Search Sources of Ultrahigh Energy Particles in our Galaxy

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Abstract: The arrival directions of ultrahigh energy particles by data of world shower arrays are considered. It is found that an arrival directions of showers extremely energy correlate with coordinates of some pulsars. It is shown that the majority of these pulsars have a short period rotate around of their axes, than it is expected average by catalogue of pulsars. The problem of cosmic rays origin is discussed.

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

1 Introduction

The origin problem of ultrahigh energy cosmic rays is one of priority in high energy astrophysics. There are two main hypotheses about the origin of cosmic rays with $E > 4 \times 10^{19}$ eV - galactic [1, 2] and extragalactic [3, 4, 5]. In a galactic model origin of cosmic rays more probably sources — supernova stars, pulsars [6, 7, 8] and etc.

Here data of extensive air shower (EAS) Yakutsk, AGASA arrays, P. Auger observatory in terms of their exposition of the celestial sphere to arrays are analyzed.

Shower cores of the Yakutsk EAS lie inside the array perimeter and the accuracy of arrival directions angle determination at energy $E > 4 \times 10^{19}$ eV is $\sim 3°$, $E > (0.8 - 4) \times 10^{19}$ eV is $\sim 5 - 7°$. The particle energy has been determined with the accuracy $\sim 30\%$. Three showers have energy $E > 10^{20}$ eV. The particle energy by data P. Auger is determined with the accuracy $\sim 22\%$, the solid angle - $\leq 1°$ [4]. The particle energy by data AGASA is determined with the accuracy $\sim 25\%$, the solid angle - $\leq 1.6°$ [9]. The particle energy by data HiREs is determined with the accuracy $\sim 25\%$, the solid angle - $\leq 1.6°$ [10].

2 Analysis

We have analyzed arrival directions of extensive air showers (EAS) by data of Yakutsk EAS array for 1974-2009. Showers with energy $E > 4 \times 10^{19}$ eV, with zenith angles $< 60°$ and the axes lying inside of perimeter of array are considered. Accuracy definition of solid angles of arrival directions is $\sim 3°$, energy $\sim 30\%$. Also we have analyzed arrival directions showers with deficit muons. We found 21 showers without muons, i.e. showers for which the readings of the muon detectors were absent (equal to zero) within limits of detection threshold > 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 $P = \Pi(P_{1i} + P_{2i})$, where P_{1i} is the probability that muon particles did not reaches the i-th detector and P_{2i} is the probability that one particle reaches the detector but it does not operate trigger. At probability $P > 10^{-3}$, this shower was excluded from consideration.

Each 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 other showers (see in detail [11]).

Also we found 5 showers for which the muon density at distances larger than 100 m was more than 3σ lower than the average expected value.

Further we have considered the arrival directions of EAS with ultrahigh energy - do they correlate with pulsars? Early we find the correlation EAS and pulsars at angular distances $R < 6°$ [12] and here we select this angular distance $R < 6°$ with energy $E > 5.5 \times 10^{19}$ eV - 43 EAS correlate from 69 [4], to array AGASA - 31 EAS correlate from 57 [6], according to array HiRes - 28 EAS correlate from 35 [9].

Thus, by data detectors which are operated constant (Yakutsk, P. Auger, AGASA) portion EAS which correlated with pulsars is $\sim 60\%$ (possible, this portion reflects a ratio of coincide of cones of optical radiation and cosmic rays ultrahigh energy).

We consider the rotation periods of pulsars [13] which correlated with EAS. We choice pulsars with definite periods with $P_0 = 0.01, 0.1$ et al. (Fig.1). Ratio number of pulsars with periods $P < P_0$ to the number of pulsars which have the periods $P > P_0$ is shown in Fig.1 (in case of Yakutsk array we have considered EAS with usual muons, we mark their as Yak.1 and with deficit muons - as Yak.2). As seen from Fig.1 majority of pulsars have short periods $P < 0.01$ sec than it is expected according to the catalogue of pulsars (except pulsars, which correlate with EAS of Yak.1, data with usual content muons).

Portion pulsars with short periods $P < 0.01$ sec which correlated with EAS (at angular distance $< 6°$) is shown in dependence of arrays (Fig.2). If to assume, that pulsars accelerate particles in a narrow cone that the given portion P of short-periodical pulsars is very high ($P = 20 - 30\%$).

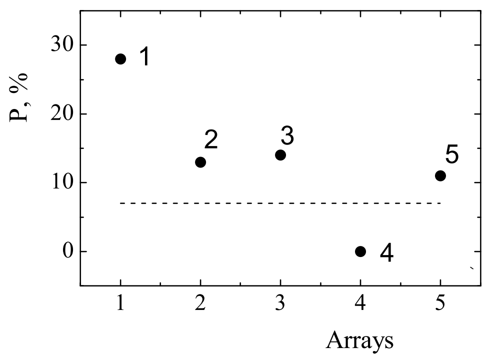

Figure 2: Potion pulsars with periods $P < 0.01$ sec. which correlate with EAS to total number of pulsars: 1 - PAO, 2 - HiRes, 3 - AGASA, 4 - Yak.1, 5 - Yak.2. Dash line - potion pulsars with periods $P < 0.01$ sec. to total number of pulsars.

In Fig.3 it is shown distances pulsars which correlated with EAS of array from Earth. Majority of pulsar which situated at distances at < 2 kpc or most contribution to correlations the arrival directions EAS gives the nearest is situated within < 2 kpc from Earth.

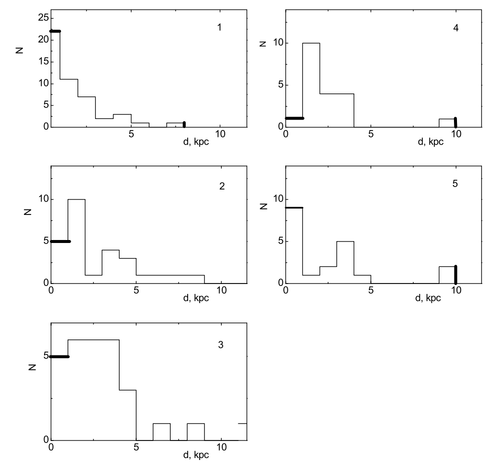

Figure 3: Distances of pulsars: 1 - PAO, 2 - HiRes, 3 - AGASA, 4 - Yak.1, 5 - Yak.2.

3 Conclusion

Most likely the main part of particles with energies $E > 4 \times 10^{19}$ eV has a galactic origin.

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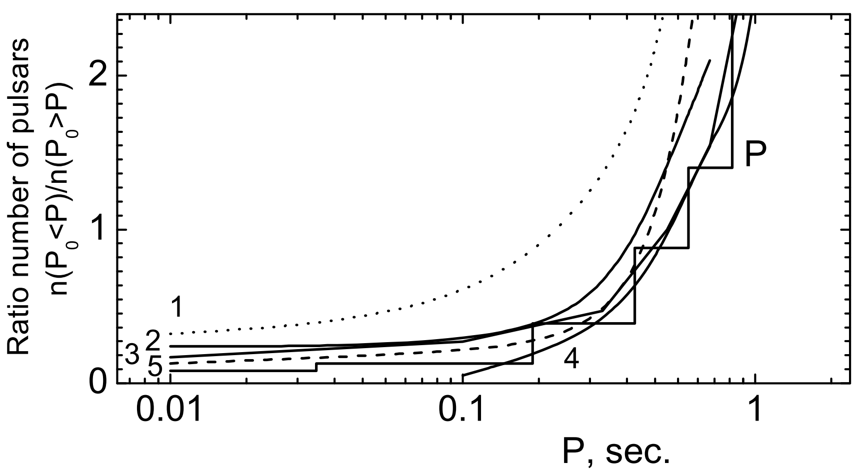

Figure 1: Ratio number of pulsars with period $P_0 - n(P_0 < P)/(n(P_0 > P)$: 1 - pulsars, which correlated with EAS of PAO; 2 - pulsars, which correlated with EAS of AGASA; 3 - pulsars, which correlated with EAS of HiRes; 4 - pulsars, which correlated with EAS of Yakutsk 1; 5 - pulsars, which correlated with EAS of Yakutsk 2; P - pulsars according catalogue.