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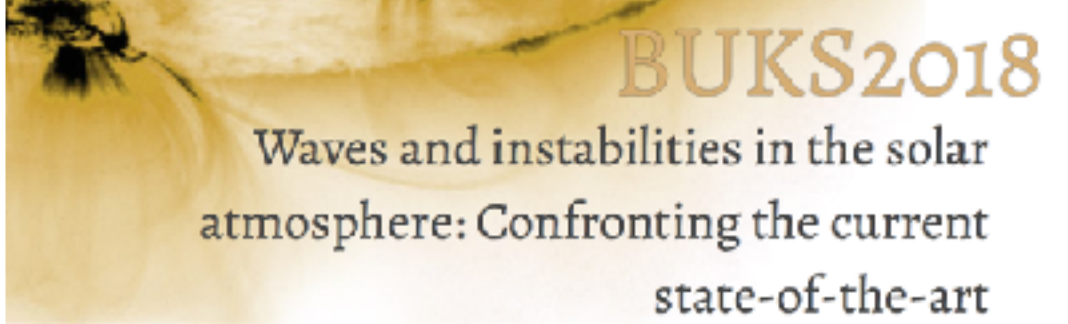

New observations on the driving mechanism and wave property of EUV waves

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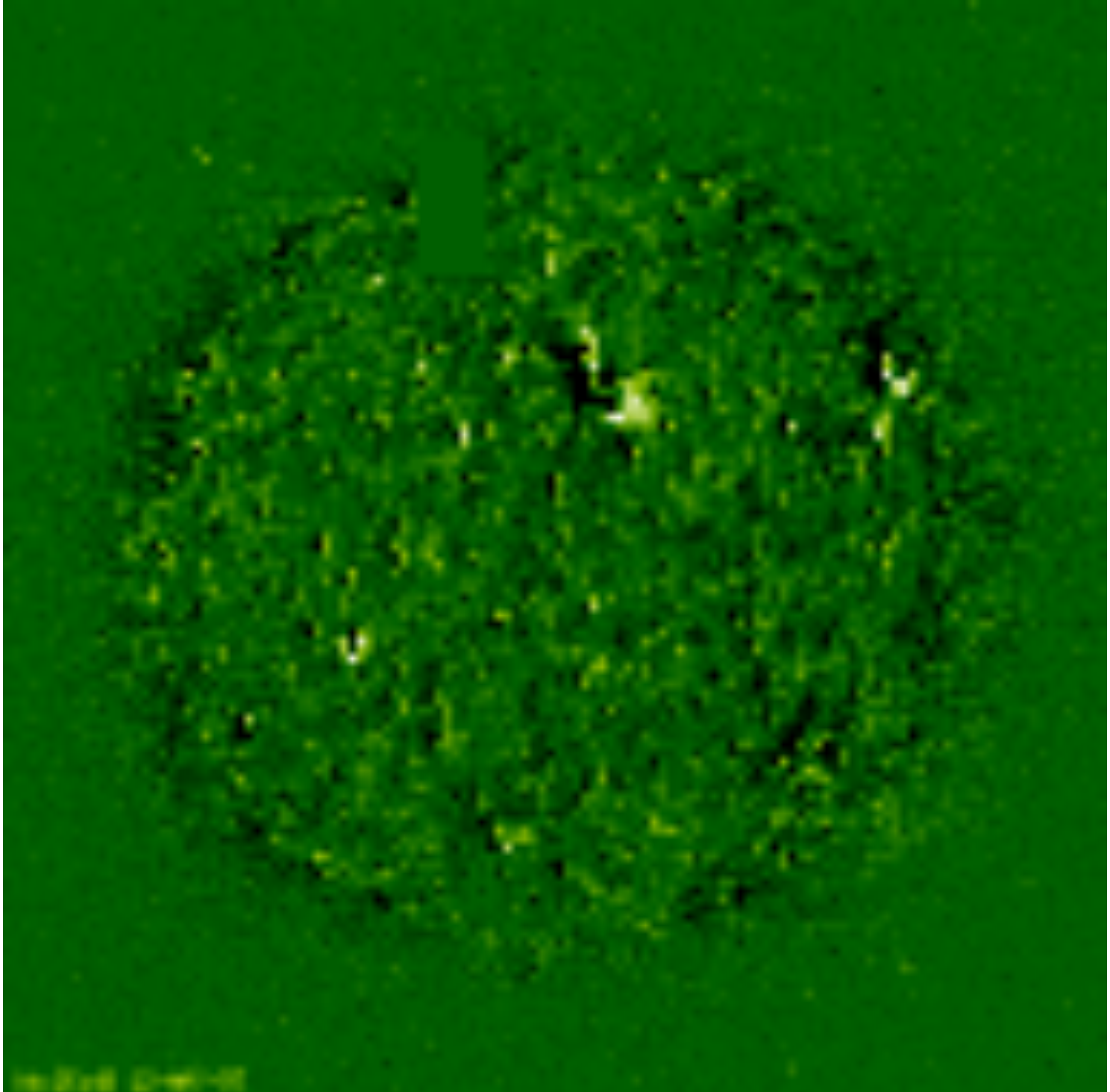
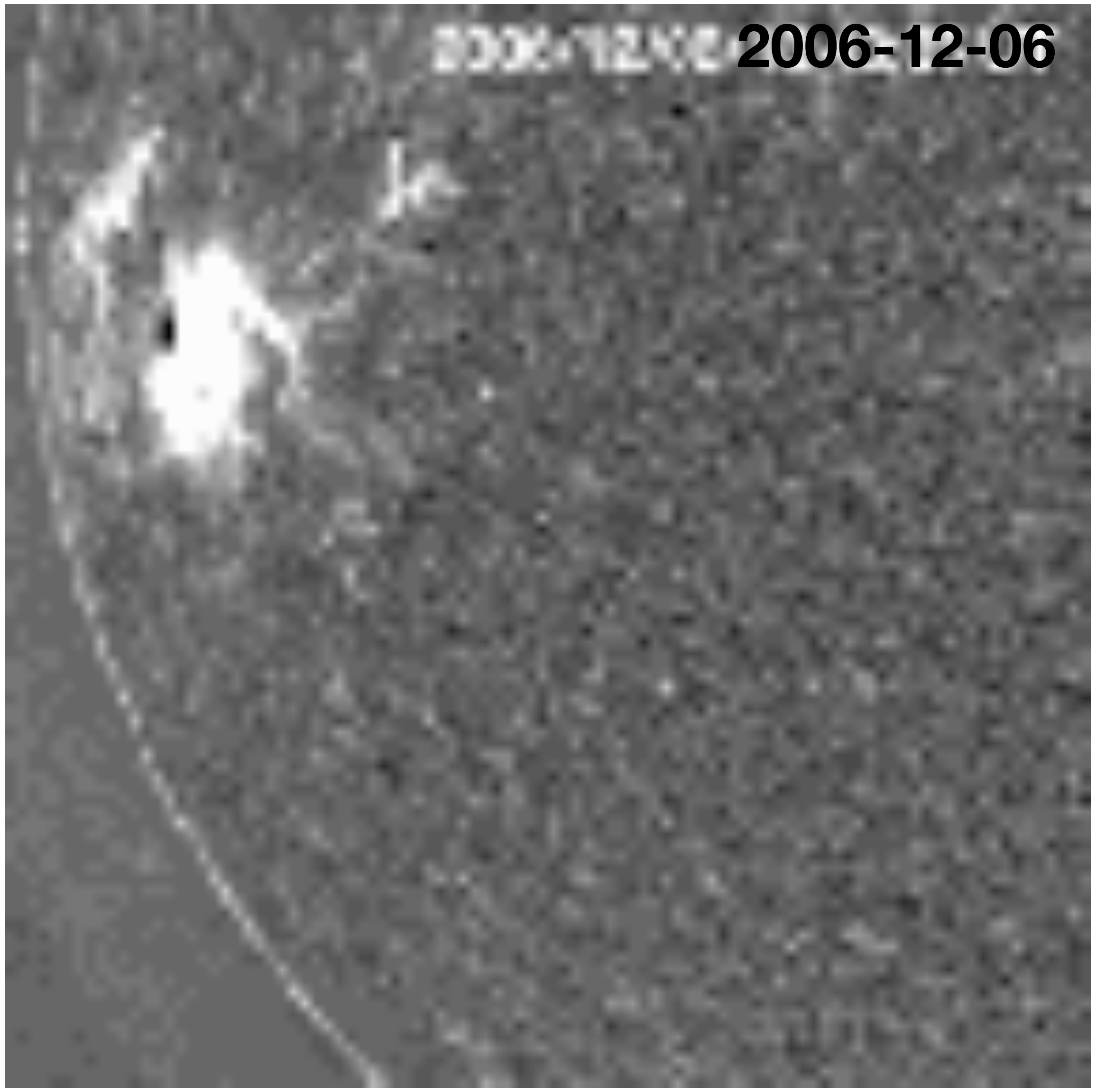


Speed: 200-400 km/s; Lifetime: ~hour; Morphology: globally arc-shaped front; closely associated with flares, CMEs, type II radio bursts. Thompson et al. 1998

Questions of EIT/EUV waves

- **Relationship of EUV waves with the chromosphere Moreton wave**
- **Driving Source**
  - It is unclear that EUV waves are driven by **Flare Pulse** or **CMEs**.
- **Physical Nature**
  - It is unclear that EUV waves are **Fast-mode magnetosonic waves** or **Non-waves**.

Chromosphere Moreton Waves

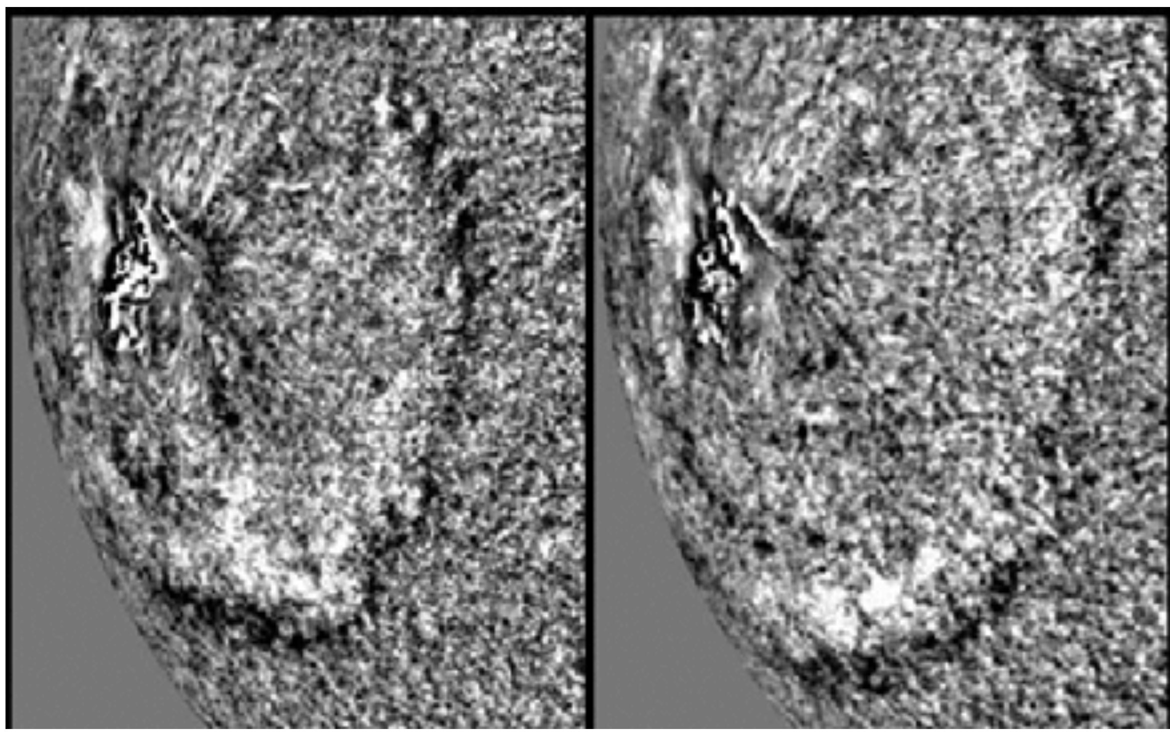


Hα Observations

1. Associated with energetic flares, CMEs, Type II radio bursts, and so on.
2. Typical propagation speeds: ~1000 km/s
3. Propagation distances: ~ 1000 Mm

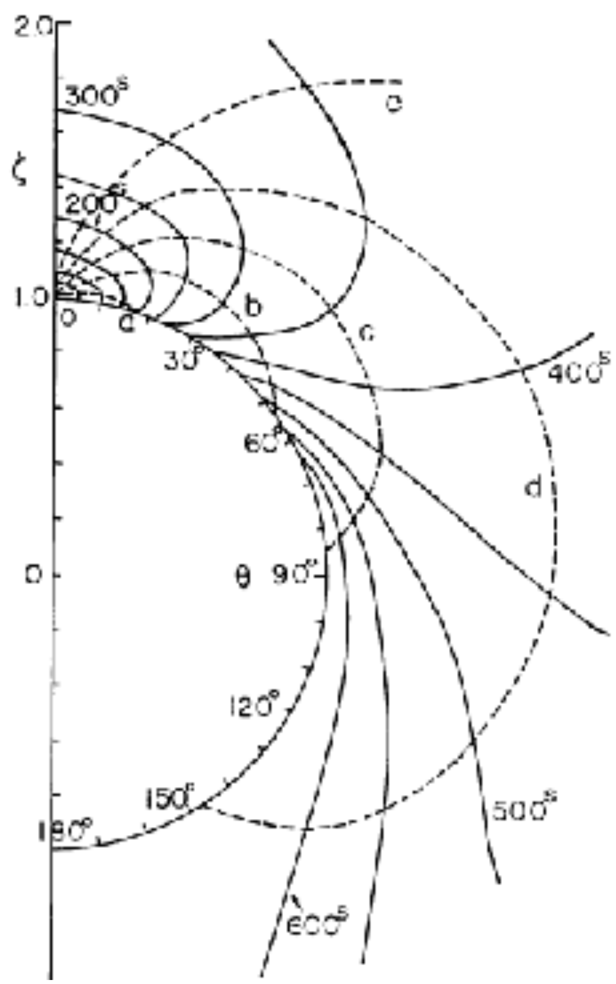
Moreton et al. 1960; Balasubramaniam et al. 2007,2010; Narukage et al. 2008, Shen et al. 2012, 2014a, 2014b

The **sound speed in the chromosphere is of the order of 10 km/s**, a shock wave with a Mach number of about 100 would be fully dissipated before having propagated over 1000 Mm.



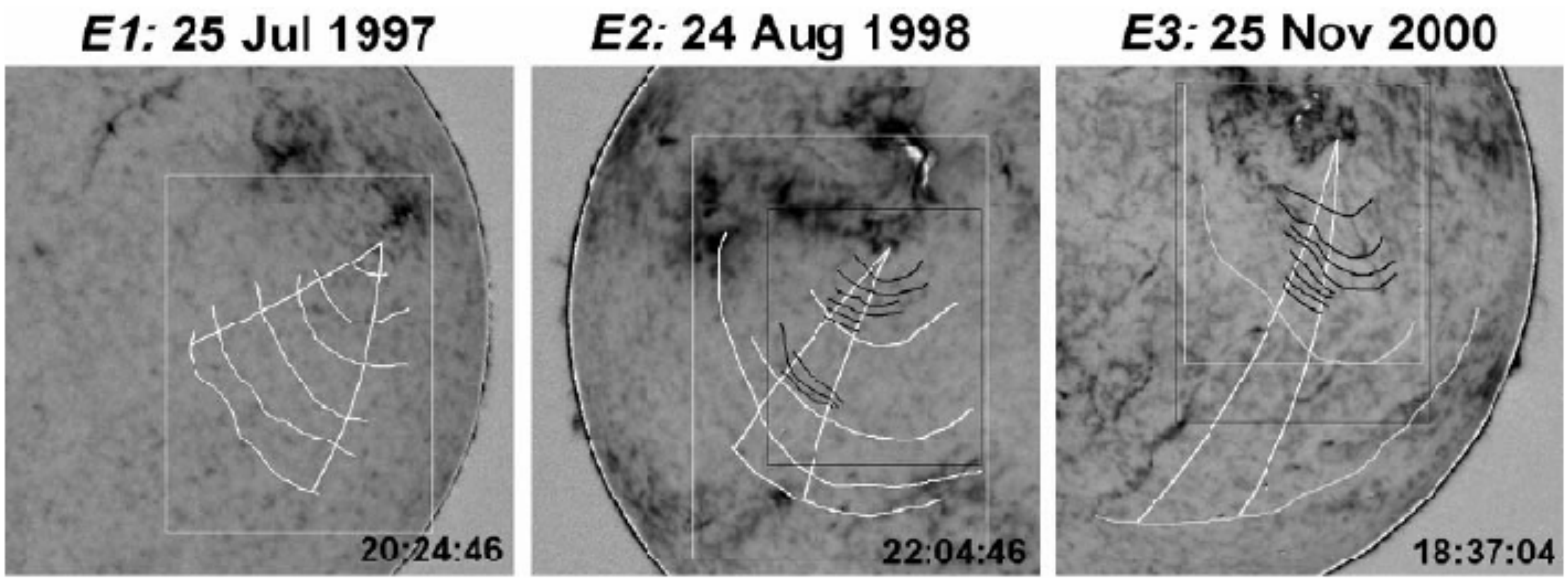
Theoretical Interpretation

Fast-mode Shock in the corona. Uchida, 1968



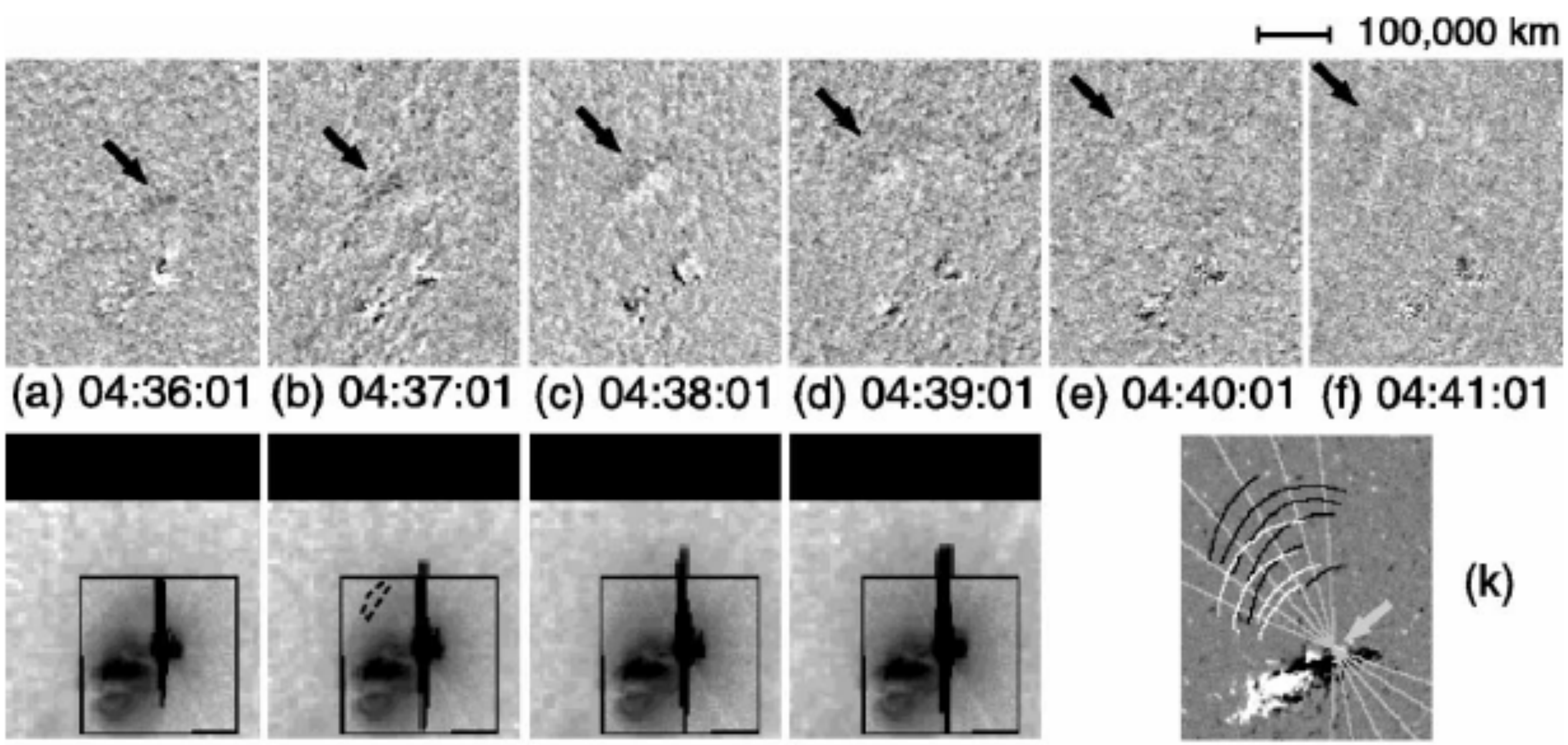
Balasubramaniam et al. 2010, ApJ

Counterparts in the corona



He I 10830 observations of Moreton waves
Black (hα), white (He I);
Vrsnak et al. 2002

Similar Shape and propagation speed



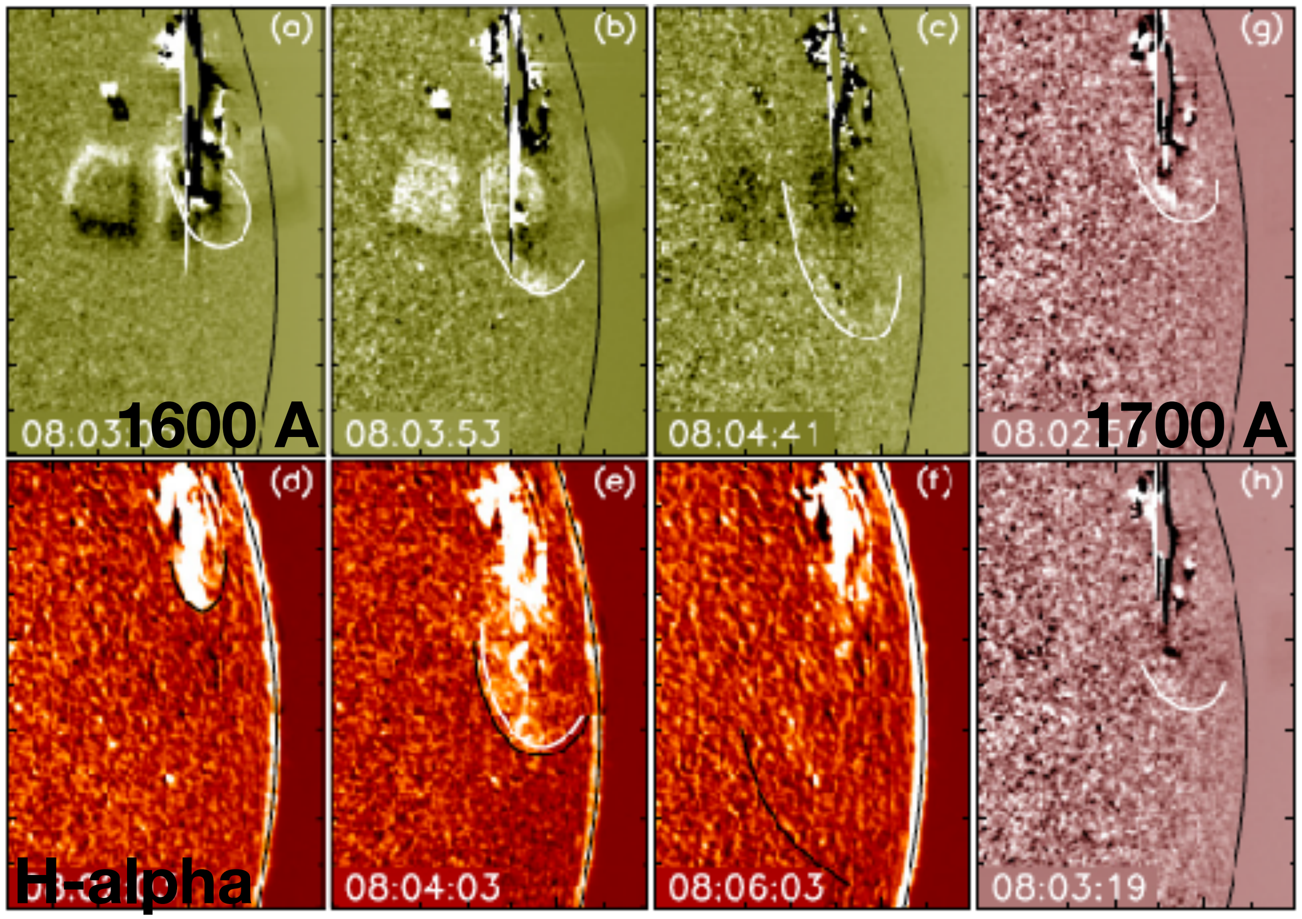
Soft X-ray Observations

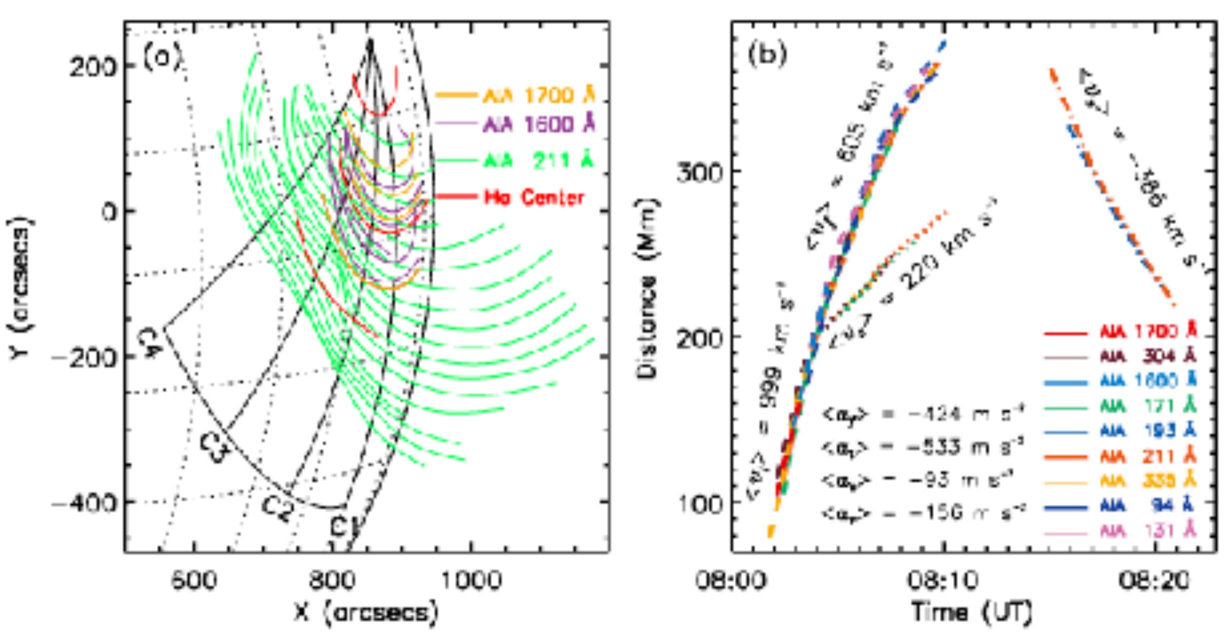
Top: Hα; Bottom: soft X-ray

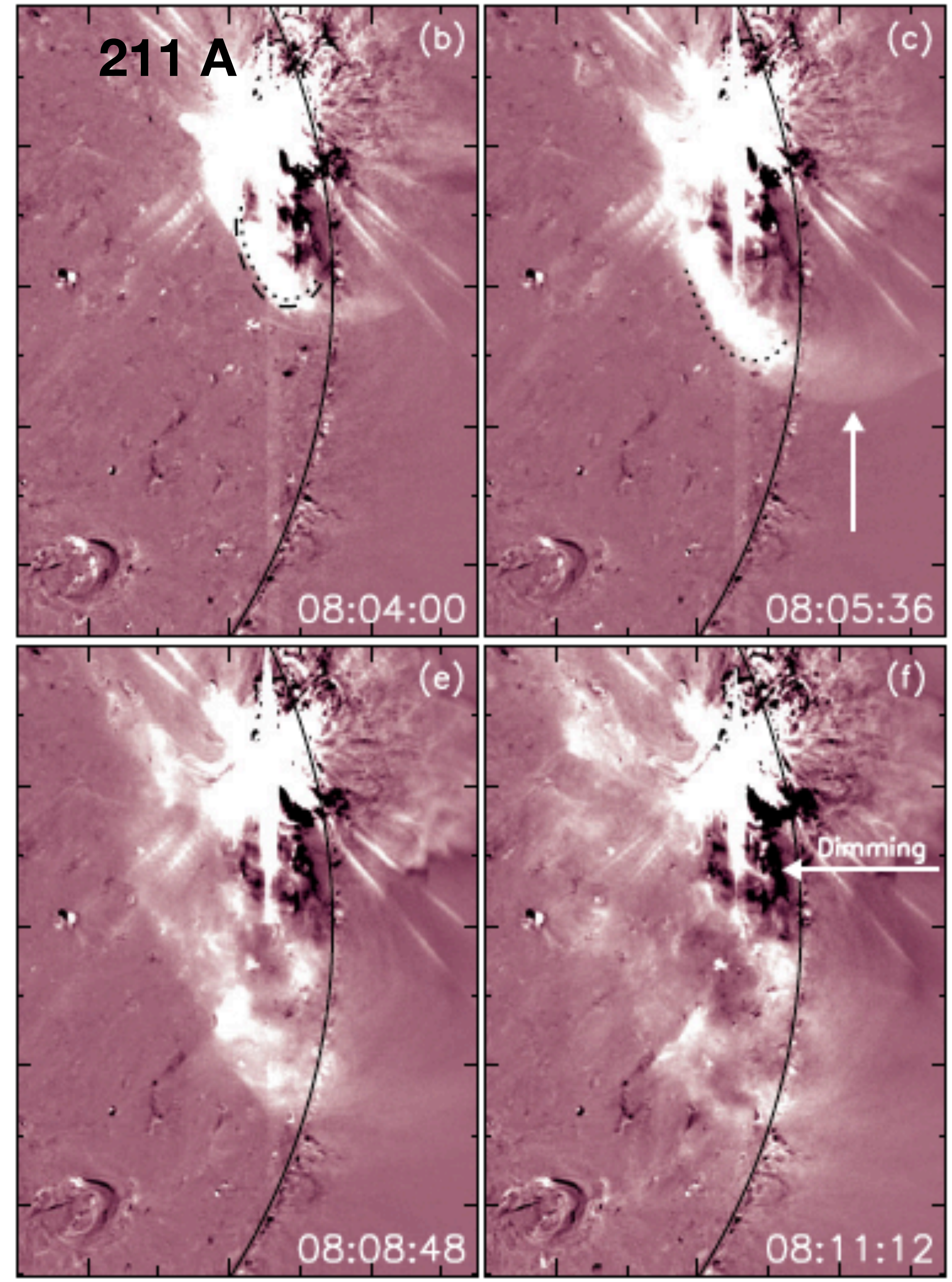
Black: Hα; White: Soft X-ray

Narukage et al. 2002

are EUV waves the counterparts of Moreton waves?



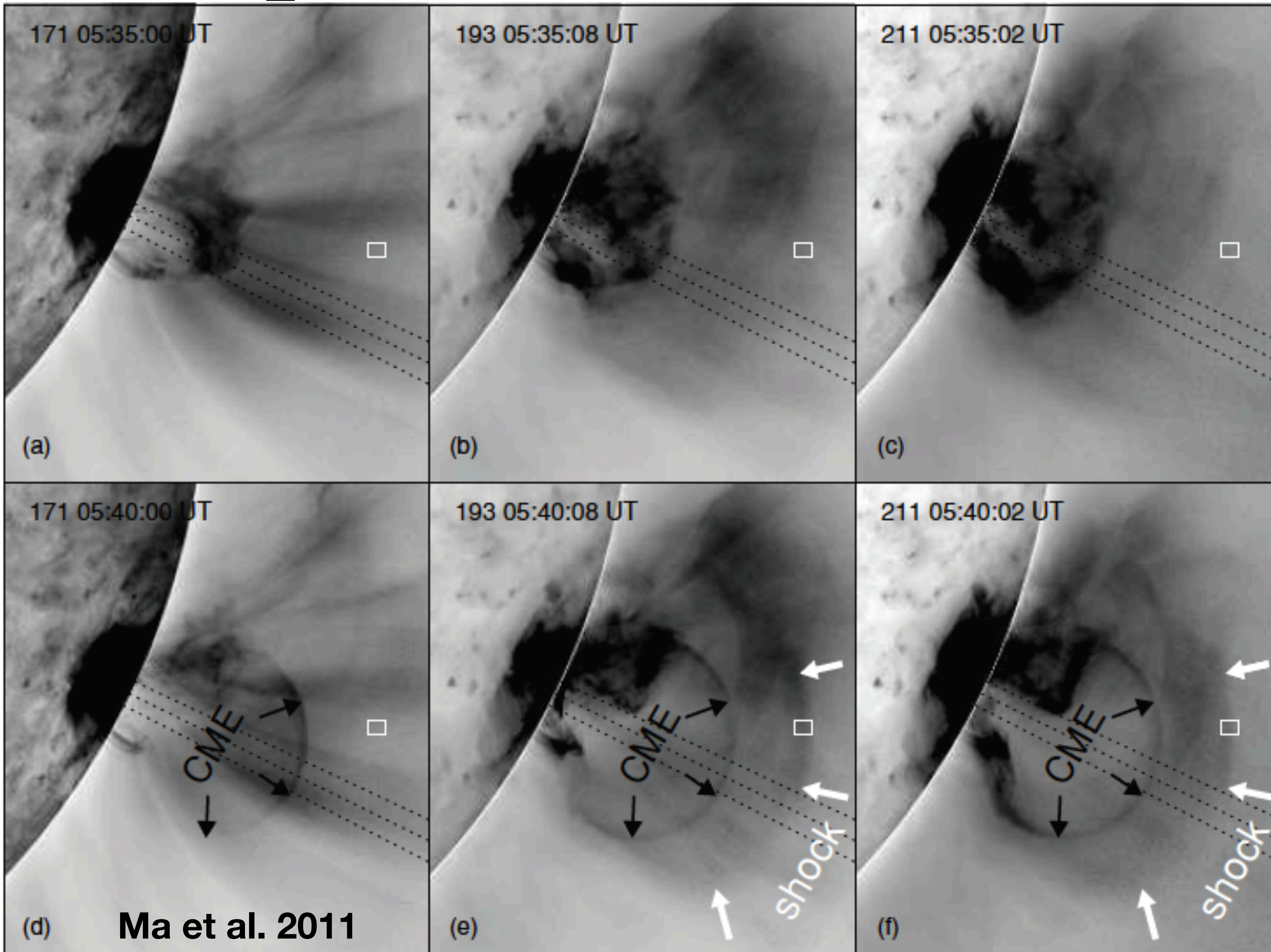




Initial speed: ~1000 km/s; Average speed: 600 km/s. Moreton wave just existed during the initial stage of the EUV wave. Shen & Liu 2012

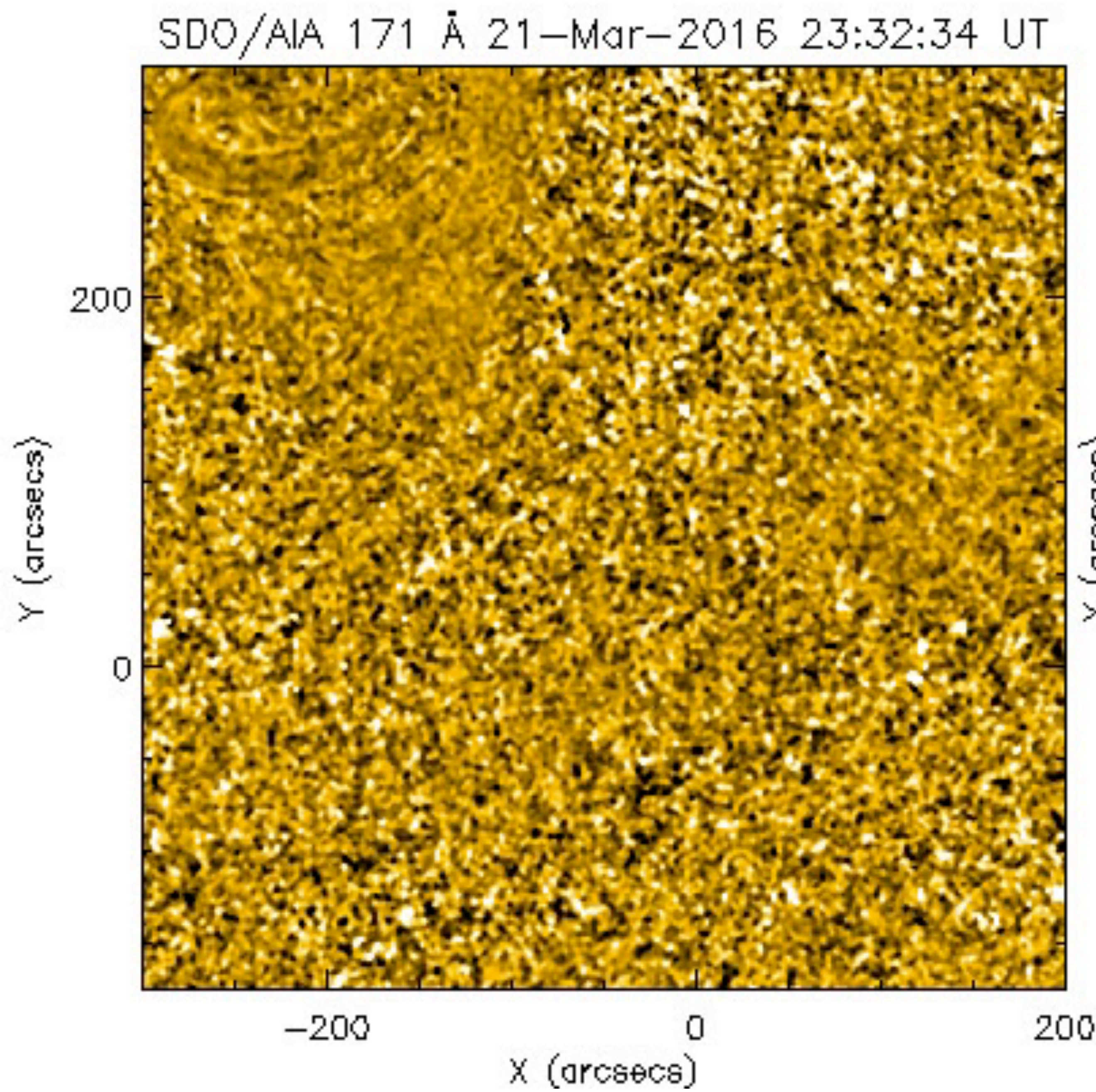
==> large-scale wave disturbances at different heights are all the counterparts of EUV waves.

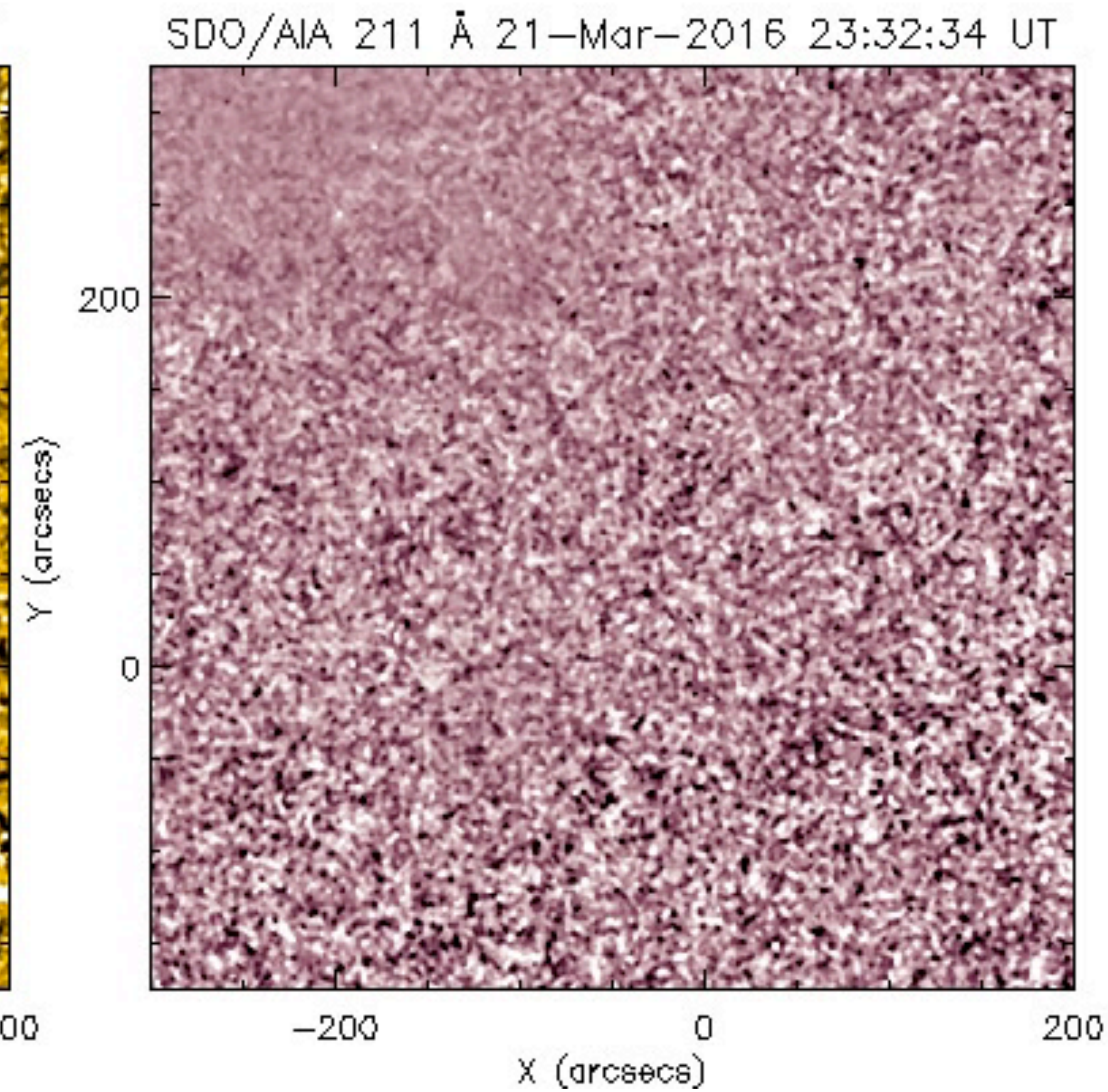
Driving Source: Flares or CMEs



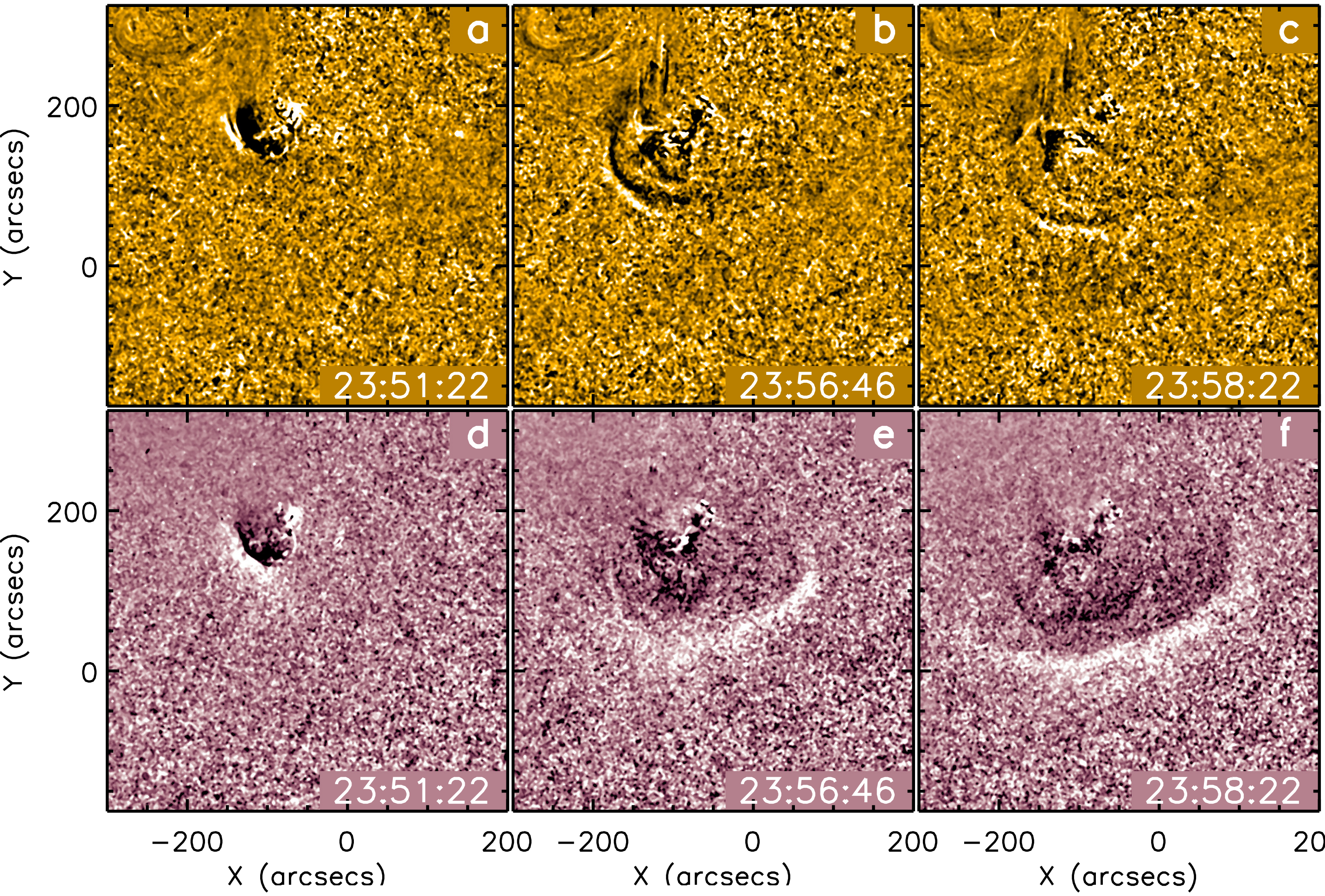
Recent high resolution observational results indicated that EUV waves are in fact driven by the associated CMEs.

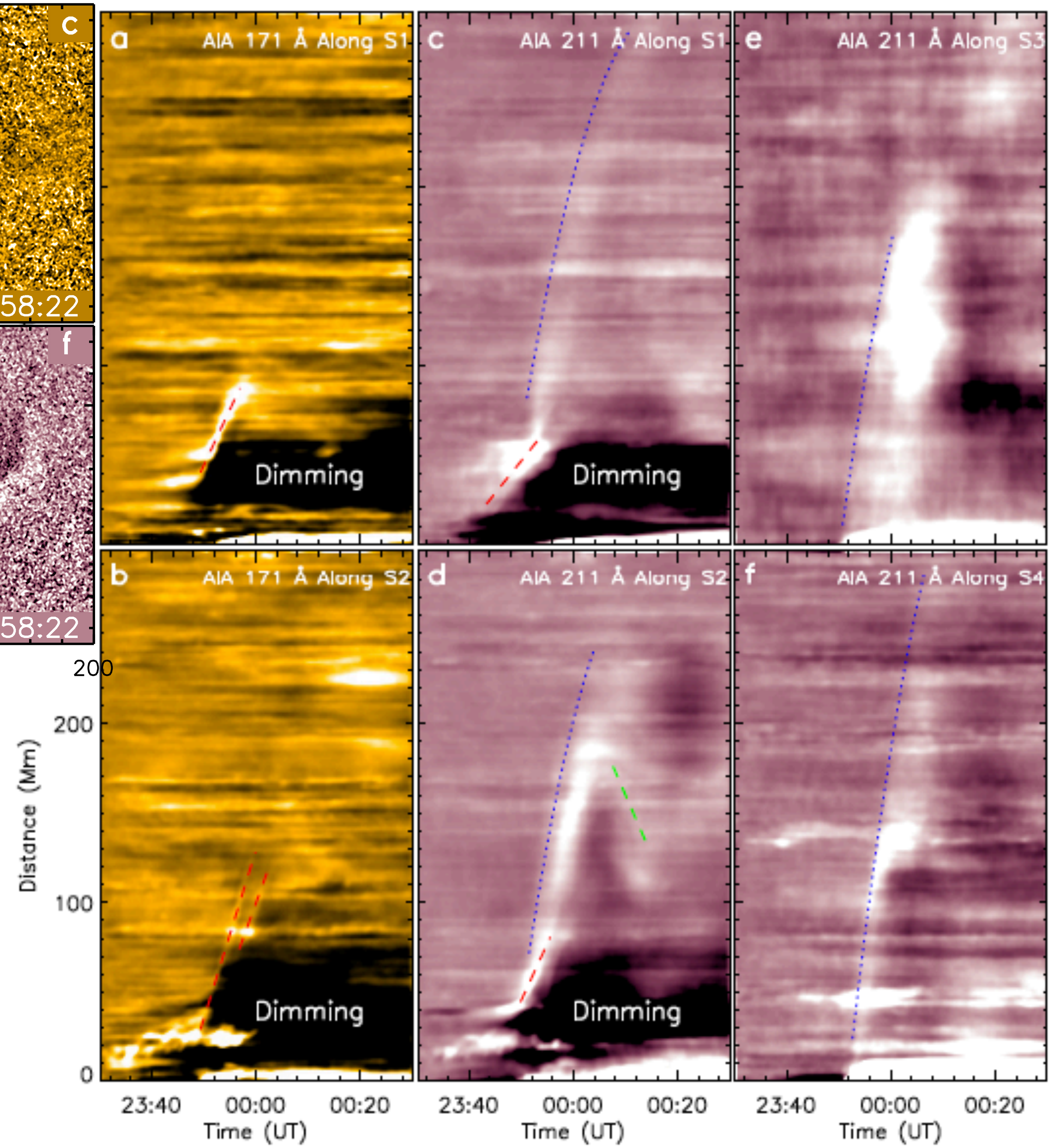
separation between EUV wave and expanding loops observed in a miniature solar eruption

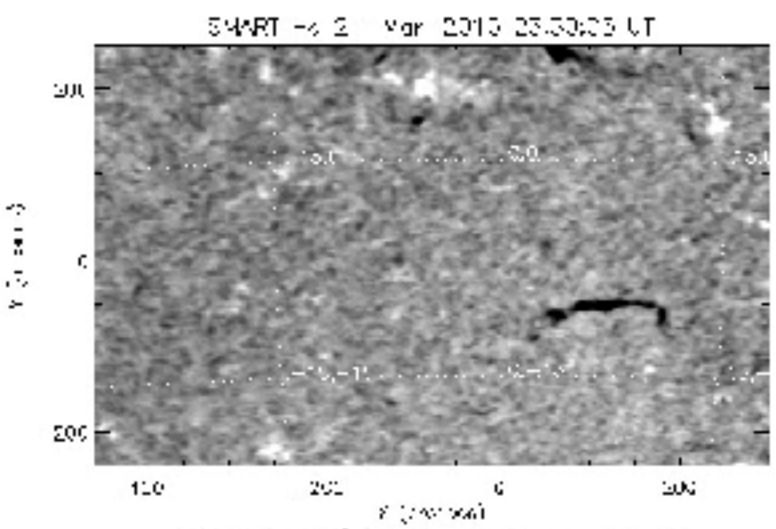


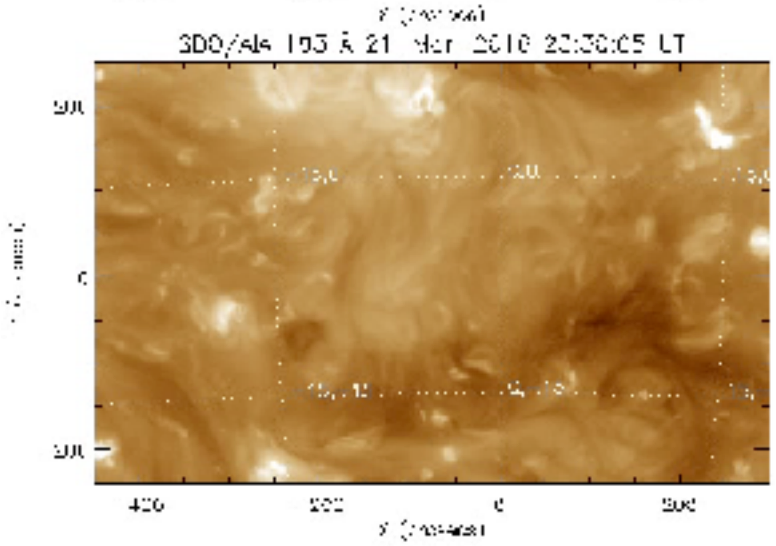


B1.9 flare, mini-filament eruption



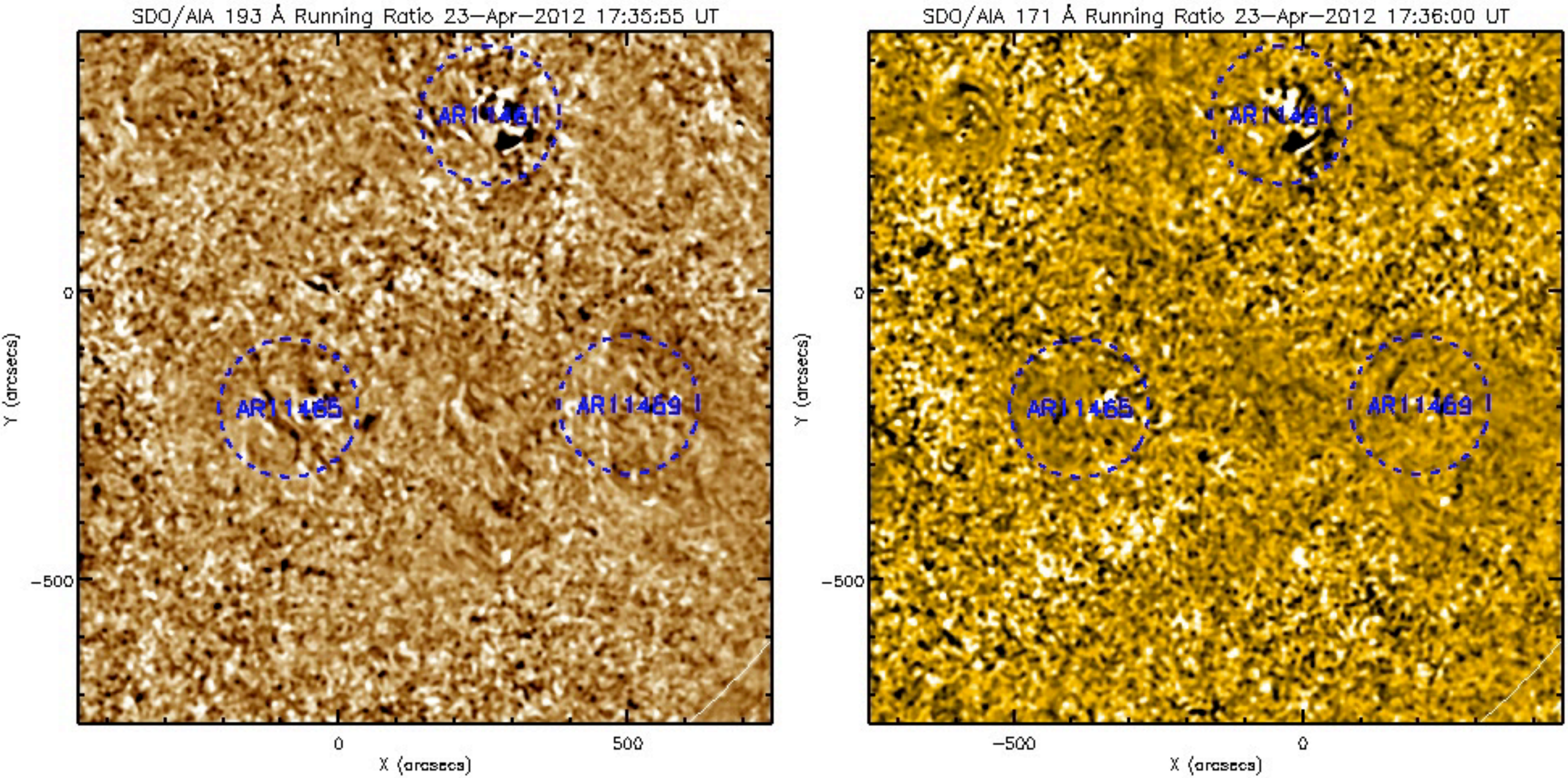




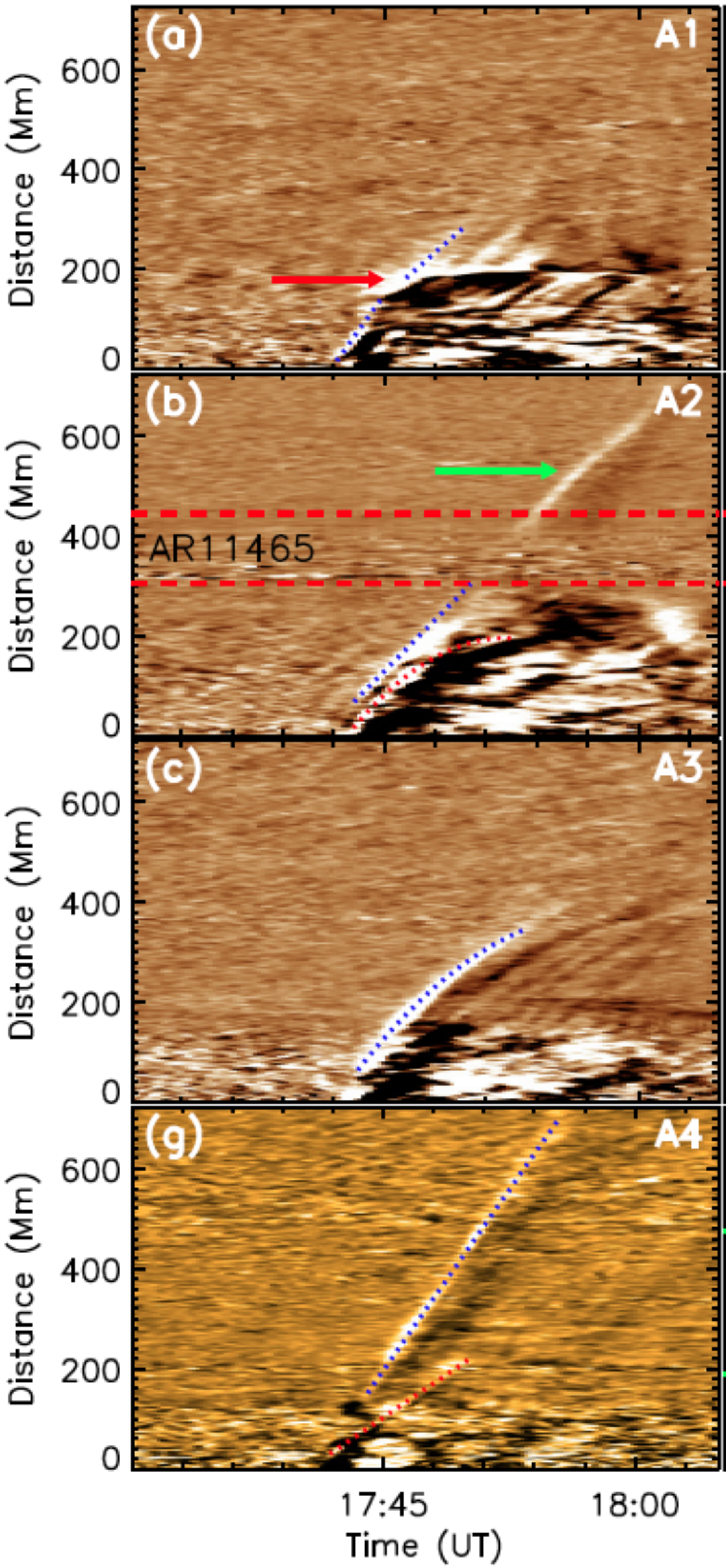


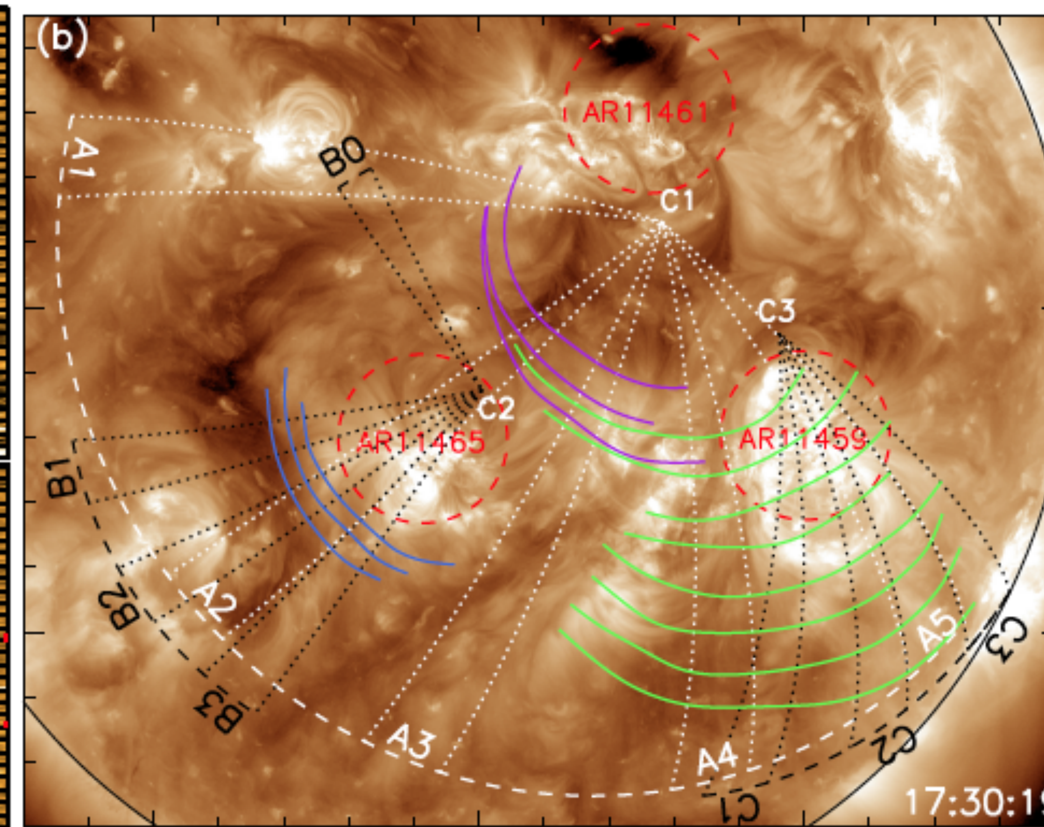
The wave speed: 182 - 317 km/s
Shen et al. 2017

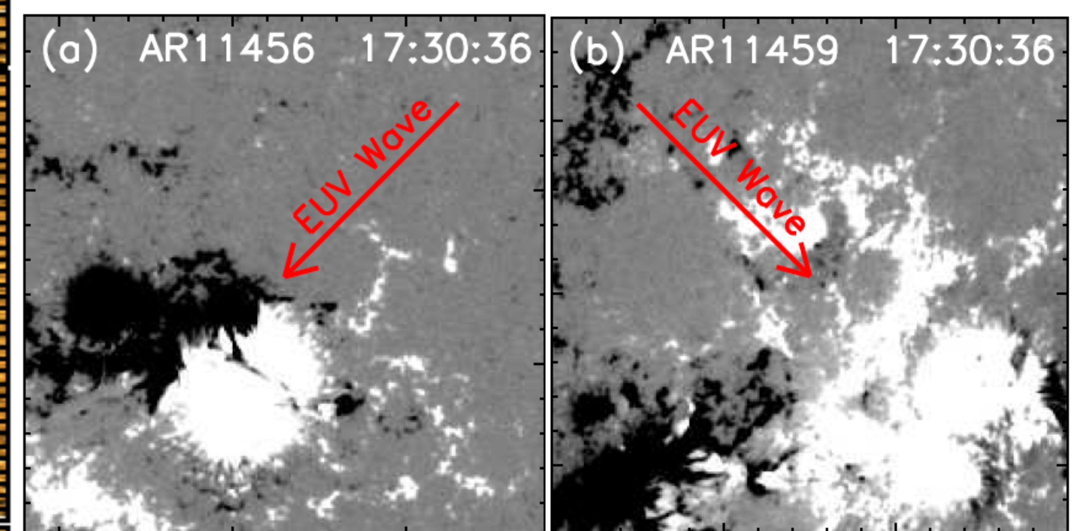
Evidence of the wave properties



Simultaneous reflection and transmission of an EUV wave during its interactions with two remote active regions; Shen et al. 2013







The difference speed gradients at the boundaries of the two active region may be the reason for producing different wave phenomena. Shen et al. 2013

So far, we almost believe that EUV waves are CME driven fast-mode magnetosonic waves in the corona.

However,

EUV waves can also be launched by other solar activities,

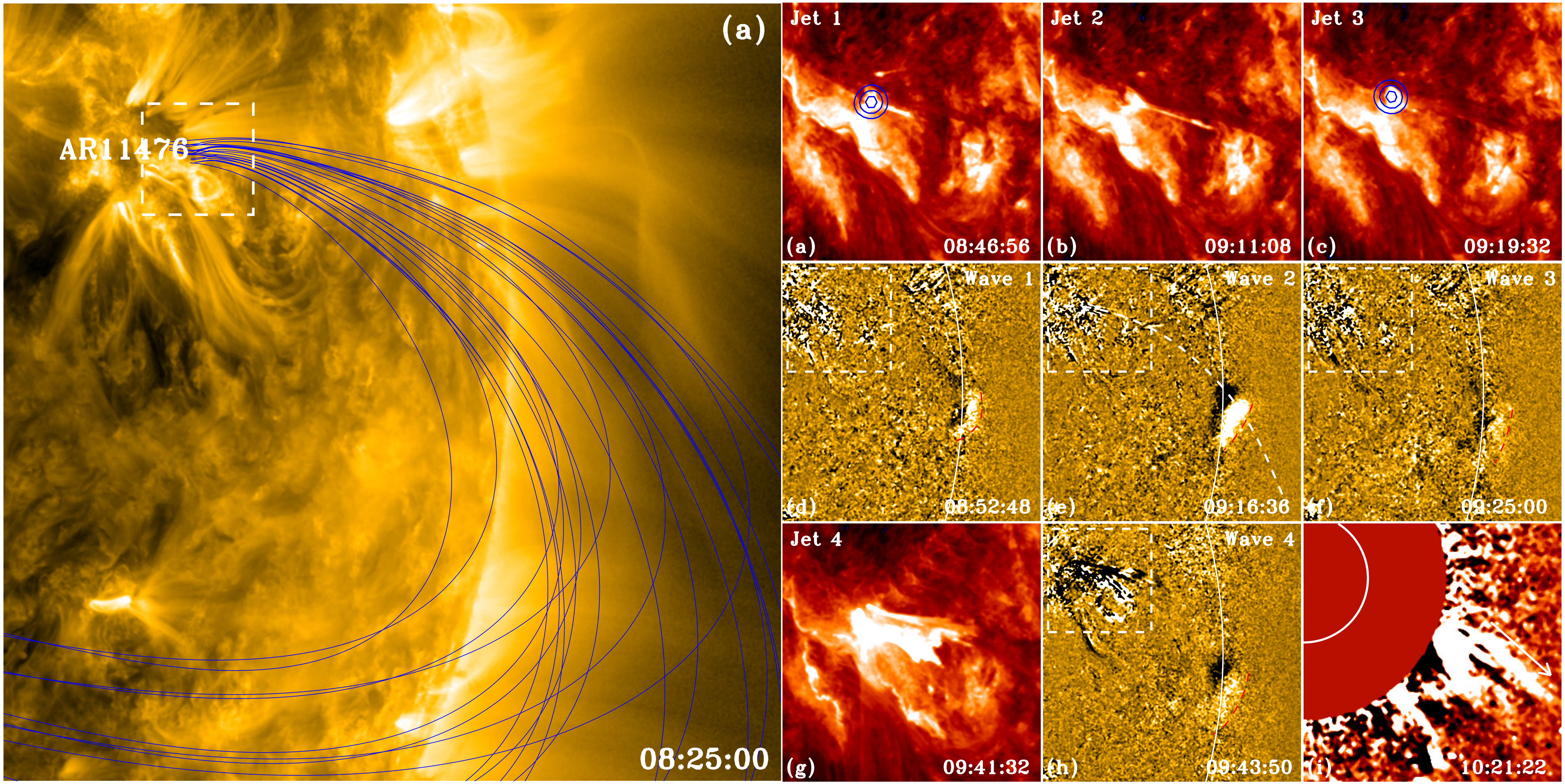
including,

1) coronal jets

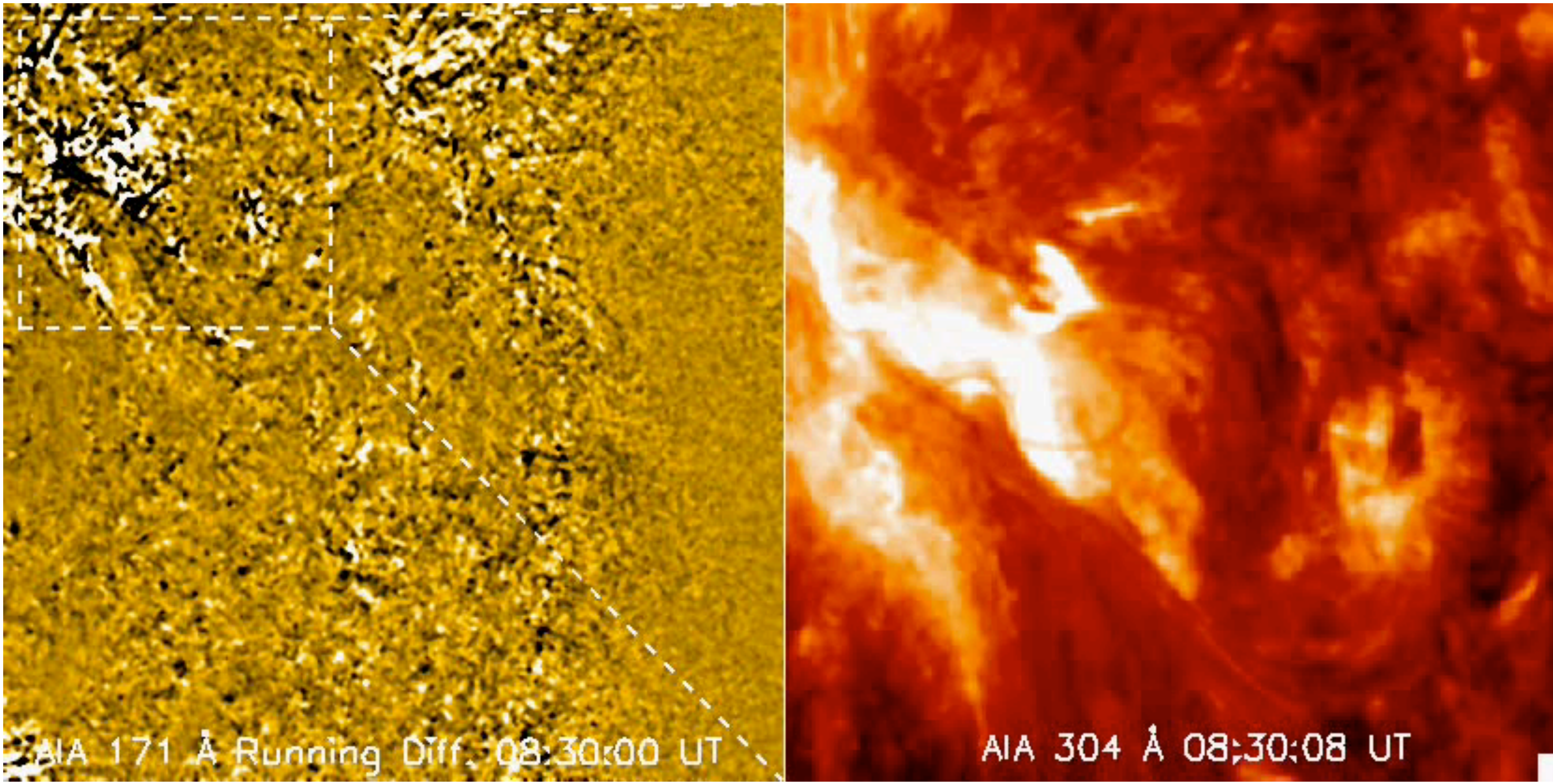
2) the unwinding motion of erupting filaments

3) the sudden expansion of coronal loops

Homologous Large-amplitude Nonlinear Fast-mode Magnetosonic Waves Driven by Recurrent Coronal Jets (Shen et al. 2018, ApJ, 861, 105)



No CMEs, but each jet was accompanied by a micro-flare, a radio type III burst, and a narrow EUV wave along a closed transequatorial loop system.


AIA 171 Å Running Diff. 08:30:00 UT
AIA 304 Å 08:30:08 UT

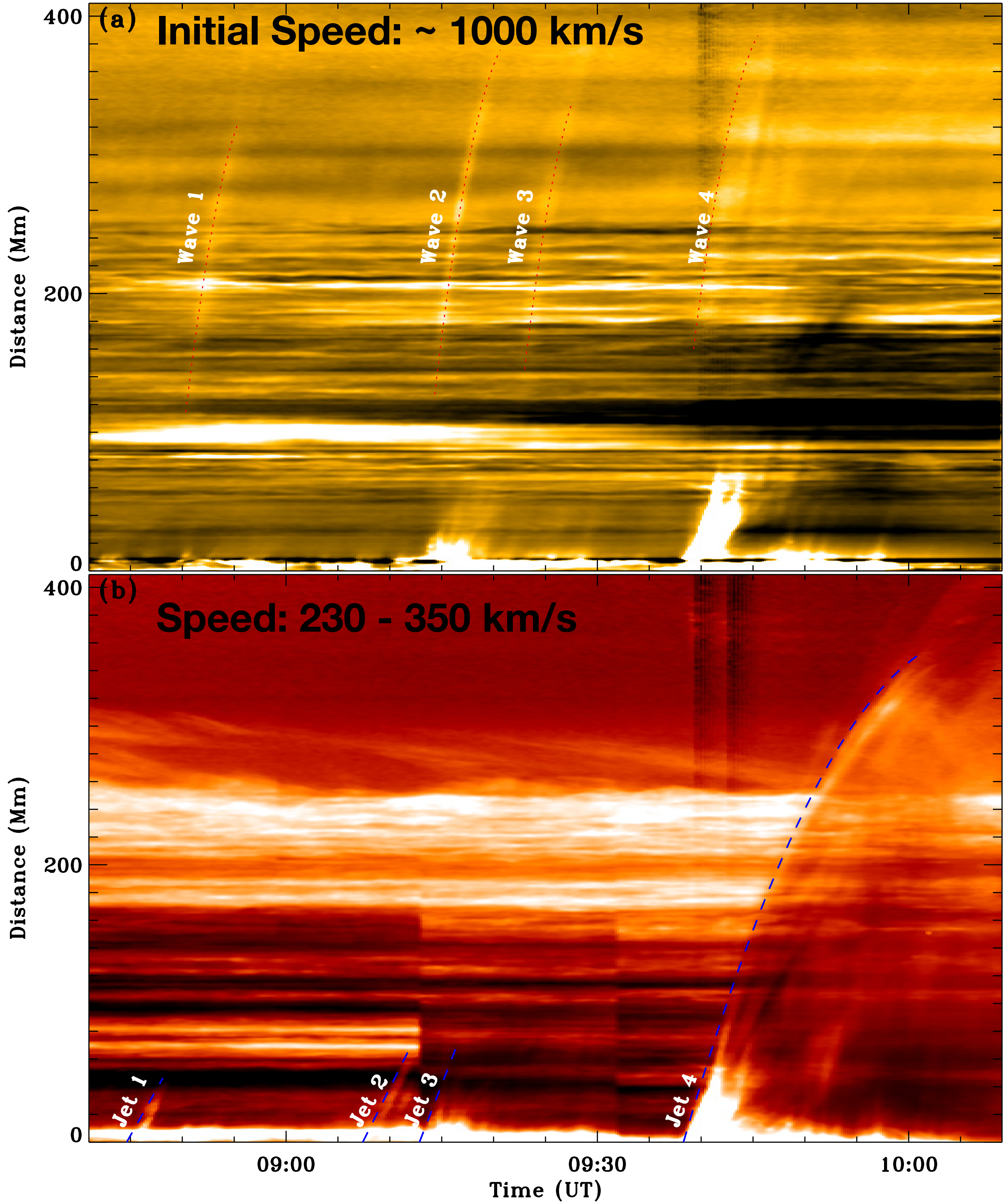
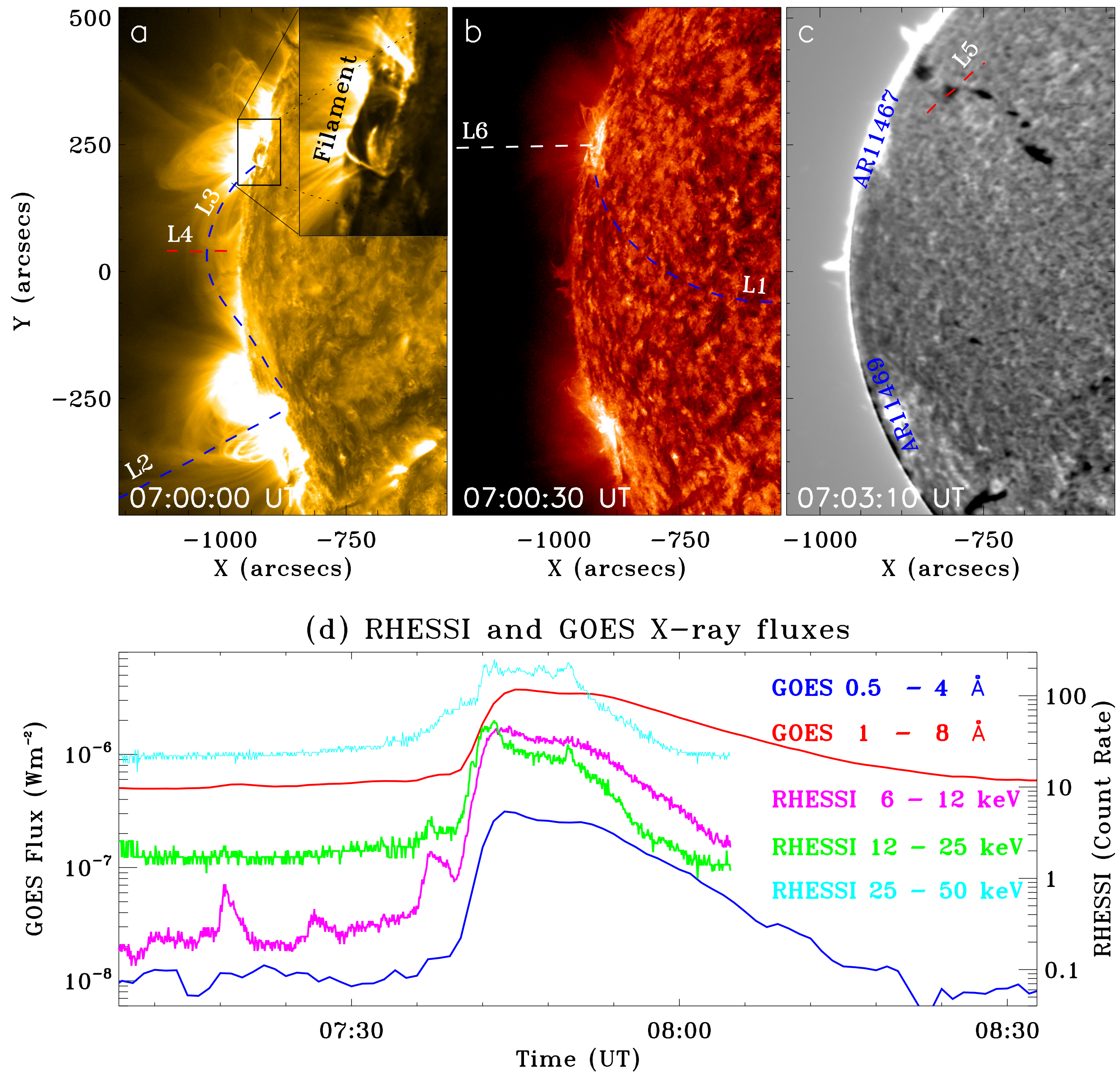


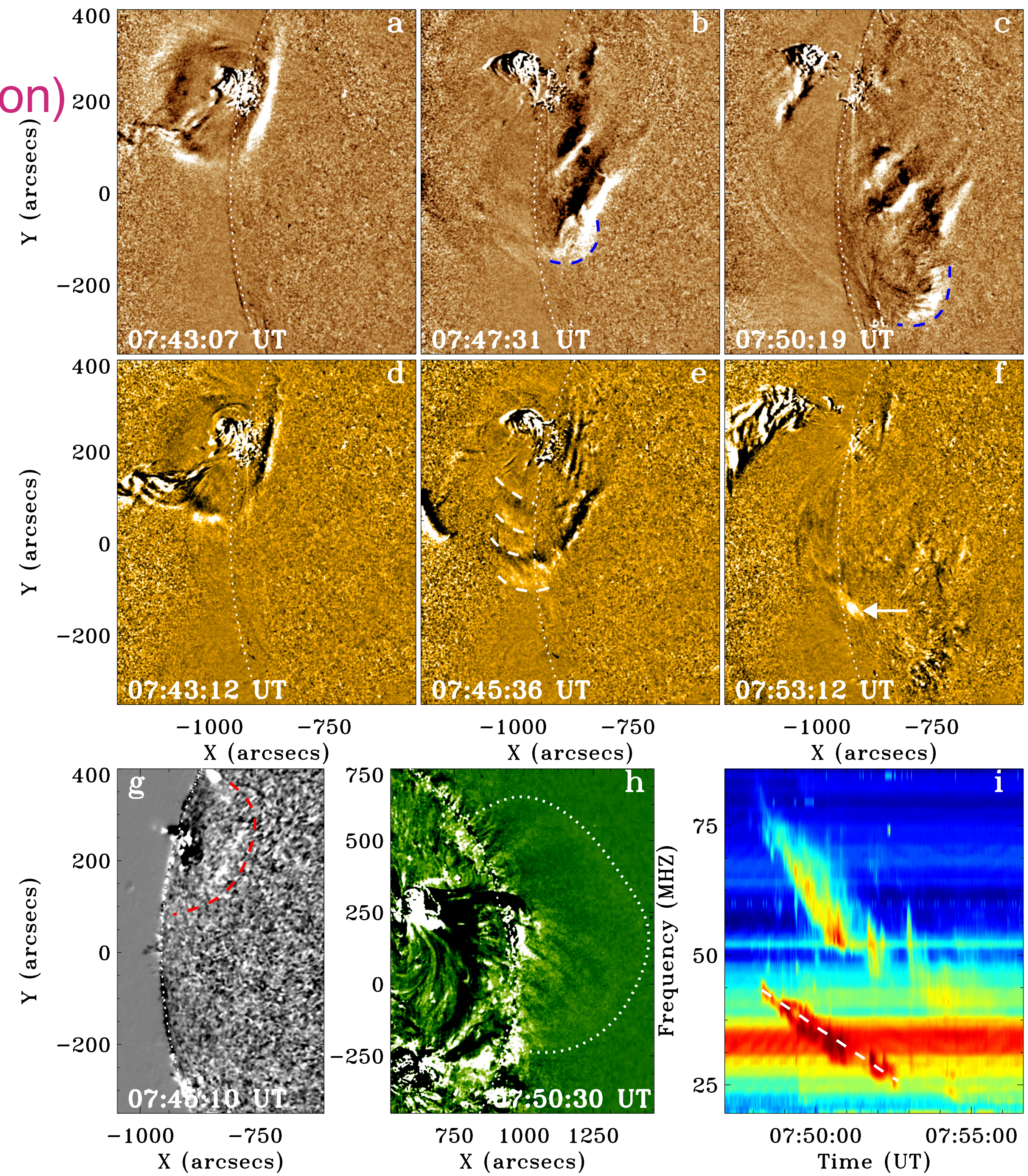
Table 1. Parameters of the associated flares, jets, radio type III bursts, and EUV waves

Items	$Flare_C$ *GOES*	$Flare_S$ (UT)	$Radio_S$ (UT)	Jet_T (UT)	Jet_S (km s^{-1})	$Wave_T$ (UT)	$Wave_S$ (km s^{-1})	$Wave_D$ (km s^{-2})	$Wave_{IS}$ (km s^{-1})
Wave 1	B4.9	08:44:20	08:49:52	08:45:40	226	08:51:24	694	1.175	921
Wave 2	B4.4	09:00:15	09:01:55	09:05:08	251	09:14:48	664	1.101	977
Wave 3	B5.2	09:09:18	09:13:45	09:14:44	325	09:23:00	712	1.219	950
Wave 4	C2.5	09:35:05	09:37:52	09:38:55	347	09:42:38	648	0.985	···

Initial speed of the EUV waves: ~1000 km/s;
average speed:648 to 712 km/s
strong deceleration during the initial stage.
==>nonlinear fast-mode magnetosonic waves

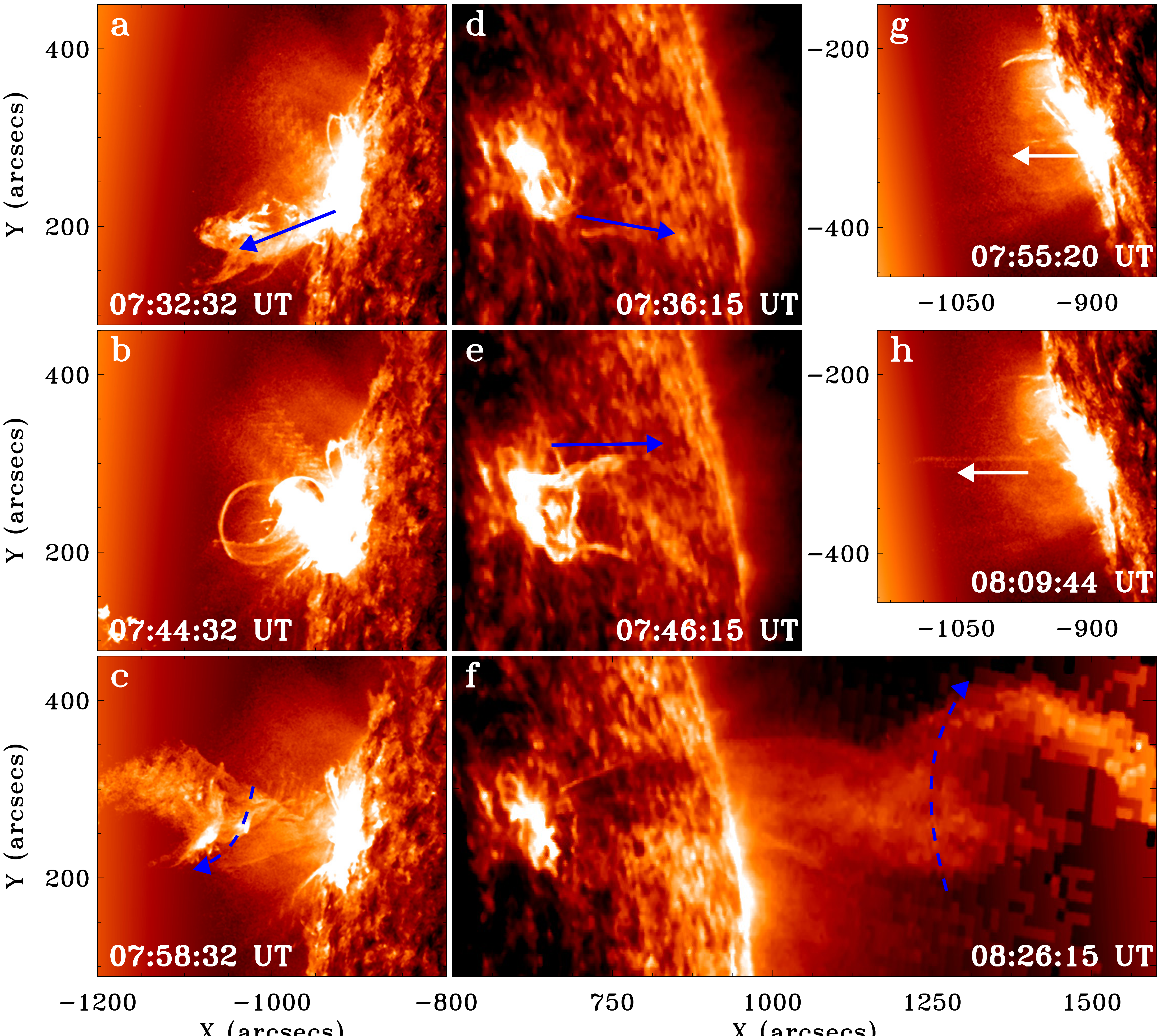
EUV wave driven by the Unwinding Motion of an Erupting Filament (Shen et al. 2018, in preparation)



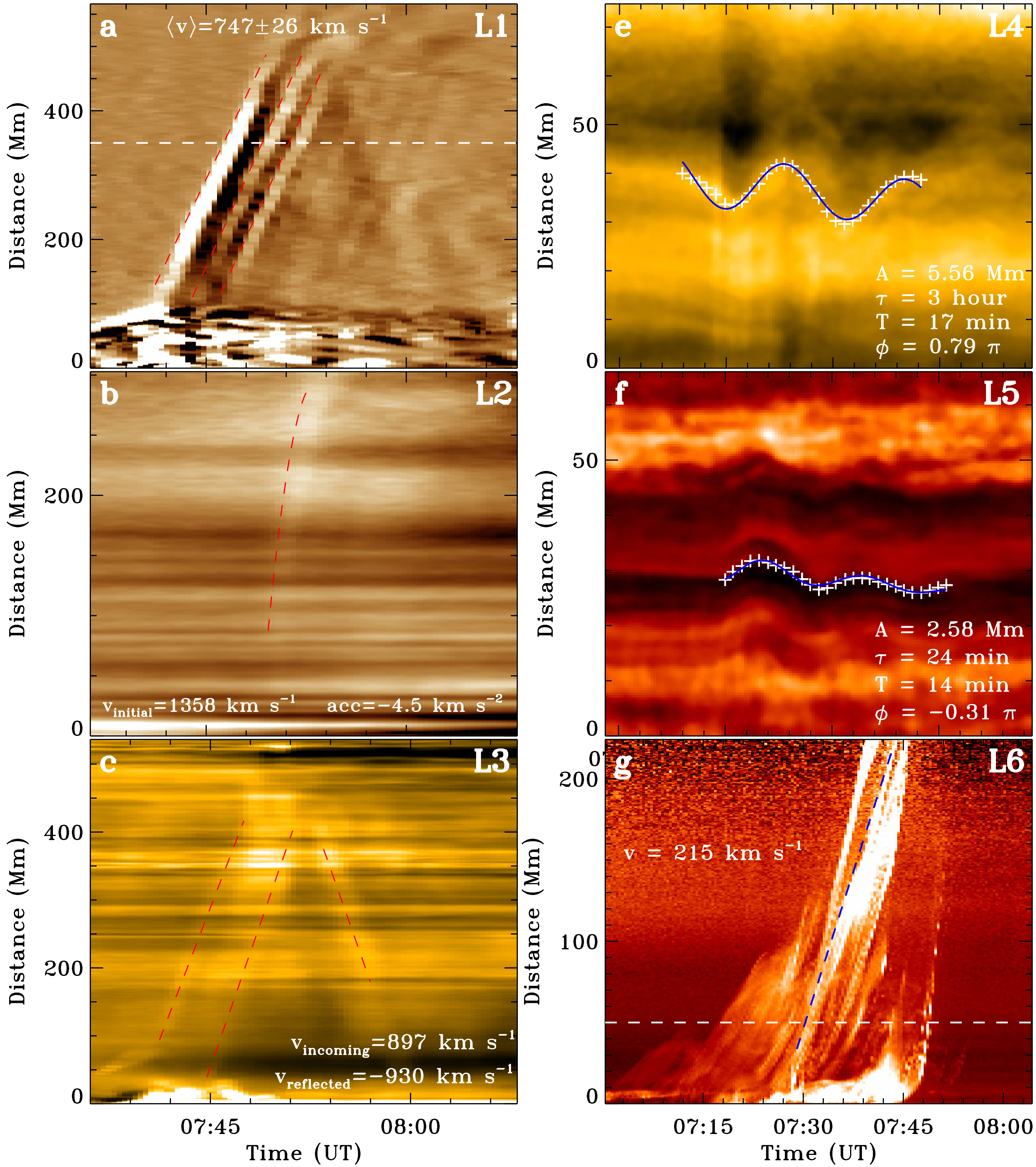


The EUV wave was accompanied by a GOES C3.7 flare, a Moreton wave, a radio type II burst, an erupting unwinding filament, and a partial halo CME.

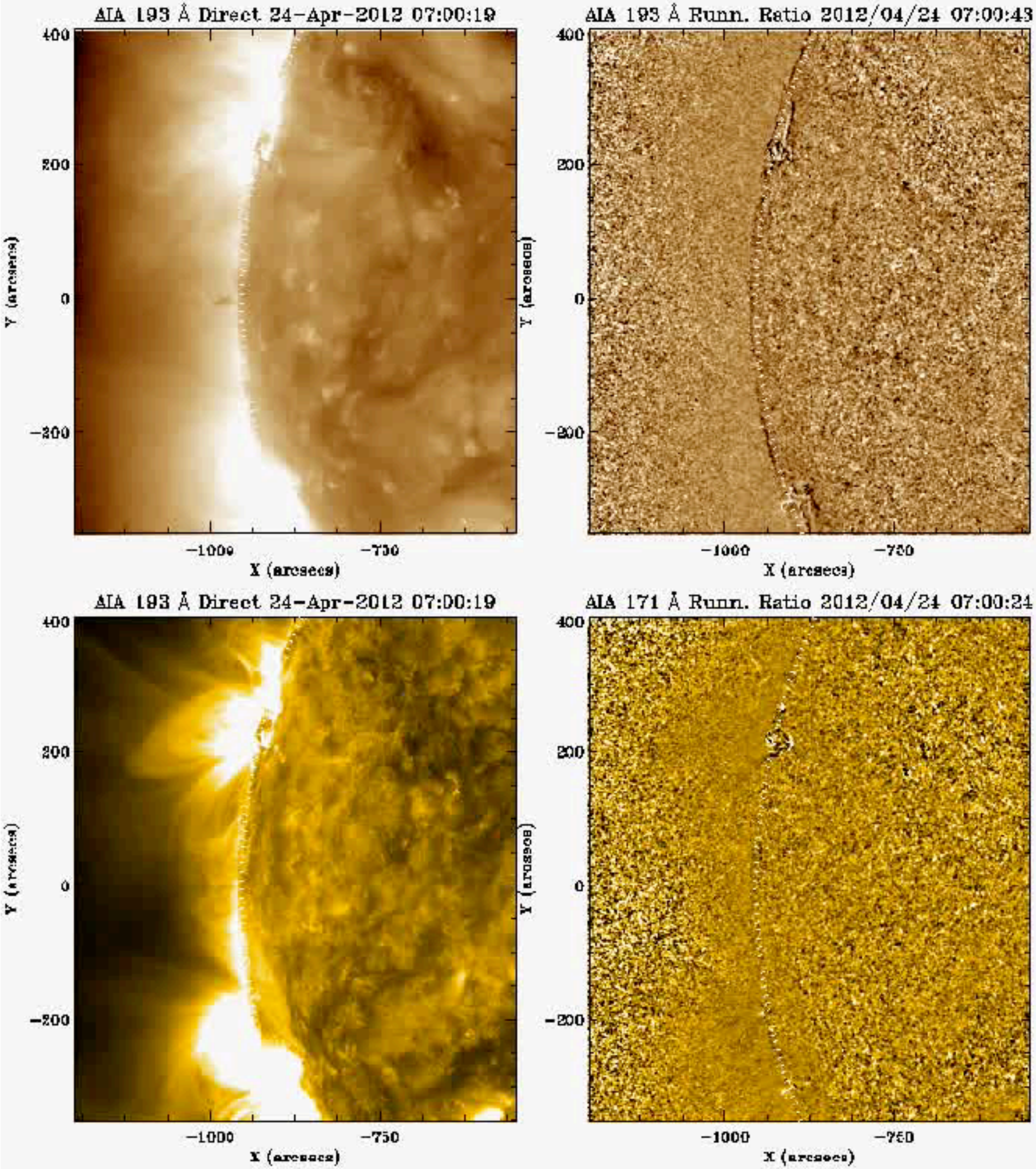
The EUV wave propagated simultaneously on the solar surface and along a closed trans-equatorial loop system, which further caused the transverse oscillation of a quiescent filament, the kink oscillation of the loop, and a secondary EUV wave above AR11467.



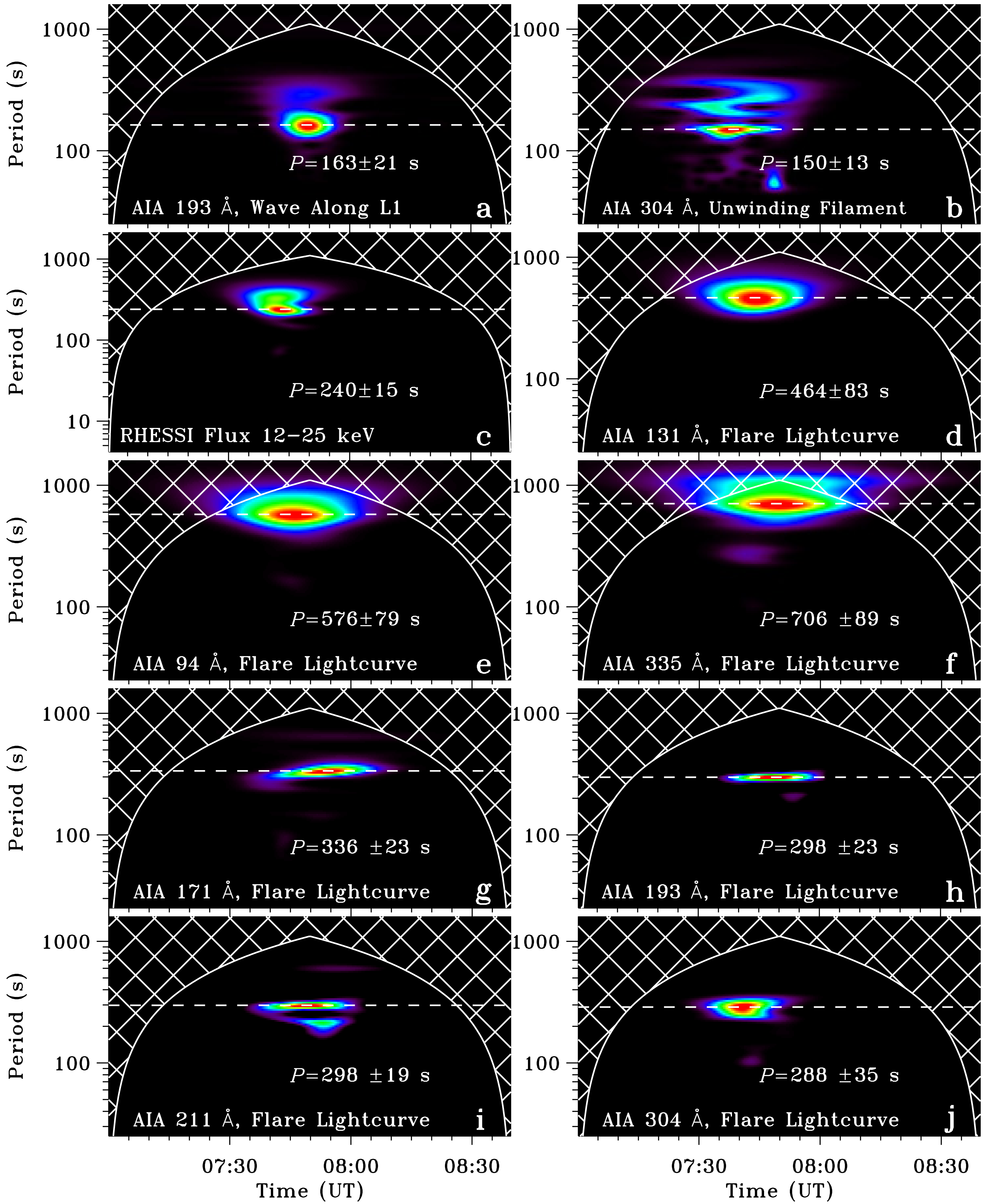
a
07:32:32 UT
b
07:44:32 UT
c
07:58:32 UT
d
07:36:15 UT
e
07:46:15 UT
f
08:26:15 UT
g
07:55:20 UT
h
08:09:44 UT
Y (arcsecs)
400
200
−200
−400
−1050
−900
−1200
−1000
−800
750
1000
1250
1500
X (arcsecs)



a
⟨v⟩=747±26 km s⁻¹
L1
b
L2
v_initial=1358 km s⁻¹
acc=−4.5 km s⁻²
c
L3
v_incoming=897 km s⁻¹
v_reflected=−930 km s⁻¹
e
L4
A = 5.56 Mm
τ = 3 hour
T = 17 min
ϕ = 0.79 π
f
L5
A = 2.58 Mm
τ = 24 min
T = 14 min
ϕ = −0.31 π
g
L6
v = 215 km s⁻¹
Distance (Mm)
Time (UT)
07:45
08:00
07:15
07:30



AIA 193 Å Direct 24-Apr-2012 07:00:19
AIA 193 Å Runn. Ratio 2012/04/24 07:00:43
AIA 193 Å Direct 24-Apr-2012 07:00:19
AIA 171 Å Runn. Ratio 2012/04/24 07:00:24
Y (arcsecs)
X (arcsecs)
400
200
0
-200
-1000
-750



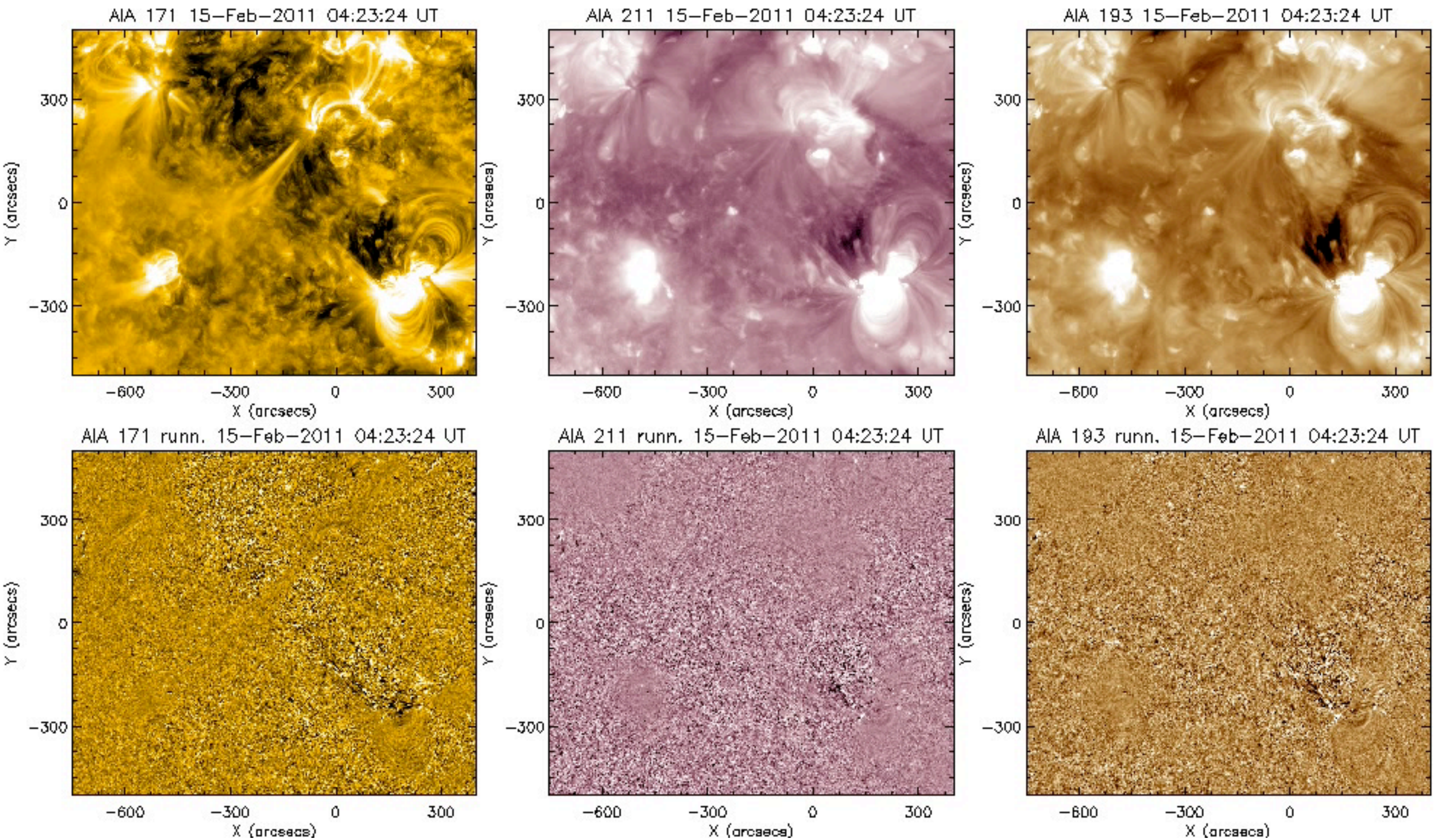
The period of the EUV wave is similar to the unwinding helical structures of the erupting filament, but largely different to that of the associated flare.

Therefore, we think that the EUV wave was most probably excited by the expanding motion of the unwinding helical structure of the erupting filament.

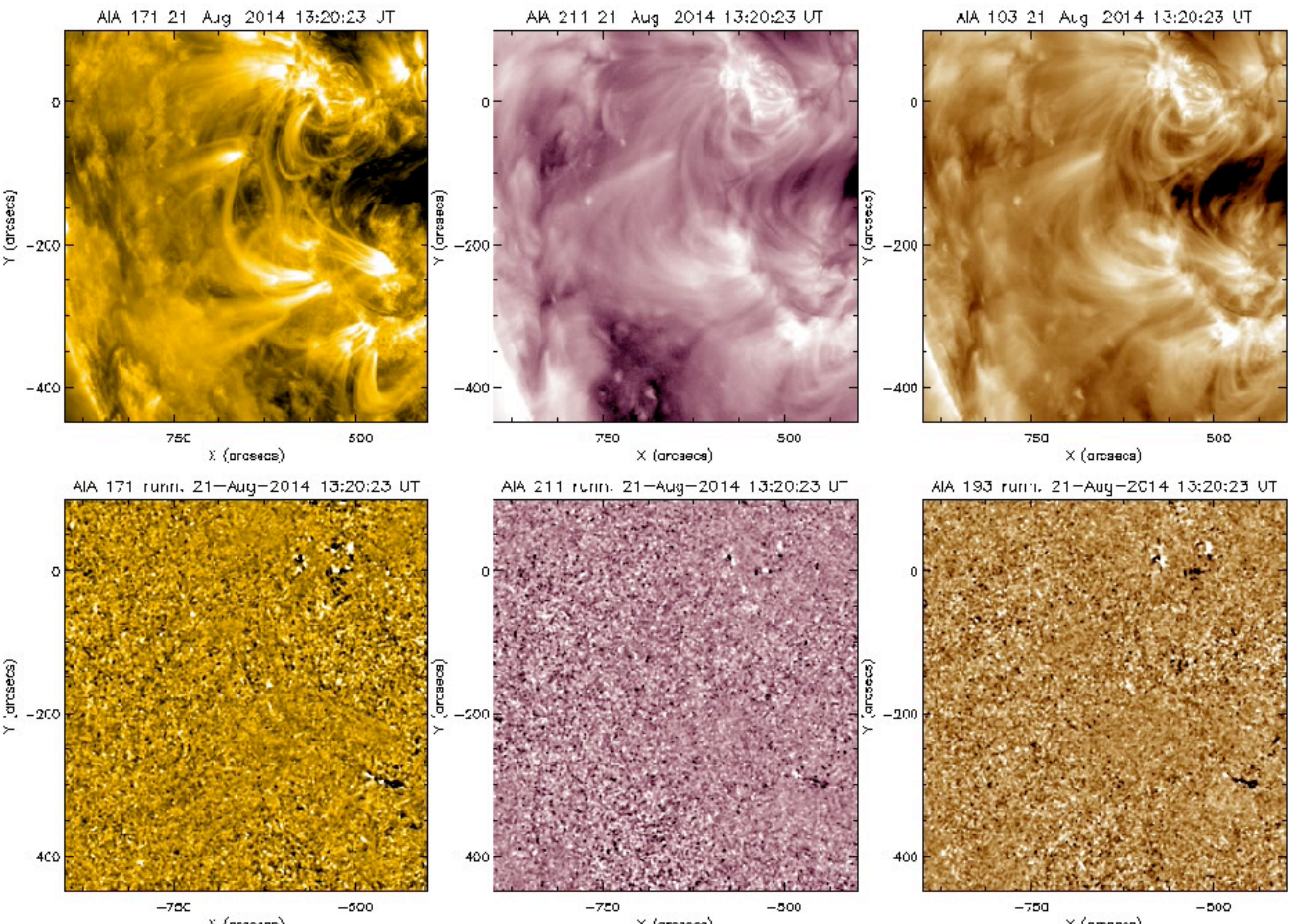
Other possibilities:

1) the shaking or oscillation of the erupting filament;
2) the dispersively evolution of the initially broad-band disturbance caused by the filament/flare eruption.

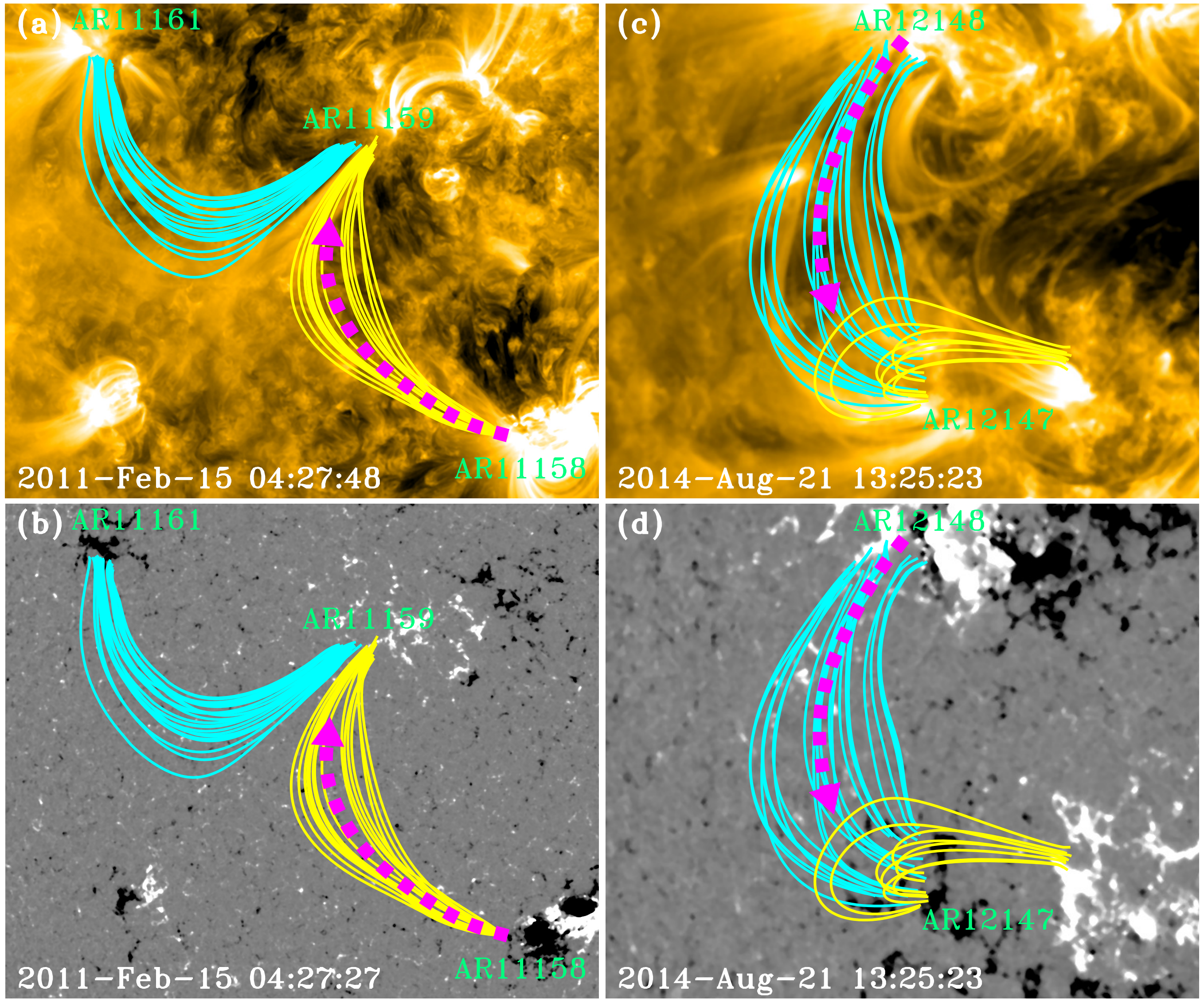
EUV Waves Driven by the Sudden Expansion of Transequatorial Loops Caused by Coronal Jets (Shen et al. 2018, ApJL, 860, 8)

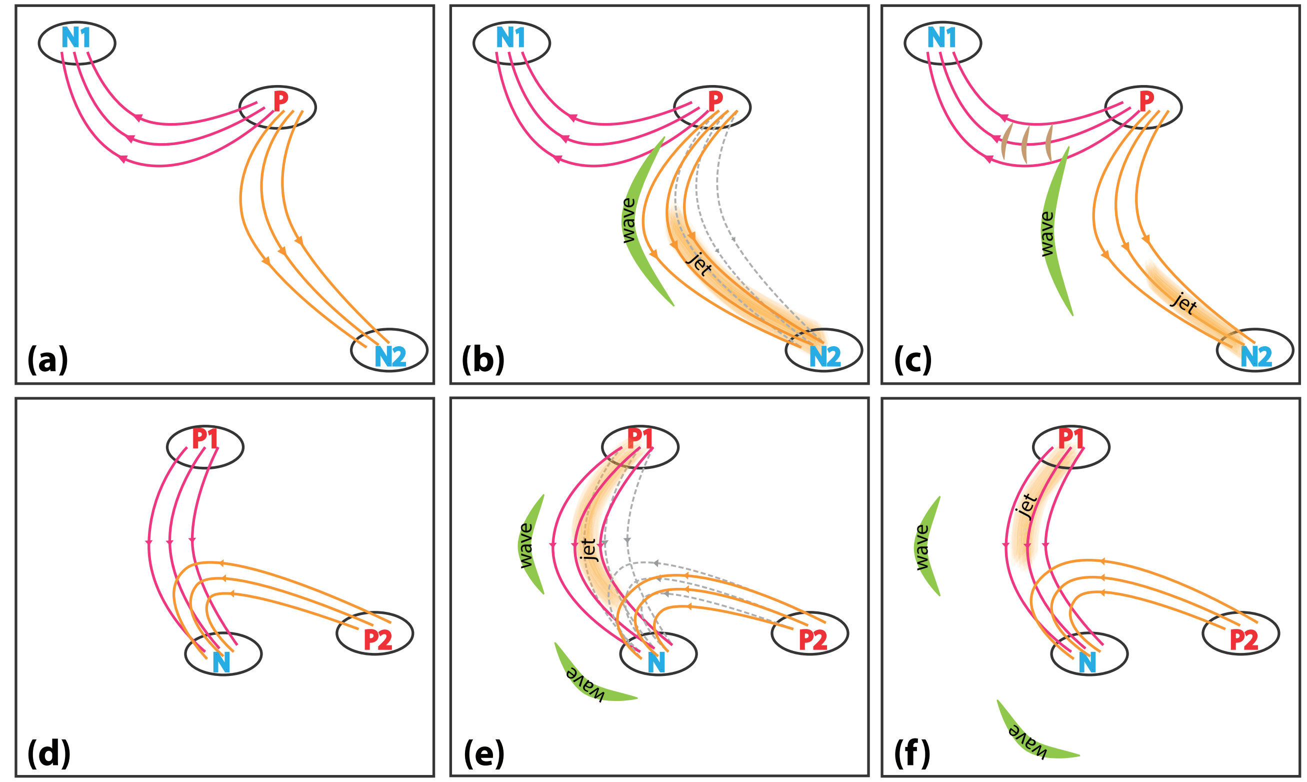


No CME; Wave speed: 466 km/s; Jet speed: 335 km/s; Case I in Shen et al. 2018



No CME; Wave speed: 360 km/s; Jet speed: 282 km/s; Case II of Shen et al. 2018





EUV waves driven by the sudden expansion of corona loops **have a shorter lifetime less than 10 minutes, much less than the typical lifetime (hour) of normal CME-driven EUV waves**.

The impingement of coronal jets upon coronal loop can effectively increase the magnetic and plasma pressures, which therefore excite the EUV waves. Since the impingement of coronal jets upon coronal loops are transient phenomena unlike CMEs that can last for a long time, therefore, such kind of EUV waves have a shorter lifetime.

Summary

- Large-scale coronal **EUV waves at different heights of the solar atmosphere showed similar shape and speed**, supporting the scenario that Moreton waves are the intersection lines of coronal fast-mode waves in the chromosphere.

- Most of the previous studies have suggested that EUV waves are driven by CMEs. However, we found that EUV waves can also be launched **by other kinds of solar activities, such as the sudden expansion of coronal loops, coronal jets, and the unwinding motion of erupting filaments**;

- EUV waves propagate at fast-mode wave speeds, and they showed **different kinds of wave phenomena,** such as transmission, reflection, and refraction. Therefore, they should be real waves in the physical nature.