

Extensive air showers of ultrahigh energy without muon component

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Abstract. Extensive air showers of cosmic rays ultrahigh energy without muon component registered by the Yakutsk array have been analyzed. Among them we found clusters and some clusters correlate with point sources of the Galaxy. The problem cosmic rays are discussed.

Keywords: showers, muons, sources

I. INTRODUCTION

We have analyzed the muon content in extensive air showers (EASs) detected at the Yakutsk array with energies $E > 5 \times 10^{18}$ eV, zenith angles smaller than 60° , and axes lying within the array perimeter. The accuracy of determining the arrival angle and energy of a shower is equal to $5-7^\circ$ and 30%, respectively. In this paper data 1987-2008 years are considered.

II. RESULTS AND DISCUSSION

Earlier we considered EAS without muons [1], [2] and etc. In [2] we showed that ultrahigh-energy showers can be conventionally classified 4 classes in terms of the muon content:

- 1) showers with usual muon content - $\sim 97\%$,
- 2) showers pour in muons - $\sim 1\%$,
- 2) showers without muons ($E > 1$ GeV) - $\sim 1\%$,
- 3) showers with high muon content - $\sim < 1\%$.

Showers with high muon content are observed only for the highest energies. This fact can be important for determining the composition and origin of cosmic rays with extremely high energies.

The detection time of EASs observed at the Yakutsk array was separated into 6-h time intervals. The time intervals when the muon detectors did not operate were excluded from the analysis. First, we selected showers without muon component, i.e., showers for which the readings of the muon detectors were absent (equal to zero) within the limits of the detection threshold, which was equal to 1 GeV. For a zero reading of muon detectors, the probability that this muon detector does not trigger for the expected particle number N is estimated as $P = \prod (P_{1i} + P_{2i})$, where P_{1i} is the probability that no muon reaches the i th detector and P_{2i} is the probability that one particle reaches the detector but it does not trigger. At $P > 10^{-3}$, this shower was excluded from consideration.

Each detection of a shower without the muon component was carefully checked. When a shower without muons was selected we demanded that for 30 min before and after this muon detector detected muons from another showers (see in detail [1]).

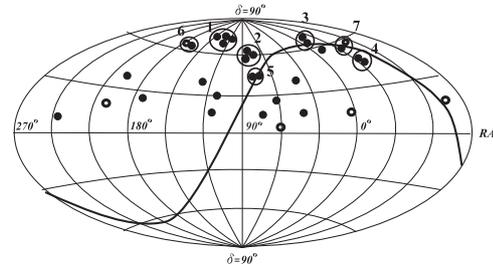


Fig. 1: Distribution of showers without muons (black circles) and pour in muon (open circles) in the equatorial coordinates, declination and right ascension, RA. Large circles denote clusters 1-7.

We found 26 showers without muon component and 6 showers for which the muon density at distances larger than 100 m was more than 3σ lower than the average expected value.

In Fig. 1 shows the distribution of showers with without muons (black circles) and 6 showers pour in muons in the equatorial coordinates (δ is declination and RA is right ascension) is shown. The distribution showers without muons and showers pour in muons (open circles) over the celestial sphere most likely is isotropic.

We observe clusters: one cluster with 4 showers, triplet and 5 doublets (see also table 1). The arrival directions of all 4 EASs of the 1-st cluster are within an angular range of 9° around the PSR 0809+74 pulsar [3], which is located at a distance of 0.3 kpc from the Earth. Probability of that arrival directions of 4 showers from 26 are within the $< 9^\circ$ from pulsar PSR 0809+74 is equal $P \sim 10^{-3}$. The method of determination of probability is in detail given in [4]. The arrival directions EASs of triplet are within angular range of 7.6° from pulsar PSR 0450+55. The arrival directions EASs of doublets 3,4,5 are within angle 9° from pulsars PSR 2217+47, 2241+69, 0458+46 pulsars, respectively which are located at a distance of less than 2.4 kpc). Near EASs of doublet 6 are not pulsars. EASs of doublets 6,7 consist of showers without and pour muons. Arrival directions EASs of doublet 7 are located $< 2.6^\circ$ from pulsar 2045+56.

As it is seen from the table 1, the pulsars are located at an angular distance of less than $\sim 1.5\sigma$ from the arrival directions of the showers of the clusters (where σ is the accuracy of the determination of the shower arrival angle).

Earlier we found out correlation of directions of

TABLE I: The arrival date of showers without the muon component which composing clusters and the pulsars correlated with them.

cluster	Date	E, EeV	δ	RA	Pulsar	D, kpc	log T, year
1	27.01.1992	13.3	70.0	148.3	0809+74	0.3	8.1
1	08.03.1994	47.4	74.0	92.5			
1	08.12.1994	21.3	76.5	123.1			
1	10.05.2001	7.1	70.0	136.2			
2	25.04.1996	8.6	60.2	81.7	0450+55	0.7	6.3
2	26.03.1998	8.3	57.6	85.4			
2	04 05 1998	6.7	60.4	66.			
3	17.11.2000	5.7	51.4	322.4	2217+47	2.4	6.5
3	13.01.2002	7.7	44.3	326.7			
4	13.03.1992	8.7	69.8	334.7	2241+69	2.3	6.7
4	30.05.1996	5.0	65.8	322.9			
5	14.04.1999	6.7	42.9	72.5	0458+46	1.7	6.2
5	04.04.2006	5.0	41.2	79.4			
6	24.04.1991	14.8	64.1	175.7	< 14°		
6	29.12.1998	7.1	66.4	172.2	no pulsars		
7	18.11.1996	8.6	57.3	312.6	2045+56	8.5	5.8
7	29.01.2003	7.8	58.6	311.9			

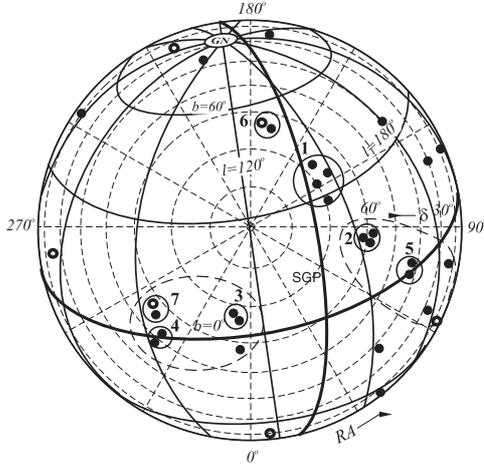


Fig. 2: Distribution of showers without on equalexposition map. The designation is the same as in Fig.1. Large dashed curves - maximum of distribution of particles.

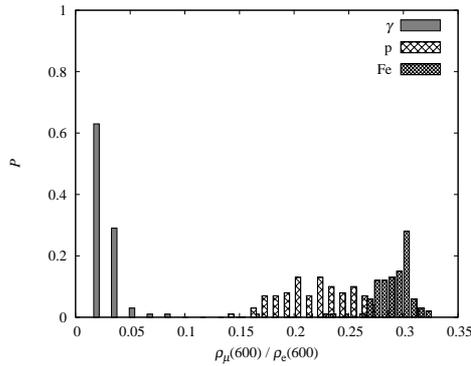


Fig. 3: A normalized histogram representing the distribution of a muon portion at core distance $R=600$ m for three different primaries. Zenith angle of primary particle $\theta = 30^\circ$. P - a portion of simulated events.

arrival of showers with the usual muon content at energy $E \sim 10^{19}$ eV with a site of pulsars which are

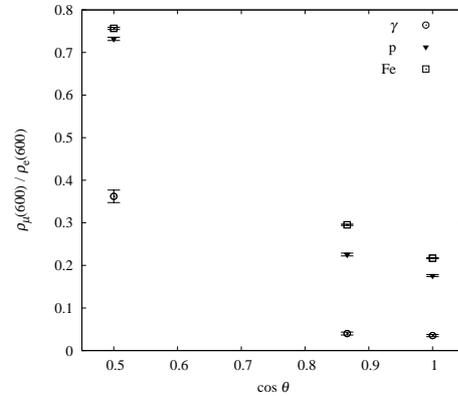


Fig. 4: Zenith-angular dependence of a muon portion at core distance $R = 600$ m for three primaries with energy.

located along magnetic force lines of the Local Arm of the Galaxy [5]. Here arrival directions of 18 EAS without muons from 26 is located within 7° (angle of accuracy of determination of arrival direction EAS) from coordinates of pulsars [3]. Chance probability such location is $P \sim 5 \times 10^{-3}$. If we decrease considered angle twice then 11 EAS without muons are located $< 3.5^\circ$. Chance probability such location 11 EAS from 26 EAS is $P \sim 3 \times 10^{-3}$. Thus we observe some a correlation arrival directions EAS with pulsars. Note that arrival directions EAS without muons correlate with pulsars irrespectively of their arrangement concerning force lines of a magnetic field of the Local Arm. Detection of correlation arrival directions of usual showers with pulsars along magnetic force lines and showers without muons with pulsars irrespectively of their arrangement to testify that most likely sources of ultrahigh-energy cosmic rays are pulsars.

Fig.2 presents the distribution particles on the map of equal exposition of celestial sphere. At the map of equal exposition the equal number of particles from the equal parts of sphere is expected. On this map it is observed 2

maximum in distribution particles: at $b \sim 0^\circ, l \sim 105^\circ$ and $b \sim 0^\circ, l \sim 170^\circ$. Possible first maximum connected with Input Local Arm Orion of Galaxy, where from it was found anisotropy of usual cosmic rays at energy $E \sim (10^{18} - 10^{19})$ eV [5], [6]. Also distribution particles has a maximum from site a galactic a plane (Fig.1, 2): $n(|b| < 30^\circ)/n(|b| > 30^\circ) = 1.7 \pm 0.6$ instead 1.2 in the case of isotropy of cosmic rays [4].

Garmonic analysis shows that 1-st amplitude A_1 and phase RA of garmonics of Fourier series are $A_1 = 0.61 \pm 0.25$, $RA = 69^\circ$ from side of a galactic plane.

It is shown [7], that muon content of showers reflects mass composition of the particles which have formed EAS. Probably, showers with the usual muon content are formed by the charged particles, showers without and pour muons - neutral particles, and showers with high muon content - more heavy particles.

Below we calculated by CORSIKA programm muon content of EAS from a primary particles at energy $E > 4 \times 10^{19}$ eV: gamma particles, protons, iron nuclei (for a lower energy we are planning to calculate later). 100 showers were simulated for each primary at tree fixed values of zenith angle using CORSIKA [8] code (version 6.900) with QGSjet [9] hadronic generator. UrQMD [10], [11] model was used as low energy hadron model. His calculations show that EAS without muons can be originated by gamma particles.

III. CONCLUSION

It is found 32 showers without and pour muon component. About half of them form clusters, which correlate with nearest pulsars. It is not exclude that showers without and pour muon components are form by the neutral particles.

IV. ACKNOWLEDGEMENTS

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