Understanding non-linear development of lower hybrid waves and ion acceleration driven by energetic ion injection through particle-in-cell simulation

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Abstract

This thesis investigates the non-linear development of lower hybrid waves driven by the ring-like energetic ions by means of one-dimensional, electromagnetic, particle-in-cell (PIC) simulations with full ion and electron dynamics. We focus on the effects of energetic ion injection on the ion-ring instabilities and the excitation mechanism of the harmonic structure of lower hybrid waves, which are observed in the Earth's magnetosphere

Chapter 1 provides an overview of the basic plasma theory, the characteristic of the lower hybrid wave, and the theory of the ion-ring instability. At the end of this chapter, the purpose of this thesis is stated.

Chapter 2 describes the methodology of this thesis. The basic algorithm of the PIC simulation and the simulation setting used in this thesis are described in this chapter.

Chapter 3 examines the ion-ring instabilities driven by continuous energetic ion injection. Most previous simulation studies solved initial value problems where energetic ions were set up only at the initial time step, but our simulations adopt the energetic ion injection model where energetic ions are gradually and continuously injected into a plasma. The continuous injection allows us to investigate the long-term and more realistic development of the instabilities. We show that the energetic ion injection significantly affects the non-linear development of the instabilities and the energy transfer from energetic ions to bulk ions. The energetic ion injection excites the broadband wavenumber range of the lower hybrid waves, which causes bulk ion acceleration through the lower hybrid wave turbulence.

Chapter 4 examines the excitation mechanism of the harmonic structure of the lower hybrid waves driven by the ring-like energetic ions. Harmonic lower hybrid waves with the frequencies of integer multiples of lower hybrid wave frequencies were

reported both for space and fusion plasmas, but their excitation mechanism is not yet fully understood. We show that the energetic ions can excite the original lower hybrid waves, i.e., the original mode, and that the harmonic modes are then excited by the non-linear wave-wave coupling process. The harmonic modes are coupled with the energetic ion cyclotron waves through the energetic ions, and when the energetic ions disappear, the harmonic modes are coupled with the ion Bernstein waves due to bulk ions.

Following Chapter 4, Chapter 5 focuses on the harmonic lower hybrid waves observed at 4000 km altitude in the polar region of the Earth's magnetosphere. Past satellite observations reported the harmonic lower hybrid waves and their relation to the ring-like energetic ions, but the excitation mechanism of the harmonic lower hybrid waves has not yet been clarified. We show that the ring-like energetic ions at 4000 km altitude in the polar region can generate the harmonic lower hybrid waves. Furthermore, we find that bulk ions can be more strongly accelerated when the harmonic lower hybrid waves can be more strongly excited, implying that the harmonic lower hybrid waves may enhance the ion acceleration.

Finally, Chapter 6 summarizes the results obtained from this study and gives a general conclusion. The results contribute to our understanding of the universal physics caused by the continuous injection of the energetic ions, which is common in space and fusion plasmas.