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CASE OF GENERATION OF HEAVY NUCLEI IN THE SUN

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SUMMARY

A case is described of flux increase of heavy nuclei ($Z > 15$) in the composition of cosmic rays registered on 23 - 24 February I964 on ELEKTRON-2 simultaneously with the detection by the Geiger counters of the same AES of bursts of Sun's X-ray radiation. During the period indicated no notable flux increase of nuclei with $Z > 2$, $Z > 5$ and of the proton component was observed. The possibility is evaluated of random coincidence in the increases of nuclei fluxes and X-ray bursts; it was found to be $1.5 \cdot 10^{-5}$. This leads to the assumption about a case of generation of nuclei in the Sun, with the escape beyond the limits of solar atmosphere of mostly heavy nuclei and of X-ray bremmstrahlung of electrons.

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A series of cases were registered during the last decade of solar cosmic ray generation during powerful chromospheric flares (class 3, 3$^+$) [I,2]. Analysis of the cases, when simultaneous measurements wer conducted of fluxes differing by the charge of solar cosmic ray components, has shown that the relative abundance of particles with different charge reflects that of the corresponding elements in the Sun [2]. It seems that this points to the fact that the mechanism of preferred acceleration of heavy nuclei, brought forth in [3], is not operational in the Sun.

However, during the flight of Soviet cosmic rockets in I959-I960 short-lived intensity increases of preferably heavy nuclei could be observed for the first time [4]. In these cases the flux of protons did not practically vary. Similar cases were also observed on Elektron-2, part of which being attended by bursts of solar X-ray radiation[5].

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Observations on AES Elektron-I and -2 allowed us to detect also more prolonged preferred increases of fluxes of heavy nuclei, with duration from a few hours to several days; one of these cases is described below (see also ref.[6]). As for the case of short-lived increases, the preferred intensity increase of heavy nuclei with charge $Z \geqslant 15 \div 20$ is characteristic here too.

Considered in the present work is the increase of the flux of nuclei registered on Elektron-2 on 23 February I964. On that day the flux of nuclei with $Z \geqslant 15$ rise by $42 \pm 14\%$ by comparison with the value of 20 February (Fig.I). The possible increase in fluxes of nuclei with $z \geqslant 2$ and $z \geqslant 5$ did not then go beyond the limits of statistical measurement errors. No notable effect was noted in the proton component of cosmic rays either [7]. Note that the period considered is characterized by significant level of solar activity, of which the characteristics are shown in Fig.I. The bulk of solar activity events in that period was linked with the radioemitting region R-7I6I [8]. The spots appeared in that region on 2I February and, developing rapidly, they occupied more than 500 millionth fractions of solar hemisphere. Most of the chromospheric flares in the period 2I - 26 February were precisely observed in that region. Ejections of matter were observed in it on 23 February [8].

Therefore, February 23rd and the adjacent days were most solarly-active of the period under consideration, which provides the basis to assume that the increase in the flux of nuclei registered on the 23rd is linked with their generation in the Sun during this time period.

Attention is drawn by the substantial general increase in the flux of X-ray and radioemission in the neighborhood of 23 February [9]. This increase has been also noted by American researchers [I0]. Besides, a series of bursts of X-ray radiation were registered on 23 - 24 February by both the X-ray device of Elektron-2 [9] and the photometers of the American satellite "SR-IV" [I0]. Taking this into account it appears to be of interest to examine the "fine" structure of flux increase of heavy nuclei on 23 - 24 February (Fig.2). It may be seen from that figure that the Čerenkov counter of Elektron-2 registered on these days several separate flux rises of nuclei with $Z \geqslant 15$. The cases of increases whose magnitude egresses beyond the limits of one or several errors of measurements, are denoted in the figure by numbers I - VIII. For example, the rise II emerges beyond the limits of three statistical errors, whereas the value of the case I egresses only beyond the limits of one error. This is why it is necessary to bring forth estimates characterizing the probability of appearance of these increases as a consequence of statistical fluctuations. The numbers shown in the figure near the cases of increases correspond to the probability of appearance per unit of time (minute) for each case separately. Then, taking into account that the total observation time (23 - 24 February) was $\Delta T_1 = 2640$ minutes, we shall obtain that about I - 3 cases of type- II - VIII increases for the period considered should be expected to be manifestations of statistical fluctuations. (The expected number of cases of increases according to statistics is equal to the product of probability density by the total observation time ΔT_1).

The probability of registration of all cases of increases (I-VIII) on account of fluctuations at $\Delta T_1 = 2640$ min will constitute $5 \cdot 10^{-2}$. This quantity was computed by the formula

$$P_{I,II,\ldots,VIII} = C_N^m P_I P_{II},\ldots P_{VIII},$$

where P_I, P_{II},...P_{VIII}- computed in the assumption of validity of the Poisons' distribution [I2], C_N^m - is the number of coincidences from N by m is equal to the number of registered increases, and $N = m\Delta T_1/\Delta t$ (Δt - being the time taken by the cases of rises). In our case m = 8,N = 96. Then

$$P = \frac{96!}{8!\cdot 88!}\cdot 1{,}5\cdot 10^{-1}\cdot 7{,}0\cdot 10^{-3}\cdot 8{,}0\cdot 10^{-3}\cdot 2{,}6\cdot 10^{-2}\cdot 7{,}0\cdot 10^{-2}\cdot$$
$$\cdot 3{,}2\cdot 10^{-2}\cdot 1{,}0\cdot 10^{-2}\cdot 1{,}0\cdot 10^{-1} = 5\cdot 10^{-2}.$$

Therefore, it is possible to assume that at least some of the observed increases are not the consequences of statistical fluctuations. This assumption is, moreover, straightened by the fact that some of the flux increases of the nucleus overlapped with bursts of X-ray emission (cases I, II, III, IV, VII). However, inasmuch as during the time period considered several X-ray bursts were observed (which can be seen in Fig.2), estimates for random coincidences in the rises of fluxes of nuclei with $Z > I5$ with X-ray bursts ought therefore to be brought forth too.

The number of random coincidences was estimated by the formula

$$N_{\text{сл}} = n_1\cdot n_2(\tau_1+\tau_2)\,\Delta T_1,$$

where n_1 is the number of rises (of specific type) in the flux of nuclei with $Z > I5$ per time unit (a minute), n_2 is the number of corresponding bursts of Sun's X-ray emission per same time unit, $\tau_1 + \tau_2$ - is the time, for which was taken the time of nonsimultanity of the beginning of the rise in the flux of nuclei with $Z \geqslant I5$ and of the X-ray burst, $\Delta T_1 = 2640$ min (i.e., the observation time of 23 to 24 February).

For subsequent calculations it should be taken into account that in the course of the total registration time of the flux of nuclei with $Z \geqslant I5$ (data of AES "Elektron-2"), $\Delta T_2 = 29400$ min, eleven cases were observed of type II rises, seventeen cases of type III, eighteen cases of type IV and fourteen cases of type VII. On the other hand the number of X-ray bursts for the period 23 - 24 February (i.e., during the time $\Delta T_1 = 2640$ min) was I2. Then for the cases II, III, IV, VII the number of random coincidences will constitute

$$II.\quad N_{\text{сл}} = \frac{11}{29400}\cdot\frac{12}{2640}\cdot 16\cdot 2640 = 0{,}07;$$

$$III.\quad N_{\text{сл}} = \frac{17}{29400}\cdot\frac{12}{2640}\cdot 16\cdot 2640 = 0{,}11;$$

$$IV.\quad N_{\text{сл}} = \frac{18}{29400}\cdot\frac{12}{2640}\cdot 16\cdot 2640 = 0{,}15;$$

$$VII.\quad N_{\text{сл}} = \frac{14}{29400}\cdot\frac{12}{2640}\cdot 24\cdot 2640 = 0{,}13.$$

The probability of four coincidences for their anticipated average number of 0.46 will be $\leqslant 1{,}5\cdot 10^{-3}$.

It should be noted that the most significant (from the standpoint of statistical guarantee) case of flux increase of nuclei with Z $\geqslant$I5 (case II) coincided also with the class I chromospheric flare on the Sun, having begun on 23 February at 0645 hours UT (the rise of nuclei flux began at 0700 hours (±4 min). The error in the determination of the instant of the beginning of rise (±4 min) is linked with the system of telemetry operation for over the given convolution the interrogation period of information accumulated constituted 8 min. If we conduct the estimate of the number of random coincidences for the type-II case and the class I chromospheric flare (just as was done above), we shall obtain

$$N_{\text{сл}} = \frac{11}{29400} \cdot \frac{1}{2640} \cdot 15 \cdot 2640 = 0{,}006.$$

For the case VII, which coincided with a class I-flare, we have

$$N_{\text{сл}} = \frac{14}{29400} \cdot \frac{9}{2640} \cdot 8 \cdot 2640 = 0{,}04.$$

The estimates conducted allow us to interpret the registered cases of rises in fluxes of nuclei with Z $\geqslant$I5 (23-24 February, I964), or at least part of them, as a result of generation of these nuclei in the Sun, with egress beyond the limits of the solar atmosphere of only heavy nuclei and electron bremmstrahlung, similarly to what was shown in [5] for the case of short-lived increases.

**** T H E E N D ****

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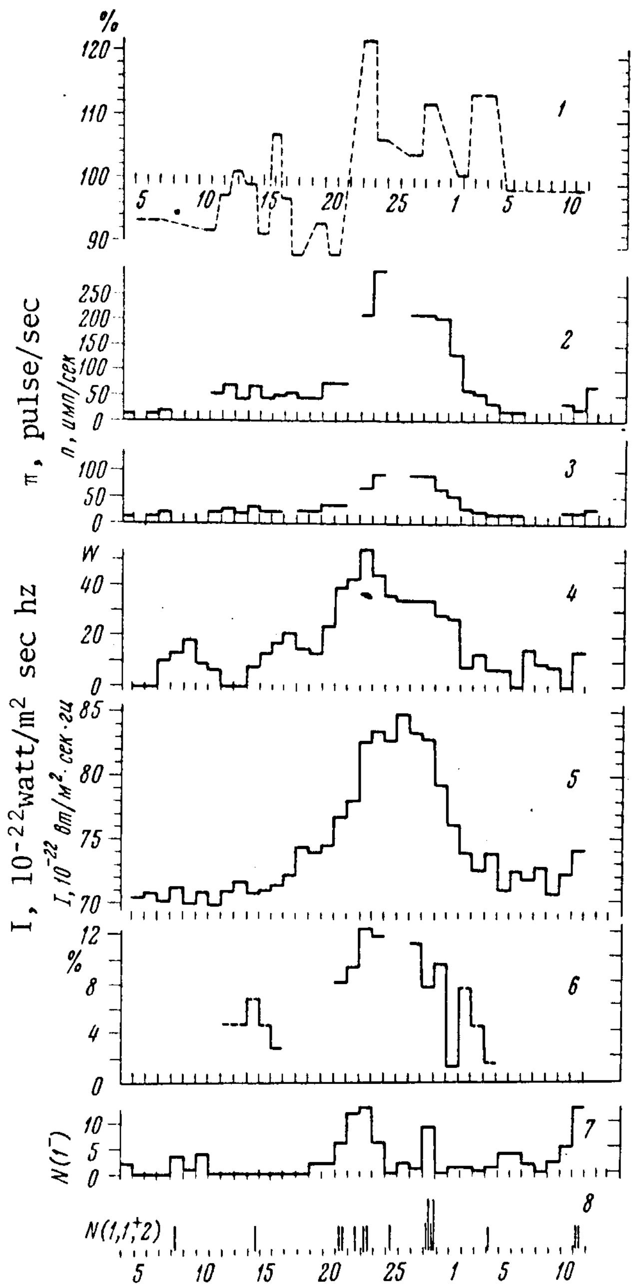

Fig.1. Solar Activity and Variation of the Nuclei of Fluxes in February - March 1964

1) fluxes of nuclei with $Z \geqslant 15$ (in % of the mean value for Feb.1964); 2), 3) Sun's X-ray radiation in the $2 \div 10$ and $8 \div 18$ A regions, according to photon counters of Elektron-2 [9]; 4) number of sunspots (Wolff number), 5) Sun's radioemission at 10.7 cm; 6) emission flux of local radiosources in the Sun's disk at 6.6 cm (in % of integral flux); 7) number of chromospheric flares of class 1 for one day; 8) chromospheric flares of classes 1 and 2 (the size of vertical strokes corresponds to the class of flare). The data 4), 5), 7) and 8) were borrowed from [11]

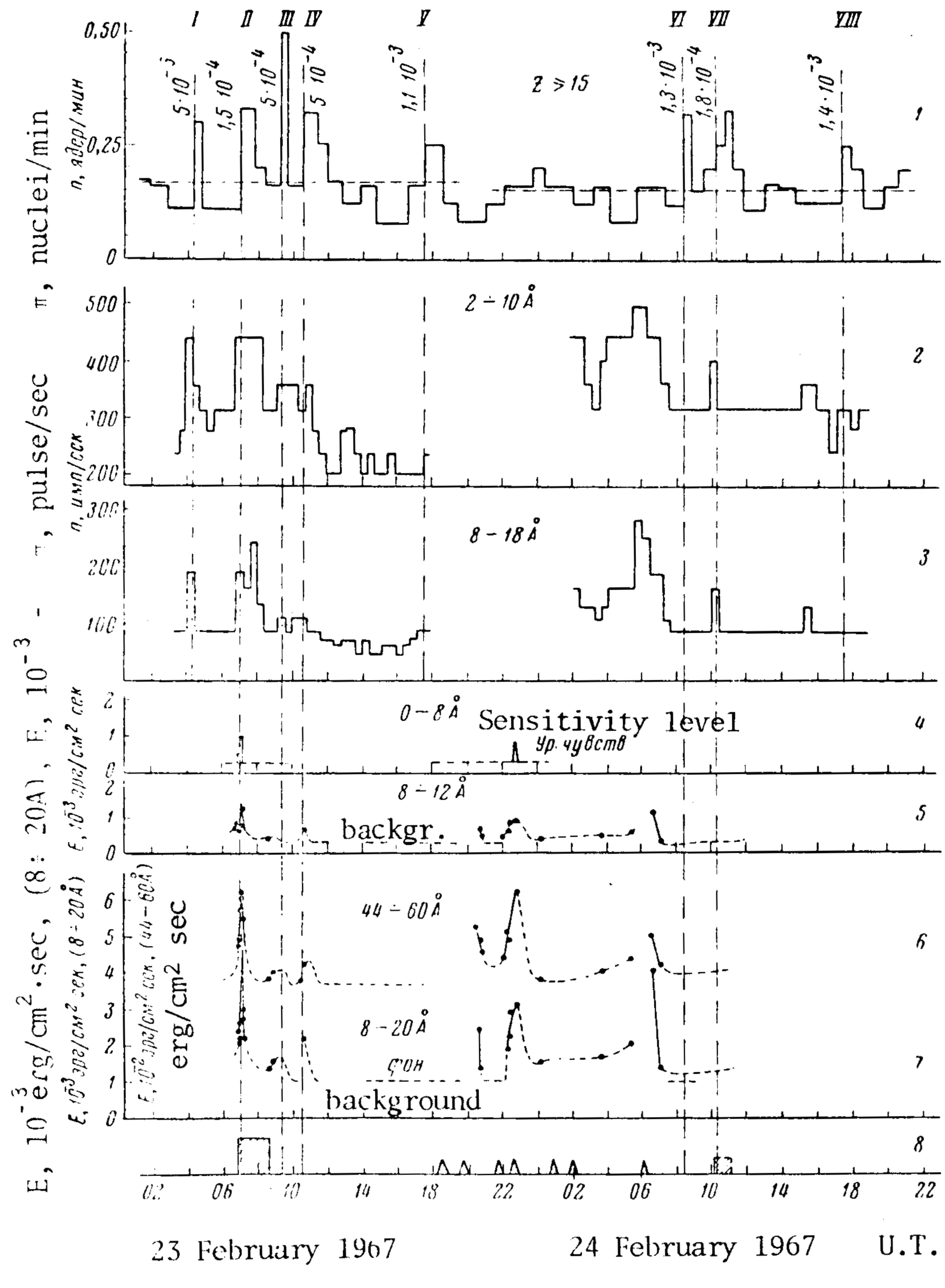

Fig.2. Fine Structure of Flux of Nuclei Increase

1) counting rate of nuclei with Z ≥ 15; 2), 3) results of measurements of Sun's X-ray radiation in the wave band 2 ÷ 10 A and 8 ÷ 18 A (according to Elektron'2's Geiger counter of photons [9]; 4), 5), 6) and 7) Data on Sun's X-ray radiation measurements on the American satellite "SR-IV" [10]; 8) chromospheric flares in the Sun after [11].

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