EUSO (The Extreme Universe Space Observatory) — Scientific Objectives —

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Abstract

The Extreme-Universe Space Observatory (EUSO)[1] is an innovative mission to explore the Extremely-High-Energy Cosmic Rays (EHECRs) with high sensitivity, and open the new window of EHE neutrino astrophysics. In this paper, we would like to discuss the scientific objectives of EUSO mission. The understanding of the EHECRs above Greisen-Zatsepin-Kuzmin cut-off[2,3] is very important not only in the astrophysics but also in elementary particle physics. AGN's and GRB's are suggested as possible sources of EHECRs, however, we can not deny the more exotic processes in their production. At present, the experimental results are not enough to discriminate models due to limited statistics. EUSO will supply the energy spectrum and the arrival direction distribution with high statistics and must clarify the origin of EHECRs. The flux information of EHE neutrino measured by EUSO will also strongly constrain models.

1. Introduction

In spite of many efforts to study Extremely High Energy Cosmic Rays (EHECRs)[4-8], their nature and origin are still in mystery. EHECRs above $10^{20}eV$ lose their energy by the interaction with microwave background radiations and can not travel more than 50Mpc[9-12]. Hence, their source must be not so far from our galaxy. Furthermore, if we assume the magnetic field of 10nG or less in the intergalactic space, EHECRs propagate almost linearly in the intergalactic space because of their high rigidity and we expect to be able to trace them back to their sources. Recently, a handful of events above $10^{20}eV$ were measured by AGASA, Fly's Eye and HiRes experiment[13-16]. However, these measurements are not conclusive, and in fact make the problem of EHECRs and made EHECRs more mysterious.

The Extreme-Universe Space Observatory (EUSO) is an ESA (European Space Agency) mission to investigate the Extremely High Energy Cosmic Rays

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and EHE neutrinos with high sensitivity. EUSO will be the first experiment to measure EHECR-induced extensive air showers from space.

2. Study of EHECR energy spectrum by EUSO

EUSO is a wide angle high resolution telescope, which has FOV of $\pm 30^\circ$ with 0.1° resolution. It will be accommodated in the International Space Station, and look down the earth atmosphere from a 400km height ISS orbit. The full aperture for EHECRs is estimated to be $500,000 km^2 sr^2$. Even conservatively assuming an observational duty cycle of 10%, one obtains an effective time averaged aperture of $50,000 km^2 sr$. This aperture is ~ 300 times larger than AGASA and ~ 10 times larger than Auger detector which is now under construction in Malargue, Argentina[17]. We expect to observe the number of events as shown in table 1. For the estimation of the rate above $10^{20} eV$, we assumed AGASA energy spectrum[13,14] or GZK spectrum[11,12].

	$\geq 4 \times 10^{19} eV$	$\geq 10^{20} eV$(AGS)	$\geq 10^{20} eV$(GZK)
AGASA (10yrs)	~ 60	10	—
HiRes (4yrs)	~ 30	—	$1 \sim 2$
Auger (10yrs)	~ 3000	~ 500	~ 50
Auger Hybrd (10yrs,10%)	~ 300	~ 50	~ 5
EUSO (3yrs,10%)	~ 4000	~ 1000	~ 100

If we require 10% or better flux accuracy in the energy spectrum measurement, it becomes clear that AGASA and HiRes can not give us enough information. Only Auger ground based detector and EUSO satisfy this condition above $10^{20} eV$. If the energy spectrum follows the GZK hypothesis, only EUSO can discuss the detailed structure of the energy spectrum above $10^{20} eV$. The maximum energy observable by EUSO is estimated to be $3 \times 10^{21} eV$ and $5 \times 10^{20} eV$ for AGASA spectrum and GZK spectrum, respectively.

3. Study of EHECR arrival direction distribution by EUSO

3.1. Large-scale anisotropy

The International Space Station orbit has an inclination angle of 50 degrees, and EUSO can survey the whole sky very uniformly. This is a very strong aspect on the study of Large-scale anisotropy of EHECRs arrival direction. We can expect large scale anisotropies associated with the galactic structure and the super galactic plane. If we assume Heavy cosmological relics in our galactic halo as a origin of EHECRs[18], we expect the excess of $20 \sim 30$ % amplitude toward galactic center direction. We can also expect anisotropy of EHECRs could be related with the matter density or AGNs distribution within 100Mpc. With EUSO, we can observe anisotropy with an accuracy of 3% and 5% at energy $4 \times 10^{19} eV$ and $10^{20} eV$, respectively.

3.2. Small-scale anisotropy

The AGASA collaboration is claiming the detection of cluster events above $4 \times 10^{19} eV$[19-21]. They observed one triplet and five doublets. According to their analysis, we can expect $200 \sim 600$ sources in the entire sky from the multiplicity distribution of events in each cluster. There are some ambiguity on this number due to low statistics, however, we can roughly estimate what we can see in EUSO. If we assume all particles(4000 events above $4 \times 10^{19} eV$) are originated from 400 same category of sources, we expect signals of ~ 10 particles per each source on average. If we assume uniform distribution of sources in a certain volume (for example, the GZK volume), we can estimate intensity variation by a factor of 50 from source to source using log(S)-log(N) relation. The minimum multiplicity, and the maximum multiplicity can be estimated to be 3 and 150, respectively. In order to identify the source with five sigma confidence level, we need to set the threshold of multiplicity to 8 particles/sources. We will see more than 80 sources amoung 400 sources above this threshold. It is worthwhile to note that the sensitivity for point sources of EUSO at five sigma level is $\sim 0.1 eV cm^{-2} s^{-1}$, this flux sensitivity is comparable or better than new generation gamma ray satellite and ground based cherenkov telescopes.

4. Study of Chemical composition, EHE Neutrinos, and etc.

In order to discriminate models for the origin of EHECRs, the identification of protons, anti-protons, gamma rays and neutrino is very important. For example, top–down model[18,22] and Z–burst model[23], we expect a composition dominated by gamma rays, and we also expect the same amount of protons and anti-protons. So far, X_{max} technique has been used to descriminate the chemical composition. This technique can also be used in EUSO too, however, we would also like to propose different method using the deflection by Galactic Magnetic Field (G.M.F.). If we can find out 80 point sources as mentioned above, we have a possibility to distinguish the electric charge of primary particles, (for example, protons, gammas, and anti-protons). For this purpose, one requires the angular resolution of $\Delta\theta \leq 0.5^{\circ}$ and energy resolution of $\Delta E/E \leq 20 \sim 30\%$. If this is achieved for the majority of the EUSO events, this technique also allows the simultaneous study the galactic magnetic field (GMF) structure. Note that the Faraday rotation method gives us information mainly near the galactic plane, however, while the proposed method also allows to study G.M.F. for high galactic latitude.

EUSO monitors a gigantic volume of atmosphere on the earth. The total mass is $\sim$ 1500 G–ton. Hence, EUSO has a strong capability to detect EHE neutrinos. The detail discussion on EHE neutrino detection capability will be discussed elsewhere in this conference.

5. Summary

EUSO has a gigantic aperture for EHECRs, and EHE neutrinos detection and will supply enough information on EHECR Energy spectrum and Small-scale, and Large-scale anisotropy of EHECR arrival direction to discriminate models.

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