ANISOTROPY OF EXTENSIVE AIR SHOWERS

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It has been generally agreed that directions of cosmic rays are essentially isotropic, with some reservations according to some indications of anisotropy suggested by a few investigations.[1]

The implication of the isotropy of primary cosmic rays seems to be that the trajectories of cosmic rays are so well disturbed by galactic magnetic fields that the memory of the original direction is lost. It is, then, natural to suppose that, if we consider the cosmic rays of extremely high energy, they are less affected by magnetic fields and hence the original anisotropy, if there is any, would show up. Attempts have been made to look for the anisotropy of extensive air showers.[2] The isotropy of extensive air showers of size ~10^5 particles has been well established.[1] However, above a size of 10^8 particles essentially no investigation had been made until the groups of M.I.T. and Cornell obtained data on the isotropy of extensive air showers of this size and suggested some possible indication of an anisotropy, although it is still uncertain.[3,4]

We wish to inquire here if there is any particular component in primary cosmic rays which is anisotropic but is buried in the majority of isotropic components. As one of the possibilities, we may consider heavy nuclei of extremely high energy. The present report describes experimental results which may concern this problem, obtained by two experimental groups. The statistics of the results are by no means satisfactory; but, since preliminary results appear to be very suggestive from the astrophysical point of view, we thought it worth while to publish them. Part of the results was obtained by the air shower project of the Institute for Nuclear Study (INS).[5] The apparatus is essentially composed of an air shower array above the ground, with which the size, N, the location of the center of the shower, and the arrival direction are determined for each extensive air shower; and an underground detector of eight square meters, with which we can measure the density of μ mesons whose energy is greater than 5 Bev at the ground surface. Another part of the results comes from the project of the Osaka City University (OCU).[6] This is also a combination of an air shower array above ground and a detector array underground. Both groups used similar distribution functions for the lateral spread of particles in estimating the size N of

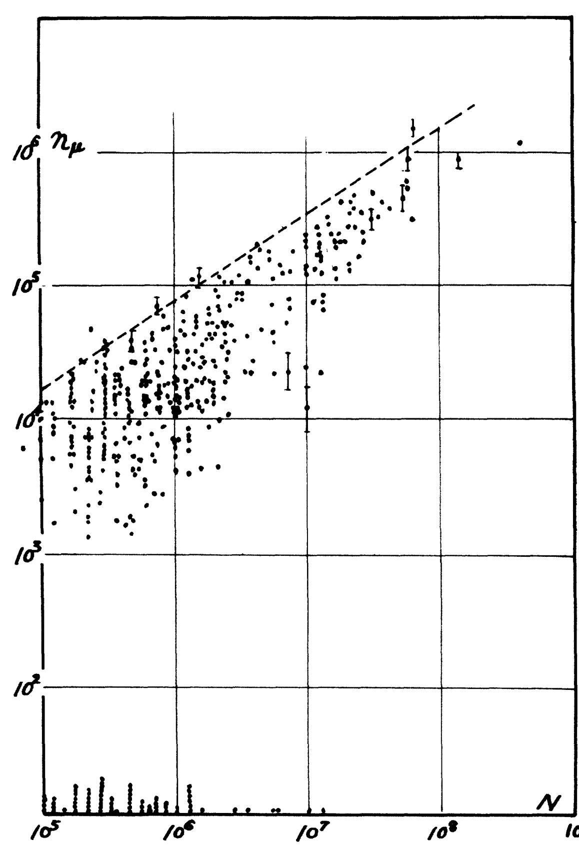

FIG. 1. Example of an N-n_μ diagram. This diagram is for the showers whose zenith angle is between 20° and 39°. The upper boundary of the distribution of points is indicated by a dashed line.

Table I. Observed numbers of μ-meson-rich air showers for the intervals of right ascension. Data for different ranges of the size are shown separately for INS and OCU. Distributions of showers without the selection with respect to the μ-meson component are also shown.

Right ascension (hr)	0-3	3-6	6-9	9-12	12-15	15-18	18-21	21-24
(a) μ-meson rich								
INS: $>10^7$	2	3	2	4	3	0	0	1
10^6-10^7	0	2	10	4	3	0	3	3
OCU: $>10^7$	0	0	2	1	0	0	1	1
10^6-10^7	3	5	1	4	2	0	0	1
Sum	5	10	15	13	8	0	4	5
(b) Without the selection								
INS: $>10^7$	25	21	21	14	28	22	17	16
10^6-10^7	29	34	32	48	32	36	24	33

each extensive air shower.[5] The total number of μ mesons, n_μ, in each shower was evaluated from the density of μ mesons measured at a certain distance from the center of the shower with the aid of an empirical lateral distribution of μ-meson component.[5]

As a possible means of distinguishing heavy-primary-initiated air showers, we propose the "N-n_μ" diagram analysis. If we plot, on the diagram whose coordinates represent the size N and the total number of μ mesons n_μ, respectively, the point representing each extensive air shower, these points are known to be distributed on the diagram within a band which spreads by a factor of several to ten, having a rather definite boundary. Figure 1 shows an example of this diagram. The reason for the relation between n_μ and N not being unique is probably that the starting point of the extensive air shower, or the altitude where the first interaction of the shower occurs, is different from shower to shower. Thus the location of the point on the diagram is considered to specify a unique combination of the total energy and the altitude of the starting point of the shower.[5]

In the case of heavy-primary-initiated showers it was shown that the ratio of n_μ to N would not fluctuate as much as in the case of proton-initiated showers and moreover that the ratio is greater.[5] Therefore, if we select showers whose n_μ to N ratios are close to their maximum possible values, heavy-primary-initiated showers would be concentrated. This criterion of selection is cer-

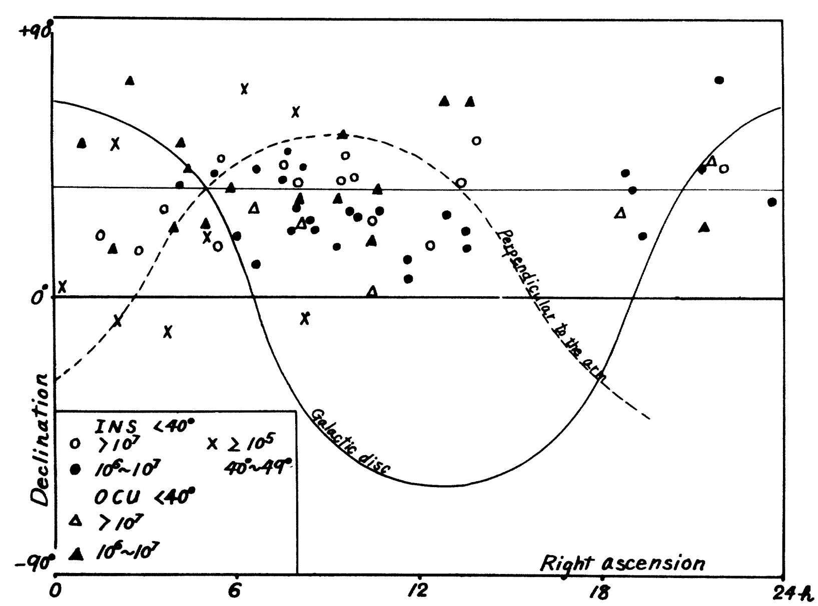

FIG. 2. The distribution of arrival directions of μ-meson-rich air showers on the celestial sphere. The zenith of the locations of observation scans the celestial sphere along the declination +35°. Showers which are very inclined and which are relatively μ-meson rich are also plotted.

tainly artificial, but we may pick up several to ten percent of all showers with a strong bias towards the heavy-primary-initiated showers. We plotted on the celestial sphere the arrival directions of those showers, whose n_μ to N ratios are between the maximum and eight-tenths of the maximum value.

Table I and Fig. 2 show the distribution in right ascension of the arrival directions for the showers of various sizes and for different series of experiments. The apparent features of this distribution are a "bright" region between 3 and 15 hr right ascension and a "hole" in the region between 15 and 18 hr, along the band around 35°N declination. On the other hand, no indication of anisotropy can be seen if we plot all the showers without respect to the above criterion. This bright region, incidentally, corresponds to the general direction which is perpendicular to the Orion arm of the galaxy where the solar system is located.[7] The probability of a statistical fluctuation producing the observed anisotropy is estimated to be less than one percent.

This apparent anisotropy leads us to the tentative conclusions that, first, at least several percent of cosmic rays in the energy range of the extensive air shower (10^{16}-10^{18} ev) are produced by heavy primaries, and second, that the maximum intensity is at right angles to the axis of the galactic arm or, probably, to the direction of more or less regular magnetic field of the galaxy.[8]

Although the conclusion is still of a temporary nature, it appears to encourage further discussions and investigations. We wish to emphasize the importance of investigations of this type at different latitudes in order to survey the part of the sky which is out of sight at our latitude. This kind of information would be crucial for the confirmation and the interpretation of the anisotropy.

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[1]Summarized in a report by A. M. Conforto, Proceedings of the International Conference on Cosmic Rays and the Earth Storm, Kyoto, Japan, September, 1961 [Suppl. J. Phys. Soc. Japan (to be published)], Part III.

[2]K. Greisen, Progress in Cosmic-Ray Physics, edited by J. G. Wilson (Interscience Publishers, Inc., New York, 1956), Vol. III.

[3]G. Clark, J. Earl, W. Kraushaar, J. Linsley, B. Rossi, F. Sherb, and D. Scott, Phys. Rev. 122, 637 (1961).

[4]J. Delvaille, F. Kendziorski, and K. Greisen, reference 1.

[5]S. Fukui, M. Hasegawa, T. Matano, I. Miura, M. Oda, K. Suga, G. Tanahashi, and Y. Tanaka, Suppl. Progr. Theoret. Phys. (Kyoto) No. 16, 1 (1960); H. Hasegawa, T. Matano, I. Miura, M. Oda, S. Shibata, G. Tanahashi, and Y. Tanaka, reference 1.

[6]S. Higashi, T. Kitamura, Y. Mishima, S. Miyamoto, T. Oshio, H. Shibata, and Y. Watase, reference 1.

[7]We might recall the work by Y. Sekido, S. Masuda, S. Yoshida, and M. Wada [Phys. Rev. 83, 658 (1951)], whose studies of the possible anisotropy of μ-meson flux very deep underground have also shown a similar feature.

[8]S. Hayakawa (private communication).

ISOTROPY OF COSMIC RADIATION*

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At a recent conference[1] several groups, including this one, reported indications of a possible anisotropy in the arrival directions of very energetic cosmic rays.[2-4] Our report was based mainly on data obtained at the MIT Volcano Ranch station in 1959-60, but also included data obtained by the Cornell group and by the MIT group at Agassiz. The apparent anisotropy, $(I_{max}-I_{min})/(I_{max}+I_{min})$, was about (25 ± 7)% for primary energies of the order of 5×10^{17} ev, and about (70 ± 30)% for energies of the order of 4×10^{18} ev. The minima were located in sidereal time between 12 hr and 18 hr, and between 18 hr and 24 hr, respectively. Another series of measurements was carried out at Volcano Ranch in 1960-61. However, events recorded in the second run were not included because analysis of data from that period has not been completed. Until that is done, we cannot make the usual plot showing the arrival directions of the individual showers in celestial coordinates. However, the apparent asymmetry shown by the 1959-60 data is strong enough so that, if the effect were real, we would expect to find a sidereal variation in counting rate during the second run. The 1960-61 data were obtained after the area of the array had been in-