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DYNAMICS OF LOW ENERGETIC IONS AND ELECTRONS NEAR SUBSTORM ONSET

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Abstract. Substorm associated behavior of the low energetic particles (30 eV – 28.5 keV) near the earthward edge of the plasma sheet is examined using the data from the CRRES during the late growth and early expansion phases of a substorm on March 12, 1991. The significance of these particles for substorm onset mechanism is discussed. During this substorm, the CRRES was located on L ~ 6.3 and ~ 20^{O} to the west from substorm onset region and observed three small bursts (100-120 s) of the ions (0.633- 9.6 keV) with quasi-period of 3-4 min. The first, less energetic (0.633-0.831 keV) ion burst occurred 2 min before the substorm onset, at the moment of weak brightening of the most equatorial arc near the latitude of ~62^{O}. The ion bursts preceded by 1-2 min the electron (7.31- 21.7 keV) bursts. The alternation of ion and electron bursts may be a signature of a ballooning-type instability developing at the inner edge of the plasma sheet near substorm onset.

1. Introduction

The substorm expansion onset is recognized by a sharp decrease of the X component in the ground magnetometer records near magnetic midnight and by the breakup of the most equatorward arc. Two basic models of substorm onset have been suggested: the near-Earth current disruption in the region of the inner plasma sheet and the near-Earth neutral line. Numerous near-geosynchronous observations are in favor of the first substorm model in which the substorm starts by a localized instability mechanism that interrupts and diverts the cross tail current into the ionosphere via field-aligned currents [Lui, 1991]. Roux et al. (1991) observed the electric field oscillations in the magnetosphere at 6.6 Re during a substorm expansion. They related these oscillations to the ballooning waves and the WTS. Maynard et al. (1996) presented the observations of brief electric field reversals from dawn-dusk to dusk-dawn direction with a quasi-period of 2-3 min at the inner edge of the plasma sheet before the substorm onset.

In this paper we have used data from the CRRES satellite [Singer et al., 1992; Korth et al., 1992; Hardy et al., 1993] to examine the dynamics of low energetic ions and electrons (LEPA data) near onset of a substorm on March 12, 1991. The CRRES was located on L ~ 6.3 (and ~ 21.5 MLT) near the earthward edge of the plasma sheet. This substorm is a sequence of optical pseudo-breakups and breakup above Scandinavia near the latitude of ~62^{O}. The large expansion of the substorm begins 7 min after substorm onset (the moment Texp).

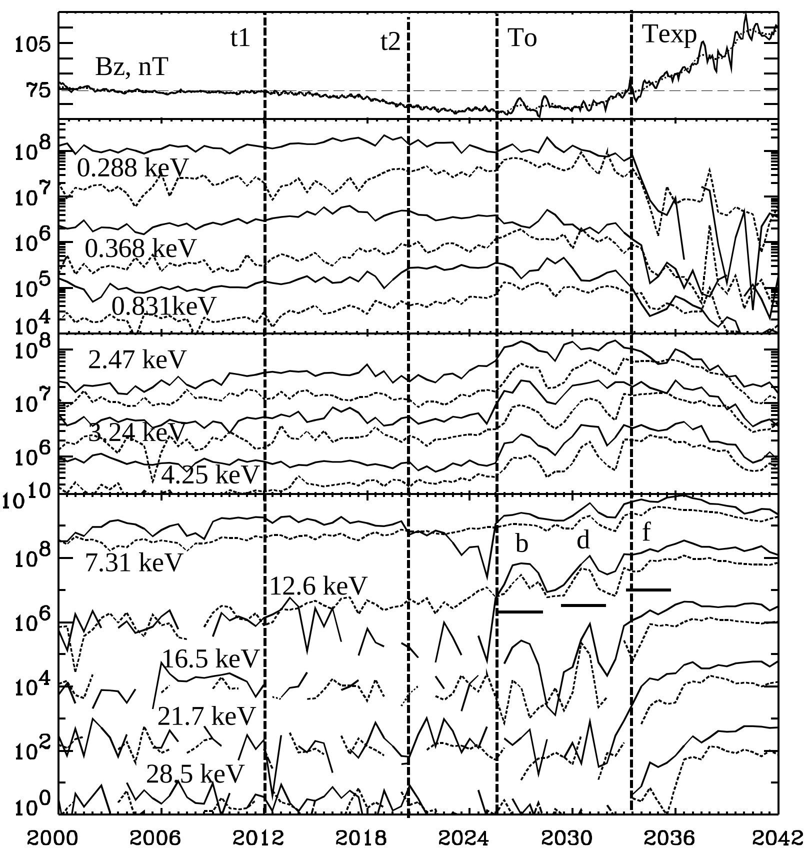

Figure 1. Substorm on March 12, 1991. Data from the CRRES. From top to bottom: the Bz component, LEPA electrons (perpendicular fluxes are shown by the solid lines and parallel ones by the dashes). Panels (2-3) and (4) refer to populations A and B, respectively (see the text).

2. Inner boundary of the plasma sheet. Injection and bursts of electrons

After pseudo-breakups (at the moments t1 and t2), the stretching of magnetic field lines increases and the CRRES encounters the Alfven layers of low-energy electrons (0.213-5.57 keV) designated as population A. The lowest energy electrons appear first at the CRRES. Simultaneously, one can see the outer boundary of old trapped electrons (7.31 – 12.6 keV), when higher energy particle fluxes decrease first (population B) during boundary moving inward. Here, the cutoff energy Wc= 5.57 keV refers to the transition between open and closed drift trajectories of electrons [Kerns et al., 1994]. Just before To, the electrons with $W \leq W_C$ (population A) move toward the CRRES position from the tail. The electrons with $W > W_C$ (population B) move on closed drift paths. As examples, the fluxes of several energetic channels, corresponding to population A (B) are shown on panels 2- 3 (4) of Figure 1.

Near the moment To, we see the first sharp injection of 7-16.5 keV electrons with the pitch angles PA~ 90^O without a significant magnetic field dipolarization. Near the moment Texp, we see the next injection of 21.7- 28.5 keV electrons with PA~ 90^O.

In the interval between To and Texp, the electron bursts (of ~100 s duration) are observed which are associated with an increase in magnetic field fluctuations. After the first burst, the fluxes of 7.31 – 12.6 keV electrons increase, after the second - of 16.5-21.7 keV electrons, and then – of 21.7- 28.5 keV electrons.

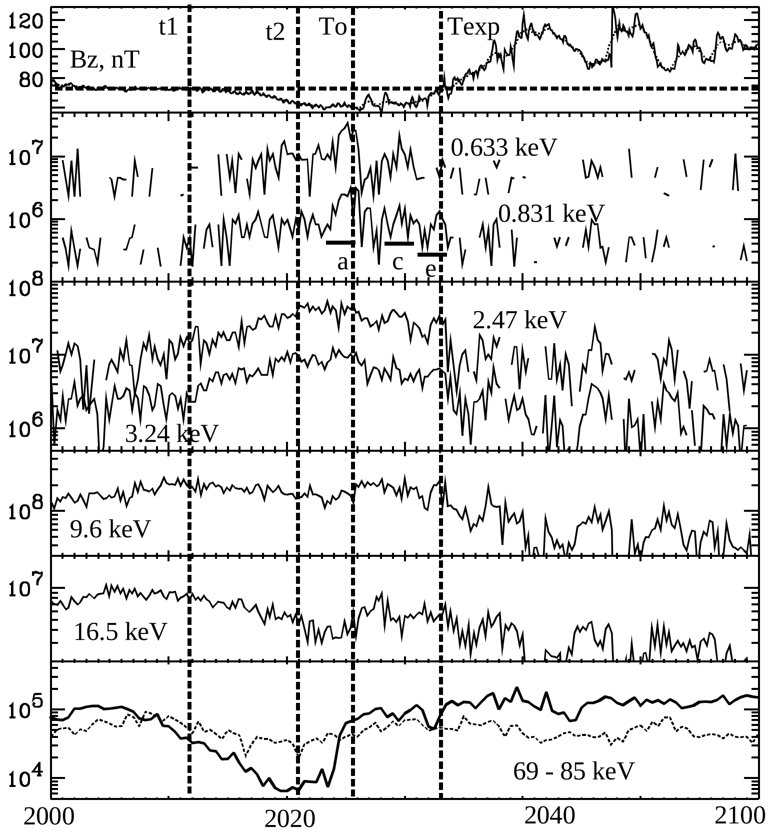

Figure 2. A substorm on March 12, 1991. From top to bottom: the Bz component, panels 2, 3 and 4, 5 referring, respectively, to populations A and B of LEPA ions and panel 6 referring to higher energy ions.

3. Dynamics of the low energy ions

During the growth phase, the stretching of magnetic field lines on the CRRES, as well as the fluxes of 0.831–7.31 keV ions (population A), increase (panels 2-3 in Figure 2), while the fluxes of 9.6–21.7 keV ions (population B) decrease (panels 4-5). The growth phase associated behavior of the particles may suggest that the transition region between different particle populations and “dipole” and “tail-like” magnetic field gets narrow and moves Earthwards.

After To, population A decreases, and population B is enhanced. Both A and B populations are depleted after Texp, when large-scale magnetic field dipolarization occurs and transition boundary removes tailward.

In the vicinity of a transition boundary, three ion bursts (100-120 s) with a quasi-period of 3.5 min are observed in the energy range of 0.633 – 9.6 keV. The beginning of a sequence of these ion bursts coincides with the enhancement of more energetic (54-147 keV) proton fluxes with PA ~ 90^O (panel 6 in Figure 2) and rapid change of proton PA distribution (PAD) to isotropic. This happens in the moment of weak brightening of the most equatorial pre-breakup arc near the latitude of ~62^O (2 min before To).

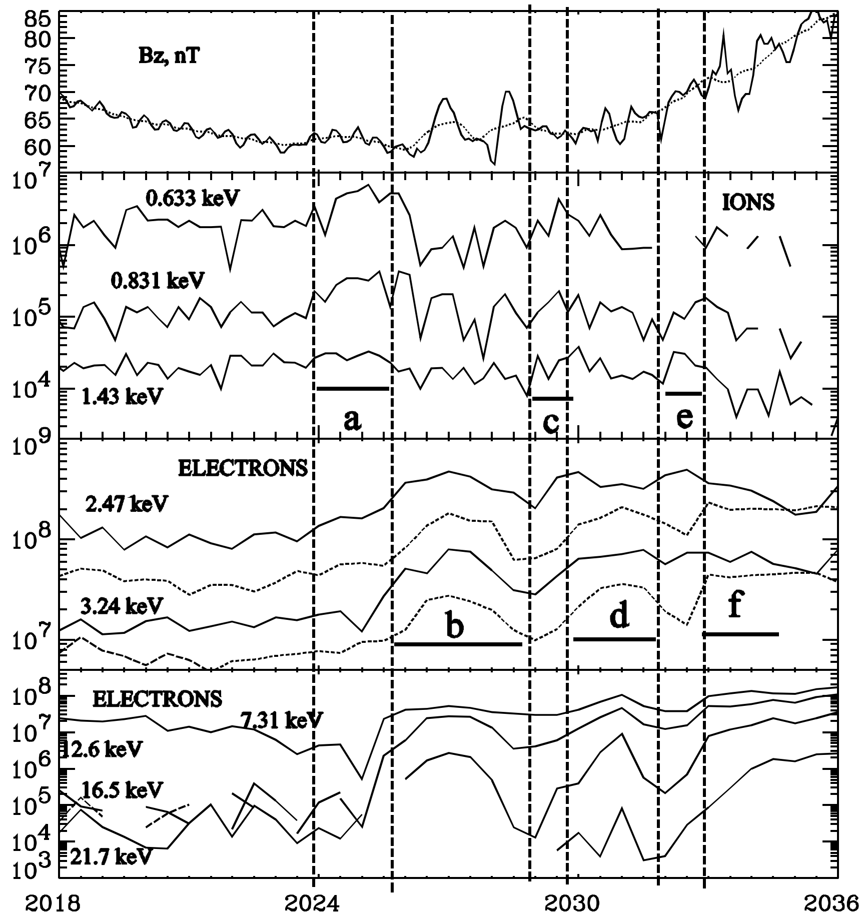

Figure 3. The alternation of low energy ion and electron bursts during a substorm on March 12, 1991.

4. Alternation of ion and electron bursts. Discussion

From Figure 3 one can see that the ion (0.633-9.6 keV) bursts occurred 1-2 min before the electron (7.31- 21.7 keV) bursts. Ion bursts may occur without significant magnetic field variations. Electron bursts were observed during small dipolarizations and increases of magnetic field fluctuations. The anticorrelation between the ion and electron bursts, found in investigated substorm on March 12, 1991, is consistent with the variations of more energetic particles near substorm onset observed in [Roux,1985; Kozelova et al., 1986; and Roux et al., 1991].

These variations of ion and electron bursts may be associated with the multiple crossings of the above supposed transition boundary that has an oscillatory behavior.

Indeed, this boundary may be unstable to westward travelling perturbations. The instability may be similar to the drift- Alfven ballooning [Roux et al., 1991]. When the instability develops with the combined effects of azimuthal drift of energetic ions and westward motion of the wave, the energetic ions and electrons, owing to their westward and eastward drift, respectively, lead to a charge separation. Intense auroral forms, associated with enhanced electron precipitation, should map the region where negative charges tend to prevail.

Figure 4 reproduces a picture from [Cladis, 1971, Figure 3] of drift-wave resonances of magnetic field lines excited by the azimuthal drift of protons. The field lines oscillate as standing waves in the meridional plane and form a wave pattern in the azimuthal direction that moves with a phase velocity equal to the mean azimuthal drift

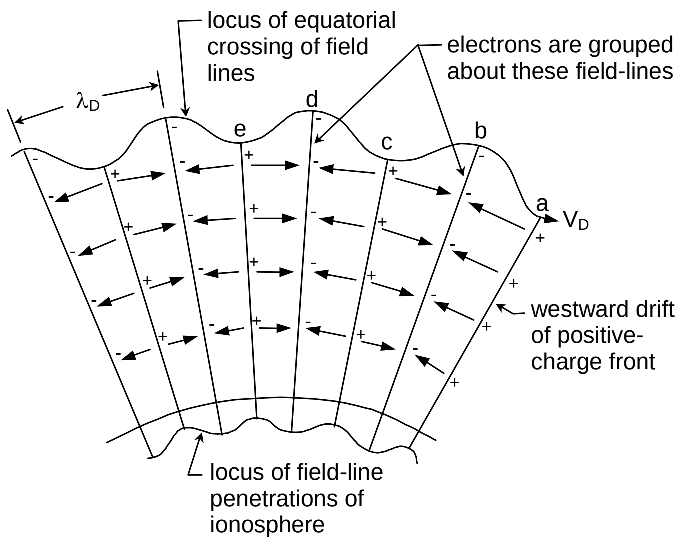

Figure 4. Illustration of drift-wave resonances of magnetic field lines during azimuthal drift of proton front, adopted from [Cladis, 1971].

velocity of the particles. In this Figure, the magnetic field lines that were originally in the same L shell are shown in their displaced positions (the wave-like line in the equatorial plane from above the north pole), according to Cladis (1971). This wave-like line in the equatorial plane may represent the transition boundary between the regions with different characteristics of plasma and magnetic field. More dipolar magnetic field lines and population B are located in the earthward side of this boundary, while the tail-like magnetic field lines and population A are located in the tailward side of the boundary. Let us compare our Figure 3 and a picture in Figure 4. Observed during substorm on March 12, 1991 ion bursts 'a', 'c' and 'e' may be associated with a minimum displacement ('a', 'c' and 'e' in Fig. 4) of magnetic field lines with the positive charge. The most displaced magnetic field lines ('b', 'd' and 'f') contain a negative charge.

5. Summary

1).During growth phase magnetic field stretching, the CRRES observed a formation of a sharp transition boundary between different particle populations: one population is low-energy (0.28-1.88 keV) electrons and ions (1- 7.31 keV) of the plasma sheet, and the other is the old trapped electrons (7.31 – 12.6 keV) and ions (9.6- 28.5 keV) on the outer boundary of energetic ion region. This transition boundary moves earthward (tailward) during substorm growth phase (expansion phase). We suppose that this boundary may be unstable to westward travelling perturbations (similar to drift- Alfven ballooning).

2). 2 min before the substorm onset, a sequence of alternating bursts of the low energy ions and electrons begins. The bursts of ions (0.633 – 9.6 keV) have the time duration of 100-120 s and quasi-period of 3-4 min and may occur without significant magnetic field variations. The ion bursts occur 1-2 min before the electron (2.47- 21.7 keV) bursts. The electron bursts are associated with a small increase of the Bz component and of magnetic field fluctuations.

These variations of the ion and electron bursts may be associated with multiple crossings of the above supposed transition boundary that has an oscillatory behavior.

3). The beginning of the sequence of low energy particle bursts coincides with the enhancement of more energetic (54-147 keV) proton fluxes. A sharp gradient of energetic ions in the ∇B-drift direction may excite the drift-wave resonance of magnetic field lines [Cladis, 1971] and support oscillations on the transition boundary. The first ion burst happened at the moment of weak brightening of the most equatorial arc near the latitude ~62^{O}.

Our analysis supports the idea of ballooning instability near the inner edge of the plasma sheet as being responsible for initiation of substorm onset.

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