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WESTWARD EXPANSION OF SUBSTORM ACTIVATION IN THE MAGNETOSPHERE

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Abstract. Dispersionless injections of energetic electrons and protons of the 'p→e' class (with highest time resolution) during substorms are studied at CRRES when spacecraft was close to the magnetic equatorial plane and near midnight. The primary interest in this study involves the dynamics of the fine-scale structures of activation during a short interval around the local dipolarization moments. We found that at a geocentric distance of ~ 6 Re the short interval of 30-40 s consists of a temporal sequence of short bursts of the protons and electrons. This sequence may be a signature of westward and/or Earthward expansion of the substorm activation when new localized regions of impulsive particle accelerarion appear outside the initial position of active region. Using the data from several detectors, which were oriented in the different directions, we estimate the velocity of development of the active region. The velocity of earthward expansion of the substorm activation was equal to (50 - 150) km/s. Dispersionless energetic electron injection coincides with the drop of the lowest energy proton flux. This drop may expand westward at the velocity of 130 - 350 km/s.

Introduction

In the near-Earth magnetosphere the energetic electron injection often delays relative to the proton injection. Birn et al (1997) examined the injection events with dispersions not exceeding ~2 min and assumed that the injection boundaries for energetic ions and electrons were not exactly identical but displaced against each other. Then the events p→e would occur when the boundaries expand azimuthally and Earthward.

However in the paper [Lui et al, 1988] it was shown that the current disruption region in r ~ 7-9 Re consisted of localized particle intensity enhancements (activation) with a short duration (10-50 s). The spatial scale of these activations can be of the order of ion gyroradius ρ_i [Ohtani, 1998]. So, the scheme proposed by Birn et al (1997) can not provide the physical interpretation of the activity expansion.

We investigated dispersionless injections of energetic electrons >21.5 keV and protons > 37 keV of the 'p→e' class (with the best possible one second resolution) during substorms at CRRES, when the spacecraft was close to the magnetic equatorial plane and near midnight. The primary interest in this study involves the dynamics of the fine-scale structures of activation during a short interval around the local dipolarization moments. The proton flux anisotropy in three particle detectors is used to determine qualitatively the location of the acceleration region relative to the CRRES and the development of this region.

Observations

We examine the three substorms when dispersionless injections of energetic electrons >21.5 keV and protons >37 keV at the CRRES are observed. The time resolution of the **B** field data used in this study was 2 seconds. The MEB instrument measures energy electrons (21.5-285 keV, 14 energy channels) and protons (37 - 3200 keV, 12 energy channels) [Korth et al., 1992]. We used MEB data from several detectors which measured the particles in the different directions. A detector looking toward dawn (dusk) measured the $J_+(J_-)$ intensity of the protons having the gyrocenters Earthward (tailward) of the CRRES. The gyrocenters of protons measured by different detectors d1-d3 located within different sectors denoted by d1-d3, respectively. Fig.1 presents these sectors sketchy. Here **X** points to the Sun (approximately Earthward in the midnight) and **Y** points to the west. The $J_+(J_-)$ intensity corresponds to the sectors in the plane with the X>0 (X<0).

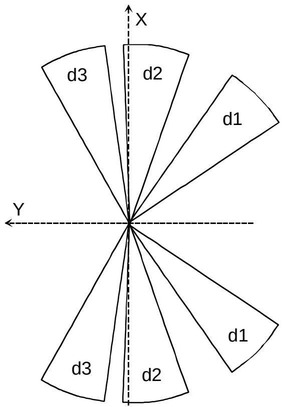

Fig. 1. Scheme of the sectors in the XY-plane where the gyrocenters of the protons measured by different detectors d1-d3 are located.

The spatial inhomogeneity of the proton population can be investigated by the anisotropy in the proton flux. Azimuthal anisotropy of the flux during an individual spin (30 s) period may represent the radial gradient of the proton population. Anisotropy of the flux in the d1-d3 detector data may represent the azimuthal gradient of the proton population.

In all events we note (stress) the following moments: "Tdip" - the local onset of a fast enough dipolarization, "b1" ("b2") the onset of the proton burst with (without) the dispersion, and "b3" ("b4") the onset of the electron flux enhancement without (with) the dispersion.

Substorm A. On Febr 27, 1991, starting at 1003 UT, a series of activations were observed at Barrow and Fort Simpson. More intensive activation lasted from 1021 to 1027 UT. At this time the CRRES (orbit 527, 23.57 MLT, mlat = - 3.95^{o} , and r = 6.1 Re) was located near the inner edge of the plasma sheet (PS).

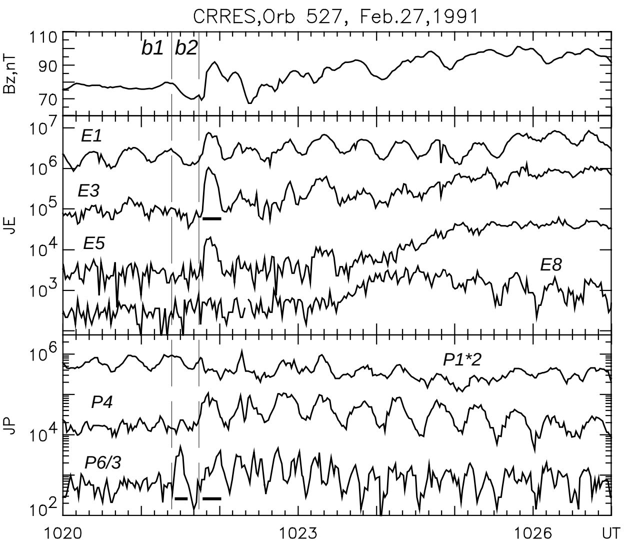

Fig. 2. Substorm A at the CRRES. From top to bottom: Bz magnetic field component and the intensity of JE electrons (in channels E1, E3, E5) and the intensity of JP protons (in channels P1, P4, P6).

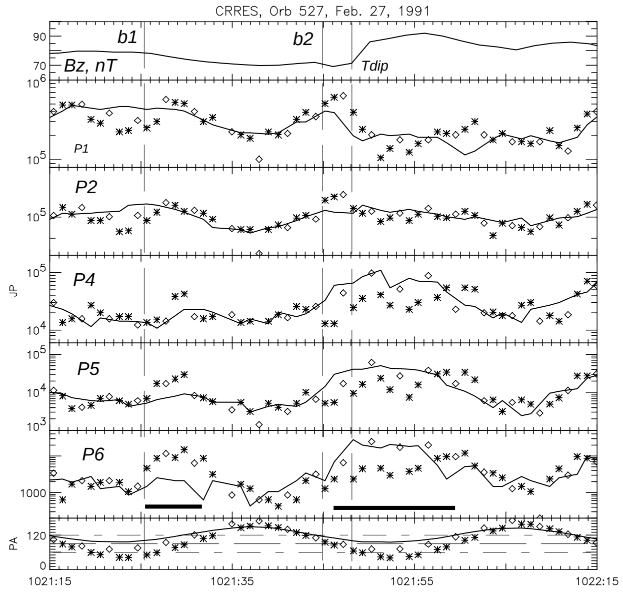

Fig. 3. Substorm A. Proton intensity JP in several channels from three detectors. For every detector the intensity JP and pitch angle (PA) of protons are shown with the same symbol.

Fig.2 presents the Bz component of the magnetic field and the electron and proton intensity in the several channels. One can see that the clear dispersionless burst of energetic electrons in the channels E1 - E7 is delayed relative to the burst of energetic protons P6. Fig.3 presents the data by three detectors d1-d3 of protons and their pitch angles (PA). It is necessary to remind that the phase when the PAs decreases (increases) corresponds to fluxes J+ (J_). Fig. 4 presents the proton and electron flux variations during the magnetic field dipolarization.

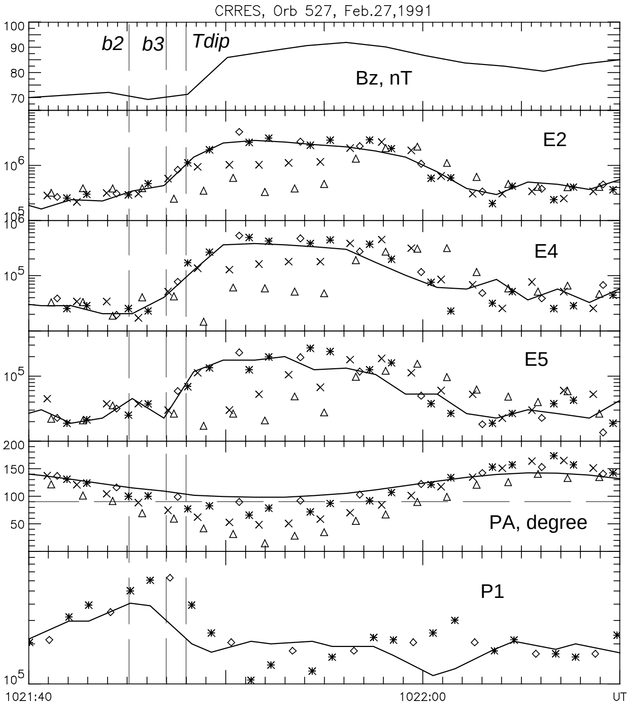

Fig. 4. Substorm A. Electron and proton intensity variations from several detectors near the local dipolarization moment.

From Figs.2-4 one can see:

Moment "b1" (22 s before the Tdip). The first short (with the duration of 6 s) burst of protons with the gyrocenters tailward of the CRRES is observed in the channels P4-P7 (85-250 keV) with a very small dispersion. In the channel P4 (ρ_i ~ 510 km), the intensity J_ increased with a 3 s delay from the burst in P6 (ρ_i ~ 670 km), indicating the Earthward activity propagation velocity of 50 km/s. The proton burst is observed only in the detectors d2-d3, indicating the westward gradient of proton population.

Moment "b2" (4 s before the Tdip). The second burst of protons with the gyrocenters Earthward of the CRRES is observed in the channels P1-P6 (37-193 keV) without the dispersion. In the higher energy channels, one can see the higher increases of proton flux J_+ in detector d1, which may indicate that the source of the protons was located eastward the CRRES.

Moment "b3" (1 s before the Tdip). Clear dispersionless burst (with the duration of 15 s) of energetic electrons in the channels E1 - E7 (21.5-94.5 keV) occurs nearly simultaneously with the impulse of Bz component. One can see the highest increases of electron fluxes within the range of PA ~ 60^{o} -120^{o} (electron acceleration perpendicular to the magnetic field). The lack of the energy dispersion is an argument for local acceleration. The electron burst coincides with the decrease (drop) of the proton flux J_+ in the lowest energy channel P1. This proton drop rises eastward of the CRRES and is replaced westward at the velocity of 350 km/s.

Thus, one can see:

1) Dispersionless burst (15 s) of energetic electrons in the channels E1 - E7 (21.5-94.5 keV) coincides with the drop of the flux of protons with the gyrocenters Earthward of the CRRES in the lowest energy channel P1 (37-54 keV), which expands westward at the velocity of 350 km/s.

2) Dispersionless electron burst is delayed relative to the dispersionless higher energy proton burst (J + in the eastside detector d1) by 2 s and occurs 1 s before the Tdip.

3) 20 s before the electron burst, the precursor in the form of the short proton burst with the 3 s dispersion is observed. This precursor propagates Earthward at the velocity of 50 km/s.

Substorm B. On Febr 8, 1991, the CRRES (orbit 482, 0.5 MLT, mlat= 0.2^{o} , and r=6.3 Re) was located within PS. The fluxes of P1-P2 (37-69 keV) protons were nearly isotropic.

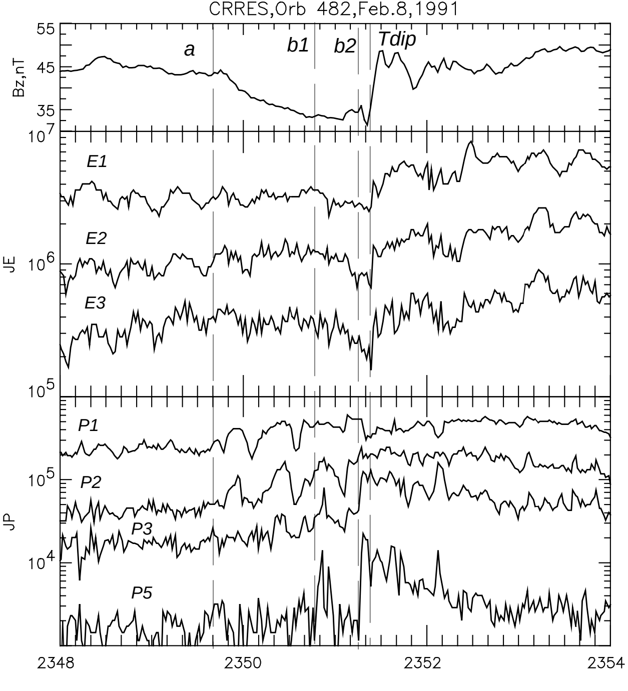

Fig. 5. Substorm B. Shown in the same format as Fig. 2.

Fig.5 presents the Bz component and the electron and proton intensity in the several channels. One can see a short precursor with the dispersion at the moment "b1" and a burst of energetic protons (without the dispersion) at the moment "b2".

Fig. 6 presents the proton and electron flux variations near the dipolarization onset. One can see that dispersion (in 3-4 s) energetic electron injection in the channels E1 - E3 (21.5-49.5 keV) coincides with the drop of the proton flux in the lowest energy channel P1 (37-54 keV) as in the substorm A. However, in the substorm B, the drop is observed in the fluxes J_{-} of the protons with the gyrocenters tailward of the CRRES. It may indicate that in this case the drop was far tailward the CRRES.

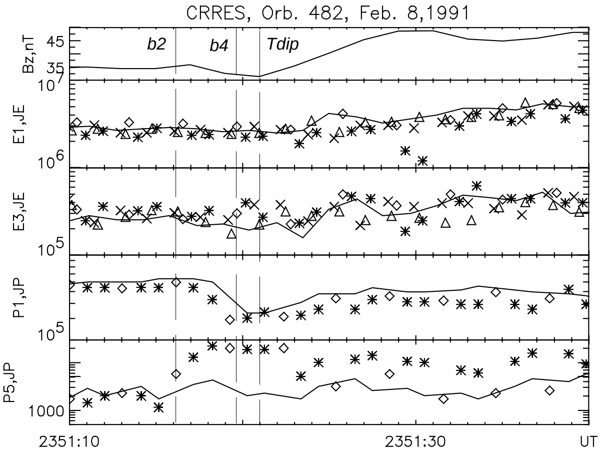

Fig. 6. Substorm B. Shown in the same format as Fig. 4.

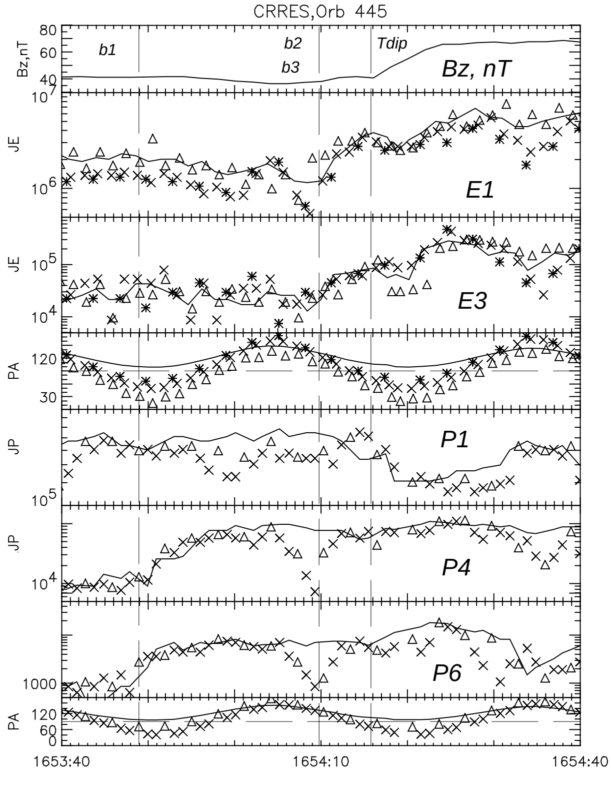

Fig. 7. Substorm C. Shown in the same format as Fig. 3 and Fig. 4.

Substorm C. On Jan 24, 1991, the CRRES (orbit 445, 23.55 MLT, mlat= - 0.9^{o} , and r=6. Re) was located also within PS [Maynard et al, 1996]. The fluxes of P1-P2 protons were nearly isotropic.

From Fig.7 one can see:1) Dispersionless injection of energetic electrons in the channels E1 - E5 (21.5-69 keV) coincides with the drop of the proton flux J_+ in the lowest energy channel P1 (37-54 keV), which expands westward at the velocity of 130 km/s.

2) Dispersionless electron injection coincides with the dispersionless higher energy proton increase westward the CRRES and occurs 6 s before the Tdip. Here the moment b2 coincides with the moment b3.

3) 20 s before the electron injection, the precursor in the form of the proton increase with the 2 s dispersion is observed. This precursor propagates Earthward at the velocity of 150 km/s.

Discussion

We found that near the substorm onset at a geocentric distance of ~ 6 Re the short interval of 30-40 s consists of a temporal sequence of such phenomena : the proton injection with dispersion in 2 s, the proton injection without dispersion, the electron injection without dispersion (simultaneously with local dipolarization onset), and finally, the electron injection with dispersion. This sequence may be a signature of westward and/or Earthward expansion of the substorm activation when new localized regions of impulsive particle accelerarion appear outside the initial position of the active region. The growth of the cross-field current instability (Lui et al, 1991) which probably trigger the current disruption may be associated with the observed bursts of energetic protons. The dispersionless character of the proton and electron injections considered here is an argument for local acceleration of the particles near the CRRES.

From Fig. 5 one can see that the increase of P1-P2 proton fluxes in the moment "a" was observed during the Bz component decrease which was morphologically similar to the magnetic signature of the explosive growth phase [Ohtani et al, 1992]. However we suppose that the analyzed here more energetic proton short bursts rather appear during the LEXO stage [Erickson et al., 2000]. The LEXO is the Local EXplosive Onset when the energy flowing toward the ionosphere increases explosive.

Conclusion

Main results of the analysis of nearly dispersionless proton and electron injections in the vicinity of the inner edge of the plasma sheet are the following.

1). Before and during dipolarization, the behaviour of the lowest energy (37-69 keV) protons and higher (69-254 keV) energy protons are different.

2). Anisotropy of different energy proton fluxes may be different. Sometimes the flux variations are noncoherent within a small spatial region comparable with the gyroradius (here ρ_i ~ 350 - 1400 km).

3). Dispersionless energetic electron injection coincides with the drop of the lowest energy proton flux. This drop may expand westward at the velocity of 130 - 350 km/s.

4). In all cases the energetic electron injection is observed 1-6 s before the sharp dipolarization onset Tdip.

5). An intensive higher energy proton burst develops just 20-30 s prior to the Tdip. The Earthward expansion of the substorm activation occurred at the velocity of (50 - 150) km/s.

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