GENERATION AND PROPAGATION OF CHORUS EMISSIONS OBSERVED BY GEOTAIL IN THE DAYSIDE OUTER MAGNETOSPHERE

Satoshi YAGITANI[1], Isamu NAGANO[1], Hiroshi MATSUMOTO[2], Yoshiharu OMURA[2], William R. PATERSON[3], Louis A. FRANK[3], and Roger R. ANDERSON[3]
[1]Kanazawa University, Kanazawa 920, Japan
[2]Radio Atmospheric Science Center, Kyoto University, Uji 611, Japan
[3]The University of Iowa, Iowa City, Iowa 52242, U.S.A.

1. Introduction

Many chorus emissions have been observed by the GEOTAIL spacecraft, mainly in the dayside outer magnetosphere. The Plasma Wave Instrument (PWI) onboard GEOTAIL makes it possible to examine not only the overall activities of the emissions but also a detailed characteristics of wave normal and Poynting directions of each of rising and falling frequency tones[1]. During the chorus activities, energetic electrons responsible for cyclotron resonance with the emissions have also been measured by the Comprehensive Plasma Instrument (CPI) with high energy and time resolutions[2]. Comparison between these high-quality in-situ wave and particle data is expected to give an experimental evidence for possible nonlinear wave-particle interactions involved in the generation mechanism of the chorus emissions.

In this paper, we analyze generation and propagation of chorus emissions observed by the PWI and compare them with the energetic electrons simultaneously observed by the CPI, in the dayside outer magnetosphere (near the magnetopause), on October 17-18, 1992.

2. Dayside Chorus Emissions Observed by GEOTAIL

The GEOTAIL spacecraft has observed many chorus emissions along almost all of its orbits just inside the dayside magnetopause. The Plasma Wave Instrument (PWI) is a powerful tool to analyze characteristics of the emissions. Overall activities of the chorus emissions are observed at the same time by the Sweep Frequency Analyzer (SFA) with high-frequency/low-time resolutions, and by the Multi Channel Analyzer (MCA) with high-time/low-frequency resolutions[1]. On the other hand, detailed frequency-time structures of each of chorus elements can be obtained by the Wave Form Capture (WFC) receiver, which measures simultaneously two electric and three magnetic wave forms in the frequency range from 10 Hz up to 4 kHz for 8.7 sec every 5 min. This enables us to compute exact wave normal and Poynting directions for each rising/falling element of the emissions from each of the electromagnetic wave forms, which has been correctly calibrated with taking into account the effect of antenna impedance[3].

A preliminary result of WFC observation of the dayside chorus emissions is summarized as follows. Most of the emissions are rising tones and structureless (banded noise), sometimes hooks (including inverse hooks), with very few falling tones. The occurrence of the emissions shows predominance in the dawn-noon sector around the magnetic equator. The frequency range of the intense emissions is between 200 Hz and 1 kHz, corresponding to 0.1-0.4 of the equatorial electron cyclotron frequency around the dayside $L \sim 10$ region. Such characteristics are consistent with the previous satellite observations of the dayside chorus emissions[4]. On the other hand, an eigenvalue analysis of the spectral matrix to evaluate wave normal directions of the chorus emissions demonstrates that for almost all the cases each of the chorus elements is composed of a single plane wave. This is also consistent with the previous observations[5][6].

Fig. 1 shows an example of dayside chorus emissions observed by the WFC at 22:05:03UT on October 17, 1992. Here a couple of rising tones appear along with a falling tone with unusual long duration. The wave normal vectors of the rising tones and the falling tone are found to be parallel and anti-parallel to the Earth's magnetic field line, respectively, suggesting that they propagated to GEOTAIL from completely different source regions.

3. Generation and Propagation Mechanisms of Chorus Emissions

Fig. 2 shows the GEOTAIL orbit in the dayside magnetosphere on October 17-18, 1992, in the x-z plane of the SM coordinate system. Time variation of wave normal directions of the chorus emissions along this orbit is shown in Fig. 3, where each dot represents the wave normal angle with respect to the local Earth's magnetic field for each of the four types (rising, mixture of rising and structureless, structureless, and falling tones) of chorus elements observed by the WFC every five minutes. In the equatorial region (before 23:00UT) each wave normal direction is concentrated around either 0 or 180 degree, parallel (northward) or anti-parallel (southward), to the Earth's magnetic field line. After 23:00UT, as GEOTAIL goes southward away from the equator, the wave normal directions become mainly southward and then gradually oblique. Such a wave normal variation with the geomagnetic latitude suggests the whistler-mode non-ducted propagation of the chorus emissions from the equator[7][8]. Since the wave normals usually make small angles to the Earth's magnetic field line in the generation region of the chorus emissions[5][7], it is quite probable that GEOTAIL was inside or at least in the vicinity of the generation region before 00:00UT on this day.

During this time period (22:00-00:00UT) of chorus observation in the possible source region, the CPI observed the distribution functions of energetic (1 kev $<$ energy $<$ 50 keV) electrons which play an important role in generating the chorus emissions through cyclotron resonance. Many kinds of theories and simulations have been proposed so far to explain amplification and nonlinear frequency shift of the emissions with simple models of energetic electrons[9]. In the present analysis, we compute linear cyclotron growth rates of the chorus emissions directly from the observed three-dimensional distributions of resonant electrons to see if there is any correlation between the simultaneous wave and particle observations.

Taking into account exact parallel resonant velocities of the electrons, we estimate electron temperature anisotropy which is a crucial parameter to determine growth rates at each frequency of the emissions[10]. However, the anisotropy estimated from the actual CPI observation seems too small to give rise to positive growth rates for almost all the time of chorus observations on this day. This inconsistency would be caused by the CPI measurement of an electron distribution function averaged over about 20 sec, which is enough time period for the anisotropy to be well reduced through pitch angle diffusion by the generated intense chorus emissions. The temperature anisotropy at the exact time of chorus generation (in much less than 1 sec) can be larger than the values actually observed by the CPI (in 20 sec).

Tentatively assuming that the anisotropy is three times larger than the actually observed one, we again compute the cyclotron growth rates shown in Fig. 4. The upper panel shows the frequency-time diagram of the computed growth rates (here we cannot compute the growth rates below about 200 Hz because that frequency range corresponds to the energy range of resonant electrons greater than 50 keV, which is out of the CPI energy coverage), while the middle and lower ones are the corresponding chorus observations by the SFA and MCA. A relatively good agreement is found between the growth rates and the observed wave spectra in terms of both frequency and time variations. This suggests that the chorus emissions observed in this time period are most likely generated through cyclotron resonance with the energetic electrons observed simultaneously.

4. Conclusion

We have discussed generation and propagation mechanisms of chorus emissions via cyclotron resonance with energetic particles based on simultaneous wave/particle measurements by GEOTAIL in the dayside outer magnetosphere. Computing the cyclotron growth rates from the velocity distributions of energetic electrons observed by the CPI, we have shown that the chorus emissions observed by the PWI are most likely generated by the energetic electrons.

In the future we will investigate further the generation and propagation mechanisms of the chorus emissions observed by GEOTAIL not only in the dayside but also in other regions of the magnetosphere on the basis of the nonlinear wave-particle interactions.

Acknowledgments. The authors thank Prof. S. Kokubun and his GEOTAIL/MGF group for the permission to use their magnetic field data.

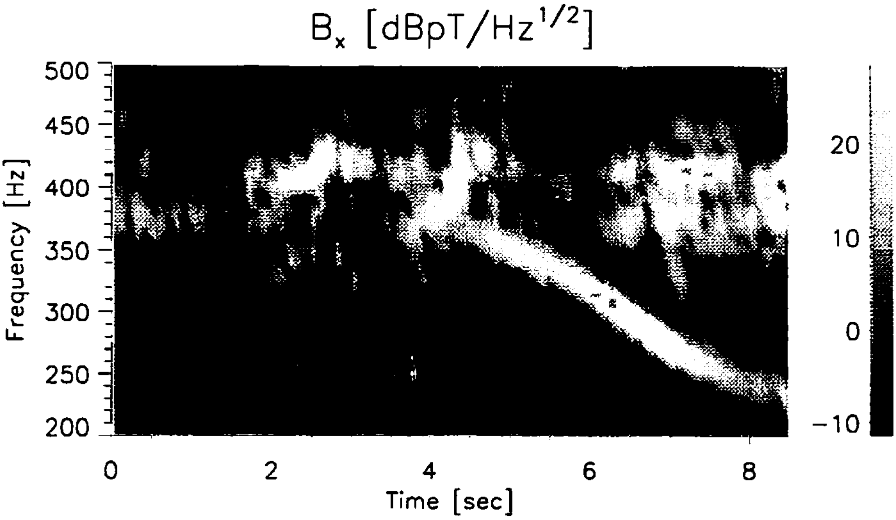
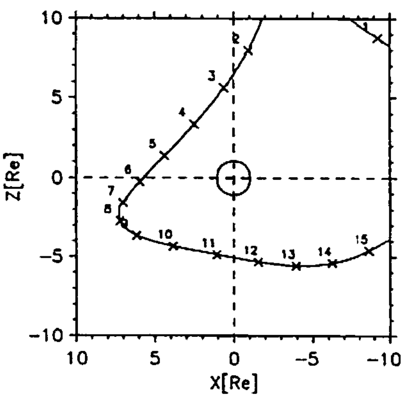


Fig. 1: An example of chorus emissions observed by the WFC at 22:05:03UT on October 17, 1992.



1	:	921017 02:00:00
2	:	921017 14:00:00
3	:	921017 16:00:00
4	:	921017 18:00:00
5	:	921017 20:00:00
6	:	921017 22:00:00
7	:	921018 00:00:00
8	:	921018 02:00:00
9	:	921018 04:00:00
10	:	921018 06:00:00
11	:	921018 08:00:00
12	:	921018 10:00:00
13	:	921018 12:00:00
14	:	921018 14:00:00
15	:	921018 16:00:00

Fig. 2: The dayside GEOTAIL orbit on October 17-18, 1992, in the SM coordinate system.

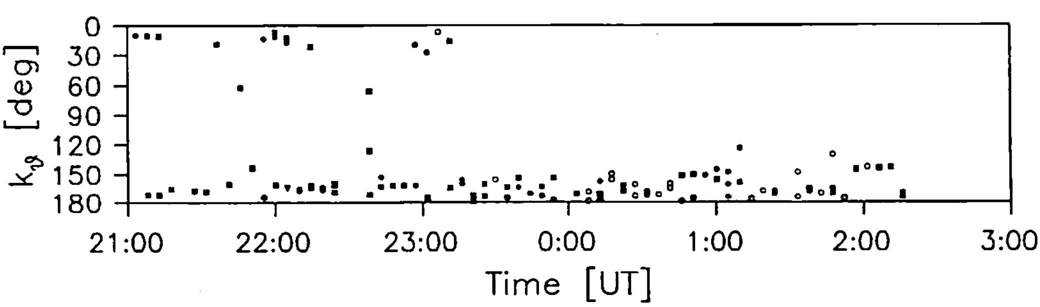


Fig. 3: Time variation of wave normal directions of dayside chorus emissions observed along the GEOTAIL orbit shown in Fig. 2.

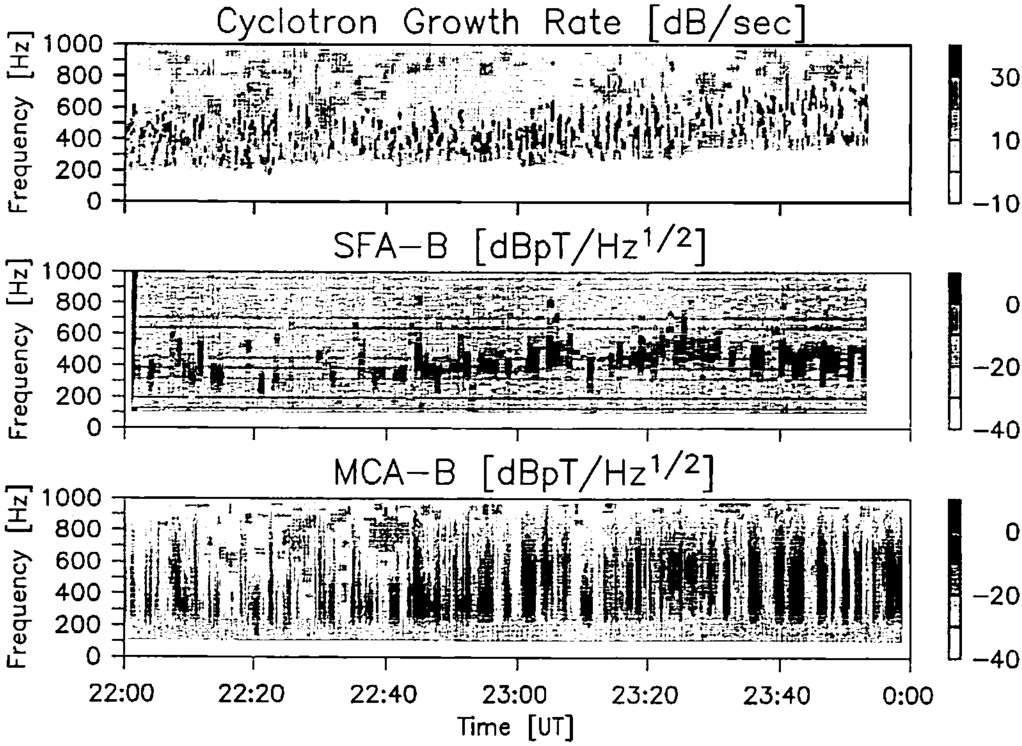


Fig. 4: Comparison of cyclotron growth rates computed from the CPI electron observation. with the SFA and MCA observations of the chorus emissions on October 17, 1992.

References

[1] H. Matsumoto et al.. *J. Geomag. Geoelectr.*. *46*, 59. 1994.

[2] L. A. Frank et al., *J. Geomag. Geoelectr.*. *46*, 23. 1994.

[3] I. Nagano et al., *J. Geophys. Geoelectr., 48*. 1996.

[4] B. T. Tsurutani. and E. J. Smith, *J. Geophys. Res.*, *82*, 5112, 1977.

[5] B. E. Goldstein, and B. T. Tsurutani, *J. Geophys. Res.*, *89*, 2789, 1984.

[6] M. Hayakawa et al., *J. Geophys. Res.*, *89*, 2811, 1984.

[7] R. K. Burton, and R. E. Holzer, *J. Geophys. Res.*, *79*, 1014, 1974.

[8] M. Hayakawa et al, *Planet. Space Sci.*, *38*, 135, 1990.

[9] Y. Omura et al, *J. Atmos. Terr. Phys.*, *53*, 351. 1991.

[10] C. F. Kennel, and H. E. Petschek, *J. Geophys. Res.*, *71*, 1, 1966.