ON THE VARIATIONS OF GALACTIC COSMIC RAYS DURING THE LAST BILLION YEARS.

V.A. Alexeev, Vernadsky Institute of Geochemistry and Analytical Chemistry, RAS, Moscow 119991 Russia; e-mail: AVAL37@chgnet.ru

Introduction: In analyzing the distribution of cosmic-ray exposure ages of iron meteorites, Shaviv [1] concluded that the intensity of galactic cosmic rays (GCR) varied with a period of 143 ± 10 Myr due to periodic passages of the solar system through the spiral arms of the Galaxy. According to more recent data, this period is equal to 147 ± 6 Myr [2]. However, this conclusion is questioned by other researchers ([3] and other). In this work, we analyzed the distribution of the ages of iron meteorites after more strict selection of ages from the available data set. We compared obtained results with results for the model set of ages assuming different periods of the GCR intensity variations.

Calculations and modeling: The distribution of 82 ages is shown in **Fig. 1** (histogram *1*). Ages were taken from [4-6]. For correction of ages belonging to paired meteorites (i.e., formed in a single collision), we used the Akaike information criterion [7, 8]. Age distribution of the corrected set is shown in Fig. 1 (histogram *2*).

Further analysis of the distribution of the corrected values of ages was made by means of calculating the values of phase (according to [8]) and the study of parameters of the distribution of these values. For each value of the age of meteorite (T), the phase (Ph) was calculated according to the ratio: $\mathrm{Ph} = T / t - \mathrm{int}\,(T / t)$. Here t is presumptive period in the distribution of ages and, accordingly, the period of changes in the intensity of the GCR [8]. (Ph values vary in the range from 0 to 1.) Further, for the selected value of t there were calculated the population characteristics of the distribution of phase values: dispersion S^2, kurtosis E_k and χ^2. This procedure was made for the 17 values of t: 100, 150, 200, ..., 850 and 900 Myr. Then, changes of each characteristic as a function of t were analyzed.

Results for the χ^2 are shown in **Fig. 2**. Here we can see: (*a*) changes of χ^2 for the corrected ages of iron meteorites; (*b*) the same for a model set of 100 random "true" values of ages, assuming no variations of the GCR intensity; (*c*) the same on the assumption of GCR variations with a period of 150 Myr, and (*d*) the same on the assumption of GCR variations with a period of 450 Myr. Models of changes of GCR intensity with such periods are shown in **Fig. 3**. For meteorites (Fig. 2*a*), we can see a convincing decrease of the χ^2 values for t ~ 400-500 Myr (Δ_2 = -44 ± 4 %) and less convincing decrease for t = 150 Myr (Δ_1 = -46 ± 13 %). Also, similar deviations from the mean values were obtained in the analysis of the distributions of the dispersion S^2 and kurtosis E_k.

Distribution of the model set of 100 values of "true" ages is shown in **Fig. 4*a***. Of course, the distribution of the "measured" values of ages will be the same if the intensity of galactic cosmic rays during the last billion years has not changed. Distribution of "measured" values of ages will have the form (see Fig. 4*b*), if the intensity of galactic cosmic rays was varied with a period of 150 Myr. The type of this distribution is significantly different from the distribution of ages of iron meteorites (cf. Fig. 4*d*). But, the distribution of the "measured" ages (Fig. 4*c*) will be in essence the same like the distribution of ages of iron meteorites (Fig. 4*d*) in the case of an assumed period of GCR intensity variations of 450 Myr.

Conclusions: The obtained data suggest the existence of the GCR intensity variations with a period of ~ 400-500 Myr during the last billion years. These variations may be due to periodic passing solar system through the spiral arms of the Galaxy. Discussed in [1, 8], changes of the GCR intensity with a period of ~ 150 Myr are less certain.

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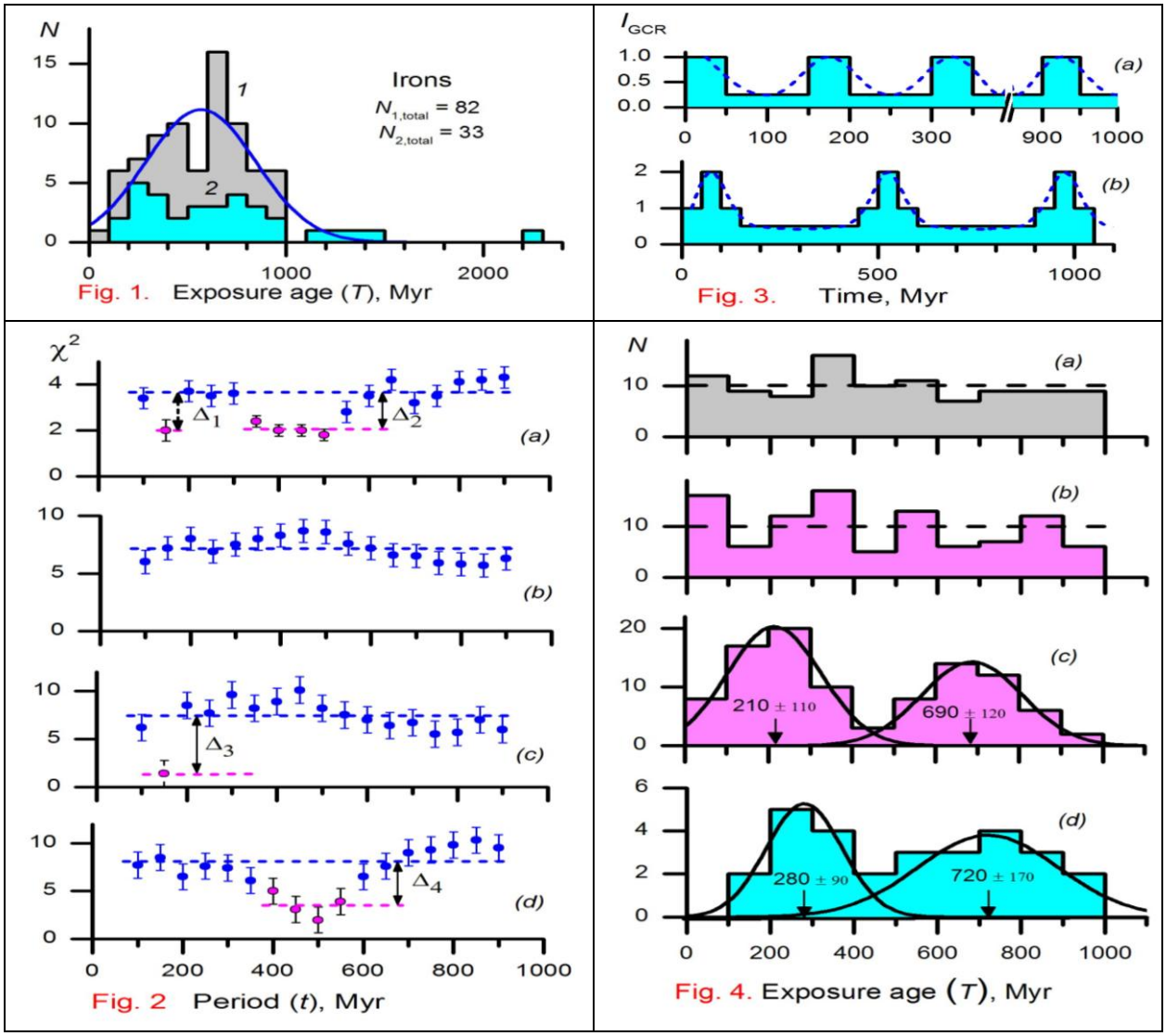

Fig. 1 Distribution of the exposure ages (T) of iron meteorites. *1* - all meteorites (N = 82, according to [4-6]); *2* – the corrected set (N = 33): after the exclusion of the paired meteorites and meteorites with a complex exposure history. Distribution is approximated by the "best" Gaussian curve.

Fig. 2 The χ^2 values calculated for the distribution of the values of phase Ph = T / t - int (T / t) depending on the assumed period of changes (t) in the distribution of the exposure ages of meteorites in the range of T = 0-1000 Myr. (a) - The corrected ages of iron meteorites (N = 28); (b) the model set of random values of age (N = 100) at a constant intensity of galactic cosmic rays; (c) and (d) are the same with changes in the intensity of GCR with a period of t = 150 and 450 Myr, respectively. Δ_1 - Δ_4 are deviations from the average values.

Fig. 3. Model of the GCR intensity changes (I_{GCR}) with a period of t (a) 150 Myr and (b) 450 Myr (solid lines) during the last billion years. Dotted lines are visual approximation of variations.

Fig. 4. Distributions of: (a) the model set of "true" values of exposure ages (N = 100) which randomly are distributed in the range of 0-1000 Myr; (b) the "measured" values of the ages for the model set; calculations are made under the assumption that the variations of the GCR intensity were with a period of t = 150 Myr; (c) the same for the proposed period variations of t = 450 Myr; (d) the exposure ages of iron meteorites after excluding paired meteorites and meteorites with a complex history of irradiation (N = 28). Dotted lines are average values. Distributions of (c) and (d) are approximated by the "best" Gaussian curves. The arrows indicate the positions of the maxima.