1999ICRC....4..136Z

OG 3.1.02

Two Components in the Galactic Cosmic Rays

V.I. Zatsepin and N.V. Sokolskaya
Skobeltsyn Institute of Nuclear Physics, Moscow State University, Moscow, 119899, Russia

Abstract

A model of two components is proposed to explain specific features of energy spectra of the Galactic cosmic rays. These components have different elemental abundance and different shapes of their energy spectra. These components are assumed to be accelerated in different sources or in different space regions of the same sources.

1 Introduction:

It is well known that elemental abundance of primary cosmic rays is similar to the local abundance in the space. However, there are some anomalous not explained yet. Among the important anomalous are high abundance of medium and heavy nuclei relatively to hydrogen and helium nuclei. In this paper we want to emphasize that medium and heavy nuclei differ not only in their high abundance but also in the shape of their energy spectra. This can be seen from the compilation made by Swordy (1993). Though the accuracy of experimental data at high energy is not very good it can be clearly seen a difference between the spectrum of protons and the spectra of nuclei of $Z \geq 6$ in the energy region above 100 GeV per nucleon, where effects of modulation and propagation become unimportant. While the spectra of nuclei have a tendency to become flatter with increasing energy, the opposite is true for protons. It can be seen that the helium spectrum is probably intermediate between them. The difference between the spectra of protons and nuclei was discussed in (Zatsepin 1995) on the base of experimental data obtained in the SOKOL experiment and in two balloon emulsion experiments MUBEE and JACEE in the energy region above 1 TeV. An additional evidence of two components (fluxes) with different slopes of energy spectra can be seen in the TIC experiment (Adams *et al* 1997) in the wider energy region from $10^{11} eV$ up to $10^{14} eV$.

2 Model

It will be shown that the following model proposing two fluxes in the Galactic cosmic rays can reasonably good fit the set of the experimental data.

1. The energy spectrum of the first flux consisting mainly of medium and heavy nuclei is not single power-law. It can be fitted in the first approximation as a sum of two single power law spectra in rigidity R: $dn/dR = a_Z \times (R^{-3.0} + 0.01 \times R^{-2.2}) \times f_1(R)$,
where R is in GV; $a_{CNO} = 393.5$; $a_{Ne-S} = 113.5$; $a_{Fe} = 36.5$ in $m^{-2} \times sec^{-1} \times ster^{-1} \times GV^{-1}$,
and $f_1(R) = (1 + (R/R_1^{max})^3)^{-0.8/3}$
2. The proton spectrum (the second flux) is represented as: $dn/dR = 11480 \times R^{-2.7} \times f_2(R)$,
where $f_2(R) = (1 + R/R_2^{max})^{-0.3}$
3. The helium spectrum is a mixture of these two fluxes and is fitted as following:
$dn/dR = 1703 \times ((R^{-3} + 0.01 \times R^{-2.2}) \times f_1(R) + R^{-2.7} \times f_2(R))$
4.We assume cosmic rays to be accelerated by shock fronts of supernova remnants up to some rigidity R^{max}. This parameter may be different for two fluxes in question. To fit data of EAS we take $R_1^{max} = 70TV$ for the flux of medium and heavy nuclei and we take $R_2^{max} = 20TV$ for protons and proton-like portion of helium to fit their spectra obtained in the direct measurements at high energies. At $R > R^{max}$ we suppose slopes of all components to be $\gamma = 3.0$. Functions f_1 and f_2 are included to smooth the transition to $\gamma = 3.0$.

Intensities in the model were normalised to the experimental data at $E_{kin} = 35GeV/n$. The intensi-

1999ICRC....4..136Z

ties of proton and helium were taken from *IMAX* experiment and $Z \geq 6$ nuclei were taken from *HEAO-3-2C* experiment. The results of calculations in the model are shown in fig.1, 2 and 3. In fig.1 the model is compared with the experimental data in spectra. The model does not pretend to fit the data at energy below $10GeV$ because we have not taken into account solar modulation and propagation effects.

The experimental data in fig.1 are:
CAPRICE:(Barbiellini *et al* 1997)
IMAX:(Menn *et al* 1997)
MUBEE:(Zatsepin *et al* 1993)
RICH: (Dwyer *et al* 1993)
SOKOL: (Ivanenko *et al* 1993)
HEAO: (Engelmann *et al* 1990)
JACEE: (Asakimori *et al* 1993, Asakimori *et al* 1998)

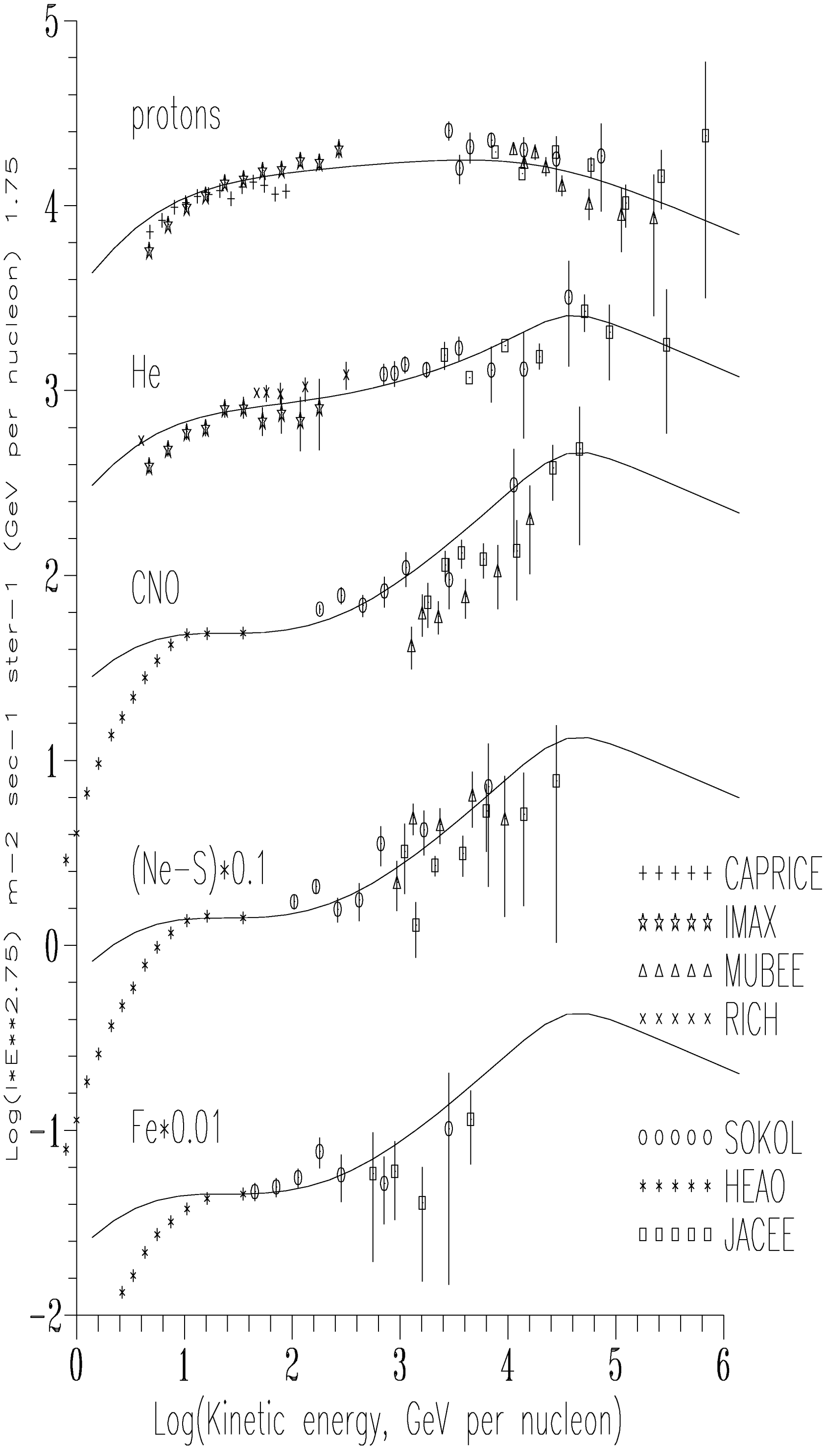

Figure 1: Spectra of Cosmic Rays, ('Fe' means nuclei of $Z > 17$)

At high energy, it must be kept in mind that absolute values of intensities may have some systematic errors. To exclude these errors in fig.2 we show how the model fits ratio of protons to nuclei of $Z \geq 6$.

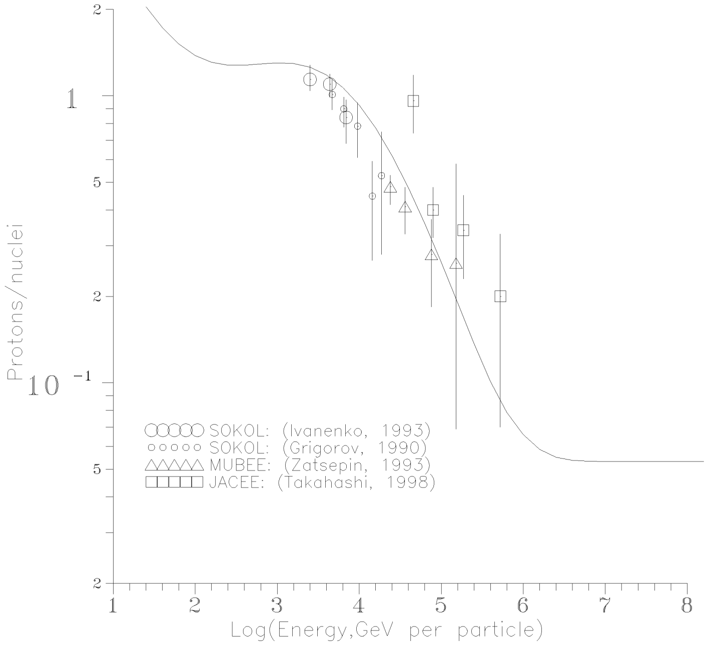

Figure 2: Ratio of protons to nuclei of $Z \geq 6$

It should be noted that in this representation the results of analysis of the SOKOL experiment by two groups (Ivanenko 1993, Grigorov 1990) do not differ while they differed strongly in intensity.
SOKOL(1): (Ivanenko *et al* 1993)
SOKOL(2): (Grigorov 1990)
MUBEE: (Zatsepin *et al* 1993)
JACEE: (Takahashi 1998)

In fig.3 is shown all particle spectrum in the model. This spectrum is compared with the TIC experiment and data of EAS. The data of the TIC experiment are still preliminary. The intensity of the TIC experiment was normalyzed to the data of IMAX and HEAO-3-2C experiments at energy $\approx$ 100 GeV per particle. The figure shows a reasonably good agreement between the model and the experimental data taking into account difficultes of reconstruction of all-particle spectrum for both the TIC experiment and the EAS data. The reconstruction for the EAS data depends on cosmic ray composition which is unknown. Besides, in the energy region from 3×10^{14} to $3 \times 10^{15} eV$ there is a problem of registration efficiency as is seen from a discrepancy between various experimental data in this region.
TIBET: (Amenomori *et al* 1995)
EAS-TOP: (Navarra *et al* 1998)
TUNKA: (Bryanski*et al* 1995)
AKENO: (Nagano *et al* 1984)
MSU: (Fomin *et al*1991)
TIEN-SHAN: (Vildanova *et al* 1994)
TIC: (Adams *et al* 1997)

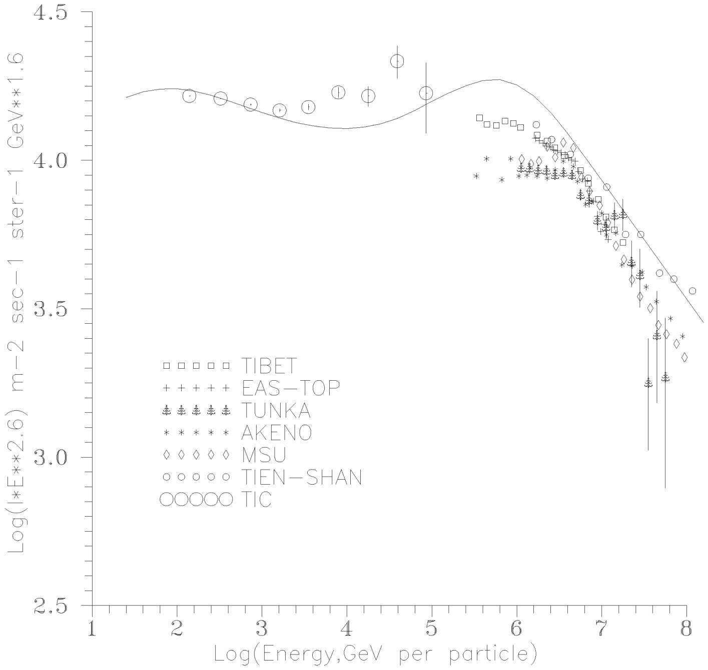

Figure 3: All-particle spectrum

3 Discussion

Diffusive acceleration on shock fronts in supernova remnants is believed to be the most preferable cosmic ray accelerating mechanism in the energy region up to $10^{14} \times Z$ eV. The unmodified shock front generates a single power-law momentum spectrum with the slope $\alpha = (\sigma + 2)/(\sigma - 1)$, where σ is compression. The strong fronts have $\sigma \approx 4$ and $\alpha \approx 2$. If through interaction with an ambient interstellar gas and accelerated particles shock front is modified the spectrum no longer obeys single power-law. In case of weakly modified shock front the shape of the spectrum in adiabatic stage may be roughly fitted with a sum of two power-laws of different indexes: α_1 for $p < 10^3 \times mc$ and α_2 above this momentum, with $\alpha_2 < \alpha_1$ (Berezhko *et al* 1996).It is just the behaviour one can see for the spectra of medium and heavy nuclei (see fig.1), and the formal fit of these spectra as a sum of two single power-law spectra may be considered as a rough description of spectra produced by modified shock fronts. Such spectra might be produced in explosions of massive stars. The interaction of a stellar wind of the massive star with ambient interstellar gas during evolution time $\sim 10^5 - 10^6 years$ leads to generation of an extend cavity . The cavity (bubble) consists of three distinct zones: (a) hypersonic stellar wind; (b) a region of shocked stellar wind; (c) shell of shocked interstellar gas (Weaver *et al* 1975). The second zone plays a mail role in cosmic ray generation, as the shock front moves through it during $t \sim 10^4 years$. This zone has significantly lower density than ambient unshocked interstellar medium and is characterized by high turbulence, which leads to effective acceleration of cosmic rays up to high energy (Berezhko *et al* 1996). The winds of massive stars are enriched with heavy elements (Wiebel-Sooth, Biermann & Meyer 1997). It is quite possible protons are not produced in this region in any detectable amount. In the framework of diffusive shock acceleration, it is possible that the proton spectrum is produced by weak shock fronts, i.e. when shock fronts come into the third zone and propagate through swept-up shells of shocked interstellar gas and then through an unshocked interstellar medium. In this case, the specrum is expected to be steeper, which is what we observe. Besides, in the unshocked interstellar medium the coefficient of diffusion may be significantly higher than Bohm coefficient, as indicated by earlier cutoff of the proton spectrum. If it is realy so, the protons might be also accelerated in explosions of small mass stars without strong winds (supernova I). The helium nuclei are accelerated mainly together with protons, but high energy helium is accelerated together with medium and heavy nuclei. The situation with very heavy nuclei $(Z > 17)$ is more uncertain because of low statistics.

References

Adams,J.H.,Jr. et al, Proc.25^{th}ICRC (Durban 1997), 3,401

Amenomori M. et al., Proc. 24^{th}ICRC (Roma 1995), 2, 736

Asakimori K. et al, Proc.23^{rd}ICRC (Calgary 1993), 2, 25

Asakimori K. et al, 1998, ApJ, 502,278

Barbiellini G. et al, Proc. 25^{th}ICRC (Durban 1997), 3,369

Berezhko E.G.,Ksenofontov L.T.& Yelshin V.K., 1996, Sov. JETP, 109,3

Bryanski S.V. et al, Proc. 24^{th}ICRC (Roma 1995), 2, 724

Dwyer J. et al,Proc. 23^{rd}ICRC (Calgary 1993), 1, 587

Engelmann J.J. et al, 1990, $A\&A$, 233, 96

Fomin Yu.A. et al, Proc. 22^{nd}ICRC (Dublin 1991), 2, 85

Grigorov N.L. 1990, Yadernaya Fiz. 51, 157

Ivanenko I.P. et al,Proc. 23^{rd}ICRC (Calgary 1993), 2, 17

Menn W. et al, Proc. 25^{th}ICRC (Durban 1997), 3,409

Navarra G. et al, 1998, Nuclear Phys B (Proc.Suppl.) 60B 105

Nagano M. et al, 1984, J.Phys.G: Nucl.Part.Phys. 10 1295

Swordy S. Proc. 23^{rd} ICRC (Calgary,1993), Rapporteur& Highlight papers, 243

Takahashi Y. 1998, Nuclear Phys B (Proc. Suppl.) 60B 83

Vildanova L.I. et al, 1994 Izv. RAN, ser.fiz., 58 79

Weaver R. et al, 1977, ApJ 218, 377

Wiebel-Sooth B.,Biermann P.L.& Meyer H.,1998,$A\&A$ 330 389

Zatsepin V.I. 1993, J.Phys.G: Nucl.Part.Phys. 21, L31

Zatsepin V.I. et al, Proc. 23^{rd}ICRC (Calgary 1993), 2, 13