ON THE RETENTION OF HIGH-ENERGY PROTONS AND NUCLEI WITH CHARGES Z > OR EOUAL TO 2 IN LARGE SOLAR FLARES AFTER THE PROCESS OF TNEIR ACCELERATION

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Abstract. The available experimental data obtained from ground-based neutron monitors and from satellites suggest that the protons with energies of up to several GeV should be retained on the Sun after the process of their acceleration. The protons are on the average retained for 15 min, irrespectively of the solar flare heliolatitude and of the accelerated particle energy ranging from 100 MeV to several GeV. One of the explanation for the phenomenon is that the particles are retained in a magnetic trap formed in a solar active region. However, there does not exist information on how the nuclei with charges $Z \geqslant 2$, whose fraction in the Sun's atmosphere is $\sim 10\%$, bihave during the retention time. The Prognoz experiments failed to find any $Z \geqslant 2$ nuclei of solar origin during large solar flares. The upper limit of the number of such nuclei does not exceed 1% of the number of $\geqslant 500$ MeV solar protons and may be accounted for by the features of the experimental methods. The absence of the $\geqslant 500$ MeV/nucleon nuclei with $Z \geqslant 2$ may be due to their retention in the magnetic trap which also retains the high-energy protons. During the trapping time (15 min on the average) the $\geqslant 500$ MeV/nucleon nuclei with $Z \geqslant 2$ may escape due to nuclear interactions and ionization loss. In this case the H concentration should be $\sim 10^{12}$ cm^{-3}, which is observed in the lower chromosphere.

1. Introduction. The period between the moments of generation of particles in a flare and their emergence in interplanetary space is understood here to be the time of particle retention by the flare. The particle generation moment is meant to be onset time of the radio, X-ray, and gamma-ray emissions. If a particular event is rapid, the time of electromagnetic radiation maximum is taken to be the particle generation moment.

The time of accelerated-particle runaway to the interplanetary space was determined in /1, 2/ using the information concerning the time of the first arrival of the $\geqslant 100$ MeV and $\geqslant 500$ MeV protons at the Earth. Considering that the diffusive mode of particle propagation does not get stationary as yet and making the natural assumptions that the $\geqslant 100$ MeV and $\geqslant 500$ MeV particles are injected to the interplanetary space simultaneonsly and traverse the same path by the moment of their detection, we may find the moment of particle runaway to interplanetary space using the kuown time of the initial detection of the $\geqslant 500$ MeV and $\geqslant 100$ MeV protons.

2. Results and discussion. The table below presents the

various data for the events detected on board Prognoz satellites. The main conclusion following from the data is that the moment of particle injection to the interplanetary space is delayed relative to the particle generation moment, irrespectively of whether the microwave radio, X-ray, or gamma-ray emission maximum times are taken to be the particle generation moment. The delays vary from several minutes to several tens of minutes for different events.

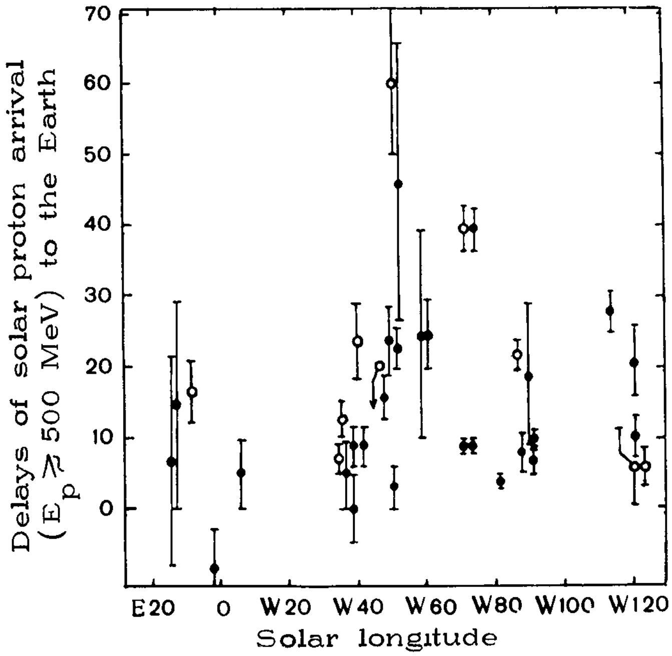
Fig. 1 shows the results of analyzing the dependence of the delay on the flare heliolatitude. The dark circles show the measurement results of /3/, the light circles are the Prognoz measurements. It may be concluded that in case of the Sun's western hemisphere the delay is independent of flare longitude. The delays for most of the events range from 10 to 20 min. The comparison between the delays inferred from the satellite and neutron monitors data shous that the delay is also independent of particle energy in the 100 MeV - 2 GeV range.

Table

The delays of the $\gtrsim$ 100 MeV and $\gtrsim$ 500 MeV solar protons injections to interplanetary space relative to the maxima of the microwave radio, X-ray, and gamma-ray emissions

N	$E_p \gtrsim$ 100 MeV, $\gtrsim$ 500 MeV							$E_p \sim$ 2 GeV
	Ref.	Date	Region Mc Math	Helio-coordinates	Flare class	Satellite	Delay, min	Delay, min /3/
1	/1/	July 7, 1966	8362		2B	Proton-3	$\lesssim$20	24$\pm$5
2	/1/	July 22, 1972	11976 ?	Post-limb flare	-	Prognoz-2	0$\div$12	-
3	/1/	Aug. 4, 1972	11976		3B	Prognoz-2	17$\pm$4	-
4	/1/	Aug. 7, 1972	11976		3B	Prognoz-2	$\simeq$6	9$\pm$3
5	/1/	April 29, 1973	12322		2B	Prognoz-3	$\simeq$40	40$\pm$3
6	/1/	Sept. 24, 1977	14942 or ? 14943	Post-limb flare	-	Prognoz-6	4$\div$8	10$\pm$3
7	/1/	Nov. 22, 1977	15031		2B	Prognoz-6	24$\pm$5	9$\pm$3
8	/2/	April 1, 1981	17539		2B-3B	Prognoz-8	60$\pm$10	-
9	/2/	April 4, 1981	17539		3B	Prognoz-8	22$\pm$2	-
10		April 10, 1981	17568		2B-3B	Prognoz-8	13$\pm$3	-

3. Discussion. Two reasons for the particle delays may be indicated. The first is the particle retention in closed magnitic fields of solar active regions /4/. The second reason is that the



• - /3/ , ◦ - the present work

Fig. 1. The high-energy solar proton delays versus flare heliolongitude

delay may correspond to the time interval between the accelerations from low to high-energies. The gamma-ray line emission and the X-rays from the flares are generated by particles with energies of several MeV /5/, whereas the particle delays were determined for the ≥ 100 MeV and ≥ 500 MeV protons. In case of neutron monitors, the mean effective energy is some 1 GeV. The entire solar cosmic ray spectrum was found in a flare region, whereas the time intervals between the moments of the emergence of low-energy protons and the associate gamma-ray line emission and high-energy protons are determined by the rate of energy gain. The ≥ 30 MeV gamma-ray data and the flare-generated neutron detection /6/ indicate that the period within which the particles are accelerated up to hundreds and thousands of MeV may not exceed a minute.

It is nof excluded, however, that the particles are accelerated in the solar corona or even in the interplanetary medium by the moving shocks. In such cases the time interval between the electromagnetic radiation generation and the high-energy particle generation may reach tens of minutes.

It should be noted that the solar nuclei $Z \geq 2$ and energies ≥ 500 MeV/nucleon were not in practice detected in large solar flares. The upper limit for the number of such nuclei relative to the ≥ 500 MeV protons was found to be a fraction of one percent in the Prognoz data, and this level may well be accounted for by the methodical features of the experimental design.

It may be assumed that the solar nuclei with $Z \geqslant 2$ (mainly the He nuclei), just as the solar protons, are retained in a magnetic trap and, within the retention time (~15 min) are lost for nuclear collisions and ionization. From the gamma-ray data it follows that the density of matter in the gamma-ray prodaction region is $n \sim 10^{12}$ cm^{-3}. Then the total thickness of matter traversed by He nuclei within 15 min is $X \sim 20$ g cm^{-2}, i.e. exceeds the nuclear and ionization paths of He nuclei in hydrogen. But the protons with energies of up to ~200 MeV must also be lost within the same period, the fact that must affect the solar proton energy spectrum in this energy range.

If the acceleration is assumed to take place up to the same rigidities, the flux of nuclei with $Z \geqslant 2$ and $E \geqslant 500$ MeV/nucleon should be compared with the $\gtrsim 1{,}4$ GeV proton flux of the same rigidity.

4. Conclusion. It should be noted in conclusion that the delay of high-energy proton runaway from the Sun and the absence of high-energy nuclei with $Z \geqslant 2$ found by the Prognoz measurements during large solar flures may be combined within a unified model relevant to particle retention in a magnetic trap located in an active region on the Sun. In this case, however, the solar proton energy spectrum should exhibit a feature at ~200 MeV. At the same time, if the charged particles are accelerated in large flares up to a certain rigidity, one must compare between the fluxes of protons and heavier nuclei of the same rigidity. If in this case the solar particle flux ratio replicates the solar atmospheric composition, the delay of the particle runaway from the Sun may be explained by, for example, a durable acceleration mechanism.

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