Large-amplitude upper-band chorus emissions observed by Van Allen Probes

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Abstract

We find large-amplitude upper-band chorus emissions near the magnetic equator measured by the EMFISIS (Electric and Magnetic Field Instrument Suite and Integrated Science) instrument package on the Van Allen Probes. The emissions propagate quasi-parallel to the geomagnetic field line. In setting up the parameters of seed electrons exciting the emissions based on theoretical analyses and observational results measured by the HOPE (Helium Oxygen Proton Electron) instrument, we calculate threshold and optimum amplitudes obtained by the nonlinear growth theory. The linear growth rates, on the other hand, are negative in the high-frequency part of the emissions. Furthermore, some chorus emissions each of which has a narrow gap at half the cyclotron frequency of electrons can also be interpreted in terms of the nonlinear growth theory and the nonlinear damping mechanism at half the cyclotron frequency f_{ce}.

1. Introduction

Chorus emissions with highly oblique wave normal angles have been observed by Cluster satellites [1] and Van Allen probes [2]. *Santolik et al.* (2014), on the other hand, reported that the wave normal angles of the emissions tend to be closer to be parallel to the geomagnetic field line as their wave amplitudes increase. According to the simulation analyses of electrons interacting with chorus emissions with parallel propagation [4], chorus emissions play key roles in radiation belt dynamics as a generator of MeV electrons and a scattering factor of energetic electrons into the atmosphere. *Li et al.* (2011) reported that upper-band chorus waves propagate more obliquely than lower-band chorus waves based on the observational results of Time History of Events and Macroscale Interactions during Substorms (THEMIS) [5]. In the present study, we focus on upper-band chorus emissions with large wave amplitudes and investigate their generation process.

2. Large-amplitude upper-band chorus

Undertaking the data analyses used by EMFISIS instrument package on the Van Allen Probes, we study upper-band chorus emissions. Figures 1 and 2 show examples of the upper-band chorus emissions and the combined with lower-band and upper-band chorus

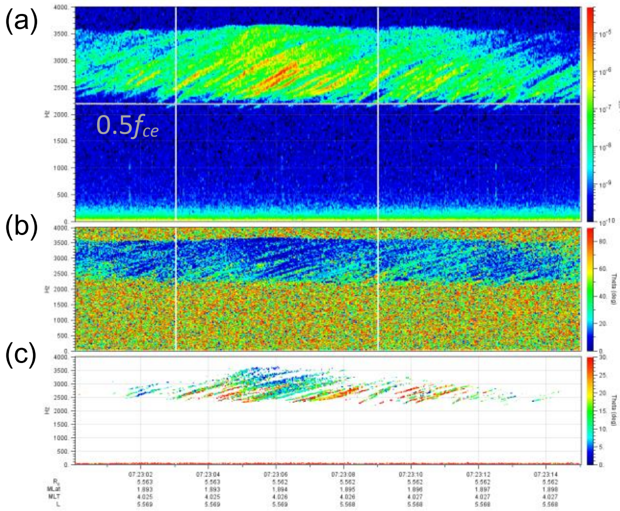

Figure 1. Measurements of RBSP-A EMFISIS on 12 January 2013. (a) Sum of the three magnetic power spectra B_{sum}. The gray line corresponds to half the cyclotron frequency. (b) Polar angle θ plotted between blue ($\theta = 0°$) and red ($\theta = 90°$). (c) Polar angle θ satisfied with $B_{sum} > 10^{-7}$ nT^2/Hz plotted between blue ($\theta = 0°$) and red ($\theta = 30°$).

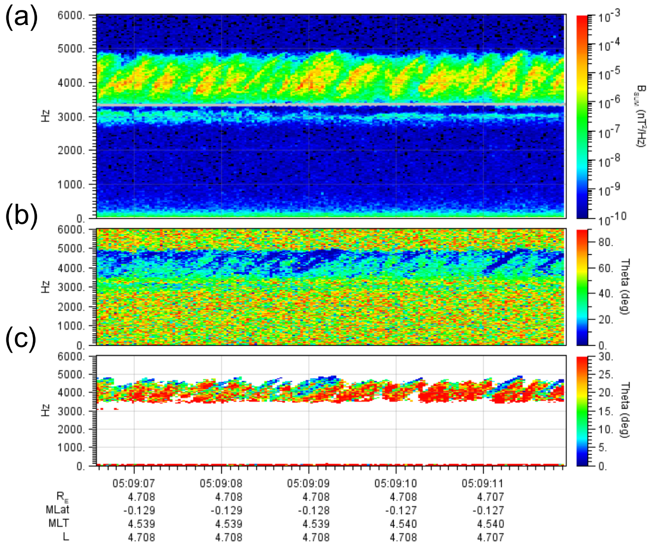

Figure 2. The same as Figure 1 but mesurements on 20 January 2013.

emissions with the narrow gap at half the cyclotron frequency, respectively. From Figures 1 and 2, we find that the wave normal angles of the emissions with large amplitudes are close to be parallel to the geomagnetic field line ($\theta < 5°$). The parallel emissions are possible to be generated by the nonlinear mechanism described in the next section.

3. The nonlinear growth theory

Assuming parallel propagation, *Omura et al.*[6,7] derived the threshold amplitude B_{th} and optimum amplitude B_{op} of chorus emissions generated through nonlinear process, and they are respectively given by

$$B_{th} = 25\,\pi^3 \frac{m_e c^6 V_p s_2^2 V_{t||}^2}{eQ^2 \omega \omega_{eh}^4 V_{\perp 0}^5 (1 - v_p^2/c^2)^3} \left(\frac{\partial^2 \Omega_e}{\partial h^2}\right)^2 \exp\left(\frac{V_R^2}{V_{t||}^2}\right), \quad (1)$$

and

$$B_{op} = 0.81\pi^{-5/2} \frac{m_e Q \omega_{eh}^2 V_{\perp 0} V_p V_g s_1}{ec^2 \omega \tau V_{t||}} \exp\left(-\frac{V_R^2}{2V_{t||}^2}\right), \quad (2)$$

where s_1 and s_2 are the coefficients related to the wave sweep rate and gradient of the magnetic field, respectively. For an angular wave frequency ω and angular electron cyclotron frequency Ω_e, the group velocity V_g, phase velocity V_p, and resonance velocity V_R are determined from the dispersion relation for chorus waves. The symbol h stands for a distance from the magnetic equator along the dipole geomagnetic field line and c, e, and m_e are the speed of light, the charge and mass of an electron. Based on theoretical analyses, we assume that the depth of an electron hole Q and a parameter specifying the nonlinear transition time in terms of the nonlinear trapping period τ are equal to 0.5, respectively.

We calculate the threshold and optimum amplitudes as functions of the wave frequency f in setting up the parameters for energetic electrons specified by the average perpendicular velocity $V_{\perp 0}$, parallel thermal velocity $V_{t||}$, and angular plasma frequency ω_{eh} based on the observational results measured by the HOPE instrument, and plot them in Figure 3a. The wave amplitudes $B_\perp$ perpendicular to the geomagnetic field B_0 are obtained from the magnetic power spectra B_{sum} and polar angle θ shown in Figure 1, plotted in the black circles. From Figure 3a, we find that the optimum amplitude is larger than the threshold one in the frequency range of the upper-band chorus emissions and that the wave amplitudes excite between the threshold and optimum amplitudes.

We also estimate a linear growth rate γ by KUPDAP (Kyoto University Plasma Dispersion Analysis Package) [8] and plot it in Figure 3b. The growth rate become positive only just around half the cyclotron frequency.

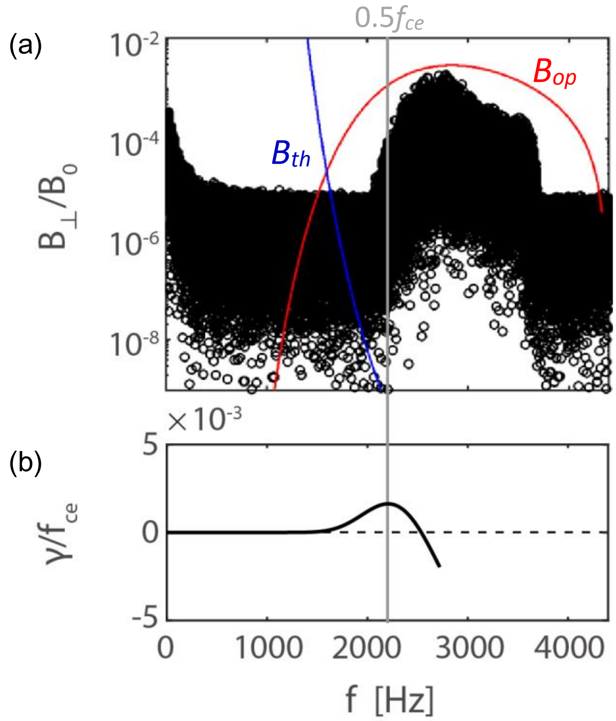

Figure 3. (a) The perendicular wave amplitudes obtained from the observational results shown in Figure 1. The blue and red lines corresponding to the threshold and optimum amplitudes based on the nonlinear growth theory, respectively. (b) The linear growth rate.

4. Conclusion

We have confirmed that the amplitudes of the large-amplitude upper-band emissions are in good agreement with those of the nonlinear growth theory. The linear growth theory, on the other hand, could not explain the growth mechanism of these emissions in almost all the frequency range. The emissions with a narrow gap at half the cyclotron frequency of electrons are also consistent with the nonlinear growth model, so that the gap is possible to take place due to the nonlinear damping mechanism induced by the longitudinal component of a slightly oblique whistler mode wave packet [6, 9-10].

5. References

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