LOW FREQUENCY RADIO OBSERVATIONS OF THE SOLAR CORONA PRIOR TO THE ONSET OF A MASS EJECTION EVENT

R. Ramesh, K.R. Subramanian and Ch.V. Sastry

Indian Institute of Astrophysics, 2nd Block, Koramangala, Bangalore 560 034.
Email: ramesh@iiap.ernet.in, subra@iiap.ernet.in, csastry@iiap.ernet.in
Phone: 91-80-5530672, Fax: 91-80-5534043.

ABSTRACT

We present here low frequency radio observations of the solar corona carried out with the Gauribidanur radioheliograph (GRH) prior to the onset of the coronal mass ejection (CME) events of 1997 April 13 (A), 1997 October 23 (B) and 1998 January 12 (C). While events A and C were preceded and accompanied respectively by the occurence of a radio noise storm, event B took place in the complete absence of any non-thermal radio emission. The radio method would be useful in independantly forecasting a mass ejection from the Sun, particularly from the ground.

Key words: Sun - corona - CMEs - radio observations.

1. INTRODUCTION

It is now well established that a CME is an explosive event in the solar atmosphere during which material weighing about $10^{14} - 10^{17}$ gm is hurled out into the interplanetary space at speeds ranging from $\sim 100-2000$ km/s. The CMEs are generally observed in white light using coronagraphs in high altitude mountain observatories and onboard Earth-orbiting spacecrafts. Unfortunately, since the high altitude coronagraphs observe CMEs projected against the plane of the sky, they are not in a position to detect the earthward directed CMEs. These events originate on the visible hemisphere of the solar disk and could give rise to severe consequences in the terrestrial environment if the speed of its leading edge is considerably greater than that of the ambient solar wind ahead. According to Gosling *et al.* (1991), nearly all the major, non-recurrent, geomagnetic storms are closely associated with the fast CMEs. The most serious effect of these storms are the power failures and disruption of radio communication. The irradiation of space by the energetic electrons released during a CME can also cause serious problems to geosynchronous satellites. However inspite of more than two decades of research, an explicit cause of these mass ejection events from the Sun has eluded our understanding. In a case study of the halo[1] CME event of 1997 April 7 using the data obtained with the soft X-ray telescope onboard *Yohkoh* (Tsuneta *et al.* 1991), a dimming of the X-ray corona prior to the onset of the event was identified by Sterling and Hudson (1997). They pointed out that the dimming is due to the disappearance of a sigmoid (S-shaped) structure, leaving a soft X-ray arcade and two 'transient' coronal holes. Hudson *et al.* (1998) carried out a study of the coronal soft X-ray structures associated with several of the halo CMEs observed with *Yohkoh* and concluded that the sigmoid to arcade pattern (loop prominence systems) is a common characteristic of the would be site of most of the halo CMEs. More recently, on the basis of a statistical study using a larger soft X-ray data set obtained with *Yohkoh*, it was shown by Canfield, Hudson and McKenzie (1999) that regions are significantly more likely to erupt if they are either sigmoidal or large. It is well known that the eruptions of quiescent filaments and associated CMEs occur as a consequence of the destabilization of large-scale coronal arcades due to interactions between these structures and, new and growing active regions (Feynman and Martin 1995). On the basis of a statistical study, they showed that in all cases in which the new flux was oriented favourably for reconnection with the pre-existing large-scale coronal arcades, the filament was observed to erupt. In this connection, we would like to point out that there is always a one-to-one correspondence between the appearance of radio noise storms and the emergence of new magnetic flux from beneath the photospheric level (McLean 1981; Benz and Zlobec 1982, and the references therein; Stewart, Brueckner and Dere 1986). In fact, Brueckner (1983) showed that during noise storm free periods, no newly emerging flux can be seen. Raulin *et al.* (1991) had noted there is some similarity between the onset behaviour of noise storms and CMEs. Some evidence exists for a correspondence between noise storms and CMEs from observations carried out with the Nancay radioheliograph (NRH) at 169 MHz (Kerdraon *et al.* 1983; Pick 1996) and the VLA at 327 MHz (Habbal *et al.* 1996). There are also reports of association between the noise storms and disappearing Hα filaments (Lantos *et al.* 1981; Kundu and Gopalswamy 1990) and outward moving disturbances (McLean 1973; Lang and Willson 1987) in the past.

---

[1] According to Hudson *et al.* (1998), CMEs whose range of position angle (PA) exceed $\sim 130°$ are classified as either partial halo or halo events.

Proceedings 8th SOHO Workshop 'Plasma Dynamics and Diagnostics in the Solar Transition Region and Corona', Paris, France, 22-25 June 1999, (ESA SP-446, October 1999)

Therefore it is possible that the observations of radio noise storms could also be used as a tool to forecast CMEs, in addition to the pre-event signatures observed at other wavelengths and which have been reported by several authors in the literature.

2. OBSERVATIONS

2.1. 1997 April 13 event

According to Chen *et al.* (1997), the CME event of 1997 April 13 was observed by the Large Angle and Spectrometric Coronagraph (*LASCO*, Brueckner *et al.* 1995) on the Solar and Heliospheric Observatory (*SOHO*) spacecraft at 16:36 UT. The event took place close to the limb in the south-west quadrant of the Sun (Figure 1) and the estimated initial velocity was about 50 km s^{-1}. The Extreme Ultraviolet Imaging Telescope (*EIT*, Delaboudinière *et al.* 1995) indicate magnetic activity throughout that day and show a growth of loops between NOAA AR 8027 (S28 W52) and AR 8031 (S30 W37). The lift-off time for this event was taken to be ~10:14 UT, when a simultaneous appearance of small brightenings was observed in both the active regions mentioned above. Except for a B1.1 class flare around 12:48 UT, no significant X-ray events were indicated by the *GOES* data. No white light flares were also associated with this event. A Hα filament disappearance from the location (S45 W30) around 12:00 UT was reported in the *SGD* (October 1997). Figure 2 shows the radio map obtained with the GRH (Ramesh *et al.* 1998) at 75 MHz around 06:30 UT on 1997 April 13 overlaid on the soft X-ray image obtained with *Yohkoh* at 06:14 UT, the same day. The measured peak brightness temperature of the radio map was approximately 0.91×10^6 K. The discrete source (located more towards the south) in our radio map is possibly a noise storm continuum because: (i) a noise storm source was observed approximately at the same location with the NRH at both 164 MHz and 327 MHz and, (ii) observations of no other non-thermal radio emission except Type I bursts were reported on that day (*SGD*, June 1997). At all the three frequencies, i.e. 75, 164 and 327 MHz, the source was seen at approximately the same location the next day also. It would therefore appear that there is no appreciable shift in the position of the source centroid due to ionospheric refraction effects in the 75 MHz GRH image.

We checked the magnetogram images obtained with the Michelson Doppler Imager (*MDI*, Scherrer *et al.* 1995) onboard *SOHO* for the emergence of new flux at the location of the noise storm source. Figures 3 and 4 show the *MDI* images obtained on 1997 April 12 and 13 respectively. One can clearly notice the emergence of new flux inside the circled portion in Figure 4. There is also good spatial correspondence between the location of the emerging flux and the noise storm source. Therefore it is possible that the flux emergence which was responsible for the occurence of the radio noise storm was also responsible for CME/filament disappearance later. The time difference between their onset might be due to the lack of sufficient magnetic pressure for the associated loop/arcade system to become unstable at the time of occurence of the former.

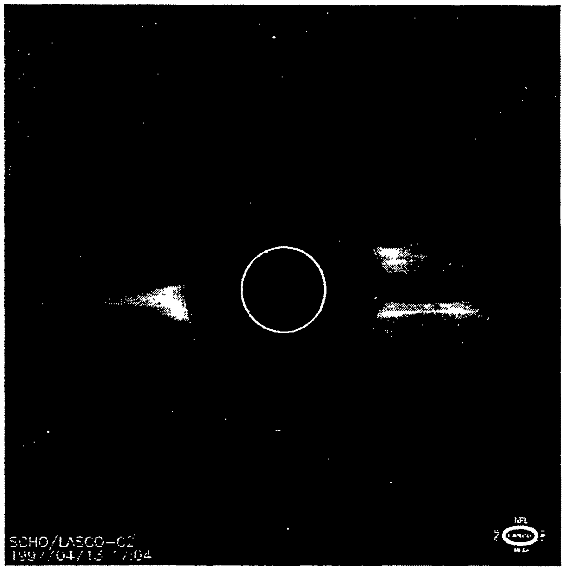

Figure 1. CME event of 1997 April 13 observed with the LASCO C2 coronagraph. Solar north is straight up and east is to the left in all the images shown in this paper.

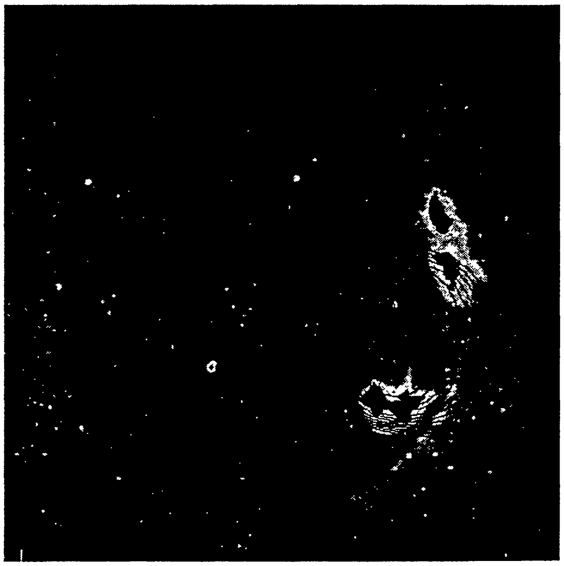

Figure 2. Noise storm source observed with the GRH at 75 MHz on 1997 April 13 overlaid on the soft X-ray image obtained with Yohkoh.

The observation of noise storm emission at three different frequencies (75, 164 and 327 MHz) in the present case indicates that the source region is columnar in shape and radiation at different frequencies originate from different heights in the column as suggested by McLean (1981). There is also a good spatial correspondence between the location of the noise storm sources, site of the filament disappearance and one of the legs of the CME. Chen *et al.* (1997) has

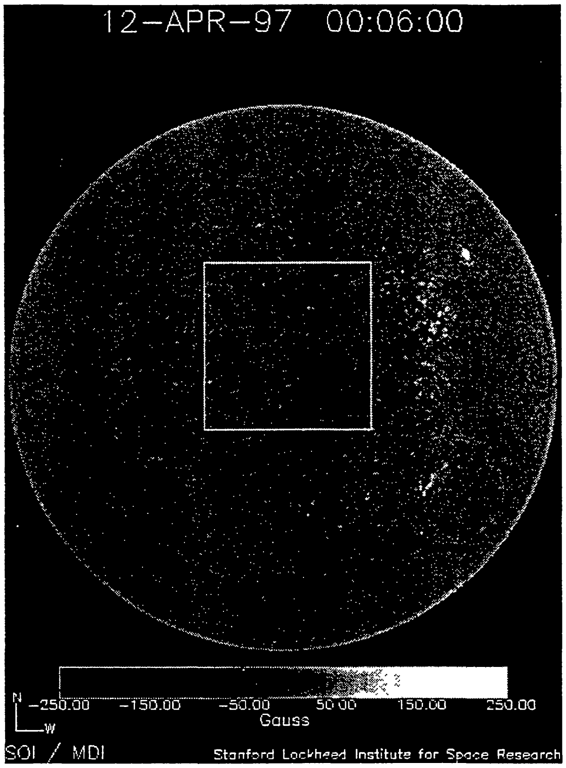

Figure 3. Photospheric magnetogram obtained with the MDI instrument onboard SOHO on 1997 April 12. The circled portion indicates the region under interest.

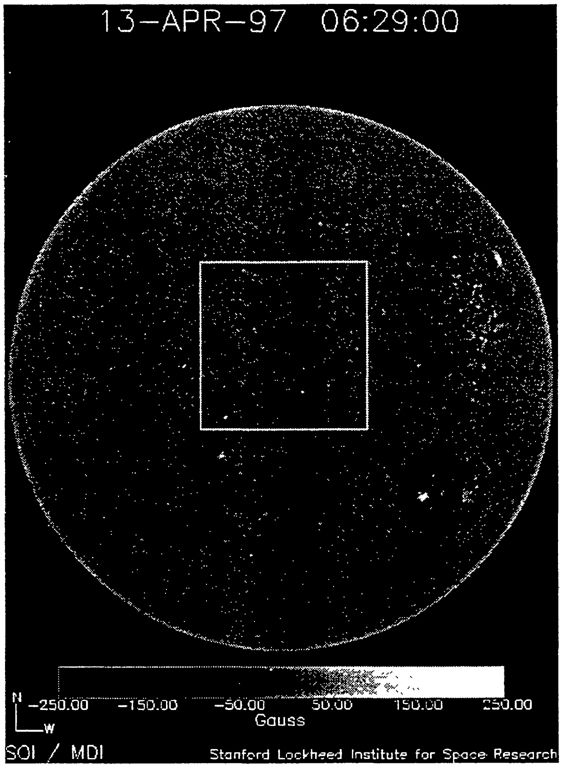

Figure 4. Photospheric magnetogram obtained with the MDI instrument onboard SOHO on 1997 April 13. One can clearly notice the emergence of new flux adjacent to the pre-existing field inside the circled portion.

described the geometry of this particular CME event as that of an expanding magnetic flux rope with the foot points remaining connected to the Sun. Given this scenario, is it possible that the columnar structure of the noise storm source is one of the legs of the CME in this particular case?. One needs to verify this. In this connection, we would like to add that in a case study of the Type I, moving Type IV radio event of 1973 March 22 and the associated ascending prominence event, it was suggested by McLean (1973) that the columnar structure of the Type I noise storm source and the filamentary ascending prominence are the same thing and, the outward moving ejecta is guided along the magnetic field lines associated with the noise storm source.

2.2. 1998 January 12 event

According to the 1998 *LASCO* CME List, a partial halo CME event was observed with the *LASCO* C2 coronagraph on 1998 January 12 around 04:00 UT. This particular event was also associated with Moreton waves from the active region(s) NOAA AR 8131/8132 (~S26 E12). The data obtained with the GRH at 109 MHz on that day around 06:30 UT indicates the presence of a discrete source close to the location of the above two active regions (Figure 5). The brightening (co-spatial with the radio source) seen in the *Yohkoh* soft X-ray image in Figure 5 is possibly a X-ray flare since several C-class flares were observed with the *GOES* X-ray satellite on that day (*SGD*, July 1998). It is possible that the discrete radio source in our radio heliogram is a noise storm continuum because: (i) observations of Type I radio bursts were reported from prior to 08:00 UT, (ii) a noise storm source was observed approximately at the same location with the NRH at both 164 and 327 MHz (*SGD*, March 1998). Though spectral observations of Type III bursts were also reported, the spatial correspondence between Nancay and Gauribidanur data points to more of a noise storm association and, (iii) a comparison of the magnetograms obtained with *MDI* on January 11 and 12 (Figures 6 and 7) clearly reveal the emergence of new magnetic flux on the latter date at the location of the noise storm source. This event was not associated with any Hα filament disappearance (*SGD*, July 1998) and in fact, no filament was found to lie close to the location of the noise storm even before the onset of the main CME event. This particular example indicates the possibility of using the occurence of a radio noise storm for forecasting the CME events in the complete absence of any signatures such as filament disappearance and/or appearance of sigmoid pattern. However, since the occurence of noise storms is a common form of nonthermal activity in the solar atmosphere, one needs to examine the percentage association (both spatial and temporal) of noise storms and the CMEs.

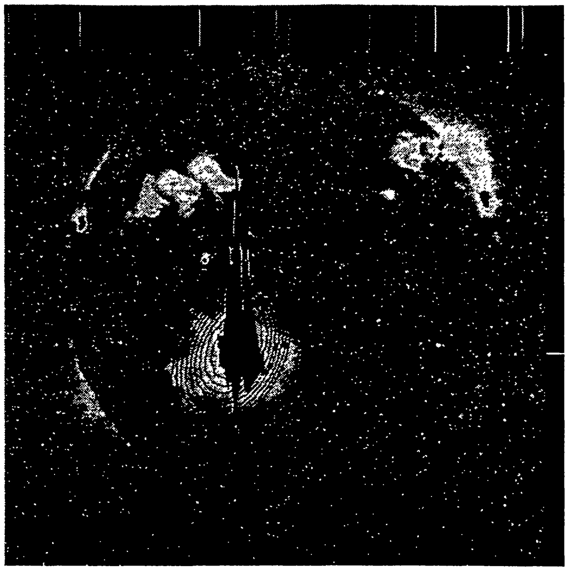

Figure 5. *Noise storm source observed with the GRH at 109 MHz on 1998 January 12 overlaid on the soft X-ray image obtained with Yohkoh.*

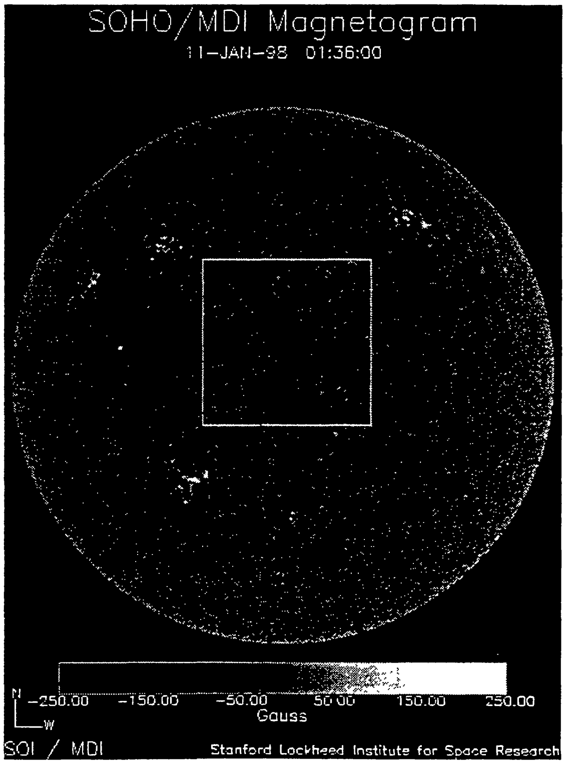

Figure 6. *Photospheric magnetogram obtained with the MDI instrument onboard SOHO on 1998 January 11: The circled portion indicates the region under interest.*

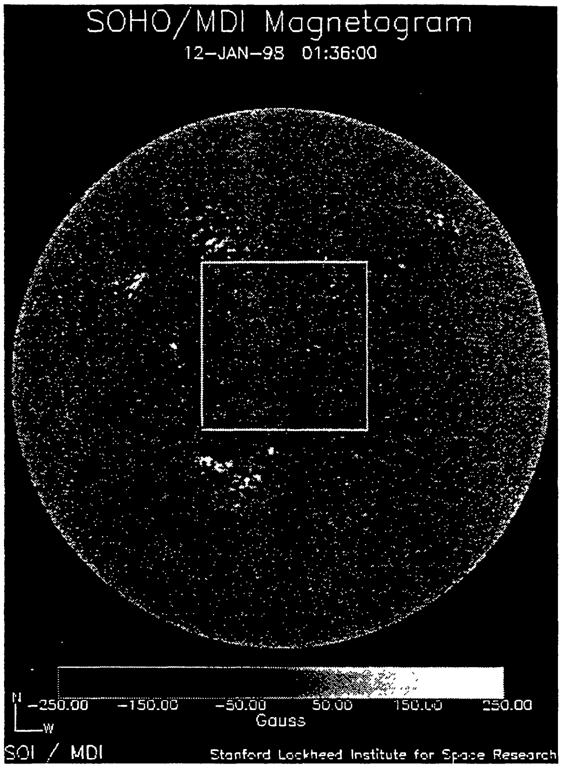

Figure 7. *Photospheric magnetogram obtained with the MDI instrument onboard SOHO on 1998 January 12. One can clearly notice the emergence of new flux adjacent to the pre-existing field inside the circled portion.*

2.3. 1997 October 23 event

The third and last event we report in this paper is the halo CME event of 1997 October 23 which was observed with the *LASCO* C2 coronagraph at 11:26 UT. This was actually the second CME event on that day. The first one took place around 05:45 UT at PA = 313° (1997 *LASCO* CME List). No X-ray flares were reported to be observed by the *GOES* satellite in association with both the events mentioned above. A Hα filament disappearance was reported on 1997 October 23 at the location (N22 E01) from $\sim$ 09:58-22:06 UT. Yet another filament disappearance event was reported at (N27 E12) on the same day from $\sim$ 12:11-13:32 UT (*SGD*, April 1998). The Sun was remarkably radio 'quiet' and no non-thermal burst emission was reported during the period 1997 October 22-26. (*SGD*, December 1997). This provided us with an oppurtunity to observe the faint radio emitting thermal structure(s) on the disk prior to the above CME events. An inspection of the radio heliogram obtained at 109 MHz on 1997 October 22 at 06:30 UT revealed the presence of a S-shaped structure close to the disk center (Figure 8). As one can see, there is a close spatial correspondence between the site(s) of the disappearing filament events reported above and the location of the S-shaped structure. But the structure was not there in the radio heliogram obtained on 1997 October 23 at 06:30 UT (Figure 9) though the reported filament disappearance(s) took place only a few hours later. This could be probably because of the CME which took place around 05:45 UT (just before our observation) at PA = 313°. Since the appearance of sigmoidal structure(s) are closely associated with the eruptive events on the solar surface, we present here a quantitative estimate of the characteristics of the structure seen in our radio heliogram. The observed half-power widths and the peak brightness temperature (T_b) were $14' \times 6'$ (EW × NS) and 1.63×10^6 K respectively. One can notice that the observed T_b is less than the coronal electron temperature ($\sim 2 \times 10^6$ K) inspite of the structure being located close to the disk center (The optical depth of the corona near the disk center is generally considered to be large since the rays travel right upto the plasma level due to negligible refraction effects). Therefore it is possible that the emission is optically thin. Hence one can calculate the electron density using the formula (Sheridan *et al.* 1978),

$$N = \left[5 f^2 T_e^{1/2} T_b L^{-1}\right]^{1/2} \quad \mathrm{cm}^{-3} \qquad (1)$$

where f is the observing frequency (in MHz) and L is the depth of the structure along the line of sight (in units of $R_\odot$). It is well known that most of the radio emission at any particular observing frequency comes from a small region close to the plasma level where the absorption coefficient is maximum. Assuming that the width of the region depends on the bandwidth of observation, in the present case we took the value of L to be $\approx 0.1'$ corresponding to our observing bandwidth of 1 MHz. The value of T_e was taken to be 2×10^6 K. Substituting all the above in equation (1), we get the value of N_e as 1.09×10^9 cm^{-3}. The corresponding plasma density at 109 MHz is 1.47×10^8 cm^{-3}. Sterling and Hudson (1997) had reported a density of 1.11×10^9 cm^{-3} for the S-shaped structure they had observed prior to the halo CME event of 1997 April 7. However it is to be noted that our estimate of the electron density is only a lower limit since we have considered only the region close to the plasma level. Assuming that the coronal plasma is a fully ionized gas of normal solar composition (90% hydrogen and 10% helium by number), one finds that each electron is associated with approximately 2×10^{-24} gm of material. Therefore the mass of the structure is given by,

$$M = 2 \times 10^{-24} N_e V \quad \mathrm{gm} \qquad (2)$$

where V is the volume of the structure. The volume was determined by multiplying the radial and lateral widths of the structure with the assumed depth, and the value is 1.31×10^{28} cm^3. Substituting all the values in equation (2), we get the mass as 2.86×10^{13} gm. The corresponding values reported by Sterling and Hudson (1997) were 2.64×10^{29} cm^3 and 4.9×10^{14} gm respectively. However it is to be noted that while the S-shaped structure reported by these authors was observed a few hours before the onset of the CME event, it is more than 24 hrs in our case. These imply that the material released during a CME comes mainly from the corona and, a substantial fraction of the mass released during a CME is stored in the pre-event sigmoid structure itself.

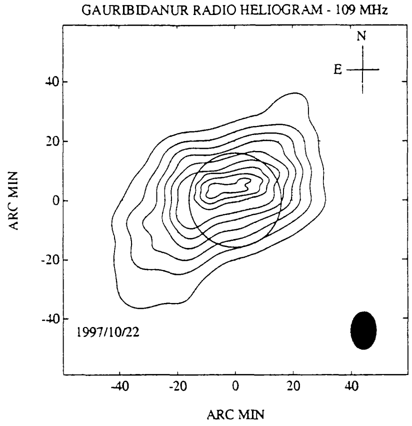

Figure 8. Radio heliogram obtained with the GRH at 109 MHz on 1997 October 22 at 06:30 UT. The open circle at the center is the solar limb and the filled circle at the bottom right is the beam of the instrument.

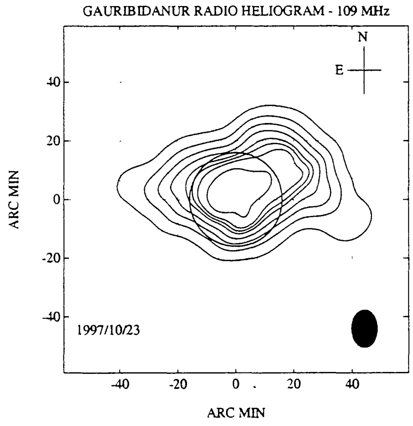

Figure 9. Radio heliogram obtained with the GRH at 109 MHz on 1997 October 23 at 06:30 UT. One can clearly notice the bulging close to the limb in the north-west quadrant indicative of the CME which took place at 05:45 UT at PA = 313°.

3. CONCLUSIONS

We have studied the coronal structures prior to the CME events of 1997 April 13, 1997 October 23 and 1998 January 12. Our conclusions are:

(1) In both the radio noise storm events presented in this paper, there is a good spatial and temporal correlation between them, the newly emerging magnetic flux from the sub-surface layers and the CMEs.
(2) The excellent spatial correspondence between the location of the radio storm sources observed at 3 widely separated frequencies indicates that the source region is columnar in shape.
(3) There is a good spatial correlation between the the location of the noise storm sources and one of the

legs of the CME.

(4) Most of the material that is expelled during a CME comes mainly from the corona.

(5) The mass of the pre-event sigmoid structure estimated by us in the present case using the radio data is lesser than the generally quoted lower limit of the mass of a CME ($\sim 10^{14}$ gm) by about an order of magnitude.

ACKNOWLEDGEMENTS

The *SOHO/LASCO* data used here are produced by a consortium of the Naval Research Laboratory (USA), Max-Planck-Institüt für Aeronomie (Germany), Laboratoire d'Astronomie (France) and the University of Birmingham (UK). The magnetogram images are a courtesy of the *SOHO/SOI-MDI* project of the Stanford Lockheed Institute for Space Research. *SOHO* is a project of international cooperation between ESA and NASA. The solar X-ray image is from the *Yohkoh* mission of ISAS, Japan. The X-ray telescope was prepared by the Lockheed Palo Alto Research Laboratory, the National Astronomical Observatory of Japan, and the University of Tokyo with the support of NASA and ISAS.

REFERENCES

Brueckner, G.E.: 1983, *Sol. Phys.*, **85**, 243.

Brueckner, G.E., *et al.*: 1995, *Sol. Phys.*, **162**, 357.

Benz, A.O. and Zlobec, P.: 1982, Proceedings of the 4th CESRA Workshop on *Solar Noise Storms*, Trieste Observatory Publication.

Canfield, R.C., Hudson, H.S. and McKenzie, D.E.: 1999, *Geophys. Res. Lett.*, **26(6)**, 627.

Chen, J., *et al.*: 1997, *Astrophys. J.*, **490**, L191.

Delaboudinière, J.P., *et al.*: 1995, *Sol. Phys.*, **162**, 291.

Feynman, J. and Martin, S.F.: 1995, *J. Geophys. Res.*, **100**, A3, 3355.

Gosling, J.T., McComas, D.J., Phillips, J.L. and Bame, S.J.: 1991, *J. Geophys. Res.*, **96**, A5, 7831.

Habbal, S.R., Mossman, A., Gonzalez, R. and Esser, R.: 1996, *J. Geophys. Res.*, **101**, A9, 19943.

Hudson, H.S., Lemen, J.R., St. Cyr, O.C., Sterling, A.C. and Webb, D.F.: 1998, *Geophys. Res. Lett.*, **25(14)**, 2481.

Kerdraon, A., Pick, M., Trottet, G., Sawyer, C., Illing, R., Wagner, W. and House, L.: 1983, *Astrophys. J.*, **265**, L19.

Kundu, M.R. and Gopalswamy, N.: 1990, *Sol. Phys.*, **129**, 133.

Lang, K.R. and Willson, R.F.: 1987, *Astrophys. J.*, **319**, 514.

Lantos, P., Kerdraon, A., Rapley, G.G. and Bentley, R.D.: 1981, *Astron. Astrophys.*, **101**, 33.

McLean, D.J.: 1973, *Proc. Astron. Soc. Aust.*, **2(4)**, 222.

McLean, D.J.: 1981, *Proc. Astron. Soc. Aust.*, **4(2)**, 132.

Pick, M.: 1996, *Astrophys. and Space Sci.*, **243**, 179.

Ramesh, R., Subramanian, K.R., Sundararajan, M.S. and Sastry, Ch.V.: 1998, *Sol. Phys.*, **181**, 439.

Raulin. J.P., Willson, R.F., Kerdraon, A., Klein, K.-L., Lang, K.R. and Trottet, G.: 1991, *Astron. Astrophys.*, **251**, 298.

Scherrer, P.H., *et al.*: 1995, *Sol. Phys.*, **162**, 129.

Sheridan, K.V., Jackson, B.V., McLean, D.J. and Dulk, G.A.: 1978, *Proc. Astron. Soc. Aust.*, **3**(4), 249.

Solar Geophysical Data, June 1997, 634, Part I.

Solar Geophysical Data, October 1997, 638, Part II.

Solar Geophysical Data, December 1997, 640, Part I.

Solar Geophysical Data, March 1998, 643, Part I.

Solar Geophysical Data, April 1998, 644, Part II.

Solar Geophysical Data, July 1998, 647, Part II.

Sterling, A.C. and Hudson, H.S.: 1997, *Astrophys. J.*, **491**, L55.

Stewart, R.T., Brueckner, G.E. and Dere, K.P.: 1986, *Sol. Phys.*, **106**, 107.

Tsuneta, S., *et al.*: 1991, *Sol. Phys.*, **136**, 37.