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Quantifying the Energetic Electron Precipitation Driven by the Combined Effects of EMIC and Whistler waves

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Energetic electron losses in the Earth's inner magnetosphere are dominated by outward radial diffusion and scattering into the atmosphere by various electromagnetic waves. The two most important wave modes responsible for energetic electron scattering into the Earth's ionosphere are electromagnetic ion cyclotron (EMIC) waves and whistler-mode waves. Although these wave modes mainly drive losses of different energy ranges (≥ MeV for EMIC waves and 10 keV-1000 keV for whistler-mode waves), their combined effect may significantly amplify precipitating relativistic electron fluxes. Also, the wave-particle resonant interaction resulting in electron scattering is well described by quasi-linear diffusion theory using the cold plasma dispersion, whereas the effects of nonlinear resonances and hot plasma dispersion are less well understood.

In this study, we analyze a special event with the first direct observations of such amplification. For this event, UCLA ELFIN CubeSats show energetic electron precipitation of a 300 keV to 2.5 MeV, whereas the THEMIS mission shows EMIC and whistler-mode waves observed around the equator in conjunction with ELFIN measurements. Our observation-driven test particle simulation demonstrates that <1 MeV precipitation is driven by electron nonlinear scattering (via phase bunching by whistler-mode waves), whereas >1 MeV precipitation is driven by the combined effect of whistler-mode and EMIC waves [1]. We have recently developed a hot plasma model [2] which agrees very well (~90% accuracy) with the exact numerical analysis of hot dispersion relation over a wide range of plasma parameters. Our results also show the importance of the hot plasma effect in altering the EMIC wave properties, especially the hot plasma effects significantly increase the minimum resonant energy, E_{min}, for the most intense EMIC waves, such effects become negligible for the higher frequency part of the hydrogen-band EMIC wave spectrum.

The nonlinear phase trapping of 300-500 keV electrons through resonances with whistler-mode waves accelerates these electrons up to 1-3 MeV and makes them resonant with EMIC waves that, in turn, quickly scatter those electrons into the loss-cone. Our results underline that precipitating relativistic electron fluxes may be controlled by local acceleration, supplementing this electron population, rather than by scattering alone. Such combined whistler-mode and EMIC waves effect provides the electron precipitation over a wide energy range of first tens of keVs to few MeVs.

References:

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2. M. Fraz Bashir, A. Artemyev, X. Zhang, and V. Angelopoulos (2022), Hot Plasma Effects on Electron Resonant Scattering by Electromagnetic Ion Cyclotron Waves, Geophys. Res. Lett., 49, e2022GL099229