Solar and Stellar Flares and their Effects on Planets
Proceedings IAU Symposium No. 320, 2015
A.G. Kosovichev, S.L. Hawley & P. Heinzel, eds.

doi:10.1017/S1743921316000247

Restricted propagation of an "EIT wave" in the low solar corona

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Abstract. We present observations of an "EIT wave" associated with an X-class flare from 2012 July 6, the propagation of which was severely restricted by the magnetic structure of the solar corona surrounding the erupting active region. The "EIT wave" was observed by both *SDO* and *STEREO-A*, allowing a three-dimensional examination of how the propagation of the disturbance was affected both by a neighbouring coronal hole and a trans-equatorial loop system. In addition, the eruption was observed at the limb by the ground-based CoMP instrument, allowing the Doppler motion associated with the eruption and resulting coronal loop oscillation to be investigated in detail. This combination of data-sets provides a unique insight into the three-dimensional evolution of the "EIT wave" and its effects on the surrounding corona.

Keywords. Sun: corona, Sun: coronal mass ejections (CMEs), Sun: flares, shock waves

1. Introduction

Globally–propagating disturbances in the solar corona were first observed by the Extreme ultraviolet Imaging Telescope (EIT; Delaboudinière *et al.* 1995) onboard the *Solar and Heliospheric Observatory* (*SOHO*; Domingo *et al.* 1995) spacecraft. Commonly called "EIT waves", they are very strongly associated with coronal mass ejections (CMEs) and tend to avoid active regions and coronal holes, instead propagating through the quiet solar corona. Typical velocities measured using *SOHO*/EIT were found to be $\sim$200–400 km s^{-1}, although more recent estimates made using the Atmospheric Imaging Assembly (AIA; Lemen *et al.* 2012) onboard the *Solar Dynamics Observatory* (*SDO*; Pesnell *et al.* 2012) have found the average velocity to be much higher, at $\sim$600 km s^{-1} (Nitta *et al.* 2013).

The interpretation of the "EIT wave" phenomenon continues to be controversial. They have traditionally been interpreted as fast–mode magnetohydrodynamic waves (e.g., Thompson *et al.* 1998), shock waves (e.g., Vršnak & Cliver 2008) or MHD solitons (e.g., Wills-Davey *et al.* 2007). Alternative interpretations, citing anomalous kinematics and pulse behaviour, have treated them as a brightening produced by the restructuring of the coronal magnetic field during the eruption of a CME. In this case, it has been suggested that the brightening is due to either stretching of magnetic field lines (e.g., Chen *et al.* 2002), Joule heating (e.g., Delannée *et al.* 2008) or continuous reconnection between the erupting CME and adjacent small–scale coronal loops (e.g., Attrill *et al.* 2007).

More recently, the very spatial and temporal resolution provided by *SDO*/AIA has provided clear evidence that "EIT waves" may be used to probe the corona through which they are propagating using coronal seismology. In particular, this technique has been used to estimate the strength of the magnetic field in the quiet solar corona (e.g.,

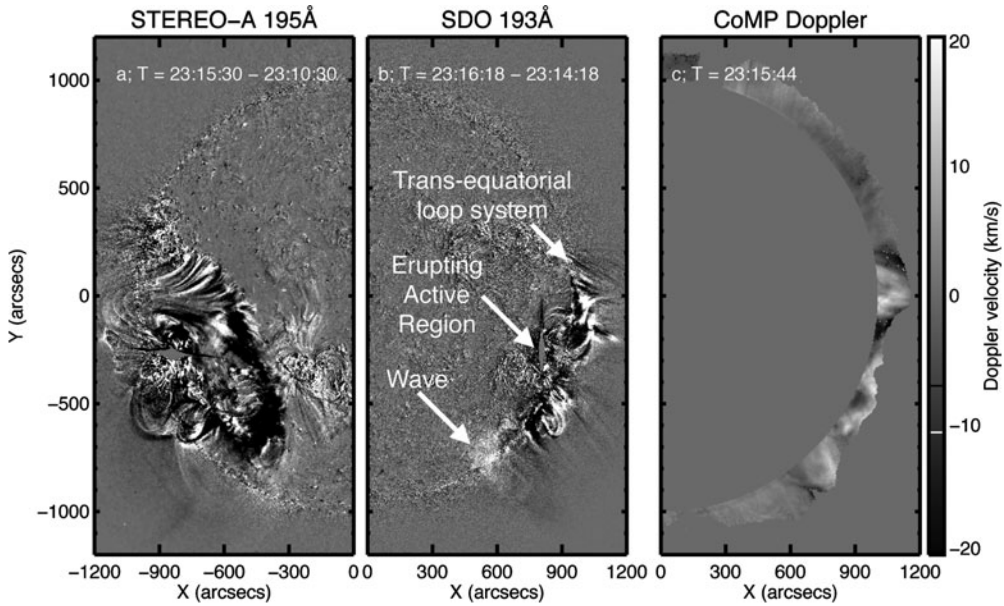

Figure 1. Running difference images from *STEREO*–A (panel a), *SDO* (panel b) showing the eruption from 7 July 2012. Panel c shows the Doppler velocity as measured by CoMP.

Long *et al.* 2013) as well as an estimate of the energy required to produce the "EIT wave" (e.g., Long *et al.* 2015).

2. Observations

A solar eruption with an associated "EIT wave" was observed on 6-Jul-2012 erupting from Active Region AR 11514. The event was well observed on the south–west of the Sun by both *SDO*/AIA and the ground–based Coronal Multi–channel Polarimeter (CoMP; Tomczyk *et al.* 2008). CoMP was originally designed to study the coronal magnetic field by observing the 10747 Å Fe XIII emission line. By fitting the Stokes-I measurements using a single Gaussian fit it is possible to estimate the line intensity, width and Doppler shift of the observations. This allows the motion of the "EIT wave" to be simultaneously studied in the plane-of-sky using the 12 s cadence of *SDO*/AIA and towards the observer using the 30 s cadence of CoMP.

The eruption was also observed on the south–west limb by the *Solar Terrestrial Relations Observatory* (*STEREO*; Kaiser *et al.* 2008) which was ∼120° ahead of the Earth on its orbit around the Sun. As a result, the eruption was studied using the 193 Å passband of *SDO* at 12 s cadence and the 195 Å passband of *STEREO*–A at 300 s cadence to allow a direct comparison to be made between observations from both spacecraft. The different fields-of-view of *SDO* and *STEREO* can be seen in Figure 1.

3. Results

It is clear from Figure 1 that the "EIT wave" was launched into a very complex coronal topology, with a trans–equatorial loop system to the north of the erupting active region and the second active region AR 11515 towards disk centre as observed by *SDO*. As a result, the "EIT wave" propagated primarily along the limb towards the south pole, and could not be tracked on-disk by *SDO*. As it did not propagate on-disk the pulse could

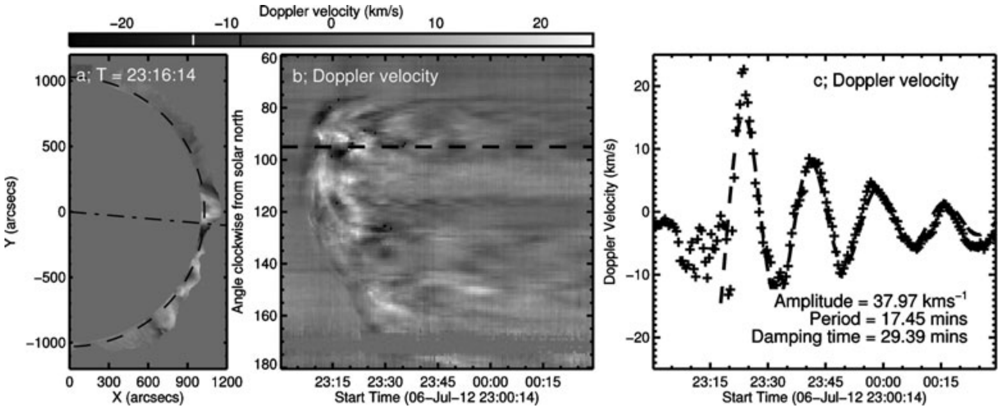

Figure 2. *Panel a*; Doppler velocity as measured by CoMP. *Panel b*; Deprojected Doppler velocity at a height of 1.09 $R_\odot$ (indicated by the dashed line in panel a). *Panel c*; Doppler velocity along the dashed line in panel b and the dot-dashed line in panel a.

not be tracked using the Coronal Pulse Identification and Tracking Algorithm (CorPITA; Long *et al.* 2014) and was therefore tracked "by eye" along the limb using a deprojected annulus. This allowed the temporal variation of the pulse to be tracked across a range of heights from 1.01 – 1.12 $R_\odot$, as above this height the pulse was too faint to identify clearly. For each height value the leading edge of the pulse was identified and fitted using a quadratic model, allowing the initial velocity to be estimated as $607 < v_{\mathrm{initial}} < 1583$ km s^{-1} with a mean of $v_{\mathrm{mean}} = 1106 \pm 314$ km s^{-1}. Similarly, the acceleration was estimated as $-376 < a < -19$ m s^{-2} with a mean of $a_{\mathrm{mean}} = -207 \pm 107$ m s^{-2}.

These measured velocity values are higher than the typical velocities of "EIT waves" made by Nitta *et al.* (2013) indicating that the pulse in this case was particularly fast. It was therefore possible to use the Sedov–Taylor relation originally derived by Sedov (1959) and Taylor (1950a,b) to make an estimate of the initial energy required to produce the "EIT wave". Although this assumes a spherical blast wave emanating from a source point, which is not strictly true in this case, it has been shown by Long *et al.* (2015) that such an approximation is consistent with the observed pulse being impulsively driven over a very short time period before propagating freely. The Sedov-Taylor relation links the variation in radius of the spherical blast wave R with time t, to the energy E and density n of the blast as,

$$\log R \approx \frac{2}{5-\alpha} \log t + \log \left(\frac{E}{n} \right)^{1/(5-\alpha)}, \tag{3.1}$$

where $\alpha < 3$ ($\alpha > 3$) for a decelerating (accelerating) blast wave (see Long *et al.* 2015, for more details). By fitting the above relation with estimates of $R(t)$ and n from AIA observations, we find $E \approx 8.6 \times 10^{31}$ ergs for the initial energy required to produce the "EIT wave". This equation assumes a variable density medium which matches the propagation of the pulse from the high density active region through the quiet corona towards the lower density coronal hole at the south pole.

Although the presence of the trans–equatorial loop system to the north of the erupting active region restricted the propagation of the "EIT wave", the impact of the pulse did result in a large amplitude oscillation of the loop system that exponentially decayed to zero. This oscillation was very clearly observed in Doppler velocity by CoMP, allowing it to be measured and quantified as shown in Figure 2. A remarkably good fit is obtained

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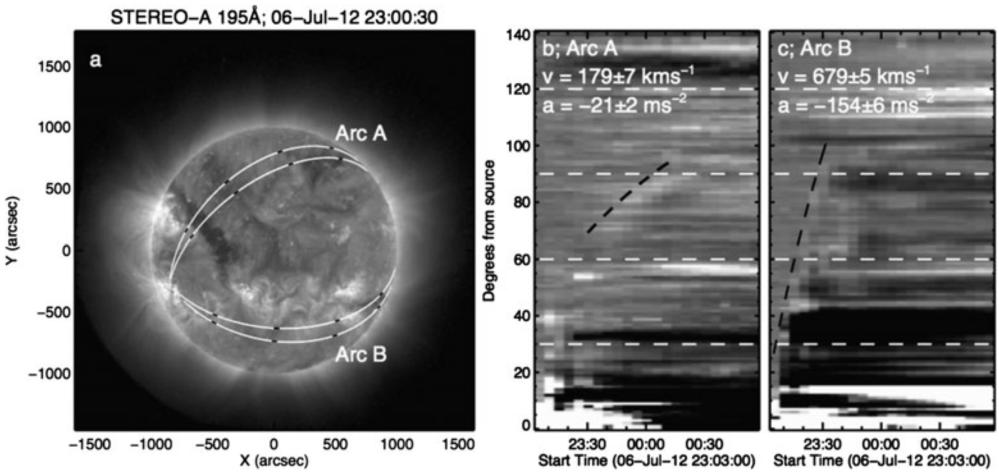

Figure 3. *STEREO*/EUVI image (panel a) indicating the arcs used to estimate the kinematics of the pulse as shown in panels b and c.

by a simple damped harmonic oscillator of period approximately 17.45 minutes, with a damping time of ~29.39 minutes.

4. Discussion and Conclusions

From the viewpoint of *SDO*, the "EIT wave" discussed here was quite fast, with a high initial energy despite the complex coronal topology into which it erupted and which restricted its propagation. Despite a partial view of the evolution, it was possible to identify and measure a clear decaying oscillation resulting from the impact of the "EIT wave" on an adjacent trans–equatorial loop system.

However, from the viewpoint of *STEREO*–A it was possible to identify and track the "EIT wave" as it propagated away from the erupting active region across the Sun. This is shown in Figure 3, where the two arc sectors used to identify the wave and estimate its kinematics are indicated in panel a, with the resulting intensity profiles shown in panels b and c. Panel c shows that it was possible to track the pulse from the source across the Sun, as it traveled with an estimated velocity of 679 ± 5 km s^{-1} and an acceleration of -154 ± 6 m s^{-2}. These values are much lower than those estimated using *SDO*, which may be a result of the lower observing cadence of *STEREO*–A (consistent with the work of Byrne *et al.* 2013).

The pulse also exhibited some very odd behaviour. As shown in panel a, Arc A studies the region from the source through the trans–equatorial loops and a coronal hole to the quiet Sun, with panel b showing the pulse propagation along Arc A. The propagation continues until, after impacting the trans–equatorial loop system and the coronal hole, instead of reappearing at the far edge of the coronal hole as previously observed (e.g., Olmedo *et al.* 2012), there is no evidence of the pulse until it reappears in the quiet Sun far from the edge of the coronal hole. This is shown in panel b of Figure 3 where the pulse appears at ~70° from the source with a velocity of 179 ± 7 km s^{-1} and an acceleration of -21 ± 2 m s^{-2}, much lower than that found for Arc B (panel c).

Although the observations from *SDO* and CoMP strongly indicate that the disturbance observed here was a large–amplitude shock wave, the observations of the disturbance from *STEREO*–A appear to be incompatible with this interpretation. Possible explanations for this "jump" in position of the disturbance point to the influence of the global magnetic topology, including the possible presence of a filament channel. However, initial indications suggest that there was no filament channel at this location and global models of the magnetic topology do not indicate any evidence of a different magnetic topology to the surrounding corona. Efforts are therefore continuing to identify the reason for this "jump" in position of the "EIT wave" observed by *STEREO*–A.

Acknowledgements

DML is an Early Career Fellow funded by the Leverhulme Trust. DPS is funded by the US Air Force Office of Scientific Research under Grant No. FA9550-14-1-0213. GV is funded by the Leverhulme Trust under Research Project Grant 2014-051. *SDO*/AIA data is courtesy of NASA/*SDO* and the AIA science team. CoMP data is courtesy of the Mauna Loa Solar Observatory, operated by the High Altitude Observatory, as part of the National Center for Atmospheric Research (NCAR). NCAR is supported by the National Science Foundation.

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