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The low limit of the number of individual sources giving the main contribution to the CR flux around the knee.

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We check the hypothesis whether only a small class of peculiar Supernovae gives the main contribution to the flux of cosmic rays (CR) in the knee region. As compared with previous work, where CR flux averaged over Supernova (SN) explosion energy, type and conditions around the explosion was calculated, the effects of CR propagation were included in calculations. Besides, new formulae for the maximal energy of accelerated particles in one SN remnant (SNR) were used. It is shown that the idea, that only small fraction of SNRs provides the main contribution to the cosmic ray flux around PeV- region obviously contradicts to a smooth character of the observed CR spectrum and to the measured anisotropy due to large fluctuations of individual SNR contribution. But in frames of the applied simplified approach even in the case, when all SNRs can accelerate CR particles up to the knee energy the calculated value of $<A^2>^{1/2}$ more or less agrees with the experimentally measured anisotropy (at $E > 100$ TeV) only if the chemical composition becomes heavier around the knee region, that compensates the D(E) increase, and nearby SNRs with $R_{SNR} < 700$ pc for some reason do not contribute to CR flux. But it looks preferentially to suggest that the number of sources providing the knee region is larger than the number of SNRs.

1. Introduction

While recent H.E.S.S. observations show that the new Galactic VHE gamma-ray emitters cluster close to the Galactic plane and this is a clear indication that they see a population of Galactic (rather than extragalactic) sources [1], in a contrast with the generally accepted opinion [2] the wide variety of CR sources classes has been discovered, most of them are not SNRs. So the question of CR origin is still open. In this paper we continue to study the effects of averaging contributions of different SNRs in the cosmic ray flux observed near the Earth. In [3], [4] CR flux averaged over SN explosion energy , type and circum-stellar conditions was calculated and it was shown that may be only a limited class of most energetic SNRs (Gypernovae) with extremely high energy gives the main contribution to the flux around 1 PeV energy. But in our calculations we did not take into account the propagation effects and relatively new achievement in the theory of a diffusive shock acceleration: the charge particles accelerated in usual SNR (with 10^{51} erg kinetic energy) can easily reach the energy E_{max} as large as the energy of the knee due to a nonlinear amplification of random magnetic field around the shock front [5,6] caused by cosmic ray streaming instability. And even some experimental evidence of this amplification in six SNRs — Cas A, SN 1006, Ticho's , Kepler's, RCW 86, RX J1713.7-3946 — can be found [7]. So we do not need to attract the Gypernovae to explain the CR spectrum up to the knee energy, may be they are needed at $E > 10^{17}$ eV. But if consider the expected maximum energy of accelerated particles [5,6,7], one can see that maximum energy depends on many parameters: square velocity of the shock, density of the circum-stellar gas, strength of magnetic field surrounding SNR, injection efficiency and so on. As a result one may expect, that the number of SNR giving the main contribution to the knee region will be less than the total number of SNR providing CRs in GeV-TeV region. But it means that fluctuations of CRs near the Earth should increase. What is the low limit of SNRs giving the main contribution to the CR flux around the knee, that does not contradict to the measured anisotropy we try to estimate below. In comparison with [3,4] we take into account a propagation of CRs in the Galaxy, because propagation effects mainly determine CR fluctuations and an anisotropy [2,8,9,10] near the Earth. Practically, the anisotropy measured experimentally (see reference in [9-11]) in the range around 100 TeV occurred to be as small as if it would be fully produced by Compton-Getting effect by the amplitude and phase [11]. Expected energy dependence which follows the D(E) is not seen at all.

2. The model of CR flux near the Earth

As was done in [3] we chose the spectrum of instantly injected CRs in every individual SNR (sited in a point $\mathbf{r}_i$ at time t_i in the Galactic plane): N_i (E, γs, E_{max}, $\mathbf{r}_i$, t_i) ~ $E^{-\gamma s}$ (with γs=2.4 or 2.15) extended up to maximal value E_{max}, and at E> E_{max} the spectrum becomes much steeper $N_i \sim E^{-5}$ [6], (also we take into account slight flattening of the spectrum before the E_{max}). In every SNR five groups of different nuclei with charge Z was simulated with the source abundance R(j=1,5): protons (0.59), helium (0.29), CNO (0.06), Ne-Ca and Fe with rigidity dependent value of $E_{max}(Z)=E_{max}(p)*Z$ and the same values of γs. In accordance with new ideas [5,6] E_{max} can be as large as 3 PeV. The absolute intensity of the CRs in every SNR was normalized by the condition that 10% of kinetic energy (10^{50} erg) is transformed to CRs [2]. The ensemble N0 of SNe explosions in our Galaxy was calculated by Monte-Carlo method (as in [12,13]) suggesting the SNe uniformly occurred in the Galactic plane with the rate 3 per century during the time T $=10^8$ years, corresponding to the survival time of CRs with energy 1 GeV in our Galaxy (N0 = 3×10^6). The diffusion coefficient D was chosen close to the value used in [9] $D \sim 3\times10^{29}$ см^2/c × $(E_{TeV}/Z)^{0.3}$. More strong energy dependence of D drastically contradicts to experimental anisotropy [9]. The total flux of all CR nuclei near the Earth I(**r** , t) at the position **r** in time t was expressed through source Grin function of CR density G(t-t_i,$\mathbf{r}$-$\mathbf{r}_i$, E), as it is often done [2, 8, 13].

$$I(\mathbf{r}, t)=\Sigma_{j=1,5}\,(c/4\pi)\Sigma_{i=1,\,N0}\,R(j)\,N_i\,(E, \gamma s, E_{max}(j), \mathbf{r}_i, t_i)\,G\,(t-t_i,\mathbf{r}-\mathbf{r}_i, E) \quad (1)$$

$$G\,(t-t_i,\mathbf{r}-\mathbf{r}_i, E)= \rho(\mathbf{r}-\mathbf{r}_i, Rd,E)=(1/8\pi^{3/2}R_d^{\,3})\exp(-((\mathbf{r}-\mathbf{r}_i)/2Rd)^2)\exp\{-(t-t_i)/\tau(E)\} \quad (2)$$

$$Rd=(D(E)\cdot t-t_i)^{1/2}, \qquad \tau(E)=10^8\,(E_{GeV}/z)^{-0.3} \quad (3)$$

It is necessary to note that this approach with Gaussian Grin function corresponds to simplified solution [2] of diffusion equations: boundaryless Galaxy, τ(E) is inverse to D(E), the CR age function has exponential form characteristic to Leaky-box model [2]. But just this approach usually is used for an investigation of fluctuations and an anisotropy of CRs [2, 8, 9, 10].

Observed anisotropy for every SN ensemble was calculated as $A=3D\times(\partial I(\mathbf{r},t)/\partial\mathbf{r})/c/I(\mathbf{r},t)$ [2] , where c – velocity if the light. Because we are interested in fluctuations of CRs, we calculated 100 ensembles of SNRs that means 100 different Galaxies like our Milky Way. Then we calculated the fluctuation of anisotropy as $(<A^2>)^{1/2}$ [9,10] and fluctuations of intensity δI by 100 samples.

3. Results

I variant. In the first variant we calculated the spectrum of CRs near the Earth, suggesting that the every SNR ejects instantly the spectrum N_i (E, γs=2.4, $E_{max}(p)$=3 PeV). Obtained spectra are presented in the upper part of Figure 1. As was expected [2] $\gamma_{obs} \sim 2.7 = 2.4 + 0.3$. In this case in spite of the propagation effects the observed spectrum looks practically as in one SNR, only one can see that relative abundances of heavy nuclei are stressed in a comparison with source abundances R(j) due to rigidity dependent diffusion coefficient D(E/Z). The investigation shows that the contribution of the remote SNRs at the distance R_{SNR}>4 kpc is only 10 %, while the contribution of nearby SNRs with 200 pc <R_{SNR}< 700 pc is ~ 20 %. But just these nearby sources determine the fluctuations and an anisotropy as many times have been discussed earlier [2, 8-10], and where it has been proposed to introduce the cut off parameter (τ_0) rejecting nearby and recent sources to overcome the divergence in the integral at analytical solution:

$$<A^2>^{1/2} \sim D(E)\,(\sigma_{SN}\,\tau_0)^{-1/2} \quad (4)$$

Here σ_{SN} – is SN rate, and $\tau_0 \sim (\sigma_{SN} D(E))^{-1/2}$ artificially changes the anisotropy $<A^2>^{1/2} \sim D^{5/4}(E)\,\sigma_{SN}^{-1/4}$. In Monte-Carlo calculations we also faced with the problem of nearby sources. In the bottom part of Figure1 the value $<A^2>^{1/2}$ is presented for SNRs at a distance R_{SNR}>200 pc and for SNRs at a distance R_{SNR}>700 pc. One can see that only last variant more or less agrees with experimental points. Practically may be this variant reproduces the picture that the Earth is located in the relatively quiet place of the Galaxy between arms at some distance from the field of active star formation zones mostly sited in Galactic arms. But when we calculate the anisotropy caused by really known SNRs, we get the same results as in [9]: the contribution of nearby known sources in different energy range can be by order larger than observed anisotropy: at the energy around 1-10 TeV the main input is from Vela, while at the energies around 1 PeV enough recent ($t \sim (2–4)\times10^3$ years ago) sources located at distance around 800 pc should give the noticeable individual input. So the idea of Erlykin &Wolfendale[12] that the one nearby source determines the bump in the knee in CR spectrum looks not as the exotic one, but vise versa — more than normal one.

On the Figure 1 the very useful effect can be seen: in the knee region the anisotropy stops to rise with increasing energy due to gradual increase of the content of heavier nuclei, for which the diffusion coefficient is less than for protons, and as a results the anisotropy also is less. In our Monter - Carlo approach anisotropy depends on the number of SNRs providing CRs flux as $\sigma_{SN}^{-1/2}$ (4), so it is obviously that in all models when only fraction of total number of SNRs provide CR flux, the anisotropy will be larger than in Figure1 and will begin to contradict to measured anisotropy.

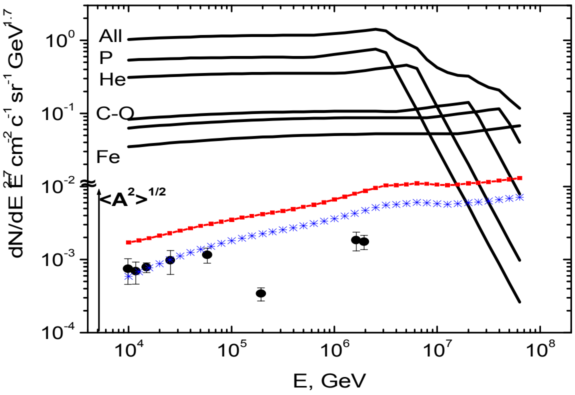

Figure 1. The upper part: spectra of all CRs and different nuclear components near the Earth if one proposes that all SNRs accelerate particles to 3 PeV with power low spectrum ~ $E^{-2.40}$. The lower part: the value of average anisotropy $<A^2>^{1/2}$ for all SNRs with R_{SNR}>200 pc (♦-♦-♦) and SNRs at the distance R_{SNR} > 700 pc far from the Erath (***). • - experimental points (ref. from [9]).

In Figure 2 we presents **II variant** of CR spectrum near the Earth, suggesting as in [4], that E_{max} can vary from SNR to SNR by randomly. We chose the simple dependence $F(E_{max}) \sim E_{max}^{-1.15}$, which provides the needed exponent of observed spectra 2.7 near the Earth, if we propose the spectrum in sources $N_i \sim E^{-2.15}$ predicted by the theory of acceleration of CRs in SNRs [2,6,7]. In this case the softening of the spectrum on their way to the Earth is caused not only by the energy dependent diffusion coefficient $D \sim E^{0.3}$ but also by the decreasing number of SNRs giving the main contribution to the high energy CRs. The observed spectrum looks much more smoothed in a comparison with the spectrum in one SNR. But anisotropy obviously contradicts to the experimental one even if R_{SNR} >700 pc. Of course, one may admit that the applied approach is too simplified [2] and a more complicated picture of the propagation (as, for example, in [14]) should be investigated. But may be SNRs are not main players at the knee energy range.

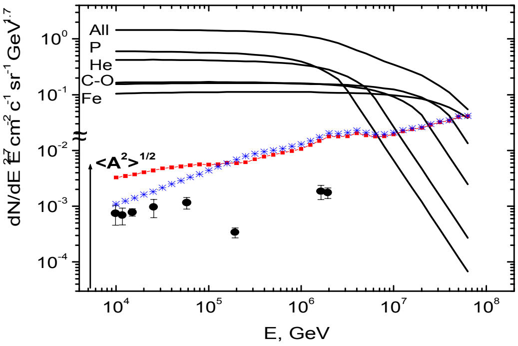

Figure 2. In the upper part: spectra of CRs in the variant when not all SNRs accelerate particles to E_{max}=3 PeV: $F(E_{max}) \sim E_{max}^{-1.15}$, and the source spectrum in one SNR $N(E) \sim E^{-2.15}$, $D \sim E^{0.3}$. In the lower part: $<A^2>^{1/2}$ for SNRs with R_{SNR}>200 pc (-♦-♦-♦) and SNRs at the distance R> 700 pc far from the Erath (***). ● - experimental points (ref. from [9]).

4.Conclusions

The idea, that only small fraction of SNRs provides the main contribution to the CR flux obviously contradicts to a smooth character of the observed CR spectrum and measured anisotropy due to large fluctuations of individual SNR contribution. But in frames of the applied simplified approach even in the case, when all SNRs can accelerate CR particles up to the knee energy the calculated value of $<A^2>^{1/2}$ more or less agrees with the experimentally measured anisotropy (at E > 100 TeV) only if the chemical composition becomes heavier around the knee region (that compensates the D(E) increase) and if nearby SNRs with R_{SNR} < 700 pc for some reason do not contribute to CR flux. But it looks preferentially to suggest that the number of sources providing the knee region is larger than the number of SNRs (as it follows from H.E.S.S. observation [1]).

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