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Study of the wave mode contributing to the ion heating events in the Earth's polar region based on the Akebono observation

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We investigate the characteristics of broadband plasma waves related to ion heating in the polar regions based on the Akebono satellite observations and dispersion relation of waves in cold plasma. Heavy ions such as oxygen ions flow out from the Earth's polar region during geospace storms. Previous studies suggested that wave-particle interactions with broadband ELF (BBELF) waves, whose intensity decreases power-law from DC to several kilohertz, play important roles in the acceleration process of heavy ions. BBELF waves appear in the spectra electromagnetic in the frequency range below fcO, where fcO represents the cyclotron frequency of oxygen ion, and electrostatic in the frequency range over fcO. Ishigaya (2017) performed an event analysis of two strong ion heating events and four weak ion heating events observed by the Akebono satellite. They found that the ratio of the electric field amplitude to the magnetic field amplitude (E_w/B_w) exceeded 10^8 m/s, larger than the Alfven speed (~2 x 10^6 m/s), in the frequency range between fcH and fLH in the strong ion heating events, where fcH and fLH indicate the cyclotron frequency of proton and the lower hybrid resonance frequency, respectively. Their results suggested the importance of the enhancement of electrostatic waves in the frequency range from fcH to fLH in addition to the enhancement of waves below fcO in the strong ion acceleration process.

Based on the dispersion relation of plasma waves in cold plasma, R-mode waves can exist as well as electrostatic waves in the frequency range from fcH to fLH. Since the phase velocity of R-mode waves propagating purely along a field line exceeds the Alfven speed, electrostatic components categorized by Ishigaya (2017) may consist of R-mode waves. To identify the wave modes of plasma waves in the frequency range higher than fcH, we reanalyzed 6 events studied by Ishigaya (2017) and compared E_w/B_w with the phase velocity of R-mode waves in the frequency range from fcH to fLH. We used electric and magnetic field amplitude data from the VLF/MCA onboard the Akebono satellite. We analyzed the spectra from 100 Hz to 1 kHz, corresponding to the frequency range from fcH to fLH during the 6 events. We calculated the dispersion relation using plasma parameters and the background magnetic field intensity used in Ishigaya (2017). We compared the observed E_w/B_w with the phase velocity of R-mode waves propagating purely along a field line, which is the condition corresponding to the largest E_w/B_w of R-mode waves. In strong ion heating events, E_w/B_w was about ten times higher than the phase velocity of R-mode waves. In contrast, in weak ion heating events, the ratio was comparable with the phase velocity of R-mode waves. These results clarify that electrostatic waves were dominant in the frequency range from fcO to fLH during the strong ion heating events and suggest that R-mode waves were dominant in weak ion heating events. Since the wave electric field vector of R-mode waves rotates around the background magnetic field in the opposite direction to the ion cyclotron motion, the cyclotron resonance condition is not satisfied between R-mode and oxygen ions in the polar region. Thus the presence of the R-mode waves does not contribute to the ion heating. The result of the present study confirmed the presence of electrostatic waves and their importance in the strong ion heating events of Ishigaya (2017).