ANISOTROPY OF COSMIC RAYS ABOVE 10^{14}eV

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ABSTRACT

A survey is made of the anisotropy of cosmic rays at energies above 10^{14}eV. It is concluded that cosmic γ-rays may have an effect in the range 10^{14}-10^{16}eV, above which protons dominate. Evidence is presented for an excess in the general direction of the Galactic plane which grows with increasing energy until about 10^{19}eV, indicating a Galactic origin for these particles. At higher energies an Extragalactic origin is indicated.

1. Introduction. Many surveys of cosmic ray anisotropy measurements have been made in recent years and a consistent picture is emerging as to the manner in which the amplitude of the first harmonic and its phase varies with energy. In our own work (Wdowczyk and Wolfendale, 1984a,b) we have extended the analysis to a study of both first and second harmonics and separately for the northern and southern hemispheres. Figure 1 gives the results for the amplitudes and Figure 2 concerns the phases.

It is our objective to explain the observed trends; this can be done most conveniently by energy range.

2. The range 10^{14}-10^{16}eV. Inspection of Figure 2 leads us to suggest that for E : 10^{14}-10^{16}eV we are dealing with a region where γ-rays contribute significantly to the anisotropy, this suggestion following on earlier work (WW 1983) which in turn was prompted by the Cygnus X-3 observations. Gamma ray sources are expected preferentially at small Galactic longitudes and this feature appears in Figure 2 (viz. the shaded area near $\ell \simeq 0°$ for 10^{14}-10^{16}eV). At higher energies γ-rays are apparently unimportant insofar as the anisotropy is concerned.

3. 10^{16}-10^{19}eV. A different feature appears at higher energies. Between about 5.10^{17}eV and 10^{19}eV there appears to be an enhancement centred on the Galactic plane but as the energy falls the pattern appears to be rotated. Figure 3 shows the situation. The obvious explanation is that we are dealing here with charged particles; the change of ϕ with falling energy is in the sense of that expected due to the curvature of the local magnetic field lines (the field analysis having come from earlier work by Karakula et al., 1972, Osborne et al., 1973, and Ellis and Axon, 1978).

4. Energies above 10^{19}eV. In our earlier work (WW 1984a,b) we defined a Galactic plane excess parameter, f_E, defined by $I(b) = I(O) \{(1-f_E + f_E \exp-b^2\}$ where b is the Galactic latitude. The analysis shows that f_E rises with energy, being ~ 0.1 at 10^{18}eV, 0.3 at 5.10^{18}eV and 0.6 at 2.10^{19}eV. However, at the very highest energies, f_E appears to drop

(to $\approx$ 0.25) indicative of the bulk of the particles being extragalactic, a result that is in accord with other work.

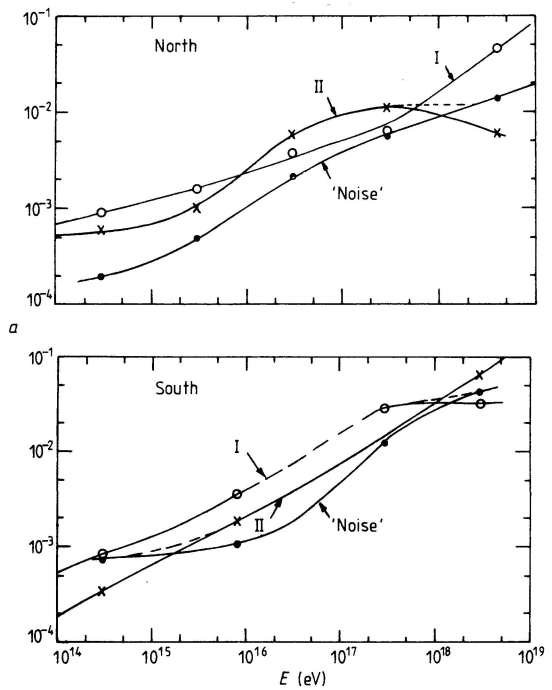

Fig. 1. Amplitudes of the first (I) and second (II) harmonics of anisotropy measurements averaged over successive decades of energy. The measurements in the Northern hemisphere (upper part) were from extensive air shower arrays located at latitudes from 43°N to 62°N. Those in the Southern hemisphere (lower part) cover the range 16°S to 37°S. The curve denoted 'noise' relates to expectation from a true distribution with zero anisotropy, measured isotropies arising simply by chance. The significance level is one standard deviation.

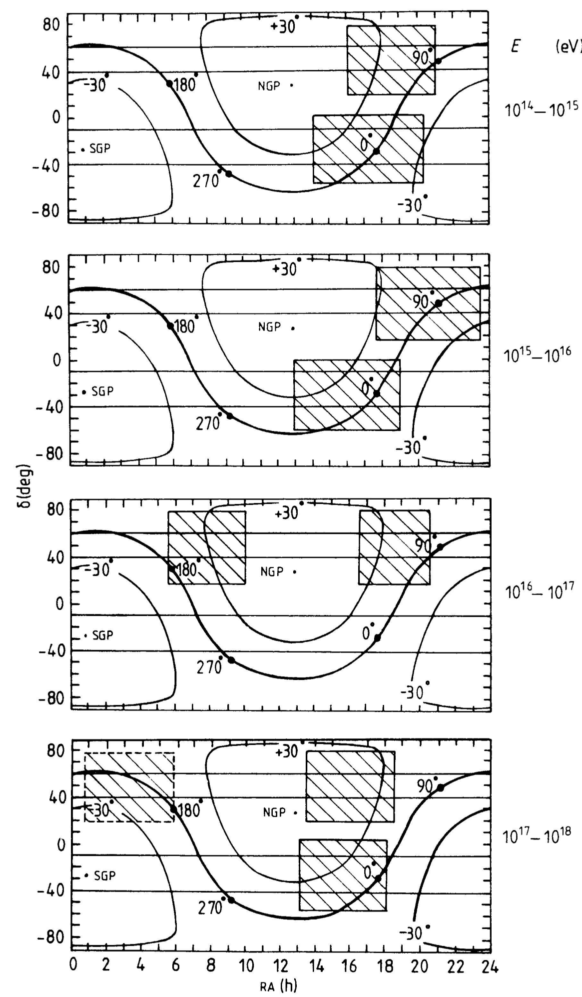

Fig. 2. Celestial plots showing the directions from which much of the excess flux arises. The data suggest the presence of an excess associated with the Galactic plane in the Inner Galaxy for the energy region 10^{14}-10^{16}eV. At higher energies the excess from the Inner Galaxy moves to Northern Galactic latitudes, reaching $b \simeq 30°$ for the range 10^{17}-10^{18}eV.

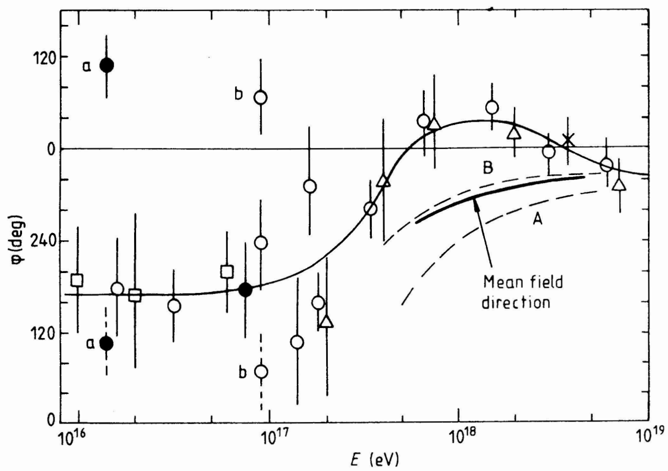

Fig. 3. Angle ϕ through which the prediction of the Galactic plane excess should be rotated in order to fit best the observed pattern of intensity against RA (after WW, 1984a). The points marked 'a' and 'b' are plotted twice. The full curve is intended to guide the eye. The broken curves give the directions from which detectors in the Northern hemisphere should record maximum intensities using the Galactic magnetic field models of Karakula et al. (1972). The data available on the very local field direction, which allows for irregularities, give the line indicated 'mean field direction' - for comparison with the trend of ϕ it should be displaced to lower energies by ~ 3.

5. Conclusions. The present analysis suggests that γ-rays play a key role in explaining the trend of anisotropy phase with energy in the range 10^{14}-10^{16}eV. Very recently support has come from the Backsan experiment (Alexeenko and Navarra, 1985) but the hypothesis cannot be regarded yet as completely proven: a 'Galactic ridge' of muon poor showers with high precision is a pre requisite. Above 10^{16}eV the behaviour of the anisotropy with energy is indicative of charged particles providing the bulk of the anisotropy, those below 10^{19}eV being Galactic and the very highest energies extragalactic in origin.

References

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