Full-wave Simulations of Ducted Whistler Waves on Fluctuating Density Background

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Extended Abstract

Spacecraft observations have shown that whistler-mode waves in the Earth's outer radiation belt often propagate nearly parallel to local field lines. This behaviour can be explained by ducting in field-aligned density enhancements; waves that become trapped retain their amplitude, and untrapped, oblique waves are damped by Landau resonance. Assumptions of thin and tenuous density ducts combined with ray-tracing simulations can explain the observations [1], but it is not clear what causes the formation of such channels. Moreover, experimental evidence for these ducts is missing because the relative density changes are below the uncertainty level of cold plasma electron density measurements provided by spacecraft instruments.

Here we focus on the possibility of ducting whistler wave energy by field-aligned ducts on the wavelength and sub-wavelength scale. Under such conditions, the geometric optics approximation is invalid. Therefore we prepared 2D FDTD (Finite Difference Time Domain) full-wave simulations in a magnetic dipole field to study the propagation of whistler-mode waves in the frequency range from $0.2\Omega_{e0}$ to $0.7\Omega_{e0}$, where Ω_{e0} is the equatorial electron gyrofrequency. We consider both regular and random distribution of the widths and heights of the density enhancements, and we study the convergence or divergence of energy density as the waves propagate to higher latitudes. In Figure 1, an example of magnetic wave amplitude distribution in randomized ducts is shown, with the wave frequency being set to $0.25\Omega_{e0}$ for a wave packet with an initial length of 15 ms. The propagation direction is estimated from the wavefronts to obtain energy-weighted wave normal angles along the field line, and the results are compared to spacecraft observations [2].

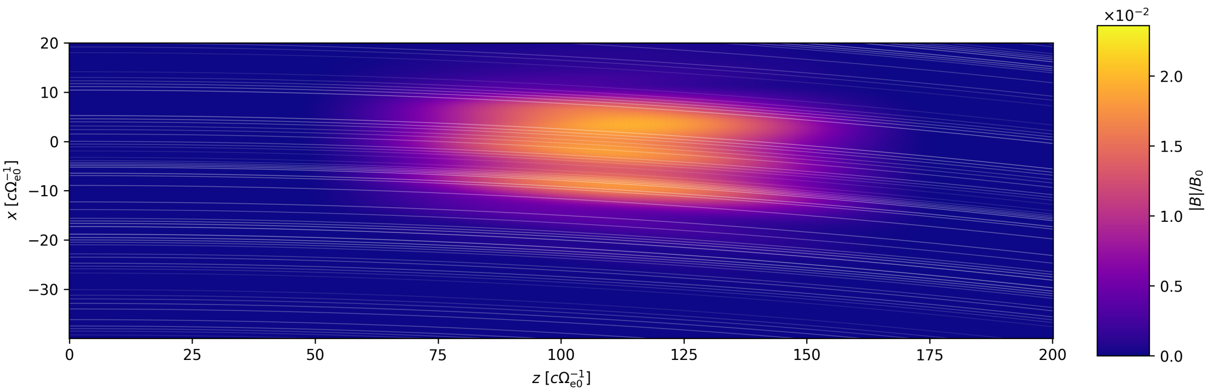

Figure 1. Amplitude of wave magnetic field propagating in field-aligned density fluctuations; 2D FDTD simulation. Contours of cold plasma density are plotted in white.

References

[1] M. Hanzelka and O. Santolik, "Effects of Ducting on Whistler Mode Chorus or Exohiss in the Outer Radiation Belt," *Geophysical Research Letters*, **46**, 11, May 2019, pp. 5735–5745, doi: 10.1029/2019GL083115.

[2] O. Santolik, E. Macusova, I. Kolmasova, N. Cornilleau-Wehrlin, and Y. de Conchy, "Propagation of lower-band whistler-mode waves in the outer Van Allen belt: Systematic analysis of 11 years of multi-component data from the Cluster spacecraft," *Geophysical Research Letters*, **41**, Apr 2014, pp. 2729–2737, doi: 10.1002/2014GL059815.