Multi-banded structure of chorus-like emission

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Abstract

Whistler-mode chorus emissions consist of individual wave packets exhibiting rising, falling tones or other spectral shapes (hooks or shapeless hiss) usually divided into two frequency bands separated by a gap at 1/2 of the electron cyclotron frequency (f_{ce}) close to the chorus source region. This configuration is often called banded chorus and it is correlated with the magnetic activity. Several theories have been published to explain how this specific configuration is generated. We present several tens of events of chorus emissions with more than two frequency bands and more than one gap that were found during more than 11 years of Cluster spacecraft measurements (from November 2000). Most of these "multi-banded emissions" were observed within 10° of geomagnetic latitude, i.e., inside or very close to the chorus source region. Most of studied events propagate with oblique wave normal angles and were detected under disturbed geomagnetic conditions.

1.Introduction

Whistler-mode chorus is formed by electromagnetic waves which are usually observed outside the plasmasphere in a wide range of L-shells (McIlwain parameters) [15]. Chorus propagates from the geomagnetic equator, where it is believed to be generated by cyclotron resonant interactions with suprathermal electrons [7]. Chorus emission likely plays a significant role in the outer radiation belt dynamics because it can contribute to the local sources of relativistic electrons in this region. It can accelerate electrons from energies on the order of a few keV to several MeV. This strong variation of fluxes of energetic electrons is observed within just a few days. Several studies have also shown that chorus is probably at the origin of the plasmaspheric hiss [2], which is another type of whistler-mode waves. It is an incoherent type of wave in a frequency band between a few hundred Hz and several kHz, and it is generally confined within the plasmasphere. This type of emission is probably responsible for the loss processes in the area of the radiation belts. Chorus waves can scatter plasma sheet electrons with energies from a few hundred eV to ten of keV into the atmosphere and form there the diffuse or pulsating auroras [16] and [12].

Chorus consists of two distinct frequency bands (lower-band and upper-band) separated by a gap at one half of the electron cyclotron frequency 1/2 f_{ce} [17] close to the geomagnetic equator. The width of the gap is variable and usually occurs in the interval between 0 and 1/2 f_{ce} [8]. The chorus frequency bands are composed of discrete wave packets with variable frequencies that sometimes change into shapeless hiss. Individual chorus wave packets usually consist of rising tones, but falling tones, hooks and more complicated structures have also been observed at short time scales (on the order of hundreds of milliseconds).

The origin of the gap is still unclear. Banded chorus was positively correlated with magnetic activity. A suggestion that Landau damping is one of the possible mechanisms explaining the existence of the gap was first mentioned by [15]. Other authors [13] presented a hypothesis to solve this problem based on the nonlinear Landau damping. In [1] the role of ducts in formation of the gap is discussed. The authors suppose that the gap can be formed if both the lower-band and the upper-band are generated within the enhanced or depleted plasma region. The frequency range of the lower band extends from 0.1 to 0.5 f_{ce} and the upper band extends from 0.5 to 0.7 f_{ce} [17]. It was found that the amplitude of the upper-band is weaker than the amplitude of the lower-band from the THEMIS measurements [10] and also from multiple satellite observations [11]. The larger wave normal angle of the upper-band than of the lower-band was also found from the THEMIS measurements [11]. The upper-band is confined to lower L-shells (< 8) and lower magnetic latitudes (up to 10°) in comparison with the lower-band chorus occurring in a wider range of magnetic latitudes and L-shells [15]. For this reason different generation mechanisms for these bands were discussed. Recently a case study of measurements without a gap at 1/2 f_{ce} obtained from THEMIS data was presented [9]. Due to several possible ways to explain the generation mechanism of the banded-emissions our statistical study of multi-banded emissions could bring a new perspective on this phenomena and it could also help create a better understanding of possible generation mechanisms of banded-emissions.

2. Observation of multi-banded emissions

The data set used in this paper is based on measurements of the Cluster wave instruments (STAFF-SA and WBD). The unique Cluster four spacecraft mission operates from the end of 2000 and chorus emissions were already observed at the beginning of the mission in November 2000 [6]. The observations which are discussed in the present paper have been primarily recorded by the Wideband (WBD) plasma wave receiver [5, 6] which performs one-axis measurements of the electric or magnetic field high-resolution waveforms. We use data from a low frequency mode of the WBD instrument

978-1-4673-5225-3/14/$31.00 ©2014 IEEE

which has a lower frequency of approximately 25 Hz and a total bandwidth of 9.5 kHz. The WBD data are continuously sampled at high time resolution, 36.5µs (sampling rate is 27.4 kHz). Simultaneous measurements of two components of the electric field and three components of the magnetic field at frequencies between 8 Hz and 4 kHz are recorded by the STAFF-SA instrument [3, 4]. They allow us to determine the value of the parallel component of the Poynting flux normalized by its standard deviation, ellipticity, planarity, the angle between ambient magnetic field and the wave vector, and power spectral density of magnetic and electric field fluctuations by using the computer program PRASSADCO [14].

These parameters help us to determine the position of the source region of analyzed wave events. Our study focuses on chorus emission with three or more frequency bands and with two and more gaps between frequency bands. These frequency bands either contain shapeless hiss, a combination of hiss and discrete structures or are composed from individual wave packets. Two examples of multi-banded emissions are shown in Figure 1 and Figure 2. In Figure 1, chorus emission consists of three frequency bands obtained by Cluster 1 and partly by Cluster 2 on December 22, 2001. All frequency bands are composed mainly of falling tones in this case. The white line corresponds to 1/2 f_{ce}. The multi-banded chorus-like emission in Fig. 2 is composed of four frequency bands. In this case the emission consists of shapeless hiss. The spacecraft position is given on the bottom in both figures. Both cases are localized close to the source region ($\lambda_m \sim 2^o$-3^o).

The time period from November 2000 till the end of 2011 (more than 11 years) has been used to visually select cases of banded whistler-mode emissions using the STAFF-SA database of measurements in the inner magnetosphere. This list corresponds to almost 2.500 hours of WBD data that we have visually inspected by using 30-second frequency-time spectrograms. In almost one half of these time intervals we have found chorus emissions with the discrete inner structure at least in one frequency band. We have found emissions that were composed of one frequency band in more than 10% of the intervals, and of two frequency bands in around 80%. We saw multi-banded emissions at least during five minutes in each of the rest of the cases. We have thus found a few tens of events of the multi-band chorus-like emissions outside the plasmapause which lasted at least 5 minutes and were detected in the region of magnetic latitudes (λ_m) within 30 degrees from the magnetic equator.

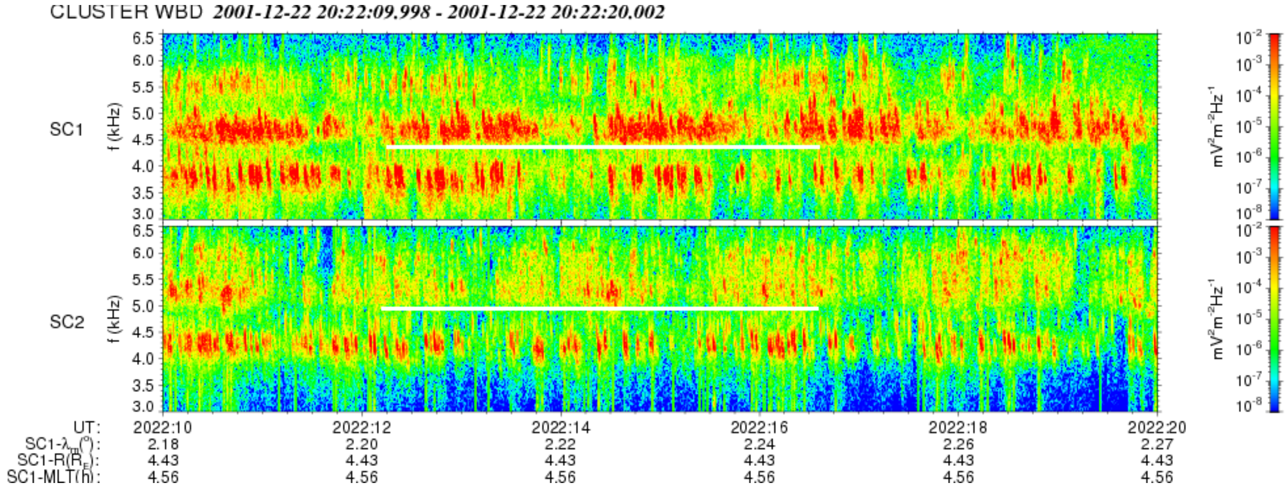

Figure 1: An example of time-frequency spectrograms of power spectral density of electric field fluctuations measured by Cluster 1 and Cluster 2 spacecraft on December 22, 2001. The spacecraft position of Cluster 1 is given on the bottom (UT – Universal Time, λ_m – geomagnetic latitude, R_E – radial distance, and MLT – Magnetic Local Time). The white lines correspond to the one half of the electron cyclotron frequency. In the upper panel three frequency bands separated by two gaps are evident. The second gap is above 1/2 f_{ce}. Frequency bands are composed of discrete wave packets in this particular case.

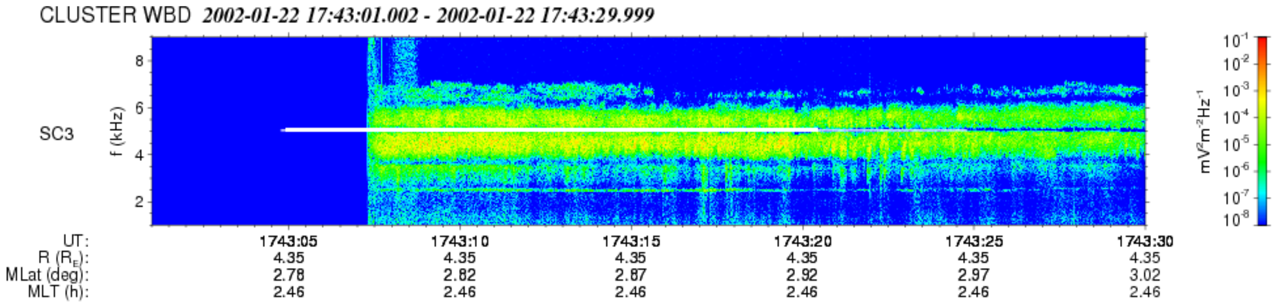

Figure 2: An example of multi-banded chorus-like emission measured on January 22, 2002 by Cluster 3. The white line corresponds to 1/2 f_{ce}. Another gap is below 1/2 f_{ce} and another one is seen above it. Spacecraft position is given on the bottom.

3. Conclusions

A new type of emissions with more than two frequency bands and with more than one frequency gap, multi-banded chorus-like emission, was found. These specific emissions were observed in approximately 10% of the total number of whistler-mode banded events outside the plasmapause. This type of banded chorus wasn't observed at the dipole magnetic latitudes greater than 15^{o}. The distribution of the multi-band chorus-like emissions in the MLT sectors is almost the same as the distribution of banded emissions. Most cases of multi-banded emissions have been found in the nightside and dawnside MLT sector and more than 75% of them were found at L-shells smaller or equal than 6. The second gap is usually (in more than 70% of cases) found above 1/2 f_{ce} at magnetic latitudes below 7^{o}. At magnetic latitudes between 7^{o} and 15^{o} it is usually found below 1/2 f_{ce} but above the lower hybrid frequency (f_{lh}). In this region of magnetic latitudes the second gap was usually localized between 0.2–0.4 f_{ce}.

Observed gaps have not been identified with multiples of any known frequency. The multi-banded emissions usually have an oblique propagation ($\theta > 20^{o}$). The average Kp index for multi-banded chorus-like emissions was ~ 3 (larger than the average Kp ~ 2 for emissions with one or two frequency bands). The geomagnetic activity has decreased at the same time as the Cluster orbit changed and crossed the equatorial plane at L-shells higher than 6. It is therefore not easy to distinguish if multi-banded chorus-like emissions almost disappeared at $L > 6$ as a result of the change of equatorial crossings to higher L-shells or as the effect of the decreasing geomagnetic activity.

We have found several tens of events of multi-banded emissions during the first 11 years of Cluster measurements. This is a small data set for a comprehensive statistical study, but we hope that it will still be useful for the future identification of parameters that have the largest influence on the formation of the multi-banded emissions. Our other future plans are to determine the frequency bandwidths of particular frequency bands and their average amplitudes. We will also try to determine how the amplitudes of these bands are changing during the propagation of multi-banded emission from the source region and how the value of the average amplitude of a particular frequency band depends on a position in the Earth's magnetosphere and on the geomagnetic activity. We will also try to determine if the frequency intervals of new gaps are related to local or equatorial electron cyclotron frequencies.

4. Acknowledgements

This work receives EU support through the FP7-Space grant agreement no 284520 for the MAARBLE collaborative research project. The work at the University of Iowa is carried out under NASA GSFC Grant NNX14AB10G.

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