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Do protons and α - particles vanish from primary cosmic rays at $E_0 > 10^{15}$ eV?

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Abstract: Gamma-families were sampled for the Pamirs altitude (600 g/cm^2) by MC0 model with some versions of PCR energy spectra and composition and in particular with those proposed by KASCADE [1]. Comparison of the calculated and "Pamir" experimental data confirm our previous conclusion that fraction of protons and α-particles does not vanish at 10^{16} eV in contrast to conclusion of collaboration KASCADE.

Introduction

Composition of primary cosmic rays (PCR) at an energy $E_0 > 10^{15}$ eV and in particular fraction of the lightest nuclei (protons and α-particles) - is an essential astrophysical characteristic, especially for the problem of the well-known knee in the PCR energy spectrum. Direct measurements at this energy are impossible, and all conclusions are based on observation of extensive air showers (EAS) and appropriate realistic model calculations. But the conclusions of different research teams sometimes are essentially different and contradictory. Thus collaboration KASCADE [1] and Tibet group [2] by comparison of experimental data on EAS with simulations on the base of QGSJet model and similar Cosmos model, correspondingly, made a conclusion that at $E_0 = 10^{15} - 10^{17}$ eV a fraction of protons and α-particles becomes vanishingly small. But this conclusion is in contradiction with results of the Experiment "Pamir" obtained with X-ray emulsion chambers (XREC). Our earlier analysis [3] of γ-families with total energy release in the XREC $\Sigma E_\gamma \geq 500$ TeV accompanied by halo gave an evidence that the fraction of protons and α-particles is not less than 20-30% at $E_0 = 10^{16}$ eV. The analysis was based on comparison of experimental data with simulations by MC0 version of quark-gluon-string model [4], developed in the Experiment "Pamir", which satisfactorily reproduce the main features of γ -families with $\Sigma E_\gamma = 100 - 400$ TeV. Later on we extended our analysis to γ-families with $\Sigma E_\gamma \geq 100$ TeV [5, 6] and analyzed ΣE_γ spectrum for γ-families with $\Sigma E_\gamma = 100 - 500$ TeV under different assumptions on the PCR energy spectrum. In this work we continue the analysis with use some KASCADE experimental data just because the contradiction between KASCADE and "Pamir" is the principal point of this paper.

Experimental data

We analyzed γ - families recorded in thin (6 cm of Pb) XREC at the Pamirs (4370 m a.s.l. or 600 g/cm^2). Densitometry measurements were made mainly at the depth of 5 cm of Pb, or 9-11 c.u. (with account for cascade incidence angle). The γ - families were selected by criteria: $\Sigma E_\gamma \geq 100$ TeV, $E_\gamma \geq 4$ TeV, $n_\gamma \geq 3$, $R_\gamma \leq 15$ cm. The total number of events $N_f = 1300$ from total exposure ~ 4000 m^{2}year. The mutual interference of neighboring cascades was properly taken into account.

Model sampling

Model sampling of γ-families ΣE_γ spectra was performed by MC0 code for $E_0 = 2 \cdot 10^{14} - 2 \cdot 10^{18}$ eV. The calculations were made under four assumptions of the PCR integral energy spectrum: (a) exponent of the spectrum $\gamma = 1.65$ at $E_0 = 2 \cdot 10^{14} - 2 \cdot 10^{18}$ eV, this implies that PCR mass composition remains constant in abovesaid range of PCR energies; (b) exponent γ increases by $\Delta\gamma = 0.4$ for all nuclei, beginning from $E_0 = 3 \cdot 10^{15} \cdot Z$ eV (Z is atomic number), this implies that mass composition becomes gradually enriched with heavy nuclei; (c) exponent γ increases by $\Delta\gamma = 2.0$ for protons and α - particles only at $E_0 = 3 \cdot 10^{15}$ eV and $6 \cdot 10^{15}$ eV, respectively, while for other nuclei $\Delta\gamma = 0.4$ as in case (b). This version of calculation implies that at $E_0 \sim 10^{16}$ eV protons and α-particles in the PCR composition virtually vanish. (d) the PCR spectra are taken from KASCADE data [7] and properly approximated (Fig.1).

Results

Fig. 2 presents experimental and calculated ΣE_γ spectra of γ -families. As is seen, experimental data at $E_0 = 10^{15} - 10^{18}$ eV are in good agreement with calculations under above assumptions (a) and (b), while contradict assumptions (c) and (d). In the variant (d) primary spectra proposed by KASCADE were applied. The calculated ΣE_γ spectra are well approximated by power law with exponents listed in Table 1. Thus the best fit to the experimental data is attained under assumption that PCR mass composition in energy range $E_0 = 10^{15} - 10^{18}$ eV becomes slowly enriched with heavy nuclei. Table 2 presents relative numbers of γ-families with $\Sigma E_\gamma \geq 100$ TeV for different PCR nuclei. As is seen for any version of PCR energy spectrum the predominant fractions of γ - families (80-90%) are produced by protons and α-particles.

Conclusion

We confirm our previous conclusion that fraction of protons and α-particles at $E_0 \geq 10^{16}$ eV is appreciable in contrast to conclusion of collaboration KASCADE. Let us note that in any case the disappearance of protons and α-particles in PCR composition at $E_0 \geq 10^{16}$ would result in decreased number of γ -families with large $\Sigma E\gamma$ and lead to

Table 1:

	PAMIR	a	b	c	d
γ	1.32 $\pm$0.05	1.13 $\pm$0.02	1.30 $\pm$0.03	1.70 $\pm$0.03	1.72 $\pm$0.03

Table 2:

	a	b	c	d
P,%	80.3	80.1	69.8	54.6
He,%	12.6	11.7	9.1	32.8
C,%	3.2	3.0	7.9	8.7
Si+Fe,%	3.2	5.2	13.2	3.9

steepening ΣE_γ spectra which contradict data of the Experiment "Pamir".

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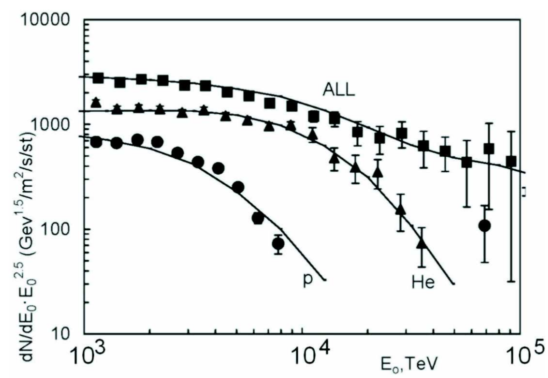

Figure 1: PCR spectra by KASCADE. Dots are experimental data, solid lines present their approximation used for model sampling in this paper.

References

[1] H.Ulrich et al. Proc.29th ICRC, Pune (2005), 6,129-132.

[2] M.Amenomori et al. Proc.28th ICRC (2003), HE 1, 107-110.

[3] A.S.Borisov et al. *Nucl.Phys.B* (Proc. Suppl.) 75A, (1999),159-161.

[4] G.F. Fedorova and R.A. Mukhamedshin. *Bull. Soc. Sci. Lettr.* Lodz, Ser. Rech. Def. V. XVI, p. 137 (1994).

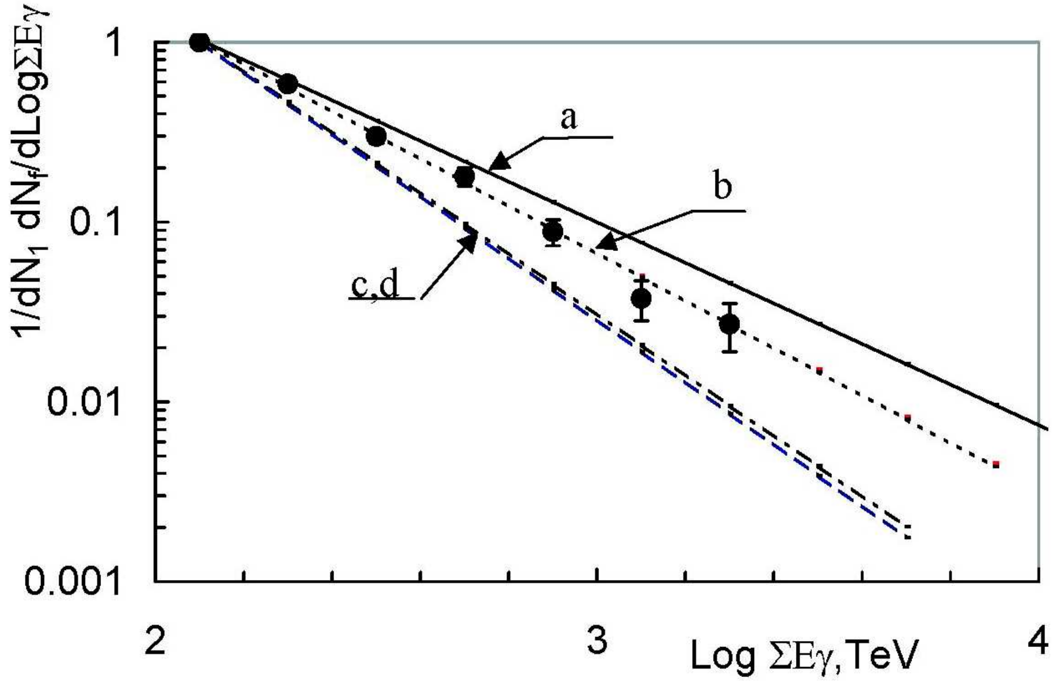

Figure 2: Spectra of energy ΣE_γ. Dots are "Pamir" experimental data, solid lines present model sampling for four versions of the PCR spectra. See Table 2.

[5] A.S.Borisov et al. *Nucl.Phys.B* (Proc. Suppl.) 151 (2006) 236-239.

[6] A.S. Borisov et al. Proc. 29th ICRC, Pune (2005), 6, 365-368.

[7] Haungs A. *Nucl. Phys. B* (Proc. Suppl.), 2006. V. 151. P. 167-174.