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On the Nature of Events with Energies Above the Energy of GZK Cutoff

V. S. Ptuskin, S. I. Rogovaya, V. N. Zirakashvili and E. G. Klepach
Institute for Terrestrial Magnetism, Ionosphere and Radiowave Propagation (IZMIRAN), 142190, Troitsk, Moscow Region, Russia
Presenter: V. S. Ptuskin (vptuskin@izmiran.rssi.ru), rus-ptuskin-V-abs2-he14-poster

The possible astrophysical origin of cosmic ray events above the GZK cutoff is discussed. The flux of particles accelerated in the bursts of Galactic sources and scattered back by random intergalactic magnetic fields is calculated.

1. Introduction

The nature of events with energies $E > 10^{19}$ eV is the central problem of cosmic ray physics. On the assumption that source distribution is uniform for the particle trajectory lengths up to the Hubble scale $c/H_0 = 5\times10^3/h$ Mpc, the characteristic cutoff of the energy spectrum of cosmic rays interacting with the 2.7 K microwave background photons is expected at about $E_b = 5\times10^{19}$ eV [1,2] (here $H_0 = 100h$ km/(s Mpc) is the Hubble constant, $h = 0.65$). The cutoff is absent if the sources are local. A proton of energy 10^{20} eV looses its energy after passing approximately 160 Mpc, and a proton with the highest observed energy 3×10^{20} eV has the path length about 20 Mpc.

The shape of cosmic ray spectrum at the highest energies is not reliably established yet, see [3,4]. The extragalactic cosmic ray component probably emerges from under the Galactic component at 3×10^{18} – 10^{19} eV and dominates at higher energies. Indications are that cosmic ray spectrum above 5×10^{19} eV does not fall down as rapidly as it is expected at the uniform distribution of extragalactic sources. In the present work we show that in principle the tail of extremely energetic particles beyond the GZK cut off might be produced by the Galactic Gamma Ray Burst events or other types of exploding sources in the Galaxy if the accelerated particles are efficiently scattered back by random extragalactic magnetic field. The bursts in the Galaxy are rare and not directly seen at the present time that allows an understanding of high observed isotropy of cosmic rays.

2. Scattered Back Particles Accelerated in Bursts of Galactic Sources

The data on intergalactic magnetic fields show that magnetic field in the Local Supercluster of galaxies can be relatively strong, $B \sim 10^{-7}$ G, e.g. [5]. The presence of such magnetic field leads to the diffusive motion of ultra high energy cosmic rays within the limits of the Supercluster, see [6,7,8] and references therein.

The GRB events were suggested as the sources of ultra high energy particles [9,10,11]. They may provide a considerable fraction of observed flux of ultra high energy cosmic rays although the active galactic nuclei probably dominate as the sources, e.g. [12,13].

According to [14], the two-stage collapse of massive star is accompanied by the propagation of shock with a Lorents factor $\Gamma = 10^3\Gamma_3$, $\Gamma_3 \sim 1$ through the relativistic wind which consists of electron positron pairs with an admixture of heavy ions including the iron ions, $Z = 26$. The maximum energy of accelerated ions is estimated as [15]:

$$E_{\max} \approx 3\times10^{20}\left(Z/30\right)\Gamma_3^{1/3}B_{-3}\left(W_{0;53}/n\right)^{1/3}\ \text{eV}, \quad (1)$$

where $B = 10^{-3}B_{-3}$ G is the magnetic field; $W = 10^{53}W_{0;53}(\Delta\Omega/4\pi)$ erg = 10^{51} erg is the kinetic energy of explosion distributed in a narrow jet with a solid angle $\Delta\Omega/4\pi = 2\times10^{-3}$; the background density in the pulsar wind is n, cm^{-3}. The mean interval between GRBs in the Galaxy at the present epoch is estimated as τ_{GRB} = (1-10)×10^4 yr, e.g. [16]. The most probable sites of GRBs are the regions of intense star formation.

After strong deviation by galactic magnetic field, the accelerated particles exit the Galaxy and interact with the intergalactic field. Taking $B = 2\times10^{-7}$ G, the Larmor radius of particles with energy $E = 10^{20}E_{20}$ eV is $r_g = 2\times10^{-2}(30/Z)E_{20}$ Mpc. Assuming that this field is random and has a principle scale L = 0.3 Mpc, one can find that the particle motion is diffusive with the diffusion coefficient $D = cl/3$, where the diffusion mean free path is determined by the approximate equation $l = L^{2/3}(E_{20}/Z)^{1/3}$ Mpc in the case of Kolmogorov spectrum of intergalactic turbulence (here L is in Mpc), and $l = L$ in the case when the intergalactic turbulence consists of random shocks and discontinuities. These expressions are valid at $r_g < L$, and $l = r_g^2/L$ at $r_g > L$.

The average energy density of cosmic rays scattered by intergalactic magnetic field and observed in the Galactic disk is estimated as

$$w_{cr} = \frac{3W_{cr}}{4\pi c l^2 \tau_{GRB}}. \quad (2)$$

Here W_{cr} is the total cosmic ray energy released in a burst. It is assumed that the bursting sources are located at distances smaller than the diffusion mean free path, and the frequency of bursts is relatively high: $\tau_{GRB} \ll l/c$.

Figure 1 shows the calculated overall spectrum of cosmic rays produced by the extragalactic (proton) sources and Galactic GRBs at $W_{cr} = 10^{51}$ erg, $\tau_{GRB} = 10^4$ yr, the differential source spectrum is of the power law form ~ $E^{-2.3}$ typical for particle acceleration by ultra relativistic shocks.

Yet another type of bursting galactic sources can be the very young neutron stars with a surface magnetic field larger than 10^{14} G and with an angular velocity about 3×10^3 radian/s. These objects could accelerate iron nuclei up to E > 10^{20} eV [17,18]. The time interval between such events in the Galaxy probably exceeds 10^3 yr.

4. Acknowledgements

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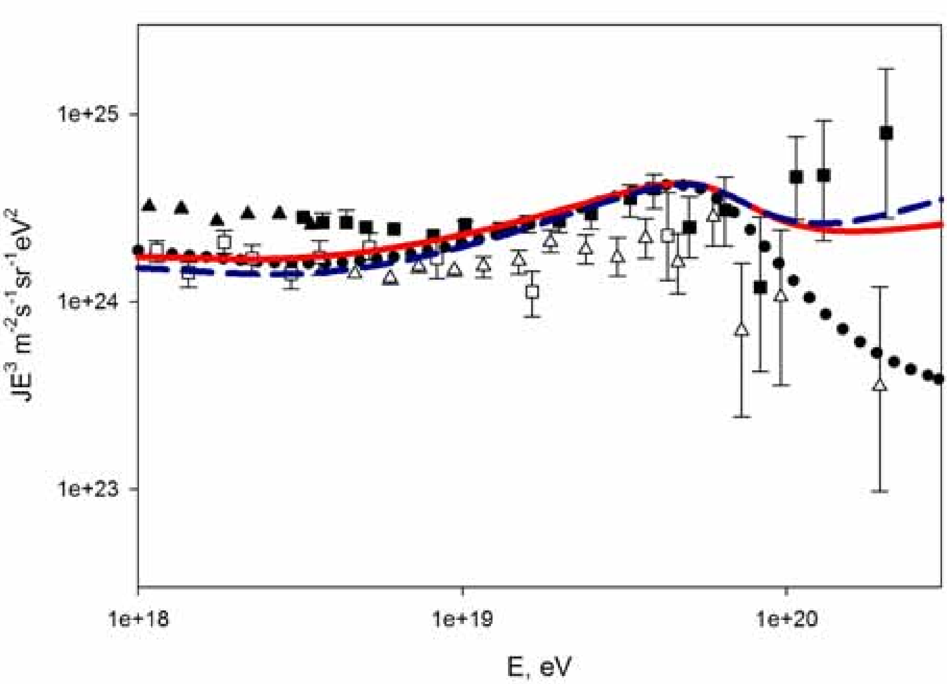

Figure 1. The cosmic ray intensity. The dotted line corresponds to the statistically uniform distribution of extragalactic sources. Two other curves show this spectrum with an addition of scattered back particles accelerated in Galactic GRBs: the solid red line corresponds to Kolmogorov spectrum of intergalactic turbulence, and the dash blue line corresponds to the intergalactic turbulence which consists of shocks and discontinuities. The Akeno - AGASSA and HiRes data are shown.