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Nonlinear wave particle interactions in oblique whistler-mode chorus emissions

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The highly nonlinear phenomena of VLF chorus and triggered VLF emissions are of great interest due to their role in electron heating and precipitation, and are widely believed to be due to nonlinear cyclotron resonance between the narrow band wavefield and the anisotropic energetic electron population (∼keV), the dominant mechanism being identified as nonlinear phase trapping. Considerable advances have been made in the theory and numerical simulation by assuming parallel (ducted) propagation [Nunn et al., 1997, 2009;Omura et al., 2008, 2009; Omura and Nunn, 2011]. Here we address the important issue of nonlinear wave particle interaction in oblique VLF wavefields. The treatment is of necessity non self-consistent. The narrow band wavefield is arbitrarily, but here chosen to be a CW field or a sophisticated model of a VLF chorus element based upon the theory of Omura et al.[2008, 2009]. We develop the electron equations of motion and then by backward trajectory integration compute resonant particle distribution function , resonant currents and thus local nonlinear growth rates. This may be done for any resonance order n and any field. As shown in Omura et al. [2008] nonlinear trapping for n=1 cyclotron resonance gives rise to a phase space hole in distribution function at the trap. Such a hole is also noted at higher order resonances (e.g. n=2) for sufficient wave amplitude and obliquity. For n=1 we find a marked saturation effect due to adiabatic effects, growth maximising at about 25pT and 2000km from the equator. For moderate obliquity $\vartheta<20$ degrees the n=1 resonance is relatively unaffected but growth rolls off sharply at high obliquity. For the n=0 resonance for obliquity $\vartheta >20$ degrees nonlinear trapping may occur giving a peak in phase space density. As trapped electrons are moving away from the equator adiabatic effects do not occur and maximum damping rates are at ∼6000kms and at obliquities ∼55 degrees. For the lower band rising chorus element model maximum n=1 growth is close to the equator, but maximum n=0 damping is found at the top of the frequency band at ∼10000km downstream. Due to the coincidence of group and resonance velocities particles may be trapped near the equator and dragged a long way before detrapping.

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