New insights into the Non Thermal Continuum radiations: The Cluster Whisper perspective

P. Canu
Laboratoire de Physique des Plasmas
CNRS, Ecole Polytechnique,UPMC, Palaiseau, France;
Laboratoire de Physique et Chimie de l'Environnement et de l'Espace

P. Décréau
CNRS, Université d'Orléans, Orléans, France

S. Rochel-Grimald
Office National d'Études et de Recherches Aérospatiales (ONERA), The French Aerospace Laboratory
Toulouse, France

and the WHISPER team

***Abstract*— The Whisper instruments on board each of the four Cluster spacecraft exploring the Earth magnetosphere, routinely observe the Non Thermal Continuum emissions (NTC). The various and combined points of view provided by 4 spacecraft in the 2-80 kHz frequency range allow the detection of the different forms of these emissions, narrow band and broad band, emitting from source regions in the plasmapause boundary layer, close to the magnetic equator but also at mid latitude. This paper presents selected examples of new knowledge gained on the NTC radiations, locations and mechanisms, coming from the 15 years of observations of Cluster-Whisper.**

Keywords—Radio Emissions, Plasma waves,Magnetopshere

I. Introduction

Planetary magnetospheres, as the sun, are powerful radio emitters. The radio emissions they radiate can provide useful information on their potential control from external sources, like solar events for example, as well as on some characteristics of the regions from which they originate, their dynamic, or through which they propagate. Understanding the mechanism(s) from which they are generated can turn them into a remote sensing tool providing the plasma parameters of these regions and of more distant objects in the solar system and beyond. Besides the well known powerful Auroral Kilometric Radiation coming from energetic electrons spiraling along magnetic auroral field lines, the Non Thermal Continuum (NTC) radiation, less powerful and generate from electrostatic emissions close to electron plasma frequency, is observed from more than four decades in the Earth's magnetosphere [Gurnett, 1975] and later in the magnetospheres of the giant planets, Jupiter, Saturn, Uranus and Neptune. The term continuum, coined from its frequency spectral shape in these initial observations, is no more representative now because of the various signatures reveals by the high frequency and time resolution by nowadays instruments, on which they are often observed as narrow banded electromagnetic emissions.

These emissions are routinely observed by the Whisper instruments on board each of the four Cluster spacecraft since their launch in 2000. New information was collected benefitting both from the good Whisper frequency and time resolution, and from the vantage four points of measurements as well as different distances separating the spacecraft during the mission. [Décréau et al., 2004, Grimald et al., 2008, Décréau et al., 2013, Décréau et al., 2015].

Significant new observations were obtained on the NTC from the more than 15 years of Whisper operations, obtained with different configuration of the spacecraft fleet. The purpose of this paper is to present some examples of these discoveries and what they bring to the knowledge of these emissions and their origins. Two such studies are briefly presented below.

II. Instrument and data description

The Cluster mission relies on four identical spacecraft and payload, launch in pairs in 2000 on an initial polar orbit of about ~ 4x19 Re, and a period of about 57h, which slightly evolved during the extended mission. The spacecraft separation was varied from about ~ 100 km to ~ 10 000 km in the first years, with a tetrahedron configuration kept on selected targeted regions. The spacecraft spin axis is perpendicular to the ecliptic plane. To support the NTC studies in providing out of plane electric measurements, the spin axis of the C3 spacecraft was tilted to 45° for 3 weeks in May 2008.

Whisper is a dual instrument providing both the electron plasma density, through the triggering, by an emitter, of the resonance at the electron plasma frequency Fpe or/and at the upper hybrid frequency Fuh, and a survey of the wave spectrum in the frequency range 2-80 kHz, from one of the 88 m tip to tip electric spheres antenna (Ey or Ez) spinning with the spacecraft, with a period of rotation of ~4s. Spectra are obtained from on board FFT on the electric waveform with 256 or 512 bins providing a 320 or 160 Hz resolution. Spectra collected every 13 ms are averaged to fit in the allowed telemetry, providing a typical time resolution of ~2.1s in normal modes and 0.3-0.8 s in burst modes.

III. WHISPER NTC OBSERVATIONS

Events 1: Mid latitude small sources generated at Fuh ~ nFce

The baseline generation mechanism of NTC is generally thought to occur close to the equatorial Plasmapause, better defined now as the Plasmasphere Boundary Layer (PBL), in regions of strong density gradient, from the conversion of electrostatic Bernstein waves into electromagnetic radiations when the upper hybrid frequency, Fuh, is close to the odd half harmonic of the electron gyrofrequency, Fuh ~ (n+1/2)Fce [Kurth et al., 1982]. Events observed by Whisper clearly show that NTC emissions were not restricted to this interpretation. Studies coming from observations at mid magnetic latitude [Grimald et al., 2008] reveal a class of emissions generated close to the exact harmonics nFce. On December 30, 2003, series of wide banded NTC were observed on the 4 spacecraft when approaching the PBL in the southern hemisphere.

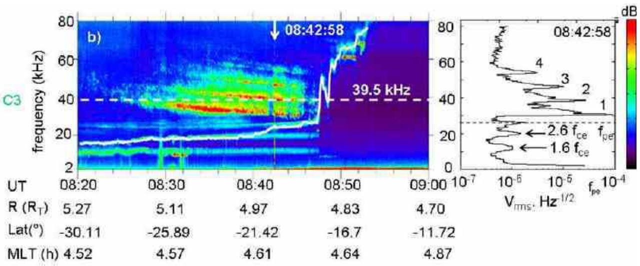

Figure 1a. Dynamic spectrogram of Cluster-3 approaching the plasmasphere. The white line indicates Fuh. Wide banded NTC are observed in the 30-60 kHz range. From ref [4]

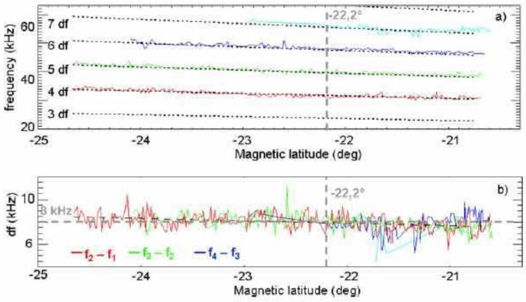

Figure 1b. Peak frequency of NTC bands (top) and frequency difference between two contiguous NTC peaks (bottom). Dashed blach lines denotes Fce From ref [4].

Figure 1a shows C3 dynamic spectra of these emissions. The white dashed line identifies the Fuh, with a strong increase in frequency, from 20 kHz to 80 kHz, after 08:45 when the spacecraft enters the plasmasphere. Four harmonic bands are observed above the local Fuh, in the band 30-60 kHz, with decreasing peak frequency as distance to the plasmapause decreases. Figure 1b overplots the frequency separation between two consecutive peaks Fs, as a function of the local magnetic latitude. All these lines correspond to a single value, *df*, with Fs = n*df*. The variation of *df*, the black dotted line on figure 1b, shows its increasing value with increasing latitude (and decreasing distance), which equals the local Fce, shown as a dash line, at a magnetic latitude ~21°, shortly before C3 encounters the steep gradient of the PBL. [Grimald et al., 2008] have shown that the NTC was coming from a small source region in the gradient, and that the downward frequency shift of the peak frequencies, Fs, was not coming from a motion of the source, but because several sources were radiating while the spacecraft was approaching the PBL. In that event, the NTC was produced when Fuh ~ nFce, which differs from the widely accepted relation first discussed by [Kurth et al., 1982], illustrating the diversity of NTC characteristics and potential generation mechanisms.

Event 2: Small size sources of wide band NTC inferred from large spacecraft separations

The NTC emissions displayed in Figure 2 were observed on August 26, 2008, when the Cluster spacecraft were separated by large distances, from 8000 km between C1 and C3 up to 25000 km between C2 and C4. They were studied in details by Décréau et al. (2015), showing that they were coming from multiple small size sources, radiating in a narrow angle beam.

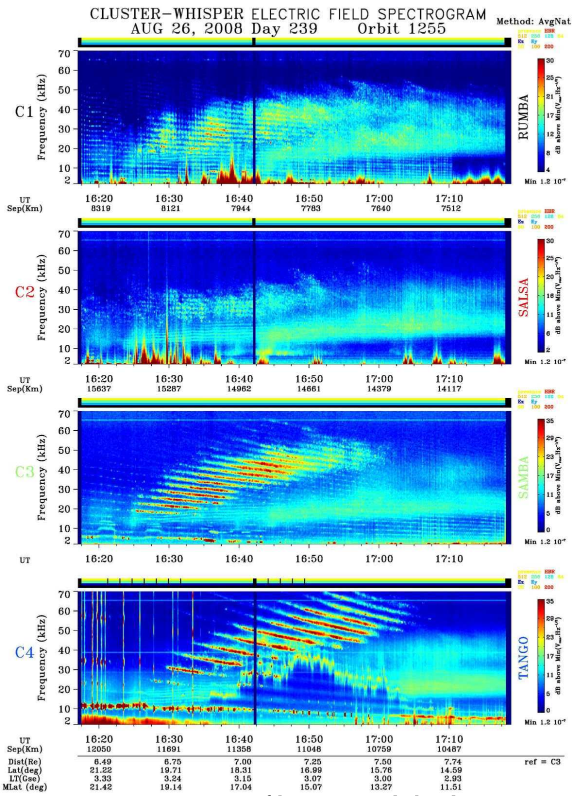

Figure 2. Dynamic spectrogram of harmonic wide bands NTC emissions observed by the four spacecraft on Aug 26, 2008.

These emissions appear on C3 and C4 as a large number of harmonics (12 to ~15) with decreasing peak frequency when the spacecraft were moving on the night-side inner magnetosphere, away from the PBL at medium magnetic latitude ~25°. Only C4 briefly brushed the plasmasphere between 16:40 UT and 17:00 UT as illustrated by the increasing frequency of Fuh, with peak value ~ 37 kHz (~17 e/cc) at ~ 16:48 UT at distance ~7 Re and 3.5 local time, which indicates an inflated plasmasphere. The Fuh profile shows a large number of fast variations in frequency, hence in density, in this region.

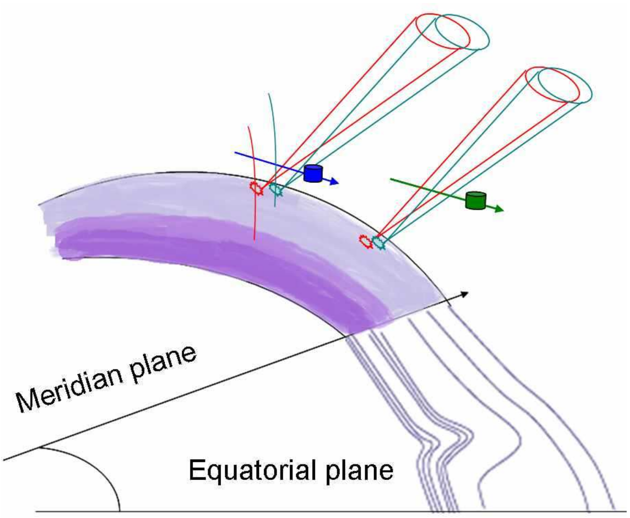

Figure 3. Interpretation of the banded NTC emissions observed on August 18, 2008. Beams (two in this sketch) of same cone angle corresponding each to a specific peak *df* are crossed near sources for C4 (blue) and at larger distance at the same time for C4 (green). From ref [3]

The detailed analysis of C4 and C3 spectra lead Décréau et al (2015) to conclude that a large portion of the plasmasphere facing the spacecraft was radiating NFC emissions over this time interval, illuminating the different satellites placed at large distances from each other. The evolutions of wave intensities in the band is consistent with the superposition of multiple narrow angle cone beams reaching the spacecraft simultaneously, as illustrated in the sketch Figure 3. The beam cone angles of two waves generated in neighboring sources are crossed at short distances by one spacecraft (C4) and at larger one by the other spacecraft (C3).

IV. PERSPECTIVES

The analysis of NTC observed by the combined four Whisper instruments during the fifteen years of Cluster operations has expanded the varieties of forms, locations and potential sources mechanisms of this radiation emanating from the conversion of electrostatic emissions close to Fuh in the PBL. The continuation of these data analysis will hopefully indicate if the various characteristics derived from NFC studies correspond to the variations induced by a common mechanism or if there is indeed different radiations emanating from slightly different plasma process. The evolution of the orbit during the extended phases of the Cluster mission will allow further exploration in longitude, latitude and distance relative to the PBL, which is probably not the sole model of source region in planetary magnetospheres. Thanks to the Cluster Science Archive (http://www.cosmos.esa.int/web/csa), all this rich setof events in the Whisper data collected so far, and the data yet to come, are publicly available, allowing the interested community to go ahead in this exploration.

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