The Origin of the Breaks in the Cosmic-Ray Spectra

Sylwester Kornowski

Abstract: Here, applying the atom-like structure of baryons described within the Scale-Symmetric Theory, we calculated the threshold energies for the 11 most important breaks in the cosmic-ray spectra: 5 for the cosmic electrons plus positrons, 1 for positrons and 5 for all cosmic particles. Obtained results are consistent with observational data.

1. Introduction

The composition of cosmic rays is as follows: protons (~86%), helium nuclei (~10%), electrons (~1%), gamma ray photons (<1%), ions and antimatter. We can see that protons dominate. The distribution of the proton energy of cosmic rays peaks at ~0.3 GeV [1]. It suggests that colliding protons create some very unstable particle-antiparticle pairs which components are electrically charged and have the rest mass close to 0.3 GeV. Such pairs can decay to two photons – they can collide with other cosmic particles.

On the other hand, the unknown in mainstream physics phase transitions of the inflation field lead to the atom-like structure of protons/baryons described within the Scale-Symmetric Theory (SST) [2], [3].

Below we described physical quantities, which are calculated in SST, which will be used in this paper. Here the symbols of objects/particles denote as well their masses.

SST shows that in the baryons, there is the core composed of the spin-1/2 electric charge with a mass of $X^{+,-} = 0.3182955$ GeV ≈ 0.32 GeV [3], which is consistent with the ~0.3 GeV for the cosmic rays. There is the spin-0 central condensate with a mass of $Y = 0.4241245$ GeV – mass of the region of the Einstein spacetime that overlaps with the Y condensate is $E_Y = 17.12$ TeV [3]. And there is a relativistic pion in the S state i.e. the azimuthal number of it is $l = 0$ [3]. Such very simple model leads to properties of particles which all are consistent or very close to experimental data – it concerns as well the mean square charge of nucleon [3].

The electric charge $X^{+,-}$ is a torus composed of the entangled Einstein-spacetime components (it is the short-distance entanglement) [3]. On surface of it can appear tori with infinitesimally larger size. Colliding protons produce the $X^{+}X^{-}$ pairs which are very important in SST because they appear in many phenomena described within SST – for example, we used them to show the relationships between SST and the Standard Model [4].

Mass of the core of baryons is $H^{+,-} = 0.7274401$ GeV – it is lower than $X^{+,-} + Y = 0.74242$ GeV because the binding energy is 14.98 MeV [3]. The $H^{+,-}$ is a proton analogue to the electron $e^{+,-} = 0.5109989$ MeV and to muon $\mu^{+,-} = 105.66$ MeV – their masses are calculated within SST [3].

The fine-structure constant calculated within SST is $\alpha_{em} = 1/137.0360$ whereas the coupling constant for the nuclear weak interactions of the nucleons/baryons, because of the exchanges of the Y condensates, is $\alpha_{w(proton)} = 0.0187228615$ [3].

The electric-charges/tori of $X^{+,-}$ and $e^{+,-}$ are built of the same number of entangled Einstein-spacetime components (so their values are the same) but the mean distances between them are different – it causes that their equatorial radii are different. For $X^{+,-}$ is $A = 0.6974425 \cdot 10^{-15}$ m whereas for electron is $\lambda\!\!\!^{-}_{bare(electron)} = A\,Z_5 = 3.8660707 \cdot 10^{-13}$ m, where $Z_5 = 554.321$ [3].

Notice that a transition from e^+e^- pair to H^+H^- pair, increases the energy the following number of times

$$F_1 = (H^+ + H^-) / (e^+ + e^-) = 1423.6 \,. \tag{1}$$

Similar value we obtain for a transition from $e^{+,-}$ to $X^{+,-}$ and a simultaneous transition from electromagnetic interactions to weak interactions of baryons

$$F_2 = (\lambda\!\!\!^{-}_{bare(electron)} / A)\,(\alpha_{w(proton)} / \alpha_{em}) = 1422.2 \,. \tag{2}$$

A mean value is

$$F = 1423 \,. \tag{3}$$

This value and the two others listed below are most important to decipher the cosmic ray spectra

$$Z_5 = \lambda\!\!\!^{-}_{bare(electron)} / A = 554.321 \,. \tag{4}$$

$$R = \alpha_{w(proton)} / \alpha_{em} = 2.56571 \,. \tag{5}$$

2. The breaks in the cosmic-ray spectrum of electrons and positrons

When there are created some fermion-antifermion pairs that decay to two photons moving directionally then the local mass density of fields decreases – it causes that number density of created electrons and positrons decreases too. Such processes deflect the curve E^3**x**$Flux = f(E)$, representing spectrum, to the right (see Fig.1).

On the other hand, dissolving binding energy (for example, from the nuclear processes) or dissolving condensates (for example, the Y condensates) increase the local mass density of fields – it causes that number density of created electrons and positrons increases too. Such processes deflect the curve E^3**x**$Flux = f(E)$ representing spectrum to the left.

Threshold energies for changes in the direction of the spectral curve can be calculated from the following formulae. For fermion-antifermion pair is

$$E_{fermion,R} = 2\, M_n\, F \text{ (to the right) ,} \tag{6}$$

where M_n are the energies/masses of fermions.

For binding energy or condensate is

$$E_{energy\text{-}condensate,L} = 2\, M_n\, F\, R \text{ (to the left) .} \tag{7}$$

In formula (7) appears the factor R because the transition from electromagnetic interactions to weak interactions of binding energy or condensates causes the energy/mass to dissolve.

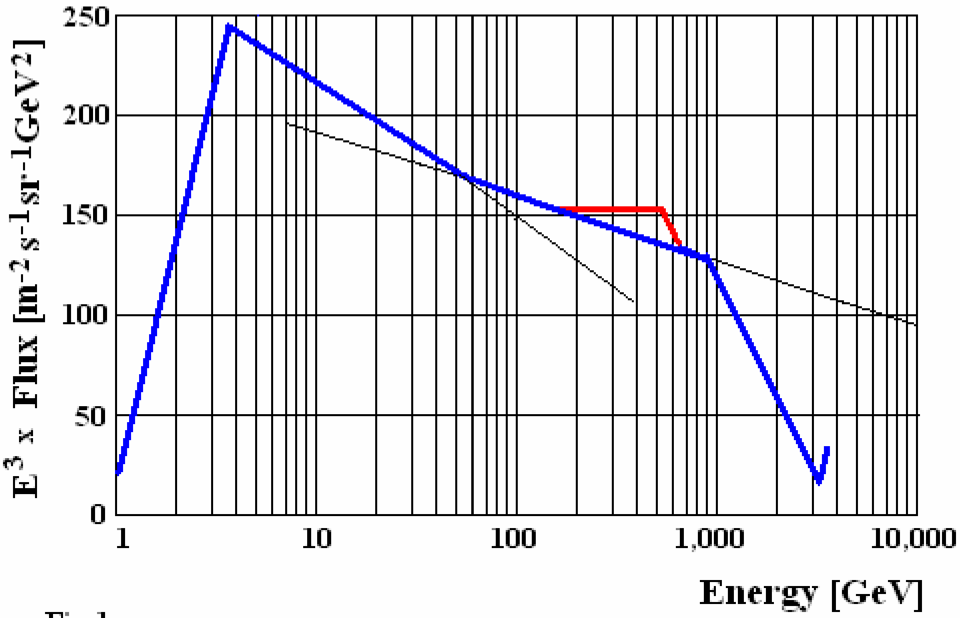

Fig.1
Some combination of the experimental flux (multipied by E^3) and the theoretical threshold energies for the cosmic e+e− spectrum from the Scale-Symmetric Theory.

The two breaks to the right are for the most speedy electrons and positrons from beta decays ($E^{+,-} = 1.3$ MeV) and for the X^+X^- pairs – from formula (6) we obtain

$$E_{E(+,-)=1.3MeV,R} = 2\, E^{+,-}\, F = 3.7 \text{ GeV ,} \tag{8}$$

$$E_{X(+,-),R} = 2\, X^{+,-}\, F = 906 \text{ GeV .} \tag{9}$$

The two breaks to the left are for the mean binding energy per nucleon in atomic nuclei ($E_{per\text{-}nucleus} \approx 8$ MeV) and for the Y condensates – from formula (7) we obtain

$$E_{E(per\text{-}nucleus)\approx 8MeV,L} = 2\, E_{per\text{-}nucleus}\, F\, R = 58 \text{ GeV ,} \tag{10}$$

$$E_{Y,L} = 2\, Y\, F\, R = 3{,}100 \text{ GeV .} \tag{11}$$

In collision of proton with antiproton there can appear six e^+e^- pairs. It is because the X^+X^- pair decays to two photons whereas the two pions in the S states can decay to four photons

$$p\, p_{anti} \rightarrow 6\,\gamma \rightarrow 6\,(e^+e^-)\,. \tag{12}$$

It leads to conclusion that the electrons have energies 6 times lower than the protons. Energy of protons we can calculate applying formula (6)

$$E_{p(+,-),R} = 2\,p^{+,-}\,F = 2{,}670\ \text{GeV}\,. \tag{13}$$

The electrons from the transitions defined by (12) have energy six times lower 2,670/6 = 445 GeV so there should be an increase in flux of electrons and positrons for such energy – see the red curve in Fig.1.

Obtained here results we can compare with observational data [5], [6], [7]. We can see that the theoretical results are consistent with observational data.

3. The break in the cosmic-ray spectrum of positrons

The positron fraction peaks around energy of 275 ± 32 GeV [8] i.e. there is a break. Assume that such positrons are from decays of positively charged muons produced by protons. Applying formula (6) we obtain

$$E_{\mu(+)=105.66MeV,R} = 2\,\mu^+\,F = 301\ \text{GeV}\,. \tag{14}$$

We can see that also this result is consistent with experimental data.

4. The break in the cosmic-ray spectrum of all particles

In Introduction we showed that there should be a maximum (i.e. a break to the right) for energy $X^{+,-} = 0.3183$ GeV.

Presented here model shows that there should be a massive break to the right in the cosmic-ray spectrum for energy $2.7 \bullet 10^{19}$ eV. It is the all-particle spectrum as a function of energy-per-nucleus for air shower. To explain it notice that there can appear a condensate composed of the Einstein-spacetime components with the short-distance entanglement which occupies the volume of the Y condensate. SST shows that then mass increases to about

$$M^{+,-} = Z_5\,E_Y = 0.95 \bullet 10^7\ \text{GeV}\,. \tag{15}$$

This mass/energy is $M^{+,-}/X^{+,-} = 3.0 \bullet 10^7$ times higher than $X^{+,-}$. The calculated threshold energy for $X^{+,-}$ is $E_{X(+,-),R} = 906$ GeV (see formula (9)) so the threshold energy for $M^{+,-}$ is

$$E_{M(+,-),R} = E_{X(+,-),R}\,M^{+,-} / X^{+,-} = 2.7 \bullet 10^{19}\ \text{eV}\,. \tag{16}$$

The same mechanism for the proton-antiproton pair leads to the knee for

$$E_{p(+,-),R} = E_{M(+,-),R}\,p^{+,-} / E_Y = 1.5 \bullet 10^{15}\ \text{eV}\,. \tag{17}$$

The same mechanism for the deuteron-antideuteron pair (D^+D^- pair) leads to the knee for

$$E_{D(+,-),R} = E_{M(+,-),R}\,(p^{+,-} + n) / E_Y = 3.0 \cdot 10^{15}\ \mathrm{eV}\ . \qquad (18)$$

Values obtained in formulae (17) and (18) are close to each other so there should be one knee for about $1.5 \cdot 10^{15} - 3.0 \cdot 10^{15}$ eV.

The same mechanism for nucleus of iron leads to the knee for

$$E_{Fe(+,-),R} = E_{M(+,-),R}\,(26\,p^{+,-} + 30\ \ n) / E_Y = 8.3 \cdot 10^{16}\ \mathrm{eV}\ . \qquad (19)$$

Indeed, the KASCADE-Grande experiment has reported observation of a second steepening of the spectrum near $8 \cdot 10^{16}$ eV [9] so next there must be a break to the right.

Obtained here 5 results for breaks in the cosmic-ray spectrum for all particles are consistent with experimental data (see Figure 24.8 in [5]).

5. Summary

Observed flux depends on evolution of the Universe and number densities of different sources of cosmic rays. It is practically impossible to write a complete function defining relationship between flux and energy of cosmic rays. Here, to simplify the considerations, we used the experimental fluxes for the threshold energies and we calculated the threshold energies for the breaks in the cosmic-ray spectra applying the atom-like structure of baryons described within the Scale-Symmetric Theory.

Calculated here the threshold energies for the 11 most important breaks in the cosmic-ray spectra are consistent with observational data.

References

[1] E. S. Seo, *et al.* (23 January 1991). “Measurement of Cosmic-Ray Proton and Helium Spectra during the 1987 Solar Minimum”
The Astrophysical Journal, 378: 763-772, 1991 September 10

[2] Sylwester Kornowski (11 May 2017). “Initial Conditions for Theory of Everything”
http://vixra.org/abs/1705.0176

[3] Sylwester Kornowski (6 June 2016). “Foundations of the Scale-Symmetric Physics (Main Article No 1: Particle Physics)”
http://vixra.org/abs/1511.0188

[4] Sylwester Kornowski (29 May 2017). “The Scale-Symmetric Theory as the Origin of the Standard Model”
http://vixra.org/abs/1705.0332

[5] K. Nakamura *et al.* (Particle Data Group, 16 February 2012). “COSMIC RAYS”

[6] A. D. Panov (2013). “Electrons and Positrons in Cosmic Rays”
J. Phys.: Conf. Ser. **409** 012004

[7] DAMPE Collaboration (29 November 2017). “Direct detection of a break in the teraelectronvolt cosmic-ray spectrum of electrons and positrons”
arXiv:1711.10981v1 [astro-ph.HE]

[8] L. Accardo (AMS Collaboration), *et al.* (18 September 2014). “High Statistics Measurement of the Positron Fraction in Primary Cosmic Rays of 0.5 – 500 GeV with the Alpha Magnetic Spectrometer on the International Space Station”
Physical Review Letters **113**: 121101

[9] W. D. Apel, *et al.* (2011).
Phys. Rev. Lett. **107**, 171104 (2011)