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Solar "EIT Waves" – What are They?

Louise K. Harra

Mullard Space Science Laboratory, University College London,
Holmbury St Mary, Dorking, Surrey, RH5 6NT, UK

Alphonse C. Sterling

NASA/Marshall Space Flight Center, SD50/Space Science Department,
Huntsville, AL 35812, USA

Abstract. There has been substantial interest in the coronal wave phenomena since its discovery several years ago using the EUV Imaging Telescope onboard SOHO (Thompson et al. 1999). One of the first explanations was that finally the coronal part of the Moreton wave had been discovered. Since then, there have been a number of results giving different explanations. We will discuss these in this paper along with the latest results on coronal waves from a spectroscopic perspective.

1. Introduction

Coronal waves appear as roughly circular propagating features emanating from the site of flare-related eruptions. They are best seen in difference images, and typically appear as a bright front with propagation speeds of a few hundred km/s, followed by a dimmed or depleted region of the corona.

In contrast, Moreton waves are seen in the chromosphere rather than the corona (e.g. Moreton 1961; Athay & Moreton 1961). Moreton waves propagate large distances away from the flare site, with velocities ranging from a few hundred to in excess of a thousand km s^{-1}, that is, somewhat faster than reported coronal-wave velocities. Uchida (1968) proposed that Moreton waves are the footprints of a fast-mode wave in the corona.

When coronal waves were discovered it was thought that they may well be the coronal MHD waves that Uchida had described. However there are not many observations of both coronal waves and Moreton waves (e.g. Eto et al., 2001, Warmuth et al., 2001) and these have given conflicting results: the former states that the coronal wave and Moreton wave they observed are different phenomena, and the latter states that they behave in the same way.

It is quite difficult to define coronal waves since they are seen most easily in difference images in EIT and the time cadence is not great. They have also been observed in the Transition Region and Coronal Explorer (TRACE) (e.g. Wills-Davey & Thompson 1999), which has much better spatial and temporal resolution, but the trade-off is a smaller field of view. These features are seen in both TRACE and EIT hence in this paper for simplicity we refer to EIT waves

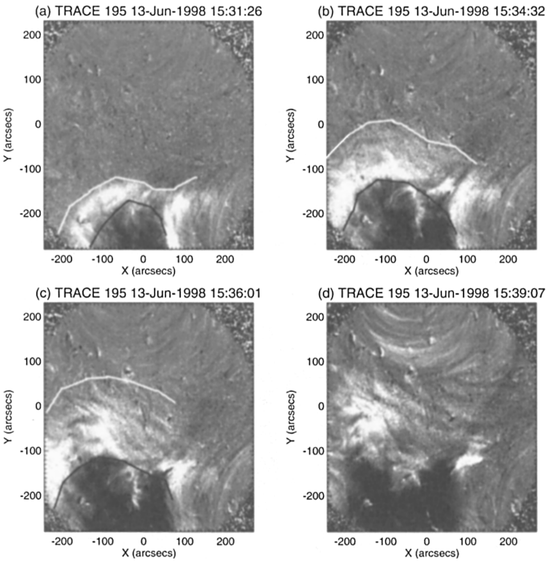

Figure 1. Percentage difference images from Harra and Sterling (2003) (a) through (c): Black curves show approximate locations of the inner edge of the "bright wave"-portion of the coronal wave, and white curves show the very approximate locations of the outer edge of the " weak wave"-portion of the coronal wave. By the time of (d), the wave structures are too indistinct to make clear identifications, but apparent movement of the east-west loop structures in the north indicate that the weak wave has reached that location.

as "coronal waves," keeping in mind that this is probably not the best general name for these features since there are many types of waves in the corona.

There are now several explanations for the existence of coronal waves including that they are coronal mass ejections lifting off the disk (e.g. Delannée and Aulanier 1999), and the coronal counterpart of the Moreton wave. In this paper, we will discuss how spectroscopic observations can attempt to distinguish between these possibilities.

2. Coronal waves and EUV spectroscopy

An example of a coronal wave is shown in Figure 1. This wave was related to an event that occurred in an active region just south of the TRACE field of view. This is an observation made with TRACE using the 195Å filter. Difference images were made, and this example shows the wavefront progressing quite clearly. There appears in this case that there is evidence for 2 separate wavefronts with the weaker one hitting the northerly active region before the main wave front does. An alternative possibility, however, is that it is a single wave front with a near-Gaussian distribution, where the northern wing of the distribution artificially appears to be a separate wavefront (M. Wills-Davy 2003, private communication).

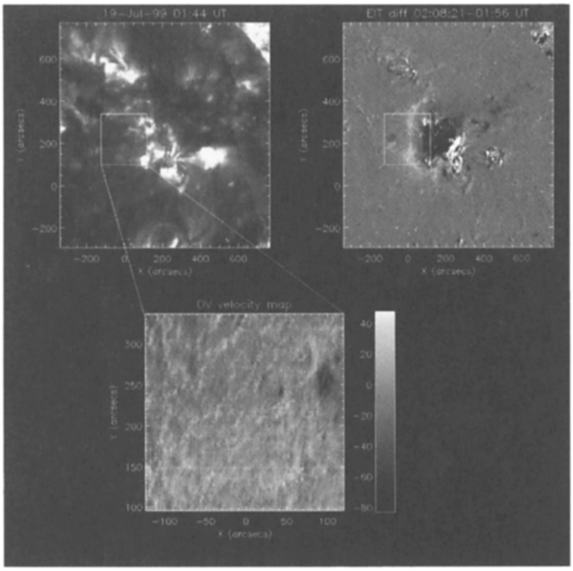

Figure 2. The upper left EIT 195 Å image shows the active region of the disk event, with the CDS FOV indicated by the box. The upper right EIT 195Å image is a difference image which illustrates clearly the coronal wave, with the CDS FOV indicated by the box. The bottom image shows the velocity map in O v; the dark area on the right edge indicates enhanced blue-shifted emission which coincides with the dimming behind the EIT wave in the upper-right image. The timing of the CDS raster is consistent with the enhanced blue shifts occurring behind the bright front of the EIT wave. From Harra and Sterling (2001)

There have been several explanations for these waves as described in the introduction. It is quite difficult to determine from imaging data alone (especially using difference images) what exactly the bright wave front is, or what the dimming region behind the front is. Dimming of coronal emission is now commonly used as a signature of coronal mass ejections (e.g. Sterling and Hudson 1997). However since imaging data have been used this could also be a change in temperature of the plasma. Spectroscopic observations have been used to determine that coronal dimming in active regions is actually depletion of material through spectroscopic means. Harra and Sterling (2001) measured blue-shifted material in dimming regions using the Coronal Diagnostic Spectrometer (CDS) on board SOHO, and Harrison and Lyons (2001) found a reduction of density in dimming regions using density diagnostic techniques.

We have looked for spectroscopic signatures in coronal waves to gather further information in order to distinguish between an MHD shock wave, or a coronal mass ejection lift-off. This is more difficult than analysis of dynamics in an active region as a coronal wave by nature is a much more global phenomena. We have found two examples of coronal waves with CDS observations.

One example is described in Harra and Sterling (2001). In this example, the CDS observed the region behind the wave front during a standard quiet Sun observation. This is illustrated in Figure 2 which shows the CDS field of view on the EIT image. The coronal wave is clearly seen. The CDS instrument has to raster in order to build up an image, and hence only catches the dimmed part of the wave. We found strong blue-shifts in the dimmed region, showing

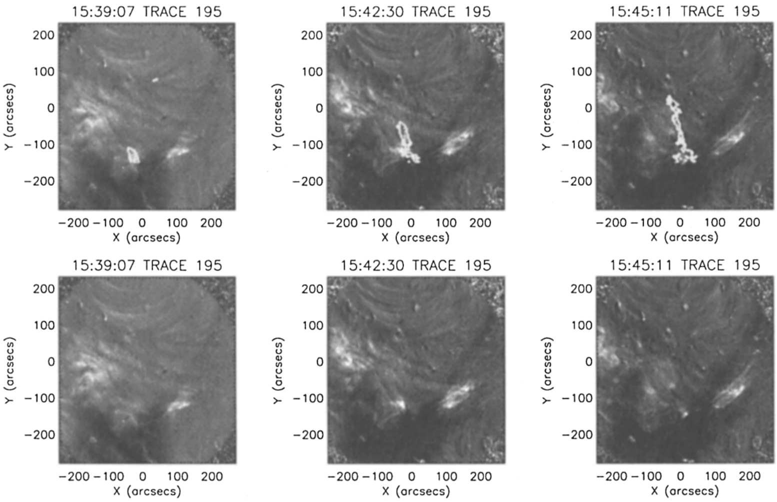

Figure 3. The top 3 images show a time series of TRACE 195 percentage difference images overlaid with the blue-shifted OV contours from CDS. This high velocity event is a filament eruption. The bottom 3 images show the same TRACE 195 images. From Harra and Sterling (20 03)

velocities of up to 80 km/s. This is a very strong velocity for the quiet Sun. This demonstrates that the region behind the wave-front is related to loss of material.

The second example we found was a coronal wave that was observed by EIT, TRACE and CDS (Harra & Sterling 2003; also see Wills-Davy and Thompson 1999). TRACE and CDS observations were taken between two active regions located in different hemispheres. CDS observations this time observed the wave front, but did not measure any significant velocities giving an upper limit of the velocity of 10 km/s. However, although there was no strong evidence for it in the image data, we were surprised to find a high velocity feature appearing in the data. This is shown in Figure 3. This high velocity feature was seen in many different temperature lines through the transition region, and into the corona. It was identified as an erupting filament.

One possible reason for the differing results in these two examples is that CDS observed different wave regions in the two cases. In the first example it observed the brightest part of the wave front along with some of the dimming region behind the wave front. In the second example it observed only a weak portion of the wave and none of the dimming, but also caught the filament.

3. Conclusions and Future Work

Our results show that spectroscopic observations are invaluable in understanding phenomena such as coronal waves that are observed in imagers. We have found blue-shifted material behind the wave front, indicating plasma leaving the corona. We have also found that a coronal wave seems to be intricately related to a filament eruption in one case. These results are consistent with the work of Chen et al. (2002) who carried out 2D simulations of a piston-driven shock. Their results suggest that the coronal wave results from the opening of field lines associated with the filament eruption.

We have observed only two examples to date spectroscopically. In order to understand coronal waves further, we need to have a good definition of what a coronal wave actually is. For example some of them could be material lifting off the Sun, and some could be related to the Moreton wave. The future space missions should help resolve these issues. For example the future ISAS/NASA/PPARC mission Solar-B due to the launched in 2006, will have on board the X-ray telescope providing TRACE-like spatial resolution but for the full Sun and at a wider range of temperatures, and the EUV Imaging Spectrometer will will provide high temporal and high spectral resolution in order to pin down the physical characteristics of these impressive global phenomena.

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