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Nonlinear Whistler Wave Physics in the Radiation Belts

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Wave particle interactions between electrons and whistler waves are a dominant mechanism for controlling the dynamics of energetic electrons in the radiation belts. They are responsible for loss, via pitch-angle scattering of electrons into the loss cone, and energization to millions of electron volts. It has previously been theorized that large amplitude waves on the whistler branch may scatter their wave-vector nonlinearly via nonlinear Landau damping leading to important consequences for the global distribution of whistler wave energy density and hence the energetic electrons. It can dramatically reduce the lifetime of energetic electrons in the radiation belts by increasing the pitch angle scattering rate. The fundamental building block of this theory has now been confirmed through laboratory experiments. Here we report on in situ observations of wave electro-magnetic fields from the EMFISIS instrument on board NASA's Van Allen Probes that show the signatures of nonlinear scattering of whistler waves in the inner radiation belts. In the outer radiation belts, whistler mode chorus is believed to be responsible for the energization of electrons from 10s of Kev to MeV energies. Chorus is characterized by bursty large amplitude whistler mode waves with frequencies that change as a function of time on timescales corresponding to their growth. Theories explaining the chirping have been developed for decades based on electron trapping dynamics in a coherent wave. New high time resolution wave data from the Van Allen probes and advanced spectral techniques are revealing that the wave dynamics is highly structured, with sub-elements consisting of multiple chirping waves with discrete frequency hops between sub-elements. Laboratory experiments with energetic electron beams are currently reproducing the complex frequency vs time dynamics of whistler waves and in addition revealing signatures of wave-wave and beat-wave nonlinear wave-particle interactions. These new data suggest that these weak turbulence processes may be playing a role in saturating the nonlinear instability.