MORETON WAVES AND THEIR RELATION WITH EIT WAVES

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ABSTRACT

Moreton waves, observed in Hα, and the recently discovered coronal transients known as “EIT waves” have remained fairly poorly understood phenomena. In particular, the issues of their mutual association and of the nature of their driver are not resolved. We discuss seven Moreton waves observed in Hα and derive their basic characteristics. Four of these events were observed simultaneously in Hα and EUV. A deceleration of the disturbances is found in all cases. In the 2 May 1998 event, the cospatiality of Moreton and EIT wave fronts is established and a detailed analysis of the evolution of the Hα wave, its kinematics and perturbation profile is carried out. The results – deceleration, broadening, and decrease of intensity of the profiles – favor the fast-mode shock (“blast wave”) scenario over the CME-associated magnetic field evolution hypothesis.

Key words: shock waves; flares; corona; chromosphere.

1. INTRODUCTION

The study of the Moreton wave phenomenon (Moreton & Ramsey 1960), a propagating arc-shaped front observed in Hα, has received a new impetus by the recent discovery of the so-called “EIT waves” (Thompson et al. 1998), globally propagating coronal disturbances typically appearing as bright rims observed with the EUV Imaging Telescope (EIT) aboard SOHO. Moreton waves have been suspected to represent the chromospheric signature of coronal shocks (Uchida 1968), so the possibility that EIT waves are the coronal counterpart to the Moreton phenomenon suggests a careful analysis of the association between these two phenomena. In particular, the main question to be answered remains the one on the driver of these disturbances.

Currently, there are several competing models of the driver. In the “blast-wave” scenario (Steinolfson et al. 1978) a flare-produced initial pressure pulse propagates through the corona as a fast-mode MHD shock (Vršnak & Lulić 2000), where the shock is observed as the bright fronts seen in EIT and as metric type II bursts (Uchida 1974). Conversely, the Moreton waves seen in Hα represent the chromospheric “skirts” of the dome-shaped coronal shock front (Uchida et al. 1973). An alternative scenario is the “piston mechanism”, in which a CME acts as a piston and generates a driven shock (see Cliver et al. 1999 and references therein). Delannée & Aulanier (1999) have recently proposed a completely different interpretation of the EIT waves, which they attribute not to a shock wave at all, but rather to the opening of magnetic field lines associated with a CME.

Neither of these models could be proved yet due to a lack of data. In particular, the association between EUV EIT waves and Hα Moreton waves is still not completely resolved. Statistical surveys of Moreton (Smith & Harvey 1971) and EIT waves (Klassen et al. 2000) point out some discrepancies between the two phenomena, in particular, on the average the former propagate 2-3 times faster than the latter, yet if they are signatures of a shock, they should be relatively cospatial, and indeed Thompson et al. (2000) report such a case, but due to insufficient data they were not able to determine how closely the two phenomena overlap. Thus, doubts remain whether Hα and EIT waves are indeed caused by the same disturbance. Since the EIT waves show a wide variety of morphological patterns, there might even be distinct classes that are caused by different physical processes.

We investigate the kinematics of seven Moreton waves, labeled E1 through E7 (see Table 1), observed in Hα by Kanzelhöhe Solar Observatory (KSO: E1, E2, E6) and Big Bear Solar Observatory (BBSO: E3, E5, E7). In the four cases where simultaneous EIT observations were available (E1, E2, E6, E7), we examine the temporal and spatial relation between the wave fronts seen in EIT and Hα. E1 and E2 have been analyzed in detail (see Warmuth et al. 2001), whereas the other events are subject to a current study. However, the preliminary results fully back the conclusions drawn from E1 and E2.
Table 1. The seven Moreton events, their associated flares and CMEs. All flares are of impulsive nature and associated with metric type II radio bursts. No EIT or LASCO data is available for E3-E5, hence the data gaps. In E4, a CME was observed by the Mark IV K-coronameter at Mauna Loa Solar Observatory. The initial Hα wave speeds were measured using the first two observed wave fronts. Due to the low image cadence of EIT, only two wave fronts could be detected in the EUV in each events, and the EIT speed is derived from these pairs.

<table>
<thead>
<tr>
<th>Event</th>
<th>Class</th>
<th>Location</th>
<th>Start-Max (UT)</th>
<th>initial Hα wave speed (km s⁻¹)</th>
<th>EIT wave speed (km s⁻¹)</th>
<th>CME</th>
</tr>
</thead>
<tbody>
<tr>
<td>E1: 03 Nov 1997</td>
<td>1B/M1.4</td>
<td>S20W15</td>
<td>09:03 - 09:10</td>
<td>≈1000</td>
<td>230</td>
<td>?</td>
</tr>
<tr>
<td>E4: 19 Aug 1998</td>
<td>1F/X3.9</td>
<td>N32E57</td>
<td>21:35 - 21:45</td>
<td>760</td>
<td>no data</td>
<td>yes</td>
</tr>
</tbody>
</table>

Figure 1. Hα (top) and EIT images (bottom) for the four Moreton events that had simultaneous Hα and EIT data coverage (E1, E2, E6, and E7). Overplotted are the visually determined wave fronts and parts of great circles along which the distances from the supposed origin of the disturbance were measured (only the two paths limiting the sector in which the measurements were carried out are shown). The images presented are the earliest frames that show wave features. The Hα images for E1, E2 and E6 are from KSO, the image for E7 is from BBSO. Each image is 23' across. Solar north is up, west is right. Times are given in UT.
2. OBSERVATIONS

Hα full-disk images were provided by KSO for E1 (35 mm film, temporal cadence: 4 min), E2 and E6 (1K x 1K camera, cadence: ~1 min, spatial resolution: 2".3 pixel−1), and by BBSO for E3-E5 and E7 (2K x 2K camera, cadence: 0.5-1 min, spatial resolution: 1".1 pixel−1). EIT full-disk images at 195 Å (Fe XII) were used for coronal observations (1K x 1K camera, cadence: ~10-30 min, spatial resolution: 2".6 pixel−1).

All flares were impulsive and associated with metric type II radio bursts. The CME association is not as clear-cut – while CMEs were observed in four cases, only very weak signatures were detected in E1 and no data is available for E3 and E5.

The onset times of the flare waves were fixed by inspecting radio data (using the time of the impulsive emission in the decimetric to metric range). The location of the source of the disturbances was determined taking into account the shape of the wave fronts and the evolution of the Hα flare. In general, the disturbances seem to emanate from the edge of the flare which was located in the periphery of the active region.

The location of the wave fronts was determined visually using difference images. The distances of the fronts from the source – r(t) – were measured along great circles on a sphere of one solar radius. Fig. 1 shows large-scale Hα and EIT images of the four events with EUV data coverage, along with the over-plotted locations of the fronts and the sectors in which we measured r(t) along several paths.

The measurement of r(t) reveals that all seven Moreton waves clearly show deceleration, with initial speeds of 750-1300 km s−1 and final speeds (before the Hα fronts vanish) of 200-650 km s−1. In E2, we were able to determine the intensity profile of the Hα perturbation and to follow its evolution. Profiles were obtained for a large number of directions (so that each pixel within the measured sector was sampled at least once) and then averaged laterally over the complete sector angle. From these profiles we deduced the maximum intensity I(t) and the locations of the leading edge r₀(t), the intensity maximum rₘ(t), and the trailing edge rₜ(t), defining the perturbation width w(t) = rₜ − r₀. The results show deceleration, profile broadening, and intensity decrease (Fig. 2).

Such a behavior is characteristic of the shock waves that are formed from a large amplitude simple wave (Landau & Lifshitz 1987). As the perturbation propagates the profile broadens because the leading (shocked) edge moves faster than the trailing one. The frontal edge propagates at the velocity vₚ = M vₘₚ (where vₘₚ is the magnetosonic speed and M the corresponding Mach number) whereas the trailing one propagates at vₜ = vₘₚ. Let us note that the measured rₜ(t) reveals deceleration rather than constant velocity (Fig. 2) implying that the real trailing edge was not in fact resolved.

Four events were observed simultaneously in Hα and EUV (E1, E2, E6 and E7), all of them featured EIT waves. The velocities of the EIT waves were in the range of 230-400 km s−1. As an example, the measured values r(t) using Hα and EIT fronts are shown in Fig. 3 for E2. In this event, it is evident that the EIT and Hα disturbances are closely associated.
since they lie on the same kinematical curve. Applying 2nd degree polynomial least-squares fits to the measured n(t) for all four events yields decelerations on the order of $a \approx 100 \text{ m s}^{-2}$. In E2, the observation of nearly cospatial and morphologically similar fronts in Hα and EUV provides further evidence for the close association of these wave phenomena. Furthermore, the wave fronts were deformed by low-lying obstacles, which implies propagation of information through a medium and therefore supports the interpretation of the fronts as waves or shocks.

Usually, the speed of Moreton and EIT waves is treated as constant. The presented analysis shows that this can be misleading, causing an artificial discrepancy between Hα and EUV signatures (see Klassen et al. 2000). If the decelerating motion is a general property of these disturbances, their EIT signatures must on average have lower mean velocities than their Hα counterparts since the former are usually traceable to much larger distances. The discrepancy is additionally increased by the low cadence of the EIT observations which allows only for a poor coverage of fast events.

Assuming a magnetosonic speed of a few hundred km s$^{-1}$ in the low corona outside of active regions (Mann et al. 1999), the Mach number at the beginning of the observable propagation of the Moreton waves can be estimated to roughly $M > 3$. The velocities at large distances (200–400 km s$^{-1}$; corresponding to the EIT wave speeds) are fairly consistent with the magnetosonic speed. Therefore, the Moreton wave represents a shock, whereas the EIT wave, typically observed farther out, may be regarded as a wave traveling at the magnetosonic speed. In contrast to the EUV, the Hα disturbance is visible only in earlier stages when the Mach number is still relatively high, since it is more difficult to perturb the inert chromosphere. This can explain the higher rate of occurrence of EIT waves compared to Moreton events, since weak disturbances, which are probably initiated more frequently, will not show up in Hα. The mentioned “velocity discrepancy” is additionally increased by this effect.

4. CONCLUSION

The presented observations reveal the close association of the Moreton and EIT waves (at least for these kinds of events; there might be EIT “waves” produced by a totally different mechanism which are not associated with Hα waves). The deceleration caused by a decreasing shock amplitude can straightforwardly explain the discrepancy between the average Moreton and EIT wave speeds. This fast-mode shock wave scenario is favored over the magnetic field evolution hypothesis of Delanné & Aulanier (1999) since: (1) the deceleration of the disturbance and its intensity profile evolution (broadening and intensity decrease) is consistent with the blast wave scenario; (2) the wave fronts are centered on the flaring site, or more precisely on its edge; (3) in E2, the Moreton wave front was deformed by low-lying obstacles implying a propagation of information through a medium, which is characteristic of a wave.

While we cannot completely rule out the CME-induced piston mechanism at the current stage of analysis, we believe that the blast-wave scenario provides a more convincing explanation. However, the blast-type shock could be launched by ejecta of a smaller scale (e.g. sprays or the ejecta observed with Yohkoh SXT) instead of an initial pressure pulse (Vršnak & Lulić 2000). Depending on their kinematics, they could either generate a perturbation which then steepens into a shock, or there could be a short phase of a driven shock, after which the shock propagates freely.

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