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Simulation study of the whistler-mode chorus generation in the Earth's inner magnetosphere

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Whistler-mode chorus emissions are coherent electromagnetic plasma waves observed in the dawn side of the Earth's inner magnetosphere. Chorus emissions appear in the spectra with varying frequencies in the typical frequency range of 0.2 to 0.8 f_{ce0}, where f_{ce0} is the electron gyrofrequency at the magnetic equator. They often have a gap at half the local cyclotron frequency. Recent observations revealed that chorus emissions play crucial roles in the evolution of radiation belt electrons (e.g., Turner et al., 2014; Su et al., 2015; Jaynes et al., 2015). The generation process of chorus has been explained by the nonlinear wave growth theory [see review by Omura et al., 2012] and has been reproduced by self-consistent numerical experiments [e.g., Katoh and Omura, 2007, 2011, 2013, 2016; Hikishima et al., 2009; Katoh et al., 2018].

In the present study, we investigate dependencies of the chorus generation process on properties of energetic electrons, the background magnetic field, and the thermal plasma condition. We carry out numerical experiments by using an electron hybrid code (Katoh and Omura, 2004, 2006; Katoh et al., 2005), which treats cold electrons as a fluid and energetic electrons as particles by the particle-in-cell method. We use a spatially one-dimensional simulation system assumed along a field line, while the spatial gradient of the background magnetic field is considered by a cylindrical field model (Katoh and Omura, 2006).

First, we conduct a series of electron hybrid simulations for different temperature anisotropy (A_T) of the initial velocity distribution function of energetic electrons. We vary A_T in the range from 3 to 9 with changing the number density of energetic electrons (N_h) so as to study whether distinct rising-tone chorus emissions are reproduced or not in the assumed initial condition. Simulation results reveal that N_h required for the chorus generation decreases as the temperature anisotropy of energetic electrons increases. We also find that reproduced spectra become hiss-like for large N_h cases.

Next, we carry out simulations by changing the spatial gradient of the background magnetic field intensity along a field line. Simulation results clarify that the small magnetic field gradient lowers the threshold amplitude for the chorus generation.

Based on the simulation results, we compare the parameter range reproducing distinct chorus emissions with estimations of the threshold (Omura et al., 2009) and optimum amplitude (Omura and Nunn, 2011). The results of the comparison revealed that the simulation results are consistently explained by the estimations obtained from the nonlinear wave growth theory. We also compared the spectra reproduced in the simulation results with the linear growth rate of whistler-mode waves estimated by the linear theory. The linear growth rate is positive in the frequency range corresponding to the lower band chorus and that the growth rate increases with increasing N_h. However, in higher N_h where we obtained distinct chorus in the simulation results, the frequency range of the enhanced emissions expands to the higher frequency range than those predicted by the linear theory. The difference becomes significant for smaller A_T cases. These results of the present study reveal that the coherent nonlinear wave-particle interaction is essential for generation of whistler-mode chorus emissions in the magnetosphere.

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