LOCAL GRADIENT OF ENERGETIC ION FLUX DURING DIPOLARIZATION ON 6-7 R_E

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ABSTRACT

Injections of energetic particles and dipolarization of magnetic field are well-known signatures of magnetospheric substorm in the near-Earth region of plasma sheet. However, the physical processes associated with these phenomena are not fully understood. The pressure gradient and anisotropy are significant parameters for understanding of physics of the substorm development. Kozelova et al (1986) found in study of GEOS 2 data that the anticorrelation between the proton and electron fluxes is connected with the western edge of the expansive auroral bulge (with the spatial extent >100 km and with duration near 10 min). Inside the active region, where the dipolarization is observed, the proton fluxes are reduced and the electric field is directed westward. The increase (or decrease) of proton flux may be interpreted as satellite entry into the region of enhanced (or decreased) plasma pressure since energetic protons give the main contribution to the pressure.

Here we examined the CRRES data from several detectors which measured the particles in a different directions. We found the similar variations of the energetic particle fluxes (protons >37 keV and electrons > 21.5 keV) associated with the local dipolarization, however these variations were observed during the shorter interval of 30-40 s (Kozelova et al, 2002). Sometimes the azimuthal anisotropy of proton fluxes of different energy may be different and the flux variations are noncoherent within a small spatial region comparable to the proton gyroradius (here from 350 to 1400 km). Dispersionless energetic electron injection coincides with the dipolarization and with the drop of the 37-54 keV proton flux. This proton drop begins eastward of the CRRES and then expand westward with the velocity of 130 - 350 km/s.

INTRODUCTION

There are two key processes in the evolution of a magnetospheric substorm: (a) a formation of the substorm current wedge (SCW) with the near-Earth current disruption in the near-geosynchronous plasma sheet and (b) the onset of magnetic reconnection (MR) in the midtail plasma sheet. There are two basic models of substorm onset and expansion: the Near- Earth Current Disruption (CD) and the Near- Earth Neutral Line (NENL) models. Both models include both the SCW formation and the NENL formation. They are distinguished by the temporal sequence in the formation of SCW and NENL.

The SCW images a partial diversion or disruption of the cross-tail current which links with the ionospheric currents through field-aligned currents. This magnetosphere-ionosphere coupling plays an important role in the substorm process.

Data from the CRRES spacecraft and the geosynchronous spacecraft GEOS 2 have been used to study the evolution of the local conditions leading up to and during CD. In this paper we present some features of the structure of both the B and E fields and of the plasma distribution occurring during a few minutes before the onset of the substorm explosive phase. These features are very important for understanding the physics of the substorm itself.

RESULTS

Energetic particle and magnetic field observations by the CRRES and GEOS 2 have been used to study the characteristics of the dynamic behavior (with different scales) of the energetic particles in the near-earth magnetosphere during substorms. Detailed investigations of the substorm development for several case studies (Kozelova et al., 1986, 2000, 2002; Lazutin et al., 1998) allow us to make the following conclusions.

Changes of particle energy density and effect of distant current near *Tdip*

We investigated dispersionless injections of energetic (>37 keV) ions and energetic (>21.5 keV) electrons on the CRRES near the magnetic equatorial plane and near midnight (Kozelova et al., 2002). We computed magnetic field *Hd* of distant currents except diamagnetic component in accordance with (Gurgiolo et al., 1979).

Maxwell's equation, $\nabla\times\mathbf{B_t} = (4\pi/c)\mathbf{J_t}$, relates the measured magnetic induction $\mathbf{B_t}$ to the total current $\mathbf{J_t}$. Both local and distant current sources contribute to the measurement of $\mathbf{B_t}$. In a magnetized plasma, such as that of the magnetosphere, current contributions come from magnetization, curvature, and gradient drifts of particles. In this paper we are interested in the diamagnetic current, which can be studied from the plasma data. The diamagnetic current and the particle magnetization are related through $\mathbf{J_c} = c\nabla\times\mathbf{M}$. If one defines $\mathbf{H_d} = \mathbf{B} - 4\pi\mathbf{M}$, then the Maxwell's equation for $\mathbf{H_d}$ is $\nabla\times\mathbf{H_d} = (4\pi / c)\mathbf{J_d}$. Here $\mathbf{H_d}$ is due to all of the currents except the diamagnetic component.

We estimated perturbation currents d**J** using the differential vectors of the computed magnetic field $\mathbf{H_d}$ and the line current model as in (Kozelova et al., 1996). We assume that localized current perturbation in magnetosphere may be deduced from differential magnetic field perturbation d**B**(t) = **B**(t+dt) - **B**(t). The line current model have been used to simulate equivalent current d**J**, associated with this perturbation d**B**. We assume that the current d**J** is restricted to the equatorial plane and have an arbitrary orientation. We estimate the magnitude, orientation and location of the current d**J** using the Biot-Savart law.

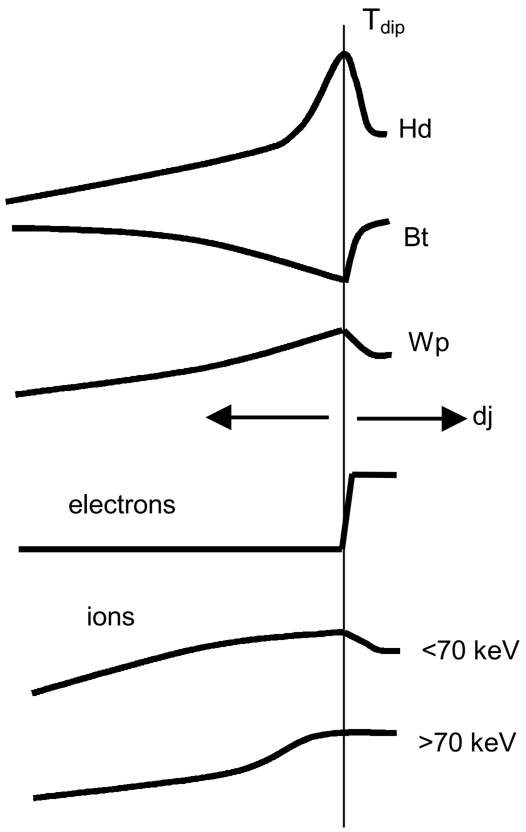

Fig.1. A schematic of the changes in the fields, currents and particle fluxes near the local dipolarization moment *Tdip* from the CRRES observations (Kozelova et al., 2002). Here *Hd* is the magnetic field of all currents except the diamagnetic component, *Bt* is the measured magnetic induction, *Wp* is particle energy density and *dj* is the perturbation currents with the diamagnetism exclusion.

Fig.1 presents a schematic of field, current and particle flux variations. Fig.2 presents their detailed development for one case study. On these figures current flow to the left is corresponded to westward current and current flow to the right is corresponded to eastward current or cross-tail current decrease (CD). From Fig. 1 and Fig.2 one can see that:

a) The particle energy density at $r \sim 6$ R_E increases toward the local dipolarization onset. Decrease of the magnetic field before *Tdip* cannot be completely accounted by diamagnetism alone. Other current sources must be active. The current of perturbation on the front of the proton injection directed westward and changed the direction eastward on the leading front of the electron injection.

b) The distant current intensity begins to increase gradually. Just prior to the moment *Tdip*, this current increases explosively when intensive high energy (> 70 keV) proton burst occurrs.

c) In the moment *Tdip* the current decreases suddenly (the CD occurs). The CD coincides with the drop of the lowest energy (< 70 keV) proton flux. The electron flux increases simulteneously.

d). Before and during dipolarization, the behaviour of the low energy (<70 keV) protons and higher energy (>70 keV) protons are different.

Thus this analysis support the idea that sharp transient increase and then transient decrease of magnetospheric cross-field current at near-geostationary distances are due to local process and may be associated with an instability which triggers the local substorm dipolarization and particle acceleration.

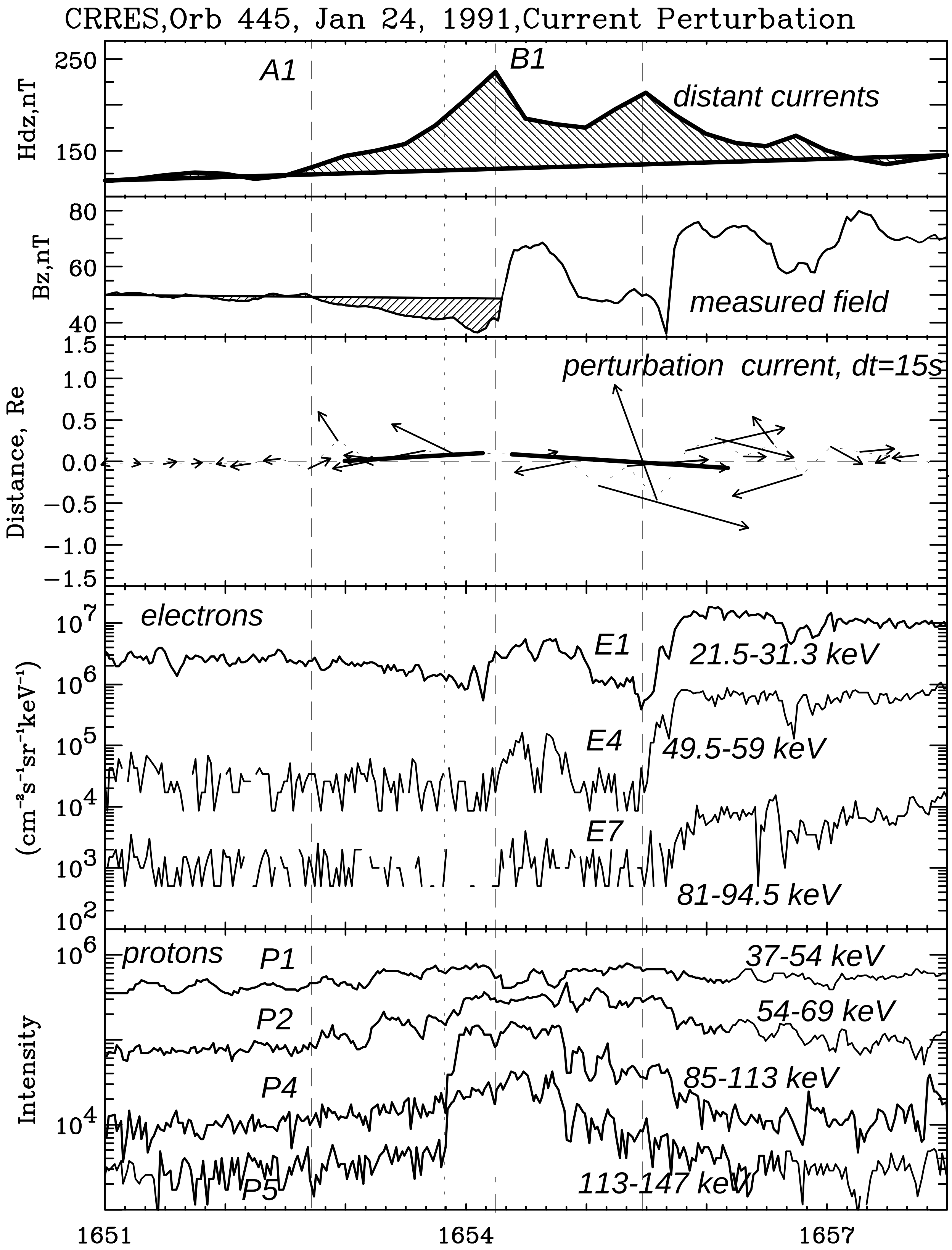

Fig.2. An example of variations of fields and particle fluxes on CRRES. From the top to the bottom: 1) and 2) Z components of the magnetic field of distant current and measured magnetic induction *Bt*, 3) position of the perturbation currents *dj* (in arbitrary units) with the diamagnetism excluded, the positive distance is parallel to the X axis with respect to the CRRES position, 4) electron fluxes in three energy channels, and 5) ion fluxes in four energy channels.

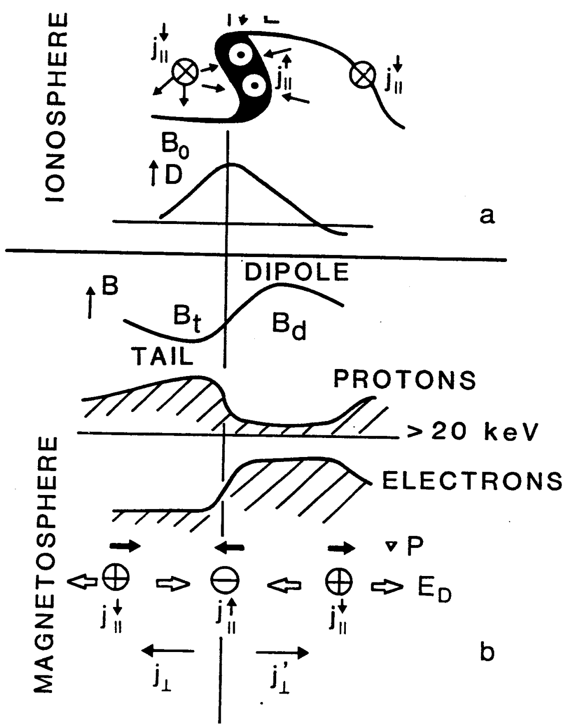

Fig.3. A schematic of distribution of fields and currents in the vicinity of the WTS from the ground (Kozelova and Lyatsky, 1984) (a) and satellite GEOS-2 (b) recordings (Kozelova et al., 1986).

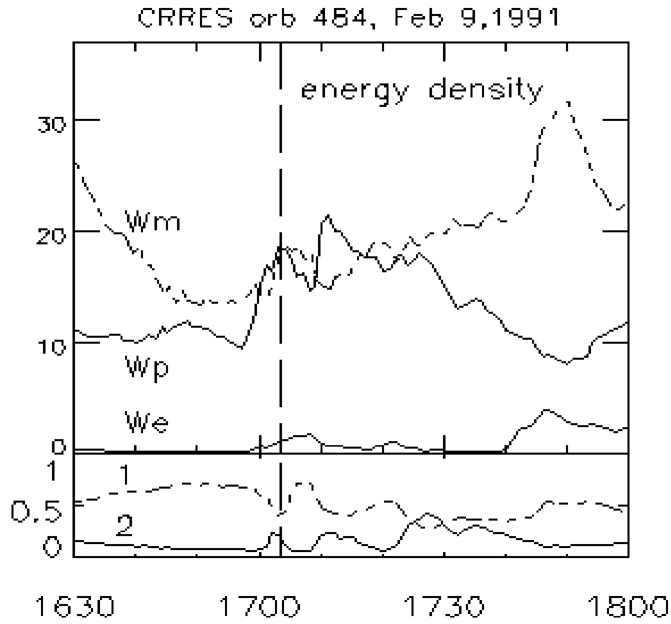

Fig.4. An example of variations of particle energy density on CRRES. *Wp* (*We*) - ion (electron) energy density and Wm - magnetic field energy density. Lower panel: relative contribution of the 37-54 keV protons (1) and the >69 keV protons (2) to total proton energy density (Lazutin et al., 1998).

The WTS in the ionosphere is an image of a dynamic particle pressure boundary

In the magnetosphere a dynamic boundary dividing the areas with different particle pressure appears during simultaneous WTS observations in conjugate ionospheric region. The ion (electron) fluxes increase west (east) of this boundary.

Kozelova et al.(1986) found in study of GEOS-2 data that the anticorrelation between the proton and electron fluxes is connected with the western edge of the expansive auroral bulge (with the spatial extent >100 km). Inside the active region, where the dipolarization is observed, the proton fluxes are reduced and the electric field is directed westward. The localized upward FAC (from the ionosphere) related to WTS is located on the western edge of this region (Fig.3). The increase (or decrease) of proton flux may be interpreted as satellite's entry into the region of enhanced (or decreased) plasma pressure since energetic protons give the main contribution to the pressure. Thus the data support the idea that the auroral bulge may be the region of decreased pressure.

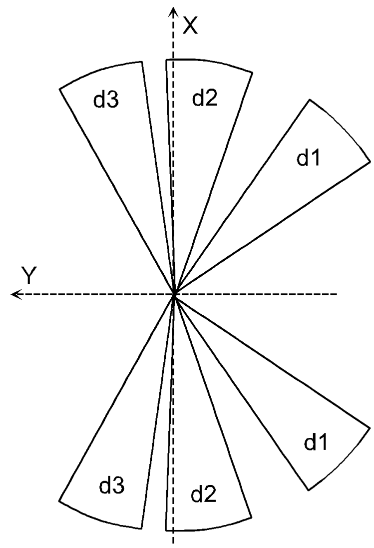

Fig. 5. Schematic of the sectors on the XY-plane where the gyrocenters of the protons measured by different detectors d1-d3 locate.

Fig.4 presents a clear anti-correlation between the relative importance of the low and high energy protons in the variations of the particle pressure during the substorm from CRRES data (Lazutin et al., 1998).

Local dipolarization coincides with the drop of the 37-69 keV ion fluxes

We investigated dispersionless injections of energetic electrons >21.5 keV and protons > 37 keV of the 'p→e' class (with best possible one second resolution) during substorms on the CRRES when spacecraft was close to the magnetic equatorial plane and near midnight. We found that near the substorm onset on a geocentric distance of ~ 6 RE the short interval of 30-40 s consist of the temporal sequence of such phenomenons: the proton injection with dispersion in 2 s, the proton injection without dispersion, the electron injection without dispersion (simultaneously with local dipolarization onset), and at last the electron injection with dispersion. This sequence may be the 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. The growth of the cross-field current instability (Lui et al, 1991) may be associated with the observed bursts of energetic protons. The dispersionless character of the proton and electron injections considered here is the argument for local acceleration of the particles near the CRRES.

Using the data from several detectors (Fig.5), which were oriented in different directions (Korth et al., 1992), we determine qualitatively the location of the acceleration region relative to the CRRES and the development of this region. We found that sometimes the azimuthal anisotropy of different energy proton fluxes may be different and the flux variations are noncoherent within a small spatial region comparable to the ion gyroradius (here ρ_i~ 350-1400 km).

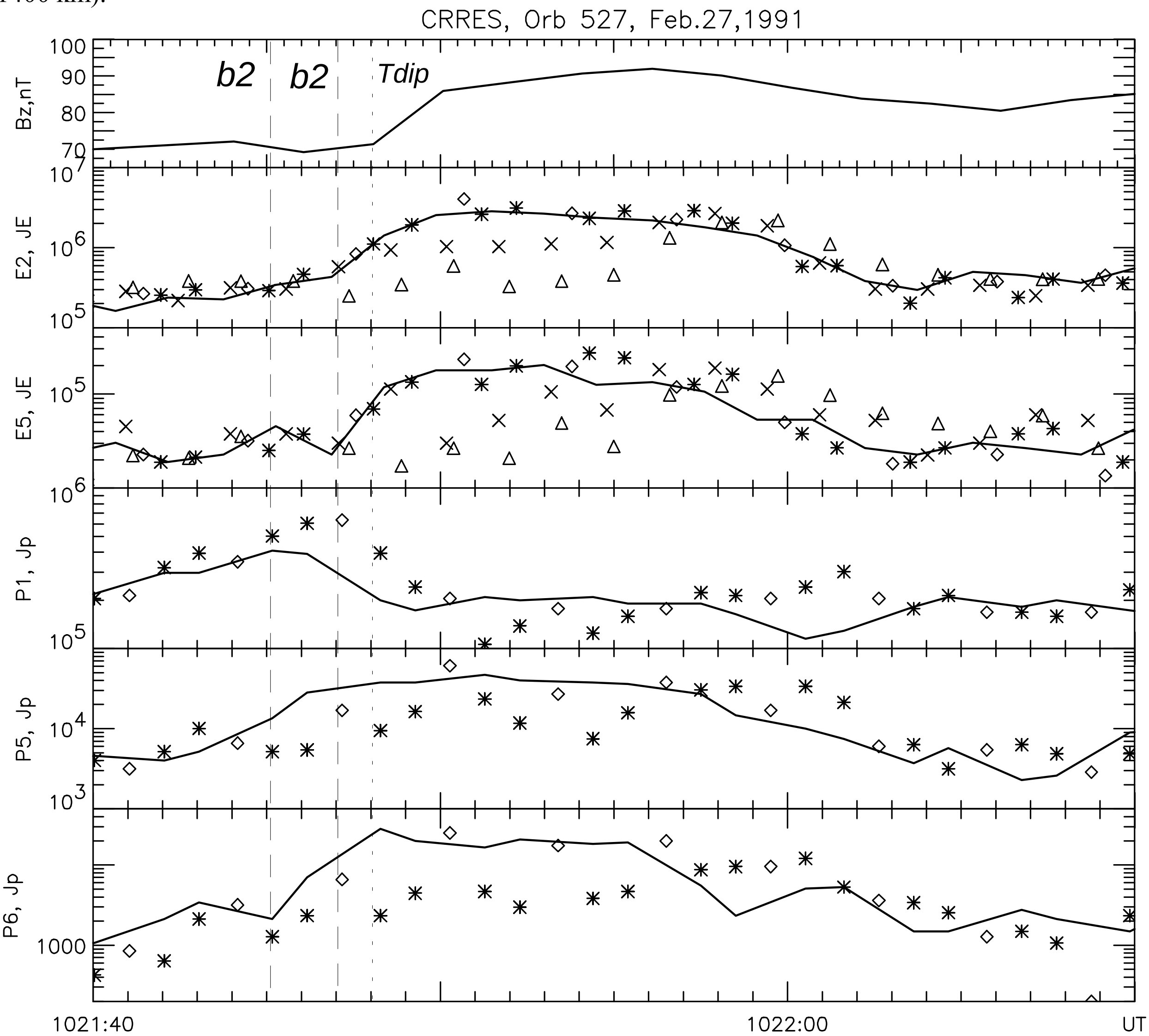

Fig. 6. An example of variations of field and particle fluxes from several detectors on CRRES. From the top to the bottom: 1) *Bz* component of magnetic field, 2)-3) - electron fluxes in two channels E2 (31.5-40 keV) and E5 (59-69 keV), and 4)-6) ion fluxes in three channels: P1(37-54 keV), P5 (113-147keV) and P6(147-193 keV). For different detectors (from East to West) the fluxes are shown with different symbol: solid line, rhombus and asterisk respectively. The 37-54 keV proton drop begins eastward of the CRRES and replaces westward.

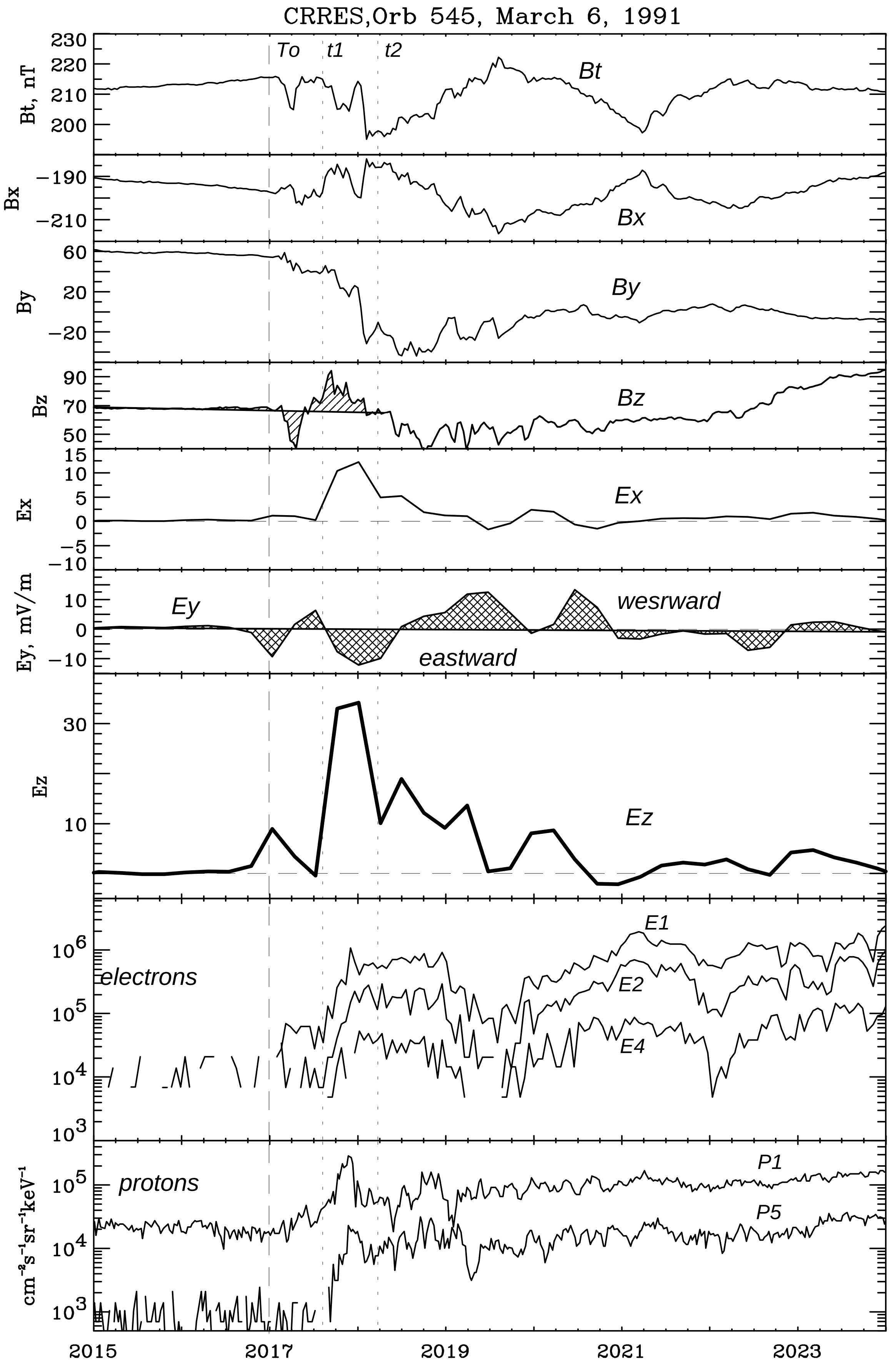

Fig. 7. Fields and particle fluxes observed by CRRES. Just before the local dipolarization, one can see one oscillation of *Ey* and *Bz* with quasi-period of ~ 50 s.

In addition, intense higher energy ion burst is observed just 20-30 s prior to the energetic electron injection. Dispersionless energetic electron injection coincides with the dipolarization and with the drop of the (37-54 keV) proton flux. This proton drop begins eastward of the CRRES and then expands westward with the velocity of 130 - 350 km/s (Fig.6).

Oscillation of B and E fields before the local dipolarization

The magnetic fluctuations during the current disruption phenomenon has been studied several reseachers. Holter et al. (1995) obtained the oscillations at low frequency with a period of 40-65 s on 6.6 Re. On 7-9 Re Ontani et al. (1995) obtained a characteristic frequency component of several times below the ion cyclotron frequency. Lui (1999) obtained a very low frequency component with a period of 30-45 s. Higher frequency components with a period of near 15 s and with a period of 3-4 s are apparent also. Roux et al. (1991) observed the electric field oscillations on 6.6 Re during a substorm expansion. They related these oscillations with the ballooning waves and the WTSs. Maynard et al. (1996) presented the observations of brief electric field reversals from dawn-dusk to dusk-dawn before the substorm onset. Erickson et al.(2000) obtaned that (1) quasi-electrostatic drift-wave oscillations with a period of 60-90 s appear during the growth phase, (2) amplitude of magnetic field oscillations with a period of 30 s increases during the explosive growth phase.

Just before the local dipolarization onset, the CRRES observed one oscillation of the azimuthal component of *E* field and magnetic *Bz* component with quasi-period of ~50 s (Kozelova et al., 2000). The peak-to-peak amplitude of the E field is about 12 mV/m and of the B field is about 50 nT. One can find a ~ 90^{o} phase shift between *Ey* and *Bz* and *Bz* lags *Ey* (Fig.7). This phase relationship is an indication of the even mode standing wave structure with the compressional component. Similar oscillations events have been observed (Maynard et al., 1996; Holter et al., 1995).

Besides, in Fig.7, one can see the tendency toward anticorrelation between particle fluxes and B field. This anticorreration may be a signature of slow magnetosonic waves. Holter et al. (1995) interpreted similar oscillation events with periods of about 45-65 s as a coupled shear Alfven-slow magnetosonic mode. These oscillations may be the result of the ballooning instability.

CONCLUSION

We have shown that the current intensification near the end of the substorm late growth phase is associated with enhancement in the particle pressure on r~6-7 R_E . Simultaneously a low frequency instability with period about 50 s is developed before local dipolarization. Intense higher energy ion burst is observed just 10-30 s prior to the *Tdip*. At this time the cross field current increases explosively. This intense ion burst may be a result from a resonance between ions and the ballooning wave (Cheng and Lui, 1998).

Then, at the moment *Tdip* this current decreases suddenly, which may be the CD as in Lui et al. (1988, 1991). Destabilization of ionosphere-magnetosphere system (local dipolarization) in a small region of space is observed coinciding with the drop of the lowest energy (< 70 keV) proton fluxes.

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REFERENCES

Cheng C. Z., and A. T. Y. Lui, Kinetic ballooning instability for substorm onset and current disruption observed by AMPTE/CCE, *Geophys. Res. Lett*., **25**, P. 4091, 1998.

Gurgiolo C., Lin C. S., Mauk B., and Parks G. K., Plasma injection and diamagnetism, *J. Geophys. Res*., **84**, NO. A5, P. 2049. 1979.

Erickson G.M., Maynard N.C., Wilson G.R., and Burke W.J., Electomagnetics of substorm onset in the near-geosynchronous plasma sheet, *Proc. 5th International Conference on Substorms, St. Petersburg, Russia, 16-20 May, 2000*,(ESA SP-443, July 2000), P. 385-388. 2000.

Holter O., C. Altman, A. Roux et al., Characterization of low frequency oscillations at substorm breakup, *J. Geophys. Res*., **100**, P. 19109, 1995.

Korth A., Kremser G., Wilken B. et al., The electron and proton wide-angle spectrometer (EPAS) on the CRRES spacecraft, *J. of Spacecreft and Rockets*, **29**, P.609, 1992.

Kozelova T. V., V. B. Lyatsky, Field-aligned current at the front of WTS, *Geomagnetism and Aeronomy*, **24**, P. 228, 1984.

Kozelova T.V., Lazutin L.L., Kozelov B.V., and Rasinkangas R., Dynamic injections, reconfiguration of magnetic field and equivalent magnetospheric currents as observed by CRRES, *Proc. Third International Conference on Substorms (ICS-3), Versailles, France, 12-17 May 1996*, ESA SP-389 (October, 1996), 429, 1996.

Kozelova T. V., Lazutin L. L., Pudovkin M. I. et al., The electric field behaviour in the magnetosphere on 6.6 RE within the active region during the substorm, *Geomagnetism and Aeronomy*, **26**, P. 621, 1986.

Kozelova T.V., Kozelov B.V., and Lazutin LL., Substorm large impulsive electric fields observed by CRRES, *Proc. 5th International Conference on Substorms, St. Petersburg, Russia, 16-20 May, 2000*,(ESA SP-443, July 2000), P. 393-396. 2000.

Kozelova T. V., Kozelov B. V., and Lazutin L. L., Particle diamagnetism and local dipolarization, *Geomagnetism and Aeronomy*, in press, 2002.

Lazutin L.L., Rasinkangas R., Kozelova T.V. et al., Observations of substorm fine structure, *Ann. Geophysicae*, **16**, P. 775, 1998.

Lui A.T.Y.,Lopez R.E., Krimigis S.M. et al., A case study of magnetotail current sheet disruption, *Geophys. Res. Lett.*, **15**. P. 721. 1988.

Lui A.T.Y., Chang C.-L., Mankofsky A.,et al., A cross-field current instability for substorm expantions, *J. Geophys. Res.*, **96**. P. 11389. 1991.

Lui A.T.W., Particle acceleration in disruption of the tail current sheet, *Phys.Chem.Earth (C)*. **24**. P.259. 1999.

Maynard N C., Burke W.J., Basinska et al., Dynamics of the inner magnetosphere near times of substorm onsets. *J. Geophys. Res*., **101**. P. 7705. 1996.

Roux A., Perraut S., Robert P., et al., Plasma sheet instability related to the westward traveling surge. *J.Geophys.Res*., **96**, P.17697, 1991.