ESTIMATION OF COMPOSITION OF COSMIC RAYS WITH $E_0 \approx 10^{17} - 10^{18}$ eV

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ABSTRACT

Fluctuations of the shower maximum depth obtained from analysis of electron and muon fluctuations and the EAS Cerenkov light on the Yakutsk array data and data of other arrays are considered. On the basis of these data the estimation of composition of primaries with $E_0 = 5 \cdot 10^{17}$ eV is receive. Estimation of γ-quanta flux with $E_0 \geqslant 10^{17}$eV is given on the poor-muon showers.

1. Introduction. In [1] the elongation rate theorem for any parameters $P = P(X_m)$ registered at observation level X was obtained:

$$ER = (\partial P/\partial \lg E_0)_X/(\partial P/\partial X)_{E_0}, \qquad (1)$$

$$ER = (X_m/X)(\partial P/\partial \lg E_0)_X/(\partial P/\partial X)_{E_0} \qquad (2)$$

From here it follows:

$$\sigma(X_m) = (\sigma P)_X/(\partial P/\partial X)_{E_0}, \qquad (3)$$

$$\sigma(X_m) = (X_m/X)(\sigma P)_X/(\partial P/\partial X)_{E_0} \qquad (4)$$

Formulae (1) and (3) are used when $P = P(X - X_m)$, (2) and (4) - for parameters $P = P(X_m/X)$.

2. Experimantal $\sigma(X_m)$ and ER. When estimating ER and $\sigma(X_m)$ from the lateral distribution function (LDF) of the EAS Cerenkov light it is necessary to use (1) and (3) [2]. Let's introduce the LDF for R = 200-600 m as $Q \sim R^{-n_Q}$. According to our data we obtain $(\partial n_Q/\partial \sec\theta)_{E_0} = 1.9 \pm 0.3$; $(\partial n_Q/\partial \lg E_0)_X = 0.13 \pm 0.02$ and $\sigma(n_Q)_X = 0.123 \pm 0.018$. Corresponding to them the meanings ER and $\sigma(X_m)$ are given in the Table.

Formulae (2) and (4) are used in the case of LDF of charged particles. At the Yakutsk array the LDF approximation as $\rho(R) \sim (R/70)^{-1}(1+R/70)^{-b}$ is accepted: $(\partial b/\partial \lg E_0)_X = 0.16 \pm 0.05$; $(\partial b/\partial \sec\theta)_{E_0} = 1.8 \pm 0.4$; $\sigma(b)_X = 0.2 \pm 0.02$. On data [3] for $E_0 = 5 \cdot 10^{17}$ eV the $X_m = 680$ g/cm^2. Obtained results are given in the Table.

Analogous estimations of ER and $\sigma(X_m)$ follow from analysis of ratios of the EAS Cerenkov light density to electrons $\lg(Q/\rho_e)$ and electrons to muons with $E_\mu \geqslant 1$ GeV $\lg(\rho_e/\rho_\mu)$ measured at R = 300 m from a shower core (Table).

Table

Parameter	ER	$\sigma(X_m)$	Work
n_Q	70±17	66±18	our
b	61±28	78±30	-"-
$\lg(Q/\rho_e)$	64±17	60±20	-"-
$\lg(\rho_e/\rho_\mu)$	70±22	71±30	-"-
$\lg(\rho_\mu/\rho_e)$	79±18	60±16	[4]
$T_{70}(\mu)$	73±23	78±22	[4]
LDF(ρ_c)	79±14	71±6	[5]
$\tau_{1/2}(\rho_c)$	70±5	60±4	[5]
$\tau_{1/2}(Q)$	45±17	60±12	[6]
LDF(Q)	-	69±14	[7]
Average	68±6	68±6	

3. Estimations of Composition. To estimate the composition of primaries we use average $\langle ER \rangle$ and $\langle \sigma(X_m) \rangle$ from the Table. In [8] it is shown that based upon superposition principle for any mixed composition $\langle \ln A \rangle = \sum w_i \ln A_i$ and for dispersion $\sigma^2_{\ln A} = \sum w_i (\ln A_i - \langle \ln A \rangle)^2$ we have:

$$\sigma^2(X_m) = \sigma^2_{\langle \ln A \rangle} + (K^2 \sigma_p^2 + C^2)\,\sigma^2_{\ln A}, \qquad (5)$$

where σ_p and $\sigma_{\ln A}$ are fluctuations of X_m at proton or any other pure composition with atomic number $\langle \ln A \rangle$:

$$\sigma_{\langle \ln A \rangle} = \sigma_p (1 - K \langle \ln A \rangle).$$

We accepted K = 0.15, C = 0.43 $\langle ER \rangle = 29 \pm 4$ g/cm^2, $\sigma_p = 56$ and 71 g/cm^2. Calculation results are shown in Fig.1. The region limited by dashed lines corresponds to experimental values $\langle \sigma(X_m) \rangle = 68 \pm 8$ g/cm^2.

It is seen that the experiment contradict the composition of the primaries at $E_0 = 5 \cdot 10^{17}$ eV only from heavy nuclei or the mixed composition with large

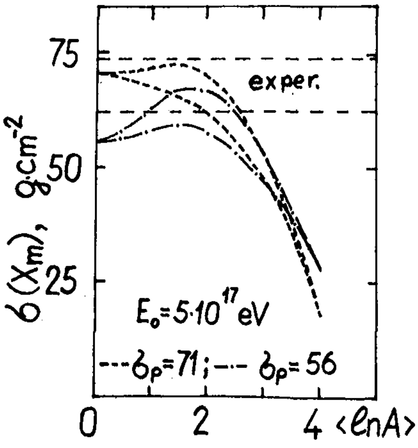

Fig.1

content of heavy nuclei.

In Fig.2 experimental fluctuations of muon number $N_\mu(\geqslant 1$ GeV) taken into account of instrumental errors are shown. The calculations on the models [3] for our experiment are shown by lines. The mixed composition of primaries included: 31% - A=1, 22% - A=4, 12% - A=14, 21% A=31 and 14% - A=51 ($\langle \ln A \rangle = 1.88$). The cross section of inelastic processes were used as in [9]. Fluctuations of X_m in showers from primary nuclei were found according to the superposition principle. Experimental meanings of X_m are taken from [3].

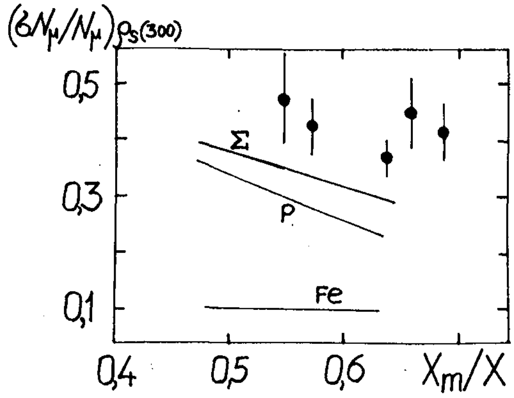

Fig.2.

As before the experiment contradicts the composition only from the heavy nuclei but the expected fluctuations at mixed composition are smaller than the measured ones. Agreement at mixed composition will be if to account cross section growth 1.5 times slower than it is in [9].

4. γ-quanta. In [10] experimental results of the muon component measured at the Yakutsk array by 3 underground scintillation detectors with total area 108 m^2 and with 1 GeV threshold are presented. Each detector consists from 6 sections with the area 6 m^2 each. 1000 showers with $\theta \leqslant 45°$ and effective registration area $3{,}7 \cdot 10^5$ m^2 for 14000 hours were selected.

The whole massif of the showers for anomalously small content of muons is analyzed. In Fig.3 one event which has the measured muon number 12 times lesser than the expected one (4,6σ deviation) is shown. Such a deviation cannot be explained by any fluctuations of the shower maximum depth and by Poisson fluctuations of the detector recordings. Therefore this shower is considered to be formed by a primary γ-quantum. If to estimate a total flux of γ-quanta with $E_0 \geqslant 10^{17}$ eV on one event for all the above registration period then their intensity is $2{,}9 \cdot 10^{-14}$ $m^{-2} \cdot s^{-1} \cdot sr^{-1}$, i.e. $\sim 10^{-3}$ from total flux of the primaries with $E_0 \geqslant 10^{17}$ eV. Its arrival direction is in the plane of the Galaxy with coordinates: $b^{II} = -8°$ and ~~longitude~~ $\ell^{II} = 153°$.

5. Conclusions Experimantal data on fluctuations of the shower maximum depth and on muon number $N_\mu(E_\mu \geqslant 1$ GeV) at $E_0 \approx 10^{17} - 10^{18}$ eV contradict to the composition only of heavy nuclei. The most clise to the experiment in this energy

range is the mixed composition which contains not less than 40% of protons ($\langle \ln A \rangle \approx 1,5+0,5$). The only proton composition is though unlikely but it is still impossible to exclude it. The γ-quanta flux is $\sim 10^{-3}$ from the total flux of the primaries at $E_o \geqslant 10^{17}$ eV.

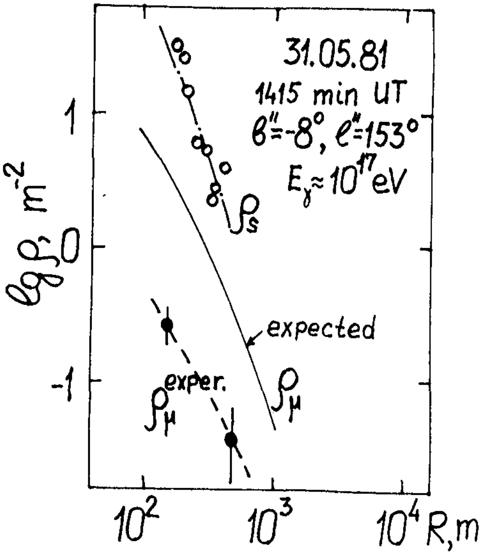

Fig.3.

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