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Magnetic reconfiguration before the X 17 Solar flare of October 28 2003

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Abstract

An active region (AR) NOAA 10486, which produced a large number of X-ray flares during October–November 2003, was observed during a multi-wavelength campaign with ground based and space instruments. We focus our analysis on the observations of October 28, 2003. The magnetic field was observed with THEMIS (Na D1) and MDI (Ni I), the chromosphere with THEMIS (Ca II 8542 Å) and with the Meudon heliograph in Hα, the EUV images with SOHO/EIT and TRACE. Two pre-events started just before the major X 17 flare. One was related to localized flux emergence and lasted until the decay phase of the X flare; while the second one involved a large scale quadrupolar reconnection, that we infer by modeling the AR magnetic field. Extended dimming areas across the equator (EIT), large arcades of post-flare loops (TRACE 195 Å) and a halo CME (LASCO) were observed consequently after the flare. We perform an extrapolation of the magnetic field above the photosphere using a linear force-free-field approximation that allows us to find the connectivity among the four polarities that would be involved in the quadrupolar reconnection event. The X 17 flare is plausibly due to the destabilisation of a twisted flux tube, the bottom part of this magnetic structure can be visualized by the presence of a filament. The destabilization is caused by converging and shearing photospheric motions towards the main magnetic inversion line. The large scale quadrupolar reconnection related to the second pre-event would favour the opening of the field above the twisted flux tube and, consequently, the coronal mass ejection.

Keywords: Sun: flare; Sun: magnetic field; Coronal mass ejection

1. Magnetic evolution of the AR10486

The active region arrives to the East limb on October 23, 2003, with an already complex configuration. A new bipole was emerging within a decaying region with no sunspots and only facular regions. The remnant active region is reversed in sign from the normal hemispheric rule, which predicts that in the South the trailing polarity should be negative for the associated cycle. The new emerging bipole in the center of the active region consists firstly of one preceeding sunspot of negative polarity and two following spots of positive polarity. This emerging bipole follows the hemispheric rule and forms a quadrupolar region with the remnant one. The preceeding spot grows and separates into two spots on October 26 while the following part continues its transit having two spots with increasing strength. To the North of the positive polarity, several bipoles emerge creating a positive island separated from the original positive spots by a negative bridge (second phase of emergence). The western portion of this island (2′) corresponds to the po-

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sitive polarity of a new emerging bipole, whose negative polarity forms a part of the bridge (3′). The onset of the large X17 flare on October 28 at 11:01 UT occurs close to this region. Such an emergence is repeated several times during the passage of the active center across the disk.

On October 28, 2003, four large polarities can be identified in the longitudinal magnetic field map obtained by THEMIS (Mein, 2002): region 1, region 2 + 2′, region 3 + 3′ and region 4 (see Fig. 1, left) . Region 1 is the remnant following part of the old region. Regions 2, 3 and 4 are the main parts of the principal emerging bipole. Regions 2′ and 3′ belong to the second phase of emergence.

2. X 17 flare

Between October 19 and November 4, 2003, 12 X-class flares were observed. The extremely high level of activity resulted from the formation of three complex beta–gamma–delta regions on the Sun (NOAA 10486, 10484, 10488). AR 10486 was characterized by a large number of energetic flares (eight flares) and CMEs. We focus our study on the X17 flare that occurred on October 28, 2003, at 11:01 UT and was related to a fast halo CME (1785 km/s) according to Vourlidas, http://www.solarmonitor.org/ptg/oct-nov-2003-xflares.html observed by LASCO in C2 and C3 and dimming areas on each side of the flare observed by EIT (Fig. 2). This very energetic flare was preceded and accompanied by less energetic pre-events. The origin of the first pre-event can be associated with the emergence and evolution of the bipole described above (bipole 2′and 3′).

This pre-event is the result of the interaction of loops anchored in the new emerging bipole connecting polarities 2′ and 3′ with loops belonging to 3 and 4 (see Figs. 3). This confined quadrupolar reconnection process was evident as early as 10:05 UT in TRACE

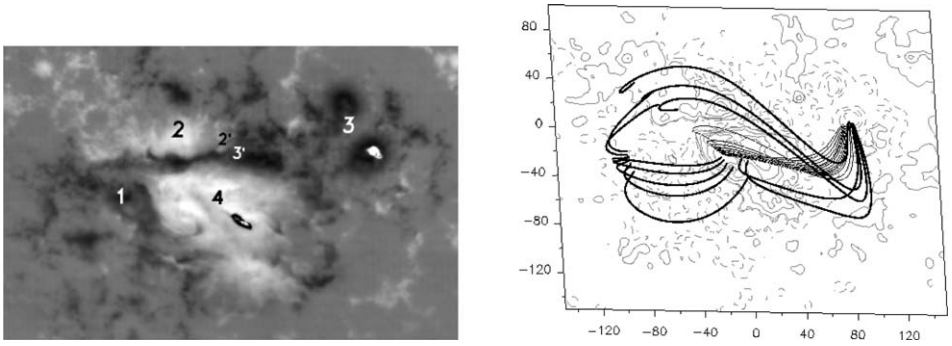

Fig. 1. Active region 10486 magnetogram (left) obtained with THEMIS in the Na D1 line (Mein, 2002) showing the four main polarities. The magnetic field is not computed in some points of the sunspots because of the presence of flare ribbons that perturb the profiles of the line. Magnetic field lines extrapolated above the quadrupolar configuration (right). The large scale quadrupolar reconnection is expected to take place in the corona. The projected site of reconnection should be between 3′ and 4. We have taken the photospheric magnetic field observed by MDI (Scherrer et al., 1995) as boundary condition. The four ribbons (see Fig. 4) are located in the anchorage points of the field lines. The pixels where the photospheric observations were perturbed by the presence of the strong flare emission were corrected by interpolating the values in the closest pixels without perturbation.

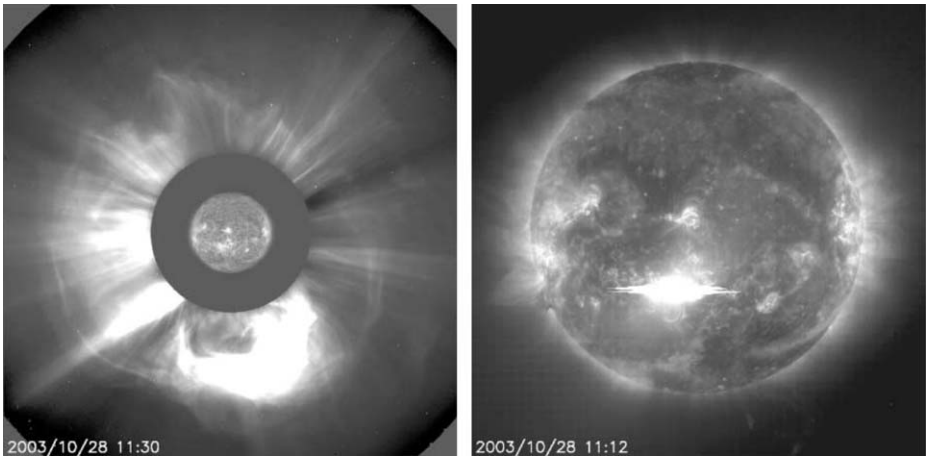

Fig. 2. October 28, 2003, (left) halo CME (LASCO), (right) major X 17 flare and dimming regions on both sides of the flare (EIT 195 Å) (Delaboudinière et al., 1995).

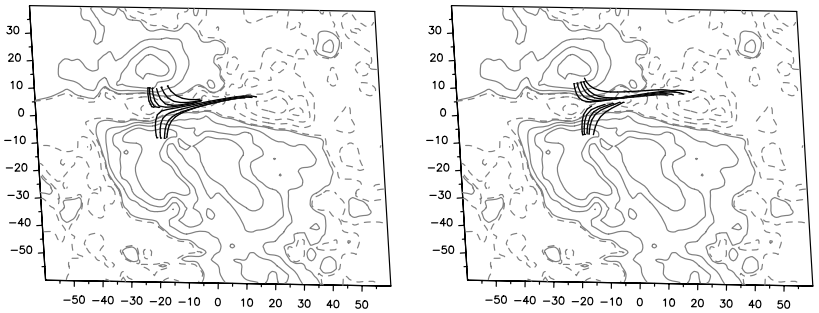

Fig. 3. Magnetic field model showing the field connectivity corresponding to the event previous to the X 17 flare observed in the TRACE image at 10:17 UT (see the magnetic contours overlaid to the EUV image in Fig. 4), extrapolated field lines before the pre-event (left), after the small scale reconnection explaining the brightness visible in the middle of the TRACE image (right). The elongated loop at the northern part of the polarity 4 extending along the neutral line (see Fig. 4 right top panel) is an evidence of the already on going magnetic reconnection process that will develop during the two ribbon X 17 flare.

images (Fig. 4 top right panel, where we have overlaid a TRACE image with MDI isocontours) and continued even during and after the intense X17 flare. Many minor emerging bipoles were evident to the East of AR 10486.

The second important pre-event was associated to the presence of four well observed ribbons in Hα and TRACE 1600 Å during two episodes between 10:12 and 10:19 UT and between 10:47 and 10:56 UT. We interpret these distant four ribbons as the signatures of

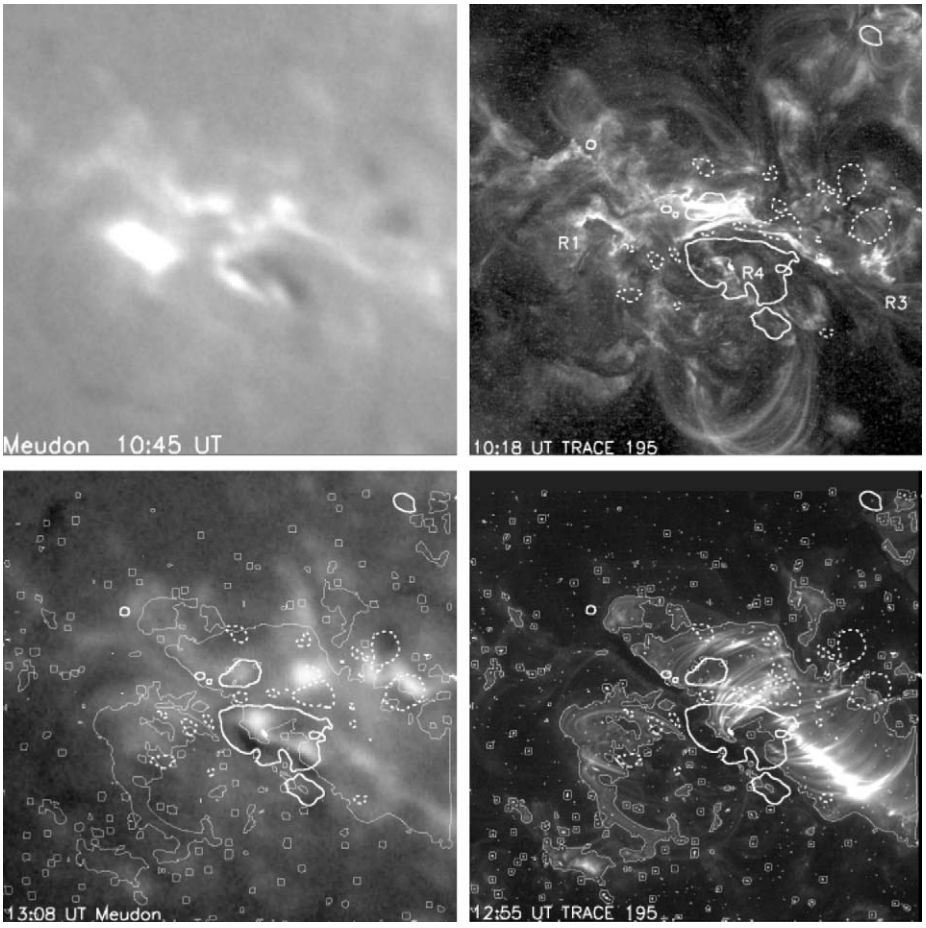

Fig. 4. October 28, 2003, (left top panel) Hα four ribbons (Meudon heliograph) at 10:45 UT and (right top panel) in TRACE 195 Å interpreted as the signatures of a large-scale quadrupolar reconnection. In the middle of the TRACE image, the small bright loops correspond to the new emerging bipole (2′, 3′ in Fig. 1) suggesting local reconnection. Magnetic contours overlay this image. (left bottom panel) Hα two ribbon X 17 flare at 13:08 UT (Meudon heliograph) and at 12:55 UT (right bottom panel) post-flare loops (TRACE). Magnetic contours overlay both images (thick lines).

reconnection occurring in the large-scale global quadrupolar field since, after modeling the coronal magnetic field, we find that these ribbons (see caption to Fig. 1 for a further explanation) are located close to the ends of the large extrapolated field lines (see Figs. 1 and 4). The result of this quadrupolar reconnection process was mainly the formation of reconnected loops showing a strong chromospheric plasma evaporation. The trace of these loops can be observed, surrounded by a thin continuous line, in Fig. 4 (bottom right panel) to the SE of the main positive polarity. Along the major magnetic inversion line we observe, at 10:22 UT, the propagation of a brightening along the long filament lying over the magnetic inversion line between the polarities 3 and 4 (Fig. 4). This filament could be supported by a twisted magnetic tube (as in the case analyzed by Aulanier et al., 1998) whose overlaying arcade we have represented in Fig. 1 (central, thinner set of field lines connecting 3–4).

The coronal evolution as seen by TRACE in 195 Å, together with TRACE observations in 1600 A (low chromosphere), indicates that the X 17 flare could be due to the destabilization of this hypothetical twisted flux tube. Polarities 3 and 4 were at their decay phase, surrounded by a ''moat region''. The convergent motions, as the flux diffused towards the main magnetic inversion line, increased the shear and favoured reconnection between the loops in the ''sheared'' arcade that would overlay the magnetic neutral line (Zhang et al., 2003).

The reconnection process, which is visible with the formation of newly reconnected loops as early as 10:05 UT in TRACE images, increased the flux in the twisted flux tube until it finally became unstable and erupted giving rise to a classical two ribbon flare accompanied by the formation of large post-flare loops (Fig. 4) (Forbes and Malherbe, 1986; Schmieder et al., 1995; Gu et al., 2001). This eruption was favoured by the large-scale quadrupolar reconnection occurring just before the flare as such reconnection remove part of the overlying arcade.

3. Conclusion

From the analysis of the magnetic field evolution, topology and multi-wavelength data before and during the X 17 flare on October 28, 2003, we conclude that a large twisted flux tube supporting the long filament lying along the main inversion line could plausibly be formed and erupted. The slow build-up of magnetic stress begins before the eruption favoured by converging motions along the magnetic inversion line. If we try to classify the X 17 flare within the scenario of ''storage and release'' models (Klimchuk, 2001), i.e. tether cutting or tether straining, it appears that two mechanisms could be present: firstly, the flux tube is built up as reconnection occurs in a sheared arcade aligned along the main neutral line. From the multiwavelength data, we speculate the following scenario. The flux tube starts to rise slowly, cutting progressively the tethers. During that time the flux in the tube increases. Then, a large-scale quadrupolar reconnection occurs in the active region in two successive episodes, which are homologous. However, the second episode is more intense, implying a more important field rearrangement. These quadrupolar reconnections remove stabilizing field lines from above the flux rope, which succeeds to break out (see Antiochos, 1999). Reconnection under the erupting flux rope starts after the eruption, forming a post-flare loop arcade.

Before the X 17 flare, and even during it, we observe a pre-event associated with a confined quadrupolar reconnection process between an emerging bipole and the pre-existing magnetic configuration. This is confirmed by our magnetic field model and topology analysis.

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