AUTOMATIC DETERMINATION OF THE PLASMA FREQUENCY USING IMAGE PROCESSING ON WHISPER DATA

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ABSTRACT

Wave of HIgh frequency and Sounder for Probing of Electron density by Relaxation (WHISPER) performs the measurement of the electron density on the four satellites of the CLUSTER project. The two main purposes of the WHISPER experiment are to record the natural waves and to make a diagnostic of the electron density using the sounding technique. The various working modes and the Fourier transforms calculated on board provide a good frequency resolution obtained in the bandwidth 2-83 kHz and a well instrumental adaptability to determine the electron density in various plasmas. In active mode, spectrograms exhibit various resonance frequencies, the number of which depends strongly of the sounding region. The main purpose of this presentation is to show methods to recognize automatically the plasma frequency resonance Fpe. And, how we identify the different resonance frequencies as upper hybrid frequency Fuh, gyrofrequencies and harmonics Fcen, and Berstein modes Fqn, Interesting resonances which are able to determine the plasma density are not always the most powerful peaks of the spectrum. Sometimes, it is difficult to select the resonance frequencies from erratic peaks. A Spectrogram is considered as a picture and techniques of image processing are developed taking into an account a global information in time and frequency. Directive filters have been adapted to increase the contrast and so define more clearly the resonance frequency pattern along the time. We present results for two different magnetospheric regions: magnetosheath and plasmasphere where the behavior of the active spectrograms is strongly different. Inside the first region, the Frechet distance is used to compare the Whisper data with the EFW potential variations. Whereas in the second region a new picture is completely reconstructed and filtering techniques are used to increase the data quality and identify the most powerful information. Moreover, physical information as dispersion relation, is injected in the data treatment to recognize and name the characteristic frequencies. Lastly, the propagation properties of the natural waves are used to increase the time resolution of the electron density. Examples and statistical validation are showed.

1. INTRODUCTION

The important quantity of data recorded by WHISPER relaxation sounder requires an automatic treatment to extract the plasma density. Previous works [1], [2], have been done concerning automatic identification of resonance frequencies working spectrum to spectrum. In the present work, we propose to take into an account more global information using up to date image processing techniques. Spectrogram will be considered as a picture and we will use the time behaviour of the resonance frequencies to recognize plasma frequency Fpe, gyrofrequency Fce and harmonics Fcen, and upper hybrid frequency Fuh and Bernstein modes Fqn. The used method depends strongly of the studied region [3], [4] and [P6-14, poster by Trotignon et al.] and two different approaches are considered. In section 2 is dedicated to the Solar Wind (SW) and the magnetosheat (MS), we clean and select resonance using information coming from an other experiment and global features of density profile are compared. Section 3 is devoted to the plasmasphere region where a more complex treatment is proposed to increase the quality and is turned temporal continuity to advantage. At last, before the conclusion, the segmentation problem is described in section 4.

2. SOLAR WIND AND MAGNETOSHEAT REGION

Inside this SW and MS region, the plasma frequency resonance is often clear. However, it exist a strong electrostatic activity in low frequency which perturb strongly the automatic detection. So, the energy maximum is not a good criterion to select the resonance frequency. We propose to use the behaviour of the temporal series of local maximum to identify the plasma frequency. To do that, we will use the potential measured by Electric Field and Waves experiment (EFW) which is in relation with the electronic density.

$$Fpe = a * V(EFW)^b$$

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Fpe is the plasma frequency, V the EFW potential and a, ß are two arbitrary values determined by statiscal calibration. The problem is reduced to compare the variation of the EFW potential with WHISPER temporal series. The first step is to look for all the existing temporal series which can be candidate for a good measurement of the plasma frequency resonance.

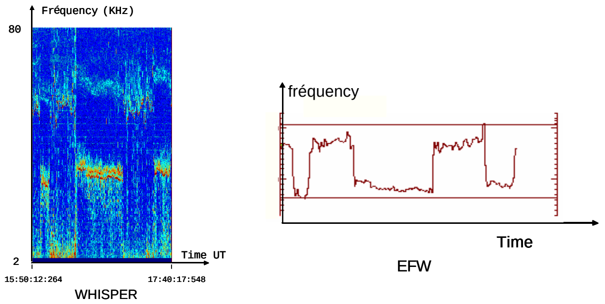


Fig 1 : WHISPER spectrogram and EFW potential curve

Using the strong variation of EFW, we identify the boundary crossings as shown Fig 1. This allows us to separate the regions and to define temporal windows Fig 2. Then, we cut frequency band out each temporal under-window which is able to contain the whole fluctuation of the EFW potential as shown Fig 3. Inside each new small window, we select the frequency with maximum amplitude, and create a temporal series. At last, these series will be compared to the EFW variation. Now, the problem consists to compare the likeness of two curves.

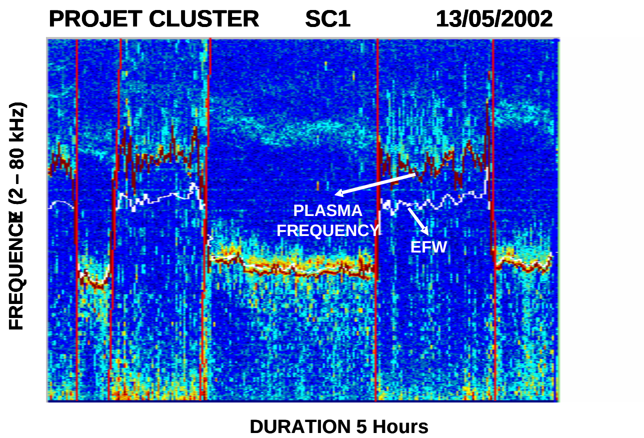
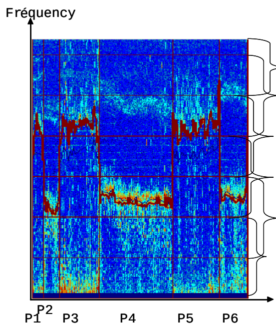


Fig 2 : Temporal cutting out of the WHISPER spectrogram using the strong variation of the EFW

To compare the two curves, we have chosen the Frechet distance [5], {6] which is defined below. To understand

$$d_f(f,g) = \inf_{\substack{a:[0,1]\to[a,a'] \\ b:[0,1]\to[b,b']}} \max_{t\in[0,1]} \left\| f(a(t)) - g(b(t)) \right\|$$

the meaning of this formula, we can compare at the following analogy: A master and his dog are walking together. The dog is kept on a leash. Sometime, the dog runs and sometime it stops. However the master and the dog follow a similar path. The Frechet distance is the shortest leash such both are in concert. This distance doesn't compare the curves dot to dot but evaluates the global resemblance. It is a good measurement to compare the likeness of two curves.



Bf6	12.5	106.1	45.8	76.7	47.0	94.6
Bf5	7.4	69.8	40.1	30.7	16.0	86.9
Bf4	8.0	59.8	21.0	104.7	21.1	78.7
Bf3	46.4	23.0	76.2	8.1	74.9	61.4
Bf2	29.2	97.2	36.0	111.6	52.8	113.9
Bf1	25.0	113.0	19.2	98.3	78.8	114.9

Fig 3 : Cutting out in frequency bandwidth and results of the Frechet distance calculation in each under-window

The Frechet distance is calculated in each frequency bandwidth as shown Fig 3. Then, we select the shorter Frechet distance inside each time period and in this way we are able to determine the good series corresponding to the plasma frequency. Then, we can calculate (a, ß) parameters to calibrate the EFW potential with the WHISPER values. Moreover, it is possible to iterate the calculation with the new EFW curve. This method allows us to recognize the resonance frequency associated with the plasma frequency and to calibrate correctly the EFW formula (1).

Results

Five months of data have been treated. This is corresponding approximately at 4000 spectrograms. The plasma frequency has been correctly recognized in 85% of time.

The main advantages of this method are

- few parameters involved
- auto-correction is possible
- possibility to determinate correctly the a, ß values in various regions to calibrate the formula (1)
- Frechet distance give confident results

However, the Frechet distance is sensible to the noise and this method is too dependent of the potential behaviour.

3. PLASMAPHERE REGION

In the plasmasphere region, the situation is more complicated. We must identify several characteristic frequencies as gyrofrequency and harmonic Fcen, plasma frequency, upper hybrid frequency Fuh and electrostatic Bernstein modes Fqn. when the plasma response is not good.. The idea is to use the temporal continuity to identify a good value of these frequencies. The first step is to clean the picture and to intensify the unclear spectra using image processing. The second step is to name (segmentation process) the different resonance lines and to deduce the plasma frequency.

3.1. Stacks images

The colour spectrogram is converted into several pictures which contain only resonances. This stage consists to look for the existing peaks above a defined level as shown Fig 4.

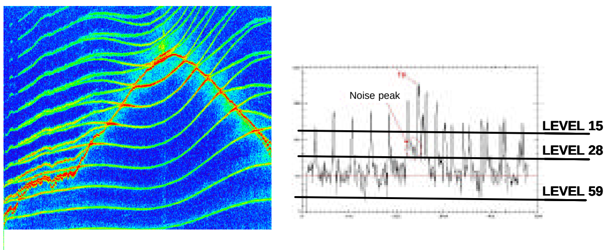


Fig 4 : The colour spectrogram is broken up into 60 binary pictures which contain only peaks

In our case, we have chosen 60 levels. The figures 5 and 6 show the found peaks between the level 0 to N where N= 15, 28, 59. For the level 59 all the peaks have been detected. In this way, the problem becomes to choose the level where all physical resonance peaks are present with a minimum of noise. The resonance frequencies appear as well defined lines. It becomes easier to identify resonances and to take into an account the temporal continuity properties. But, to get best continuous lines, we must select a picture at high level.

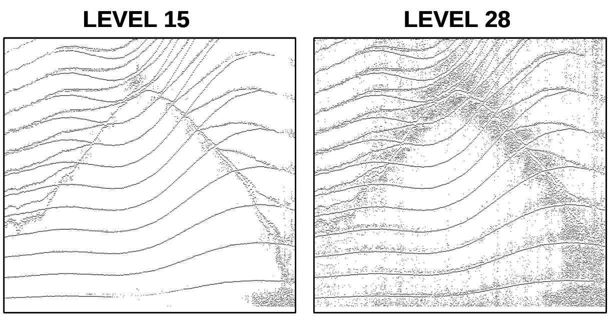


Fig 5 : Examples of binary pictures for the level 15 and 28.

As shown level 28 on Fig 5, it appears some erratic peaks around the lines, in particular, close to the plasma frequency. This noise is perturbing strongly the automatic reconnaissance and an image processing is needed to clean the picture. The image processing has two main purposes. The first is to intensify the bad spectra to fill the line where some holes are present. The second is to clean the picture without to move the resonance frequency values. Before to apply methods to increase the image quality, it is necessary to have a good criterion to choose the starting picture among the 60 stacks pictures.

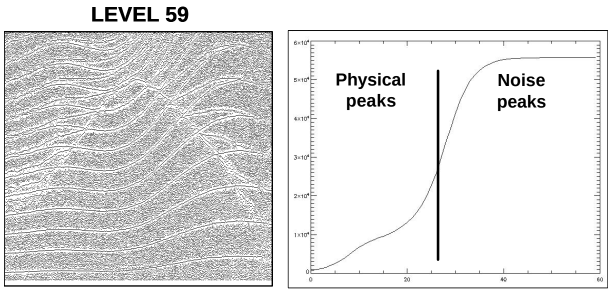


Fig 6 : The left panel shows the last binary picture where is drawn all peaks. The right panel shows the histogram of the stacks images

Drawing the histogram of the stacks images (see Fig 6), we see clearly that two regions exist. First region corresponds to high energy peaks and a second where the number of peaks increases roughly which indicates us that the noise level is touched. The separation of these two regions is given by inflexion point and determines the picture which contains the whole physical information with a minimum of noise. The starting picture will be chosen at this inflexion point.

3.2. Noise reduction

Two methods are proposed to increase the picture quality; the top hat and the Nagao filter methods. The top hat method will be used to decrease the noise around the plasma frequency. While, the Nagao filter will be used to ameliorate the temporal continuity of the lines using the local directional properties. Moreover, Nagao filter is able to smooth the noise.

3.2.1. Top hat filter

The energy around the plasma frequency is always greater than other part of the spectrum. So, some no interesting peaks have similar amplitude as Fce, Fqn. To normalize locally the spectrum, we look for the tendency (kind base line) of the spectrum. We calculate this “base line” using a process of the morphology technique. In our case, we have used a « open » process named top hat. Then, we subtract this tendency at the spectrum as shown Fig 7 top panel. This method is very efficiency to clean noise around the plasma frequency; the result is given Fig 7.

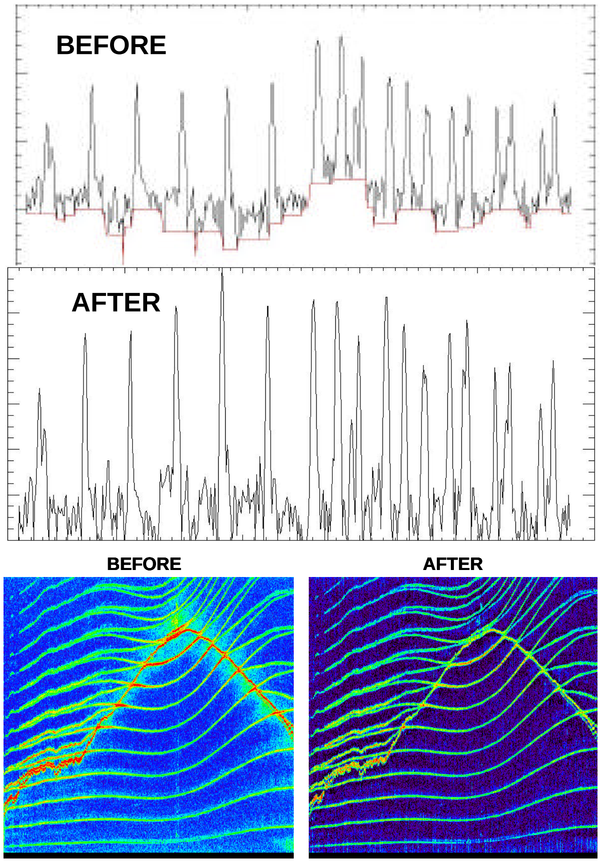


Fig 7 : Result after top hat process, the noisy peaks decrease strongly

3.2.2. Nagao directional filter

The NAGAO filter [7] is a non-linear directional filter. The objective is to intensify the picture structures look like a line. Adapted windows are defined around the central pixel. A variance calculation of the amplitude is done.

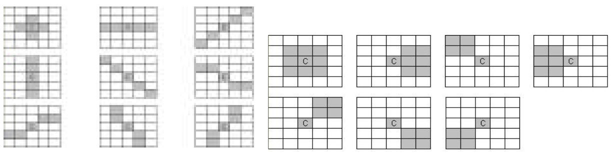


Fig 8 : Two examples of Nagao filter

The effect is to smooth pixels in the line direction and to homogenize the noise. For us, the aim is to appear a temporal continuity. Several kinds of windows can be defined by the user. Examples of Nagao filters are given in Fig 8. The second filter is the most common choice. In our case, we have chosen the first which is more adapted at our problem. The variance is calculated in each under windows and the amplitude of the central pixel is replaced by the average amplitude of the under window whose the variance is the smallest. This filter is non-linear and can be apply several times. The global energy of the picture increases.

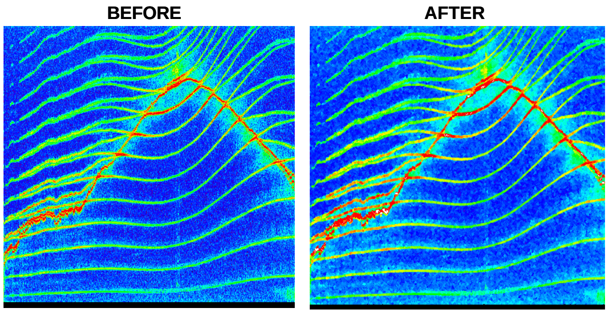


Fig 9 : Effect of the Nagao filter on the colour picture. The lines are intensified and become a little bit wider

The effect is to intensify the line (see Fig 9) and to smooth the noise. Fig 10 shows the result after to have applied the both methods i.e. top hat and Nagao filter. We see clearly that the noise has disappeared and the lines are become well defined.

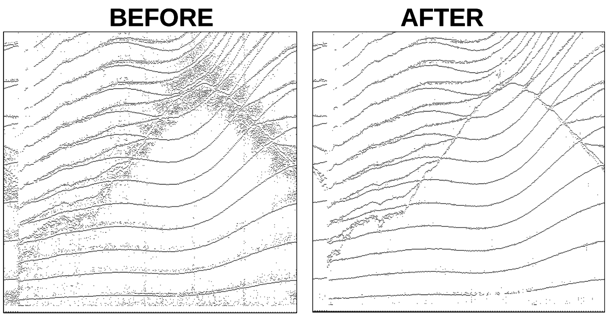


Fig 10 : Result on the binary picture level28 after Nagao and top hat processing

Such image is ready for a segmentation step. However, these methods work correctly when the density variations are smooth. But, the reader must keep in mind that it is not always the case in particular when density plumes exist. Other image processing is under development, more adapted to complex situations.

4. SEGMENTATION BY HOUGH TRANSFORM

The last step is to name the lines. Different methods can be used. Actually, we have chosen the Hough transform [8]. The Hough transform consists to define a structure and to calculate the total energy of this structure at each frequency. The structure is detected when the energy maximum is. For example, to identify the gyrofrequency and harmonics, we add the pixels amplitude inside a small segment with a slope and harmonic segments; we scan all the slope angles and harmonic frequencies. The energy maximum is at one angle and one frequency when the structure is detected.

This method is very robust in relation to noise. The structure is defined by one or several properties which characterise the pixels together for examples, the Fp, Fqn lines verify the Hamelin diagram or the Fcen lines are harmonics. The Fig 11 shows the result for the harmonic lines, the gyrofrequency and harmonics are detected correctly everywhere.

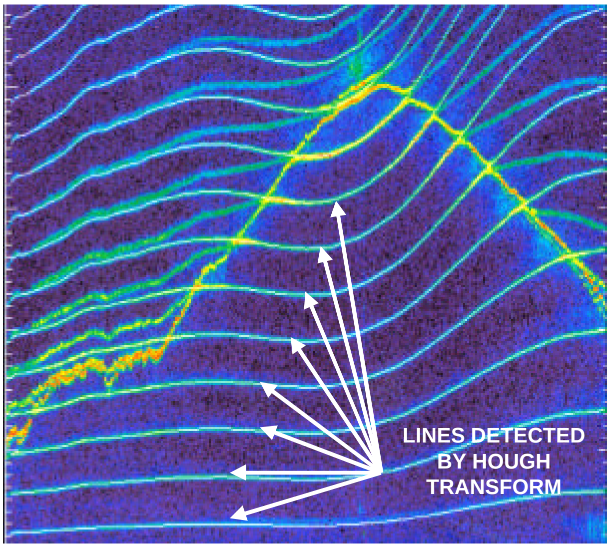


Fig 11 : Detection of the gyrofrequency and harmonic structure by Hough transform

Using a binary image, we are able to name automatically the lines and to generate temporal series which contain only one kind of frequency as Fpe, Fce and Fuh. This segmentation step is at the beginning and other methods must be tested. In particular, statistic and classification methods can be used to identify structures. Furthermore, active contours can be promising and will be investigated. The WHISPER spectrogram features are various and it will be necessary to use several kinds of techniques suited to the picture.

5. CONCLUSION

Usually, the WHISPER experiment provides very good resonance but sometime the plasma response is mixed with unknown peaks which perturb the automatic reconnaissance. Moreover, the plasma response is strongly dependant of the geophysical region and specific method must be developed. We have proposed to take advantage of the recent development of the image processing. Image processing techniques take into account global information and can help us to recognize low powerful resonance inside unclear spectrum. Non linear filters can inject locally energy on significant frequency and ameliorate noisy image. The task is difficult and it is necessary to bring into play several techniques. The last step segmentation is undertaken and the obtained results are promising to produce automatic plasma frequency detection, at least high-performance semi-automatic software. But a lot of work is still outstanding.

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