SOLAR TYPE II RADIO BURSTS: EMISSION FROM SHOCK SEGMENTS WITH A COLLAPSING TRAP GEOMETRY?

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ABSTRACT

The nature of the band-split type II burst radio emission is discussed. Examples are shown in which the extrapolations of band-split lines of type II bursts recorded in the hecto-kilometric wavelength range fit to the local frequency jump caused by the passage of the associated interplanetary MHD shock wave at 1 AU. Such cases favour the interpretation of band-split in terms of the emission from the upstream and downstream shock region. On the other hand type II bursts sometimes show relative band-splits smaller than 10%, indicating that even low amplitude shocks can excite the type II burst emission. This implies that an additional mechanism is accelerating electrons at such shocks. It is proposed that the band-split type II emission is excited at quasi-perpendicular shock segments forming a collapsing trap geometry. In such a configuration a particular magnetic field line intersects the shock front twice forming a system of two approaching magnetic mirrors in which electrons can be accelerated.

Key words: Sun: radio emission, shock waves, MHD.

1. INTRODUCTION

Solar radio type II bursts are observed over a broad frequency range, from decimeter to kilometer wavelengths (Nelson & Melrose, 1985, Bougeret, 1985). The emission is characterized by a relatively narrow bandwidth ($\Delta f/f \approx 20\%$) showing a comparitively slow drift from high to low frequencies in the dynamic radio spectrum (Figure 1). The frequency drift is typically $\approx 1$ MHz s$^{-1}$ in the metric range, dropping down to $\approx 0.1$ Hz s$^{-1}$ in the kilometric range (Vršnak et al., 2001, 2002a). Such a frequency drift corresponds to source velocities of $v \approx 100$-1000 km s$^{-1}$, indicating that the emission is exited by MHD shocks sweeping through the corona and interplanetary (IP) space.

Type II burst emission shows the fundamental (F) and harmonic (H) emission band, both frequently split in two parallel lanes that show a similar intensity and frequency drift characteristics (Figure 1; see also the examples in Vršnak et al., 2001). Such an emission, presumably excited in a single source, can be explained in different ways (see Vršnak et al., 2001 and references therein). Here we present arguments favoring an interpretation in terms of plasma emission from upstream and downstream shock regions (Smerd et al., 1974, 1975), in particular from the quasi-perpendicular shock segments forming a collapsing trap geometry.

2. OBSERVATIONS

In the analysis we utilize measurements of 44 band-split type II bursts observed in the metric-to-kilometric wavelength range, as well as some of the results based on the measurements and presented by Vršnak et al. (2001, 2002a,b). Out of the 44 events, 12 events were recorded by the radio spectrograph of the Astrophysikalisches Institut Potsdam covering the frequency range 40-800 MHz (Mann et al., 1992) and 6 were observed by Culgoora Solar Observatory radio spectrograph sweeping over the frequency range 18-1800 MHz (Prestage et al., 1994). The dynamic spectra of 10 type II bursts recorded in 1-11 MHz range and 16 events recorded below 1 MHz are provided by The Radio and Plasma Waves Investigation aboard the Wind spacecraft (Bougeret et al., 1995).

A procedure analogous to the one proposed by Smerd et al. (1974, 1975) was applied in the analysis of the chosen set of type II bursts. The source velocity $v^*$ was estimated from the frequency drift of the lower frequency branch of band-split ($\partial f_L/\partial t$). The velocity of the source relative to the solar wind $v = v^* - w$ was then estimated using different model values for the solar wind speed $w(R)$. On the other hand, measurements of the relative bandwidth, defined as $BW = (f_u - f_L)/f_L$, where $f_u$ is the frequency of the upper frequency branch of band-split, provide


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the value of the density jump \( \frac{\rho_2}{\rho_1} \) at the shock front. The jump is related to the Alfvén Mach number \( M_A \) through the Rankine-Hugoniot relations (jump conditions at the shock front; cf. Priest, 1982). From the evaluated values of \( v \) and \( M_A \), the Alfvén speed can be determined as \( v_A = u/M_A \), and the magnetic field as \( B = \frac{v_A}{\mu_0 m_e n} \).

The results show that BDW and \( v \) are statistically related; Whereas the band-split increases in IP space, the velocity decreases (Vrsnak et al. 2002a,b). The outcome is that the analysis gives a plausible behaviour of the magnetic field and the Alfvén velocity from the corona to the Earth (Vrsnak et al. 2002a,b). These facts are indirectly in favour of the upstream/downstream interpretation of the band-split of solar radio type II emission.

In Figure 2 we present a more direct justification of the upstream/downstream interpretation. The graphs show dynamic spectra of two IP events, represented as the inverse frequency \( 1/f \) versus time \( t \) (the dynamic spectrum of the event drawn in Figure 2b is shown in Figure 1). Such a representation of the spectrum is very useful (cf. Reiner et al., 2001) since in the IP space the density decreases as \( n \propto R^{-2} \), so \( R \propto \sqrt{1/n} \propto 1/f \). When the emission source moves at a constant radial velocity, in the \( 1/f \) versus \( t \) representation the emission lane follows a straight line.

The measurements of the lower frequency branch (LFB) are represented in Figure 2 by circles and the bold line showing the linear least squares fit. The upper frequency branch (UFB) is drawn by crosses and the thin line. The amplitude of the local frequency jump caused by the passage of the shock front at 1AU is shown by the vertical line (compare with the lower-right panel in Figure 1).

The two graphs shown in Figure 2 are revealing that in these two events the type II burst band-split emission originates from the upstream and downstream shock regions. We note that in the type II bursts not showing the band-split, the extrapolation of the emission lane frequently points to the base or the peak of the local frequency jump caused by the passage of the associated shock (e.g., see the fragment of the emission lane denoted as "Z" in the main panel of Figure 1a and the associated local plasma frequency jump at around 01:30 UT).

3. SUMMARY OF RELEVANT OBSERVATIONAL FACTS & IMPLICATIONS

In the following we briefly summarize the observational results relevant for the interpretation of the band-split type II burst emission.

1. Examples can be found in which extrapolations of LFB and UFB of IP type II bursts point to the base and the top of the local frequency jump associated with the shock passage at 1 AU.

2. The relative band-split BDW and source velocity \( v \) are (statistically) related: the velocity decreases in the IP space, whereas BDW increases.
3. The band-split in IP-events can attain BDW > 0.7 (see Vršnak et al., 2002a).

4. Band-split in C-, UC-, and IP-events can be BDW < 0.1 (cf. Mann et al., 1996, Vršnak et al., 2002a,b).

5. Band-splitting is more frequently observed in coronal than in UC/IP type II bursts.

6. In IP space the orientation of the magnetic field changes randomly, covering the whole 0 < φ < 360° range. In the case of the event shown in Figure 1 one finds φ ≈ 100°, i.e., the magnetic field was nearly perpendicular to the Sun-Earth direction.

7. The electron plasma oscillations dominate in the upstream shock region, whereas the low-frequency waves are found in the downstream region (Gurnett, 1985). Therefore both can only be present in the shock transition region.

From these observational facts the following implications can be drawn:

- Since the low- and high-frequency oscillations are both necessary to excite the emission at the fundamental plasma frequency (being dominant band in IP type II bursts; Bougeret, 1985) the items 7 indicates that the type II burst emission must originate from the shock transition region and/or its close vicinity (see e.g. Mann et al. 1995).

- Item 1 directly favours the upstream/downstream interpretation. Note that such a relationship can be expected only in case when the radio emitting segment of the shock is heading towards the Earth, and when solar wind density along its trajectory is comparatively “stable”, following the n ∝ R⁻² dependence.

- Item 2 is consistent with the upstream/downstream interpretation since such a relationship between the shock velocity and its amplitude is expected when shocks are propagating in a decreasing Alfvén velocity medium.

- Item 3 favours quasiperpendicular propagation since in the β ≈ 1 IP-plasma there is an upper limit for the amplitude of the longitudinal shock (BDW < 0.22 for β = 1, the limiting value decreasing with increasing β; cf. Priest, 1982).

- The quasiperpendicular nature of the shocks generating band-split type II burst emission also explains the item 5: Conditions for the quasiperpendicular propagation are more easily found in the corona due to the bipolar nature of the active region field.

- Item 6 shows that the IP field is not purely radial but has fluctuations which provide magnetic field line geometry appropriate for the quasiperpendicular propagation.
• Item 4 indicates that some of the shocks exciting band-split emission are very weak - an additional acceleration mechanism is needed to explain the electron population that is energetic enough to excite the plasma emission.

4. INTERPRETATION AND DISCUSSION

Bearing in mind the facts mentioned in the previous section we propose that the band-split type II burst emission originates from the quasiperpendicular shock regions at the locations where the shock and the field lines form a collapsing trap geometry (Figure 3). In the coronal and IP environment it is likely that there are regions where the shock front intersects a particular set of magnetic field lines twice (see Sect. 3, item 6). Note that such a geometry can be sometimes inferred from in situ plasma measurements (Bale et al., 1999).

In the collapsing trap geometry, which can be formed either due to the field line curvature or the shock front bending, the plasma is trapped between two approaching magnetic mirrors (gray region in Figure 3). The electrons accelerated at the shock front bounce between the mirrors, each time gaining energy (Mann et al. 2002).

In this way even weak shocks (showing small BDW) can generate plasma emission. The trapped electrons emit at the upstream plasma frequency \( f_L \propto \sqrt{n_1} \), creating the lower frequency branch of the band-splitting. After a short time (determined by the shock/field geometry and the shock speed) the shock front overtakes a given field line entirely. The excited plasma is compressed to \( n_2 \), and emits at \( f_U \propto \sqrt{n_2} \) creating the upper frequency branch.

Finally we stress one more important aspect of the model. In each reflection the electron velocity component parallel with the magnetic field line increases and the pitch angle of the trajectory decreases. This means that a fraction of accelerated electrons escape from the trap before the shock embraces a given field line (Vandas & Karlický, 2000). These electrons escape along the downstream magnetic field lines which are nearly parallel with the shock. If the shock front is inclined with respect to the general density gradient (denoted as \( \nabla n_1 \) in Figure 3) the escaping electron beams will create a fast-drifting radio signatures with starting frequency \( f_L < f < f_U \). The downward directed ones (denoted as HB in Figure 3) will have a positive frequency drift and those moving upwards (HB in Figure 3) will show a negative frequency drift. Obviously, such a radio signature corresponds to the well-known herring-bones in type II bursts (cf. Nelson & Melrose, 1985).

1 Note that the model is qualitatively similar to the "wavy shock model" (Zlobec et al., 1993, Vandas & Karlický, 2000). For the role of the collapsing trap in the reconnection outflow jet in flares see Somov & Kosugi (1997).

REFERENCES


Mann, A., Aurass, H., Voigt, W., Paschke, J., 1992, ESA SP-348, 129


Vandas, M., Karlický, M. 2000, Solar Phys. 197, 85


Vršnak, B., Magdalenič, J., Aurass, H. Mann, G. 2002a, this issue
