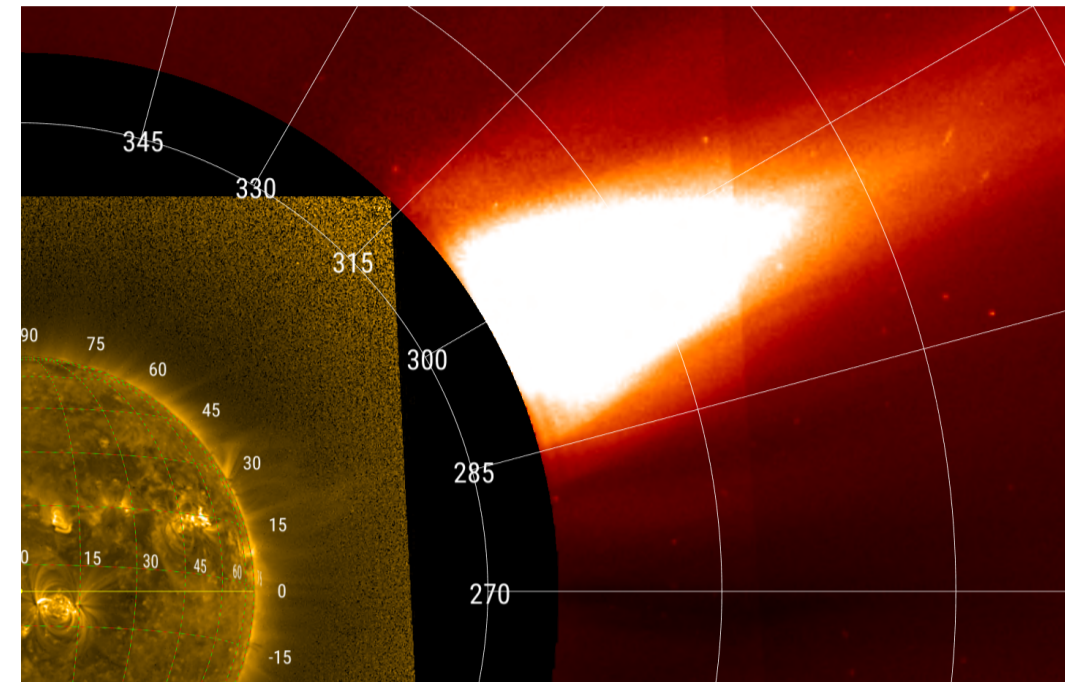


Abstract

On the 1st and 3rd April 2017 two large solar eruptions, which were associated with an M4.4 and an M5.8 class flare, respectively, were observed on the solar western limb with the Sun Watcher with Active Pixels and Image Processing (SWAP) EUV solar telescope on board the Project for On Board Autonomy 2 (PROBA2) spacecraft. The large field-of-view of SWAP, with the exceptional addition of the satellite being in a favorable off-pointed position to view the events, allow us to study the eruptions up to approximately 2 solar radii, where space-based coronagraph observations begin. SWAP observations reveal off-limb erupting features as well as on disk EUV waves initiated by these eruptions. Using this unique set of observations, the evolution of these two events is tracked and the propagating speeds of both the eruptions and the on-disk EUV waves are calculated.

HOP 334 Campaign and SWAP Off-pointing

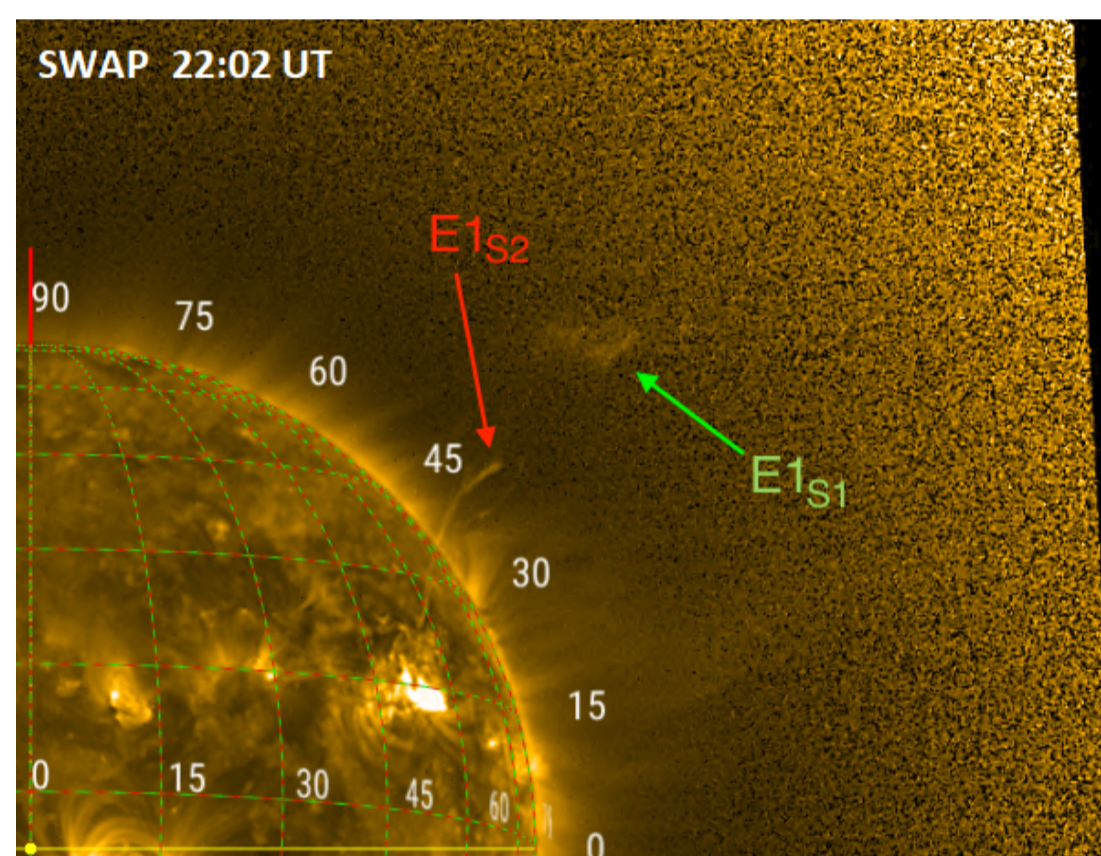
- ▶ The HINODE Operation Plan 0334 campaign (27 March - 4 April, 2017): large array of satellite and ground observations.
- ▶ PROBA2 satellite carried out 10 off-points
- ▶ Wide field-of-view (54 arcmin) + off-point allows SWAP to observe up to 2.5 solar radii, overlapping with the LASCO coronagraph observations.
- ▶ Four M-class flares were observed by SWAP towards the limb of the Sun while it was off-pointed, two are presented here.



Combined LASCO-C2 and non off-pointed SWAP image (JHelioviewer Müller et al., 2017)

1 April 2017: M4.4 Flare and Eruption

- ▶ Flare observed between 21:35 and 22:05 UT on April 1, 2017.

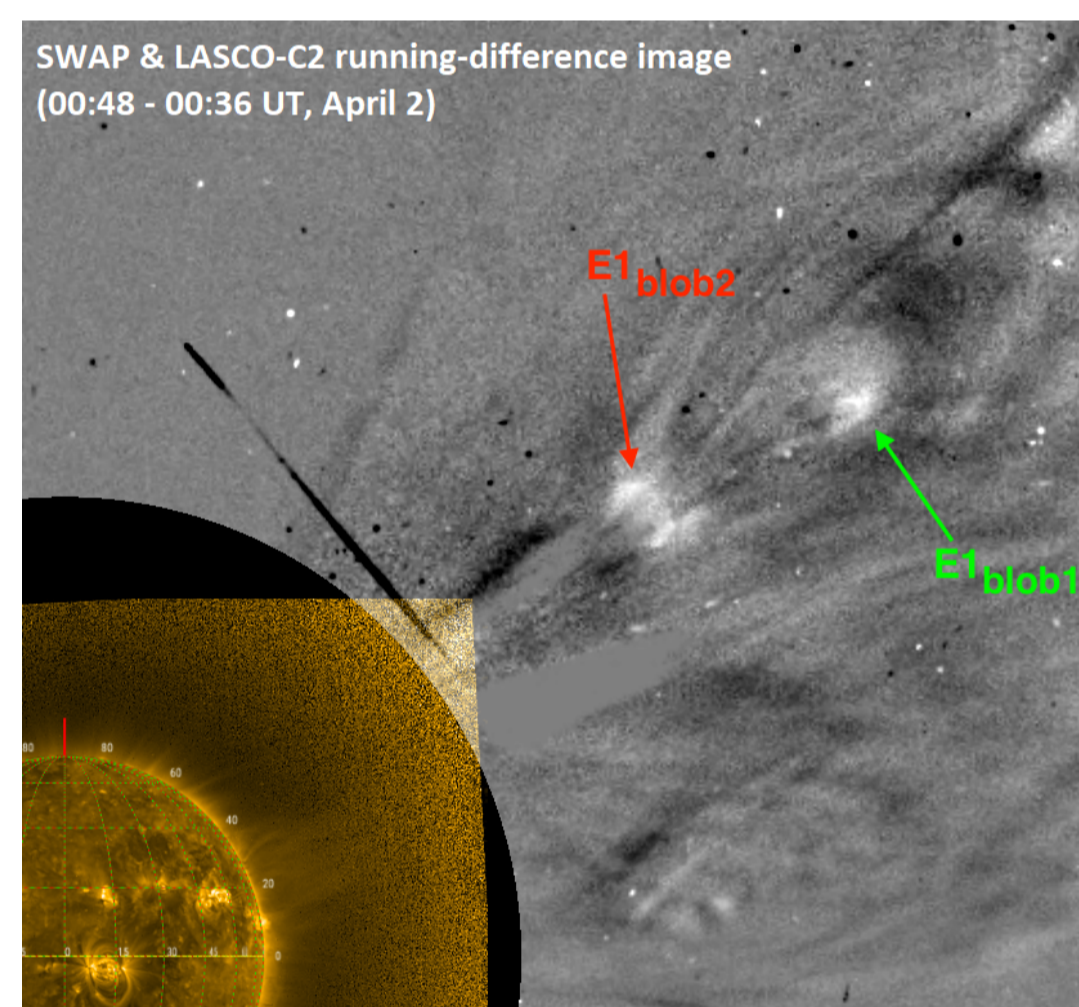
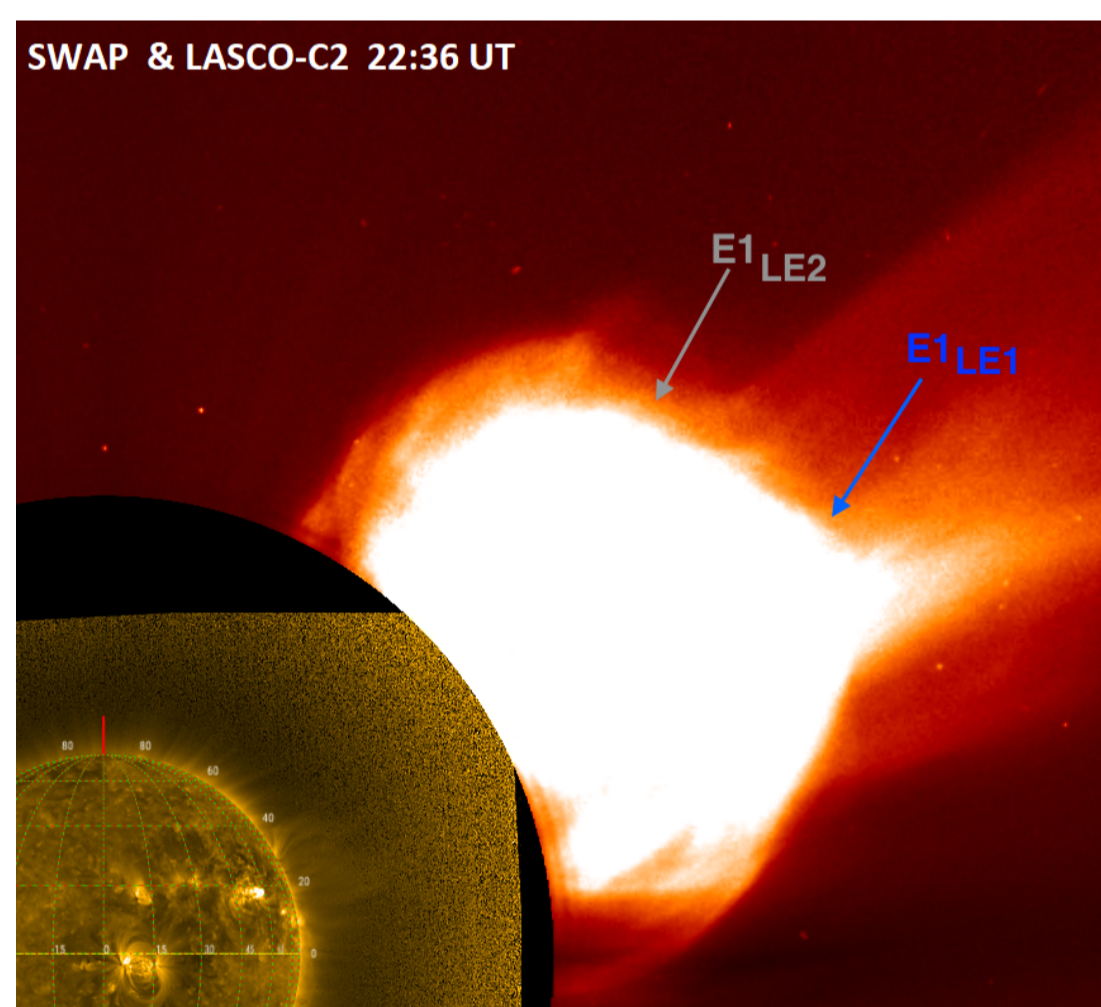


SWAP off-limb features

- ▶ “Blob” ($E1_{S1}$) and jet like structures ($E1_{S2}$) observed in SWAP from 22:00 to 22:13 UT off the west limb.

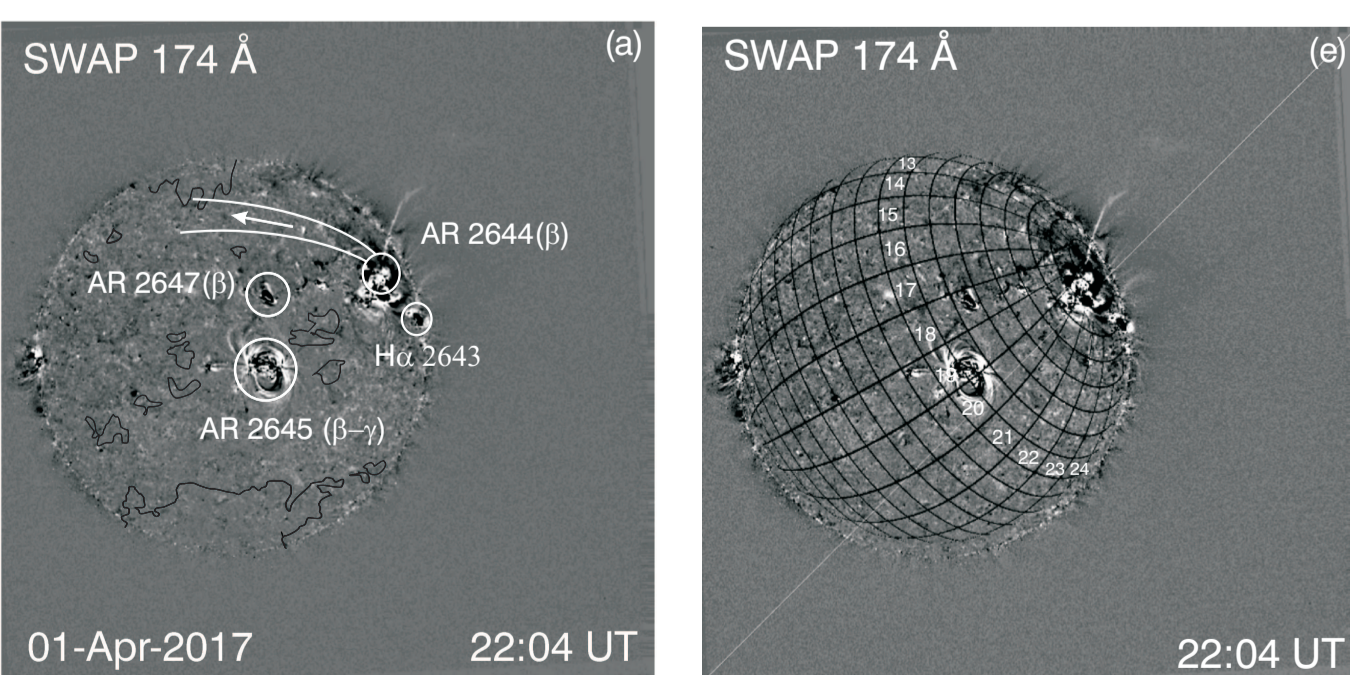
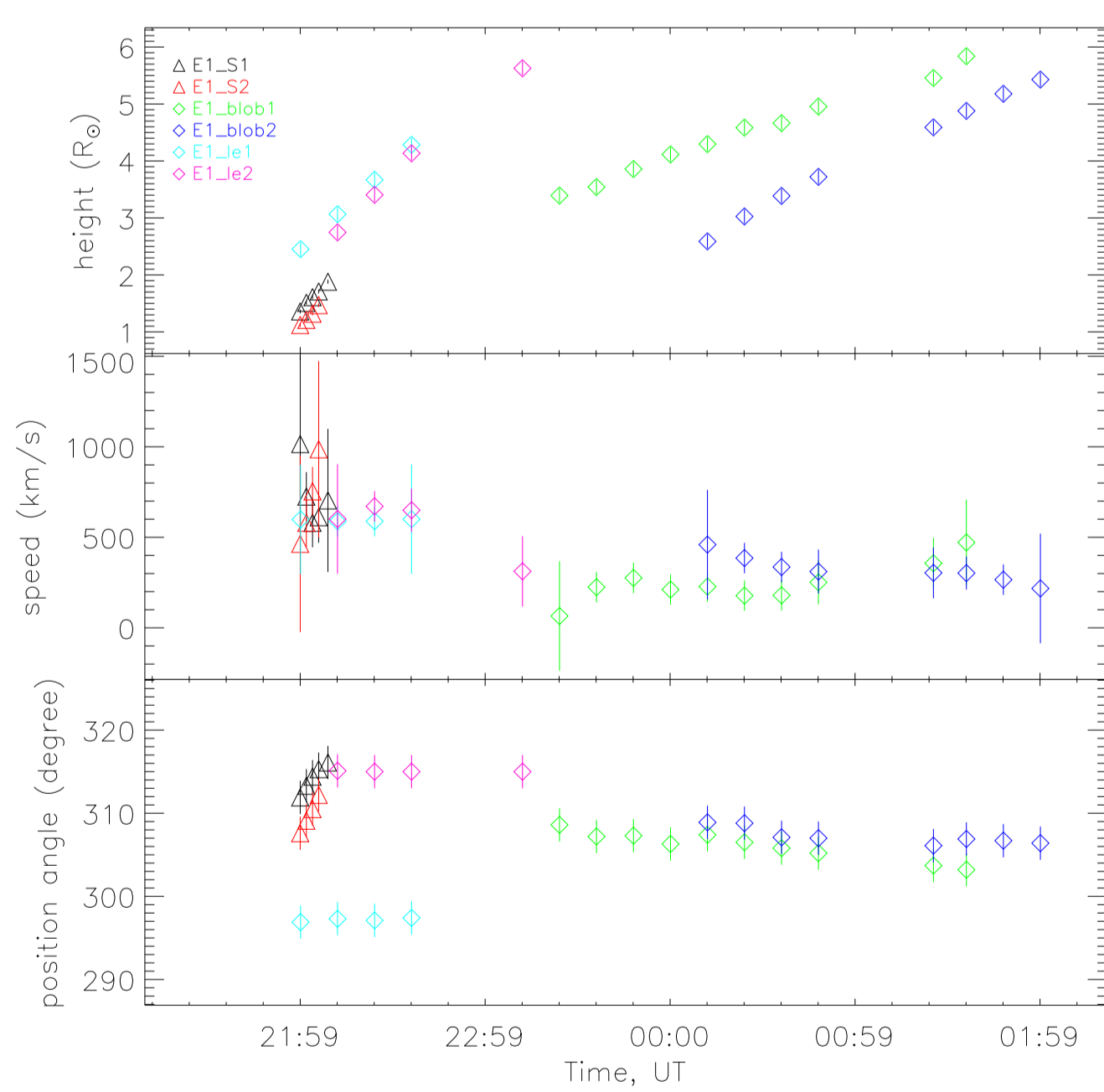
LASCO-C2 features

- ▶ Leading edges of the CME are tracked at position angles (PA) 300 $E1_{S2}$ and 315 $E1_{S2}$ where features were seen in SWAP.
- ▶ Two blob-like features identified in the core of the CME - seen in running difference image at PA 305 ($E1_{blob1}$) and 307 degrees ($E1_{blob2}$).



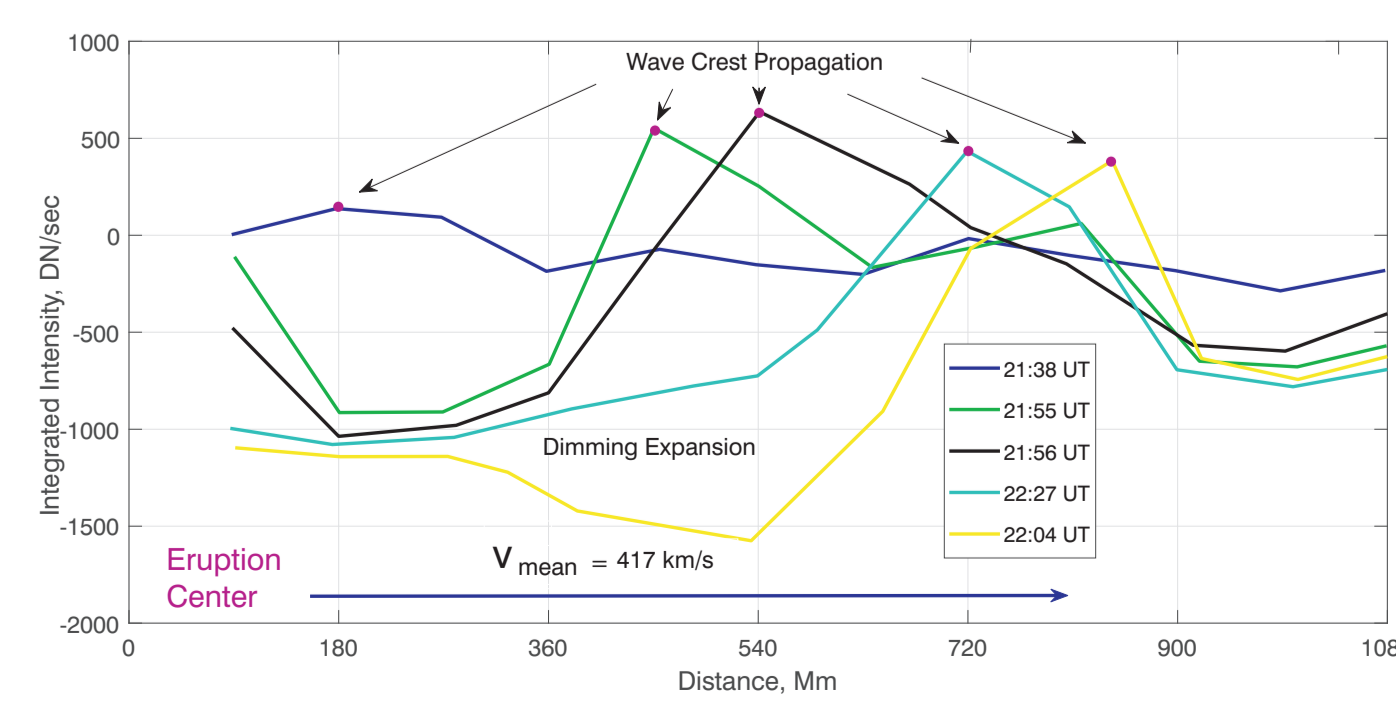
Height-time diagram:

- ▶ Features are manually tracked and the height, calculated speeds and PAs of different features in SWAP and LASCO images are shown with time.
- ▶ Both features tracked in SWAP appear to fit better with the feature $E1_{blob1}$ from the core of the CME seen in LASCO (although the second core feature seen in LASCO does not fit with any SWAP features).
- ▶ Average speeds were between 690 – 730 km/s for features tracked in SWAP and 240 – 600 km/s for those in LASCO.



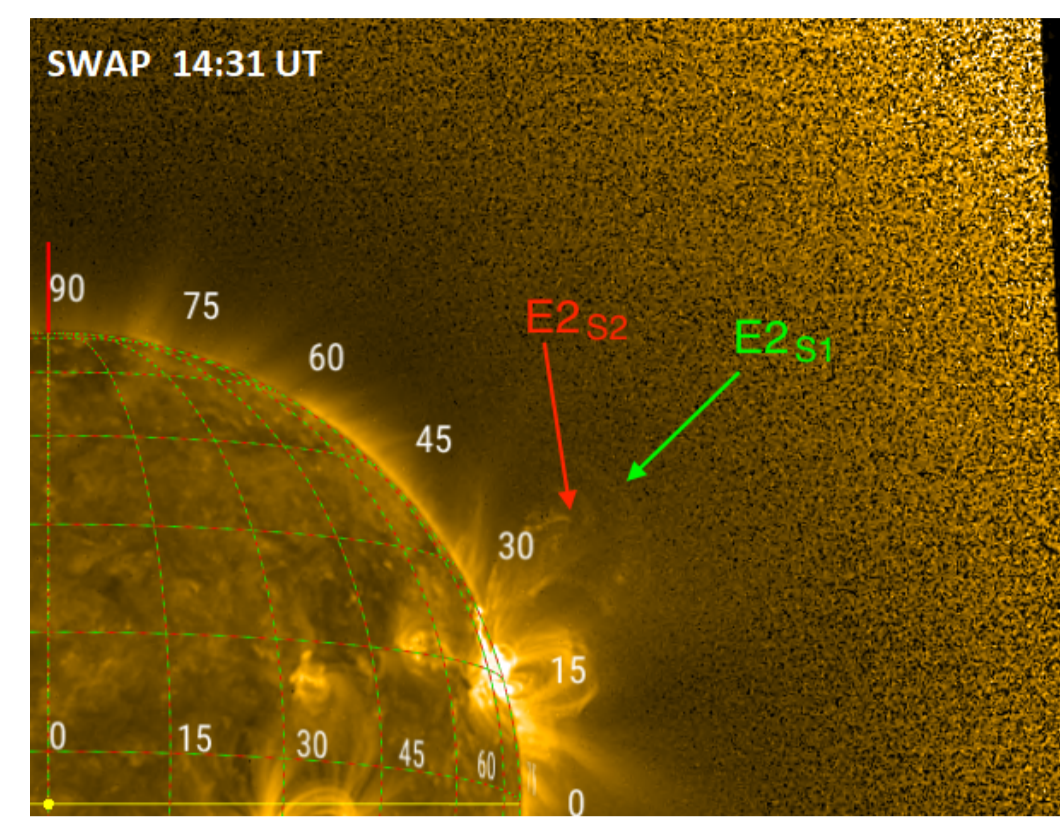
On disk EUV wave dynamics:

- ▶ Eruption and dimming areas are extracted and the EUV wave crest is followed using the ring analysis method (Podladchikova & Berghmans, 2005).
- ▶ Base-difference calibrated SWAP images are divided into 24 angular sectors.
- ▶ For one sector (in quiet Sun) the integrated intensity with distance from the center of the eruption is shown for five different times.
- ▶ The wave crest propagates in front of the expanding dimming.
- ▶ Average speed for the wave crest is 417 km/s.



3 April 2017: M5.8 Flare and Eruption

- ▶ Flare observed between 14:19 - 14:34 UT (including a rare Lyman Alpha profile observed by PROBA2/LYRA).

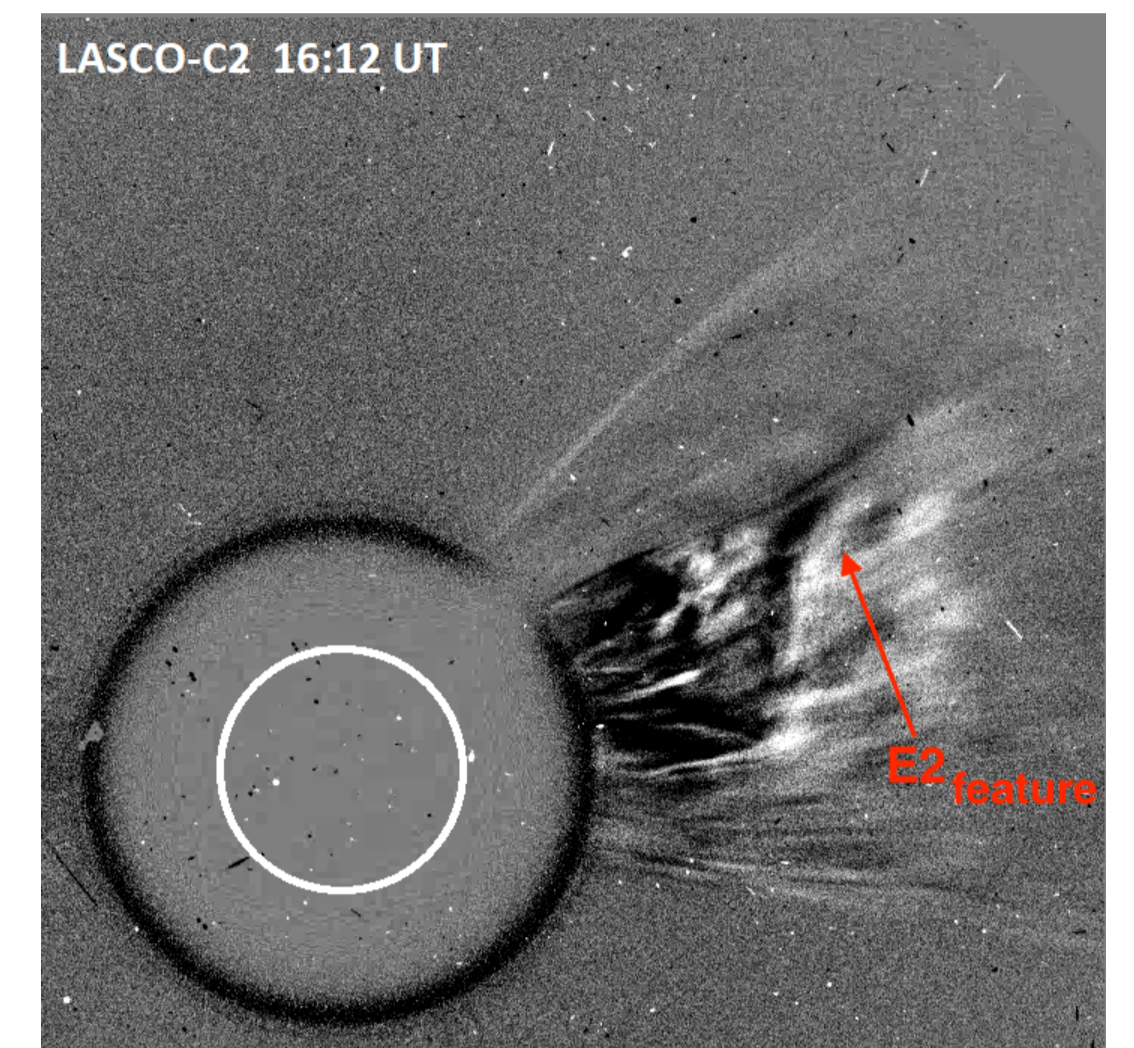
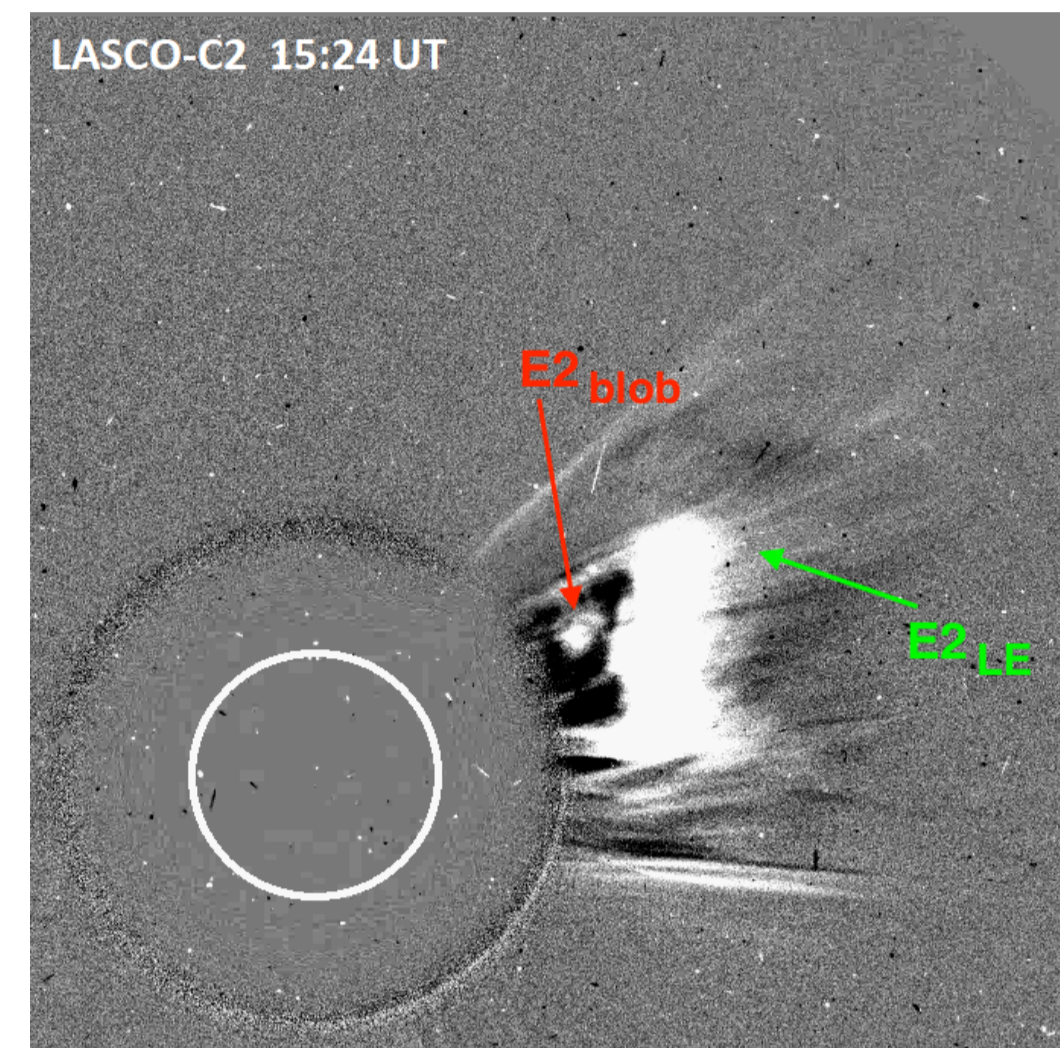


SWAP off-limb features

- ▶ A large scale loop-like structure is seen from around 14:26 UT, with a more complex feature following.
- ▶ The leading edge ($E2_{S1}$) and top of this complex feature ($E2_{S2}$) are tracked.

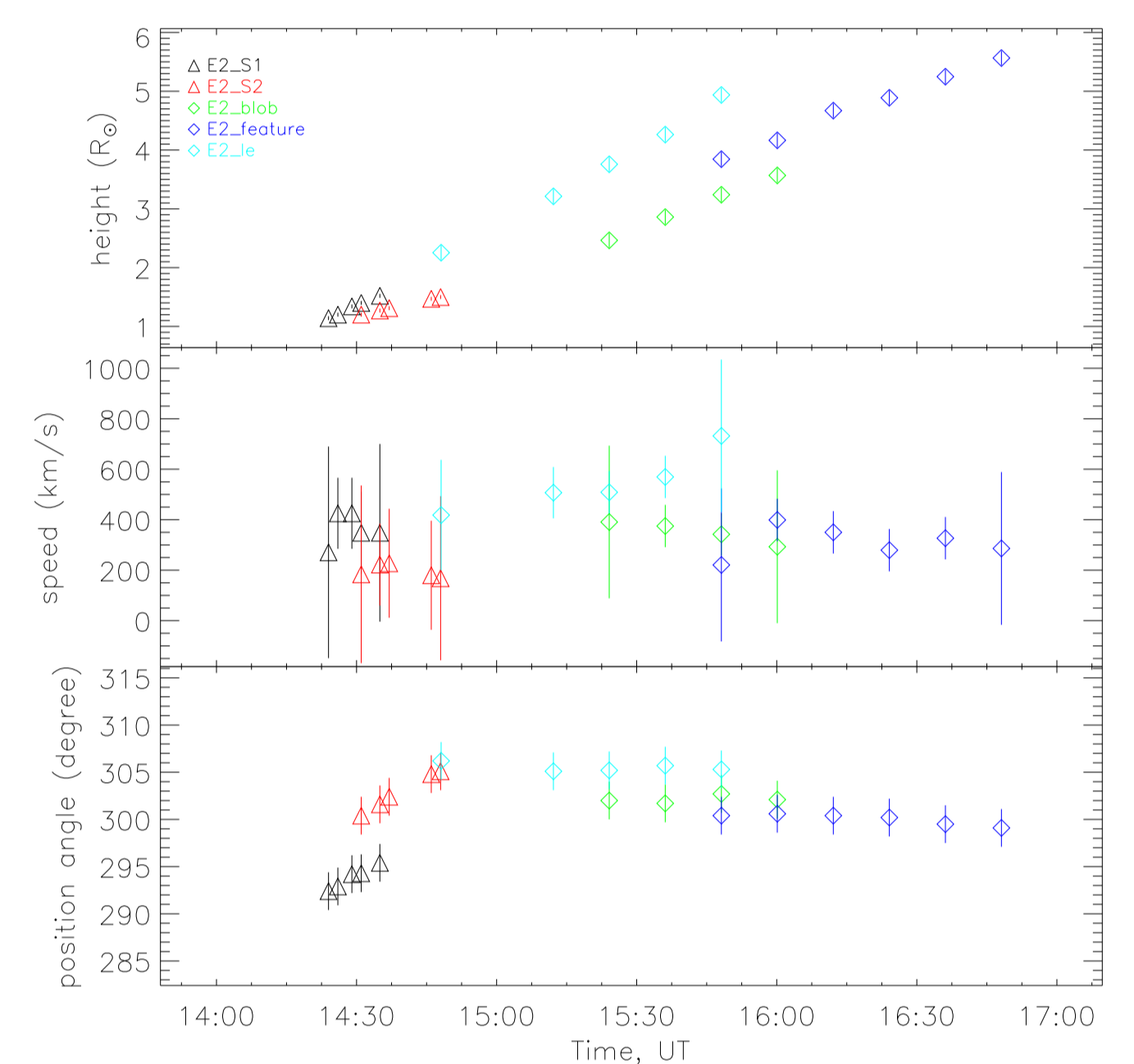
LASCO-C2 features

- ▶ Leading edge of CME is not circular, so tracked at PA 305 $E2_{LE}$.
- ▶ Two features in the core of CME ($E2_{blob}$ and $E2_{feature}$) seen in LASCO-C2 are also tracked.



Height-time diagram:

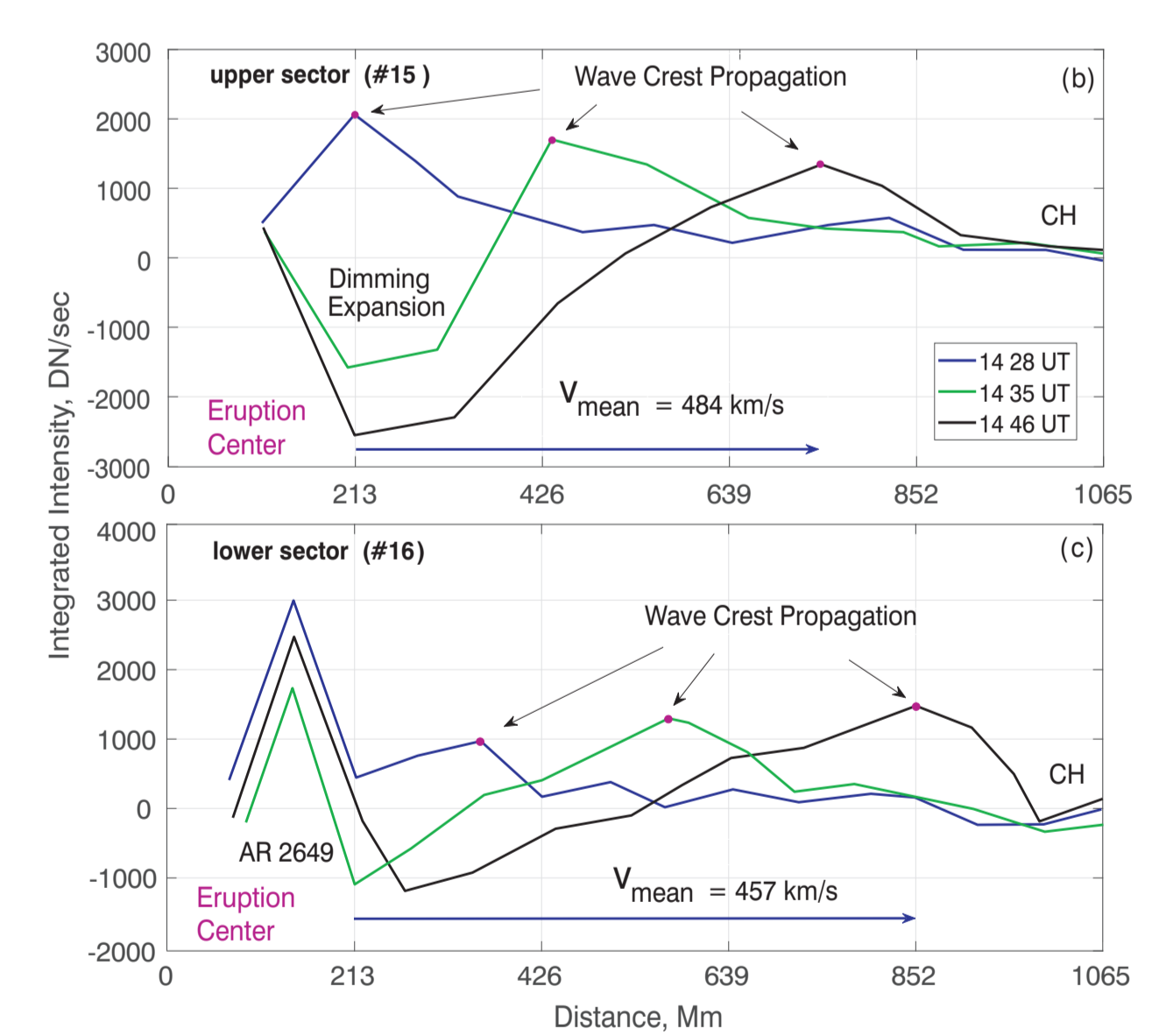
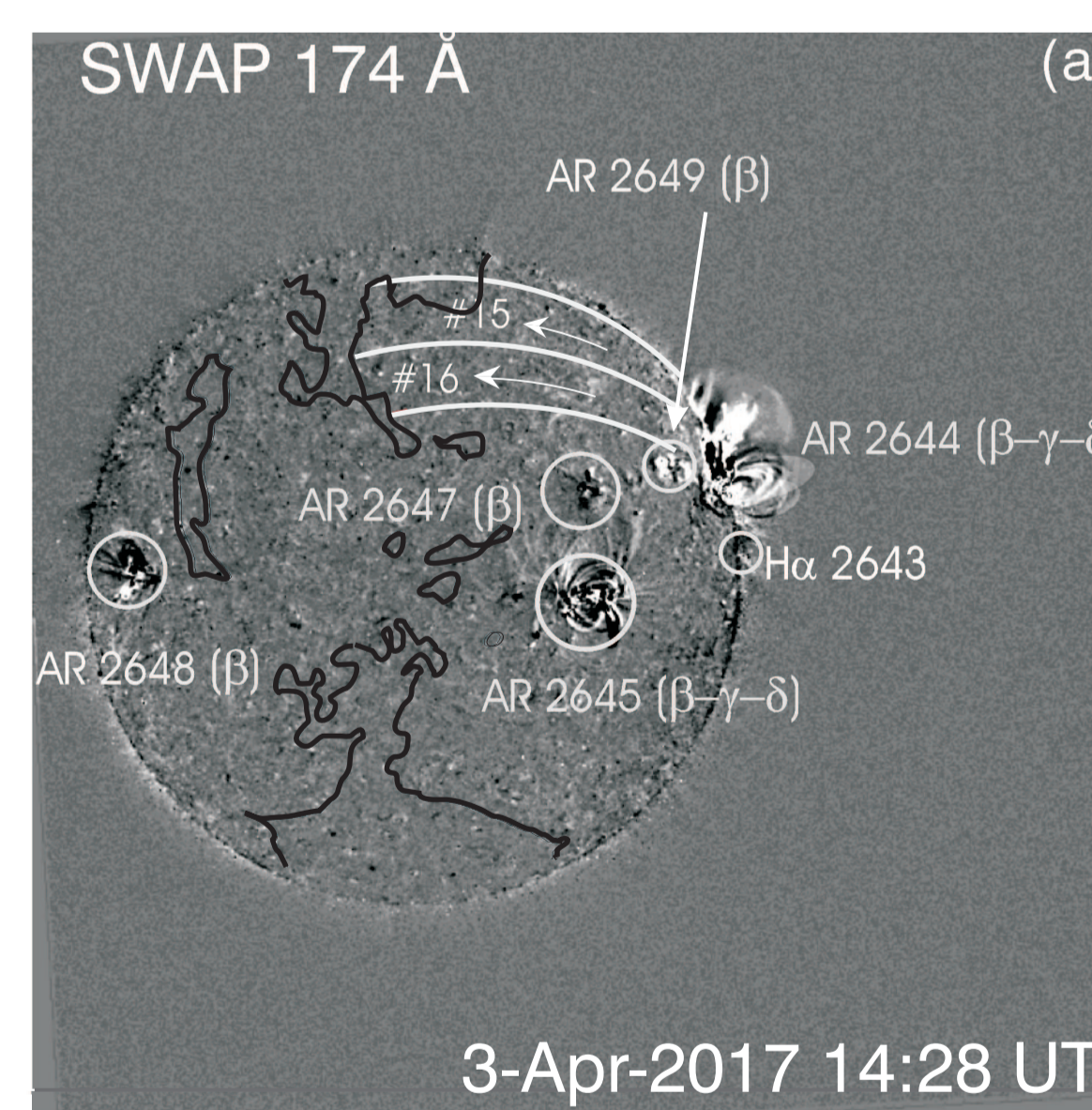
- ▶ The heights of the two features tracked in SWAP ($E2_{S1}$ & $E2_{S2}$) seem to correspond with the leading edge $E2_{LE}$ and core ($E2_{blob}$) CME features seen in LASCO, respectively.
- ▶ Features in SWAP change PA by around 5 degrees, while in LASCO features the PA doesn't change greatly.
- ▶ Average speeds were between 190 – 370 km/s for features tracked in SWAP and 310 – 550 km/s for those in LASCO.



On disk EUV wave dynamics:

- ▶ The integrated intensity with distance from the eruption center is calculated for two sectors: 15 (upper) and 16 (lower).
- ▶ The initial wave propagation in sector 16 is affected by NOAA AR 2649 as shown by the drop in the intensity profile.

- ▶ Initially, the wave speeds are identical in both sectors $v \approx 485$ km/s.
- ▶ At greater distances from the eruption center the wave amplitude and speed decrease faster in sector 15 as it encounters the coronal hole borders earlier.



Summary

- ▶ The events described are two rare examples of EUV observations that overlap with coronagraph observations, providing crucial additional data points to track the early evolution of the CMEs.
- ▶ As well as enabling us to follow the CME evolution at greater heights in EUV, these observations can also be used to increase our understanding of the connection between different observable features (both on disk and off-limb) of an eruption.
- ▶ However, the issue of the low signal to noise ratio near the edge of the field-of-view of SWAP remains and indicates the need for future observations in the middle corona which are not restricted by noise levels.

References

Müller, D., Nicula, B., Felix, S., Verstringe, F., Bourgoignie, B., Csillaghy, A., Berghmans, D., Jiggins, P., García-Ortiz, J. P., Ireland, J., Zahniy, S., & Fleck, B. 2017, *Astron. Astrophys.*, 606, A10
Podladchikova, O. & Berghmans, D. 2005, *Solar Phys.*, 228, 265

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