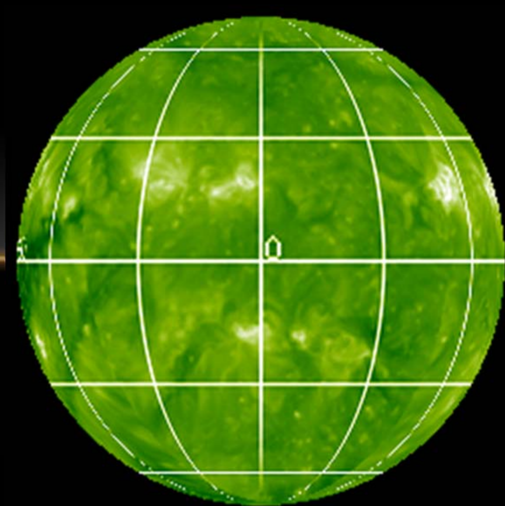
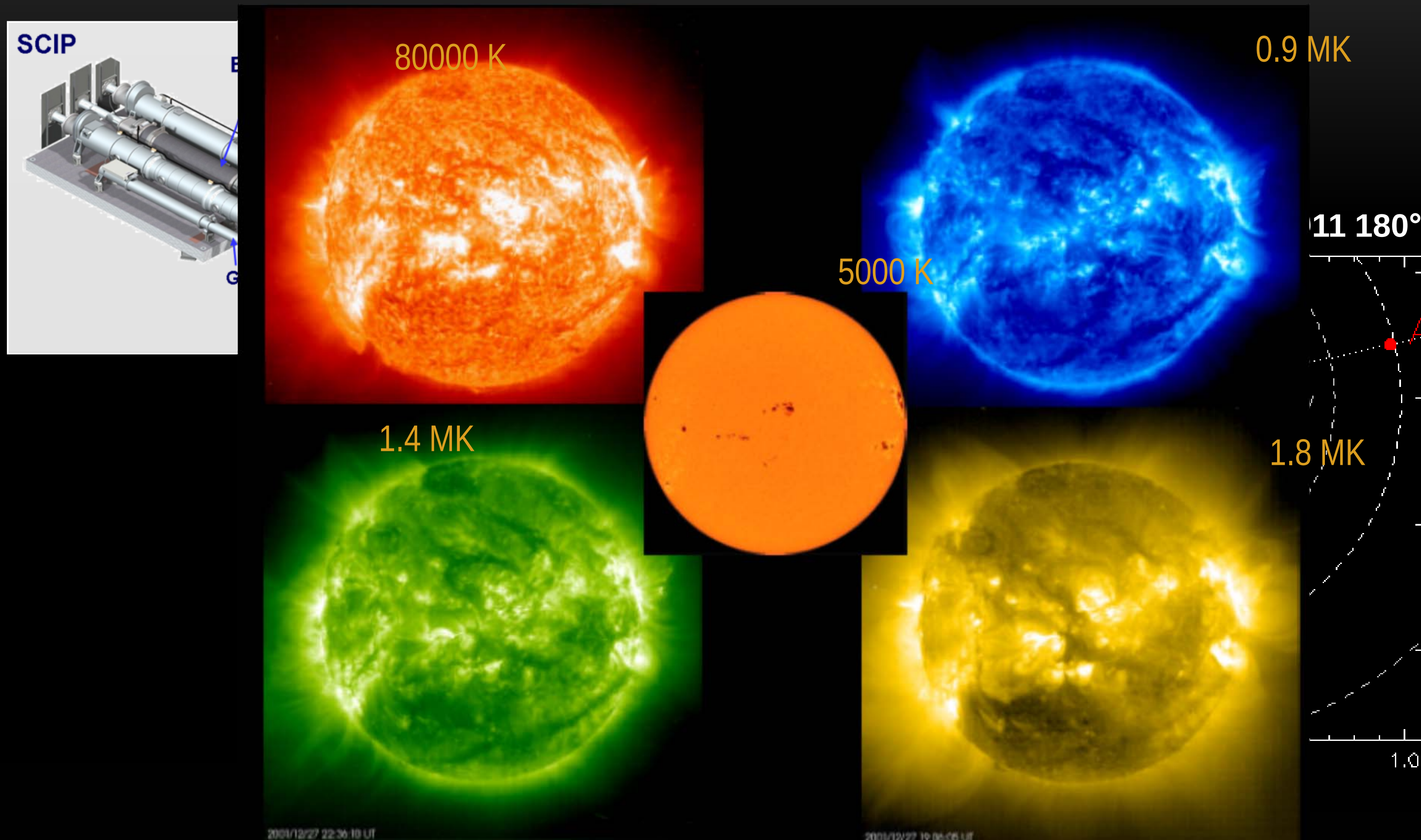
NEW VIEWS OF THE SOLAR ATMOSPHERE FROM STEREO AND SDO



Angelos Vourlidas

NRL

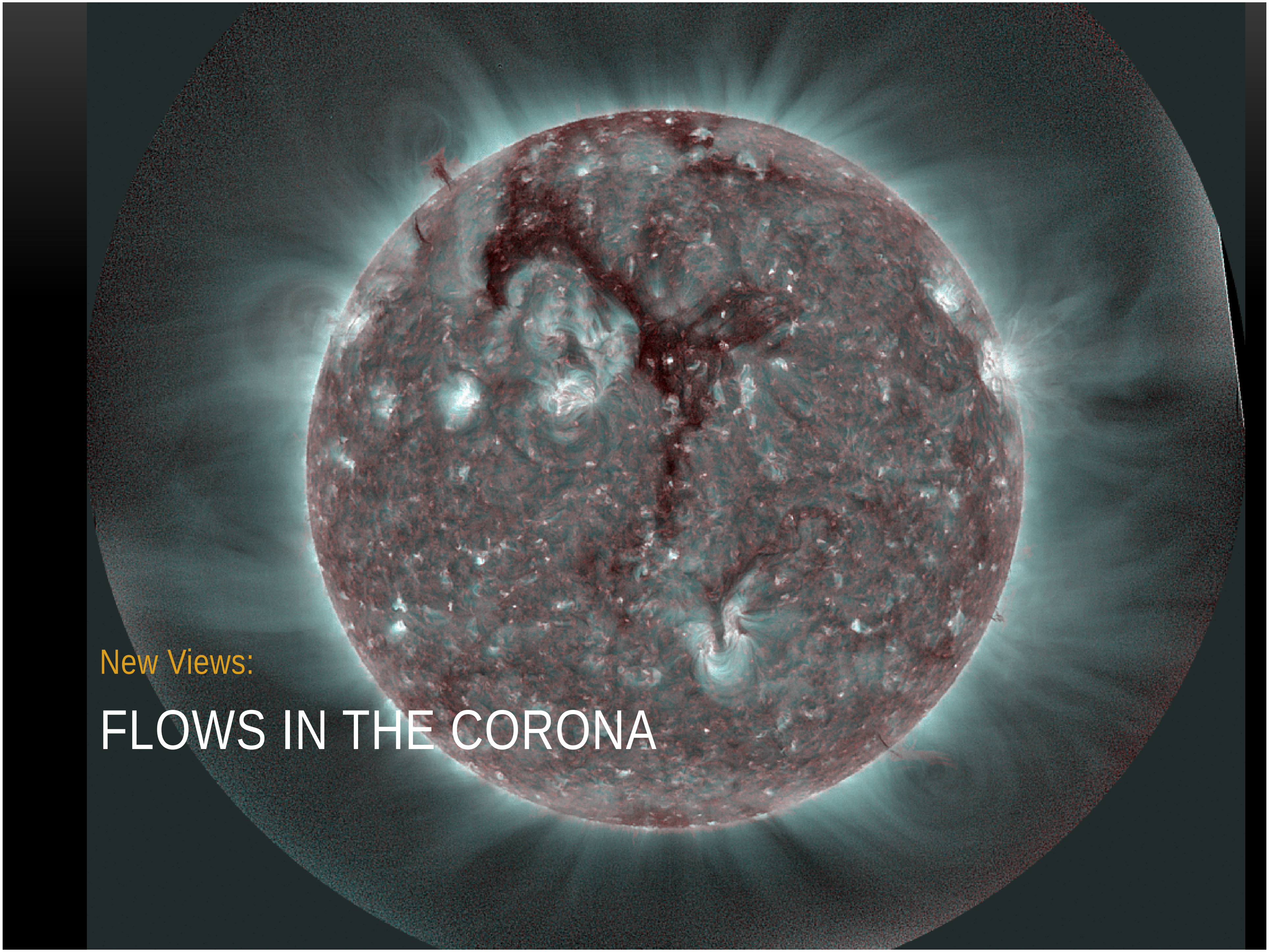
EUVI TELESCOPE ON STEREO



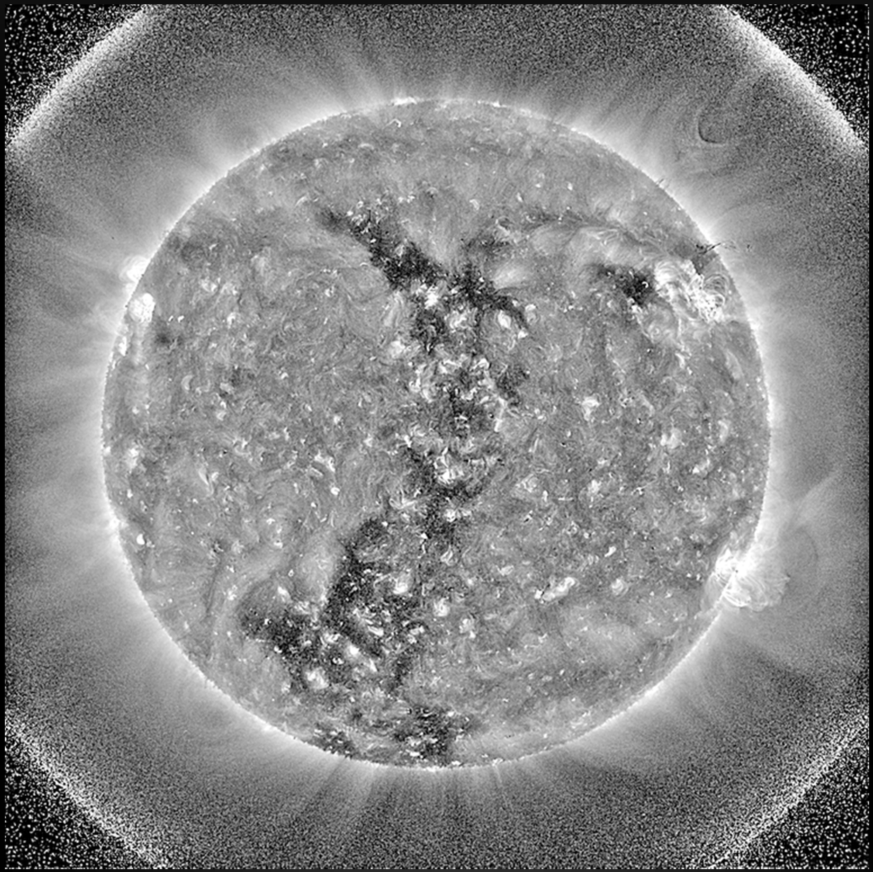
Current EUVI View

SDO AIA

Observing the Sun's atmosphere with the Solar Dynamics Observatory
5,000 K
5,000 K
50,000 K
100,000 K
600,000 K
1,200,000 K & 20,000,000 K
2,000,000 K
2,500,000 K
6,300,000 K
400,000 K
& 10,000,000 K
& 15,000,000 K
OUR EYE ON THE SUN
SOLAR
DYNAMICS
OBSERVATORY
NASA
HMI • AIA • EVE
uclan

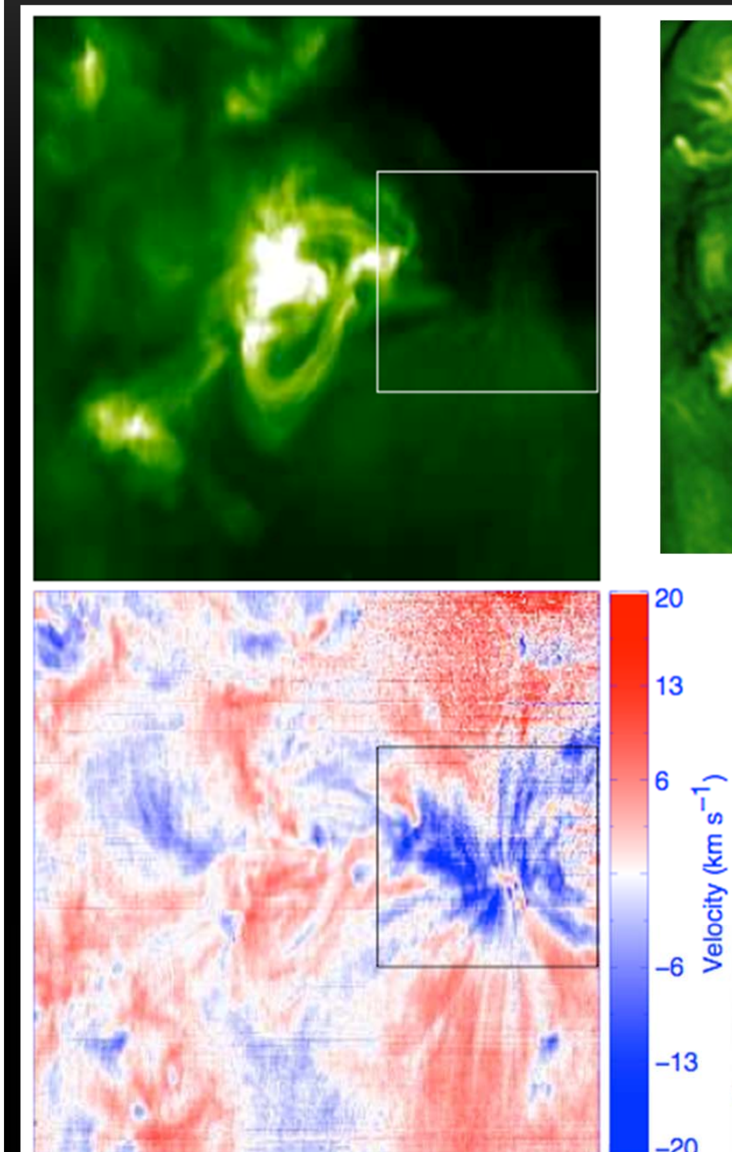

New Views:
FLOWS IN THE CORONA

FLOWS SEEN OVER THE FULL SUN (SDO)

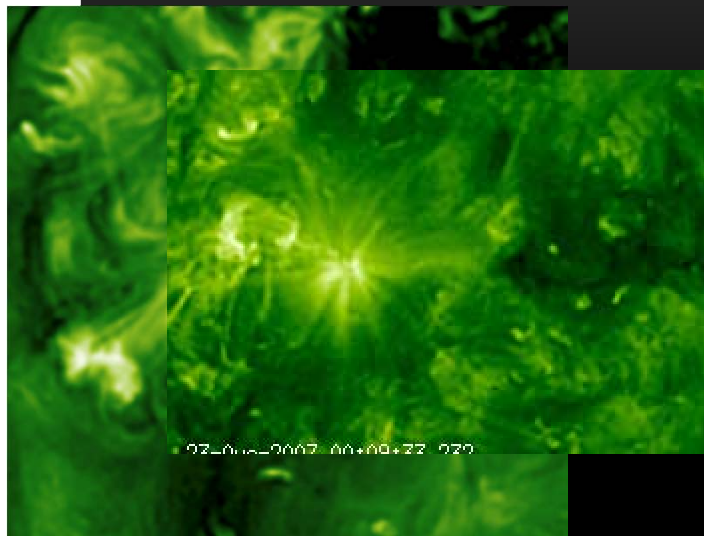


193 Å
~1.4 MK

August 23, 2007



From Doschek, et al., *ApJ*, 686, 1362, 2008



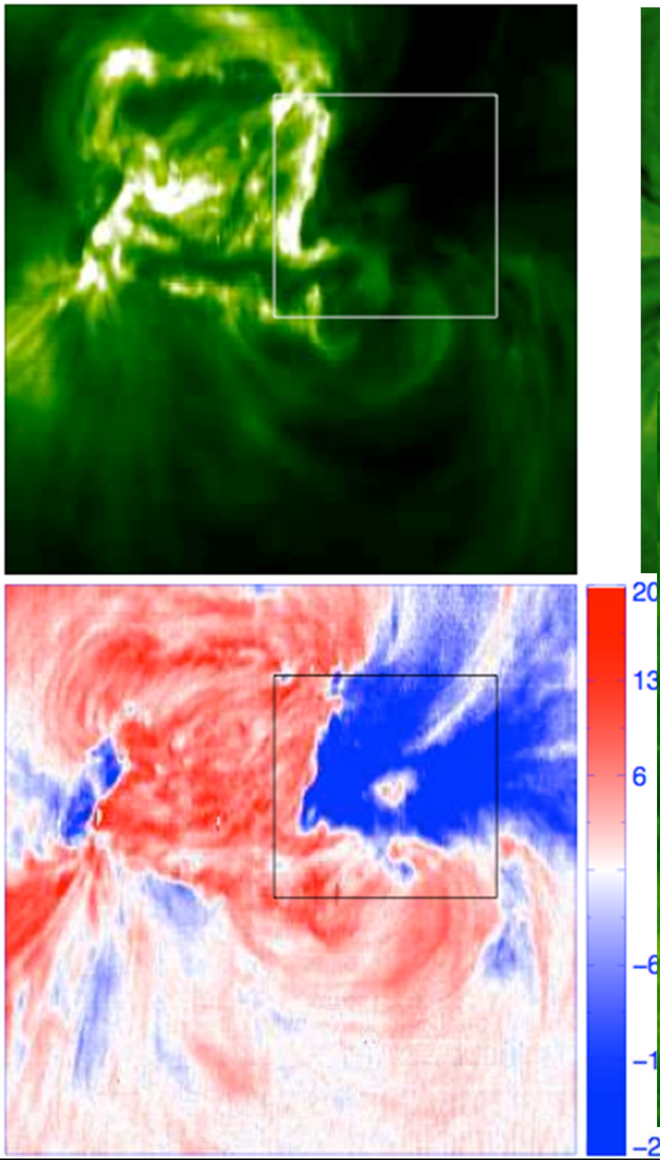
EUVI B 195 (06:55 UT)
wavelet processed snapshot of the region in Doschek et al paper

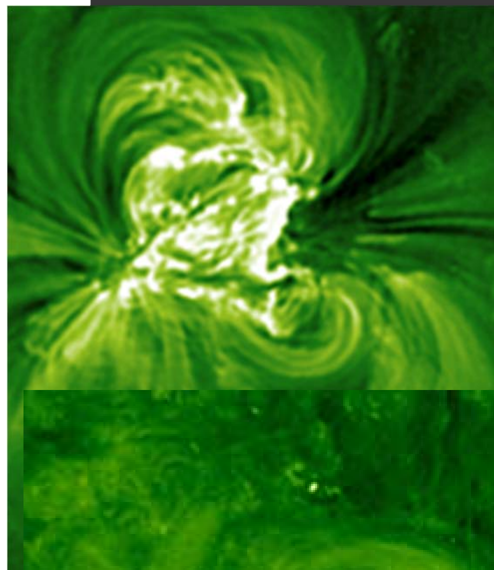
Top: FeXII 195.12 A intensity

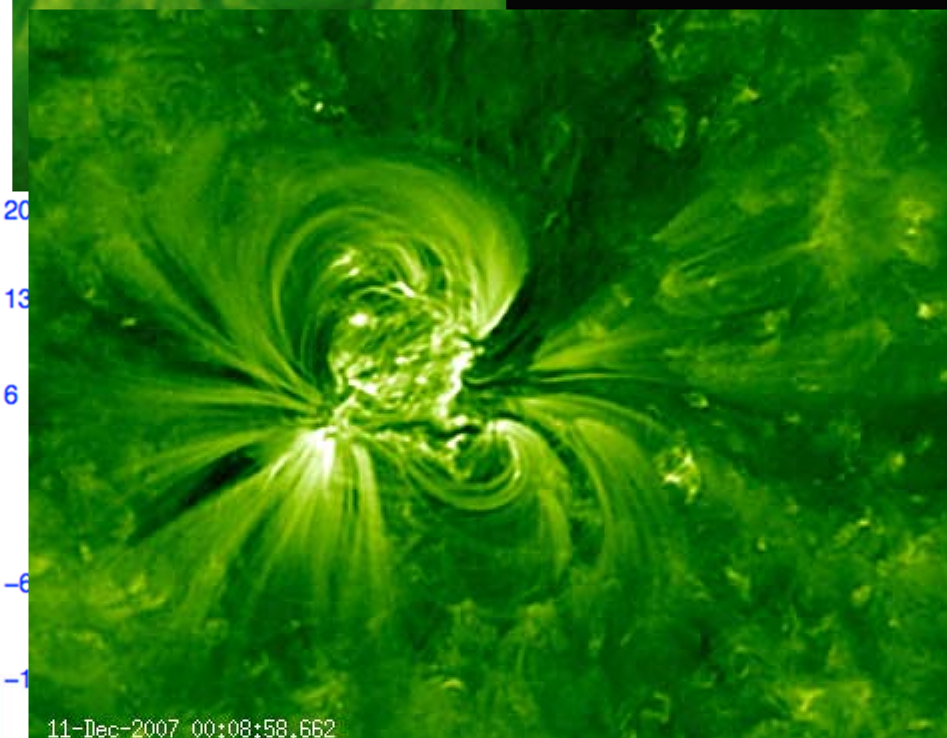
Bottom: Doppler Map obtained with Hinode/EIS. (blue is towards the observer)

December 11, 2007

Also from
Doschek, et al., *ApJ*, 686, 1362, 2008







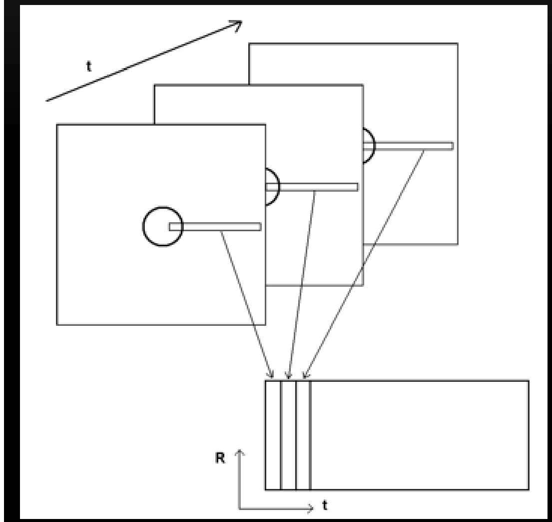
UT)

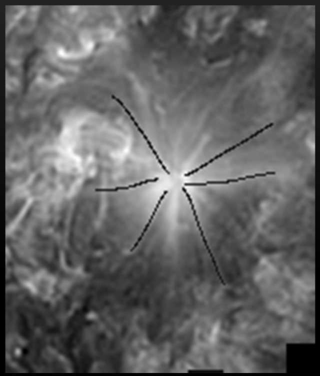
Top: FeXII 195.12 A intensity

Bottom: Doppler Map (blue is towards the observer) obtained with the HINODE/EIS.

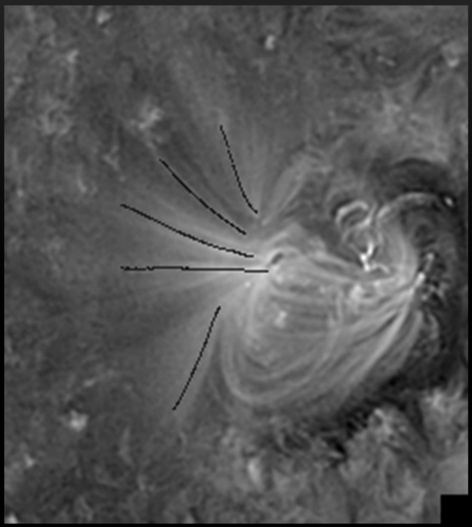
HOW CAN WE MEASURE THE SPEED OF THE DISTURBANCES?

Original idea: Use of Height-Time Maps (J-maps) available in solarsoft (Sheeley et al. 1999, 2000).



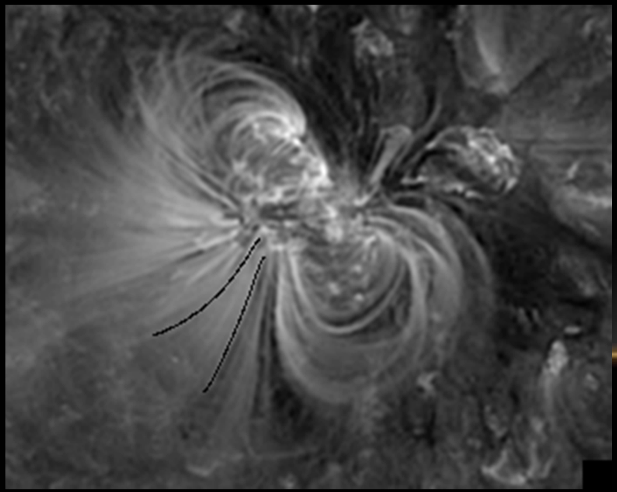


2007/08/23 EUVI B 171

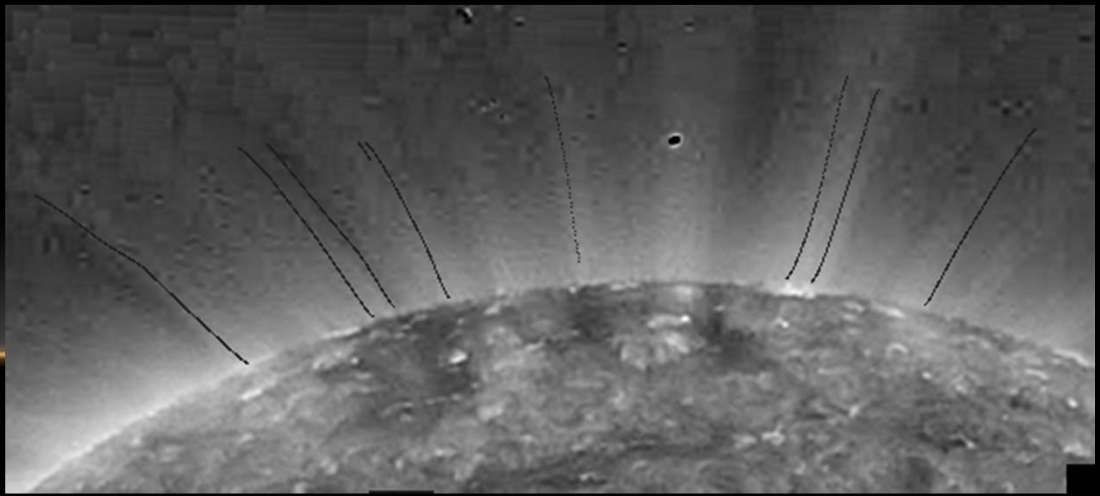


2007/02/20 EUVI B 171

2007/12/09 EUVI B 171



2008/03/25 EUVI B 171



TIME-DISTANCE MAPS

1) Wavelet-processed images are de-rotated by 8 hour segments.
2) Paths manually defined by point-and-click on the Region of Interest
3) K-maps created through each 8 hour segments.

S/C A

Distance along the path

Time

- Using the time-distance maps we are able to find the **projected** speed of the density enhancements.
- For reliable speed assessments, tracked features must remain <u>constant</u> throughout the 8 hour period.

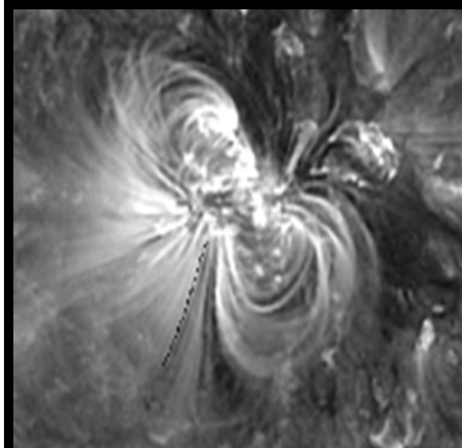
KINEMATICAL CHARACTERIZATION
(STENBORG ET AL 2011, A&A, 526, 58)

A **qualitative** analysis shows that, the traveling disturbances are stronger when:

i) closed field lines are nearby apparently open field lines,

ii) closed field lines are nearby another closed field lines that end up on different foot points.

Example of **quantitative** analysis



December 9, 2007 [00:00 UT - 08:00 UT]

--- Projected Speed of a sample of intensity variations as they move along the selected ray ----

The seven cases analyzed (including "on-disk" and "off-limb" cases) result in projected speeds in the range 50 - 140 km/s

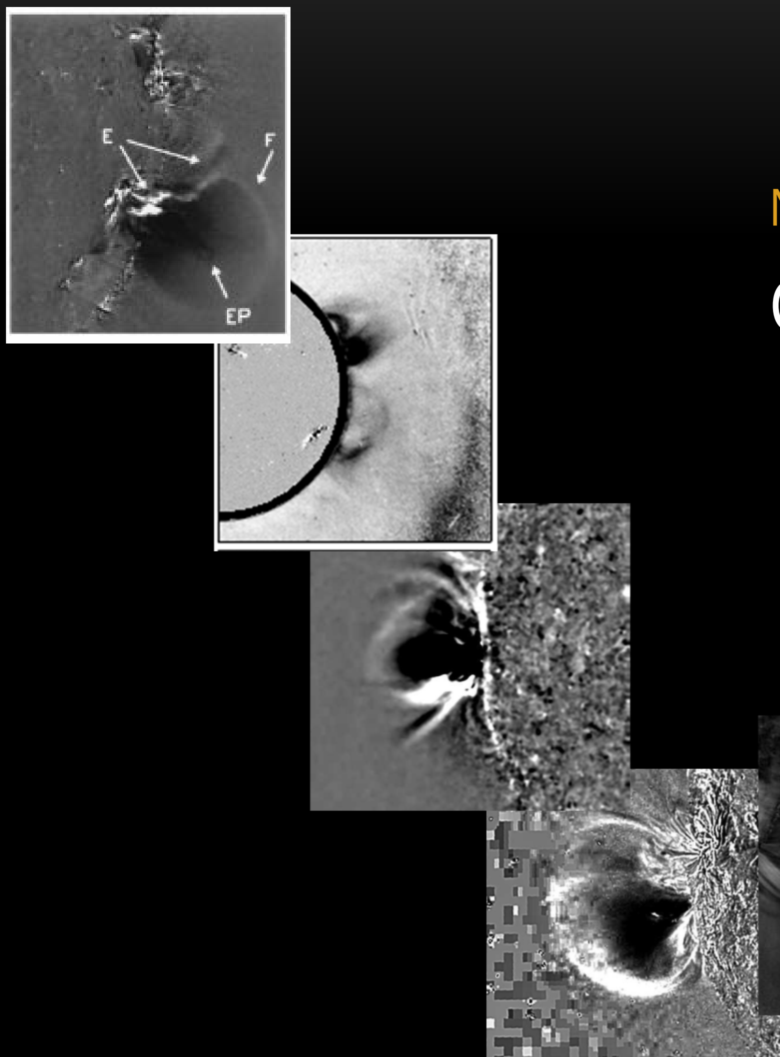
IMPLICATIONS

Flows are omnipresent. They appear everywhere there is a loop structure (quiet sun, active regions, coronal holes).

High speeds (60-150 km/s). Close to acoustic speed.

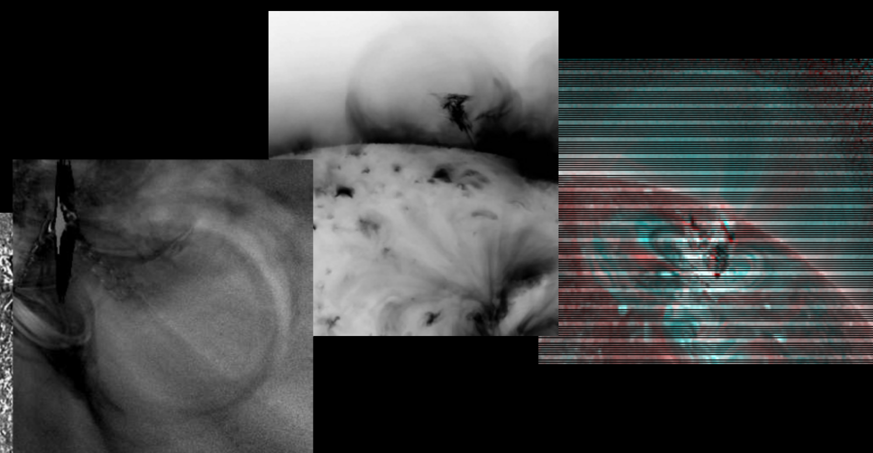
Flows are quasi-periodic (16 min or harmonics).

How are they related to the solar wind?!



New Views

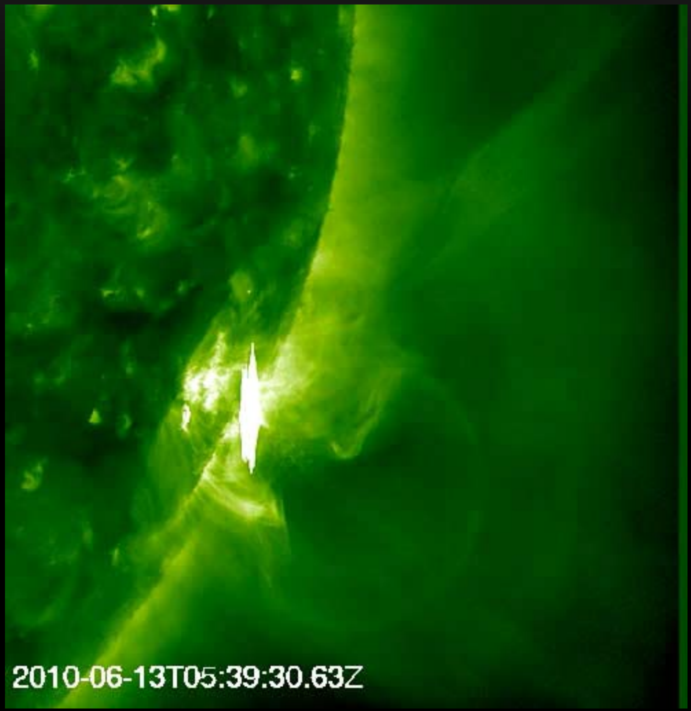
CME INITIATION



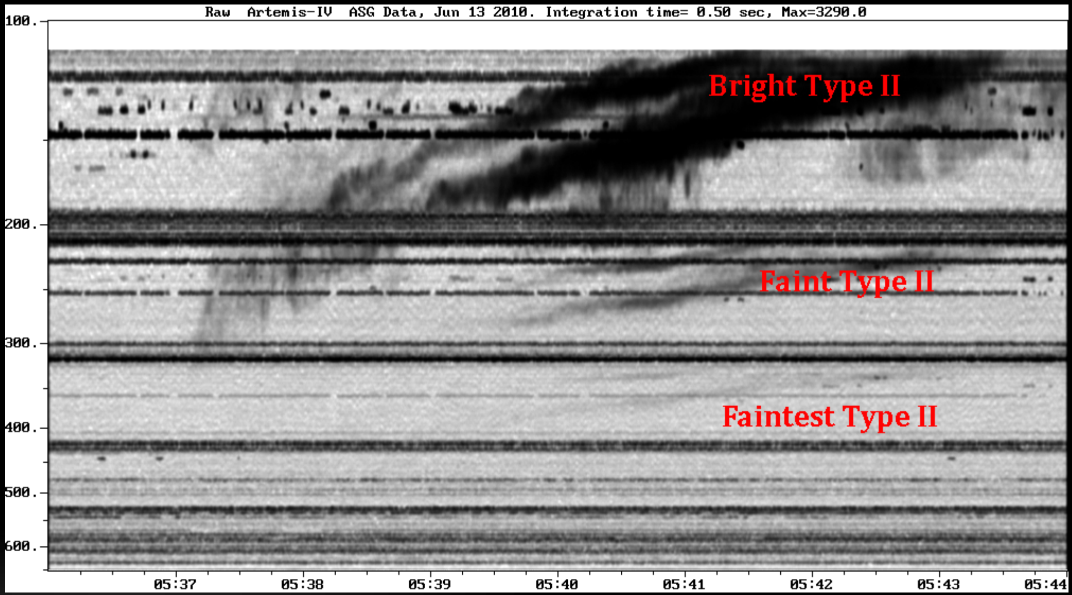
JUNE 13, 2010

Patsourakos et al, (2010), Kozarev et al (2011), Ma et al (2011)

See S1-12 by A. Kouloumvakos



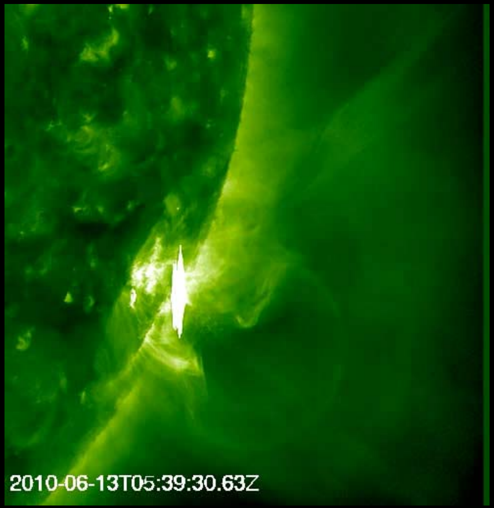
Clearest evidence of wave formation in the EUV (so far)

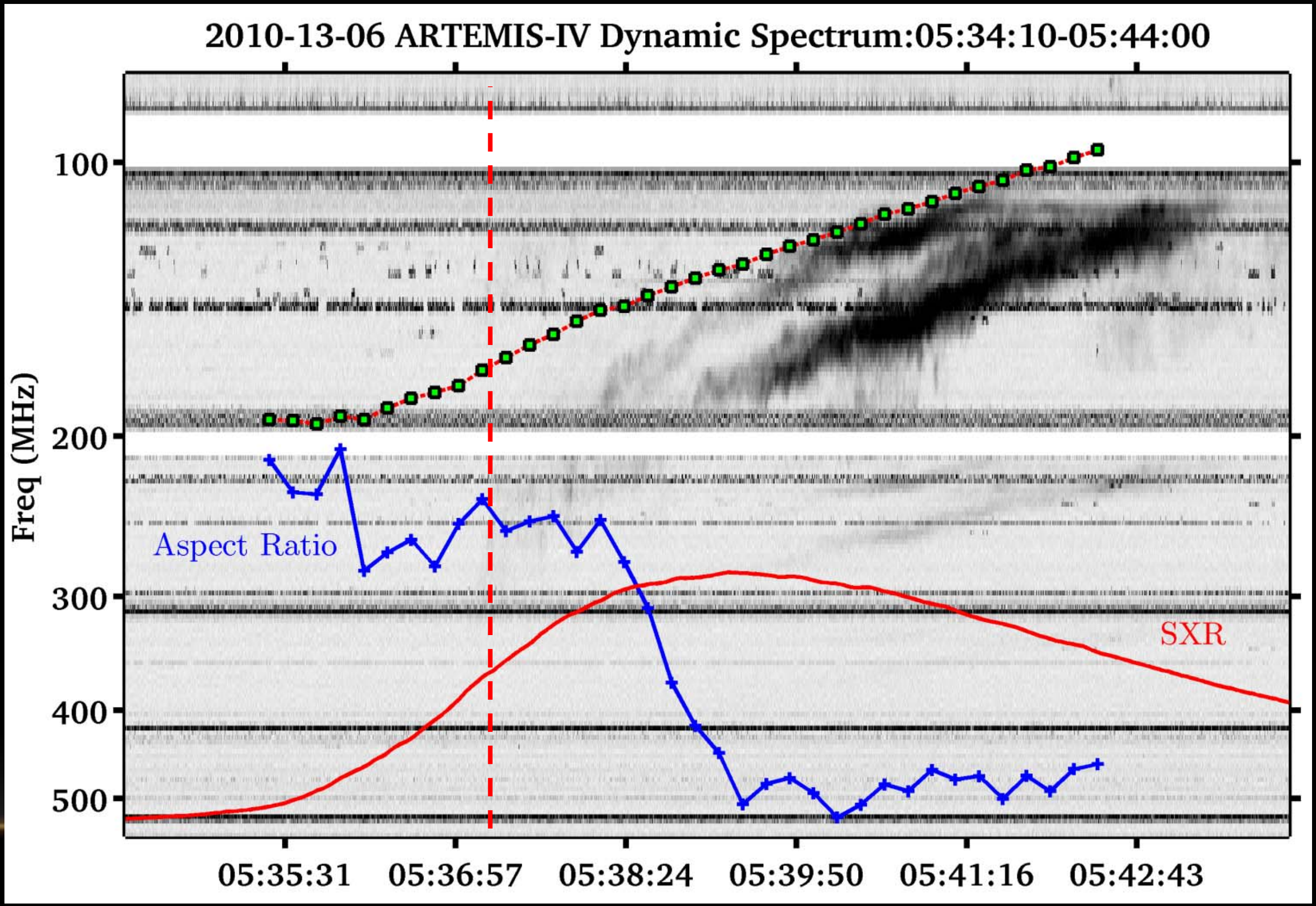


ARTEMIS radio spectrum shows 3 type-II lanes

COMPARING EUV TO RADIO HEIGHT-TIME

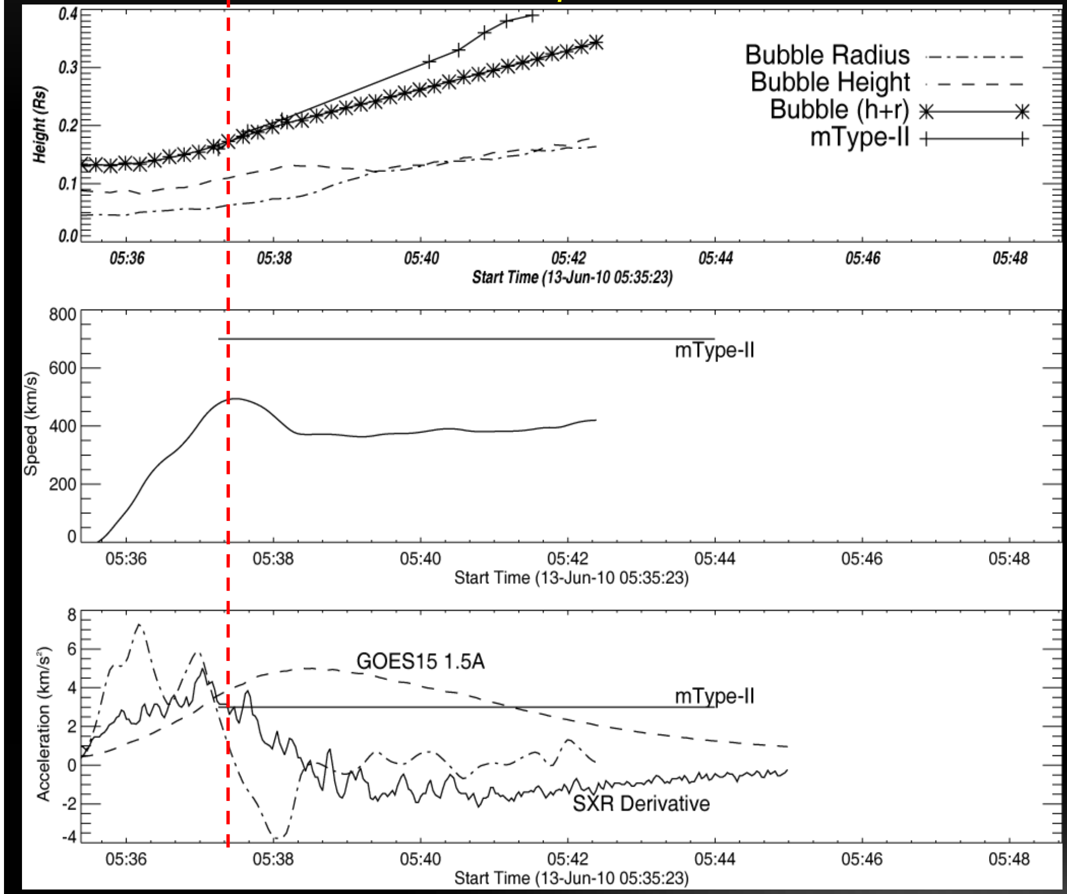
Plasma frequency of
CME front from
Baumbach-Allen model ($n_e(r) \sim R^{-16} + R^{-6}$)





JUNE 13, 2010 KINEMATICS

EUV wave ‘decouples’ from front



CONCLUSIONS:

Bubble acceleration is over BEFORE SXR flare peak.

Speed: TypeII ≠ bubble
Timing: TypeII = Wave

CME acceleration last ~ 2mins only.

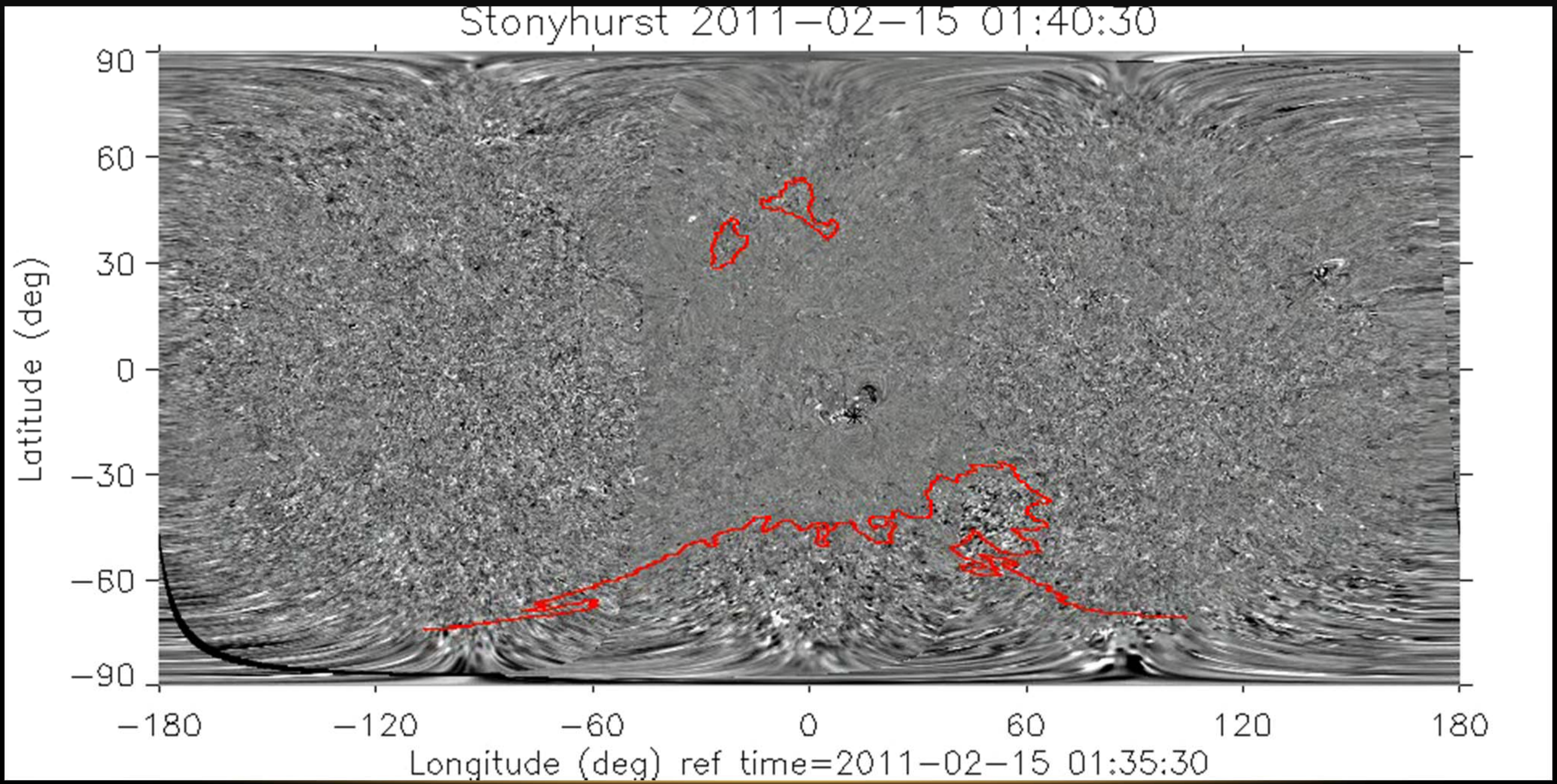
Interpretation: Piston--driven shock becomes blast wave.

OTHER IMPULSIVE EVENTS

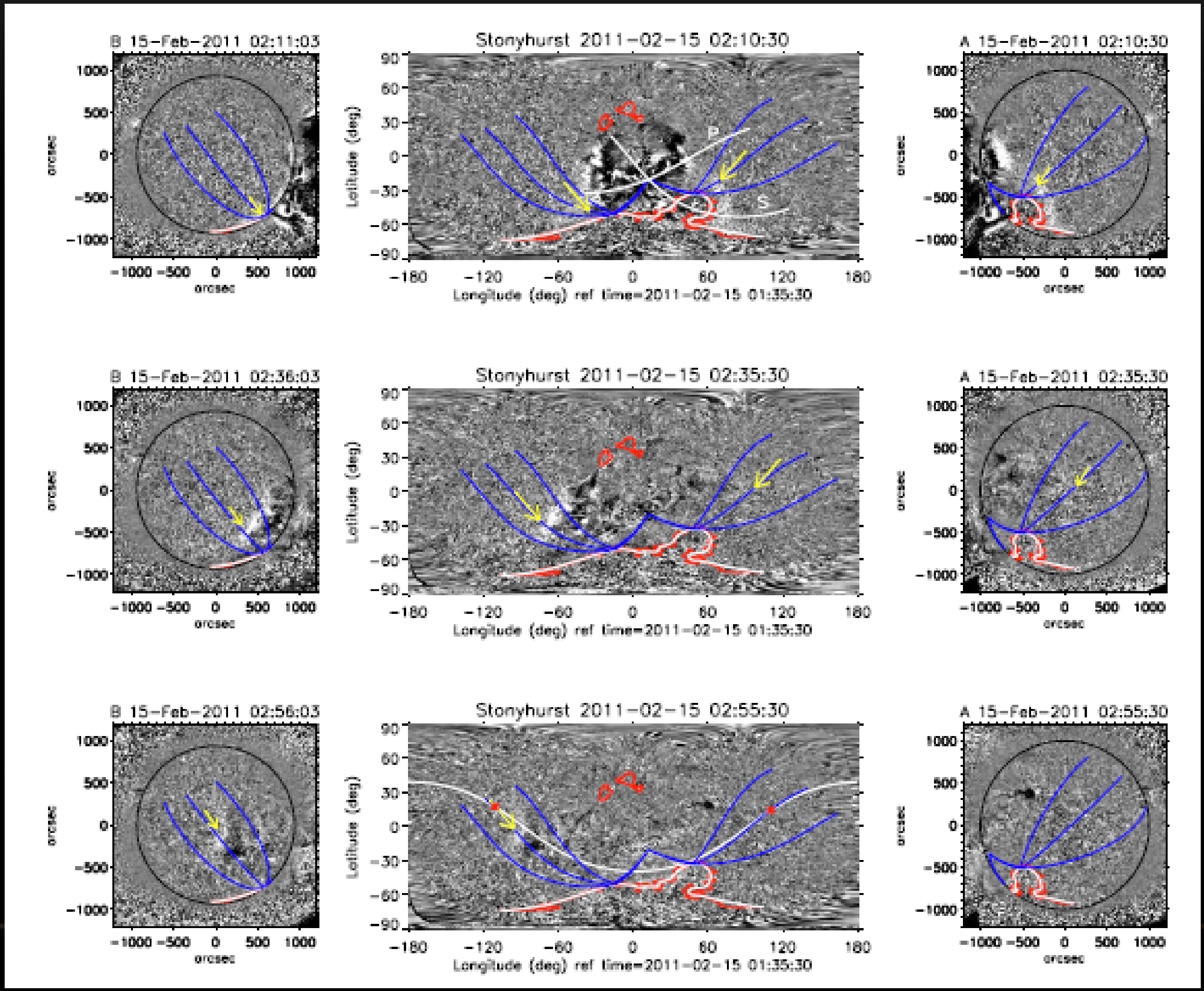
Date	Metric Type II	EUV Wave	SXR Flare
06/03/2007	✓	✓	C 5.3
01/02/2008	✗	✓	C 1.3
03/25/2008	✓	✓	M 1.7
02/13/2009	?	✓	B 2.3
12/16/2009	IV + cont	✓(weak)	C 5.3
01/17/2010	✓	✓	✓ *(occulted)*
06/13/2010	✓	✓	M 1.0
11/03/2010	✓	✓	C 3.0
02/11/2011	✗	✓	< B 3
02/15/2011	✓	✓	X 2.2
02/24/2011	✓	✓	M 3.5
03/08/2011	✓	✓	M 1.5

FEBRUARY 15, 2011

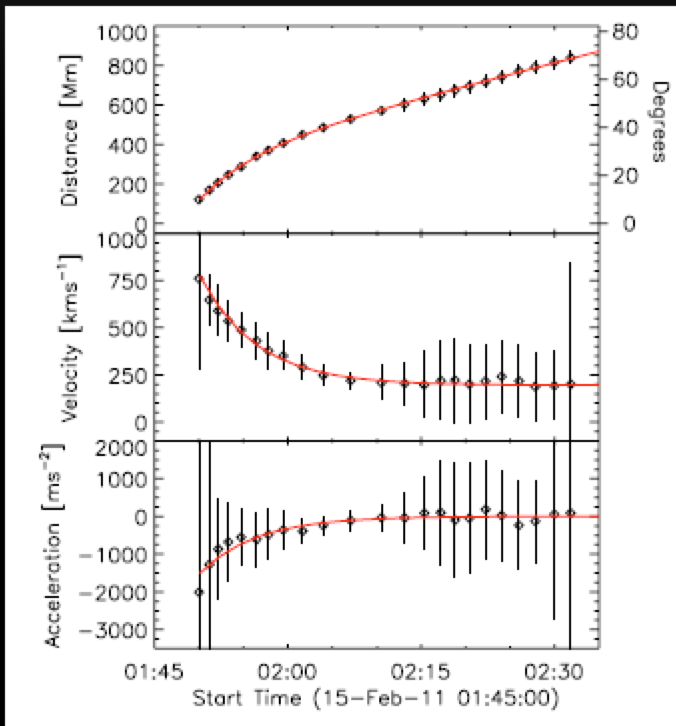
Olmedo et al (2011)



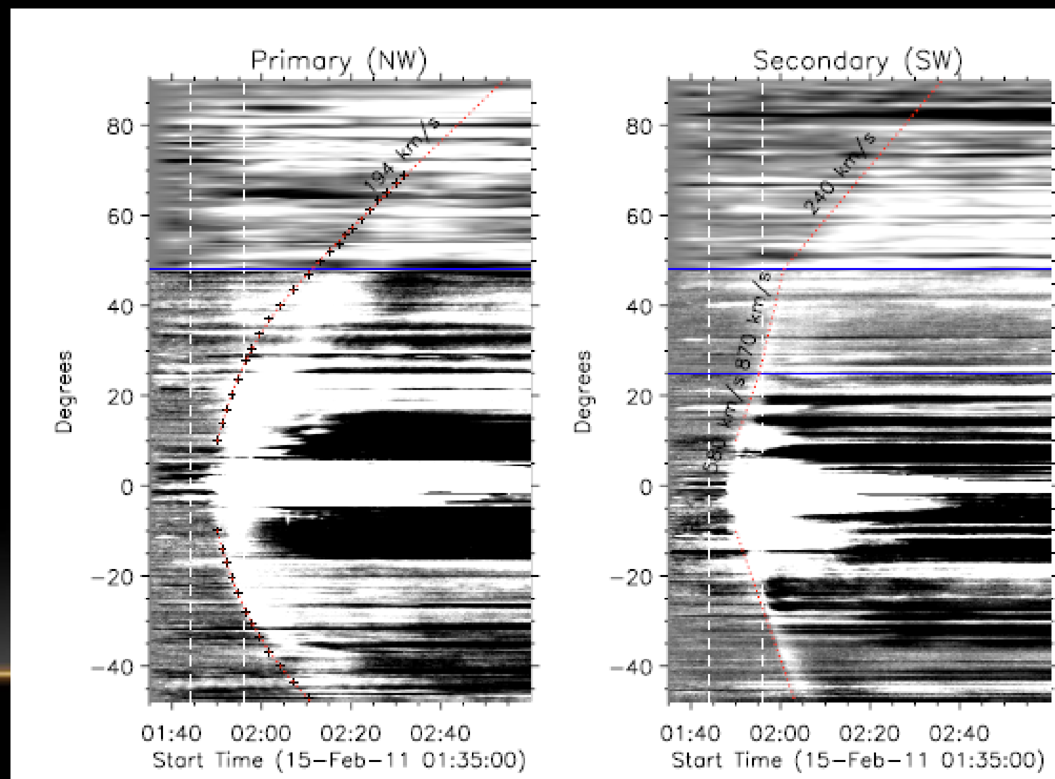
REFLECTION & TRANSMISSION OF WAVES



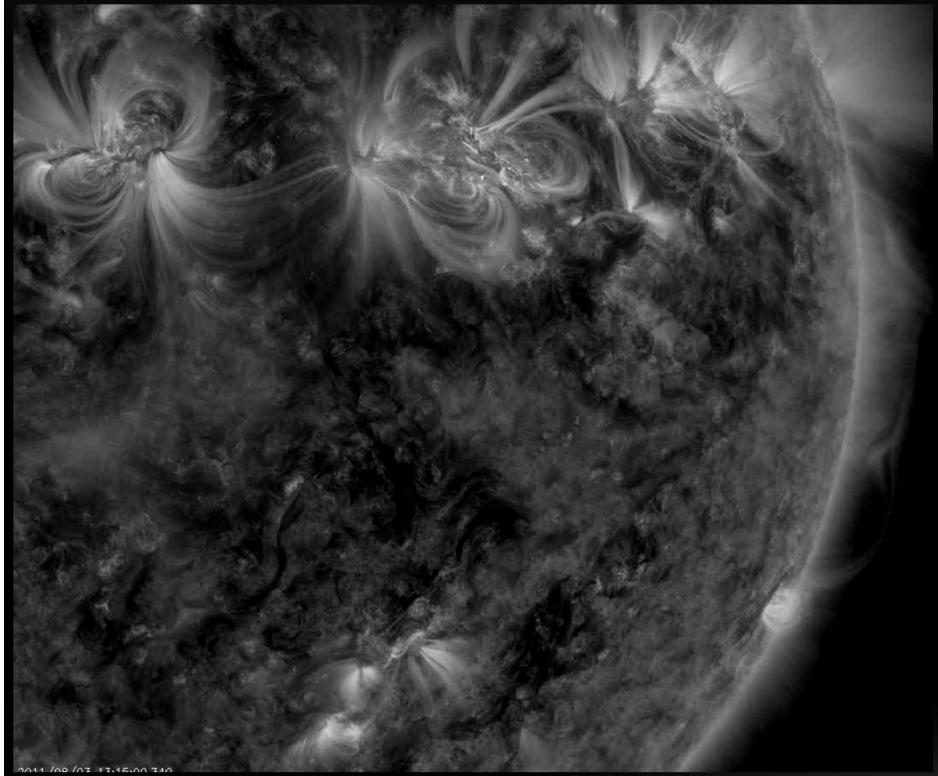
WAVE TRANSMISSION THROUGH A CORONAL HOLE

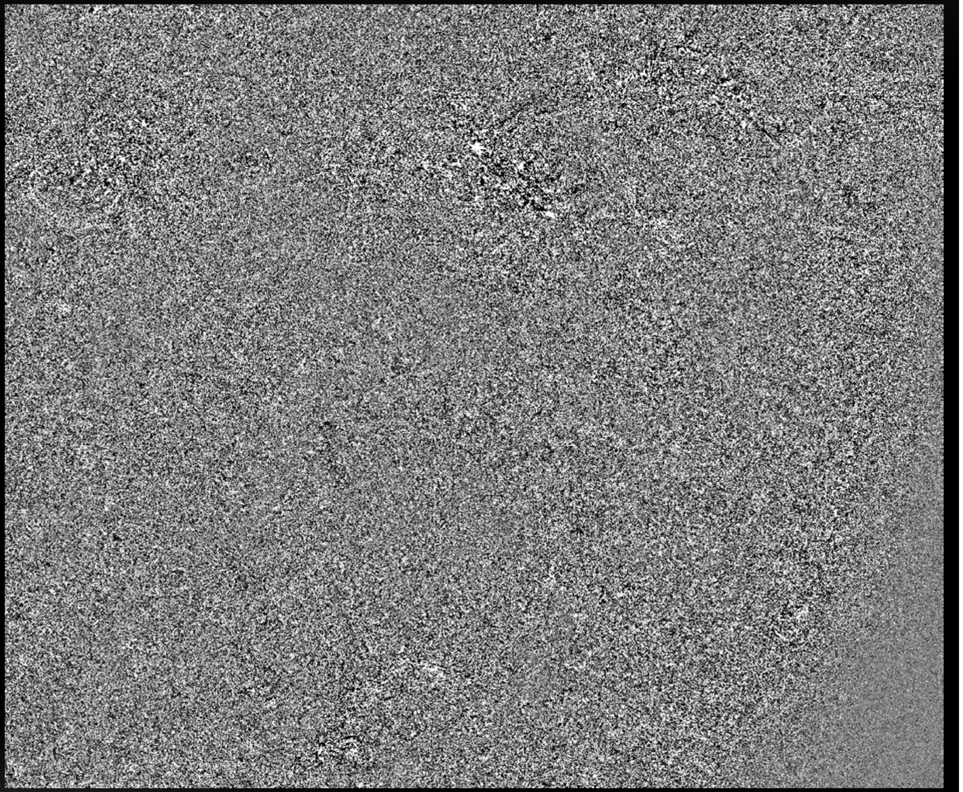


- 1^{st} detection of wave transmission through a coronal hole.
- Proves unequivocally the wave nature of EUV/EIT wave.
- Verifies prediction of Schmidt & Ofman (2010) simulations.



AUGUST 3, 2011 CME





IMPLICATIONS

Impulsive CMEs seem to go through an inflationary phase.

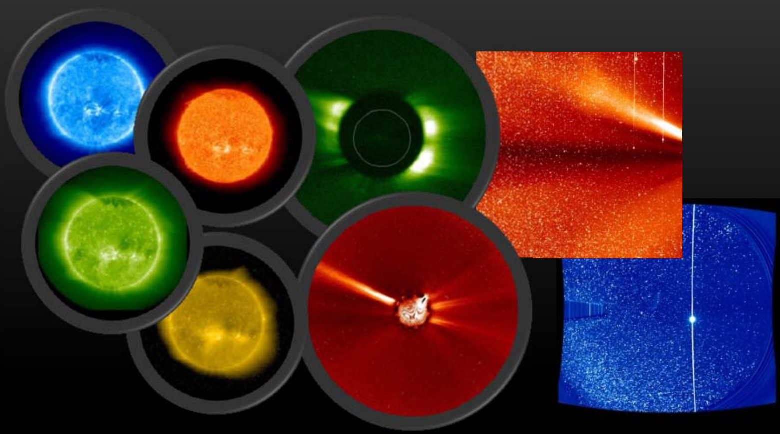
Type II duration = lateral expansion duration.

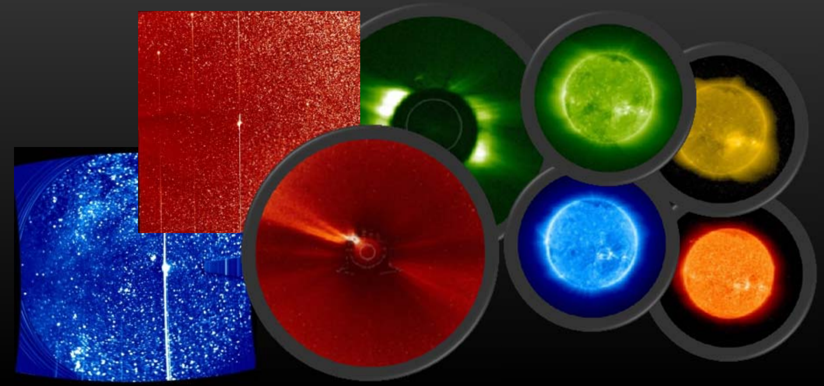
Waves, shocks may be driven by the lateral NOT radial CME expansion.

The bubble appearance depends on acceleration gradient NOT speed magnitude (impulsiveness).

EUV CME measurements may be misleading and not describe the actual CME long-term behavior.

High cadence analysis using differencing could introduce artifacts. It should be prefromed carefully.



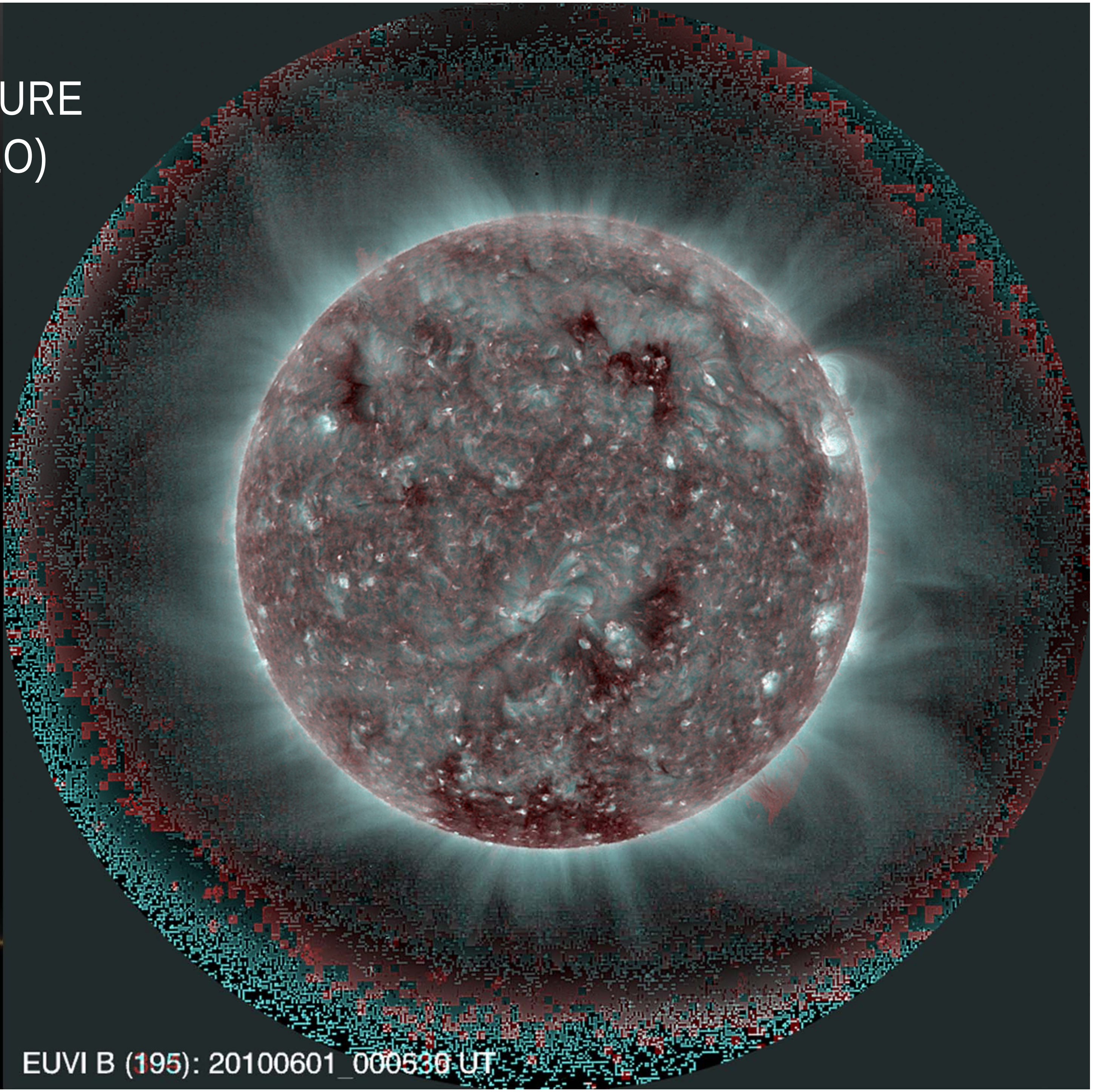


New Views

IMAGE OVERLOAD

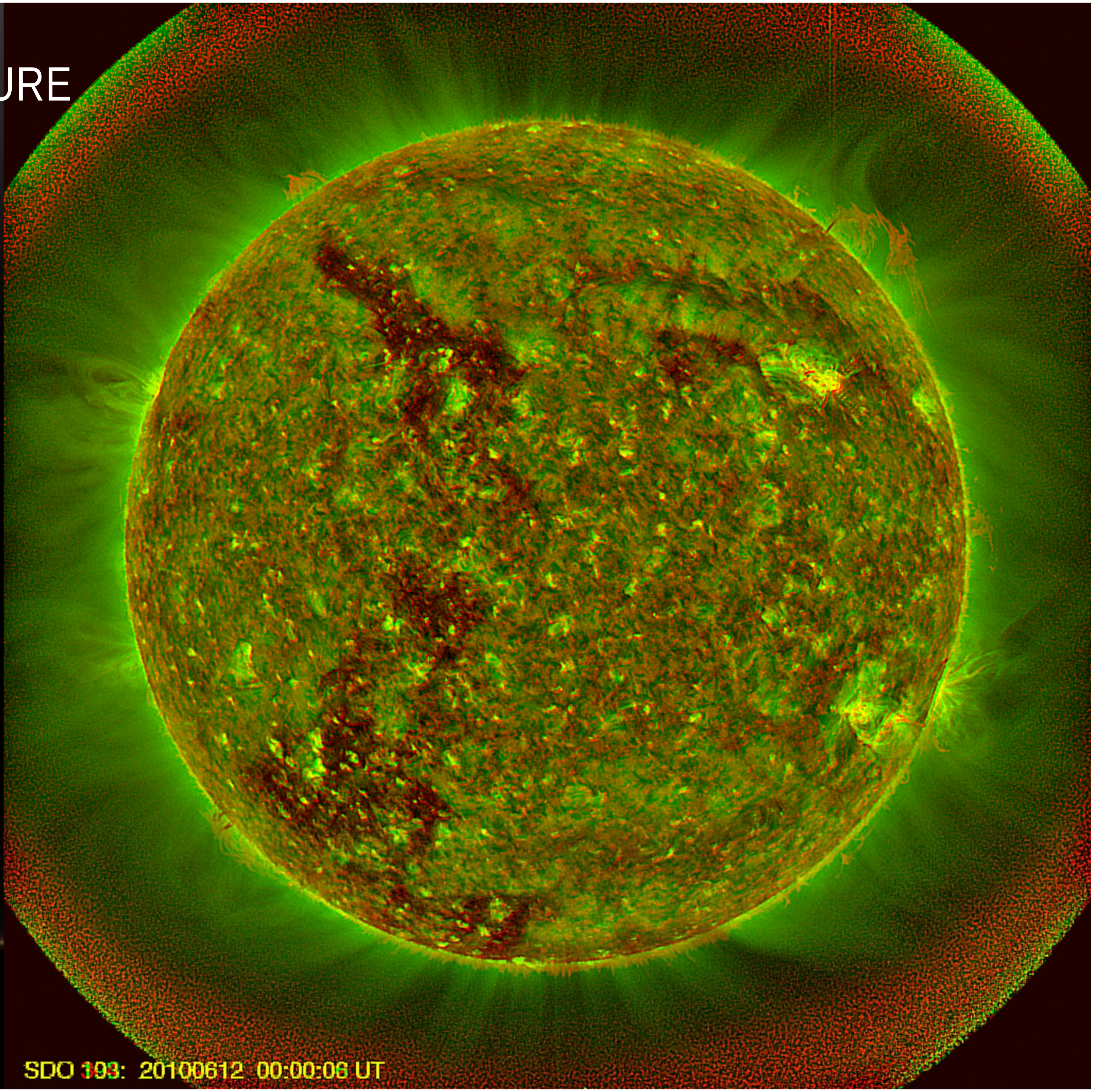
TWO-TEMPERATURE MOVIES (STEREO)

304 Å (80,000 K)
195 Å (1.4 MK)



TWO-TEMPERATURE MOVIES (SDO)

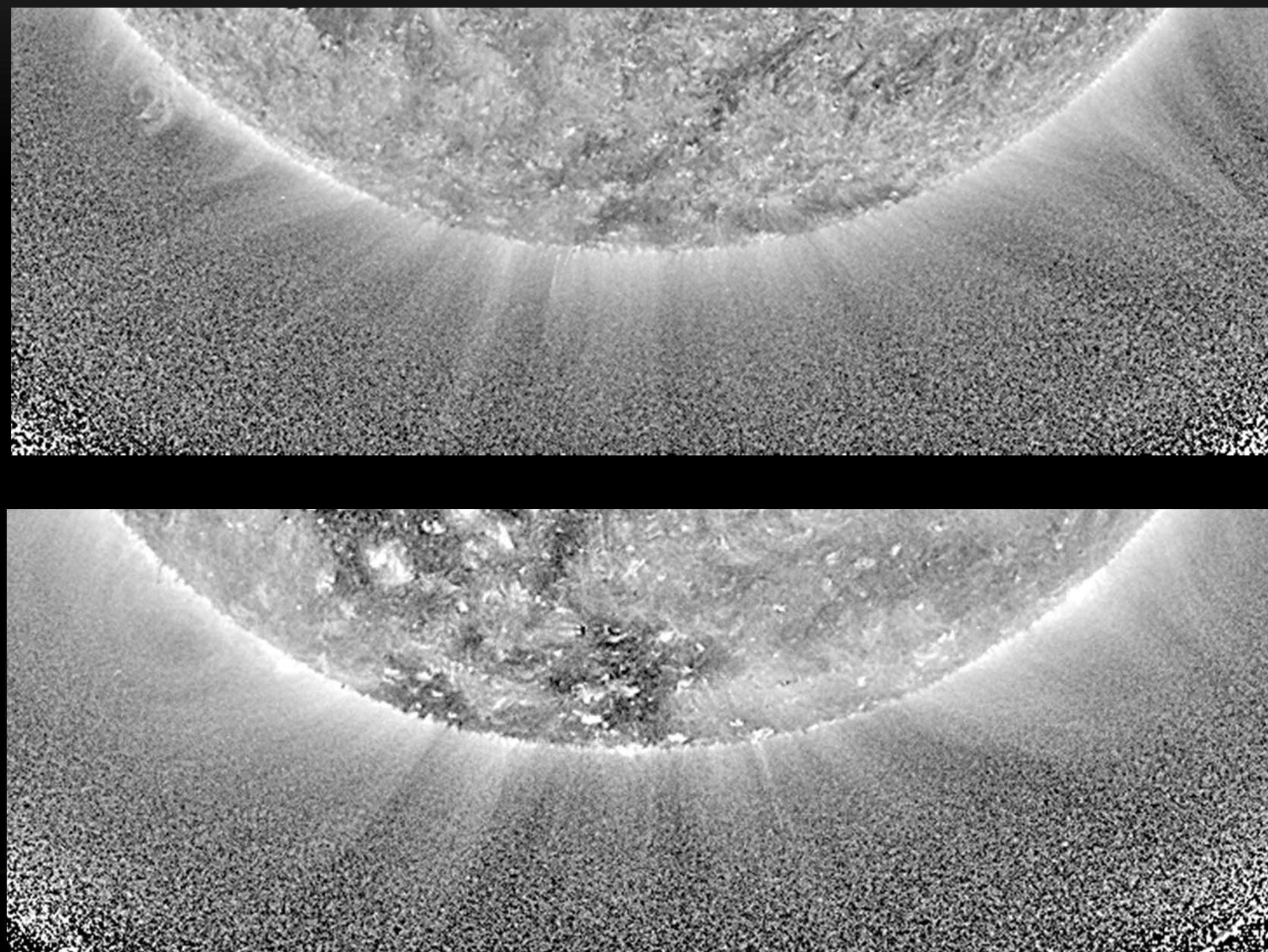
304 Å (80,000 K)
193 Å (1.4 MK)



OUTFLOWS IN CORONAL HOLE (SDO)

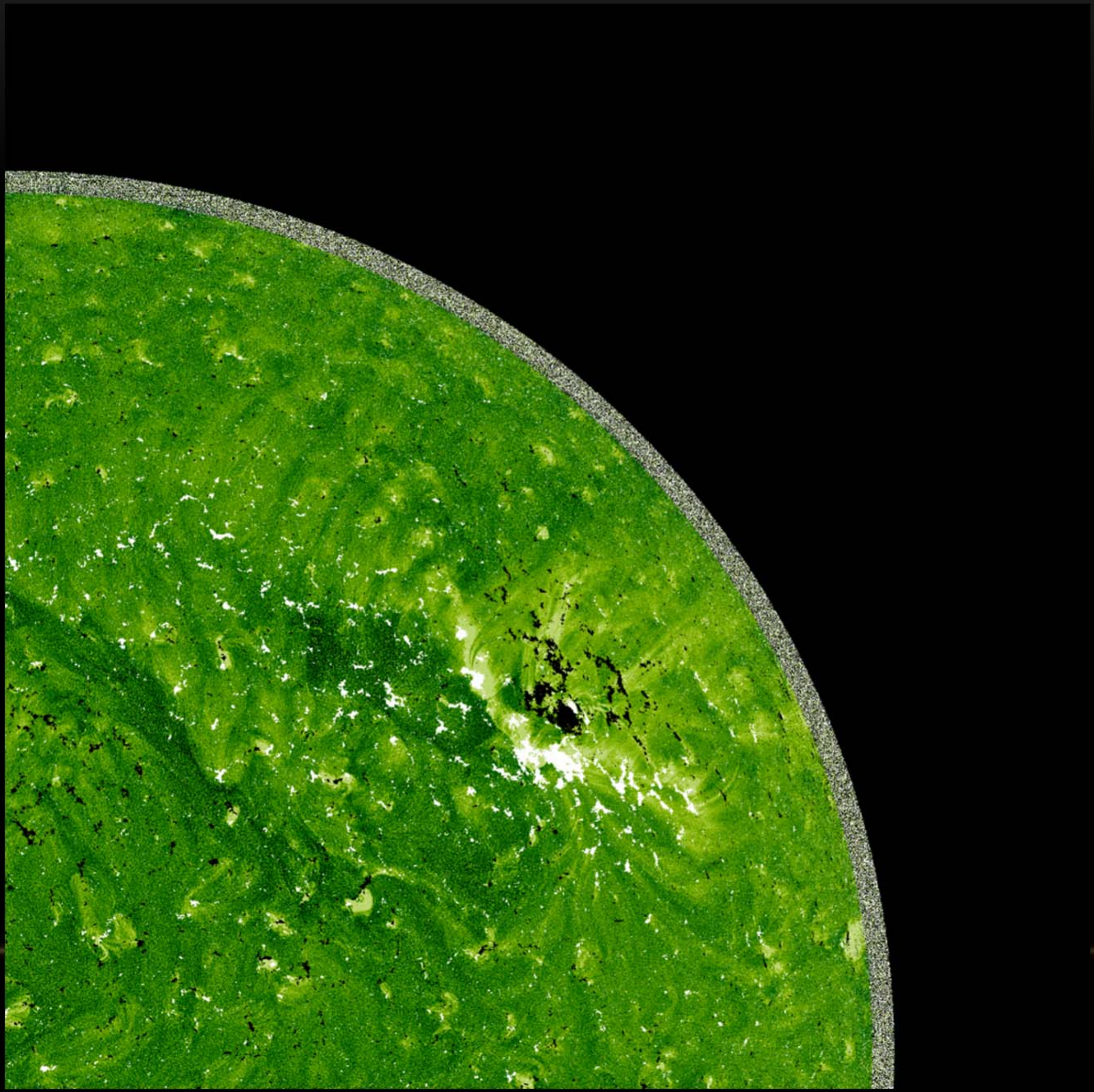
171 Å
~0.6-0.9 MK

193 Å
~1.4 MK



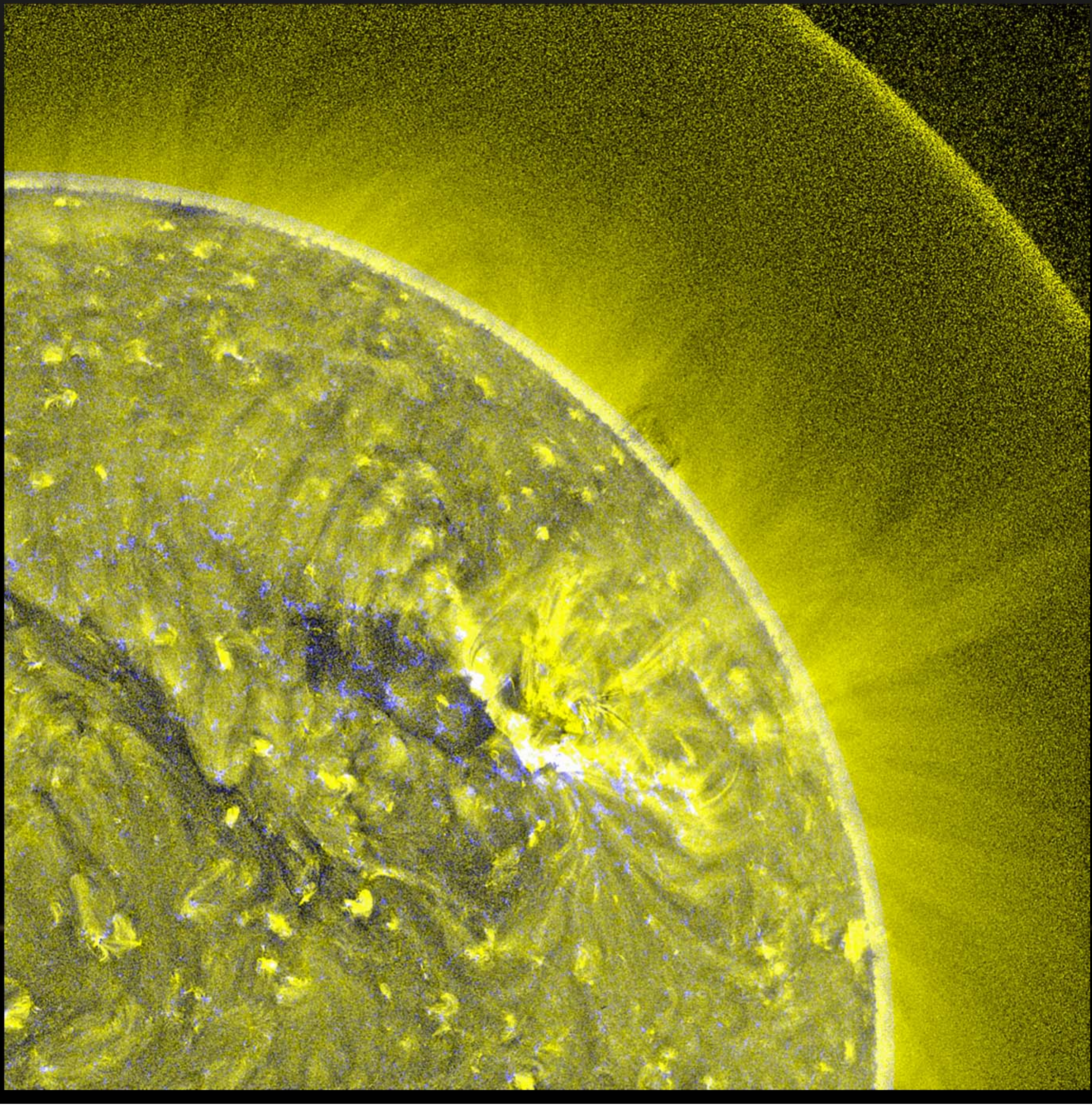
RELATIONSHIP TO PHOTOSPHERIC MAGNETIC FIELD

193 Å
~1.4 MK



RELATIONSHIP TO PHOTOSPHERIC MAGNETIC FIELD

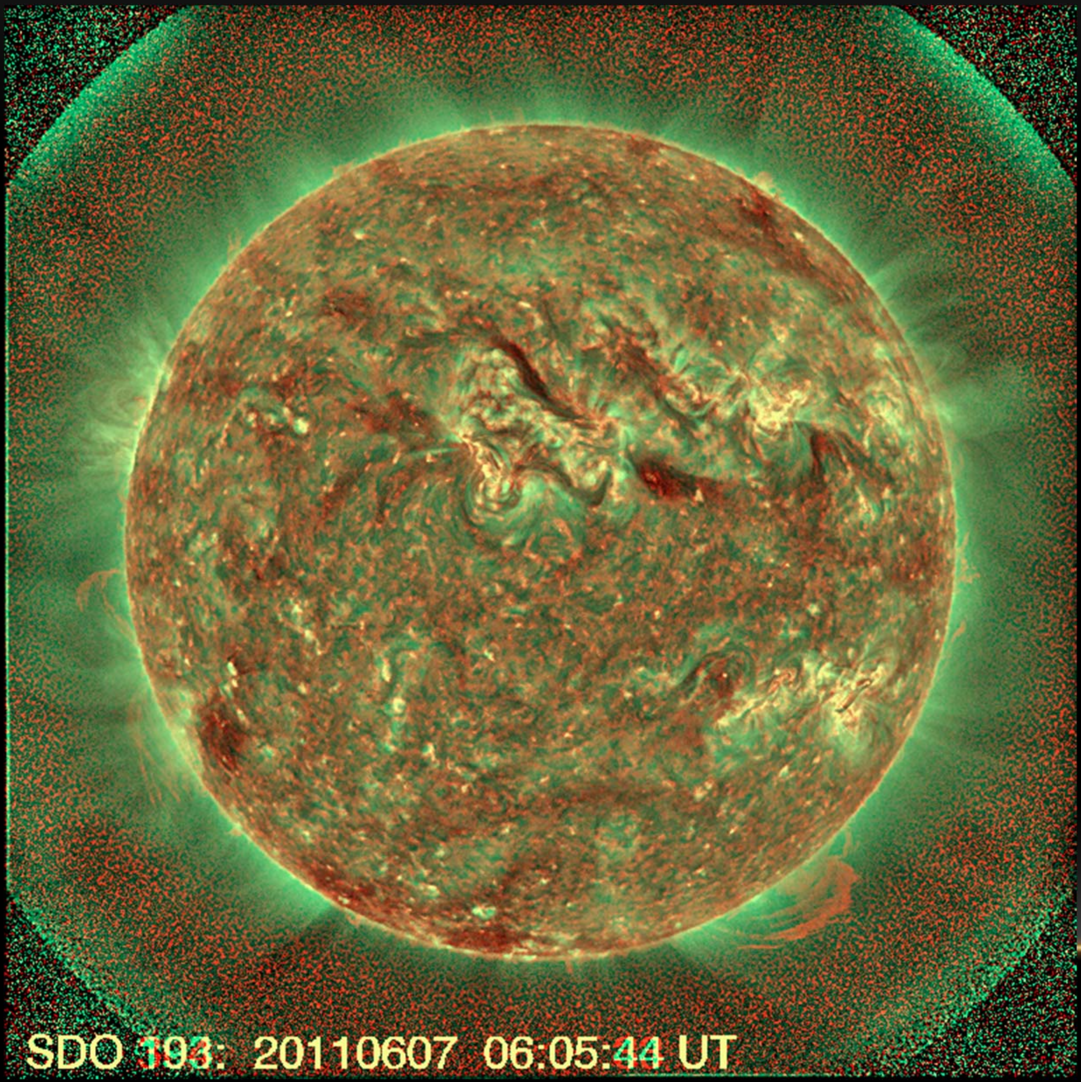
193 Å
~1.4 MK

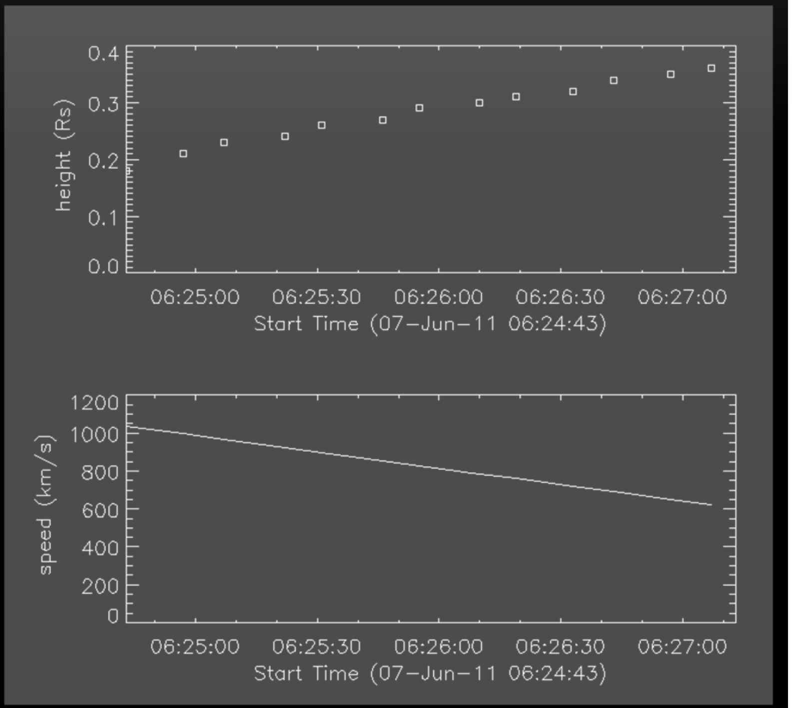


BACKUP SLIDES

JUNE 7, 2011

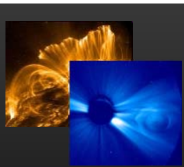
Wavelet-enhanced AIA movie provided by G. Stenborg





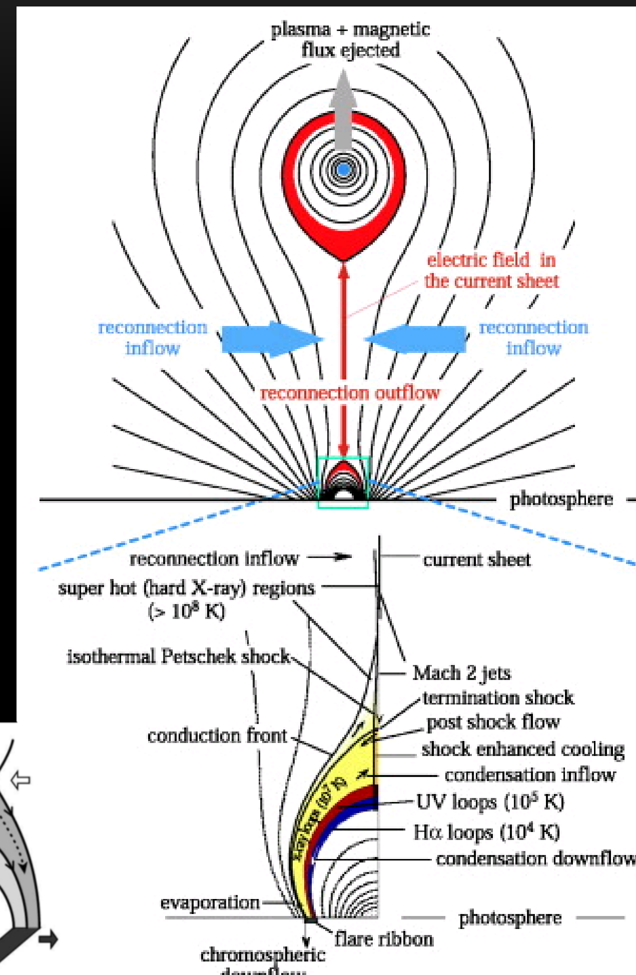
Green: AIA 193 A

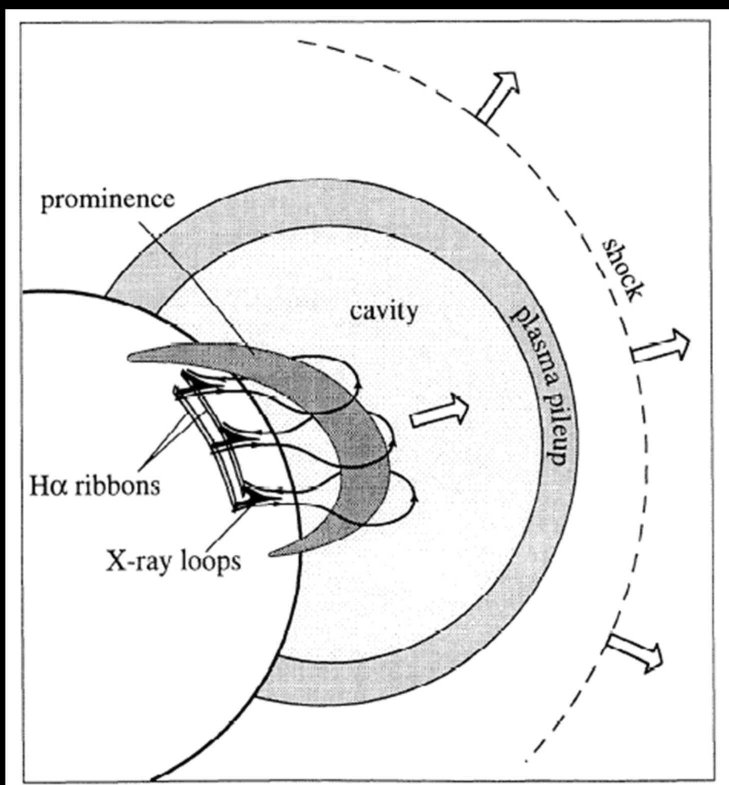
Red: AIA 304 A



THE “STANDARD” FLARE-CME CONCEPT

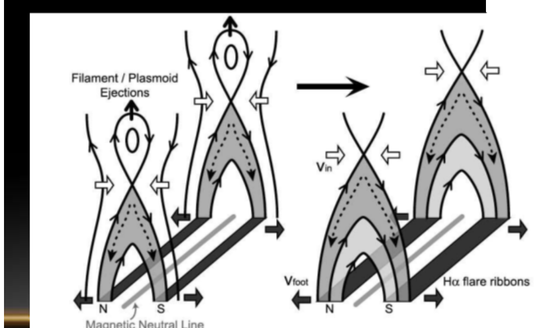
Still at cartoon level (pick your favorite from *solarmuri.ssl.berkeley.edu/~hhudson/cartoons*)





Forbes 2000

Flare Ribbons

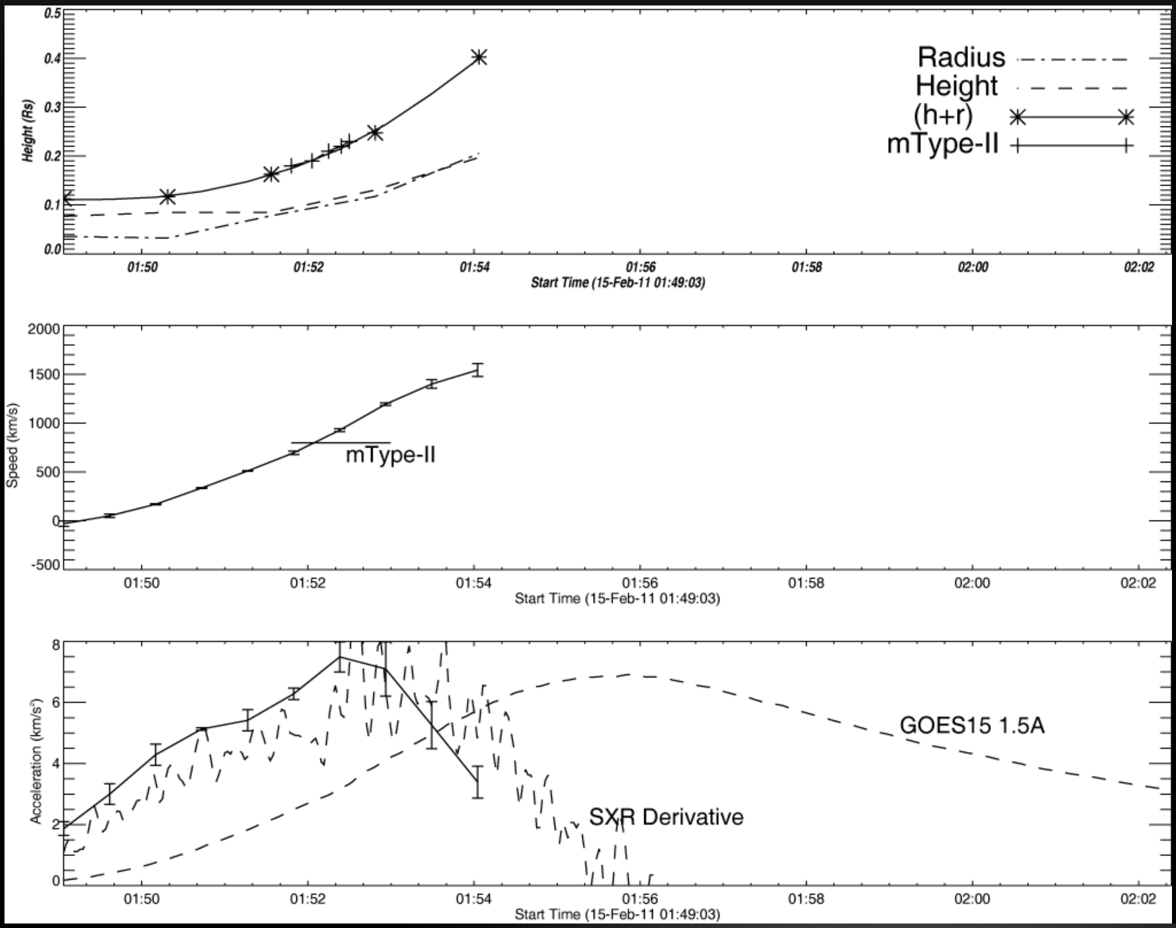


Asai et al 2006

Lin & Forbes 2002

FEBRUARY 15, 2011

Face-on for SDO . Use EUVI-A 171A images for bubble fitting



CONCLUSIONS:

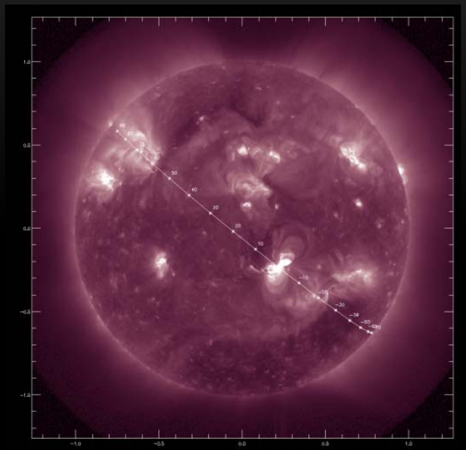
Bubble acceleration is over BEFORE SXR flare peak.

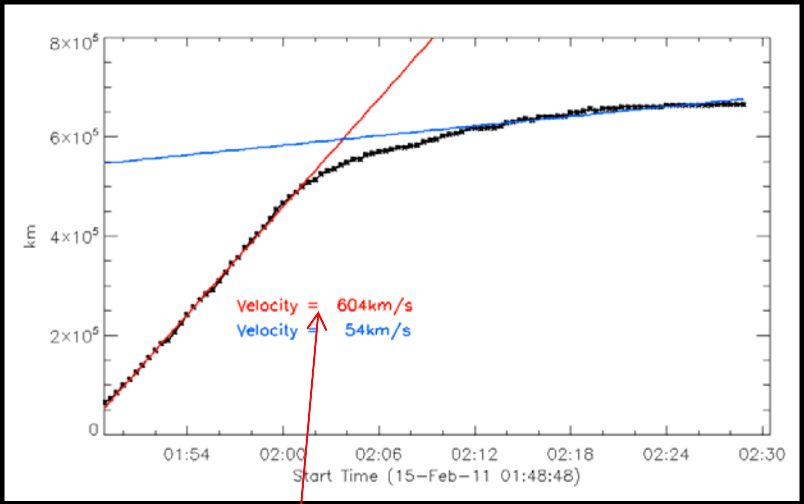
Speed: TypeII = bubble
Timing: ? (wave formation time uncertain)

CME acceleration last ~ 3mins only.

Interpretation: Piston--driven shock becomes blast wave.

WAVE SLICE SHOWS DECELERATION AT ACTIVE REGION

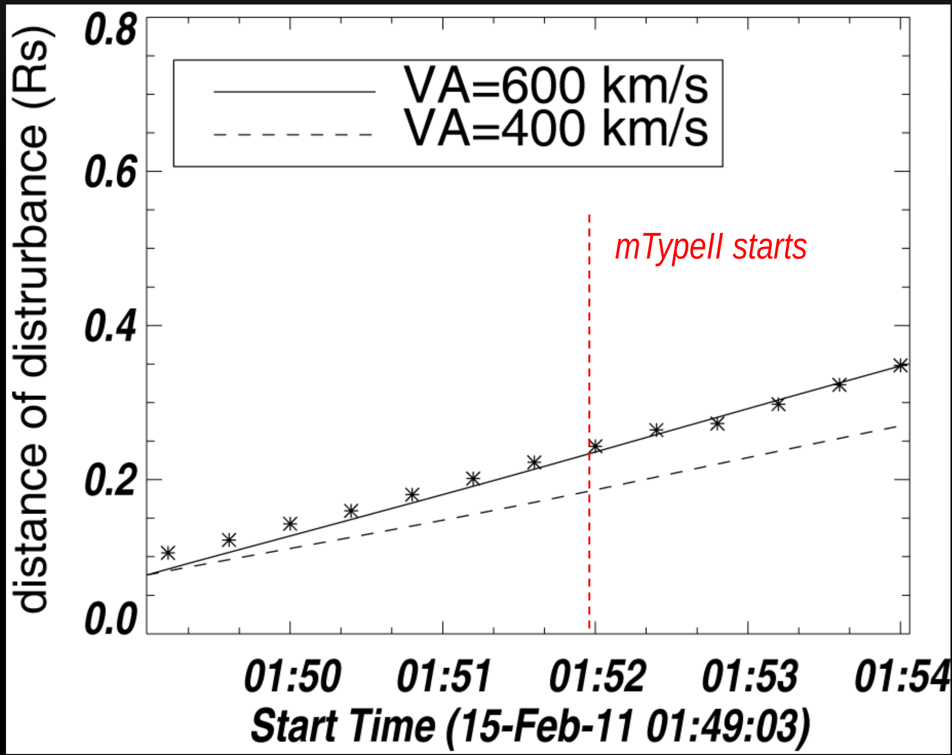




Note wave speed (600 km/s).

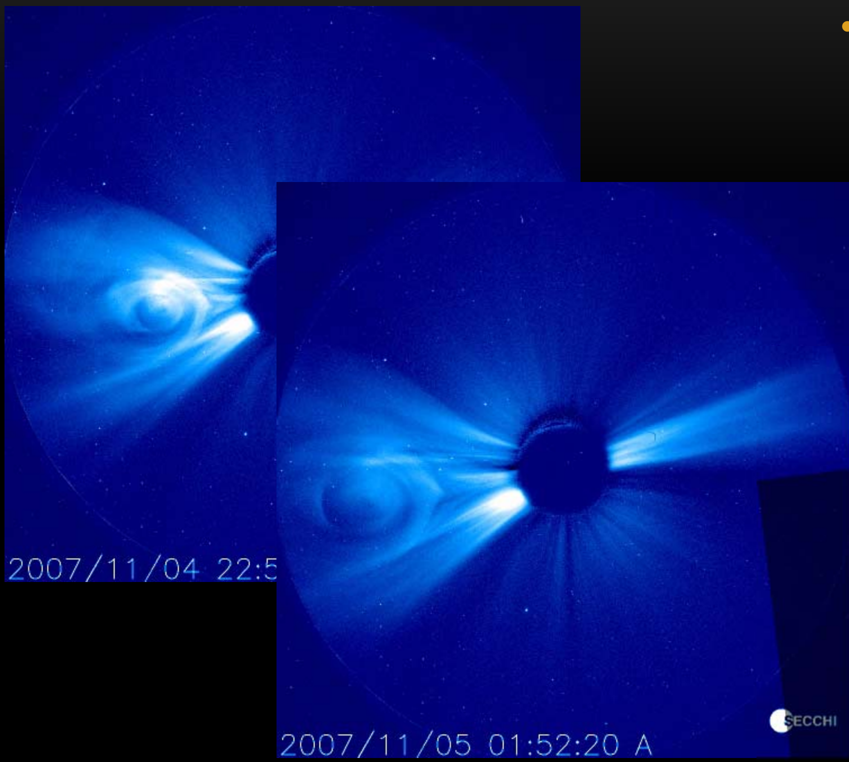
FITTING THE EUV WAVE TRACK WITH A WAVE MODEL

Using model in Temmer et al(2009).
Exponential profile for wave amplitude.
Constant Alfvén speed.

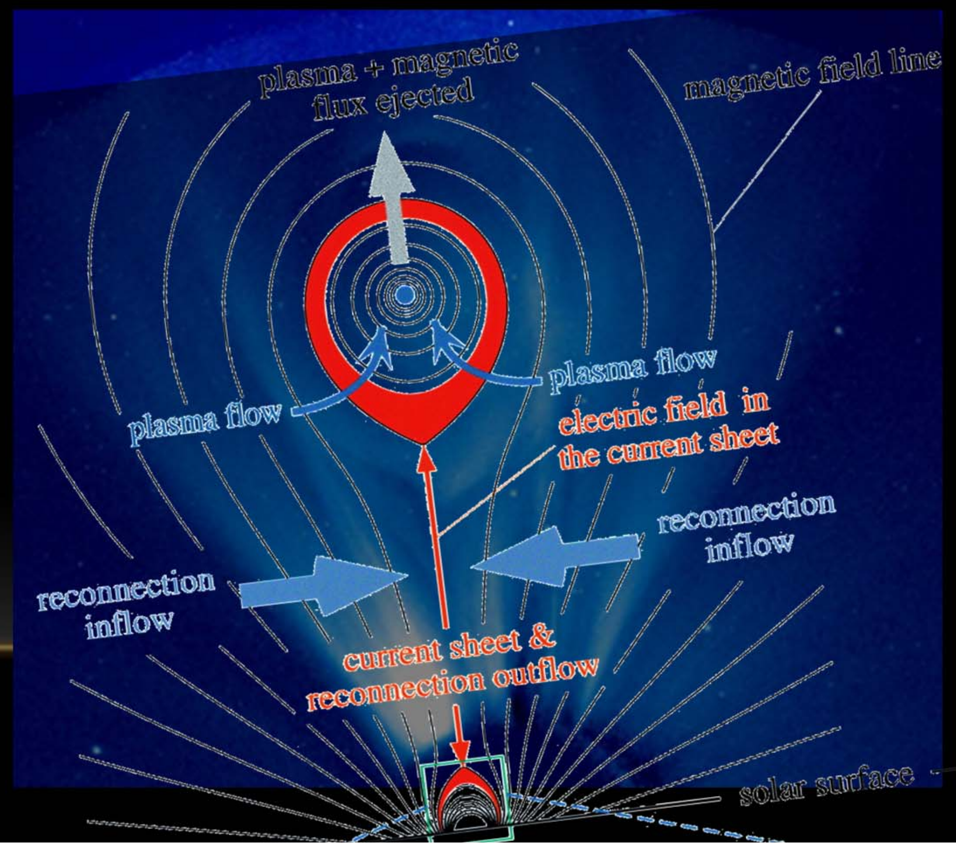


EUV wave = exponentially decaying [$f = e^{-0.1}$] disturbance through a 600 km/sec Alfvenic environment.

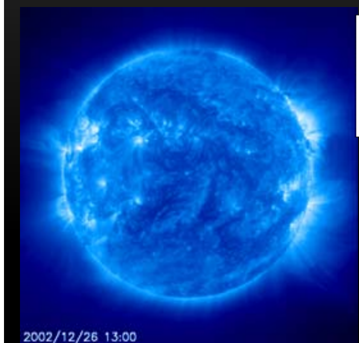
CME INTERNAL STRUCTURE

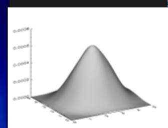


- The tip of the post-CME current sheet is visible.
  - The current sheet should be visible in the low corona.

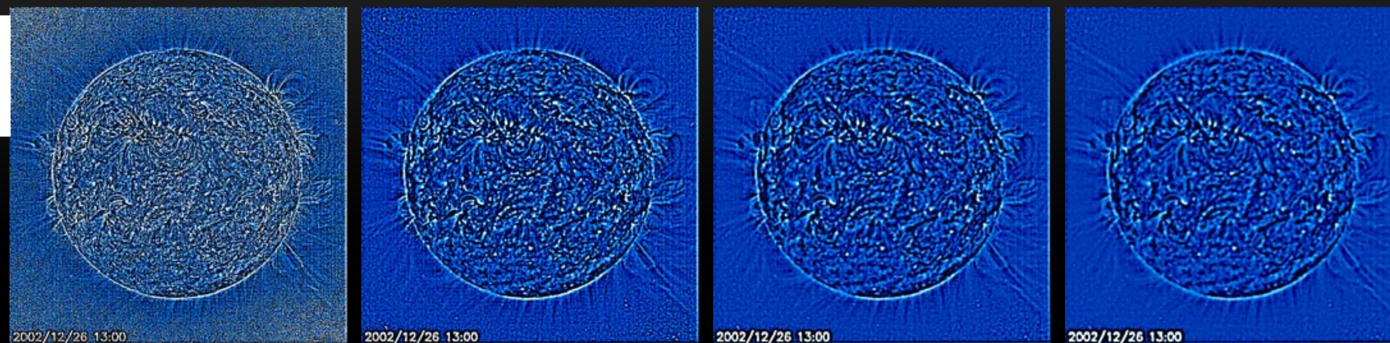


The 2D “a trous” algorithm

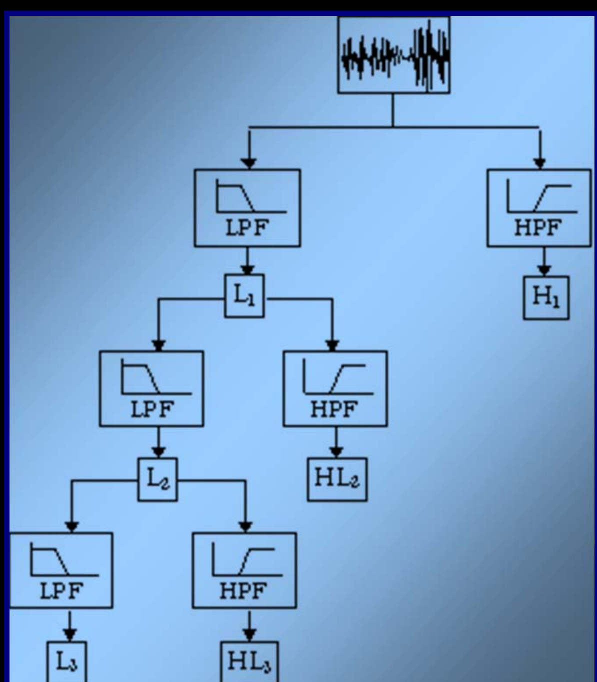




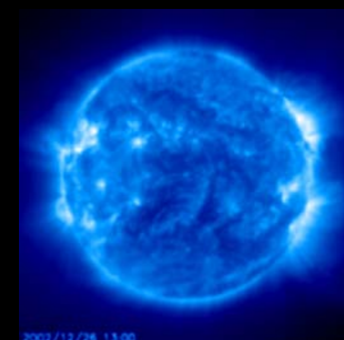
2D B_3-spline



Wavelet scales 1 to 4 (W_i)



Smoothed image corresponding to decomposition based on 25 scales



$$I_k^{treated} = \left[\log(I_k) - \log\left(R^i\right)\right] + \sum \alpha_j . \left(\omega_j - W_j^i\right)$$

For comparison, smoothed image corresponding to decomposition based on 50 scales