Evaluation of Whistler-mode Chorus Amplification During an Injection Event Observed on CRRES

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Abstract

The excitation of nightside chorus emissions is investigated during an injection of plasmasheet electrons into the inner magnetosphere. CRRES data of the electron phase space density are used to model the distribution of injected electrons and the path-integrated growth of chorus waves is then evaluated with the HOTRAY code. The results indicate that slightly higher electron anisotropy than that obtained from the 5 minute-averaged electron distribution data is required to reproduce the observed wave intensity, suggesting that the injected electron anisotropy is reduced due to pitch-angle scattering by the enhanced chorus waves within the 5 minutes interval.

1. Introduction

Chorus emissions are whistler-mode plasma waves propagating through the Earth's magnetosphere at frequencies below the electron gyrofrequency (a few hundreds Hz ~ several kHz). Chorus consists of discrete elements associated with rising and falling tones, each of which lasts for a few tenths of a second [*e.g.*, 1, 2] in two distinct frequency bands [3, 4]. There are similarities between the structure of chorus and triggered whistler-mode emissions and in recent years many papers have been written on the theory and simulations of triggered whistler-mode emissions [5-7]. The linear cyclotron growth of the chorus wave is very important but has not been well understood. The main purpose of the study is to quantify wave amplification of lower-band nightside chorus during the linear growth phase using observed particle data, and compare the simulated results with wave observation.

2. CRRES Observation During an Injection Event

The data used in this study are obtained from the Combined Radiation Release Experiment Spacecraft (CRRES). A typical chorus excitation event was observed during orbit 561 on March 13, 1991 when CRRES was near the magnetic equator. The electron pitch angle distribution (left panel in Figure 1) is measured at 07:26 UT as a function of equatorial pitch angle for energy between 163 eV and 28.5 keV. Simultaneously, an intensification of lower-band chorus occurs at 07:26 UT (blue line) shown in Figure 1 (right panel) in association with wave power spectral intensity during a quiet period starting at 06:32 UT (black line) for the lower-band chorus with frequencies between 0.1 f_{ce} and 0.5 f_{ce}. Peak chorus wave intensity at 07:26 UT (above the dotted red line) is about 5 orders of magnitude (~ 50 dB) larger than that in the quiet time period starting at 06:32 UT over a broad frequency band between 0.18 f_{ce} and 0.32 f_{ce}. The data are averaged over a period of ~ 5 minutes starting at the depicted time to obtain good counting statistics.

To evaluate the effect of such resonant interactions on the wave growth and damping we first model the phase space density of the relevant resonant electrons using an analytical distribution function. The observed electron phase space density is shown in dotted lines in Figure 2a and the solid lines represent the modeled contours. The superimposed dashed lines represent the n = 1 cyclotron resonant ellipses for field-aligned chorus waves with different frequencies normalized to the electron cyclotron frequency. Figure 2b shows the effective pitch-angle anisotropy for the resonant electrons calculated using equation (2.20) in [8]. The electron anisotropy calculated from fitted electron distribution is comparable to 0.4 for the higher energy (10s of keV) electrons, and becomes smaller for the lower energy electrons (< 1 keV). Since the electron distribution function is averaged over a time scale (5

minutes), which is much longer than the time scale for typical wave growth (typically < 1 s for whistler mode waves), the electron distributions could be partially isotropized by pitch-angle scattering with the excited chorus waves, leading to a decrease in observed anisotropy, suggesting that the injected electron anisotropy responsible for wave growth should be larger than the observed value shown in Figure 2b. Therefore, we perform ray tracing computations using a slightly higher electron anisotropy of A = 0.5 for all suprathermal electrons.

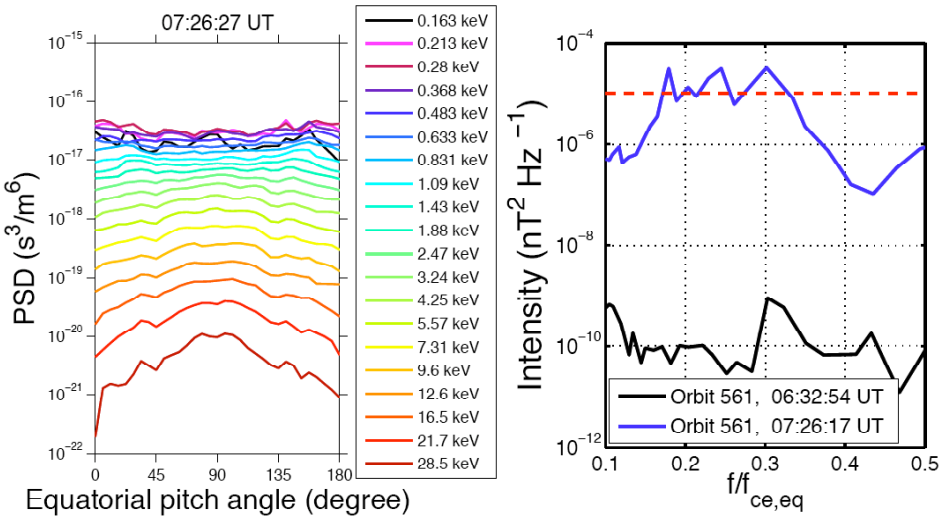

Figure 1. Left panel: Electron PSD (s^3m^{-6}) as a function of equatorial pitch angle for various energy levels (0.163 keV ~ 28.5 keV) at 07:26 UT on March 13 1991. Right panel: Wave intensity as a function of wave frequency normalized to the equatorial electron cyclotron frequency for the relatively quiet time at 06:32 UT (black line) and for the selected event at 07:26 UT (blue line). The dashed red line represents the wave intensity of 10^{-5} nT^2Hz^{-1}.

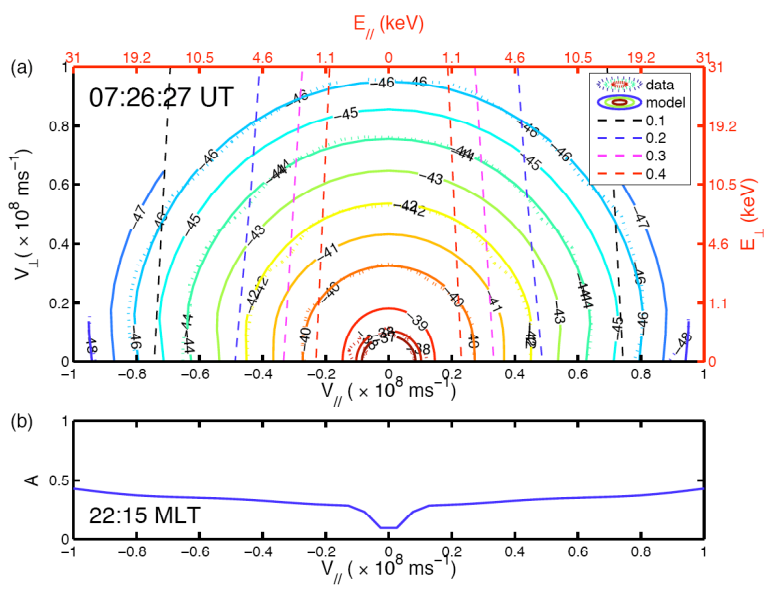

Figure 2. (a) The contours of the electron phase space density (*ln* (s^3m^{-6})) as functions of perpendicular and parallel velocity (ms^{-1}) (or corresponding perpendicular and parallel kinetic energy (keV) indicated by red axis). The dotted lines are from the electron PSD data based on LEPA measurement and solid lines represent the contours of electron PSD computed from the model. The dashed lines are the resonant eclipses for various frequency chorus waves. (b) Electron anisotropy as a function of parallel electron velocity (ms^{-1}).

3. Path-integrated Wave Growth with HOTRAY

In this study we evaluate wave growth (and damping) and particle diffusion based on linear and quasi-linear theory. Whistler-mode wave growth rates were obtained by solving the full electromagnetic dispersion relation using the HOTRAY code described by [9]. We assume chorus propagation in a dipole magnetic field and use a diffusive equilibrium density model based on [10] adjusting the parameters according to the density data from CRRES observation. In order to obtain a realistic path integrated wave gain at the equator, rays are first launched from the equator towards the northern hemisphere with various wave normal angles to obtain the final position and wave parameters of the ray which experiences the maximum gain. Subsequently, the optimum ray with strongest amplification is traced towards the southern hemisphere to calculate the wave gain, and finally is stopped when the gain drops below -30 dB due to severe Landau damping. Figure 3 shows the path-integrated wave gain as a function of magnetic latitude for rays with different frequencies. Different colors represent the waves with different frequencies each normalized to the equatorial electron cyclotron frequency. Strong wave gain (> 50 dB) near the equator occurs over the frequency range of 0.18 Ω_e ~ 0.32 Ω_e, consistent with the most intense chorus emissions shown in Figure 1 (right panel). Interestingly, approximately 50 dB amplification is also required to account for the peak power spectral intensity of chorus emission observed (Figure 1 (right panel)) during the injection event (at 07:26:UT) compared to the quiet period (at 06:32 UT). This suggests that the linear phase of chorus wave excitation can be well simulated by HOTRAY, assuming an injected electron anisotropy A = 0.5.

In our current study chorus waves are assumed to grow from the noise level and produce observable waves for path integrated gain > 50 dB. Since we kept electron pitch angle distribution constant for the whole simulation, the whistler mode instability due to anisotropy is sustained and the wave amplitude of the chorus wave does not saturate. In the real magnetosphere, however, we suggest that non-linear saturation occurs, which limits the observed wave intensity, for path integrated gain above ~50 dB. In the region of wave growth until wave gain peaks, electrons keep providing free energy to waves which become more oblique. Thereafter, Laudau damping becomes to dominate and waves are attenuated very quickly. In addition, our calculations indicate that intense wave growth (G > 50 dB) can occur to a level where non-linear processes control wave intensities over a region within 10° of the equator (Figure 11a and 11b), consistent with both theoretical predictions and CRRES data on the distribution of nightside chorus [12].

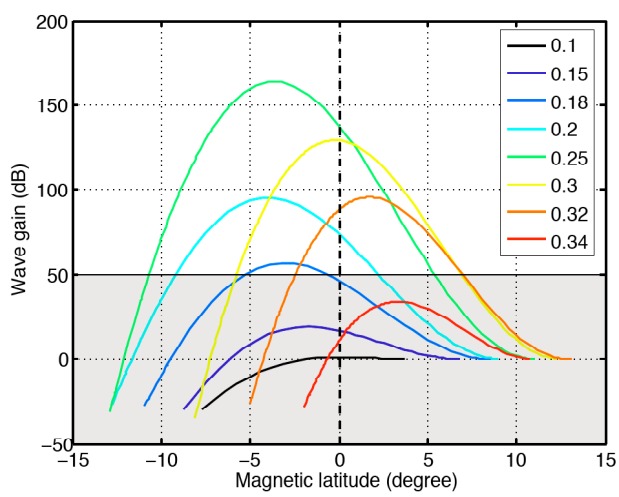

Figure 3. Path-integrated chorus wave gain using modified electron anisotropy of A=0.5 as a function of magnetic latitude (λ) for various frequency waves normalized to the equatorial electron cyclotron frequency. Black dashed line represents magnetic equator and dotted lines with different colors indicate the corresponding wave gain less than 20 dB of the peak gain. The shaded region represents wave gain is smaller than 50 dB showing waves do not reach observable value.

4. Conclusion

In this study we have used the HOTRAY code to evaluate the path-integrated wave gain of whistler-mode chorus based on the electron PSD data from CRRES and the results have been compared with observed wave

intensity from the Plasma Wave Instrument. The principal object of the study was to investigate the frequency and angular distribution of excited waves using linear and quasi-linear theory. The main results can be summarized as follows:

1. Lower-band ($0.1\ f_{ce} < f < 0.5\ f_{ce}$) nightside chorus is driven by the anisotropic distribution of the injected plasmasheet electron population at energies between 1 keV and 20 keV.
2. Path integrated gain for nightside chorus computed using HOTRAY based on the 5-minute averaged electron distribution data cannot reproduce the observed wave spectrum. We suggest that this is due to a substantial relaxation in electron anisotropy caused by pitch angle scattering of chorus waves over the observing interval of 5 minutes. Pronounced wave gain (G > 50 dB) computed using a slightly higher anisotropy (A = 0.5) to simulate the injected electrons prior to scattering is able to reproduce the observed wave frequency spectrum associated with strong wave frequency range between $0.18\ f_{ce}$ and $0.32\ f_{ce}$.
3. Waves in a certain frequency range initially grow but are ultimately attenuated by strong Landau damping as they propagate away from the equator and become more oblique.
4. Strong nightside lower-band chorus is confined within ~10° of the equator at all wave frequencies and chorus rays were Landau damped before they were able to magnetospherically reflect, consistent with [12].

5. Acknowledgments

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6. References

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