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TWO RELATIVISTIC SOLAR PROTON COMPONENTS IN SOME SPE

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Abstract

The data on temporal, spectral and pitch-angle characteristics of relativistic solar cosmic rays (SCR) at the Earth's orbit and near the Sun have been analyzed to prove a possible existence of two different components (a prompt and a delayed one) in some solar proton events (SPE). As physical reasons for origin of these particle populations, the magnetic bottle and the coronal shock interacting with the streamer in the corona are suggested.

Introduction In the recent years some essentially new results concerning the temporal, spectral and pitch-angle distribution (PAD) characteristics of relativistic SCR at the Earth's orbit and near the Sun have been obtained (Cliver et al., 1982; Perez-Peraza, 1986; Borovkov et al., 1987; Miroshnichenko and Sorokin, 1987, 1989; Bieber et al., 1986; Mullan et al., 1984). In particular, there were evaluated the instants of SCR ejections from the Sun and their arrival to the Earth with an accuracy of 1-5 min (Cliver et al., 1982), the characteristic times and upper energy limits of the acceleration mechanism operated by the magnetic reconnection at the periphery of the expanding magnetic bottle (Perez-Peraza, 1986) and in the shocked current sheet (Mullan et al., 1984). On the basis of experimental data, Borovkov et al. (1987) pointed to a possible existence of two separate components (a prompt and a delayed, or global ones) in some SPE. By numerical solution of the inverse propagation problem, PAD (Miroshnichenko and Sorokin, 1987) and ejection time profiles (Miroshnichenko and Sorokin, 1989) near the Sun were obtained. It turned out that the spectra of the prompt component (PC) were harder than those of the global one (GC) (Miroshnichenko and Sorokin, 1989; Bieber et al., 1986). This report deals with consideration of data showing the existence of two possible components in SPE's and physical interpretation of the results obtained.

Analysis of data Relativistic SCR study allows us to clarify characteristics of the solar accelerator under the extreme conditions (short acceleration time, upper energy of particles, etc.). Systematic differences in the SPE time profiles and original heliolongitudinal distribution of the SPE time profile semiwidth were interpreted by Borovkov et al. (1987) as manifestation of two populations of particles - PC and GC - existing in some SPE. We have made an additional analysis of 4 SPE described in Borovkov et al. (1987) (Fig. 1) by using the known formulae: $V \cdot T_n = A_n + B_n \cdot V$; $V \cdot T_m = A_m + B_m \cdot V$, where T_n and T_m are the times of beginning and maximum of SPE, A_n, A_m are the summary interplanetary paths of the first particles and the main bulk of them, B_n, B_m are the times spent by particles of the respective polulations in the corona, and V is the velocity of particles. All the times in this report are measured relative to the onset of type II radioburst.

Fig. 2 shows the plots of $V \cdot T_m$ relations constructed for the SPE's shown in Fig. 1. One can see that the delayed events of 12.10.1981 and 26.11.1982 consist of the delayed component (B_m=const) alone. The prompt event of 7.12.1982 contains the prompt component ($B_m \approx 0$), as well as the delayed one, including low-energy protons and electrons of $\geqslant 2$ MeV (light square). The prompt event of 16.02.1984 seemed to consist of the PC alone.

Fig. 3 shows the SPE distribution of the quantity B_n, and one can see two maxima (see also Cliver et al. (1982)). For most events, release of the first particles from the corona begins after the time $\bar{B}_n \approx$ 8 min from the beginning of type II radioburst (first maximum), for the rest of the events $\bar{B}_n \approx 30$ min and it is nearly equal to the value of $\bar{B}_n \approx$ 29 min found by Bazilevskaya and Sladkova (1986) for protons with the mean energy of ~ 40 MeV. So, two components seem to exist in the population of "first" particles too, B_n, as well as B_m (Bazilevskaya and Vashenyuk, 1979) being energy independent for the delayed component.

The existence of two components in some SPE's is evidently proved by the anisotropy data, too. Fig. 4 (Duggal et al., 1971) shows time profiles of anisotropic, A, and scattered, B, components in the 18.11.1968 GLE. It is seen that A and B profiles are similar to the profiles of prompt and delayed SPE (Fig.1), respectively. The time shift between them is nearly the same as between the GC and PC in Fig. 3. The situation in Fig. 4 is typical of many SPE's and it is unrealistic to suppose an ideally reflecting boundary behind the Earth's orbit creating the scattered component in all these cases. As interplanetary conditions couldn't change significantly during the time of SPE development (Fig. 4), one can suppose that PAD was formed just near the Sun and was retained during the interplanetary propagation (it is possible if the scattering process is nearly compensated by the adiabatic focusing (Earl, 1976)). So, PC is evidently ejected from the corona in an anisotropic manner (as calculations in Miroshnichenko and Sorokin (1987) show also) and GC seems to have an isotropic source.

<u>Discussion and conclusions</u> The data presented do not allow an unambiguous interpretation, but some conclusions can be done. Independence on energy of "coronal" times B_n and B_m for the GC seems to point out its connection to the coronal magnetic bottle (Mullan, 1983). Particles of all species and energies begin to escape simultaneously at the moment $\bar{B}_n \approx 30$ min as the bottle is destructed due to the instability and proceed to leak out during the time B_m (it can contain also the time of leaking from the corona (Bazilevskaya and Vashenyuk, 1981) and the diffusion time). The halfwidth of ejection profiles

in the events of 19.11.1949, 23.02.1956 and 7.12.1982 (25, 19 and 12 min, respectively (Miroshnichenko and Sorokin, 1987, 1989)) are comparable with the time delay between the moment of SCR generation and the time of their release from the corona (5-50 min, average 1000 s) in expanding magnetic bottle model (Mullan, 1983).

Particles of PC begin to escape at time $B_n \gtrsim$ 8 min, i.e. before the bottle opening. Impulsive character and large amplitude of the PC increase require insistantly that an independent source be involved situated on the open field lines which are ordered in structures of the coronal streamers transferring into the heliospheric current sheet at 1-1.5 $R_\odot$ (Korzhov, 1977). One of possible models of PC generation is shown in Fig. 5. Coronal shock advancing before the expanding bottle heats the current sheet of a streamer (which may originate from the same active center) causing fast reconnection and acceleration of particles (hatched region) inside it. Some estimates of maximal energy gained by protons in such a kind of acceleration give 1.8-3.7 GeV (Perez-Peraza, 1986). The accelerated particles leave the Sun along the current sheet undergoing simultaneously the azimuthal drift with the velocity $V_d \approx 0.7V_\perp$ (Fisk and Schatten, 1972). By such a drift one can explain the seemingly paradoxical fact of delayed arrival of the first particles in well connected ($\sim 60°$W) events (Cliver et al., 1982). Besides, diverging field lines remain radial up to $\sim 20\ r_\odot$ (Korzhov, 1977), hence the particle flux at this distance should be significantly collimated. It is indirectly confirmed by the PAD calculations (Miroshnichenko and Sorokin, 1987) near the Sun. On the other hand, because of its large dimensions ($\sim 100°$) the magnetic bottle is expected to give rather isotropic particle flux at the opening. However, on the whole this problem is still open to question (Vashenyuk et al., 1989).

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