Evolution of flux rope, CME and associated EUV wave in the 10-Sep-2017 X8.2 event

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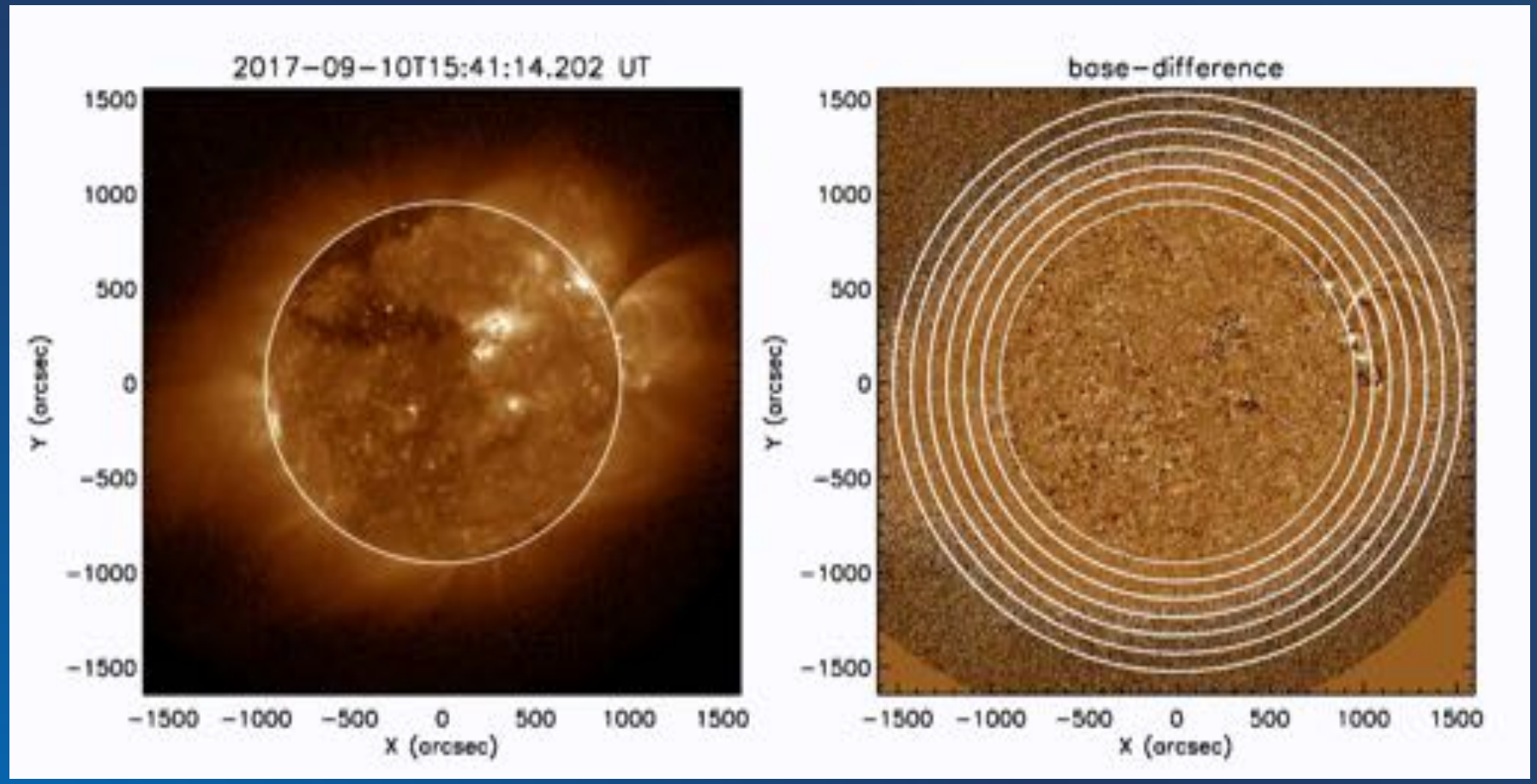
Extreme CME/X8.2 flare on 10 September 2017 and its associated EUV wave observed with GOES-16 /SUVI 195 Å



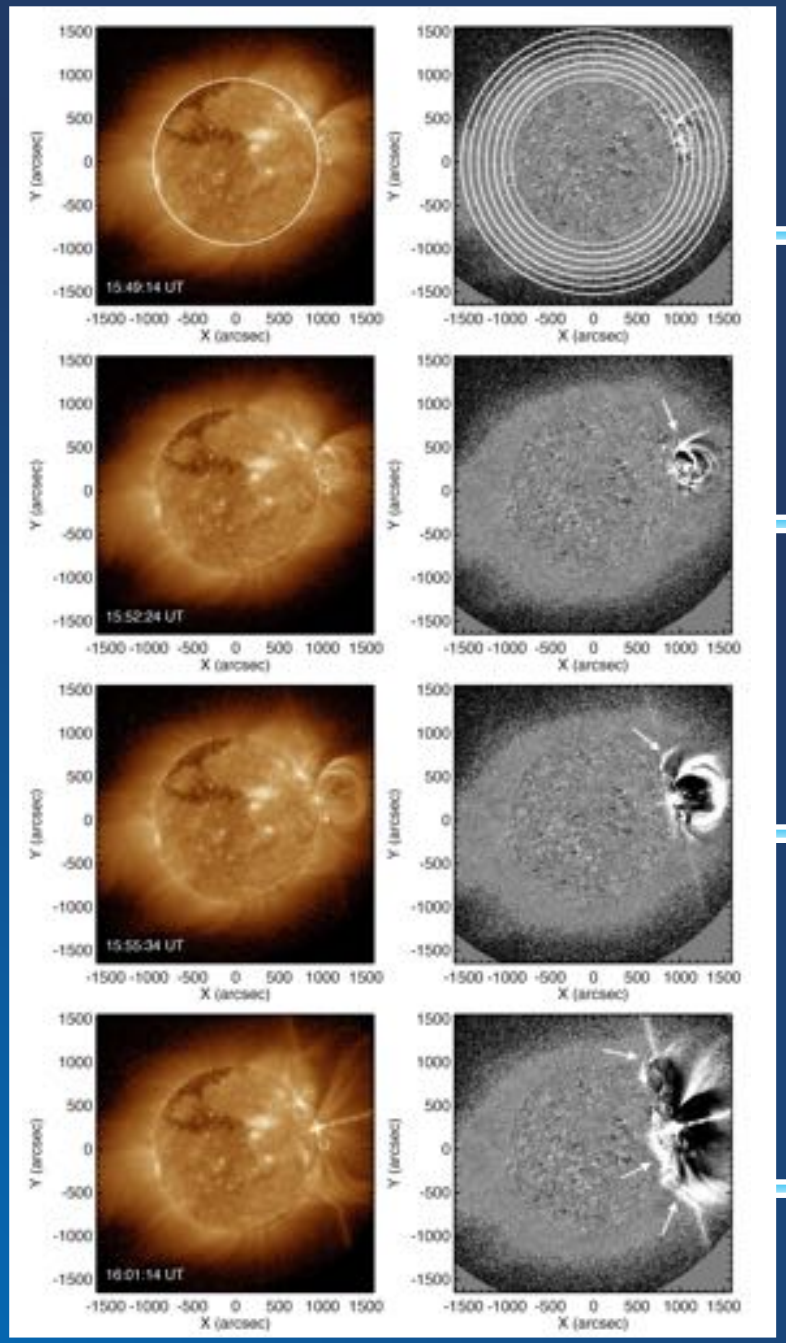
Extreme event

1. X8.2 flare
2. Halo CME
   > 3000 km s^{-1}
3. Wide-spread SEP
   > 230°
4. GLE event on
   Mars and Earth

Goal ⇨ Study of CME lateral and radial acceleration and EUV wave kinematics for September 10th 2017 event

Related studies:
Seaton & Darnel 2018;
Guo et al. 2018; Li et al. 2018;
Warren et al. 2018; Long et al. 2018.

Event overview in SUVI 195 Å filtergrams



Direct images Base difference images

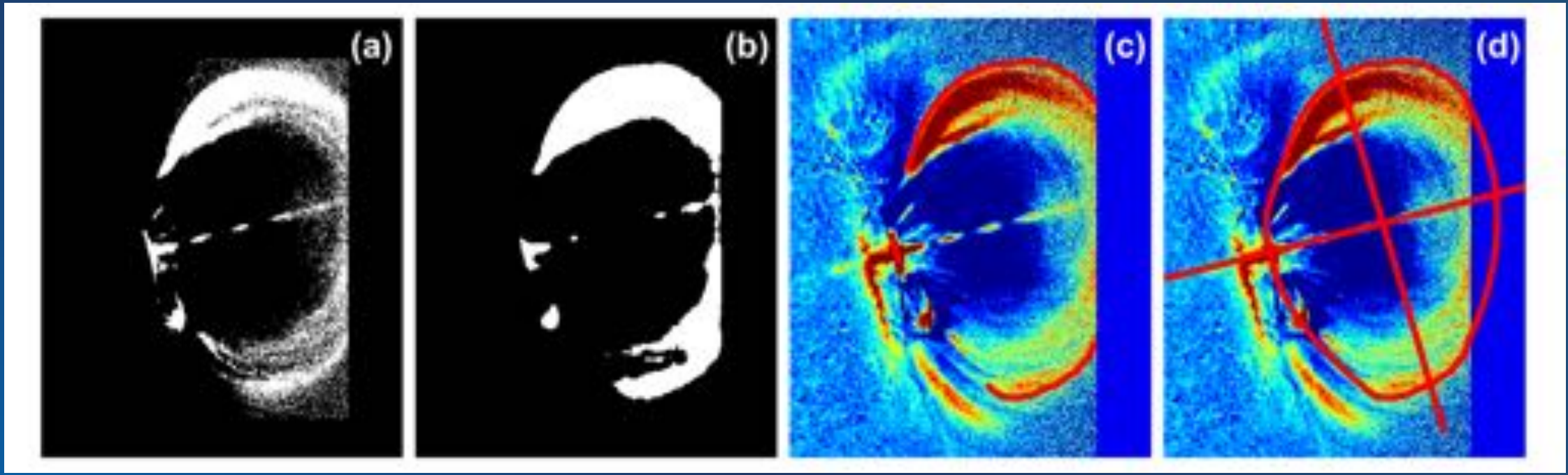
Circular slits at heights from 1.0 to 1.6 Rs above the solar surface for the derivation of wave kinematics above the limb.

At 15:52 UT we can identify the wave for the first time, as it is formed ahead of the CME flanks expanding toward the North.

At 15:55 UT the EUV wave appears as a sharp front above the limb growing to a large extension in height, up to the borders of the SUVI field-of-view. On the South, the wave above the limb is seen after about 15:58 UT.

On the disk the EUV wave can be first identified at 15:54 UT.

The segmentation of CME bubble to trace its radial and lateral propagation

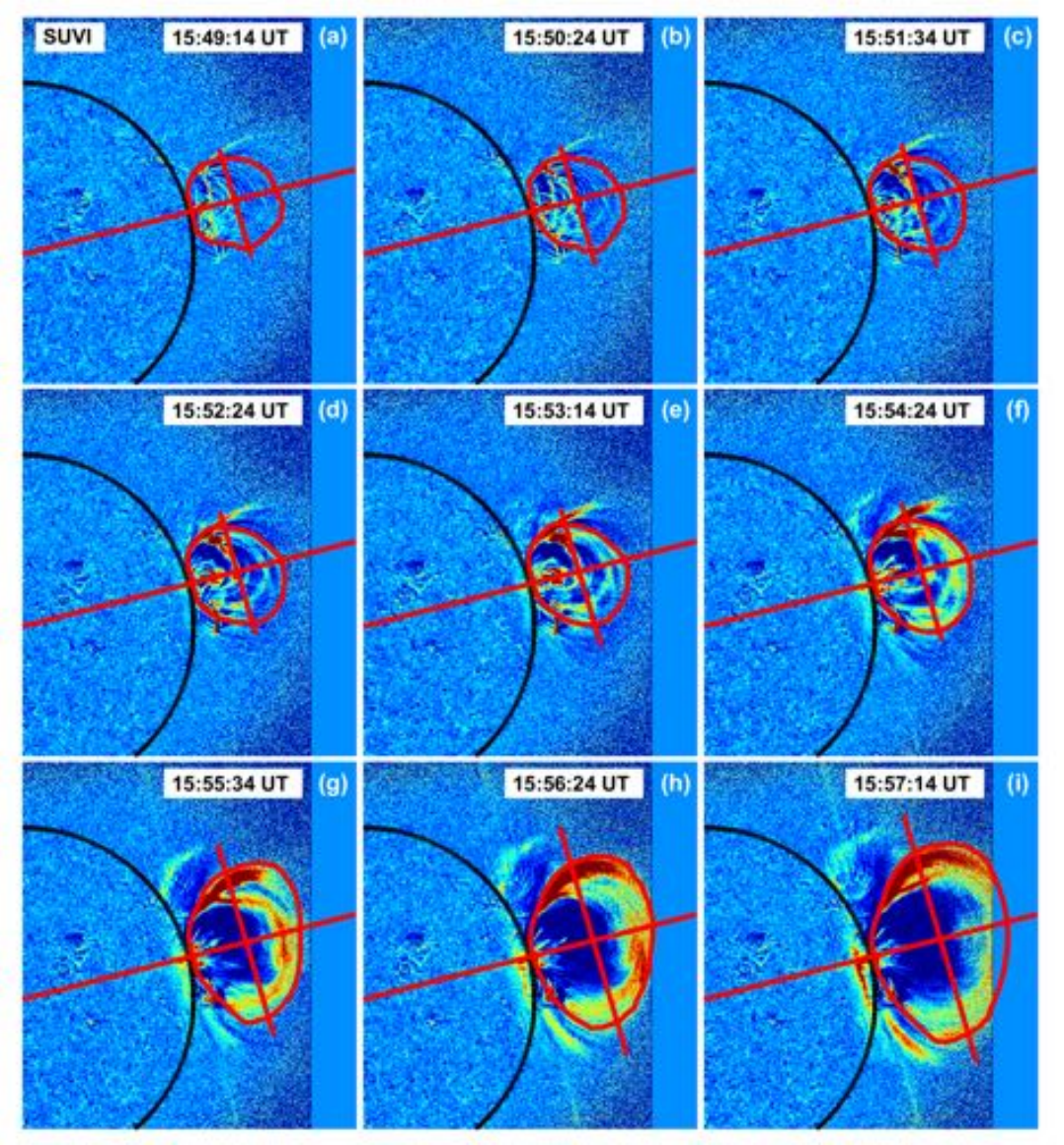


Binary map derived by thresholding.

Segmented CME bubble after median filtering.

Borders of the visible and interpolated parts of the CME bubble (red contour)

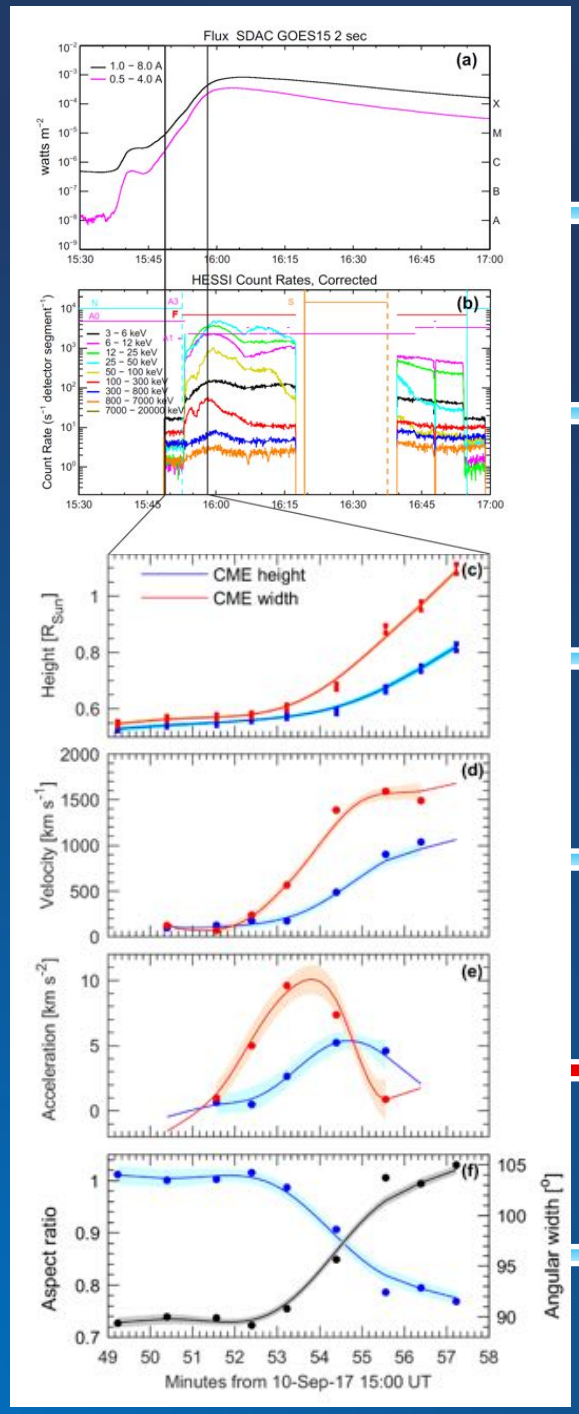
The segmented CME bubble for all SUVI 195 Å images at 15:49 – 15:57 UT



We segment the CME bubble and follow its evolution.

The shape of the CME bubble transforms from roundish to an ellipse, indicative of a strong lateral overexpansion during its evolution.

The evolution of CME lateral and radial motion



Flare emission recorded in the GOES 0.5-4 and 1-8 Å soft X-ray bands

RHESSI hard X-ray count rates from 12 to 300 keV

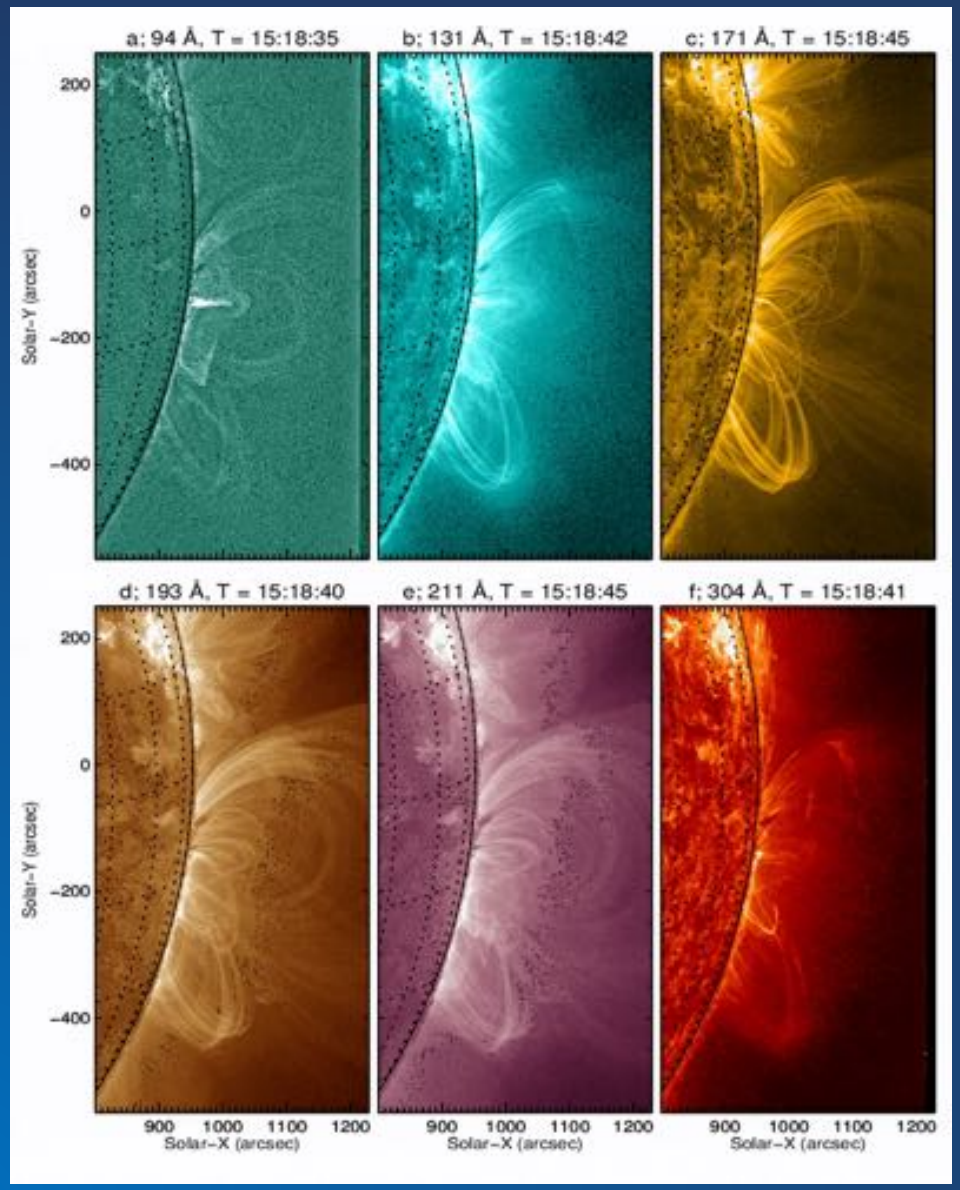
CME height-time and width-time profiles

Radial velocity: 1000 km s^{-1} at 0.85 Rs above the limb.
Lateral velocity: 1600 km s^{-1} reached within 4 min.

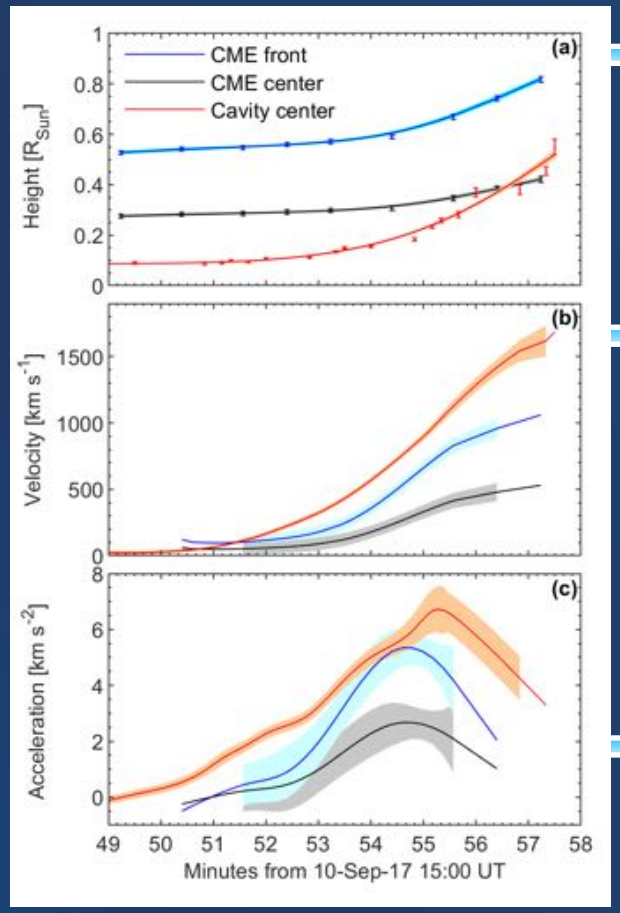
Radial peak acceleration: 5.3 ± 0.6 km s^{-2}.
Lateral peak acceleration: 10.1 ± 1.1 km s^{-2} - the highest value ever reported!

Fast decrease of CME aspect ratio of CME height to CME width

The evolution of CME cavity as observed by SDO/AIA in 94, 131, 171, 193, 211 and $\dot{A}$ filters



Combined radial evolution of CME shell and cavity



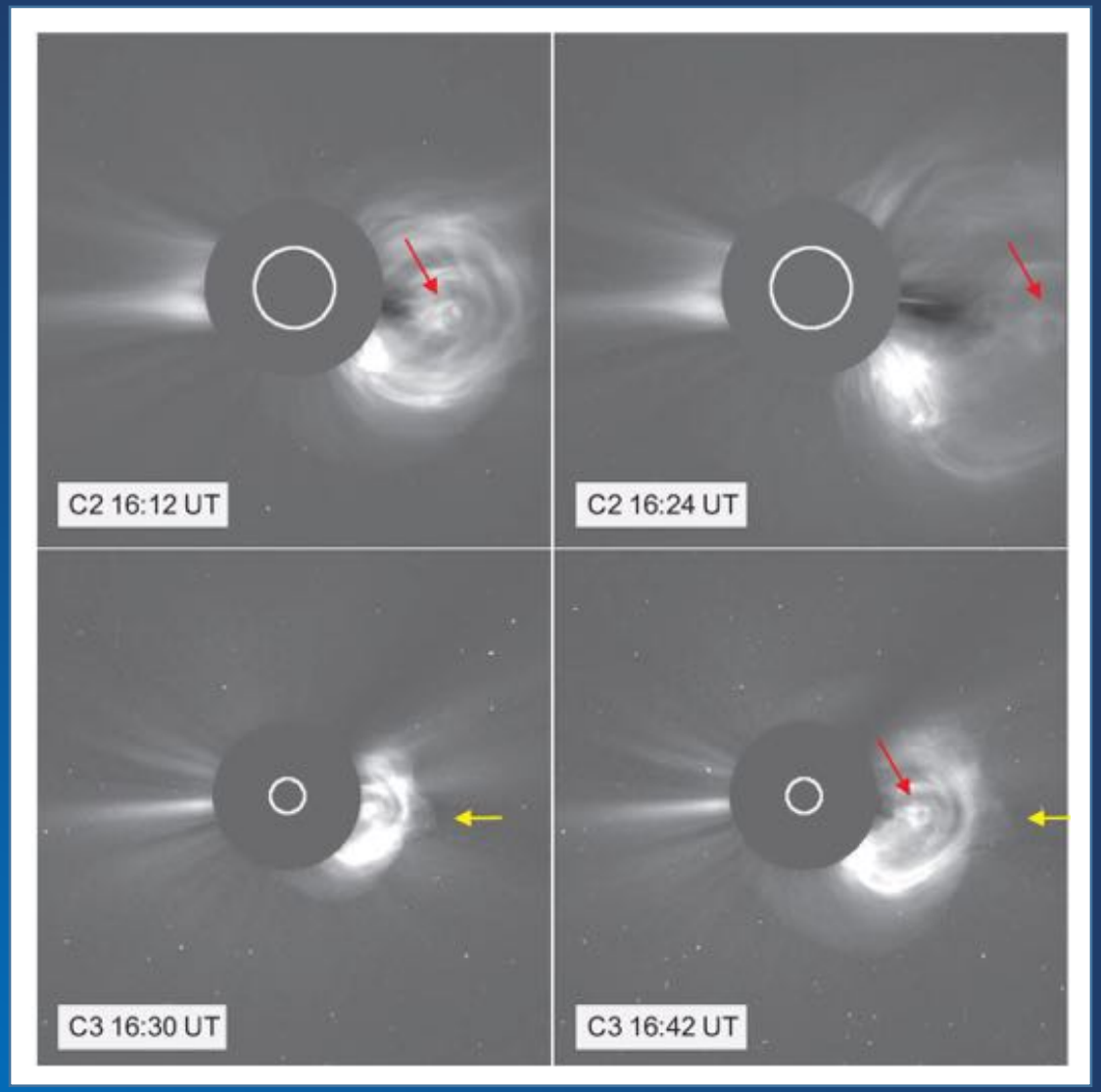
The cavity/flux rope moves forward inside the CME shell.

The speed of the cavity/flux rope driving eruption is higher than that of the CME bubble.

CME peak acceleration:
Cavity: 6.7 ± 0.6 km s^{-2} at 15:44:40 UT.
Front: 5.3 ± 0.6 km s^{-2} at 15:55:20 UT.

Veronig et al. 2018, ApJ, under revision

The evolution of CME cavity/flux rope as observed by LASCO white-light coronagraph

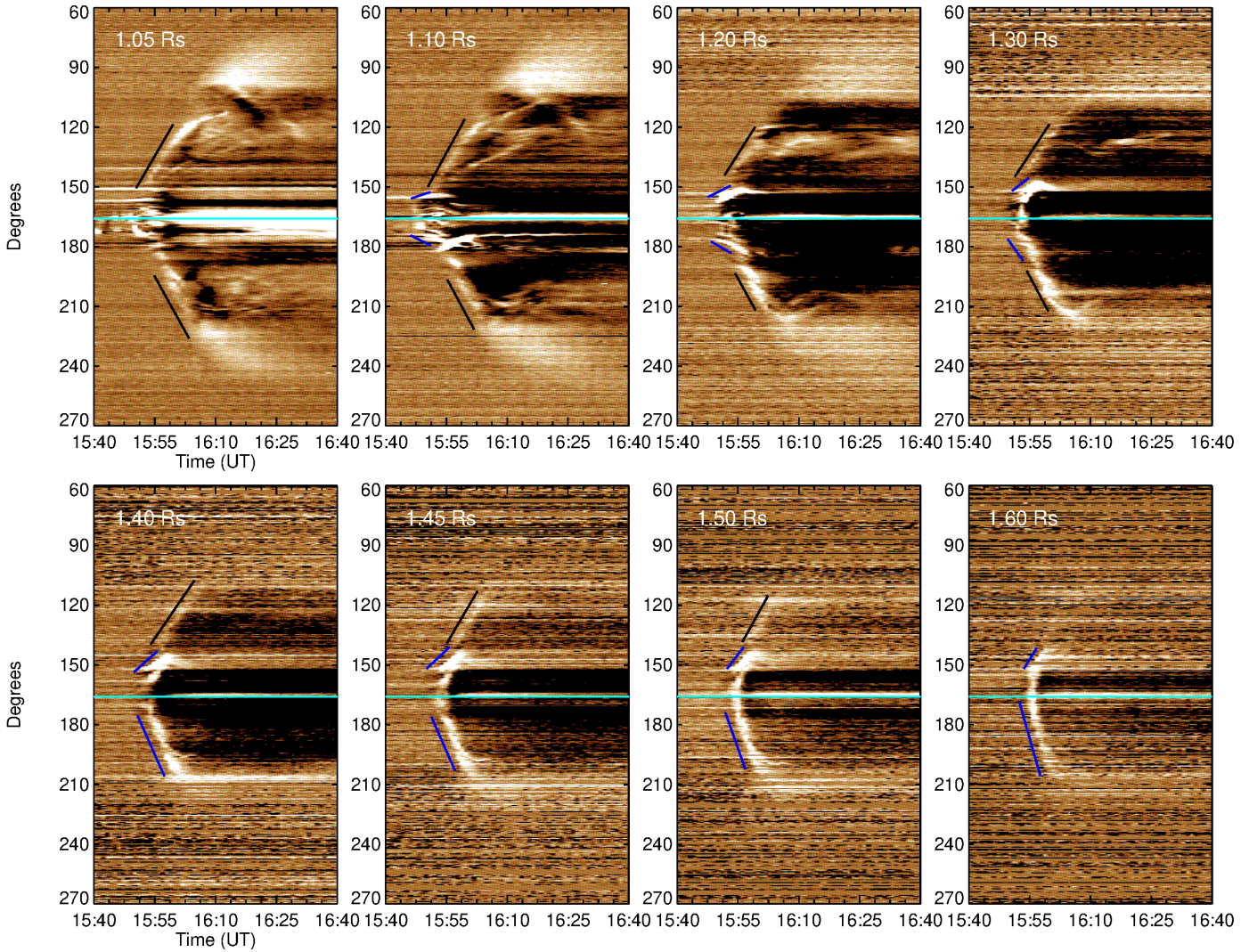


The deformation (“nose”) of outer CME front is related with faster motion of CME cavity/flux rope in radial direction.

Veronig et al. 2018, ApJ, under revision

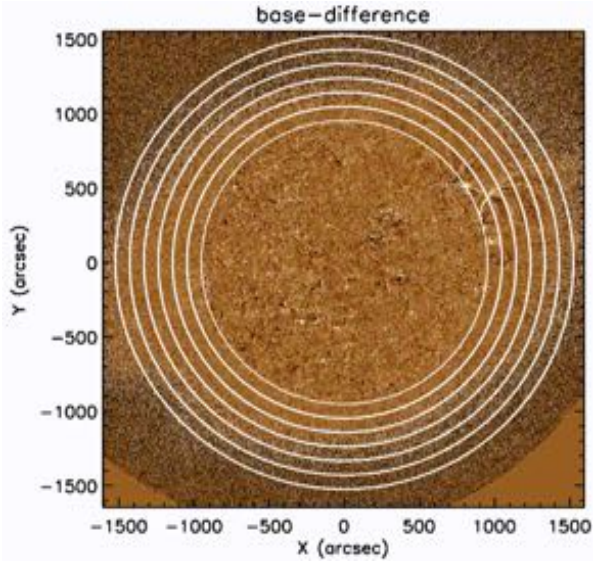
Kinematics of the EUV above the limb

Stack plots



Cyan line – center of eruption.
Blue line – CME flanks. **Black line** – EUV wave front.

Circular slits at heights from 1.0 to 1.6 Rs above the solar surface

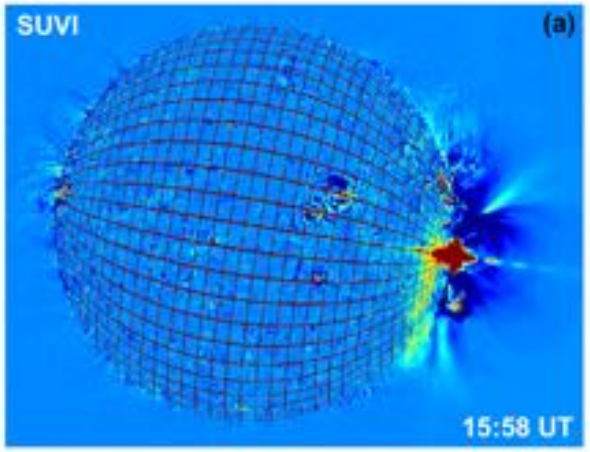


Northern direction:
750 – 1200 km s^{-1} at 1.05 – 1.5 Rs.

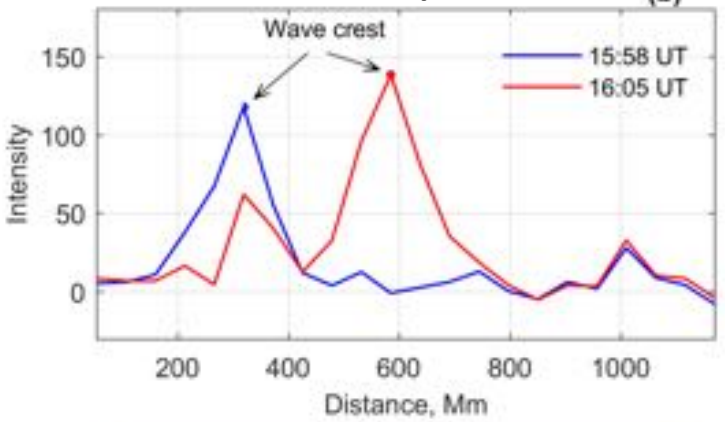
Southern direction:
750 – 950 km s^{-1} at 1.05 - 1.3 Rs.

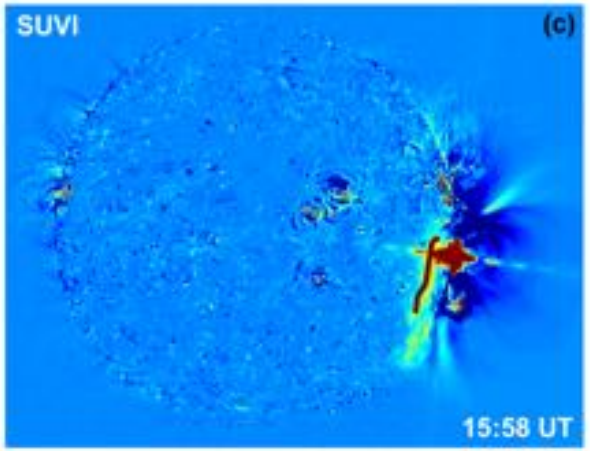
Kinematics of the EUV wave on the disk

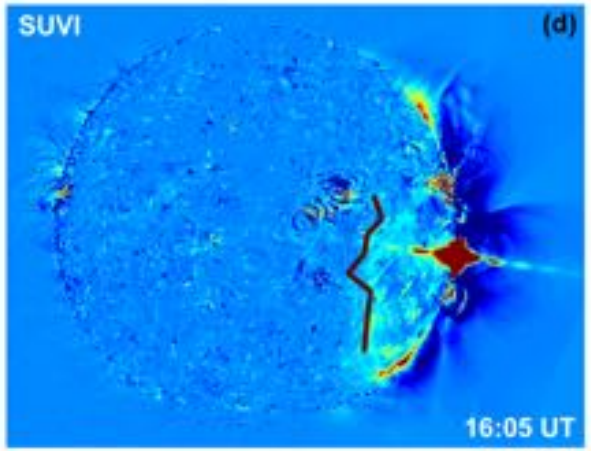
Kinematics of direct EUV wave from the source region



Intensity depending on the distance from the eruptive center



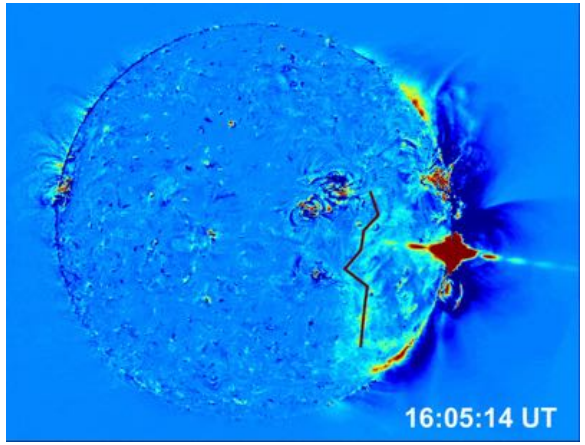




SUVI base difference images rotated to North up.

The areas of the wave crest are determined from intensity perturbation profiles (ring analysis method, Podladchikova and Berghmans, 2005).

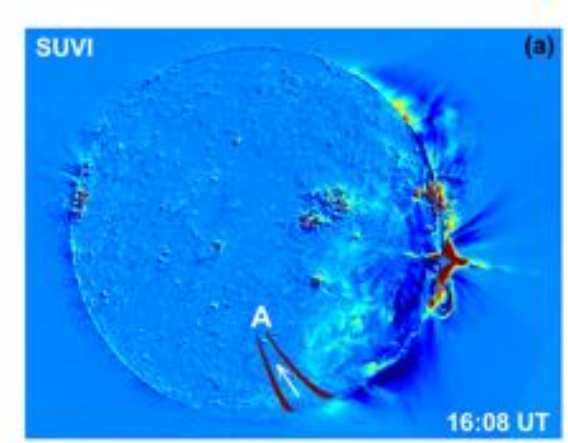
The propagation of the EUV wave with the detected wave fronts



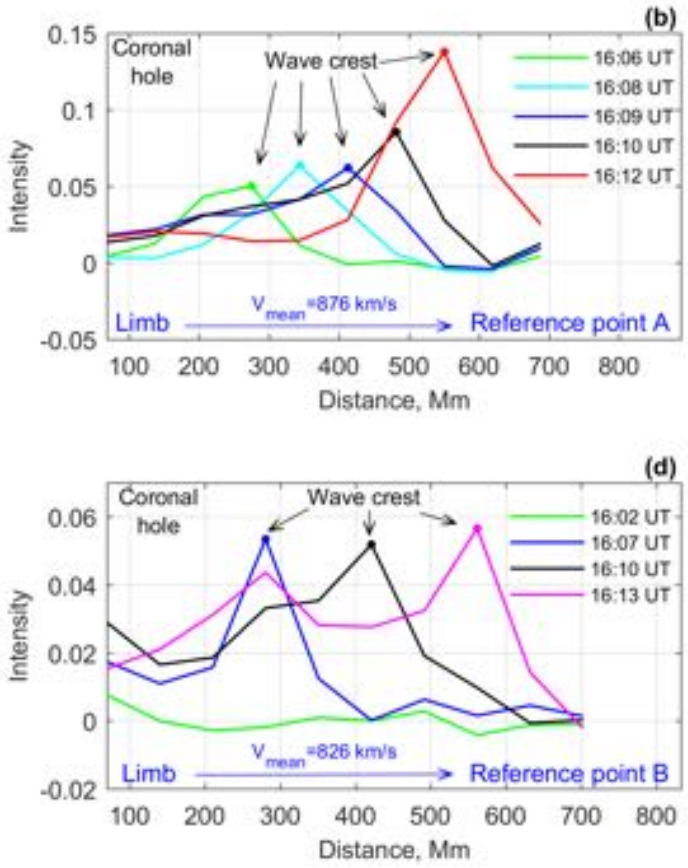
EUV wave speed: 630 - 1010 km s^{-1}.

Kinematics of secondary wave fronts observed with SUVI

Analysis of EUV wave kinematics with SUVI images from the South limb to North-East

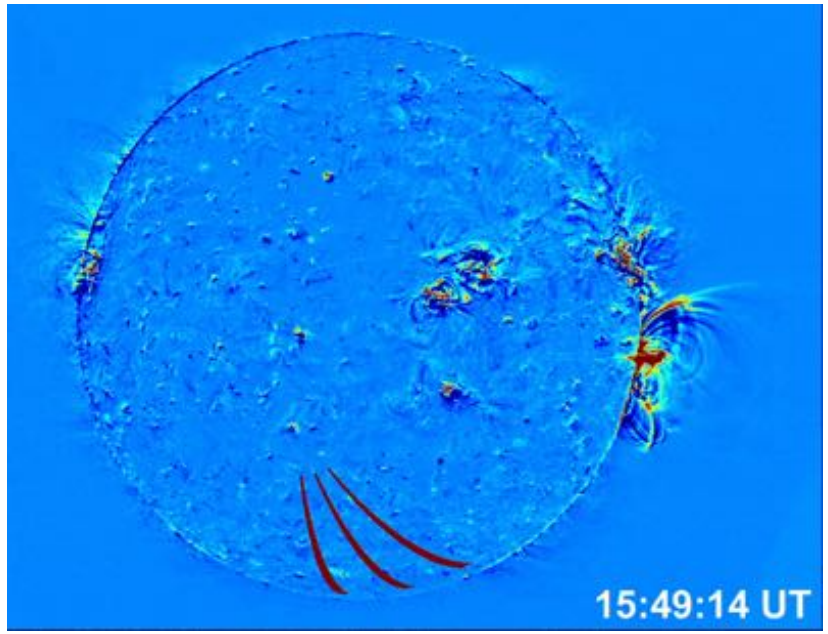


SUVI 195 Å base difference images



Dependence of the mean intensity on the distance from the eruptive center

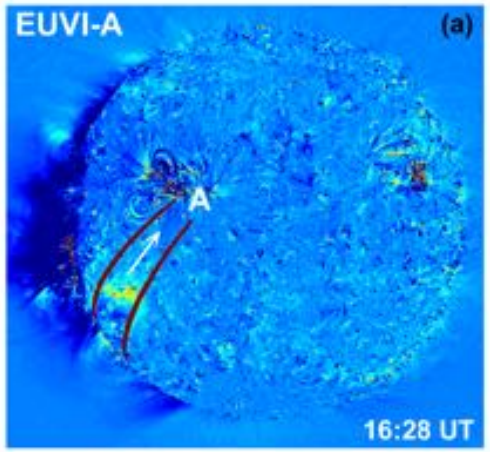
The propagation of EUV wave observed with SUVI

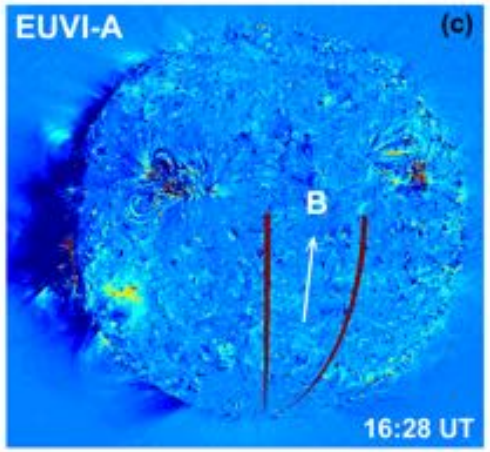


Base-difference images over 15:49-16:25 UT

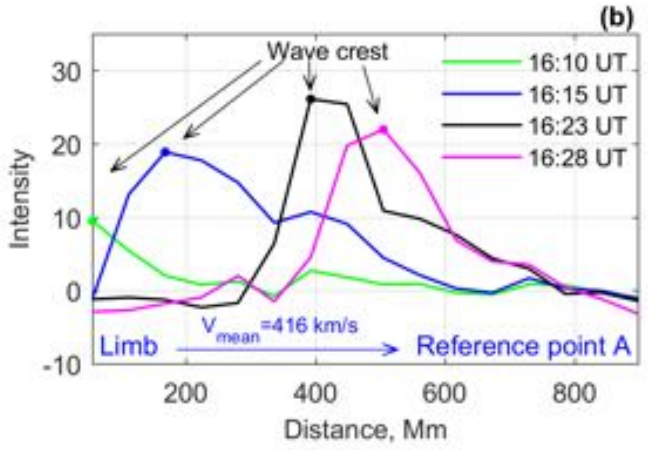
Kinematics of secondary wave fronts observed with STEREO-A

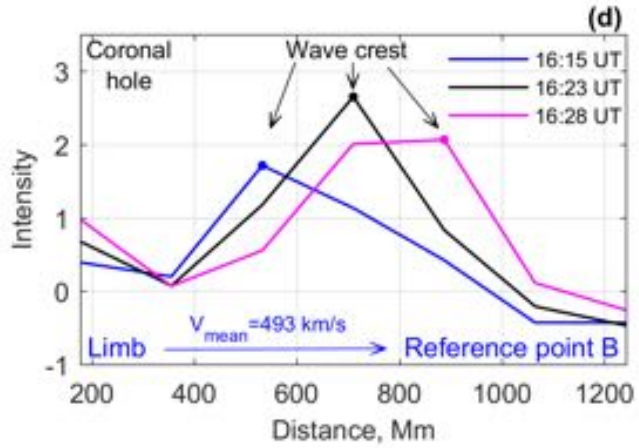
Analysis of EUV wave kinematics with STEREO-A images from the South-East and South limb





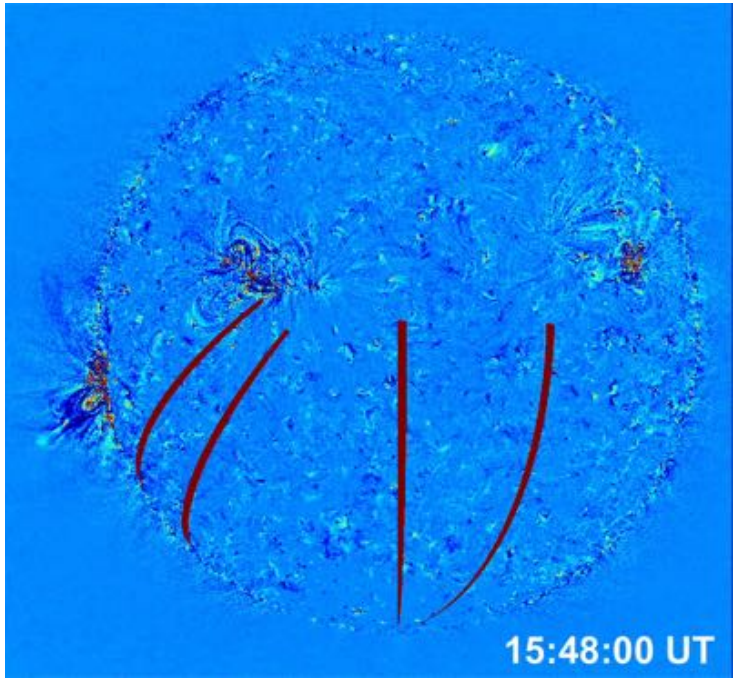
STEREO-A 195 Å base difference images





Dependence of the mean intensity on the distance from the eruptive center

The propagation of EUV wave observed with STEREO-A/EUVI



Base-difference images over 15:48-16:35 UT

At 16:28 UT the wave crest reached a distance of 1100 Mm (a) and 1730 Mm (c) from the source region.

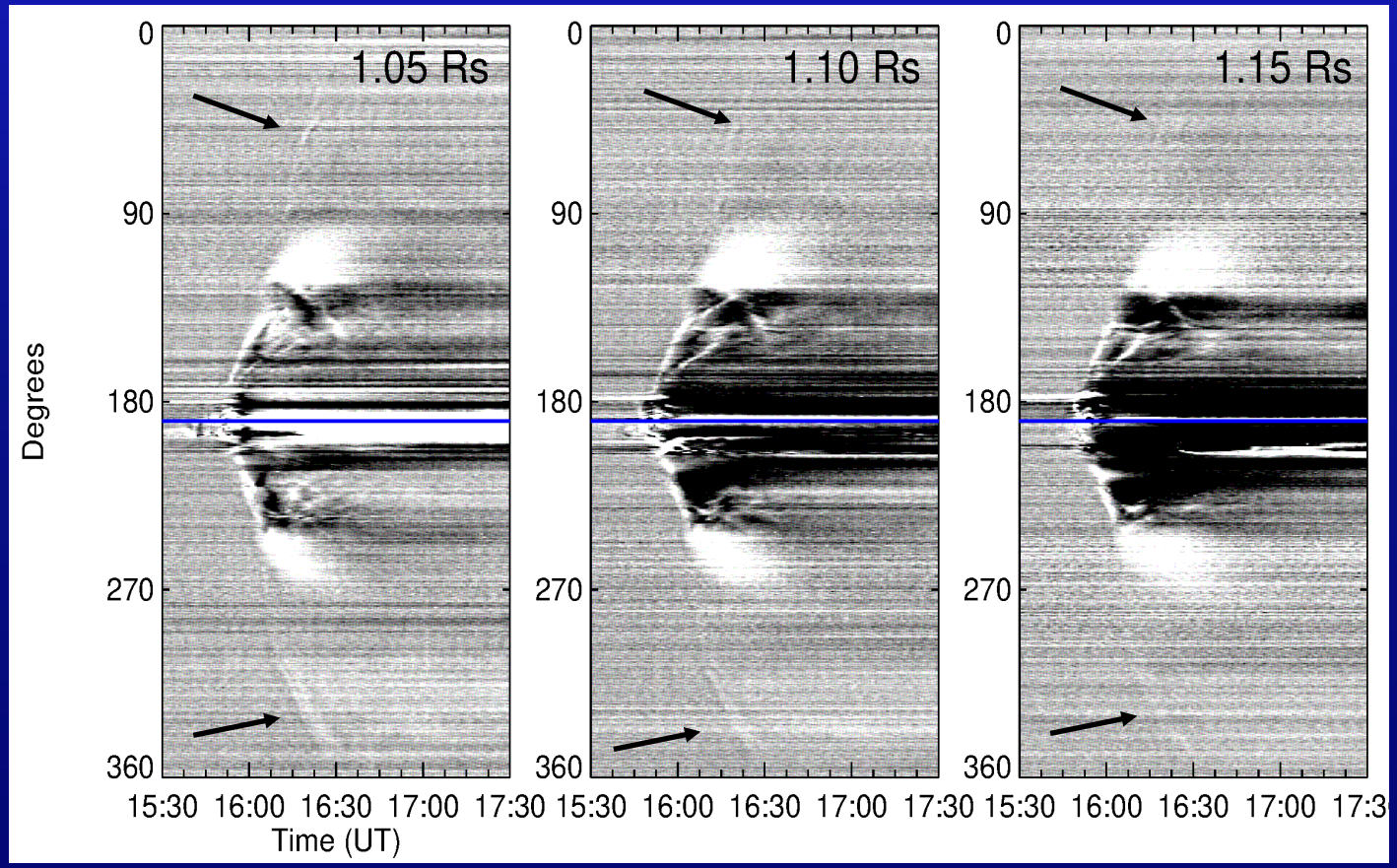
Transmission of this EUV wave through the polar coronal holes

Stack plots generated along circular slits at different heights above the solar surface from 1.05 to 1.15 Rs

EUV wave speed inside coronal hole:
North: ~1100 km s^{-1}
South: ~2500 km s^{-1}

See also Liu et al., 2018

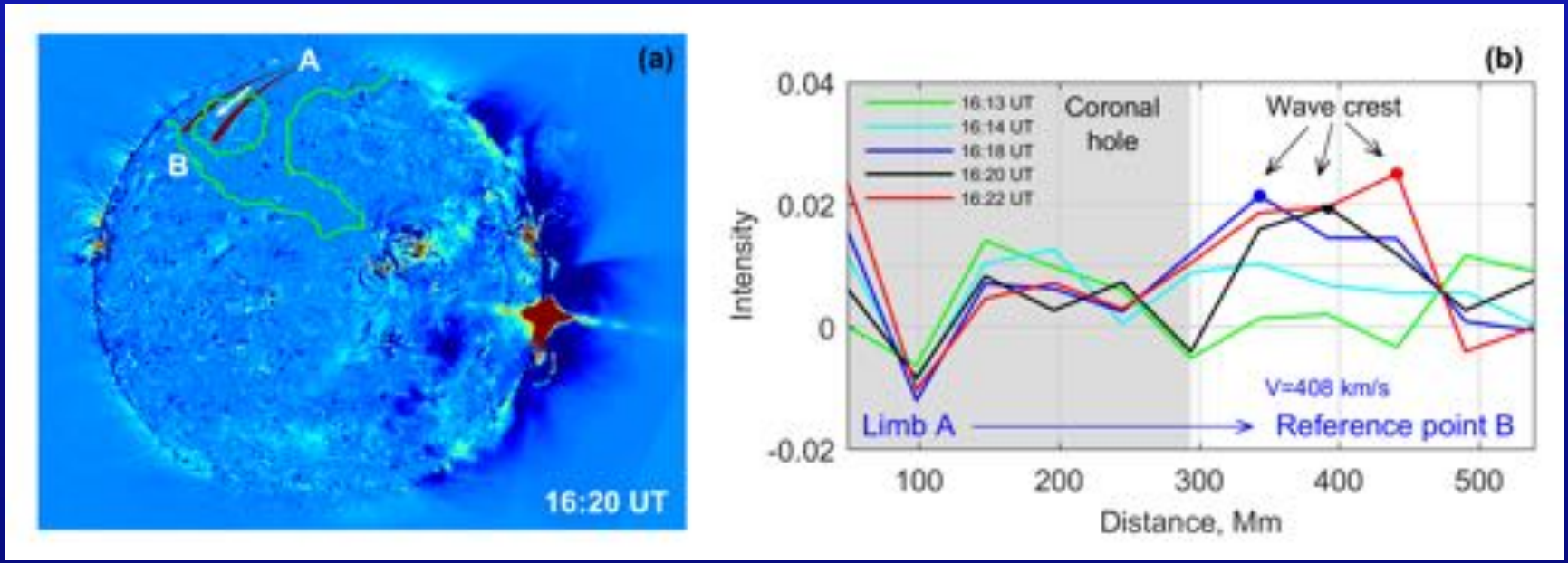
EUV wave dynamics above the limb



We see that the EUV wave propagates with a higher speed inside the coronal hole.
This is attributed to the higher Alfven speed in the coronal hole, due to its lower density.

Transmission of this EUV wave through the polar coronal holes

EUV wave dynamics on the disk



Podladchikova et al. 2018, in preparation

SUVI 195 Å base difference images

Dependence of the mean intensity on the distance from the eruptive center

The EUV wave moving from the back side of the Sun (with respect to SUVI) over the North limb through the coronal hole propagates later over the "island" (marked by green contours) with a speed of 408 km s^{-1}.

Summary

1. The CME associated with the X8.2 flare on 10 September 2017 shows an unprecedented fast overexpansion.

→ Peak acceleration of the lateral CME motion: 10.1 km s^{-2}. The highest value ever reported!

→ Peak acceleration of the lateral CME motion: 5.3 km s^{-2}. **Among the highest values reported!**

2. The evolution of CME cavity/flux rope is also observed by LASCO white-light coronagraph

→ The deformation ("nose") of outer CME front is related with faster motion of CME cavity/flux rope in radial direction than that of CME bubble.h

3. We determined the fast propagation speeds of the associated EUV wave and observed the transmission of the EUV wave through both coronal holes.

→ **Above the limb:**
750 – 1200 km s^{-1} at 1.05 – 1.5 Rs (Northen direction)
750 – 950 km s^{-1} at 1.05 - 1.3 Rs (Southern direction)
On the disk:
630 – 1010 km s^{-1} (direct waves from the source region)
370– 1010 km s^{-1} (secondary waves)

Thank you for your attention!