LOCAL TIME OCCURRENCE OF SOLAR TYPE III BURSTS AT SATURN'S ORBIT

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Abstract

We report on solar radio bursts observed by the RPWS experiment on board the Cassini spacecraft in the period from 1st January 2004 to 31st March 2010. In this time intervals of about six years a limited number of strong solar type III bursts, less than 300, has been recorded. This is mainly due to the solar activity which reaches its minimum in 2008–2009. In this study we consider type III solar bursts observed at frequencies lower than 1.2 MHz generated in the interplanetary medium. We analyse the solar bursts with the aim to estimate the Cassini local time (LT) occurrence rate, where the Kronian day has been divided into eight LT sectors. Our results are combined with the Cassini orbits where the LT and the distance to the planet are taken into consideration. We show that the type III burst occurrence rates depend on the solar activity, however the day side sector (midday to early afternoon) exhibits the lowest rate of occurrence.

1 Introduction

Type III bursts are one of the earliest discovered forms of solar radio emissions. They are produced by packets of electrons which are accelerated in active regions and traverse the corona and the solar wind at a speed of 0.1 to 0.3 times the speed of light in vacuum. Many of these electron beams occur near the onset of impulsive flares. In the dynamic spectrum the type III bursts appear as intense bands of emission with a drift rate of about 80 MHz s^{-1} at a frequency of 100 MHz. The flux density of type III bursts has been found to be variable in the frequency range between 20 kHz and 60 MHz with a peak of about 10^{-16} W $m^{-2}Hz^{-1}$ at 50 kHz [Dulk et al., 1998]. Along their path, the electron beams generate Langmuir waves close to the plasma frequency and some of the energy of the Langmuir waves is converted into electromagnetic radiation. A relation between the

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plasma frequency f_p (in Hz) and the local plasma density n_e (in m^{-3}) of the medium is given by

$$f_\mathrm{p} = 9\sqrt{n_\mathrm{e}} \tag{1}$$

The evolution of the electrons to regions of lower density is traced out by radio waves progressing to lower frequencies. Hence, type III bursts which occur at the metric, the decametric and the hectometric wavelengths originate entirely in the corona, in the solar wind region (or the outer corona), and in the interplanetary medium, respectively.

Type III bursts in the interplanetary medium (hereafter IPM) were first detected by the radio instruments on Alouette-I and routinely by later space radio experiments such as ISEE-3, Ulysses, Geotail, and Wind. Those experiments have been devoted to study type III features like electron beams [Dulk, 1990] as well as inferring the Archimedean spiral structure of the IP magnetic field [Reiner et al., 1998]. Spacecraft observations provided strong evidence that streams of fast solar electrons of approximately 10 to 10^2 keV energies excite type III solar radio bursts [Frank and Gurnett, 1972]. The electrons interact with the ambient plasma exciting plasma waves which in turn couple into electromagnetic waves at the local plasma frequency and/or its second harmonic [Dulk, 1985].

More recently, Thejappa et al. [2007] and Bonnin et al. [2008] investigated the type III radio wave propagation in the IPM. Thejappa et al. [2007] used Monte Carlo simulation to derive the refraction and the scattering effects on the fundamental and harmonic components of type III bursts. Bonnin et al. [2008] analysed the directivity of solar type III radio bursts at hectometer and kilometer wavelengths using radio data recorded simultaneously by the Wind and Ulysses spacecraft. They selected more than 1000 type III bursts observed between 1995 and 2005, a period spanning the 1996 minimum and 2001 maximum of the solar cycle 23. The authors found that the average directivity diagram exhibits no significant variation with the solar activity. Propagation effects occurred in the IPM where the refraction and the scattering are associated with regular density gradients and random density fluctuations, respectively.

The purpose of this paper is to use the Cassini/RPWS instrument to analyse the occurrence of type III bursts observed at frequencies lower than 1.2 MHz, a frequency limit imposed for SKR investigations. We attempt to study the LT occurrence rate and its possible dependence on propagation effects which may occur in the interplanetary medium or inside the Kronian magnetosphere.

2 Type III Burst Occurrence

In 1997, the Cassini spacecraft was launched to arrive at Saturn in 2004. The solar type III bursts were recorded by the Cassini Radio and Plasma Wave Science Investigations (RPWS) [Gurnett et al., 2004], which has three 10 m long antennas to measure plasma and radio waves from 1 Hz up to 16 MHz. During the approach to Saturn and up until about day of year (DOY) 289, 2004, Cassini was relatively far from Saturn and until 2005 the spacecraft orbits remained almost constantly outside the magnetosphere. Most of the recorded solar type III bursts occurred during 2004 and 2005 (78%). Until 2006, Cassini spent most of the time in the morning sector (06–08 LT). From 2006, the apoapsis was shifted towards earlier LT to lie predominantly inside the magnetosphere, but the number of bursts decreased simultaneously. For 2008 and the beginning of 2009, the midday sector (12 LT) dominated, and for the last year of this study (spring 2009–spring 2010), Cassini spent most of the time in the evening sector (18–21 LT).

The sunspot number is a measure of the solar activity and is assumed to give an approximate estimate of the burst rate. This is illustrated in Fig. 1, which shows the monthly sunspot number [SIDC-team, 2010] in the upper panel and the monthly number of recorded bursts stronger than 10 dB above the background in the lower panel. Here the number of bursts are also given for each year and for year 2004 in two periods, DOY 1–DOY 289 and DOY 290–DOY 366. A clear, but not perfect correlation between the panels can be seen. During 2004–2005 a large number of bursts was measured but few burst were recorded for 2007–2009. Year 2010 shows increases of the sunspot number and the number of solar bursts indicating an approach towards solar maximum.

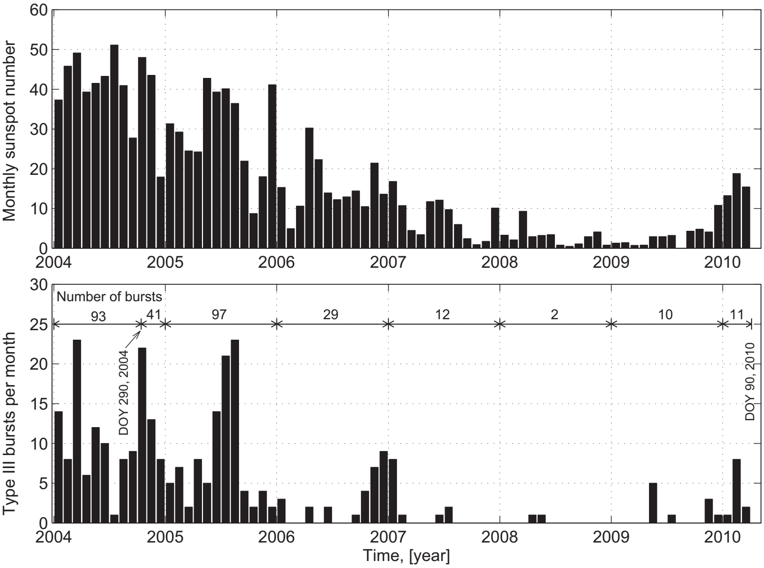

Figure 1: The upper panel shows the monthly sunspot number [SIDC-team, 2010] and the lower panel the number of solar type III bursts per month stronger than 10 dB above the background. The yearly number of bursts is also shown in the lower panel with year 2004 split into two periods: DOY 1–DOY 289 and DOY 290 until the end of the year. A total of 295 strong type III bursts were recorded.

An analysis of the solar type III burst occurrence with respect to Cassini LT has been performed for the period DOY 290, 2004–DOY 90, 2010. The result is presented in Fig. 2. Panel (a) displays the solar type III burst occurrence per LT and (b) the number of hours Cassini spent at each LT with a rather even distribution between LT. Panel (c) shows the burst occurrence per LT divided by the number of hours Cassini spent at each LT, or in other words panel (a) divided by panel (b), with normalisation such that the sum over all

LT give 100%. The dominance of the morning sector in panels (a) and (c) is attributed to the higher burst occurrence during 2004–2005 when Cassini was in the morning sector.

In panel (d) the cumulated daily sunspot number [SIDC-team, 2010] per LT is displayed. Here, a resolution of one hour has been used for the Cassini LT. Panel (e) shows the burst occurrence per LT divided by the number of sunspots per LT [panel (a) divided by panel (d)] normalised in the way that the sum of all LT equals 100%. This panel shows that, even when solar activity is taken into account, less bursts were observed at noon and early afternoon. Finally, panel (f) is similar to panel (e) but the years of low solar activity (2007–2009) have been excluded from the analysis.

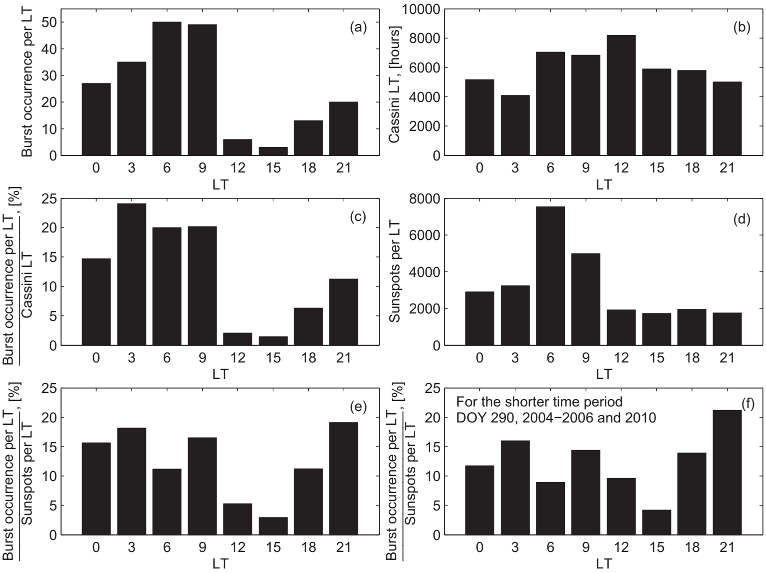

Figure 2: Analysis of the solar type III burst occurrence versus Cassini LT for the period DOY 290, 2004 to DOY 90, 2010. The panels indicate: (a) the solar type III burst occurrence with respect to LT, (b) the number of hours Cassini spent at different LT, (c) the type III burst occurrence per LT divided by the time Cassini spent in each LT sector, (d) the accumulated sunspot number per LT based on the daily sunspot number [SIDC-team, 2010], (e) the burst occurrence per LT divided by the number of sunspots per LT, and (f) the same as panel (e) but for the shorter time period 2004–2006 and 2010 when the burst occurrence rate was rather high (see Fig. 1).

3 Discussion and Conclusion

We have analysed the local time occurrence of solar type III bursts as observed by the Cassini/RPWS instrument. A number of 295 strong bursts occurred in the time interval of about six years from 1st January 2004 to 31st March 2010. We show that the local time occurrences of those bursts are clearly higher in the night-early morning sector of the Kronian magnetosphere.

One may assume that this effect is due to the Cassini orbit and its corresponding local time. According to Fig. 2b the number of hours Cassini spent at different LT is variable with a minimum and a maximum of about 4000 hours and 8000 hours corresponding, respectively, to 03 LT and 12 LT. Despite this 'nearly' regular time coverage, the type III bursts occurred mainly in a specific sector of the Kronian magnetosphere. The normalised occurrence (see Fig. 2c) has a peak around 03 LT, i.e. when the Cassini spacecraft was mainly on the night-side of the planet and a minimum at 12–15 LT. But this is the result of the higher burst occurrence during 2004–2005 when Cassini was in the morning sector. Also the variation of the sunspot number is found to be similar to the variation of the type III burst occurrences. Hence, only two bursts have been recorded in the year 2008 (see Fig. 1) which is in agreement with the solar activity which reached its minima in June 2008. Furthermore, taking the sunspot number as an estimate of the burst rate the night-early morning sector shows a higher occurrence than predicted and the afternoon sector a lower (see Fig. 2e). There is no reason to believe that the night-early morning sector is more adjusted and adapted than the other ones for the type III reception by the RPWS instrument. Nevertheless, it is not possible to explain this particular type III occurrence on the night-early morning side of the planet by an effect of the solar activity.

There may also be the possibility that a low monthly sunspot number (of the order of about five and below) is not a good indicator of the probability to observe the strong solar type III bursts used in this study. In order to investigate this hypothesis, the years 2007–2009 were excluded and an identical investigation was made for the remaining years (2004–2006 and 2010). Since much of the time for the excluded years was spent at 12–15 LT, the number of sunspots decreased for these LT and in particular for 15 LT. The result is that the burst occurrence per LT divided by the number of sunspots per LT (compare with Fig. 2e–f) changes: for 12 LT from 5% to 10% and for 15 LT from 3% to 4%. Consequently, the sector 15 LT still shows an unusual low occurrence, but this is most likely a result of the low number of type III bursts recorded for this particular LT.

The low burst occurrence for 15 LT could also indicate that a particular phenomenon may take place close to, or in, the Kronian vicinity. This may be related to some screening effects in the Kronian magnetosphere at frequencies higher than the local plasma frequencies. It has been reported by Hoang et al. [1994] that there are frequently cut-offs of radio emission well above the plasma frequency. However, this is mainly the case in the interplanetary medium where large scale density structures may exist, as suggested by Lecacheux et al. [1989]. Inside the Kronian magnetosphere, the Enceladus plasma torus, at 4–6 Kronian radii and about 10° latitude, has the highest electron density reaching plasma frequencies of 50–100 kHz [André et al., 2008; Persoon et al., 2009]. In the solar wind and the magnetosheath of Saturn the densities should not cause cut-off above some tens of kHz. Although no screening effect higher than 100 kHz can be predicted in terms of a cut-off at the plasma frequency, bursts impinging on a density gradient at an inclined angle are reflected at a frequency higher than the plasma frequency, $f_{\text{cut-off}} = f_{\text{p}}/\cos\alpha$, where α is the angle between the direction of the burst and the density gradient [Davies, 1965].

Interesting to note is that during most of the time of high solar activity (2004–early 2006) Cassini passed through the 15 LT sector close to periapsis mainly within the Enceladus plasma torus. Possibly the presence of the plasma torus in combination with an oblique incidence makes the detection of type III bursts difficult although the bursts should still be visible at frequencies lower than 1.2 MHz.

The future increase of the solar activity will be an opportunity to analyse more solar bursts and to confirm, or not, our investigations.

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