Excitation of obliquely propagating whistler waves by an electron beam

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Isotropic electron beams are considered to explain the excitation of whistler waves that have been observed by STEREO in the Earth's radiation belt (Catell et al., Geo. Res. Lett., vol. 35, L01105 (2008)). Besides their large amplitudes ($\sim$240mV/m), another main signature is the strongly inclined propagation direction relative to the ambient magnetic field. Electron temperature anisotropy with $T_{e\perp} > T_{e||}$, which preferentially generates parallel propagating whistler waves, can be excluded. The instability is considered to arise due to the interaction of the Doppler-shifted cyclotron mode $\omega = -\Omega_e + kV_b$ with the whistler mode in the wave number range of kc/$\omega_e \leq 1$ (ω_e: electron plasma frequency). Fluid and Vlasov dispersion analysis have been used to calculate the growth rate of the beam-excited whistlers with dependence of the most relevant parameters. One of these is the beam velocity (V_b) which, for instability, has to be larger than about $2V_{Ae}$, where V_{Ae} is the electron Alfven speed. With increasing V_{Ae} the propagation angle (θ) of the maximally growing whistler waves shifts from $\theta \sim 20^0$ for $V_b=2V_{Ae}$ to $\theta \sim 80^0$ for $V_b=5V_{Ae}$. The growth rate is reduced by finite electron temperatures and disappears if the electron plasma beta (β_e) exceeds $\beta_e \sim 0.2$. As a further step in linear theory, stationary waves are analyzed that allows for a prediction of the conditions under which nonlinear stationary waves (whistler oscillitons) may exist. Subsequently, spatial profiles of whistler oscillitons are calculated using the full nonlinear fluid approach as well as electromagnetic particle simulations. A remarkable feature of the analysis is the obtained (nonlinear) wave polarization is quite different from the linear predictions. The results are in good coincidence with the STEREO observations.