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INTERNATIONAL CONFERENCE ON COSMIC RAYS AND THE EARTH STORM Part III

III-2-22. Energy Spectrum and Anisotropy of Air Shower (Tokyo Air Shower Project)

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In the following, experimental studies by Tokyo Air Shower Project on the energy spectrum, possible anisotropy of cosmic rays and possible existence of heavy primaries and gamma rays in the energy region of the EAS will be discussed referring to studies by other groups.

1) First, regarding the energy spectrum. The M.I.T. group reported the energy spectrum above 10^{16} ev up to 10^{19} ev which was expressed by a single power law of exponent about 2.2. Russian groups and Japanese groups reported the possible existence of a break in the energy spectrum, around several times 10^{15} ev.

2) Arrival direction of EAS has been generally believed to be isotropic.

3) Possible existence of heavy-primary-initiated EAS was suggested or presumed on various occasions, though there has been no experimental evidence.

The size spectrum was studied and an apparent break or the change of the exponent, γ_s, was observed. The size spectrum of those EAS which were considered to have started within 200 g/cm^2 from the top of the atmosphere was studied (γ_s'), in order to reduce the ambiguity of the relation between the size and the primary energy because of the fluctuation of the starting point of EAS in the atmosphere. Also, the spectrum of the total number of mu-mesons was considered to reflect the energy spectrum more directly than the size spectrum. The study of these spectra was reported in III-2-2 of the present Proceedings.

All of the above three spectra showed clear break or change of exponent within a decade of energy range corresponding to the size 10^5. The change of these exponents is tabulated in the following:

	small size N<3.10^5	large size N<5.10^5
γ_s	1.3±0.1	1.8±0.1
γ_s'	1.4±0.2	1.9±0.2
γ_μ	2.2±0.2	3.2±0.3

These breaks may either be caused by the break in the primary energy spectrum or reflect an abrupt change of the nature of EAS with respect to the primary energy. On these two possibilities, the former appears to be the case being supported by the following experimental results. The number of nuclear active particles with the energy $\geq 10^{11}$ ev and the total energy carried by these particles are proportional to the size of EAS without showing the break in the range of the size 10^4 to 10^6. Also the relation between the average number of mu-mesons and the size does not show a break. These smooth relations may mean that the energy partition between the electron-photon component, mu-meson component and the nuclear active component does not change radically over a wide range of the primary energy.

Thus, it is concluded that the energy spectrum of cosmic rays has a break or changes its exponent within a decade or, in other words, the energy spectrum of cosmic rays shows the different nature below and above the energy range around a few times 10^{15} ev. We may relate this change of spectrum to either the change of source of cosmic rays or the change of the nature of propagation, or the change of the life time of cosmic rays in the Galaxy with the energy. Of course, also the change of composition of primaries may be deeply related to this problem.

In this connection I should review the report by Prof. Zatsepin in this session III-2-7. Suppose that only heavy nuclei are accelerated and protons are produced as the result of fragmentation, and that for the given total energy, heavier nuclei are stored in the Galaxy for a longer time than lighter nuclei. It is expected that the fluctuation of the nature of the air shower are considerably reduced for heavy-primary-initiated EAS, simply because they are essentially the superposition of many showers and the fluctuation is to be well averaged. Observations by Russian groups seem to show the decrease of the fluctuation as the size N increases and the argument relating this observation to predominant existence of heavy primaries was presented by Zatsepin.

Coming to the other subject, I shall summarize the work of the Tokyo Air Shower Project and the Undergound Group of Osaka City University regarding the following questions:

1) Is an appreciable part of AS produced by heavy primaries?

2) Is an appreciable part of AS also produced by gamma rays?

3) If heavy-primary or gamma-primary-initiated EAS are selected, are their arrival directions still isotropic?

Studies were reported in III-2-3 and III-2-4. As the conclusion of these studies:

1) The existence of heavy-primary-initiated EAS is tentatively concluded. Its frequency relative to all EAS with the size of 10^7 is a few percents.

2) The arrival direction of these EAS appears to be concentrated in a region 0^h-12^h or 0^0-180^0 of right ascension, which corresponds to the region of the sky perpendicular to the Orion arm of the Galaxy.

The implication of these conclusions, being combined with the results by M.I.T. group and Cornell University has been discussed in the session of Origin, in relation to the structure of Galactic arm.

Discussion

Yamaguchi, Y.: I want to know more precise criteria on "μ rich" and "μ less".

Miura, I.: "μ rich" showers are those whose content of μ is more than 80% of the maximum content for a certain size of the shower. "μ less" means that the content is less than one thirtieth of the average.

Kaplon, M. F.: Couldn't the μ poor showers be a result of fluctuations on both the primary interaction and the depth of the interaction?

Miura: It is quite probable and, therefore, I do not want to put too much emphasis in the part of the "μ less".

Powell, C.F.: I would like to remark that we must be cautious in drawing conclusions about the primary spectrum from that observed for the penerating component or the γ rays, because the interpretation depends upon assumptions about the physical process ocurring in the atmosphere. We should be discussing this question in later Jet sessions, but I may say that there are reasons to believe that there is a satisfactory consistency between the γ ray spectrum in the atmosphere and the μ meson spectrum; and that we can account for many features of the spectra. I would like to emphasize that there is a most intimate and important connection between the detailed studies of the characteristics of nucleon disintegrations and the interpretation of experiments in extensive air showers.

Nishimura, J.: A comment on the change of the exponent of the primary particles. We have exposed a large emulsion chamber, about 10 m^2, at Mt. Norikura about one year, and have got many examples of high energy nuclear events. The exponent of the energy spectrum obtained is 2.3 ± 0.3 around 10^{14} ev. This energy corresponds to $>10^{15}$ ev at the high altitude of the atmosphere. Thus our result is consistent with your steep spectrum in this energy region.

Pinkau, K.: The $n_\mu-N$ diagram might possibly be explained by the fact that high energy EAS are recorded just only at their maximum development, where N is large, since otherwise they would be recorded with low values of N and be observed by the much more numerous EAS of smaller energy. On the other hand, EAS of small energy are recorded both before and after maximum development due to fluctuation on point of origin, so we expect, even on proton primaries, quite naturally, larger fluctuation for smaller EAS. This has a bearing on the slope of the energy spectrum, since low energy points have been rejected (perhaps unjustified) due to n_μ, while more high energy points will have been kept in the spectrum (due to smaller fluctuation in n_μ). Thus the spectrum might be steeper than presented here.

Shapiro, M.M.: Regarding the steepening of the spectrum at energy $>10^{15}$ ev, is there any strong argument against the following interpretation: at progressively higher energies, it becomes progressively easier for particles generated inside the Galaxy to escape, and thus produce a relative deficiency of primary particles at the highest energies?

Oda, M.: That is exactly what we are inclined to think.

Greisen: This is not so much a question as a challenge. It seems to me that cosmic ray physicists have too much predilection for showing data on *log-log* graph paper and then drawing straight lines. With crude data one line is enough, and a power law is deduced. If the data are a little better one always needs two lines and then one deduces a "break" in the spectrum. At lower cosmic ray energies, the same procedure is usually followed and the slope of the line is about 1.0. When the study concerns air showers, the small showers demand a slope of 1.5–1.9 while the largest showers suggest a slope of 2.0–2.5 (in the integral energy spectrum). I claim that the "sudden breaks" which have been discussed so much may be imposed on the data by resolving power of the apparatus and the method of analysis. Would it not be more realistic, and a better fit, to represent the whole energy spectrum not by straight-line segments, but by a smooth curve of slowly increasing slope? No abrupt changes in primary spectrum, nature of interaction, or composition of the primaries would then have to be assumed.

Oda: We do not necessarily say "the sudden break". But I still think that this is not a continuous change of the exponent but that, above 10^6 of the size, the spectrum is well expressed by a single power law and below 10^5 the exponent is quite different. There is a change, probably not a sudden, within not too wide range of the size.

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III-2-23. Bolivian Air Shower Joint Experiment

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The contents of this article are similar to III-2-15 and the separate manuscript was not presented.