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III-4-32. Development of EAS in the Atmosphere

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I would like to speak, here, about the development of air showers from the results which are mainly obtained by Dr. Kamata's group, Tata Institute in India and our group at Mt. Norikura. The summary of the results which have been presented in ordinary session is as follows;

Dr. Kamata has given his result, firstly about the direct measurement of zenith angular distribution at 8500 m for AS of $20/m^2$ in density, and he concludes that the altitude of the maximum counting rate for vertical AS of 10^5 size is about 5000-5500 m a. s. l. I think, using the analysis for fluctuation of starting point, that the altitude of shower maximum for such AS is estimated about 7000 m a.s.l. Secondly, he has given lateral density distribution at 7000 m as $r^{-1.0}-r^{-1.5}$ that is almost simillar to that at deeper atmosphere.

Tata Institute has given following results;

(1) The observed densities of mu-meson and also low energy N-component, fixing the size and the distance from axis, show large fluctuation.

(2) There is clear positive correlation between the fluctuations of densities of mu-meson and N-component. The result may be understood as a following scheme that low energy N-component and mu-mesons are proportional to the integrated number of high energy N-component at N-cascade maximum but electrons at observing altitude fluctuate by nearest N-interaction due to survival of high energy nucleons which have considerable energy compared to the primary. Our result that the steepness of lateral structure of electrons has positive correlation to high energy N and negative to low energy N-component, also supports above scheme.

(3) A large fluctuation in lateral structure and the tendency that average steepness increases with the size of AS were shown.

(4) The character of core at lower size is changing below about 10^5 in size. From the rates observed at mountain altitude and sea level, the change is due to character of high energy nuclear interaction.

The results of Norikura observation are as follows;

(1) There is a large fluctuation in lateral density distribution near axis due to nearest high energy nuclear interaction and multi-core structure. At distant range also there is similar variation but amplitude is less. About 5% of observed showers can not be expressed by using unique age parameter.

(2) Absorption length of rate has been obtained as about $100\ g/cm^2$. It varies depending on lateral density distribution, from 125 to $94\ g/cm^2$. The minimum value of $94\ g/cm^2$ which corresponds to steep lateral distribution group will be effective interaction mean free path for high energy nucleon.

(3) Apparent attenuation length for size, using size spectrum for different zenith angle, has been obtained as 140, 170 and $200\ g/cm^2$ for the rate 10^{-11}, 10^{-12} and $10^{-13}/sec\ cm^2$ sterad. These correspond to the maximum estimation of mean attenuation length.

(4) Energy spectrum of N-component has been obtained as $E^{-1.3}$ and the total number of N-component increases with size as $N^{0.6}$. From the former, assuming equilibrium state between N-component and electrons, attenuation length is estimated as about $150\ g/cm^2$, and from the later, one can estimate that the effect of electron photon component which is produced in earlier stage of shower development is becoming important with the size.

(5) Using the energy flow detector, we found the characteristic change at about 10^5

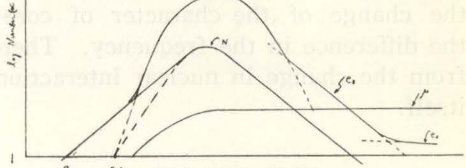

Fig. 1.

in size. Below this size, energy flow near the axis is subject to wide fluctuation. It will be due to the fluctuation of starting point of AS that is expected to be important when the attenuation length is smaller than the product of exponent of size spectrum and interaction mean free path.

Finally, I want to speak qualitatively about one of the possible image for the development of EAS in the atmosphere which is shown in Fig. 1. In the figure, electron component is classified into three parts, namely, e_1 shows effect of earlier stage of N-cascade (with large fluctuation at smaller size) e_2 is a semi-equilibrium state between electron and N-components and e_3 is accompanied electrons by mu-mesons. It is very difficult to discuss about the showers below size 10^5 because of large fluctuation, but for the region 10^5 to 10^6, there are evidences which support that we are observing the state e_2, for example, the fact that the ratio of total number of N-component to size is nearly equal to that of cosmic radiation unassociated with AS (without mu-meson effect) and the fact that attenuation lengths estimated from energy spectrum of N-component, and from apparent attenuation length and also from the relation between energy dissipation and mean energy of electrons, are consistent with each other. Above 10^6, because of slow increase of N-component with the size, the situation may be thought to be in e_1 naturally. However, one question is open to discuss, about the inconsistency between apparent attenuation length which becomes longer with size and estimated attenuation length from energy relation which seems to remain almost constant. For this problem, I have put one possibility, in the figure, at the starting point of EAS, assuming the slow start of development by heavy nucleon components only, up to certain energy.

To avoid confusion, the relation between various relations are as follows;

L_{in}; interaction mean free path

L_{ef}; effective interaction mean free path to start EAS

λ_{ob}; absorption length of rate of EAS

λ_{ap}; apparent attenuation length of size $(=\gamma\lambda_{ob})$

λ_e; attenuation length of size

λ_n; attenuation length of N-particles

$$L_{in} < L_{ef} < \lambda_{ob} < \lambda_{ap}$$

70 95 100 140–200 g/cm² (depend on size)

$\sim 50\ \mathrm{g/cm^2} < \lambda_e < \lambda_{ap}$ in e_1 state

$\lambda_e = \lambda_n$ in e_2 state

$\lambda_n \geq 130\ \mathrm{g/cm^2}$ ($\approx 150\ \mathrm{g/cm^2}$) minimum corresponds to the energy spectrum of exponent -1.5.

Discussion

Peters, B.: In a paper given at the Moscow Conference I had shown that if a break in the primary spectrum occurs and if this change is a function of magnetic rigidity, then there must be a region in the primary energy spectrum (extending over more than a decade) in which the nature of the primary particles changes, the average mass of the primary is increasing and becomes roughly proportional to the energy which it carries.

When you state that your observations rule out a change in the primary energy spectrum but require a change in the nature of nuclear interaction of primaries above a certain energy, how can you distinguish between an effect produced by a change in the character of the nuclear interactions and an effect produced by an increase in the mass of the primary producing the interaction?

Miyake, S.: We have observed at sea level and Mountain altitude and found that the change of the character of core of EAS occurs at nearly the same size except the difference in the frequency. Therefore, we may conclude that this change comes from the change in nuclear interaction or at least from the change in EAS phenomena itself.