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論文題目	Study on Nonlinear Acceleration of Electrons by Oblique Whistler Mode Waves		

In this thesis, nonlinear interactions between obliquely propagating whistler mode waves and energetic electrons in the Earth's magnetosphere are analyzed. Most of the previous studies relating to whistler mode waves focus on parallel waves. This thesis is a significant study revealing the complicated dynamics in the Earth's radiation belt. There are 6 chapters in the thesis.

Chapter 1 gives general introduction. The environments of the Earth's magnetosphere and the characteristic of whistler mode waves are introduced. Nonlinear theory of parallel whistler mode wave-particle interaction is described. The importance of extending researches from parallel waves to oblique waves is presented.

In Chapter 2, propagation condition of an obliquely propagating coherent wave is analyzed by solving the cold plasma dispersion relation, and a wave model with the oblique whistler mode dispersion relation are developed. The relation between wave group velocities and the Poynting vectors of oblique whistler mode waves with frequencies 0.1–0.8 electron gyrofrequency is analyzed. The analyzed result shows that the wave group velocity propagates nearly parallel to the background magnetic field with wave frequency less than half the cyclotron frequency or a small wave normal angle. Thus, in the following chapters, one-dimensional simulations can be applied in calculating oblique wave-particle interactions. The numerical Green’s functions are also introduced in this chapter.

In Chapter 3, the gyroaveraging method, which reduces the simulation from two-dimensional to one-dimensional by averaging the cyclotron motion to the gyrocenter, is introduced. The validity of the method applied in oblique wave-particle interactions is confirmed. The evidences of separating multiple resonances in the gyroaveraging method are demonstrated, and the possible ranges of the resonances, which information is useful for numerical simulations, are calculated. Test particle simulations for constant wave models at different wave normal angles and electrons starting at different kinetic energies and equatorial pitch angles are performed to reveal the physical process and the efficiency of electron acceleration by multiple resonances.

In Chapter 4, test particle simulations of electrons interacting with an oblique wave packet are performed. Tracing the evolution of relativistic electrons in a phase space of kinetic energy and equatorial pitch angle, numerical Green’s functions of the chorus wave-particle interactions are obtained. Landau resonance and cyclotron resonance are compared by analyzing the electron acceleration and pitch angle scattering. There are some important findings. First, for relativistic electrons, the Landau resonance accelerate electrons more efficiently than the cyclotron resonance. The proximity between parallel group velocity and parallel phase velocity of oblique whistler mode waves makes interaction time of Landau resonance longer than cyclotron resonance. The longer interaction time leads to more effective acceleration. Second,

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the effective acceleration is contributed by the wave perpendicular electric field rather than the parallel electric field.

In Chapter 5, the stationary wave condition, which leads to a long interaction time between an oblique wave packet and a Landau resonant electron, are introduced. Through test particle simulations of a wave propagating at a small wave normal angle, the formation mechanism of the frequency spectra gap at half the electron gyrofrequency of whistler mode chorus emissions is verified. Nonlinear wave damping through Landau resonance is one of the mechanisms dividing chorus emissions into the upper band and the lower band, while cyclotron resonance does not contribute to the damping for oblique waves. In addition, the nonlinear wave damping is due to parallel components of the wave and particles for low energy (~keV) electrons and perpendicular components for high energy (10~ keV) electrons.

The results of this thesis are summarized in Chapter 6, and some suggestions of future works are also listed in this chapter.