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Large-scale Coronal Waves Observed with EUVI/STEREO

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We report first observations and analysis of flare/CME associated large-scale coronal waves (so-called "EIT waves") observed with high time cadence by the EUVI instruments onboard the recent STEREO mission. The EIT instrument onboard SOHO for the first time directly imaged global disturbances in the solar corona, but the observations are severely hampered by the low cadence of EIT (12-15 min). Thus, the nature and origin of these large-scale disturbances are still not sufficiently constraint by observations, and it is an intense matter of debate whether EIT waves: a) are the coronal counterparts of Moreton waves observed in the chromosphere; b) are caused by the flare explosive energy release or by the erupting CME; c) are waves at all or rather propagating disturbances related to magnetic field line opening and restructuring associated with the CME lift-off. The high cadence full-disk coronal imaging by the EUVI instruments on the twin STEREO spacecraft provide us with the unprecedented opportunity to study the *dynamics* and origin of flare/CME associated coronal waves. We present first studies of global coronal waves observed with EUVI finding wave deceleration, indicative of an MHD blast wave (Veronig et al. 2008, ApJ Lett., in press).

Large-scale coronal waves observed with STEREO/EUVI

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Introduction

Large-scale large-amplitude waves and shocks in the solar corona occur in association with flares and coronal mass ejections (CMEs). The existence of flare-related global disturbances has been first inferred from Moreton waves, which appear as arc-like fronts in chromospheric Hα filtergrams, moving away from the initiation site at velocities of 500–1000 km/s (Moreton & Ramsey 1960). It was soon recognized that Moreton waves could not be propagating in the chromosphere, where no wave mode has such high velocity. The first interpretation was by Uchida (1968) that Moreton waves are the surface-track of a coronal fast-mode magnetohydrodynamic (MHD) wave front.

The Extreme-ultraviolet (EUV) Imaging Telescope (EIT) onboard SoHO for the first time directly imaged propagating global disturbances in the corona, and these so-called *EIT waves* were assumed to be the coronal counterparts of the Moreton waves (Thompson et al. 1998). Thereafter, coronal waves were found to be a quite frequent phenomenon, and it became an intense matter of debate whether these EUV waves:

a) are really the coronal counterparts of Moreton waves;
b) are caused by the flare or the CME (blast or driven wave);
c) are waves at all.

One important limitation of coronal wave studies so far is the low cadence of EIT (12–15 min), i.e. too low to study wave kinematics beyond a rough velocity estimate. This deficit is now overcome by the Extreme Ultraviolet Imagers (EUVI) onboard the recent Solar Terrestrial Relations Observatory (STEREO) spacecraft which regularly perform EUV full-disk imaging with a cadence as good as 2.5 min.

EUVI observations of the wave of 2007 May 19

We study the coronal wave observed with high cadence by EUVI STEREO-A in association with the GOES B9.5 flare and double CME on 2007 May 19. **Figs. 1 & 2** show the evolution of the wave in EUVI 171 Å and 195 Å running ratio images. The wave is most pronounced towards W and NW which relates to the direction of the two associated CMEs. Applying circular fits to the two earliest wave fronts, we derived the center of the wave on the NW border of AR 10956, indicated in **Fig. 3.**

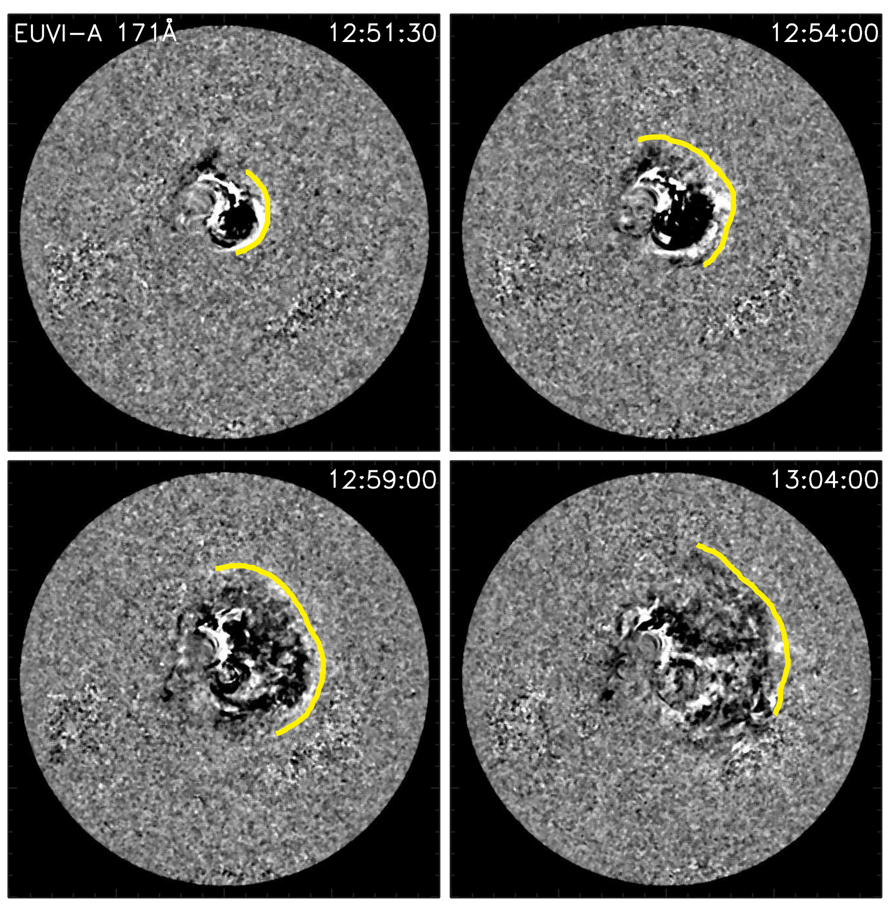


Figure 1: Coronal wave observed in EUVI 171 Å running ratio images (available with a cadence of 2.5 min).

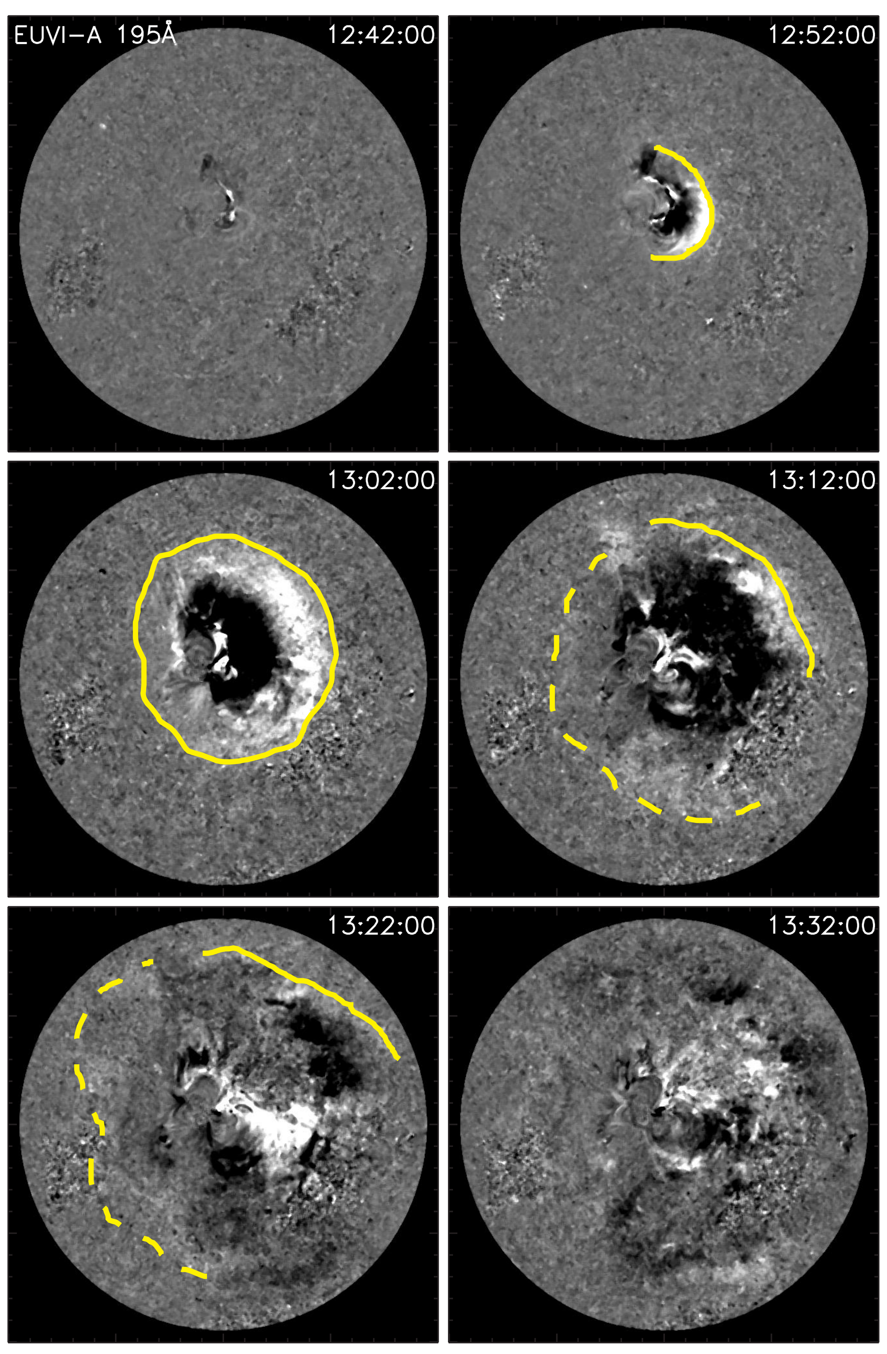


Figure 2: Coronal wave observed in EUVI 195 Å running ratio images (10 min cadence).

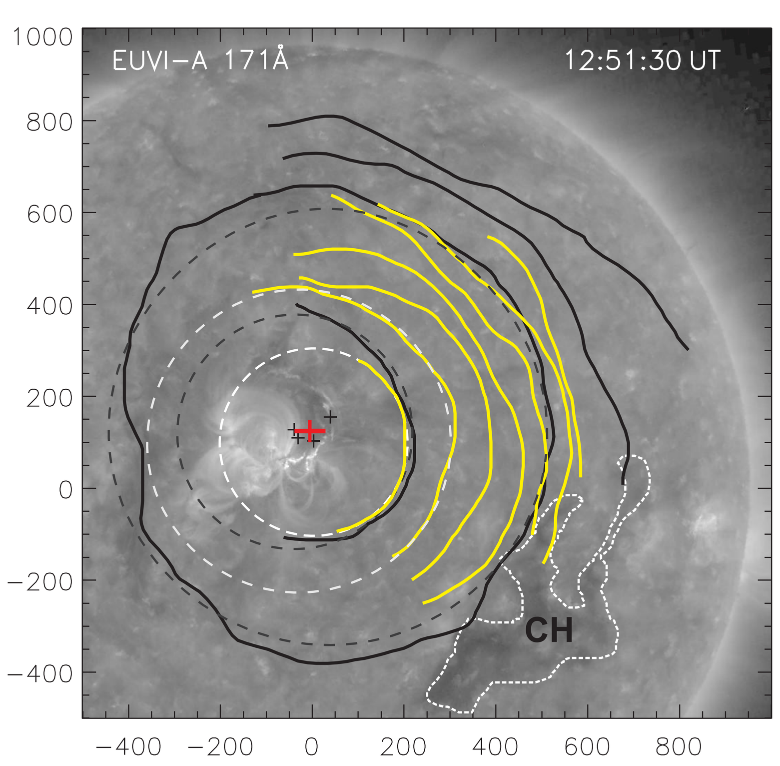
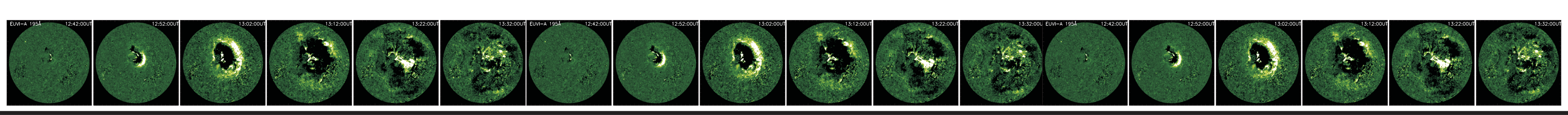


Figure 3: Section of an EUVI 171 Å image. Wave fronts identified in 171 Å and 195 Å images are indicated by yellow and black lines. Dashed lines show the circular fits to the earliest wave fronts, from which the wave centers (crosses) were derived. The dotted curve outlines a nearby coronal hole (CH), where the wave is refracted and reflected.



Kinematics and dynamics of the wave

Fig. 4 shows the wave kinematics derived by calculating the mean distance of the wave fronts from the wave center along great circles on the solar surface. From the linear fit to the time-distance data we obtain a mean wave velocity of 260 km/s.The second-order polynomial fit gives a start velocity of 460 km/s, a (constant) deceleration of -160 m/s^2 and an extrapolated wave launch time (intersect with x-axis) at 12:45 UT. The inset in **Fig. 4** shows the wavefront velocity derived by numerical differentiation of the measured time-distance data. The velocity evolution clearly demonstrates that the wave decelerates, with the earliest velocities as high as 400–500 km/s. This is considerably faster than the velocities reported for EIT waves (170–350 km/s; Klassen et al. 2000), which we attribute to the much better cadence of EUVI, allowing us to study the early wave's evolution.

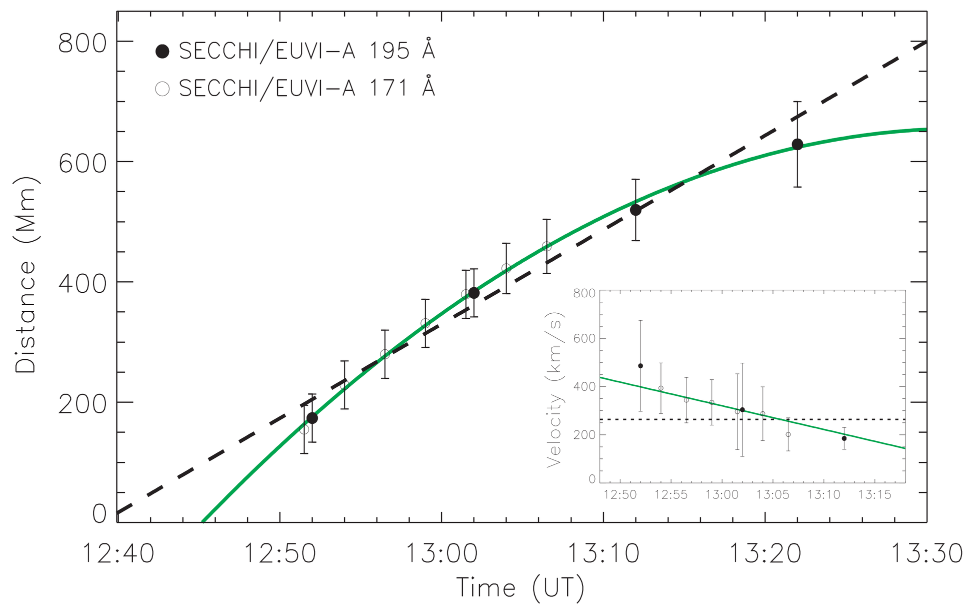


Figure 4: Wave kinematics: combined distance vs. time diagram derived from the wave fronts observed in EUVI 195 Å and 171 Å images together with the linear and quadratic least-squares fits to the data. The inset shows the wavefront velocity, obtained by numerical time derivative, together with the applied fits.

Fig. 5 shows the associated eruptions in Hα images from Kanzelhöhe Observatory. Two filaments and two associated CMEs erupt. Filament1 (associated in direction and timing with CME2 at PA 260°) disappears from the Hα filter at 12:46 UT, whereas filament2 (associated with CME2 at PA 310°) is visible until 12:56 UT. **Fig. 6** shows a summary plot of the wave, flare and CME evolution. We plot: a) the wave time-distance curve (EUVI/STEREO-A), b) the back-extrapolated time-distance diagram of CME1 (LASCO/SoHO), c) the time-distance diagram of CME2 (COR1/STEREO-A), d) the flare HXR flux (RHESSI), and e) the flare SXR flux (GOES). The wave's launch time estimated from the quadratic fit to the EUVI wave kinematics is 12:45 UT (cf. **Fig. 4**). The flare HXR flux starts rising at 12:50 UT with the first and highest peak at 12:51:30 UT. At this time, we already observe the first EUVI wave front. Such timing argues against a flare-origin of the wave, since the wave needs time to build up a large amplitude or shock to be observable.

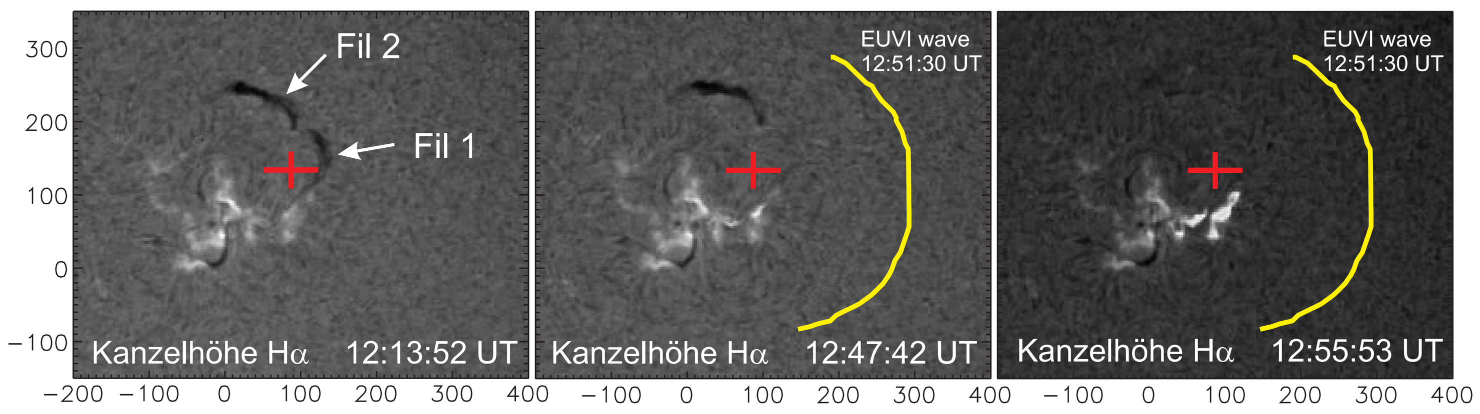
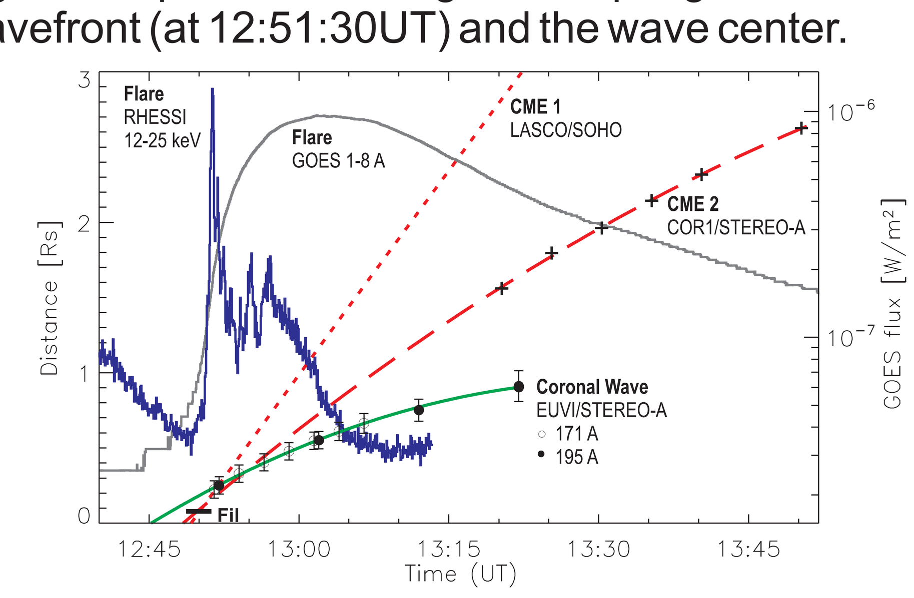


Figure 5: Kanzelhöhe Observatory Hα filtergram sequence showing two erupting filaments. For comparison, we also plot the first EUVI wavefront (at 12:51:30UT) and the wave center.

Figure 6: Summary of the evolution of the wave, the flare and the two erupting CMEs. Note that the peak of the RHESSI hard X-rays, indicative of the impulsive flare energy release, occurs *after* the derived launch time of the wave. This result favors wave initiation by the CME rather than by the flare.



Conclusions

The wave deceleration together with the closely related timing of the wave and the erupting filament1/CME1 (in contrast to the flare peak which occurs too late) as well as the wave front shape which is roughly concentric with filament1, hint at wave initiation by the CME expanding flanks. In such a scenario, the wave is only driven over a limited distance and then decays into an ordinary MHD wave (Veronig et al. 2008).

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