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Simulation study of nonlinear development of lower-hybrid wave instabilities : energetic-ion mass dependence

Mieko Toida and Tsubasa Kotani

[1] National Institute for Fusion Science, National Institutes of Natural Sciences, Toki, Japan

[2] Graduate School of Science, Kyoto University, Kyoto, Japan

e-mail (speaker): toida.mieko@nifs.ac.jp

Energetic ions with a ring-like distribution in a velocity space perpendicular to the magnetic field can be produced in both magnetically confined fusion plasmas and space plasmas. In the magnetically confined fusion plasma, the ring-like energetic ions are generated by neutral beam injection for plasma heating. In a space plasma, the ring-like energetic ions are produced by particle acceleration by a collisionless shock wave and by magnetic reconnection.

Lower hybrid waves (LHWs) can be excited by the ring-like energetic ions. Such LHWs were observed in fusion plasmas and in the geomagnetosphere. In a fusion plasma, the species of energetic ions are hydrogen (H) isotopes and helium (He). In the magnetosphere, both energetic H and He ions with ring-like distributions were observed. Thus, various ion species can contribute to excitation of the LHWs.

According to a linear theory for the LHWs instabilities driven by energetic ions, the growth rate of the LHWs can be roughly given by

$$\gamma \propto \frac{n_h q_h^2}{m_h} \left. \frac{\partial f_h}{\partial v_\perp} \right|_{v_\perp = \omega/k}$$

where m_h, q_h, n_h and f_h are the mass, charge, density, and velocity distribution function of energetic ions. This indicates that the growth rate decreases with increasing m_h. However, the dependence of m_h on nonlinear development of the LHWs instabilities has not been fully understood.

In this study, we investigate nonlinear development of the LHWs instabilities using an electromagnetic particle in cell code with full ion and electron dynamics. Firstly, we do simulations for the initial value problem, setting various values of energetic-ion mass. We discuss how the time variation of the LHW amplitudes and the energetic-ion velocity distribution f_h depend on the energetic-ion mass m_h in the nonlinear development of the instabilities. Next, we investigate the long-time development of the instabilities, by doing simulations where the energetic ions are continuously injected into a plasma. It is found that when the energetic-ion mass is large, the LHWs finally grow to large amplitudes even though the initial growth of the LHWs is slow.

The dependence of energetic-ion mass on acceleration of background ions [1] and nonlinear excitation of harmonic LHWs [2] will be also discussed.

[1] T. Kotani, M. Toida, T. Moritaka, and S. Taguchi, J. Phys. Soc. Jpn. **90**, 124501 (2021).

[2] T. Kotani, M. Toida, T. Moritaka, and S. Taguchi, Geophysical Research Letters **50**, e20222GL102356 (2023).