Characteristics of whistler-mode chorus emissions in planetary magnetospheres inferred from recent simulation studies

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Abstract:

We discuss characteristics of whistler-mode chorus emissions in planetary magnetospheres, based on results of recent simulation studies. A series of simulations revealed dependencies of the spectral characteristics of chorus on the number density of energetic electrons [Katoh and Omura, JGR 2011] and on the inhomogeneity of the background magnetic field [Katoh and Omura, JGR 2013]. The simulation results showed that the wave amplitude of chorus tends to decrease for the case of small magnetic field inhomogeneity, because the threshold wave amplitude in generating chorus becomes small. While the wave amplitude of chorus is relatively small in the Jovian magnetosphere than that in the terrestrial magnetosphere, this difference can be explained by the relationship between the chorus intensity and the magnetic field inhomogeneity.

In this presentation, we show our future plan of the cross-reference simulations for the investigation of chorus in planetary magnetospheres. In the cross-reference simulations, the range of the variation of the magnetic field inhomogeneity in the inner Jovian magnetosphere will be investigated by MHD simulations, and then the spectral characteristics of chorus under the reproduced magnetospheric setting will be studied by electron hybrid simulations. Our cross-reference simulations will provide important clues in understanding the generation mechanism of chorus and the role of chorus in the relativistic electron acceleration process occurring in planetary magnetospheres, by comparing with the observation results of Jovian chorus by Galileo spacecraft [e.g., Katoh et al., JGR 2011] as well as chorus in the terrestrial inner magnetosphere.

References:

Katoh, Y., F. Tsuchiya, Y. Miyoshi, A. Morioka, H. Misawa, R. Ujiie, W. S. Kurth, A. T. Tomas, and N. Krupp, J. Geophys. Res., 116, A02215, doi:10.1029/2010JA016183, 2011.

Katoh, Y. and Y. Omura, J. Geophys. Res., 116, A07201, doi:10.1029/2011JA016496, 2011.

Katoh, Y. and Y. Omura, J. Geophys. Res. Space Physics, 118, 4189-4198, doi:10.1002/jgra.50395, 2013.

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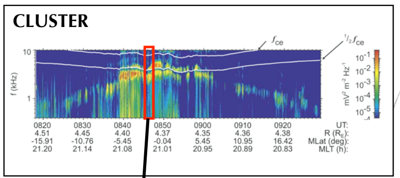
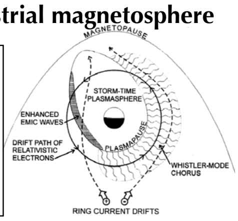
Outline

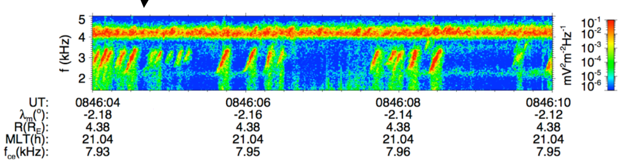
1. Introduction
2. Simulation model
3. Properties of chorus generation
4. Summary

Whistler-mode chorus in the terrestrial magnetosphere





[*Summers et al.*, 1998]



[*Santolik et al.*, 2008]

Chorus in planetary magnetospheres

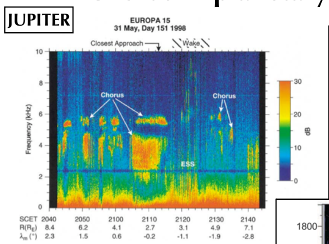


Fig: Chorus emissions observed by Galileo in the equatorial region of the Jovian inner magnetosphere [*Kurth et al.*, PSS 2001]

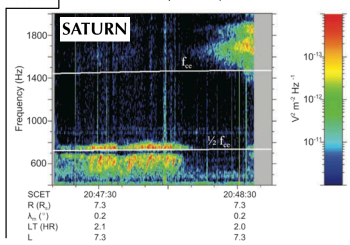


Fig: Typical example of chorus emissions observed by Cassini/RPWS during injection events in Saturn's magnetosphere [*Hospodarsky et al.*, JGR 2008]

Purpose of the present study

- Understanding properties of chorus generation process
- We conduct a series of electron hybrid simulations of the chorus generation by changing **magnetic field inhomogeneity** and **number density of energetic electrons**
- We study spectra of reproduced chorus by comparing with theoretical estimations and observations

Basic equations: Electron Hybrid model

[e.g., *Katoh and Omura*, JGR 2004, GRL 2007]

Cold electrons are treated as a fluid
energetic electrons are treated as particles

$$\frac{\partial \mathbf{v}_f}{\partial t} = -(\mathbf{v}_f \cdot \nabla)\mathbf{v}_f + \frac{q_f}{m_f}(\mathbf{E} + \mathbf{v}_f \times \mathbf{B})$$

$$\frac{d(m_p \mathbf{v}_p)}{dt} = q_p(\mathbf{E} + \mathbf{v}_p \times \mathbf{B})$$

$$\mathbf{J} = q_f n_f \mathbf{v}_f + \sum_p q_p \mathbf{v}_p$$

$$\frac{\partial \mathbf{B}}{\partial t} = -\nabla \times \mathbf{E}$$

$$\frac{\partial \mathbf{E}}{\partial t} = \frac{1}{\mu_0 \varepsilon_0}\nabla \times \mathbf{B} - \frac{1}{\varepsilon_0}\mathbf{J}$$

Simulation model & initial settings

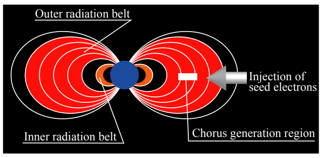
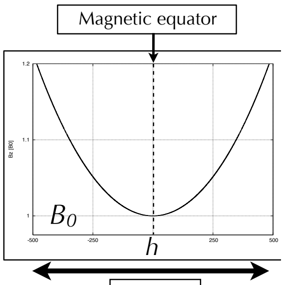


Fig: Schematic illustration of radiation belts



- Electron Hybrid code
- 1D, field aligned system
- Loss-cone velocity distribution with a temperature anisotropy
- neglecting electrostatic waves

$\omega_p/\Omega_{e0} = 4.0$ $\quad v_{th,\parallel} = 0.225c$

$v_{th,\perp} = 0.6c$

$N_h = 5.22 \times 10^{-4} N_0$

Initial conditions for the study of properties of chorus generation

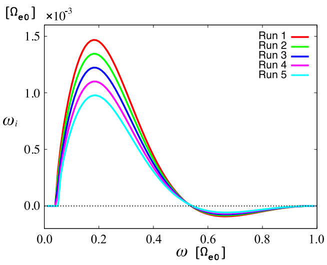
Case 1: Different number density of energetic electrons at the magnetic equator (corresponding to different linear growth rate)

Case 2: Different magnetic field inhomogeneity with the same property of energetic electrons at the magnetic equator

Case 1: number density of energetic electrons

We conducted simulations under the settings of different linear growth rates

- **Run 1: N_h +20%**
- **Run 2: N_h +10%**
- **Run 3: N_h = 8x10^{-4} N_{cold}**
- **Run 4: N_h -10%**
- **Run 5: N_h -20%**



$\omega_{pe} = 4\,\Omega_{e0}$ $\quad v_{th,\parallel} = 0.225c$

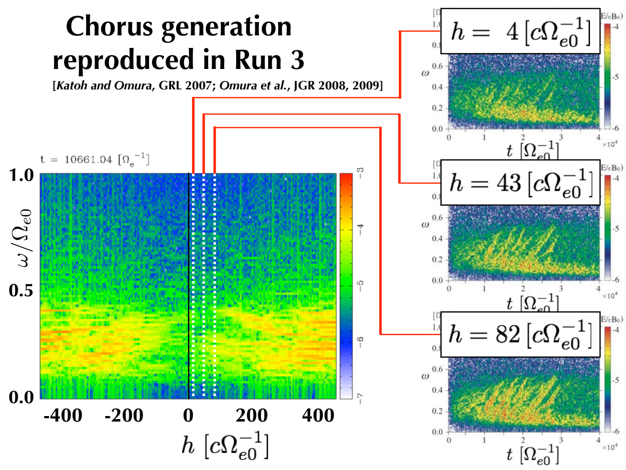
$v_{th,\perp} = 0.6c$

Fig: Linear growth rates for Run 1-5

(cf. *Xiao et al.*, 1998)

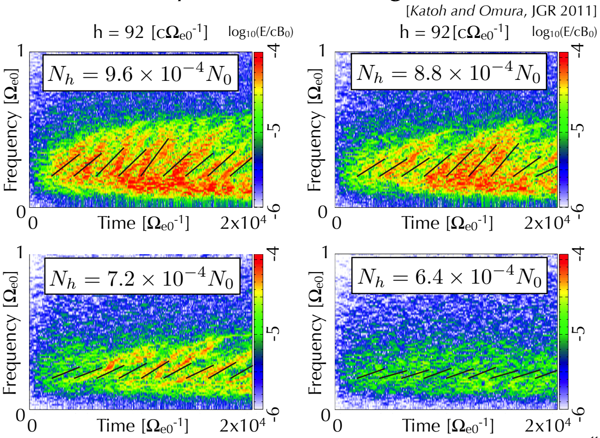
Chorus generation reproduced in Run 3

[*Katoh and Omura*, GRL 2007; *Omura et al.*, JGR 2008, 2009]

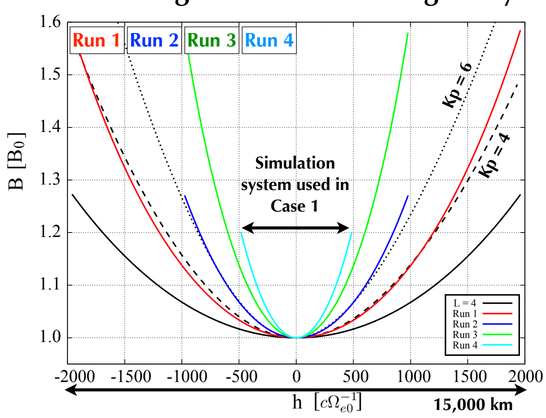


Simulation by different linear growth rates

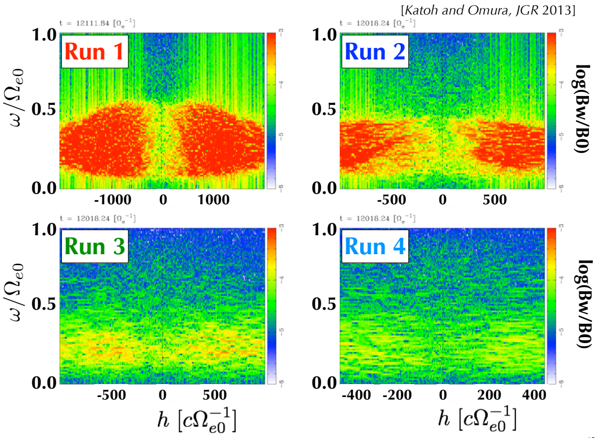
[*Katoh and Omura*, JGR 2011]



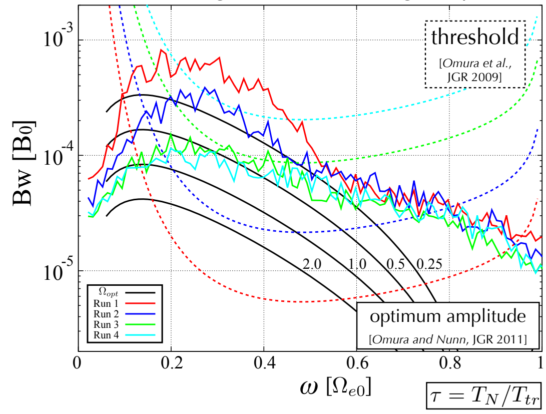
Case 2: Magnetic field inhomogeneity



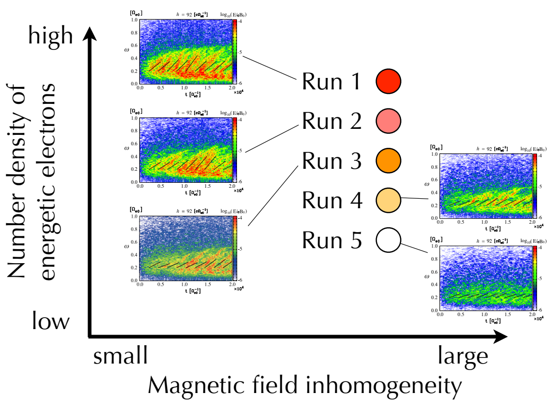
Simulation results with different inhomogeneities



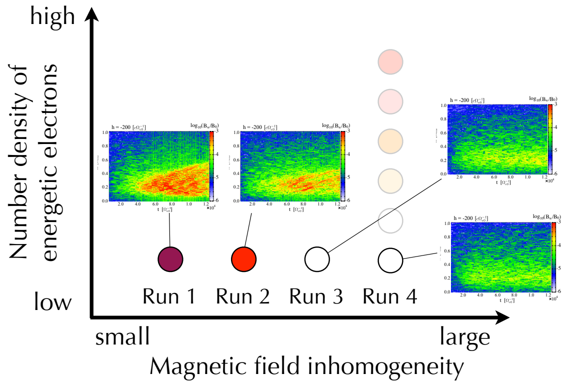
Comparison of theories and results of Case 2 (different magnetic field inhomogeneity)



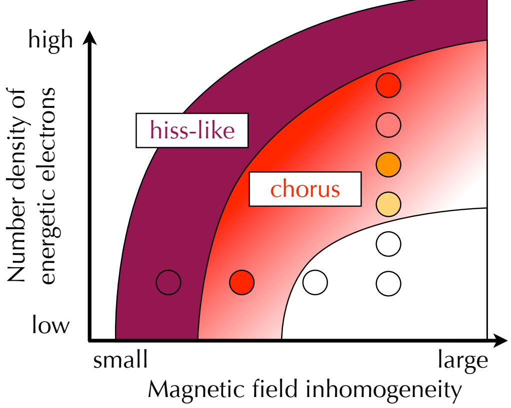
Summary of simulation results: Case 1



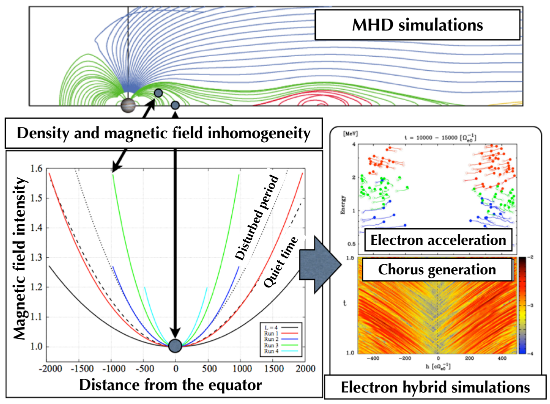
Summary of simulation results: Case 2



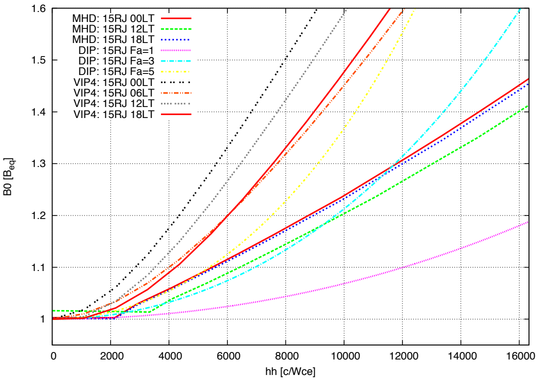
Properties of chorus generation



Planning of "Cross-reference" simulations



Jovian magnetic field inhomogeneity: MHD/empirical model comparison



Summary

- We studied properties of the chorus generation in planetary magnetospheres based on the recent simulation results
- Chorus emissions are generated when the wave amplitude exceeds the threshold wave amplitude for chorus generation
- The magnetic field inhomogeneity controls threshold
  - For the case of large inhomogeneity, chorus become intense
  - For the case of small inhomogeneity, number of rising tones will be generated due to the small threshold, resulting in hiss-like emissions
- These properties should be evaluated by further numerical experiments by *"cross-reference"* simulations, by *in situ* measurements of CLUSTER, THEMIS, VAPs, and forthcoming ERG satellites, and by observations at ground stations

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