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Effects of density ducts on whistler-mode waves in the Earth's magnetosphere

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Whistler-mode waves are natural electromagnetic emissions occurring in the magnetosphere of the Earth and other planets. They play a crucial role in formation of electron radiation belts. Whistler-mode waves are frequently found to be significantly affected by the plasma inhomogeneity such as density variation[1]. Here we report, using Van Allen Probe measurements, whistler-mode waves trapped by two types of density enhancements in the Earth's magnetosphere, with different distribution characteristics. In order to study effects of density enhancements (sometimes called density ducts) on whistler-mode waves in the Earth's magnetosphere, we have carried out several two-dimensional (2-D) particle-in-cell (PIC) simulations.

Figure 1 presents, during a geomagnetic quiet period (Fig. 1a), that Van Allen Probe-A detected a large-scale flat-topped density crest and a small-scale bell-shaped density crest (Fig. 1b) both accompanied with whistler waves (Fig. 1c) at L-shell ~ 6 and magnetic latitude about $-14°$. The wave normal angles indicate that whistler waves are almost quasi-parallel inside the density crests but very oblique on the boundaries (Fig. 1d), although they propagate nearly along the magnetic field and from the equatorial direction (Fig. 1e). The most interesting is that these whistler waves are more intense near the outer (larger L-shell) boundary inside the flat-topped density crest but in the center of the bell-shaped density crest.

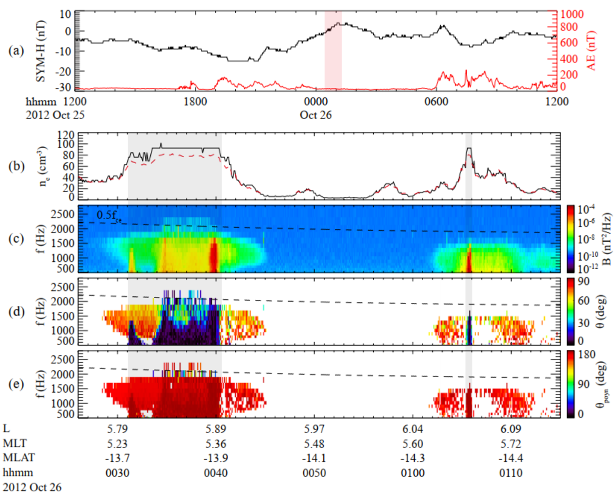

Fig. 1. (a): SYM-H and AE index; Van Allen Probe-A observations: (b): the electron number density inferred from the spacecraft potential (dotted line) and the upper hybrid frequency (solid line); (c): magnetic wave spectral intensity; (d): the wave normal angles; (e): the angles between magnetic field and Poynting vectors.

By using 2-D gcPIC code[2,3], we numerically simulate the evolution of the whistler waves in the presence of different density ducts. The overview of simulation results showing spatial-temporal evolution of whistler waves is presented in Fig. 2. The density duct (indicated by solid line) is assumed as field-aligned (between two dotted lines) based on diffusive equilibrium. The whistler waves are excited by anisotropic ($T_{e\perp} > T_{e\parallel}$) hot electrons distributed uniformly in the equatorial plane. Figure 2 shows whistler waves excited around the equator can be ducted by density crests, and then propagate to high latitude with less damping or more growth. And whistler waves concentrate near the outer (larger L-shell) boundary inside the large-scale flat-topped density duct but in the center of the small-scale bell-shaped density crest, consistent with observations. More simulations indicate that the difference is mainly due to the spatial scale of the density duct.

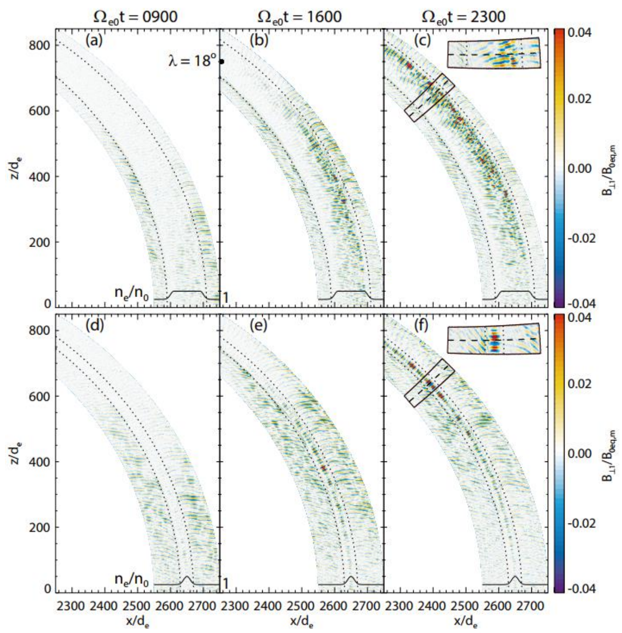

Fig. 2. 2-D PIC simulation results: spatial profiles of perpendicular magnetic fluctuations for (a-c) simulation case 1 and (d-f) simulation case 2 at $\Omega_{e0}t$ = 900, 1600, and 2300, respectively. The regions bounded by an approximate rectangle are zoomed in shown in the top right corner in Fig. 2c, f.

References

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