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Dynamics of nonlinear obliquely propagating whistler modes: Charge transport and parametric decay in space plasmas

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In this work we present results on the nonlinear evolution of large amplitude obliquely propagating whistler waves which can give rise to non-thermal particle energy distributions and parametric processes involving whistler waves and electron acoustic modes that are present in these electron energy distributions. Recent satellite observations have identified the presence of large amplitude whistler plasma waves in the Earth's radiation belts and solar wind that propagate obliquely with respect to the Earth's magnetic field. It has been suggested that these large amplitude whistlers are a mechanism for the rapid acceleration of radiation belt electrons to relativistic energies.

In the first part of this presentation, we focus on the aspect of non-diffusive charge transport from large amplitude obliquely propagating whistler waves with arbitrary wave amplitude. For this study 1D-3V (x,v_x,v_y,v_z) and 2-1/2D (x,y, v_x,v_y,v_z) relativistic particle-in-cell (PIC) simulation models are used with self-consistent electromagnetic fields to account for the feedback effects of particles on the large amplitude whistler waves. Using special initial conditions (force balanced density, velocity and electromagnetic field perturbations obtained from linear wave theory) to launch these large amplitude waves, we show that these wave fields are capable of thermalizing an electron distribution and can accelerate a non-interacting seed population from ∼100eV into the range of ~20 to 30keV through the mechanism of electron trapping in the Landau resonance of the quasi-electrostatic mode. The simulations reveal the presence of compressional wave steepening effects as well as particle trapping and wave field distortion and damping that follow thereafter. In k-space, the number of electrostatic wave field harmonics is shown to increase with increasing obliqueness of the large amplitude mode: from two harmonics for 30 degrees wave field angle (with respect to background B-field) to approximately seven for 70 degrees. Finally, from a large series of simulation runs we obtained empirical wave amplitude scaling relations for the four important time scales: wave steepening time, particle trapping time, wave damping, and particle acceleration time. The lower initial perturbation amplitude leads to a wide separation of these time scales whereas large amplitudes ($\delta B/B_o \sim 0.1$) compress the scales, causing trapping and acceleration to occur nearly simultaneously.

In the second part of the study, a set of nonlinear kinetic simulations were conducted that are relevant to satellite observations of the parametric decay of a whistler wave into a backscattered whistler and electron acoustic wave [1]. It is shown that this process is the source of spiked electrostatic fields observed in the outer radiation belt and that have been shown to rapidly accelerate ∼10 to 100eV electron populations into the ∼1 to 2keV range. We present a set of kinetic particle simulations illustrating single and multiple parametric decay channels of a whistler into a backscattered whistler and ion acoustic mode that show remarkable agreement with predictions made using a simple ponderomotive force as the coupling mechanism. However, a similar process does not occur for the electron acoustic mode as the Langmuir coupling dominates in this scenario. Our results suggest that it may be necessary to have a relative drift between hot and cold electron populations to observe the parametric decay of a whistler wave into an electron acoustic wave in space plasma conditions.

References

[1] O.V. Agapitov, V. Krasnoselskikh, F.S. Mozer, A.V. Artemyev, and A.S. Voloktin, "Generation of nonlinear electric field bursts in the outer radiation belt through the parametric decay of whistler waves", Geophys. Res. Lett., 42, 3715-3722 (2015).