INNER MAGNETOSPHERE SUBSTORM FINE STRUCTURE AND ENERGETIC PARTICLE DYNAMICS

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ABSTRACT

Measurements of the energetic particles and magnetic field on board of CRRES are used to study fine structure of the substorm intensifications in the inner magnetosphere. The importance of the energetic protons in the preparation and development of the current disruption process is discussed.

INTRODUCTION

To understand the process of the current disruption in the midnight sector of the inner magnetosphere, its preparation, development and propagation to other locations it is necessary to accumulate experimental data on the fine temporal and spatial structure of the substorm active phase. Several case studies on the matter have been published based on the geostationary satellites (Arnoldy *et al.,*1986, Lui *et al*., 1988,1992) and other with a quasy-geostationar such as CRRES (Ohtani *et al*., 1992, Maynard *et al*., 1996, Rasinkangas *et al*., 1994, 1996). In recent studies of several CRRES orbit data (Lazutin *et al*., 1998,1998a) it was shown, that substorm onset, or following intensifications consist of several 15-90s activations, which can be identified as the substorm elementary instability. During activations fast energetic electron increase may coincide with elementary step of magnetic field dipolarization, whereas enhanced proton fluxes often are registered before the onset of the intensification (identified from electron and magnetic field dynamics) creating additional local pre-onset magnetic field line stretching, or near the end of intensification, again increasing taillike field line stretching and quenching dipolarization.

In present paper we examine CRRES orbit 545 with two substorm onsets representing two typical satellite position in respect to the active region and two typical relations of the fine structures of the electron and the proton injections. New details of the substorm activations will be described and we will discuss in conclusion how the observed properties may influence our understanding of the current disruption process.

OBSERVATIONS

There were two substorm onsets or intensifications during CRRES 545 orbit on March 6, 1991: at 16.33 and 20.10UT. Ae index (not shown) was greater than 500nT and started to increase earlier, at 15UT, therefore we are not insisting that at 16.33 it was classical substorm onset. But such important signatures as magnetic field dipolarization and energetic particle injections have been registered and therefore we are justified to attribute both intervals to substorm onset phenomena. These two substorms of the orbit 545 represent two different categories of the onset observations: the first when satellite is located close to the active region and the second when it is situated at a distance, in our case tailward of it, at the trapping boundary.

Figure 1 present 10 minutes of the first onset. Usually such particle increase are addressed as dispersionless injections but in fact the fine structures of the electrons and ions are different and time profiles of the same particle species are energy dependent. We have specially chosen channels to underline this difference, between neighbor channels changes are gradual. This feature indicates that what we observe are extremely localized phenomena.

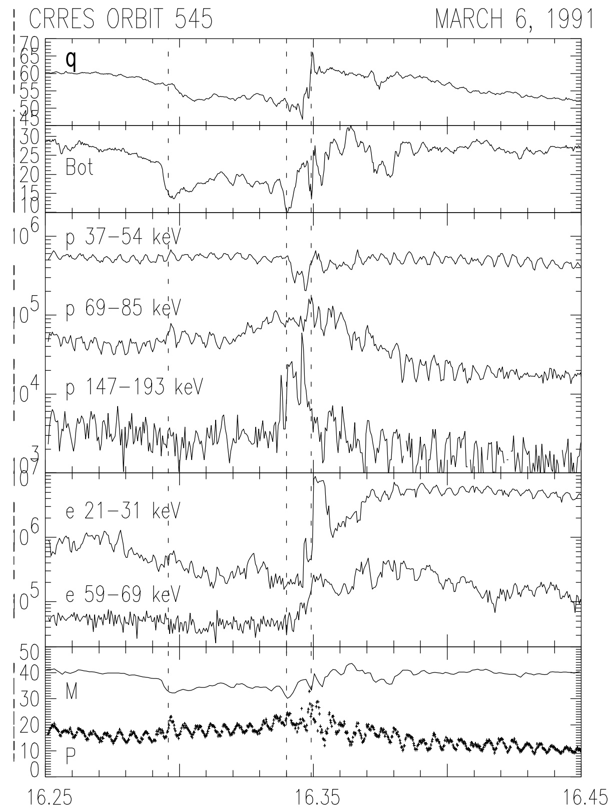

Fig.1. Magnetic field and energetic particle measurements, CRRES orbit 545, dT=2s. From the top to the bottom: magnetic field line inclination and intensity, proton and electron differential fluxes and ions/magnetic field energy density.

The substructures with duration less than 2 minutes can be noticed in particle increase profiles. Such *activations* being the reflection of basic substorm onset instabilities are typical for the CRRES measurements. Activation structures are present also in magnetic field dipolarization accompanying particle injections. Usually there are one or two activations where sharp increase if electron intensity coincides with equally sharp step of the magnetic field dipolarization. Previous and following activations are less prominent, their epicenter being located aside of the satellite, but when satellite is in the center of activation, changes might be very fast. Figure 2 shows four electron energy spectra taken during one second at the beginning of the activation marked on Figure 1 by the last dotted line. Only by 0.3s separates two successive measurements with one order increase of the electron intensity between them.

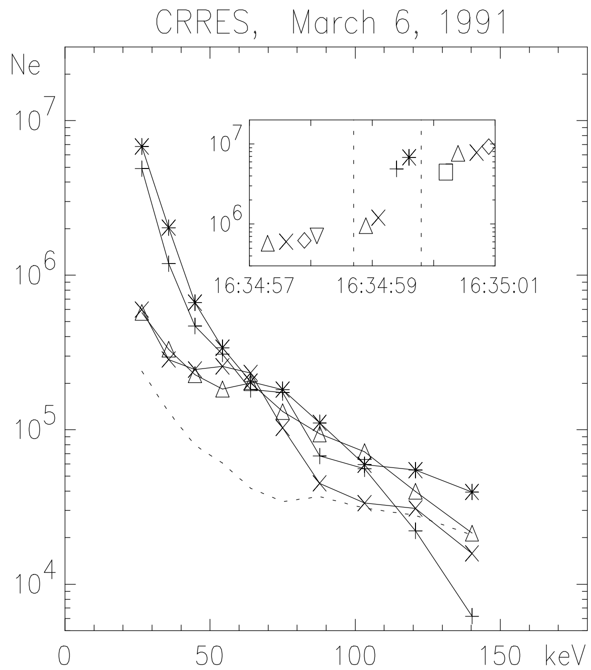

Figure 2. Electron energy spectrum measured two minutes before (crosses) and during local activation increase (first four points on the inserted box).

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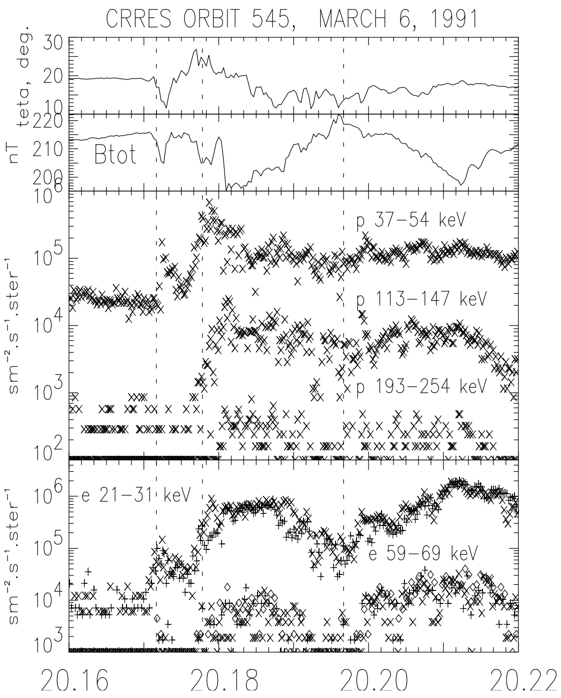

Fig. 3. The same as Figure 1 for the second substorm interval of the CRRES orbit 545 (recovery from the dropout). Measurements of one ion and three electron detectors are used without averaging.

The proton intensity increase has been registered before the main local activation. It was a two step process – at first satellite encounter enhanced low energy protons, and immediately before the main activation the high-energy protons arrived. These results in an increase of the particle energy density as compared with the energy density of the magnetic field and this ratio reached highest value before the beginning of the local activation. Again it is typical feature for the CRRES location in the active region.

The second type of the injection is illustrated by Figure 3 of the substorm, which took place four hours later. Particle injection was preceded by considerable decrease of the flux, known as a dropout event. Here we also observe steplike character of the magnetic field dipolarization (as a decrease of Btot) and the activation structures in particle temporal profiles might be easily recognized, but there are two essential differences from the first type of injection. First, there are no delay in the arrival of the electrons and ions, particle are increasing simultaneously, and the second, the amplitude of the increase are one order lower, then at the inner magnetosphere. The process might be understood in general as the trapping boundary movement through the satellite location. Note how after the first two sharp recovery steps magnetic field started to increase again and particle intensity was synchronously decreasing until 20:19:40, and then increasing again. Similar simultaneous but gradual increase of the electrons and/or ions together with gradual dipolarization might be observed also inside the trapping boundary but at the considerable distance from the active region.

DISCUSSION AND CONCLUSIONS

From the auroral observation it is known, that classical auroral breakups are usually initiates on the equatorial arc and then activity expanded northwest. When activity is in progress, activations are often observed in several latitudinaly separated regions and activity propagation might went in all directions, equatorward including (Ohtani, 1998). There are three main mechanisms or carriers responsible for the transference of the activity from disturbed region to undisturbed one. It is plasma waves or shocks, the most often discussed mechanism, it is a distant effect of the activation currents and it is a drift of the enhanced auroral particles from the active region. As soon as the local conditions are near the limit of the stability, any of these mechanisms can start local activation. In this work we are discussing only one of them, the role of the energetic protons, or ions in preparation of the local activations.

We are using the ratio of the ion energy density to the magnetic field one at the equatorial plane β as an index of stability of the local conditions. It is rather typical situation described above (Figures 1) when several minutes before the onset satellite enters the region of the enhanced flux of middle energy protons, which increase β considerably and then just before the onset of the local intensification energetic protons arrive making final increase of β. In our case CRRES magnetic latitude was about 6°, therefore magnetic field energy density was considerably higher, But when CRRES was close to the equatorial plane the condition $\beta > 1$ was achieved (Lazutinet al, 1998,1998a).

The commonly accepted scenario for the substorm onset in the inner magnetosphere is a current disruption model. There are no restrictions in the model which do not allow multiple current disruptions or repetitive disruptions registered as activations. Therefore described above fine temporal and spatial structure of substorm intensifications can be agreed with current disruption model. It is interesting to discuss the role of the auroral and energetic protons in this process. Drifting protons carries the equatorial current, which has to be disrupted. It is difficult to assume that necessary fast local particle decrease may be created by the precipitation: ions are not as easily precipitated as electrons. Moreover, ions are assumed to be accelerated during breakup, compensating possible decrease. We think, that local current decrease might be created merely by spatial redistribution of the ions, in a manner described in the meander model of Heikkila and Pellinen, (1977) but applied to the inner magnetosphere region. Arrival of the enhanced energetic ion flux may shift tailward drift trajectories of the plasmasheet ions, which have a positive radial gradient at the inner plasmasheet and therefore decrease their local intensity. That is exactly what we observe in Figure 1 and which is typical for other injection events of the first type. And that may trigger local instability.

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