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Interplanetary radio emission due to interaction between two coronal mass ejections

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Abstract

We report on the detection of a new class of nonthermal radio emission due to the interaction between two coronal mass ejections (CMEs). The radio emission was detected by the Radio and Plasma Wave Experiment (WAVES) on board the Wind satellite, while the CMEs were observed by the white-light coronagraphs of the Solar and Heliospheric Observatory (SOHO) mission. There was no type II radio burst (metric or interplanetary) preceding the nonthermal emission. The radio emission occurred at a distance beyond 10 R_s from the Sun, where the two CMEs came in contact. Using H-alpha and EUV images, we found that the two CMEs were ejected roughly along the same path. We argue that the nonthermal electrons responsible for the new type of radio emission were accelerated due to reconnection between the two CMEs and/or due to the formation of a new shock at the time of the collision between the two CMEs.

1. Introduction

Radio observations in the decameter-hectometric regime (21-300 m or 1-14 MHz in the frequency domain) obtained by the Radio and Plasma Wave Experiment (WAVES) [Bougeret et al., 1995] on board the Wind satellite [Acuna et al., 1995] have been useful in studying large-scale coronal mass ejections in the near-Sun interplanetary (IP) medium [see, e.g., Kaiser et al., 1998; Reiner and Kaiser, 1999; Gopalswamy et al., 1998]. WAVES data routinely provide information on CME-driven shocks [Gopalswamy et al., 2000; 2001a], shock-accelerated electrons [Reiner et al., 2000, and references therein], and even moving plasma structures [Leblanc et al., 2000]. These observations have not only confirmed many of the old results, but also lead to a number of new discoveries on the interplanetary propagation of CMEs [Gopalswamy et al., 2000; 2001a,b]. Gopalswamy et al. [2001b] recently detected intense continuum like radio enhancement due to the interaction between a CME-driven shock and the core of a preceding CME. The radio enhancement occurred towards the end of a narrow-band type II burst. In this letter, we report on the detection of a new type of radio emission, which arises solely due to the interaction between two CMEs. No other radio emission was observed before or during the interval of CME interaction. Inner coronal images in H-alpha and EUV revealed that the two CMEs were ejected roughly along the same path. The results presented in this letter have important implications to our understanding of the interplanetary propagation of coronal mass ejections.

2. Observational Results

2.1. Radio Burst

The RAD2 receiver of the WAVES experiment, which records radio emission in the frequency range 1.075-13.825 MHz, detected a broad band, continuum-like radio burst between 0230 and 0500 UT on September 3, 1999 (see, Fig. 1). The radio burst occurred near 1.5 MHz and had a bandwidth of ~1 MHz. The burst was highly structured, with a precursor lasting for about 10 min, followed by an intense non-drifting continuum (0300 to 0336 UT) and a weak drifting feature (0336 to 0430 UT). There was also a weak extension of the radio emission to lower frequencies, as observed by the RAD1 receiver (1 MHz - 30 kHz). There were no other radio bursts prior to the radio emission in question, except for a set of type III bursts towards the end of September 2. These type III bursts correspond to a set of four metric type III bursts during the period 22:57 to 23:48 UT as reported in the Solar Geophysical Data (September 2, 1999). A set of weak features between 01:30 and 02:00 UT is most likely Jovian emission (see Fig. 1). Thus the low frequency radio emission starting at ~2:30 UT on September, 3, 1999 does not have a counterpart at higher frequencies, and seems to originate only in the WAVES/RAD2 domain. The radio emission due to interacting CMEs reported in Gopalswamy et al. [2001b] clearly followed a narrow-band type II burst, whereas in the present case, the type II burst follows a continuum burst.

2.2. White-light CMEs

The Large Angle and Spectrometric Coronagraph (LASCO) [Brueckner et al., 1995] on board the Solar and Heliospheric Observatory (SOHO) mission continuously monitors the solar corona up to a heliocentric distance of 30 R_s, except for an inner circular region of radius ~2 R_s corresponding to the inner occulting disk. The plasma frequency range of the solar corona within the LASCO field of view includes the spectral range of the RAD2 receiver. When we examined the LASCO images at the time of the radio emission in question, we found two white-light CMEs above the south limb in projection. The central position angle of the two CMEs were roughly the same (185°) and both were relatively wide. The first CME was rather slow (290 km s^{-1}), while the second CME was twice as fast (590 km s^{-1}). Figure 2 shows the two CMEs (CME1 and CME2) at one instance as observed by the LASCO/C3 coronagraph. CME1 was at a heliocentric distance of ~8 R_s, while CME2 was at a distance of ~15 R_s. Figure 3 shows the height-time plots of the leading edges of the two CMEs. At the time of the radio burst, the leading edge of CME2 just caught up with the trailing edge of CME1. The collision occurred at a projected heliocentric distance of ~10 R_s. The interval of IP radio emission is shown by the two vertical lines in Fig. 3 along with a section of the dynamic spectrum. Clearly, the onset of the radio emission coincides with the time at which CME2 caught up with trailing edge of CME1. The close temporal association between the onset of the radio burst and the time of interaction between the two white light CMEs suggests that the radio emission is a direct consequence of the CME interaction. CME1 was too slow to drive any shock in the outer corona due to the hump in the fast-mode speed [Gopalswamy et al., 2001a]. The ability of CME2 to drive a shock is marginal because of the relatively high fast-mode speed, and increasing solar wind flow. Furthermore, there was no metric type II burst associated with either of the CMEs.

2.3. Solar Sources

In order to identify the solar sources of the CMEs, we examined the EUV images at 195 Å obtained by SOHO's extreme-ultraviolet imaging telescope (EIT) and H-alpha images from Meudon Observatory. These images revealed that both the CMEs originated from roughly the same region on the solar disk. Such an analysis is necessary to make sure that the interaction we observe in the coronagraph images is not a mere superposition in the sky plane. The source region consisted of two active regions, AR 8686 (S24 W09) and AR 8679 (S36 W17) with several filaments nearby. CME1 was associated with the eruption of a thick quiescent filament (F1 in Fig. 4a) around 12:00 UT from S35 W35. CME2 was associated with the eruption of an active region filament (F2 in Fig. 4a) to the southeast of the first. The H-alpha image in Fig. 4b shows that both the filaments had erupted by 07:04 UT on September, 3, 1999. The first eruption corresponds to a weak EUV dimming elongated in the northwest - southeast direction (see Fig. 4c). The second eruption produced much deeper dimming with the early stage of the CME clearly seen in EUV. From the EUV data, we found that CME2 accelerated southward with an initial speed of ~125 km s^{-1}. The filament F2 became an eruptive prominence in the field of view of the Nobeyama radioheliograph. The second eruption also resulted in a C-class GOES flare in AR 8679, starting, peaking and ending at 23:35, 23:48 and 23:57 UT, respectively. The set of type III bursts mentioned in section 2.1 was associated with this flare. Since the two CMEs originated from the same general area on the solar surface, they are likely to interact with each other because the earlier CME is slower than the later.

3. Discussion and Conclusions

The low frequency radio emission is most likely due to plasma emission. The emission frequency is equal to either the fundamental or the first harmonic of the local plasma frequency. Assuming harmonic emission, the starting frequency of 1.5 MHz corresponds to a plasma density of 7×10^3 cm^{-3}. This density prevails at a distance beyond $\sim 10\ R_s$ from the Sun. Nonthermal radio emission originating at such distances with no high frequency counterpart requires that nonthermal electrons are produced locally, at $\sim 10\ R_s$. We examined the radio dynamic spectra (18 - 2000 MHz) obtained by the Hiraiso radiospectrograph and found no radio emission at the time of the WAVES radio burst that would suggest particle injection from near the solar surface. In fact, the GOES light curve and microwave (17 GHz from Nobeyama radioheliograph) intensity from the eruption region were rather flat between 01:00 and 04:00 UT on September 3, 1999. Thus the nonthermal electrons responsible for the radio bursts must have been generated at the location of interaction between two CMEs.

Nonthermal electrons could have been produced in two possible ways: 1. At the time of the interaction, reconnection between the magnetic field lines of the two CMEs might have taken place, resulting in the production of particles. The situation is similar to the reconnection between newly-emerging and preexisting flux in solar flares, except that the process takes place at 10 Rs from the Sun. 2. The second CME, which was not driving a shock might have started doing so when it encountered the slow, first CME. This happens because the denser-than-ambient first CME presents a region of lower Alfven speed, and hence better conditions for shock formation. It must be pointed out that we are dealing with the formation of a new shock due to collision between CMEs, which is different from the strengthening of a preexisting shock reported in Gopalswamy et al. [20001b]. This is also consistent with the observed slow-drift feature observed at lower frequencies, following the bright continuum-like event. This new type of radio emission is a clear evidence for the production of nonthermal particles long after the eruption on the Sun. One cannot rule out a combination of the reconnection and shock processes so that the continuum and the type II bursts can be accounted for. These observations also reveal the complex conditions in the interplanetary medium that seriously affect the propagation of CMEs.

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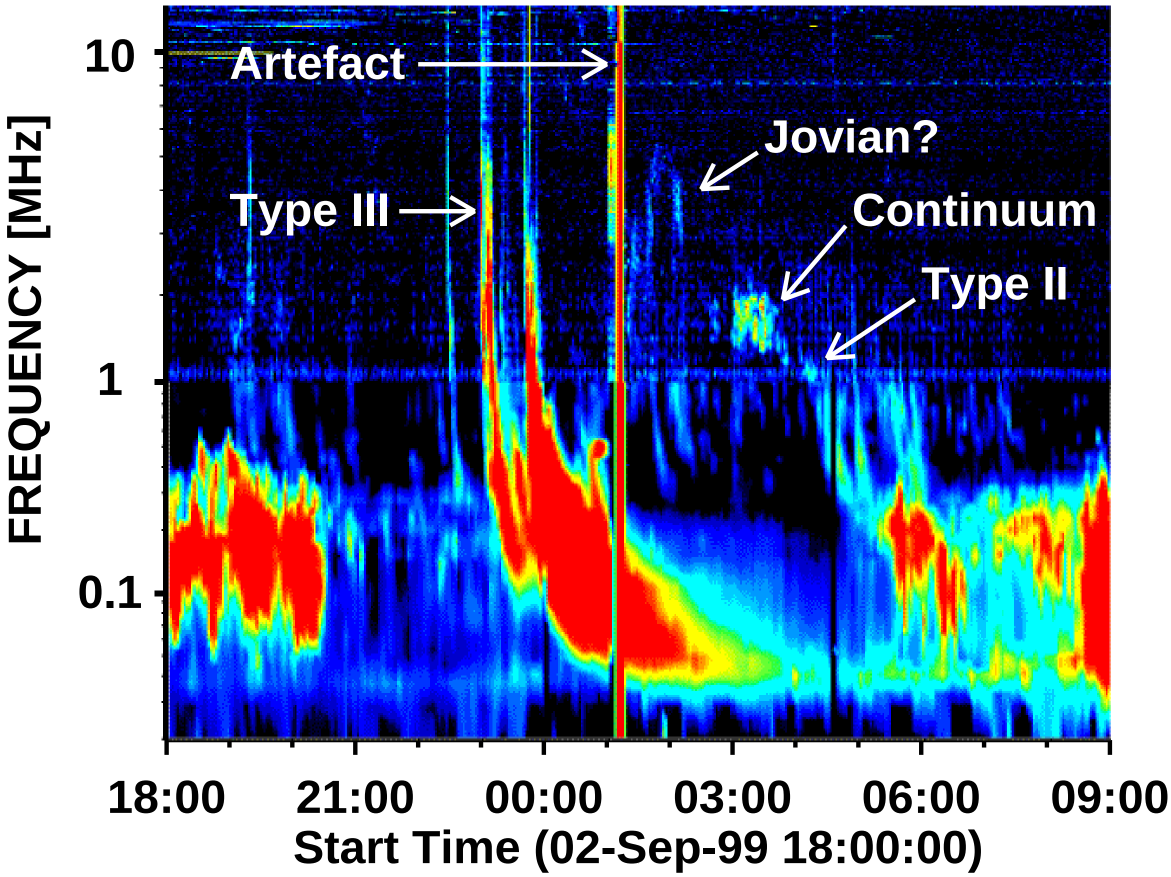

Figure 1. Dynamic spectrum obtained by Wind/WAVES from 30 kHz to 14 MHz during September 2-3, 1999. The new type of radio emission is marked "continuum". The type II bursts were associated with the second CME. The weak irregular features between 01:30 and 2:00 UT are most likely Jovian bursts.

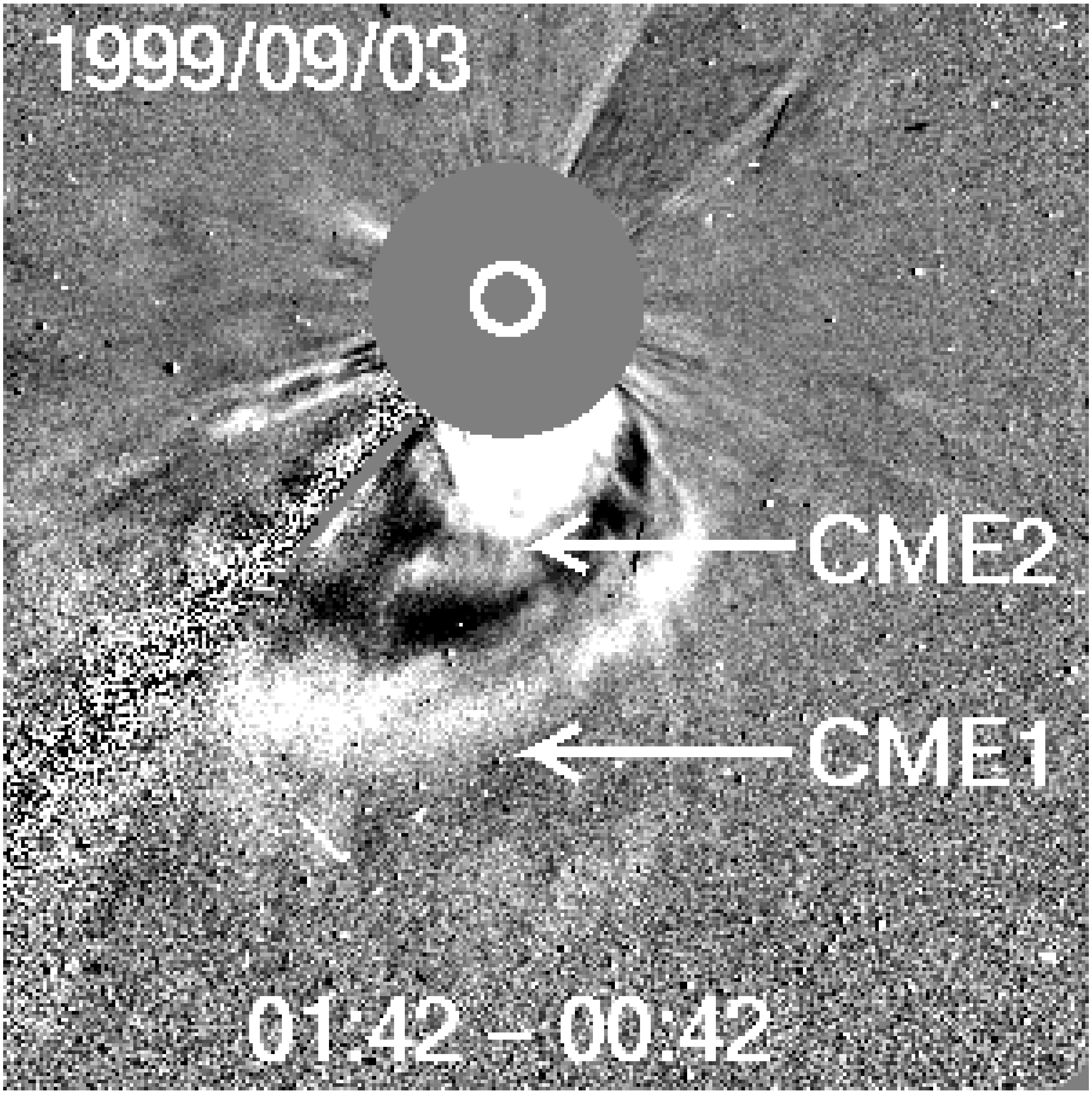

Figure 2. (SOHO/LASCO difference image (01:41 UT minus 00:42 UT) on September, 3, 1999 showing the two CMEs, marked CME1 and CME2. The white circle represents the optical disk of the Sun. The occulting disk of the C3 coronagraph is represented by the gray disk. Solar north is to the top and east is to the left.

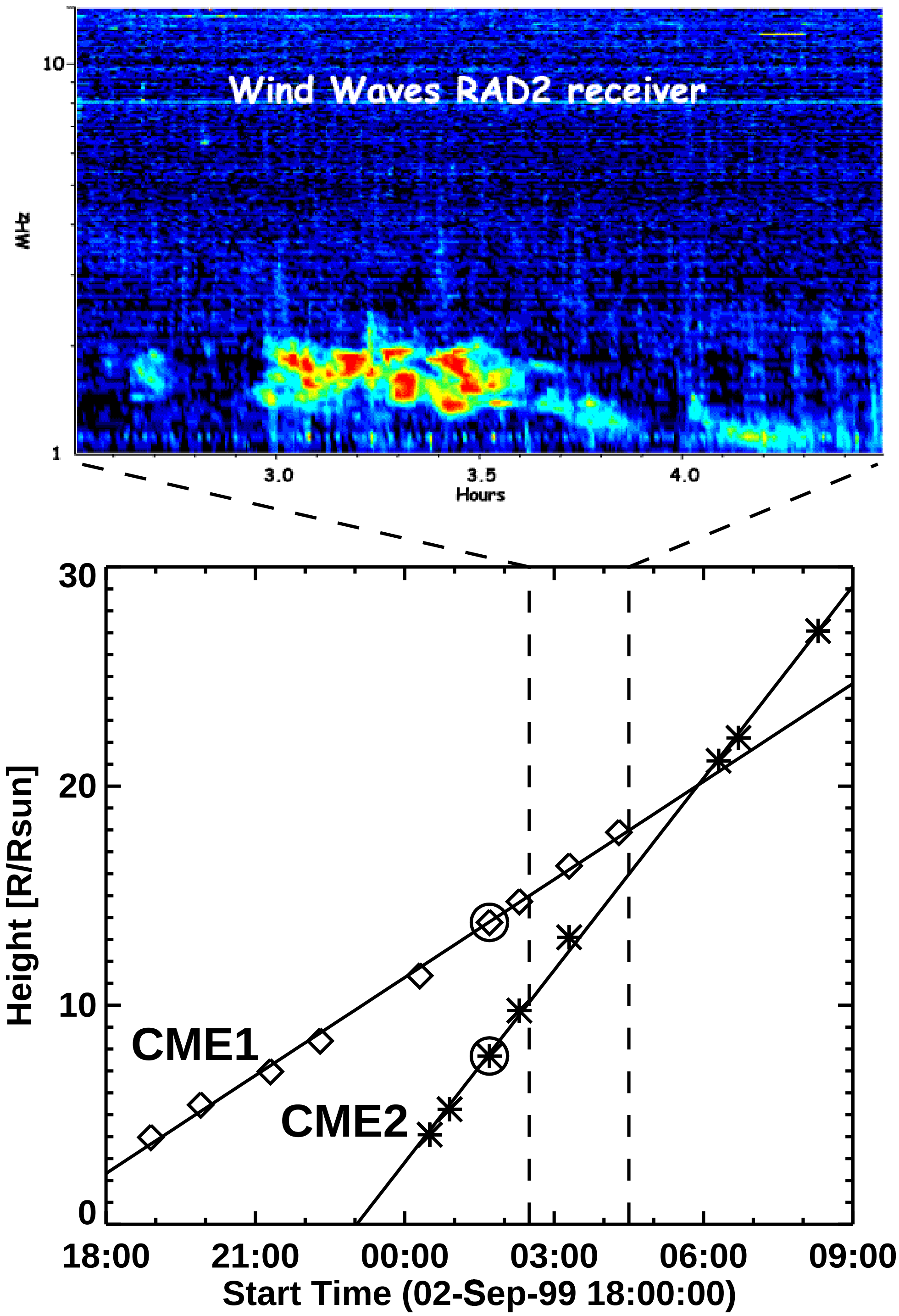

Figure 3. Height-time plots of the leading edges of the two CMEs, with the interval of radio emission marked by the two vertical dashed lines. The trajectories of the leading edges intersect at 06:00 UT on September, 3, 1999, but the radio emission begins much before the intersection, because CMEs have thick frontal structures. A section of the RAD2 dynamic spectrum showing just the new type of radio emission is also shown at the top. The data points corresponding to Figure 2 are circled.

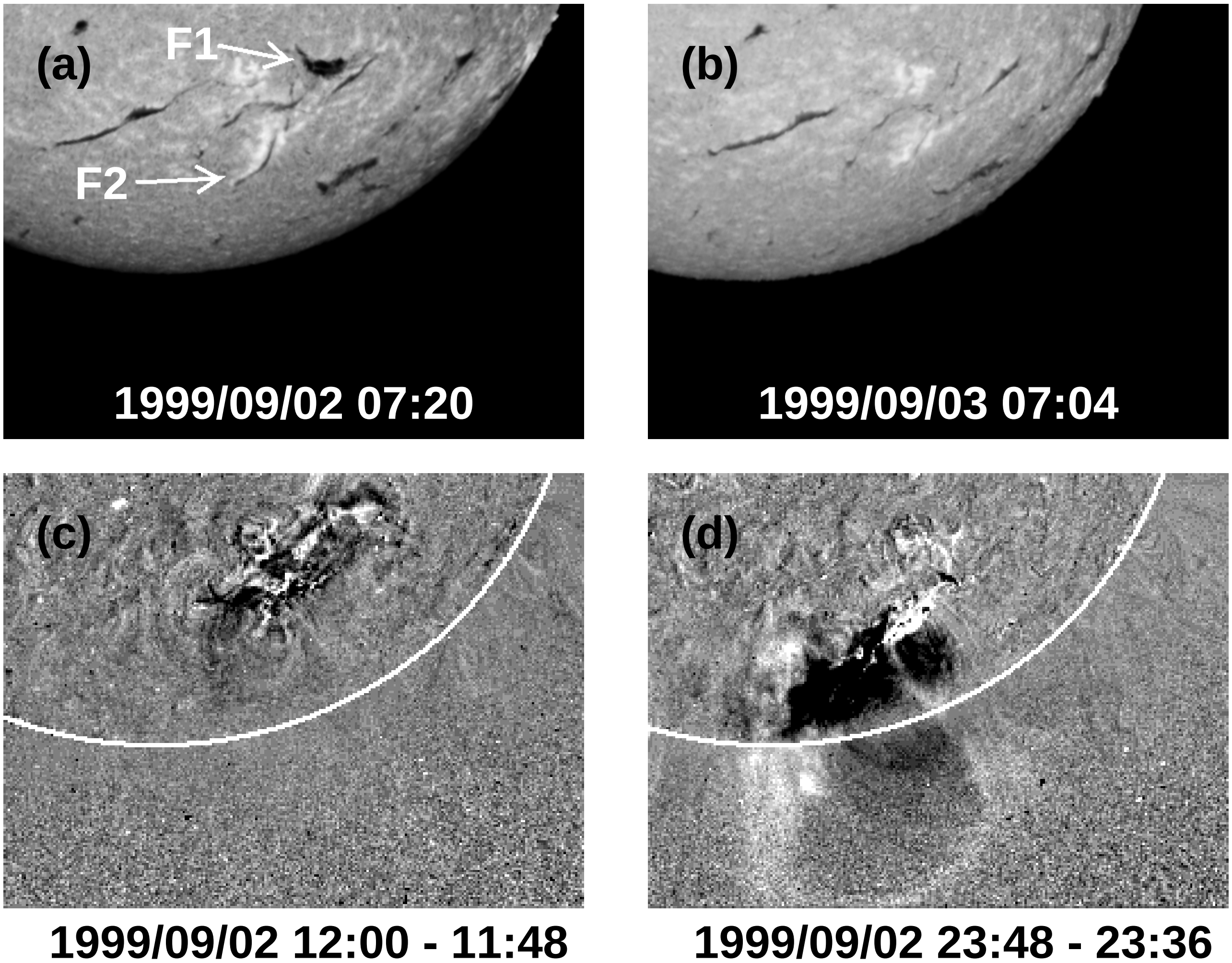

Figure 4. H-alpha pictures and SOHO/EIT running difference images showing the solar sources of the two CMEs. The H-alpha images show the disappearance of the two filaments F1 and F2, in association with CME1 and CME2, respectively (a, b). The dark regions in the EIT images (c,d) represent depletion of material from the corona due to the launch of the CMEs. The bright structure seen radially above the dimming region of CME2 (in d) is probably the early stage of the CME itself.