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Decay of Nonlinear Whistler Waves: 1D versus 2D

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It has been known that large-amplitude and monochromatic plasma waves are often unstable nonlinearly. One of well-known instabilities for large-amplitude parent waves is the parametric instability, in which forward-propagating parent wave (P_0) decays into a backward-propagating daughter (D_1) wave and a forward-propagating sound wave (S_1), i.e., $P_0 \rightarrow D_1 + S_1$, which is also referred as the parametric decay. There is a number of studies in a one-dimensional (1D) spatial system for parametric instabilities of various finite-amplitude parent plasma waves, such as circularly-polarized Alfven waves, (right-handed-polarized) high-frequency whistler waves, high-frequency (light mode) radio waves, and Langmuir waves.

Our previous 1D particle-in-cell (PIC) simulation study [1] has confirmed that the parametric decay of a finite-amplitude and monochromatic whistler wave with a frequency close to the electron cyclotron frequency ω_{ce} takes place at a timescale of several hundreds of the electron gyro angular period. In the present study, we extend our previous 1D PIC simulation study to a 2D one for examining a nonlinear development of an electron-scale, finite-amplitude, and monochromatic electromagnetic whistler wave with a frequency close to the electron cyclotron frequency in a self-consistent manner.

It is shown that the present 2D decay process is also different from the one seen in the previous 2D simulation of ion-scale whistler waves [2] and the 1D modulational/parametric instabilities in the previous studies. A large-amplitude, monochromatic and parallel parent whistler wave with (ω_0, k_{x0}, 0) decays into two sideband daughter quasi-parallel whistlers with ($\omega_0 - \omega_1$, $k_{x0} + k_{x1}$, $\pm k_{y1}$) and two quasi-perpendicular modes with (ω_1, k_{x1}, $\pm k_{y1}$), where ω_0 and k_{x1} are small. Then, a longitudinal electrostatic wave is also enhanced at ($2\omega_0$, $2k_{x0}$, 0) by a secondary three-wave interaction with the sideband daughter quasi-parallel whistlers. The low-frequency quasi-perpendicular mode and the longitudinal electrostatic mode are on branches of the nonlinear eigenmode, which disappears when the decay process of the parent wave is completed. The timescale of the present 2D decay instability is shorter than a hundred of the electron plasma angular period, which is much faster than the 1D parametric decay whose timescale is several hundreds of the electron gyro angular period.

1. T. Umeda, S. Saito, and Y. Nariyuki, "Electron acceleration during the decay of nonlinear whistler waves in low-beta electron-ion plasma," *Astrophysical Journal*, **794**, 1, October 2014, 63 (10pp.), doi:10.1088/0004-637X/794/1/63

2. S. Saito, Y. Nariyuki, and T. Umeda, Physics of Plasmas, "Nonlinear damping of a finite amplitude whistler wave due to modified two stream instability," **22**, 7, July 2015, 072105 (7pp.), doi: 10.1063/1.4926523.