Magnetospheric Ducts for Whistler-Mode Waves

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Observations performed by the NASA Van Allen Probes satellites demonstrate that in the equatorial plasmasphere the electron plasma is highly inhomogeneous in the direction perpendicular to the ambient magnetic field. Density profiles measured by the satellites contain many irregularities with different geometries and scale-sizes. When the size of the irregularity is small and the background magnetic field considered to be constant within it, the irregularity is called a "narrow" duct. These ducts can be formed by the density enhancement, depletion, single gradient, and a shelf-like structure. The last ones consist of a homogeneous part "sandwiched" between two gradients pointing in the same direction (see Figure 1A reproduced from [1]).

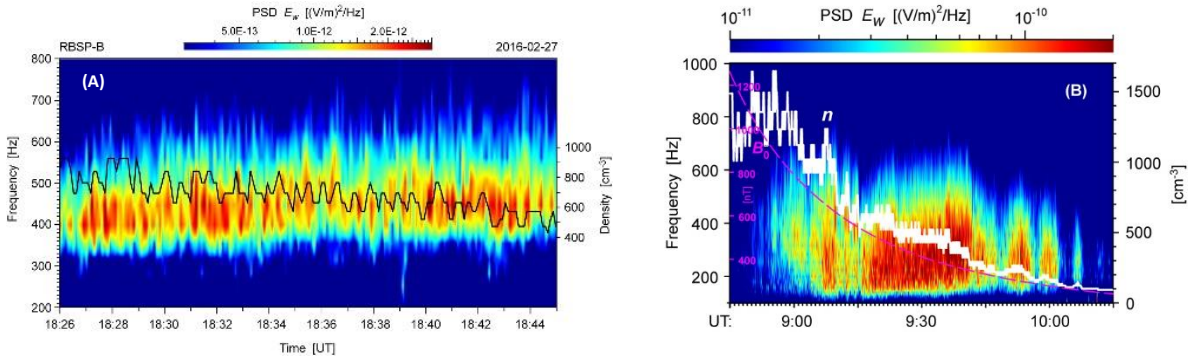

Figure 1. Narrow (A) and wide (B) ducts observed by RBSP-A in the equatorial magnetosphere on February 27, 2016.

Observations also demonstrate that whistler-mode waves can be localized across the field inside a relatively broad magnetospheric region by a combined effect of the transverse gradients in the plasma density and the ambient magnetic field (see Figure 1B adapted from [2]). Together these gradients produce an effective large-scale, high-density "wide" duct. Simulations of the quasi-longitudinal, time-dependent, two-dimensional electron-MHD model reveals that the criterion for wave trapping inside the wide duct is the same as for the wave trapping inside the classical high-density duct produced by the symmetric, Gaussian-like profile of the density in the uniform ambient magnetic field. Simulations also reveal that this criterion can be used to determine the parallel wavelength of the wave with a known frequency trapped by the density and magnetic field inhomogeneities with known parameters.

The main results from our study can be summarized as follow. Observations, conducted by satellites in the equatorial magnetosphere demonstrate that VLF whistler-mode waves are always guided along the ambient magnetic field by the density inhomogeneties. These inhomogeneities may have different shape and spatial size, they may require variation of the magnetic field, or the field may be constant, but in all cases the wave guiding is described by the same physical mechanism. The analysis of this mechanism demonstrates that it is possible to determine some parameters of the guided waves (e.g., the parallel and perpendicular wave numbers) from the parameters of the duct. Thus, in general, the magnetospheric duct works as filter – it guides waves with some particular parameters only.

References

[1] Streltsov, A.V., (2022). On a guiding of whistler-mode waves by density gradients. *J. Geophys. Res.: Space Phys., 127*, e2022JA031056, doi:10.1029/2022JA031056.

[2] Streltsov, A.V. (2021). Whistlers in the plasmasphere. *J. Geophys. Res.: Space Phys., 126*, e2020JA028933, doi:10.1029/2020JA028933.