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A method for direct measurements of wave-particle interactions in the Earth's inner magnetosphere

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Whistler-mode chorus emissions are one of frequently-observed plasma waves in the Earth's inner magnetosphere. Generally, chorus emissions are characterized by a sequence of intense and coherent emissions with frequency shift. Chorus emissions are generated near the magnetic equator by nonlinear wave-particle interactions and are emerged from whistler-mode waves generated through an instability driven by a temperature anisotropy of energetic electrons in the kinetic energy range from a few to tens of keV. Chorus emissions have a potential to accelerate relativistic electrons from the kinetic energy range of several hundred keV to a few MeV. Furthermore, chorus emissions induce the pitch angle scattering of energetic electrons and relativistic electrons. Precipitation of electrons as a result of the pitch angle scattering is one of candidate processes causing diffuse or pulsating auroras observed at the ground. A number of previous studies treat the acceleration (or wave-generation) and the pitch angle scattering of energetic electrons as the diffusion problem of the phase space density and calculate the diffusion coefficients from the wave spectrum. However, the location where the wave-particle interaction occurs efficiently has not been identified yet by the direct observation. Direct measurements of both the energy exchange and the pitch angle scattering of energetic electrons contribute the thorough understanding of wave-particle interactions in the Earth's inner magnetosphere.

Fukuhara et al. (2009) proposed Wave-Particle Interaction Analyzer (WPIA), which is a new instrumentation measuring a relative phase angle between a wave magnetic field vector and a velocity vector of each particle and calculates the energy exchange between waves and particles. The WPIA, which enables us to directly detect wave-particle interactions in space plasmas, will be installed on the ERG satellite of JAXA/ISAS. Katoh et al. (2013) formulated measurable values of the WPIA as the Joule heat W_{int} and discussed the feasibility of measuring W_{int}. In the present study, in addition to the method to detect the energy exchange, we propose a method to directly detect the pitch angle scattering of resonant particles. The method is calculating G that is the pitch angular component of the time variation of the momentum of particles.

We apply the proposed method to results of the one-dimensional electron hybrid simulation reproducing the generation process of chorus emissions around the magnetic equator [Katoh and Omura, 2007]. In the result of the analysis, we obtain significant values of G for electrons in the kinetic energy and pitch angle ranges satisfying the cyclotron resonance condition with the reproduced chorus emissions. We compared the result of the analysis of G with the temporal variation of both the pitch angle distributions and the wave spectra observed at fixed points in the simulation. While the velocity distribution function varies similarly in both hemispheres, the obtained time variation of the momentum is only significant in the pitch angle range corresponding to electrons moving northward (southward) in the southern (northern) hemisphere, indicating the pitch angle scattering of electrons by chorus emissions propagating away from the equator. The results of the present study demonstrate that the proposed method enables us to identify the location where wave-particle interactions occur in the simulation system. Furthermore, we re-examine the formula of the measurement values W_{int} to detect the energy exchange, based on the discussion of the quantity G.

Keywords: whistler-mode chorus emissions, pitch angle scattering, WPIA, ERG mission, electron acceleration, wave-particle interactions