2nd URSI AT-RASC, Gran Canaria, 28 May – 1 June 2018

Statistical Survey of Interplanetary Type II and Type III Radio Bursts

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Abstract

Type II and type III radio bursts are generated by electron beams accelerated at shock waves ahead of coronal mass ejections and solar flares, respectively. While these emissions of coronal origin are frequently detected by ground-based observatories, we need dedicated instruments in space due to the ionospheric cutoff at $\sim$ 15 MHz to measure radio sources generated farther in the interplanetary medium. Here, we report a statistical analysis of 50 type II and 152 type III radio bursts observed by Solar TErrestrial RElations Observatory (*STEREO*)/Waves experiments between 125 kHz and 16 MHz. We have found that type II radio bursts are preferably observed at higher frequencies when compared to type III radio bursts in this frequency range. The flux density of type II radio bursts is statistically $\sim 10^{-18}$ $\mathrm{Wm^{-2}Hz^{-1}}$ and frequency independent. On the other hand, the flux density of type III radio bursts is larger for the lower frequencies. Finally, we derived empirical relations of exponential rise and decay times of type III radio bursts. Better understanding of solar radio emissions can lead to improvement of our space weather capabilities.

1 Introduction

Type II and type III bursts are associated with beams of suprathermal electrons which interact with the ambient plasma generating radio emissions at the plasma frequency f_p (the fundamental emission) or at its second harmonic $2f_\mathrm{p}$ (the harmonic emission). As the electron beams propagate outward from the Sun, radio emissions are produced at progressively lower frequencies corresponding to a decreasing ambient solar wind plasma density [1]. Type II bursts are generated by electron beams accelerated at the shock fronts driven by Coronal Mass Ejections (CMEs), while type III bursts are a consequence of impulsively accelerated electrons associated with solar flares. Although type II bursts generated in the solar corona are routinely measured from the ground, spacecraft observations of type II bursts originating further from the Sun, in the interplanetary medium – especially with a good signal to noise ratio – are necessary as the Earth's ionosphere blocks radio signal in the decametric and hectometric ranges. By tracking these radio bursts in direction and frequency, it is possible to predict the arrival of CMEs at Earth. In addition, CMEs interacting with each other and with solar wind streams can enhance their geo-effectiveness.

The Solar TErrestrial RElations Observatory (*STEREO*) mission, launched in 2006, consists of two identical spacecraft orbiting the Sun which provides us with a unique stereoscopic view of the Solar-Terrestrial system. The *STEREO*/Waves instrument provides comprehensive measurements of all components of electric field fluctuations between 2.5 kHz and 16 MHz that corresponds to radio emissions generated in radial distances from 1 $\mathrm{R_S}$ above the Sun's surface up to 1 au. Here, we use measurements recorded by the High Frequency Receiver (HFR) which consists of two receivers: HFR1 (125 kHz – 2 MHz with direction-finding capabilities) and HFR2 (2 MHz – 16 MHz without direction-finding capabilities).

2 Discussion and Results

We performed a statistical analysis of 50 and 152 time–frequency intervals when type II and type III radio bursts were observed by *STEREO*/Waves, respectively. We used a list of type II emissions compiled by Robert MacDowall from NASA/GSFC (https://ssed.gsfc.nasa.gov/waves/data_products.html). We analyzed events observed between May 2007 and February 2012. The list of type III radio bursts (May 2007 — February 2013) has been already used to study radio source locations and radio flux variations with frequency [2].

Figure 1 shows frequency distributions of radio spectra of of type II and type III radio bursts in our study. We have found that type II radio bursts are predominantly presented at higher frequencies, while type III radio bursts are more likely observed at lower frequency channels. Preferable measurements of type II radio bursts at higher frequencies can be explained by CME–streamer and CME–CME interactions, which typically occur closer to the Sun, and lead to radio enhancements of these emissions. On the other hand, the high frequency cutoff of type III radio bursts is probably related to a presence of solar flares originated on the far side of the Sun, which blocks the radio signal.

Figure 2 displays the flux density of type II and type III radio bursts. We have found that type II radio bursts have

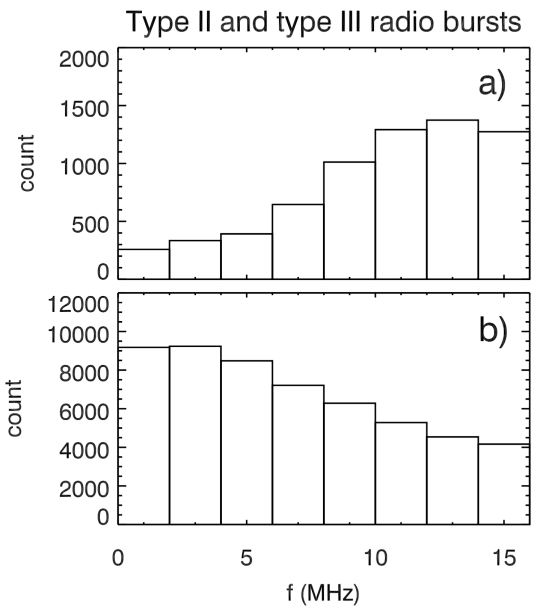

Figure 1. Results of the statistical survey of type II and type III radio bursts. (a), (b) Histograms of observed frequencies of type II and type III radio bursts, respectively.

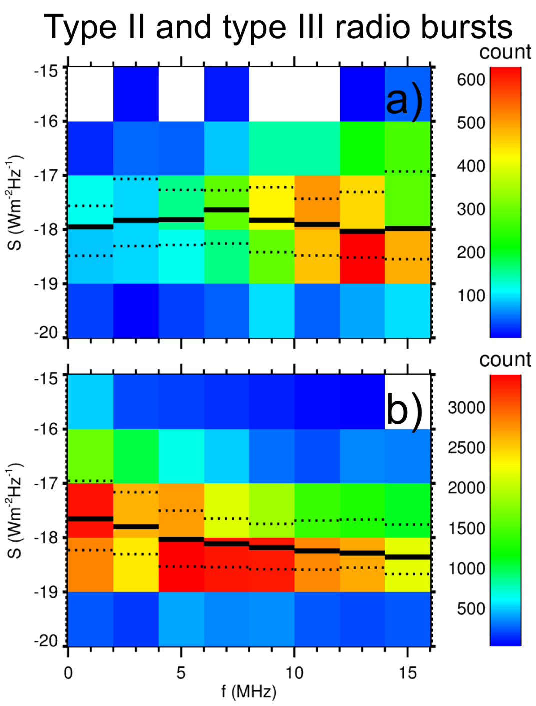

Figure 2. Results of the statistical survey of type II and type III radio bursts. (a), (b) Flux density of type II and type III radio bursts, respectively. Solid lines are median values. Dotted lines represent 25th and 75th percentiles.

statistically the flux density $\sim 10^{-18}$ Wm^{-2}Hz^{-1} and the frequency variations are negligible. On the other hand, type III radio burst flux density decreases with frequency which is consitent with previous studies [2]. Our results suggest that a receiver sensitivity of $\sim 10^{-19}$ Wm^{-2}Hz^{-1} is sufficient for resolving spectral features of type II and type III radio bursts in a given frequency range.

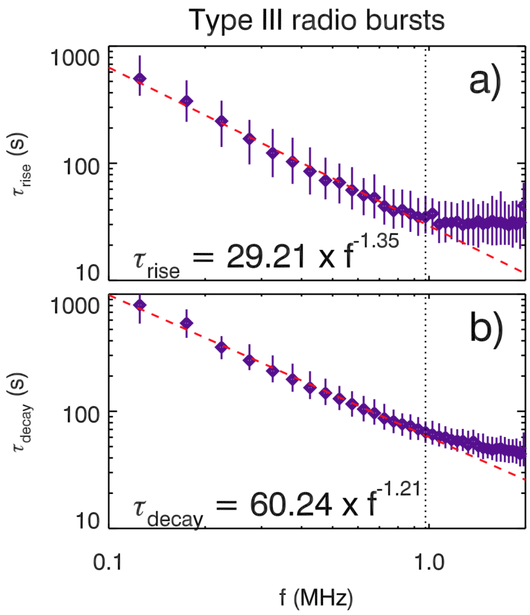

Figure 3. Results of the statistical survey of type III radio bursts. (a), (b) Median values of rise and decay times of type III radio bursts, respectively. Error bars are 25th and 75th percentiles. Results of power-law fitting below 1 MHz (vertical black dotted line) are denoted in red.

Finally, we analyze time profiles of solar radio emissions. While interplanetary type II radio bursts are typically intermittent and patchy, we focus on type III radio bursts because they are frequently characterized by an exponential rise followed by an exponential decay. We have investigated time profiles of type III radio bursts case by case. Figure 3 shows calculated median values of exponential rise/decay times $\tau_{\rm rise}/\tau_{\rm decay}$ as a function of frequency measured by the HFR1 receiver (125 kHz – 2 MHz). Next, we analyze radio observations below 1 MHz due to insufficient time resolution of the *STEREO*/Waves instrument ($\sim$ 38 s). We have assumed that $\tau_{\rm rise}/\tau_{\rm decay}$ are statistically frequency dependent as $\sim af^b$, *i.e.* a power law depedence. This model fit the data very well at both $\tau_{\rm rise}$ and $\tau_{\rm decay}$. Obtained empirical relation for $\tau_{\rm rise}$ can be used to estimate time resolution requirements for prospective radio instruments in space. We conclude that a time resolution of $\sim$ 0.7 s is needed for the analysis of rise times of type III radio bursts at 16 MHz.

3 Acknowledgements

V.K. acknowledges support by an appointment to the NASA postdoctoral program at the NASA Goddard Space Flight

Center administered by Universities Space Research Association under contract with NASA and the Czech Science Foundation grant 17-06818Y.

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