

# Two Case-studies of large-scale EUV waves: Feb 13<sup>th</sup>, 2009 and Jan 17<sup>th</sup>, 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”)  $\Leftrightarrow$  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:*

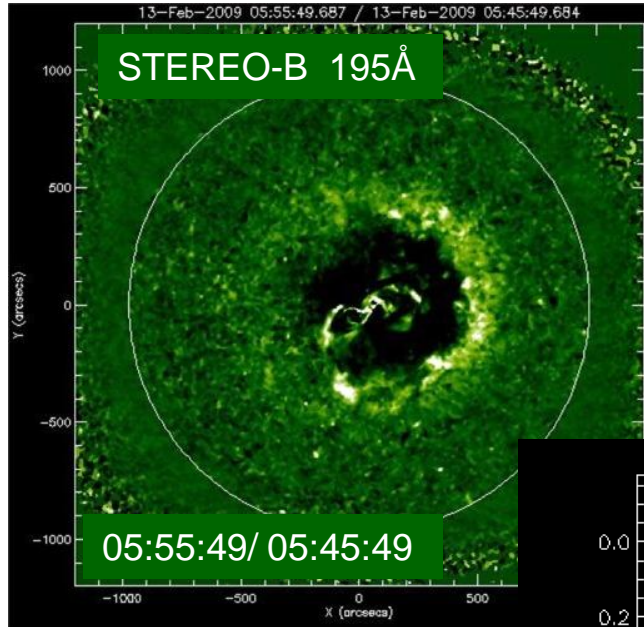
Wills-Davey and Attrill (2010), Warmuth (2010), Vršnak & Cliver (2008), Mann (2007), Warmuth (2007), Chen and Fang (2005), Vršnak (2005)

# 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)

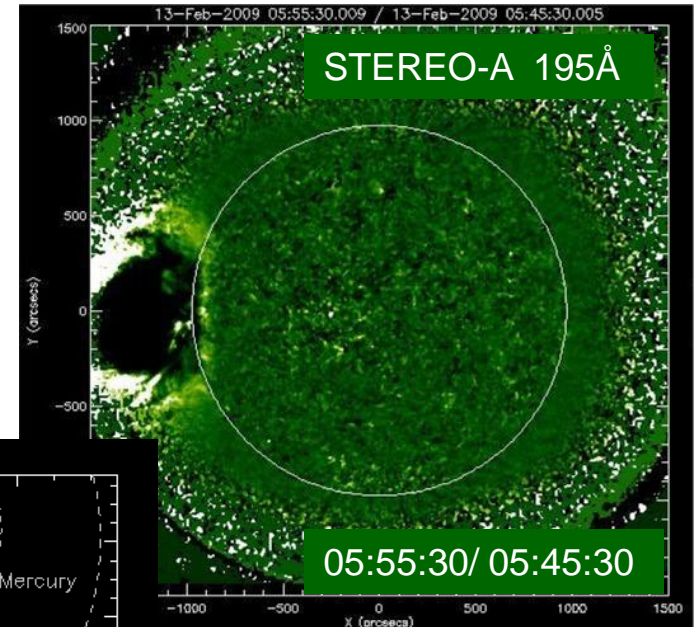
# Event 1: Feb 13<sup>th</sup> 2009

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

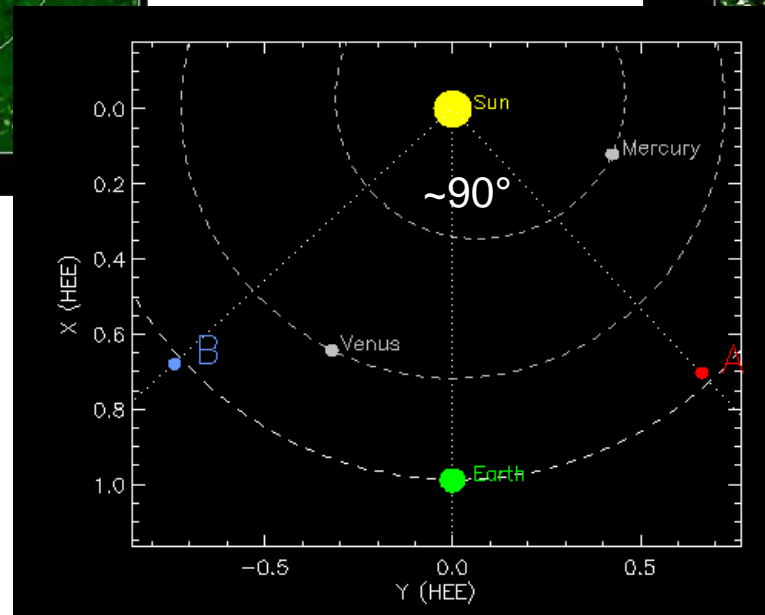


x/y-range = [-1200", 1200"]

Associated  
GOES B2.3 flare



x/y-range = [-1500", 1500"]



Event also studied in  
[Patsourakos et al. \(2009\)](#) and  
[Cohen et al. \(2009\)](#)

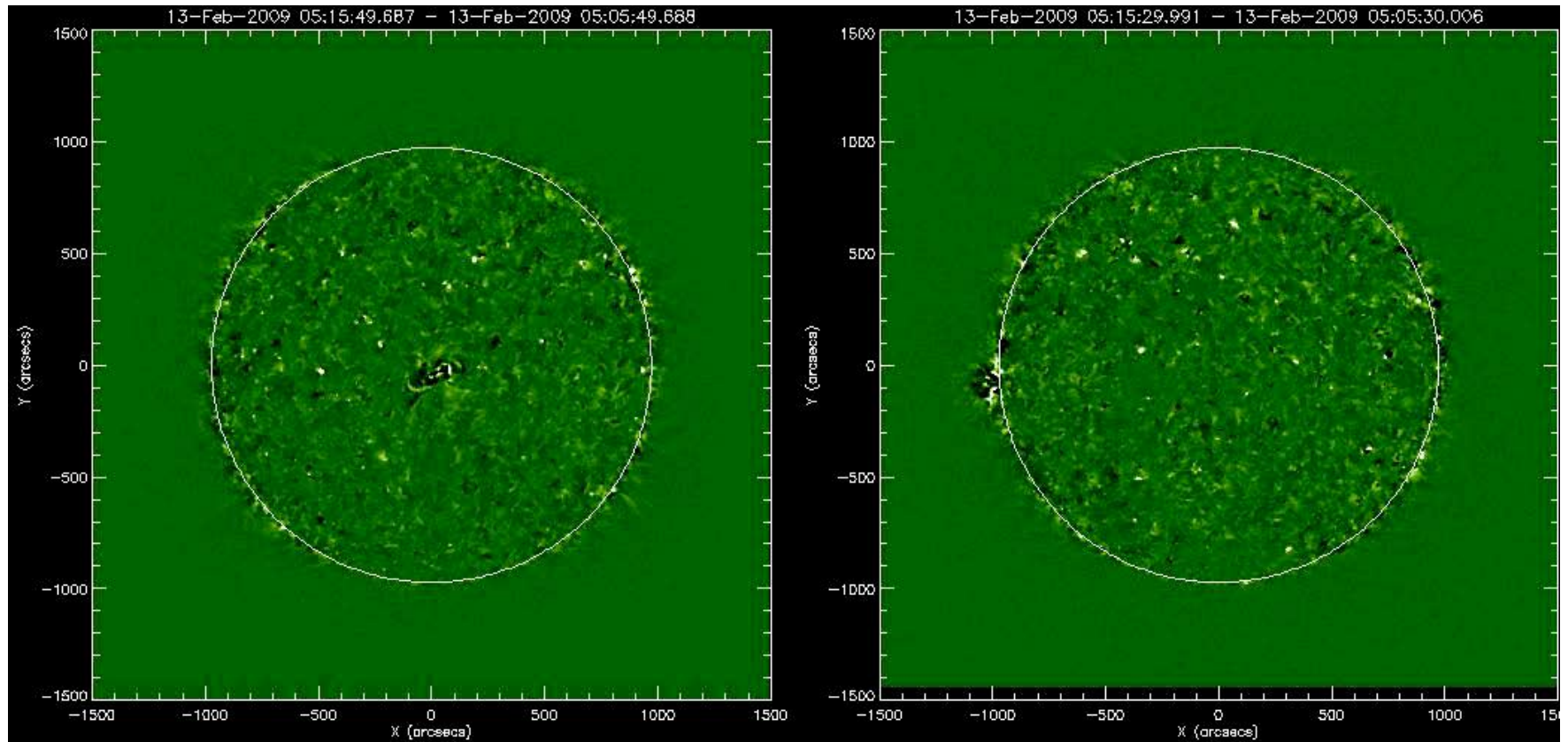
# Event 1: Feb 13<sup>th</sup> 2009

- STEREO-A and STEREO-B  $\sim 90^\circ$  apart (quadrature)

Running difference images in EUVI 195 Å filter

STEREO-B

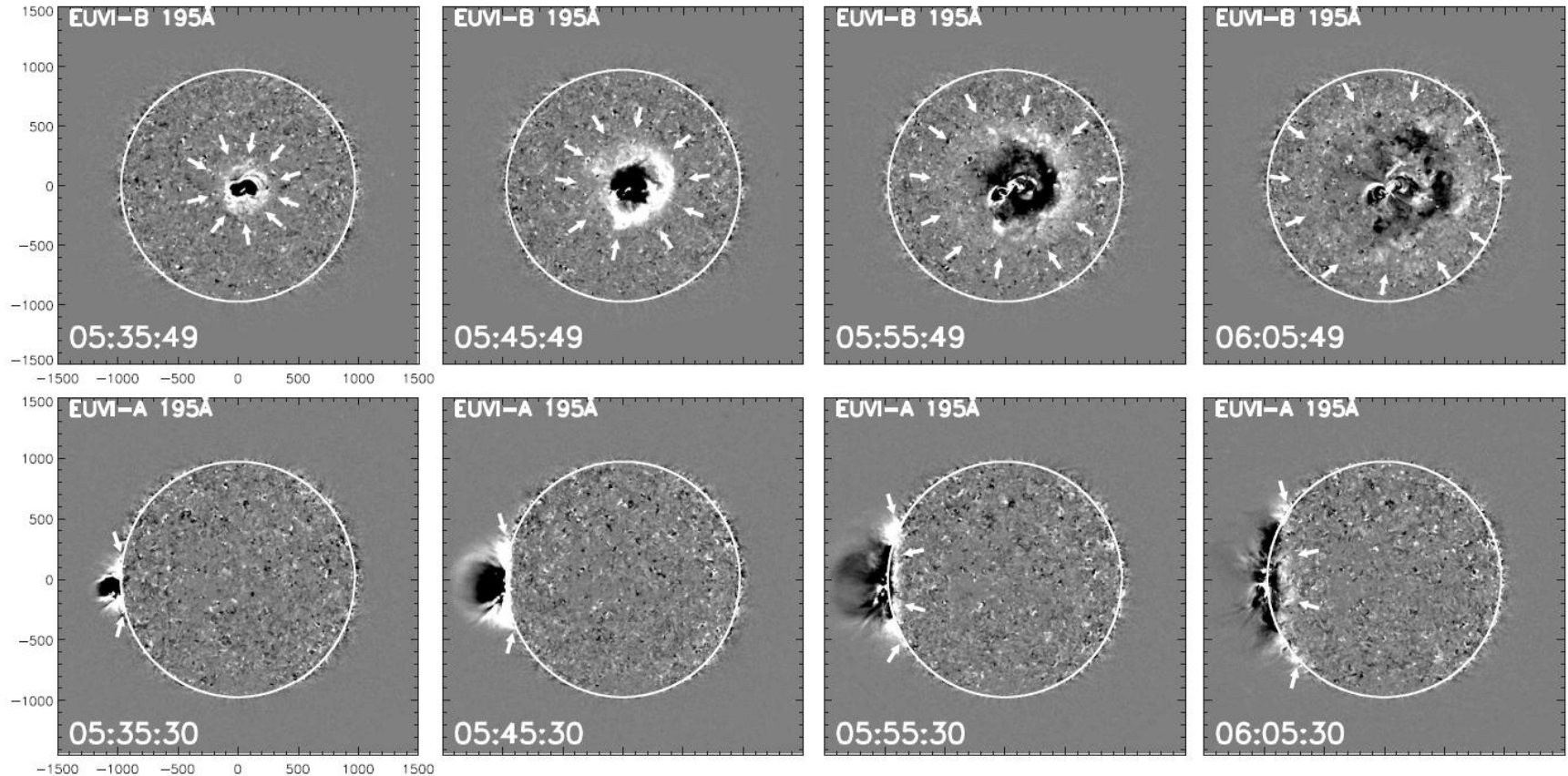
STEREO-A



Kienreich, Temmer & Veronig ApJ Lett. (2009)

# Event 1: Feb 13<sup>th</sup> 2009

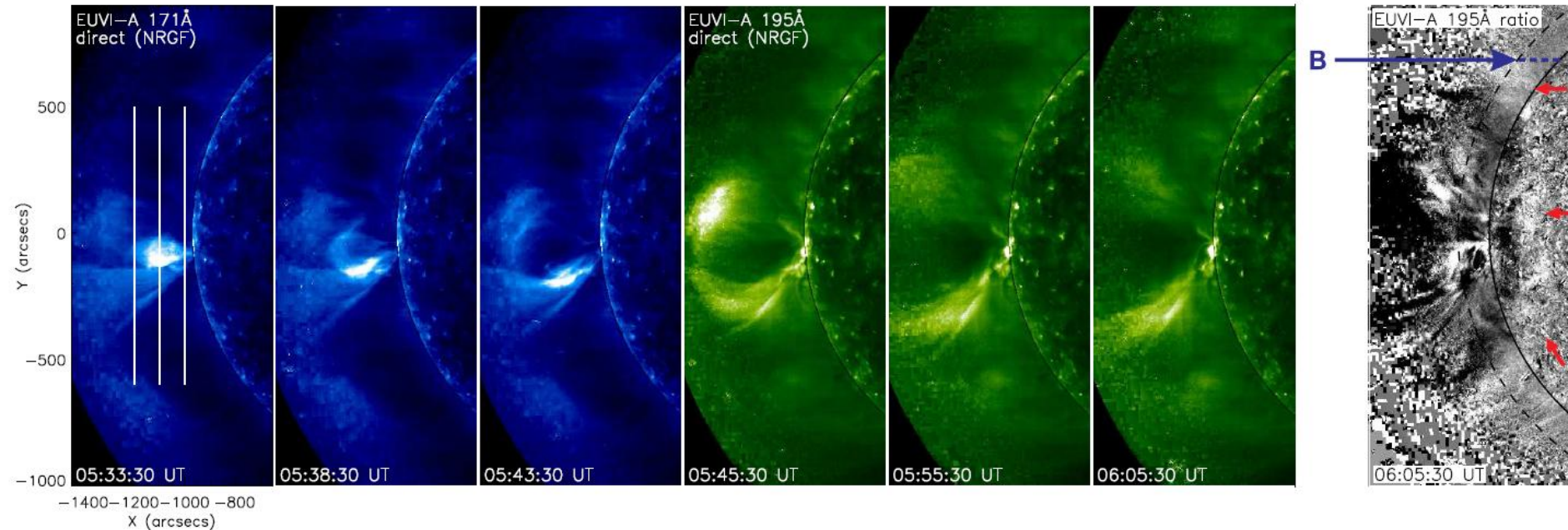
- Coronal wave in EUVI 195 Å in STEREO-B (top) and STEREO-A (bottom)



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

# Event 1: Feb 13<sup>th</sup> 2009

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

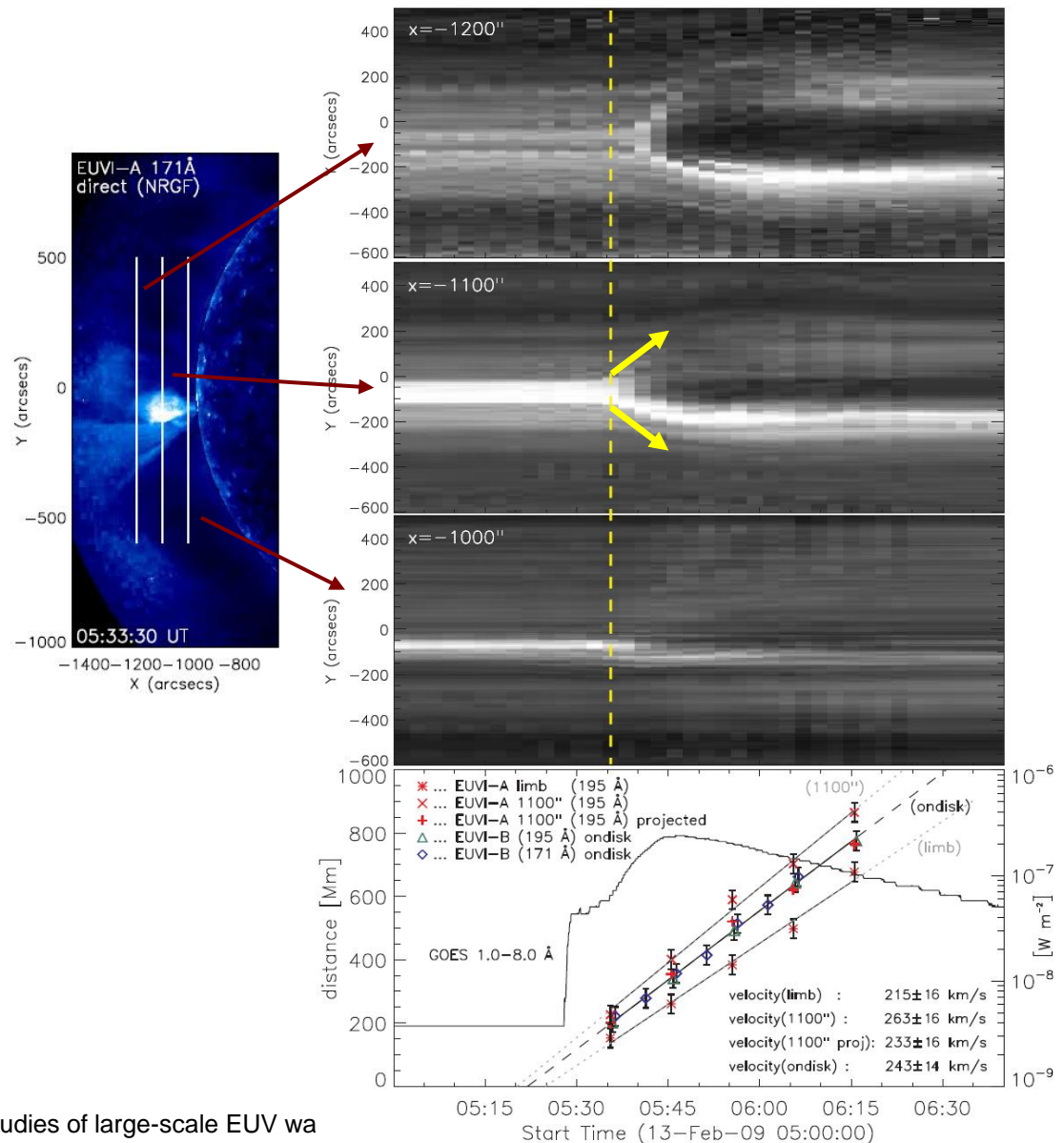


Kienreich, Temmer & Veronig *ApJ-Lett.* (2009)

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

## Driver of the wave:

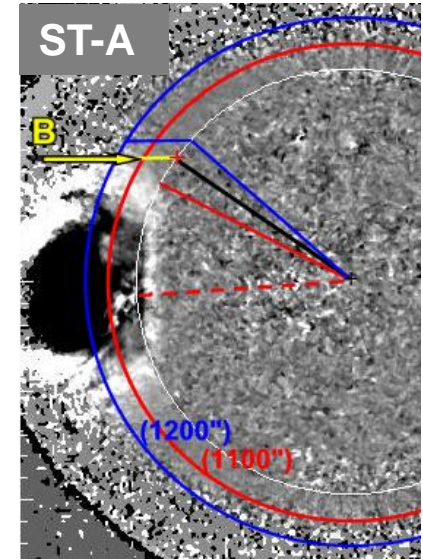
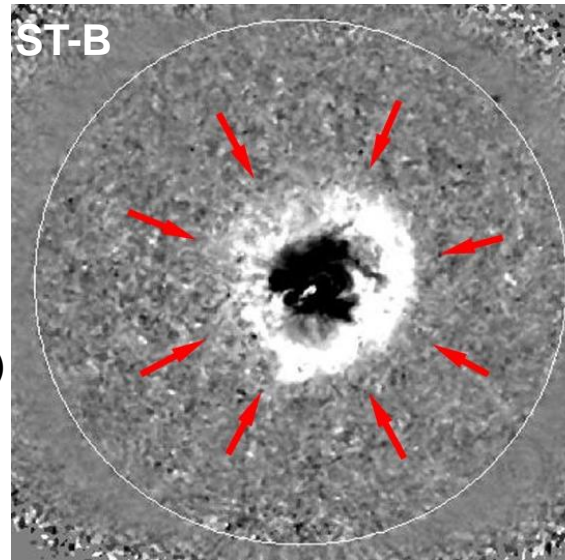
- CME expanding flanks
- 3 slits  $y=[-600'',500'']$  at different heights above solar surface
- Stack plots to illustrate lat. evolution of CME flanks
- $x=1000''$ : no visible change in lat. expansion
- $x=1100''$  and  $x=1200''$ : first strong expansion of CME flanks then stagnation  $\rightarrow$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





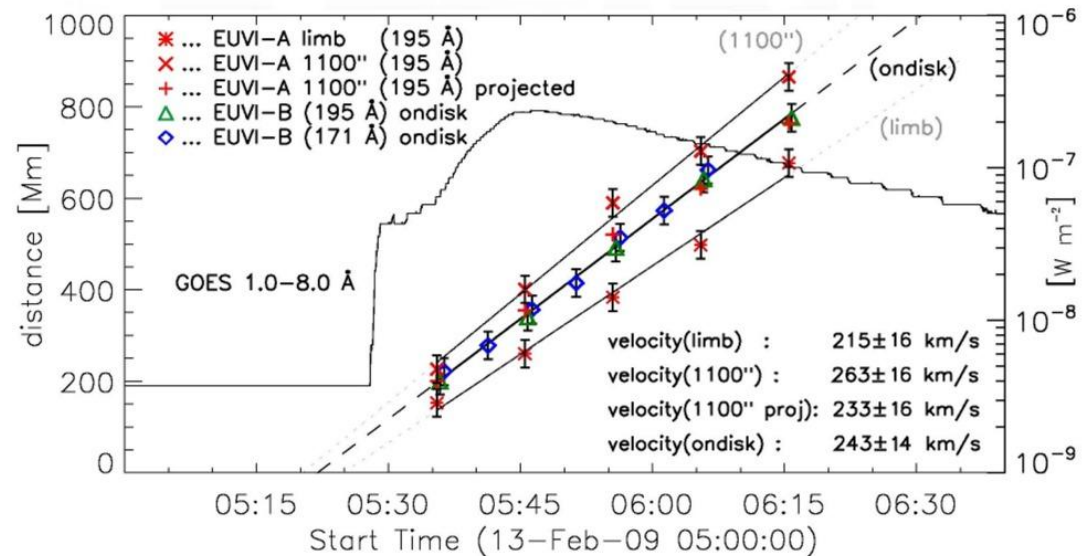
## Wave kinematics:

- 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

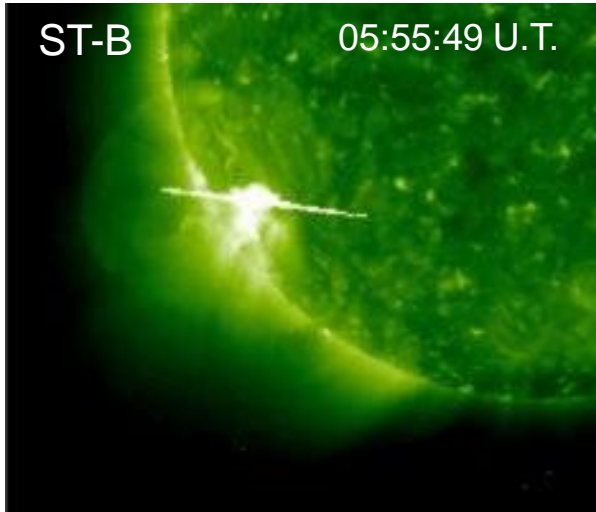


- Wave:
  - $v \sim 260$  km/s (const.)
  - $H \sim 80\text{--}100$  Mm
- driven by CME flanks

Kienreich, Temmer & Veronig (2009)

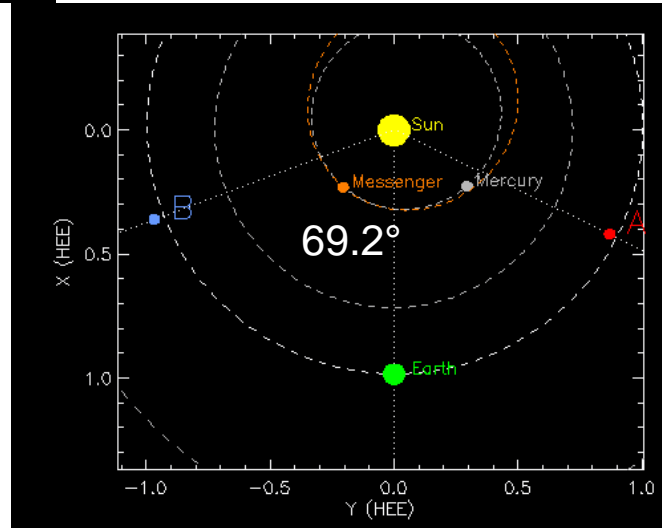


## Dome-shaped large-scale EUV coronal wave



- 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  $57^\circ$  to  
the east

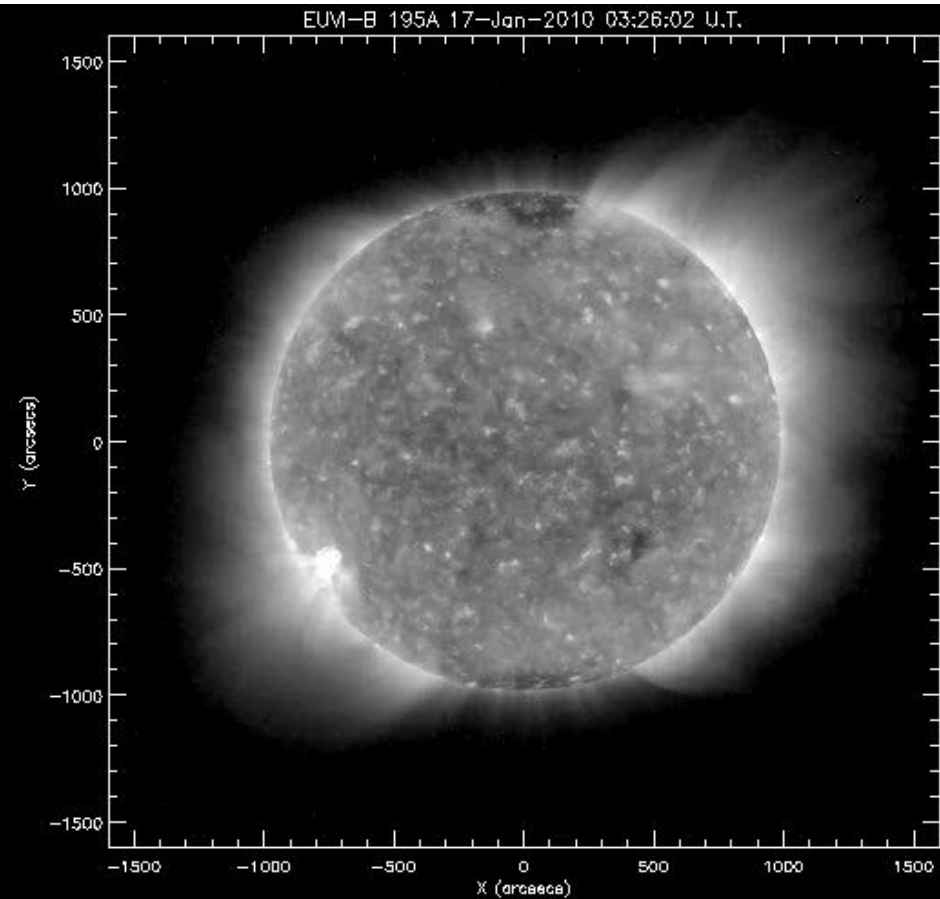
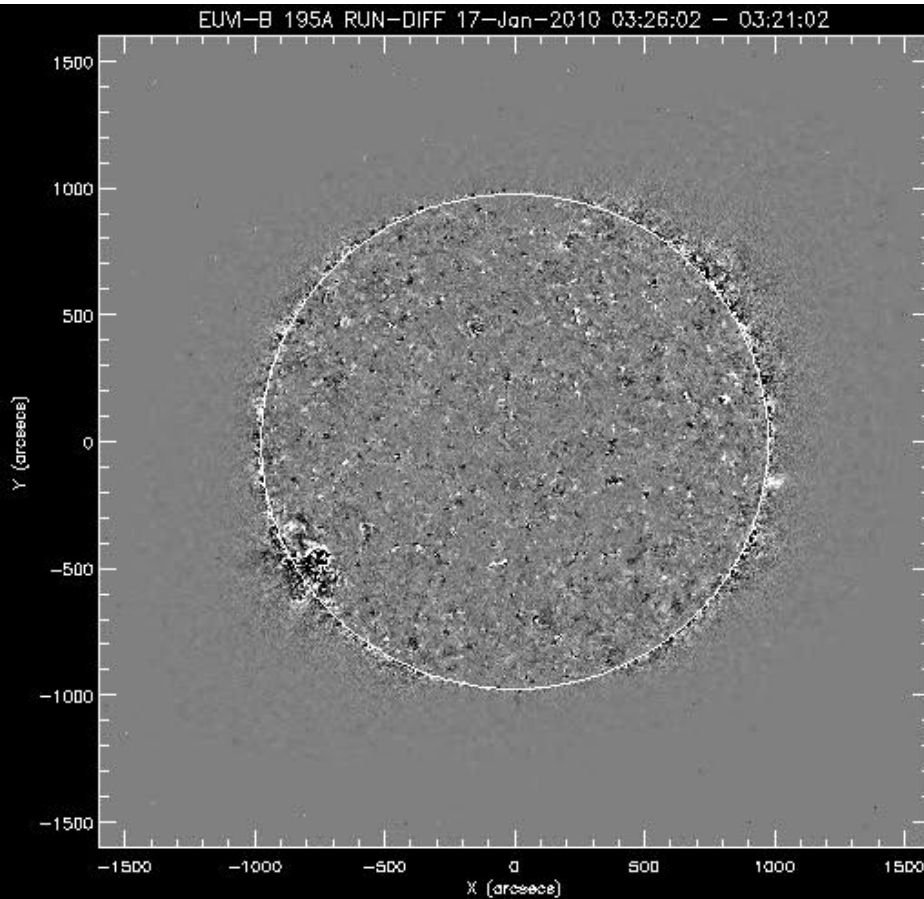


Event  $36^\circ$  behind Eastern  
solar limb for an **Earth-**  
**based** vantage point

# Event 2: Jan 17<sup>th</sup> 2010

195Å running-difference images ( $\Delta t = 5\text{min}$ )

195Å direct images

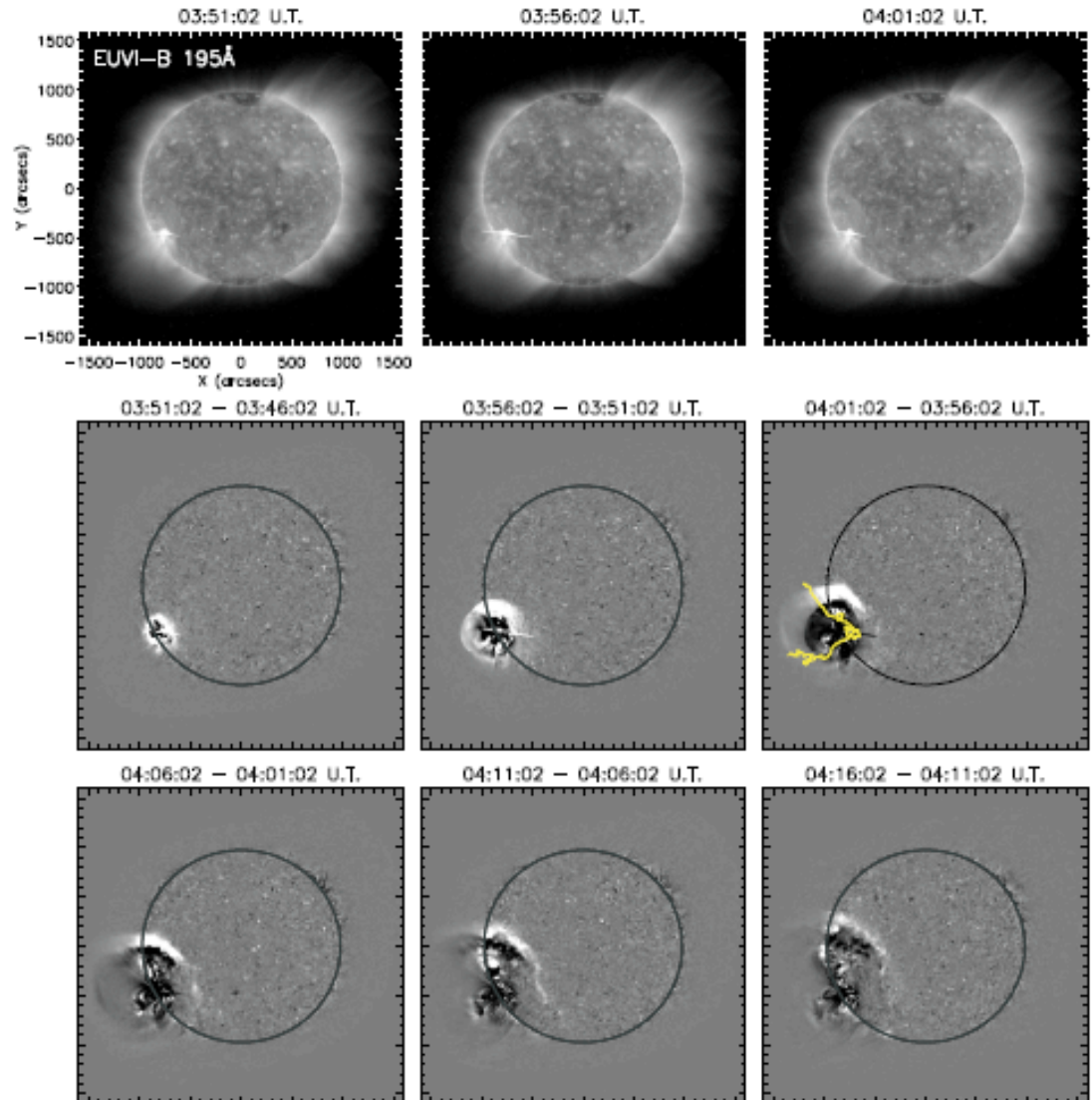


Veronig, Muhr, Kienreich, Temmer & Vršnak ApJ. Let. 2010 (submitted)

avi

# Event 2: Jan 17<sup>th</sup> 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**



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

He II 304Å : T ~ 0.07 MK

→ here Si XI !!!

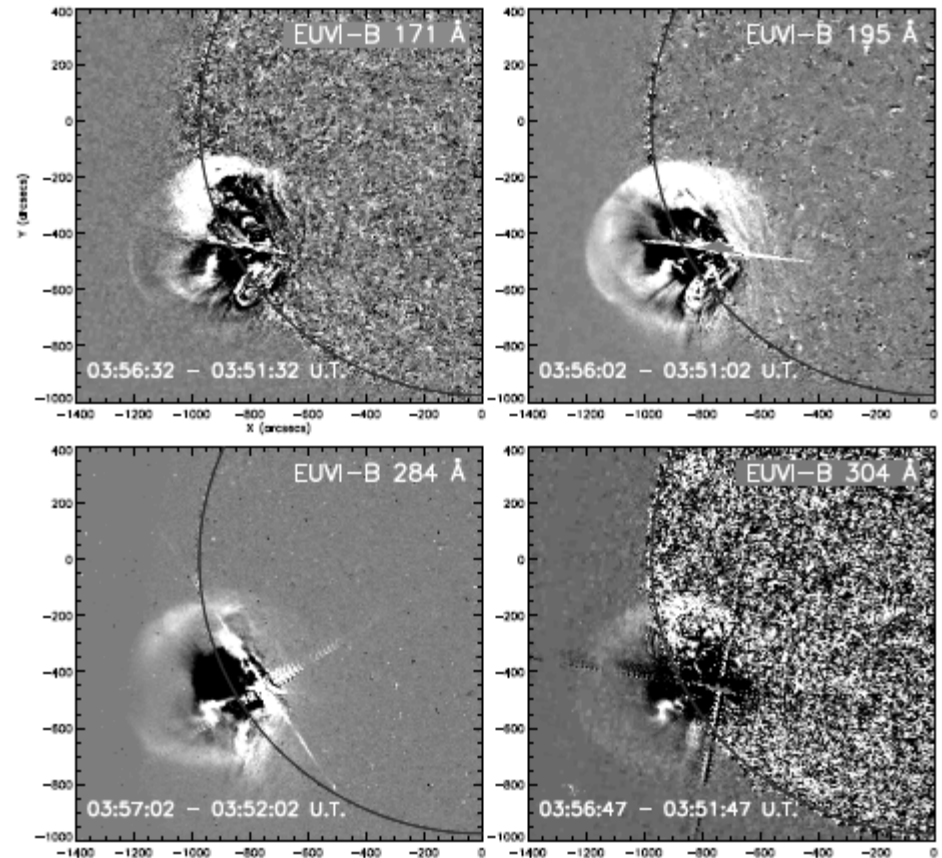
Fe IX 171Å : T ~ 1 MK

Fe XII 195Å : T ~ 1.5 MK

Fe XV 284Å : T ~ 2.25 MK

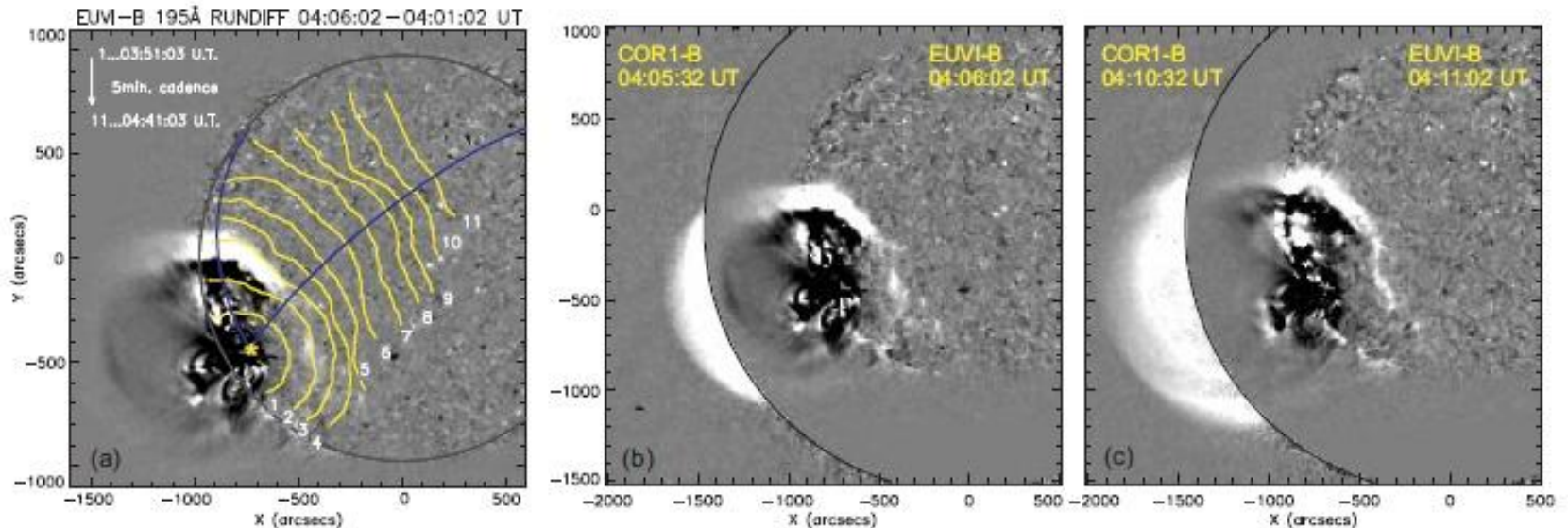
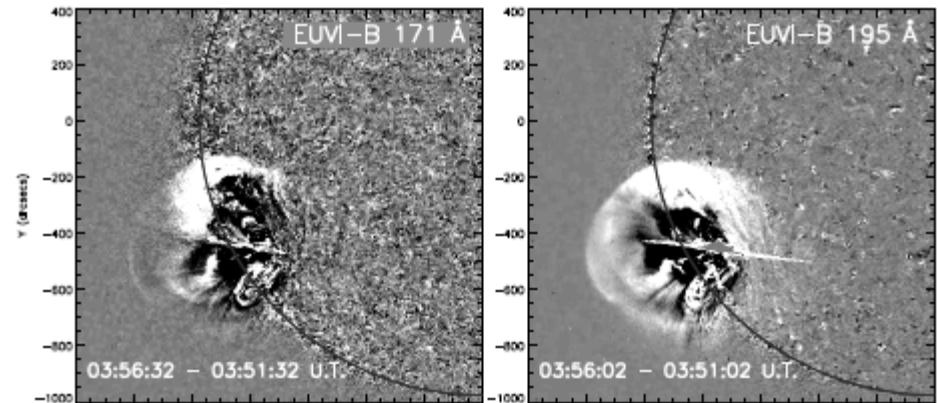
- in all 4 spectral channels :  
on-disk signature of the  
wave fits perfectly with  
wave signature above limb

→ 1...2.3 MK range



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

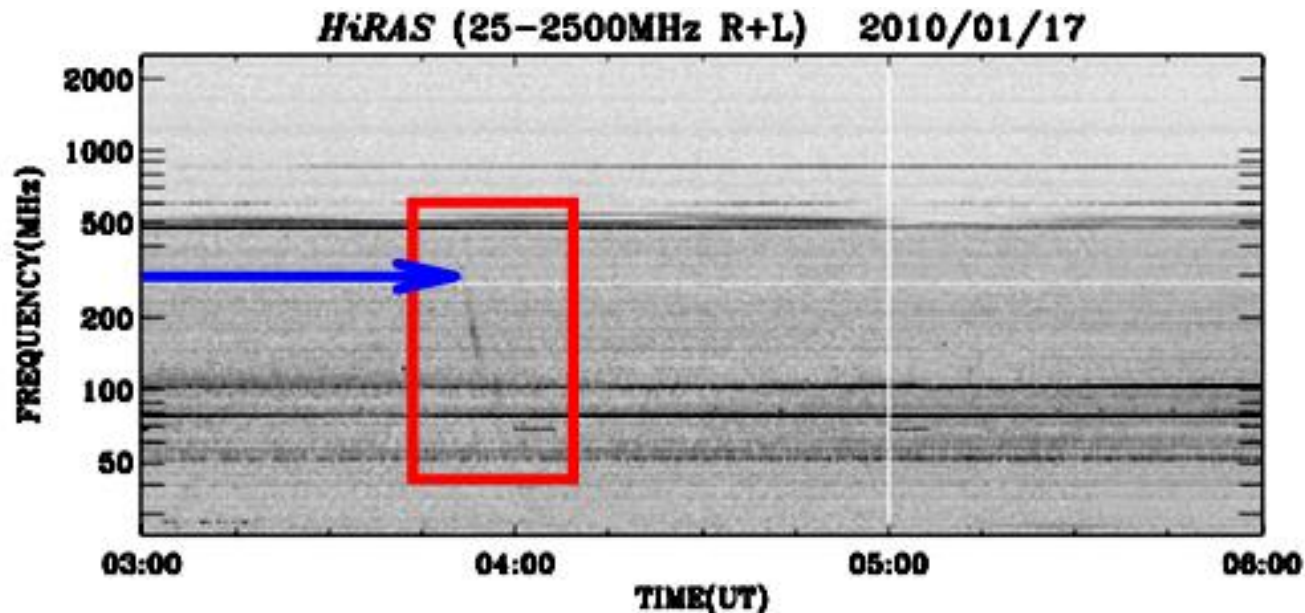
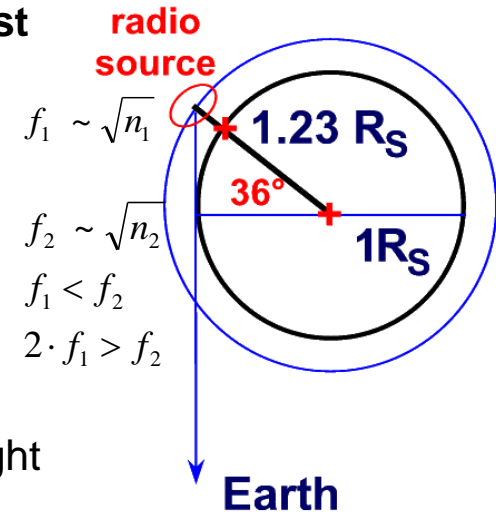


# Event 2: Jan 17<sup>th</sup> 2010

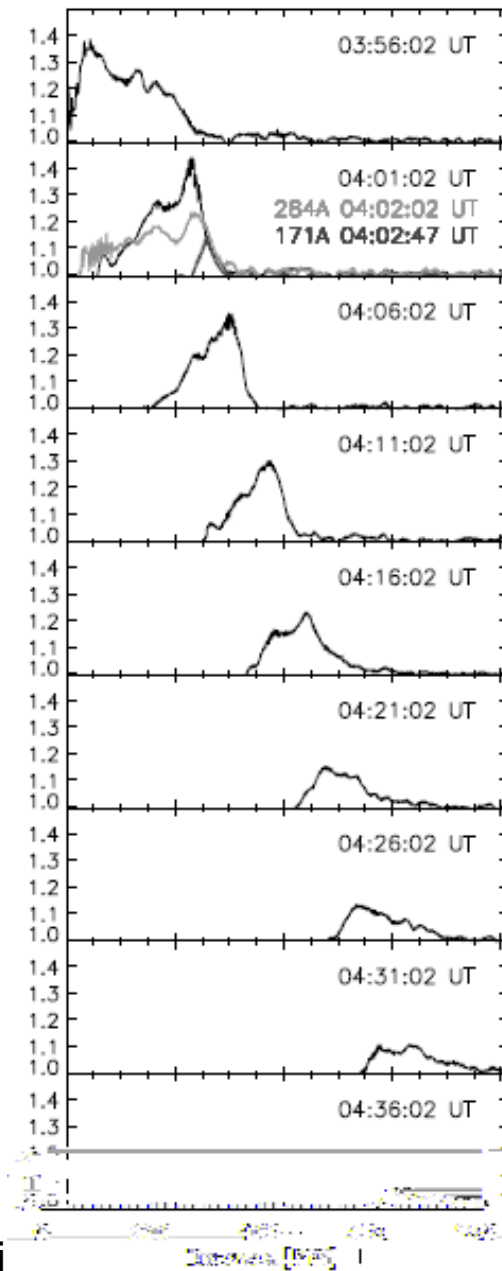
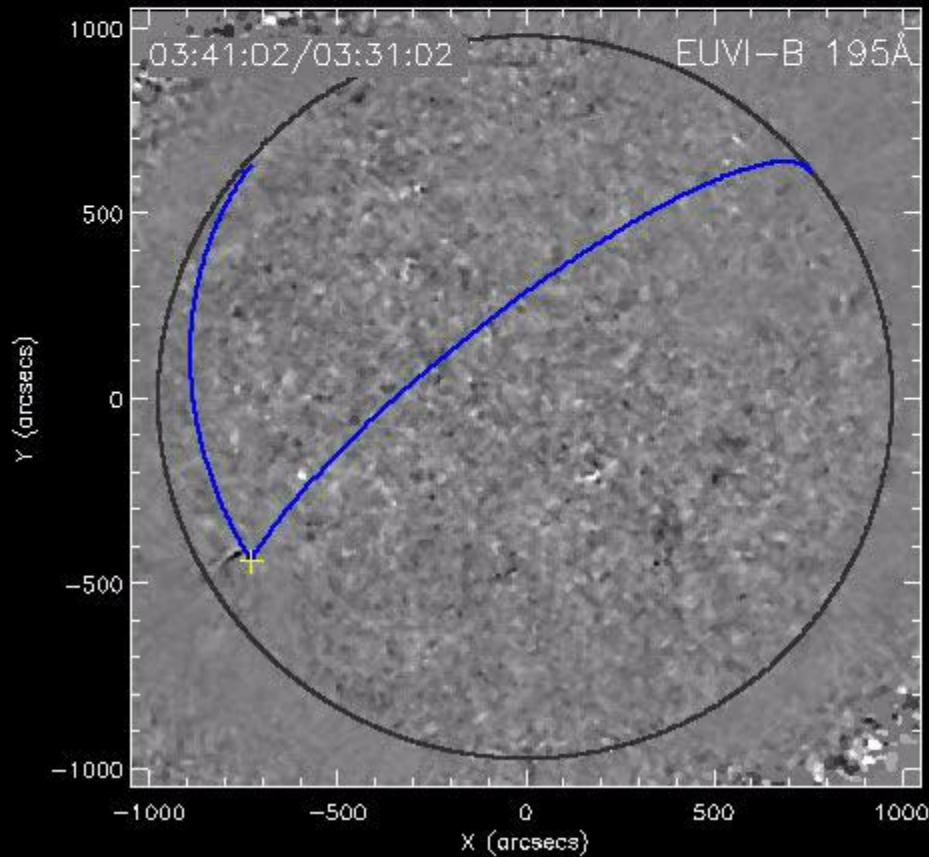
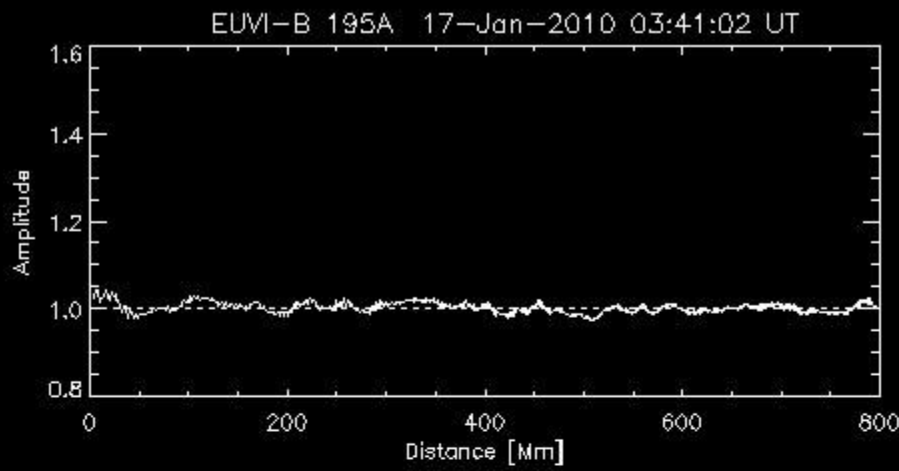
**HiRAS** (Hiraiso Radio Spectrograph): **high-frequency type II burst**  
 emission at first harmonic of plasma frequency ( $2 \cdot f_1$ )  
 drifting from  $\sim 310$  MHz to  $\sim 80$  MHz during  $\sim 03:51$ – $03:58$  U.T.

wave center at  $57^\circ$  (EUVI-B)  $\rightarrow$  for Earth  $36^\circ$  behind Eastern limb  
 corresponding to occultation height  $\sim 0.23 R_S$  ( $\sim 160$  Mm)

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



# Intensity Profiles





# Event 2: Jan 17<sup>th</sup> 2010

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

$v_{\text{wave}}$  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

