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ON THE DISK Hα AND RADIO OBSERVATIONS OF THE 2003 OCTOBER 28 FLARE AND CORONAL MASS EJECTION EVENT

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ABSTRACT

We present the evolution of the Hα and radio emissions seen by the Meudon Hα telescope and the Nançay radioheliograph, which are associated with the X17.2 flare and halo CME of 2003 October 28. The remarkable characteristic of this event is its spatial extent that it reached in a few minutes. At 164 MHz, radio images show that the emission covers the whole disk of the Sun and extends as far as 1.8 $R_{\odot}$ from the Sun's center. The radio emissions, the Moreton wave seen in Hα, and the CME all show a similar temporal and spatial development, and the three phenomena are likely to be related. We show that multifrequency radio imaging observations obtained at high cadence can accurately visualize the initial on-the-disk development of fast halo CMEs and also provide physical parameters such as their speed and angular expansion.

Subject headings: Sun: activity — Sun: corona — Sun: particle emission

1. INTRODUCTION

The coronal mass ejection (CME) phenomenon is defined through coronagraph observations that detect a brightness enhancement with an outward motion. The underlying physical process, and in particular the relationship between CMEs and Hα flares, which often occur conjointly, are still not fully understood. It is not unusual to present these two energy release channels in the corona as independent and to refer to other transient activities in the corona as either caused by flares or driven by CMEs. The radio imaging observations, near the limb, of fast flare-related CMEs (e.g., Maia et al. 1999) show that the activity frequently originates from localized emissions in the vicinity of the flare site and that it progressively covers the angular extent of the CME in less than 10–15 minutes. Halo CMEs that originate on the visible solar hemisphere are often connected with on-the-solar-disk Hα, X-ray and ultraviolet (XUV), soft X-ray, and radio manifestations that reveal that multiple loop systems participate in the erupting process and lead to the opening of the magnetic field. This large-scale destabilization of the magnetic field could be interpreted as resulting from the interaction of a coronal disturbance (revealed by the presence of radio type II bursts) with these magnetic loop systems at distant locations (Pohjolainen et al. 2001, 2005; Maia et al. 2001, 2003). Hα Moreton waves, which appear as arc-shaped fronts propagating away from the flare region at speeds of 1000 km s^{-1}, are often considered as the chromospheric trace of these coronal disturbances (Uchida 1968). In the case of the 1998 May 2 halo CME event, Pohjolainen et al. (2001) linked both spatially and temporally an Hα Moreton wave to the successive components of a type II burst. The comparison between radio and Hα emission was, however, possible for one bright Hα feature only, of narrow extent, which could be easily tracked through the solar disk. Events for which Moreton waves, radio imaging, and CMEs observations all together are available are presently very rare.

In this Letter we present a multiwavelength analysis of one major event of solar cycle 23 that took place on 2003 October 28. This event was characterized by an X-ray flare (X17.2) observed in the NOAA AR 10486 (S16°, E08°), an Hα Moreton wave, a halo white-light CME, hard X-ray emission above 100 keV, and a long-duration radio emission. This event was also associated with energetic particles detected in situ in the interplanetary medium. The radio features occurring during this event are impressive sources that cover most of the solar disk; they track the progression of the CME and of the particularly well-developed Hα Moreton wave. We exclusively focus on the link between the radio outburst, the Moreton wave, and the halo CME.

The data used in this study are the Meudon Hα movies, the white-light images from the Large Angle and Spectrometric Coronagraph (LASCO; Brueckner et al. 1995), the radio images at four different frequencies (410, 327, 236, and 164 MHz) obtained by the Nançay Radioheliograph (NRH; Kerdraon & Delouis 1997), the radio spectra recorded by the Bleien CALLISTO spectrometer (Benz et al. 2005), and by the Nançay Decameter Array (DAM; Lecacheux 2000).

2. WHITE-LIGHT AND Hα OBSERVATIONS

Shortly after the onset of the X17.2 flare, LASCO observed a fast-moving CME. Figure 1 shows LASCO C2 images of the event at 11:30 and 11:54 UT. Two different features can be seen on those images: a diffuse bright halo completely surrounding the occulting disk and a brighter looplike component propagating in the south direction. Both have comparable velocities, about 2500 km s^{-1}, and leave the sun at approximately the same time, around 11:04 UT, plus or minus a few minutes.

The Meudon heliograph observed the core and wings (± 0.5 Å) of the Hα line on the full sun with a time resolution of 1 minute. The event is very complex, with flare signatures, filament eruptions, and a large-scale fast-moving disturbance. This disturbance is mostly visible in difference images of the red wing (difference between two successive images) as a bright front followed by a dark region. Some Hα running-difference images of the event are shown in Figure 2 on which three regions of the wave front are indicated by arrows. These features are seen in other images so that their propagation on the disk can be analyzed. The feature labeled "C" in Figure 2

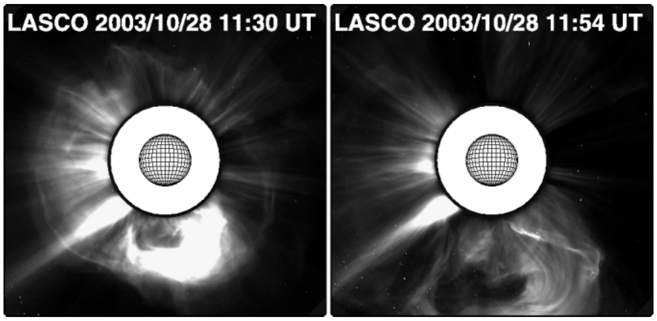

FIG. 1.—CME on 2003 October 28 as seen by LASCO. The grid inside each image corresponds to the photospheric disk of the sun. The CME is seen as a halo encircling the sun.

is rather fast, with a velocity (corrected for propagation along a sphere) of about 2100 km s^{-1}, and is first seen at 11:04 UT. Feature B is weaker and more diffuse and can be detected only in three images, yet its velocity can be estimated to be approximately 1800 km s^{-1}. Feature A is the slowest, with an initial velocity of about 1300 km s^{-1} and, although rather faint, can be tracked easily. This wave front corresponds to the observational characteristics of a Moreton wave (Uchida 1968). The high velocities measured correspond to super-Alfvénic velocities in typical coronal conditions and show the propagation of a shock with a velocity comparable to that of the CME.

3. OVERVIEW OF THE RADIO OBSERVATIONS

Figure 3 shows the radio flux at four different frequencies and the DAM spectrum. The preevent activity consists of type III bursts and of a broad frequency continuum. The dominant sources of the continuum measured by the NRH at distinct frequencies are located east of AR 10486. An intense outburst, detected over the whole NRH frequency range, suddenly takes place at 11:02 UT. It consists of type III bursts and, after 11:03:30 UT, of an intense continuum. After 11:04:30 UT (see Fig. 4), the activity becomes more complex with a type II–like feature detected by the DAM and type III bursts, and the continuum drifts toward lower frequencies. This continuum originates from several distinct locations.

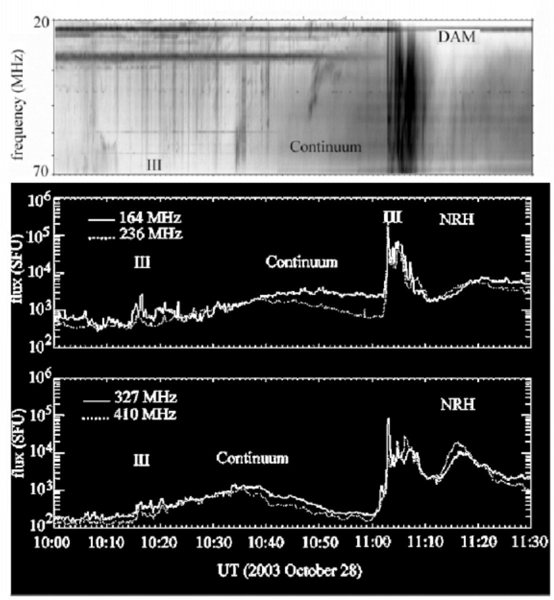

FIG. 3.—*Middle and bottom*: Flux measured at four frequencies by the NRH. *Top*: Radio spectrum measured by the DAM spectrograph. An outburst is seen following type III emissions and a continuum increase. This outburst rises well above preevent values at all frequencies, after 11:02 UT.

3.1. *The Outburst*

The radio emission following the sudden flux increase of 11:02 UT is composed of series of type III, which are detected from the low corona up to the interplanetary medium. These type III bursts are first located on the west edge of the broad Hα flare (see Fig. 2), but a few seconds later, the radio sources positions start to drift. Figure 5 shows images at 410 and 327 MHz, from 11:02:41 to 11:03:31 UT, of

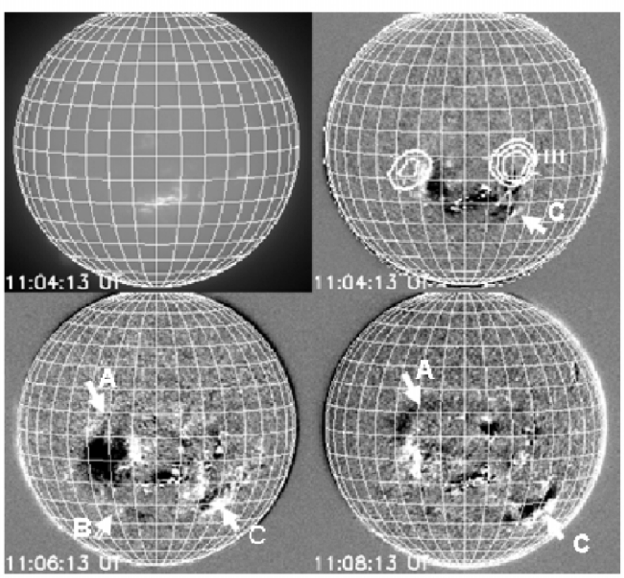

FIG. 2.—Hα flare (*top left*). The three other frames are running differences of Hα images. The radio sources observed at 164 MHz, measured at 11:02:32 UT are superposed on the top right frame. The eastern and western positions correspond, respectively, to the continuum and to the type III bursts. The source of type III bursts, indicated in this figure, is detected from 11:02:24 UT to 11:02:38 UT (see text). The two bottom frames show the Moreton wave. The arrows indicate three regions of the wave front.

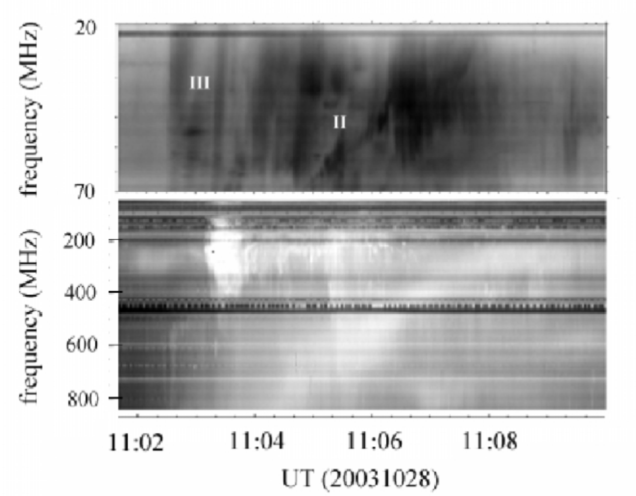

FIG. 4.—Radio spectrum measured by the DAM spectrograph (*top*) and the CALLISTO spectrograph (*bottom*).

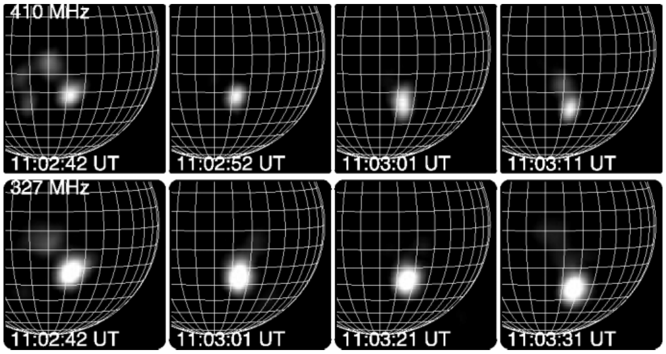

FIG. 5.—Nançay images at 410 and 327 MHz illustrating the drift in position with time of type III sources.

some of the sources associated with these type III bursts. The positions of the bursts at different times show a progression toward the south. In the 50 s period shown, the burst positions moved about 10° south and 5° west. The corresponding projected "velocity" of these sources is about 2500 km s^{-1}. This group of bursts is seen also at lower frequencies. In Figure 6, the corresponding positions, measured at 236 and 164 MHz, are reported on a Michelson Doppler Imager (MDI) image. Type III bursts can be seen, up to 1 $R_\odot$ from the flare region. Other type III burst locations, not reported in the figure, are detected in the north solar hemisphere.

After 11:03:31 UT the images at 410 MHz show a very complex structure. There is a simultaneous sudden increase of the radio emission at all frequencies below 410 MHz (see Fig. 3). The decameter type II–like feature is detected a few minutes later. Figure 7 shows that the emitting sources at 410 MHz cover a vast area of the sun, are mostly stationary, and last at least a few tens of seconds, although short-duration type III bursts are associated with some of them. Figure 8 compares the radio emission at 410 MHz, at 11:04:11 UT, with the positions of the Moreton wave front at 11:05:13 UT. Note that we use the Hα images at 11:05 UT because this is the first image in which the wave front can be reliably reconstructed. Given a velocity of about 2000 km s^{-1} for the Moreton wave, the wave front at 11:04 UT should be located slightly behind the wave front shown in the figure but should have roughly the same shape. The important observation is that the Moreton wave front seems to bound the emissions seen in radio.

Shortly after the time when the broad source is seen at 410 MHz, the flux level drops at 236 MHz, and a similar very broad source becomes visible at this frequency after 11:06:30 UT. Three 236 MHz images taken at 11:06:49, 11:06:59, and 11:07:19 UT are shown in Figure 9. The source extent is consistent with the expected front of the Moreton wave if we note that at this frequency one must compensate for projection effects of a few tenths of a solar radii above the solar surface. Later on, at 164 MHz the source becomes visible. As shown in Figure 10, the 164 MHz emission at 11:08:28 UT covers most of the solar disk, and in subsequent images, a progression of the emission toward the south is evident. This emission is seen at 11:10:57 UT extending to 1.8 $R_\odot$ from the Sun's center.

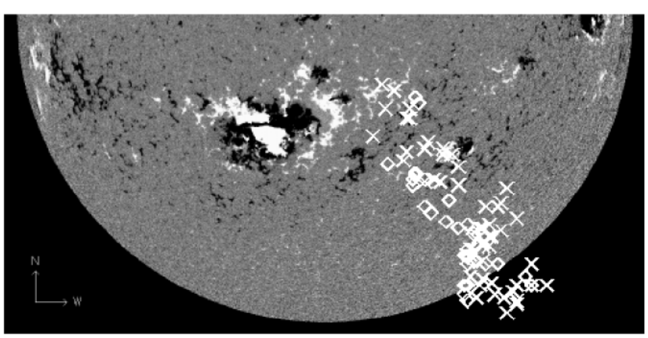

FIG. 6.—Positions of type III bursts at 236 MHz (*diamonds*) and 164 MHz (*crosses*) observed between 11:02:30 UT and 11:06:30 UT reported in a MDI magnetogram measured at 09:35 UT.

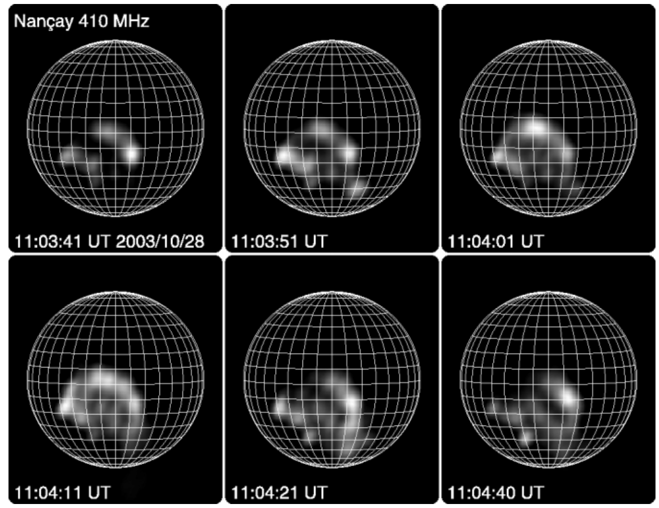

FIG. 7.—Nançay images at 410 MHz showing a very broad emitting region.

4. DISCUSSION

This brief analysis of some outstanding features of the radio emissions associated with the 2003 October 28 event illustrates well the global nature of the phenomenon. Starting from what is a large active region, the activity engulfs a large portion of the corona. The projected positions of the type III bursts appear to trace the same pattern as the southwest front of the Moreton wave. These radio sources are located approximately along and around the inward extrapolation of the west edge of the CME. The most original feature of the event is the very broad emission region seen in Nançay images from 410 to 164 MHz. Radio emissions are the signature of the magnetic field restruc-

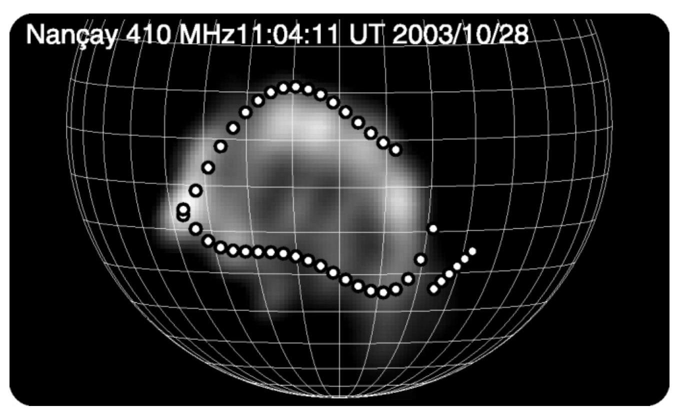

FIG. 8.—Nançay image at 410 MHz with the position of the Moreton wave (at 11:05:13 UT) superposed. The shape of the Moreton wave front and of the radio emission correspond rather well.

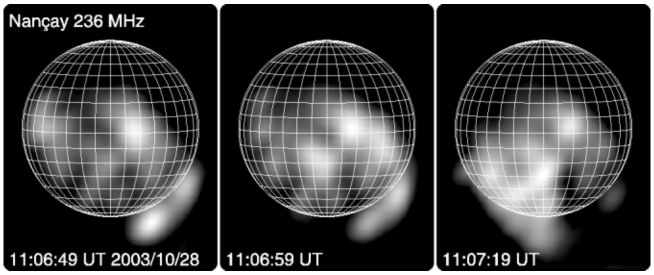

FIG. 9.—Nançay images at 236 MHz showing a very broad emitting region covering a large fraction of the solar disk.

turing at the edges of the CME. Here, we have followed for the first time the propagation of a well-formed Moreton wave[1] and the evolution of the radio emissions at different frequencies. As the radio emissions coincide with the Moreton wave, we can conclude that the lateral expansion of the CME is related to the disturbance traced by the Moreton wave. One important conclusion for solar-terrestrial research is that multifrequency radio imaging observations obtained at high cadence allow accurate visualization of the initial on-the-disk development of fast halo CMEs and also provide physical parameters related to these CMEs, such as their speed and angular expansion. Finally, the radio imaging data show that as for many other events, multiple sources of nonthermal origin are detected far from the flare region. A further study will discuss the solar origin of interplanetary energetic electrons that were also detected in situ in association with this event.

[1] The Hα movie showing the Moreton wave is available at ftp://ftpbass2000.obspm.fr/pub/meudon/papers/28OCT03.mpg.

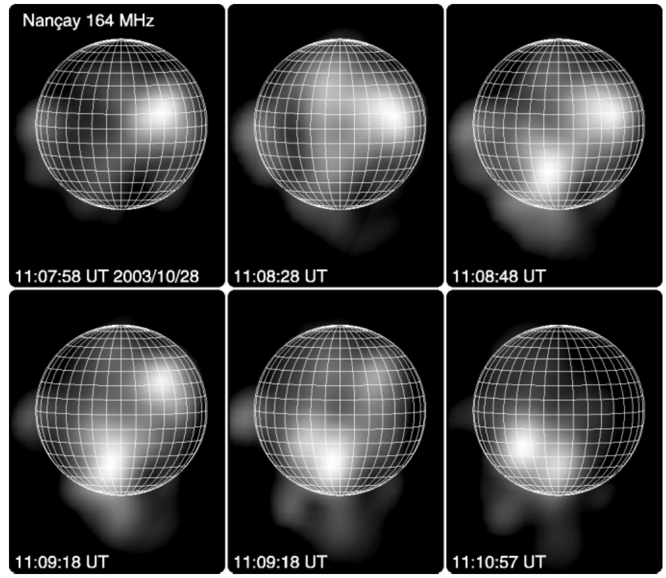

FIG. 10.—Nançay images at 164 MHz showing a rather large emitting region that covers most of the solar disk, extending up to 1.8 $R_{\odot}$ from the Sun's center in the south.

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