 (2006).
- [5] Landau L.D; and Pomeranchuk I.J.: *Dokl. Akad. Nauk., SSSR*, Vol. 92, pp. 535 and 735, 1953..
- [6] Kifune T, *ApJ*, Vol. 518, p. L21, 1999; Amelio-Camelia G et al, *Nature*, Vol. 393, p. 763, 1998.