WAVE PHENOMENA ASSOCIATED WITH THE X3.8 FLARE/CME OF 17-JAN-2005

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ABSTRACT

We report high-cadence Hα observations of a Moreton wave observed at Kanzelhöhe Solar Observatory (KSO), Austria, associated with the 3B/X3.8 flare of 2005 January 17. The Moreton wave can be identified in about 40 Hα frames over a period of 7 min, whereas the associated EIT wave can only be measured on-disk in one frame. First results from distance measurements are presented which reveal a spread in the wave velocity for different directions of wave propagation.

Key words: flares; flare waves; multiwavelength.

1. INTRODUCTION

Wave-like disturbances on the Sun were first observed in sequences of chromospheric Hα images and are now widely known as Moreton waves (Moreton & Ramsey 1960; Athay & Moreton 1961). These chromospheric signatures are assumed to be the “ground trace” of coronal fast mode MHD waves which are related to solar flares (Uchida 1968, 1970). Recently, large-scale coronal transients were discovered by the Extreme-ultraviolet Imaging Telescope (EIT; for a description of the EIT instrument, see Delaboudinière et al. 1995) on board the Solar and Heliospheric Observatory (SoHO). These often globally propagating disturbances are observed as EUV emission in the low solar corona and are now commonly called “EIT waves” (Thompson et al. 1998, 1999). There exist several kinds of wave-like disturbances that are observed with EIT, and EIT events with sharply defined wave fronts are presumed to be the coronal counterparts of the chromospheric Moreton waves (Thompson et al. 1999; Wurmuth et al. 2001, 2004). Due to the low time cadence of the EIT instrument (~12 min), detailed tracking of the wave propagation is difficult (most often the EIT waves are observed only in one or two images). Through this circumstance also the comparison to the disturbances seen in Hα, i.e. Moreton waves, is made more difficult.

Nowadays, propagating disturbances are observed in images over a broad spectral range from radio to X-rays (Khan & Aurass 2002; Narukage et al. 2002; Hudson et al. 2003; White & Thompson 2005; Vršnak et al. 2005). However, the actual cause and their relation to flares and/or CMEs is still under debate. A recent review on the issue of large-scale waves in the solar atmosphere in observations and from the theoretical point of view is given by Vršnak (2005). In the present study we analyze the observation of a Moreton wave observed in Hα images taken by the Kanzelhöhe Solar Observatory with high temporal resolution. In addition, the simultaneous observation of an EIT wave is studied. The wave phenomena were associated with the X3.8 flare/CME of 2005 January 17.

2. DATA AND METHODS

Fig. 1 shows the complex evolution of the integrated GOES flux for the 3B/X3.8 long duration flare event of 2005 January 17. The first sudden enhancement of ac-
tivity to M2 level occurs at \( \sim 8 \) UT. After that a steady increase over \( \sim 100 \) minutes to X2 level is revealed. The final impulsive enhancement reaches X4 level with the peak at 09:50 UT. During this final phase also the chromospheric Moreton wave is observed. Within the time range where the Moreton wave is observed also a coronal EIT wave is revealed.

The Kanzelhöhe Solar Observatory (KSO) provides full disk images in the spectral line of \( \text{H} \alpha \) taken with high time cadence of approximately 5 seconds, which is particularly suitable for the observations of Moreton wave phenomena. Additionally, images are taken at the off-band center wavelength of \( \text{H} \alpha + 0.4 \) Å (red wing) and \( \text{H} \alpha - 0.3 \) Å (blue wing), respectively, with a cadence of about 1 image per minute in each wing. The wave fronts were determined by two independent observers by analyzing difference images over the time span 09:43:25–09:50:38 UT. Fig. 2 shows a sample of running difference images from the blue wing of the \( \text{H} \alpha \) spectral line; the front of the wave becomes clearly visible as bright leading edge followed by a dark wake. In the same way the wave fronts are observed in difference images of the \( \text{H} \alpha \) line center whereas in the red wing the leading edge is observed in absorption. In total, we were able to visually determine \( \sim 30 \) wave fronts in the \( \text{H} \alpha \) line center as well as 6 in the red and 5 in the blue wing, respectively. From the obtained wave fronts we calculated their distance and speed from the assumed ignition site of the wave (cf. Fig. 3). The center of the wave phenomenon was derived by fitting a circle to the earliest visually determined \( \text{H} \alpha \) wavefront (the projection effect due to the spherical surface is taken into account, see also Warmuth et al. 2004).

From EIT observations in the Fe XII (195 Å) bandpass, only one wave front could be determined. The difference image from which the front was extracted is shown in Fig. 4.

3. RESULTS

In the following we present an analysis that is based on the wave fronts observed in the center of the \( \text{H} \alpha \) spectral line. From a preliminary study using also \( \text{H} \alpha \) wing data a similar outcome is revealed. Since the EIT wave front could be determined on-disk only once, it was not taken into account for the study of the wave kinematics.

Fig. 3 shows all the wave fronts that could be determined within the time span 09:43:25–09:50:38 UT. In addition also the EIT front is drawn (green line; the shift between KSO observations and EIT due to a different pointing was taken into account). The location of the wave ignition (indicated as red cross in Fig. 3) lies outside the major flaring area, but within a region of secondary brightening. As can be seen, the angular extent of the fronts starts with \( \sim 60^\circ \) and extends across a maximum sector of \( \sim 110^\circ \) (it is known that Moreton waves show an angular extent of no more than \( \sim 180^\circ \); Smith & Harvey 1971). The wave front revealed from EIT at 09:46:47 UT (cf. Fig. 4), fits well into the propagation of the Moreton wave. From Fig. 3 it can be seen that it lies between the two \( \text{H} \alpha \) red wing fronts at 09:46:08 and 09:47:33 UT.

In Fig. 5, 10 great circles through the assumed initial center are shown together with the \( \text{H} \alpha \) line center wave fronts. The distance was measured along these great circles, taking into account the curvature of the surface.
Fig. 4. EIT difference image. The wave front is indicated by arrows. This front is drawn as green line in Fig. 3. Due to the low time cadence of EIT (~12 min), the wave front is seen on the disk only once.

Fig. 5. The 10 great circles are shown along which the distances of the wave fronts are measured. Indicated with different colors are the different directions for the distance measurements. The colors correspond to the color-coded data points of Fig. 6.

Fig. 6 shows distances plotted against time obtained from measurements of points on the propagating wave front along the 10 great circles shown in Fig. 5. The first front is obtained at a distance of ~170 Mm, the maximum distance is ~520 Mm from the ignition site. From a 2nd order polynomial fit for all data points (Fig. 6 - grey line) we obtain an approximate start time of the wave at 9:42 UT. The wave has a mean speed of ~930 km s\(^{-1}\) and a deceleration of ~-1220 m s\(^{-2}\). The fits shown as blue and green line in Fig. 6, respectively, are obtained for two different directions, namely along the blue and the green great circle in Fig. 5. The two fits show a systematic difference. The propagation velocity of the wave into the western direction is of ~980 km s\(^{-1}\). A significantly lower speed of ~710 km s\(^{-1}\) is revealed for the wave propagating in the northern direction (green line).

4. DISCUSSION AND CONCLUSION

In the present study we show first kinematical results obtained from a Moreton wave observed with high-temporal resolution by KSO. The wave could be gathered in over 40 Hz images and enabled us to track the wave up to a distance of ~520 Mm from its ignition location. On average, maximum distances measured for Hz Moreton waves are in the range of 300 Mm from the initial site (cf. Warmuth et al. 2004). The first observed front (gathered in a red wing image) is not obtained in the closest vicinity of the flare but has a distance of ~170 Mm from the assumed wave center. This can be explained by the time/distance that is needed for the blast wave to steepen into a shock (Vršnak & Lulić 2000). We stress that the accuracy of the obtained distances is strongly dependent on the visually determined wave fronts, and the definition of the ignition location of the wave center. To minimize at least the errors in the determination of the wave fronts they were gathered by two independent observers. The fronts from both observers are in very good coincidence; the results shown in the present paper are only from one observer.

By analyzing the wave kinematics from distance vs. time diagrams we could back-extrapolate an approximate start time at ~9:42 UT which coincides well with the impulsive increase of HXR emission observed by RHESSI. Measuring the fronts along different directions of their propagation, we found a distinct difference in distance as well as velocity. A lower speed than the average is obtained for the northern propagation, most probably related to the presence of a coronal hole in the vicinity of the northern pole. For EIT waves a “stopping” is reported when the wave approaches the coronal hole during its propagation over the solar disk (Thompson et al. 1998). Results from simulations are in agreement with the observations and show that the waves are deflected away from active regions and coronal holes (Wang 2000; Wu et al. 2001). According to our results we assume a similar behavior for the Moreton wave which has to be studied in more detail for this event.

ACKNOWLEDGEMENTS

M.T., A.V., and A.H., gratefully acknowledge the Austrian Fonds zur Förderung der wissenschaftlichen Forschung (FWF grant P15344).
Figure 6. Distances calculated from points on the wave front which are measured along great circles in 10 different directions from the wave center (cf. Fig. 5). 2nd order polynomial fits are shown for all data points (grey line) and for the data from the northern/western direction of wave propagation (green/blue line which corresponds to the green/blue great circle in Fig. 5). The approximate start time of the wave is indicated by an arrow.

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