User Guide to the WHISPER Science Datasets in the Cluster Science Archive (CSA)

prepared by

the WHISPER team

Document Status Sheet

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Version 1.6	2017-05-15	Updated following CAA/CSA team comments
Version 1.7	2022-03-01	Updated following recommendations from CAA operational review #11 and CSA/WHISPER progress meetings

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List of Acronyms

BM	Burst Mode
CAA	Cluster Active Archive
CR	Calibration Report
CSA	Cluster Science Archive
DSP	Digital Signal Processor
DWP	Digital Wave Processing
EDI	Electron Drift Instrument
EFW	Electric Field and Wave
FFT	Fast Fourier Transform
FGM	Flux Gate Magnetometer
GUI	Graphic User Interface
HK	House Keeping
ICD	Interface Control Document
NM	Normal Mode
PSD	Power Spectral Density
SW	Solar Wind
WEC	Wave Experiment Consortium
WHISPER	Waves of HIgh frequency and Sounder for Probing of Electron density by Relaxation

1 Introduction

The WHISPER (Waves of HIgh frequency and Sounder for Probing of Electron density by Relaxation) instrument provides two major science datasets:

- electric field spectra in the 2–80 kHz frequency range
- the electron density

The latter can be deduced from the characteristics of natural waves monitored whenever WHISPER is in natural mode (i.e. when the transmitter is off) and/or from resonances triggered in sounding mode.

This document is provided as a user guide for the CSA WHISPER datasets and explains key science WHISPER datasets. Section 6 provides some important recommendations on the usage of the WHISPER data products. A complete description of the WHISPER CSA data products is given in the Interface Control Document (ICD, CAA-EST-ICD-WHI). More detailed information about the WHISPER data processing, in particular about density extraction techniques, is given in the WHISPER calibration report (CR, CAA-EST-CR-WHI).

2 Instrument Description

The WHISPER experiment (Décréau et al., 1993; 1997; 2001) is a part of the Wave Experiment Consortium, WEC, which includes five instruments (Pedersen et al., 1997; WEC Instrument User Manual, 2000). WHISPER consists basically of a receiver, a transmitter, and a wave spectrum analyser, associated with parts of two other WEC instruments: the sensors of the EFW (Electric Field and Wave) experiment and data processing functions of the DWP (Digital Wave Processing) experiment.

The WHISPER instrument provides two functions:

- the continuous survey of the natural plasma emissions in the 2-80 kHz frequency band
- the measurement of the electron density of the plasma, (a) from the measurements of the relaxation sounder, an active radio frequency technique which aims at identifying the electron plasma frequency in the 4-82 kHz range, or (b) from natural plasma emissions

Figure 1 illustrates the WHISPER instrument measurement principle in sounding mode: a signal of a narrow frequency is emitted from one antenna at time t, exciting the surrounded plasma and potentially triggering plasma characteristic frequencies. The signal is then received on the other antenna at t+Δt and processed on-board as shown in the right panel: the waveform is Fourier transformed to construct a part of the power spectrum: only 6 frequency bins centered on the transmitted frequency and covering a 1 kHz bandwidth are selected. The process is then iterated at a different transmitted

frequency (far enough to the previous one to avoid plasma response overlapping) to construct the complete power spectrum (see section 3 for further details).
In Natural mode, there is no emission and the power spectrum is obtained as the Fourier transform of the received wave form over the full WHISPER frequency range.

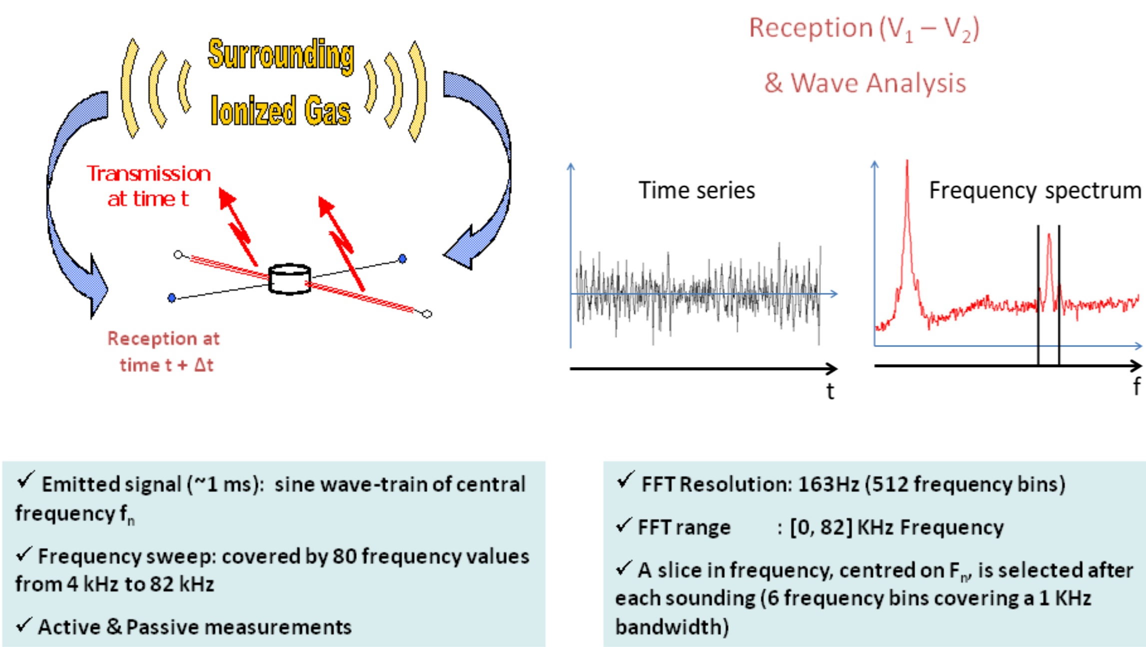

Figure 1: WHISPER instrument schematic operation of sounding mode. Left panel shows the measurement principle. Right panel shows the on-board processing chain of the received signal and selection of a part of the power spectrum.

The WHISPER frequency range includes electrostatic and electromagnetic natural emissions of interest to the Cluster objectives, in particular in the vicinity of the plasma frequency from which the total electron density may be determined.

WHISPER key datasets are electric-field spectra (obtained in sounding mode and/or in natural mode). Data are usually presented in the form of dynamic spectrograms, in which the colour-coded electric-field amplitude is plotted as a function of time (on the X-axis) and frequency (on the Y-axis). The spectrograms bear important information about explored regions. The characteristic signatures of natural or actively triggered waves indicate the nature of the ambient plasma regime and, combined with the spacecraft position, reveals the position of key magnetospheric boundaries encountered during a specific time interval.

Figure 2 shows a 24-hour spectrogram for data acquired in natural mode (top panel) and in sounding mode (bottom panel) where typical natural and active signatures are observed in different magnetospheric regions.

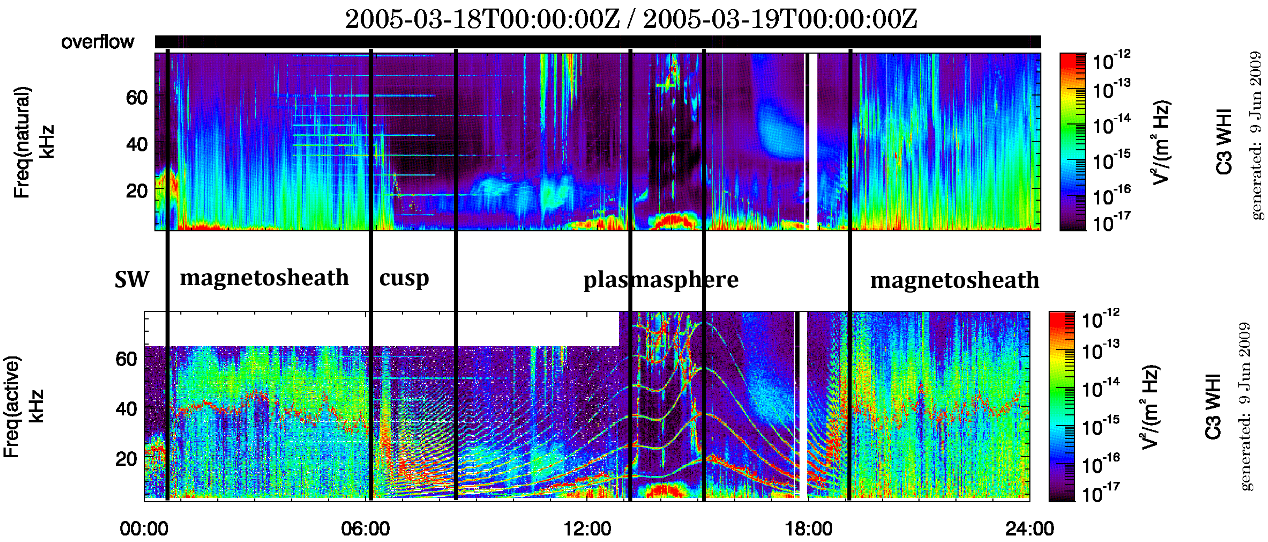

Figure 2: NATURAL and ACTIVE spectrograms for C3 on March 18, 2005 exhibiting several typical magnetospheric signatures of solar wind (SW), magnetosheath, cusp, and plasmasphere.

3 Instrument Operations

Two modes of operation are used alternatively:

- natural mode when the transmitter stays on stand-by
- sounding mode during which the transmitter triggers plasma resonances prior to reception

In both cases, a pair of EFW sensors is used as a double-sphere electric dipole antenna, whose potential difference is band-pass filtered, digitised, multiplied by a window function, and finally analysed in frequency by an on-board FFT processor which computes a full frequency spectrum every 13.33 ms. It covers part or all of the full frequency range in 512 or 256 bins, with a frequency resolution of 162.8 Hz in the 512-bin FFT option or 325.5 Hz in the 256-bin FFT option, depending on the given telemetry allocation and on the chosen temporal resolution of the electric field spectra (ground processing always gives 512 spectrum values, duplicating values when in 256-bin FFT option - the same value is used as for the previous frequency). The complex signal allows to derive the amplitude (modulus) of the potential difference at each bin. Phase information is not transmitted to ground.
Furthermore, all frequency bins for amplitude are not transmitted to ground, bin selection depending on the operation mode. For example, in the standard sounding operation mode, 480 bins from 512 are transmitted covering the 2-80 kHz or 4-82 kHz frequency range for natural or active spectra, respectively.

3.1 Natural mode

In natural mode, one spectrum is acquired every 13.3 ms. Either 16 or 64 of on-board spectra are accumulated to smooth sporadic features and improve the signal to noise ratio. This results in accumulated spectra covering either 0.213 s or 0.851 s, respectively. Either 1 out of 8 '*0.213 s*' spectra or 1 out of 4 '*0.851 s*' spectra is selected and transmitted to ground. This results in time resolutions of 1.7 s or 3.4 s, respectively (depending on instrument operations). Information on on-board operations is given in supporting parameters of the natural mode data. One can also find the used configuration in the **C[i]_CT_WHI_NATURAL_EVENT** dataset (where [i]=1-4).

When in burst mode (BM) telemetry operations, the on-board compression (accumulation and selection) of spectra is less dramatic, resulting in a time resolution of either 0.326 s or 0.658 s, depending on the chosen frequency resolution.

These spectra are called **NATURAL** spectra. In all telemetry modes, the measured integrated amplitude in the 2–80 kHz band is accumulated over each time acquisition, prior to FFT processing, forming a quantity called **WAVEFORM ENERGY**, available every 13.3 ms. It is accumulated on-board similarly to natural spectra then transmitted to ground (with no selection).

Note that in the datasets available at CSA, accumulated quantities are converted to averaged quantities.

3.2 Sounding mode

In sounding mode, the WHISPER instrument operates like a classical relaxation sounder. It uses the two long double sphere antennas of EFW to transmit and receive. Figure 3 illustrates the principle of the frequency sweep and acquisition steps over the frequency band.

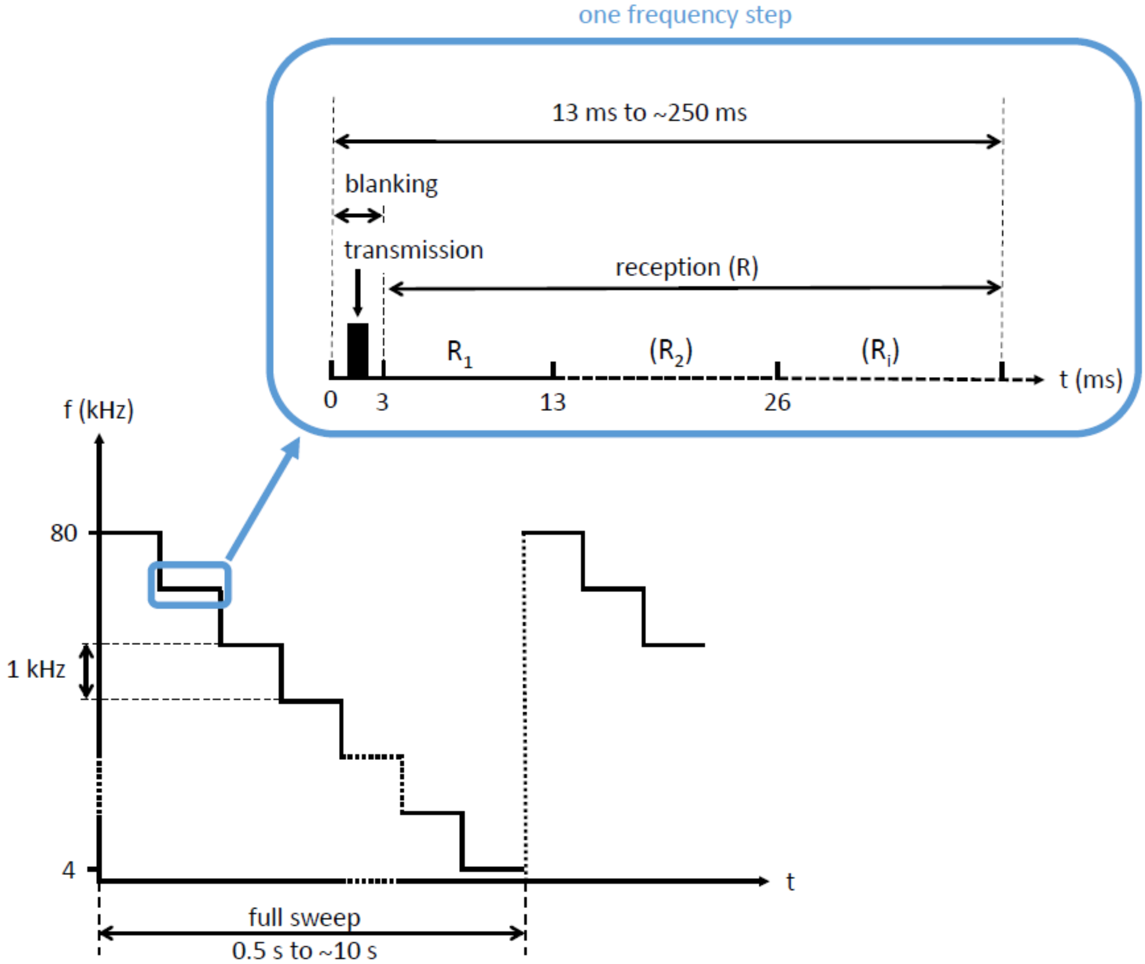

Figure 3: Principle of a frequency sweep over the full WHISPER frequency band. Details for one frequency step, with transmission period (while receiver is blanked) and reception period are provided in the upper part (adapted from Décréau et al, 1997).

The WHISPER transmitter sends, through the conductive outer braids of one of the antennas, a wave train during a very short time interval (1.024 ms or 0.512 ms). Each train pulse covers a frequency band of 976.6 Hz (or twice this value) centered on a frequency chosen from one of the frequency tables available on-board, selected by telecommand. A few milliseconds after, the WHISPER radio receiver connected to two of the EFW spheres is switched on. The received signal is subsequently listened and analysed by FFT over the whole frequency range but only the bins whose frequency is inside the frequency band of the emitted wave train are selected (usually 6 bins, 162.8Hz in bandwidth), thus forming a part of the **ACTIVE** spectrum. The wave train frequency is then shifted according to the selected table and the process is repeated until the whole frequency range (4-82 kHz) is covered and the full **ACTIVE** spectrum is constructed.
Note that the frequency table used during a full sweep is depicted in figure 3 as a regularly decreasing step function with time while it is not the case on-board. Several

frequency tables are preloaded on-board, they have been built in such a way that there is no influence between two successive transmitted frequencies, by ensuring a minimal difference between them.

In addition to the frequency bins retained in each frequency step to construct an **ACTIVE** spectrum, bins recorded 13.3 ms before excitation may also be retained as part of a **PASSIVE** spectrum (see figure 4). As a consequence, whenever an active sweep is complete, both an ACTIVE spectrum and a PASSIVE spectrum may be available. In addition, provided the frequencies of the retained passive bins are the same as the ones of the next transmitted pulse, the time delay, for a given frequency, between PASSIVE and ACTIVE spectra becomes very short (less than 40 ms). The values are then compressed quasi-logarithmically to 8-bit words. The information about PASSIVE spectra during ACTIVE soundings can be sent to the ground (then contained in the **C|i]_WHI_PASSIVE_ACTIVE** dataset) and/or used to compute active-to-passive ratio that can also be sent to the ground (then contained in the **C[i]_WHI_ACTIVE_TO_PASSIVE_RATIO** dataset). These datasets can exist independently for a time period, depending on the chosen on-board data compression strategy, set by telecommand according to the telemetry allocation at the time of operations.

Comparison of passive and active conditions at a given frequency during a single frequency sweep is possible because the succession of the frequency steps in a sweep are ranged in such an order that the relaxation time is sufficient and passive measurements cannot be perturbed by previous soundings. In general, natural spectra are useful to know if an active signature is affected by a high-level natural emission, or if it's a true local signature of the plasma. PASSIVE spectra have been implemented to give this information at the same time than ACTIVE spectra, and with the same on-board construction technique.

The sounding mode is operated alternately with the natural wave mode, with all four spacecraft following closely the same time line. Typically, 3 s (or 4 s) of sounding mode (two ACTIVE spectra) are followed by 49 s (or 100 s) of natural wave mode, leading to a standard 52 s (or 104 s) sounding recurrence time.

In sounding mode, the implications of the different processing options on the science data characteristics is less straightforward than in natural mode, where it touches mostly the time and frequency resolutions. The on-board data compression strategy is chosen accordingly to the telemetry rate to allow or not the transmission to the ground of passive spectra values and/or active to passive ratios, leading to more complete information when in Burst mode.

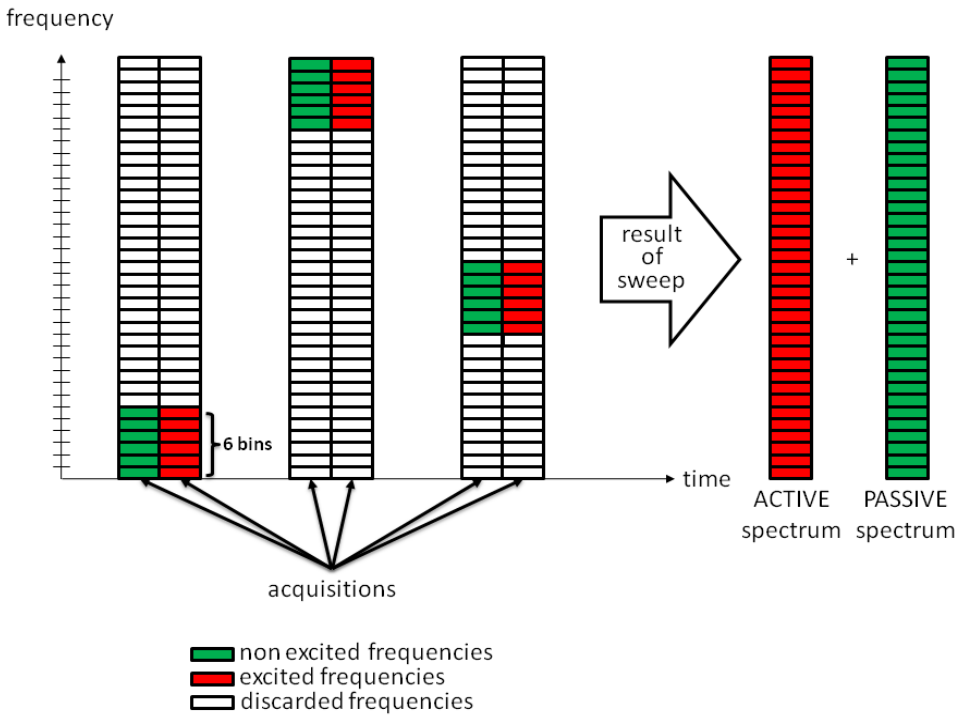

Figure 4: Principle of **ACTIVE** and **PASSIVE** spectra acquisition in WHISPER sounding mode. Bins recorded prior to excitation are kept to construct the PASSIVE spectrum.

Several WEC modes have been designed to coordinate all the WEC instrument operations and to optimize the telemetry resources. The associated WHISPER modes and associated command words are described in the WEC Instrument user manual and the WHISPER ICD (CAA-EST-ICD-WHI).

3.3 Operations caveats

Four information, related to on-board instrument operations, may help the WHISPER dataset user to carry out specific analyses:

- C4 operation mode since September 2003
- interferences influence on WHISPER data quality
- overflows influence on WHISPER data quality
- EFW receiving antenna which can be of interest for direction finding studies

Time periods affected by interferences or overflows are reported in a dedicated caveat dataset as described in section 5.3.

C4 operation mode: After September 2003, due to WHISPER on-board software corrupted, C4 spacecraft always operates at a 104 s sounding recurrence. In the standard (most frequently used) sounding cycle, the four spacecraft sound simultaneously every 104 s, and C1, C2 and C3 also sound 52 s later, but C4 does not transmit, it continues to monitor natural waves. Such a duty cycle is used for all WEC operations, both in nominal (NM) telemetry mode and in burst (BM) mode, when the time resolution of natural wave measurements is, on average, improved by a factor of 5.

Interferences: Occasionally, WHISPER spectra may be corrupted by different perturbations due to EDI, spurious signals from an on-board power converter, or a bug in the FFT transform from WHISPER DSP (related to the processor voltage). These interferences usually appear in the spectrograms as continuous lines at given frequencies (in particular at 35kHz, 40kHz and 65kHz for the interferences related to the FFT bug). Figure 5 gives an example of WHISPER spectrograms where the EDI interferences are visible on C1 and C3 and the interferences related to the FFT bug are visible on C2 and C4. Time intervals where interferences can possibly affect measurements quality are listed in a dedicated caveat dataset (see section 5.3) that is delivered to the user automatically together with the spectral data.

Note:

EDI Code Repetition Frequency files (**CP_EDI_CRF** CSA product) indicate time intervals and frequencies that are potentially affected, and the probable extent of the perturbation. These interferences are automatically removed in the density extraction process, as far as possible.

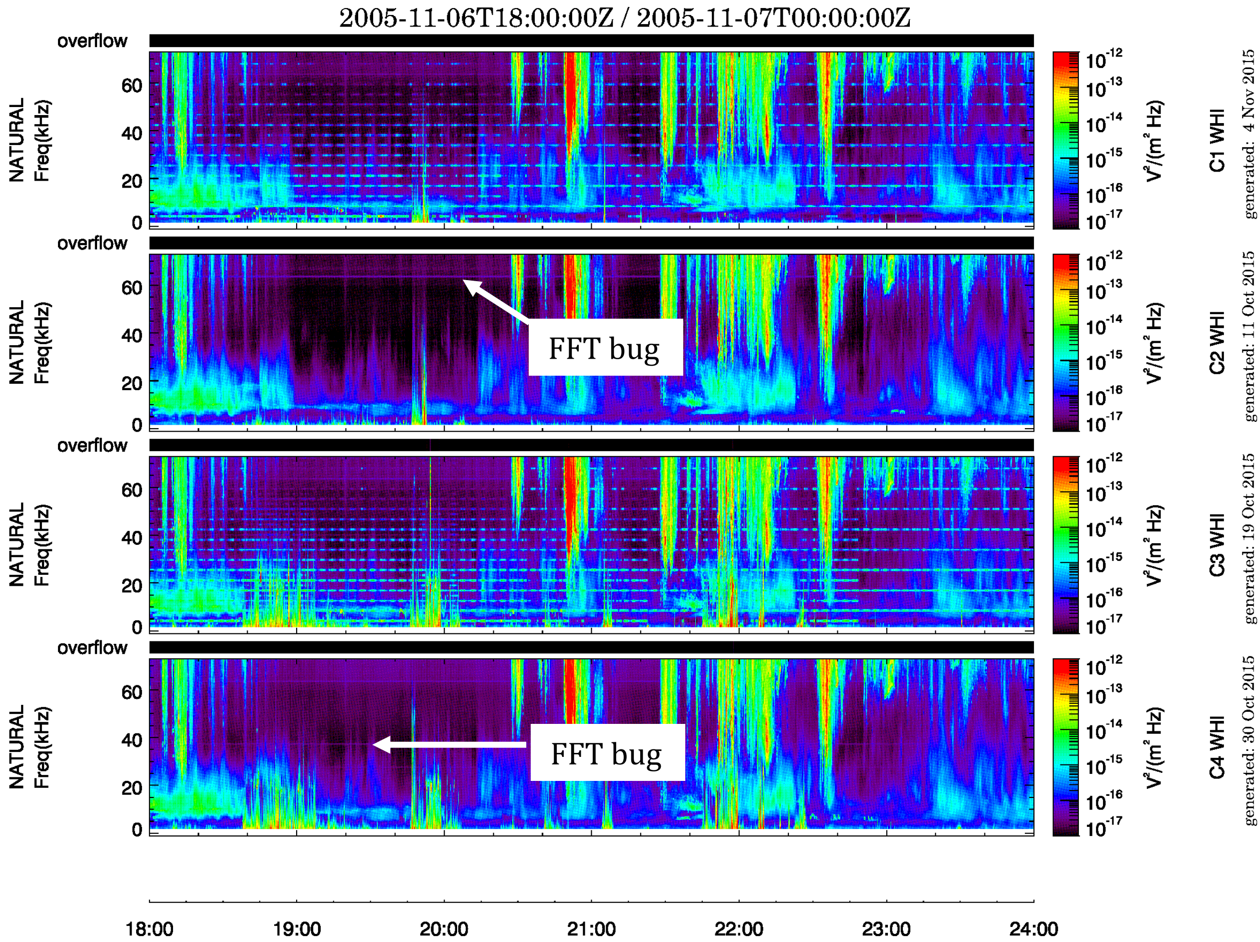

Figure 5: Example of NATURAL spectrograms for the 4 Cluster spacecrafts on September 06, 2005. EDI interferences appear as horizontal harmonic lines on C1 and C3 spectrograms, with fundamental frequency depending on the EDI operation mode. Effect of the FFT bug can be observed on C2 and C4 and appears as horizontal lines at 35 kHz and 65 kHz.

Overflows: Overflows concern natural measurements and correspond to signal samples exceeding the dynamical range of the analog-to-digital converter and are closely related to the operation mode of the WHISPER instrument. As several gains are available on-board and the instrument automatically switches from high gain to low gain whenever too many overflows are encountered, the overflows influence on WHISPER measurements should be limited. However, the user should always consider checking the coded overflow rate in the CSA WHISPER product, as described in the WHISPER ICD (CAA-EST-ICD-WHI). Overflow value is between 0 and 1 so that 0 means no overflow and 1 means full saturation. Figure 6 shows an example of a relative saturation due to overflows. Overflows are colour-coded in the upper bar, giving an idea of the saturation of the receiver. In this example, plasma signatures cannot be exploited when full saturation occurs, as indicated by the white colour in the overflow bar. Time intervals where overflows can possibly affect measurements quality are listed in a dedicated caveat dataset (see section 5.3).

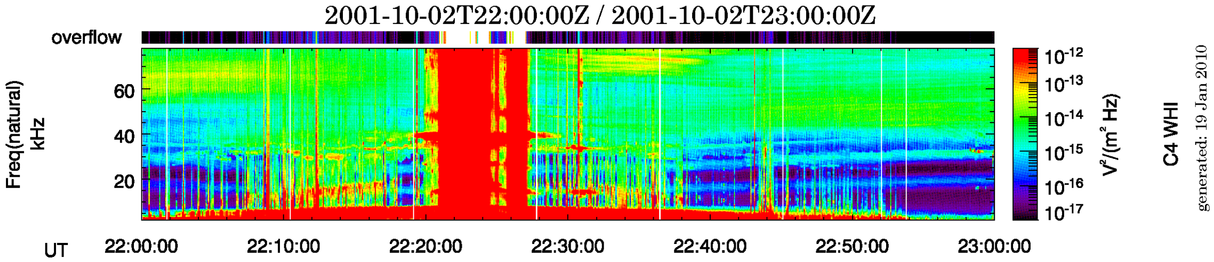

Figure 6: Example of a WHISPER electric spectral power density spectrogram affected by overflows on C4 for October 02, 2001, around 22:25 UT. The upper bar gives the colour-coded overflow rate.

Receiving antenna: Most of the time, WHISPER observes natural waves in the 2-80 kHz band, using one of the two 88-m long EFW antennas: Ey (formed by EFW probes p3 and p4) or Ez (formed by EFW probes p1 and p2), separated from the spacecraft-built frame Z-axis by 45 and 135 degrees, respectively. Note that the two antennas can have different characteristics (Gustafson et al 1997, 2001).

The default receiving antenna was set to Ez, but after successive technical problems on the EFW sensors, it had to be changed by telecommand on several satellites, as illustrated in table 1 (where ½ stands for a reception with only one receiving probe, i.e. when one of the two EFW probes forming the antenna is inoperative). In that case, the reception is performed between the remaining EFW probe and the spacecraft body. Table 1 gives the receiving configuration for the 4 satellites for regular operations and during BM3 (in a dedicated column – see section 3.4.1) with respect to mission time. Note that on C2 and C3, both EFW probes failed on Ez, preventing any significative measurements during BM3.

The measured electric field power spectral density (PSD) values are corrected on ground to take into account measurements on a ½ antenna. Note that ACTIVE and NATURAL quicklooks (see section 5.4) are not corrected from this effect, but that the information on the receiving antenna (including reception on ½ antenna) is shown as color-coded bars above the spectrograms.

	C1		C2		C3		C4		
		BM3		*BM3*		*BM3*		*BM3*	
Start of the mission	**Ez**	**Ez**	**Ez**	**Ez**	**Ez**	**Ez**	**Ez**	**Ez**	default configuration
2001-12-28T03:03	**½Ez**	**½Ez**							p1 failure on C1
2002-01-17T23:38	**Ey**								switch Rx to Ey on C1
2002-07-29T09:07					**½Ez**	**½Ez**			p1 failure on C3
2002-08-18T09:34					**Ey**				switch Rx to Ey on C3
2007-05-13T03:24			**½Ez**	**½Ez**					p1 failure on C2
2007-07-07T05:40			**Ey**						switch Rx to Ey on C2
2009-10-14T07:00	**½Ey**								p4 failure on C1
2009-12-06T14:05	**½Ez**								switch Rx to Ez on C1
2014-11-03T20:59						**Ø**			p2 failure on C3
2015-10-12T19:38				**Ø**					p2 failure on C2

Rx: reception

Table 1: Receiving antenna used for Whisper for the 4 satellites. The Ø symbol indicates that both probes failed, preventing any meaningful measurement.

3.4 Special operations

3.4.1 WHISPER operations during BM3

BM3 slots are 6 minutes periods reserved to dump the instrument's internal burst memory, occurring twice per orbit. During BM3s, WHISPER operates in a default BM mode in which receiving parameters are pre-selected and cannot be modified by telecommand, so that they can be different from the operations before and after the BM3. As the receiving antenna can be different (potentially set to an antenna where one EFW probe is inoperative) and the gain value can differ, this may result in significant differences in the Power Spectral Density measured by WHISPER, as illustrated by figure 7 (BM3 occurs around 03:00).

WEC is also taking advantage of these time periods to perform a number of operations on several instruments, leading to systematic data gaps in WHISPER data. There is a 3 minutes data gap before BM3 slot due to DWP reset. There is also a data gap after BM3 slot which duration is 14 minutes due to EFW reset, STAFF and WHISPER calibration (first BM3 on orbit) or 3 minutes due to EFW reset (second BM3 on orbit).

Note that the receiving antenna used during BM is always Ez, whatever the operation mode selected by telecommand. Measurements performed during BM3 are thus affected by the failures of EFW p1 and p2 probes and even impossible when both probes are inoperative, as it the case for C2 and C3 at the end of the mission, see *BM3* columns in table 1.

All the information about operational configuration, around and during BM3, is available in the **C[i]_CT_WHI_NATURAL_EVENT** and **C[i]_CT_WHI_ACTIVE_EVENT** datasets**.**

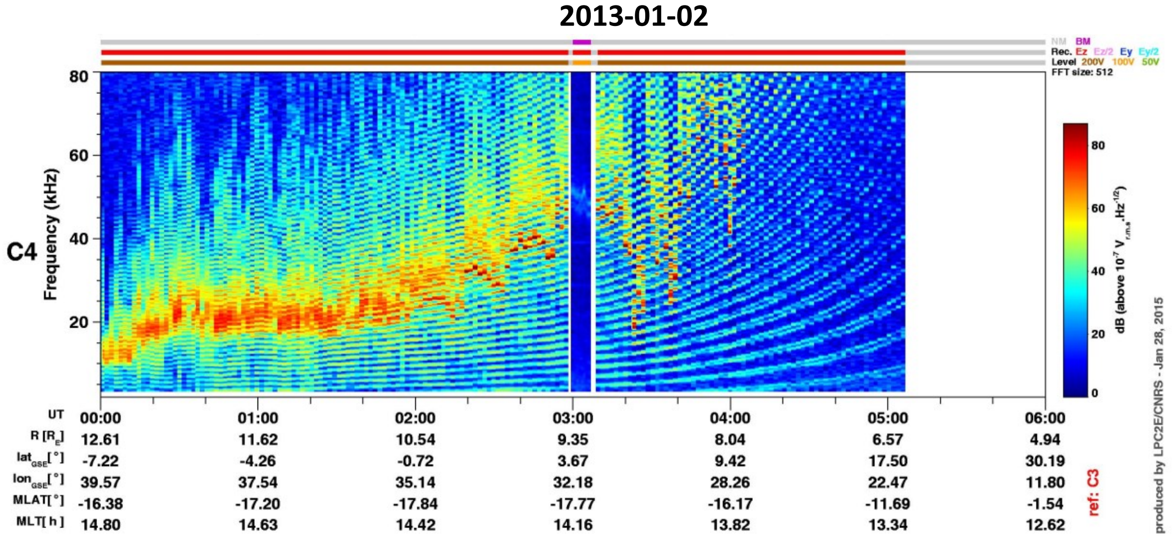

Figure 7: Example of BM3 for C4 around 03:00 on January, 2nd 2013. The colour bars above the spectrogram indicate the changes in the operational parameters.

3.4.2 2008 C3 tilt campaign

In May 2008, the Cluster mission operated a "tilt campaign" where two of the spacecraft (C3 and C4) were placed at distances as close as ~40 km from each other and the spin axis of C3 was tilted by an angle of about 45°, while C1 and C2 were at distances of ~10.000 km. This campaign gave the opportunity, for the first time in space, to measure 3D geometric characteristics of the electric field and to derive, through a dedicated directivity angle analysis, the source position of a selected radio wave event with the WHISPER experiment (Décréau et al, 2013). The interpretation of these data must be performed with a special attention to attitude auxiliary data. Tilt operations started on April 24th with a return a nominal tilt orientation on May 30th.

4 Measurement Calibration and Processing Procedures

4.1 Instrument sensitivity

The minimum measurable electric field level estimated in-flight is 0.1 $\mu V_{rms}.m^{-1}$ while the overall sensitivity of the WHISPER instrument estimated in-flight (average noise level) is 0.005 $\mu V_{rms}.m^{-1}.Hz^{-1}$, i.e. ten times lower than the targeted value.

WHISPER operates in the high frequency bandwidth and the measurements are not so much perturbed by the low potential fluctuation of the transmitting probe. However, the response efficiency depends on the orientation of the antenna with respect to the static magnetic field, sometimes leading to spin-modulated amplitude. The analyser calculates frequency spectra of the electric field every 13.3 ms and before transmission to the ground, accumulates them for a time period significantly shorter than the spin duration. The standard accumulation duration corresponds to the spacecraft rotation of about 20° (corresponding to an accumulation of 16 spectra; this value can be lowered for specific operations in BM). In the burst telemetry rate, it is possible to transmit several of the standard accumulated spectra during a spin period.

4.2 On-board calibration

One appreciable advantage of WHISPER instrument, shared by most wave instruments, is that calibration files are stable over the mission lifetime. Conversion of raw spectra to physical units can be performed at an early stage of data handling, immediately after telemetry decommutation. The calibration procedure is still executed once per orbit, to check the instrument's health. But during the years since launch, the calibration files have never needed any revision. We may note that amplitudes of waves from distant radio sources (type III solar bursts), as measured from the four different WHISPER instruments, are equal to within 1 dB, less than the experimental uncertainty which is estimated to be 2 dB. Furthermore, the conversion from bin number to frequency is well defined due to the high stability of the on-board oscillators, and does not evolve with time.

4.3 On-ground processing

The potential difference measured between the two EFW probes forming the receiving antenna is converted to an electric field using a fixed effective antenna length of 88 m, as for all other WEC instruments.

Note:

A different value is used for the conversion is used in the following cases:

- in the case of an EFW probe failure: the physical antenna length is taken at half of the nominal physical value i.e. 44 meters
- during the commissioning phase, when antennas were deployed sequentially (see the WHISPER calibration report for more detailed information)

In reality, the Cluster antenna effective length depends on the plasma regime (and in particular on the Debye length). Scientific studies requiring precise signal amplitudes may need a better estimation of the antenna effective length (Béghin et al., 2005).

Analysis on the ground of the resonance pattern observed in ACTIVE sounding spectra, plus comparison with the associated PASSIVE spectra when possible, allows the identification of characteristic frequencies of the surrounding plasma, in particular the plasma frequency F_{pe}, and hence the total electron density $N_e = F_{pe}^2/\alpha$ where α is a constant: $\alpha = e^2 / (4\pi^2 \varepsilon_0 m_e) = 80.7$ kHz^2.cm^3. In practise, each ACTIVE bin with a significantly higher signal than the corresponding PASSIVE (about 20 dB higher) is a potential local resonance.

Different types of resonances and natural wave signatures (cut-offs) are actually observed in the Earth's environment, depending on the encountered region. The user of WHISPER densities should always consider studying signatures on spectrograms to ensure the correct derivation of the density and be aware that only a full understanding of the plasma signatures can allow an inarguably derivation of the electron density. Figure 8 gives an example of several signatures on a WHISPER ACTIVE spectrogram. Electron gyroharmonics are clearly visible (F_{ce}'s) as well as Bernstein's modes (F_q's) and the upper hybrid frequency (F_{uh}). Figure 9 shows an example of a WHISPER NATURAL spectrogram showing a clear cut-off corresponding to the plasma frequency (Fp).

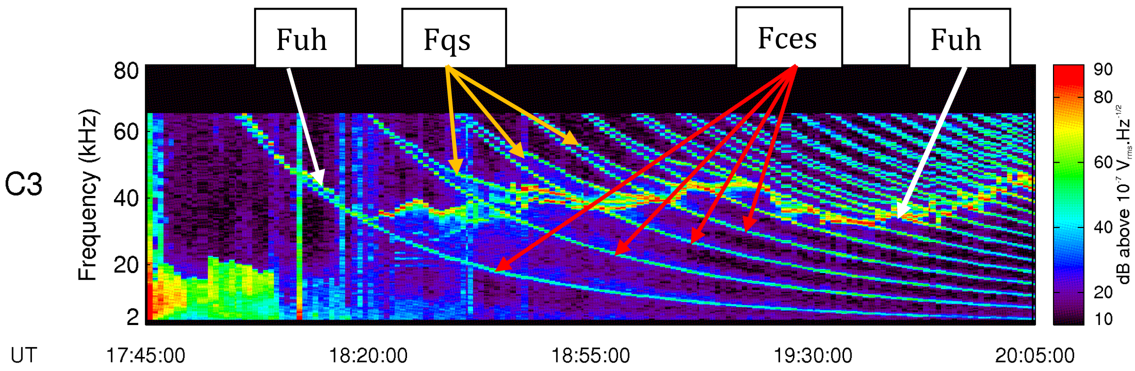

Figure 8: Example of an ACTIVE spectrogram obtained on C3 on January 30, 2009, showing resonances excited at the outward leg of the plasmasphere.

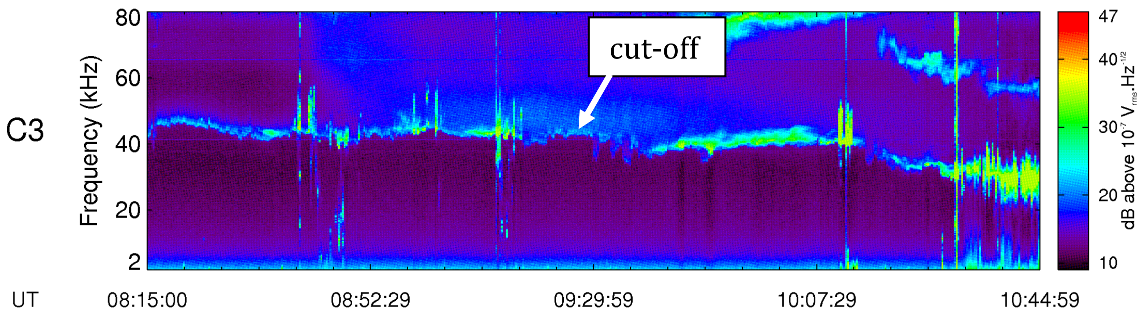

Figure 9: Example of a NATURAL spectrogram obtained on C3 on January 15, 2007, showing a clear natural cut-off in the Solar Wind.

4.4 Density production algorithms

Several algorithms have been developed to derive the total electron density from both ACTIVE and NATURAL spectra, using both EFW spacecraft potential and FGM magnetic field measurements. The algorithms are applied to various plasma regimes such as solar wind and magnetosheath, plasmasphere, cusp, and tail (Trotignon et al, 2006, 2010; Rauch et al, 2006, Masson et al, 2010). The density extraction procedure is based on a semi-automatic process requiring human intervention or, for the most recent years, on a fully automatic process but must sometimes be performed fully manually for specific studies (i.e. cross-calibration and scientific studies). Detailed information about the density determination algorithms are given in the WHISPER calibration report. The WHISPER density dataset has a record-varying parameter that indicates the algorithm used for the derivation of the density value. Note that the density determination can be relatively intricate in some regions (e.g. in the nightside magnetosphere) and cannot be performed on a routine basis.

5 Key Science Measurements and Datasets

The details of the WHISPER contribution to the Cluster Science Archive are described in the WHISPER ICD (CAA-EST-ICD-WHI). The full list of WHISPER data products is given in Appendix A. This section describes the most important datasets and the key parameters within these datasets.

5.1 Science datasets

Key science measurements provided by the WHISPER instrument consist of:

- natural wave spectra
- wave energy
- wave spectra acquired in sounding mode
- electron number density

Among the different parameters available in the WHISPER datasets, the measured electric spectral power density and the extracted electron density are of prime interest. Other parameters are also available and are mostly interesting for instrument team members or refined instrument diagnostics.

5.1.1 Electric spectral power density

This parameter can be found in three WHISPER datasets, related to:

- **Natural spectra**

The electric spectral power density in natural mode can be found in the **C[i]_CP_WHI_NATURAL** datasets ([i]=1-4) and is expressed in units $V^2.m^{-2}.Hz^{-1}$, assuming a 88 m tip-to-tip antenna length (or 44 m for the case of a failed EFW probe or a specific length during commissioning). Let us recall that a NATURAL spectrum is the average of a number of spectra accumulated on-board (for details, see section 3). There are a number of important supporting parameters in the datasets. The number of accumulated spectra is given by the **Average_Number** parameter in the same dataset. A spectrum covers a time interval from *tc-dt* to *tc+dt* where *tc* (the central time) and *dt* are given by the parameters **time_tags** and **Delta** in the same dataset. The frequency of each frequency bin is given by the **Spectral_Frequencies** parameter. The **overflow_code** gives an idea of the saturations encountered during the on-board data processing; in order to limit saturation effects, the gain in dB used during the acquisition may automatically be changed: the **gain_change_number** parameter indicates how many times it has been changed during a spectrum acquisition.

Notes:

- The **Spectral_Frequencies** parameter always contain 512 values in order to reproduce the on-board frequency table. However, only a part of the frequency bins is transmitted to ground (240 or 480 bins, depending on the operational mode). The spectrum values for non-transmitted frequency bins are then assigned to the defined fill value (-1). This applies to the first and/or the last values of the spectrum, corresponding to the beginning and/or end of the frequency range.
- It is not always possible to retrieve the actual gain associated to a particular spectrum. As already mentioned, a spectrum is obtained by on-board accumulation of several spectra acquired with a gain, set by telecommand, that can be fixed or automatic. The **gain_command** parameter of the ancillary **C[i]_CT_WHI_NATURAL_EVENT** dataset indicates if the gain is fixed or automatic and gives possible values for the gain. When fixed, the gain is the same during the whole accumulation process. When automatic, the gain can switch (between two levels) between two successive acquisitions during the accumulation process. In that case, the gain actually used during an accumulation can only be determined when the **gain_change_number** parameter described above is equal to 0 (no gain switch during accumulation, the highest gain was used for every accumulated spectrum) or equal to the number of accumulated spectra (systematic gain switch, the lowest gain was used for every accumulated spectrum).

- **Active spectra**

The electric spectral power density in active mode can be found in the **C[i]_CP_WHI_ACTIVE** dataset ([i]=1-4). The supporting parameters are the same as for the natural spectra.

Notes:

- As for the Natural spectra dataset, the presence of fill values (-1) in the first and/or last values in the spectrum indicates non-transmitted frequency bins. In addition, some particular Active modes of operation also limit the number of values to be transmitted to ground by sending only one spectrum value (the highest signal) for each pair of consecutive frequency bins, leading to the presence of fill values inside the spectrum. This occurs for instance during BM3.
- The same remark on the gain actual value applies, with the difference that the information on gain is given by the **gain_command** parameter of the ancillary **C[i]_CT_WHI_ACTIVE_EVENT** dataset.

- **Waveform energy**

The electric waveform power density in the whole WHISPER frequency band (2-80 kHz) can be found in the **C[i]_CP_WHI_WAVE_FORM_ENERGY** datasets ([i]=1-4) and is expressed in $V^2.m^{-2}.Hz^{-1}$, assuming a 88 m tip-to-tip antenna length (or 44 m for the case of an antenna including a failed EFW probe or a specific length during commissioning). As in the previous cases, the values are averaged over a number of accumulated spectra computed on-board every 13.3 ms, and given by the **Average_Number** parameter in the same dataset.

5.1.2 Electron density

The on-ground derived total electron density is given by the **C[i]_CP_WHI_ELECTRON_DENSITY** datasets ([i]=1-4) and is expressed in cm^{-3}. See section 6.3 for recommendations to the users of the electron density. A number of important supporting parameters are included in this dataset:

Spectrum_Type This parameter indicates the type spectrum used for each density value, i.e. A for ACTIVE spectrum (from plasma resonances) and N for NATURAL spectrum (from natural wave cut-offs).

Computation_Method This parameter indicates the algorithm (2 digit coded) used for each density value determination, as described in the WHISPER calibration report. This is completed by parameter **External_Data** which indicates an option related to the use of external data: e.g. E for the EFW spacecraft potential. The use of external data enables a better estimation of the density by limiting the search band for the plasma signatures and thus minimising false determinations (strong interferences). Moreover, when no signature in NATURAL spectra is exploitable, the EFW spacecraft potential may be used to give a proxy of the density, as described in the note on algorithm code below (see also the WHISPER calibration report).

Uncertainty This parameter is expressed in cm^{-3} and is an estimate of the uncertainty of the computed electron density. This is related to the width of the resonance peak (for an ACTIVE spectrum) or of the cut-off frequency (for a NATURAL spectrum). It depends on the used algorithm, as described in the WHISPER calibration report.

Contrast This parameter can be seen as a quality factor of the plasma signature used for density extraction. It is normalised, from 0 for a bad contrast to 1 for the best contrast. It depends on the used algorithm, as described in the WHISPER calibration report. It is important to note that this is the local contrast of the plasma wave signature that is used for the density measurement (resonance or cut-off) but is not a proper degree of confidence on the accuracy of the density value.

Quality This parameter can take 2 values: 3 for density extraction by a fully or semi-automatic pipeline (standard quality) and 4 for manual processing (high quality). Although all density values given by the fully or semi-automatic pipeline are considered as reliable, a manual extraction will always give better estimates. All the density values provided by the CSA archive may be considered as reliable values. This is because all the ambiguous density values have already been filtered during the extraction process (manually or by software). However, the density results from a ad-hoc process which cannot prevent, unfortunately, some densities being wrongly determined.

Note:

When no signature in NATURAL spectra is exploitable (about 50% of available NATURAL densities at CSA), but ACTIVE signal is available, the EFW spacecraft potential is sometimes used to give a proxy of the density: the spacecraft potential is recalibrated using an ad-hoc empirical formula and linearly distorted between two successive identified WHISPER ACTIVE density values. The result is given as the **Electron_Density** parameter at times of natural WHISPER spectra with a **Computation_Method** set to 20 or 21 and an **External_Data** set to E (then easily filterable for the user). Let us recall that this note only concerns density values extracted from WHISPER NATURAL spectra (i.e. when the parameter **Spectrum_Type** is set to N).

5.1.3 Electron gyrofrequency

In the plasmasphere, where the magnetic field is high enough, the electron gyrofrequency (directly related to the magnetic field magnitude though the relation $F_{ce}[Hz] = 28 \cdot B_0[nT]$) and harmonics can be triggered by WHISPER while operating in sounding mode, as illustrated by figure 8. Such signatures in ACTIVE mode can thus be exploited to derive an estimation of the electron gyrofrequency. Ad-hoc algorithms, based on pattern recognition methods and taking advantage of the presence of several harmonics (hence lowering the uncertainty) have been developed and applied to the period 2001-2005 on an experimental basis. These values are available at CSA, in a dedicated dataset (**C[i]_CP_WHI_ELECTRON_GYROFREQUENCY**) containing the derived value of the electron gyrofrequency and associated uncertainty. This dataset must be handled with care, as the derivation procedure is not straightforward.

5.2 Ancillary datasets

Some additional datasets are also provided to help users with interpretations, such as House Keeping (HK) parameters, instruments parameters or sounding times. They are listed in Appendix A.

5.3 Caveats

The WHISPER team also provides one caveat dataset: **Measurements quality caveats** (**C[i]_CQ_WHI_CAVEATS**, where [i]=1-4). This dataset gives several kinds of information that can affect the measurements quality such as overflows and/or interferences. Corrupted data periods are also indicated (caused by on-board anomalies, on-ground processing errors or software bugs). Time intervals with artefacts such as interferences and overflows are determined on a manual basis with significant margins before and after the event occurs. Listed intervals are not considered as bad data but users should pay particular attention when doing statistics or automatic analyses for these periods, since interferences, overflows or corrupted data could be misinterpreted.

Each caveat given in these datasets is associated to a validity time range (ISO format).

5.4 Quicklooks

Two Quicklook plots, produced routinely by the WHISPER team, are delivered to CSA for browsing purpose: one for the ACTIVE mode and one for the NATURAL mode. Each Quicklook contains electric field spectrograms for the 4 spacecraft, for 6 hours of data.
In addition, several technical and supporting parameters are given (as colour-coded bars on the top of each spectrogram):

- for quicklooks in ACTIVE mode: telemetry mode, actual antenna used during acquisition (Ez, Ey or ½Ez, ½Ey in the case of EFW probe failures), transmitted level, FFT size
- for quicklooks in NATURAL mode: overflow rate, telemetry mode, actual antenna used during acquisition (Ez, Ey or ½Ez, ½Ey in the case of EFW probe failures), FFT size. The total energy received in the WHISPER frequency band is also given as an independent plot above spectrograms. Two quantities are plotted: the energy measured on-board (as given in the **C[i]_CP_WHI_WAVE_FORM_ENERGY** dataset)

and the energy reconstructed on ground by integrating spectra over frequency (which is not provided in the archives). Note that the two curves do not completely agree as they are obtained from two distinct datasets.

Figures 10 and 11 show examples of a 6-hour quicklook in ACTIVE and NATURAL mode, showing typical plasma signatures corresponding to a plasmasphere crossing.

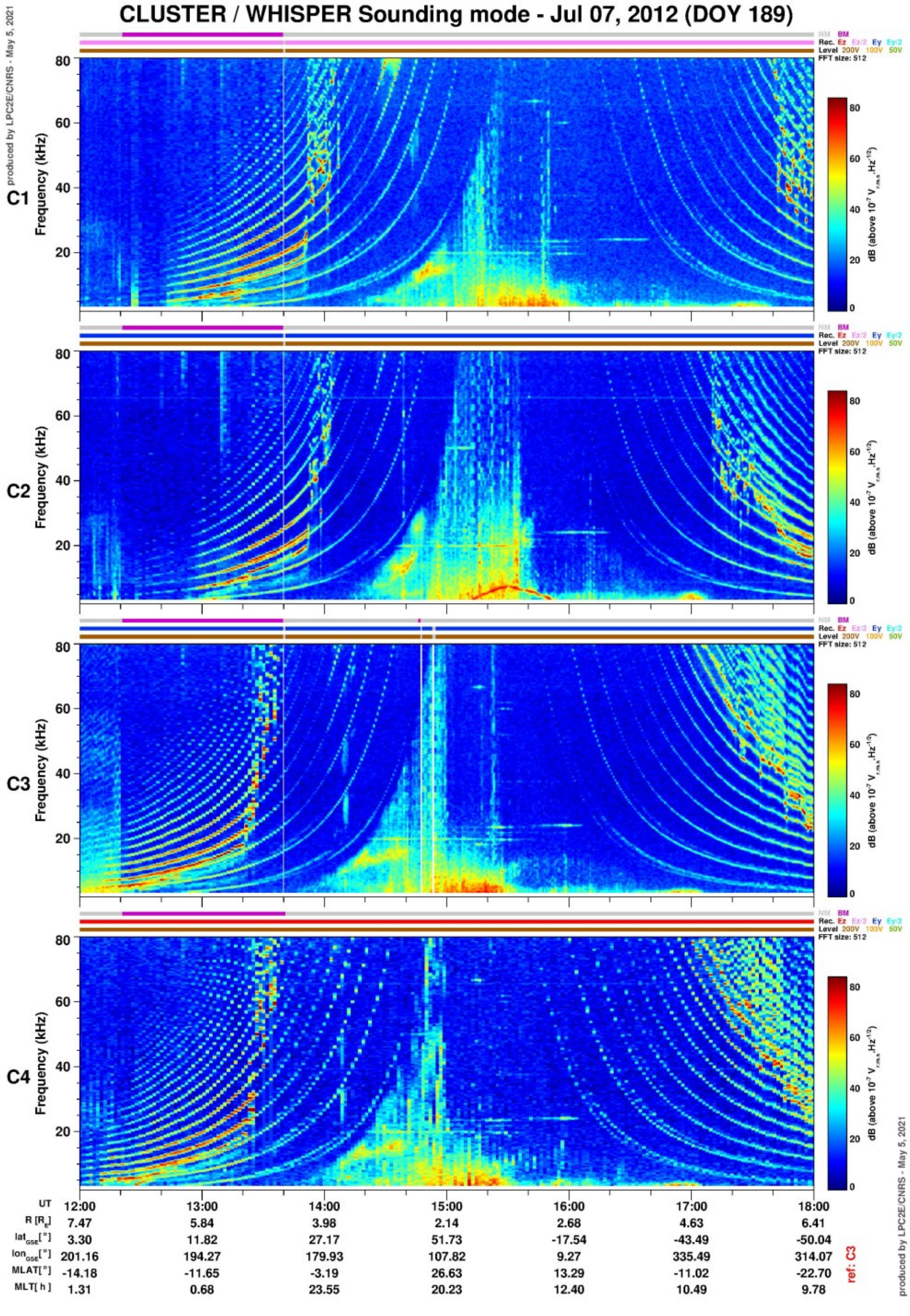

Figure 10: Example of a CSA WHISPER quicklook in ACTIVE mode, showing spectrograms of electric spectral power density for the 4 spacecraft, as well as technical parameters (colour bars).

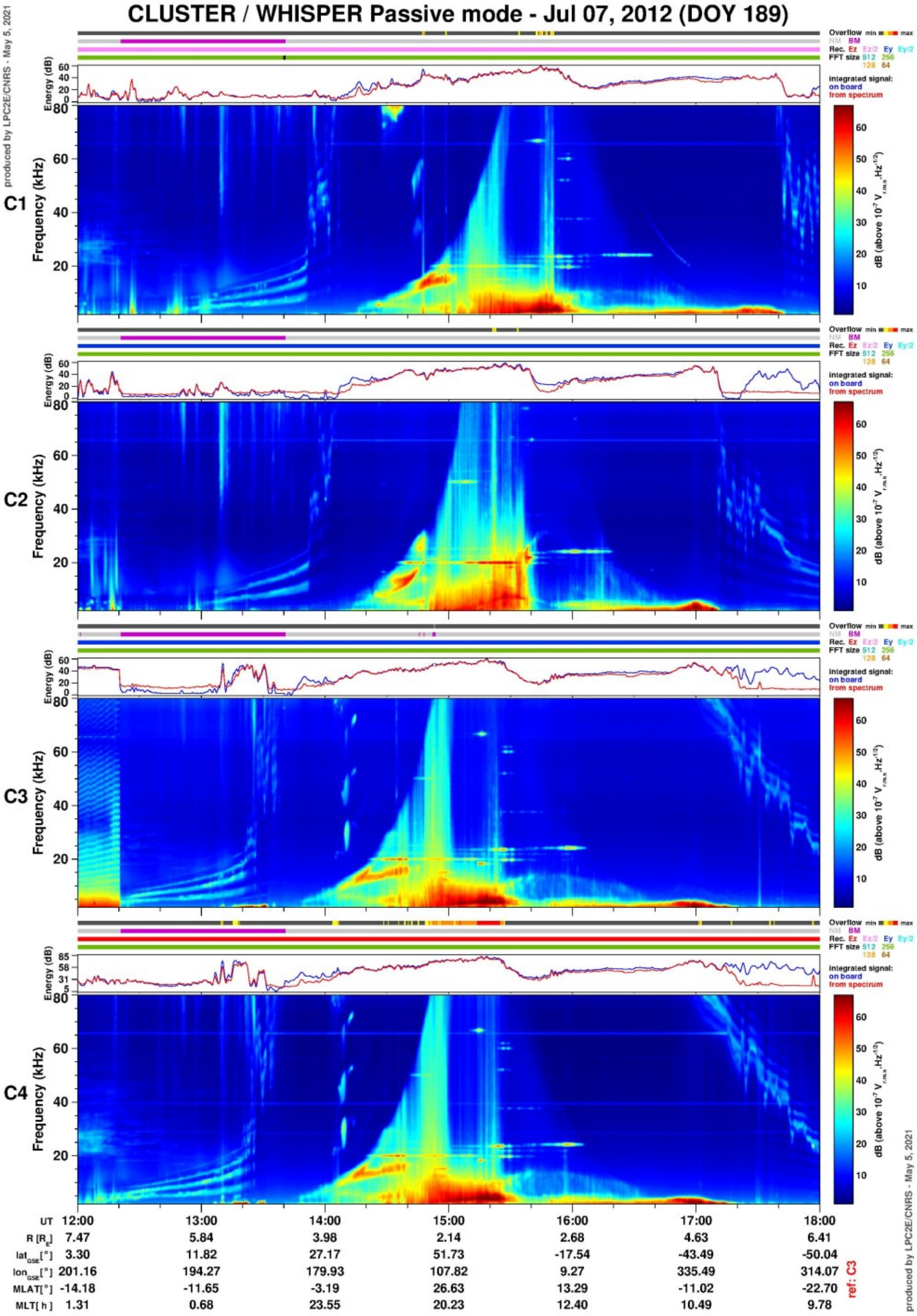

Figure 11: Example of a CSA WHISPER quicklook in NATURAL mode, showing energy, spectrograms of electric spectral power density for the 4 spacecraft, as well as technical parameters (colour bars).

5.5 Graphical Products

The CSA web interface offers visualization functionality and allow the user to plot some of the WHISPER measurements. Figure 12 presents an example for C1 for a 24 hour-period. From top to bottom, the plot gives the electric spectral power density in sounding mode (for 2-80 kHz and 2-30 kHz frequency ranges), the electric spectral power density in natural mode (for 2-80 kHz and 2-30 kHz frequency ranges) and the determined electron density extracted from all spectra (in black) and from active spectra only (purple dots).

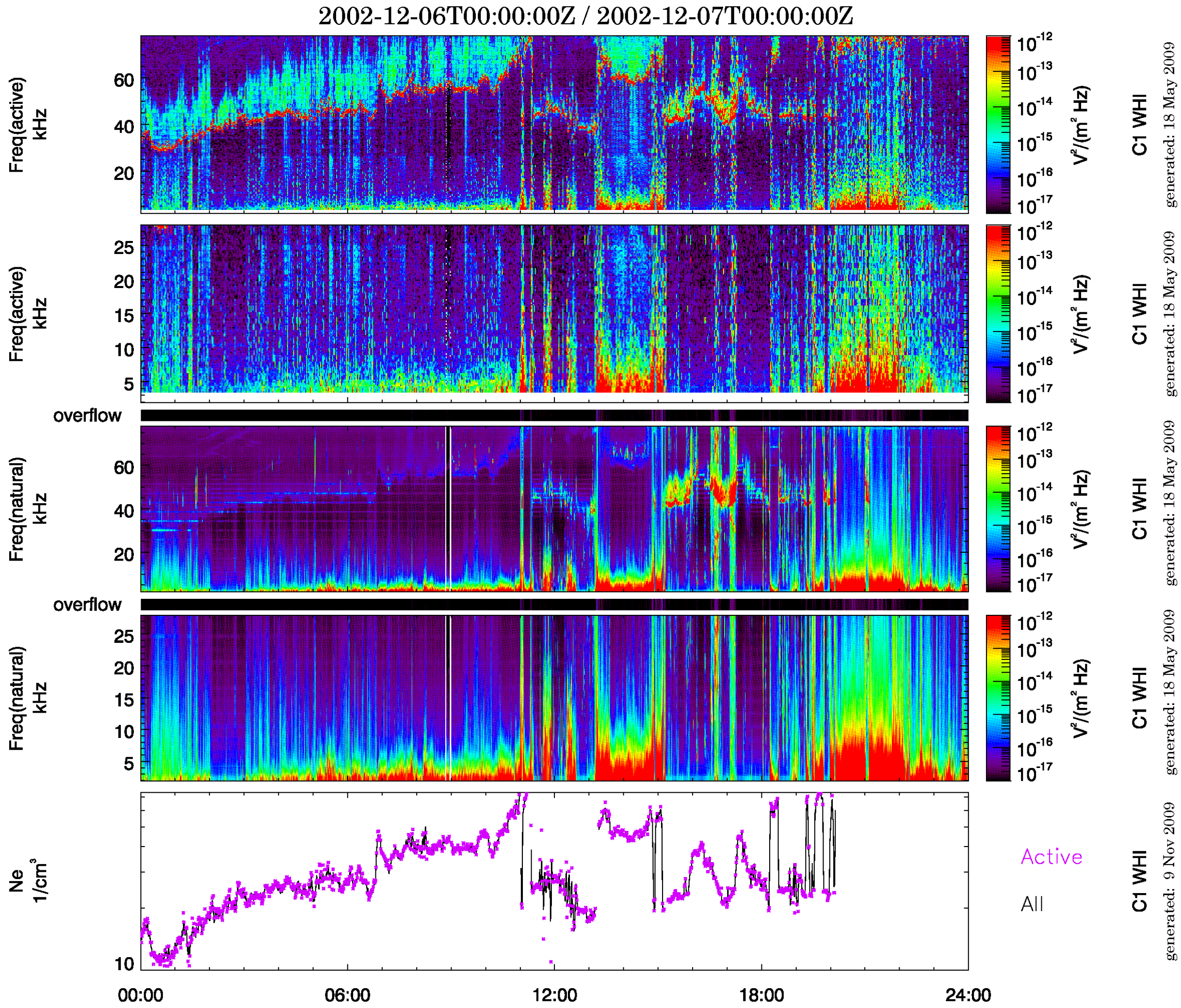

Figure 12: Example of a CSA WHISPER on-demand plot. Panels 1-4 show from top to bottom the electric spectral power density for ACTIVE (two frequency ranges) and NATURAL spectra (two frequency ranges). The bottom panel shows the electron density, with a different colour for densities extracted from ACTIVE spectra.

6 Recommendations

6.1 General recommendations on WHISPER datasets

It is strongly recommended to first look at WHISPER NATURAL and ACTIVE spectrograms on the CSA before downloading data of particular interest. In some cases, WHISPER spectra may be corrupted by interferences and/or overflows that make the measurements interpretation intricate. The CAVEAT dataset gives time intervals where interferences and overflows can affect significantly data quality; they are automatically added to the downloaded data. Useful supporting parameters are included in the data file to help the user in the data analysis.

6.2 Recommendations on WHISPER electric spectral power density datasets

When ACTIVE and/or NATURAL spectrograms show strong signal levels, and when clear plasma signatures such as resonances (for ACTIVE) and cut-offs (for NATURAL) are observed, a valuable plasma diagnostic becomes possible, in particular the natural cut-offs can be identified as local or not and the density may be reliably determined.

6.3 Recommendations on WHISPER total electron density dataset

It is highly recommended to use the **uncertainty** and **contrast** parameters to select total electron density values associated to the plasma signatures according to their signal-to-noise ratio (see section 5.1.2).

Densities extracted from ACTIVE measurements being the most reliable values, it is advised to use them in priority. Nevertheless, a much better time resolution is obtained by using densities from NATURAL spectra because there are much more NATURAL spectra measured than ACTIVE. Figures 13 and 14 give examples of density extraction in different magnetospheric regions, obtained by different extraction algorithms.

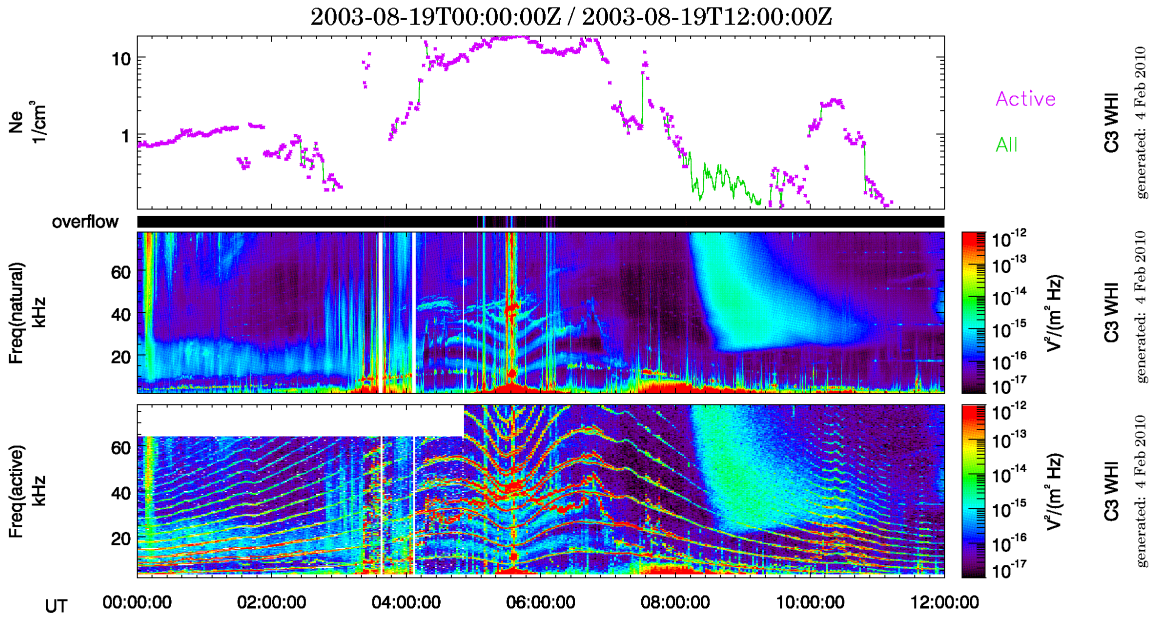

Figure 13: Example of density values and NATURAL and ACTIVE spectrograms (from top to bottom) for C3 on August 19, 2003, corresponding to a plasmasphere crossing. Density values extracted from the ACTIVE WHISPER spectra are plotted as purple points whereas green line represents the density extracted from both ACTIVE and NATURAL measurements.

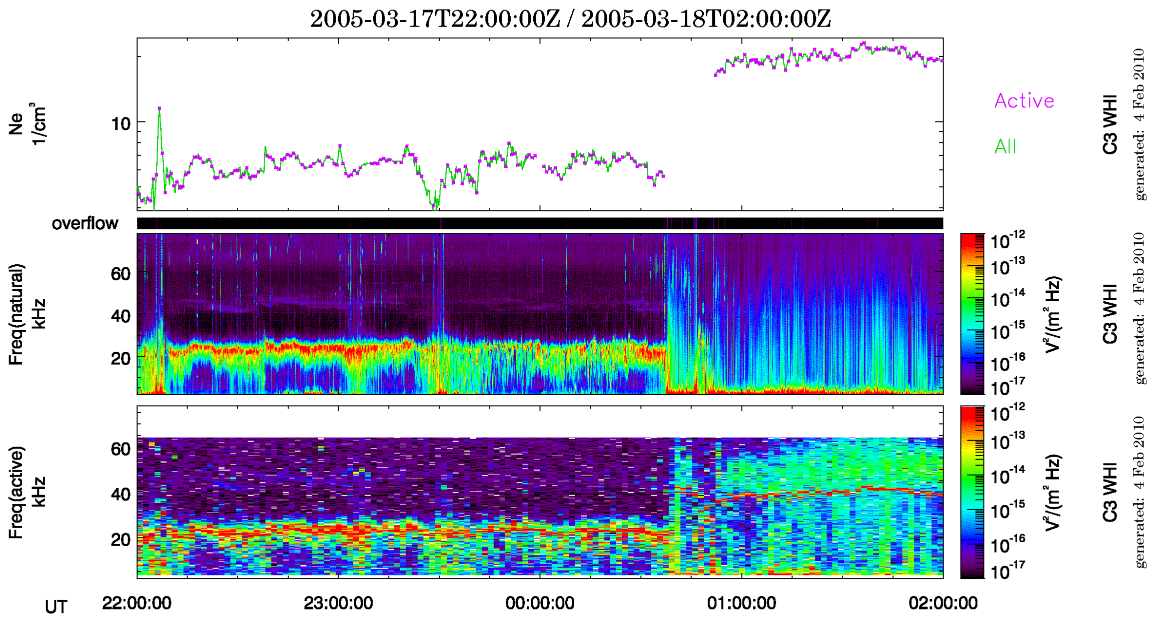

Figure 14: Example of density values and NATURAL and ACTIVE spectrograms (from top to bottom) for C3 on March 17, 2005, corresponding to solar wind/magnetosheath transition. Density values extracted from the ACTIVE WHISPER spectra are plotted as purple points whereas green line represents the density extracted from both ACTIVE and NATURAL measurements.

The user is also invited to check the algorithm code to ensure that the NATURAL density values come from WHISPER measurements. Indeed, as explained in the Note in section 5, when no plasma signature is exploitable, the recalibrated EFW spacecraft potential may be provided as a proxy of the density. When the time interval between two successive active measurements becomes large, the plasma condition may vary in such a way that the recalibration process cannot be guaranteed to be accurate in the whole interval.

7 References

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APPENDIX A - List of WHISPER CSA datasets

A.1 Science datasets

Dataset Title	Dataset id	Content
Electric Spectral Power Density (natural spectra)	C[i]_CP_WHI_NATURAL	time (ISO), frequencies (kHz), electric PSD ($V^2.m^{-2}.Hz^{-1}$) , instrument parameters
Electric Spectral Power Density (active spectra)	C[i]_CP_WHI_ACTIVE	time (ISO), sounded frequencies (kHz), electric PSD ($V^2.m^{-2}.Hz^{-1}$), instrument parameters
Electric Spectral Power Density (passive emission during sounding)	C[i]_CP_WHI_PASSIVE_ACTIVE	time (ISO), frequencies (kHz), electric spectral power density ($V^2.m^{-2}.Hz^{-1}$), instrument parameters
Integrated electric power density	C[i]_CP_WHI_WAVE_FORM_ENERGY	time (ISO), electric waveform power density ($V^2.m^{-2}.Hz^{-1}$), instrument parameters
Electron Density	C[i]_CP_WHI_ELECTRON_DENSITY	time (ISO), electron density (cm^{-3}), determination parameters

PSD: Power Spectral Density

A.2 Ancillary datasets

Dataset Title	Dataset id	Content
Electron gyrofrequency in plasmasphere	C[i]_CP_WHI_ELECTRON_GYROFREQUENCY	time (ISO), electron gyrofrequency (kHz), uncertainty (kHz)
Data Processing Caveats	C[i]_CQ_WHI_CAVEATS	time range (ISO), caveat
Instrument parameters during natural mode	C[i]_CT_WHI_NATURAL_EVENT	instrument parameters during natural mode
Instrument parameters during active mode	C[i]_CT_WHI_ACTIVE_EVENT	instrument parameters during sounding (active) mode
Sounding Times	C[i]_CP_WHI_SOUNDING_TIMES	time (ISO) of active spectra
Active to Passive Spectral Power Density Coded Ratio	C[i]_CP_ACTIVE_TO_PASSIVE_RATIO	time (ISO), frequencies (kHz), active to passive spectral power density ratio instrument, parameters
Preliminary Electron Density, Wave Spectral Density (spin resolution)	C[i]_PP_WHI	preliminary spin resolution measurements of the electron density and plasma wave spectral density from the original Cluster Science Data System Common Data Format (CDF) Prime Parameters
Preliminary Electron Density, Wave Spectral Density (1-minute average)	CL_SP_WHI	1 min averaged measurements of the electron density and plasma wave spectral density from the original Cluster Science Data System Common Data Format (CDF) Prime Parameters
Housekeeping data	C[i]_CP_HK	pulse emission parameters during sounding mode

A.3 Graphical datasets

Dataset title	Dataset id	Content
WHISPER quicklooks in Active mode	CM_CG_WHI_QL_ACT_PS CM_CG_WHI_QL_ACT_JPEG	Wave spectrograms in ACTIVE mode, 6 hours per plot
WHISPER quicklooks in Natural mode	CM_CG_WHI_QL_NAT_PS CM_CG_WHI_QL_NAT_JPEG	Wave spectrograms in NATURAL mode, 6 hours per plot