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Solar Energetic Particle Events at the Rise Phase of the 23rd Solar Activity Cycle Registered aboard the Spacecraft "INTERBALL-2"

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Abstract. The experiment with 10K-80 aboard the INTER-BALL-2 (which detects protons with energies >7, 27–41, 41–58, 58–88, 88–180 and 180–300 MeV) registered six events of the solar energetic particle (SEP) increase. These events are during the initial rise phase of the 23rd solar activity cycle. Solar flares with the SEP generation are accompanied by coronal mass ejection (CME). Here we analyze the dynamics of the differential energy spectrum at different phases of the SEP increase.

Key words. Solar energetic particles—coronal mass ejection—interplay-netary shock—differential energy spectrum.

1. Introduction

In recent years the paradigm to understand the events of SEP increases has been changed (Reames 1995). The SEP events are classified as the gradual and impulsive. In the first case, the energetic particles are accelerated at the point of intersection of the magnetic field lines on the surface of the shock wave formed by CME. It is important to note, that gradual events are observed in a wide range of heliolongitudes. On the other hand, the impulsive events are observed in a narrow cone of longitudes, <30°. In the present paper we analyze these two types of events.

2. Instrumentations

In this work we used the proton spectrometer data from the INTERBALL-2 satellite launched into the near-Earth orbit on August 29th, 1996. The apparatus 10K-80 registers protons in one integral channel E_p > 7 MeV and in five differential channels from 27 to 300 MeV.

3. Data

We describe below the six SEP events:

- **The event on November 4th, 1997** was observed associated with the active region NOAA 8100 where there was the flare X2/2B (S14W33). The maximum of brightness was observed at 0558 UT. The SOHO spacecraft registered the CME

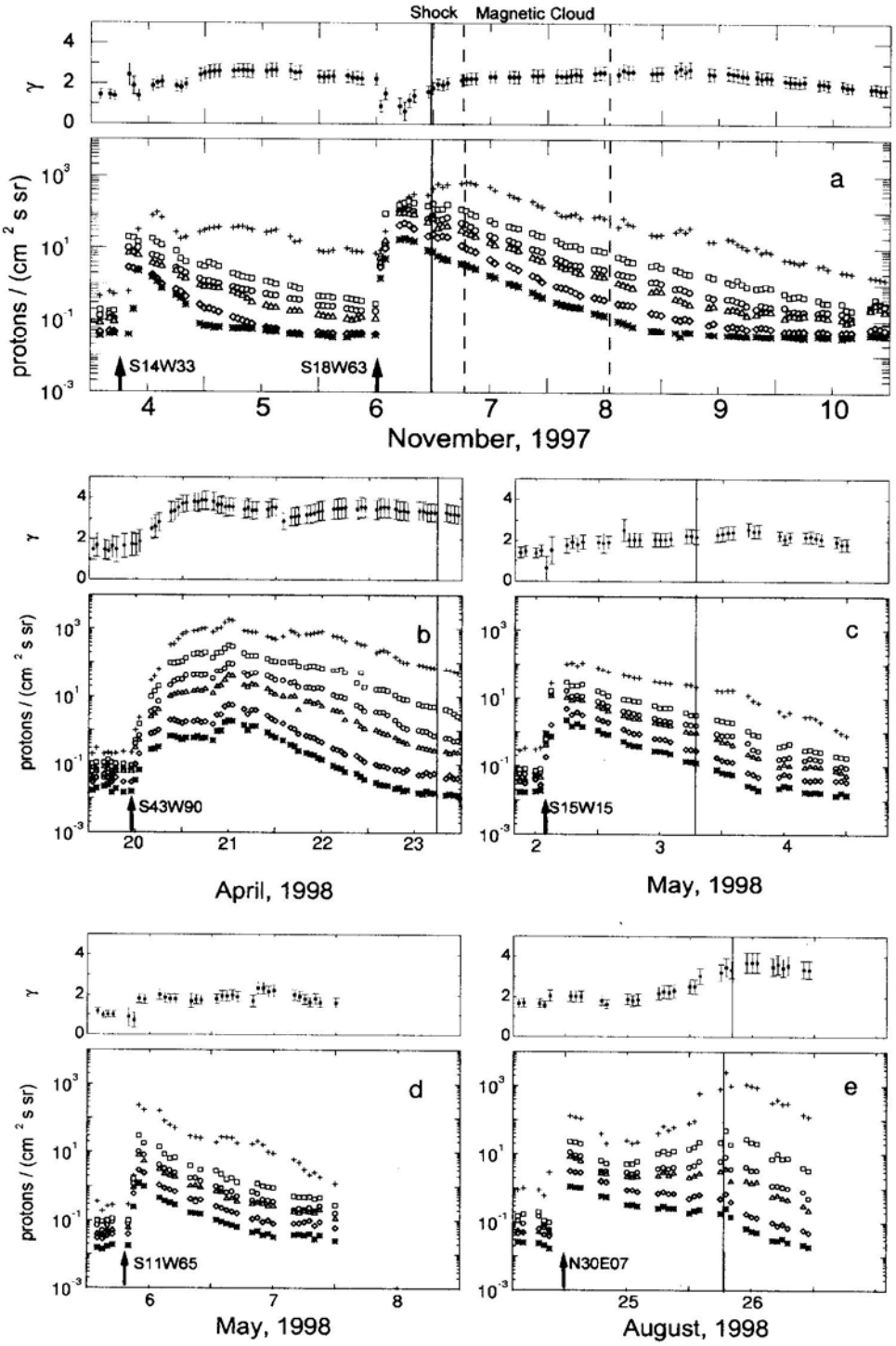

Figure 1. Temporal profiles of SEP increase from the considered solar events registered with the 10K-80 and corresponding evolution of differential energy spectra. The solid vertical lines are Shockwaves. The dashed vertical lines are magnetic cloud boundaries.

between 0552 and 0608 UT. At 0640 UT, ~ 40 min. after the flare, the 10K-80 detected the beginning of SEP intensity increase in all channels. Fig. l(a) presents times when the solar flare was observed.

- **The event on November 6th, 1997** is the largest one observed in the last nine years in the soft X-rays by many spacecrafts and which was detected with neutron monitors as GLE. The flare X9/2B was in the same active region NOAA 8100. Its coordinates were (S18W63) with a maximum intensity in H_α at 1155 UT on November 6. At that time the movement of the CME from the west limb of the Sun has been observed. About 30 min. later, a sharp increase was observed for the protons with energies from 27 to 300 MeV (Fig. l(a)).
- **The event on April 20th, 1998** is associated with the active region NOAA 8194 where the flare Ml/EPL (S43W90) with a maximum in H_α at 1021 UT followed by the CME with a velocity V~ 1000 km/s took place. One of the features of this event is that in about 40 hours the temporal profiles (Fig. l(b)) of SEP intensities have been essentially modulated, thereby both the character and the time are the same for all energetic channels. It led to the appearance of the second maximum. It appears to be connected with the interplanetary disturbance from the CME.
- **The event on May 2nd, 1998** (Fig. l(c)) is associated with the active region NOAA 8210, where the flare X1/3B (S15W15) with a maximum in H_α at 1342 UT took place, which was followed by a CME with a velocity $V \approx 2500$ km/s. This event was detected with the neutron monitor network. The propagation time is ~ 40 min. This event is characterized by a short increase to the event maximum and a gradual decrease of the intensity for all energies.
- **The event on May 6th, 1998** (Fig. l(d)) is also associated with an active region NOAA 8210, where the flare X2 /1N (S11W65) with a maximum H_α at 0809 UT accompanied by the type IV radioburst has been taken place. This event was also detected with neutron monitors. Approximately 35 min. after the flare the sharp increase of SEP intensity in the energy region from 7 to 300 MeV started. This event is characterized by the rapid increase of the charged particle intensity to the maximum during a period of about one hour for the above energies.
- **The event on August 24th, 1998** is associated with an active region NOAA 8307 here the flare X1/3B (N30E07) with a maximum H_α at 2212 UT has taken place. This event was observed up to relativistic energies also. The temporal intensity profiles (Fig. l(e)) during the whole event have been repeatedly modulated. The modulation degree is inversely proportional to the magnetic rigidity of the charged particles. (See in detail Timofeev and Starodubtsev (1999, 2000) and references therein).

4. Discussion

Thus, it should be noted that only one event, namely that of April 20th, 1998 refers to the purely gradual events. The increase of SEP on May 6th, 1998 can be classified as an impulsive event. In our opinion, the rest events are mixed types.

The observed SEP events were accompanied by CMEs. On the boundary of these CMEs shock waves were formed, part of which reached the Earth's orbit as interplanetary shocks. In our experiment, during the initial SEP growth phase, a hard power spectrum of running particles from the shock wave was observed. (A theory of

cosmic ray acceleration at the front of running shock wave was developed by Berezhko *et al.* (1988)). This spectrum monotonically increased up to the maximum value of the SEP (see Fig. 1). During the decay phase of SEP intensity, the flow isotropization was observed, and the spectrum became invariant within the experimental errors.

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