Arrival Directions of Ultrahigh Energy Showers

V.A. KOLOSOV, A.A. MIKHAILOV
Yu.G. Shafer Institute of Cosmophysical Research and Aeronomy of SB RAS, Yakutsk, Russia
mikhailov@ikfia.ysn.ru

Abstract: Arrival directions of ultrahigh energy extensive air showers (EAS) by world arrays data are analyzed. It is shown that arrival directions of ultrahigh energy EAS are correlated with pulsars of Local Arm Orion of Galaxy. The problem of cosmic rays origin is discussed.

Keywords: cosmic rays, ultrahigh energy, origin, pulsar, array, extensive air shower.

Introduction

We have analyzed extensive air showers (EAS) by data of Yakutsk, P. Auger, AGASA EAS arrays with energy $E>4 \times 10^{19}$ eV. We consider in a case of Yakutsk data array 2 variants: 1) an arrival directions of EAS with usual content of muon particles, 2) an arrival directions of EAS with deficit content of muon particles.

We have analyzed the Yakutsk EAS array data whose shower core lie inside the array perimeter and accuracy of arrival angle determination is ~ 3º. The particle energy is estimated with the accuracy ~30%. Three showers have energy $E>10^{20}$ eV. The particle energy by data P. Auger is determined with the accuracy ~22%, the solid angle - ~1º [1]. The particle energy by data AGASA is determined with the accuracy ~25%, the solid angle - ~1.6º [2].

We do not analyzed EAS of data HiRes array [3] because this array operate only during dark time of day and without detailed knowledge of registration EAS it is impossible to define exposition from separate parts of celestial sphere to array.

1. Experimental Data

Fig.1 presents the distribution of 34 particles by Yakutsk array data with the energy $E>4 \times 10^{19}$ eV on the map of equal exposition of the celestial sphere for the period of 1974-2009 (the method to construct this map is based on the estimation of the expected number of showers in the celestial sphere [4]). On the map of equal exposition the equal number of particles from the equal parts of sphere is expected. The Fig. 1 shows the distribution of the showers in the map of celestial sphere in second system on equatorial coordinates $\delta$ (a declination) and RA (a right ascension). As it is seen the distribution of showers is almost isotropic.

But 13 EAS are located near a galactic plane within the angular cone $\theta<45º$ from axis $b=0º$, $l=90º$ (b, l - galactic coordinates) of the axes Local Arm Orion of Galaxy. From them 11 EAS are located <6º from pulsars [5].

Fig.2 presents the distribution of 26 particles by Yakutsk array data with the energy $E>8 \times 10^{18}$ eV. Distribution of EAS with deficit muons is not isotropic, from a galactic plane some excess a observed number of EAS is observed: $n(\mid b\mid<30º)/n(\mid b\mid>30º) = 1.9 \pm 0.7$. In case of isotropy this ratio will be equal 1.2 according to [6].

We have found among these EAS 5 doublets and from them 4 doublets are located at one region of a celestial sphere: $\delta=20º-75º$ and RA=60º-80º. The fifth doublet which consists of two EAS: one without muons and the other - with poor muons, is located near Input of the Local arm of the Galaxy Orion.

From direction RA=60º-80º we find a maxima distribution EAS with usual content muons at energy interval $E=5 \times 10^{18}-4 \times 10^{19}$ eV [7].

Further, we determined a correlation between the arrival directions of particles and pulsars. To this end we took the following directions: (i) over the entire celestial sphere region visible by the array and (ii) along the field lines of large-scale regular magnetic field of Orion Arm within a cone with angles <45º (dashed line in Fig.1) from the field-line axis with the galactic coordinates $b=0º$ and $l=\pm90º$. This direction along lines of a magnetic field of Local Arm Orion was chosen, because the magnetic field minimally deviates particles moving along field lines.
land the probability of correlation between shower arrival directions and pulsars will be increased.

We calculated the angular distances $\delta$ between the arrival direction of each particle from $N_1$ particles and all pulsars. We determined the number $N_2$ of EAS observed within the angular distances $\delta$ from pulsars. A given particle was considered only once. The probability $P$ of chance of the number of particles $N_2$ was calculated by the Monte-Carlo method through simulation $N_3$ events (this number of particles we determine from experimental data) distributed isotropy within a solid angle $<45^\circ$ (dashed line in Fig.1) around the axis $b=0^\circ$ and $l=\pm90^\circ$ (galactic coordinates) of Orion Arm, with take account exposure of celestial sphere to array [4]. The number of simulation was determined by the accuracy of determining the chance that no correlation between arrival directions of Yakutsk

<table>
<thead>
<tr>
<th>Array</th>
<th>$E$, eV</th>
<th>$\delta$, deg</th>
<th>$N_1$</th>
<th>$N_2$</th>
<th>$P$</th>
</tr>
</thead>
<tbody>
<tr>
<td>P. Auger</td>
<td>$&gt;4 \times 10^{19}$</td>
<td>3</td>
<td>69</td>
<td>6</td>
<td>$4 \times 10^{-2}$</td>
</tr>
<tr>
<td>Yakutsk</td>
<td>(0.8-4) $\times 10^{18}$</td>
<td>6</td>
<td>898</td>
<td>265</td>
<td>$10^{-3}$</td>
</tr>
<tr>
<td>Yakutsk</td>
<td>(0.8-4) $\times 10^{19}$</td>
<td>3</td>
<td>898</td>
<td>140</td>
<td>$3 \times 10^{-2}$</td>
</tr>
</tbody>
</table>

Note: $\delta$ - $N_1$ – number of considered EAS, $N_2$ – number of EAS inside Arm $<45^\circ$ which correlated pulsars, $P$ – probability.

EAS data with usual, deficit muons with pulsars. chance probability and reached $10^6$ in some case. Analysis shows We did not find any correlation between arrival directions EAS of AGASA data and pulsars. But we find at energy $E>4.10^{19}$ eV a correlation between arrival directions by data EAS P. Auger observatory and pulsars (Table 1). Also we find at energy $E=(5-8)\times 10^{18}$ eV and $E=(8-40)\times 10^{18}$ eV a correlation between arrival directions by data EAS Yakutsk data with usual muons and pulsars (Table 1). These results confirm our early result [8].

3 Conclusion

Most likely pulsars are sources of cosmic rays ultrahigh energy.

References