Astron. Astrophys. 140, 205–209 (1984)

ASTRONOMY
AND
ASTROPHYSICS

Research Note

The relationship between coronal transients, Type II bursts and interplanetary shocks

H. V. Cane

Netherlands Foundation for Radio Astronomy, Dwingeloo, The Netherlands

Received October 25, 1983; accepted June 25, 1984

Summary. Recent observations have shown that the picture of coronal mass ejections (CME's) driving the shocks which produce coronal (C) Type II radio emission, faces severe difficulties. Meanwhile the correspondence between a large number of interplanetary (IP) shocks and CME's has been established. These results can be understood if there are two types of shocks i.e. that coronal shocks (observed via their radio emission) are not the progenitors of IP shocks. However a relationship between C shocks and IP shocks has been established. This is that C Type II bursts associated with IP shocks which generate IP radio emission, commence at lower frequencies than other C Type II bursts. A possible scenario which can explain this result and yet be consistent with a two shock model, is one in which the C shock commences below the transient, which later drives an IP shock, and radio emission is generated when the C shock catches up to the mass ejection. Within the limitations of available data the model fits some events. No model satisfies all the observations.

Key words: shock waves – coronal transients – solar radio radiation – solar flares

1. Introduction

It has long been assumed that interplanetary (IP) shocks are driven by material ejected from the solar corona (see e.g. Hundhausen, 1972). Although the first observations of coronal mass ejections (CME's) were obtained in the early-1970's, it was not until recently that a spacecraft has been suitably located to enable a study of the IP consequences of CME's. Using Helios and Solwind data, Schwenn (1982) and Sheeley et al. (1983) have shown that "almost all" low-latitude, high-speed CME's were associated with shocks at Helios 1. Thus, although there is not a one-to-one correspondence between CME's and IP shocks, a relationship between certain subsets of these phenomena has been established.

One of the earliest results from studies of solar-terrestrial relations was the occurrence of geomagnetic storms after meter-wavelength Type II bursts (Roberts, 1959). Type II bursts were also shown to precede IP shock observations (Hundhausen, 1972). Soon after the discovery of Type II bursts, it was realized that the emission must be generated by a shock so it was reasonably assumed that the coronal (C) shocks which produced the radio emission were the progenitors of IP shocks. This assumption was extended to imply that C shocks are the bow shocks of CME's and that the Type II radio emission should be associated with the leading edge of CME's (Dulk et al., 1976; MacQueen, 1980).

2. CME's and C Type II bursts

Early studies (Gosling et al., 1976) showed that all transients with velocities greater than $400\,\mathrm{km\,s^{-1}}$ were associated with a C Type II burst, and this result provided support for the scenario described above. However recent observations have cast serious doubts on this supposed relationship between C Type II bursts and CME's. These observations are discussed by Wagner (1982) in a report of the conclusions of the SERF Mass Motions Workshop in Annecy, France, 1981. The three major points are:

1. Evidence for Type II sources behind the leading edges of loop transients (Gary, 1982; Gary et al., 1983).
2. Velocities of Type II disturbances are greater than velocities of CME's (Gergely, 1984).
3. Commencement of mass motions before flares (Sawyer et al., 1982). These points are also discussed by Wagner and MacQueen (1983). Note however, that point 1 is weakened by the uncertainties in derived source positions because of radio wave refraction in the ionosphere and by possible wave ducting in the corona (Dulk et al., 1979).

Early observations of Type II bursts showed that they were flare related and commenced within a few minutes of the maximum in Hα (Roberts, 1959). Type II bursts always commence after the impulsive phase, as indicated by Type III bursts and hard X-ray bursts, and led to the idea that the responsible disturbances were generated in the impulsive phase (Kundu, 1965). The time gap of a few minutes corresponded to the time it took the disturbance to reach a height where it was capable of generating radio emission.

In contrast, it has been found for a number of flare-related CME's that extrapolation of the height-time curve to the low corona intercepts the time axis before the flare commences (see Wagner, 1982). The straight extension of the height-time curve appears justified because of the lack of observed acceleration for flare-related CME's (MacQueen and Fisher, 1983).

The observations discussed above have led Wagner and MacQueen (1983) to propose that the shock which excites the C Type II radio emission arises from the impulsive flare input and that the outward propagation of this shock is not physically coupled to the transient. Kosugi (1976) reached a similar conclusion from the analysis of a specific event.

Since the paper by Wagner and MacQueen a further important result has been obtained. A comparison of Solwind CME data and

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Send offprint requests to: H. V. Cane, Astronomy Program, University of Maryland, College Park, MD 20705, USA

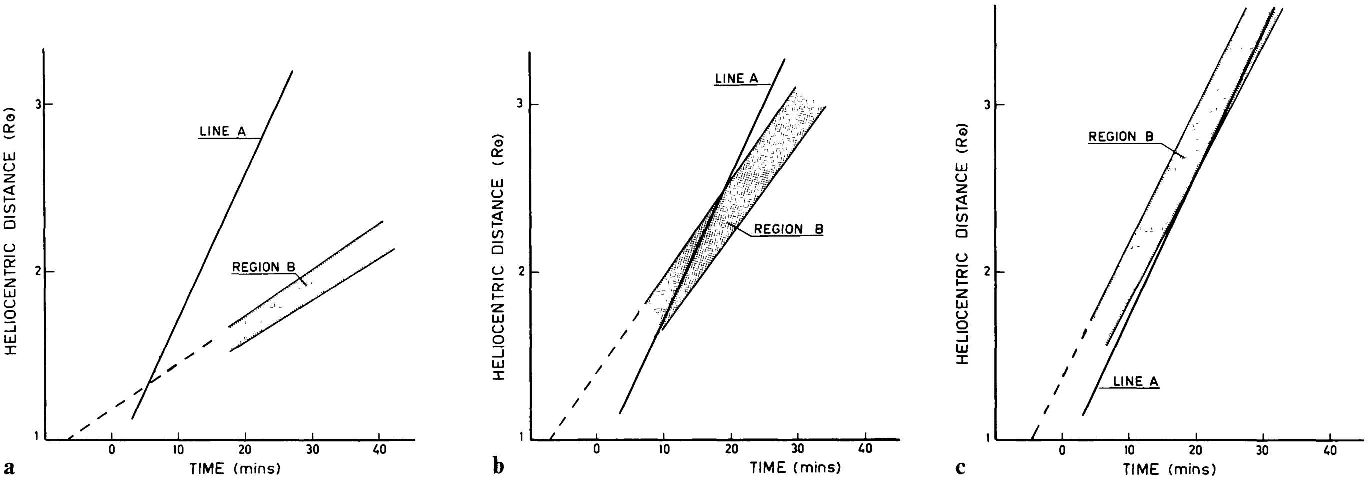

Fig. 1a–c. Schematics showing the height range of interaction between a shock of velocity 1000 km s^{-1} (represented by line A) and a 0.3 solar radii thick region of a transient (represented by region B) with velocity of (**a**) 300 km s^{-1} (**b**) 700 km s^{-1} and (**c**) 900 km s^{-1}. The height of the interaction is a function of the transient velocity. For the slow transient the line A does not intersect region B and so there is no radio burst

Culgoora radio spectra (Sheeley et al., 1984) has shown that not all fast CME's are associated with a C Type II burst. Likewise, some Type II bursts are not associated with CME's. Neglecting the effects of the ambient medium and assuming that velocity is the only parameter to be considered, the first result provides support for the idea that C shocks are not the bow shocks of CME's. This was not mentioned by Sheeley et al. Instead, in discussing the second point, they introduced the concept of two classes of C Type II bursts, those that are driven and those that are blast waves. This concept was also discussed by Rust (1983) in trying to explain why some C Type II bursts are associated with IP shocks and particle acceleration whereas the majority are not. This scenario is no less complex than introducing the concept of two shocks. Moreover, Uchida has consistently maintained that the disturbances responsible for coronal Type II radio bursts are blast waves (see discussion IAU Symp. 91, p. 255, 1979). Uchida (1974) has suggested that Type II bursts are produced in regions of low Alfven velocity where the shock strengthens. He has obtained agreement with observations employing such a model. The observed high coincidence of CME's and C Type II bursts could indicate that, given a CME, this is the most likely place for a blast wave to steepen. The enhanced density would mean a lower Alfven velocity. In other words, C Type II bursts are not directly related to CME's but that given the presence of a CME this is where the radio emission will be generated.

3. Interplanetary Type II events

Observations of IP Type II events as made by the radio astronomy experiment on ISEE-3 have been reported by Cane et al. (1982) and Cane and Stone (1984). These events have been associated with solar flare phenomena and IP shocks. The majority of the events were preceded by a C Type II burst and in the reports it was assumed that the low frequency events were the direct continuation of the meter wavelength bursts. This could not be shown directly because of the lack of data coverage between about 20 and 2 MHz. However an analysis of the drift rates of the IP emission (less than 500 kHz) led Cane (1983) to suggest that this low frequency emission was not the extension of the meter wavelength phenomenon. Assuming a close relationship between IP shocks and CME's a separate origin for C and IP shocks does not disagree with the model of Wagner and MacQueen.

The separateness of C and IP shocks is apparently in discord with the result (Cane and Stone, 1984; Robinson et al., 1984) that the starting frequencies of C Type II bursts associated with IP Type II events are lower than the average for all C Type II bursts. However the model presented in the next section can explain this apparent relationship between C and IP shocks without necessitating that they be the one and the same shock. The model assumes that IP Type II events are only associated with the fastest transients. Although a detailed comparison of IP Type II events and CME's has not been made, initial comparisons (Cane and Stone, 1984) indicate that the CME's associated with IP Type II events are fast (velocities >1000 km s^{-1}).

4. The model

The model is based on the three points in Sect. 2 and on the assumption that (i) C Type II emission is preferentially generated within the density enhancements of CME's and (ii) that IP Type II events are associated with the fastest transients.

In the model C shocks are initiated near the solar surface and have velocities of 1000 km s^{-1}. Coronal transients are initiated a few minutes earlier at about 1.3 solar radii and have velocities which range from 300–900 km s^{-1}. Transient velocities have been observed up to 1825 km s^{-1} (Sheeley, private communication) but the values used are just for illustration of the basic idea. The region effective for production of radio emission is 0.3 solar radii thick.

Figures 1a–c show height versus time plots for transients (region B) with velocities (a) 300 km s^{-1}, (b) 700 km s^{-1} and (c) 900 km s^{-1}. The C shock is represented by line A. Figure 1a shows that for a slow transient the C shock and region B intersect briefly, low in the corona where the transient is evolving. Figure 1b corresponds to the most common class of event. Line A intersects region B over the height range 1.6–2.5 solar radii. This range corresponds to plasma frequencies from about 80–25 MHz, the frequency extent of typical Type II bursts. Finally, Fig. 1c shows that C Type II emission will commence high in the corona (i.e. at a low frequency) when the transient is fast.

Table 1. Properties of 15 events for which there is information about the coronal mass ejection and the meter wavelength Type II burst. ΔT is the time difference between the projected initiation time of the mass ejection (T_{proj}) and the start of the Type II burst (T_{II}). Δt is the time difference between the start of the impulsive phase (T_{imp}) and T_{II}. The upper and lower values for T_{imp} correspond to the start of the Hα and the start of the associated Type III bursts respectively. The heights and Type II velocities are deduced from the data

Date	T_{proj}	T_{imp}	T_{II}	ΔT	Δt	F_S	V_{TR}	Ht	V_{II}
	U.T.			min		MHz	km s^{-1}	R_0	km s^{-1}
07 29 79	0315	0321	0330.5	14.5	8.5	60	500	1.6	
		0329.5			1.0				3480
08 26 79	0130	0130	0205	35	35	40	450	2.4	–
09 02 79	0000	0006	0042.5	42.5	36.5	25	750	3.8	
		0033			9.5				3053
11 15 79	2150	2122	2237.5	47.5	25.5	50	1200	5.9	
		2226			11.5				4640
02 27 80	0330	0327	0344.5	14.5	17.5	60	600	1.8	–
04 03 80	0710	0707	0708.5	− 1.5	1.5	50	1100	–	–
		0705.5			3.0				
04 12 80	2030	2039	2053	23	14	45	400	1.8	
		2040			13				446
06 29 80	0230	–	0241	11	–	90	560	1.5	
		0233			8				290
11 22 80	2250	–	2307.5	17.5	–	80	450	1.7	
		2306			1.5				3093
02 05 81	2300	2224	2248.5	−11.5	24.5	80	560	–	–
		2248.5			–				
02 23 81	0650	0655	0704	14	9	50	540	1.7	
		0658			6				773
03 25 81	2055	2040	2042.5	−12.5	2.5	45	1030	–	–
		2043			− 0.5				
04 01 81	0130	0115	0137.5	7.5	22.5	30	1250	1.8	
		0133			4.5				1289
05 08 81	2230	2203	2233.5	3.5	30.5	45	1000	1.3	–
		–			–				
10 12 81	0430	0427	0436	6	7	100	1000	1.5	
		0432			4				580

The model implies that the starting frequencies of C Type II bursts are related to CME velocities. Some data exist to test this relationship. The paper by Sheeley et al. (1984) presents CME velocities and projected lift-off times for a number of events in which a Type II burst was detected at the Culgoora observatory. The starting frequencies and times of all Culgoora Type II bursts are given in the catalog of Robinson et al. (1983). Using these data the relationship between Type II starting frequency and time, and transient velocity has been investigated. Only the events with a single Type II burst and with both harmonic and fundamental bands present were used. In addition it was necessary to discard events with uncertainties in the projected transient timing. This meant that there were only 15 events which could be used and these are listed in Table 1. The time differences are also shown in Table 1. The difference between the transient projected start time (T_{proj}) and the start of the Type II burst is given by ΔT. The difference between the start of the impulsive phase (T_{imp}) and the start of the Type II burst is given by Δt. The impulsive "phase" is defined by either the start of the Hα or the start of associated Type III bursts. These are given in the upper and lower row respectively. Using the Hα time there were only 4 events in which the impulsive phase started after the transient lift-off time. Using the Type III bursts this was augmented to 9 events. In other words the transient preceded the flare in less than 60% of the cases for these 15 events. For 3 events it can be seen that the Type II burst started before the transient lift off time. The data for the other 12 events can be used to determine if the transient and the radio burst are related. The relationship between the two phenomena according to the model presented is shown in Fig. 2. The height reached by the leading edge of the transient;

$$H = V_{\mathrm{TR}} \Delta T,$$

where V_{TR} is the velocity of the transient. The calculated heights are given in Table 1. These heights can then be compared with the starting frequencies and this comparison is shown in Fig. 3. The fact that the heights increase with decreasing frequency is consistent with there being a relationship between the radio emission and the transient. Assuming the Culgoora density model i.e. that the 80 MHz and 40 MHz levels occur at 1.6 and 2 solar radii (heliocentric distance) respectively, the data suggest that the distance d, between the leading edge of the transient and the lower part of the radio emitting region is zero (for clarification see Fig. 3).

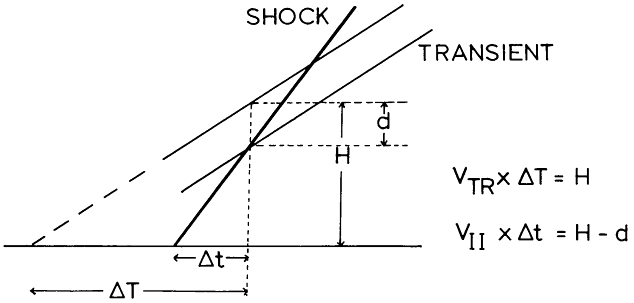

Fig. 2. A sketch showing that the height at which the radio emission commences is a function of the timing difference between the projected transient lift-off time and the impulsive phase and of the transient velocity V_{TR} and the coronal shock velocity V_{II}. The calculated height depends on the assumed distance d

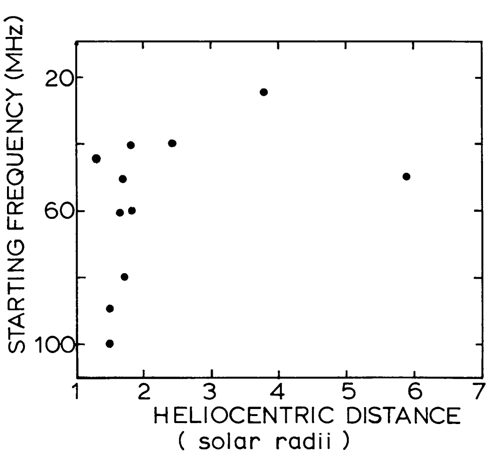

Fig. 3. Deduced height at which radio emission is generated assuming it comes from the associated transient. These heights are calculated assuming the emission is generated at the leading edge of the transient i.e. d is zero. Assuming the emission is generated within the transient then the points should be shifted to the left by the distance d

In other words this plot is actually more consistent with the radio emission coming from the transient than from behind if the Culgoora density scale is correct. However the question of coronal densities is still open to debate. For a further test of the model presented one needs information about the coronal shock velocities. However one can calculate the velocities assuming the model and see if they are reasonable. The coronal shock velocity V_{II} is given by;

$$V_{\mathrm{II}} = (V_{\mathrm{TR}} \Delta T - d)/\Delta t .$$

For the 9 events left to test this parameter the calculated velocities range from 290 to 4640 km s^{-1} and are shown in Table 1. For these calculations the start of the Type III bursts was used to define the impulsive event and the distance d was taken to be 0.3 solar radii. The calculated velocities are within the range obtained from the drift rates of meter wavelength Type II bursts.

5. Discussion

Below I list the various observations or reasons for and against the two scenarios discussed above.

5.1. CME's drive shocks responsible for C Type II bursts

For:

1. This picture is the simplest without consideration of a number of observations listed below.
2. In energetic events C Type II bursts exhibit a phenomenon called herringbone structure (Roberts, 1959). This structure consists of fast drift bursts emanating from the Type II burst and results from the streaming of electrons up and down field lines, presumably after acceleration at the shock. Sometimes the electrons escape to the IP medium and hence must be on open field lines. Presumably there are only closed field lines within CME's. Since there is no gap observed between the backbone of a Type II burst and the herringbone these emissions must be generated in the same region and therefore in front or outside of a CME.

Against:

1. Some Type II radio emissions have been located behind the leading edge of the associated transient.
2. Velocities of C Type II bursts are higher than those observed for CME's.
3. Type II bursts are flare related and commence after the flare commences. Some transients have extrapolated starting times which precede the associated flare.
4. There are fast CME's without C Type II bursts.

5.2. CME (IP) shock and coronal shock separate

For:

1. Many of the properties of C Type II bursts suggest that they are blast waves rather than driven waves as they would be if they were the bow shocks of CME's.
2. There are C Type II bursts without CME's.

Against:

1. The introduction of two shocks is a complicated model.
2. IP Type II bursts and C Type II bursts are apparently related because the starting frequencies of C Type II bursts associated with IP Type II events are lower than those for all C Type II bursts.
3. Most IP Type II bursts are preceded by a C Type II burst.

6. Conclusion

A model has been proposed which can account for the apparent relationship between IP and C Type II bursts in the framework of the model described by Wagner and MacQueen (1983). To explain C Type II bursts which occur in the absence of CME's it is proposed that C Type II emission occurs preferentially, but not necessarily, within CME's where the blast wave is most likely to strengthen. It has been shown that this model can explain a number of phenomenon. However there appears to be no model which explains all the observations.

Acknowledgements. I wish to thank T. E. Gergely and N. R. Sheeley for useful discussions and for critically reading the manuscript. This work was commenced when the author was a guest at the Raman Research Institute, Bangalore, India.

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