Parametric study of chorus wave excitation using simulation in a dipole field

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introduction

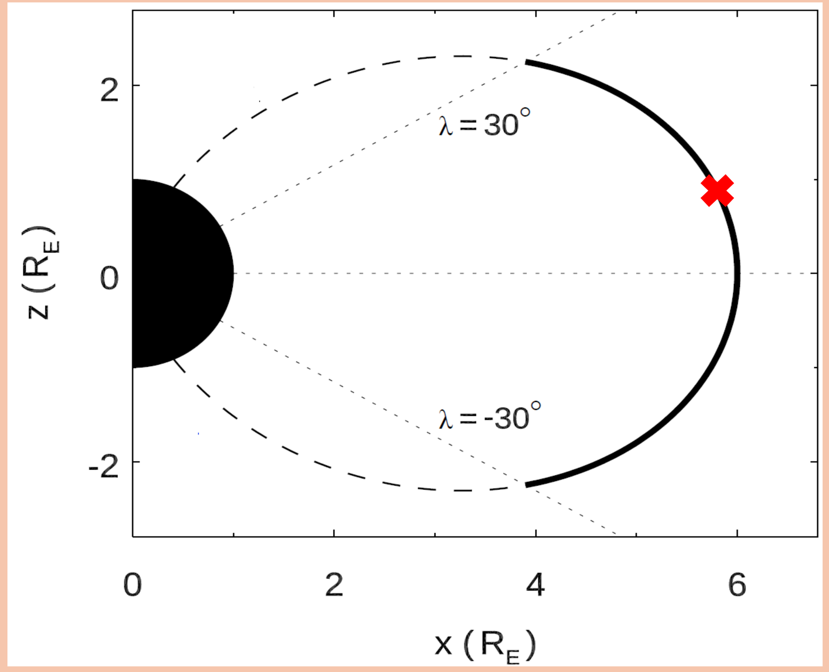
Whistler-mode chorus waves are electromagnetic emissions in the Earth's inner magnetosphere that play a key role in the generation of pulsating aurora. Their excitation is associated with nonlinear wave-particle interactions. In this study, we perform a parametric investigation of rising-tone chorus wave excitation using simulations in a dipole magnetic field. Three types of waves are identified: whistler waves, single-element chorus waves, and hiss-like chorus waves. We further examine the dependence of their saturation wave amplitude on the number density and temperature anisotropy of energetic electrons and derive an empirical formula describing this relationship. These results provide valuable guidance for parameter selection in chorus wave simulations and offer theoretical support for modeling wave amplitudes.

Model description

- One-dimensional (1-D) general curvilinear plasma simulation code (GCPIC) model in a dipole field
- Representative plasma parameters both outside (ω_{pe} / Ω_{e0} ~5) and inside (ω_{pe} / Ω_{e0} ~20) the plasmasphere
- δf algorithm
- Cold and energetic electrons
- Parallel temperature of energetic electrons $T_{||}$=20 keV (Li et al., 2011)
- Number density of energetic electrons n_h/n_{e0}=0.001-0.1 (Gao et al., 2014)
- Temperature anisotropy of energetic electrons $T_{\perp}/T_{\parallel}$=1.1-5.2 (Fu et al., 2014; Yue et al., 2016)
- Temperature of cold electrons 2eV

Simulation Results

1. Simulation domain



2. Three types of whistler-mode waves

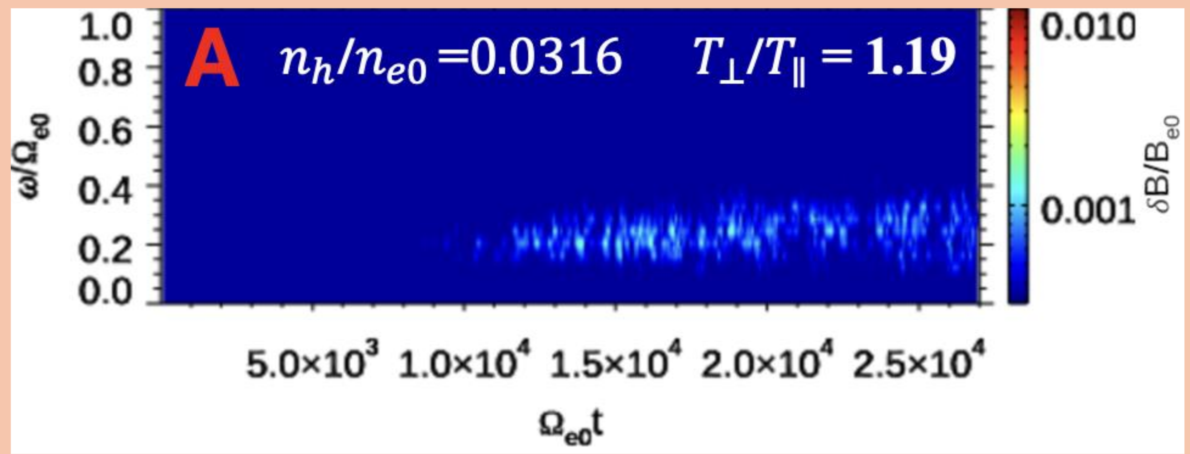


Figure A. Whistler waves

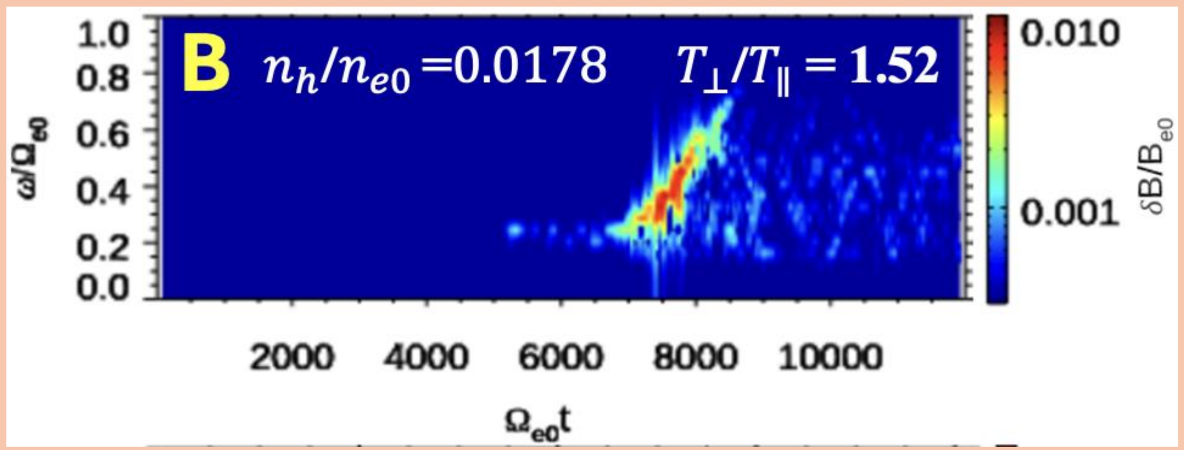


Figure B. Single-element chorus waves

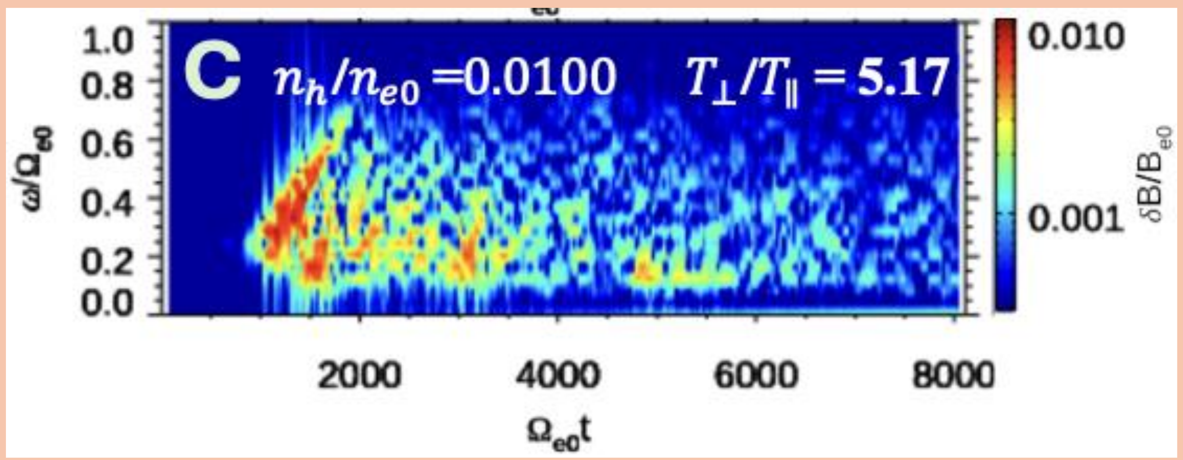
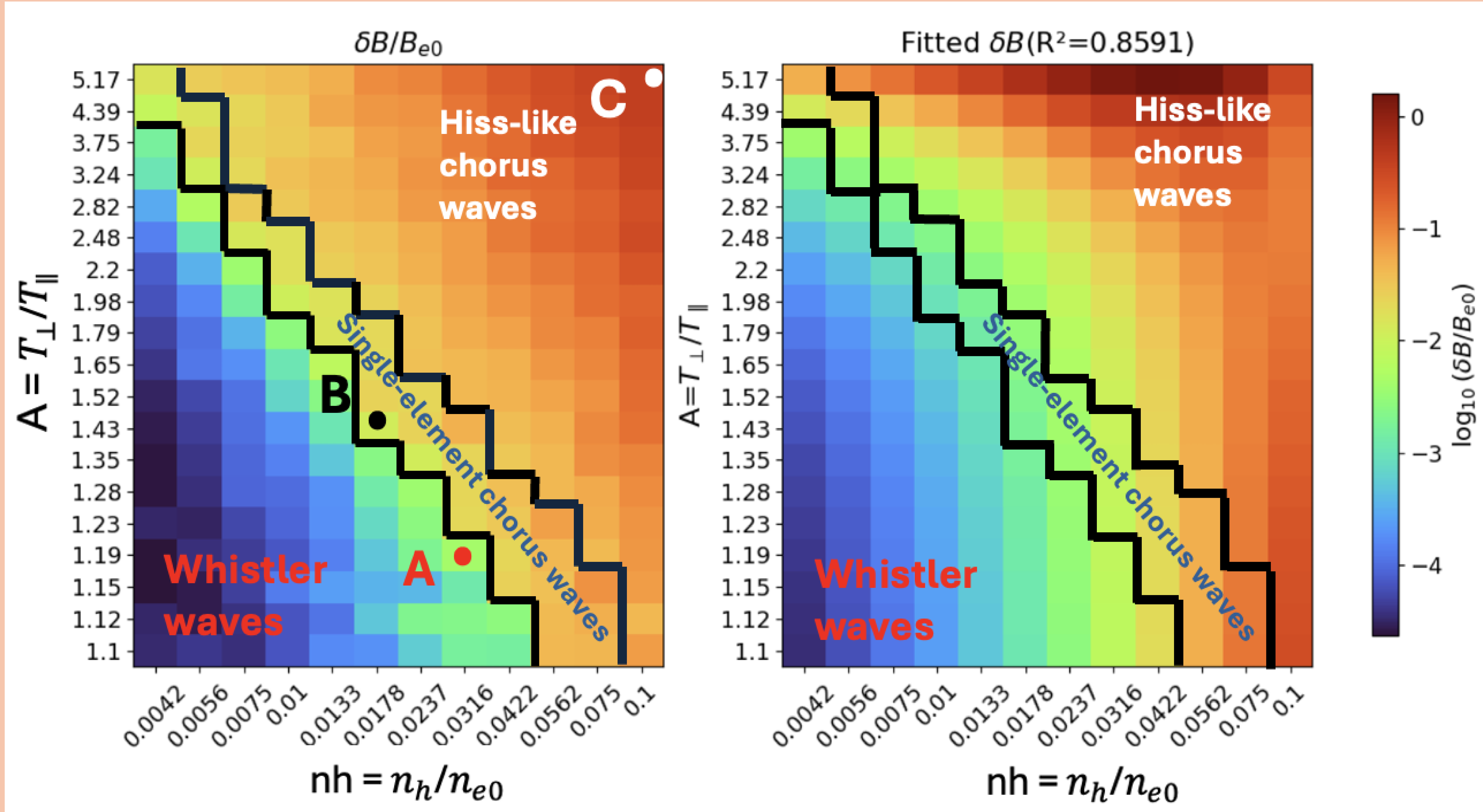


Figure C. Hiss-like chorus waves

Simulation Results

3. Parametric study of wave excitation and saturation wave amplitude

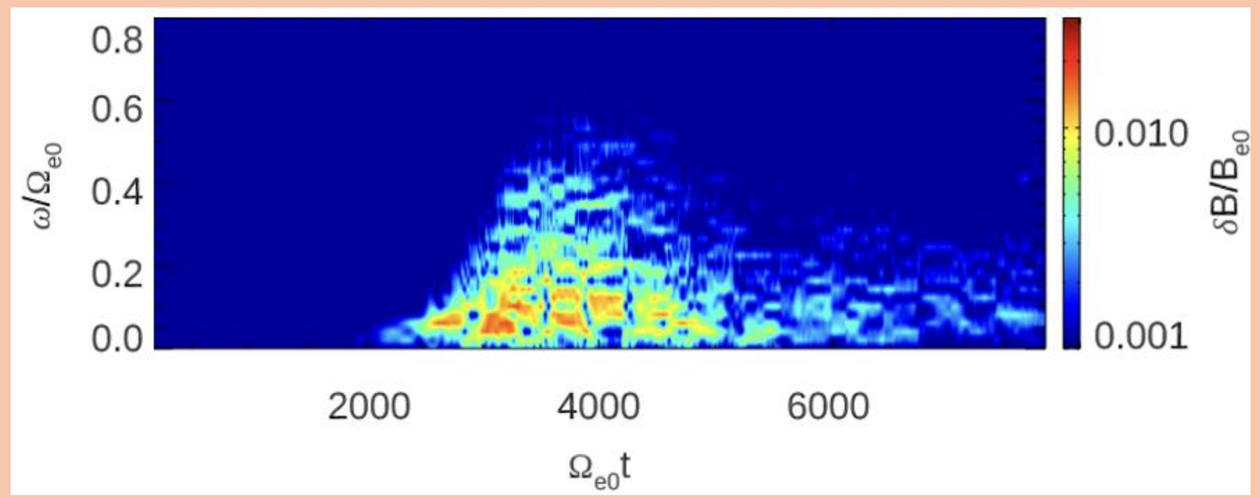


$$\delta B = 29\sqrt{nh} + 0.81A + 3.3A\cdot nh - 37.37nh\sqrt{A} - 7.07$$

Three parameter regions corresponding to whistler waves, single-element chorus waves, and hiss-like chorus waves are distinguished.

We fit the saturation wave amplitude as a function of A and nh. The fitted parameter R^2 is 0.86.

4. Excitation of Hiss Waves at higher plasma density



Additionally, at higher plasma density (ω_{pe}/Ω_{e0}=20), the hiss waves can be generated in a wide parameter range.

Conclusion

- Three distinct parameter regimes are identified for the excitation of whistler waves, single-element chorus waves and hiss-like chorus waves.
- An empirical relation between the saturation wave amplitude and the temperature anisotropy and number density of energetic electrons has been derived.
- In high-density regions inside the plasmasphere, hiss waves can be easily excited.

Refernence

Fu, X., et al. (2014), Whistler anisotropy instabilities as the source of banded chorus: Van Allen Probes observations and particle-in-cell simulations, J. Geophys. Res. Space Physics, 119, 8288–8298, doi:10.1002/2014JA020364.
Gao, X., et al. (2014), New evidence for generation mechanisms of discrete and hiss-like whistler mode waves, Geophys. Res. Lett., 41, 4805–4811, doi:10.1002/2014GL060707.
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