OBSERVATION OF CONTINUUM RADIATION CLOSE TO THE PLASMAPAUSE: EVIDENCE FOR SMALL SCALE SOURCES

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Abstract

We briefly present observations of nonthermal continuum (NTC) radiations obtained close to the sources at the plasmapause by the Whisper instruments on Cluster. The examples considered illustrate the variety of the characteristics of the NTC such as the overall bandwidth of the emissions. The omnipresent multiple narrow bandwidth components are further evidence that the emissions could be generated from multiple, closely spaced, short scale regions (a few 10 km).

1 Introduction

The so-called nonthermal continuum radiations (NTC) are among the most frequent emissions observed in magnetospheric wave spectra. Its detection performed in or close to all giant planetary magnetospheres have confirmed its astrophysical importance (see the review by Kurth, 1992). More than 3 decades of observations and theories resulted in agreement on its general characteristics. It has two main components, one almost structureless which is trapped inside the magnetospheric cavity [Gurnett et al., 1975] and a narrow band component, first reported by Kurth et al. [1981], which can escape the magnetosphere whenever its frequency is above the plasma frequency of the boundary regions like the magnetopause. The source region was found to be mainly close to the plasmapause and the generation mechanism a conversion from electrostatic emissions at or close to the upper hybrid frequency F_{uh}. However many points are still to be investigated. For example, there is still no definitive agreement on the generation mechanism, linear or nonlinear mode conversion, as well as the key parameters which drive this conversion. There are little information on the precise source locations. Recent global observations performed by the Image spacecraft suggested that notches structures in the plasmasphere can be source of the NTC, at least for its newly discovered component at kilometric wavelength [Green et al., 2002]. The first studies performed by combining the direction finding

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capability of the four Cluster spacecraft has also provided new information on the source location close to the plasmapause [Décréau et al., 2004].

Examination of the details in NTC spectra can provide new clues on source(s) location(s) and mechanism. Beyond the banded emissions lanes, often harmonically spaced which strongly suggest a relationship with the enhancements of electrostatic emissions close to the plasmapause when F_{uh} is close to $(n + 1/2)$ harmonics of the electron gyrofrequency [Kurth et al., 1981, Kurth, 1982], very little attention was given to the existence of fine structures within these narrow band, typically with $\sim$ 100 Hz bandwidth, first reported by Kurth et al. [1981]. These last authors suggested that such very narrow bands could be due to a nonlinear interaction between the F_{uh} and a low frequency wave. From consideration of the spectral details in the NTC observations performed by GEOS and ISEE spacecraft and the identification of similar features with bandwidth of a few tens of Hz, Etcheto et al. [1982] first suggest that the individual emission regions can be very localized, within radial distance as low as about 10 km. Observations at high resolution performed more recently by the Polar and Cluster spacecraft have reach a similar conclusion of rather small size source regions [Menietti et al., 2003, 2005].

The Whisper instruments on the Cluster spacecraft monitor the NTC on a routine basis with a good time and frequency resolution. Because the Cluster orbit encounters the plasmasphere on almost every pass, Whisper can observe the details of the NTC close to the sources, i.e. before they have been reflected/diffused at the magnetospheric boundaries and their original spectral details modified. We presented here a few examples of such observations, which first illustrates the variety of the active regions and secondly strongly support sources regions composed of numerous and closely separated very small size active regions, which further question the key parameters driving the generation mechanism.

2 Instrumentation

Cluster is a constellation of four identical spacecraft which were launched by pairs in the summer of 2000. There are positioned in a tetrahedral configuration with a separation that varies with time, from 100 to 10 000 km, on a 4–19 R_E polar orbit. The Whisper instrument, flown on each spacecraft, has two main components [Décréau et al., 2001]. First, a relaxation sounder provides the characteristic frequencies of the surrounding plasma, in particular the plasma frequency. Secondly, a plasma wave receiver samples the electric components of the wave in the frequency range 2–80 kHz. The signal is provided from one of the two orthogonal spheres antennae, located on symmetric radial boom of length 88 m tip to tip. The waveform sampled is Fast Fourier transformed on board with a resolution of 64, 128, 256 or 512 bins that can be selected by telecommand, providing a frequency resolution of 1.2, 0.640, 0.320 or 0.160 kHz, the two last values being routinely used. Data selection and averaging is then performed by the Digital-Wave Processing experiment (DWP) in order to adapt the data flow of one spectrum every 13 ms to the allocated telemetry. The typical time resolution is about 2.1 s in Cluster normal bit rate and 0.6–0.8 s in high bit rate. The instrument sensitivity is about $2 \cdot 10^{-7}$ V/Hz$^{-1/2}$.

3 Observations

The NTC displayed on Figure 1 were observed by Cluster 1, 2 and 4, (C1, C2, C4) on May 30, 2003 while the spacecraft were approaching the sources at the plasmapause. This is evidenced here by the large increase of the plasma frequency from 10 to 80 kHz between 04:00 and 05:45 UT for C1. The distance from Earth was about 5 R_E, the local time was $\sim$ 19 LT and the GSE latitude $\sim$ - 30° (south). The separation distance of C1 from C2 was $\sim$ 6000 km and $\sim$ 7000 km from C4. Data from C3 were unavailable

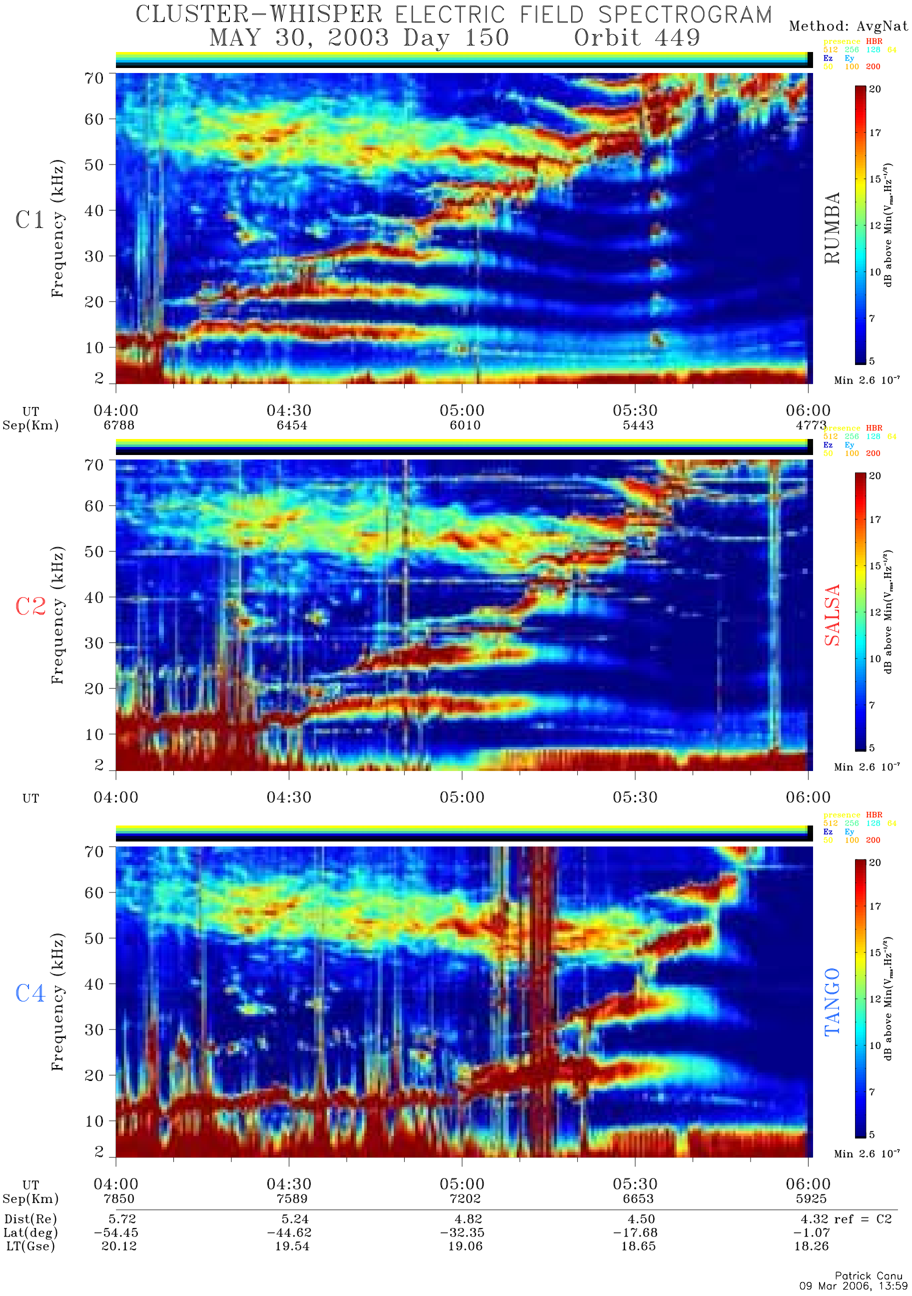

Figure 1: Dynamic spectrogram of continuum radiations simultaneously observed by Cluster close to the plasmapause. Note the differences in the density gradients observed by each spacecraft.

for this timeframe. The frequency and time resolution for Whisper were 320 Hz and 2.1 s, respectively. The vertical spikes seen at about 05:15 on C4 are artifacts due to the saturation of the receiver triggered by intense electrostatic emissions at F_{uh} observed at $\sim$ 20 kHz. This time period was magnetically active with Kp values of 7 and 8 in the 12 hours preceding these observations. The location of the spacecraft when F_p reached 40 kHz was 4.9, 4.65, 4.37R_E at 18.7, 18.6 and 18.8 magnetic local time (MLT), respectively, for C1, C2, C4, consistent with a plasmapause receding towards Earth. An other possibility would be that the spacecraft were very close to a “bite out”, like those identified by the Image spacecraft [Green et al., 2002] or plume which could be expected in the bulge region. But this notch would have to be very sharp in order to account for the large variations in the density gradients over small scale space. Hence, a contracting plasmasphere is the preferred interpretation of the observations. Intense NTC bands are detected simultaneously by the 3 spacecraft, with decreasing frequency as they neared the plasmapause. This band is limited to a frequency range where the ratio between the plasma and electron gyrofrequency at the plasmapause is about $F_p/F_{ce} \sim$ 6–7 for C1, 4–5 for C2 and 3–4 for C4. A more detailed view for C1 and C4 is provided on Figure 2. The

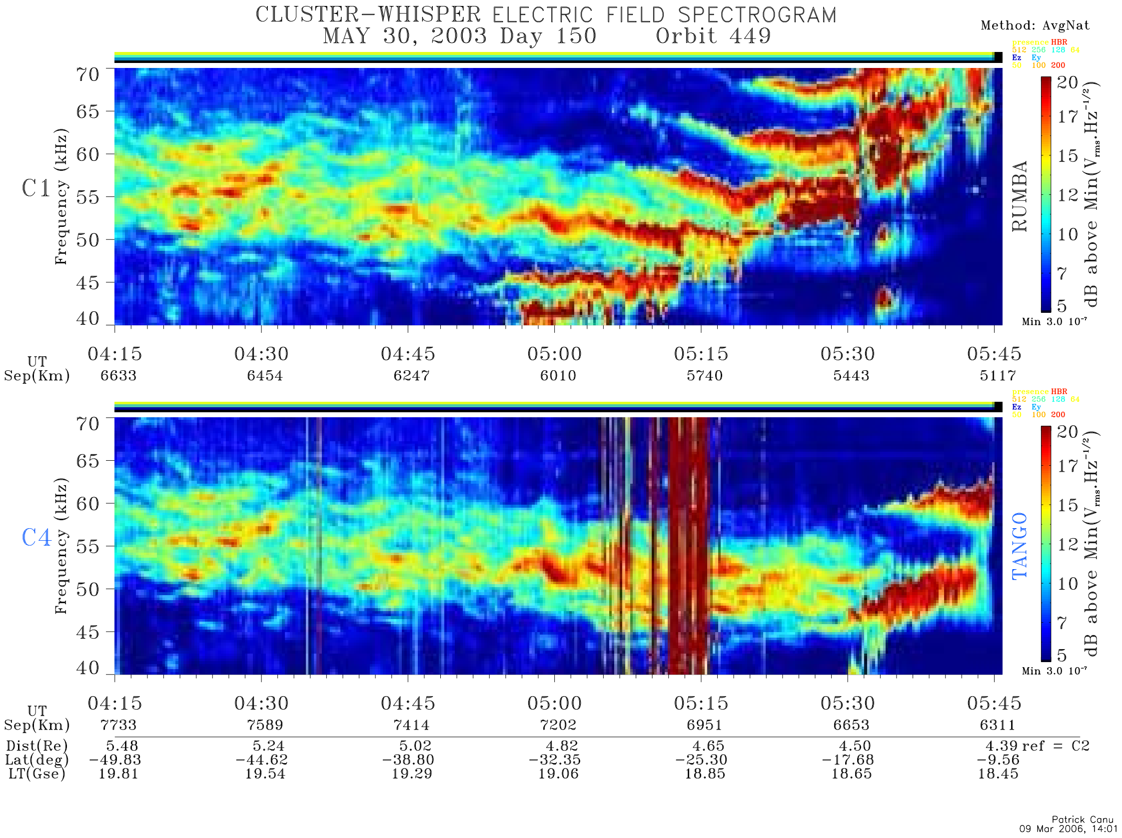

Figure 2: Enlargement of the period displayed on Figure 1

electrostatic emission at F_{uh} on C1 rises from 40 kHz at 05:00 UT to 70 kHz at 05:45 UT. The strong, almost constant frequency bands, with frequency separation close to the harmonic local F_{ce} are the so-called Fq frequencies which correspond to the zero group velocity of the Bernstein modes [Christiansen et al., 1978; Décréau et al., 2001; Canu et al., 2001]. NTC emerging from a Fq band at 50 kHz at ∼05:00 UT on C1 support the generation of narrow band NTC by conversion from Fq, suggested by Canu et al. [2001] and is a strong indication that this spacecraft is crossing, at least, part of the sources. Generation of NTC by Bernstein-Fq modes will be discussed in a forthcoming paper. The NTC are seen as multiple, oscillating frequencies, with frequency oscillations similar to the ones observed in the F_{uh} and Fq frequencies. A more detailed examination shows that the bandwidth of individual tones is as low as the instrument frequency resolution (320 Hz), so they are not resolved. Similar observations show examples where they are neither resolved at Whisper's best resolution of 160 Hz (see below). Their actual bandwidth is probably lower, in agreement with previous work [Etcheto et al., 1982; Canu et al., 2001; Menietti et al., 2005]. The frequency separation between each narrowband is well below the local F_{ce} ($\sim$ 12 kHz). This further suggests that the radiations, observed here very close to or at the sources, are emitted from small scale, closely spaced regions. We can also notice that, despite the fast reconfiguration of the plasmasphere, the large motions of the plasmapause, and the fast local density fluctuations, the active region does not evolve significantly, emitting in an overall 20 kHz bandwidth for more than 3 hours (not all shown). One can finally remark that there are no significant differences in the NTC observed by the spacecraft, hence no beaming effect. At 04:00 UT, SC1 & 4 were separated by one hour in local time and almost 20° in latitude.

A second example of narrowband emissions close to the sources is provided on Figure 3

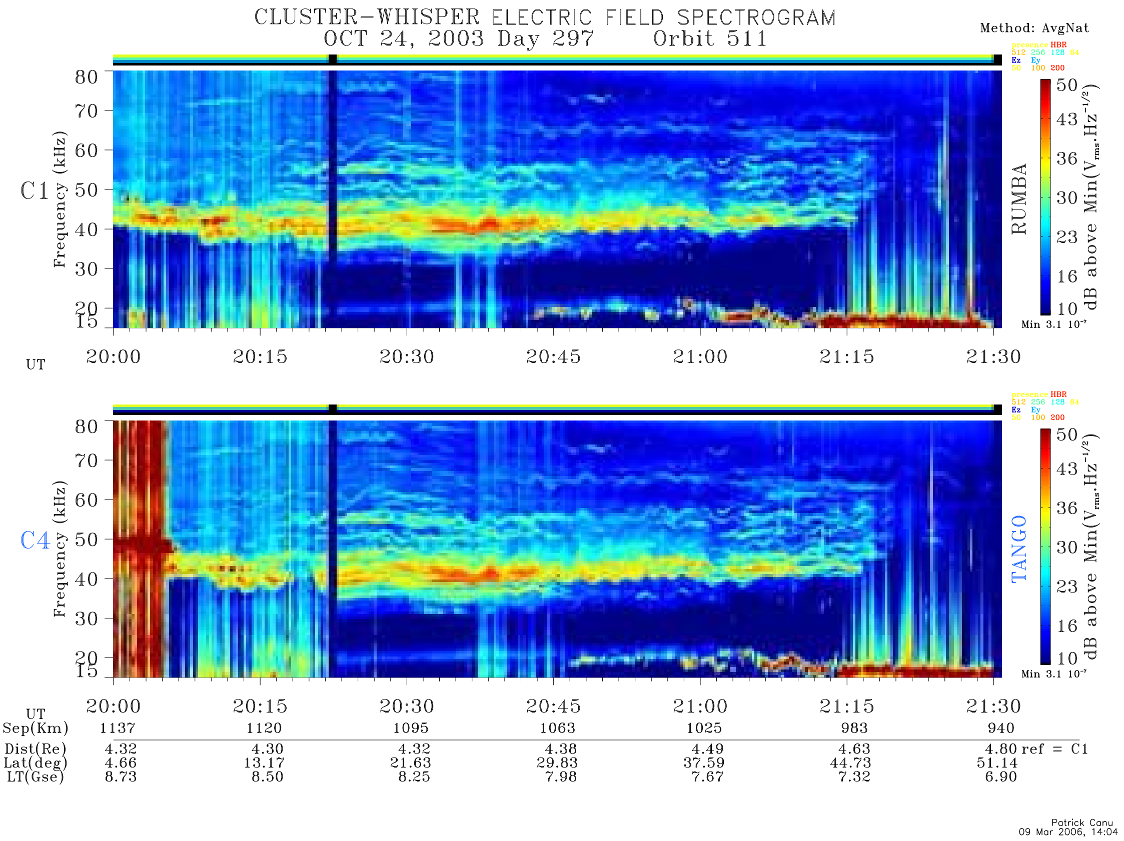

Figure 3: Spectrogram of oscillating bands of continuum radiations.

for C1 and C4. For more than one hour, narrow band NTC are observed as the Cluster were receding from the plasmapause. The F_{uh} is smoothly decreasing in frequency from $\sim$ 40 kHz at 20:00 UT down to $\sim$ 30 kHz at 21:00, as identified from the relaxation sounder data (not shown). The vertical bars at $\sim$20:00 on C4 are due to saturation of the receiver by intense F_{uh} at the perigee. Densely packed narrow band emissions are seen from the local F_{uh} frequency up to the top Whisper's frequency range at 80 kHz, with quasi-periodic fluctuating frequencies with a period of about 2 minutes. Spacecraft separation is typically about 700–1000 km. Here again, the observed bandwidth of individual tones matches the instrument resolution of 320 Hz. The frequency separation, also at the limit of instrument resolution, has no relationship with the local gyrofrequency close to the plasmapause ($\sim$ 14 kHz). Despite the fact that these emissions are produce in a rather wide region if we assumed that they are generated where their frequency is close to the local F_{uh} (density ranging from 10 to 80 e/cc), one can notice that the oscillations are often closely in phase over the full frequency range. This holds well for the lowest part of the spectra, up to 50 kHz, a small drift can be observed for the highest frequency tones. This suggests a global oscillation of a relatively large source region. The picture of small scale source regions for the individual tones observed for more than one hour with almost constant amplitude and small frequency fluctuations around a constant central frequency implies that the source mechanism is not very sensitive to variations of the local parameters, mainly density and warm electrons fluxes. The final example, displayed, Figure 4, is also obtained close to the plasmapause, which is observed at slightly different times by the four Cluster, as evidenced by the decreasing F_{uh} seen between 03:45 and 04:15. Spacecraft separation was in the range 2000-4500 km. The observed tone bandwidth also matches the instrument frequency resolution which is 160 Hz here. The noticeable feature is that some of the individual tones observed at the same time can have increasing and decreasing frequencies, the increasing tones with a gradient of about 10 kHz/hour, the decreasing ones of $\sim$ 5 kHz/hour. This does not fit the picture of frequency variations due to global expansion or contraction of the plasmasphere, first proposed by Gough et al. [1982]. The density irregularities at the plasmapause, as reported from Cluster observations [Darrouzet et al., 2004] is suggested to play a key role in the generation of NTC [Décréau et al., 2004, Menietti et al., 2005]. This is well supported by the data of May 30, 2003 (Fig 1), where NTC frequency oscillations are observed while density fluctuations are simultaneously present at the plasmapause. But this is not confirmed by the smooth variations seen in the bands reported on this last example.

4 Discussion and Conclusion

While observations of NTC performed at high time and frequency resolution do not question the general view of an emissions generated near the plasmapause from electrostatic emissions close to F_{uh}, these detailed observations provide new information and open new questions. The Whisper observations of NTC close to the sources, briefly reported here, further suggest that these emissions are generated as multiple, almost contiguous, narrow band, components. The frequency separation between individual bands is well below the local F_{ce}, hence they have to be explained by closely spaced, small size source regions. A crude estimation from a radial density gradient of $\sim$ 65 e/cc / R_E (Figure 1) and a

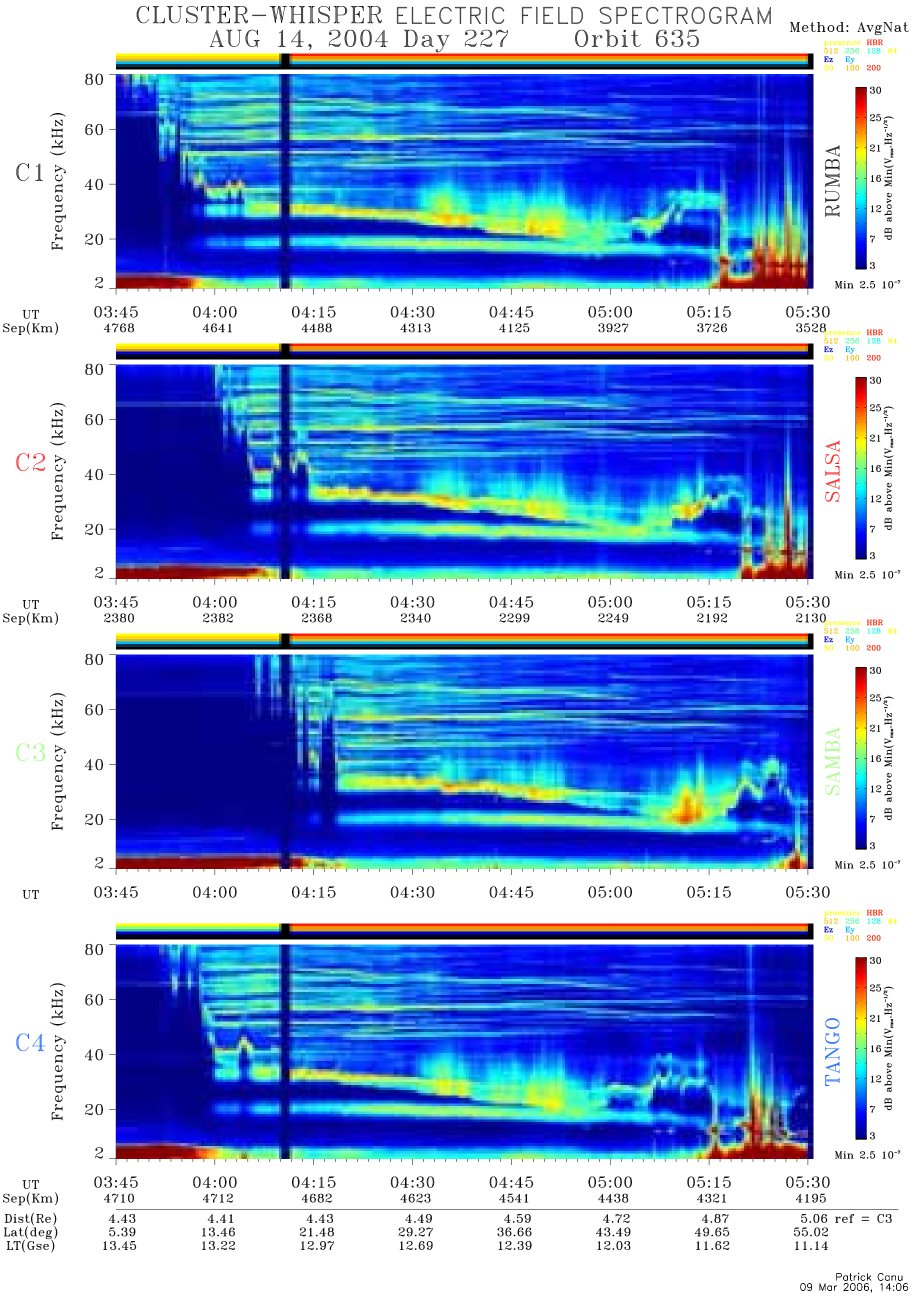

Figure 4: Multiple narrows band of NTC with both increasing and decreasing tones. The plasmapause is at left.

100-200 Hz bandwidth, indicates a radial extension of about a few 10 km. The overall band of observation can vary widely, from a single narrow band (not shown here) to a spatially confined region, like in Figure 1 where the observed band is about the local gyrofrequency at the source (15–20 kHz), and to very broad frequency range (Figures 3 and 4), from the local plasma frequency to beyond Whisper's upper range of 80 kHz. From these observations, one can question the conclusion reached by Horne [1990] of a critical gradient required for generating the bands. The hour long observations in Figure 1 and 2 occurred in regions where the gradients have large variations, as evidenced from the different plasmapause observations provided by the 3 Cluster spacecraft, furthermore, in regions of high density fluctuations, as derived from fast frequency fluctuations in the observed electrostatic emissions. The natural idea of a resonant cavity [Menietti et al., 2003] to account for the very narrow band of the NTC is also difficult to justify if one consider the Whisper observations reported here. In such a cavity, the local parameters, size, density, …have to be kept almost constant for the emission's duration, conditions which are hardly met on May 30 and Oct 24. On this last example, the frequency of each band oscillates periodically by about 2–3 kHz, which corresponds to $\pm 1 - 2$ e/cc. Despite of these oscillations, the amplitude of the electric field for these bands is almost constant for more than one hour. The continuity of observations is strong evidence that the same localized sources of emissions are active. It is more appropriate to invoke global oscillations of the plasmasphere, and difficult to imagine having multiple resonant cavities active over this timescale in such global variations. Whatever can be the origin of the variations (surface waves, radial oscillations, even propagation effects) they do not significantly affect the emission mechanisms operating at the small size scale. What parameters induced emissions of NTC over a small or a large frequency range. What is the origin of the multiple small scale sources at the plasmapause. What makes a source active for hours while the surrounding plasma with similar parameters does not produce any emissions. These questions, relevant to the generation mechanism, will have to be addressed in future work.

Acknowledgments

We warmly thank the teams at ESOC, JSOC and Sheffield (UK) for their constant and efficient support of Cluster operations. This work is supported by CNES under contract 503U20.

References

Canu, P.,Décréau, P.M.E., Trotignon, J.-G., Rauch, J.-L., Séran, H.C., Fergeau, P., Lévêque, M., Martin, Ph., Sené, F.X., Le Guirriec, E., Alleyne, H., and Yearby, K., Identification of natural plasma emissions observed close to the plasmapause by the Cluster-Whisper relaxation sounder, *Ann. Geophys.*, **19**, 1697-1709, 2001.

Christiansen, P. J., Gough, M. P., Martelli, G., Bloch, J. J., Cornilleau, N., Etcheto, J., Gendrin, R., Jones, D., Beghin, C., and Décréau, P. M. E.: Geos-1 identification of natural magnetospheric emissions, *Nature*, **272**, 682, 1978.

F. Darrouzet, P. M. E. Décréau, J. De Keyser, A. Masson, D. L. Gallagher, O. Santolik, B. R. Sandel, J. G. Trotignon, J. L. Rauch, E. Le Guirriec, P. Canu, F. Sedgemore, M. André, J. F. Lemaire, Density structures inside the plasmasphere: Cluster observations , *Ann. Geophys.*, **22**, 2577-2585, 2004.

Décréau, P. M. E. et al., Early results from the Whisper instrument on CLUSTER: an overview, *Ann. Geophys.*, **19**, 1241-1258, 2001.

P. M. E. Décréau, X. Vallières, P. Canu, F. Darrouzet, M. P. Gough, A. M. Buckley, and T. D. Carozzi, Observation of continuum radiations from the Cluster fleet: first results from direction finding, *Ann. Geophys.*, **22**, 2607-2624, 2004.

Etcheto, J., P. J. Christiansen, M. P. Gough, and J. G. Trotignon, Terrestrial continuum radiation observations with GEOS-1 and ISEE-1, *Geophys. Res. Lett.*, **9**, 1239-1242, 1982.

Gough, M. P., Non-thermal continuum emissions associated with electron injections - Remote plasmapause sounding, *Planet. Space Sci.*, **30**, 657-668, 1982.

Green J. L., S. Boardsen, S. F. Fung, H. Matsumoto, K. Hashimoto, R. R. Anderson, B. R. Sandel, and B. W. Reinisch, Association of kilometric continuum radiation with plasmaspheric structures, *J. Geophys. Res.*, **109**, A03203, doi: 10.1029/2003JA010093, 2004.

Gurnett, D. A., The earth as a radio source - The nonthermal continuum, *J. Geophys. Res.*, **80**, 2751-2763, 1975.

Horne, R.B., Narrow-band structure and amplitude of terrestrial myriametric radiation. *J. Geophys. Res.*, **95**, 3925–3932, 1990.

Kurth, W. S., Detailed observations of the source of terrestrial narrowband electromagnetic radiation, *Geophys. Res. Lett.*, **9**, 1341-1344, 1982.

Kurth, W. S., Continuum radiation in planetary magnetospheres, in *Planetary Radio Emissions III*, H. O. Rucker, S. J. Bauer, and M. L. Kaiser (eds.), Austrian Academy of Sciences Press, Vienna, 329–350, 1992.

Kurth, W. S., D. A. Gurnett, and R. R. Anderson, Escaping nonthermal continuum radiation, *J. Geophys. Res.*, **86**, 5519-5531, 1981.

Menietti, J.D., Anderson, R.R., Pickett, J.S., Gurnett, D.A., and Matsumoto, H.. Near-source and remote observations of kilometric continuum radiation from multi-spacecraft observations, *J. Geophys. Res.*, **108 (A11)**, 1393, 2003.

Menietti J.D, O. Santolik, J.S. Pickett and D.A. Gurnett, High resolution observations of continuum radiation, *Planet. Space Sci.*, **53**, 283-290, 2005.