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UHE Neutrons in Galactic Cosmic Rays

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Abstract

The upper limit on the neutrons fraction in the primary cosmic ray spectrum have been evaluated, on the base of new 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 bean evaluated as function energy for given percentage portion of neutrons in cosmic ray flux. From the comparison with measurement of the anisotropy coefficient the upper limit on the portion of galactic neutrons in the cosmic ray flux is estimated.

1 Introduction:

The neutrons as non charged particle can not be accelerated in space by shocks. Its presence in the space indicates on interactions of relativistic particles with ambient matter or radiation. The neutron trajectory is straight line in magnetic and electric fields. This property made its similar to the photons but many times energetic because of its large rest mass. The neutrons can transport effectively energy from central part of source to the cosmic space. The neutrons are generated in the same high energy inelastic nucleon or nuclei collisions where π^0 are producing which sequentially decaying to the gammas. The neutron's lifetime and consequently its range of passed distance is dependent on its energy. The collection radius of neutrons with energy E is $R = c \cdot \frac{E}{m_n} \cdot \tau_n$ where m_n- neutron mass, c-light velocity, τ_n -neutron lifetime. The surprisingly simple observation is made that neutrons of accessible energies have a decay lifetime sufficient for them to reach the Earth from some PeV gamma ray sources. Up to date no neutron component has been observed in the cosmic ray flux, current techniques based on air shower measurements would not distinguish between proton - induced cascades and those initiated by neutrons. Nevertheless, the X-ray binary source 2A 1822-37.1241 was claimed by Clay et al. 1992 on the base of he data recorded by the Sydney Giant Air Shower as neutral particle's emitters at energies above 10^{17} eV. 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.

2 Neutrons in Cosmic Space:

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 Cosmic Ray Interactions:

The type of neutrons generation determine mass compositions of primary cosmic rays. The mass compositions can be considered from poor protons to poor iron nuclei.

2.1.1 Disintegration of Nuclei: The angular distribution of the charged component of cosmic ray is isotropic because turbulent galactic magnetic field bending its trajectories. The anisotropy for iron nuclei even for highest energy do not exceed observational data (see curve labelled Fe on the figures 1 and 2). Indirect methods estimations of cosmic ray mass composition favour heavier (iron) nuclei in cosmic spectrum for high energy in some experiment. In steady state case i.e. the galactic magnetic field long time are trapped nuclei, the passed distance can exceed mean free path on fragmentation of nuclei in galactic photons background radiation. If passed distance significantly exceed mean free path then nuclei with mass number A are dissociated completely and number of neutrons is equal to 1/2A. For the large propagation distance it is possible to find simple expression for the upper limit on neutron spectrum. It is the case when propagation distance significantly exceeds the interaction length of photo-dissociation process. The upper limit of flux of neutrons producing by cosmic ray composed only which the nuclei with mass number A and power law spectrum $K \cdot E^{-\gamma}$ can be writes by following formula.

$$I\left(E_n\right) = \cdot K \cdot E_n^{-\gamma} \cdot A^{-\gamma+2} / 2 \qquad \text{if } E_n >> E_{th} \qquad (1)$$

where E_{th} is the threshold energy per nucleus for photo-dissociation process. The spectrum of neutrons is a power law with the power index of the parental nuclei. In details the photo dissociation process has been calculated by Tkaczyk 1994, 1995, on background photons with production of UHE neutrons.

2.1.2 Inelastic Collisions: Recently , it was shown that in Active Galactic Nuclei the neutrons from γ-p and

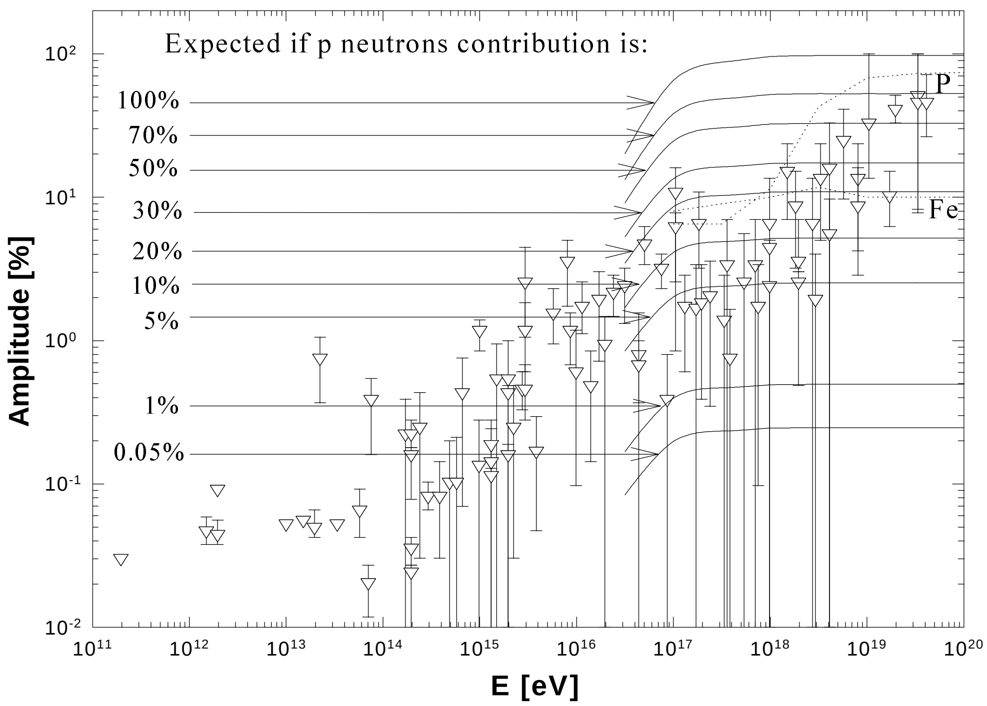

Fig 1. A comparison of anisotropy expected due to neutrons (described in text) and measurements northern and southern hemisphere compilation by Smith and Clay, 1997.

p-p interactions can carry a substantial fraction of the initial luminosity away from the central source Atoyan, 1992 and Tkaczyk, 1994. 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.

2.2 Point Sources:

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 ultrarelativistic 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 radius R 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 more efficient then the acceleration of electrons. This is because nuclei, being more massive than electrons, have larger gyroradii. 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 $10^{-5}\gamma_n$ [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

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

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 if

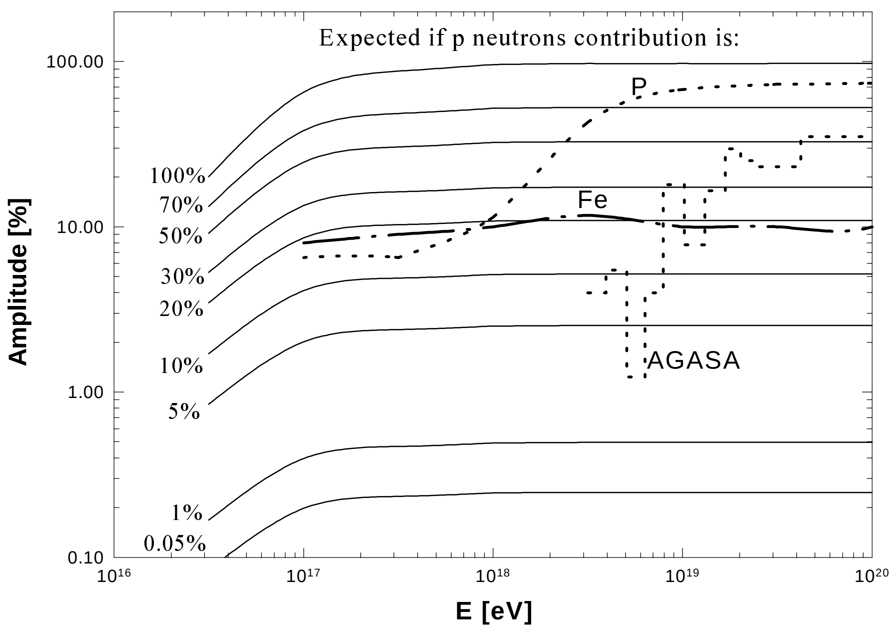

Fig 2. Comparisons of expected anisotropy amplitude (see text) and measured by AGASA Takeda et al., 1999

energy of neutrons are greater then 10^{17} eV. When density of point sources is significant then its give substantial contribution to the cosmic ray density. In this case properties of neutrons are the same as for generated by cosmic ray nuclei.

3 Upper Limit on Neutrons Contents from Anisotropy Measurements:

We assumed that the Galaxy is a disk with a radius of 15 kpc and thickness of 0.4 kpc. The density of cosmic ray (neutrons) are uniform in galactic disk.

The collection volume of neutrons with given energy depends on their lifetime and size of galactic disk.

3.1 Data from EAS arrays northern and southern hemisphere: The flux of cosmic rays at Earth is composed with isotropic charged component and anisotropic neutrons. The flux of neutrons from given direction is proportional to the thickness of galactic disk in that direction. The expected amplitude of anisotropy has been calculated for selected fraction of neutrons in cosmic ray spectrum. For details of calculation see Tkaczyk (1997).The calculated anisotropy for indicated fraction of neutron in cosmic ray spectrum is shows by full lines on the figure 1 and figure 2. Experimental data point with error bar on figure 1 collected by Shmit and Clay (1997) from EAS arrays on northern and southern hemisphere. The curve labelled P and Fe shows respectively the amplitude expected for poor proton or iron mass composition of cosmic ray Tkaczyk (1999).

3.2 AGASA data : Figure 2 shows the amplitude of anisotropy calculated on the base of proposed model, the curve are labelled as on figure 1, in comparison with amplitude measured by AGSA array (doted break line) Takeda et al., (1999). We should note that AGASA data are for energy greater then 3×10^{18} eV where usefulness of considered method to estimation of upper limit of neutrons fraction in cosmic ray spectrum is limited due to 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 anisotropy from daughter neutrons.

4 Discussion and Conclusions:

Considering anisotropy measurements (amplitude in percent) the method evaluations of portion of UHE neutrons in the primary cosmic ray flux, has been re-examined on the base of the World data from EAS arrays on northern and southern hemisphere . Figure 1 shows the comparisons of the predicted anisotropy by described model and experimental data. On the base of this comparisons we can generally hold previous estimation Tkaczyk (1997), made on the base of very old measurements, that contribution of the neutrons in cosmic ray spectrum is around 20%. But the theoretical line and data point positions on the figure 1 can indicate that may be the fraction of neutrons in cosmic ray spectrum are not constant in whole energy range $E>3\times10^{16}$ eV. For energy $\sim10^{17}$ eV neutrons fraction can reach 30% . But for energy 5×10^{17} eV it can not exceed 10 %. So may be some type the line of neutrons for energy $\sim10^{17}$ eV is expected in cosmic ray spectrum. We should note that method used here is mostly sensitive for energy $\sim10^{17}$ eV. The neutrons fraction on the level, 20% is accepted by experimental data on figure 1 up to energy 10^{19} eV. Above energy 10^{19} eV the data points with amplitude ~ 30% needs 50% fraction of neutrons in primary cosmic rays spectrum. The neutrons fraction 50% is maximal possible in the considered model, it is the case when primary poor iron beam is completely destroyed in propagation process. The higher fraction then 50% needs extra contribution from neutrons sources. Nevertheless from figure 2 to be in accord with AGASA amplitude measurements in energy range 3×10^{18} - 8×10^{18} eV neutrons fraction is needed on the level 10% . Around energy 10^{19} eV fraction is 20% but for $E>10^{19}$eV do not exceed 50% . It last value is in accord with theoretical prediction in the case when poor iron are primary beam in the cosmic ray spectrum

Acknowledgements

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