Two Case-studies of large-scale EUV waves: Feb 13th, 2009 and Jan 17th, 2010

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Coronal waves: interpretation

- *Large scale propagating coronal disturbances first observed with EIT (Thompson et al. 1998) v = 200…400 km/s (Klassen et al. 2000)*
- *Vivid debate about the physical nature of coronal waves*
  - *Pure MHD (shock-)waves* vs. *"pseudo-waves" (CME expansion-related)*

e.g. Delannée & Aulanier (1999), Mann et al. (1999), Wills-Davey & Thompson (1999), Delannée (2000), Wang (2000), Wu et al. (2001), Warmuth et al. (2001), Chen et al. (2002), Ofman & Thompson (2002), Ballai (2005), Vršnak et al. (2006), Attrill et al. (2007), Wills-Davey et al. (2007), Long et al. (2008), Veronig et al. (2008), Gopalswamy et al. (2009), Kienreich et al. (2009), Patsourakos & Vourlidas (2009), Patsourakos et al. (2009), Wang et al. (2009), Cohen et al. (2009), Podladchikova et al. (2010), Dai et al. (2010), Ma et al., Veronig et al. (2010) [STEREO-era]

  - *Driver:* flare ("blast wave") ⇔ CME ("piston" or "bow shock").

e.g. Thompson et al. (1998), Warmuth et al. (2001, 2004b), Biesecker et al. (2002), Khan & Aurass (2002), Hudson et al. 2003, Zhukov & Auchère (2004), Cliver et al. (2005), Podladchikova & Berghmans (2005), Vršnak et al. (2006), Veronig et al. (2008), Magdalenić et al. (2009)

Recent reviews:

Wills-Davey and Attrill (2010), Warmuth (2010), Vršnak & Cliver (2008), Mann (2007), Warmuth (2007), Chen and Fang (2005), Vršnak (2005)

STEREO SECCHI observations

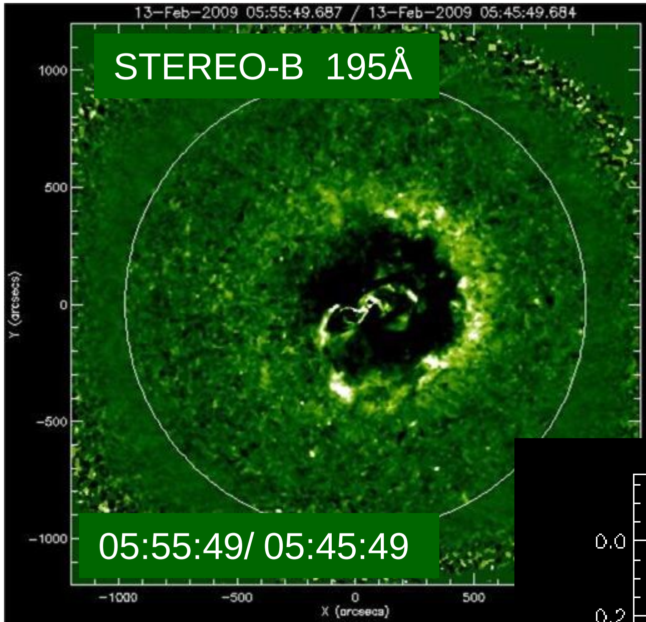
- PRE-STEREO era: waves are under-sampled in wave studies using EIT (cadence 12–15 min).

- STEREO/SECCHI-EUVI (Wülser et al. 2004, Howard et al. 2008) provides regular full-disk imaging in EUV with:
  - high cadence (as good as 75 sec)
  - large FOV (1.7 Rs)
  - "3D imaging" capability due to the two STEREO vantage points

- This presentation – Results from two coronal wave events observed with EUVI:
  Event 1: STEREO in quadrature $\Rightarrow$ 3D structure (Kienreich et al. 2009)
  Event 2: complete wave-dome visible (Veronig et al. 2010; submitted)

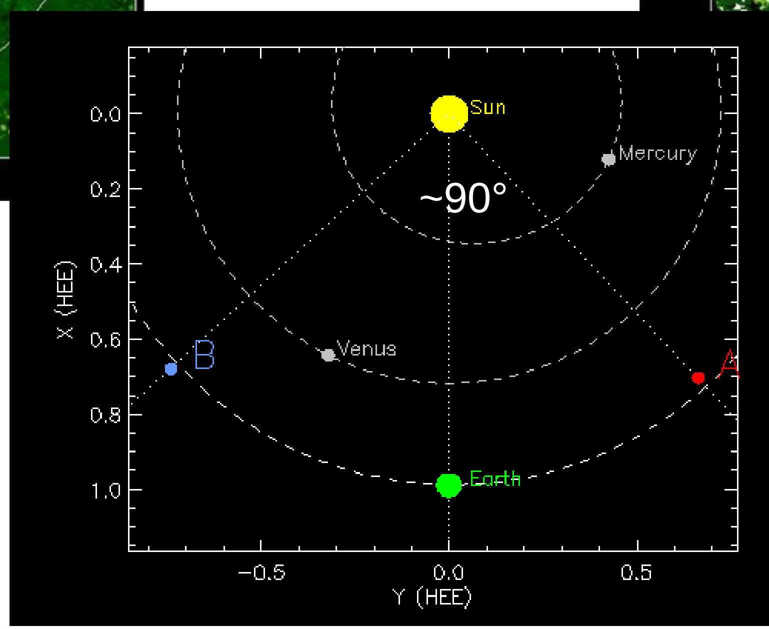
Event 1: Feb 13th 2009

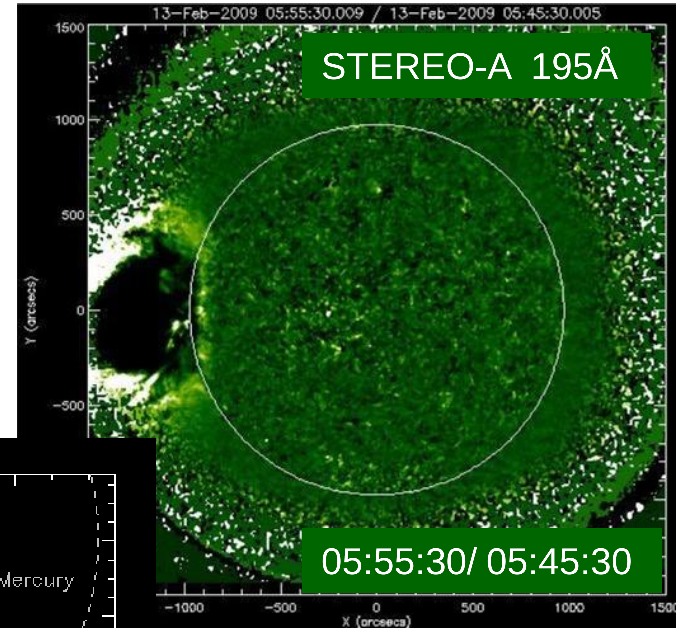
STEREO A and STEREO B ~ 90° apart (quadratur)



x/y-range = [-1200“,1200“]

Associated
GOES B2.3 flare





x/y-range = [-1500“,1500“]

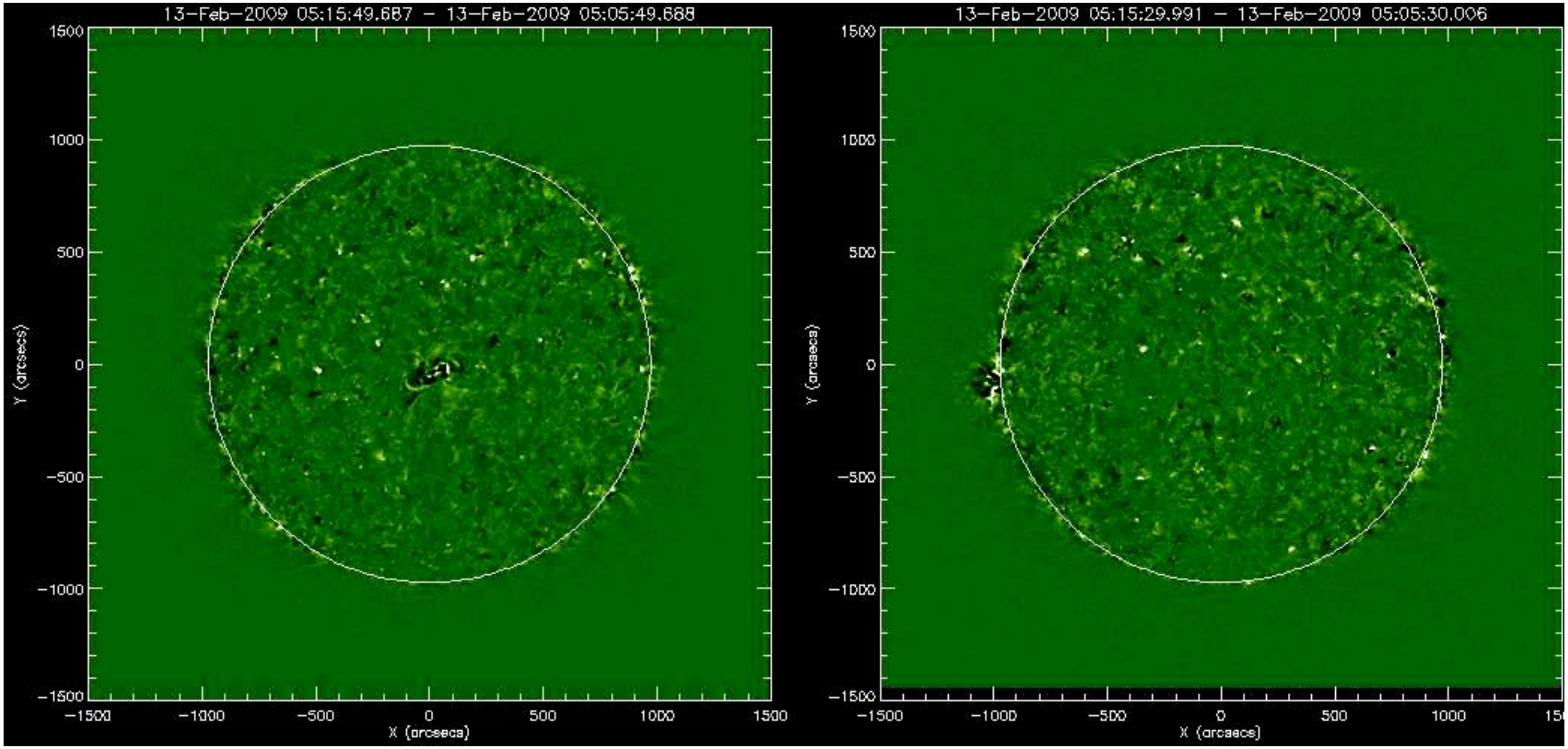
Event also studied in Patsourakos et al. (2009) and Cohen et al. (2009)

Event 1: Feb 13th 2009

- STEREO-A and STEREO-B ~90° apart (quadrature)

Running difference images in EUVI 195 Å filter

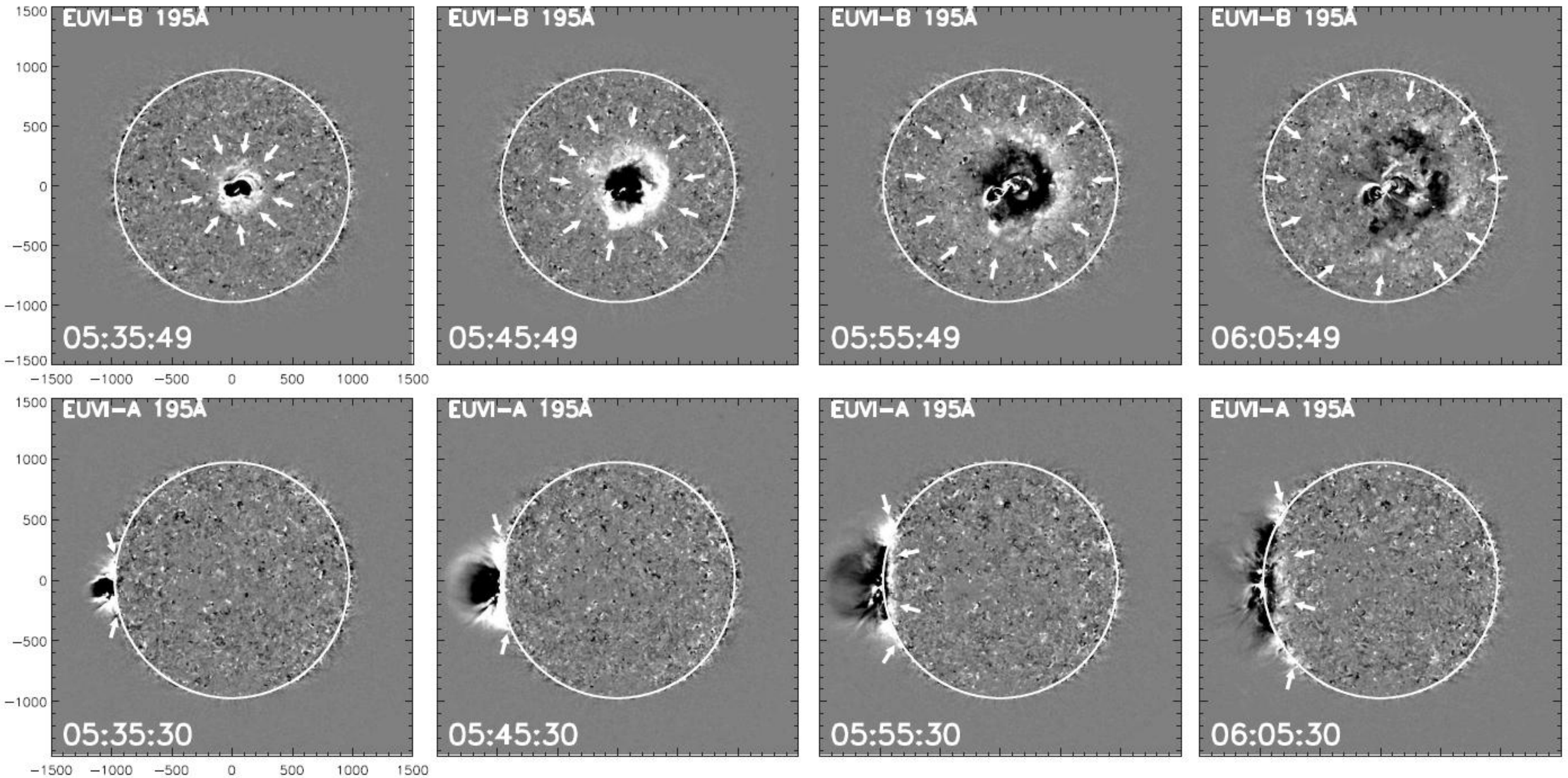
STEREO-B　　　　　　　　　　　　STEREO-A



Kienreich, Temmer & Veronig ApJ Lett. (2009)

Event 1: Feb 13th 2009

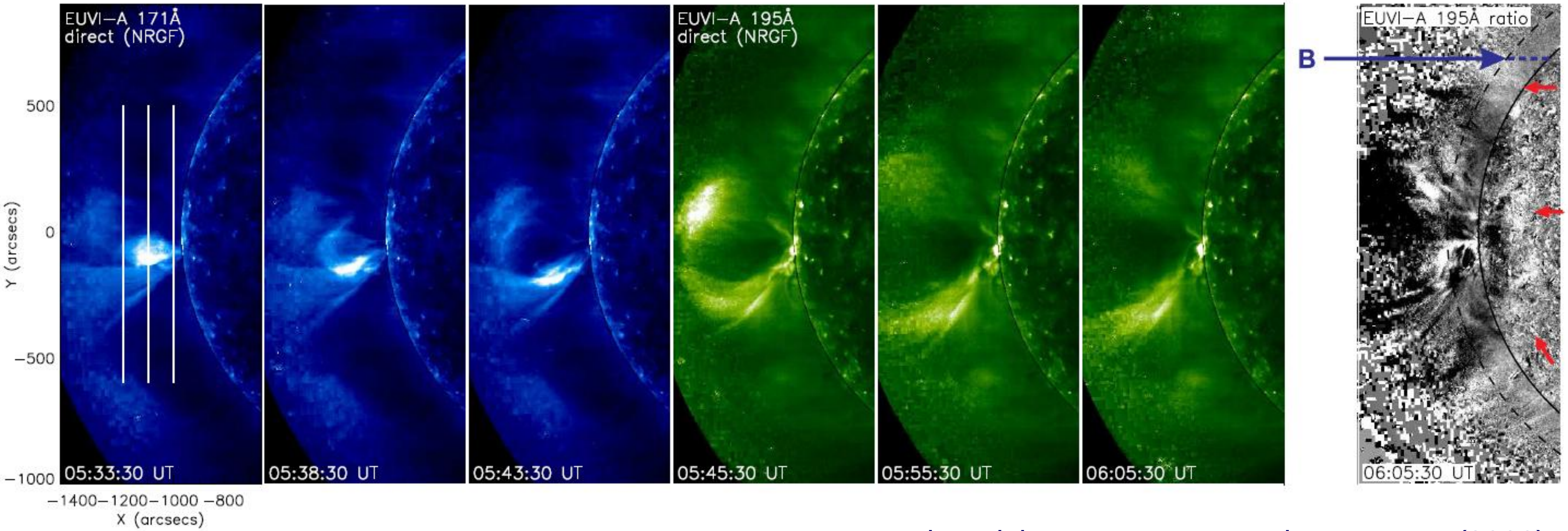
- Coronal wave in EUVI 195 Å in STEREO-B (top) and STEREO-A (bottom)



Kienreich, Temmer & Veronig ApJ Lett. (2009)

Event 1: Feb 13th 2009

- EUVI-A 171 & 195 Å images (NRGF-filtered) revealing the erupting CME and the coronal EUV wave ahead of it



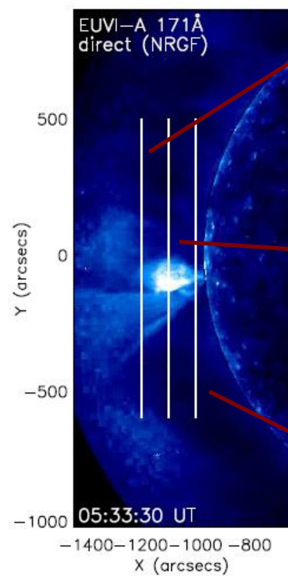
Kienreich, Temmer & Veronig ApJ-Lett. (2009)

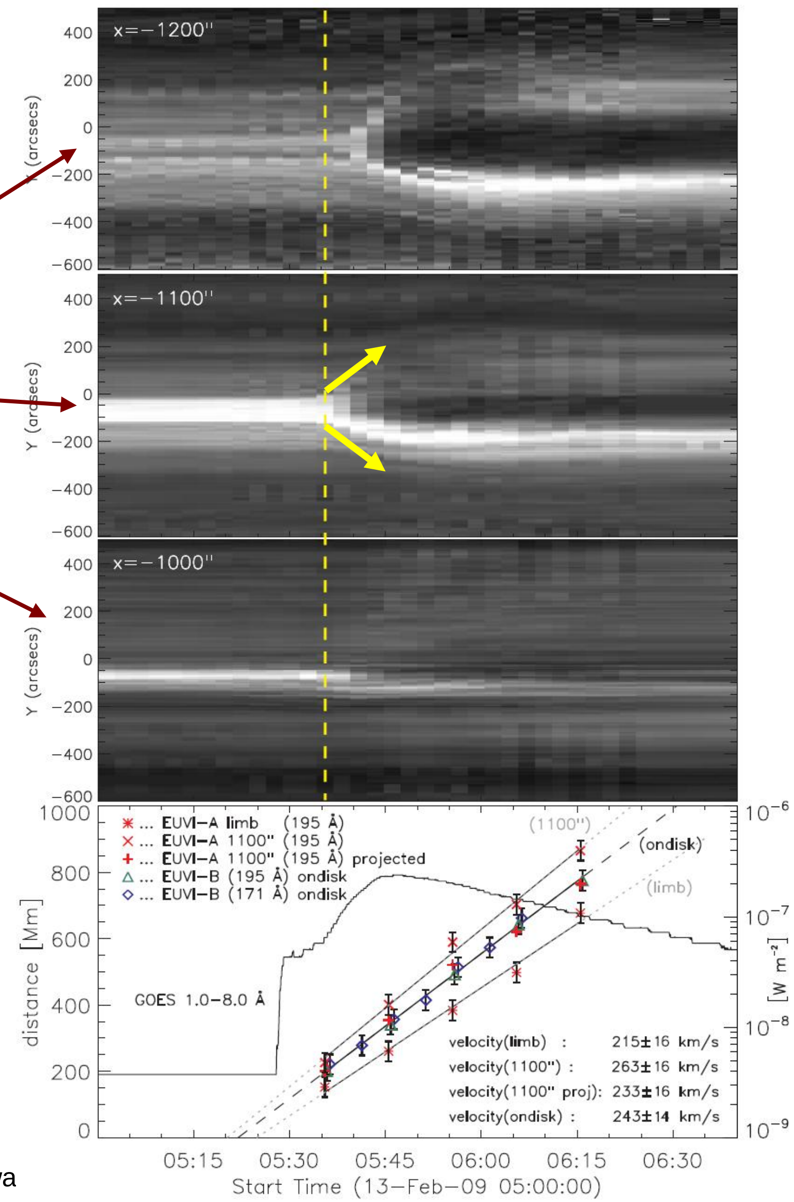
Comparison of evolution of CME flanks and coronal wave as seen from EUVI-A

Event 1: Feb 13th 2009

Driver of the wave:

- CME expanding flanks
- 3 slits y=[-600”,500”] at different heights above solar surface
- Stack plots to illustrate lat. evolution of CME flanks
- x=1000” : no visible change in lat. expansion
- x=1100” and x=1200” : first strong expansion of CME flanks then stagnation ➔ tuning-fork
- x=1100” : same onset time of expansion as first observed coronal wavefront (ondisk)





Event 1: Feb 13th 2009

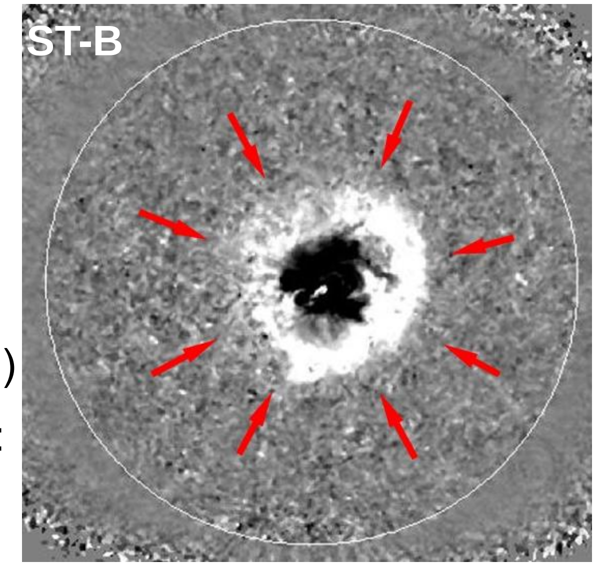
Wave kinematics:

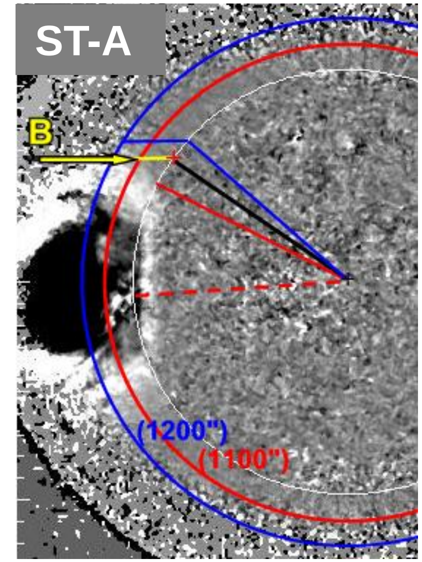
- on-disk measurements (ST-B): 171 & 195 Å
- plane of sky measurements:
  - along limb
  - diff. heights (1100”,1200”…)
- **projected wave fronts (ST-A)**: intersection of wave with 1100” projected onto limb

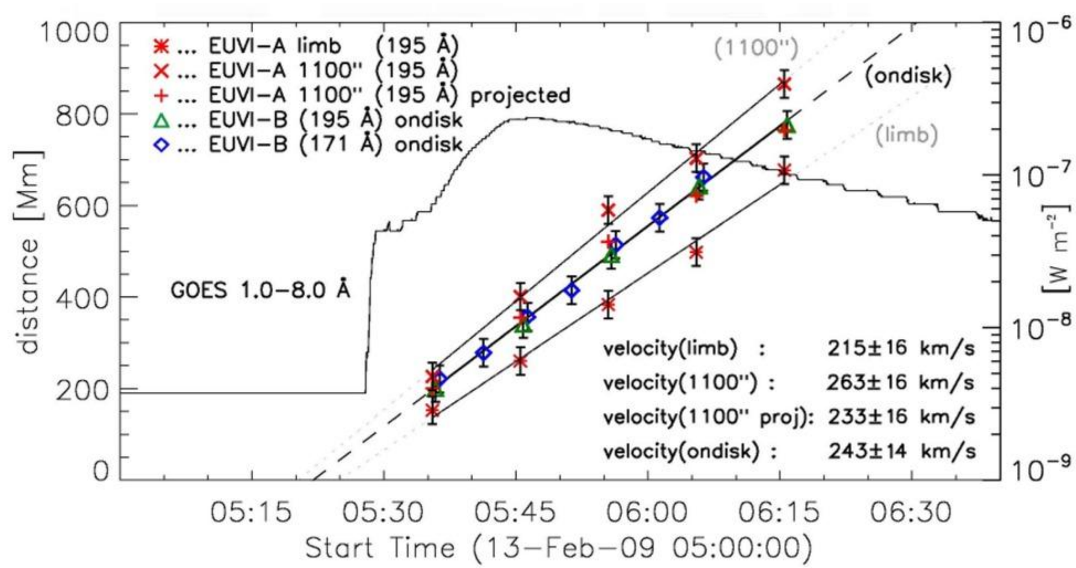
→ Wave:
v ~ 260 km/s (const.)
H ~ 80–100 Mm

→ driven by CME flanks

Kienreich, Temmer & Veronig (2009)

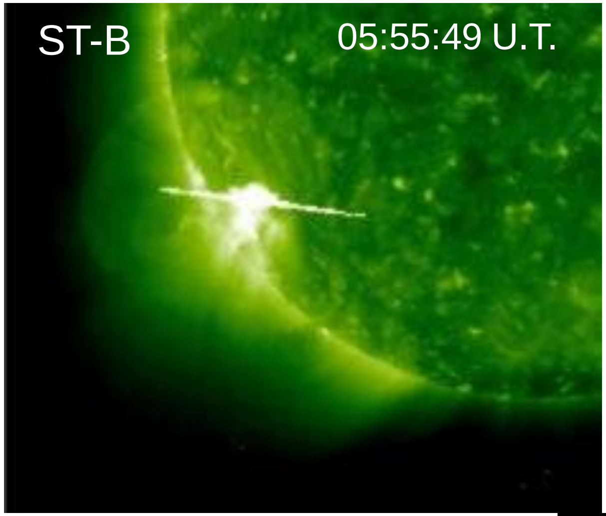






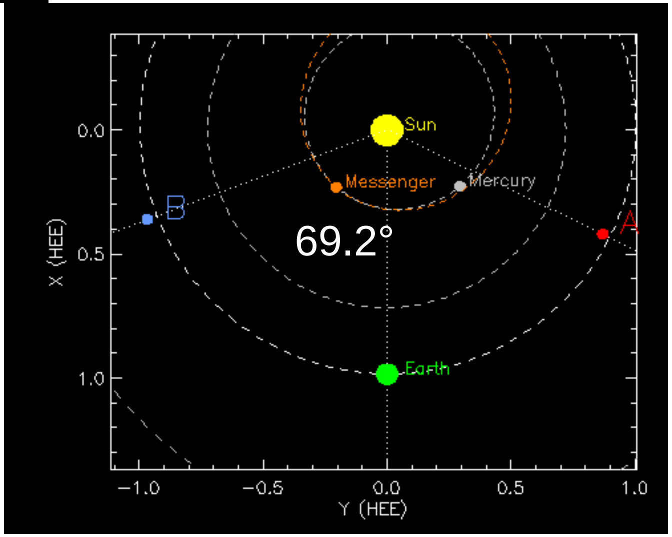
Event 2: Jan 17th 2010

Dome-shaped large-scale EUV coronal wave



- spherical form and sharpness of dome‘s outer edge inside erupting CME loops
- low-coronal wave signatures above limb perfectly connect to the on-disk signatures
- the lateral extent of expanding dome is much larger than that of coronal dimming / cavity
- associated high-frequency type II burst indicating shock formation low in the corona

Seen from EUVI-B: meridional distance 57° to the east

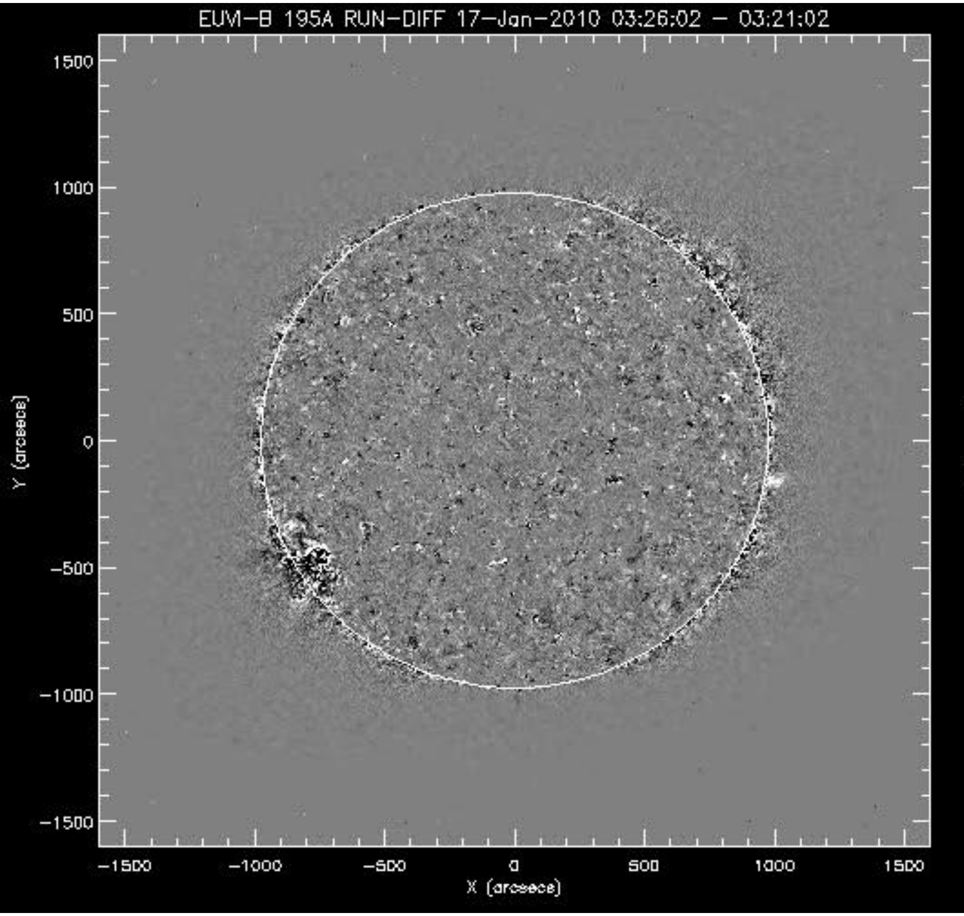


Event 36° behind Eastern solar limb for an Earth-based vantage point

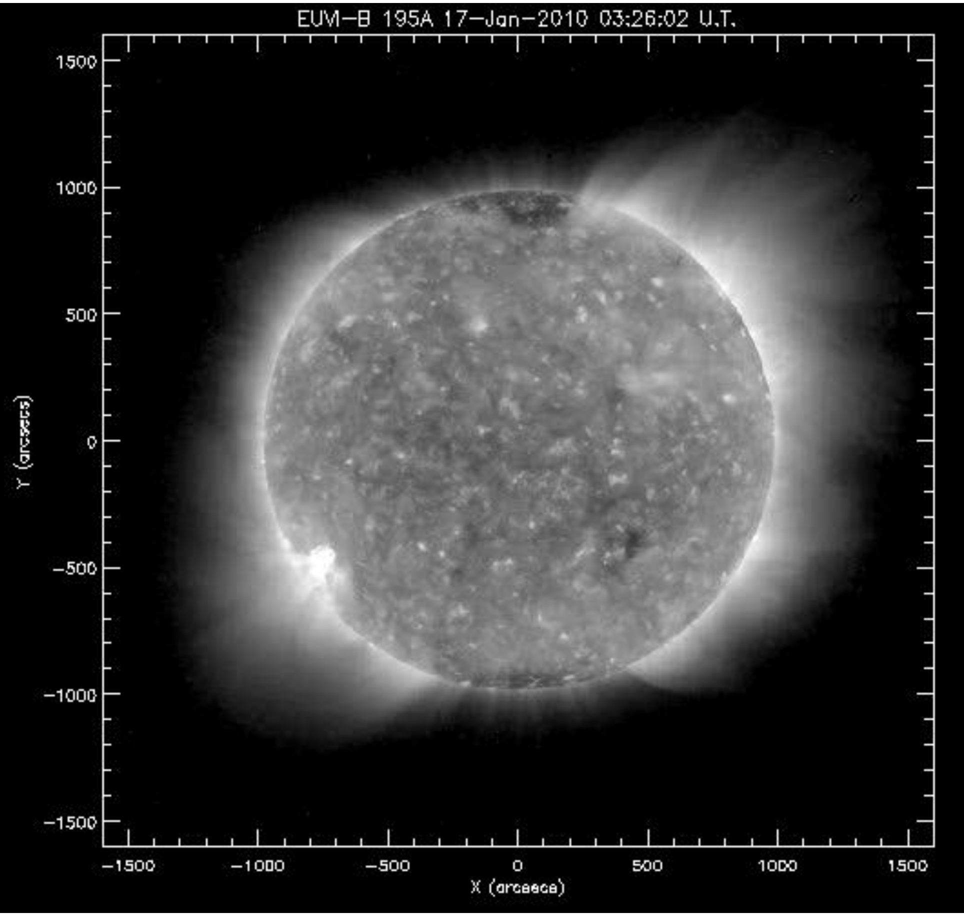
I. Kienreich, A. Veronig and M. Temmer : Two case-studies of large-scale EUV waves: Feb 13th, 2009 and Jan 17th, 2010
STEREO Workshop SWG 21, Dublin, March 22–26 2010

Event 2: Jan 17th 2010

195Å running-difference images (Δt = 5min)



195Å direct images

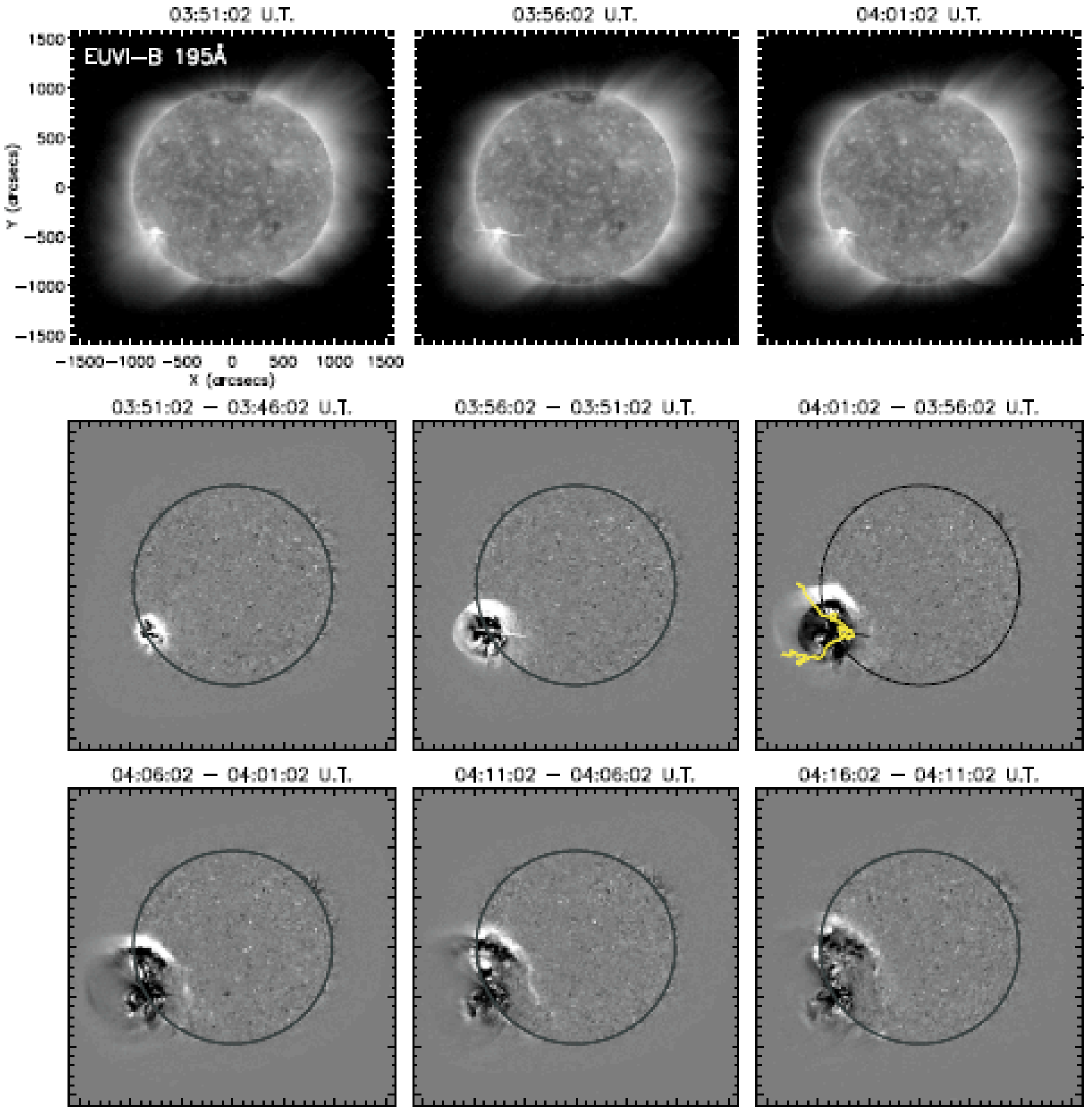


avi

Veronig, Muhr, Kienreich, Temmer & Vršnak ApJ. Let. 2010 (submitted)

Event 2: Jan 17th 2010

- early wave evolution on the disk and above the limb
- Note the dome shape in the images at 03:56 and 04:01 U.T. ➔ also visible in direct images
- on-disk signatures of wave perfectly connect to the wave dome
- yellow contours indicate maximum extent of coronal dimming (from base-ratio image 5:01/3:36)
- Sharp regular edges suggest shock front NOT erupting CME loops



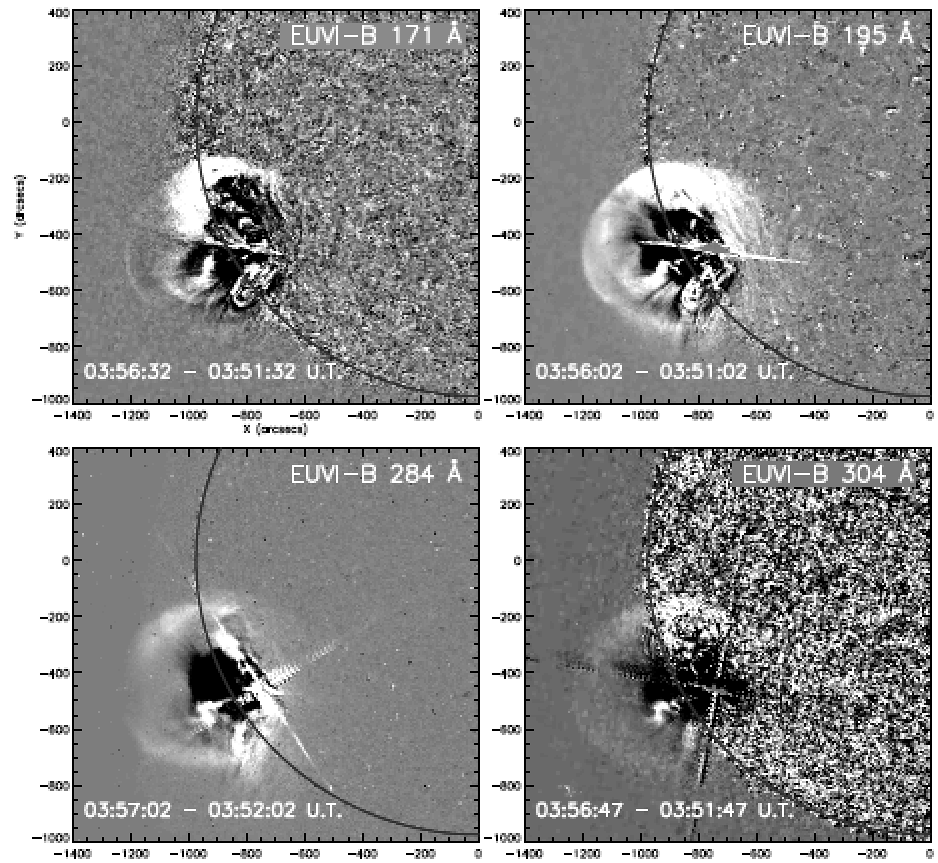
Event 2: Jan 17th 2010

The wave dome was observed in all four EUVI-B spectral channels

He II 304Å : T ~ 0.07 MK
➔ here Si XI !!!
Fe IX 171Å : T ~ 1 MK
Fe XII 195Å : T ~ 1.5 MK
Fe XV 284Å : T ~ 2.25 MK

- in all 4 spectral channels : on-disk signature of the wave fits perfectly with wave signature above limb

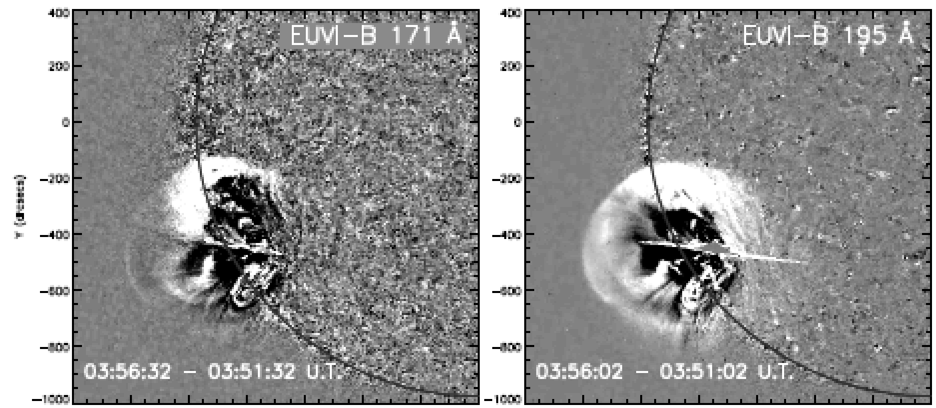
➔ 1…2.3 MK range

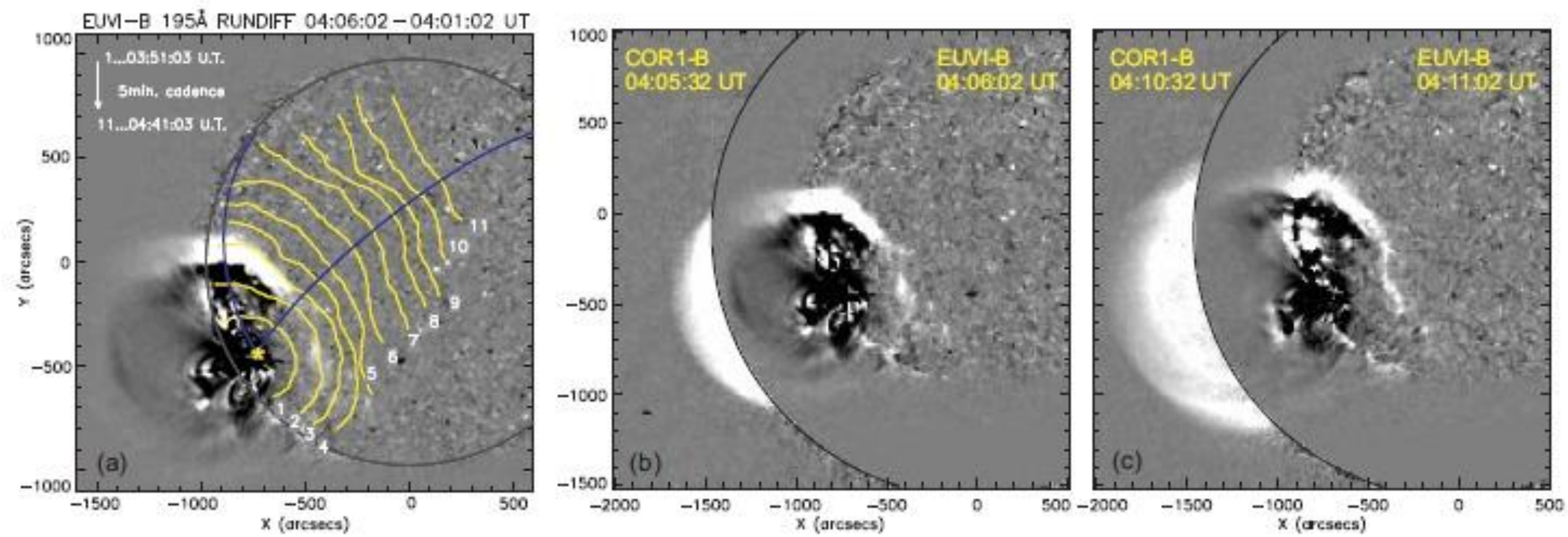


Event 2: Jan 17th 2010

The wave dome was observed also in COR1-B

- COR1 signature connects exactly to EUVI wave signature above limb
- outer edge corresponds to shock ahead of CME rather than leading edge of CME
- left frame: yellow curves represent visually identified wavefronts





Event 2: Jan 17th 2010

HiRAS (Hiraiso Radio Spectrograph): **high-frequency type II burst**
emission at first harmonic of plasma frequency ($2 \cdot f_1$)
drifting from ~310 MHz to ~80 MHz during ~03:51–03:58 U.T.

wave center at 57° (EUVI-B) ➔ for Earth 36° behind Eastern limb
corresponding to occultation height ~ 0.23 R_S (~ 160 Mm)

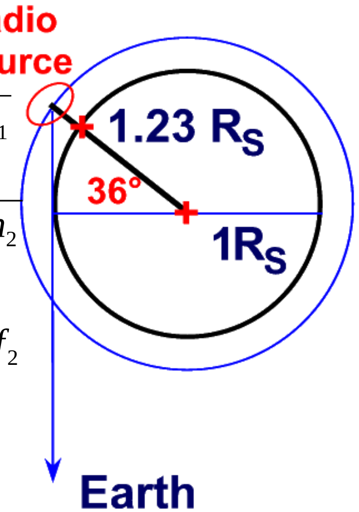
➔ shock is formed relatively low in the corona
derived formation height consistent with observed wave dome height

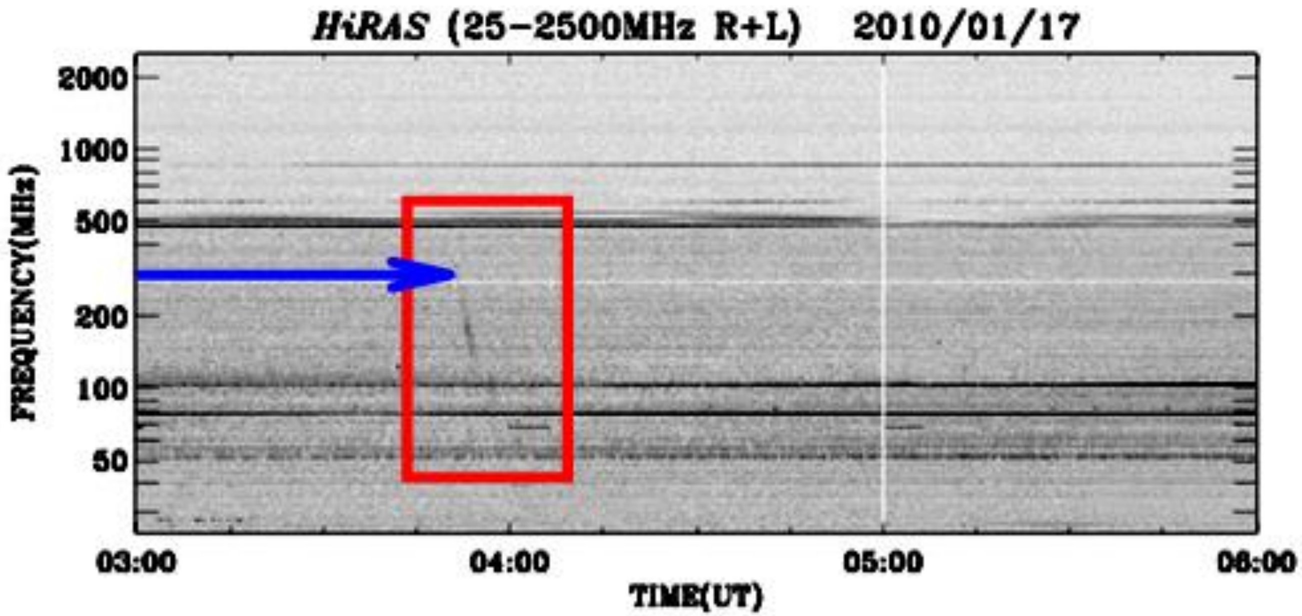
$f_1 \sim \sqrt{n_1}$

$f_2 \sim \sqrt{n_2}$

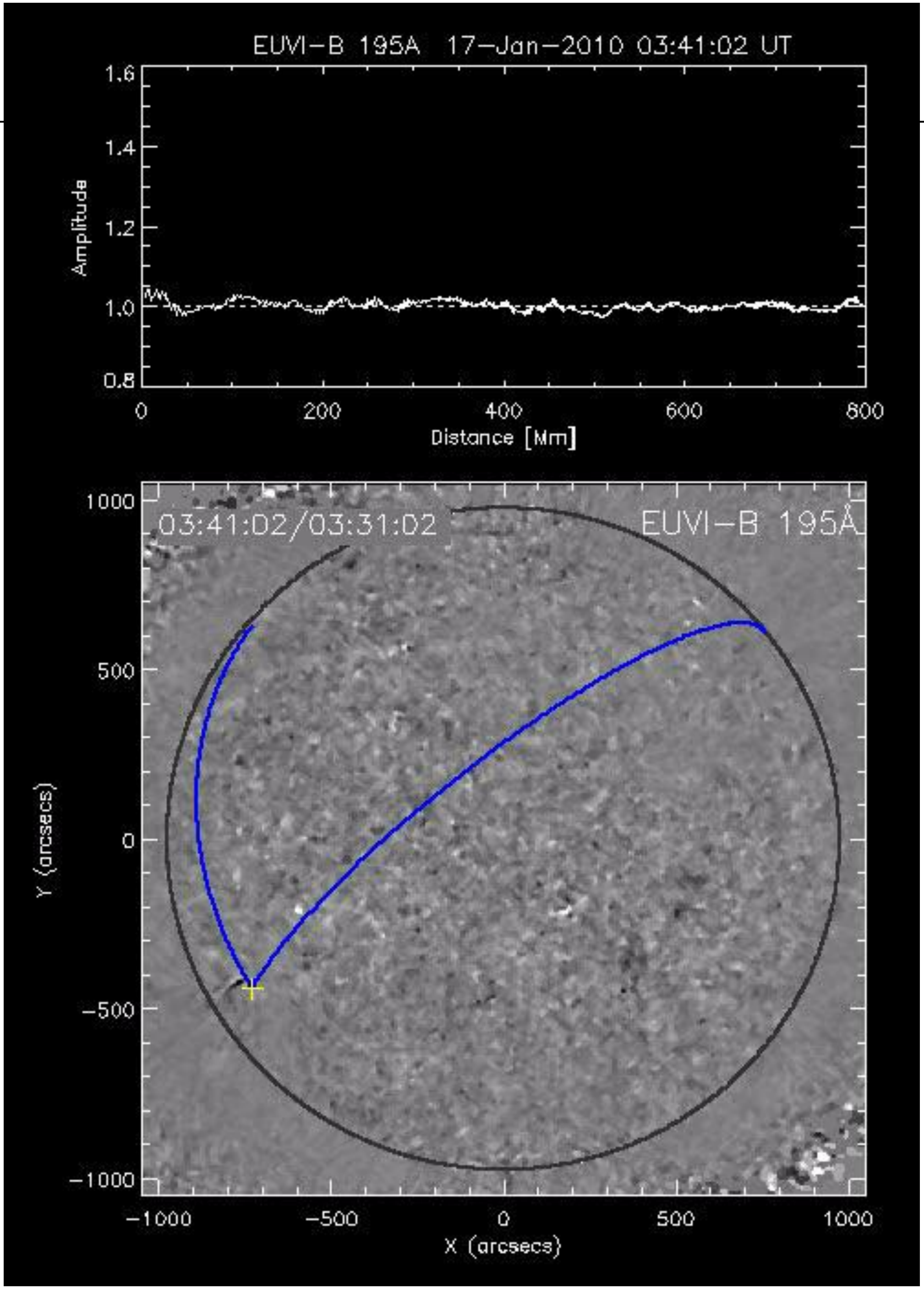
$f_1 < f_2$

$2 \cdot f_1 > f_2$





Intensity Profiles



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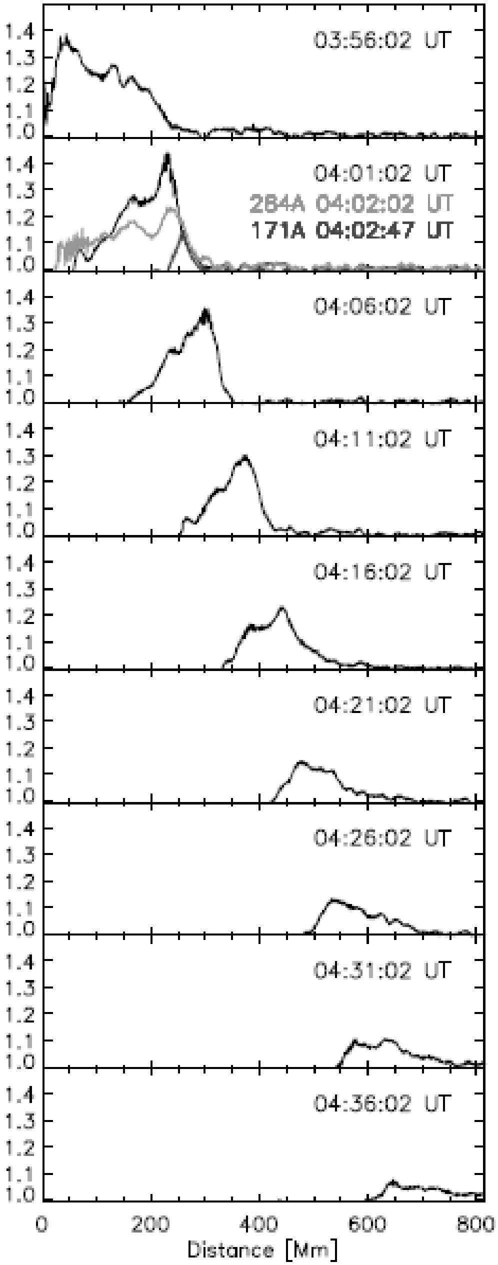

Event 2: Jan 17th 2010

kinematics of the wavefronts (on-disk) in all 4 EUVI-B channels

v_wave from the linear fit; remains constant up to 950 Mm

red symbols: upward motion of wave dome (EUVI-B and COR1-B)

evolution of perturbation amplitude from 195Å intensity profiles

Conclusion:

fast-mode MHD wave

weak shock (integral constant)

driven upwards (CME) &

free lateral wave-propagation