A Study of the Generation Process of Whistler-Mode Chorus Emissions by Self-Consistent Particle Simulation

Yuto Katoh[1,2]***, Yoshiharu Omura***[1]

[1]Research Institute for Sustainable Humanosphere, Kyoto University, Gokasho, Uji, Kyoto 611-0011, Japan, yuto@rish.kyoto-u.ac.jp, omura@rish.kyoto-u.ac.jp

[2]Planetary Plasma and Atmospheric Research Center, Graduate School of Science, Tohoku University, Aramaki-Aza-Aoba, Aoba, Sendai, Miyagi 980-8578, Japan, yuto@pparc.geophys.tohoku.ac.jp

Abstract

We study properties of the generation process of chorus emissions by a self-consistent particle simulation reproducing rising tones. Recently the generation mechanism of chorus has been explained by the nonlinear trapping theory. Energetic electrons having highly anisotropic velocity distribution feed the energy source of chorus, while the wave growth and frequency rising are explained by roles of nonlinear resonant currents. The results of theoretical analyses suggest the variation of wave characteristics of chorus depending on properties of the anisotropic electrons. By performing simulations with different initial velocity distributions, we discuss wave characteristics of reproduced chorus emissions.

1. Introduction

Whistler-mode chorus is a group of coherent emissions with rising tones observed in the dawn side of the inner magnetosphere. It is well known that the activity of chorus enhances during geomagnetically disturbed periods, while the energy source of chorus is considered to be fed by energetic electrons supplied into the inner magnetosphere through earthward particle injections during substorms. Radial transport with conserving the adiabatic invariants results in the formation of anisotropic velocity distribution of energetic electrons in the equatorial region of the inner magnetosphere, and seed waves of chorus are excited through the instability driven by the temperature anisotropy. Although a number of theories have been proposed to explain the generation mechanism of chorus, the detailed physics how coherent rising tones are generated from the narrowband seed waves has not been clarified yet. More recently we have reproduced chorus emissions by a large-scale self-consistent particle simulation using an electron hybrid model. By analyzing the simulation result, we have found important insights showing essential physics of the chorus generation process.

In the present study, we investigated the properties of the generation process of chorus emissions by using a self-consistent particle simulation. The results of theoretical analyses suggest that the characteristics of chorus emissions depend on properties of the anisotropic electrons contributing wave generation process. By performing simulations with different initial velocity distributions, we discuss the variation of wave characteristics of reproduced chorus emissions.

2. Simulation model

We study the generation process of chorus emissions by a large-scale self-consistent particle simulation using an electron hybrid model [1]. In the electron hybrid model, we treat background cold electrons as a fluid and energetic electrons as particles using the standard Particle-In-Cell method. In the present study, we solve the evolution of purely electromagnetic plasma waves by Maxwell's equations with computing currents arising from the motions of both cold and energetic electrons so as to self-consistently simulate cyclotron resonant interaction between plasma waves and mirroring energetic electrons in the region close to the magnetic equator. We assume a field-aligned one-dimensional simulation system with taking into account the spatial variation of the intensity of the background magnetic field. By using a cylindrical field model [2], we also take into account the bounce motion of energetic electrons in the simulation system.

3. Results and discussion

Recently we have reproduced chorus emissions by using the electron hybrid code [3]. This simulation was carried out using the computational time of two weeks with 512 CPUs of supercomputers (Fujitsu PRIMEPOWER HPC2500) of Kyoto University. For the initial setting of the simulation, we loaded energetic electrons with highly anisotropic velocity distribution and assumed no triggering waves except for thermal noise naturally arising from the thermal motion of energetic electrons. In the simulation result, narrowband whistler-mode waves are excited through the instability driven by the temperature anisotropy, and then coherent chorus elements with rising tones are successively appeared from the narrowband waves. We also found in the simulation result that the efficient acceleration of relativistic electrons by nonlinear wave trapping is simultaneously occurred during the chorus generation [4].

The simulation result exhibited important keys to understand essential physics of the chorus generation process. Based on the simulation result, we have proposed a physical model of chorus wave generation using the nonlinear trapping theory [5]. The results of theoretical analyses suggest that the characteristics of chorus emissions depend on properties of the anisotropic electrons contributing wave generation process. Especially, the proposed model suggests that the frequency sweep-rate of chorus elements depends on the saturation level of the linear growth of whistler-mode waves. By performing simulations with different initial conditions of energetic electrons, we discuss the variation of wave characteristics of reproduced chorus emissions and its relationship with properties of energetic electrons.

It is widely recognized that chorus emissions play important role in the rebuilding process of the outer radiation belt during the recovery phase of geomagnetic storms. Since nonlinear trapping is a key issue not only in the generation process of chorus but in the acceleration of relativistic electrons, detailed investigation of nonlinear resonant interaction with coherent whistler-mode waves is necessary to understand the dynamics of radiation belt electrons.

4. Acknowledgments

Computation in the present study was performed with the KDK system of RISH and ACCMS (Academic Center for Computing and Media Studies) at Kyoto University. This work was partially supported by Kyoto University Active Geosphere Investigations for the 21st Century Centers of Excellence Program (KAGI21) and Grant-in-Aid 17340146 and 17GS0208 (for Creative Scientific Research "The Basic Study of Space Weather Prediction") of the Ministry of Education, Science, Sports and Culture of Japan. Y.K. is supported by a research fellowship of the Japan Society for the Promotion of Science for Young Scientist.

5. References

1. Y. Katoh and Y. Omura, Acceleration of relativistic electrons due to resonant scattering by whistler mode waves generated by temperature anisotropy in the inner magnetosphere, *J. Geophys. Res.*, *109*, A12214, doi:10.1029/2004JA010654, 2004.

2. Y. Katoh and Y. Omura, A Study of Generation Mechanism of VLF Triggered Emission by Self-Consistent Particle Code, *J. Geophys. Res.*, *111*, A12207, doi:10.1029/2006JA011704, 2006.

3. Y. Katoh and Y. Omura, Computer simulation of chorus wave generation in the Earth's inner magnetosphere, *Geophys. Res. Lett.*, 34, L03102, doi:10.1029/2006GL028594, 2007.

4. Y. Katoh and Y. Omura, Relativistic particle acceleration in the process of whistler-mode chorus wave generation, *Geophys. Res. Lett.*, 34, L13102, doi:10.1029/2007GL029758, 2007.

5. Y. Omura, Y. Katoh, and D. Summers, Theory and simulation of the generation of whistler-mode chorus, *J. Geophys. Res.*, in press.