"PIPETTE" BIRTH MECHANISM OF GALAXY COSMIC RAYS AND THE PROBLEM OF FRACTURES IN THEIR SPECTRUM

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Cosmic rays with energies, $E \le 10^8$ eV, are bearing at the Solar and named Solar rays. More energetic ones are named galaxy cosmic rays (GCR) and their origin is unknown though there are some hypothesizes. The "shock wave" hypothesis about GCR acceleration in magneto-active plasmas by the front of the shock waves, arising due to the Super-new stars explosions, is the most popular one [1]. One more the "pinch mechanism" of GCR acceleration in cylindrical pinches of cosmic plasma was suggested and studied in our previous works [2-7]: the perturbations of necks type spontaneously arise and grow due to flutter instabilities in plasma pinches shrinking by magnetic fields of pinches surface currents. In the present work on the ground of the "pinch model" the formula for GCR intensity, very consistent with observations (Fig.1), is derived and probable reasons of fractures arising in GCR spectrum (Fig.2) are discussed.
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1. THE GCR INTENSITY FORMULA

The "pinch mechanism" of acceleration leads single-significantly to the GCR intensity formula, very consistent with observations (α is a normalization factor):

$$j(\varepsilon) = \alpha\beta^2\gamma^{-\nu}, \qquad (1)$$

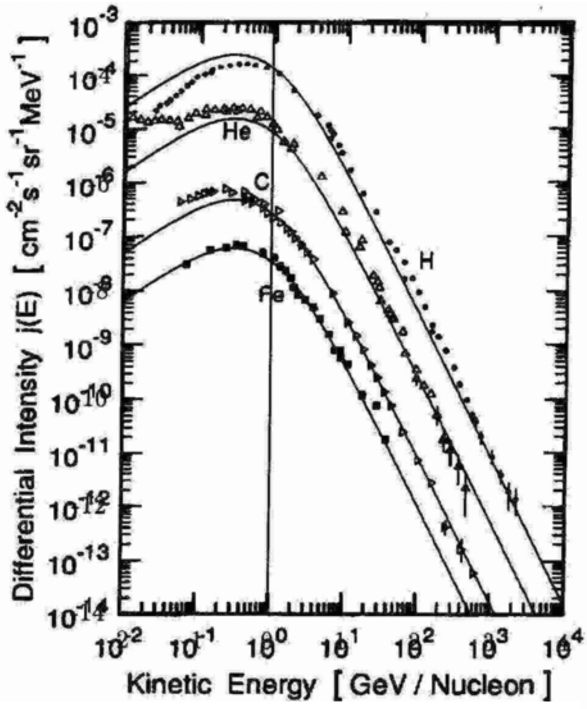

Fig. 1. Comparison of the observable GCR intensities (points) with the curves corresponding to the formula:

$$j(\varepsilon) = \alpha_Z^0 \beta^2 \gamma^{-\nu}$$

It worth to note that to derive this formula there were used:

1) the original equations of relativistic magneto-hydrodynamics $\partial_i(nu^i) = 0$, $\partial_i(T_k^i) = 0$, where n is the medium particle density, u^i - is 4 dimensional speedy and T_k^i is energy-momentum tensor. However, in proper coordinate system plasma is considered non-relativistic, with usual adiabat $p = p_0(n/n_0)^s$, and scin-current J_0 = const creates in cylindrical pinch of radius a

$$\nu = 1 + \sqrt{3}, \; \beta = \text{v/c}, \; \gamma = \frac{1}{\sqrt{1-\beta^2}},$$

$\varepsilon = \gamma - 1 = E_{kin}/m_p c^2$ is non-dimensional kinetic energy (look the Fig.1) .

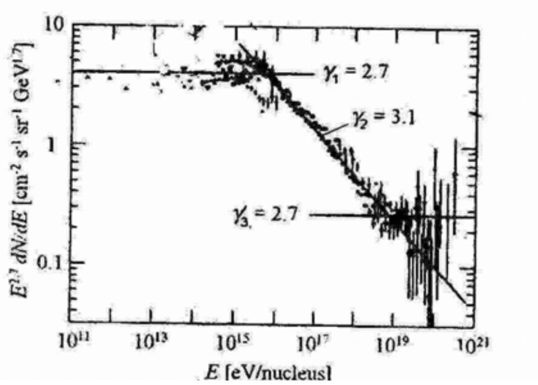

Fig. 2. The observable fractures in GCR spectrum

the pressure $p = B^2/8\pi = p_0(a_0/a)^2$;

2) two arguments in the 1D "narrow canal" approximation are τ=ct and z . Then we introduce the next non-dimensional magnitudes:

$c_0^2 = sp_0/[(s-1)n_0 m_i c^2$ = const,

running density $\rho_*(\tau, z) = na^2/n_0 a_0^2$ and functions:

$$x(\tau, z) = c_0^2/\rho_*, \; y(\tau, z) = Arc\cosh(\gamma),$$

defined by two non-linear equations:

$$(\gamma/x)'_\tau + (u/x)'_z = 0, \qquad (2)$$

$$u'_\tau + \gamma'_z + \gamma x'_z + u x'_\tau = 0;$$

3) then we introduce inverse functions $\psi(x, y)$, $\varphi(x, y)$ in accordance with formulas:

$$\tau = T(x, y) = (\beta\psi - \varphi)W,$$

$$z = Z(x, y) = (\psi - \beta\varphi)W, \; W = xe^{-x}\gamma,$$

obtain equations for them

$$\varphi'_y = \psi'_x + (\psi/x), \; \psi'_y = x(\varphi - \varphi'_x)$$

and on this ground the main equation of the problem:

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$$\hat{L}\varphi + \varphi''_{yy} = 0$$

(3)

$$\hat{L}\varphi = x\varphi''_{xx} + (2-x)\varphi'_x - 2\varphi,$$

where $\hat{L}$ is the operator of Lagerr polynomials $\lambda_n = L_n^{(1)}(x)$ satisfied equations $\hat{L}\lambda_n = -(n+2)\lambda_n$ (n=0,1,2,3...);

4) a general solution has the form: $\varphi = \sum_{n=0}^{\infty} K_n \lambda_n(x)\mu_n(y)$ and for second functions we obtain the main equation of the problem:

$$\mu''_{yy} = (n+2)\mu,\ \mu_n = \exp(-|y|\sqrt{n+2}); \quad (4)$$

5) in the ultra-relativistic case, when γ>>1, it is possible to leave two terms n=0, n=1. But null term n=0 describes periodical perturbations along whole, endless pinch which in conditions of the space can not arise spontaneously. It is considered that in reverse time limit t→ -∞ the perturbations were absent; rather their "baits" were exponentially small. Therefore the term with n=0 it is necessary to truncate, and only the single local solution remains

$$\varphi_1(x,y) \approx K_1\lambda_1(x)\gamma^{-\sqrt{3}}; \quad (5)$$

6) the number of particles accelerated in one pinch, obviously, is

$$N = \int(\pi a^2 n\gamma - \pi a_0^2 n_0)dz = \int(dN/du)\,du = \int(dN/d\varepsilon)d\varepsilon.$$

From here it follows the formulas $\beta dN/d\varepsilon = dN/du = \pi a_0^2 n_0(\rho_* - 1/\gamma)dZ(x,y)$, where $dZ(x,y)/dy = Z'_x dx/dy + Z'_y$. But total derivative $dZ(x,y)/dy$ is calculated for fixed time moment, when $dT(x,y) = T'_x dx + T'_y dy = 0$, and $dZ/dy = Z'_y - Z'_x(T'_y/T'_x)$. Denoting

$$\Psi(x,y) = \psi - \varphi'_y,\ \Phi(x,y) = \varphi - \psi'_y,\ W = \gamma x e^{-x},$$

we shall find derivatives:

$$T'_x/W = \beta\Psi - (\Phi/x), \qquad T'_y/W = \Psi - \beta\Phi,$$

$$Z'_x/W = -(\beta/x)\Phi - \Psi,\ Z'_y/W = \beta\Psi - \Phi$$

and the spectrums

$$\beta\frac{dN}{d\varepsilon} = \frac{dN}{du} = -\pi a_0^2 n_0(c_0^2 - \frac{x}{\gamma})(\frac{e^{-x}}{\gamma})\frac{\Phi^2 + x\Psi^2}{\Phi + x\beta\Psi}; \quad (6)$$

7) it is seen from relations

$$p = p_0(a_0/a)^2,\ x = c_0^2/\rho_*,$$

$$\rho_* = na^2/n_0a_0^2 = (a/a_0)^{4/5} = (n/n_0)^{-2/3}$$

that particles are accelerating moving from narrow places to thickenings, where $a \to \infty$ and $\rho_* \to \infty$, $x \to 0$. And in the limit $x \to 0$, when $\psi = 0$, we receive the spectrums

$$\beta\frac{dN}{d\varepsilon} = \frac{dN}{du} = -\frac{A_0}{\gamma}\varphi_1(x=0,y), \quad (7)$$

where $A_0 = \pi a_0^2 n_0 c_0^2$=const. In the limit $\gamma = 1 + \varepsilon >> 1$ we receive:

$$\varphi_1(x=0,y) = K_1\lambda_1(x=0)\gamma^{-\sqrt{3}} \text{ and}$$

$$dN/d\varepsilon = const\cdot\gamma^{-(1+\sqrt{3})} \quad (8)$$

This spectrum well describes the total ultraviolet energy region.

8) we receive the particles flux intensity multiplying the spectrum and velocity v=cβ

$$j(\varepsilon) = \mathrm{v}\frac{dN}{du} = c\beta^2\frac{dN}{d\varepsilon} \approx \alpha\beta^2\gamma^{-\nu}, \quad (9)$$

where $\nu = 1 + \sqrt{3}$, and constants $\alpha = \alpha_i$ are different for observable GCR nuclei with different charges Z_i. Apparently they point proportion of different elements in GCR sources. For example amount of helium in them is less in 2.5 times (here it has already burnt out), but of iron more in 70 times (here it has synthesized) than at the average in Universe. Apparently, the total formula (1) for $\alpha = \sum_i \alpha_i$ is suitable for arbitrary energies of GCR particles (such an opinion was pronounced, in particular, in the work [10]). But the situation is complicating due to the fractures in GCR spectrum the nature of which is discussed below.

2. THE PROBLEM OF FRACTURES IN THE GCR SPECTRUM

At the energies $E_1 = 5\cdot10^{15}$ eV $E_2 = 5\cdot10^{18}$ eV in the GCR spectrum there are two fractures (see Fig.2) the nature of which is not clear. The modern detectors on satellites beyond atmosphere cannot already register so vigorous particles of the primary GCR spectrum. And all information about GCR for energies $E>10^{14}$ eV is received only from the ground observation of the secondary particles of "wide atmosphere downpours" (WAD) arising due to collisions of primary particles and nuclei of air molecules. However, on the base of WAD observations one can not to define single-significantly either there are fractures in the primary GCR spectrum or no. And last years there appeared some works (look [8-10]) in which it is supposed there are not fractures at all in the primary GCR spectrum but ones arise only in the secondary spectrums of WAD.

Vividly speaking, WAD is like "a fur-tree" with the central hadronic trunk and branches going down away the side with short "thorns"-paths. And as it is shown in the work [11] one of the reasons of appearing the first fracture of "knee" type at the energy E_1=3-5 PeV may proved to be the underestimation of WAD energy due to a measurement method. Namely one can suppose the hadronic trunk of WAD at the energy $E<E_1$ does not reach the earth surface and detectors correctly locate the total energy of secondary particles. But at the energy $E>E_1$ the low part of powerful hadronic trunk of WAD, apparently, goes into the ground ("goes into sand", bearing in part delayed neutrons), and substantial part of energy avoids the registration, that and leads to arising of the observable fracture.

Above this purely methodical reason, in works [8-10] it is noted the possibility of birth the new, at being present unknown particles at the energies $E>E_1$ or the new states of nuclear matter. And it is assumed during particles disintegration there may be born, in particular, Z- and W-bosons of the weak interaction disintegrating fast into muons and neutrino, which are not registered by present day WAD detectors. Similar situation arises under the known in the quantum chromodynamic process of Drell-Yan, when due collision of two hadrons there bears a pair of high-vigorous but hardly registered heavy muons. Neglecting by their energy also must exhibit itself as an observable fracture in GCR spectrum.

In the theory of Gaizenberg-Fermi-Landau collisions of the high-vigorous nuclei are studied (look reviews [12,13]). It considers at the frontal collisions there arises the flattened (in accordance with Lorentz) ellipsoid of anew born particles which are in thermodynamic equilibrium. Presently such a complex is usually named by the "quark-gluon plasma sack", which widening transforms to the "peony condensate" and then to hadronic down- pours. In accordance with the theory of Fermi-Landau the average number of resulting particles is

$$\langle N\rangle \approx \sqrt{E_{sci} / E_{\pi}^{0}} \quad , \tag{10}$$

where E_{sci} is the total energy of primary particles in the system of the center of inertia (SCI), and $E^0{}_\pi = m_\pi c^2 = 140$ MeV is the rest energy of peony. That formula is approximately consistent with observations at the energies achieved in modern accelerators.

If the primary particle with the energy $E_0 = mc^2\gamma_0$ collides with rest nucleus of the mass M, then in SCI we have:

$$E_{sci} = Mc^2\sqrt{1+(m/M)^2+2(m/M)\gamma_0} \; .$$

For example, the GCR proton with energy E_0=5 10^6 GeV and γ_0 =5 10^6, is capable, in principle, to bear 5 milions of nucleons. But if it collides with the rest nucleus of oxygen-16 then in SCI we have the energy

$$E_{sci} \approx c^2\sqrt{2mM\gamma_0} = 1.3\ 10^4 \text{ GeV}$$

and in accordance with the formula of Fermi-Landau it may bear only 300 primary particles-nucleons. Every such a nucleon goes on to move with final energy E_1^{fin}=17TeV, having the factor $\gamma_1 \approx 1{,}7{\cdot}10^4$ and all they bear subsequent cascades of particles.

Nevertheless, such a picture does not reveal a GCR spectrum fracture sharply enough at the energy $E_1=5\times10^{15}$eV, that for proton corresponds to relativistic factor $\gamma_{min}=5\times10^6$. Bellow we give the "half-quantitative" explanation of this critical value.

3. THE "COLLECTIVE" REASON OF FRACTURES IN GCR SPECTRUM

In the theory of Fermi-Landau the collective interactions are not taken into account. In the review [13] it is said on this point: "the existence of collective interactions is extremely probable as well, however the section of those processes is the small part of the whole section. And the model of individual collisions is close to reality…". But in our opinion, it may be correct for relatively moderate energies and fails for ultra-high energies near fractures in GCR spectrum. First let us return to the primary Gaizenberg theory, where the number of secondary particles is not defined by the formula (10), but by another formula (look [13])

$$\langle N\rangle \approx E_{sci} / E_{\pi}^{0} \, , \tag{11}$$

and, for example, with the primary proton and the nucleus oxygen-16, mentioned above, instead of 300 particles now we have 300^2 = 90 thousands of secondary particles born in one act of collision, but not in cascades. If they are nucleons then with every of them it will be connected the final energy E_1^{fin}=(17/300)TeV=57GeV, corresponding for nucleon to only relatively small relativistic factor $\gamma_1 \approx 57$.

In the Fermi-Landau theory on frontal collision and integration of two nucleus the phase of formation the primary Loretze-compressed ellipsoid is considered as momentary. In more common case we shall consider collisions, in first, as not central ("face into face") but splayed ones, at which the given birth quark-gluon sack gains moment of rotation. And, in second, at the phase of sack growth we shall describe its inside part by most simple hydrodynamic equation of "pair quark breeding" taking into account their leaving from the sack

$$\frac{dn}{dt} = \frac{n^2}{2}\langle\sigma\cdot \text{v}\rangle - \frac{n}{\tau} . \tag{12}$$

Here n is quark density, σ is the section of the quark-anti-quark pair birth and τ is the quark "life time" in the sack. Breeding begins if dn/dt ≥ 0 i.e. under condition $n \geq 1/\langle\sigma v\rangle\tau$, where the multiplication vτ approximately equals to the "sack" radius R_s.

A proton radius is considered usually being to $r_p = 1{,}2\times10^{-13}$ cm and its volume to $V_p = (4/3)\pi\ r_p^3$. Accordingly, for nucleus with N nucleons and 3N quarks we have the radius $R_N = N^{1/3} r_p$ and the volume $V_N = NV_p$. Therefore, the quark density in all "rest" nuclei is the same and equals:

$$n_q^0 = 3N/V_N = (9/4\pi) r_p^{-3} \approx 4 \cdot 10^{38}\ \text{cm}^{-3}.$$

In moving "sack" the density is necessary to multiply at the final factor γ_1, and then the condition of collective quarks breeding has the form

$$\gamma \geq \gamma_{\min} = \frac{1}{n_q^0\langle\sigma\cdot v\rangle\tau} = \frac{4}{9}\left(\frac{\pi\cdot r_p^2}{\sigma}\right)\frac{r_p}{R_{меш}} , \tag{13}$$

where πr_p^2 =4,5 10^{-26} cm. At the compact packing of N=90000 nucleons in the "sack" its radius is $R_s = N^{1/3} r_p$ = =45 r_p and then the value is γ_1=57 for the section of the quark pair birth $\sigma_p \approx 5\ 10^{-4}\ r_p^2 = 8\times10^{-30}$ cm^2. Thus, taking into account the collective interactions points at the existence of definite critical "threshold".

It worth note the found section σ_p allows another interpretation in the frame the "stringed model of hadrons" that is close but somewhat differ from the "sack" model. How it is pointed in the review [12]; " in the string model … a hadron is presented as the quark system tightened by gluon tubes and at the collision strings is "entangled", strained and broken. At that, at the ends of the break there bears the quark-anti-quark pair so that, may be, the magnitude σ_p, defined above, is possible interpret simply as minimal geometrical section of gluon tube before it's the break?

At last, note that at the non-central collision of two original hadrons it may arise common ball of gluon tubes and quark pairs rotating quickly around horizontal axis (since the primary particle falls from above and, vividly speaking, such a ball is like a chain, wound around windlass of the well, with water bucket lifted up). At the disintegration of such rotating ball there must arise cascades, that at the earth surface will give "spots-foot-prints" located along straight line. How it was noted in the work [10], such a phenomena is named the "lining up of group of separate cascades" and observed in WAD but only at the energies of primary particles beginning from E≈10 PeV, i.e. from the right of the fracture of "knee" type and not observed at the energies from the left of this fracture (look Fig.2). That peculiarity underlines the threshold character of fractures of GCR spectrum.

At last, one may suggest second fracture of "ankle" type at the energy $E_2 = 5\times10^{18}$ eV comes at the "Great Integration" all four forces of Nature, when resulting "ball", apparently is like the "bit of Universe" in the moment of Big Bang. However, here it is necessary further experimental investigations.

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1) possibility of new interpretation of fractures in GCR spectrum as secondary phenomenas in WAD at the probable absence of real fractures and
2) possibility of explanation of the "lining up of group of separate cascades" in WAD presented above.

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«ПИПЕТОЧНЫЙ» МЕХАНИЗМ РОЖДЕНИЯ ГАЛАКТИЧЕСКИХ КОСМИЧЕСКИХ ЛУЧЕЙ И ПРОБЛЕМА ИЗЛОМОВ ИХ СПЕКТРА

Б.А. Трубников

Космические лучи с энергиями $E \leq 10^8$ eV рождаются на Солнце и называются солнечными лучами. Более энергичные лучи называются галактическими космическими лучами (ГКЛ), и их природа неизвестна, хотя имеется несколько гипотез. "Ударно-волновая гипотеза" об ускорении ГКЛ в магнитоактивной плазме фронтами ударных волн, возникающих вследствие взрывов сверхновых звёзд, является наиболее популярной [1]. Еще один – "пинчевый механизм" ускорения ГКЛ в цилиндрических пинчах космической плазмы был предложен и исследован в наших работах [2-7]: возмущения типа перетяжек спонтанно возникают и нарастают за счет желобковых неустойчивостей, развивающихся в плазменных пинчах, сжимаемых магнитными полями, рождаемыми поверхностными токами пинчей. На основе модели сжимаемого пинча получена формула интенсивности ГКЛ, хорошо согласующаяся с наблюдениями (Рис.1), и обсуждаются возможные причины появления изломов в спектре ГКЛ (Рис.2).

"ПІПЕТОЧНИЙ" МЕХАНІЗМ НАРОДЖЕННЯ ГАЛАКТИЧНИХ КОСМІЧНИХ ПРОМЕНІВ І ПРОБЛЕМА ЗЛАМІВ ЇХНЬОГО СПЕКТРА

Б.А. Трубніков

Космічні промені з енергіями $E \leq 10^8$ eV народжуються на Сонці і називаються сонячними променями. Більш енергійні промені називаються галактичними космічними променями (ГКП), і їхня природа невідома, хоча мається кілька гіпотез. "Ударно-хвильова гіпотеза" про прискорення ГКП у магнітоактивній плазмі фронтами ударних хвиль, що виникають унаслідок вибухів наднових зірок, є найбільш популярною [1]. Ще один – "пінчевий механізм" прискорення ГКЛ у циліндричних пінчах космічної плазми був запропонований і досліджений у наших роботах [2-7]: збурювання типу перетяжок спонтанно виникають і наростають за рахунок жолобкових нестійкостей, що розвиваються в плазмових пінчах, стиснутих магнітними полями, народжуваними поверхневими струмами пінчів. На основі моделі стисливого пінча отримана формула інтенсивності ГКП, що добре погоджується зі спостереженнями (Мал.1), і обговорюються можливі причини появи зламів у спектрі ГКП (Мал.2).