EUSO science

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EUSO is a mission to explore the extreme universe by the probe of Ultra High Energy Cosmic Rays (UHECRs) and UHE neutrinos [1]. EUSO monitors a gigantic volume of atmosphere from Space and measures showers induced by UHECRs and UHE neutrinos. Scientifically, it is important to measure the energy spectrum of UHECRs well beyond GZK energy with high statistics. EUSO ensures the observation of UHECRs up to 10^{21}eV even in the case of GZK mechanism working [2-7], and gives us a clear picture of the existence / non-existence of the GZK effect and the behavior of the spectrum beyond GZK energy, which represents the contributions from nearby sources. The anisotropy study of UHECR arrival directions in a small scale angle above GZK energy may allow us to identify individual source, because of the limited propagation distance and the high rigidity of particles. If event clusters observed by AGASA are real, it is expected from Monte Carlo simulation that EUSO will see ~100 particles from individual brightest sources and will give us a good opportunity to test the relativity in high precision. The UHE neutrino is a unique channel to explore the universe much deeper than UHECRs. EUSO essentially can measure UHE neutrinos free from background proton showers. The number of GZK neutrino events in a EUSO three years' mission is expected to be only a few. Nevertheless, it is a definitely conceivable opportunity to begin UHE neutrino astrophysics at GZK energy.

1. Introduction

So far, there were many efforts to study Ultra High Energy Cosmic Rays (UHECRs), however, their nature and origin are still a mystery. UHECRs above 4×10^{19} eV lose their energy by the GZK process (photo-pion production in the interaction with microwave background radiations) and their propagation distances are effectively limited as to 30 Mpc - 100 Mpc [2-7]. The sources of UHECRs must be not so far from our galaxy. Furthermore, if we assume a magnetic field of 10nG or less in the intergalactic space, UHECRs propagate almost linearly in the intergalactic space. Due to the limitation on the source distance by the GZK effect and the high rigidity, UHECRs may be traced back to their sources above GZK energy. There are realistic simulation studies on the propagation of UHECRs including the extragalactic magnetic field and the

GZK effect [8-12]. Some results suggest promising possibility for the astronomy by UHECRs.

From the experimental point of view, a handful of events above 10^{20} eV were observed by the AGASA, Fly's Eye, HiRes and Auger experiments. But there are two major problems; low statistics, and the uncertainty of the energy calibration. Therefore, these measurements are not conclusive and it is a strong requirement that new generation experiments, EUSO, Auger, and Telescope Array must provide data with high statistics and a better energy calibration.

The Extreme-Universe Space Observatory (EUSO) is an ESA (European Space Agency) space mission to investigate the extreme Universe by using the UHECRs and UHE neutrinos. EUSO will be the first experiment to measure UHECRs and UHE neutrinos from space. EUSO provides an enormous number of UHECRs above GZK energy with fully calorimetric observation, and possibly a handful of events as candidates for UHE neutrinos.

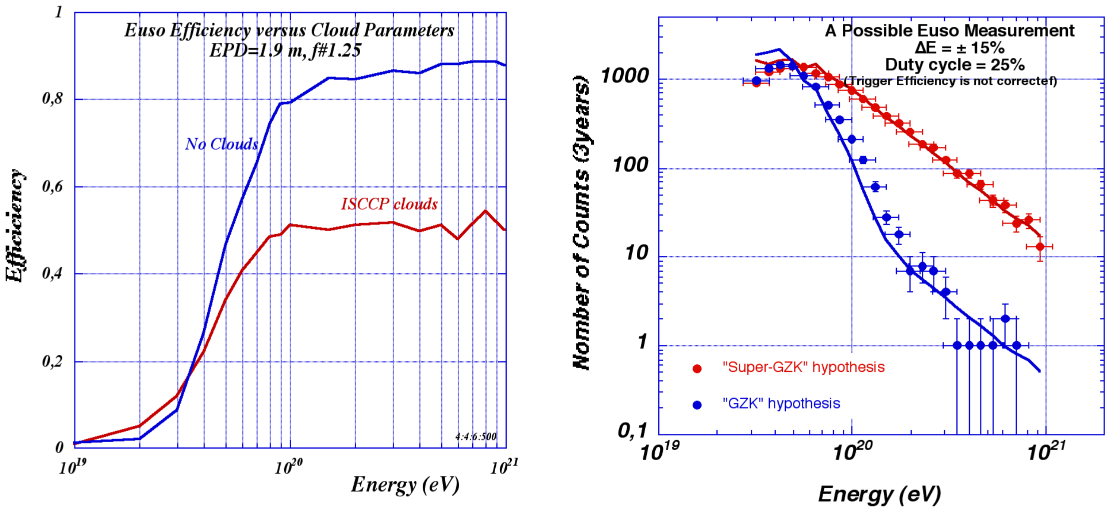

Figure 1, Left: The detection efficiency for UHECRs by EUSO. The threshold energy is estimated at about $5x10^{19}$ eV. Right: Expected observations of the energy distribution of events in the GZK hypothesis and in the Super-GZK hypothesis.

2. UHECR Energy Spectrum

EUSO is a wide angle high resolution telescope, which has a FOV of ±30° with a 0.1° resolution. It will be accommodated in the International Space Station (ISS) and look down the earth atmosphere from a 400km height ISS orbit. The full aperture for UHECRs is estimated to be 500,000 km^2sr. Even with conservative assumption of observational duty cycle of 10%, one obtains an effective time averaged aperture of 50,000km^2sr. This aperture is ~300 times larger than AGASA and ~10 times larger than Auger detector, which is now under construction in Malargue, Argentina. If we require a 10% or better flux accuracy in the energy spectrum measurement above GZK energy, it is clear that AGASA and HiRes can not give us enough information. Only the Auger ground-based detector and the EUSO space-based detector satisfy this condition. 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 ~ 10^{21} eV, even with the GZK hypothesis as shown in right panel of figure 1.

3. Anisotropy of UHECR arrival direction

The International Space Station orbit has an inclination angle of 50 degrees and moves North and South over the earth. EUSO has essentially 2π acceptance due to the nature of the air fluorescence detection technique, and can, as a consequence, survey the whole sky very uniformly due to the ISS motion. This is a very strong aspect in the study of the large-scale anisotropy of UHECR arrival directions. We can expect large scale anisotropies associated with the galactic structure or the super galactic plane. If we assume Heavy Relics in our galactic dark halo as an origin of UHECRs[13], we expect the excess of a 20~30 % amplitude towards the galactic center direction. We can also expect anisotropy of UHECRs could be related with the matter density or AGN distribution within 30 - 100Mpc. With EUSO, we can observe large scale anisotropy with an accuracy of 3% and 5% at an energy of 4×10^{19} eV and 10^{20} eV , respectively.

The AGASA collaboration claimed the detection of cluster events above 4×10^{19} eV [14-16]. AGASA observed one triplet and five doublets. According to the sophisticated analysis, we can expect the source density of $\sim10^{-5}$ Mpc from the multiplicity distribution of events in each cluster. This number is close to the density of AGNs [8]. This source density corresponds to 200 - 600 sources in the GZK horizon.

If we assume all particles (~4000 events above 4×10^{19} eV will be observed by EUSO) originate from 400 sources, we expect signals of ~10 particles per source on average. Then, assuming the uniform distribution of sources in a certain volume (for example, the GZK volume), we can estimate an intensity variation by a factor 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 a five sigma confidence level, we need to set the threshold of multiplicity to about 8 particles/sources, by taking into account the confusion limit with the EUSO angular resolution and the magnetic bending effect of 2-3 degrees. We will see more than 80 sources among 400 sources above this threshold.

It is interesting to reconstruct the energy spectrum of cosmic rays from individual bright UHECR sources, which are identified as astronomical objects with known redshift parameters. We can compare the observed energy spectrum from each individual source with the expected single source spectrum with a GZK cutoff feature with a known redshift. This comparison can provide a good calibration of the energy scale and a tool to test the Lorentz invariance at high gamma-factor regime $\gamma = 10^{11}$.

It deserves to be mentioned that the sensitivity for point sources of EUSO at a five sigma level after a three years' mission is about 0.2 eV $cm^{-2}s^{-1}$, and is comparable to a new generation gamma ray satellite and ground-based Cherenkov telescopes. For time variable sources (of course, we need to assume neutral particles) EUSO also has a meaningful sensitivity due to the huge instantaneous aperture. For example, the flux sensitivity is 10~30 $eVcm^{-2}s^{-1}$ for flaring sources with 1 day observation. Time variable sources for UHECRs are definitely limited and only galactic sources or nearby sources can become candidates, because the attenuation length of gamma rays and the neutron decay length are about a few Mpc at $10^{20\text{-}21}$eV. If they are exotic neutral particles, this limitation does not apply.

4. UHE Neutrinos

In order to discriminate models for the origin of UHECRs, the study of the UHE neutrino flux is very crucial. For example, in top–down models and Z–burst models, we expect a large flux of neutrinos. Irrelevant of the models or the origin of UHECRs, it is attractive to study the violent phenomena in the deep Universe. The UHE neutrino detection is one of the most challenging themes in the EUSO mission. EUSO monitors a gigantic volume of atmosphere on earth, and its mass corresponds to 1500 G–ton. Of course, we can use the X_{max} technique to distinguish UHE neutrinos. However, in the EUSO experiment, we can also apply a much simpler method to discriminate UHE neutrinos as shown in the left panel of Figure 2. The neutrino can be identified as a shower with an inclined short track. Because of the small cross section of neutrinos, the neutrino produces an air shower deep in the atmosphere. In comparison to showers produced by protons, the neutrino shower develops at low altitude, in other word; at a higher density part of the atmosphere, then it develops faster than a normal shower. Therefore, we can recognize the UHE neutrino as an inclined short track shower. As shown in the left panel of Figure 2, EUSO has enough capability to distinguish UHE neutrinos from UHE proton showers.

Several papers are submitted in this conference concerning the improvement of photon detectors, trigger logic, and optical through-put. These efforts make the EUSO energy threshold lower and will significantly improve not only the capability of the cross-calibration between EUSO and ground-based detectors, but also the capability of UHE neutrino detection.

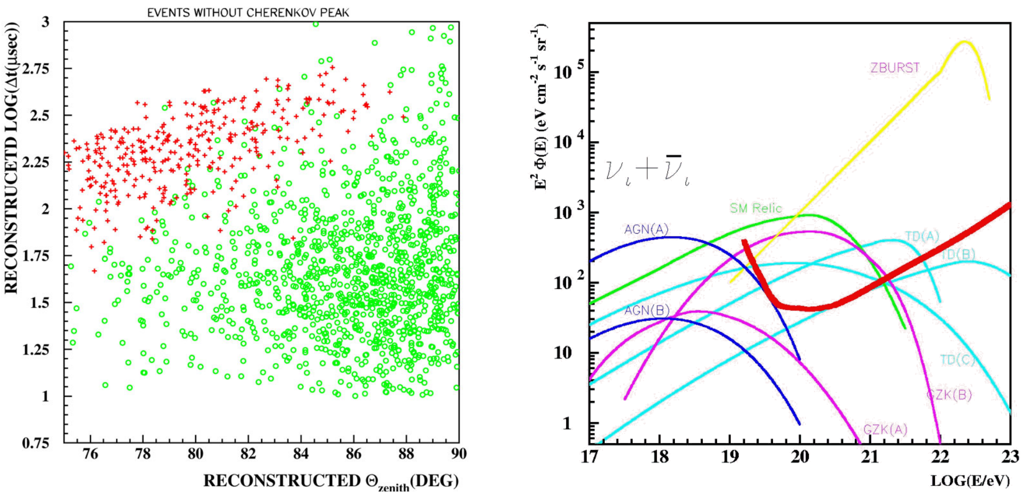

Figure 2 Left: Discrimination of proton and neutrino showers. Neutrino showers can be identified as events with short tracks and large zenith angles. Right: EUSO sensitivity for UHE neutrinos. EUSO sensitivity represented with thick red curve with theoretical predictions

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