CLARK LAKE RADIO OBSERVATIONS OF CORONAL MASS EJECTIONS

N. Gopalswamy
Astronomy Program
University of Maryland
College Park, Maryland 20742

Abstract

We review some recent studies of mass ejections from the Sun using 2-D imaging observations of the Clark Lake multifrequency radioheliograph. Radio signatures of both fast and slow coronal mass ejections (CMEs) have been observed using the Clark Lake radioheliograph. Using temporal and positional analysis of moving type IV and type II bursts, and white light CMEs we find that the type II's and CMEs need not have a direct cause and effect relationship. Instead, the type II seems to be generated by a "decoupled shock", probably due to an associated flare. The moving type IV burst requires nonthermal particles trapped in magnetic structures associated with the CME. Since nonthermal particles can be generated independent of the speed of CMEs, moving type IV bursts need not be associated only with fast CMEs. Specific examples are presented to support these views.

1. Introduction

Coronal mass ejection (CME) has become a topic of primary interest over the past decade because of its interaction with coronal structures such as streamers and its association with shock waves (manifested as type II bursts) and other distrubances such as plasmoids or magnetic arches (manifested as type IV bursts). Such magnetic structures can be inferred from multifrequency radioheliographic observations (Gopalswamy and Kundu 1989a,b,c). Only a handful of simultaneous observations of CMEs and radio bursts are available and hence their exact physical relationship (e.g., the location of the radio sources with respect to the overall white light transient event) is poorly understood. Extensive reviews of CME radio burst associations are available in literature (e.g. Dulk, 1980; Stewart, 1985; Bougeret, 1985; Hildner et al, 1986). Here we concentrate only two aspects of this association: (i) Is the type II burst due to a shock piston driven by CME or by a blast wave from flare? (ii) Is there any CME speed limit to be associated with radio burst generation? We use specific events observed by the Clark Lake radioheliograph (Kundu et al 1983) and simultaneously by the Coronagraph

E. R. Priest and V. Krishan (eds.), Basic Plasma Processes on the Sun, 495–500.

Polarimeter aboard SMM satellite (SMM-C/P) to address these questions.

2. CME - Type II Association

Based on Skylab observations, there was no clear picture of the relative location of type II bursts and CMEs, which is crucial to understanding their association. MacQueen (1980) showed an example of a type II burst located in front of the leading edge of the CME, suggesting that it was being driven by the CME. Using observations from the P78-1 Solwind Coronagraph and the Culgoora radio heliograph, Sheeley et al (1984) and Robinson and Stewart (1985) found that some type II bursts lay at the leading edge of the CME, and others behind it, but rarely were they seen to precede the leading edge of the CME.

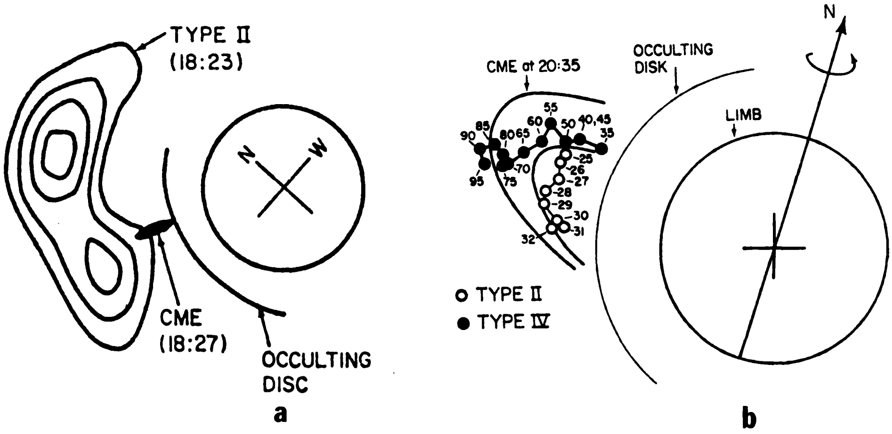

Figure 1. a) Superposition of type II centroids on the SMM-C/P difference image for the June 27, 1984 event. b) Superposition of type II and moving type IV centroids on the SMM-C/P CME loop for the February 17, 1985 event.

In order to understand the physical relationship between CME and type II, one has to consider the following: (i) CME - type II source timing (ii) relative location, (iii) relative velocities and (iv) directions of motion. A type II burst observed (Gary et al 1984) well below the associated SMM-CME leading edge was interpreted as due to blast waves produced by flare that followed the initiation of mass ejection (Wagner and MacQueen, 1983). However, Steinolfson (1984) presented an alternative model to the same event arguing that the shock was driven by the CME and attributing the type II-CME location to the specific geometry needed for the shock-drift acceleration proposed by Holman and Pesses (1983). Steinolfson's (1984) model explains a lower projected height for the type II relative to CME leading edge, but it was outside the CME loop all the time, attaining larger relative height at later times.

In Fig. 1(a) a type II burst at 30 MHz is superposed on the SMM-C/P image of June 27, 1984 CME (Gopalswamy and Kundu, 1987). The CME is a single clump of material with a small speed (350 km s^{-1}). The type II has a large extended structure with two prominent centroids, one ahead of and the other far north of it. The centroids are separated by a distance of ~ 2.2 $R_\odot$. The nearest type II centroid is ~ 0.4 $R_\odot$ ahead of the CME and the farthest one is ~ 1.5 $R_\odot$ away. The overall size of the type II burst is ~ 20 times bigger than that of the visible ejection. Clearly a bow shock ahead of such a small CME is inconsistent with a huge shock implied by the type II. If the shock were generated during the associated flare (which took place ~ 30 min after the initiation of CME) then it takes ~ 9 min to reach the observed height implying a speed of ~ 1500 km s^{-1}. This is ~ 5 times larger than the CME speed and hence the type II might have overtaken the CME. Type II bursts with speeds and trajectories different from those of CMEs have been reported earlier (Gergely, Kundu and Hildner, 1983).

Another example (Kundu et al, 1989) of a type II burst with speed and trajectory different from those of a CME which took place on February 17, 1985 is shown in Fig. 1(b). The filled circles are the centroids of a moving type IV burst. The open circles represent the centroids of 50 MHz type II burst. The speed of the CME and moving type IV are ~ 200 km s^{-1} in the radial direction whereas the type II centroid moved nearly parallel to the limb with a speed of ~ 1100 km s^{-1}. The type II burst started near the northern leg, but moved southward. The location of the type II burst is ~ 0.57 $R_\odot$ below the leading edge of the CME loop. Therefore, the relative locations, directions of motion and speeds of the CME and type II burst strongly suggest that the shock was not generated by the CME. Apparent metric burst source heights tend to be greater than the actual source heights, due to ducting (e.g. Duncan, 1979). Since in this case the apparent height of the type II lies below the CME, we can be confident that the actual height is also below the CME. Therefore, the type II shock might not have been piston-driven by the CME. The best alternative is that the associated flare, (evidenced by metric type III bursts and sharp rise in GOES soft X-rays - Kundu et al 1989) generated the shock. In addition to these examples none of the SMM-CME observations associated with metric type II bursts indicate a cause and effect relation between CMEs and type IIs (Wagner, 1984; Gopalswamy and Kundu, 1989b).

3. Radio Signatures of Coronal Mass Ejections

Based on Skylab CMEs and their temporal association with metric type II/type IV bursts, Gosling et al (1976) concluded the following:

a) If the speed of the CME, $V_{CME} < 400$ km s^{-1}, no type II or type IV bursts can be associated with the CME.

b) If 400 km $s^{-1} < V_{CME} <$ 700 km s^{-1}, either a type II or a type IV burst can be associated with the CME.

c) If $V_{CME} >$ 700 km s^{-1}, a type II - type IV burst pair can be associated with the CME.

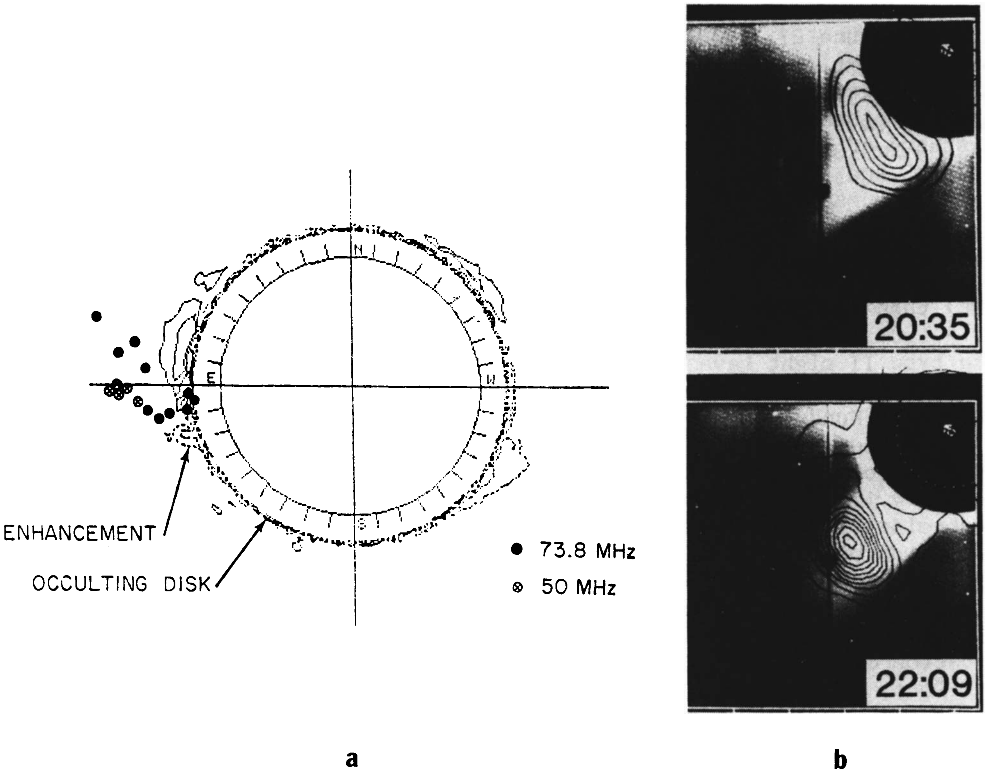

Figure 2. a) Superposition of moving type IV centroids on the Mauna Loa K-coronameter coronal enhancement picture for the February 2, 1986 event. b) Superposition of type II and moving type IV contours on the SMM-C/P CME for the February 17, 1985 event.

This result was based on temporal association. All positional comprisons were done by extrapolating radio and white light observations. During the period of operation of SMM, there were several simultaneous observations which compared the white light features of CMEs with imaging observations of radio bursts (Wagner et al 1981; Gary et al, 1984; Hildner et al 1986; Gopalswamy and Kundu, 1987; 1989b). Most of these events were high speed CMEs, except for the June 27, 1984 event (Gopalswamy and Kundu, 1987) which had a CME speed of ~ 350 km s^{-1} (still close to the 400 km s^{-1} limit), and the results obtained were in agreement with Gosling et al.'s (1976) conclusions. Observations with the SMM-C/P instrument during the sunspot minimum years 1985-1986 have indicated that slow CMEs with speeds $\lesssim$ 100 km s^{-1} occur far more commonly than previously realized (Hundhausen, 1988). Since the Clark Lake multifrequency radioheliograph had a sensitivity far superior to what was available with other instruments, we find that radio bursts of both type

II and type IV could be associated with slow CMEs.

Moving type IV bursts need not have any speed restriction because they primarily depend on non-thermal particles trapped in moving magnetic structures such as plasmoids and loops that accompany the CMEs. Therefore, even in principle, the speed requirement of Gosling et al (1976) seems inconsistent. If there are no non-thermal particles generated during a CME event, then the only radio signature possible is the enhanced thermal emission due to the denser coronal material contained in the CMEs as the thermal bremsstrahlung depends on the thermal electron density. Such an enhanced thermal emission was first reported by Sheridan et al (1978) for a Skylab era CME.

On February 2, 1986 a moving type IV and a continuum were observed associated with a coronal enhancement observed by the Mauna Loa K-coronameter and a filament eruption. The speed of the moving type IV burst was ~ 140 km s^{-1} with almost identical speed for the associated erupting filament (Gopalswamy and Kundu, 1989a). There was no SMM-C/P observations for this day. However, it is known that the Hα filament material found in the cores of several CMEs move only slightly slower than the associated CMEs (Hundhausen, 1988). Hence we believe that the CME speed may not greatly exceed 140 km s^{-1}. Fig. 2(a) shows the centroids of moving type IV bursts associated with the coronal enhancement.

During the February 17, 1985 event (Kundu, 1987; Kundu et al, 1989), both moving IV and tupe II bursts were associated with a slow CME (speed ~ 200 km s^{-1}). In Fig. 2(b) we have superposed the moving type IV burst on the SMM-C/P image for two instants showing that the type IV was always confined to the densest part of the CME (see Fig. 1(b) for the motion of type IV centroids). While the CME and type IV bursts had nearly the same speed and direction, the type II burst location was behind the CME and the motion was transverse. Therefore, only the type IV source can be directly associated with the slow CME. These events show that moving type IV and type II bursts can be associated with slow CMEs with speeds as low as 200 km s^{-1}, contrary to the earlier belief.

4. Conclusions

Temporal association between type IIs and CMEs is quite likely in the corona. However, present imaging studies of type II-CME association do not seem to indicate any causal relationship between CMEs and type II shocks. Type II shocks seem to be generated by flare explosions associated with CMEs. Our observations lead to the conclusion that the association of moving type IV bursts with CMEs depends on the availability of non-thermal particles and the ability of the instrument which detects these emissions. The CME speed requirement to be associated with radio emission does not seem to hold.

Acknowledgements

Research reported in this review, was performed in collaboration with Prof. M.R. Kundu and Drs. E.J. Schmahl, S.M. White, P. Cargill and E. Hildner. This work was supported by NSF grant ATM 88-16008 and by funds from the University of Maryland Astronomy Program, College of Computer, Mathematical and Physical Sciences and the office of Graduate Studies.

References

Bougeret, J.-L.: 1985, in "Collisionless Shocks in the Heliosphere: Review of Current Research", B.T. Tsurutani and R.G. Stone (eds.), American Geophys. Union, Washington, D.C., p. 13.

Dulk, G.A.: 1980, in "Radio Physics of the Sun' (eds: M.R. Kundu and T.E. Gergely), p. 419.

Duncan, R.A.: 1979, Solar Phys. 63, 389.

Gary, D.E., Dulk, G.A., House, L., Illing, R., Sawyer, C., Wagner, W.J., McLean, D.J., and Hildner, E.: 1984, Astron. Astrophys. 134, 222.

Gergely, T.E., Kundu, M.R., and Hildner, E.: 1983, Astrophpys. J. 268, 403.

Gopalswamy, N. and Kundu, M.R.: 1987, Solar Phys. 111, 347.

Gopalswamy, N. and Kundu, M.R.: 1989a, Solar Phys. 122, 145.

Gopalswamy, N. and Kundu, M.R.: 1989b, Solar Phys. 122, 91.

Gopalswamy, N. and Kundu, M.R.: 1989c, Solar Phys. (submitted).

Gosling, J.T., Hildner, E., MacQueen, R.M., Munro, R.H., Poland, A.I., and Ross, C.L.: 1976, Solar Phys. 48, 389.

Hildner, E. and 20 co-authors: 1986, in "Energetic Phenomena on the Sun", M.R. Kundu and B. Woodgate (eds.), NASA Conference Publication No. 2439, p. 6-1.

Holman, G.D., and Pesses, M.E.: 1983, Astrophys. J. 267, 837.

Hundhausen, A.J.: 1988, in the Proc. Sixth International Solar Wind Conference (ed. V.J. Pizzo, T.E. Holzer and D.G. Sime), NCAR Technical Note 306, Vol. I, p. 181.

Kundu, M.R., Erickson, W.C., Gergely, T.E., Mahoney, M.J., and Turner, P.J.: 1983, Solar Phys. 83, 385.

Kundu, M.R.: 1987, Solar Phys. 111, 53.

Kundu, M.R., Gopalswamy, N., White, S.M., Cargill, P., Schmahl, E.J. and Hildner, E.: 1989, Astrophys. J. 347, 505.

MacQueen, R.M.: 1980, Phil. Trans. Roy. Soc. Lon. A297, 605.

Robinson, R.D., and Stewart, R.T: 1985, Solar Phys. 97, 145.

Sheely, N.R., Stewart, R.T., Robinson, R.D., Howard, R.A., Koomen, M.J., and Michels, D.J.: 1984, Astrophys. J. 279, 839.

Sheridan, K.V., Jackson, B.V., McLean, D.J., and Dulk, G.A.: 1978, Proc. Astron. Soc. Australia 3, 249.

Steinolfson, R.S.: 1984, Solar Phys. 94, 193.

Stewart, R.T.: 1985, in "Solar Radio Physics", Cambridge Univ. Press, Cambridge.

Wagner, W.J.: 1984, Ann. Rev. Astron. Astrophys. 22, 267.

Wagner, W.J., and MacQueen, M: 1983, Astron. Astrophys. 120, 136.

Wagner, W.J., Hildner, E., House, L.L., Sawyer, C., Sheridan, K.V. and Dulk. G.A.: 1981, Astrophys. J. 244, L123.

DISCUSSION

FORBES: In my numerical simulation of a magnetically driven CME, the fast shock first appears just above the prominence, and below what one might think of as the top of the CME. So I believe your interpretation of the location of the shock relative to the CME is consistent with my simulation.