Flare & CME Observations with STEREO/EUVI

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http://www.lmsal.com/~aschwand/ppt/2009_SWG_Pasadena_Flare.ppt

Content of talk :

Flares & CMEs with:

1) Impulsive EUV emission
2) Postflare EUV emission
3) Occultation
4) EUV dimming
5) Loop oscillations
6) Eruptive filaments

References:

-Aschwanden, Wuelser, Nitta, & Lemen 2009, Solar Physics (subm.)
"Solar Flare and CME Observations with STEREO/EUVI"
http://www.lmsal.com/~aschwand/eprints/2009_euvi.pdf

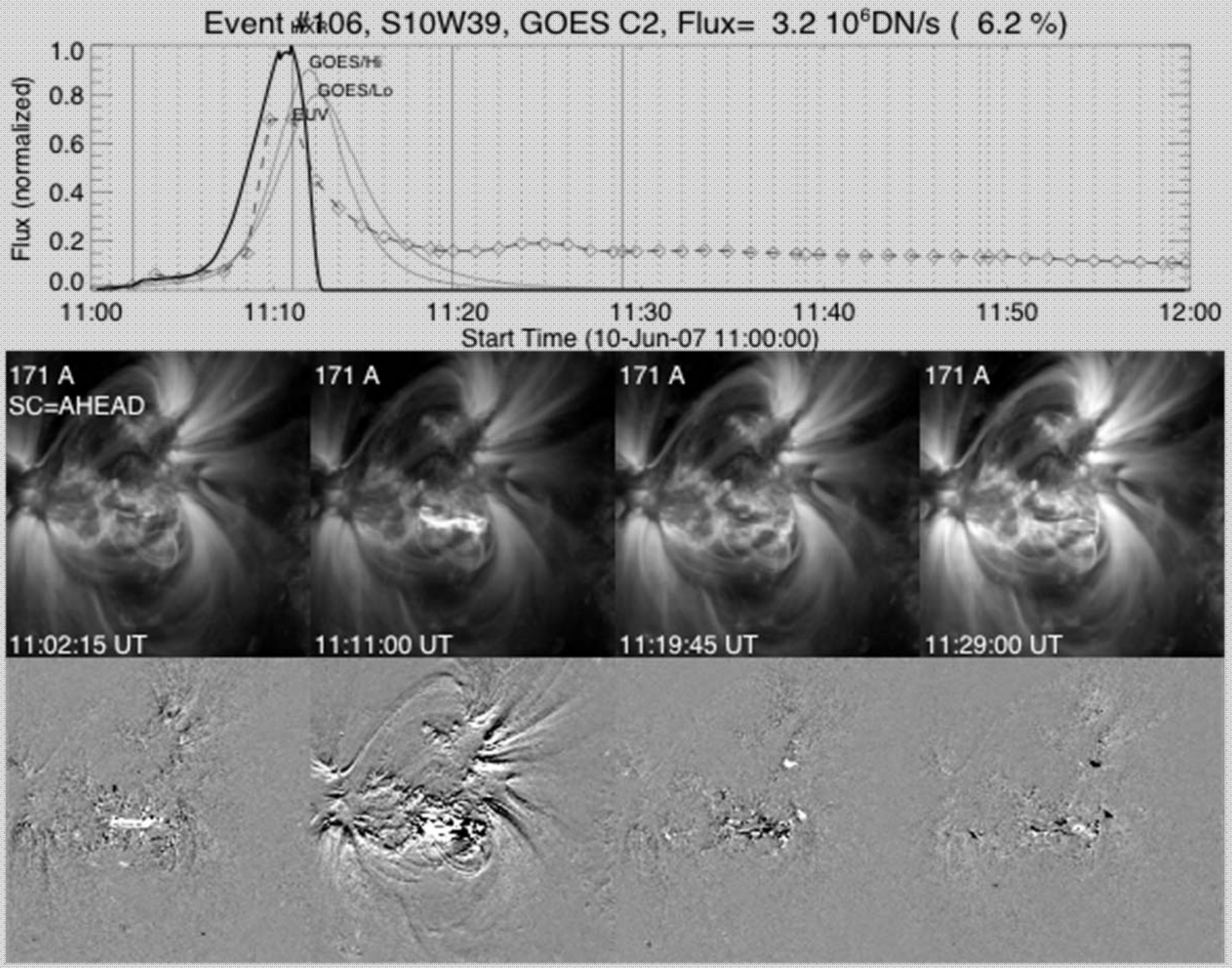
-Aschwanden,M.J. 2009, Space Science Reviews (Special Issue on Coronal Seismology)
"The 3D Geometry, 3D Motion, and Hydrodynamics of Oscillating Coronal Loops",
http://www.lmsal.com/~aschwand/eprints/2009_ISSI.pdf

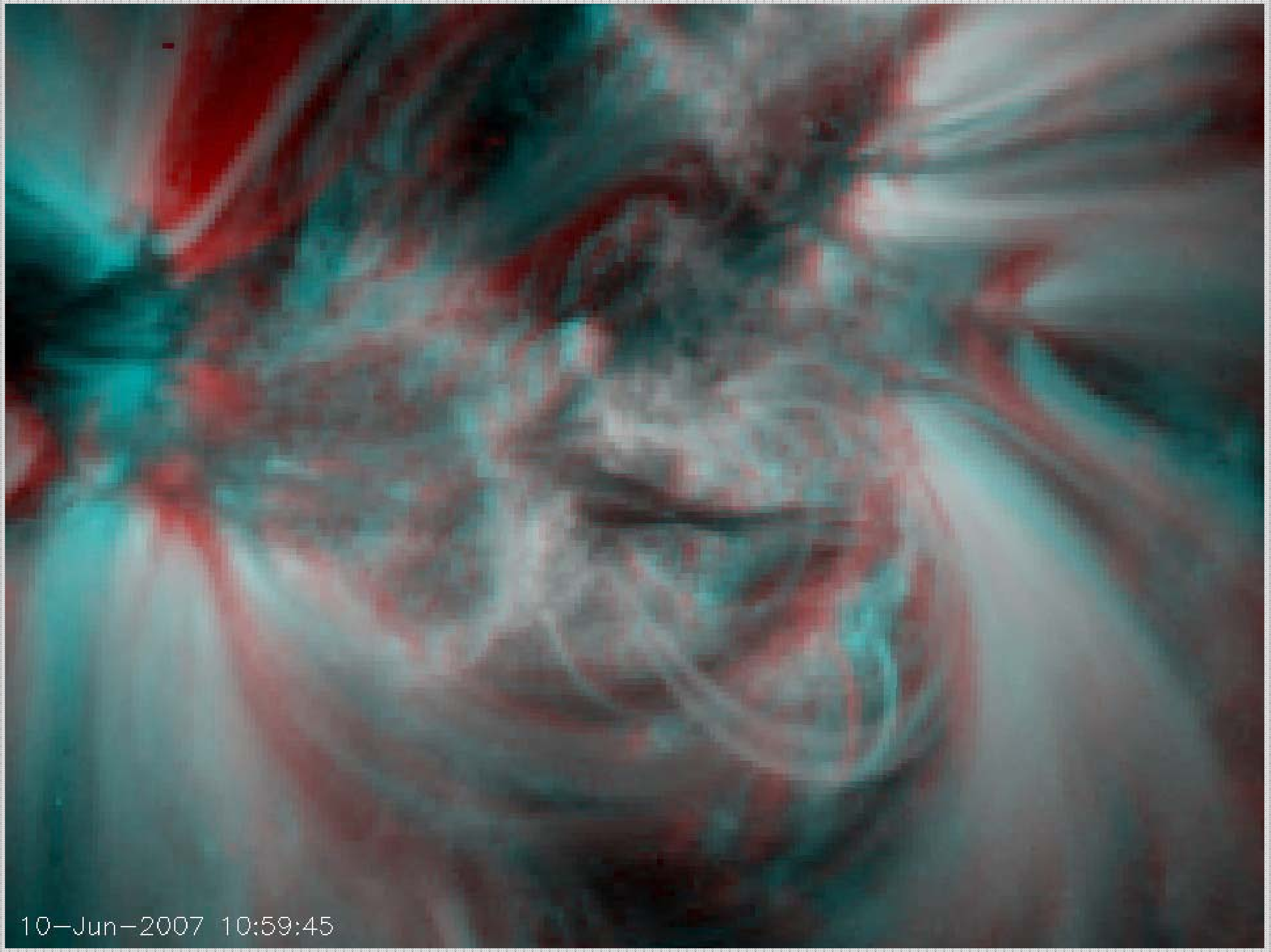
Statistics of Flares & CMEs observed with EUVI during first 2 years

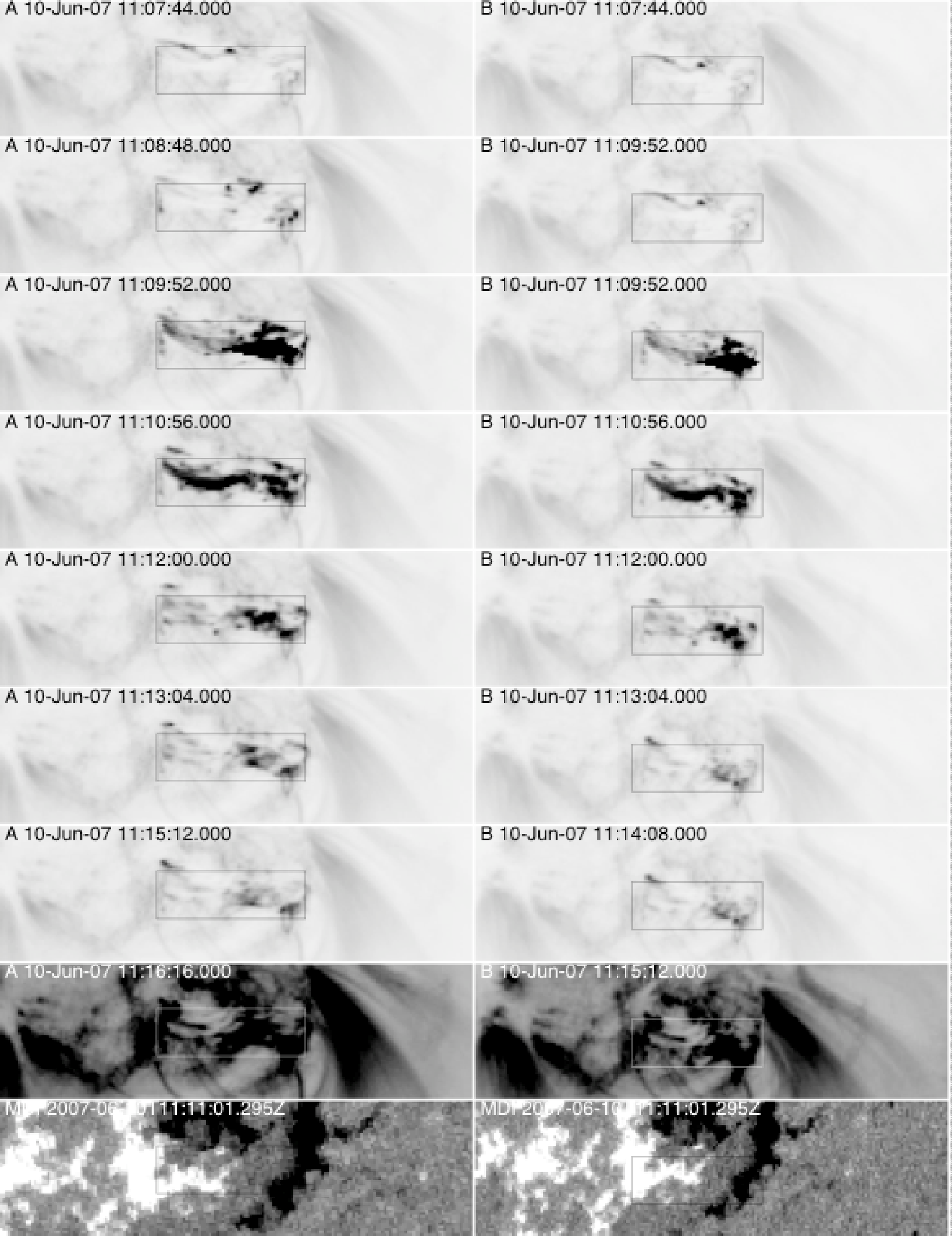
Number of catalogued events	185 (100%)
Number of GOES > C1 class events	90 (49%)
Number of GOES > M1 class events	11 (5%)
Number of RHESSI > 12 keV events	171 (92%)
Number of CME detections (LASCO, Cor 1,2)	68 (37%)
Events with impulsive EUV	147 (79%)
Events with postflare loops	135 (73%)
Events with occultation	45 (24%)
Events with EUV dimming	31 (17%)
Events with waves or oscillations	10 (5%)
Events with eruptive features	5 (3%)

http://secchi.lmsal.com/EUVI/euvi_events.txt

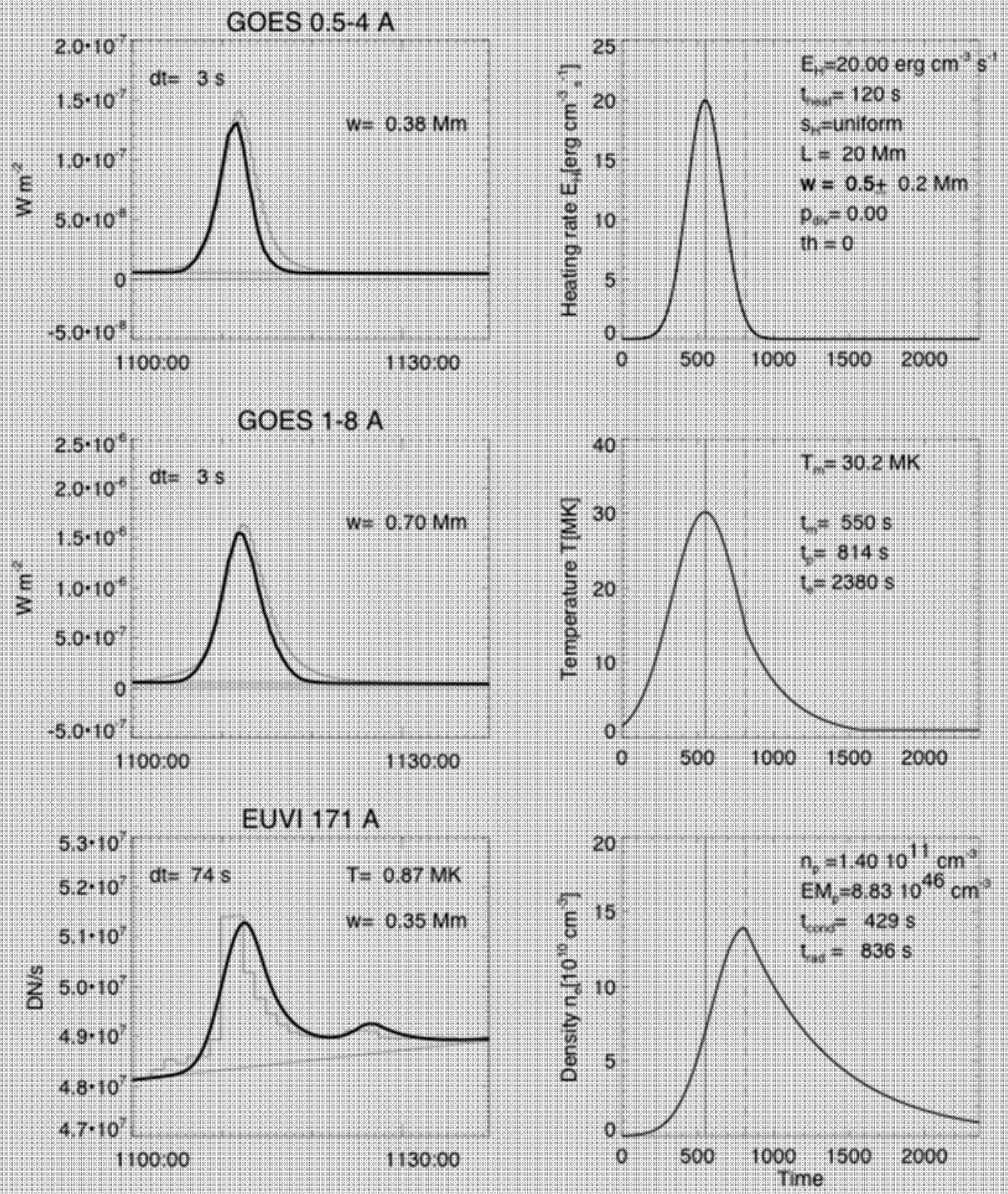
Flare/CMEs with Impulsive EUV emission




10-Jun-2007 10:59:45

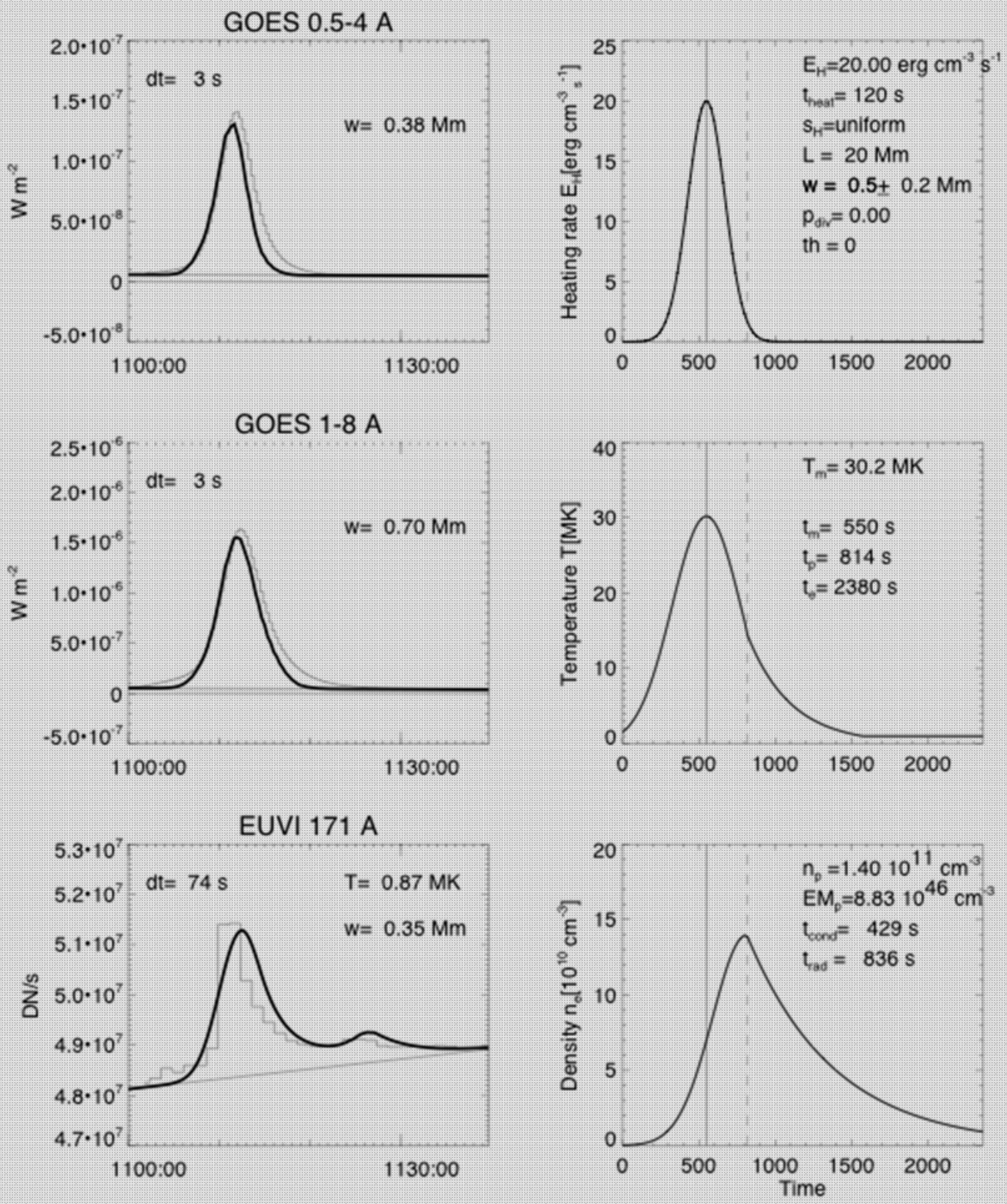


A filamentary structure in the core of the flare region above the neutral line brightens up impulsively coincident with the soft X-ray peak, while no delayed postflare EUV emission is observed.



Stereoscopic triangulation reveals the altitude of the central filamentary structure closely above transition region, far below the other active region loops:

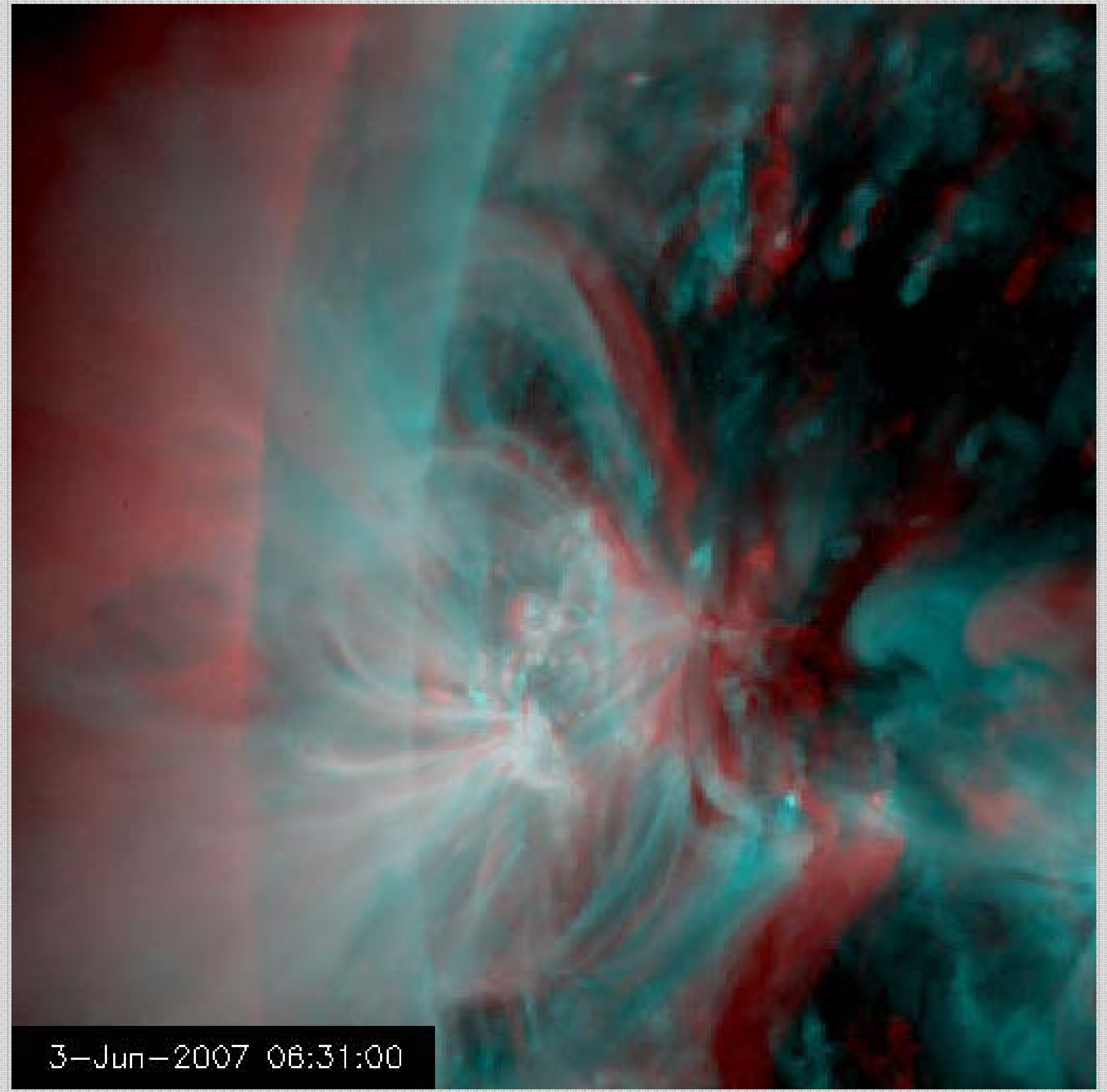
h ~ 1.8+/-2.4 Mm

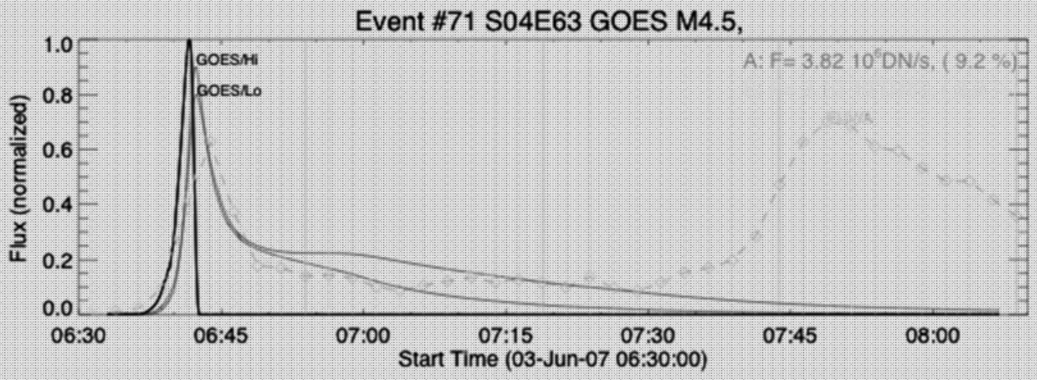


Hydrodynamic modeling of GOES and EUVI light curves yields an impulsive heating function (t_{heat}~120 s) for a short structure (L=20 Mm), and a conductive cooling time of ~7 min.

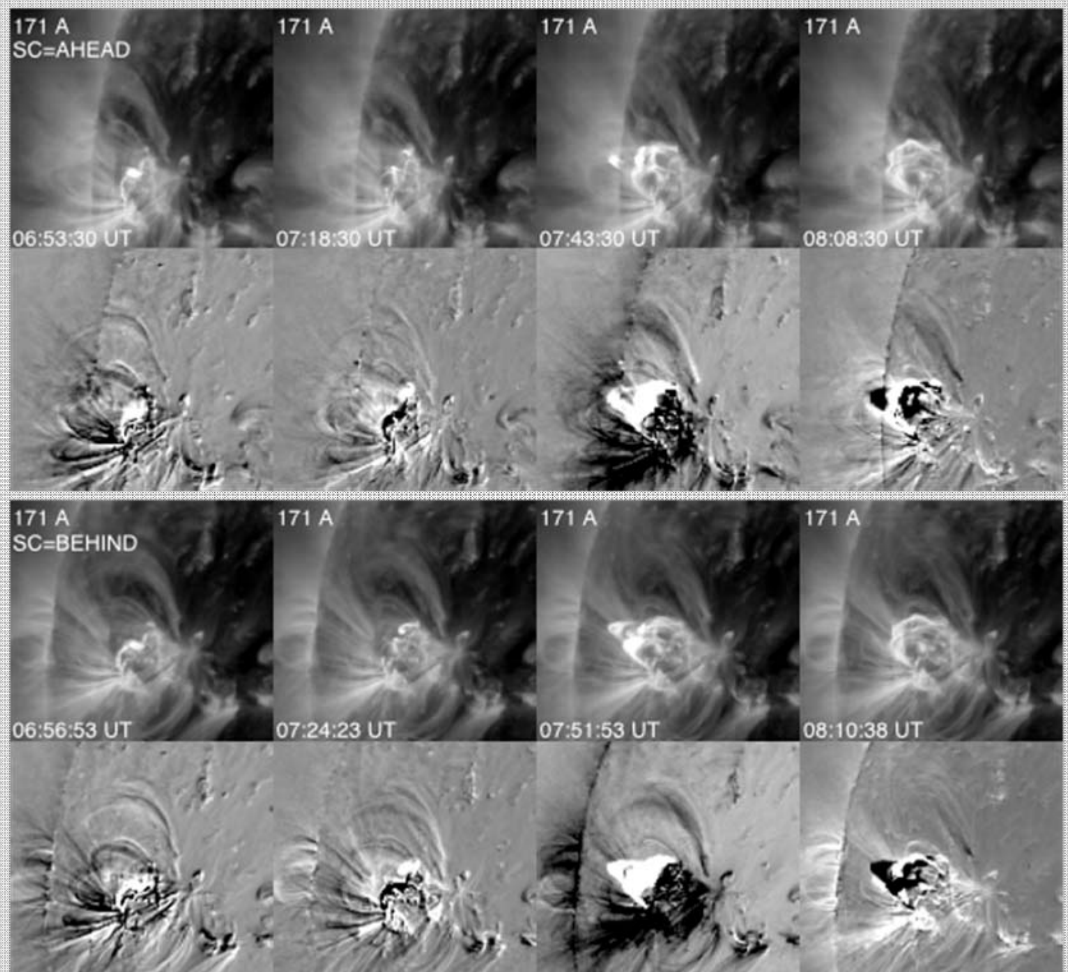
→ Impulsive EUV emission from impulsively heated non-erupting filament, but no delayed postflare EUV emission.

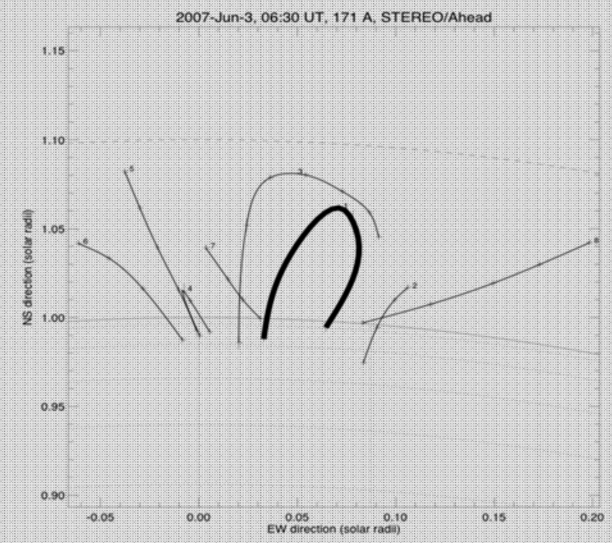
Flare/CME with Postflare EUV Emission





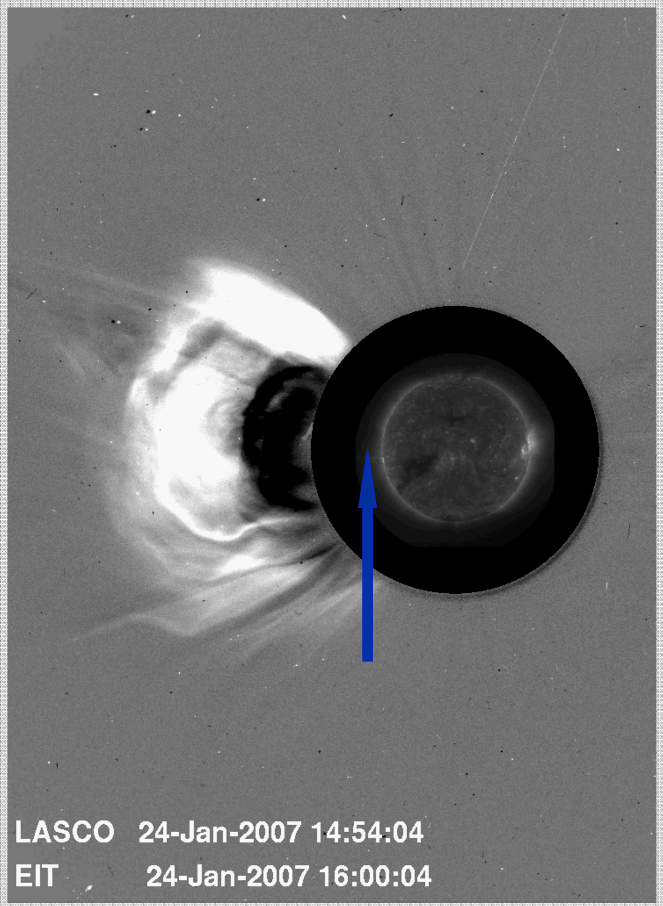
EUV light curve shows impulsive EUV (with SXR) and delayed (~1 hr) postflare EUV emission.

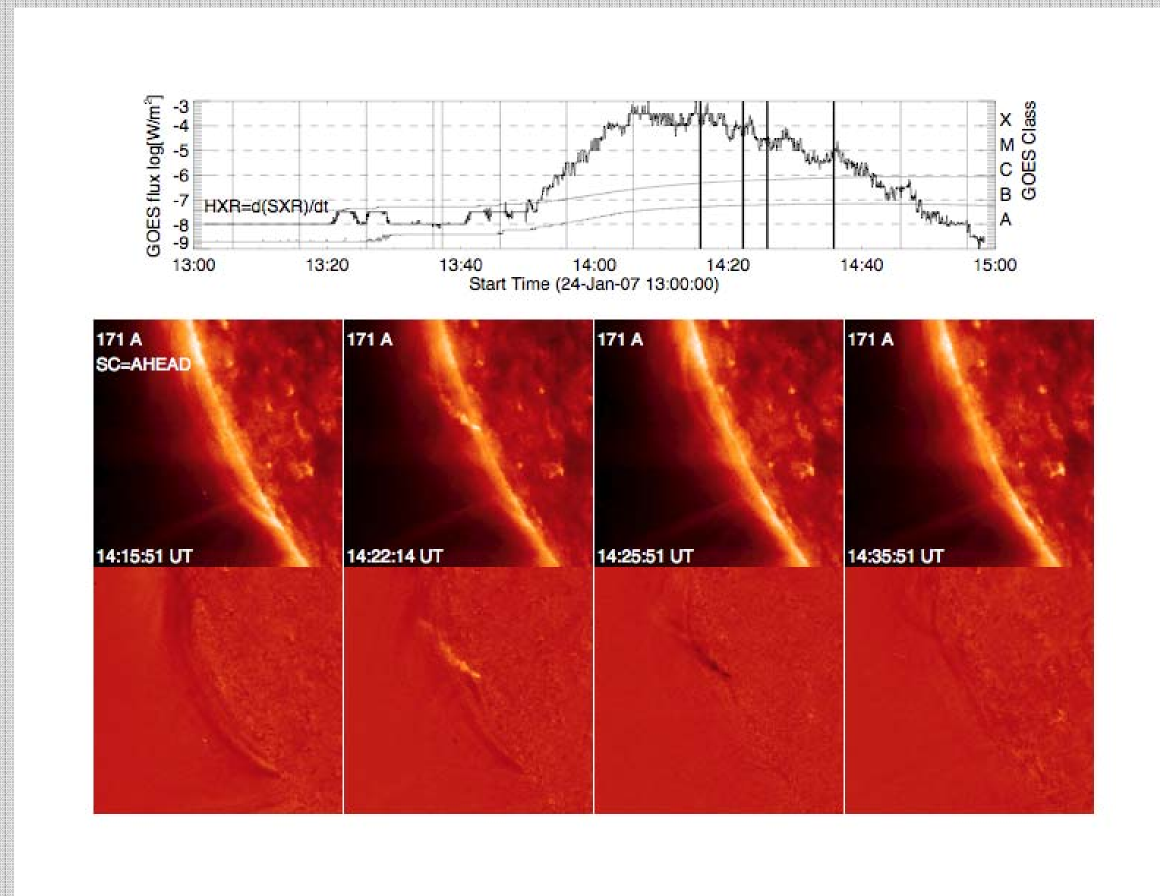




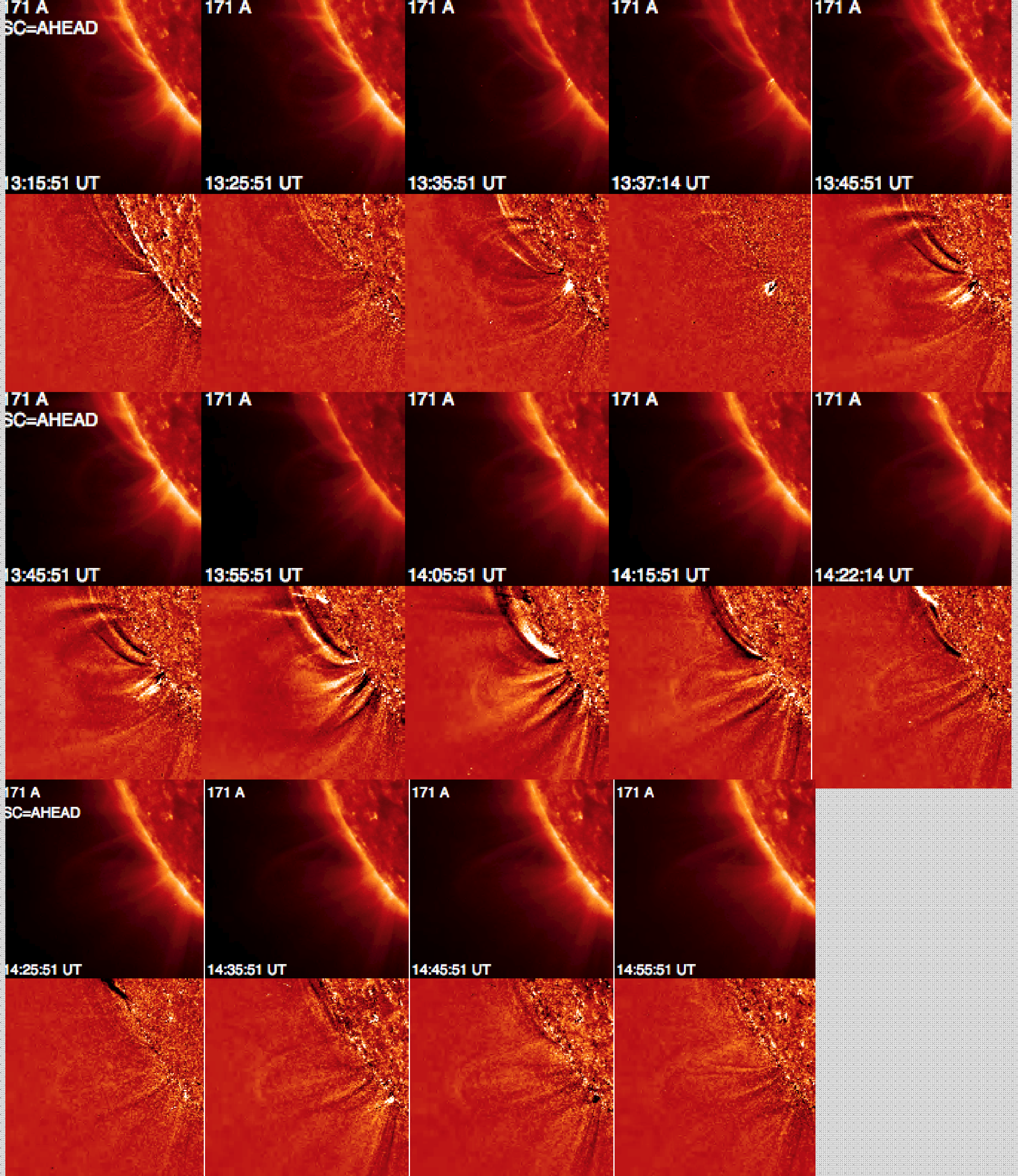
Postflare loops appear about ~1 hr after soft X-rays, once they cool down to T~1 MK.

CME/occulted flare : 2007-Jan-24 14:00 UT





Flare location behind the limb (>10 deg)
GOES soft X-ray flux starts to rise at 13:45 UT (occulted)
EUVI shows a prominence at 14:22 UT (1 frame, 5 min cadence)
LASCO observes CME front at 3 solar radii at 14:54 UT
--> propagation speed v ~ 500 km/s

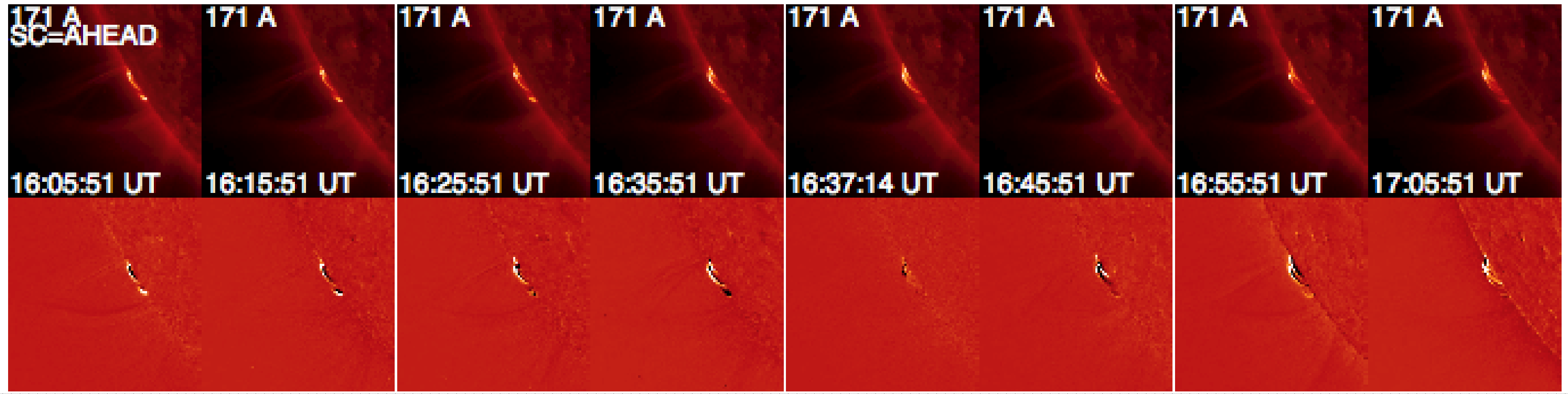


Flare start ~ 13:35 UT

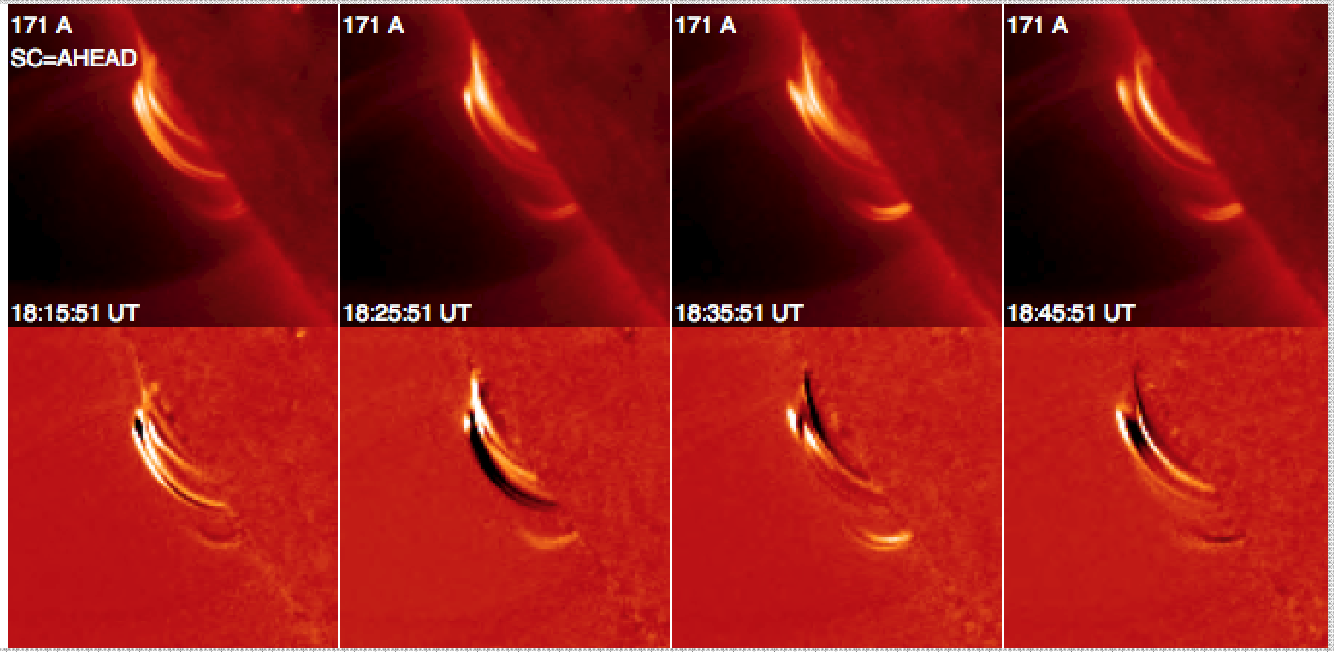
AR loops are shaken by filament eruption and first brightening above limb, while flare location is occulted, GOES light curve starts to increase at 13:50 UT

Flare peak ~ 14:05 UT

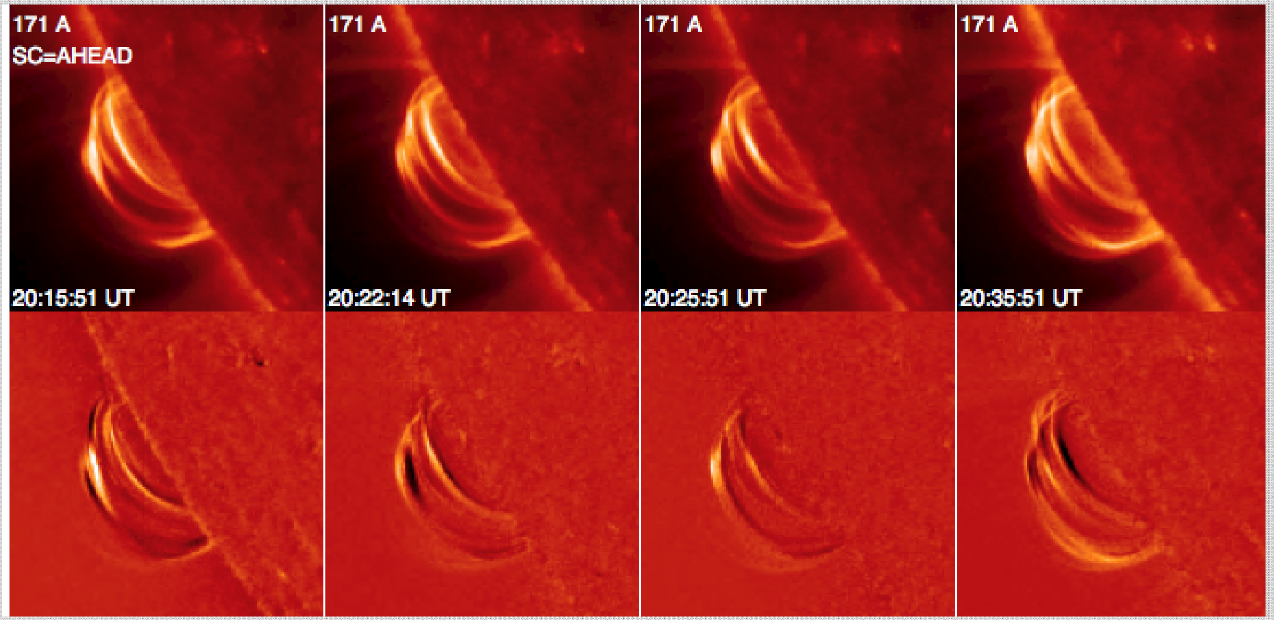
AR loops are shaken strongest (damped oscillations ?),
but all postflare loops are still occulted,
GOES light curve shows steepest increase (HXR max) at 14:10 UT



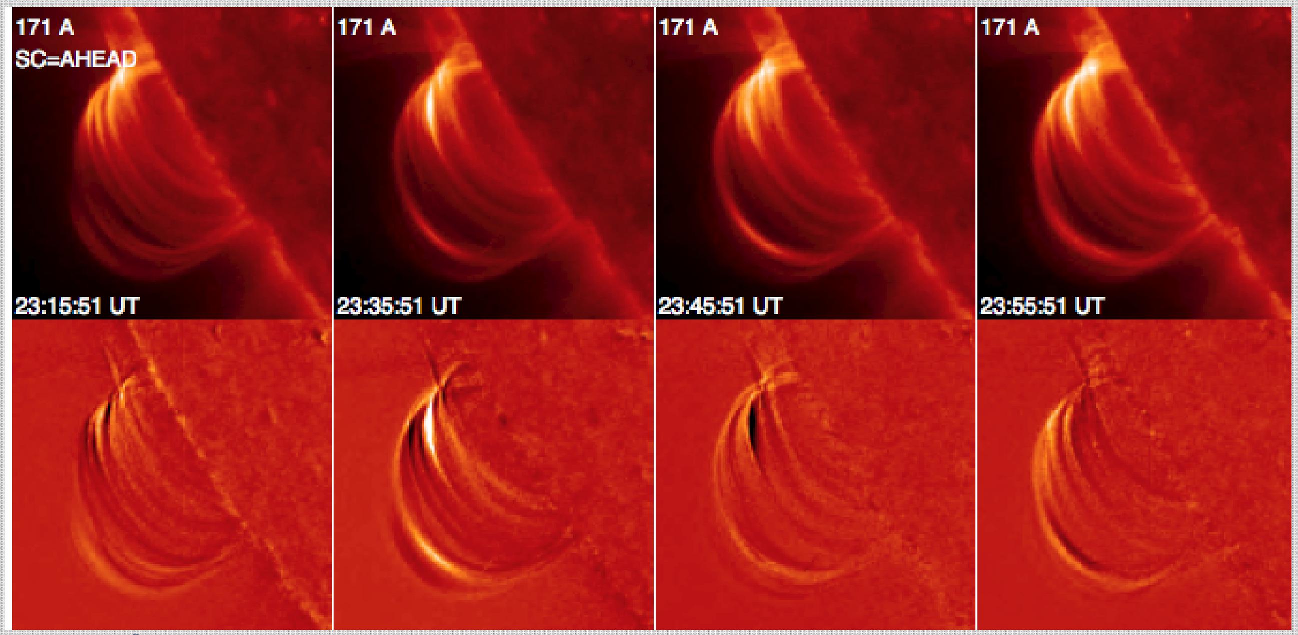
+2 hrs later: Postflare loop expands behind limb and the top of the arcade becomes visible



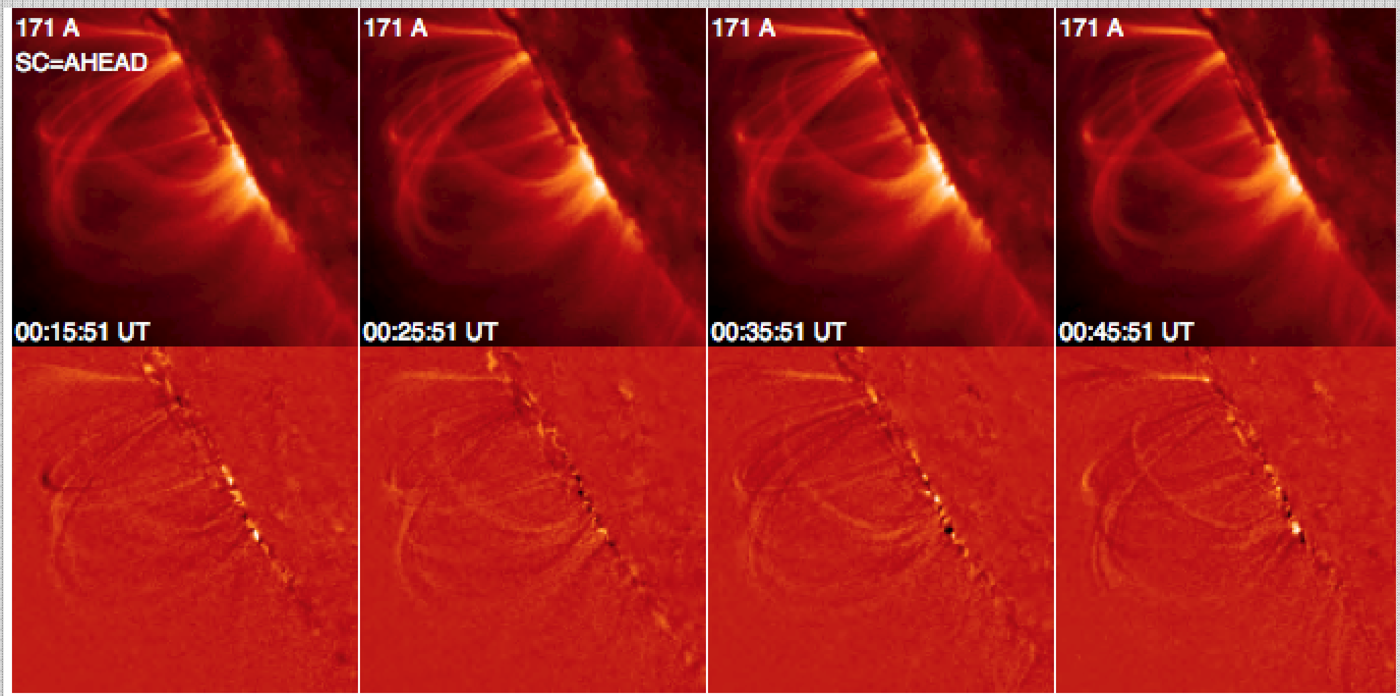
+4 hrs later: Postflare loop system expands higher and EM of postflare loops still increases



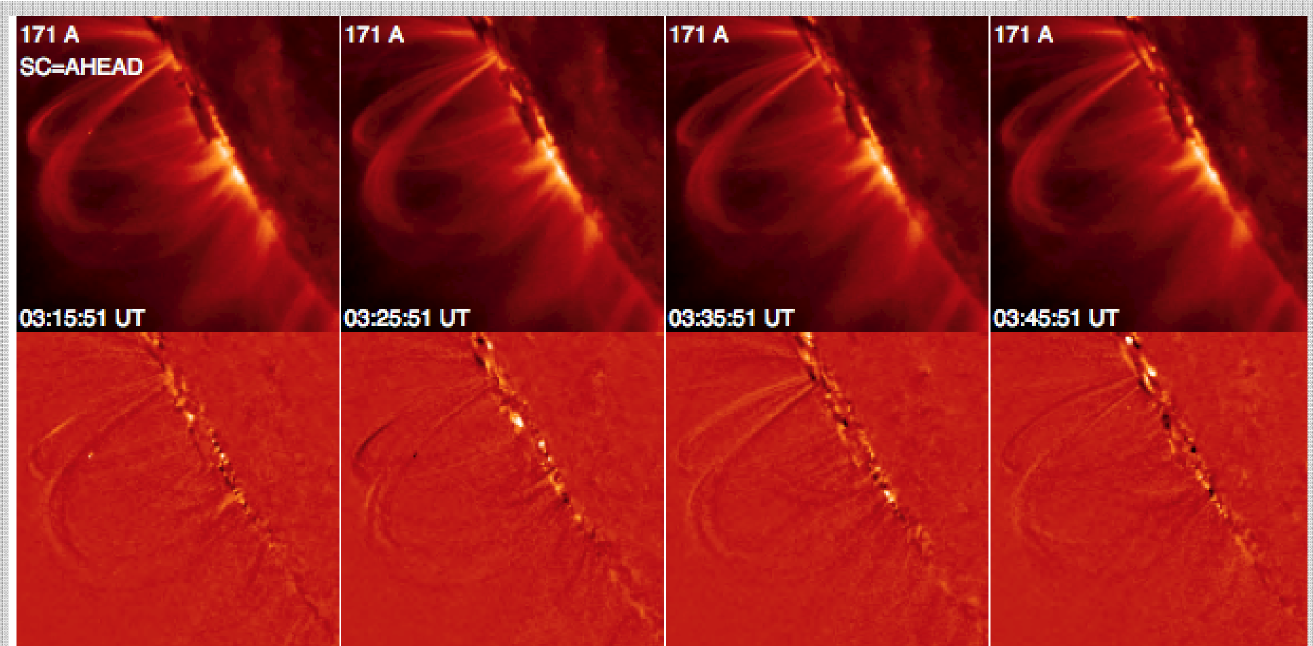
+ 6 hrs: Post flare loops expand higher



+ 9 hrs:

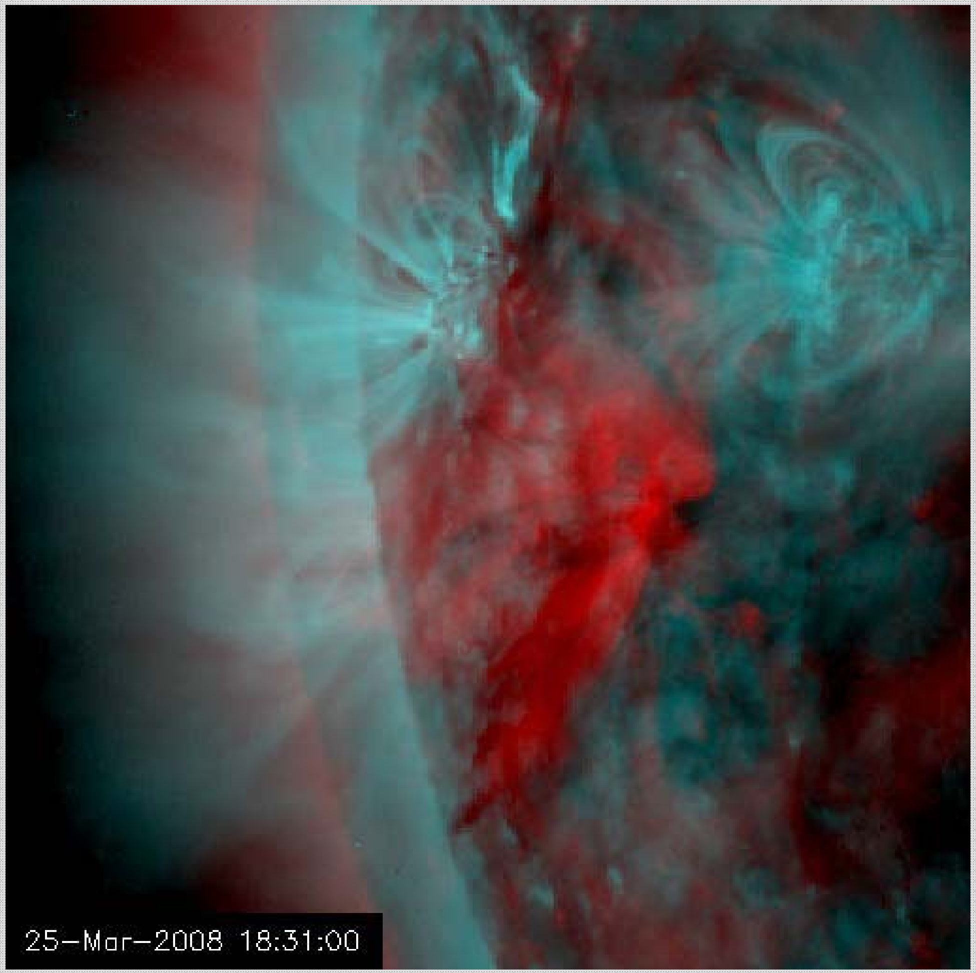


+ 34 hrs:

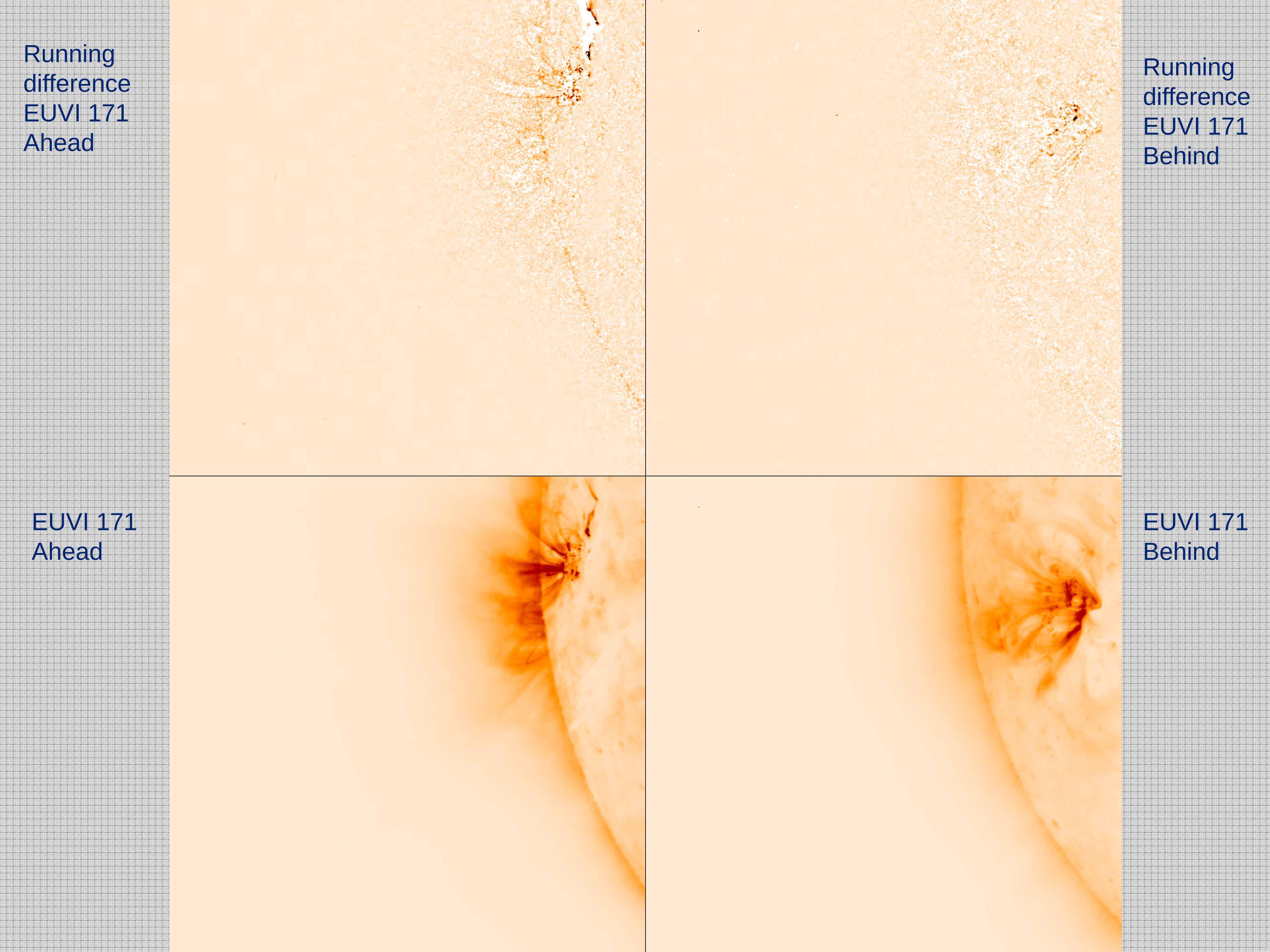


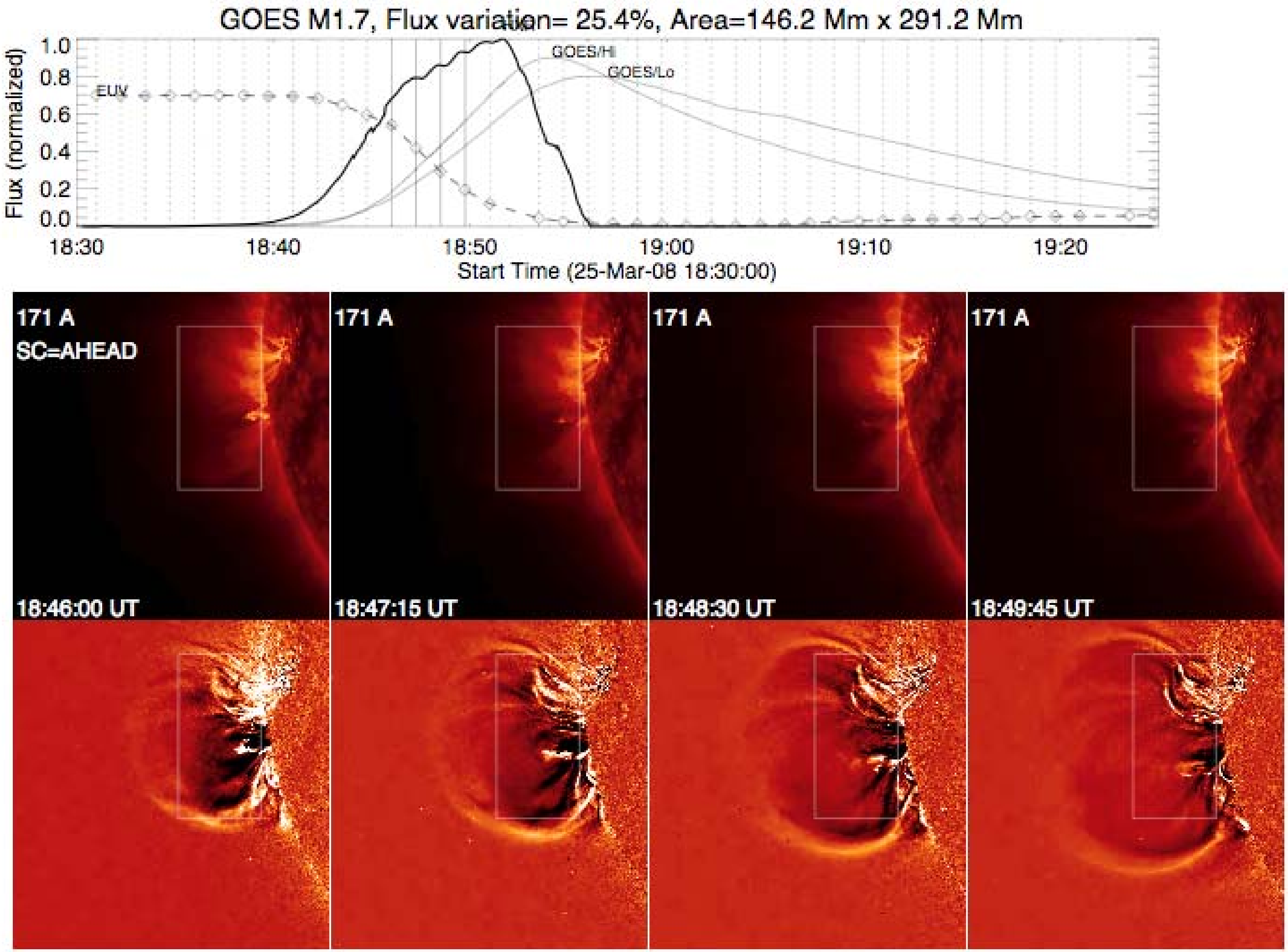
+38 hrs: loop densities decrease, longer cooling times

Flare/CME with EUV Dimming: 2008 Mar 25

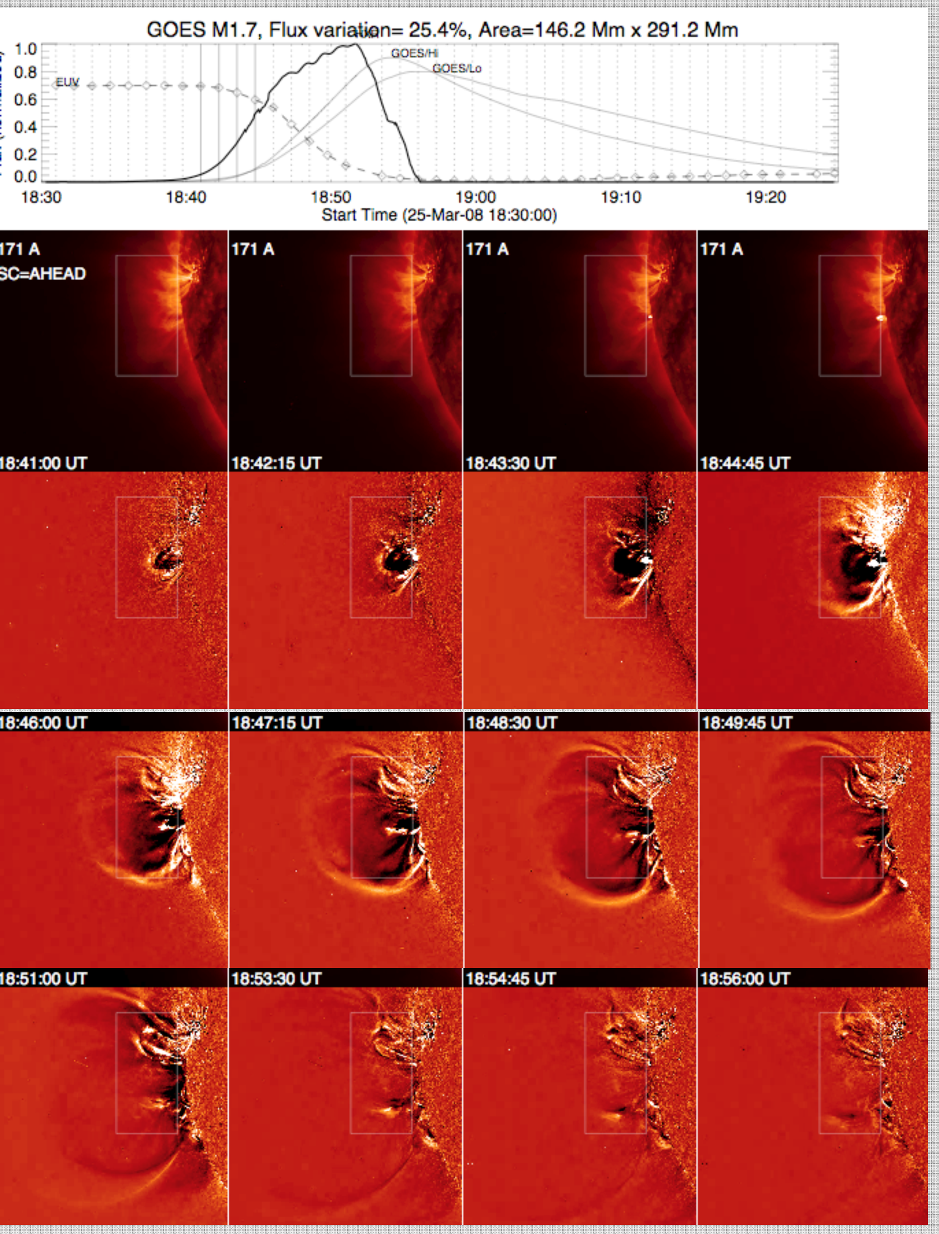


Corona above (occulted) flare and CME shows strong EUV dimming with adjacent loops oscillating (EUVI cadence = 75 s) and EIT waves.


Running difference EUVI 171 Ahead
Running difference EUVI 171 Behind
EUVI 171 Ahead
EUVI 171 Behind

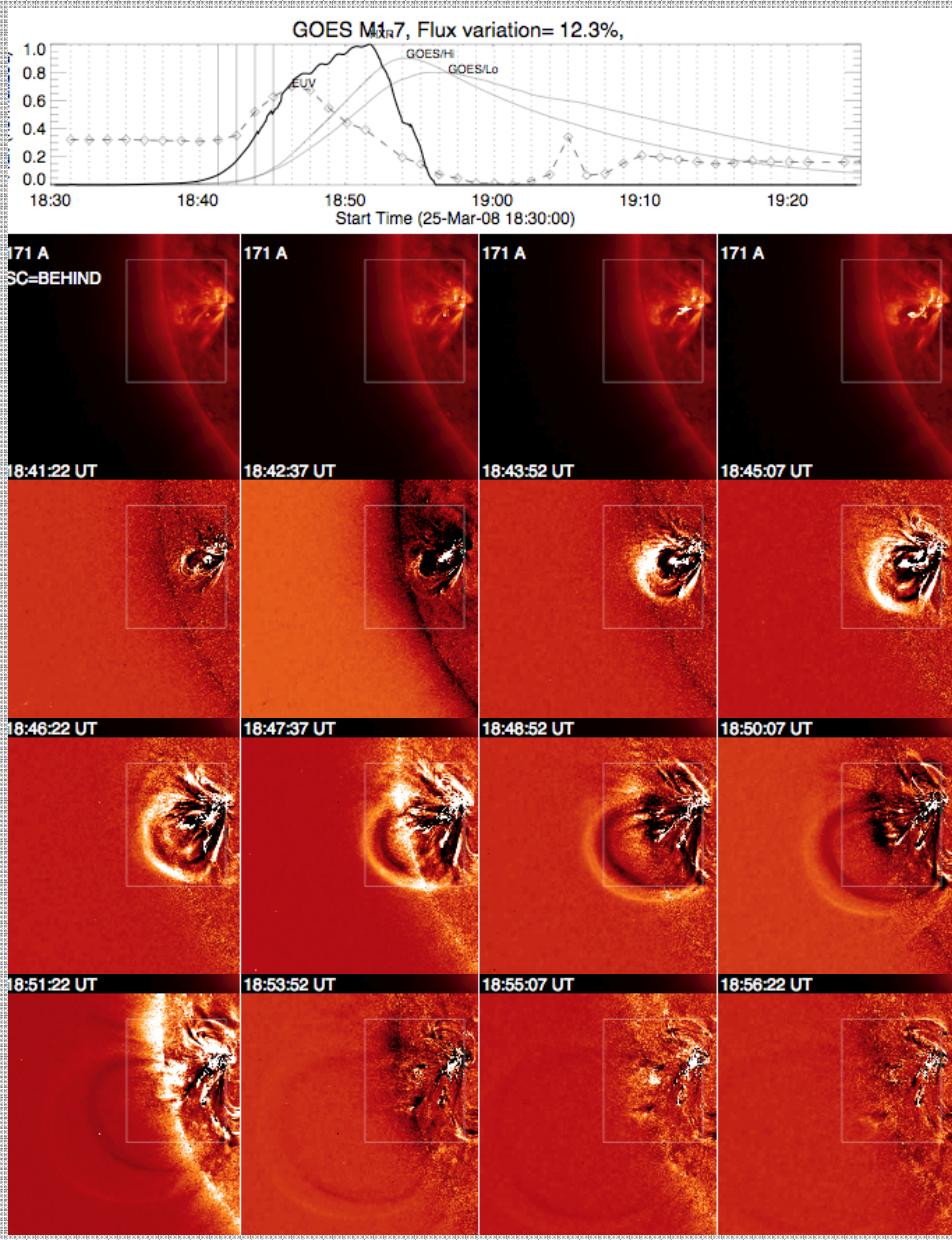


EUV dimming above limb by ~25% (averaged over AR),
e-folding dimming time constant ~ 8 min.



EUVI 171, Ahead : Dimming 25%

R_{sun} = 1.008 AU, Angle to Earth=23.4^0



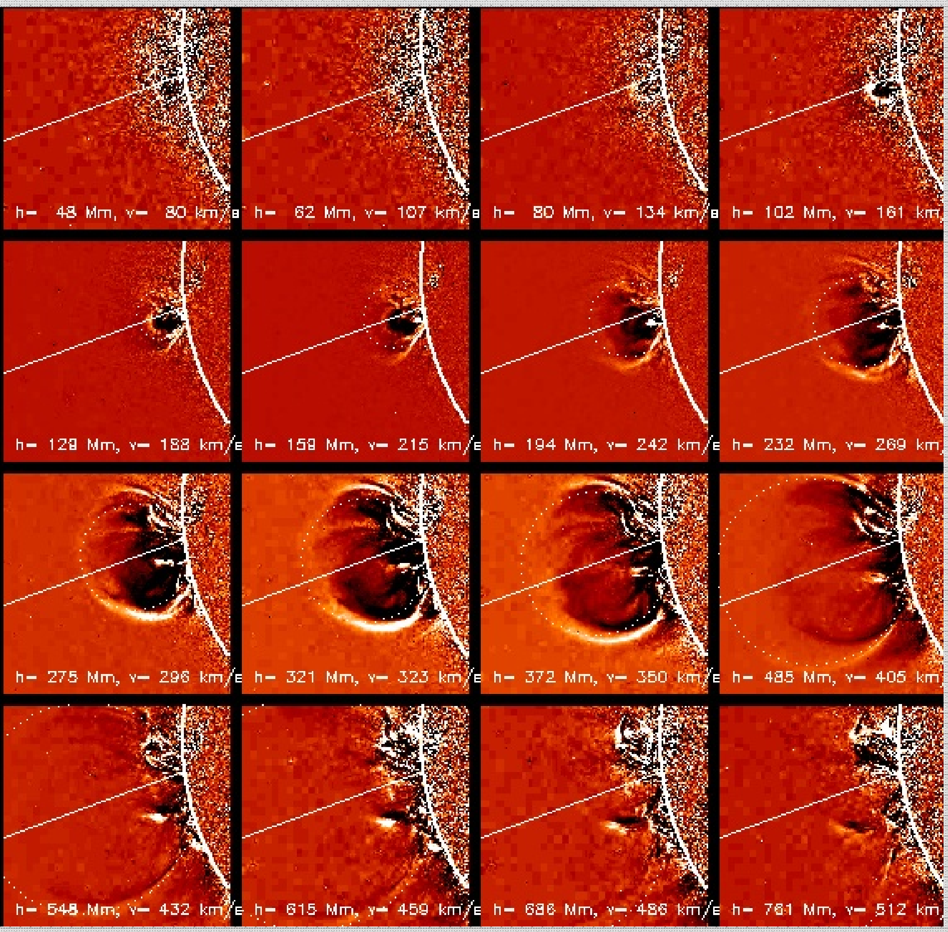
EUVI 171, Behind : Dimming 12%

R_{sun} = 0.963 AU, Angle to Earth=23.7^0

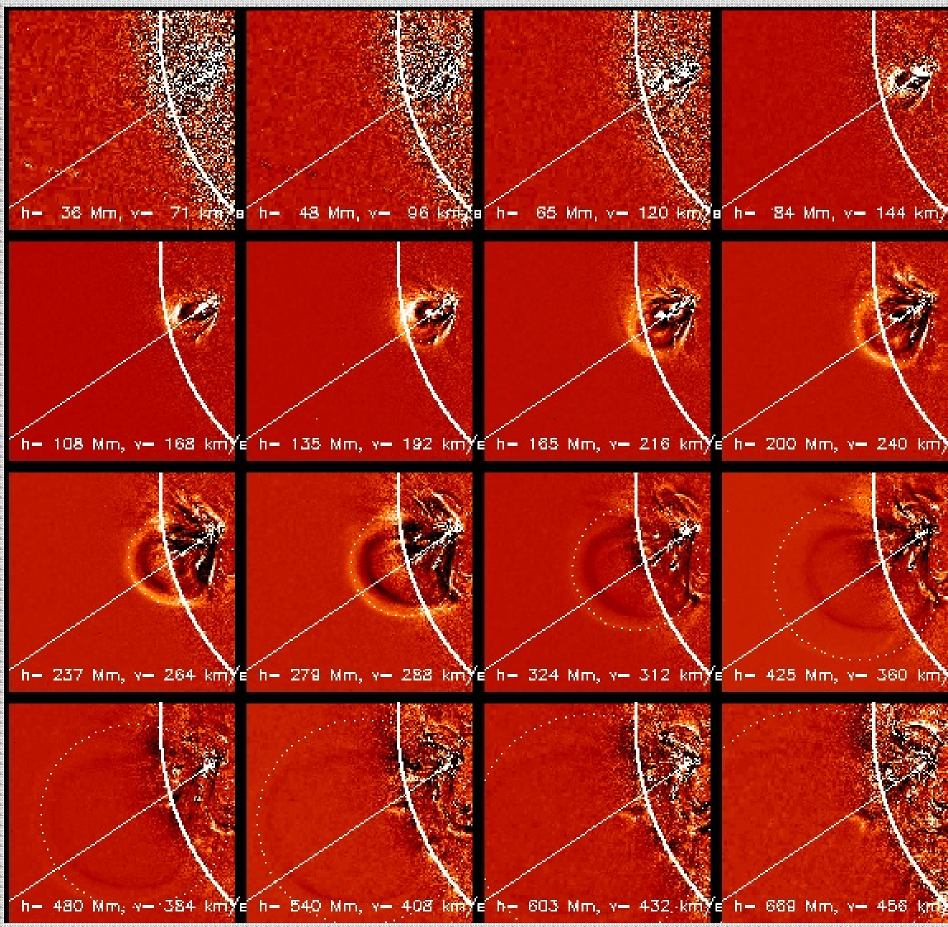
Cadence = 75 s, Spacecraft separtion=47.1^0

CME expansion : spherical bubble geometry

Constant acceleration: $h(t)=h_0+v_0*(t-t_0)+a*(t-t_0)^2$, h_0=30,000 km, a=0.36 km/s^2,



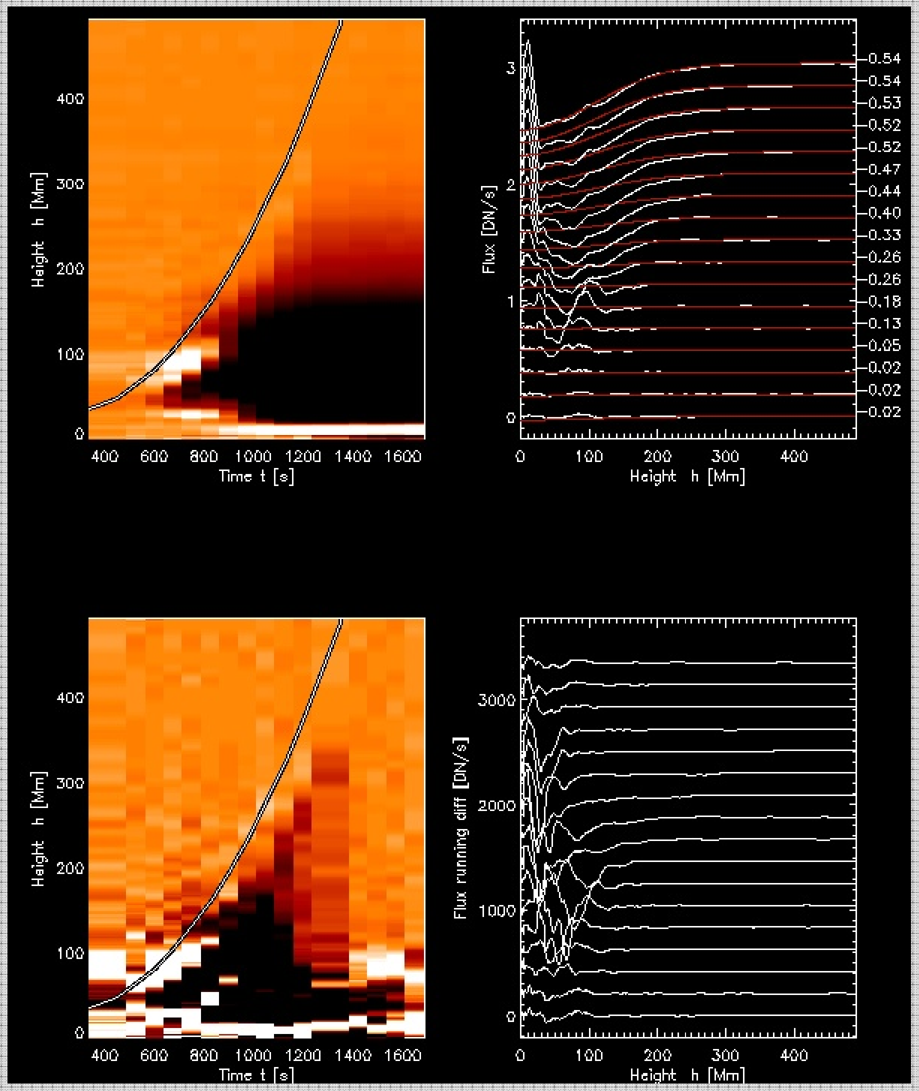
EUVI 171, Ahead
CME above limb



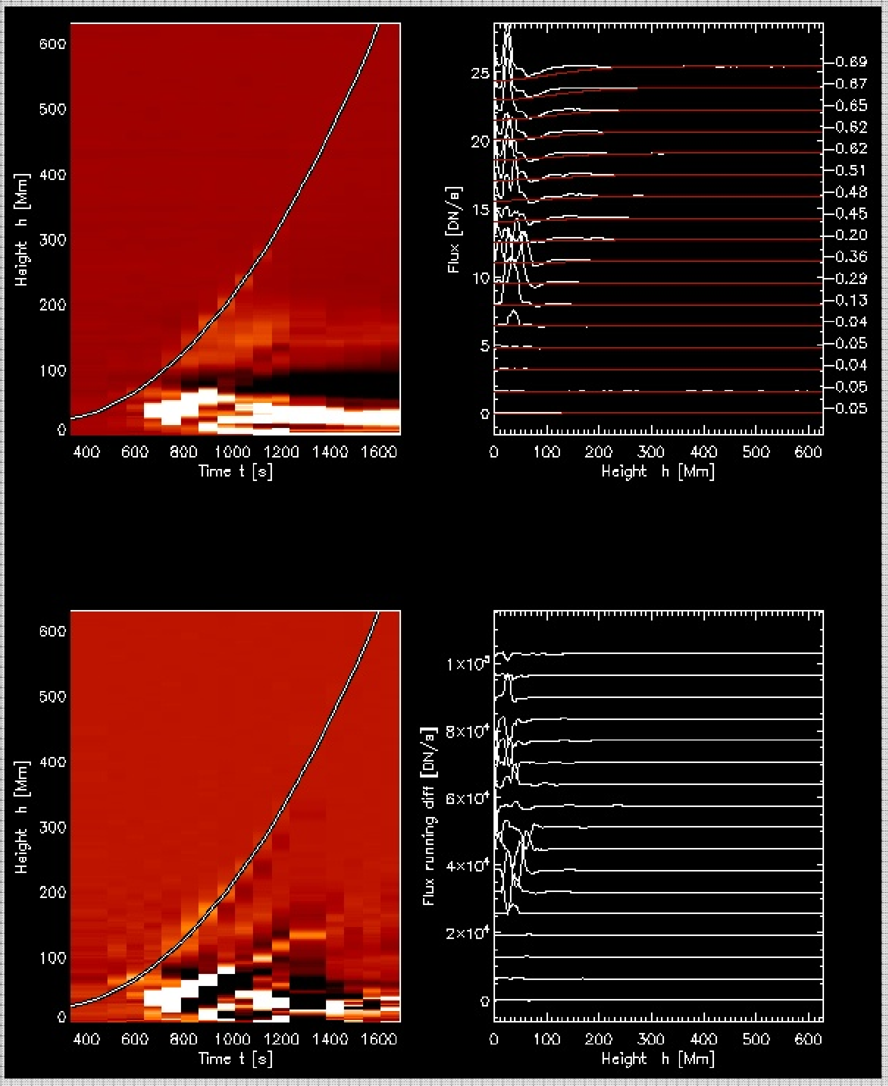
EUVI 171, Behind
CME initially on disk

EUV Dimming vs. altitude

EUVI 171: Ahead (-54% at dimmest location, limb)



EUVI 171: Behind (-69% at dimmest location. disk)



Theoretical models of CME expansion and CME dimming

Model assumptions:

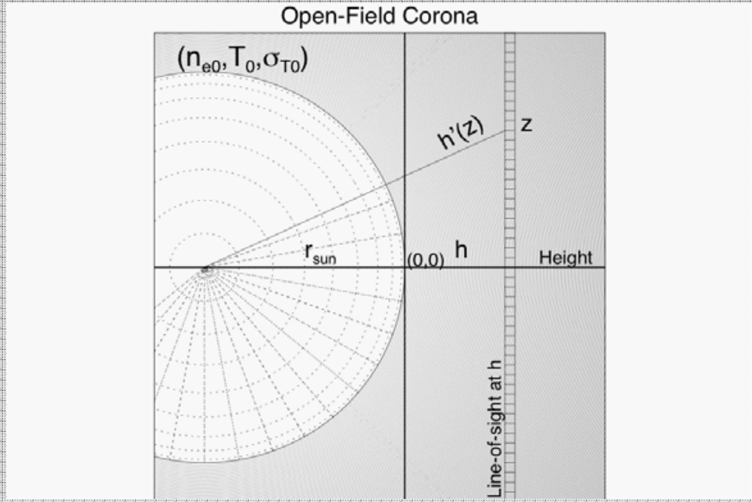
- Coronal dimming (SXR, EUV) is caused by coronal mass ejection
- Adiabatic expansion of CME "bubble"

- Vertical Acceleration during initial motion of CME "bubble"
  (by Lorentz force that drives CME)

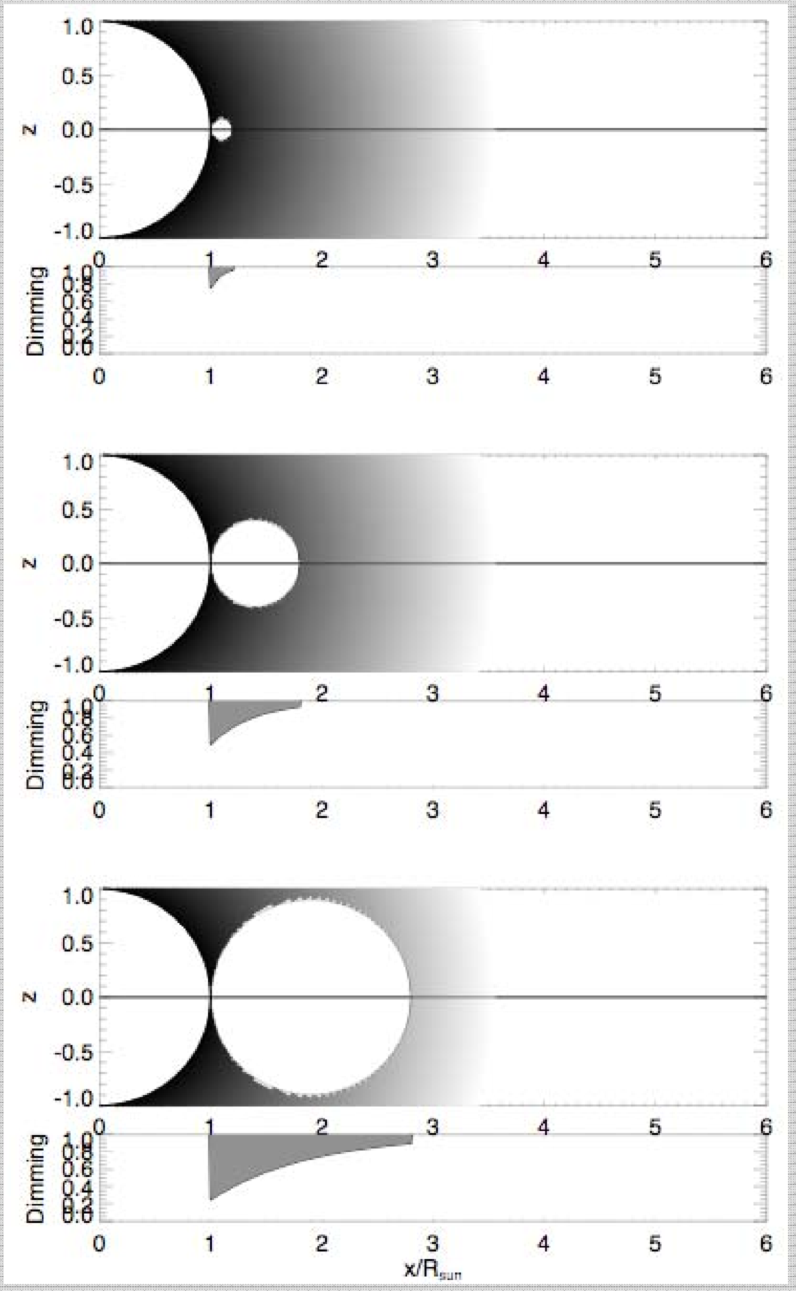
- Flux or Emission measure profile in EUV:

Line-of sight intergration:

a) CME above limb:



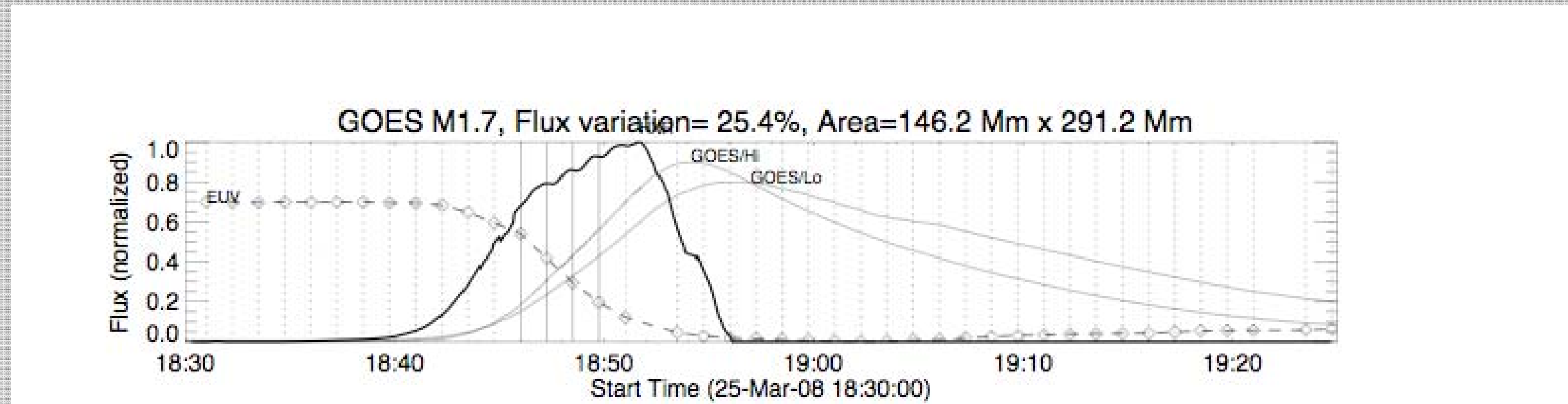
b) CME at disk center:

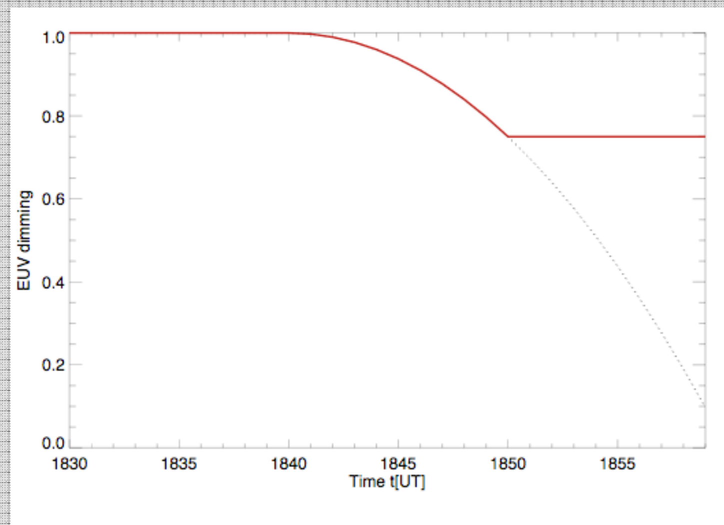


CME emission measure:
(becomes quickly negligible for adiabatic expansion)

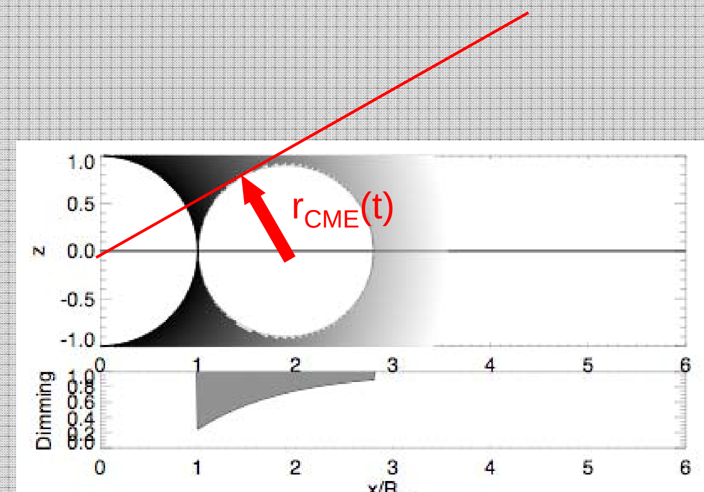
EUV emission measure foreground+background dominates and its column depth decreases proportionally to the CME expansion speed (z_{eq}=equivalent column depth):

EUV dimming:



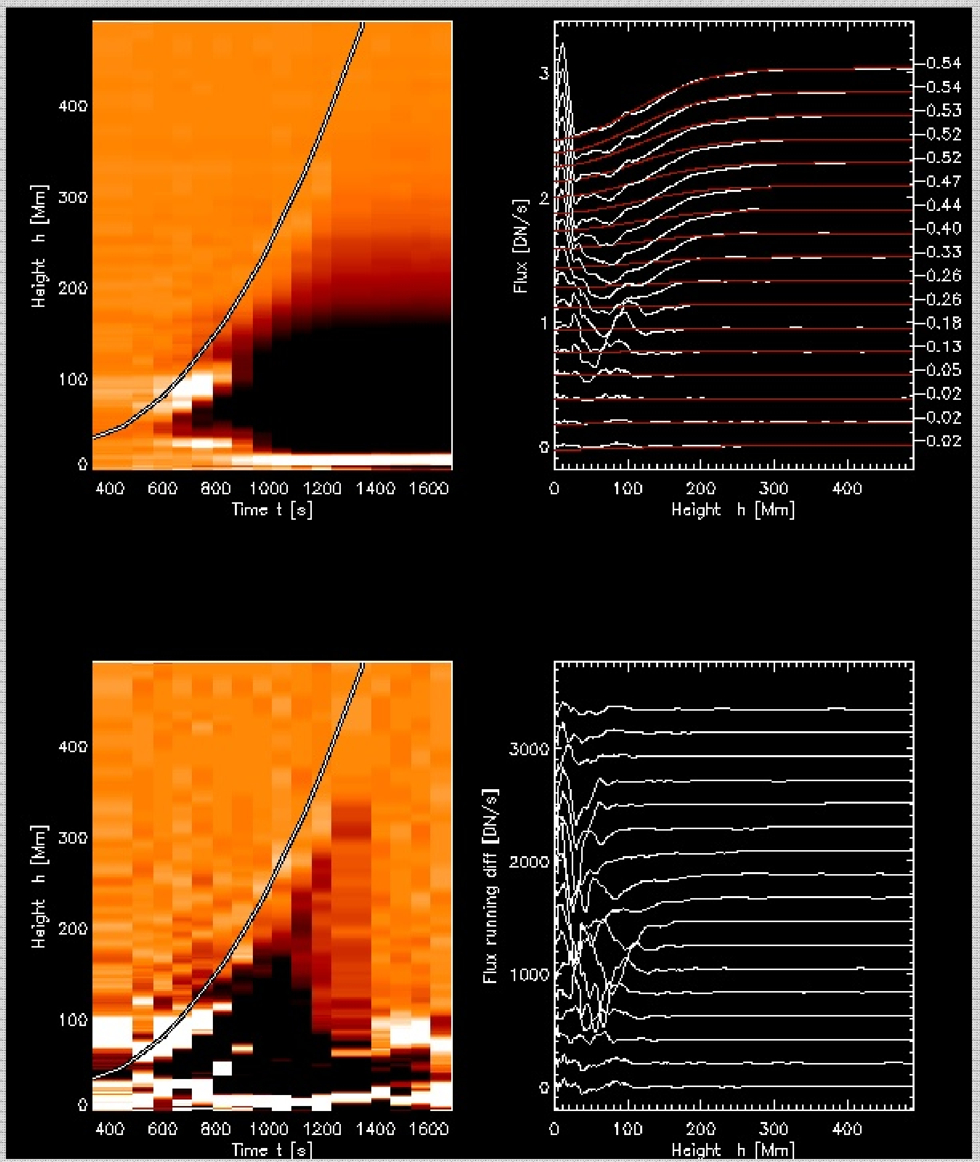


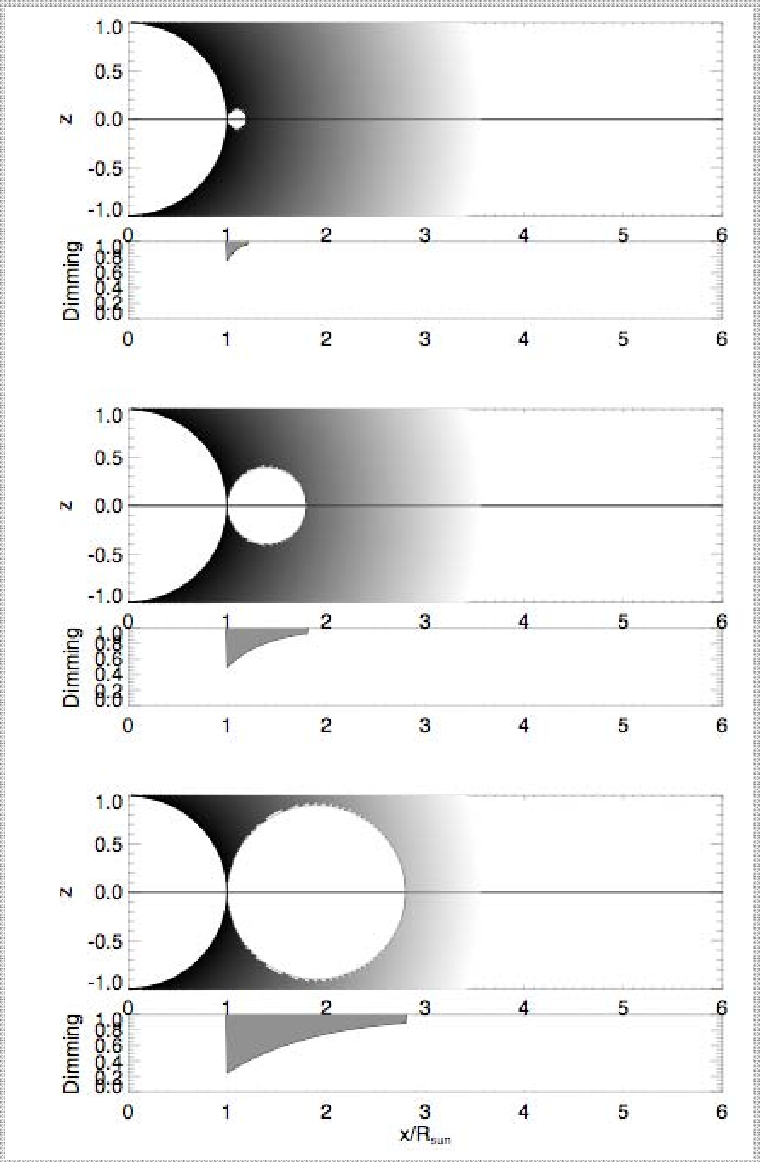
Maximum EUV dimming (-25.4 %) obtained after free expansion stops at the maximum CME opening angle.



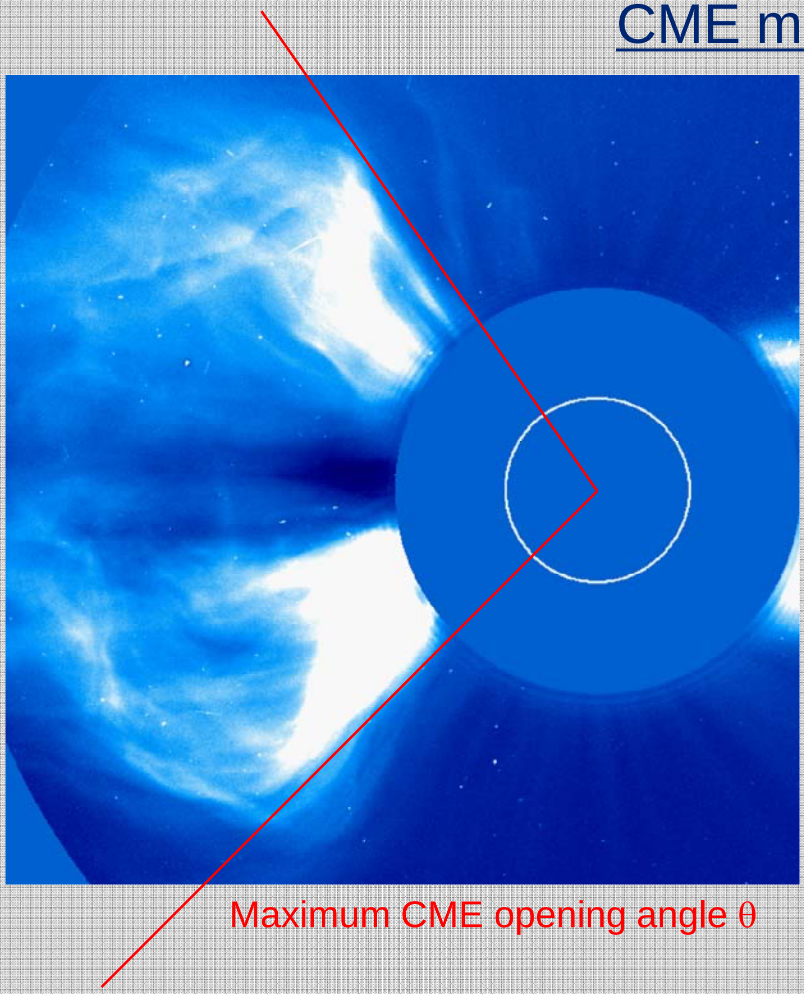
Free expansion with constant acceleration: $r_{CME}(t) \sim t^2$:

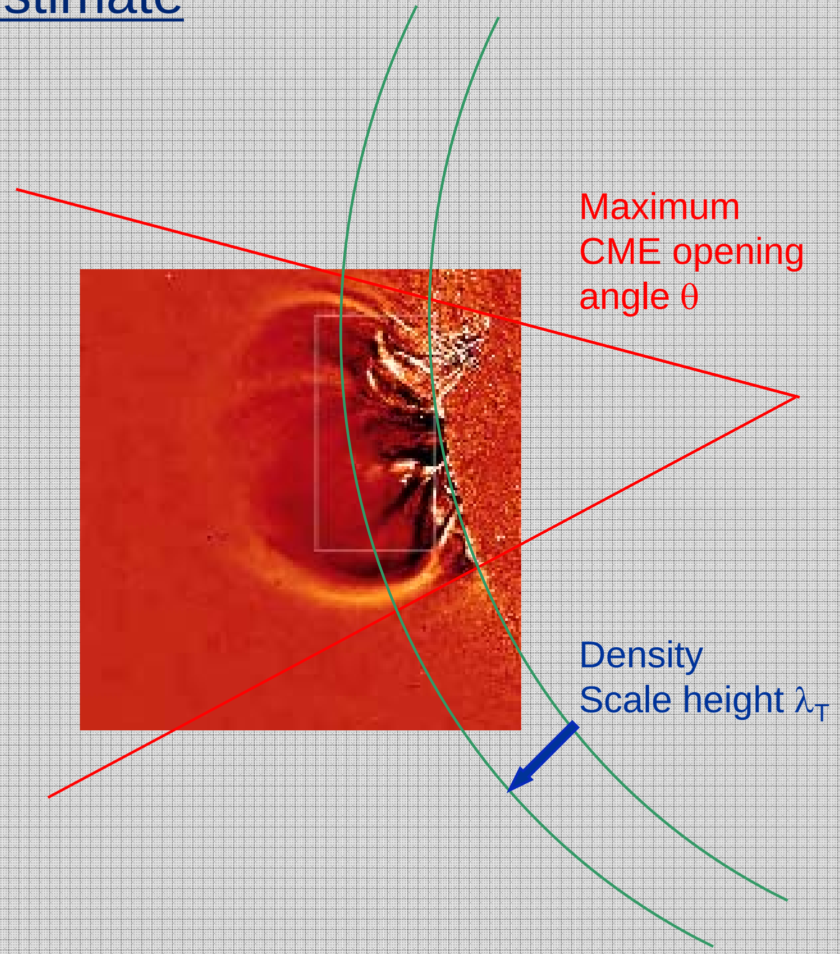
Height-dependent modeling of EUV dimming $EM(h,t)/EM(t,t_0)$:





CME mass estimate

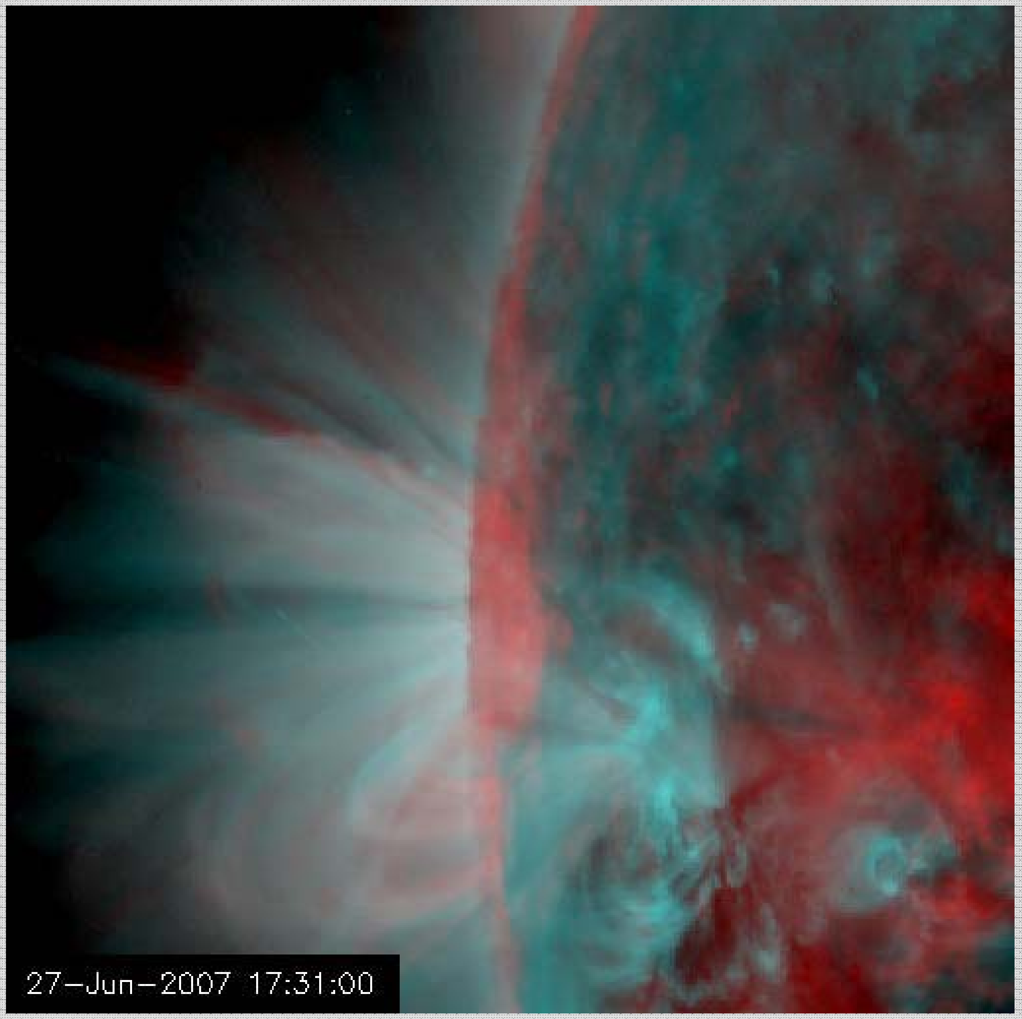




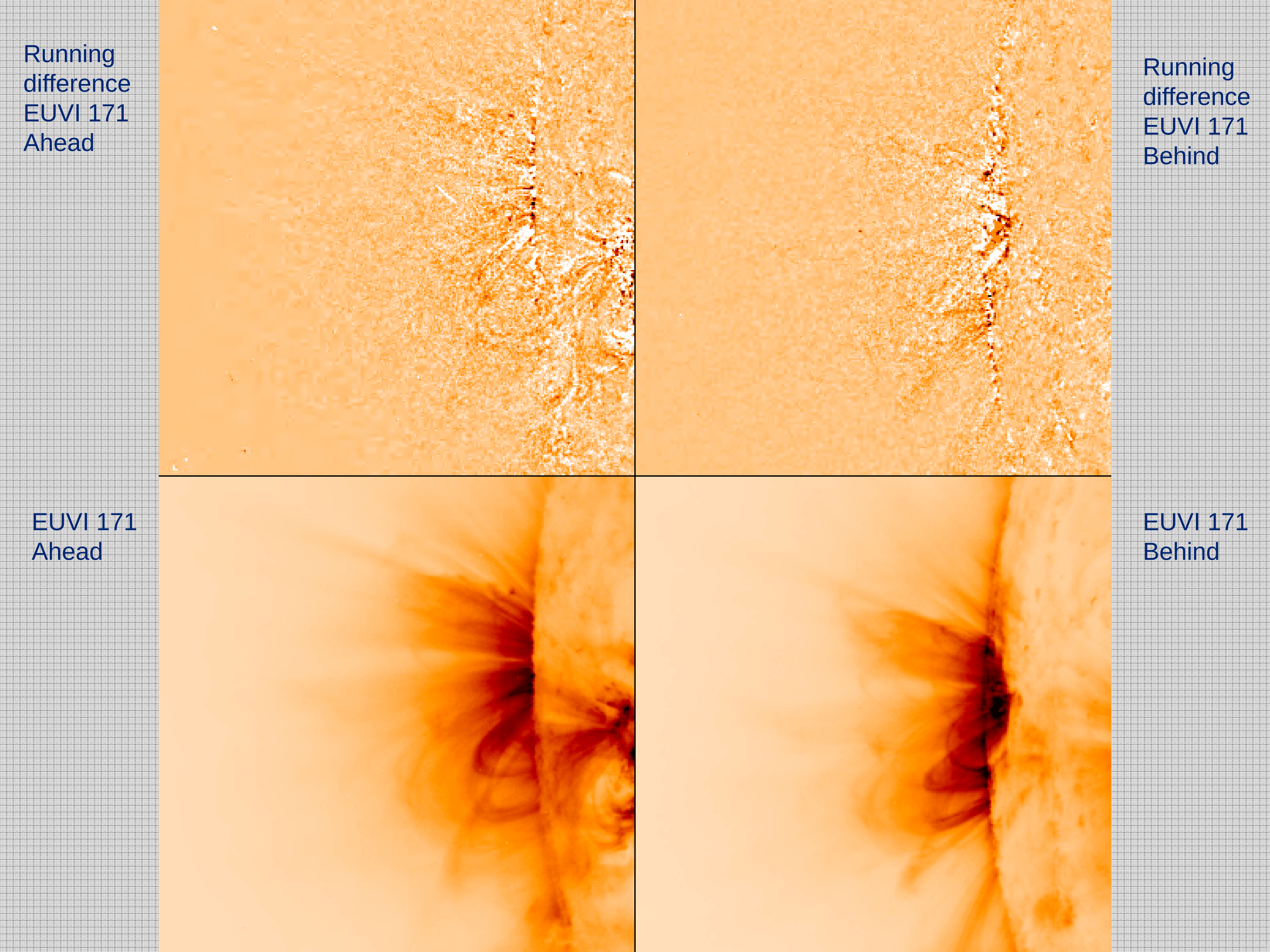
CME volume:

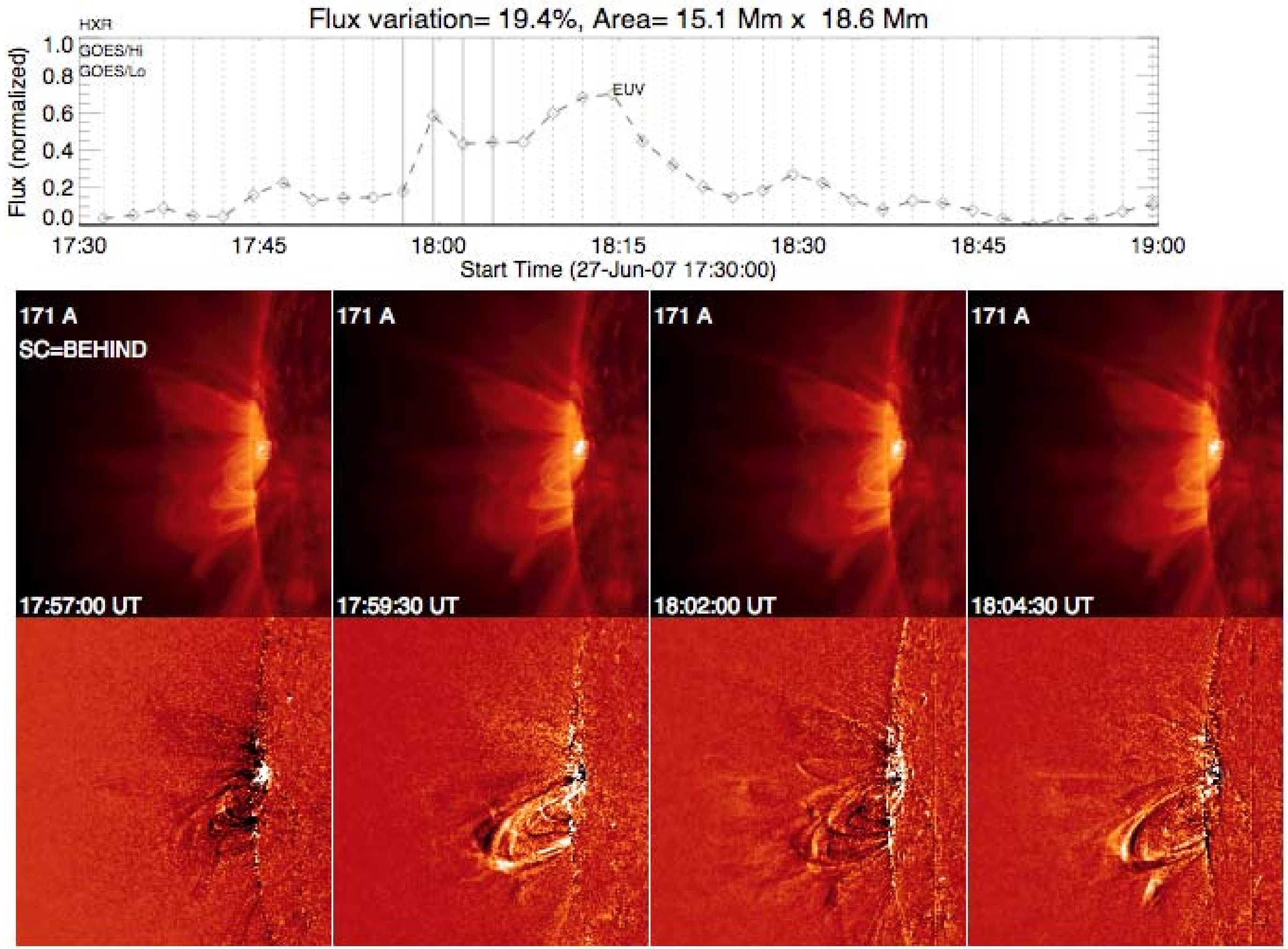
CME mass:

Flare with Loop Oscillations: 2007 Jun 27



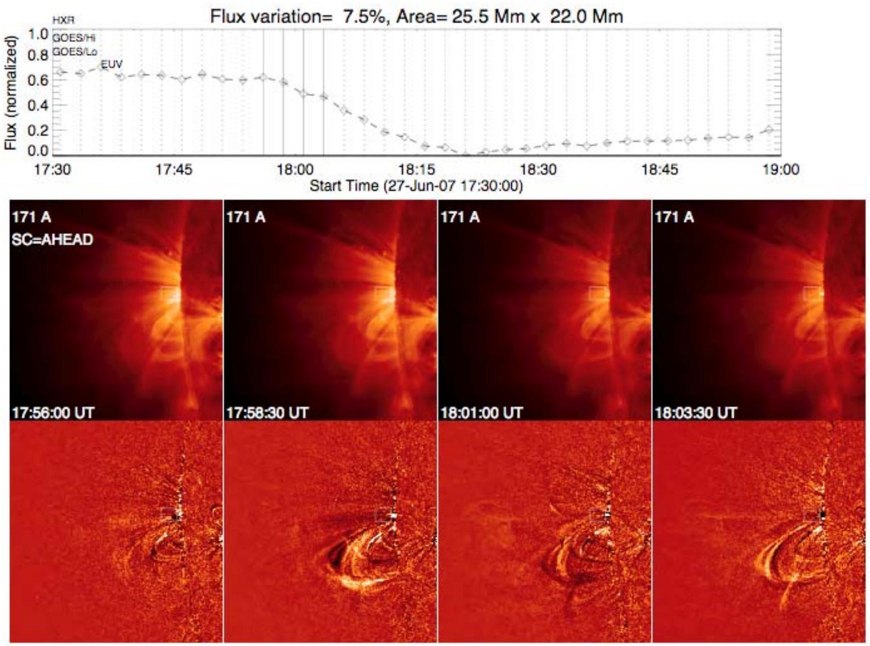
Corona above (occulted) flare and CME shows localized EUV dimming above flare and prominent loops oscillating (EUVI cadence = 150 s).

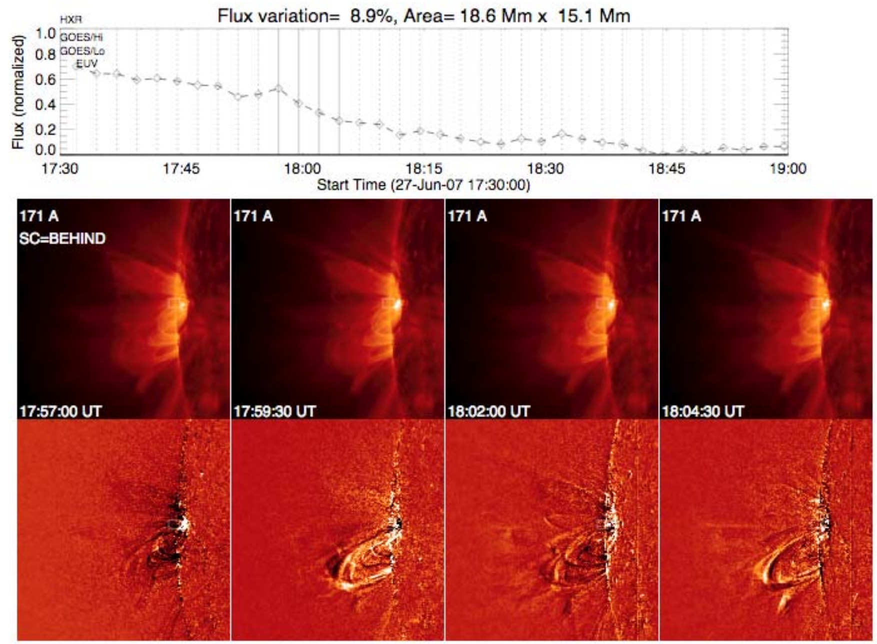

Running difference EUVI 171 Ahead
Running difference EUVI 171 Behind
EUVI 171 Ahead
EUVI 171 Behind



EUV brightening by ~19.4% at flare site,
e-folding cooling down to T=1 MK during ~ 5 min

Localized EUVI dimming above flare site

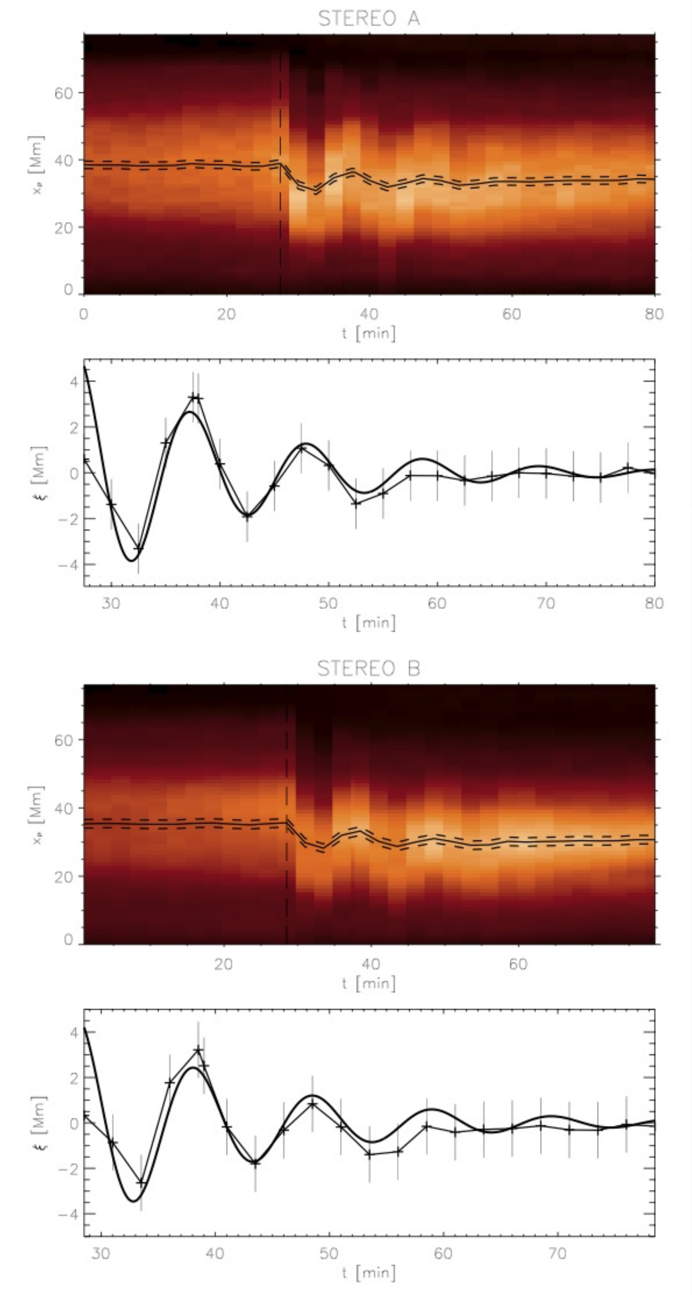


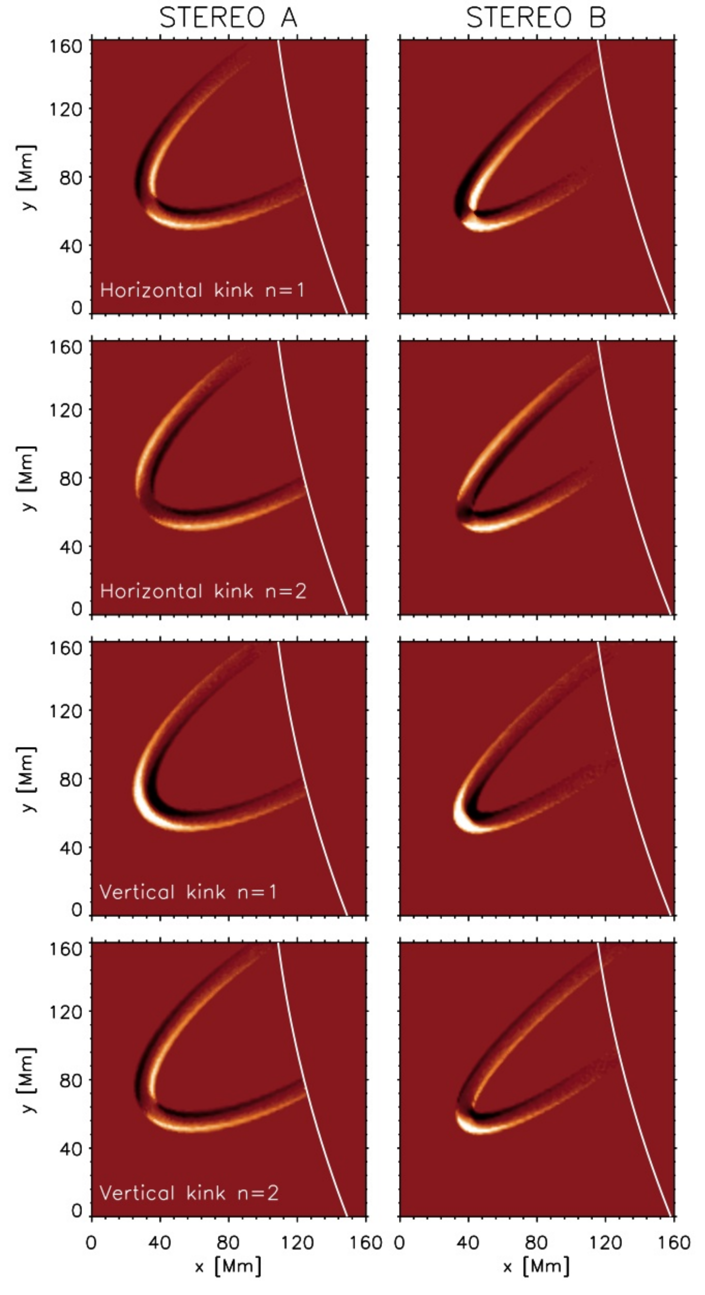


EUVI 171, Ahead : Dimming 7.5%
R_{sun} = 0.957 AU, Angle to Earth=9.4^0

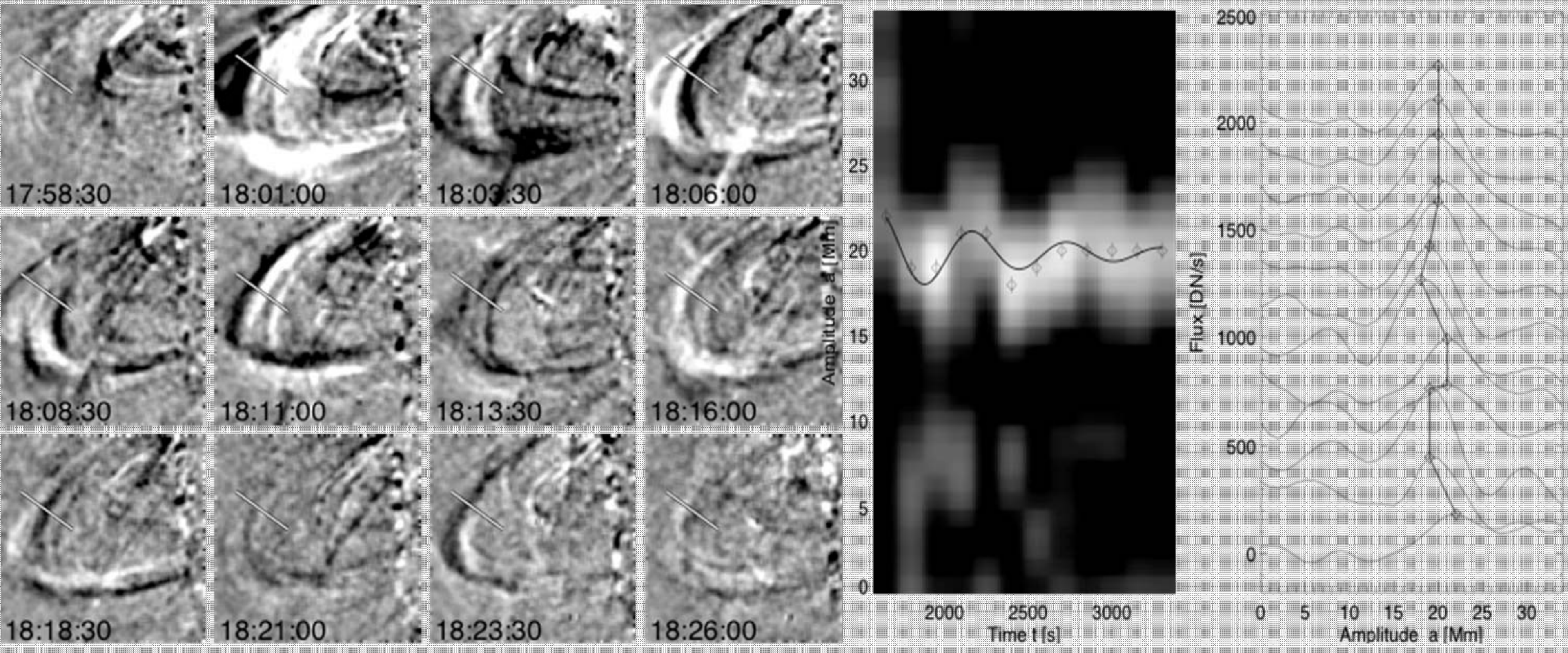
EUVI 171, Behind : Dimming 8.9%
R_{sun} = 1.078 AU, Angle to Earth=5.8^0

Cadence = 150 s, Spacecraft separtion=15.2^0

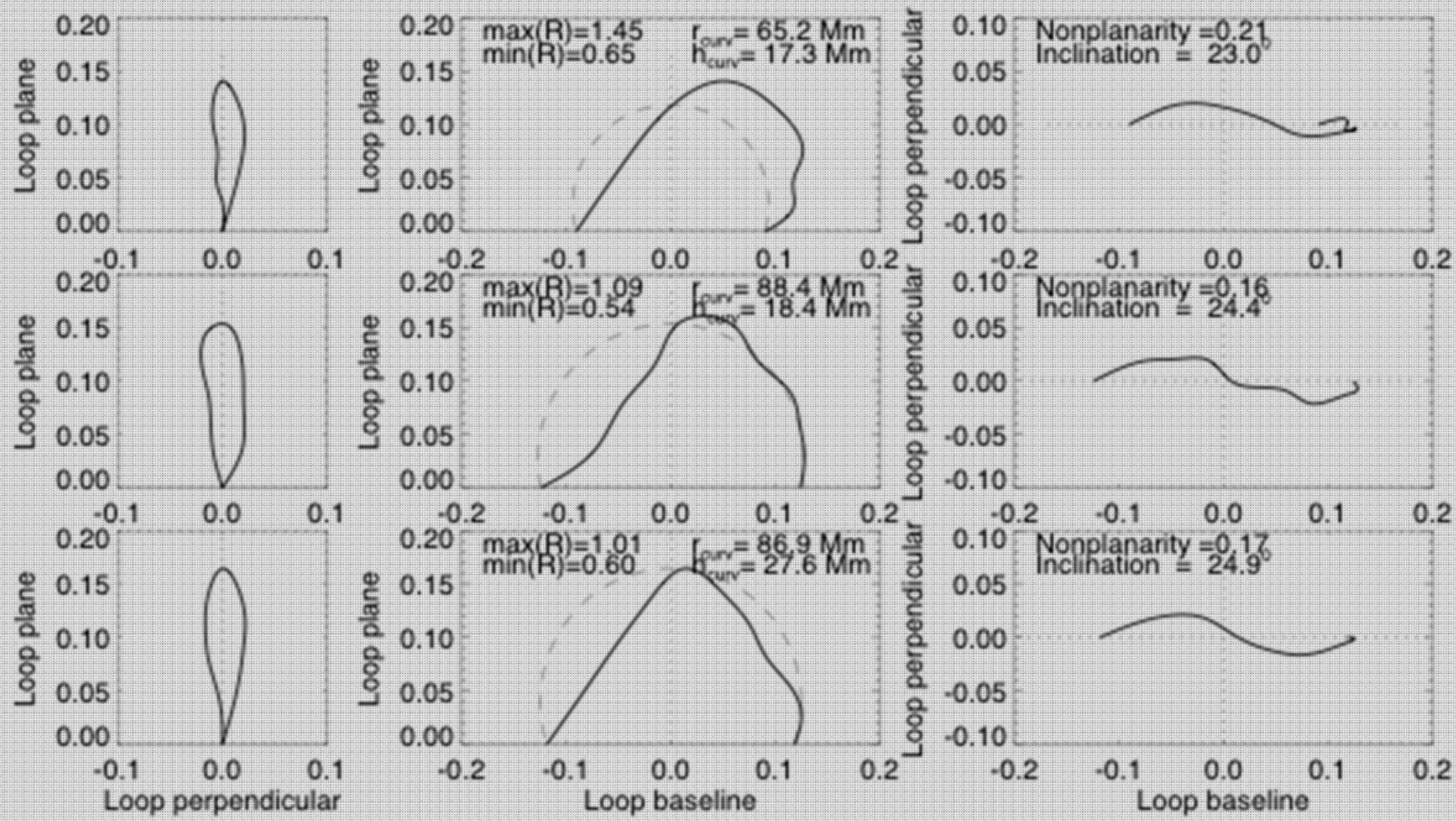




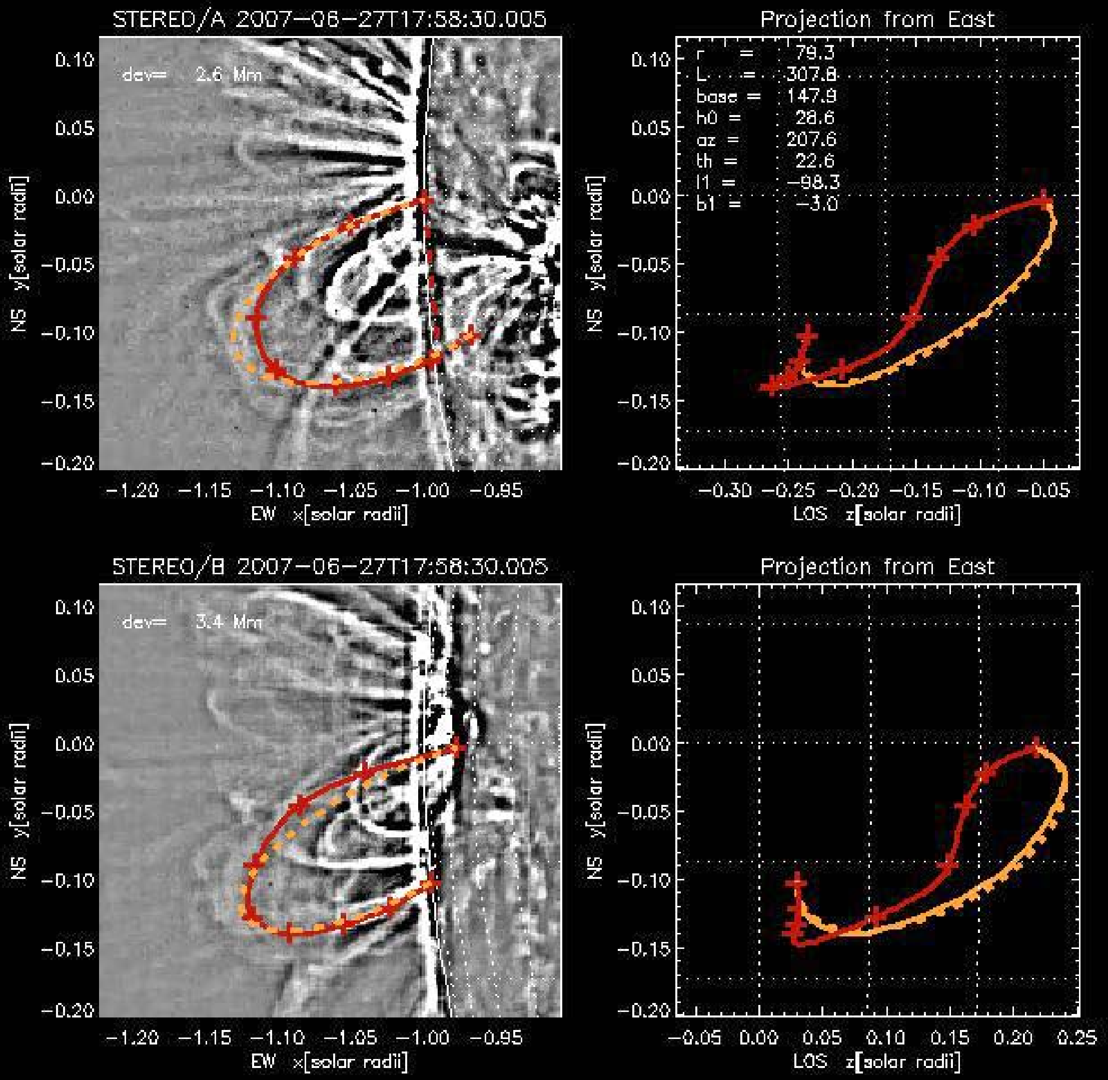
Loop oscillations: period P=645 s, damping time=930 s, horizontal polarization (Verwichte et al. 2008)



Time series analysis of oscillation amplitude reveals
fast kink-mode MHD mode with period of P~565 s (~9 min)
And exponential damping time of t_d~1600 s.



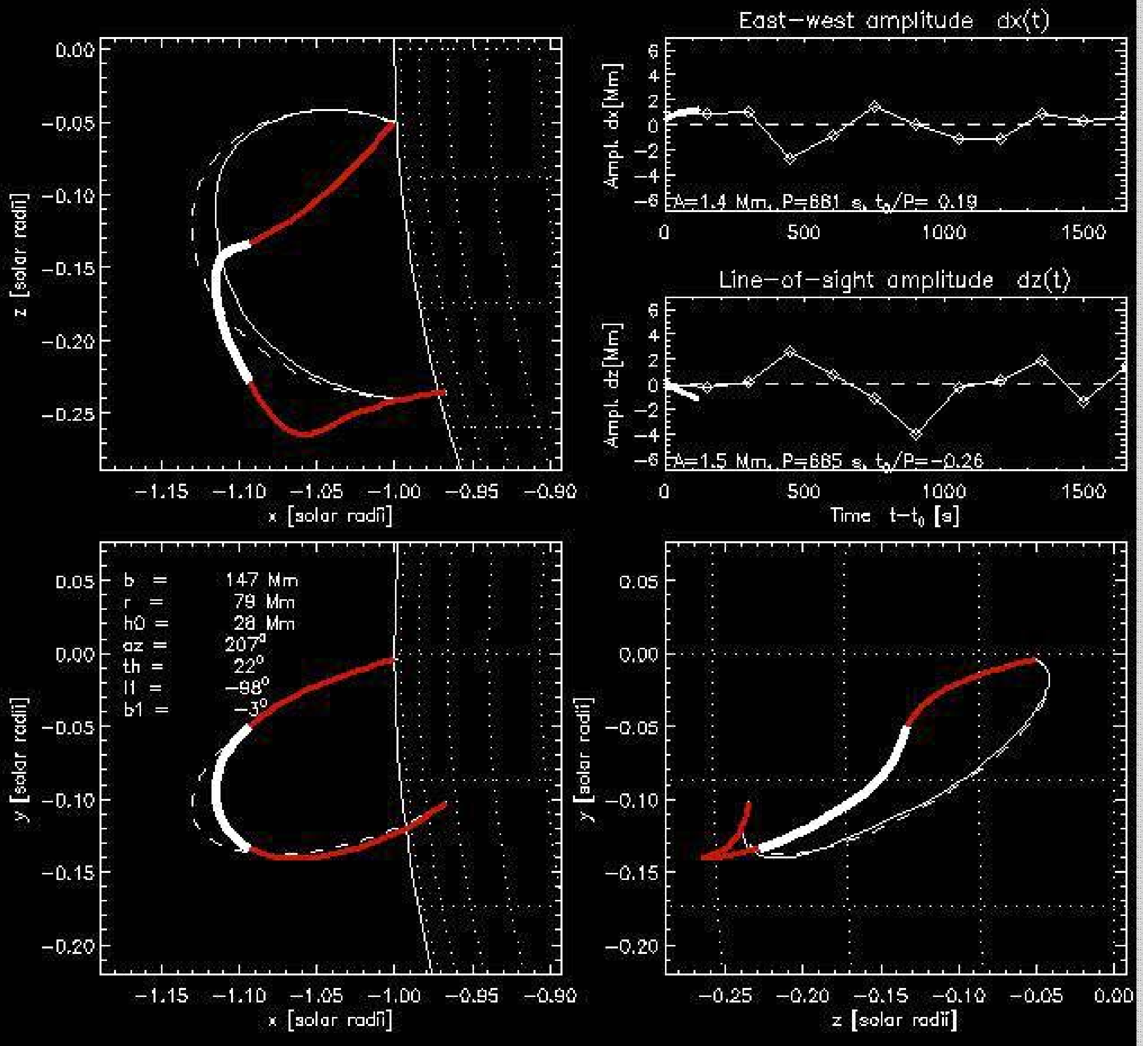
Stereoscopic triangulation reveals that the oscillating loop is non-circular, non-planar, but has a helical shape with ~0.75 turn of twist.



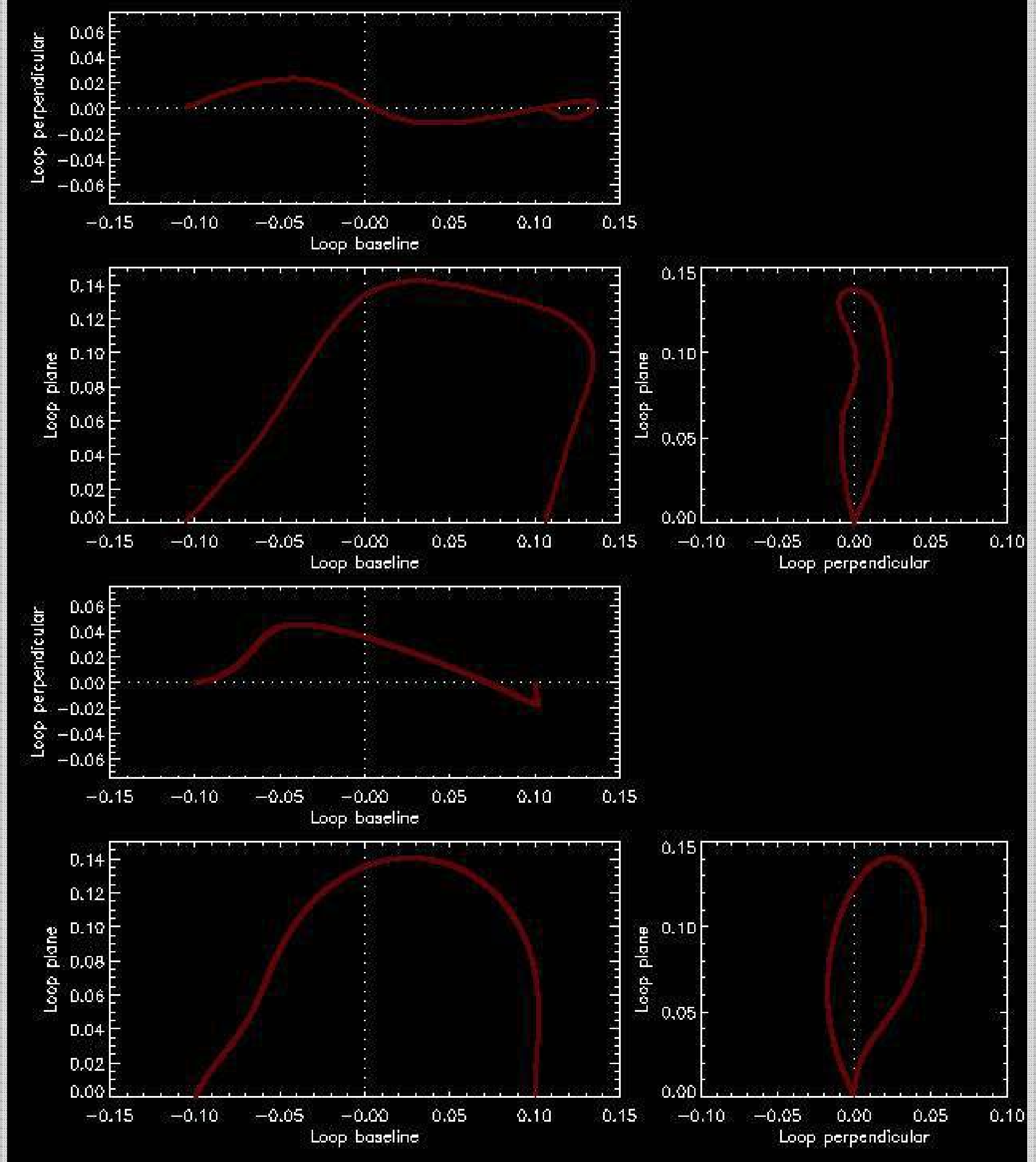
First reconstruction of 3D motion of oscillating loop:

[x(t),y(t),z(t)]

→Torsional oscillation (circularly-polarized kink-mode)



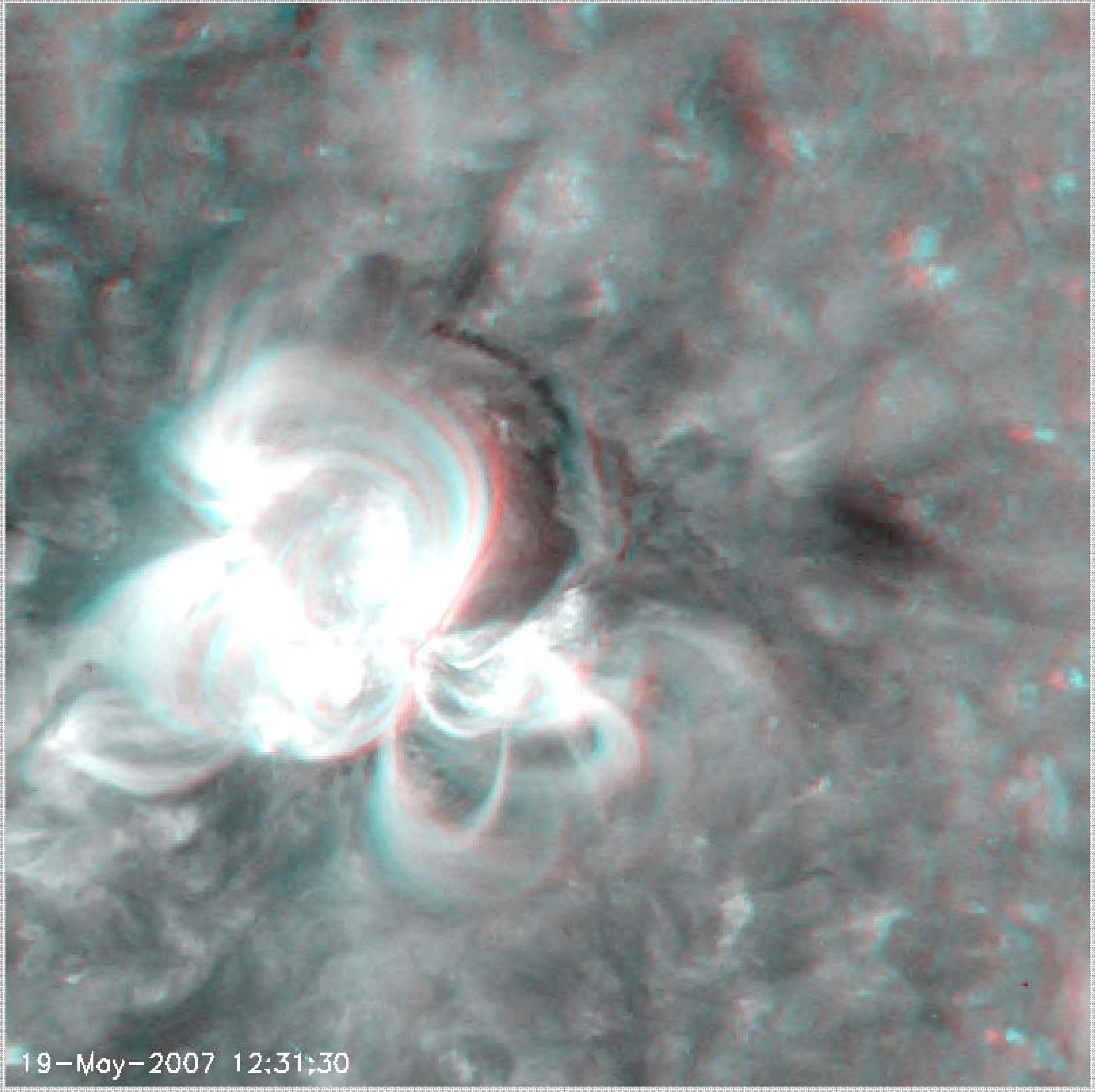
East-west amplitude dx(t)
Ampl. dx[Mm]
A=1.4 Mm, P=681 s, t0/P= 0.19
Line-of-sight amplitude dz(t)
Ampl. dz[Mm]
A=1.5 Mm, P=665 s, t0/P=-0.26
Time t-t0 [s]
z [solar radii]
x [solar radii]
y [solar radii]
b = 147 Mm
r = 79 Mm
h0 = 28 Mm
az = 207°
th = 22°
l1 = -98°
b1 = -3°



Orthogonal projection of stereoscopically triangulated 3D motion

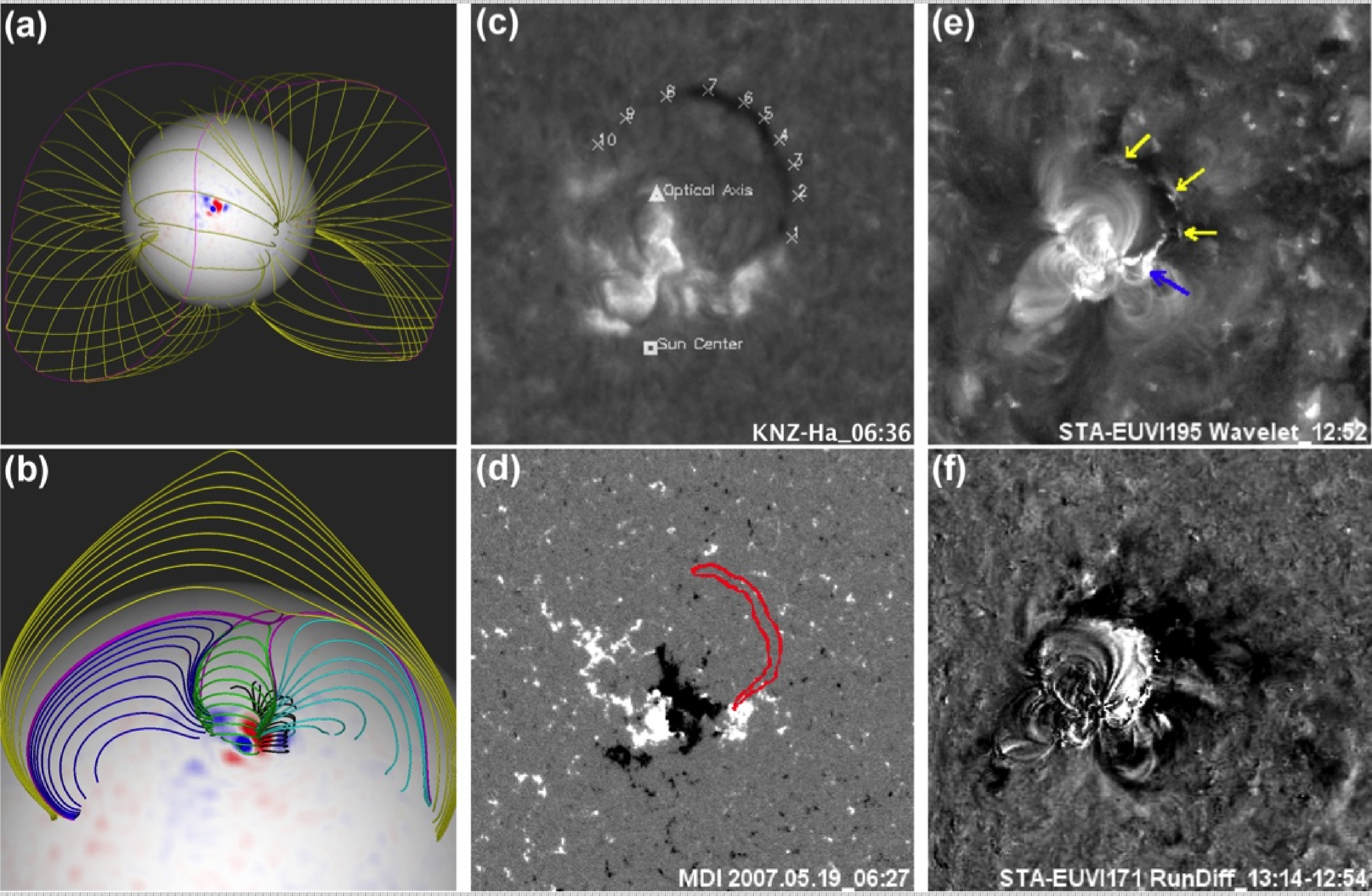
Simulation of torsional oscillation of helical loop with 0.75 turns of twist

Flare/CME with Eruptive Filament



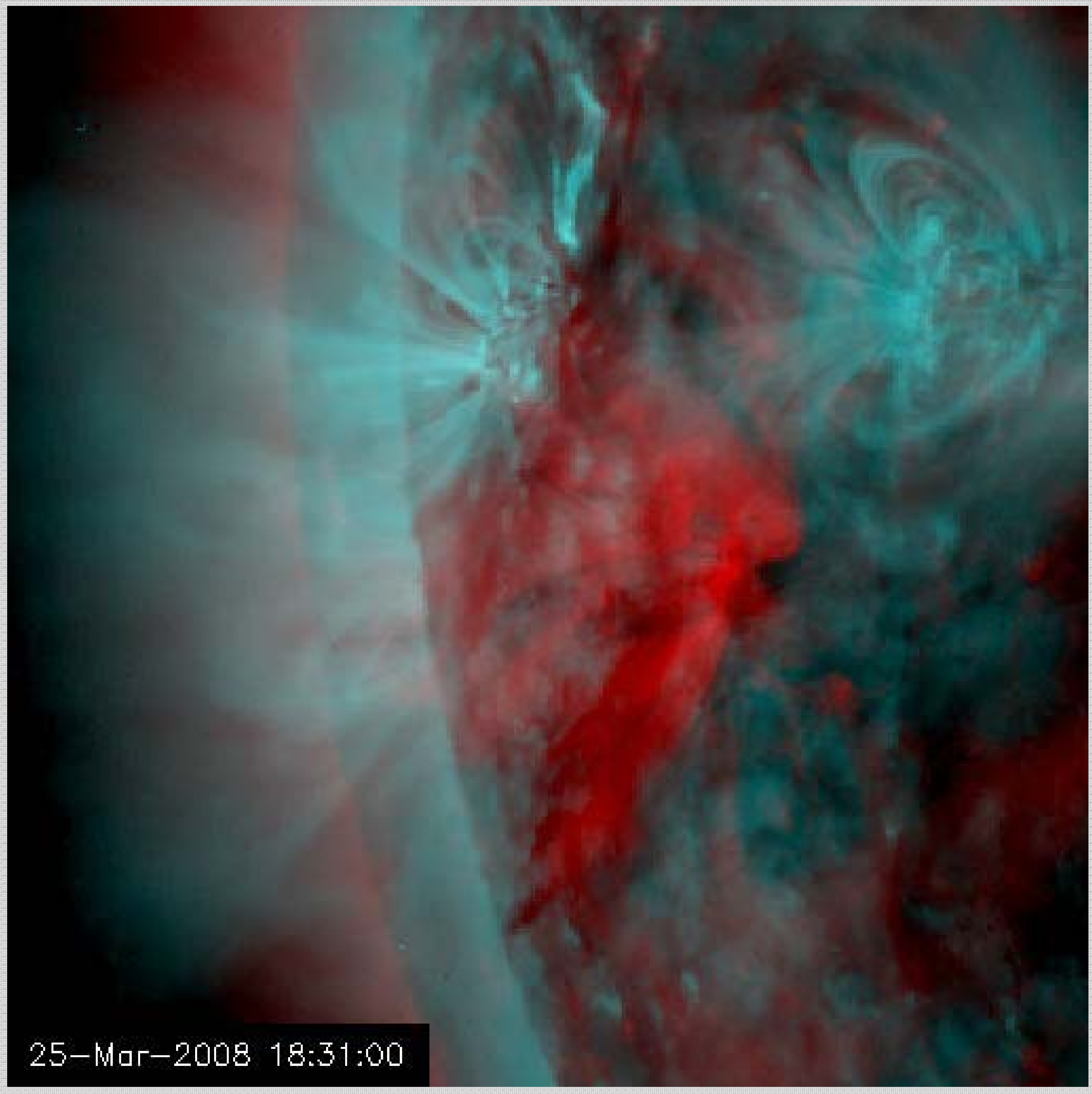
Courtesy of Jean-Pierre Wuelser

PFSS model | Hα + EUVI 304 A | EUVI 195 A



SoHO/MDI

(courtesy of Yan Li)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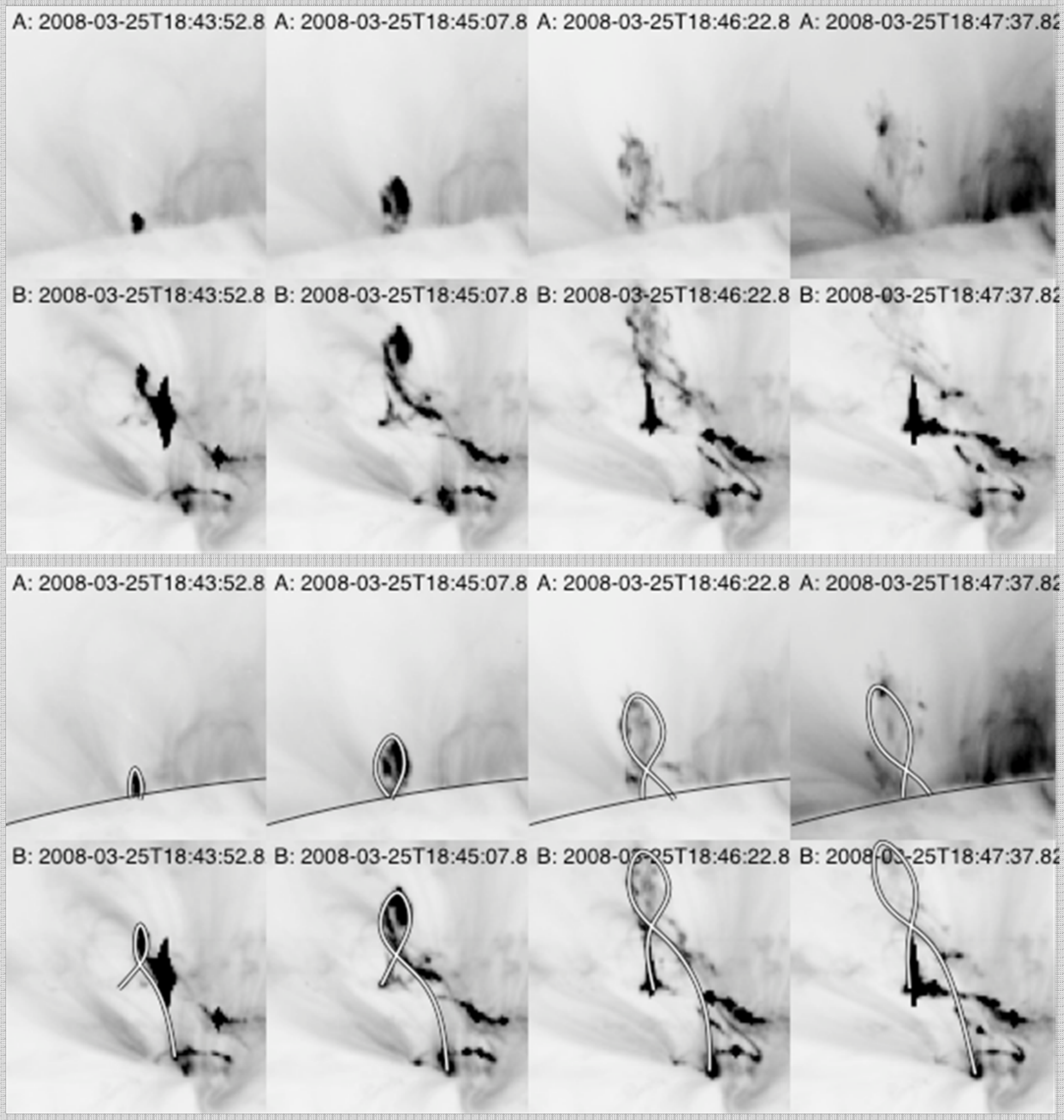

Eruptive filament with ~1.5 turn of twist

→ Kink instability

CONCLUSIONS

(1) Flares with dominant impulsive EUV emission indicate impulsive heating of either a non-erupting filament or flare ribbons.

(2) Flares with delayed EUV emission provide diagnostic on the cooling of postflare loops from soft X-rays to EUV temperatures.

(3) Occulted flares allows us to determine CME-related coronal dimming uncontaminated from postflare emission.

(4) Flares/CMEs with EUV dimming allow us to the 3D volume of the “evacuated CME corridor”, to quantify the rapid CME expansion, the CME speed and acceleration in the lower corona, and to estimate the CME mass.

(5) Coronal loop oscillations, triggered by flares and CMEs, probe the forces that disturb the corona during CME launch.

(6) Erupting filaments provide diagnostics on the kink instability and initial CME expansion geometry.