Anisotropy of Cosmic Rays of Energy 10^{15}eV to 10^{17}eV Observed at Akeno

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ABSTRACT

Anisotropy of cosmic rays is studied with EAS data by muon trigger. The present results support those obtained by electron trigger which suggest the significant anisotropy of second harmonics with phase around 100° in right ascension for showers of 10^{16}-10^{17}eV, and predominant arrival direction of 230° in right ascension for muon-rich showers. It seems that the phase of the first harmonics in the energy range below 10^{17}eV is about 300° in right ascension and the second harmonics near $6X10^{14}$eV is statistically significant with an amplitude of 0.39±0.13% in direction of 83±10° in right ascension.

1. Introduction

Anisotropy of arrival direction of cosmic rays in the energy range larger than 10^{15}eV has been studied by various selection conditions on air showers at the EAS Array of Akeno. The results by the trigger of electron density were reported in the previous conference(Hara et al. 1981 and 1983a). In comparison, selection of air showers by discriminating muon density(muon trigger) has the following advantage. (1) Muon size N_μ is less fluctuating than electron size Ne as an estimater of primary energy Eo. (2) The muon detectors are the proportional counters in shielded room, of which response is less affected by the temperature variation.

The EAS recorded by muon trigger(case I) is available since the autumn of 1982 for Eo larger than 10^{15}eV. About 90,000 EAS's are accumulated during two years of 1983 and 1984 and are analyzed for anisotropy. Also presented in this paper is the result by another muon trigger(case II), though whose result is preliminary. In this trigger, the event rate per hour is recorded without detailed informations in each detector of the array. The number of accumulated showers is $1.1X10^6$ during half a year since June 1984.

2. Experimental condition and method of analysis

The EAS Array at Akeno(Hara et al. 1979) has nine muon stations, with a threshold energy of 1 GeV. Effective area of each station which consists of 50 proportional counters is 25 m^2. The following two experiments have been performed with muon trigger.

In case I, when more than 4 muons hit each of 4 muon stations located near the central area of the array, the EAS data are recorded. The location of EAS core, zenith angle and electron size are determind from electron data. Primary energy of each observed shower is estimated from N_μ(Hara et al. 1983b).

In case II, the rate of air showers when more than 5 muons which are spatially separated from each other hit one of 9 muon stations is recorded. The median energy of these showers is found to be $6X10^{14}$eV by the analysis of AS data obtained by the calibration run with the same trigger condition. The harmonic analysis is applied to get the anisotropy after the correction of non-observation period by the method described in Hara et al.(1983a). The anisotropy of muon-rich showers is studied in case I as well as the anisotropy of total showers. The showers whose N_μ to Ne ratio is 2 times larger than the mean value over all the showers are defined as muon-rich showers.

3. Results and Discussions

Results of case I are presented in Table 1 for the total showers and in Table 2 for muon-rich showers. The obtained amplitude and phase of maximum intensity in right ascension are listed in the tables as well as the number of showers N in each energy bin and the parameter of reliability k where the probability of obtaining amplitude greater than r from the uniform distribution is given by $w(>r)=\exp(-k)$ $(k=r^2N/4)$. Also in Fig.1a and b, the phases of first and second harmonics are shown as a function of primary energy respectively. In the figures, open circles designate the results for total showers and closed circles for muon-rich showers.

Table 1 (Case I. Total showers)

		first harmonics			second harmonics		
Eo	N	amplitude (%)	phase (degree)	k	amplitude (%)	phase (degree)	k
$1.3X10^{15}$eV	1480	3.1±3.7	46± 68	0.36	0.9±3.7	104±117	0.03
2.8	15461	0.6±1.1	284±104	0.15	0.9±1.1	93± 73	0.31
6.0	24558	1.6±0.9	313± 33	1.53	0.2±0.9	49±116	0.03
$1.3X10^{16}$eV	20289	1.7±1.0	290± 34	1.40	0.1±1.0	37±180	0.00
2.8	16129	2.2±1.1	299± 29	1.95	1.5±1.1	129± 21	0.94
6.0	9388	2.2±1.5	293± 39	1.09	3.2±1.5	72± 13	2.37
$1.3X10^{17}$eV	3203	1.9±2.5	288± 77	0.28	1.5±2.5	73± 47	0.18
2.8	758	5.9±5.1	340± 50	0.66	5.9±5.1	155± 25	0.65
6.0	127	7.2±12.6	103±100	0.16	15.3±12.6	144± 24	0.74

Table 2 (Case I. Muon-rich showers)

		first harmonics			second harmonics		
Eo	N	amplitude (%)	phase (degree)	k	amplitude (%)	phase (degree)	k
$1.3X10^{15}$eV	280	5.2±8.5	106± 93	0.19	16.5±8.5	149± 15	1.90
2.8	4842	4.4±2.0	215± 27	2.31	1.9±2.0	49± 30	0.45
6.0	8583	1.1±1.5	134± 81	0.25	1.4±1.5	62± 32	0.40
$1.3X10^{16}$eV	6421	2.5±1.8	260± 40	1.00	1.9±1.8	133± 26	0.60
2.8	4310	1.6±2.2	317± 77	0.28	0.7±2.2	80± 93	0.05
6.0	2462	2.8±2.9	14± 59	0.48	1.4±2.9	31± 60	0.11
$1.3X10^{17}$eV	737	10.6±5.2	317± 28	2.08	4.1±5.2	60± 36	0.32
2.8	112	5.5±13.4	342±139	0.08	6.2±13.4	90± 62	0.11

Although the present results are quite preliminary, the following features can be noted.

(1) The first harmonics shows a roughly constant phase around 300° below

10^{17}eV. This is slso seen in Fig.2a, where thin circles indicate the harmonic diagrams for energy bin from 2.8X10^{15} to 1.3X10^{17}eV each and bold circle indicates that of sum(amplitude, 1.59±0.47% and phase, 298°±17° R.A. with k=5.63) for this energy region.

(2) The second harmonics of total showers appear to show a tendency of maximum intensity at phase 91°±28° in right ascension with amplitude of 0.50±0.48% below 10^{17}eV, as seen in Fig.2b, where the designations of circles are the same in Fig.2a.

(3) Muon-rich showers have the maximum phase of the first harmonics near 220° below 10^{16}eV. Fig.3 shows the data for energy from 2.8X10^{15}eV to 1.3X10^{16}eV and those sum indicated by thin and bold circles respectively.

The features (2) and (3) are consistent with the results obtained by electron trigger(Kifune et al. 1985), though present results are not statistically significant. For the feature (1), anti-sidereal amplitude is 0.80±0.48% for the same energy region which is relatively small compared with that of sidereal time variation. The phase of about 300° is different from the results

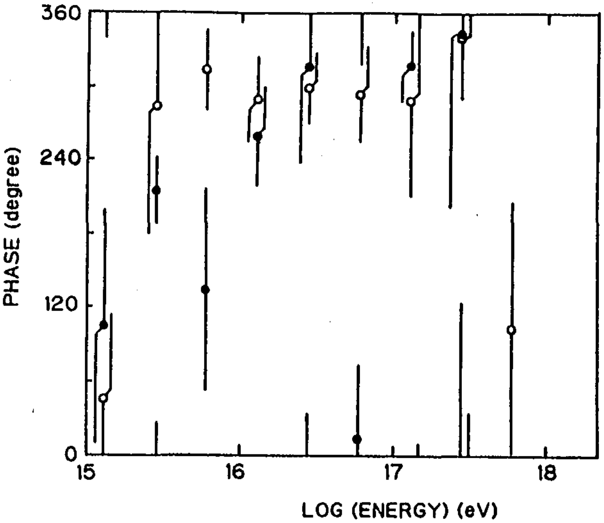


Fig.1a Phase of first harmonics

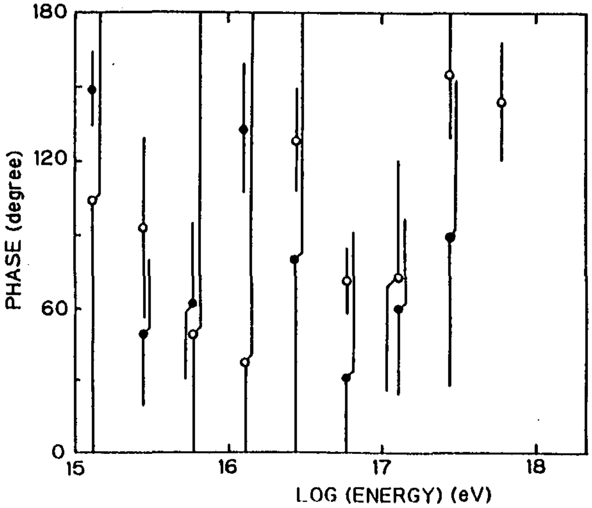


Fig.1b Phase of second harmonics

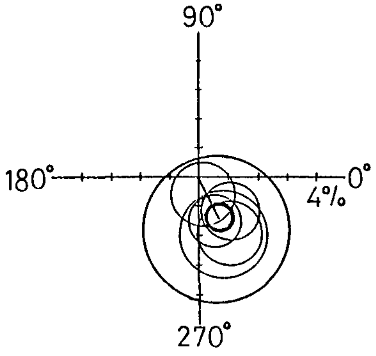


Fig.2a Harmonic diagram of first harmonics for total showers below 10^{17}eV.

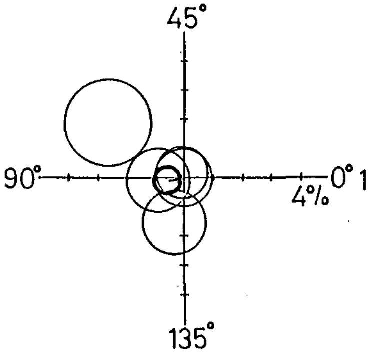


Fig.2b Harmonic diagram of second harmonics for total showers below 10^{17}eV.

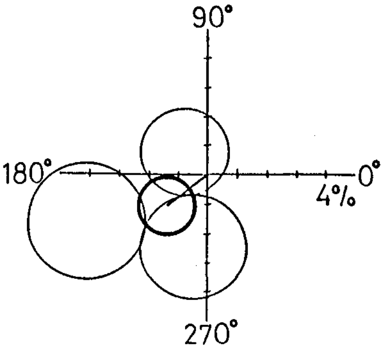


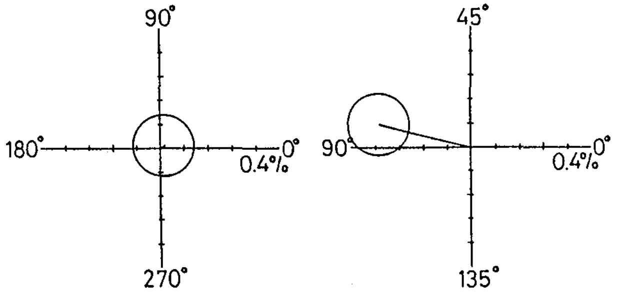
Fig.3 Harmonic diagram of first harmonics for muon-rich showers below 10^{16}eV.

obtained by electron trigger below 3X10^{16}eV, even if the magnitude of error is taken account of. One of the posibilities to explain this difference is to attribute it to the difference of triggering bias. If we presume muon size to be better estimater of primary energy than electron size, the data triggered by electrons include contaminations of events which have different primary energies in the same electron size bin, so the reliability of energy dependence of the anisotropy for the case of electron trigger is possibly less than that for muon trigger, especially for lower energy. However in present stage we need to examine this feature more carefully.

Table 3 (Case II)

	first harmonics			second harmonics		
Time variation	amplitude (%)	phase (degree)	k	amplitude (%)	phase (degree)	k
Sidereal	0.02±0.13	33±180	0.01	0.39±0.13	83± 10	4.14
Solar	0.10±0.13	142± 78	0.27	0.07±0.13	52± 57	0.13
Anti-sidereal	0.07±0.13	187±104	0.15	0.29±0.13	27± 13	2.39

The preliminary results in case II are presented in Table 3, and harmonic diagrams of first and second harmonics for sidereal time are shown in Fig.4a and b respectively. It appeares that second harmonics of sidereal time variation has statistically significant amplitude of 0.39±0.13% with k=4.14. The phase of maximum intensity is 83°±10°. The similar results in the second harmonics are obtained by muon triggered data at 2X10^{15}eV conducted by Murakami et al.(1985) at Akeno.



(a) (b)

Fig.4 Harmonic diagram of (a)first harmonics and (b)second harmonics, for 6X10^{14}eV in case II.

It should be noted that statistics are not sufficient at present, and observations are being continued to confirm the anisotropy of cosmic rays.

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