

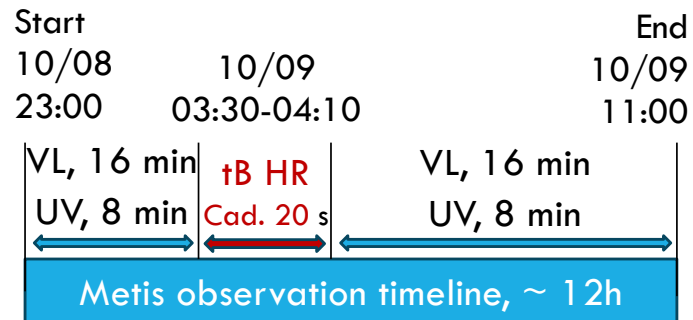
# OBSERVATION OF A CME OBSERVED BY SOLAR ORBITER METIS CORONAGRAPH IN OCTOBER 2022



**Il Metis Science Meeting**

**Giuliana Russano**  
 INAF – OACN  
 De Leo Y., Frassati F., Jerse G., Mancuso S.  
 January 27-29, 2025  
 Capodimonte Astronomical Observatory, Naples, Italy

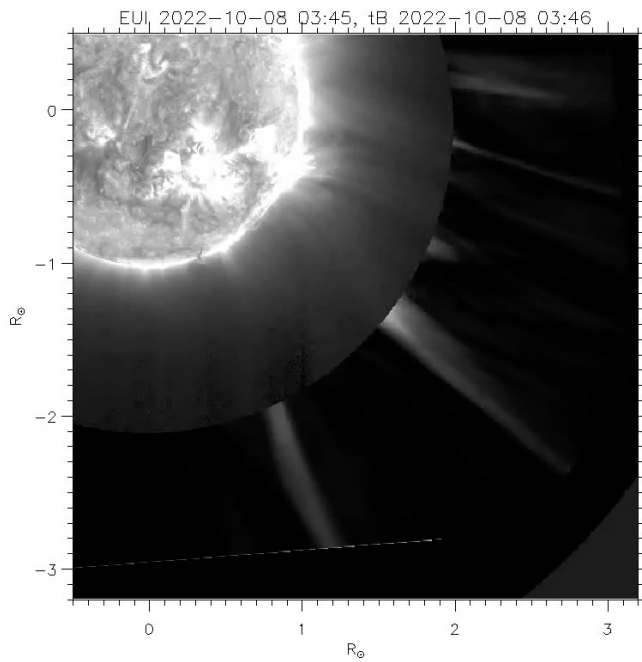
# METIS OBSERVATIONS



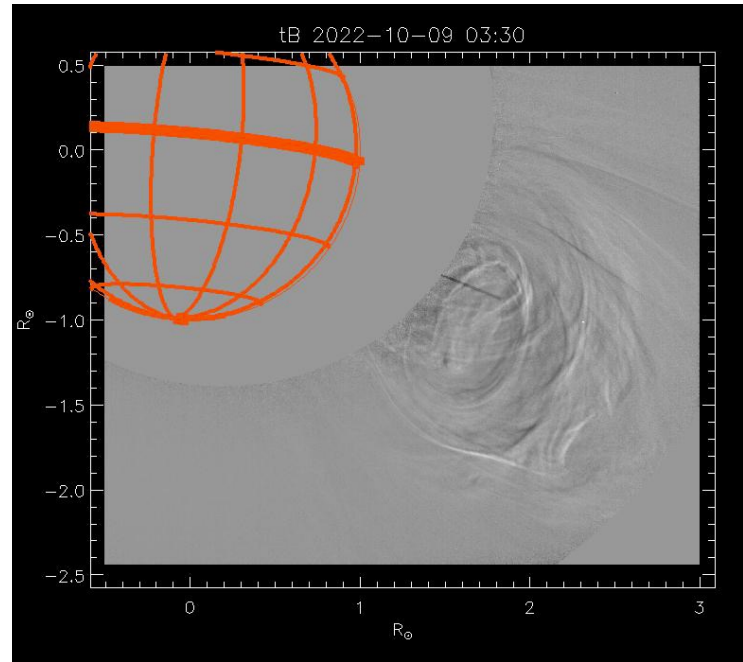
- Metis observation info**

  - Exposure time:  
VL 210 s, UV 420s
  - Spatial scale
    - VL  $4.5 \cdot 10^3 \text{ km/px}$
    - UV  $9.0 \cdot 10^3 \text{ km/px}$
  - SoLO Sun distance 0.3 AU

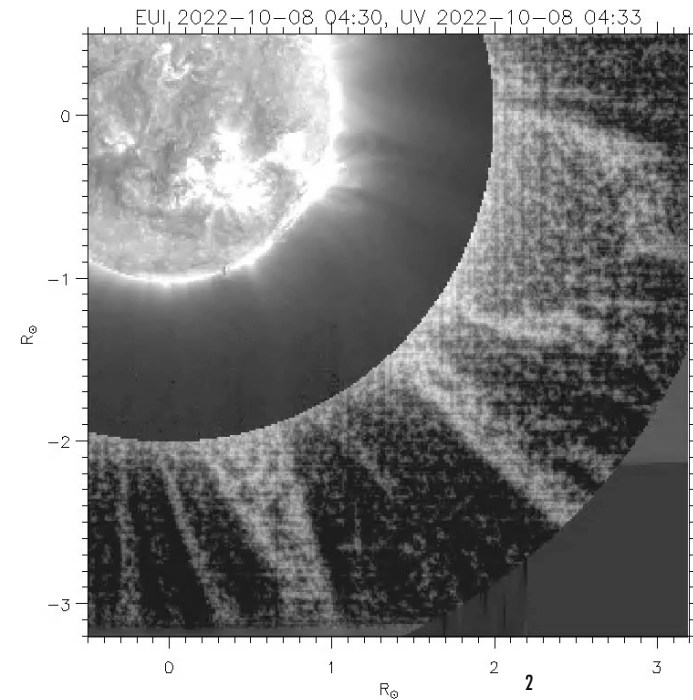
EUI/FSI 17.4 nm + Metis total B  
16 min cadence (~12 h)



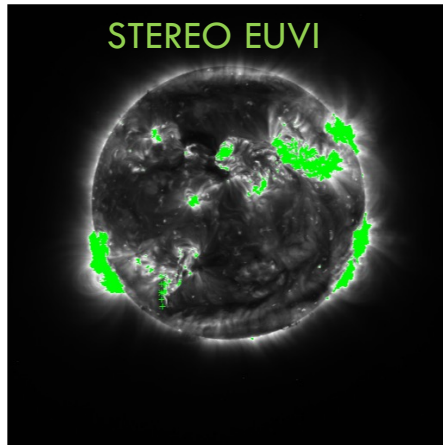
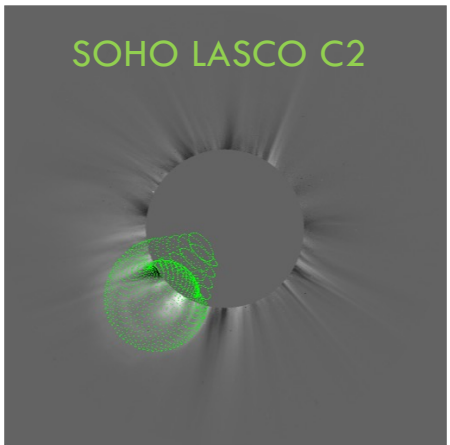
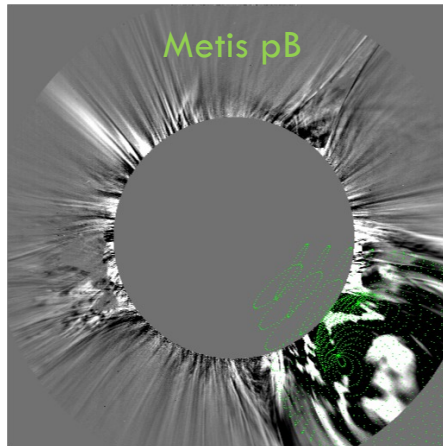
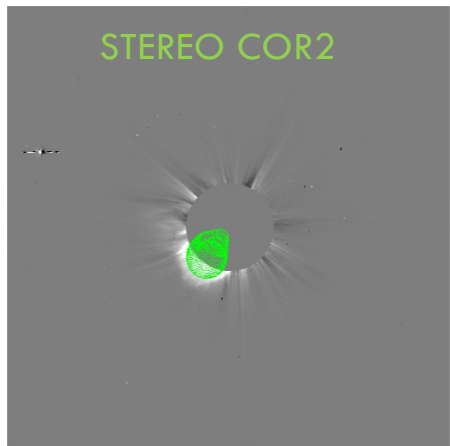
Metis total B HR  
20 s cadence (40 min sequence)



EUI/FSI 17.4 nm + Metis UV  
8 min cadence (~12 h)

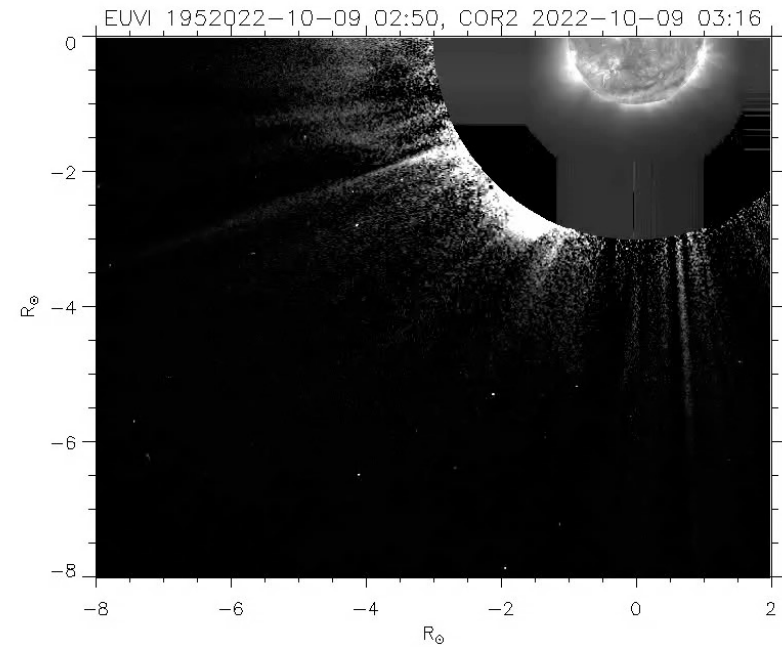
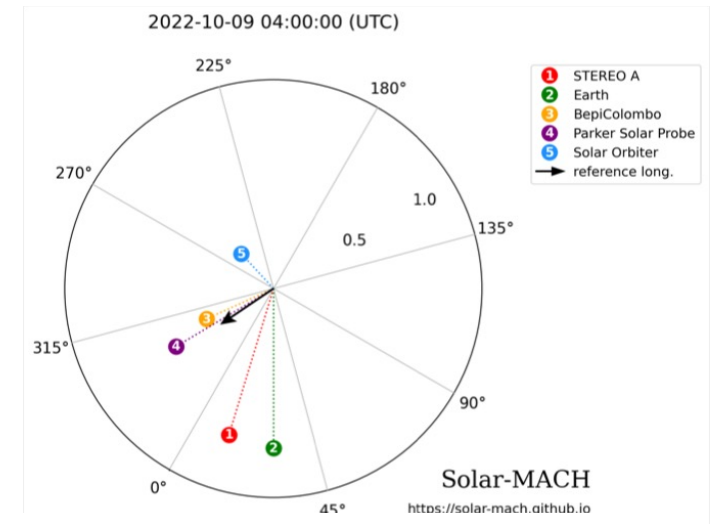


# ORBITS CONTEST AND GCS RECONSTRUCTION

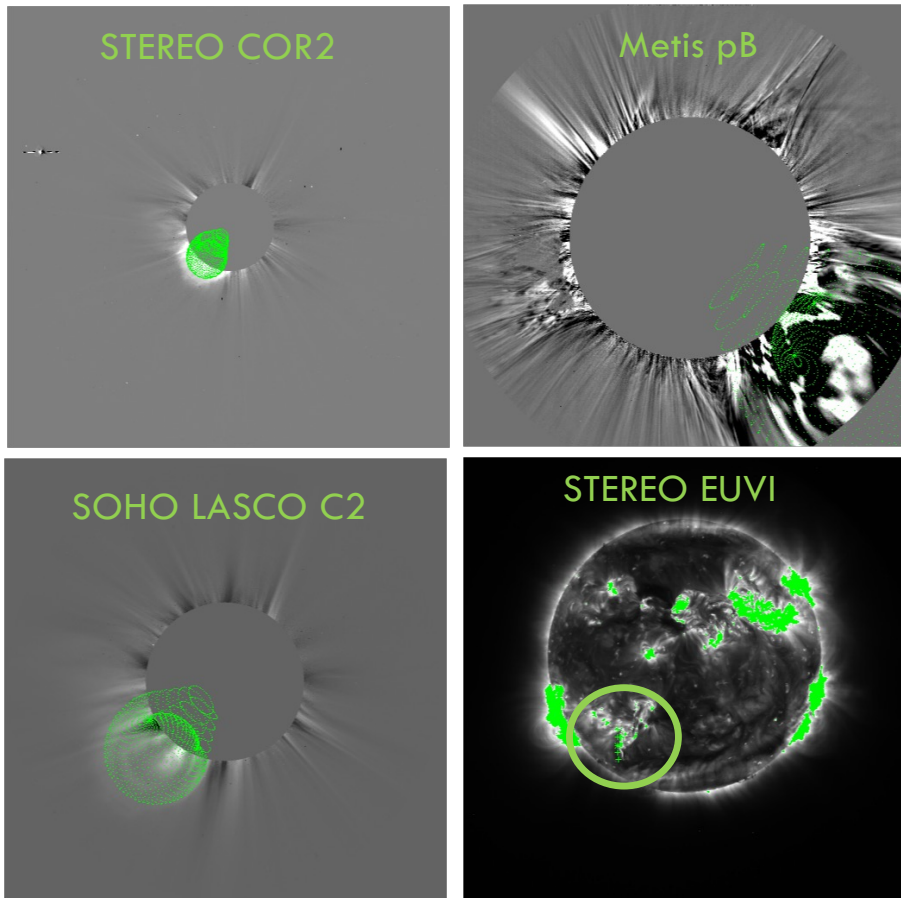


Results from  
rtscgcloud.pro  
IDL/SolarSoft routine:

- Source region Carrington Long.  $334^\circ$
- Source region Carrington Lat.  $-34^\circ$
- Distance from the Sun of CME front apex 4.5 solar radii

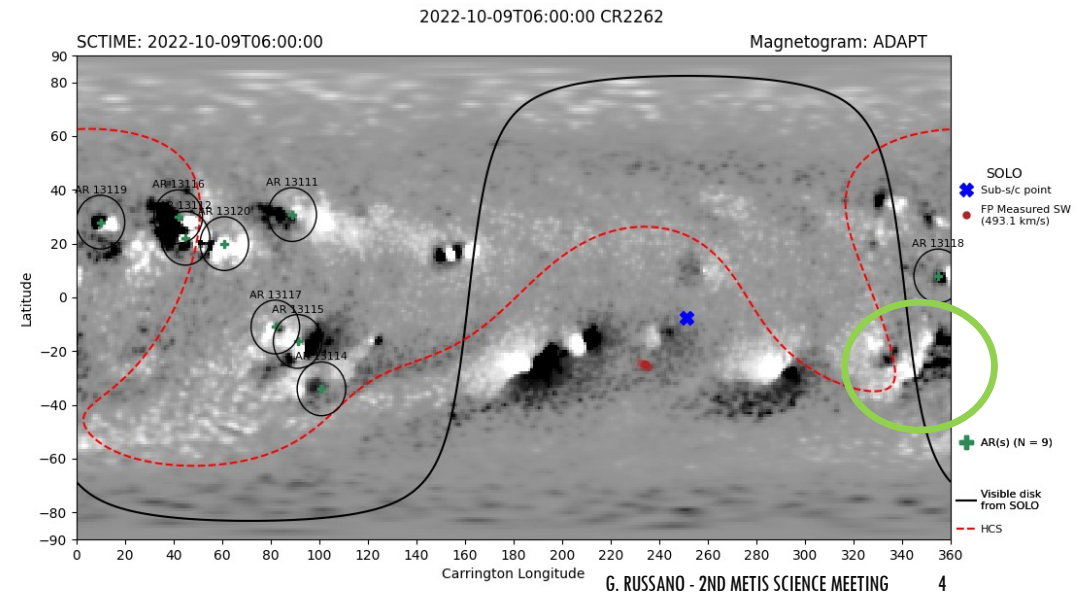
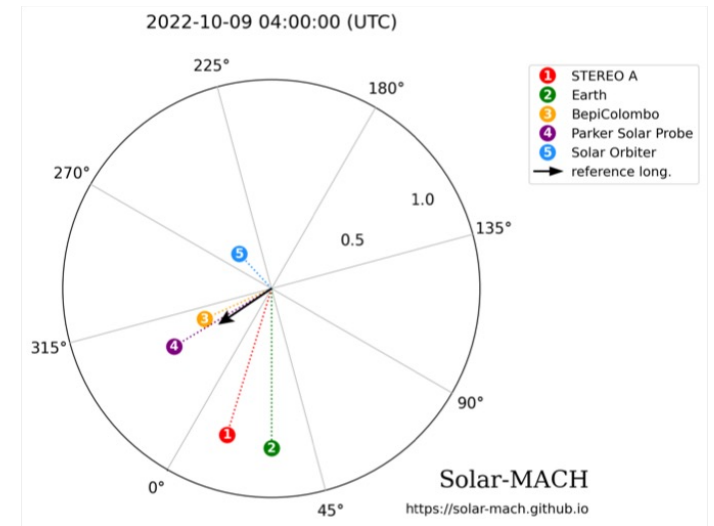


# ORBITS CONTEST AND GCS RECONSTRUCTION



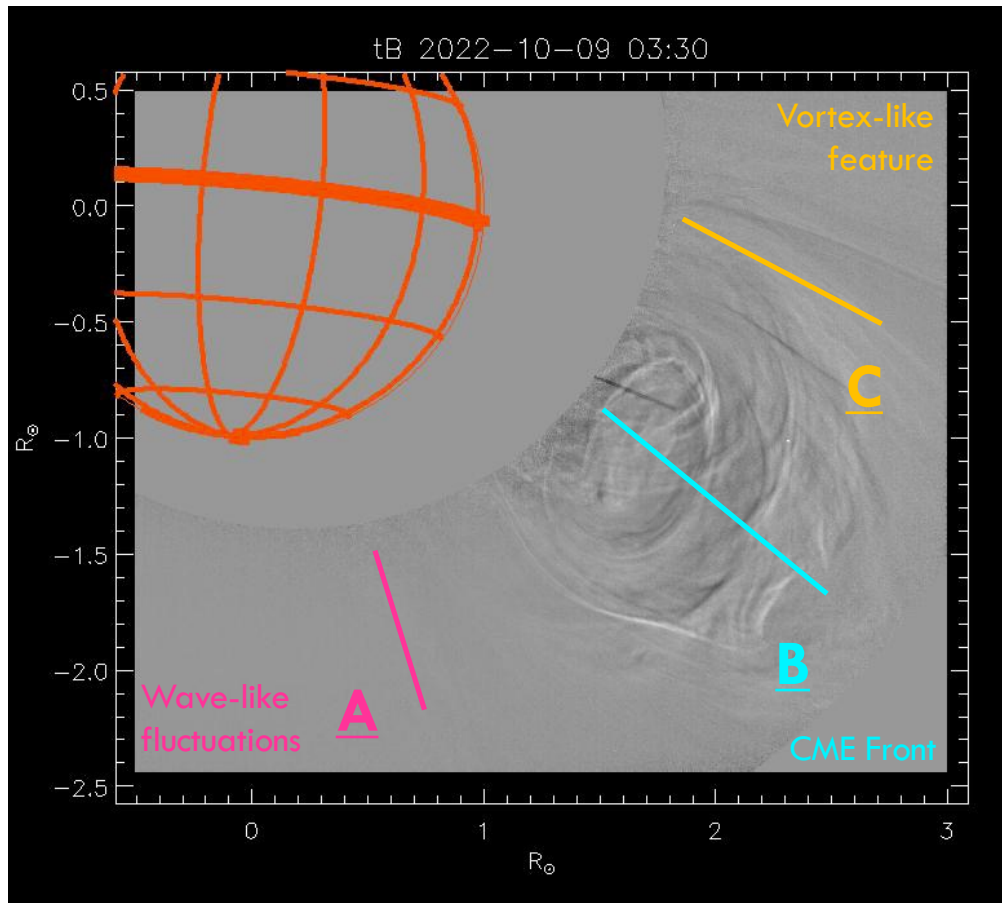
Results from  
rtscgcloud.pro  
IDL/SolarSoft routine:

- Source region Carrington Long.  $334^\circ$
- Source region Carrington Lat.  $-34^\circ$
- Distance from the Sun of CME front apex 4.5 solar radii

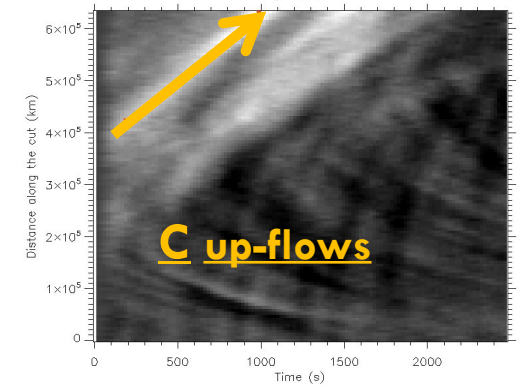
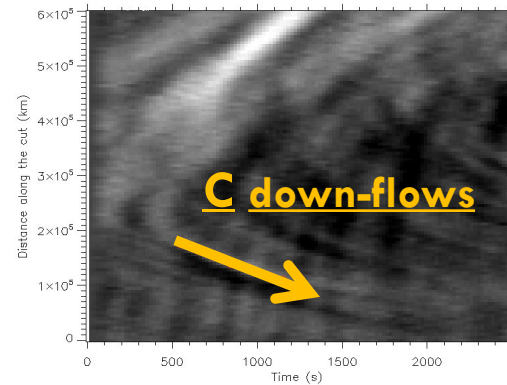
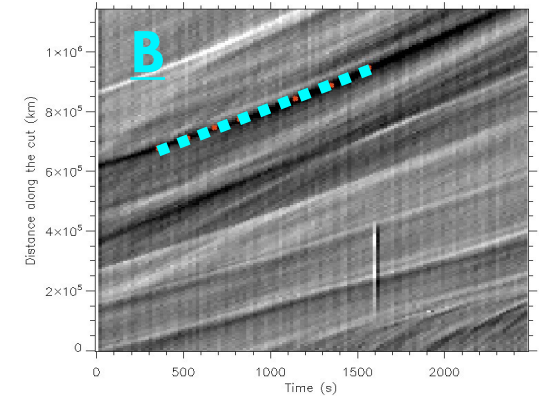
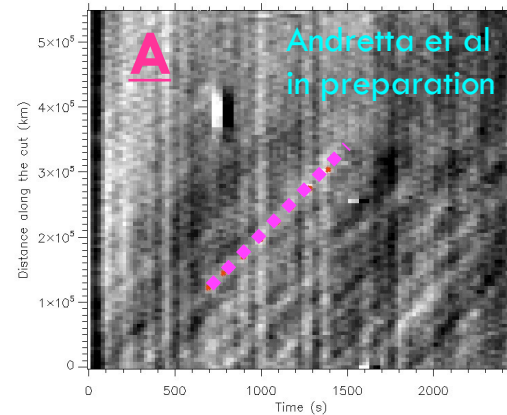


# KINEMATICS OF THE EVENT

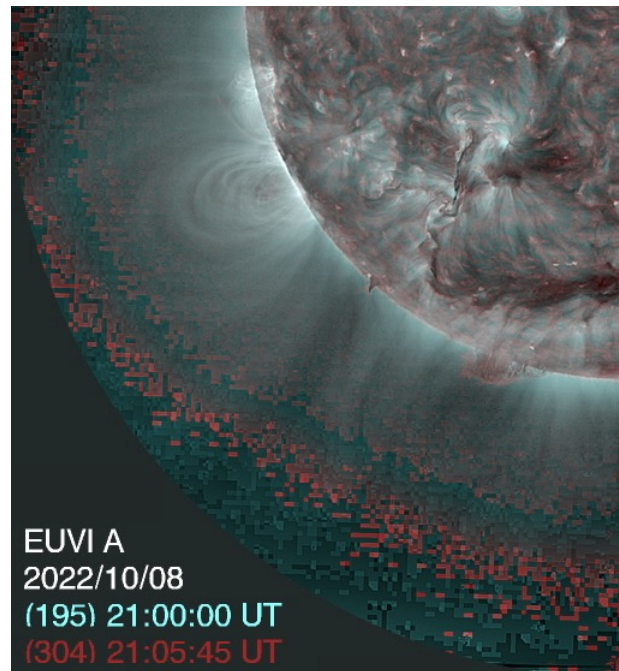
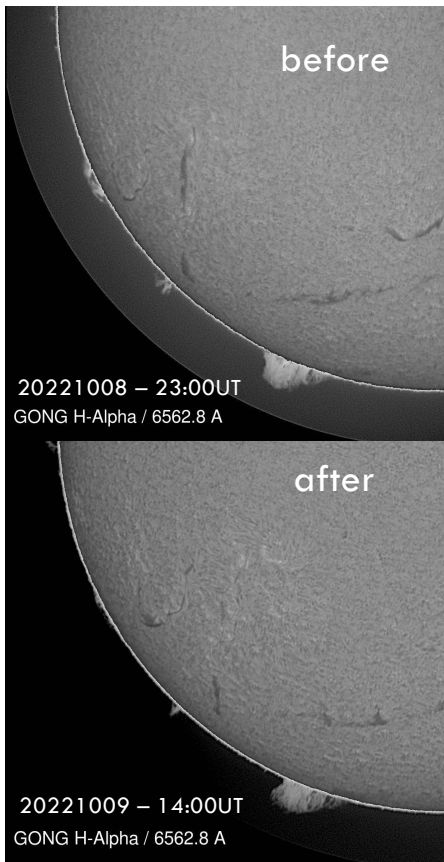
## TIME-DISTANCE METHOD



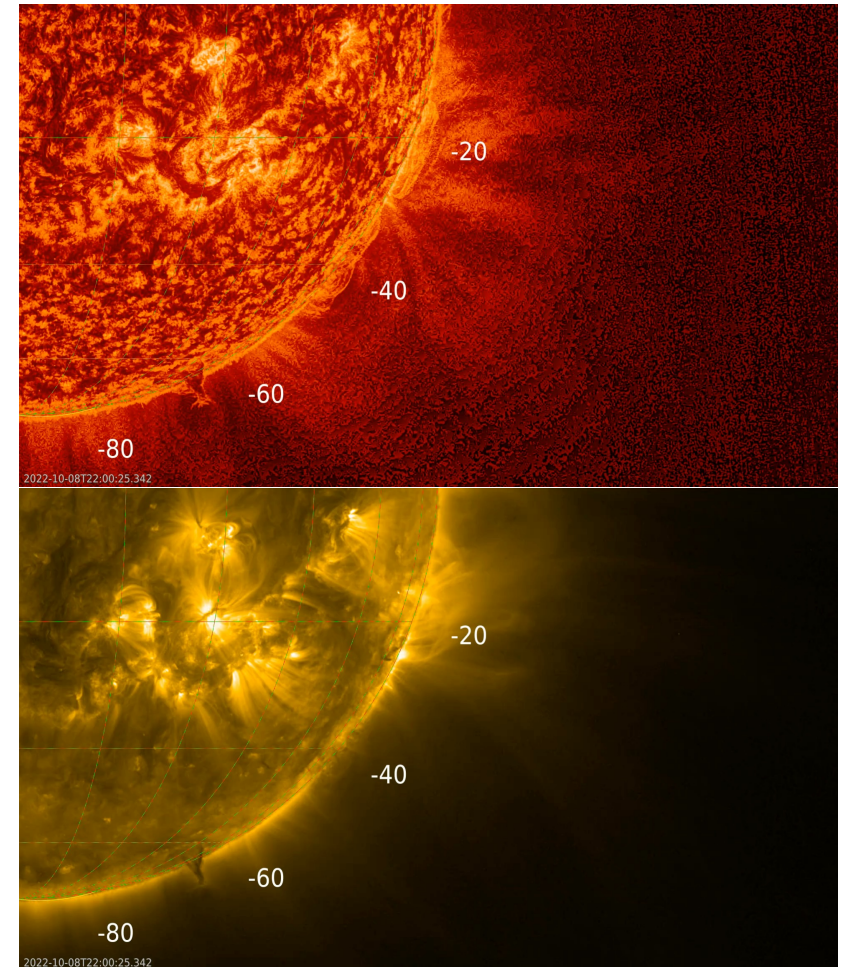
Feature ID	PoS velocity [km/s]
A: streamer fluctuations	220
B: CME front	188 (radial 192)
C: up-flow	165
C: down-flow	-70



# ON DISK OBSERVATIONS

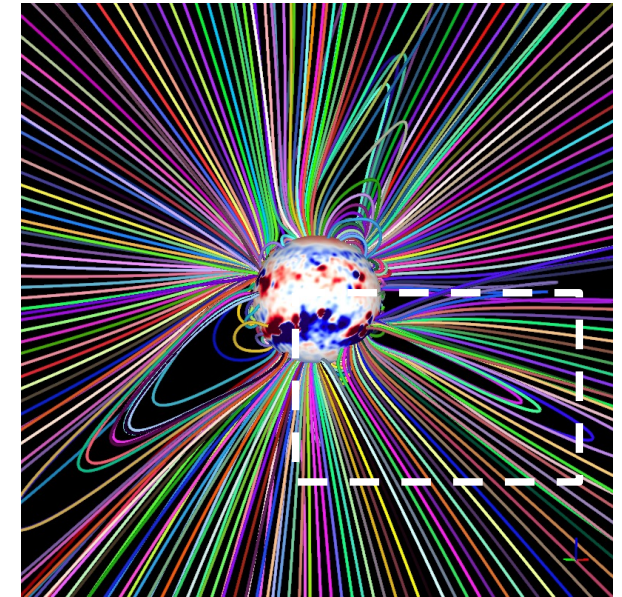
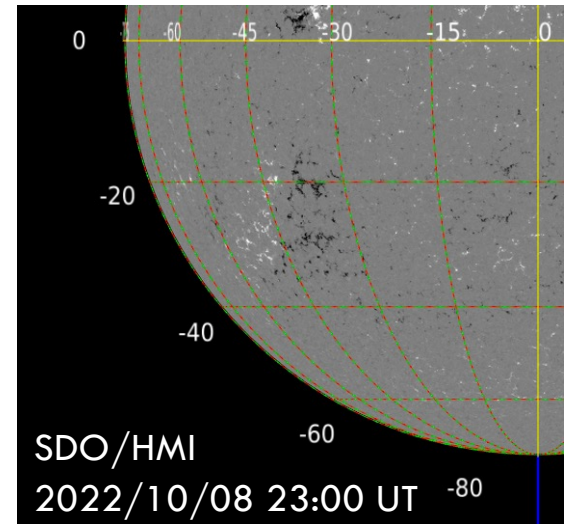


EUI/FSI 30.4 and 17.4 nm



# STEALTH CMES VS. REGULAR CMES

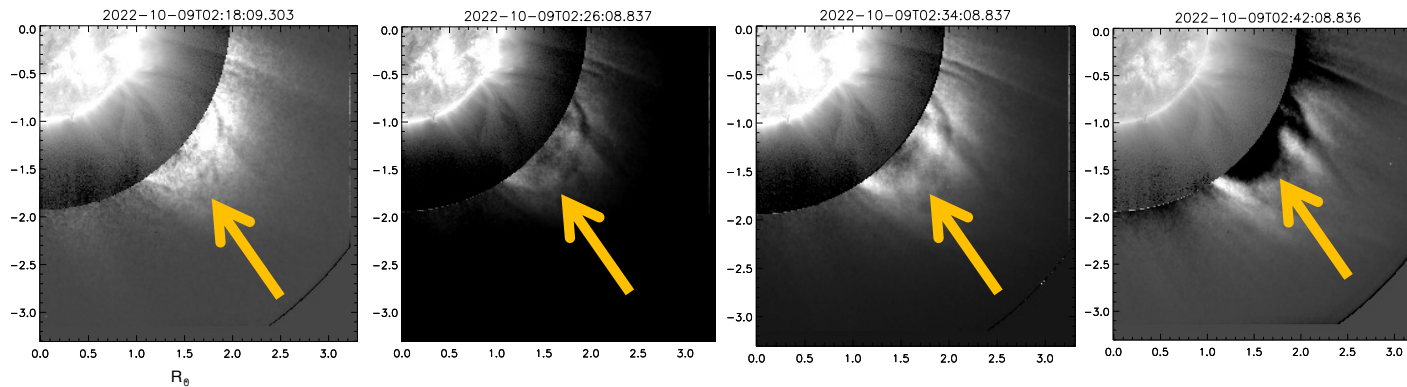
- **Characteristics** (Robbrecht 2009, Lynch 2016, 2021, O’Kane 2021):
  - lack typical low-coronal signatures (e.g. filament eruptions, X-ray flares, flare ribbon, or EUV dimmings)
  - slow speeds (less than  $500 \text{ km s}^{-1}$ ), gradual events with classical flux-rope morphology
  - origin in the mid-corona ( $\sim 1.2$  to  $3.0 R_{\odot}$  from Sun centre)
- **Formation mechanisms:**
  - originate in quiet Sun regions with weak magnetic fields
  - often associated with the shearing of magnetic fields along polarity inversion lines (PILs)



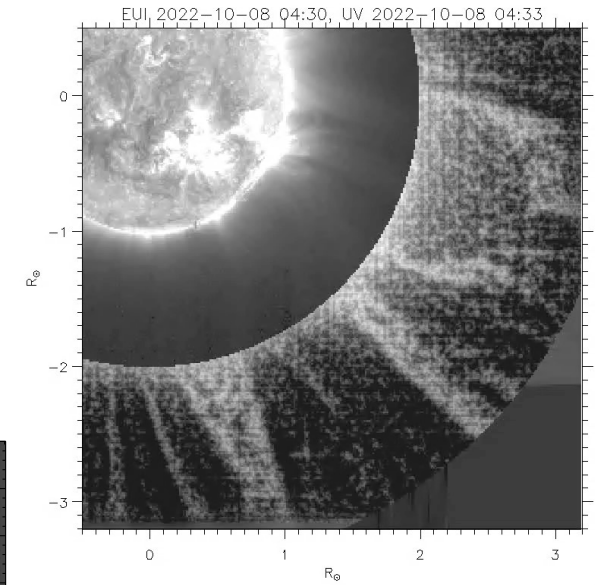
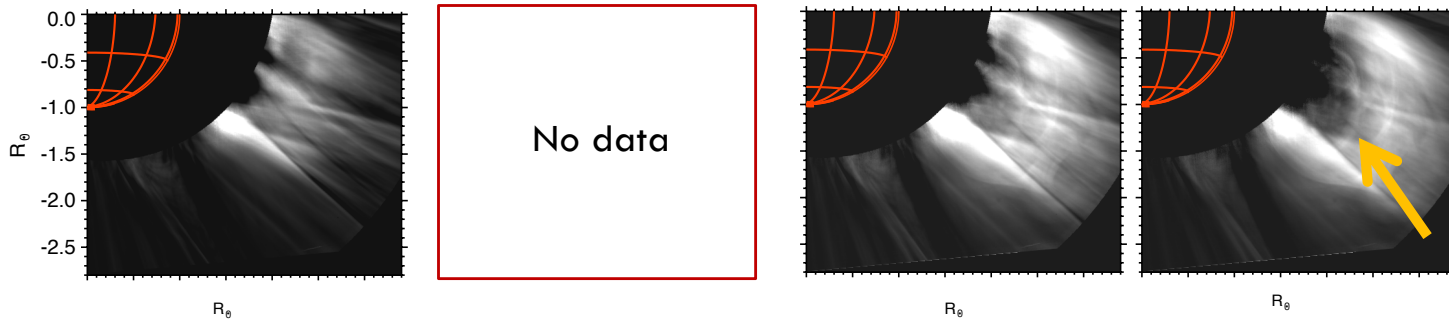
**Magnetic extrapolations (PSI) as seen from SoLO**

# UV DARK RING

UV



pB



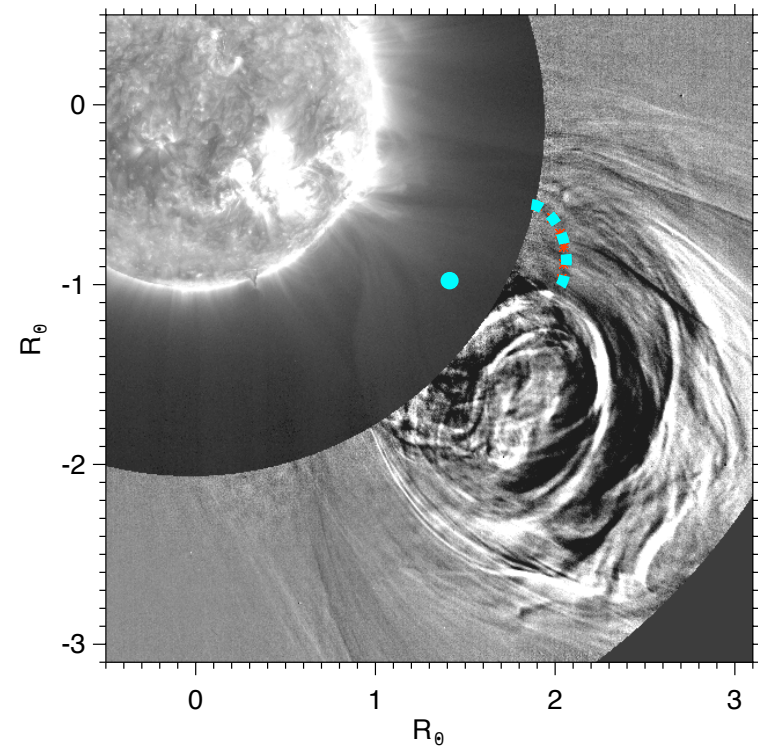
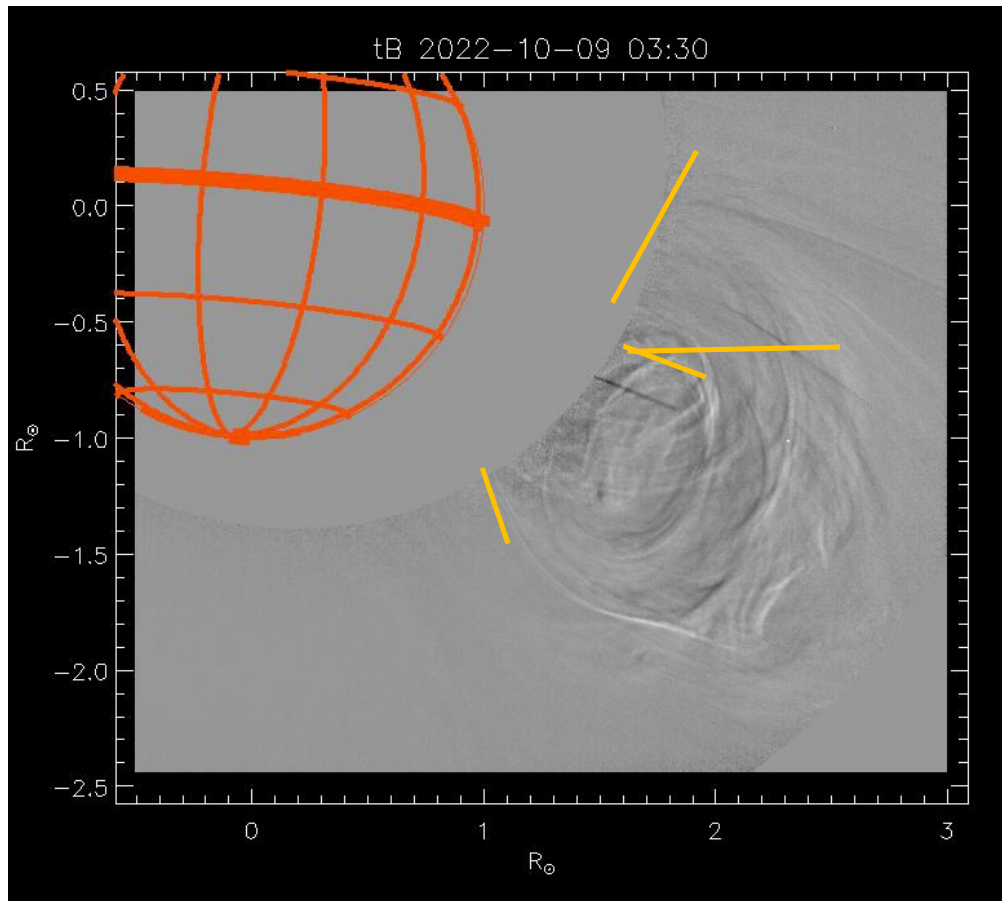
- edge of the CME front
- observable in EUI/FSI 17.4 nm

Some hypotheses about its nature:

- Environment density effect
- Doppler dimming effect

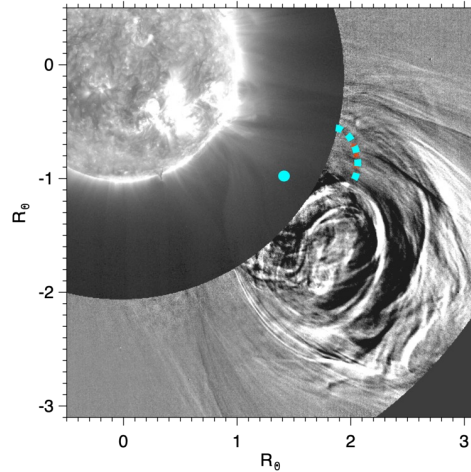


# WAVES IN TB HIGH CADENCE



- Two wave trains:
  - One on the CME west side, lasts all the time (dimming width  $\sim 55$  Mm or  $0.07 R_{\text{sun}}$ )
  - One at the base of the cavity, leaves at 4:00 UT
- Origin in the middle of the cavity?

# WAVES SPEED



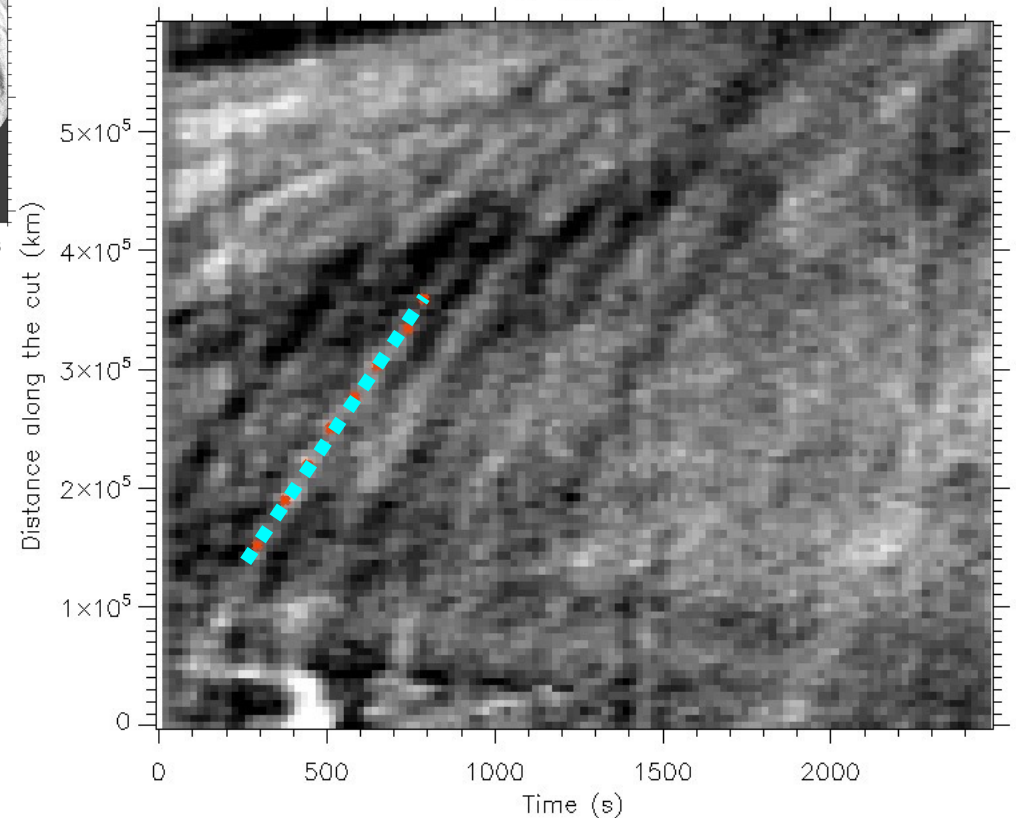
Time-Distance method:

- Select direction of the center of the circle
- Select points to fit by hand on the diagram
- Second order fit

**Velocity** :  $552 \pm 32$  km/s

**Acceleration** :  $-68 \pm 29$  m/s<sup>2</sup>  
(big uncertainty)

**Frequency** :  $\sim 1.8$  min or 9.2 mHz  
(wavelets method: frequency content 8 and 5 mHz)



Box width: 80 Mm, 0.11 R<sub>sun</sub>  
Box Length: 597 Mm, 0.8 R<sub>sun</sub>

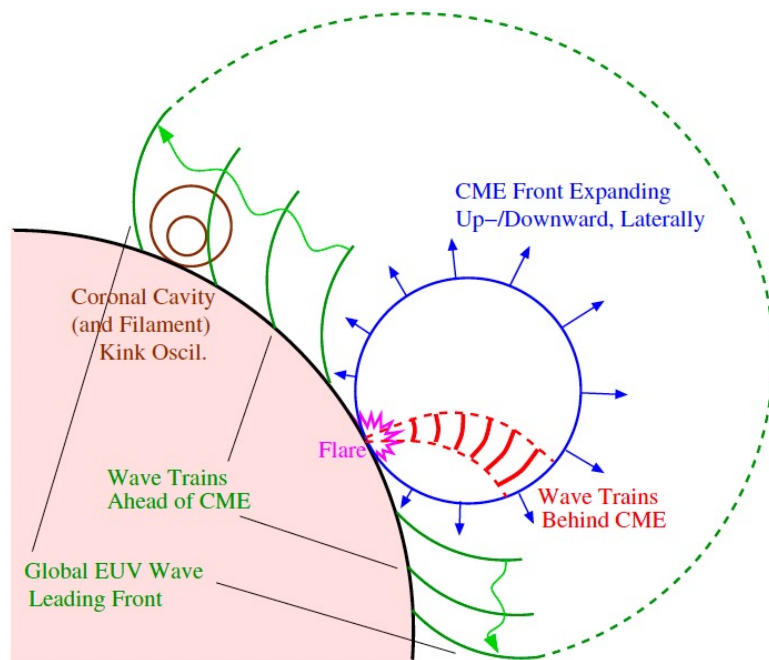
# WAVES NATURE

- **Quasi-periodic fast-mode (QPF) wave trains?**
  - Reference Liu W. et al 2012:
    - Observed in AIA, 12 s cadence
    - Speed from 1000 km/s decelerating to 600 – 300 km/s
    - 2 minutes periodicity
    - CME lateral expansion, CME speed 250 km/s
    - X-flare + EUW wave
- Other hypothesis taken into account:
  - Quasi-periodic pulsations (QPP) of solar emission (Nakariakov et al 2006, 2009, 2021)
  - Global oscillations in coronal loops such as kink or sausage modes.

Observations	QPF modes	Metis coronal waves
Heliocentric height	$< 1.5 R_{\odot}$	Within $3 R_{\odot}$
Velocity	1400 km/s decelerating up to 650 km/s	$\sim 500$ km/s decelerating
Frequency	2 min	1.8 – 2 min
Lateral expansion	Yes	Yes
CME velocity	250 km/s	192 km/s
EUV wave	Yes	No
X flare	Yes	No
Coherent travel distance	$\gtrsim R_{\odot}/2$	$\gtrsim R_{\odot}/2$

# WAVES NATURE

- **Quasi-periodic fast-mode (QPF) wave trains?**



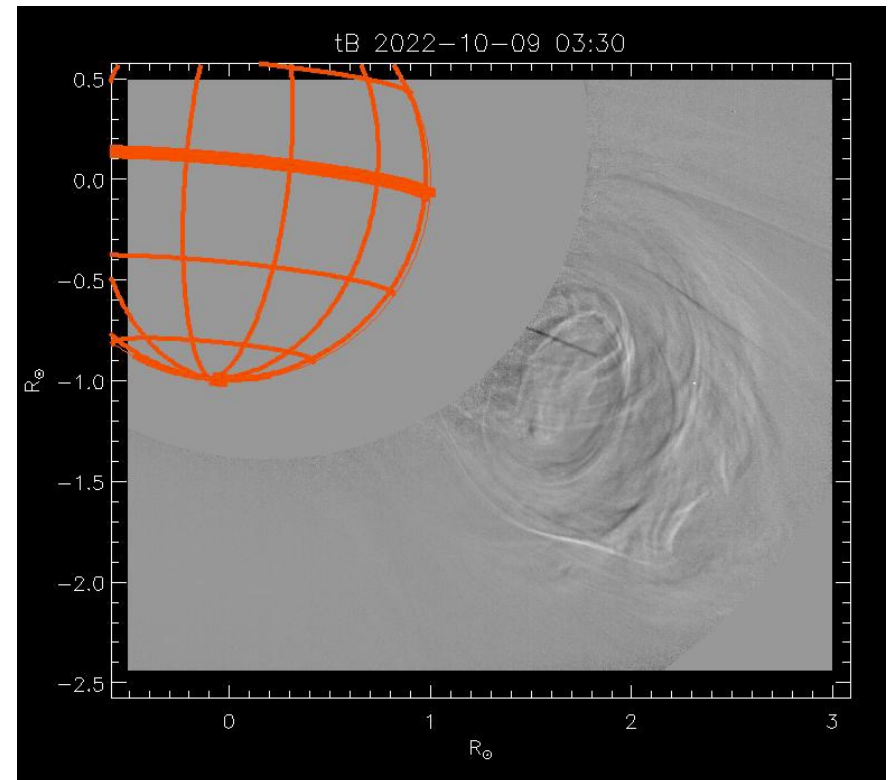
Liu W. et al 2012

Observations	QPF modes	Metis coronal waves
Heliocentric height	$< 1.5 R_{\odot}$	Within $3 R_{\odot}$
Velocity	1400 km/s decelerating up to 650 km/s	$\sim 500$ km/s decelerating
Frequency	2 min	1.8 – 2 min
Lateral expansion	Yes	Yes
CME velocity	250 km/s	192 km/s
EUV wave	Yes	No
X flare	Yes	No
Coherent travel distance	$\gtrsim R_{\odot}/2$	$\gtrsim R_{\odot}/2$

# CONCLUSION AND FUTURE WORK

- Write the paper!!!
- AIA 17.1 and 19.5 nm inspection still going on
- Delving into the literature of other wave modes
- Any other suggestion?

Thank you for the attention!



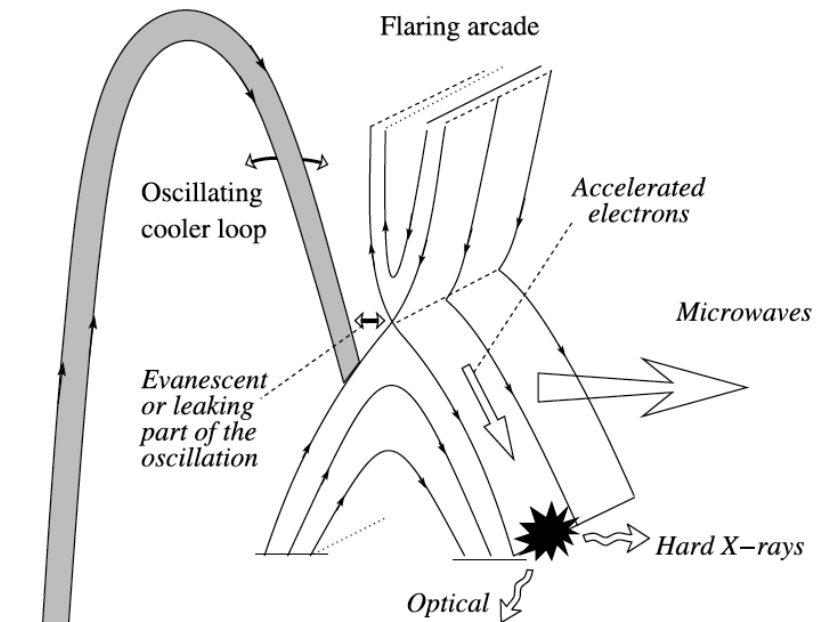


# BACKUP SLIDES

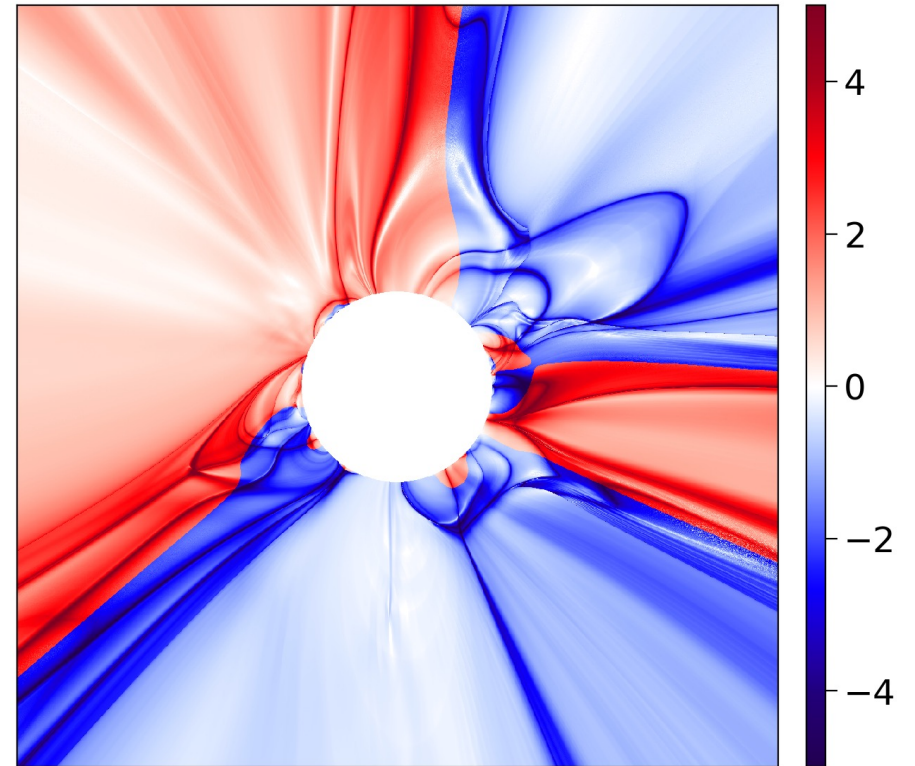
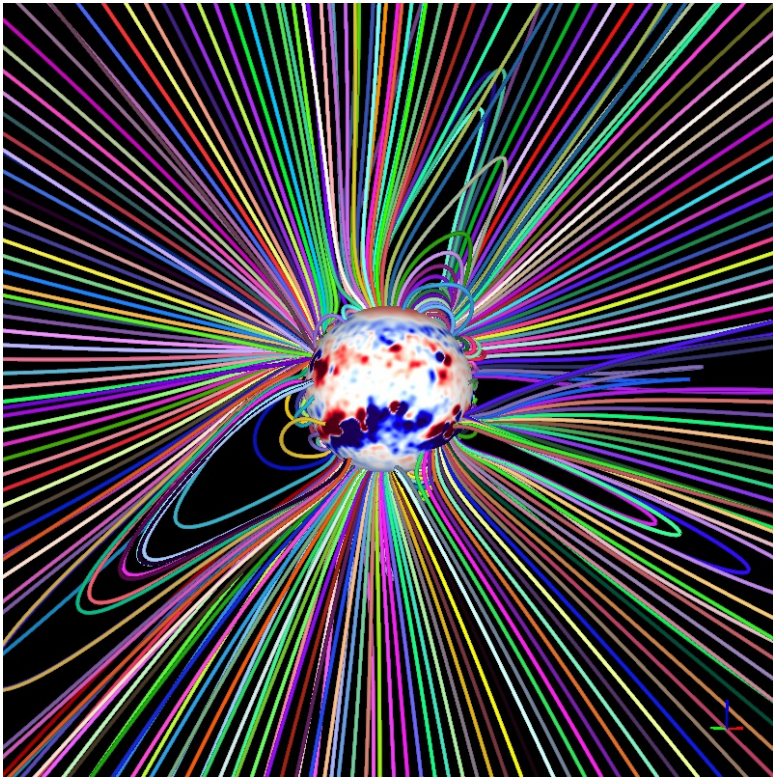
# QUASI-PERIODIC PULSATIONS (QPP)

NAKARIAKOV ET AL

- associated with slow magnetoacoustic waves propagating in the solar corona, driven by plasma structures such as loops, plumes, etc.
- Projected phase velocities: They generally vary from a few tens to hundreds of km/s ( $< 150$  km/s).
- They tend to dampen rapidly with increasing height, usually within a few tens of megameters (Mm).
- Slow magnetoacoustic waves are often associated with plasma flows propagating along the magnetic field, and originate in the chromosphere with oscillation periods of about 3 minutes.



# MAGNETIC CONFIGURATION

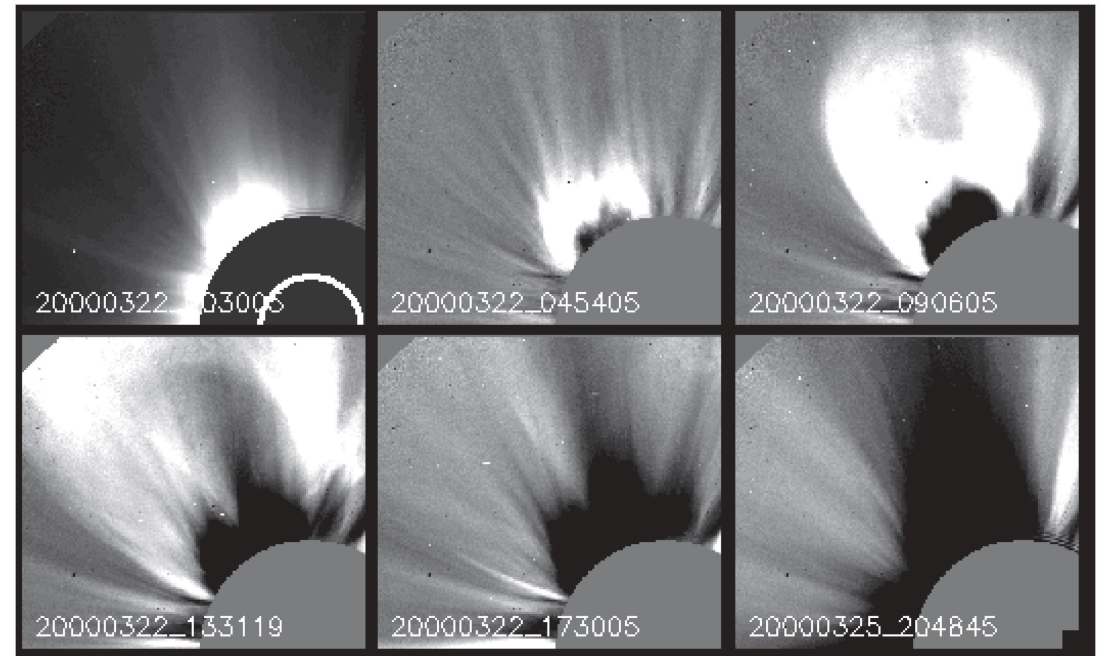




# STREAMER BLOWOUT (SBO)

Other idea:

- Streamer blowout (Vourlidas+, 2018) :
  - gradual swelling of a coronal streamer, followed by a wide, slow CME
  - typically exhibiting a three-part structure, that leaves the streamer significantly depleted
  - on average 40.5 hours, but some can last for days
  - wider and more massive than average CMEs)



# PSEUDOSTREAMER CMEs (WANG 2023)

- pseudostreamer CMEs have a consistent fan-like structure due to lateral confinement by the surrounding magnetic field
- These eruptions include coronal jets, filament eruptions, footpoint flares, and EUV waves.
- Various examples of pseudostreamer eruptions including:
  - jets from coronal holes and ARs.
  - Filament eruptions in Ars
  - Interacting pseudostreamer lobes
  - Events associated with EUV waves
  - Events associated with large-scale loop expansion

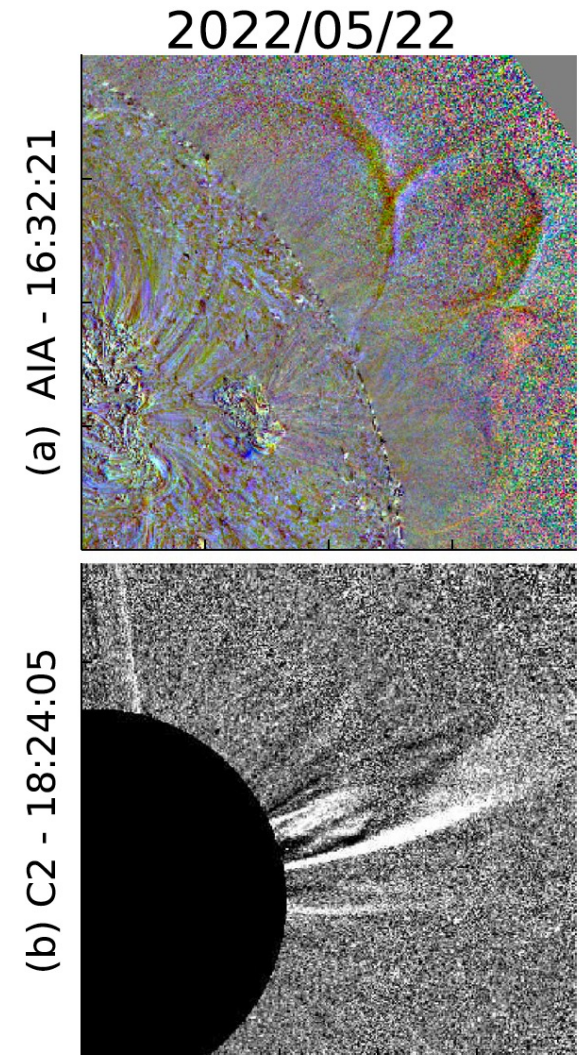
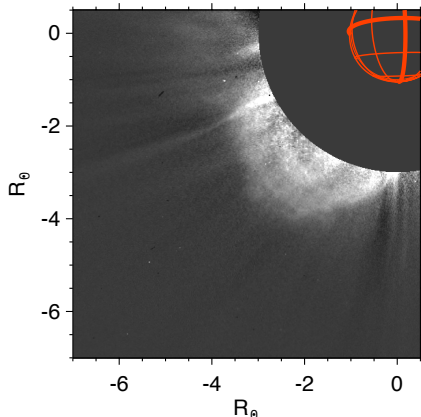


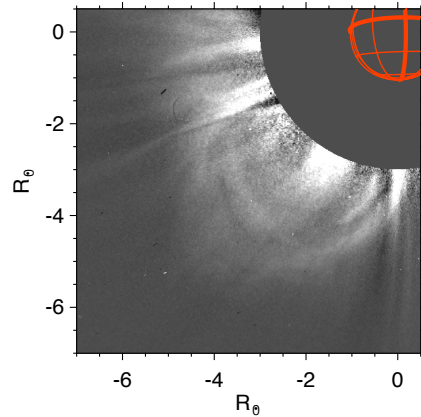
Figure 18. Gradual expansion of a large-scale loop system above the northwest limb on 2022 May 22, driven by a slowly rising 30.4 nm filament. The loop system is bounded by the north polar hole and a longitudinally extended equatorial hole of positive polarity. (a) Three-color (21.1, 19.3, 17.1 nm) running-ratio image recorded at 16:32:21 UT. (b) LASCO C2 running-difference image recorded at 18:24 UT, showing a fan-shaped CME with a width of only  $\sim 20^\circ$ .

# CORONAGRAPHIC OBSERVATIONS

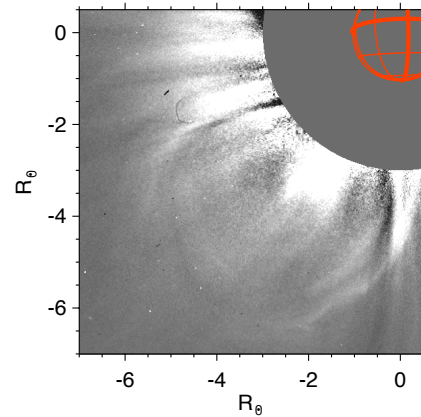
COR2, 2022-10-09 04:16



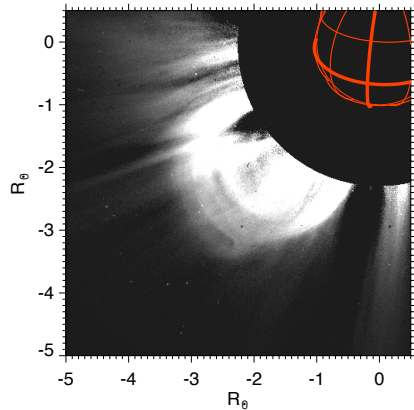
COR2, 2022-10-09 05:16



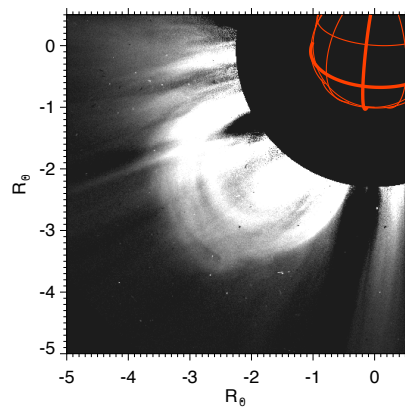
COR2, 2022-10-09 06:16



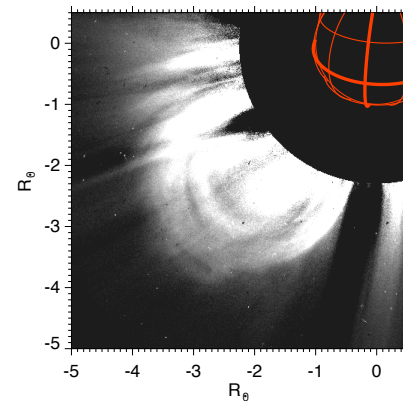
Lasco/C2, 2022/10/09 04:16



Lasco/C2, 2022/10/09 04:28



Lasco/C2, 2022/10/09 04:40

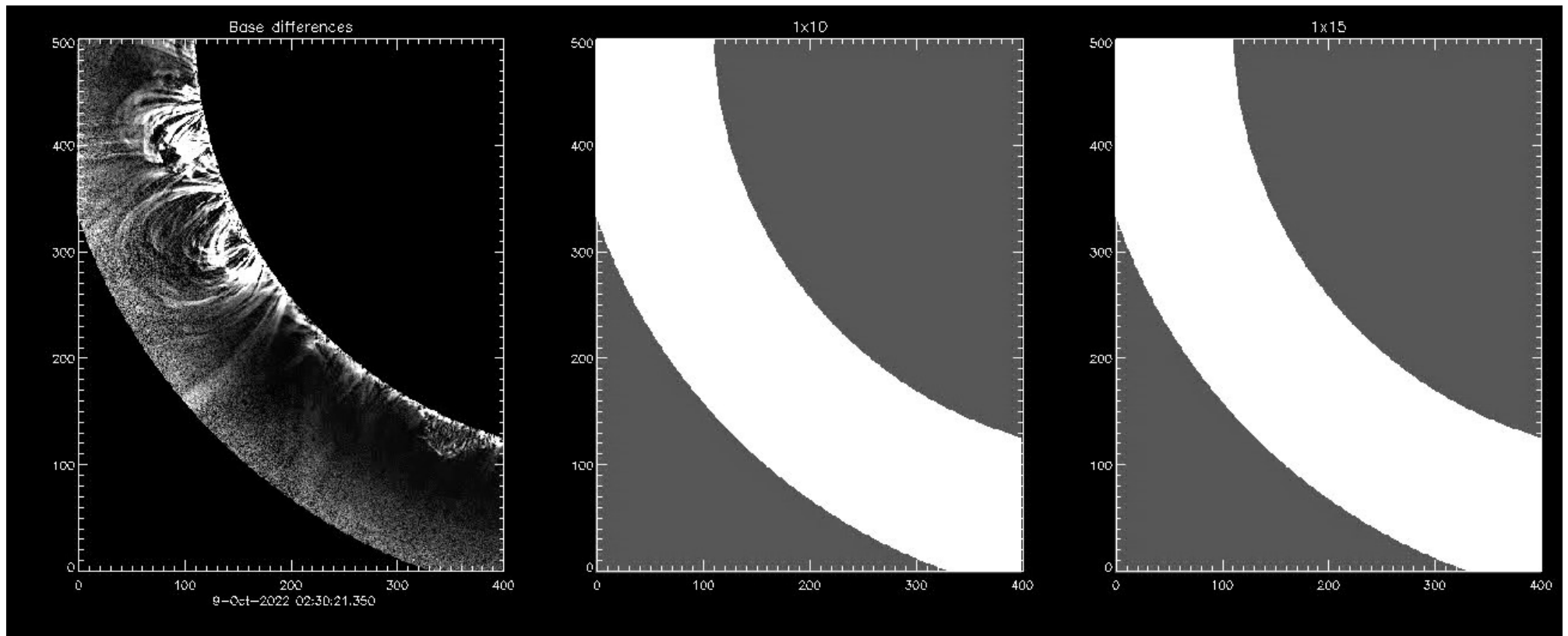


## Other instruments

- EUI cadence 15 min
- Lasco cadence 12 min
- SOHO Sun distance 0.99 AU
- Cor2 cadence 60 min
- STEREO Sun distance 0.96 AU

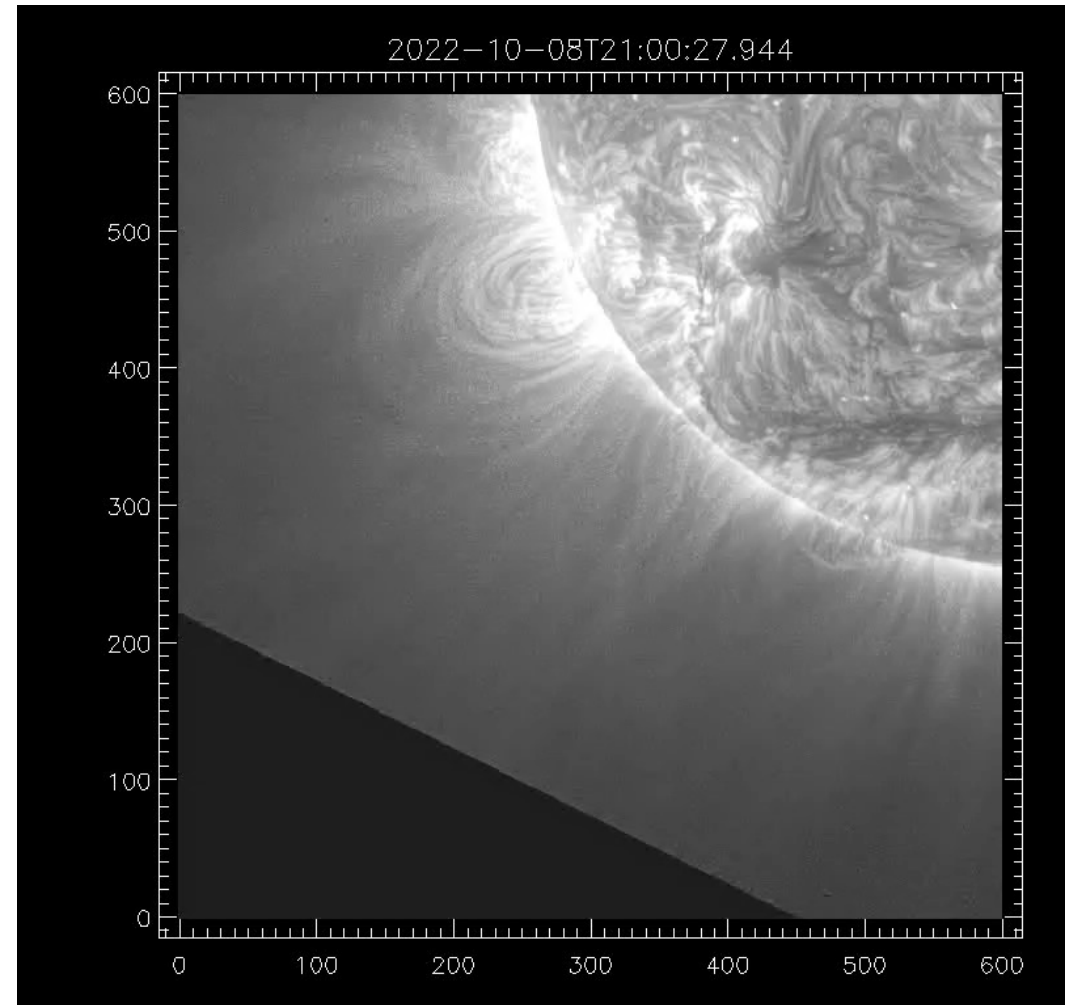
# ON DISK OBSERVATIONS

AIA 17.1 nm, cadence 12s  
2022/10/09 between 2:30 and 3:30 UT



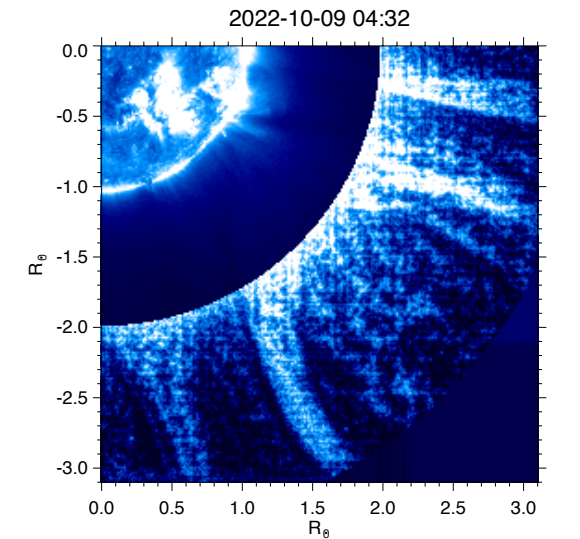
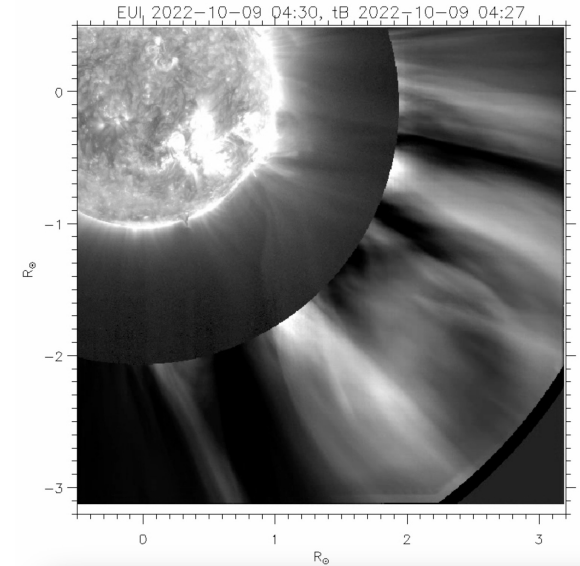
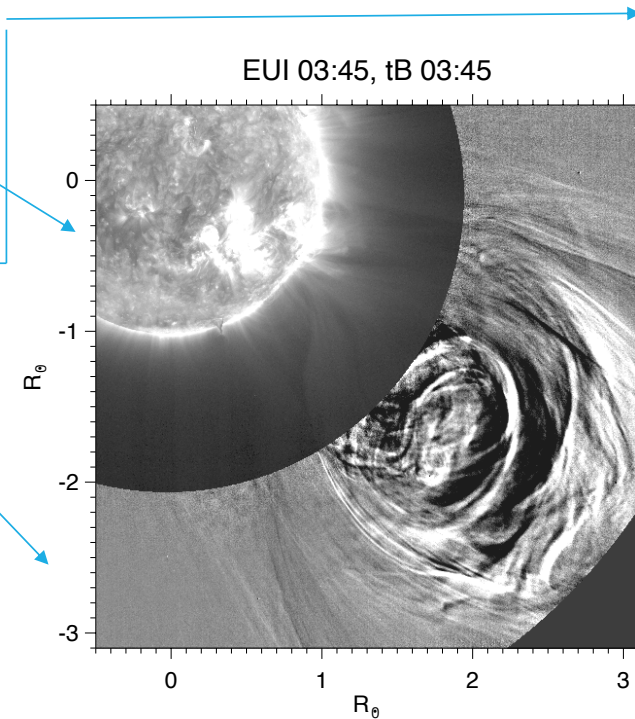
# ON DISK OBSERVATIONS

SUVI 19.5 nm

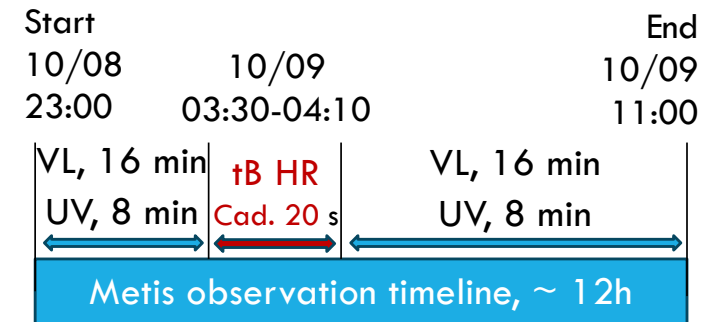


# ENHANCEMENT ALGORITHMS

- EUI: Multiscale Gaussian Norm. (MGN, Morgan+ 2014)
- Metis tB: minimum image subtraction
- Metis tB HR: pixel-by-pixel time average of 5 images, norm. runn. Diff
- Metis UV: Wavelet Optimized Whitening (WOW, Auchere+2023)

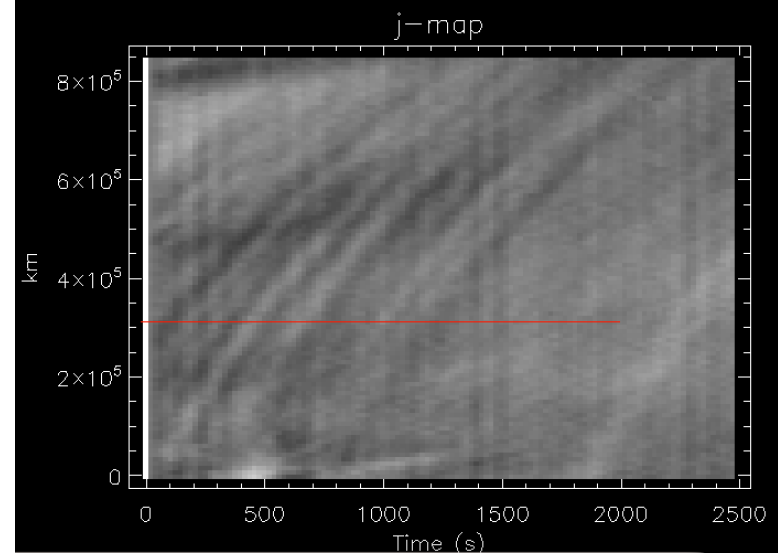
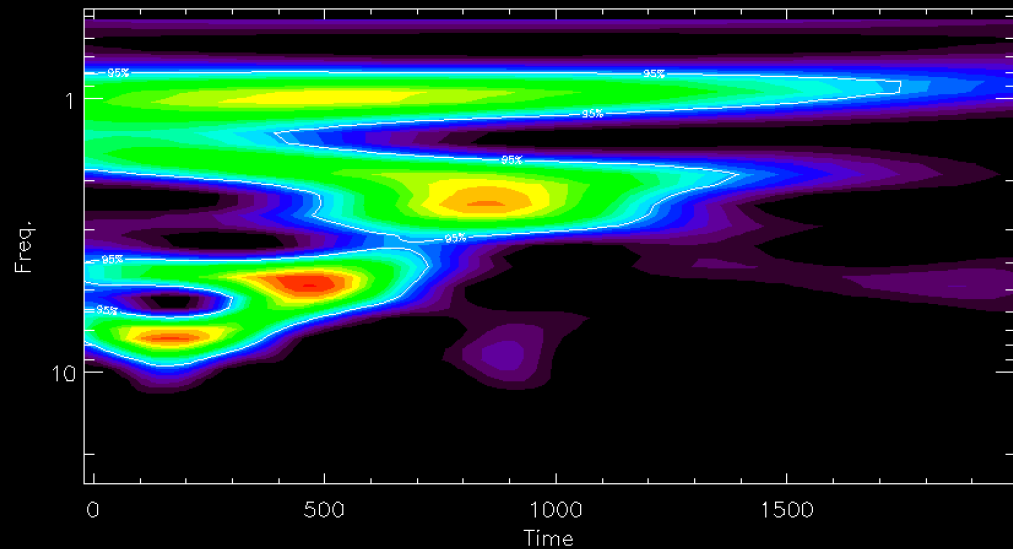
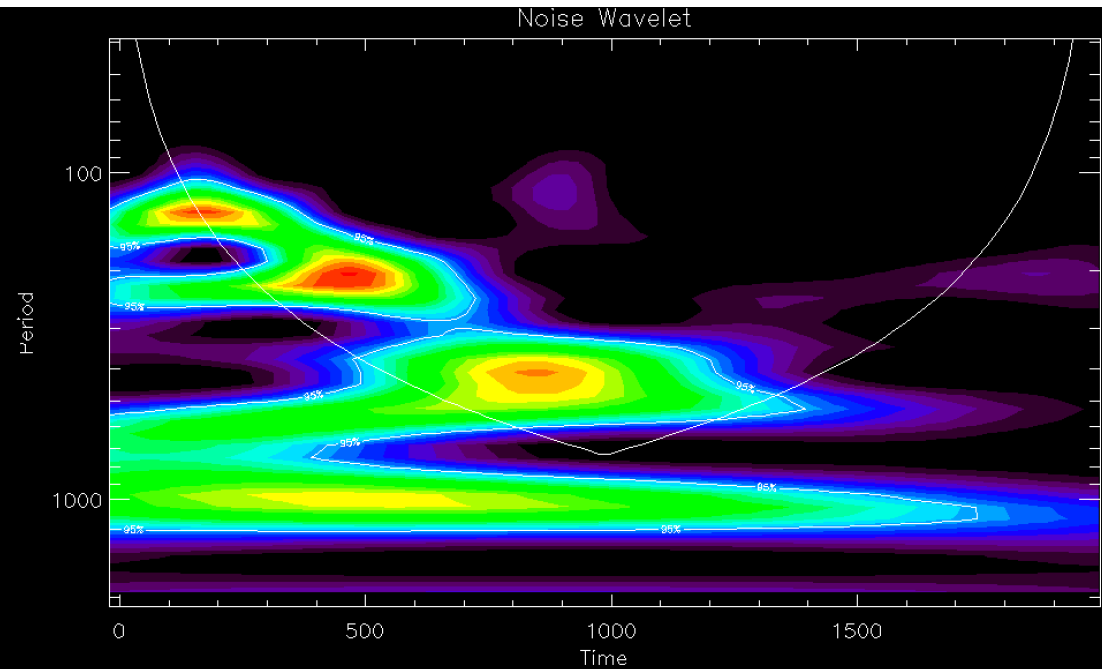
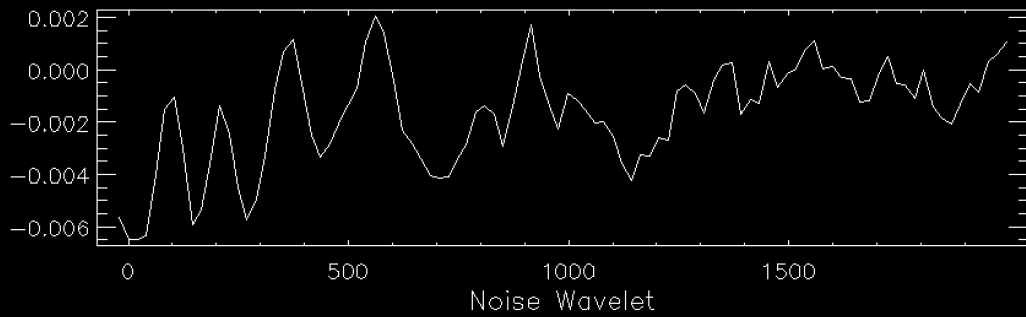


# TIME-DISTANCE STUDY



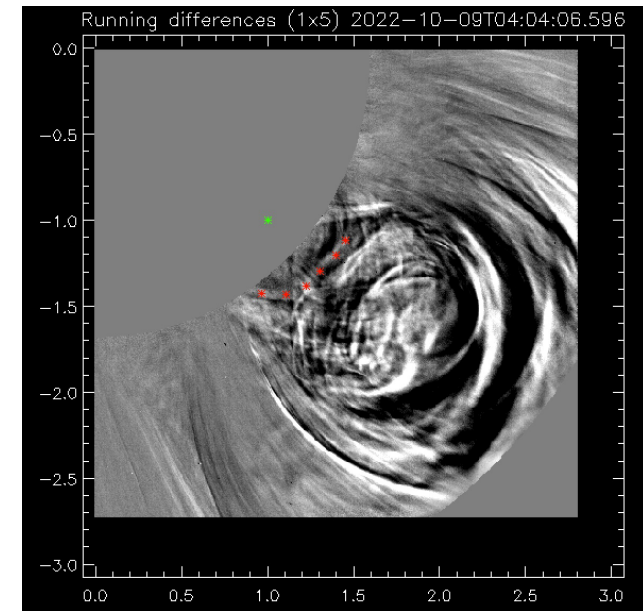
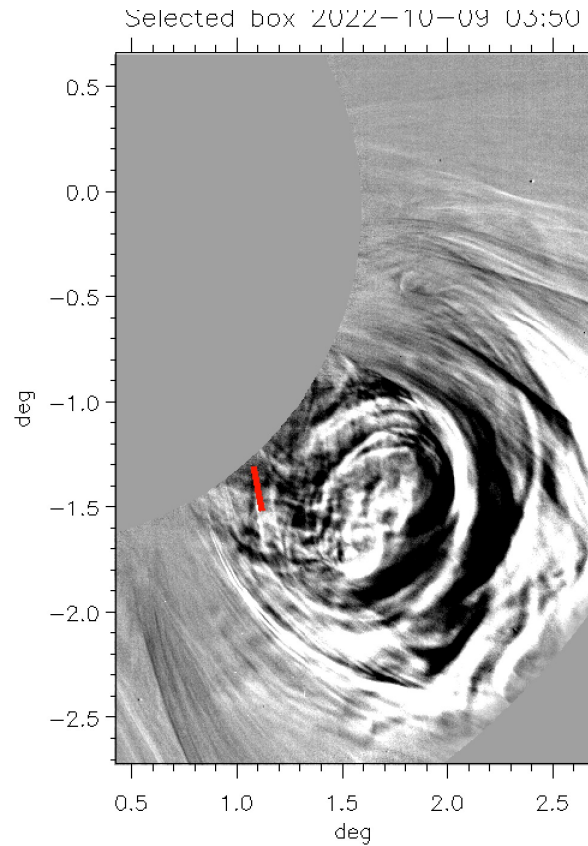
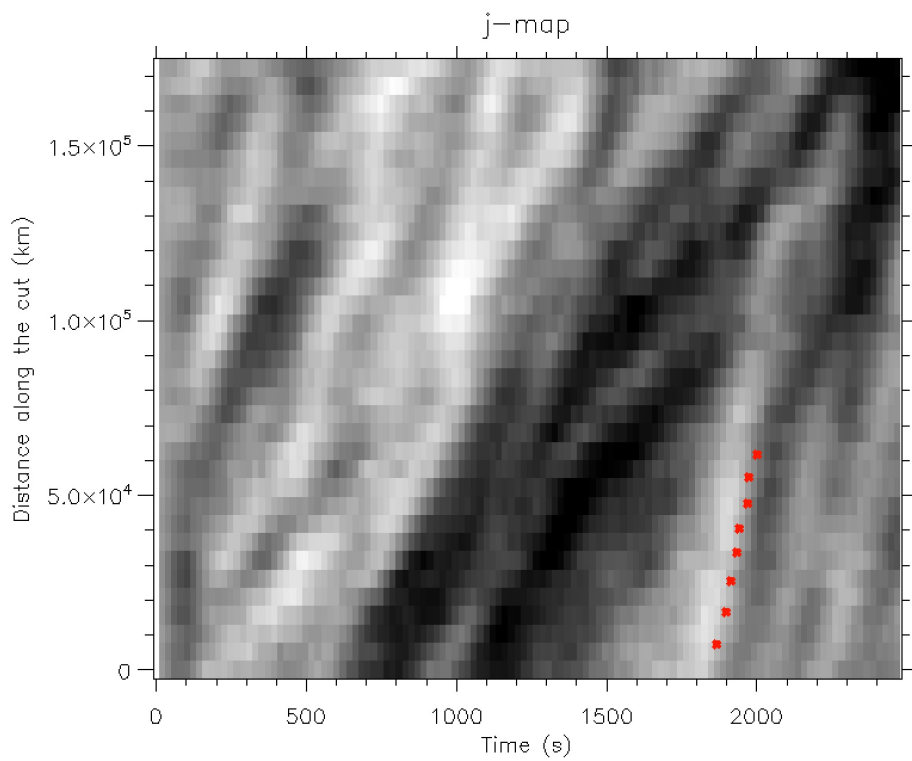
- Wave velocity:  $\sim 500$  km/s
- Extrapolation of time of wave departure from Sun surface:  $\sim 50$  min ( $\sim 2:40$  UT, nothing in AIA)
- Dimming width dimension:  $\sim 55$  Mm or  $0.07 R_{\text{sun}}$
- CME front velocity  $192$  km/s
- Extrapolation of time of CME departure from Sun surface:  $\sim 6$  h ( $\sim 21:00$  UT, visible in AIA and SUVI)

# WAVELET METHOD





# BASE WAVES



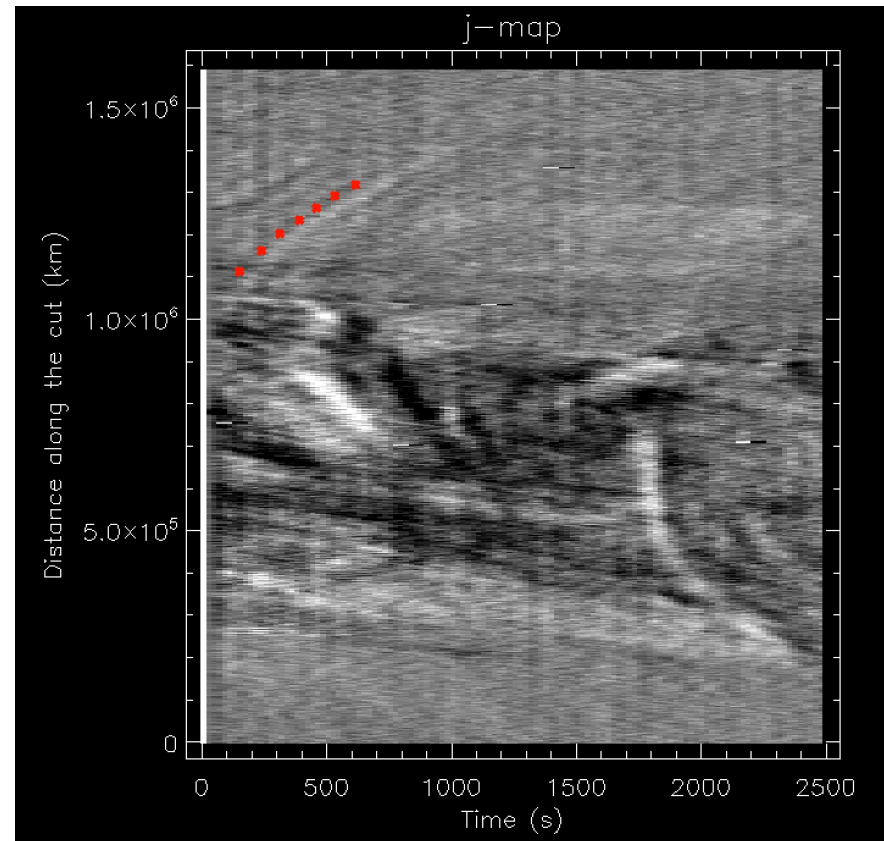
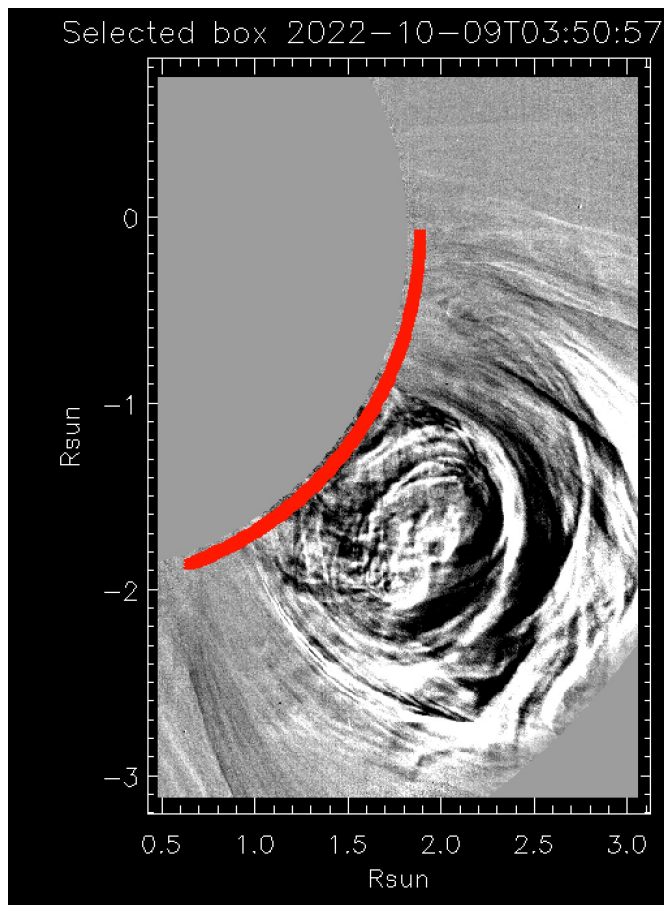
V  $\text{ladfit}$ : 427  $\pm$  80 km/s

Frequency: 2.7 min, or 6.2 mHz

Box width: 7.9 Mm, 0.01 R<sub>sun</sub>

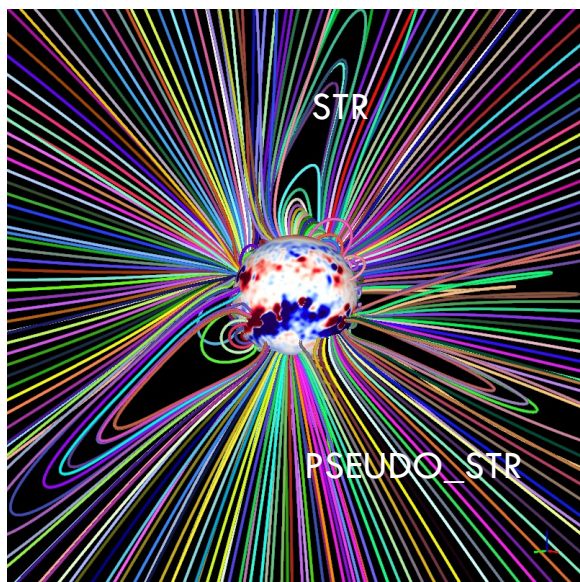
Box Length: 179.4 Mm, 0.25 R<sub>sun</sub>

# AZIMUTHAL CUT

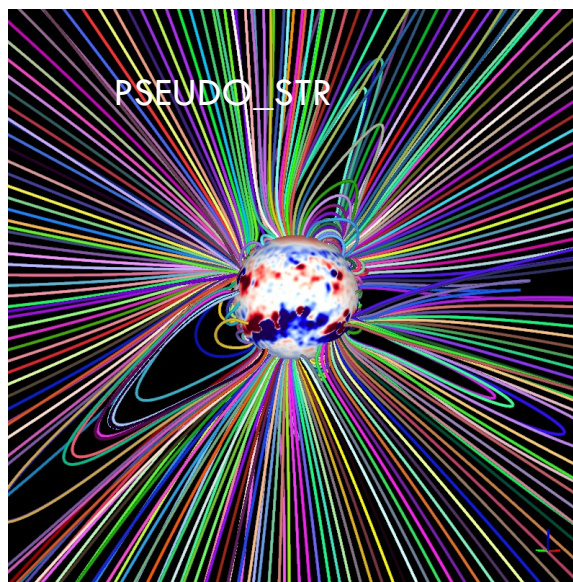


Tangential velocity:  $540 \pm 98$  km/s  
Frequency: 2.2 min, or 7.4 mHz

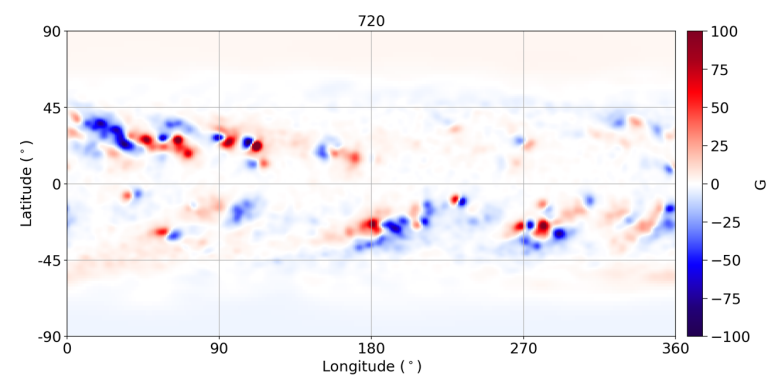
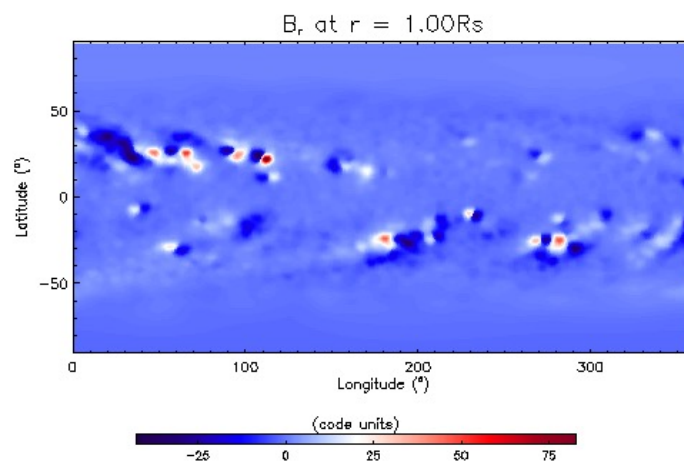
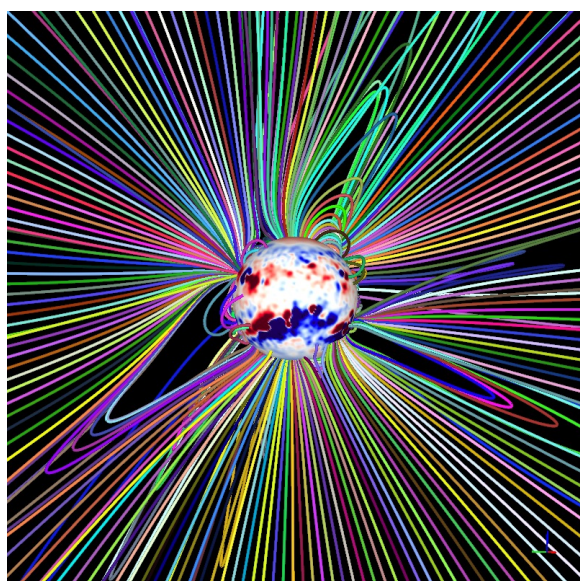
Box width: 15 Mm, 0.02 Rsun  
Box Length: 1595 Mm, 2.3 Rsun



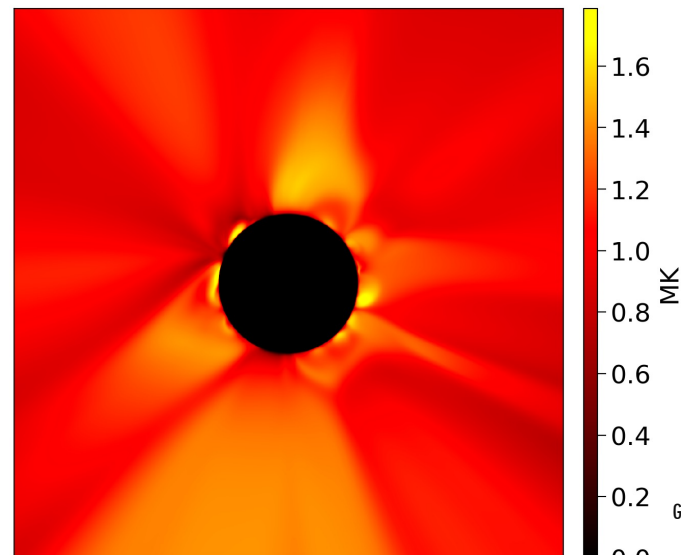
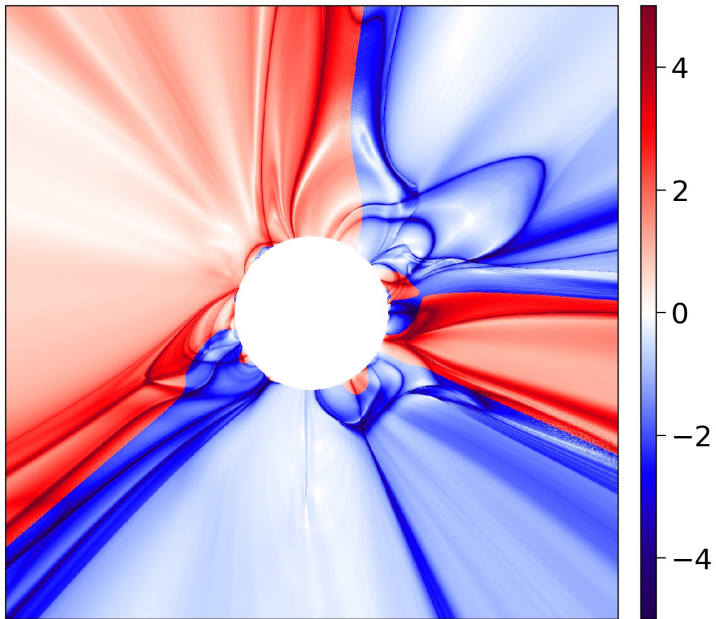
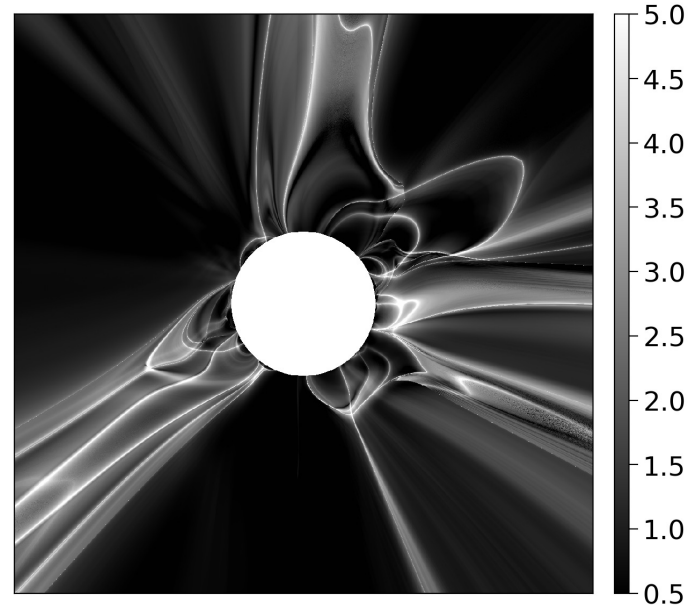
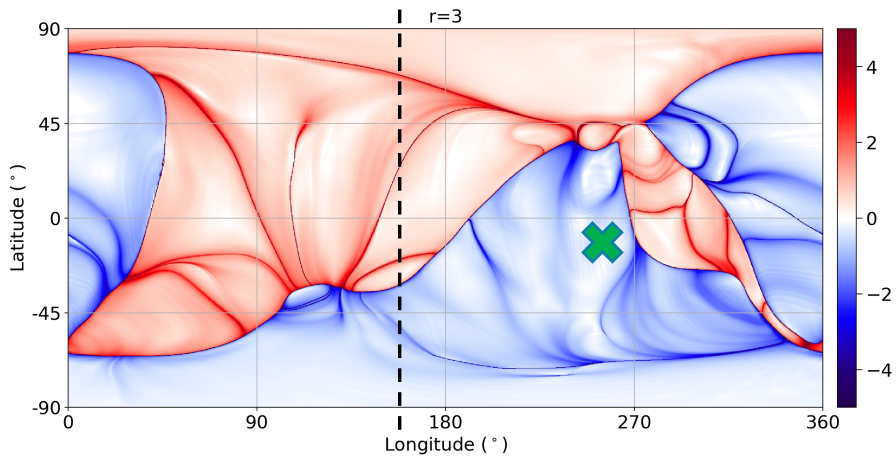
8 October 2022



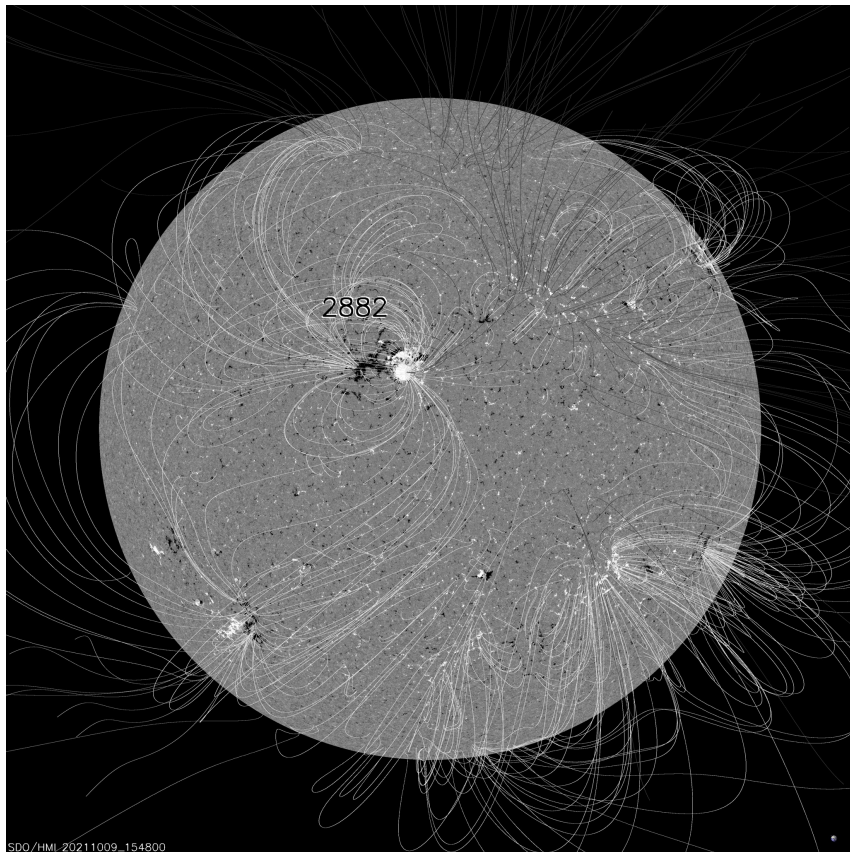
9 October 2022



8 October 2022



# ON THE DISK



CHIMERA Coronal Holes at 8-Oct-2022 23:24:04.843 UT

