ANALYSIS OF A MORETON WAVE ASSOCIATED WITH THE X17.2/4B FLARE/CME OF 28-10-2003

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Abstract. The fast Moreton wave of 28-Oct-2003 associated with the extreme X17.2 solar flare/CME event is studied. It can be followed in four sectors, spanning almost over 360° on the visible solar disc. The mean wave velocity lies in the range of v~900–1000 km s⁻¹. We find two wave ignition centres on opposite edges of the source region, which may indicate that the wave is driven by the CME expanding flanks.

Key words: Moreton waves - solar flares waves - chromosphere - corona

1. Introduction

Moreton waves were first documented by Moreton and Ramsey (1960) in Hα filtergrams as disturbances propagating with typical velocities in the range of ~500–1000 km s⁻¹ and angular extents of ~90–130° (e.g. Warmuth et al., 2004; Veronig et al., 2006). They are interpreted as the intersection line of an expanding, coronal fast-mode wave and the chromosphere (Uchida, 1968). Large-scale waves directly imaged in the corona, so-called EIT waves, were first detected by Thompson et al. (1998). Similarities in the propagation characteristics led to the assumption that a fraction of EIT waves is the coronal counterpart of the Moreton waves observed in the chromosphere (e.g. Thompson et al., 1998; Warmuth et al., 2001; Vršnak et al., 2002). A basic question regarding the nature of Moreton and EIT waves is the ignition agent, i.e. whether they are generated by flares or CMEs (see e.g., reviews by Vršnak, 2005; Chen and Fang, 2005; Warmuth, 2007).
In this paper, we study high-cadence Hα observations of an exceptional Moreton wave that occurred on 28-Oct-2003 in AR 10486 in association with the extreme X17 flare/CME event. The wave is special due to its propagation angle of almost 360°, and was already studied with particular emphasis on the radio aspect by Pick et al. (2005). Another Moreton wave with similar characteristics was launched from the same AR on 29-Oct-2003 associated with a X10 flare/CME event (Balasubramaniam et al., 2007).

2. Data and Observations

The Moreton wave under study was launched during a strong flare/CME event which occurred in NOAA AR 10486 (S16°, E08°) on 28-Oct-2003. NOAA AR 10486 was a complex βγδ region, and was surrounded by several other large and complex ARs (e.g. AR 10484, AR 10488). The time range between 19-Oct-2003 and 4-Nov-2003 was characterized by an extreme level of solar activity during which 12 X-class flares were produced. On 28-Oct-2003 AR 10486 was birthplace of a X17.2/4B flare (GOES peak 11:10 UT) and associated fast halo CME ($v \approx 2500$ km s$^{-1}$; LASCO CME catalogue: http://cdaw.gsfc.nasa.gov/cme_list/).

The Moreton wave is studied in chromospheric Hα filtergrams recorded by the Meudon Heliograph (France) and could be observed during the time interval 11:02:14–11:13:10 UT. Due to its special construction, the heliograph allows simultaneous observations of the full Sun at three different wavelengths in the Hα spectral line: Hα centre, Hα + 0.5 Å and Hα − 0.5 Å. The bandwidth of the Lyot filter is 0.5 Å. The imaging cadence is ~1 min.

3. Results

Figure 1 shows a running difference image sequence in the Hα blue wing. The Moreton wave appears as a bright, arc-like transient disturbance, propagating away from the flare site in different directions, spanning almost over the full visible solar disc. We studied the wave kinematics separately for four different directions, in which the wave could be distinctively followed. The four sectors 1–3, 4–6, 7–8, 9–11 (denoted by hours on the clock-face) are indicated in Figure 1. We note that the wave fronts in direction 9–11 were disturbed due to reflection and refraction at the strong magnetic fields around AR 10488, which resulted in the wave propagation towards North
Figure 1: Sequence of Hα–0.5 Å running difference images. The identified leading edges of the Moreton wave fronts (seen as bright fronts in Hα blue wing observations) are drawn by black lines. The different sectors are indicated in image (e) and (f). Each image shows a FoV of 2000″ × 2000″.

after 11:06 UT (sector 12 in Figure 1).

The Moreton wave ignition site was estimated by applying circular fits to the earliest observed wave fronts (see Figure 2), whereby the projection effect due to the spherical solar surface was taken into account (following Warmuth et al., 2004). The result was rather surprising, since we found for the four directions two separate ignition centres at the coordinates \([-191'', -316'']\) and \([-5'', -368'']\) on opposite east-west edges of the source AR. This means that actually two waves were launched simultaneously.

![Figure 2: Hα–0.5 Å image at 11:12 UT. Overlaid are the visual determined leading edges (drawn for four times to get better statistics) of the first and second visible wave fronts (marked as white lines) for the sectors (a) 9–11, (b) 1–3, (c) 7–8, (d) 4–6. Superposed are the ellipses (black) which correspond to fitted circles in the deprojected heliographic 2D plane, used for calculating the starting locations (black pluses) and their mean values (white crosses). The shown FoV is \(x=[-600'', +400'']\), \(y=[-700'', +100'']\) with the origin at the centre of the Sun.](image)

To derive the wave kinematics, for each point of the wave fronts the distance from its respective ignition site was calculated along great circles on the solar surface. Figure 3 shows the distance-time diagrams for the four different propagation directions. The wave was first visible at \(\approx 90\) Mm in direction 1–3, and can be followed up to 500 – 600 Mm in different directions. While the wave fronts in directions 1–3, 4–6 and 9–11 are

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Figure 3: Kinematics of the Moreton wave observed on 28-Oct-2003. Distance vs. time diagrams derived separately for four different propagation directions. The dashed and dotted lines indicate the linear and quadratic fit to the kinematic curves, respectively. The first two data points for direction 4–6 were excluded in the fitting process, since they are quite uncertain due to the wave passage of a filament.

quite intense, the wave is hardly visible in direction 7–8, probably because of strong magnetic field regions along its path. In direction 4–6 the winking of a filament can be observed after the wave has passed it (≈11:04), which makes the wave front determination difficult for this phase.

Linear and quadratic functions are fitted to the kinematic curves (see Figure 3) from which the extrapolated start times are derived in the range of 10:59:40–11:01:40 UT. The mean velocities derived from the linear fits are 940±10 km s⁻¹, 1050±10 km s⁻¹, 880±30 km s⁻¹, and 1020±20 km s⁻¹ for the orientations 1–3, 4–6, 7–8, and 9–11, respectively. The quadratic fits indicate wave deceleration for directions 1–3 and 9–11.

### 4. Summary and Conclusions

A Moreton wave associated with a X17.2/4B flare and a fast halo CME \( (v \approx 2500 \text{ km s}^{-1}) \) has been analysed. The distance-time diagrams of the
wave revealed a mean wave velocity of $\approx 900-1000$ km s$^{-1}$ and a starting time of $\approx 11:00-11:02$ UT, which roughly corresponds to the first peak in the $>150$ keV hard X-ray flux observed by INTEGRAL (see Figure 1 in Kiener et al., 2006 and Hurford et al., 2006) at 11:02:40 UT, as well as to the linearly back-extrapolated CME starting time of $\approx 11:01-11:02$ UT (LASCO CME catalogue). However, we note that at the time of the first hard X-ray peak, the Moreton wave is already observed in H$\alpha$ filtergrams, which argues against an initiation by the flare pressure pulse. The two wave ignition centres on opposite edges of the source AR, determined by fitting the early Moreton wave fronds suggest a scenario, where the CME expanding flanks initiate the wave.

References