論文内容の要旨

論文題目　Observational Studies of Substorm Initiation Processes
（サブストーム開始を担う磁気圏プラズマ過程の観測的研究）

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Substorm is a phenomenon in which a nightside aurora and the Earth's magnetosphere are intermittently disturbed in a large scale. The transition from the quiet state to the disturbed sate is the substorm expansion phase onset and is characterized by the sudden initiation. The substorm expansion develops within a few min, while an overall evolution time scale of substorm is a few hours. The goal of this study is to understand a mechanism of substorm. At the present knowledge, even how the substorm evolves into the disturbed state, called expansion phase, is not well understood. The aim of this dissertation is to unravel how a substorm expansion phase initiates in the magnetosphere by experimentally testing some of hypothesized processes inexplicitly taken into conventional substorm models. It will be described that the near-Earth tail (Xgsm~ -10 Re) region near the magnetic equator of the midnight sector is the ideal region for these experimental tests. In the near-Earth tail plasma sheet in the equatorial plane, the plasma processes possibly relevant to substorm expansion, namely plasma instabilities and the disturbances caused from the fast plasma flows, are expected to be detected. There have been many proposed substorm initiation models that assumes different processes in the near-Earth tail region in a different order. Detailed examinations and specifications of chains of processes are required. We searched out six dipolarization events that satisfy severe selection criteria in which the spacecraft was in the magnetic equatorial plane of the near-Earth tail plasma sheet for the period of the interest. Magnetic field and low-energy particle data from the Geotail satellite are analyzed.　The concurrent global auroral images from the POLAR satellite are also used. This fortuitous data set enables us to further the understanding of the processes of the near-Earth tail. In this dissertation, three observational studies, which provide new critical insight into substorm initiation scenario, are presented: (1) two-stage aspect of substorm onset is established; (2) low-frequency magnetohydrodynamic waves are characterized with new methodology; (3) the presence of the ballooning instability prior to substorm onset is established. Each synopsis is:

(1) Detailed inspection of the aurora imager data in the course of this study have led us to recognize that, in five of them where large-scale auroral activities are obtained, activities develop in a two-staged manner. This two-stage aspect has been suggested by *Lui* [1991] and others, but not necessarily and widely accepted by the community. Approximately 4 min after the emergence of the first aurora, the second aurora appears. This time lag is consistent with the scenario that the near-Earth tail activation is responsible for the first aurora, the disturbance propagate in the acoustic speed to the mid-tail to produce the earthward fast flow that is then responsible for the second aurora. This time lag is calculated from the argument that the near-Earth tail disturbance is propagated with the acoustic wave to the mid-tail at Xgsm ~ -20 Re, then the fast flow propagated back to the near-Earth tail at the observed speed of 800 km/s. For three out of six dipolarizations, the auroral disturbances developed with the two-stage onset, having the time difference between the stages from 3 to 5 min. The association of the second aurora activation and the earthward fast flow is confirmed by the comparison with these timings. For two out of three two-stage onset events, earthward fast flow was observed in the near-Earth tail, having the consistent timing with the scenario that the fast flow caused the second stage of auroral activation onsets. The observations of the two-stage onsets were not achieved before this study, owing to the lack of the fortuitous data and the concrete prediction of the time difference of two auroras. The result emerges that there should be tailward propagating acoustic waves (fast mode waves) and that there should be plasma instabilities excited in the near-Earth tail without the disturbance from the mid-tail. These two processes are examined in the following observational studies.

(2) The previous spacecraft observations indicate that low-frequency (0.006-0.025 Hz) fluctuations of the magnetic field appear a few min prior to a substorm-associated dipolarization onsets. "Low-frequency fitting method" is developed to examine the low-frequency fluctuation detected in the near-Earth tail prior to the local onset of the substorm. For the low-frequency fluctuations, the magnetic field and the plasma velocity fluctuations are related via wavevector and the ambient field parameters. Analyzing the combination of the magnetic field and the particle data enable us to estimate modes, wavevectors, and frequencies in the plasma rest frame.
The main finding from this method is the detection of the tailward fast mode wave at the substorm onset in the near-Earth plasma sheet for the first time.

(3) The ballooning instability has been proposed as a trigger of substorm onset. In order to detect the ballooning instability, we considered as follows. Since the ballooning instability deforms the magnetic field-line curvature at the magnetic equator, this effect can be observed as the magnetic field fluctuations in the spacecraft frame. For four out of six events, this magnetic fluctuation in Xgsm components was found from the wavelet transformation analysis, while the propagation direction of Ygsm components stayed small as expected from the ballooning instability.
From the analysis of these magnetic field fluctuations with the ion velocity, the wavelengths were estimated and were found to be in the order of the ion Larmor radius of ~3000 km. The ballooning mode waves appeared a few min prior to the substorm onset, when the plasma beta was high (20-70) in the near-Earth tail plasma sheet.

Finally, possible relevance to the substorm expansion phase onset is discussed. Since the low-frequency waves determined from this study may explain some of the auroral spatial features, we propose the substorm initiation scenario that includes the two-stage onset of substorm expansion, the low-frequency waves, and the possible corresponding auroral spatial features.