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TIMING AND LOCATION OF PHENOMENA DURING AURORAL BREAKUP: A CASE STUDY

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ABSTRACT

We performed a multi-instrument ground-based and satellite study of substorm-related phenomena during auroral breakup. Our study is limited to the short (a few minutes) time interval around the breakup onset. A mapping made on the basis of event-oriented magnetospheric model places the pre-breakup arc into the near-Earth region ($r \approx 10\ R_E$) where thin and intense current sheet develops. Disruption of the current sheet was observed in the same region. The plasmoid was observed in the mid-tail. Backtracing the plasmoid onset time and location confirmed that reconnection related to the substorm onset could operate in the near-Earth thin current sheet. These observations are in agreement with the idea that the reconnection and current disruption signatures, as well as auroral breakup are different manifestations of the one process. © 2002 COSPAR. Published by Elsevier Science Ltd. All rights reserved.

INTRODUCTION

The ISTP provided a unique possibility to combine the data from different magnetospheric domains as well as from ground and ionosphere. Nevertheless till now the interpretation of the data is not complete and sometimes contradictory. The origin of substorms is still actively debated. Several plasma sheet processes are considered as candidates for the magnetospheric substorm onset mechanism. Besides the two most popular mechanisms - near-Earth reconnection [e.g. Baker *et al.*, 1996; Sergeev *et al.*, 1996] and current disruption [e.g. Lui, 1996], some of their modifications and combinations are also under discussion [e.g. Shiokawa *et al.*, 1997; Ohtani *et al.*, 1999] as well as mechanisms based on the idea of ionosphere-magnetosphere feedback [e.g. Maynard *et al.*, 1996]. Apparently inconsistent observations supporting these different views pose the problem of more accurate timing of the plasma sheet signatures relatively to auroral breakup which is a conventional proxy for substorm onset. To solve this problem one needs a multi-instrument study including both plasma sheet and conjugate auroral observations. Another important problem is the mapping of the auroral breakup into the magnetosphere. It is clear that use of "standard" magnetospheric magnetic field models for the mapping of ionospheric structures can lead to erroneous results. Indeed, such models have an intrinsic limitation because they are constructed on averaged data, and the averaging combines many different conditions and situations. In this paper, we tried to solve these problems on the basis of the multi-instrument study including the data from three ISTP satellites. We performed an analysis of the current disruption and reconnection signatures and their possible relation to auroral breakup. The event under study occurred at ~21 UT on 15 December 1996.

EVENT-ORIENTED MODEL OF THE MAGNETOSPHERIC MAGNETIC FIELD

Recently a new approach (Hybrid Input Algorithm) suitable to model the magnetotail configuration during individual events has been developed by Kubyshkina *et al.* [1999]. As input the HIA includes, besides the magnetic field measurements, some complementary information. One important addition to the input parameters is the location of isotropy boundaries of energetic particles measured at low altitudes. In particular, this makes possible an estimation of the thin current sheet location and its thickness.

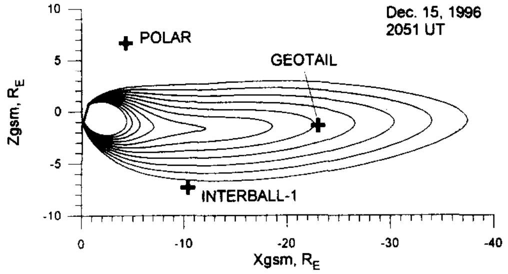

Fig. 1. Field lines of the magnetospheric magnetic field calculated using the HIA approach for the event on Dec 15, 1996. The line closest to the Earth corresponds to CGLat=60°, farthest - to CGLat= 70°. Locations of three ISTP satellites are shown as well.

During the substorm event of ~21 UT on Dec. 15, 1996 three ISTP satellites (Polar, Interball-1, and Geotail) provided the information on the magnetic field and plasma parameters from different magnetospheric domains. The Polar satellite was above the northern polar cap. Interball-1 was in the southern tail lobe at X=-10 R_E, and Geotail was well within the plasma sheet at X=-23 R_E. For modelling of the magnetosphere during the growth phase the magnetic measurements from Polar and Interball-1 have been used as well as the total (plasma plus magnetic) pressure measured by Geotail. The latest is a measure of the magnetic field in the tail lobe at the Geotail distance. In addition, the isotropy boundaries of energetic particles registered by the low-altitude satellite NOAA-12 have been included into the set of the HIA input parameters. As a result, the magnetic field model for the moment right before the breakup has been constructed. Figure 1 shows the magnetic field lines connecting the northern and southern ionosphere at corrected geomagnetic latitudes (CGLat) between 60 and 70° with interval of 1°. The main feature of this model deduced from the HIA application is the intense (~40 nA/m^2) and thin (~0.12 R_E) current sheet at distance 9-15 R_E.

TIMING AND LOCATION OF THE OBSERVED PHENOMENA

Auroral display and dynamics were controlled by the Polar UV imager, two all sky cameras of MIRACLE network in Finland and two auroral TV cameras situated on Kola Peninsula, north-west Russia (data not shown). Auroral observations showed that the breakup occurred at CGLat ≈ 64° and occupied the longitudinal sector of both Interball-1 and Geotail footprints. According to the constructed model the pre-breakup arc maps into the thin current sheet (X=-11 Re).

Near the time of auroral arc brightening (~2053 UT) the Interball-1 satellite registered sharp reduction of the magnetic field (marked by vertical dashed line in Figure. 2). Only the Bx-component changed, the other components of the magnetic field (not shown) did not change significantly at least for several minutes. This means that the current disruption occurs at the distance of Interball-1. The Geotail satellite started to observe the plasmoid signatures (tailward plasma flow, bipolar variation of the Bz component of the magnetic field) about 1 minute later (Figure 3). The electric field and energetic particle anisotropy measurements (not shown) also confirm this. Three vertical lines in Figure 3 mark the moments of the breakup onset, the first plasmoid signatures, and the passage of the plasmoid core (O-type neutral line).

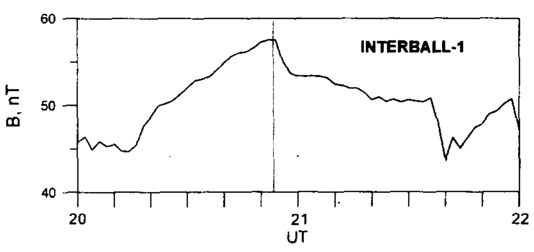

Fig. 2. Total magnetic field variations around the substorm onset measured by the Interball-1 satellite.

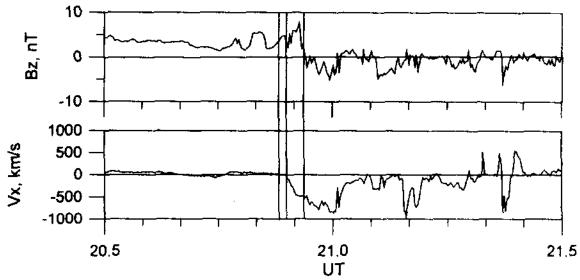

Fig. 3. The Geotail satellite measurements showing the plasmoid signatures.

TEMPORAL AND SPATIAL RELATIONSHIP BETWEEN PHENOMENA AROUND THE SUBSTORM ONSET

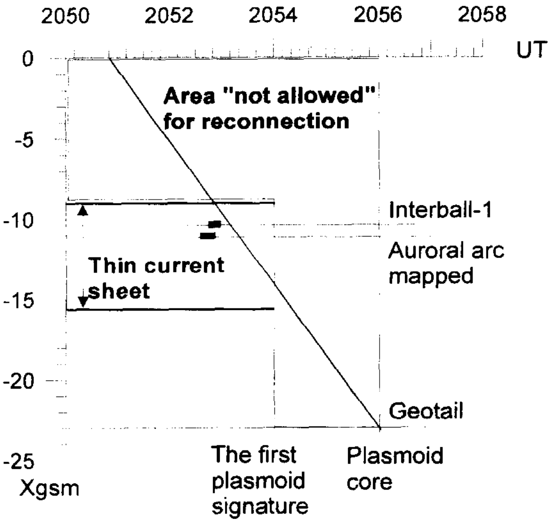

Fig. 4. Diagram showing time and location (observed and estimated) of phenomena occurred during onset of the substorm

A diagram in Figure 4 summarizes the observation in co-ordinates (X , UT). Two horizontal lines with coordinates X=-9.0 and -15.5 R_E bound the thin current sheet, location of which has been estimated using the HIA. Other three horizontal lines mark the location of current disruption (Interball-1), projection of the brightened auroral arc onto the equatorial plane, and location of Geotail. Note, that actual current sheet disruption had occurred some time before it was detected; the time delay is due to signal propagation from the neutral sheet to the satellite (distance ~5 R_E). Assuming that the signal propagates with the Alfven velocity and taking the plasma density in the plasma sheet equal to 0.15 cm (as ^{3}it was measured by the Interball-1 before it encountered the tail lobe), magnetic field equal to 50 nT (as measured by Interball-1 in the lobe), and suggesting the thickness of plasma sheet surrounding the thin current sheet as 1-5 R_E, one can conclude that the current disruption could occur between 2052:48 and 2052:58 UT. This interval is shown by the thick bar on the horizontal line marking the current disruption location.

We found that locations of the current disruption and auroral arc source in the magnetosphere are close. Let us suggest that the auroral brightening is due to ~1 keV electron beam generated (by some unknown mechanism) in the region of the disruption. Such particles reach the ionosphere in some 5 seconds. On the other hand, if the brightening is due to arrival of the Alfven wave generated by the disturbance of the current sheet (as some authors believe) at X=-10 R_E, the delay (for the plasma sheet with density of 0.15 cm) mi^{3}ght be as large as 20 second [e.g. Sergeev, 1992]. Thus, the arc could be generated between 2052:40 and 2052:55 UT. The interval is shown by the thick bar on the line marking the location of the arc mapped to the tail. Thus, keeping in mind the uncertainties related to unknown parameters of plasma sheet and unknown mechanism of the auroral arc brightening, we conclude that the relationship between the current disruption and breakup may exist indeed.

The plasmoid detected by Geotail is, most likely, the result of reconnection process occurred somewhere closer to the Earth. The plasmoid core was registered at ~2056 UT, and plasma velocity was some 500 km/s. Let us assume that the velocity was constant during the plasmoid evolution. An inclined line on the diagram represents the plasmoid trajectory. The source of the plasmoid (presumably, reconnection site) should be placed somewhere at this line. On the other hand the darkened area on diagram shows where the plasmoid could not originate. Indeed, the plasmoid generation process should start earlier than 2054 UT when the first plasmoid signatures has been detected, and it can not develop at the distances less than 8-9 R_E because the reconnection can not develop on dipole-like magnetic field lines. Thus, the "allowed" for reconnection part of the plasmoid trajectory lies within the thin current sheet region. Indeed, it is reasonable to expect the reconnection within the thin and intense current sheet where magnetic field lines are highly stretched. Moreover the trajectory lies very close to the points where we expect the generation of the brightening arc and the current disruption to appear. This means that reconnection may also be the reason for generation of the particle beam or Alfven wave responsible for auroral breakup. It is interesting to note that Angelopoulos *et al.* (1999) showed that the bursty flows and current disruption are identical near substorm onset, and they near-coincidental with the earliest substorm indicator at $X=-10\ R_E$. Our study shows that when viewed from tailward side the plasmoid origin also maps at the same near-Earth location.

CONCLUSION

Our consideration shows that both reconnection and current disruption may play the role in generation of the auroral breakup. Moreover, it is quite possible that both these processes might have occurred simultaneously in the same place.

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