AGASA Results and EUSO

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Abstract

Recently AGASA group reevaluated the energy estimation of AGASA events and showed that the energy spectrum of cosmic rays extends without any sign of GZK-cutoff. Clustering of ultrahigh energy events within experimentlal angular resolution suggests the astronominacal point sources and their distribution in whole sky may reveal the magnetic configuration of our galaxy and extragalactic magnetic field. Based on the AGASA results, we discuss what we can expect EUSO.

1. Energy Spectrum

The differential energy spectra of primary cosmic rays from the world data determined by various methods or groups is shown in Figure 1 from 10^{14}eV to 10^{21}eV[1]. The flux is multiplied by E^3 to see the details of the spectrum. At the highest energy region, the recent results have been reported from AGASA[2] and HiRes[3]. The solid squares are from the Akeno 1km^2 array[4], and the solid circles are from AGASA whose energy is reduced by 10% to normalize to that of the 1km^2 array. Since the detailed evaluation of the systematic error of AGASA is ±18%[2], this 10% reduction of energy may be accepted. It is shown that the energy spectrum has been determined at Akeno systematically over 5 decades in energy by the scintillation detector arrays and is in good agreement with that in the lower energy region.

Open and closed triangles above 10^{17}eV are from the HiRes results[3]. Open circles above 10^{17}eV are from Fly's Eye results[5]. Both of them are determined by the fluorecence technique. According to the recent measurement of fluorescence efficiency in dry air[6], the photon yield used by the HiRes group is smaller than 13% than the new measurement. That is, the energy determined by the HiRes group is possibly largely estimated. If this is true, the energy spectrum of HiRes may be shifted to the left in the figure and doesn't agree with most of spectra observed in the lower energy region. There must be any unknown factors in energy estimation by fluorescence technique on the ground. This will be discussed in Section 3. It is also pointed that the field of view of HiResI is too narrow to determine the energy spectrum without detailed knowledge of the

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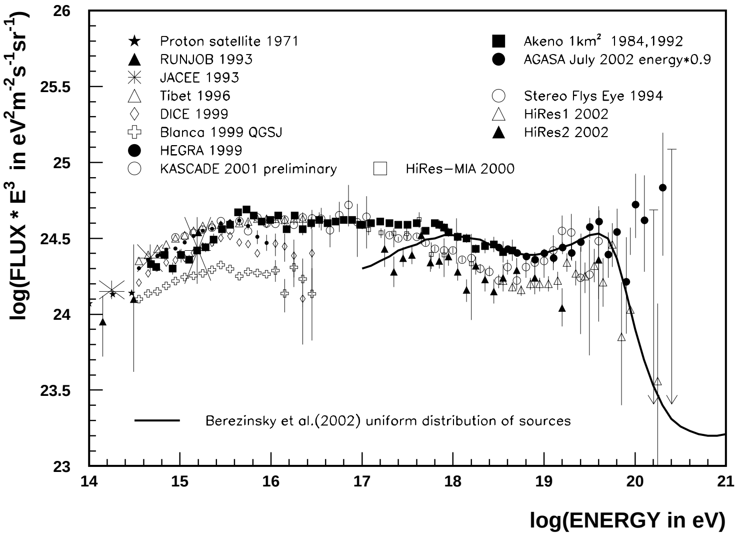

Fig. 1. Differential energy spectra determined by Akeno 1km^2 array[4] - AGASA[2] and Fly's Eye[5] - HiRes[3], compared with those determined by other experiments at lower energy regions, whose references are found in Takeda et al.[2].

primary composition and the shower development fluctuation[1].

A solid curve in the figure is an expected one in the case of uniform distribution of the sources in the universe by the recent estimation by Berezinsky et al.[7] The structure of energy spectrum in cutoff energy region is similar to the previous estimations and the AGASA spectrum extends beyond this cutoff energy ($\sim 3\sigma$). Whether the energy spectrum extends beyond this cutoff may be examined with the Auger experiment within a few years after its operation. The next generation experiments should be prepared assuming the extension of the spectrum beyond the present highest energy observed.

2. Arrival Direction Distribution

The arrival directions of 11 10^{20}eV events of AGASA are plotted by closed circles on an equi-exposure map of AGASA in Figure 2, together with the events of other observations. Though the energies of four largest events from Haverah Park were reduced to $10^{19.88}$ in 2001 [8], they are also plotted by open squares. Recently Nagano reanalyzed the INS-Tokyo event, whose energy was reported as 4×10^{21} eV[9], with the method applied to the analysis of AGASA and estimated as about 2.5×10^{20} eV[10]. Though the original energy is too large, it is still one of the highest energy events reported so far and is plotted by an open triangle.

The SUGAR events whose energies were estimated to be nearly above 10^{20}eV[11] are also analyzed by using the AGASA lateral distribution of muons. Among 9 candidate events, at least two events (SU14427 and SU6179) may be above 10^{20}eV[10]. These are nearly on galactic plane, but outside this map. Though the number of events are still small, it should be noted that 9 events among 21 events are within $\pm 10°$ from the galactic plane, if we iclude the SUGAR two events outside the map.

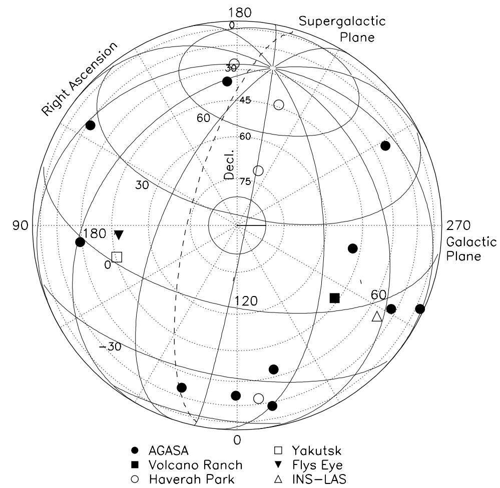

Fig. 2. Arrival direction distribution for candidate events above 10^{20}eV plotted in the equi-exposure map of AGASA. The center of the circle is the equatorial pole and the galactic latitude and longitude are shown by solid curves in each 30° and the supergalactic plane is shown by a dashed curve.

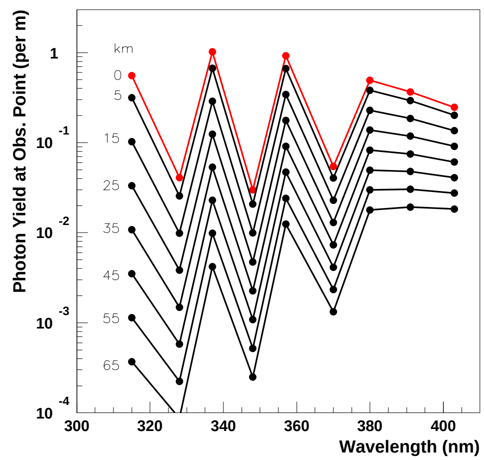

Fig. 3. Wavelength dependence of attenuation of photons at various distances from the shower trajectory to the observation point.

If we plot only AGASA events above 4×10^{19}eV, there are one triplet and five doublets, whose arrival directions are within experimental angular resolution[12]. The vectors, the difference in the galactic coordinate between two event directions are deflected to about 40° from the vertical to the galactic plane[13]. Since the galactic magnetic field is directed from 270 to 90 degrees in galactic coordinates, protons outside from our galaxy may be deflected north direction almost vertically to the galactic plane. In addition to this deflection, protons may be deflected by the z component of field.

Therefore if we can measure such a deflection, it may help not only to know the origin of cosmic rays, but also to know the magnetic configuration of our galaxy and extragalactic magnetic field. For the next generation experiment, it is clear that the observation must cover the whole sky, especially whole the galactic plane from its center to the anticenter.

3. Advantage of Fluorescence Experiment from Space

The difficulty of energy determination of fluorescence technique on the ground lies in the evaluation of attenuation of photons from the shower trajectory to the observation points. In this process the differences of wavelength dependence of (1) fluorescence and Cherenkov photon yields, and (2) Rayleigh and Mie scattering, must be taken into account. For example, it is shown in Figure 3 how the observed photons change with distance as the function of wavelength. Here only fluorescence yield and Raighleigh scattering are taken into account. In actual case, the wavelength dependence of attenuation due to Mie scattering must be taken into account. The more difficulty is the subtraction of Cherenkov light. Since the wavelength dependences of Cherenkov and fluorescent photons are quite different, the proportion of subtraction in each wavelength band must be carefully taken into account in each event according its geometry.

Main advantages in analysis algorithm of fluorescence experiment from space are that the attenuation of photons doesn't depend much on the wave length and the exposure doesn't depend on energy above the threshold energy. Though there are inherent difficulties in space experiment, those will be possible to be overcome as will be discussed in the following presentations.

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