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On the Possibility of Radio Emission from Quasi-parallel and Quasi-perpendicular Propagation of Shocks

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Abstract. A set of 21 solar type II radio bursts observed using Hiraiso radio spectrograph have been analysed to study the direction of propagation of coronal shocks. A simple analysis is carried out to find the approximate angle between the shock normal and magnetic field by solving the Rankine-Hugoniot MHD relation with assumption of Alfven speed and plasma beta. From this analysis, it is suggested that both quasi-parallel shocks (favourable) and quasi-perpendicular shocks can generate type II bursts depending upon the circumstances of the corona.

Key words. Radio emission — shocks — type II bursts.

1. Introduction

The direction of propagation of shock with respect to the magnetic field is important for understanding of plasma hypothesis. It is very difficult to determine the angle by using the remote observations of solar type II radio bursts due to lack of direct knowledge about the magnetic field and the uncertainty about the location and trajectory of the source regions. Earlier attempts to resolve this issue using both theoretical as well as observational evidences contradict each other (e.g., McLean & Labrum 1985; Mann *et al.* 1995; Thejappa *et al.* 1997; Aurass *et al.* 1998)

2. Analysis of type II bursts

2.1 *Relative instantaneous bandwidth*

The relative instantaneous bandwidth of the backbone of type II bursts can be estimated from the relation, $\Delta f/f = (f_u - fi)/fi$, where f_u and fi are the upper and lower frequencies at a particular time of a type II burst (Mann *et al.* 1995). The mean relative instantaneous bandwidth for the 21 type II bursts is in the range of 0.17 — 0.7 (the fifth column in Table 1). The error in estimating this value would be 10—15% due to the diffuse edges of the backbone of type II bursts.

Table 1. List of properties of type II bursts from Hiraiso

Date	Burst time(UT)	Freq. range	$\langle f_h/f_f \rangle$	$\langle \Delta f/f \rangle$	$\langle N2/N1 \rangle$	D_f MHz s^{-1}	V^*_{shock} km s^{-1}
950203	0155 – 0214	130 – 55	..	0.28	1.90	0.25	875
950221	0328 – 0342	90 – 50	2.15	0.27	1.61	0.07	405
950313	0656 – 0711	60 – 40	1.97	0.31	1.72	0.05	517
950702	0002 – 0010	170 – 80	?	0.24	1.54	0.21	475
950702	0007 – 0017	95 – 50	2.0	0.23	1.51	0.08	437
950702	0017 – 0023	80 – 40	2.0	0.36	1.85	0.13	978
950916	2110 – 2114	50 – 30	2.0	0.34	1.80	0.05	773
951012	0306 – 0312	300 – 120	?	0.17	1.37	0.43	440
951012	0604 – 0620	350 – 50	2.0	0.48	2.19	0.50	550
951013	0504 – 0520	400 – 45	2.05	0.57	2.47	0.52	636
960422	0446 – 0449	300 – 30	1.95	0.41	2.00	0.41	603
960822	0759 – 0807	110 – 70	2.10	0.34	1.80	0.13	497
970512	0454 – 0508	80 – 30	..	0.39	1.93	0.06	525
970521	2011 – 2023	140 – 30	2.0	0.50	2.25	0.17	808
970727	2025 – 2031	130 – 35	2.05	0.34	1.80	0.25	945
970924	0248 – 0258	80 – 30	?	0.34	1.80	0.08	700
971103	0437 – 0448	260 – 55	2.0	0.60	2.56	0.40	672
971104	0559 – 0606	230 – 30	?	0.70	2.89	0.45	957
971114	0131 – 0139	100 – 40	2.10	0.43	2.07	0.13	752
980126	2228 – 2243	95 – 30	2.0	0.29	1.67	0.08	570
980127	2215 – 2218	180 – 80	2.0	0.33	1.77	0.43	930

*This estimate is based on the observed drift rate noted above and a density enhancement factor 4.

2.2 *Density jump*

From *in situ* measurements of interplanetary shock waves it was suggested that the radiating source of solar type II radio bursts is in the vicinity of the transition region of upstream and downstream region of shocks (Mann *et al.* 1995). Also the instantaneous bandwidth of solar type II radio burst is assumed to be due to the density jump. Then the relative instantaneous bandwidth of a type II burst can be related to the density jump across the shock as, $\Delta f/f = \sqrt{N_2/N_1} - 1$, where N_1 and N_2 are the electron densities in the upstream and downstream respectively. Using this relation and the derived values of relative instantaneous bandwidth, we obtained the density jump to be in the range 1.37-2.89.

2.3 *Angle between shock normal and magnetic field*

The Alfven-Mach number represents the strength of the shock: $M_A = V_{Shock}/V_A$. TO start with, assuming $V_A = 350$ km s^{-1} (possible explanation for assuming this value of V_A is given below), the Alfven-Mach number was estimated for each type II burst to be in the range between 1.2 and 2.8.

The Rankine-Hugoniot relation relates all the quantities of shocks in both upstream (ahead of the shock) and downstream (behind the shock) regions. For an oblique shock, the Rankine-Hugoniot MHD relation is given (Priest 1982) as,

$$(M_A{}^2 - X)^2\{\gamma\beta X + M_A{}^2\cos^2(\theta)[(\gamma-1)X - (\gamma+1)]\} + M_A{}^2 X\sin^2(\theta)\{[\gamma + (2-\gamma)X]M_A{}^2 - X[(\gamma+1) - X(\gamma-1)]\} = 0 \quad (1)$$

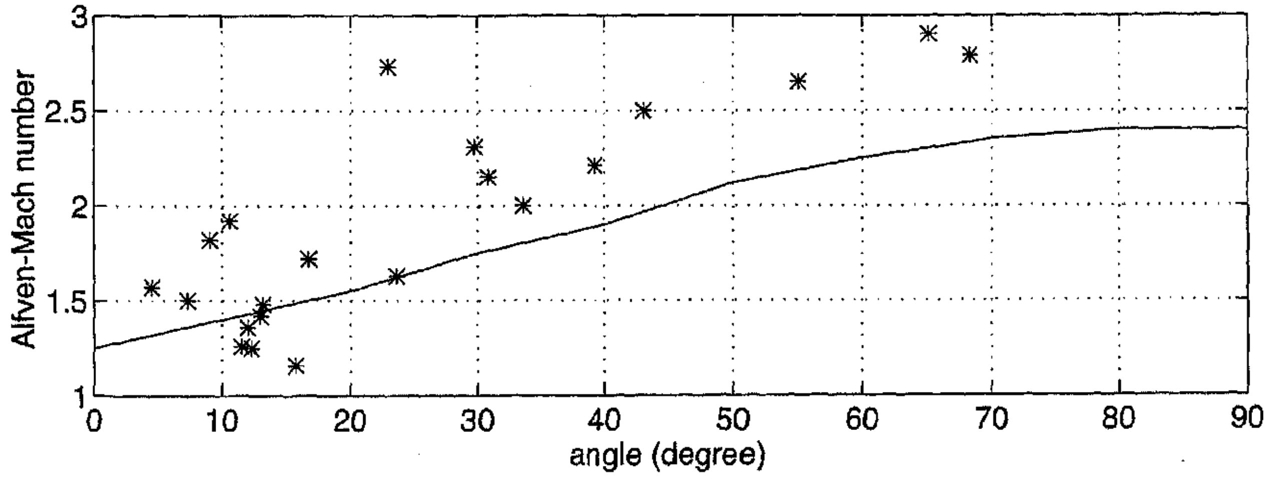

Figure 1. Plot showing the angle between shock normal and magnetic field for all type II bursts. (Please see the text for more details).

where $X = N_2/N_1$, $\gamma = 5/3$ and β is the plasma beta. Utilizing the derived values of Alfven-Mach number and density jump and assuming a plasma beta of 0.4, the angle between shock normal and magnetic field has been determined for each type II burst using the above relation. The results are shown in Fig. 1. In this figure, the solid line is the dependence of critical Alfven-Mach number on the angle for a plasma beta = 0.4. (which was obtained theoretically by Mann *et al.* 1995). Our observations are shown by the symbol '*' which gives the derived values of Alfven-Mach number and the angle between the shock normal and magnetic field. It is apparent that many of the type II bursts (~ 18) show the angle below 45°. This means that these type II bursts may be generated by quasi-parallel shocks. Only three cases show the angle above 45° which means that they may be generated by quasi-perpendicular shocks. The spread in the Alfven-Mach number is due to the range of values of shock speed as given in Table 1.

3. Discussion

Earlier observational results have shown that the Alfven speed has a range of values depending upon the magnetic field and electron density. For example, assuming the basic plasma parameters, magnetic field B = 1G, coronal temperature $T = 2 \times 10^6$ K and electron density $N_e = 5 \times 10^{13}$ m^{-3} for a four-fold Newkirk's model at 60 MHz level, the Alfven speed (V_A) and plasma beta (β) are estimated as 308 km s^{-1} and 0.4 respectively. These values are estimated using the relations $V_A = 2.18 \times 10^{16} B/(m_e N_e)^{1/2}$ m s^{-1} and $\beta = 3.47 \times 10^{-28} N_e T B^{-2}$ (McLean & Labrum 1985). A mean value of Alfven speed in the distance range 1.2 - 4$R_{\odot}$ where type II bursts are generated, lies between ~350 - 450 km s^{-1} (Bougeret 1985). Hence the assumption of V_A = 350 km s^{-1} and $\beta = 0.4$ seems to be a reasonable one in (1). The effect of variation of the parameters Alfven speed and plasma beta in the direction of propagation of shocks will be published elsewhere.

Our analyses are in agreement with Mann *et al.* (1995), Thejappa *et al.* (1997) and Aurass et al. (1998) that both quasi-parallel and quasi-perpendicular shocks are involved in the generation of type II radio emission. However, the shock normal angles estimated by using the assumption of Mann *et al.* (1995) do not represent the actual values. Because, they suggested that the type II emission is originated at the transition regions and the bandwidth of the emission is a measure of density jump across the shock. But, recent spacecraft observations show that Langmuir waves occur only in the upstream regions, indicating that type II emission occurs only in the upstream regions (Lengyel-Frey *et al.* 1997; Thejappa *et al.* 1997; Bale *et al.* 1999). In any case, if the emission is assumed to occur at the fundamental, the bandwidth is determined by the spectral width of the Langmuir waves due to thermal motion of electrons, doppler broadening due to thermal motions of ions and due to the density fluctuations in the ambient plasma, not the density jump across the shock. The complexity of the processes involved is high and it may not be easy to understand all the features from solar spectrograph data alone.

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