論文の内容の要旨

# Generation mechanism of flickering aurora

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At the altitude of the ionosphere, the brightest auroral phenomena are driven by a substorm triggered in the Earth's magnetosphere through field-aligned currents. The spatiotemporal auroral variation reflects not only the magnetospheric disturbance but also dynamic physical processes at the magnetosphere and ionosphere (M-I) coupling region. Auroras formed at the M-I coupling region are characterized by fine-scale structures on the order of a few kilometers, and it is often suggested that dispersive Alfvén waves (DAWs) play an important role in the formation mechanism. Flickering auroras, which are known to have the fastest temporal variation among the auroral phenomena, may be generated by electromagnetic ion cyclotron (EMIC) waves, which are one type of DAWs, and they often appear before or during the auroral breakup. Open questions about flickering auroras are a upper limit of the flickering frequency and what conditions are needed to form flickering auroras. This thesis has the purpose of answering these questions by determining their generation mechanisms using high-speed fine-scale imaging observations.

First, we designed a continuous observational system with a high spatiotemporal resolution, which was automatically controlled by a real-time auroral auto-detection system based on a machine learning technique. It was found that the accuracy of the auroral auto-detection was approximately 80% by comparison with the results judged by auto-detection and eye. It was also found that the amount of data was decreased by 75% using the auroral auto-detection system. We were finally able to obtain a continuous observational system with a spatial resolution of ~50 m at the 100 km altitude and a temporal resolution of 320 frames per second (fps) over three winter seasons.

In order to clarify the necessary conditions for flickering auroras, we statistically investigated the basic property of flickering auroras using the automatic detection of flickering auroras. It is found that the occurrence rate is basically proportional to the background non-flickering auroral intensity and that the bright auroras without the flickering modulation occasionally appears as the isolated arc. These results indicate that it is hard to excite EMIC waves within a weak and narrow acceleration region. It is also found that the flickering frequency is narrowband and has no correlation with the background auroral intensity and the substorm phase. These signatures suggest that the flickering aurora occurs at the low-altitude acceleration region. This result shows that the low-altitude acceleration region would play an important role in the excitation of EIMC waves. For the first time, it was also found that the flickering amplitude (%) decreases with the background non-flickering intensity. This variation would be formed by the difference between the electron velocity determined by the parallel potential drop and the phase velocity of EMIC waves.

We also found the first evidence that flickering auroras may be modulated by $H^+$-band EMIC waves, based on 160 fps optical observations. The fastest flickering aurora of 40–80 Hz transiently coexisted with the typical 10 Hz flickering as a result of $O^+$-band EMIC waves within the brightest aurora around the magnetic zenith. This result is strong evidence that flickering auroras are generated by multi-ion EMIC waves.

As an application of the high-speed imaging observations, we focused on the rapidly moving features of the pulsating aurora. A pulsating aurora has modulations of a few hertz embedded in the main pulsation. During a pulsation ON-phase, repetitive expansions are often observed around the edges of pulsating patches. Approximately 80% of all the deduced expansion speeds were less than 70 km $s^{-1}$ at ionospheric altitudes, which is less than the projected Alfvén speed from the magnetospheric equator to the ionosphere. The rapid motions with speeds of tens of kilometers per second are unlikely to be explained by obliquely propagating chorus elements, which are known to cause 3 Hz modulation, because the perpendicular speed of the oblique chorus waves is faster than the Alfvén speed. One of candidates to generate the rapid spatial motions is the slow-mode Alfvén wave.

Our high-speed fine-scale imaging observation is helpful to visualize wave-particle interactions and to monitor plasma environments in the M-I coupling region.