Ray tracing study of lower-band whistler mode emissions in outer radiation belts

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Introduction

- Results of (1) based on 11 years of Cluster satellites measurements show typical parameters of whistler-mode waves in range of equatorial frequencies from 0.1 to 0.5 Hz, for latitudes in the interval (-55°, 55°).
- The data were filtered so that they contain only waves with planarity greater than 0.5 and aligntropy greater than 0.2 (right-hand polarized). These values were computed by SVD methods from [2].
- We observe increase of the wave magnetic energy B_2 in the lower internal L = (4.0, 5.5) and fluctuations of about one order of magnitude in the upper internal L = (5.5, 7.0).
- Wave normal angle θ is centered about 15°, with distinct increase of median values up to about 30° in range L = (5.5, 20), more prominent in the lower internal L = (5.5, 7.0).
- By weighting the θ_k distribution by B_2, the increase of θ_k at lower latitudes almost disappear.
- Methods, models and ray examples

- We use 3D ray tracing in a hot plasma to simulate whistler mode waves originating at the equator and propagating to the northern hemisphere. Since the propagation in longitudinal direction is not significant, we restrict our simulation to the meridional plane.
- Density model assumes an exponential decrease of equatorial density of electron-proton plasma with a latitudinal dependence based on semi-empirical model from [1]. Possible Kp dependence of density distribution is not included.
- Interaction with plasmapause is not considered, propagation stops at r = 1.36.
- Magnetic field is approximated by a dipole and then by a model of strongly compressed magnetic field from [6] to match some properties of better models like Tangemnunk [5].
- Initial θ_k are produced from Gaussian distribution with a standard deviation of 17° and a mean value of 0°. Taken from [12].
- To model hot plasma, we add 1% of 1 keV electrons and protons (1 eV).
- Anisotropy, defined as a = 1 - k_{para}/k_{perp}, is taken to be constant everywhere with three different values: 0.0, 0.5 or 1.0.
- Ducting is modeled by Gaussian peaks in density aligned to starting field lines, peak value 0.5% and background density, n = 0.01 cm^-3.
- Wave energy density is calculated as W = 1/2 n B^2 = 4π k_{par} θ^2 ω^2, where K is the dielectric tensor (Hermitian).
- For each setting of magnetic field, hot/cold, anisotropy, ducting we take 25 values of θ_k from 0° (0.0, 0.5, 1.0), 5% and θ_k distributions with K_{para} from 0.3 to 0.5, 0.01. Propagation is stopped at θ_k = 55°, or at the equator after magnetic reflection (the case of unducted waves), or when amplitude is too small, A < 1.0.
- During propagation we assume conservation of Poynting flux (before the inclusion of damping/growth).
- For ducted waves, increase of energy due to diverging or converging magnetic field lines is taken into account.
- For unducted rays, the increasing/decreasing distance of three rays (outmost minus innermost) with close starting points serves as the geometric factor; every unducted ray was therefore simulated twice with difference in initial χ = 0.1.

Statistical results

- Ray paths continuing after magnetospheric reflection on θ_k are not included in the statistics (determined by Poynting vector direction).
- Lower and upper L-intervals are treated both separately and together. Some fluctuations in separated data are due to waves traveling between the two intervals.

Conclusion

- Presented increase in B_2 of ducted rays due to converging-dipole field lines is in qualitative agreement with the Cluster data.
- Unducted rays experience stronger damping than ducted rays and therefore cannot increase the answer in B_2.
- Assumption of linearly compressed magnetosphere (applicable to daytime) naturally leads to even smaller growths or even decreases in B_2, but here sources in high latitude border θ_k packets can be considered.
- Considerable increase in wave energy density is observed in unducted waves due to decreasing group velocity. Weighting of θ_k by W leads to increase of the angles at higher latitudes, which is not observed in the data.
- When we assume that a significant portion of waves coming from source is unducted, weighting of ω by a bump at lower θ_k, is not seen in the experimental data, which means that the waves are mostly ducted or there is a mechanism that increases wave energy of quasi parallel waves.
- Uniform distribution of frequencies is not supported by the measured data and might lead to distortions of hot plasma effects, especially with anisotropy.

REFERENCES