HE.1.2.02

Fraction of gamma-hadron families similar to that of Fe induced against heavy chemical composition of primary cosmic rays in the energy region around 10^{16} eV.

M.Kalmakhelidze[1],R.Mukhamedshin[2], N.Roinishvili[1], S.Slavatinski[3],M.Svanidze[1]

[1]*Institute of Physics, Academy of Sciences of the Georgian Republic, Tamarashvili 6, Tbilisi, Georgian Republic, SU-380077.*

[2]*Institute for nuclear Physics, Russian Academy of Sciences, 117312 Moscow, Russia*

[3]*Lebedev Physical Institute, Russian Academy of Sciences, 117924 Moscow, Russia*

Abstract

One-dimensional and multi-dimensional methods of image recognition are elaborated and applied to analyze of gamma-hadron families with the aim to select families similar to that induced by Fe nucleus of primary cosmic ray. The fraction of them appears much less than that expected if primary cosmic rays are enriched by heavy elements.

1 Introduction:

The attempt of selections of families similar to that induced by Fe nuclei by means of image recognition methods were done in the several papers. All of them claim that compositions enriched with heavy components are in contradiction to experimental results. Only compositions near to the normal can satisfy them. The description of the method and short review of the mentioned works are given in section 2. In the next subsection our original investigations are brought. The most encouraging is the result of reconstruction the fraction of Fe families inputted into calculations by the method, which is proposed. The main conclusion is again – only results at the normal composition are consistent with the experiment.

The details concerning experimental data, used models and analysed chemical composition are given in reference (Kalmkhelidze et al, 1999), HE1.2.14.

2 Selections of families generated by iron nuclei. A short review:

An attempt to determine a fraction of iron nuclei in PCR on a database of X-ray emulsion chamber was undertaken in works (Asimov et al, 1987; Chilingarian et al, 1983, 1985, 1987; Yuldashbaev et al, 1997). A multi-dimensional analysis of image recognition was suggested for this task by two groups of authors almost simultaneously (Asimov et al, 1987; Chilingarian et al, 1983, 1985, 1987). The sense of it is to define some limiting value for a chosen parameter, P_{lim}, such that event with $P_{fam} \geq P_{lim}$ can be considered as a family similar to that generated by iron. This event is attributed to a "Fe" group of families. Otherwise, if $P_{fam} < P_{lim}$ then family is added to group "P". A fraction of families, f ', "similar to iron" is determined by this way. Obvious such selection is effective if distributions of the chosen parameter of families generated by iron and proton sufficiently differ. A multi-dimensional method of image recognition means that limiting values are defined for several parameters P_{lim}^1, P_{lim}^2, P_{lim}^3 etc. Families which simultaneously satisfy the requirements:

$$P^1 \geq P_{lim} \qquad P^2 \geq P_{lim}^2 \qquad P^3 \geq P_{lim}^3$$

and so on, are attributed to group "Fe". Fractions of families induced by nuclei A and satisfying limiting conditions (looking like Fe produced events) are designated R_A.

Two types of errors occur in the image recognition method. The error of the first type is to attribute families from proton to "Fe" group (R_P) and the error of the second type is not to "recognise" iron family and not to added it to "Fe" group, $(1 - R_{Fe})$. The quality of the selection is defined by values of these two errors. As more sensitive are the parameters to atomic number the stronger differ distributions of parameters for P and Fe families. As a consequence cleaner and more complete is the selection as both errors are small. If not only proton and iron induced families are involved then the error of the first type includes all families from nuclei A (except Fe) falsely attributed to the "Fe" group.

Quasi-scaling models were used for determination of limiting values of parameters P_{lim}^{i} in the all three mentioned works. Training sets of families generated by P and Fe were simulated. Distributions of various parameters allowed determination of the boundary quantities P_{lim}^{i}. It was found (Asimov et al, 1987; Chilingarian et al, 1983, 1985, 1987) that it is impossible to use simultaneously more than two parameters because of limited statistics of families. Therefore either $E_\gamma R_\gamma$ and parameter of asymmetry of a family **b** or $E_\gamma R_\gamma$ and n_γ were used in (Chilingarian et al, 1983, 1985, 1987). Another parameter of asymmetry, α, and parameter **d**, (for definition see in (Kalmkhelidze et al, 1999)), or their combination with R_γ were involved in (Asimov et al, 1987). Parameters **d**, α and 1/ R_γ^E in different combinations were analysed in (Yuldashbaev et al, 1997).

The fraction of families attributed to group "Fe", f ', is equal to

$$f' = f \times R_{Fe} + (1-f) \times R_P \qquad (1)$$

where **f** is the real fraction of families generated by iron. From (1)

$$f = (f' - R_P) / (R_{Fe} + R_P) \qquad (2)$$

Authors of the all three works applying the described method to families of Pamir Collaboration have found that the fraction of families generated by iron does not exceed 2-3 %, i.e. that the compositions of PCR with domination of iron contradict to the experiment.

The method of selection families generated by iron was essentially improved in work (Tamada, 1997), where experimental data of Pamir-Chacaltaya Collaborations were used. For recognition of an image of a family produced by iron author of (Tamada, 1997) used a neural net method, with the help of which multi-dimensional analysis is reduced to one-dimensional. 15 parameters describing a family were used in (Tamada, 1997. With the help of neural net the set of them was reduced to one, y_p, and condition which attributes a family to the "Fe" group was $y_p > 0.5$. The quality of selection making by this way has appeared to be rather high: $R_P \approx (1 - R_{Fe}) \approx 15$ %.

Also the next step on the way of CC study was made in (Tamada, 1997): not only families produced by P and Fe but also generated by other nuclei (He and CNO, SiMg groups) were examined there. It means that these nuclei also contribute to group "Fe". Following our consideration in this case Eq. (1) should be transformed to:

$$f' = \sum (f_A \times R_A) \qquad (3)$$

and accordingly

$$f = (f' - \sum' (f_A \times R_A)) / R_{Fe} \qquad (4)$$

Here f_A is a fraction of families generated by nuclei A, R_A - their fraction faulty attributed to group "Fe" (except R_{Fe}, R_{Fe} is a true portion), f ' – the part of families satisfying the limiting condition. Contributions of all nuclei are summarised in $\sum(f_A \times R_A)$, whereas iron families are not included in $\sum'(f_A \times R_A)$. Let us underline that we designate a true value of Fe induced families as f_{Fe} but a value estimated by Eq. (4) as **f**. The training sets define R_A and the given chemical composition of PCR determine f_A :

$$f_A = \varepsilon_A \times C_A / \sum (\varepsilon_A \times C_A) \qquad (5)$$

Here C_A is fraction of the nucleus A in the given PCR and ε_A - efficiency of a family production by it. The conclusion of (Tamada, 1997) is the same as in the previous works: the heavy composition of PCR is excluded by experimental data concerning γ-hadron families.

3 Selections of families generated by iron nuclei. Original consideration:

We have used methods similar to multi-dimensional (Asimov et al, 1987; Chilingarian et al, 1983, 1985, 1987) and one-dimensional (Tamada, 1997) approaches as a following step of chemical composition researches. Before starting CC analysis we have found parameters n_γ, R_γ, and **d** sensitive to A and not correlated between each others (see (Kalmkhelidze et al, 1999)). In contrast to (Tamada, 1997) we used only them. The parameters were analysed in their reduced form:

$$X_P = (P - P_p) / \delta P_p \qquad (6)$$

Here P is a value of some parameter in a given family either experimental or simulated, P_P - average values of the same parameter in families induced by protons, δP_P - dispersion of this parameter in proton families.

In reduced form of variables all distributions are dimension less and for families generated by protons are dispersed around average values $X_P = 0$. At multi-dimensional analysis simultaneously three conditions were used to attribute a family to "Fe" group:

$$X_{nh} > X_{nh\,lim}, \quad X_{R\gamma} > X_R \quad \text{and} \quad X_d > X_{d\,lim} \qquad (7)$$

For one-dimensional analysis a new parameter, X_3, was introduced:

$$X_3 = (X_{nh} + X_{R\gamma} + X_d)/3 \qquad (8)$$

For this parameter a value $X_{3\,lim}$ was also found and a family was attributed to "Fe" group if its

$$X_3 > X_{3\,lim} \qquad (9)$$

Limiting conditions P_{lim} were determined with the help of integral distributions of X_P for families induced by P and Fe using training sets simulated by MCO model (Fedorova,1994).

It is apparent that both errors R_P and 1- R_{Fe} depend on chosen limits $X_{nh\,lim}$, $X_{R\gamma\,lim}$, $X_{d\,lim}$, and $X_{3\,lim}$. We investigated two sets of limiting parameters. First, at which R_P = 5%, i.e. only 5% of proton families are falsely attributed to "Fe" group, and second, such that the errors of the first and second types are approximately equal $R_P \approx (1-R_{Fe})$. True values of fractions of iron induced families, f_{Fe}, and expected part of families, selected to "Fe" group, f ', for different chemical compositions are brought in Table 1 at two sets of limiting parameters $X_{P\,lim}$. Let us remind that f_{Fe} is fully determined by the given CC while f ' is the result of processing of simulated data.

Table 1 True portion of Fe families, f_{Fe}, and expected fraction of Fe-like families, f ', at various chemical compositions.

	CC	f_{Fe} %, true	f ' %, one-dim.	f ' %, multi-dim.
R_P=5%	Normal	2.8	13.	11.
	Heavy	16.4	21.	19.
	Superheavy	31.	30.	28.
	exp.		**12. ± 3.**	**11. ± 3.**
R_P=20%	Normal	2.8	26.	27.
	Heavy	16.4	35.	37.
	Superheavy	31.	47.	47.
	exp.		**29. ± 4.**	**25. ± 4.**

Table 1 is composed using training sets for various nuclei P, He, CNO, SiMg and Fe. R_A was determined for each nucleus and then the sum $f' = \sum(f_A \times R_A)$ was found. We should like to pay attention to the fact that for the normal composition the true iron families is lost among families selected in "Fe"group.

To check the efficiency of the used method we have investigated how it reproduces f_{Fe} at various chemical compositions. The results (f) are given in Table 2 for one particular selection (multi-dimensional selection, R_P=20%). Results of the other three selections (multi-dimensional R_P = 5% and one-dimensional at R_P=20% and 5%) are identical.

Table 2 Fractions of iron induced families, **f**, at various chemical compositions calculated by Eq. (4). Multi-dimensional selection, R_P = 20%.

	P	Normal	Heavy	S. heavy	Fe	f_{Fe}, %

P	**0.2 ± 2.5**	-4.3 ± 2.5	-2.6 ± 2.5	-1.2 ± 2.5	27. ± 2.5	0
Normal	8.7 ± 1.7	**4.2 ± 1.7**	5.9 ± 1.7	7.3 ± 1.7	36. ± 1.7	2.8
Heavy	21. ± 2.4	16. ± 2.4	**18. ± 2.4**	19. ± 2.4	48. ± 2.4	16.4
S. heavy	35. ± 2.7	30. ± 2.7	32. ± 2.7	**34. ± 2.7**	62. ± 2.7	31.
Fe	79. ± 6.4	75. ± 6.4	76. ± 6.4	78. ± 6.4	**106.±6.4**	100.
Exp.	5.9 ± 5.0	**1.4 ± 5.0**	3.1 ± 5.0	4.5 ± 5.0	33. ± 5.0	?

In Table 2 rows correspond to simulated compositions, columns to compositions by means of which corrections were done using Eq. (4) . For comparison of **f** with the true values of f_{Fe} the letter for each simulated compositions are given in the last column of the Table.

Table 2 demonstrates rather encouraging result. Irrespective to the composition used for corrections (for exception of pure Fe), the fractions **f** are close to corresponding true value. For pure proton composition **f** ≈ 0, for normal < 10% and etc. As it is expected the best agreement of **f** with true f_{Fe} is obtained if the composition for corrections is close to the “real”. The corresponding figures are underlined in Table 2. From the above the following procedure of processing of experimental data is suggested. After determining an experimental value f ‘ corrections should be done for various CC, for example for five compositions testing in Table 2. Then receiving preliminary result (five values for **f**) one takes that at which chemical composition determining corrections is closest to obtained **f**. This is shown in the last row of Table 2. The final value of found fraction of Fe induced families is underlined.

3 Conclusions:

The total analysis of our experimental data was as follows. Four values of fractions of families similar to iron, f ', were found corresponding to two type of the methods (multi-dimensional and one-dimensional) and two sets of limiting parameters for R_p=5% and R_p=20%. They are brought in Table 1. Values **f** were reproduced by the help of Eq. (4). Quantities **f** are given in the last row of Table 2 corresponding to various correction compositions. Table 2 shows, that only normal composition gives self consistent values **f**. In this case true values f_{Fe}=2.8% and set of experimental quantities of **f** fluctuates from 1.4% to 4.5%. In the case of the heavy composition the experimental fraction **f**=3.1% contradicts to true value f_{Fe} =16.4%. Even more disagreement shows the superheavy composition: true f_{Fe} = 31% while obtained **f** is equal to 4,5%.

References:

Asimov S A et al 1987 Proc. 20th ICRC v 5 p 304

Chilingarian A et al 1983 Proc. 18th ICRC v.5 p 252, p 487; 1985 Proc. 19h ICRC v 6 p 392; 1987 Proc. 20th ICRC v 5 p 312, v 1 p 390

Fedorova G F and Mukhamedshin R A 1994 Bull Soc. Sci. Lettr. Lodz Ser. Rech. Def v XVI p 137.

M.Kalmakhelidze, N.Roinishvili, M.Svanidze this volume HE 1.2.14

Tamada M 1997 J. Phys. G: Nucl. Phys. 23 p 497

Yuldashdaev T et al. 1997 Proc. 25th ICRC v 4 p 89