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Nonlinear Wave Growth of Whistler-mode Hiss Emissions in the Plasmasphere

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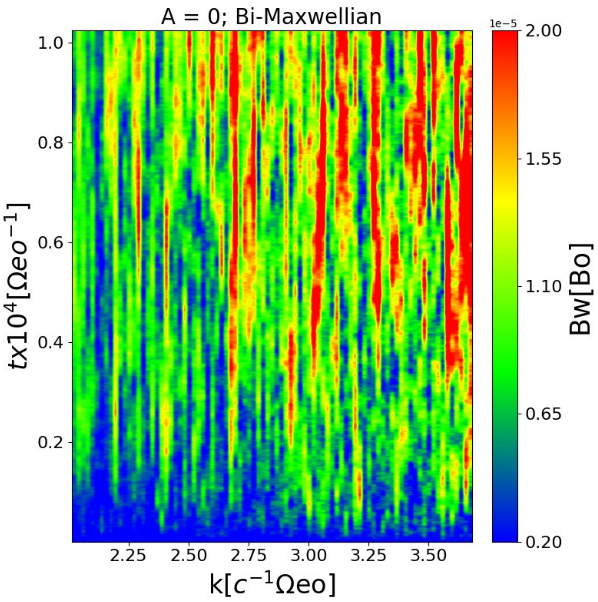
Whistler-mode waves in plasmas grow from thermal fluctuations receiving energy from energetic electrons through pitch angle diffusion to lower pitch angels. The wave growth due to the diffusion is well described by the linear growth rates. As the wave grows to an amplitude large enough to cause nonlinear trapping of resonant electrons, the nonlinear wave growth occurs because of formation of nonlinear resonant currents which induces frequency variation and wave growth simultaneously. Depending on the shape of the velocity distribution function near the resonance velocity, either electron holes or hills are formed which result in rising or falling tone emissions. The frequency variation and the spatial gradient of the background magnetic field play important roles in the nonlinear wave growth [1]. We have investigated the transition of the linear growth process to the nonlinear growth process by performing full-particle simulations with different levels of thermal fluctuations and different gradients of the background parabolic magnetic field [2]. We find coherent waves with frequency variation appear out from the waves growing due to the linear growth rate. Coherent waves grow through propagation in an optimum parabolic configuration of the background magnetic field. Even in a system with uniform background magnetic field and without positive linear growth rates, we find that small coherent wave packets are formed from thermal fluctuation because of nonlinear wave growth due to frequency variation. Coherent waves can exist simultaneously with nonlinear trapping potentials at different velocities in the velocity phase space, which correspond to different frequencies. Multiple nonlinear wave growth processes of coherent waves at different frequencies result in generation of hiss emissions as we find in the plasmasphere.

To confirm the hypothesis of nonlinear wave growth process, we performed a PIC simulation in a uniform magnetic field and open boundaries. We assumed isotropic Maxwellian distribution for energetic electrons. With the temperature anisotropy A= 0, the linear growth rate is negative for all frequency ranges of whistler mode. In the PIC code, however, thermal fluctuations exist, and there grows several wave packets out from the fluctuations due to the nonlinear wave growth process.

The figure shows the wave number spectra of the perpendicular magnetic field component. Wave packets are formed at discrete wave numbers separated with each other. In the process of the wave growth, the wave number changes to higher values, which corresponds to higher frequencies. Because of the frequency variation, the nonlinear wave growth process takes place. We also performed simulation runs with different numbers of super-particles which controls the thermal fluctuation level. A larger number of super-particles makes the thermal fluctuations lower. The cases with lower initial thermal fluctuations exhibit correspondingly fewer number of wave packets with smaller wave amplitudes.

Based on these simulation cases with different parameters, we can conclude that nonlinear wave growth takes place even with negative linear growth rates even in a uniform background magnetic field. Nonlinear wave growth in a uniform background magnetic field is due to frequency variations. Linear growth from thermal fluctuation enhances evolution of nonlinear wave growth.



References

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