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Lessons learned from WHISPER relaxation sounder in ten years of CLUSTER mission

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Abstract

The four WHISPER instruments, part of the Wave Experiment Consortium on board the multi satellite CLUSTER mission, include each a relaxation sounder aimed to measure with a good precision and reliability the frequency positions of F_p, electron plasma frequency, and of F_{ce}, electron gyro-frequency. Those quantities give access to electron density and intensity of magnetic field, key parameters defining local plasma regime. WHISPER sounder's design and realization, based on the expertise provided by successful missions operated in late seventies and eighties (GEOS, ISEE, Viking), is characterized by use of a processor devoted to on board frequency analysis via FFT. This choice makes those relaxation sounders unique of their kind, allowing in particular a complete plasma diagnostic to be made in only 1.5 s, almost one order of magnitude faster than in the past. The CLUSTER mission itself is unique, by its multi-point capability, and by its orbit, which along the mission allowed exploring a large variety of key regions of the magnetosphere. We present in this paper a few examples of WHISPER instrument behaviour and results, exploring in particular magnetosheath, polar cap, outer and inner plasmasphere. In the latter region, F_p and F_{ce} frequency values are far above the working frequency range of the instrument. This range, however, includes the lower hybrid frequency, F_{lh}, which shows up as a clear resonance triggered by the sounder, and allows measurement of Ne whenever $F_p/F_{ce} < 1$.

1. Introduction

The CLUSTER mission is a multipoint observatory devoted to explore the magnetosphere. It needed four point measurements of plasma density, a key variable, with sufficient reliability and precision to estimate gradient vectors of this quantity. After the success of relaxation sounders on board missions like GEOS, ISEE, or Viking, it has been decided to embark such instruments on board each of the four CLUSTER satellites. The instrument built to this aim, called WHISPER (The Waves of HIgh frequency and Sounder for Probing of Electron density by Relaxation), combines two experiments to: (i) measure the natural emissions in the frequency band 2-80 kHz, and (ii) measure electron density and magnitude of magnetic field via a relaxation sounder [1]. The relaxation sounder allows a full plasma diagnostic performed in only 1.5 s, almost one order of magnitude faster compared to earlier realizations. After 10 years in orbit, all four WHISPER instruments are functioning satisfactorily. In this paper, we present the instrument's design (section 2), how it behaves in various regions of magnetosphere encountered along an orbit (section 3). In section 4, an example of the recently observed low hybrid resonance near orbit perigee (now reaching altitudes < 2000 km) is presented. Section 5 gives a short conclusion.

2. WHISPER design

In both facets of the WHISPER instrument (survey of natural waves, or active plasma diagnostic) the electric signal measured on one double sphere antenna is digitised and analysed in frequency in the 2 - 80 kHz bandwidth. An on-board FFT processor delivers frequency spectra (power spectral density, amplitude only) at a resolution of 160 or 320 Hz. In its active mode, the Whisper sounder triggers the medium to deliver an active spectrum where a number of resonances show up. Values of electron plasma frequency, F_p, and of F_{ce}, electron gyro-frequency, are determined after interpretation of the active spectrum transmitted on ground. WHISPER sounder operates as

described in figure 1. It transmits a pulse (figure 1-a) formed by a sine wave train of short duration (1.0 or 0.5 ms) centred at a frequency f_n. After a few milliseconds delay, the electric field present in the medium is recorded and analysed in frequency (figure 1-c). The frequency slice around f_n (1 kHz or 2 kHz) is copied as part of the active spectrum under construction. The next sine wave train is transmitted 27 ms later, at a frequency f_{n+1}, according to a table where f_n and f_{n+1} are separated of few kHz (figure 1-b) in order to avoid possible interferences between resonances triggered by two successive transmissions. The signal received is analysed and then the frequency slice around f_{n+1} is copied as another brick of the active spectrum, and so on. The chosen frequency table covers, in its nominal version, the 4 - 80 kHz range. It comprises a lower frequency range covered by 1.0 ms pulses, and a higher frequency range covered by 0.5 ms pulses, such that after 52 steps, the frequency range is totally covered. The complete process is performed in less than 1.5 s, and repeated in order for the spinning antenna (at ~4.0 s spin duration) to explore complementary orientations from one sweep to the other. After two successive sweeps, sounding operations give place to natural wave measurements.

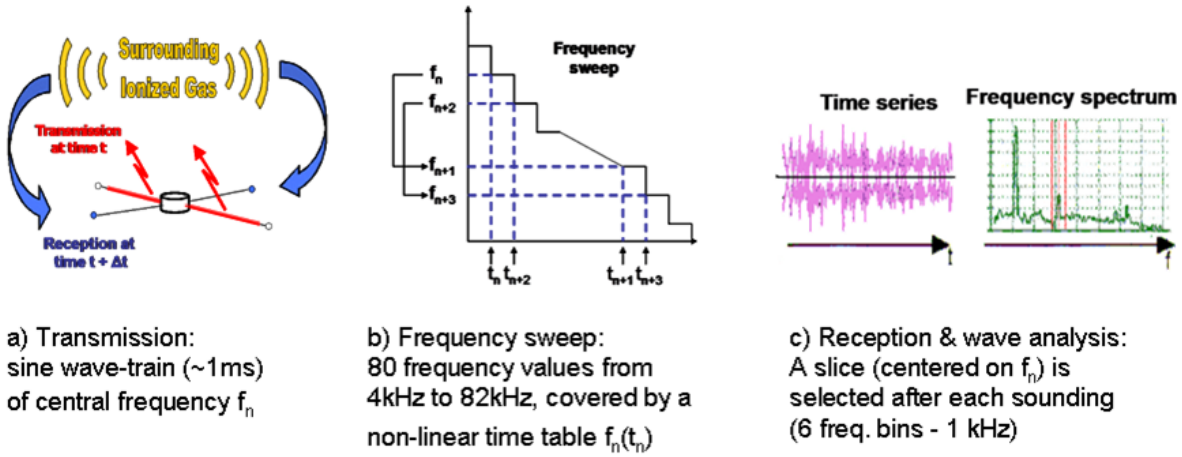


Fig. 1 Description of main sequences (1.5 s total duration) allowing constructing an active spectrum which, after interpretation on ground, provides one value of electron density.

A ground analysis of the resonance pattern present in the active spectrum allows identifying characteristic frequencies as F_p and, in magnetized regions, F_{ce} [2]. Typically, 3.0 s of sounding mode (two sweeps) are followed by 49 s of natural wave mode (delivering 11 frequency spectra transmitted to ground under nominal telemetry conditions). All four spacecraft follow the same time line (time tagged operations, at a common precision of a one second boundary clock). That strategy allows calculating the instantaneous space gradient vector of density, hence to inform about interesting spatial properties of the medium, independently of time variations.

3. Observations in regions explored during the first mission phase

Figure 2 displays frequency time spectrograms measured by the WHISPER instrument on CLUSTER spacecraft C1 on 9th November, 2002, cumulating results obtained respectively during natural mode operations (medium panel) and during sounding operations (lower panel). Upper panel is obtained from OVT tool [3]. It shows Cluster orbits during this day (using standard colour code, black, red, green and purple, respectively for C1, C2, C3 and C4), and projected magnetic field lines for C2 positions (one hour apart), in Y-Z plane of GSM coordinate system.

Noting the different colour scales used respectively for the passive spectrogram (medium panel) and the active spectrogram (lower panel), some features are seen under both instrumental conditions, as the radio type III near 14:00 UT. Clear differences reflect the presence of resonances triggered by the sounder. In particular, the gyro frequency F_{ce} and its harmonics show up when the satellite crosses the outer plasmasphere (from 00 to 02 UT), then the region over polar cap (from 02 to 08 UT). A single resonance at upper hybrid frequency F_{uh} (such that $F_{uh}^2 = F_p^2 + F_{ce}^2$) is observed in addition, as well as, above F_{uh}, Bernstein mode resonances in each gyro-harmonic band. In the low latitude boundary layer (from 19 to 24 UT), a single resonance shows up, at F_{UH} (very close to F_p). It is clear

that, in several parts of the orbit, no reliable and accurate plasma diagnostic could have been made without sounding the medium, in particular in the polar cap and in the noisy low latitude boundary layer.

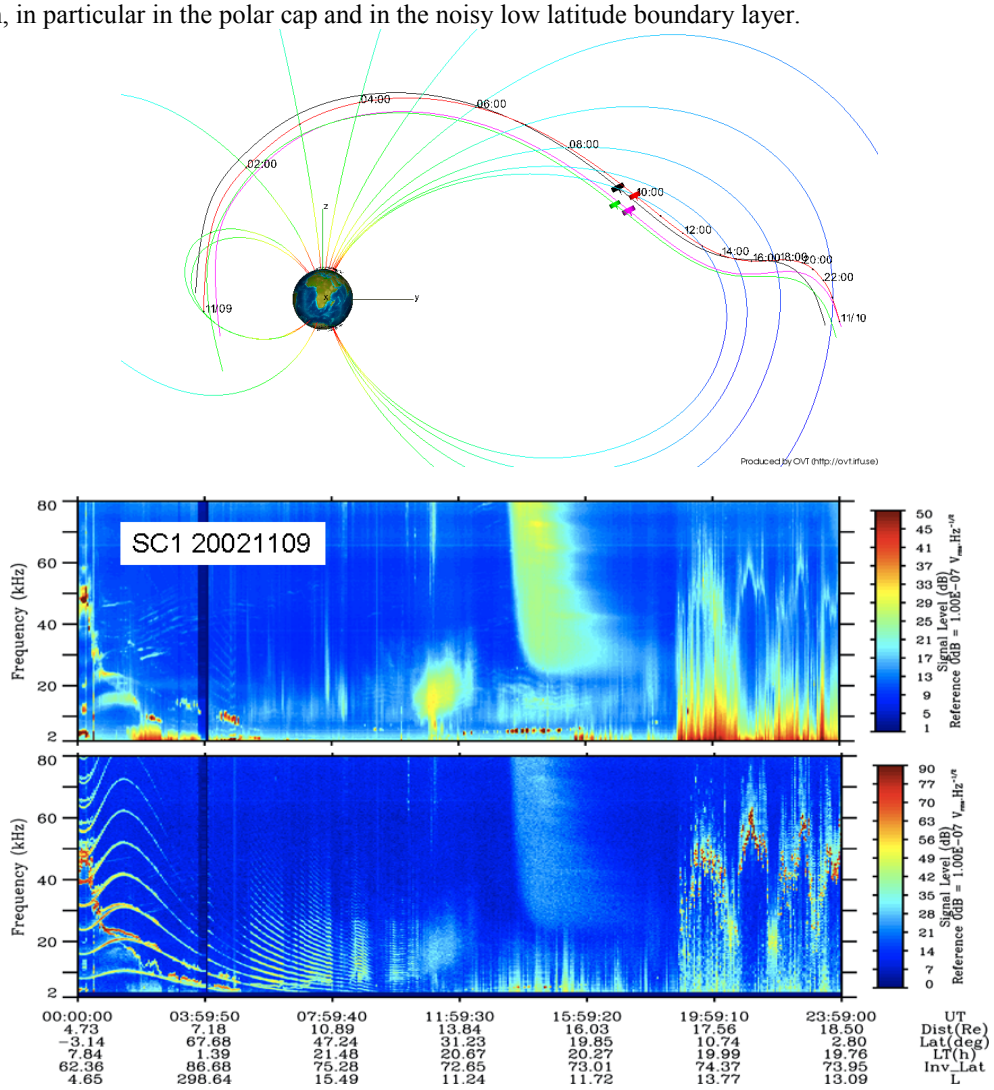


Fig. 2 CLUSTER orbits (top) and frequency time spectra measuring respectively natural waves (centre) and stimulated waves (bottom).

Figure 3 shows variations of density values during the 18:45 to 24:00 UT interval for the same day. At that position along orbit, C1 is the closest to Earth, measuring the lowest density. The gradient vector calculated along the orbit (not shown) is indeed opposite to Earth, directed toward magnetosheath.

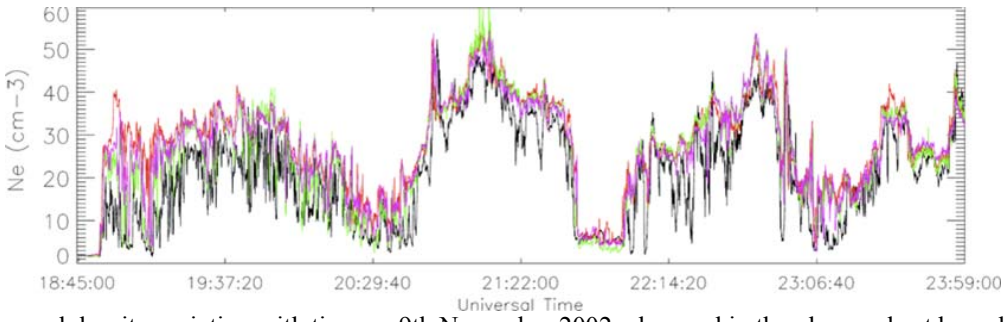
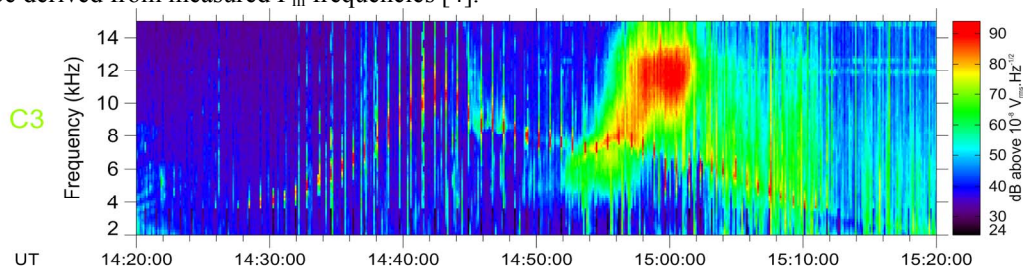


Fig. 3. Compared density variation with time on 9th November 2002, observed in the plasma sheet boundary layer.

4. Triggering lower hybrid resonance at low altitude

The lower hybrid frequency F_{lh} reflects the coupling between ion and electron motions in a magnetized medium. WHISPER relaxation sounder triggers clear resonances at this frequency (figure 3). The F_{lh} value depends of three variables: magnetic field amplitude, density and effective mass (related to the composition in term of fractional abundance of ions present in the medium), which vary with plasma regime encountered. The first one can be estimated from a model, or measured, with a good accuracy. A reasonable guess about effective mass can be made when $F_p/F_{ce} > 1$ (in this case before 14:40 UT) and, when $F_p/F_{ce} < 1$ (here after 14:45 UT), plasma density values can be derived from measured F_{lh} frequencies [4].



UT	14:20:00	14:30:00	14:40:00	14:50:00	15:00:00	15:10:00	15:20:00
R(Re)	1.99	1.60	1.31	1.27	1.51	1.89	2.32
Lat_gsm(deg)	-7.00	10.34	35.52	55.08	44.63	28.51	16.67
LT_gsm(h)	13.77	13.00	11.53	7.98	4.41	3.01	2.34
L	2.29	1.68	1.75	3.54	3.04	2.53	2.56

Fig. 4 Combined spectrogram measured recently (31st October, 2010) at low altitudes by CLUSTER C3 satellite. Active spectra can be recognized by their low frequency limit (4 kHz) contrasting with a lower limit (2 kHz) for the passive (natural wave mode) spectra. F_{lh} resonances show up in red colour.

5. Conclusion

WHISPER instrument has fulfilled its promises, allowing in addition to discover new capabilities of the relaxation sounder technique. A very rich database is archived in the CAA (CLUSTER ACTIVE ARCHIVE) built at ESTEC, ready for scientific investigations.

Acknowledments

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