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PRELIMINARY ANALYSIS OF TYPE III RADIO BURSTS FROM STEREO/WAVES DATA

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Abstract. Solar Type III radio observations in the range 125 kHz − 16 025 kHz from the STEREO/Waves experiment have been preliminary analyzed. These bursts are generated by energetic electrons traveling away from the Sun along open magnetic field lines. A subset of 88 burst has been selected for this study. The dependence of the observed intensity radiation as a function of time at given frequency has been fitted with a Gram-Charlier type A function. The flux density spectra for all the selected type III radio bursts at each frequency channel have been determined. This preliminary analysis gives an empirical expression for the frequency drift rate as a function of frequency for the type III radio bursts.

1. INTRODUCTION

Type III bursts arise from impulsively accelerated electrons streaming outward from the Sun on magnetic field lines that are open to the interplanetary medium. The propagating electrons produce a radio emission known as a type III radio burst (Dulk et al. 2000). The frequency, related to the local plasma frequency ($f_{\rm pl} \propto \sqrt{n_{\rm e}}, \quad n_{\rm e} \propto 1/R^2, f_{\rm pl} \propto 1/R$), drifts downward as the emission region rapidly propagates outward. Since the radio burst is generated by local plasma emission processes, radio emissions at high frequencies (high plasma densities) occur very near the Sun $\sim 2R_\odot$ for 16 MHz, while those at low frequencies (low plasma densities) occur far from the Sun ($\sim$ 1 AU) for 20 kHz. These type III radio bursts are therefore characterized by a rapid drift to lower frequencies due to the near-relativistic speeds of the burst electrons. The type III radio bursts can be used to infer density and interplanetary magnetic field models in the inner Heliosphere (Leblanc et al. 1998), and to understand better the physics of the radio emissions associated with coronal mass ejections as they propagate from a few solar radii from the photosphere out to 1 AU and beyond.

The terrestrial ionosphere is opaque to radiation at frequencies below some threshold limit depending on the state of the ionosphere. Thus the lower frequency or longer (decametric and kilometric) wavelength interplanetary radio bursts cannot penetrate the ionosphere. If ground-based radio telescopes can access the high-frequency coro-

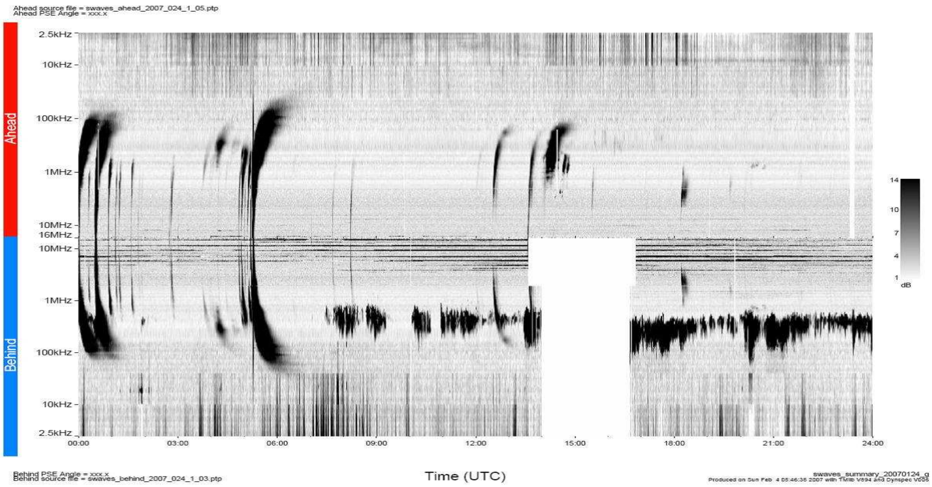

Figure 1: STEREO/Waves dynamic spectrum on January 24, 2007 – several type III radio bursts are observed between 00:00 and 01:00 UTC and at 05:30 UTC.

nal radio emission, the lower frequency interplanetary radio bursts must be detected from space.

2. OBSERVATIONS

STEREO (Solar TErrestrial RElations Observatory) (Kaiser 2007) is the third mission in NASA's Solar Terrestrial Probes program. This mission, launched on October 2006, provides a unique and revolutionary view of the Sun-Earth System. The two nearly identical observatories - one ahead of Earth in its orbit, the other trailing behind - trace the flow of energy and matter from the Sun to Earth. The solar longitudinal separation of the two spacecrafts is increasing during the mission, as well as their respective distance from the Earth along its orbit.

The STEREO/Waves (SWAVES) (Bougeret et al. 2008) experiment is a set of two identical radio receivers placed onboard the two STEREO spacecrafts. Each of them consists of three receivers: the Low Frequency Receiver covering the 2.5–160 kHz range, the High Frequency Receiver covering the 125 kHz–16 MHz range and the Fixed Frequency Receiver providing measurements at 30 or 32 MHz. The sensors are a set of three mutually orthogonal 6 m long electric monopole antennae. Each analysis channel can be connected to one of the three antennae – monopole configuration, or to an electrical combination of two of the three antennae – dipole configuration.

The criteria that were used in the selection of the bursts were the following: (1) the burst should be isolated in time from other bursts, (2) the intensity of burst radiation should be much above background, and (3) the burst should be present in a majority of frequencies. The first criterion ensures that the radio emission is related to a single package of electrons. The second and third criteria restrict the analysis to those bursts which permit accurate measurement of parameters. In this way, a subset of 88 bursts, from November 2006 to the end of September 2007, has been selected (typical type III bursts selected for the analysis are presented in Fig. 1).

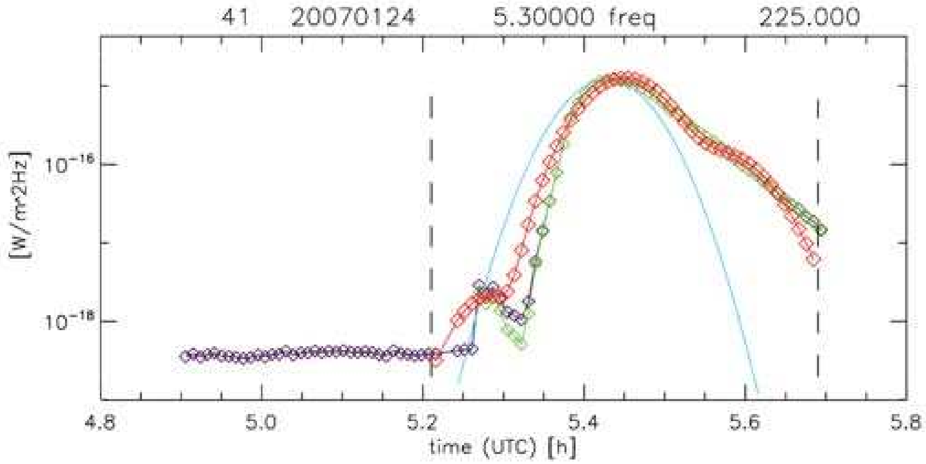

Figure 2: An example of a power spectral density time profile, for an event recorded by STEREO A on January 24, 2007, about 5.30 h UTC at 225 kHz. Violet (black, for the gray scale figure) diamonds display the power spectral density. The green (light gray) diamonds connected with a green (light gray) solid line display the power spectral density after removing the background. The solid blue (light gray) line is the result of a fitting of the latter with a Gaussian function and the red (black) diamonds between the vertical dashed lines display the result of a fitting with a Gram-Charlier type A function. The two vertical dashed lines are the time interval corresponding to plus and minus 5 times the time dispersion of the initial gaussian fit.

3. ANALYSIS

The power spectral density at the receiver input is measured in units of $[\mathrm{V}^2\mathrm{Hz}^{-1}]$. The conversion from power spectral density into incoming flux density in units of $\left[\mathrm{Wm}^{-2}\mathrm{Hz}^{-1}\right]$ is obtained by using the galactic background signal as done by Dulk et al. (2001).

For the subset containing the 88 Type III events we have applied the following analysis procedure. For each of the events and at each of the frequency channels between 125 kHz and 3 MHz, we have examined the profile of the power spectral density as a function of time. Such a profile is displayed in Fig. 2 for an event recorded by Stereo A on January 24, 2007, about 5.30 h UTC at 225 kHz (note that this spectral profile correspond to the part of dynamical spectra showed in Fig. 1). More precisely, we have fitted the time profiles using a Gram-Charlier type A function instead of a Gaussian fit. The description of Gram-Charlier function can be find, for example, in Kendall (1994).

In Fig. 2 we show an example of such a fit. The green (light gray, for the gray scale figure) diamonds connected with a green (light gray) solid line display the power spectral density after removing the background. The solid blue (light gray) line is the result of a fitting of the latter with a Gaussian function and the red (middle gray) diamonds between the vertical dashed lines display the result of a fitting with a Gram-Charlier type A function. The two vertical dashed lines are the time interval corresponding to plus and minus 5 times the time dispersion of the initial gaussian fit. From Fig 2 it can be clearly seen that the Gram-Charlier function provides a better fit than the Gaussian one. This is confirmed by the comparisons of the Pearson's χ^2 goodness of fit.

As a next step, we examine the maximum of the power spectral density time profiles for all of the 88 type III bursts and at each of the frequency channels between 125 kHz and 3 MHz. On the average for our subset, the maximum power spectral density occurs at around 0.8 MHz. This result, which still needs to be explained, is in total agreement with the study performed by Bonnin (2008) from an extensive analysis of WIND and ULYSSES radio observations.

As a third step in our analysis we examine the frequency drift rate of type III radio bursts. At higher frequency type III bursts are characterized by a rapid drift rate, while at lower frequency the drift rate is slower. The frequency drift rate is a direct consequence of the mechanisms leading to the emission of type III bursts. As a stream of fast electrons originating from the Sun travels outward thorough the solar corona, it produces radio waves at frequencies equal to the fundamental and to the second harmonic of the local plasma frequency. Since the density of solar plasma decreases with increasing distance from the sun, the type III bursts exhibit negative frequency drift rate. Furthermore, by assuming a constant beam speed it is possible to deduce coronal electron density models as a function of distance (Leblanc et al. 1998). On the other hand assuming a given density model, it is possible to deduce the beam speed (Alvarez and Haddock 1973, Bonnin 2008).

For our 88 bursts subset we have computed the frequency drift rates obtained from all the maxima of the power spectral density profiles at each of the covered frequencies. In our analysis we use dimensionless form of all quantities with scale factors: 1 MHz for frequency, 1 AU for distance, 1 s for time and 1 $\mathrm{m\,s^{-1}}$ for velocity. The general linear equation for the frequency drift rate in log–log scale is:

$$\log\left|\frac{\mathrm{d}f}{\mathrm{d}t}\right| = \log b + \alpha\,\log f, \tag{1}$$

or, with $\log b = a$,

$$\frac{\mathrm{d}f}{\mathrm{d}t} = -10^{a}\,f^{\alpha}. \tag{2}$$

The negative sign denotes that the starting frequency is observed to drift from high to low values. The least square fit of a straight line through all of our observed maxima gives:

$$\alpha = 1.80 \pm 0.05 \qquad \text{and} \qquad a = -1.70 \pm 0.03. \tag{3}$$

This result is in good agreement with result obtained by Alvarez & Haddock (1973).

In the fourth step of our analysis, we assume a given density model for the solar wind and retrieve the electron beam speed $V(R)$ as a function of the heliocentric distance R. Actually, using the result of our fitting, the frequency drift can be written as:

$$-0.02\,f^{1.80\pm0.05} = \frac{\partial f}{\partial R}\frac{\mathrm{d}R}{\mathrm{d}t} = \frac{\partial f}{\partial R}V(R). \tag{4}$$

Assuming a simple $1/R^2$ density variation for the solar wind, that is a $1/R$ variation for the plasma frequency (i.e. $f = \mathrm{k}\frac{1}{R}$ where k is numerically equal to plasma frequency in MHz at a distance of 1 astronomical unit), this implies:

$$V(R) = \mathrm{K}R^{\,0.2\pm 0.05}, \tag{5}$$

where $\mathrm{K} = 0.02\,\mathrm{k}^{0.80}$.

This result, which is also in very good agreement with Bonnin (2008), shows that the electron beam speed dependance with distance from the Sun is very weak. The beam speed is almost constant.

4. CONCLUSION

(i) The fitting of the power spectral density time profiles using Gram-Charlier type A functions gives better results than the fitting with Gaussian (normal) distribution.

(ii) The global maximum of the power spectral density distributions occurs at approximately 0.8 MHz. This result still needs to be explained.

(iii) Our preliminary analysis gives an empirical expression for the frequency drift rate as a function of frequency for the type III radio bursts: $\frac{\mathrm{d}f}{\mathrm{d}t} = -0.02\,f^{1.80}$ in units $[\mathrm{MHz\,s^{-1}}]$.

(iv) From the frequency drift rate, we have deduced that the electron beam speed, $V(R)$, is a weak function of the heliocentric distance.

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