# Study of the resonant interactions of relativistic electrons and large-amplitude whistler-mode waves

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We carry out test particle simulations of relativistic electrons interacting with obliquely propagating large-amplitude whistler-mode waves in the Earth's inner magnetosphere. Recent observation revealed large-amplitude whistler-mode waves propagating obliquely with respect to the ambient magnetic field [Cattell et al., 2008]. Yoon [2011] suggested that the observed large-amplitude whistler-mode waves can contribute the energization of radiation belt electrons to relativistic energies (MeV) within a few seconds. However, details of the acceleration process by oblique whistler-mode waves have not been understood yet. In the present study, by referring observation results of large-amplitude whistler-mode waves in the magnetosphere, we discuss resonant interactions between oblique whistler-mode waves and relativistic electrons.

The cyclotron resonance is dominant in the interactions between resonant electrons and whistler-mode waves propagating parallel to the background magnetic field, while the Landau resonance should also be taken into account for obliquely propagating whistler-mode waves.

For the study of resonant interactions, we develop a test particle simulation code to solve the motion of energetic electrons under the presence of whistler-mode waves. We first assume monochromatic whistler-mode waves of frequency of 0.2 fce, where fce is the electron gyrofrequency. The wave amplitude is constant in time and assumed to be 1 % of the intensity of the background magnetic field. We assume relativistic electrons having the initial kinetic energy of 0.66 MeV with various initial pitch angles and gyro-phases. The time scale of the simulation is 100000 gyro-periods, corresponding to 0.95 sec for the parameters at L=4 of the Earth's magnetosphere. For the case of monochromatic whistler-mode waves propagating purely parallel to the background magnetic field, a part of resonant electrons are trapped by the waves and oscillate in the velocity phase space. The width of the oscillation in the velocity phase space can be estimated by the trapping velocity. We estimate that the trapping velocity is typically less than 0.01% of the initial velocity of the relativistic electrons under the condition assumed in the present study, which is consistent with the simulation result. Next, we carry out a series of simulations by changing the wave normal angle of whistler-mode waves. In these simulations, Landau resonance with the longitudinal wave component occurs simultaneously with the cyclotron resonance. We find that higher-order cyclotron resonances also occur in the simulation results and that the magnitude of the oscillation of electrons resonating with the oblique whistler-mode wave is not larger than that in the case of parallel propagating whistler-mode waves. The results of the present study clarify that the developed test particle code is useful for the quantitative evaluation of the energizing process of relativistic electrons by whistler-mode waves of arbitral wave normal angle. By conducting simulations for various properties of whistler-mode waves such as the wave frequency and wave amplitude, we investigate the effect of the wave characteristics on the resonant interactions between relativistic electrons and large-amplitude whistler-mode waves.