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Galactic UHE neutrons

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Abstract. The AGASA and SUGAR data indicates on some anisotropy of cosmic rays from the Galactic Centre. This anisotropy can be due to secondary neutrons produced in the photo-production and photo-disintegration processes of nucleus interactions with background photons. The upper limit on the quantity of neutrons in the primary cosmic ray spectrum have been evaluated, on the base of measurements of anisotropy of high energy of cosmic rays. The trajectories of neutrons are straight line in Galaxy. The contribution of galactic UHE neutrons to the cosmic ray flux should provide some anisotropy. The coefficient of anisotropy has been evaluated as function energy for given percentage portion of neutrons in cosmic ray flux. The galactic model origin of cosmic ray is discussed.

1. Introduction

The gamma rays up to energy 10 PeV have been observed from the galactic pulsars. If these gammas are from π^0 decay, with the π^0 produced by more energetic protons (or nuclei) in the propagation processes in the matter or electromagnetic field. Further, if the gammas are indeed from high-energy protons, the protons energies must be much greater than one PeV. It has been suggested that the protons and nuclei from this and other pulsars may account for the majority - perhaps all - of the observed primary cosmic rays in the PeV - EeV range. It is suggested that neutrons produced in the same nuclear and nuclei collisions, which produce the gammas should be detectable at UHE energies. Nuclei heavier than protons accelerated in pulsar system and striking target nuclei or photons in the pulsar environment will be dissociated into their component nucleons with a high cross section. These will be a source of neutrons of energy 1/A times that of the parent nucleus and multiplicity (in general) of A/2, where A is the nucleus mass number. If alpha particles and other heavier nuclei are a significant fraction of cosmic rays accelerated in the Galaxy (as they are from evidence of primary composition arriving at the Earth), this will be a more efficient source of neutrons that inelastic charge exchange of primary protons. The motivation to work out this paper was to evaluate maximal contribution of neutrons to the primary cosmic ray spectrum admits observed anisotropy of cosmic rays.

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2. The model description

In general if the cosmic rays are galactic origins in whole energy range. Propagation processes in soft photon and magnetic fields form the mass composition and the spectrum of primary cosmic ray. The observations of gamma rays point sources, gamma rays diffusion components and theoretical expectation indicates on possibilities effective production of ultra high energy (UHE) neutrons as well in point sources or as the diffusion galactic component generated by cosmic ray interactions.

2.1 Assumptions

- The charged component of cosmic ray is isotropic and galactic origin.
- The neutrons are galactic origin from point sources or interaction of charged component. Proton interacts with ambient matter producing neutrons by (pp) but nuclei by photo dissociation on background photons.
- The Galaxy is a disk with a radius of 15 kpc and thickness of 0.4 kpc.
- The collection volume of neutrons depends on their life-time and size of galactic disk.

2.2 Method

The collection radius of neutron with energy E is:

$$R = c \cdot \frac{E}{m_n} \cdot \tau_n \quad (1)$$

where m_n -neutron mass, c- light velocity, τ_n neutron life time. The angular distribution of the charged component of cosmic ray is isotropic because turbulent galactic magnetic field bending its trajectories. From assumptions the cosmic rays flux is simple sum of flux charge I_c and neutron I_n components: $I_{CR} = I_c + I_n$. Let we introduce p parameter defined as follow:

$p = \frac{I_n}{I_c + I_n}$ -it shows the contribution of neutrons in cosmic ray flux.

The same expression can be rewrite in forms:

$$I_c = \frac{(1-p) \cdot I_n}{p} \quad . \qquad (2)$$

The anisotropy coefficient (amplitude first harmonic) defined as

$$\delta\,[\%] = \frac{I_{cr\,max} - I_{cr\,min}}{I_{cr\,max} + I_{cr\,min}} \qquad (3)$$

is simplified to the formula

$$\delta\,[\%] = \frac{p \cdot (I_{n\,max} - I_{n\,min})}{2 \cdot (1-P) \cdot I_{n\,max} + p \cdot I_{n\,max} + p \cdot I_{n\,min}} \quad . \qquad (4)$$

The coefficient δ has been calculated taking that $I_{n\ max}$ and $I_{n\ min}$ can be write as follow:

$I_{n\ max}$ *=if R<25 kpc* then *R else 25 kpc*

$I_{n\ min}$ *=if R<0.2 kpc* then *R else 0.2 kpc*

where *R* from eq(1)

Figure 1 shows the anisotropy coefficient for selected value of *p* parameters. The anisotropy is growing with p. Anisotropy coefficient δ is constant above the energy ~3×10^{17} eV common for all p. Below this energy δ dramatically decreases to 0.

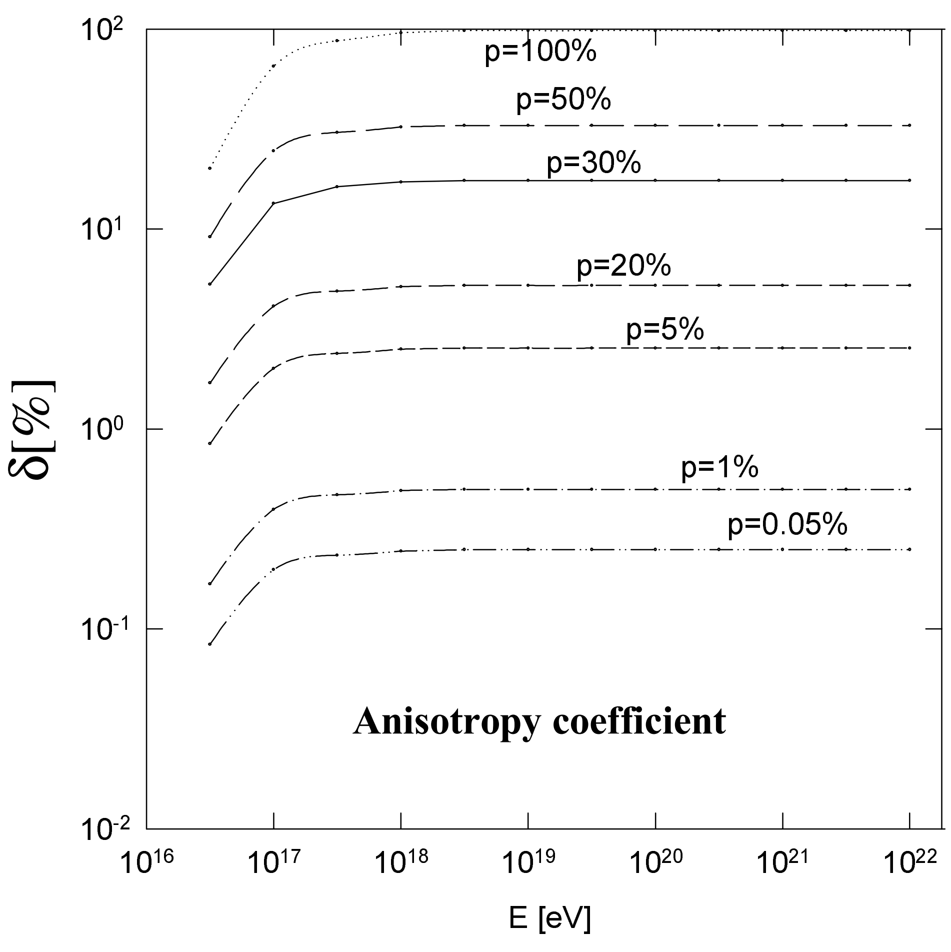

Fig. 1 The anisotropy coefficient for selected value of *p* parameters.

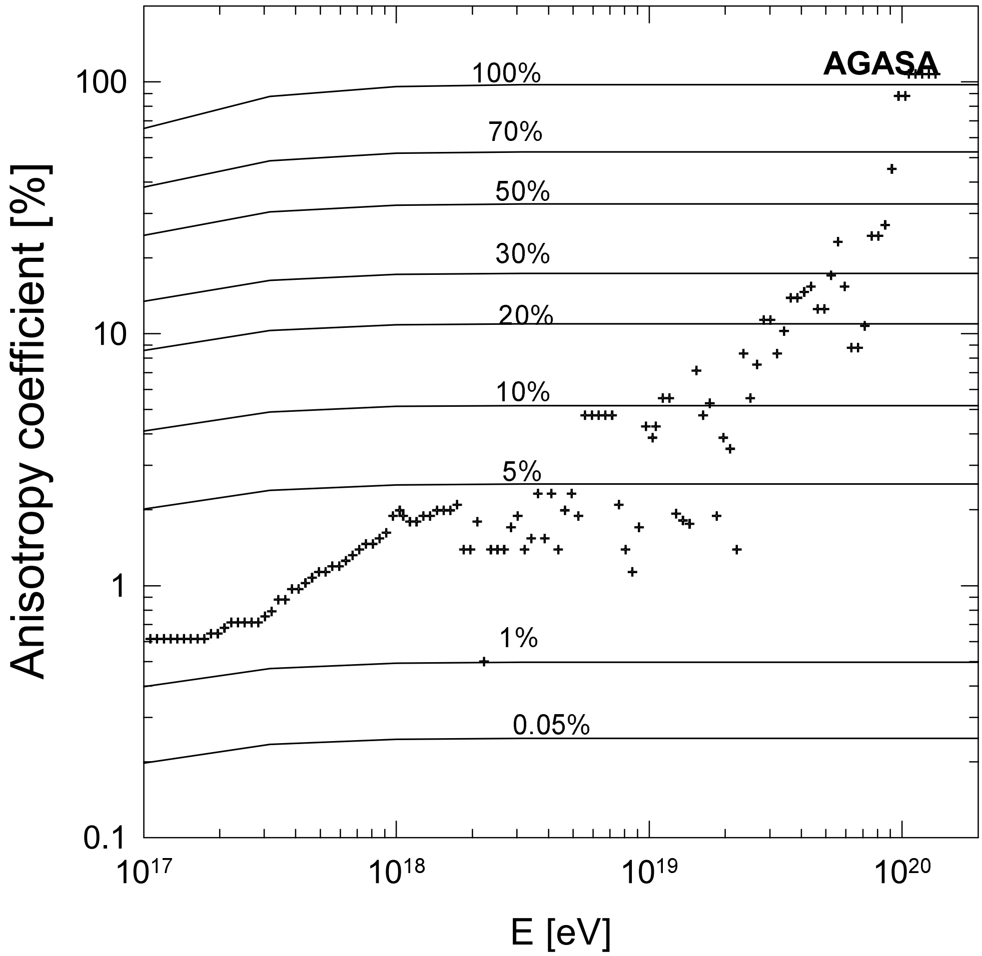

Fig. 2 Comparisons of expected anisotropy coefficient (see text) and measured by AGASA Hayashida et al., (1999).

The flux of cosmic rays at Earth is composed with isotropic charged component and anisotropic neutrons. In case uniform sources distributions the flux of neutrons from given direction is proportional to the thickness of galactic disk in that direction if collection distance of neutrons exceed the size of galactic disk in given direction else is proportional to collection radius *R*. The expected amplitude of anisotropy has been calculated for selected fraction of neutrons in cosmic ray spectrum .The calculated anisotropy for indicated fraction of neutron in cosmic ray spectrum is shows by lines on the figure 1.

Searches for anisotropy in the arrival directions of high energy cosmic rays have been made by many experiments so far and the arrival direction distribution of cosmic rays is found to be quite isotropic over a broad energy range. Up to now an anisotropy of amplitude 4% around 10^{18} eV was found in first harmonic by AGASA experiment. In the significance map with beam size of 20°, a 4.5σ excess near the Galactic Center region has been seen Hayashida et al. (1999). In reanalysed experimental data from SUGAR array Bellido et. al.,(2000), the excess from the Galactic centre have been seen but little shifted in comparisons with AGASA position and smaller significance

Figure 2 shows the coefficient of anisotropy calculated on the base of proposed model, the curve are labelled as on figure 1, in comparison with anisotropy measured by AGSA array (hair crosses) Hayashida et al., (1999).

We should note that proposed methode to estimation of upper limit of neutrons fraction in cosmic ray spectrum is limited for very high energy because increasing anisotropy of charger component of cosmic rays. Only poor iron mass composition of cosmic rays for these energies saved almost isotropy charged component and sufficient.

3. Discussion and conclusion

The method to evaluation of portion of UHE neutrons in the primary cosmic ray flux has been proposed based on anisotropy measurements. The galactic or nearest extragalactic the point PeV gamma rays souses can be observes as the neutrons one. In core of the source, the nuclei can be accelerated up to ultra-relativistic energies either by first - order Fermi mechanism at the shock front or by generalised second - order Fermi acceleration due to plasma turbulence developing in some layer below the front. The nuclei can be efficiently accelerated to a higher energy than can protons for the source of given radius and the same strength of magnetic field. If the region where particle acceleration occurs contains a reasonable admixture of nuclei, then standard models for shock acceleration suggest that the acceleration of nuclei is efficient. The neutrons lose energy due to the interactions: n-p and γ-n. If the total "gramage" or matter traversed by neutrons as they stream outward, is less then 80 g cm^{-2}, then the energy losses are negligible. Relativistic effects should be taken into account: because of relativistic time dilation, neutrons with a Lorentz factor γ_n can travel a distance 10^{-5} γ_n [pc] before decaying. The flux of neutrons at distance d from the cosmic ray source is a product of emission flux and probability of neutron decay

$$I_d(E_n) = 1/2 \cdot K \cdot E_n^{-\gamma} \cdot A^{-\gamma+2} \cdot \exp(-d \cdot m_p / c \cdot \tau \cdot E_n) \qquad (5)$$

where τ is the life time of a neutron in its rest frame and c is the velocity of light. The flux $I_d(E_n)$ has the maximum at the energy of neutrons $E_n^{max} = d \cdot m_p / c \cdot \tau \cdot \gamma$. The ranges exceeding distance d have the neutrons with energy greater than E_n^{max}. The cosmic ray sources distributed at radius *d [kpc]* should be observed in neutrons with energy greater then $E_n^{max}[PeV] = \frac{105}{\gamma} \cdot d[kpc]$, where γ is the power index of cosmic ray spectrum. So the distribution of arrival directions of neutrons are formed mainly by galactic size if energy of neutrons are greater then 10^{17} eV.

The neutrons from γ-p and p-p interactions can carry a substantial fraction of the initial luminosity away from the central point gamma ray source Atoyan, (1992). For power law spectrum of parental protons the daughter neutrons have also power law spectrum with the same power index as is for gammas from π^0 decay

The neutrons can be produced in time of propagation of nuclei in soft photon batch. If nucleus with mass number A are dissociated completely and number of neutrons is equal to 1/2A.

Figure 2 shows the comparisons of the predicted anisotropy by described model and AGASA experimental data. We can notice that contribution of neutrons to the cosmic ray flux in the wide energy range 10^{17}-10^{20} eV is not constant if anisotropy is only due to neutrons in the cosmic ray spectrum. In more narrow energy range 10^{18} eV where experimental data has higher significance the neutron contributions are less 5% if theirs come from point sources distributed uniformly in Galaxy. For higher energy the conclusion should be draw carefully because data has lower significance and usefulness of applied method are limited. Nevertheless we can notice that anisotropy growing with energy what permit larger portion neutrons cosmic ray spectrum. We should note that if neutrons comes from photo dissociation of heave nuclei the contribution can be even 50%. That situation is optimal because charge component are almost isotropic in this energy range. The anisotropy of neutrons should be the some order of magnitude as their parent nuclei. This property gives in future some a chance in more precise measurements to distinguish between origin of UHE neutrons from the point sources or diffusive propagation of cosmic rays in galactic space. This possible high admissive portion of neutron in cosmic ray flux evidently will supports the photo dissociation of heavy nuclei as main process formation of cosmic ray spectrum in that energy range.

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