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XXIV ICRC
ROME 1995

AUGUST 28 – SEPTEMBER 8, 1995

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On the Formation of Relativistic Particle Beams in Extended Coronal Structures: I. Evidences for Two Separate Sources of Solar Cosmic Rays

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Abstract

We analyze the neutron monitor (NM) data on the spectral and pitch-angle characteristics of solar cosmic rays (SCR). To obtain new information about SCR source we use three independent methods: 1) intercomparison of the intensity-time profiles of SCR measured by different NMs for the same event: 2) vT_m-technique (v is the particle velocity and T_m - the time of maximum increase at 1 AU): 3) distribution of SPEs on a specific parameters $T_{1/2}$ - the width of intensity-time profile at its half height. Besides, we take into account the data on SCR anisotropy and energy spectra at different phases of SPEs. Our results provide a set of evidences for two separate sources of SCR in certain SPEs, i.e., two SCR components prompt (PC) and delayed (DC) ones. It is shown, in particular, that Ground Level Events (GLE) of October 22, 1989 and May 24, 1990 have had both components.

1 Introduction

Study of solar cosmic rays (SCR) at relativistic energies (E > 500 MeV for protons) provides an unique opportunity to obtain new information about acceleration processes in space plasma under extreme conditions, in particular, to clarify some features of the solar acelerators and to estimate a number of important parameters of SCR sources (upper energy limits of the acceleration mechanisms, times of particle ejection from the Sun, etc.). Out of 54 GLEs observed since 1942 until now, 14 have been recorded in the current solar cycle 22. Some of these SPEs display a set of peculiarities which seem to need interpretation on a new concept base. In particular, the shape of intensity-time profiles of certain SPEs implies the presence of two SCR populations - prompt and delayed ones [1]. In [2] we summarize the accumulated evidences for two-source ejection of relativistic particles and describe the analysis of SCR data that allow us to separate two components. Some of the results [2] are given below.

2 Evidences for Two-Component Ejection

It is well known that the form of intensity-time profiles contains important information about the duration of SCR ejection and their transport through the corona and the interplanetary space. Typical profiles of GLEs are shown in Figs.1 and 2 for the

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events of October 22-23 and September 29, 1989, respectively. These data evidently display a distinctive two-peak structure. According to [3,4] such a structure of the later event may be interpreted as a two-fold ejection of SCR. A less distinctive but noticeable two-peak structure was observed, in particular, by the Apatity NM during the SPE of May 24, 1990. The first (sharp) peak, in our opinion [2], corresponds to the arrival of a certain population (the PC), and the second (smooth) peak is due to a different population (the DC).

The existence of two components in certain SPEs is evidently proved by the anisotropy data. Fig.3 shows the dependence of the increase at given NM station on the angle distance of their mean asymptotic direction from the anisotropy axis ($\theta = 0°$) of the SCR flux (boxes A and B in the upper left diagram) during the November 18, 1968 GLE; at right are the time profiles corresponding to the anisotropic component registered by NMs of box A and the scattered component of NMs in box B [5]. If an equilibrium exists between the processes of scattering and focusing in the interplanetary medium [6] then the pitch-angle distribution in the SCR flux will be retained in course of particle transport from the Sun to the Earth. The situation shown at Fig.3 is typical for many SPEs, and in all these cases one can not always find any suitable shock or any other ideally reflecting boundary behind the Earth's orbit producing the scattered component, as it is often supposed [7]. So, the scattered component is evidently ejected from the corona in an isotropic manner and cannot be attributed to an isotropization during transport in the interplanetary space. Therefore, it seems likely that profiles A and B correspond to the PC and DC in this event.

To derive essentially new information from the GLE data it was suggested [4] to use a specific parameter $T_{1/2}$ - the half-width of the profile as measured at the level of half of maximum intensity. This parameter seems to be a measure of the time the main bulk of particles spend in the corona after acceleration. The plot of $T_{1/2}$ against heliolongitude of the proper flare for 42 GLEs shows [4] that the points form two groups, corresponding to two distinct heliolongitude distributions - with $T_{1/2} > 1\ hr$ and high anisotropy near the time of maximum intensity, and with $T_{1/2} > 1\ hr$ and low anisotropy. Such a division in two classes of SPEs may point out to different types of sources (PC and DC). The following 14 GLEs were found to contain the pulse-like time profile conjugated with a very hard spectrum: November 11, 1949; February 23, 1956; May 4, 1960; July 20, 1961; November 18, 1968; November 22, 1977; May 5, 1978; December 7, 1982; February 16, 1984; September 29, October 22 and November 15, 1989; May 24 and May 26, 1990.

Separate existence of two SCR components can be revealed also by by the vT_m-technique developed in [8] relying upon the relations: $vT_n = A_n + vB_n$ and $vT_m = A_m + vB_m$, where T_n and T_m are the times of onset and maximum of SPE, respectively, A_n and A_m - the total interplanetary paths travelled by the first particles and the main bulk of them, B_n and B_m - the times spent by the particles of the respective population in the corona. Fig.6 shows the SPE distribution on the quantity B_n [9,10], and one can see two maxima. For the most of SPEs a release of the first particles from the corona begins after the time $B_n = 8\ min$ from the beginning of type II radioburst (I maximum), for the rest of the events $B_n = 30\ min$ (II maximum), and it is nearly equal to the value of $B_n = 29\ min$ for protons with the mean energy of $\sim 40\ MeV$ [11]. So, two components seem to exist in the population of first particles, too. Independently, it was found [11] that in some SPEs the time delays for the first protons at the energies of 100 MeV and 2 GeV were nearly the same. A similar analysis for the May 24, 1990 and October 22, 1989 events shows (Figs.5-6) that both SPEs contained both the PC and DC of SCR populations.

3 Conclusion

The observational results considered above provide evidences of two components (apparently independent) - prompt and delayed ones - in relativistic SPEs. In accordance with the previous investigations [1,4,10,13] we suggest a tentative picture in which a source of the DC is placed in the flare site at low coronal level, and a source of the PC - in extended magnetic structures in the upper corona. A scenario of acceleration and quantitative estimations of expected spectra of accelerated particles for both components will be given in the Part II of this work [14].

Figure Captions

Fig. 1 *Intensity-time profiles of the October 22-23, 1989 event by the NM data at three high-latitude stations.*

Fig. 2 *Intensity-time profiles of the September 29, 1989 event by the NM data at four stations with different cutoff rigidities.*

Fig. 3 *Prompt (A) and delayed (B) components of SCR in the November 18, 1968 GLE [5]. The angle $\theta = 0°$ corresponds to nominal IMF direction.*

Fig. 4 *SPE distribution on parameter B_n [9, 10]. Asterisk notes the value B_n = 29 min obtained in [11] for proton with the mean energy of 40 MeV.*

Fig. 5 *Results of vT_m-analysis of intensity-time profile for the May 24, 1990 event.*

Fig. 6 *Results of vT_m-analysis of intensity-time profiles for the October 22-23, 1989 event.*

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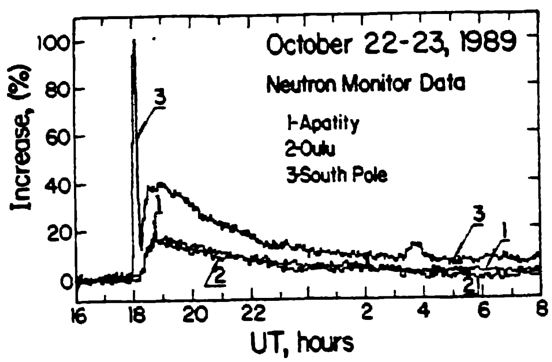
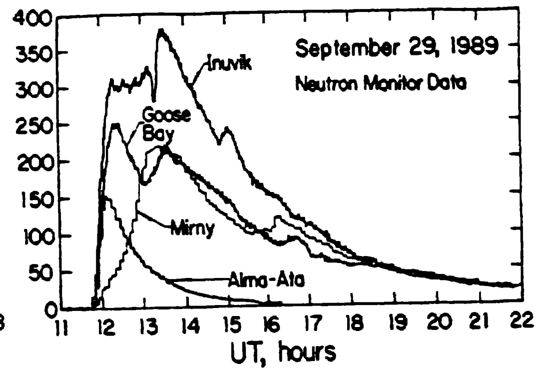


Fig.1.



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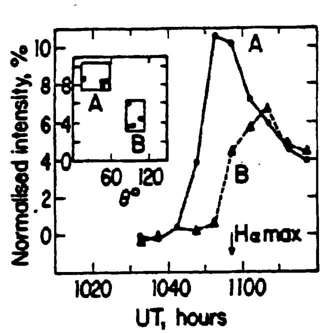

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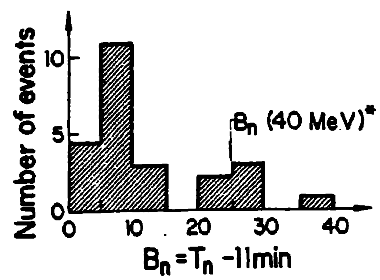

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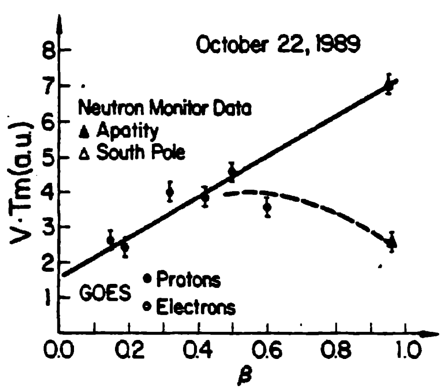

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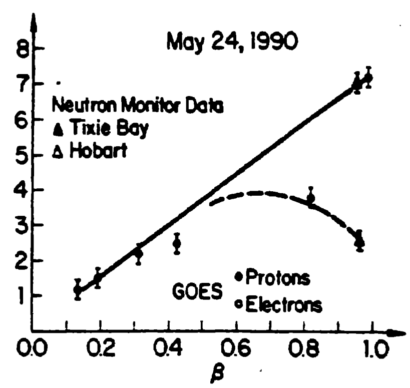

Fig.6.

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