THE HALO CME EVENT OF 23 OCTOBER 1997 – LOW-FREQUENCY RADIO OBSERVATIONS OF THE PRE-EVENT CORONA

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Abstract. We report low-frequency observations of an enhancement in the solar corona prior to the halo coronal mass ejection of 23 October 1997, with the Gauribidanur radioheliograph. The Sun was 'quiet' and no radio bursts were observed either prior to or in the aftermath of the event. The radio method would be useful in studying the pre-event structures associated with the eruptive solar activity, particularly from the ground.

1. Introduction

It is now well established that a coronal mass ejection (CME) is an explosive event in the solar atmosphere during which material weighing about $10^{14}-10^{17}$ g is hurled into the interplanetary space at speeds in the range of $\sim 100-2000$ km s^{-1}. The CMEs are generally observed in white light using coronagraphs in high altitude mountain observatories, and onboard Earth-orbiting spacecrafts. Unfortunately the coronagraphs in the terrestrial environment observe these events projected against the plane of the sky and hence are not in a position to detect particularly the earthward directed CMEs. These events originate on the visible hemisphere of the Sun and look like a halo of excess brightness completely surrounding the occulting disk of a coronagraph, propagating radially outward in all directions from the Sun (Howard *et al.*, 1982). According to Hudson *et al.* (1998), a CME whose range of position angle (PA) exceed $\sim 130°$ is classified as either partial halo or halo event. It is well known that such an event could give rise to severe consequences in the Earth's 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. But 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 CME of 7 April 1997 using the data obtained with the soft X-ray telescope onboard *Yohkoh* (Tsuneta *et al.*, 1991), a dimming of the corona prior to the onset of the event was identified by Sterling and Hudson (1997). They attributed

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the dimming to the disappearance of a sigmoid (S-shaped) structure, leaving behind 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 is a common characteristic of the would be site of most of the halo CMEs. Canfield, Hudson, and McKenzie (1999) carried out a statistical study using a larger set of soft X-ray obtained with *Yohkoh*, and showed that regions are significantly more likely to erupt if they are either sigmoidal or large. In view of this recent interest in the study of the pre-event signature(s) of solar eruptive events, we present the characteristics of the enhanced radio emission observed by us prior to the halo CME of 23 October 1997, in this paper.

2. Observations

The radio data reported were obtained with the Gauribidanur radioheliograph (GRH, Ramesh *et al.*, 1998) on 22 and 23 October 1997 around 06:30 UT. The observing frequency was 109 MHz and the integration time used was 145 ms. The Sun was 'quiet' and no transient emission was seen in our records. Also no radio bursts were reported during the period 22–26 October 1997 in the *Solar Geophysical Data* (December 1997). This provided an oppurtunity to look for diffuse radio emitting thermal structure(s) associated with the CMEs observed during the above period. According to St. Cyr, the Large Angle Spectrometric Coronagraph (LASCO, Brueckner *et al.*, 1995) on board the Solar and Heliospheric Observatory (SOHO) observed a halo CME on 23 October 1997 at $\sim$ 11:26 UT (1997 LASCO CME list). This was actually the second CME on that day. The first one took place around 05:45 UT at PA $=$ 313°. Apart from two Hα filament disappearances ($\sim$ 09:58–22:06 UT at N22 E01, and $\sim$ 12:11–13:32 UT at N27 E12), the above two CMEs were not associated with any transient activity at both the optical and X-ray wavelengths (*Solar Geophysical Data*, April 1998). An inspection of the soft X-ray picture of the solar corona obtained with *Yohkoh* on 22 October 1997 revealed the the presence of an inverse S-shaped structure near the disk center (Figure 1). Its orientation was consistent with the hemispheric rule reported earlier for similar structures noticed in the *Yohkoh* soft X-ray images by Rust and Kumar (1996), i.e., inverse-S in the north and S in the south. The radioheliogram obtained with the GRH on the same day (Figure 2) showed enhanced emission close to the location of the sigmoid in Figure 1, over a disk area of $\approx 21' \times 9'$. The estimated brightness temperature (T_b) of the enhancement was $\sim 7.24 \times 10^5$ K. Figure 3 shows the radioheliogram obtained on 23 October 1997. No enhanced emission was observed by us on this day, particularly near the disk center. This could be probably due to a restructuring of the corona in the aftermath of the CME which took place around 05:45 UT (just before our observing time at 06:30 UT) at PA $=$ 313°. It is interesting to note that the sigmoid structure in the soft X-

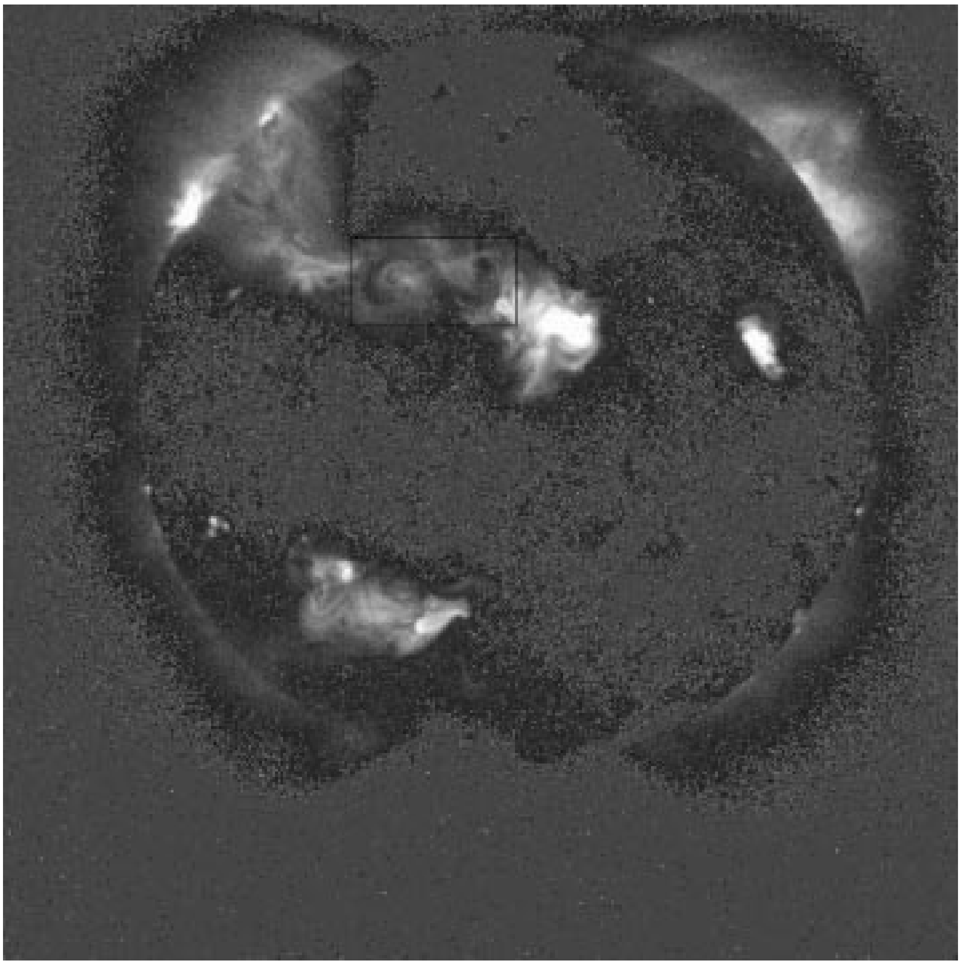

Figure 1. X-ray picture of the solar corona obtained with the soft X-ray telescope onboard *Yohkoh* on 22 October 1997 at 20:24:41 UT. North is straight up and east is to the left. The rectangular box close to the disk center indicates the location of the sigmoid.

ray image obtained on 22 October 1997 (Figure 1) also disappeared the next day (*Solar Geophysical Data*, December 1997). Therefore, it is possible that the radio enhancement in Figure 2 might be associated with the X-ray sigmoid observed in the pre-CME conditions. Figure 4 shows the LASCO C2 coronagraph image obtained on 23 October 1997 at 06:37 UT. One can notice that there is a good correspondence between the various elongated features in the radioheliogram in Figure 3, and those in the coronagraph image.

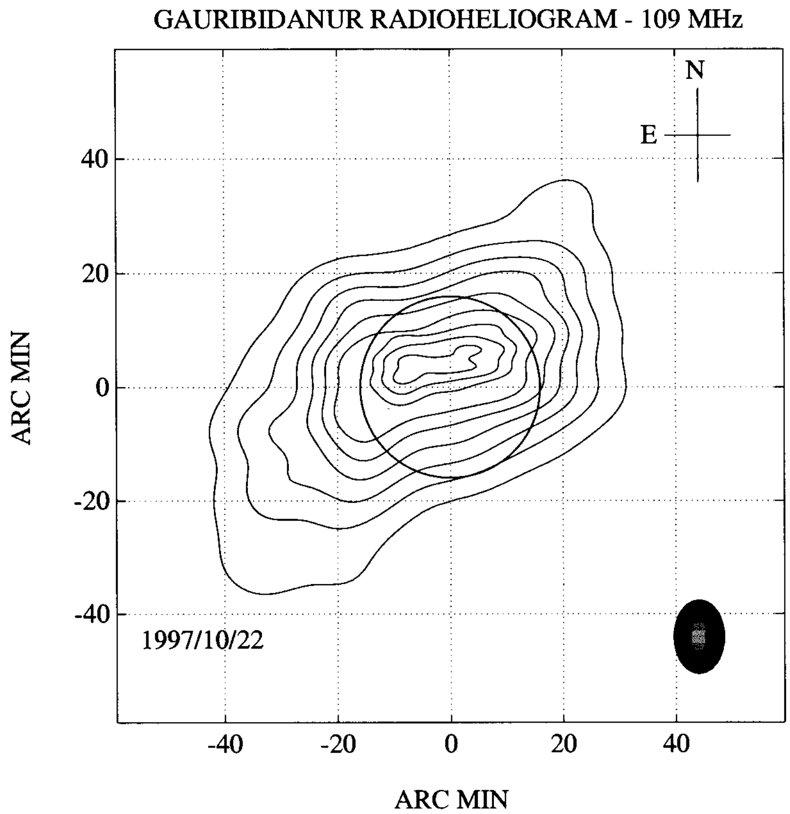

Figure 2. Radioheliogram obtained with the GRH at 109 MHz on 22 October 1997 at 06:30 UT. The contour levels are 82, 72, 62, 52, 42, 32, 22, 12, 2% of 1.36×10^6 K. The open circle at the center is the solar limb and the filled circle at the bottom right is the beam of the instrument.

3. Analysis and Results

It is well known from ray-tracing calculations for the past several decades that the radio brightness temperature in the direction of the Sun's center at frequencies $\leq$ 100 MHz is generally about 60% of the electron temperature (T_e) of the appropriate coronal levels (Smerd, 1950). Based on observations at different frequencies in the range 20–125 MHz with the Clark Lake radioheliograph (Erickson, Mahoney, and Erb, 1982; Kundu *et al.*, 1982), it was pointed out by Kundu, Gergely, and Erickson (1977) that the corona is optically thin at low frequencies except for the emission from discrete sources which are due to thermal bremsstrahlung originating in optically thick regions. Therefore one can calculate the electron density of the enhancement in Figure 2 using the following relation (Sheridan *et al.*, 1978; Gopalswamy and Kundu, 1992), i.e.,

$$N_e = \left[5 f^2 T_e^{1/2} T_b L^{-1}\right]^{1/2} \quad \mathrm{cm}^{-3} \,, \tag{1}$$

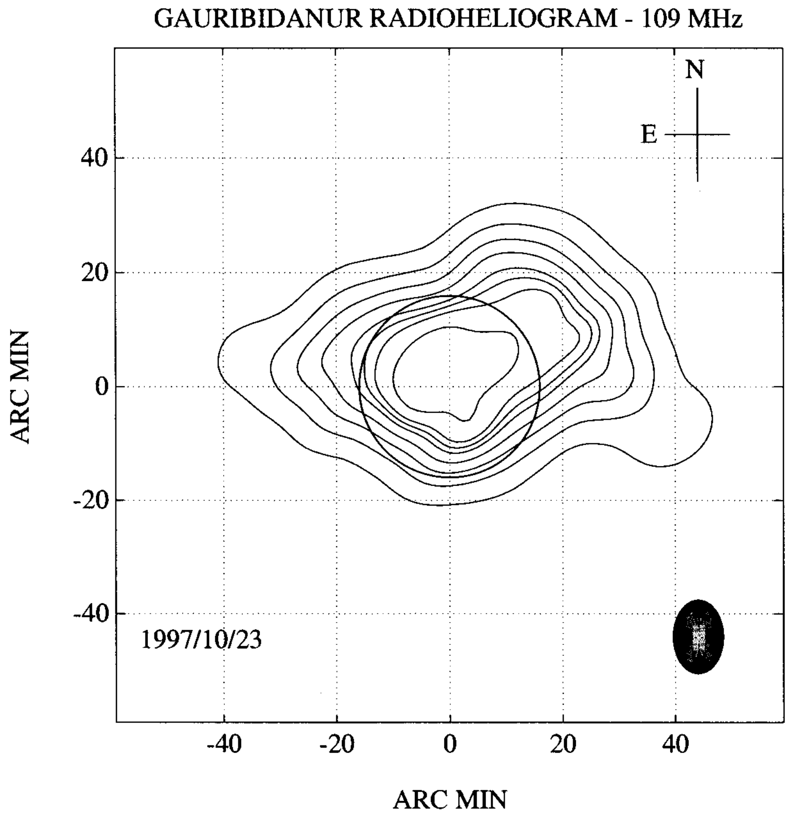

Figure 3. Radioheliogram obtained with the GRH at 109 MHz on 23 October 1997 at 06:30 UT. The contour levels are 79, 68, 57, 46, 35, 24, 13, 2% of 1.02×10^6 K.

where f is the observing frequency (in MHz), and L is the depth of the region along the line of sight (in units of $R_\odot$). We assumed $T_e \approx 1.4 \times 10^6$ K for the present calculation (Fludra *et al.*, 1999). The main uncertainity here comes from the lack of information on the depth of the region along the line of sight. 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 (1 MHz, in the present case), and taking Newkirk's density model for the solar corona (Newkirk, 1961), we found from our calculations that $L \approx 0.1'$. Substituting the various values in Equation (1), we get $N_e \approx 3.42 \times 10^8$ cm^{-3}. This is about a factor of 2 higher than the corresponding plasma density at 109 MHz which is 1.47×10^8 cm^{-3}. Compared to the above, Sterling and Hudson (1997) had reported a density of 1.11×10^9 cm^{-3} for the S-shaped structure observed prior to the halo CME of 1997 April 7. We would like to add here that the density of the enhancement observed in the present case agrees well with the values reported earlier for discrete thermal sources seen in the low frequency radio maps of the

Figure 4. LASCO C2 coronagraph image obtained at 06:37 UT on 23 October 1997. Solar north is straight up and east is to the left. The field of view of the LASCO C2 coronagraph extends from 2 $R_{\odot}$ to 6 $R_{\odot}$.

Sun (Lantos and Alissandrakis, 1994; Ramesh, Subramanian, and Sastry, 1999). 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} g of material. Therefore, the mass of the enhancement is given by

$$M = 2 \times 10^{-24} N_e V \quad \text{g}\,, \tag{2}$$

where V is the volume of the region of enhanced emission. In the present case the volume was determined by multiplying the length and width of the region with the assumed depth, and the value is 2.95×10^{28} cm^3. Substituting the different values in Equation (2), we get the mass as 2.02×10^{13} g. The corresponding values reported by Sterling and Hudson (1997) were 2.64×10^{29} cm^3 and 4.9×10^{14} g, respectively.

4. Conclusions

We observed an enhancement close to the disk center prior to the halo CME event of 23 October 1997, in the radio heliogram obtained with the GRH at 109 MHz.

There is a close correspondence between the region of enhanced radio emission and a sigmoid structure in the soft X-ray picture of the solar corona, also obtained during the pre-CME period. The electron density and mass of the radio enhancement are less, compared to the respective values of a similar X-ray sigmoid reported earlier by Sterling and Hudson (1997), by about an order of magnitude. The present estimates are probably the limiting values of the respective parameters since we considered only a small region of the corona close to the 109 MHz plasma level. Also it is to be noted that while the pre-event structure reported by the above authors was a few hours before the onset of the CME, it is more than 24 hr in our case. Our main conclusions are:

(1) It is possible to observe a radio enhancement in the metric corona prior to the onset of a CME, under favourable conditions. A substantial fraction of the material released during the main CME event might come from the pre-event structure.

(2) The observed radio enhancement in the present case is possibly more due to an increase in the density since the observed radio brightness (due to thermal bremsstrahlung) of the 'quiet' Sun in optically thin regions is $\sim \int N_e^2 \, \mathrm{d}l$, where d$l$ is the pathlength.

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