



# Detection and Dynamics of Waves and Flows in the Inner to Middle Solar Corona

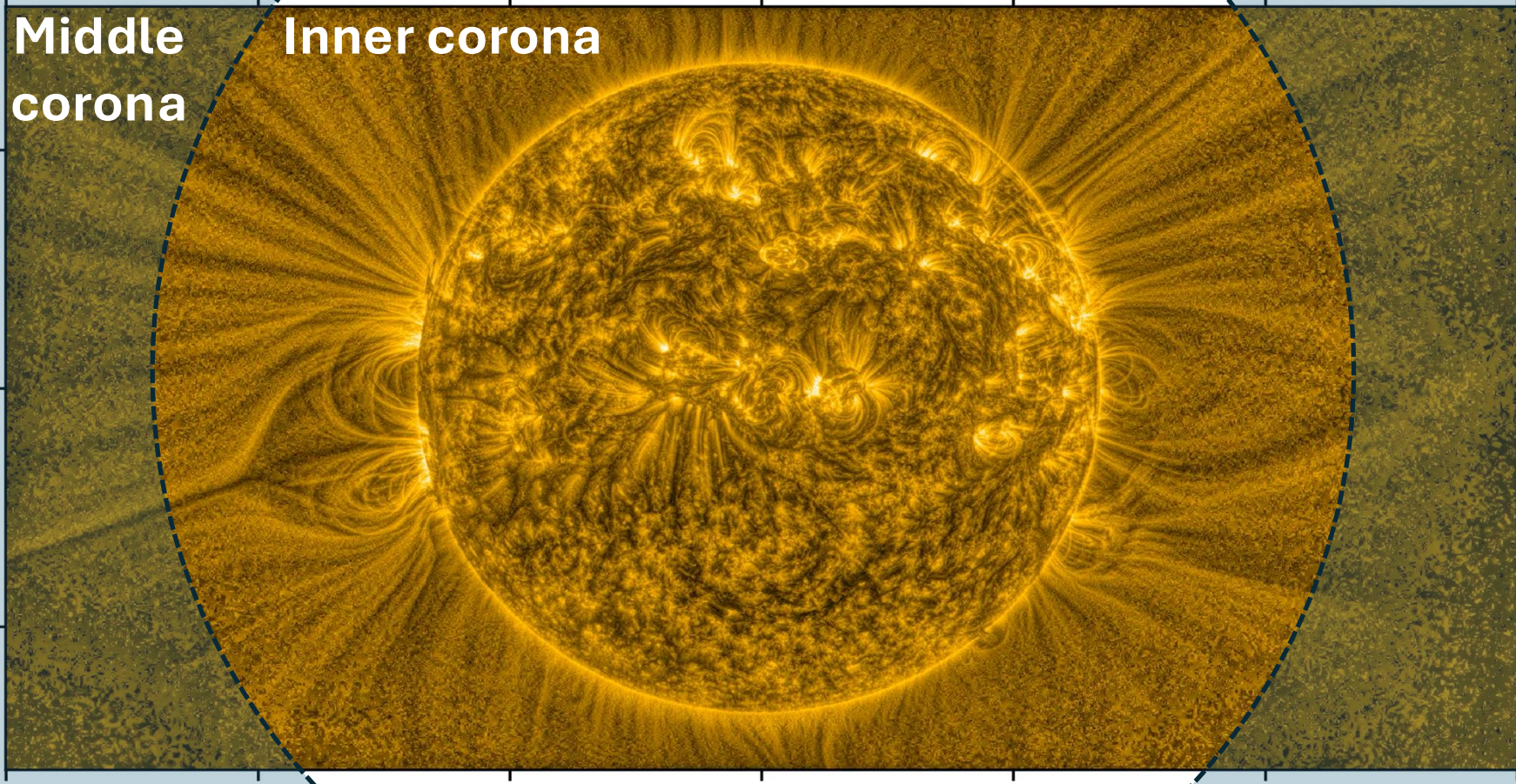


Dipankar Banerjee

Indian Institute of Space Science and Technology

Slide Courtesy: V. Pant, T. Samanta, Ritesh Patel, Arpit Srivastava, Andrei Zhukov,  
Vincenzo Andretta, A. Debrabandere

wow map 001 2025-03-22T10:06:45



**Middle  
corona**

**Inner corona**

Helioprojective Latitude (Solar-Y)

2000"

0"

-2000"

-6000"

-4000"

-2000"

0"

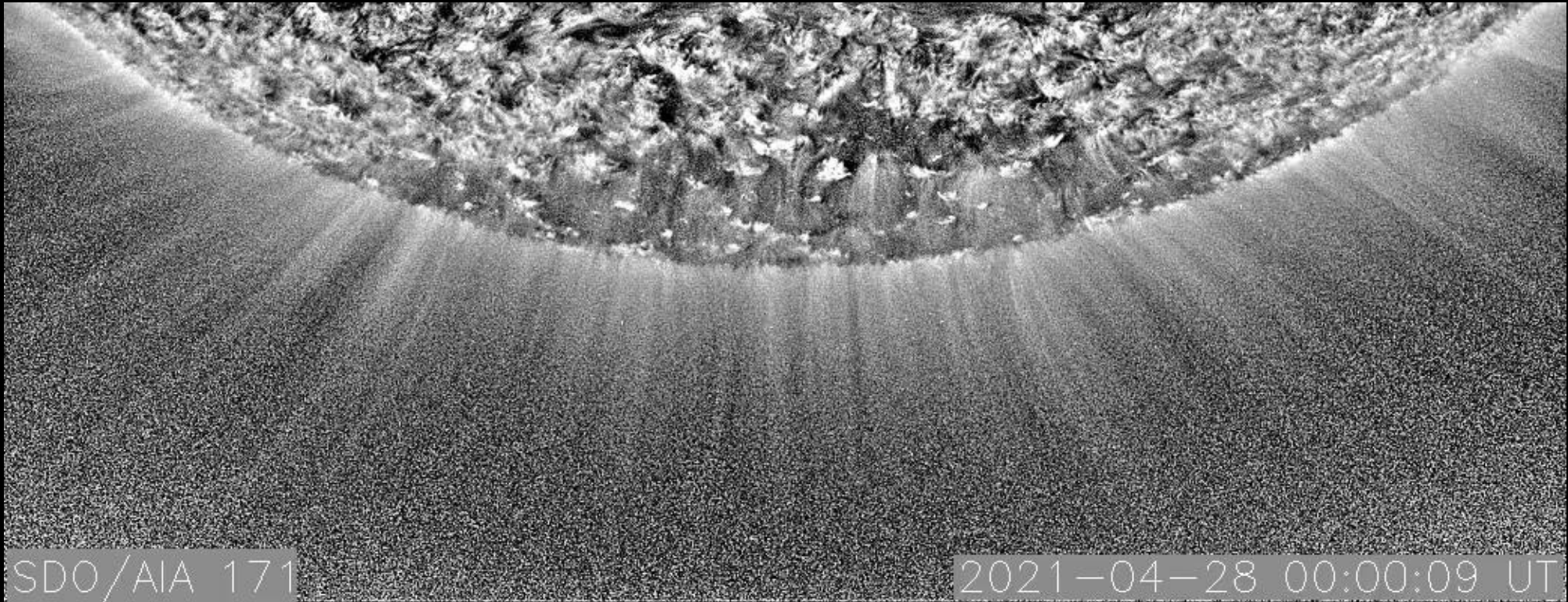
2000"

4000"

6000"

Helioprojective Longitude (Solar-X)

*Arpit Kumar Shrivastav*



Questions?

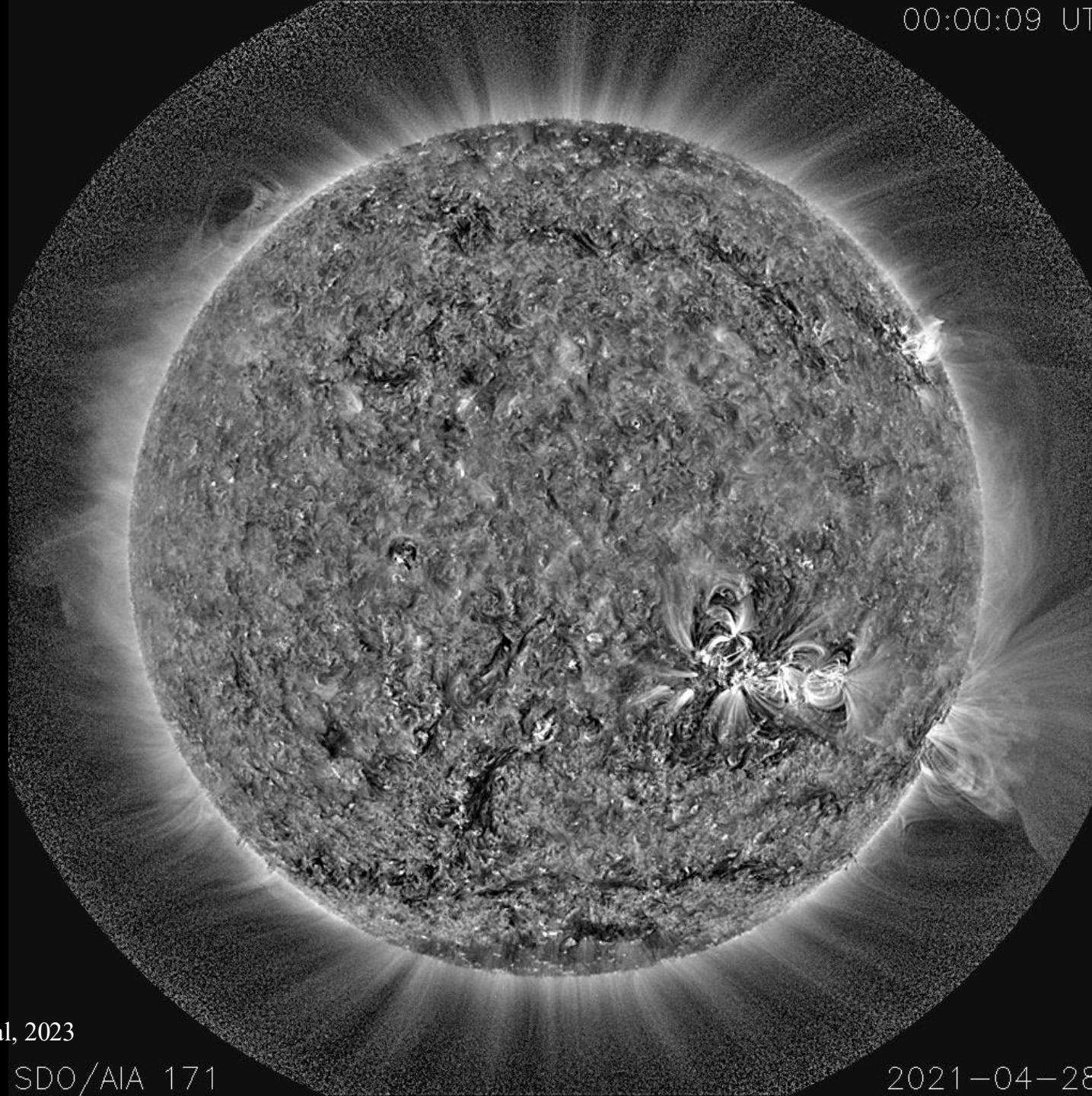
Source?

Nature

Small-scale reconnection at coronal base in coronal holes producing waves and flows (*Roaufi et al, 2023*)

Waves vs. Flows

00:00:09 UT



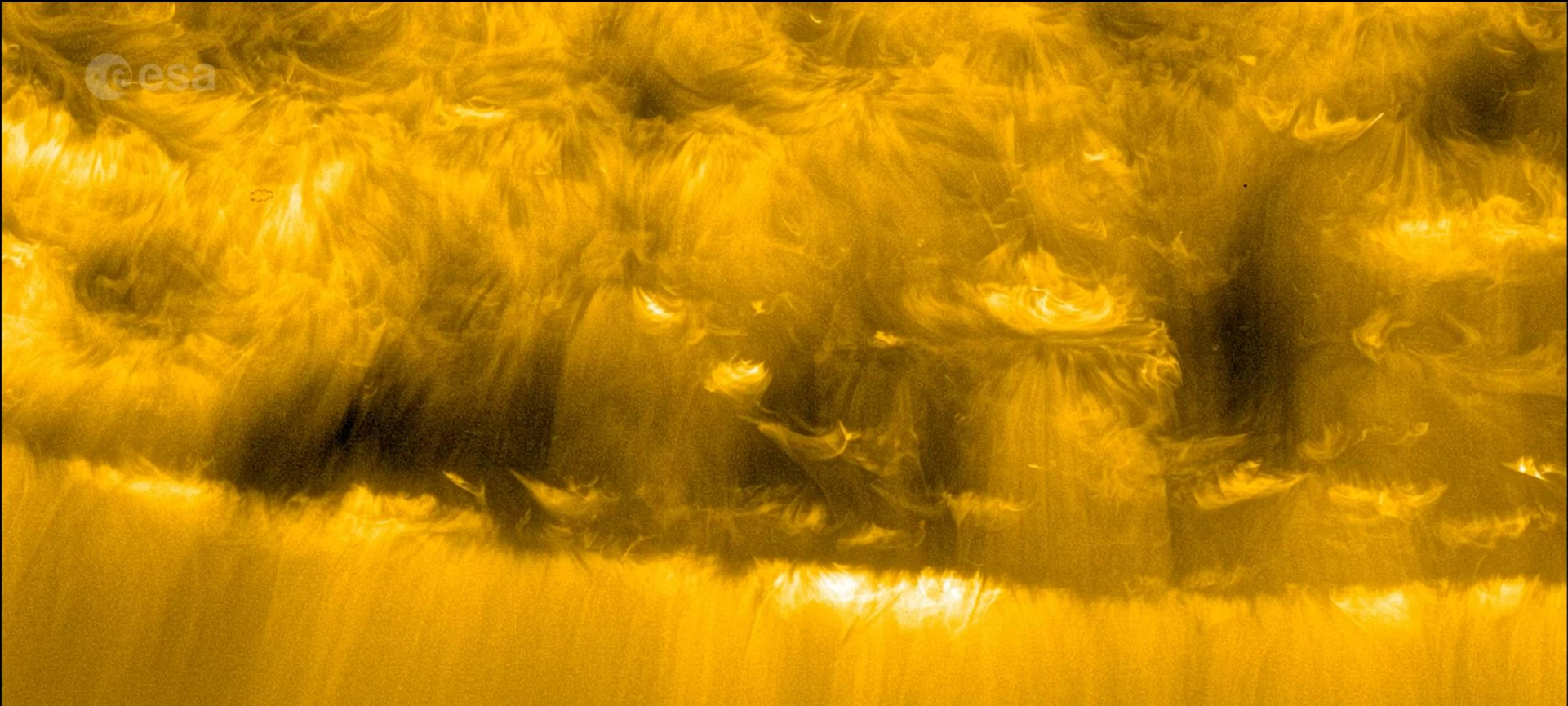
**Is there a  
preference on  
some magnetic  
topology**

streamers?  
pseudo-  
streamers?

Roaufi et al, 2023

SDO/AIA 171

2021-04-28



To characterise the properties of these propagating disturbances you need imaging and spectra

2022-03-30 UT 04:53:30

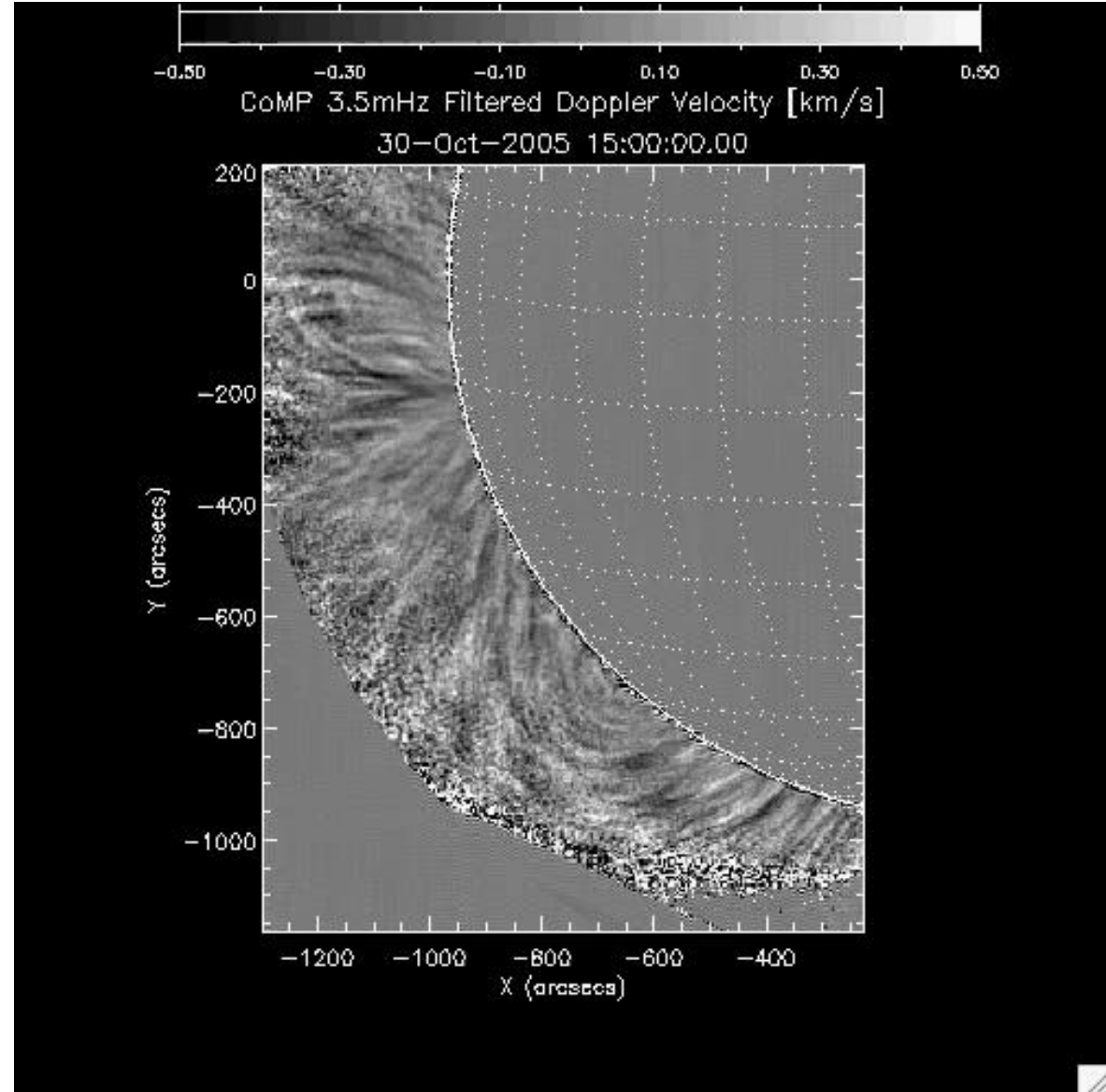
©ESA SO/HRI

Chitta et al. 2021, Science



# Waves in inner corona (COMP Era)

- Kink/Alfvénic waves are ubiquitous in the solar corona ( $\sim 1.3\text{-}1.4 R_{\text{sun}}$ )
- Carry energy large enough to heat the solar atmosphere
- **Upward and downward propagating waves** (Morton 2015)
- Alfvén wave turbulence observed at loop tops in the closed loops.
- Wave behavior at higher heights  $\rightarrow$  not known ?

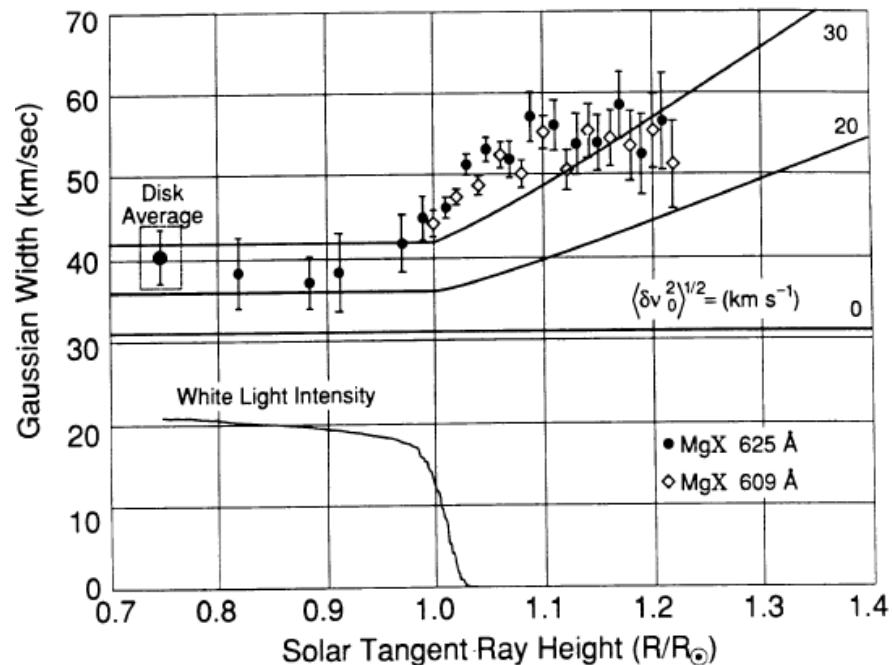


# Waves dissipation and solar wind acceleration in middle corona (**From Spectral line width studies**)

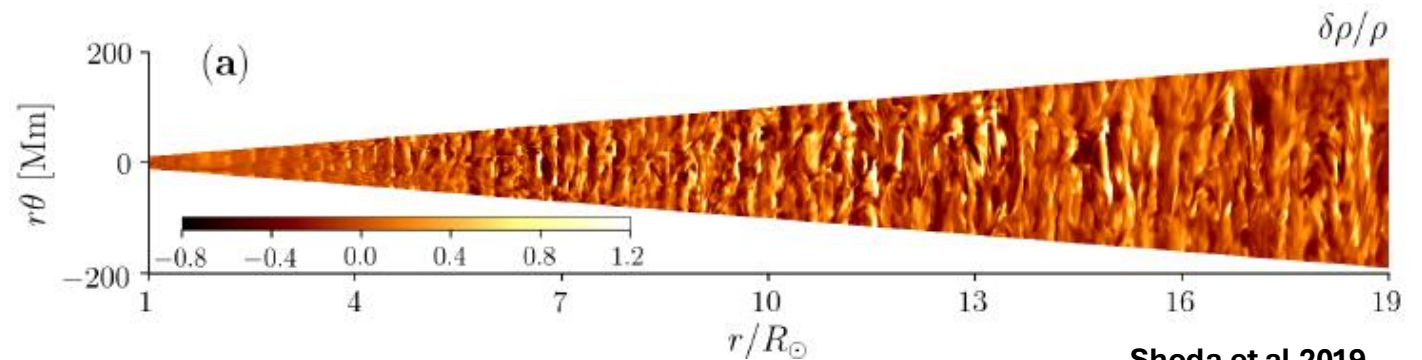
Solar atmosphere is inhomogeneous to large distances ( $\sim 10 R_{\text{sun}}$ )

Density inhomogeneity leads to enhance wave dissipation through unitubulence (Magyar et al 2017) or parametric decay instability.

Not clear at what height these dissipation processes starts ?



Hassler et al 1990

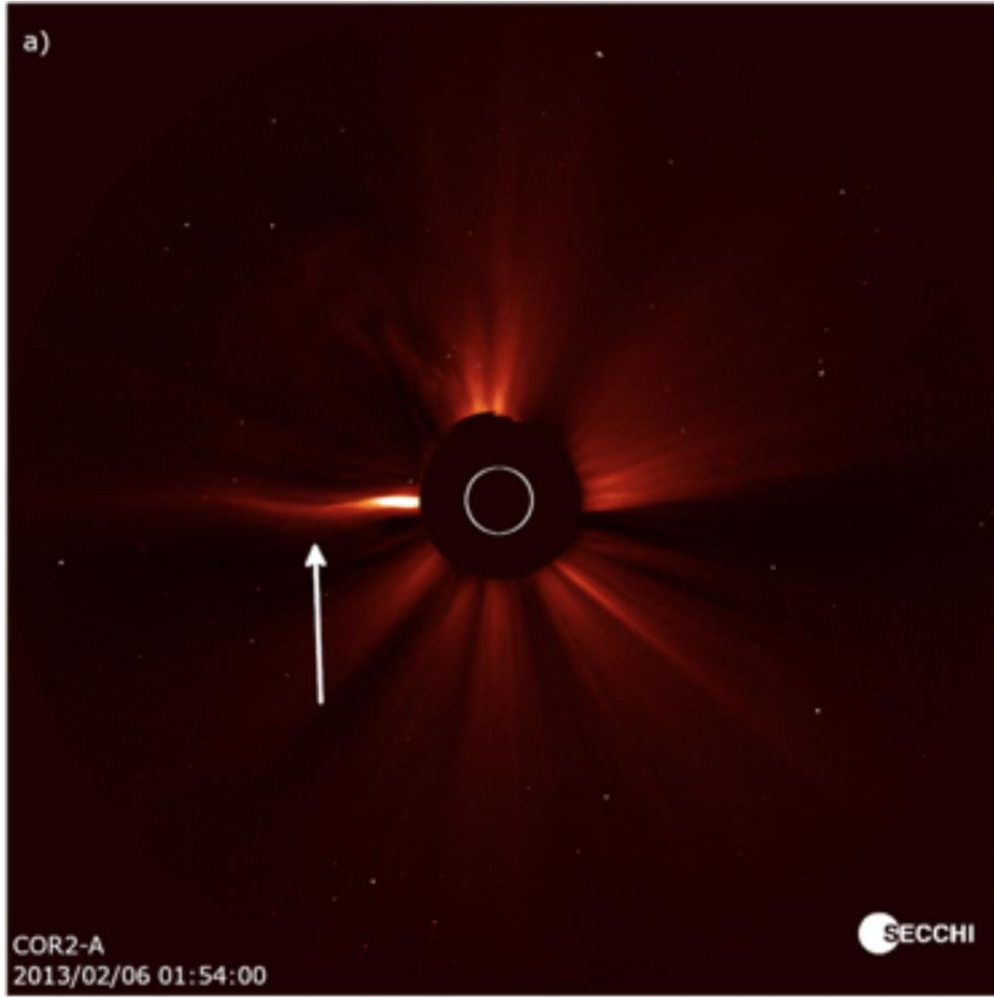


Shoda et al 2019

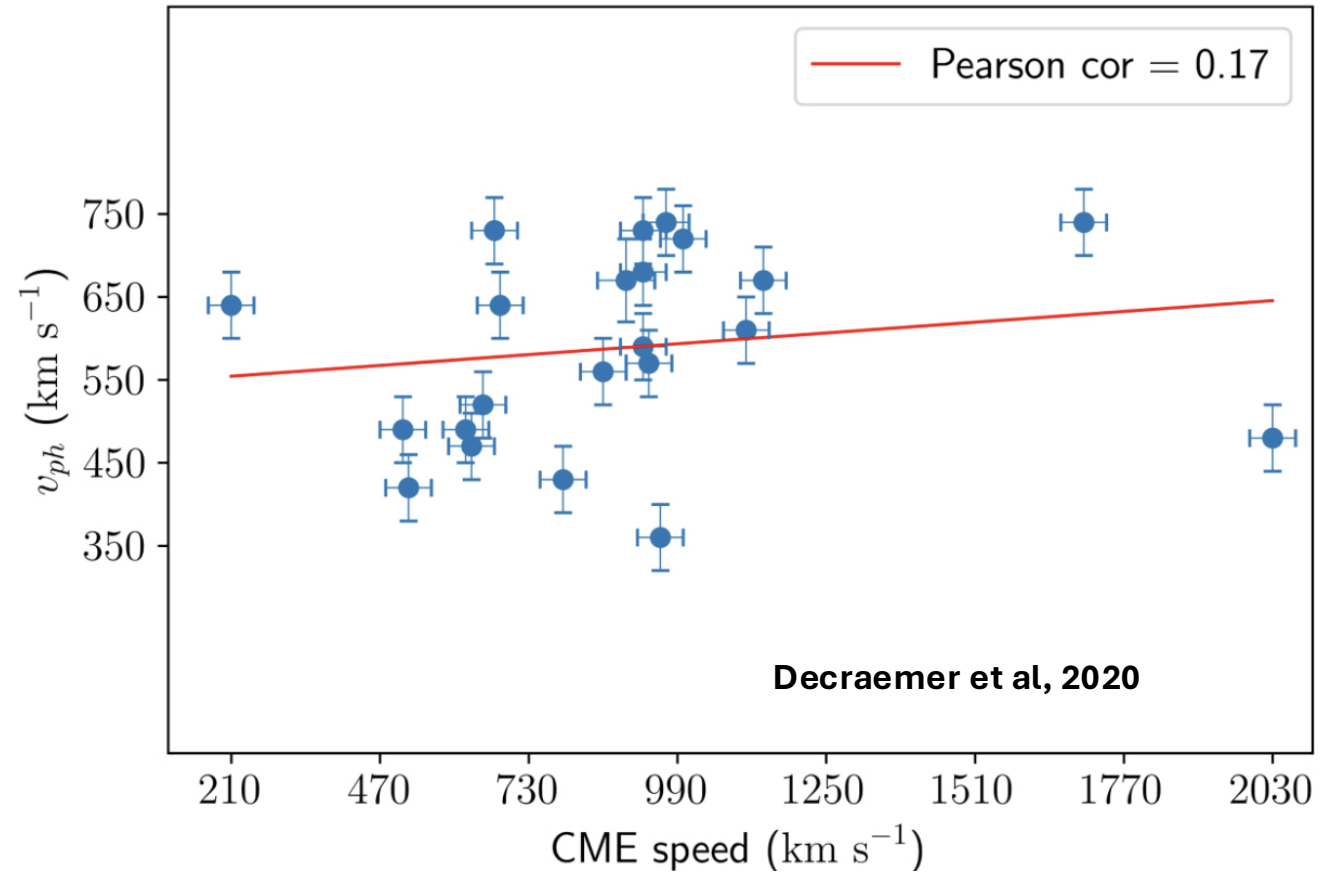
Alfvén wave damping and parametric decay instability processes happen in inner and middle corona. Quantification of height is not known.

Similar results from SUMER, CDS, EIS

# Waves in middle corona (in Streamers)

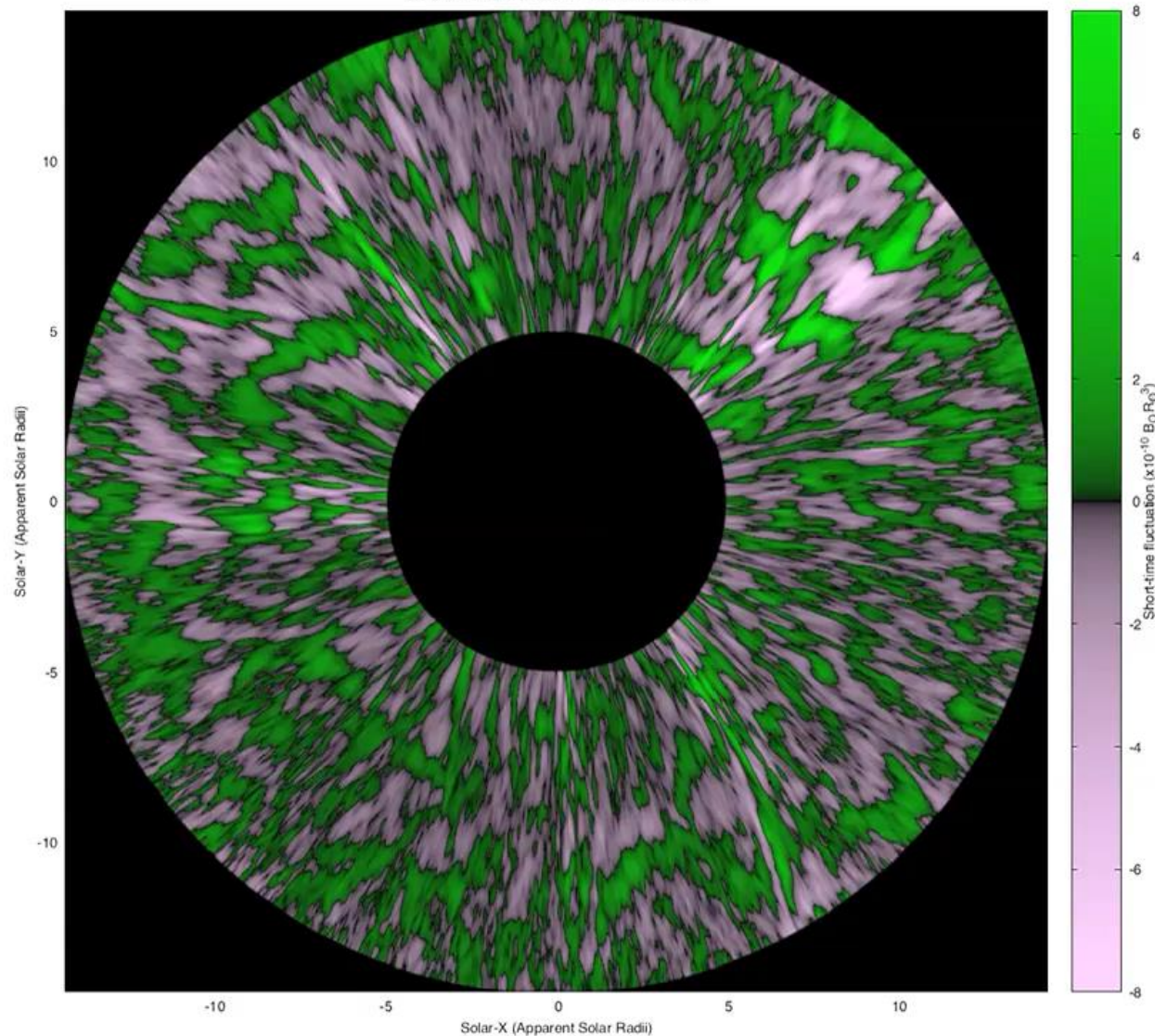


Longest kink waves in the solar system.



Streamer waves -> Phase speed independent of CME speed -> Kink Eigen modes.

L8-temporal-unsharp: 2014-04-14T02:46:00.005



# Flows in middle corona

Origins of bright outflows?

DeForest et al, 2018

# Ubiquitous Outflows and inflows in the middle corona

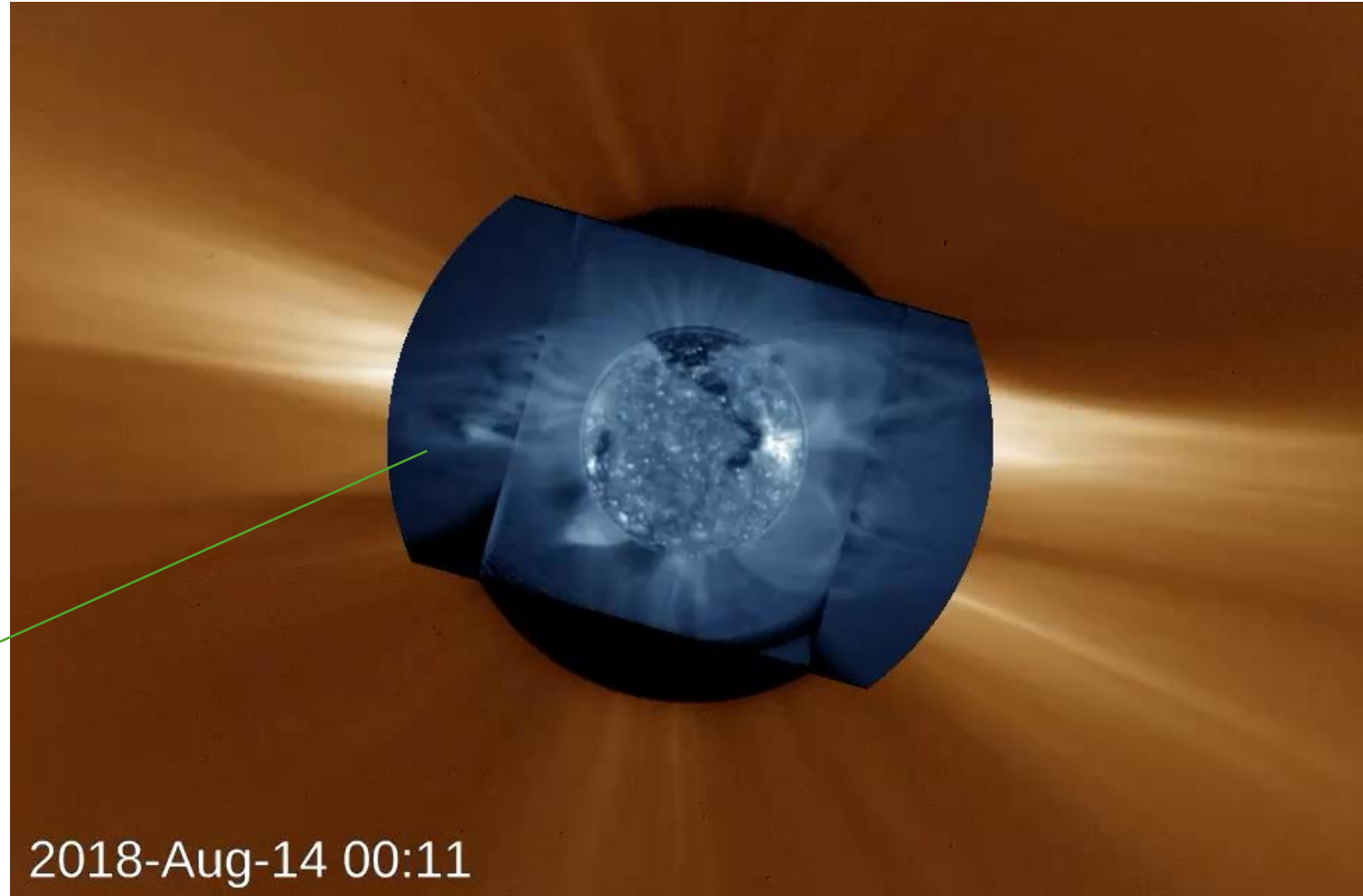
Question?

White light

Vs.

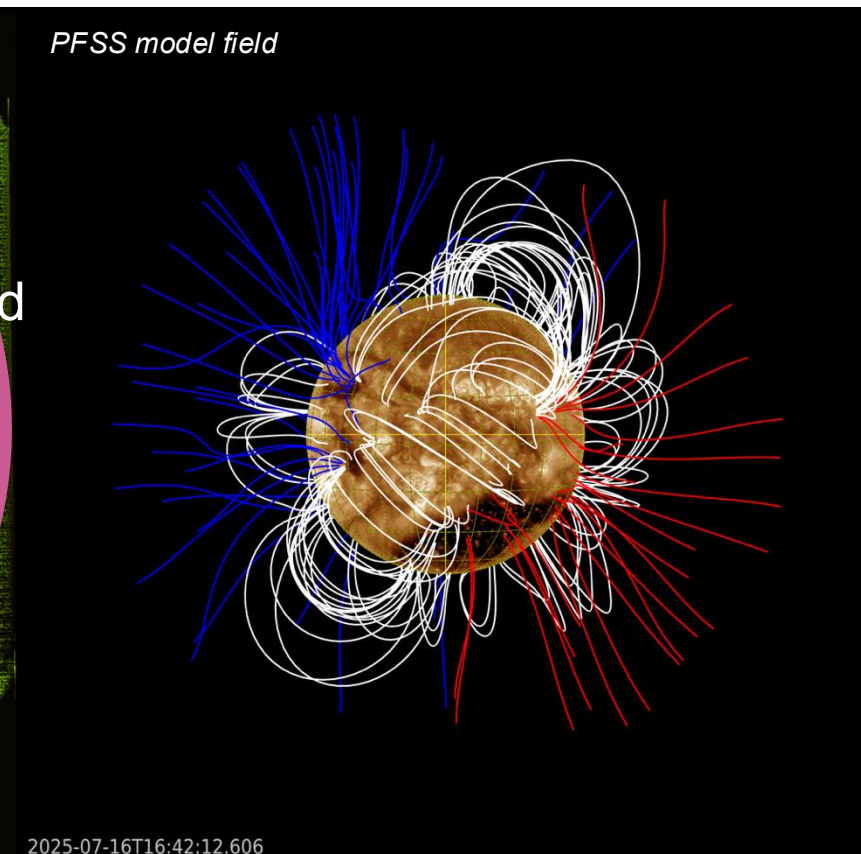
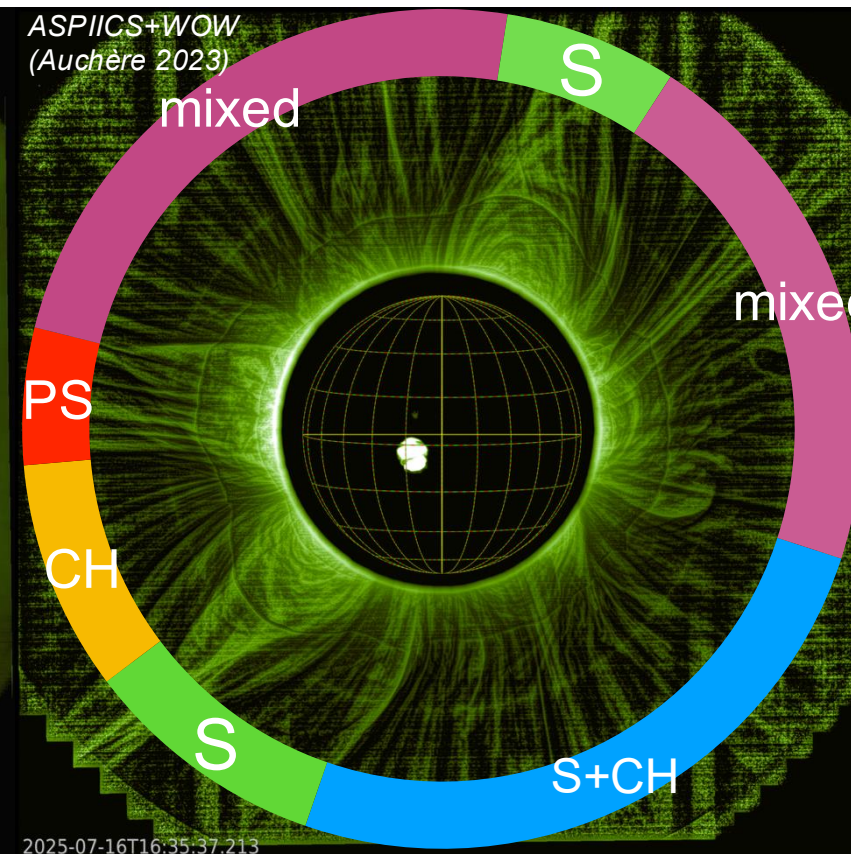
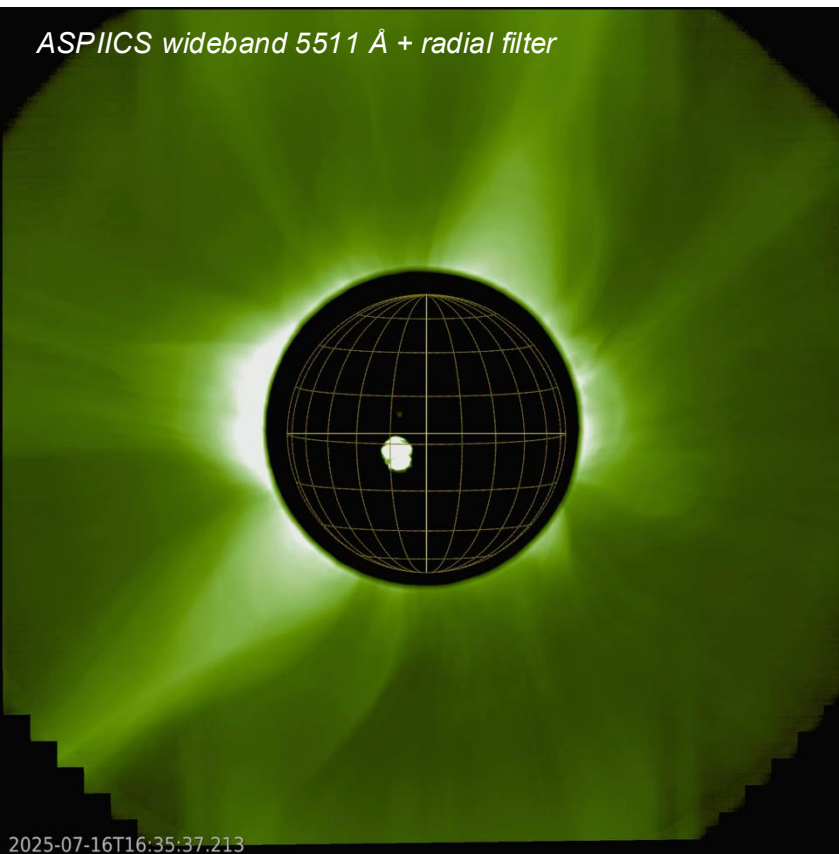
EUV

Inflows.  
Origin?



- White light counterparts of these outflows and inflows?
- Origin of inflows?
- Lot for turbulent flows. Origin?

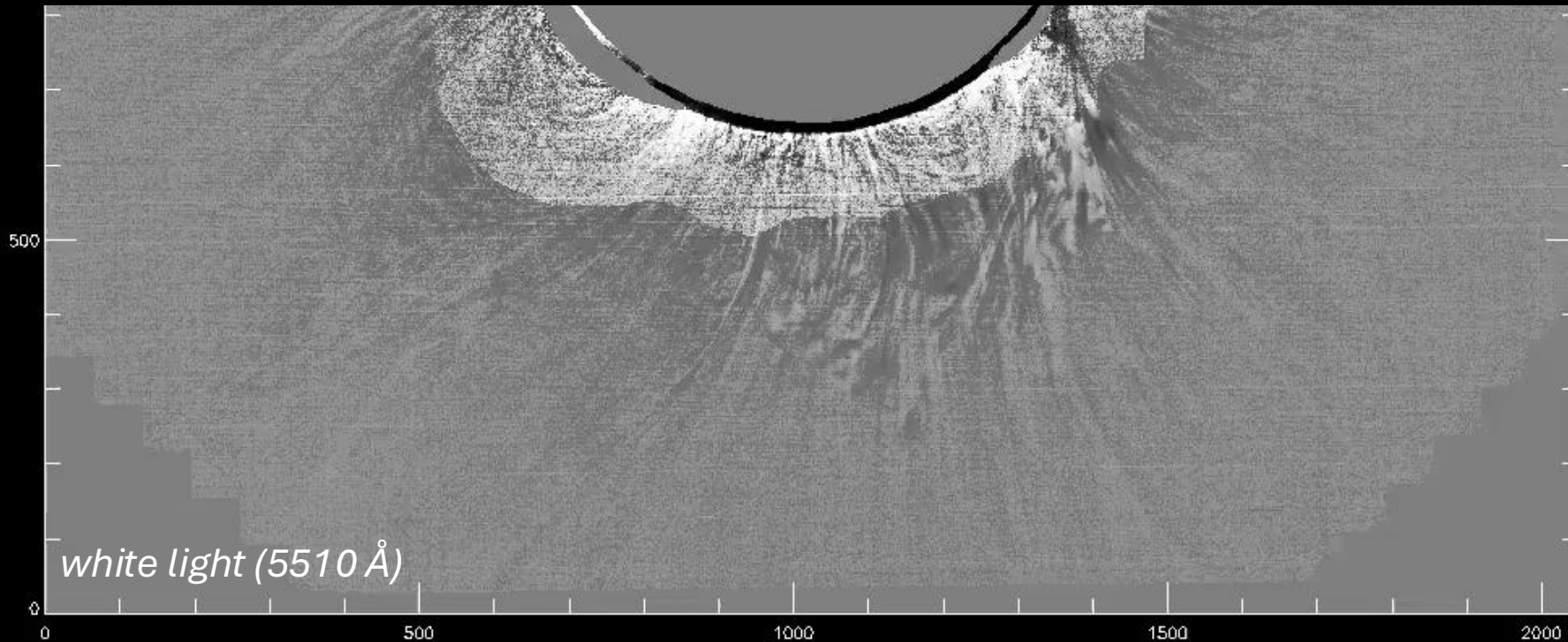
# Slow solar wind origin (ASPIICS ERA)



S: streamer (edge-on)  
 PS: pseudo-streamer (edge-on)  
 CH: coronal hole

CH+S: coronal hole + streamer (face-on)  
 mixed: no clear magnetic topology

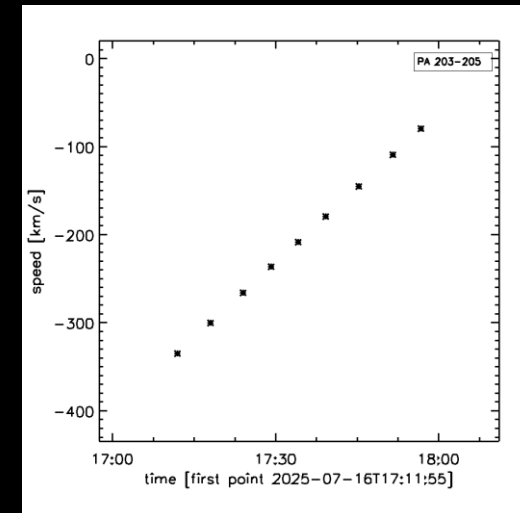
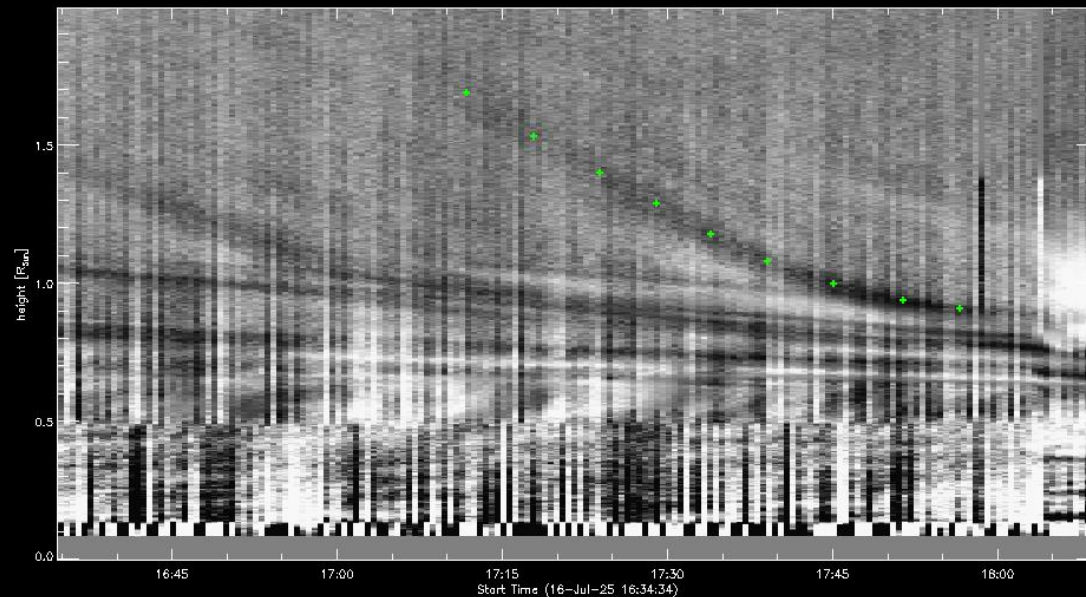
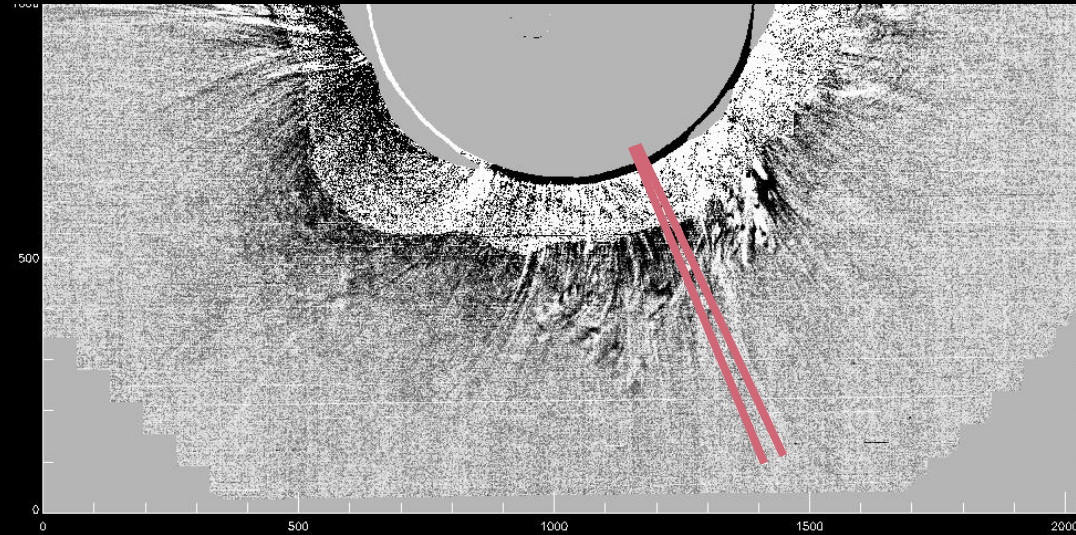
# Slow solar wind origin



- ASPIICS shows rich small-scale dynamics in the slow solar wind formation region: jets, waves, outflows, inflows...

# Slow solar wind origin

- This example shows the coronal dynamics in a  $2^\circ$ -wide sector centered at the position angle of  $204^\circ$ .
- Constant-speed outflows and decelerating inflows are overlapping along the line of sight.
- The speeds of both outflows and inflows are a few hundred km/s.

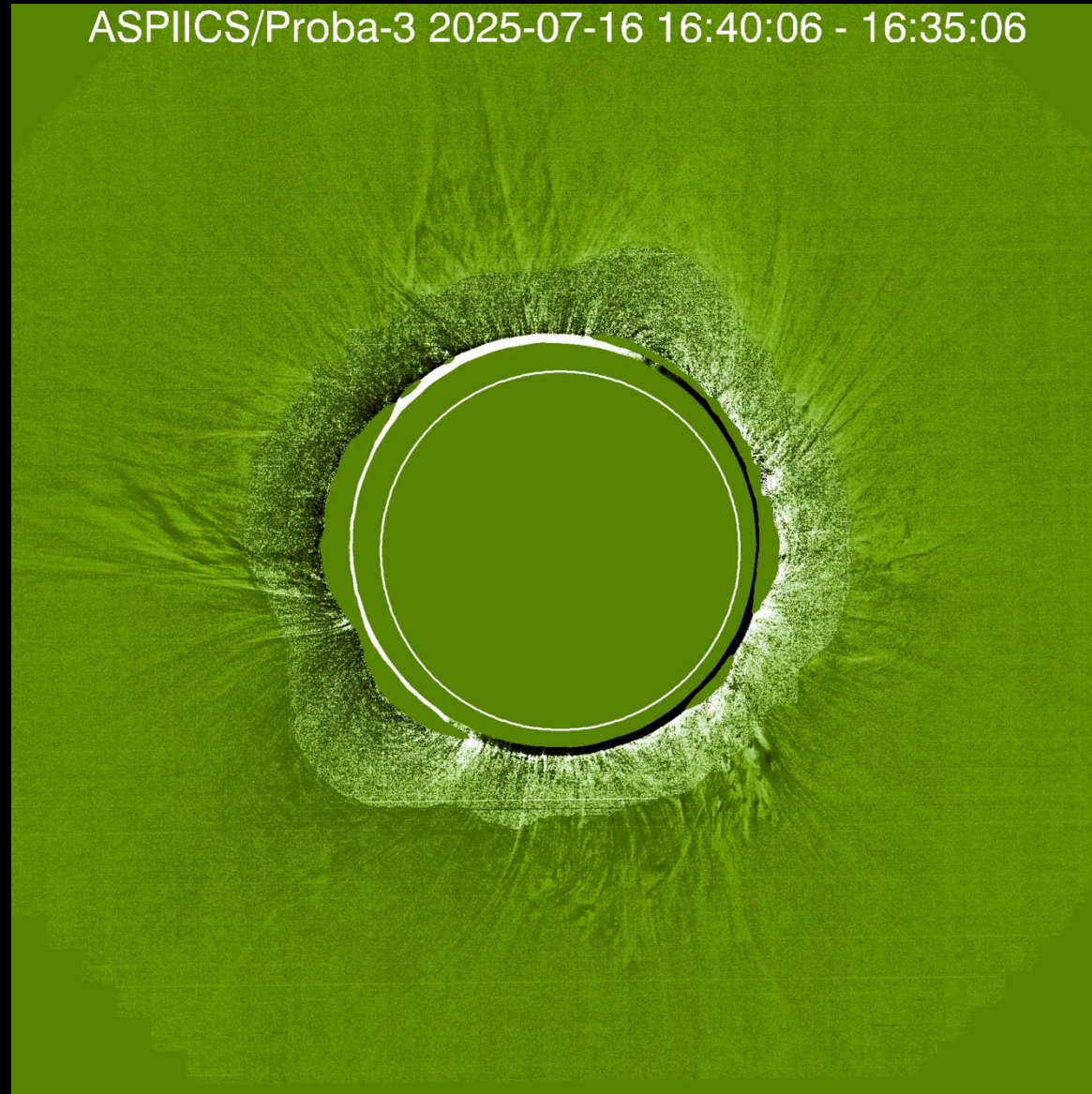




# Slow solar wind origin

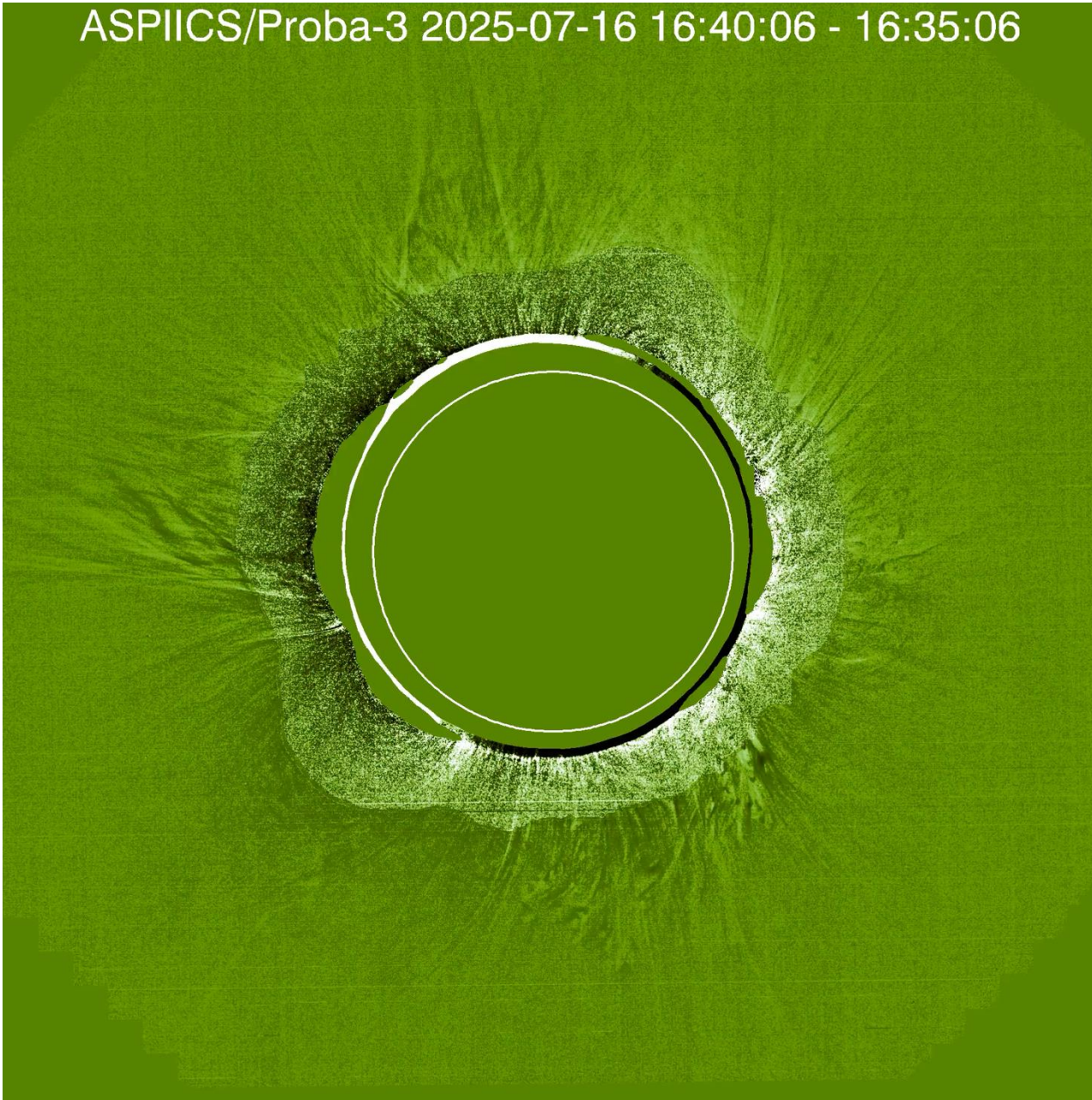


- A sequence of total brightness images taken in the ASPIICS wideband (5511 Å).
- 5-min difference images, advancing by 30 s.



- Major artefacts:
  - stitches between images taken with different exposure times,
  - large-scale brightness flickering (especially in the inner part of the field of view), probably due to small ( $\sim 1''$ ) changes of the spacecraft pointing,
  - wide bands stemming from bright structures (detector artefact).

ASPIICS/Proba-3 2025-07-16 16:40:06 - 16:35:06

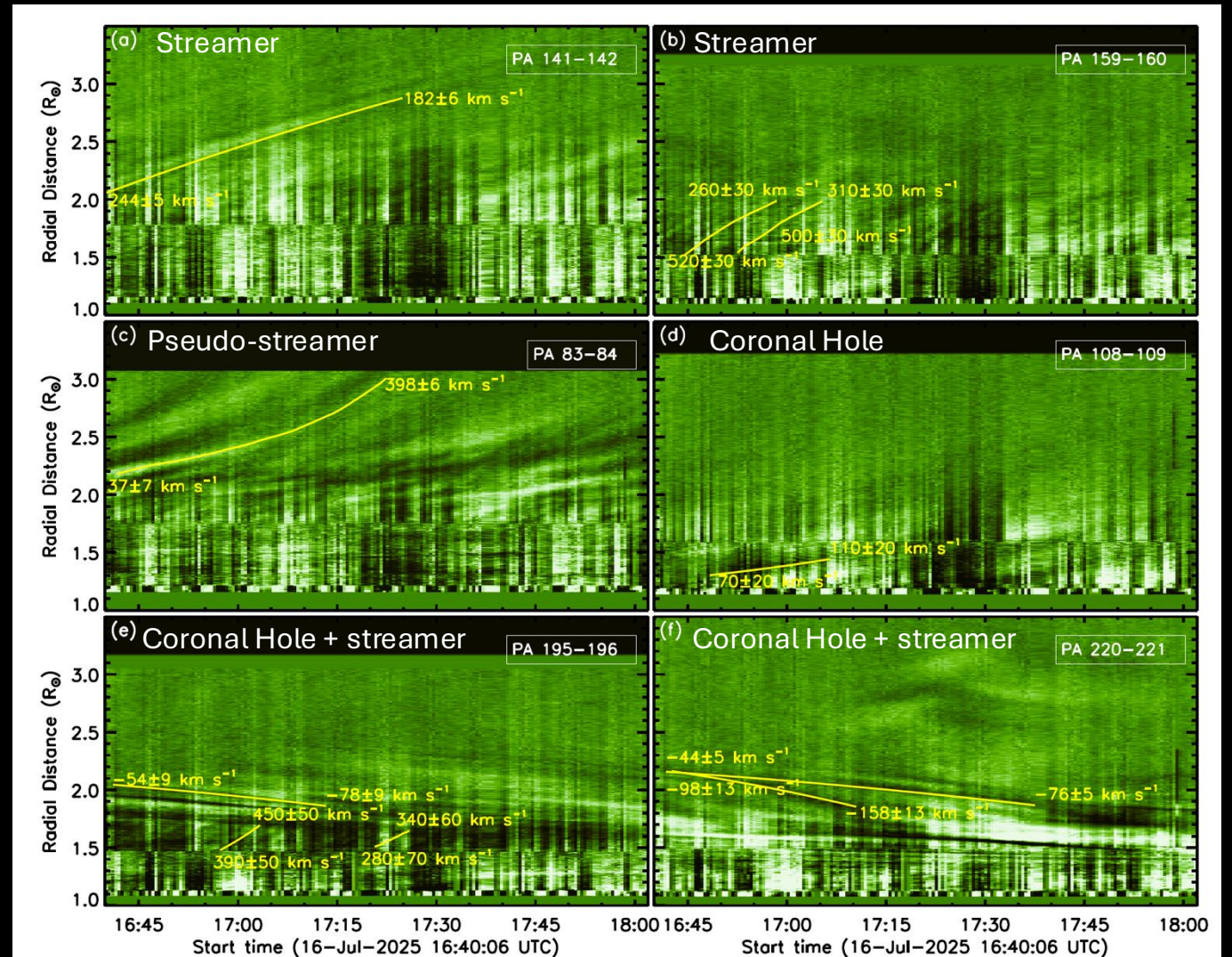


Zhukov et al (2026)

- **ASPIICs** observations revealed ubiquitous, faint (0.5%–2%) small-scale structures—such as blobs, jets, inflows, and waves—traveling at speeds between 14 and 520 km/s.
- These dynamic features consistently originate from streamers and pseudostreamers, offering vital new constraints on the mechanisms that generate the slow solar wind.

# Main dynamic features observed in the slow solar wind formation region

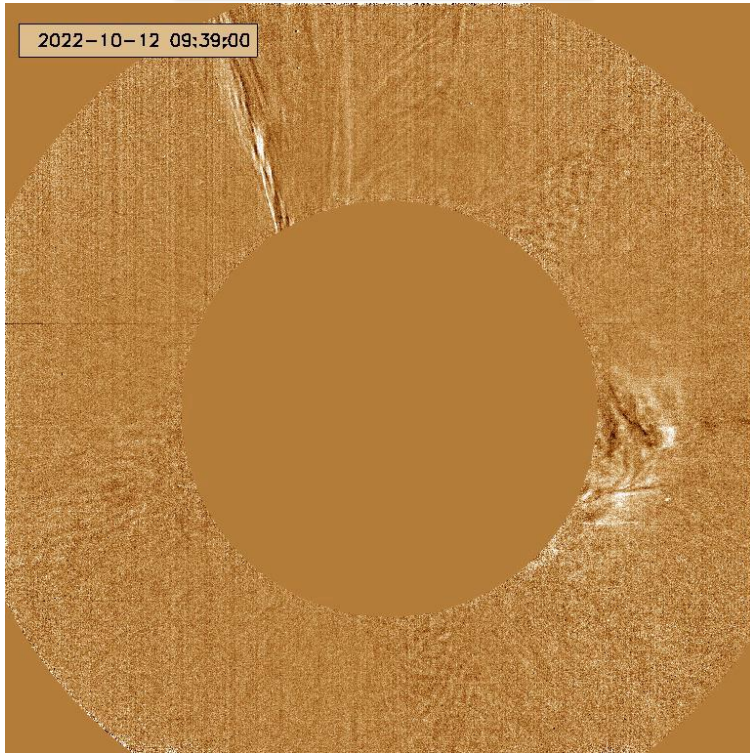
- **Blobs** (cf. *Sheeley et al. 1997, Jones & Davila 2009*), probably produced by the pinch-off and/or interchange reconnection at the streamer cusp.
- **Quasi-periodic pressure waves**, probably produced by the p-mode leakage into the corona (cf. *Andretta et al. 2025*).
- **Inflows** (cf. *Wang et al. 1999, Sheeley & Wang 2002*), produced by the reconnection in the streamer current sheet.
- **Helical jets** (cf. *Romano et al. 2025*) produced by the interchange reconnection in pseudo-streamers.
- **Outflows** in a coronal hole (or in a background/foreground streamer) - weak and slow due to projection effects?





# Overview of Metis high-cadence observation: Some features

Cadence: 20 s

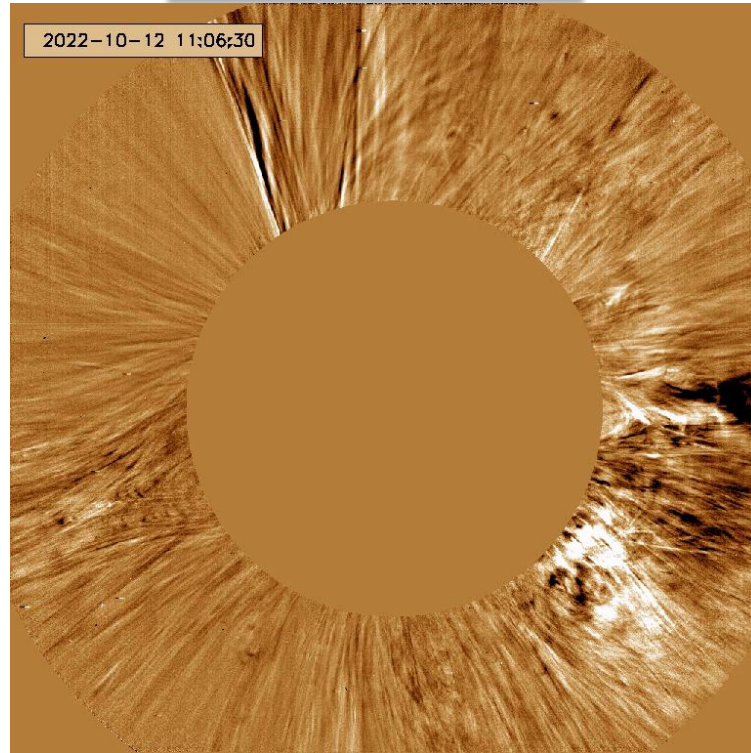


Periods < 1 minute filtered out

←  
Alfvén waves  
Acoustic-like waves  
Small scale flows  
More...

→  
Outflows  
Downflows  
More...

Cadence: 120 s



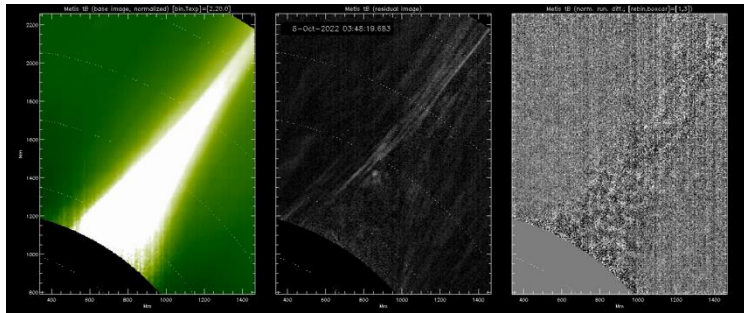
Periods < 6 minutes filtered out



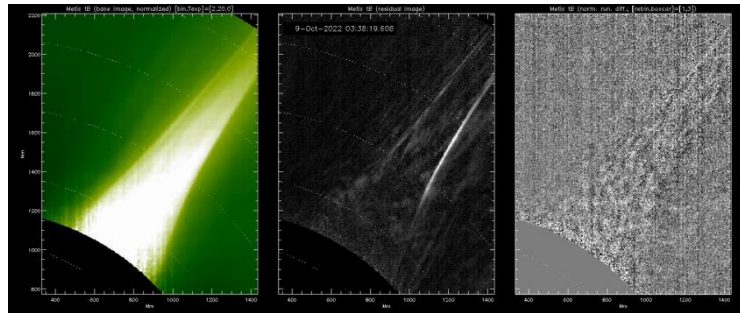


# A closer look: 2nd perihelion (October 2022)

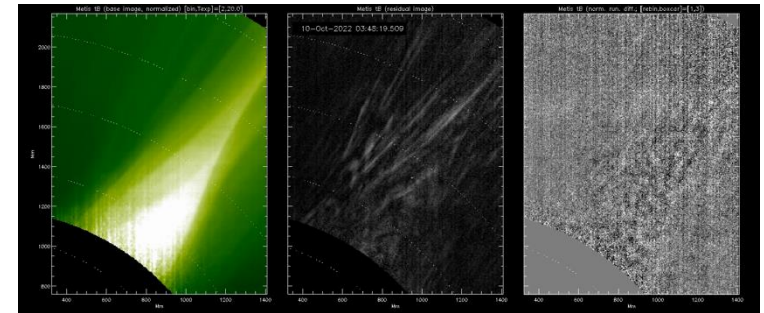
Cadence: 20 s, duration: 41 minutes, run each day for several days



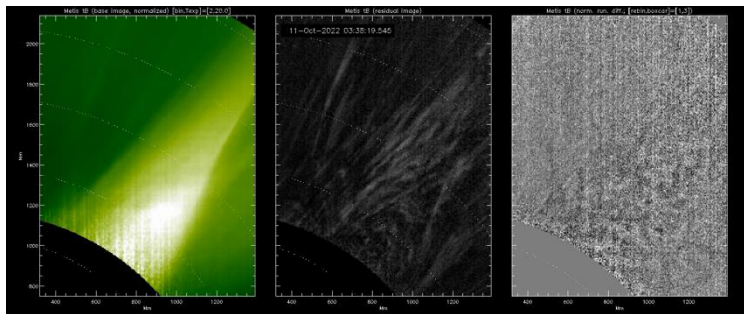
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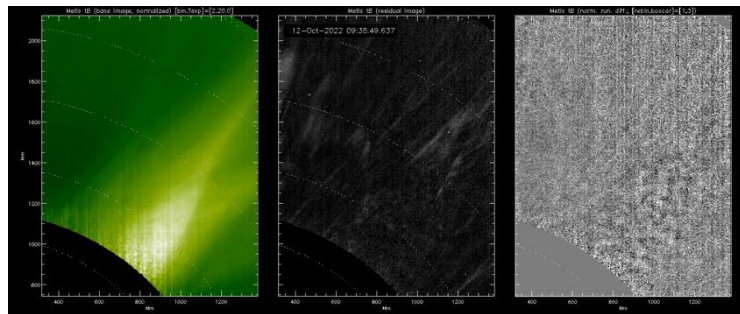
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2022-10-10



2022-10-11



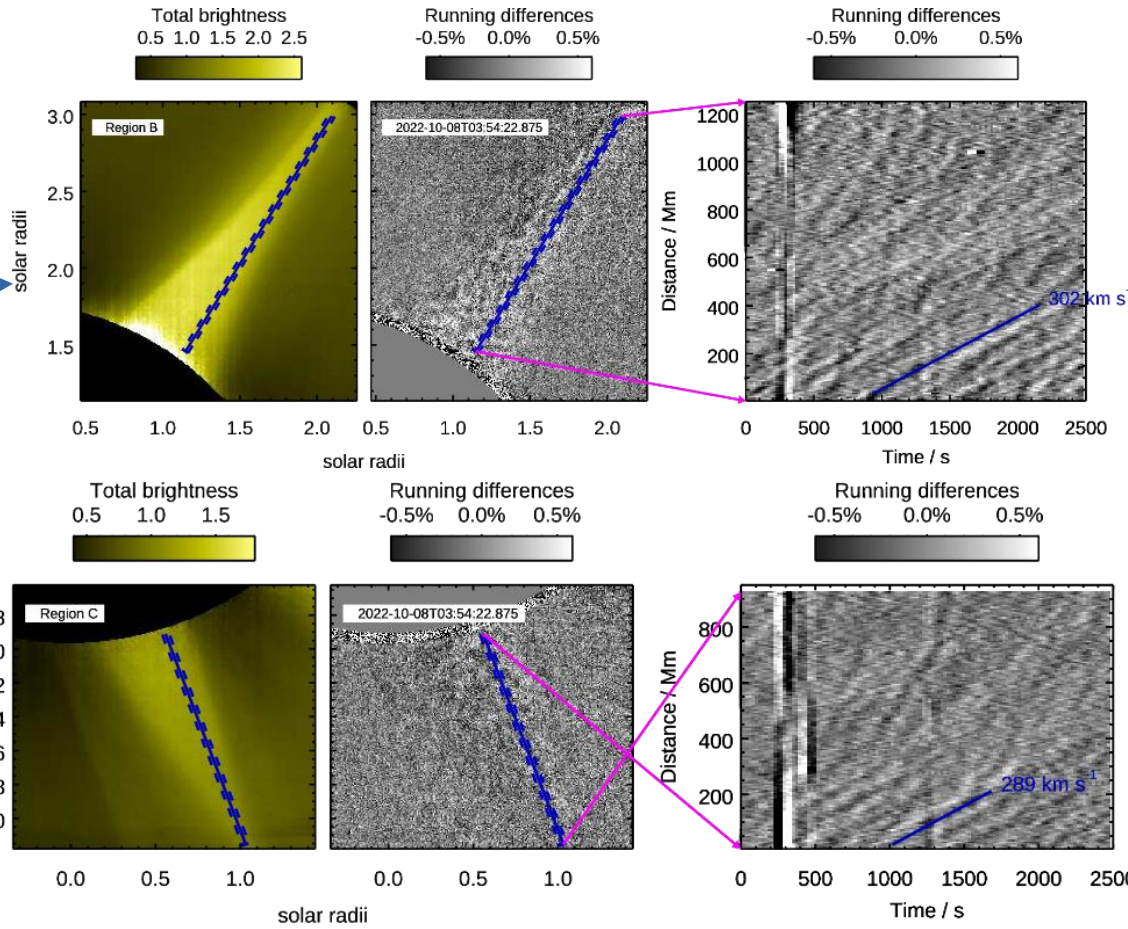
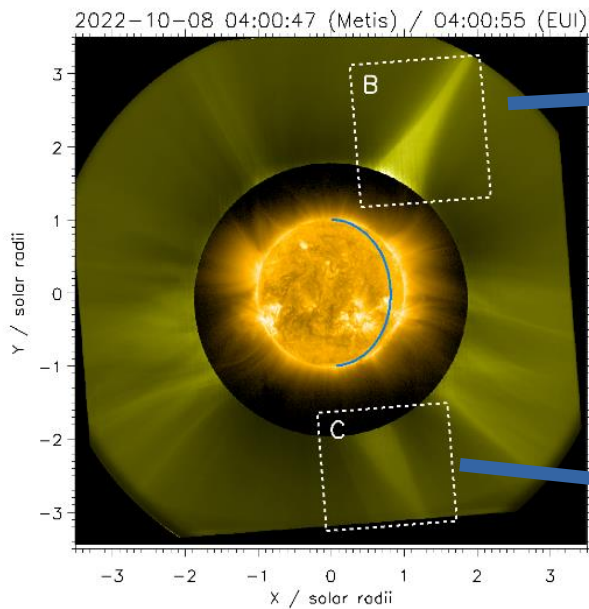
2022-10-12

Density fluctuations persistent over at least 5 days in the same region



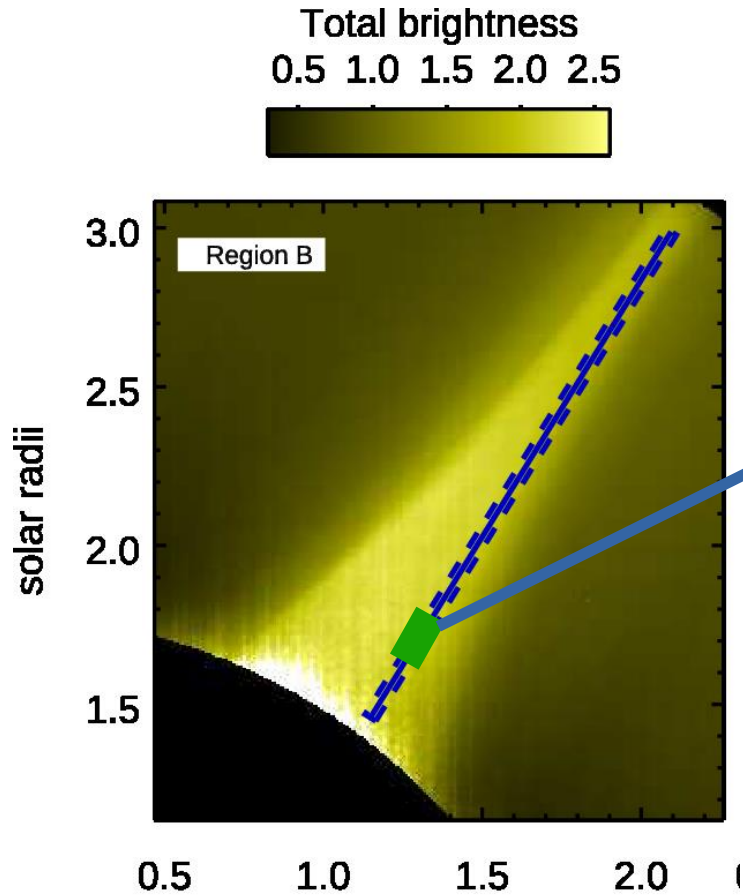
# Time-distance diagrams: 2nd perihelion (October 2022)

Cadence: 20 s, duration: 41 minutes

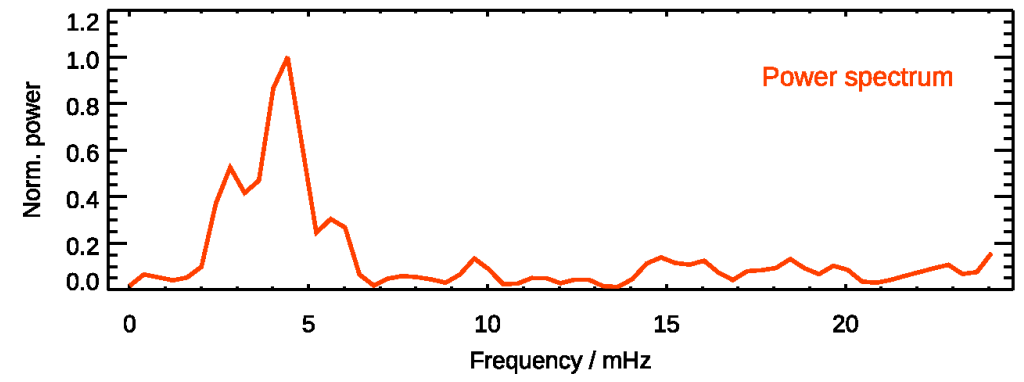
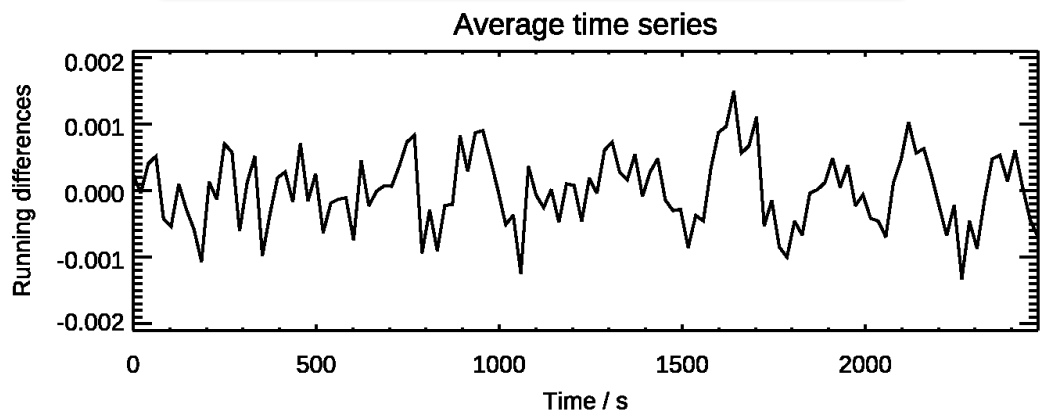


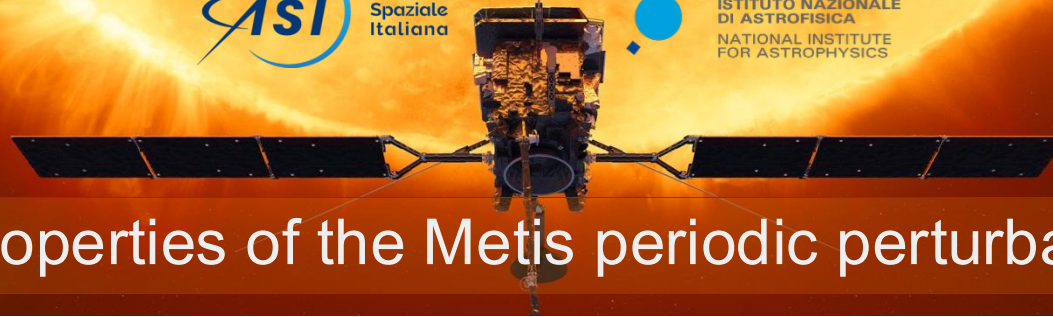


# Average time series: 2nd perihelion (October 2022)



Cadence: 20 s, duration: 41 minutes





## Summary: Properties of the Metis periodic perturbations



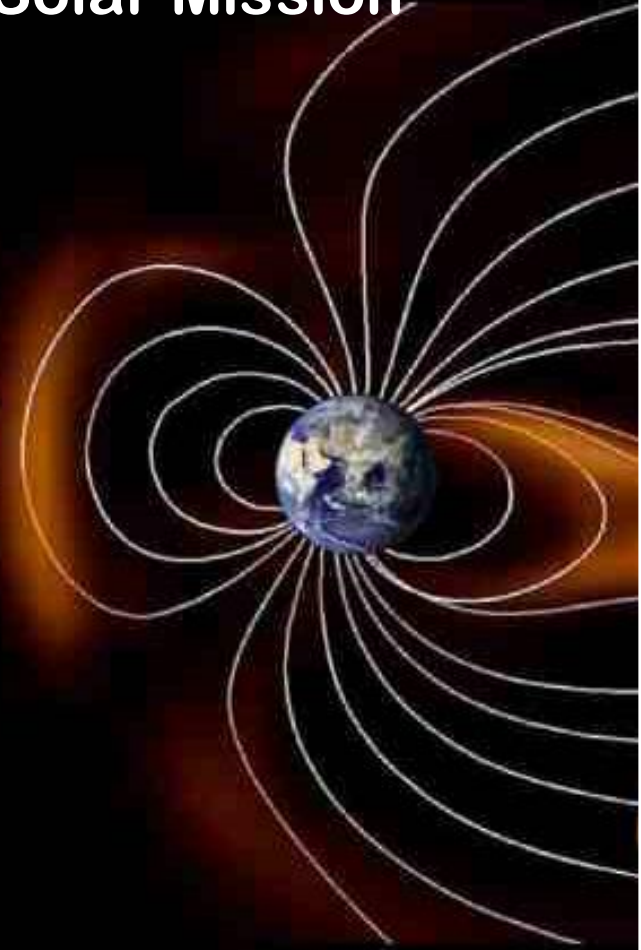
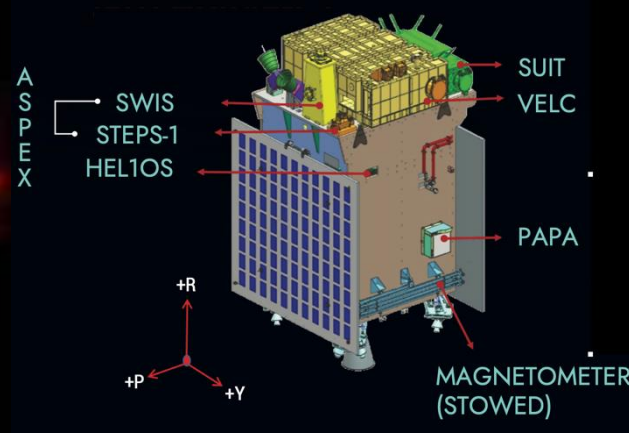
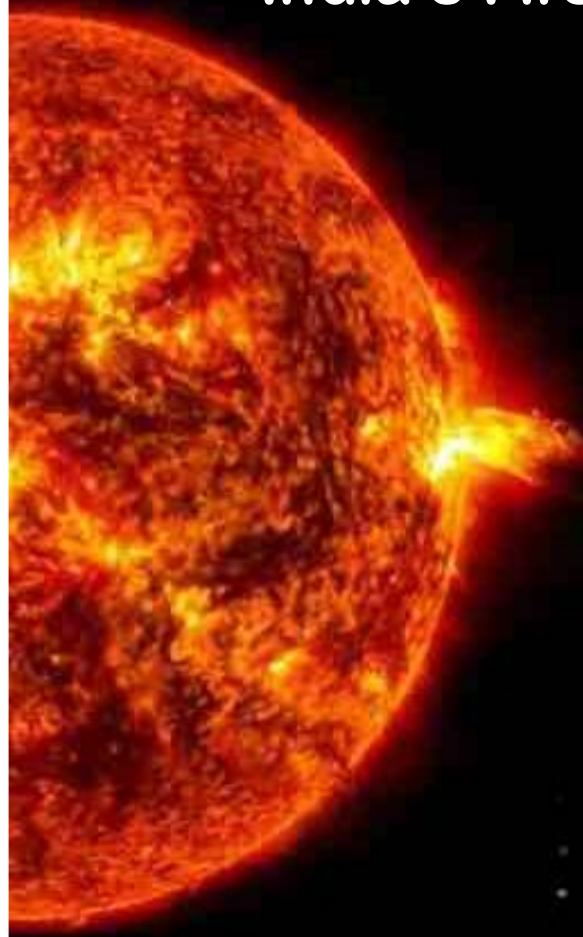
### Main properties:

- **Periods:** of the order of 3 - 5 min (5 - 3 mHz)
- **Amplitudes:** ~0.1% of background.
- **Phase speed:** of the order of 200 – 400 km s<sup>-1</sup>
- **Coherent:**
  - ❖ at least for the duration of the observations (up to 2 h). No sign of damping.
  - ❖ over large volumes (several tens or even hundreds of Mm).
- **Ubiquitous** in bright, near-stationary structures, but detectable also at their edges.
- **Persistent:** Observed in the same structure for many days, at least for the duration of the high cadence program.
- **No obvious dependence on magnetic topology:** Detectable both in streamers and pseudo-streamers.

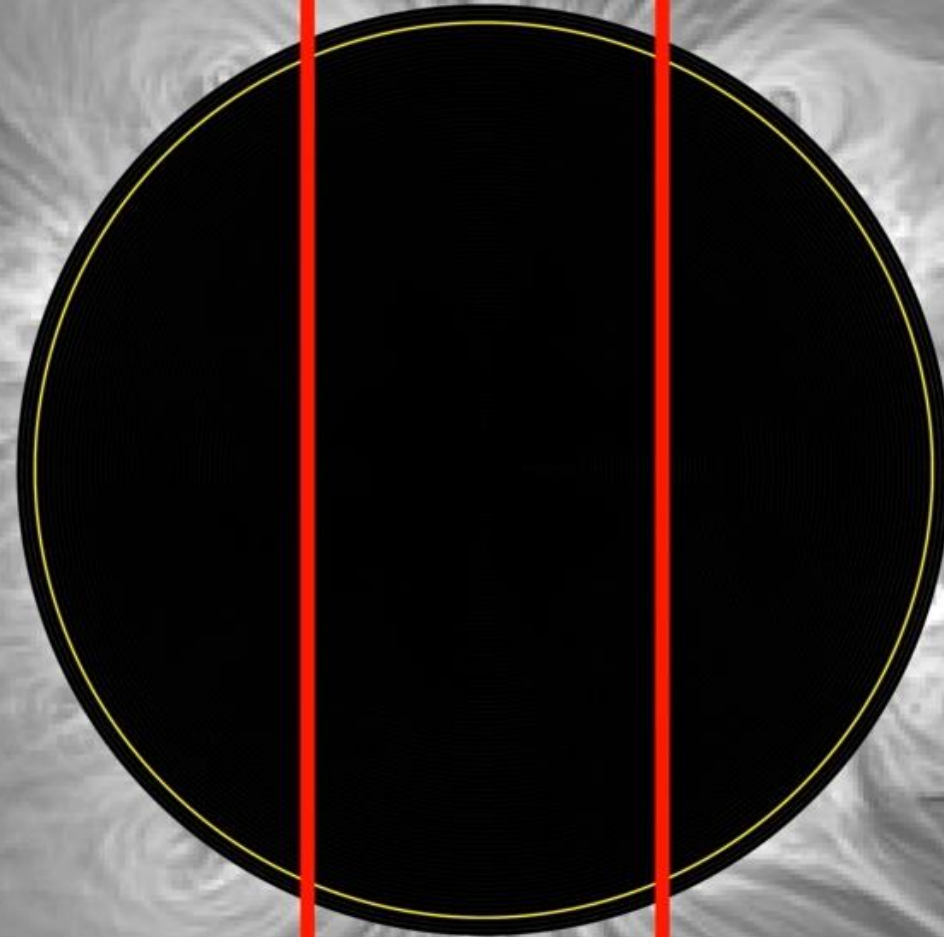
Andretta et al. (2025), A&A 701, A199

# Aditya-L1

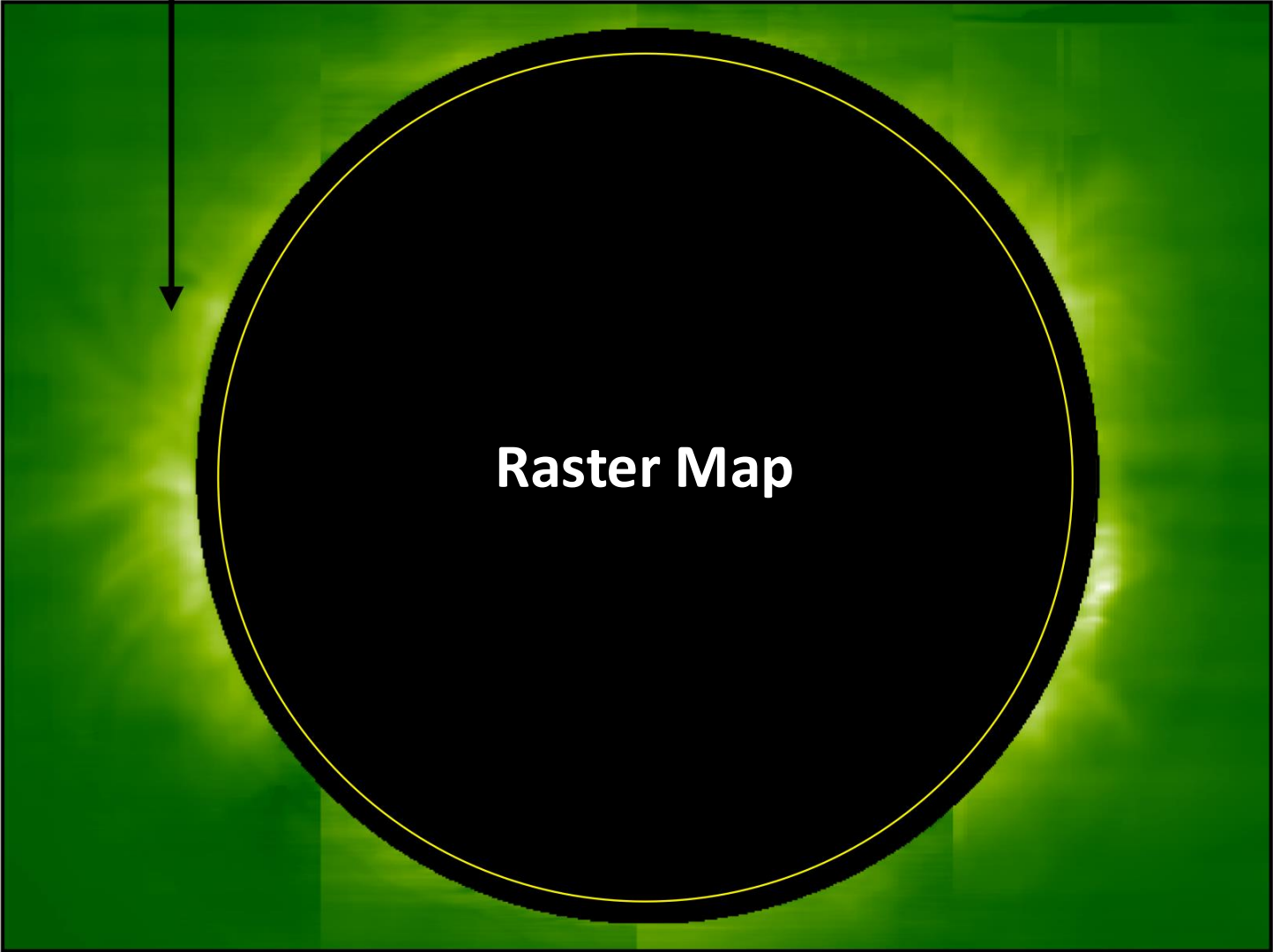
India's First Observatory Class Solar Mission



# Sit-and-Stare or Raster Scan

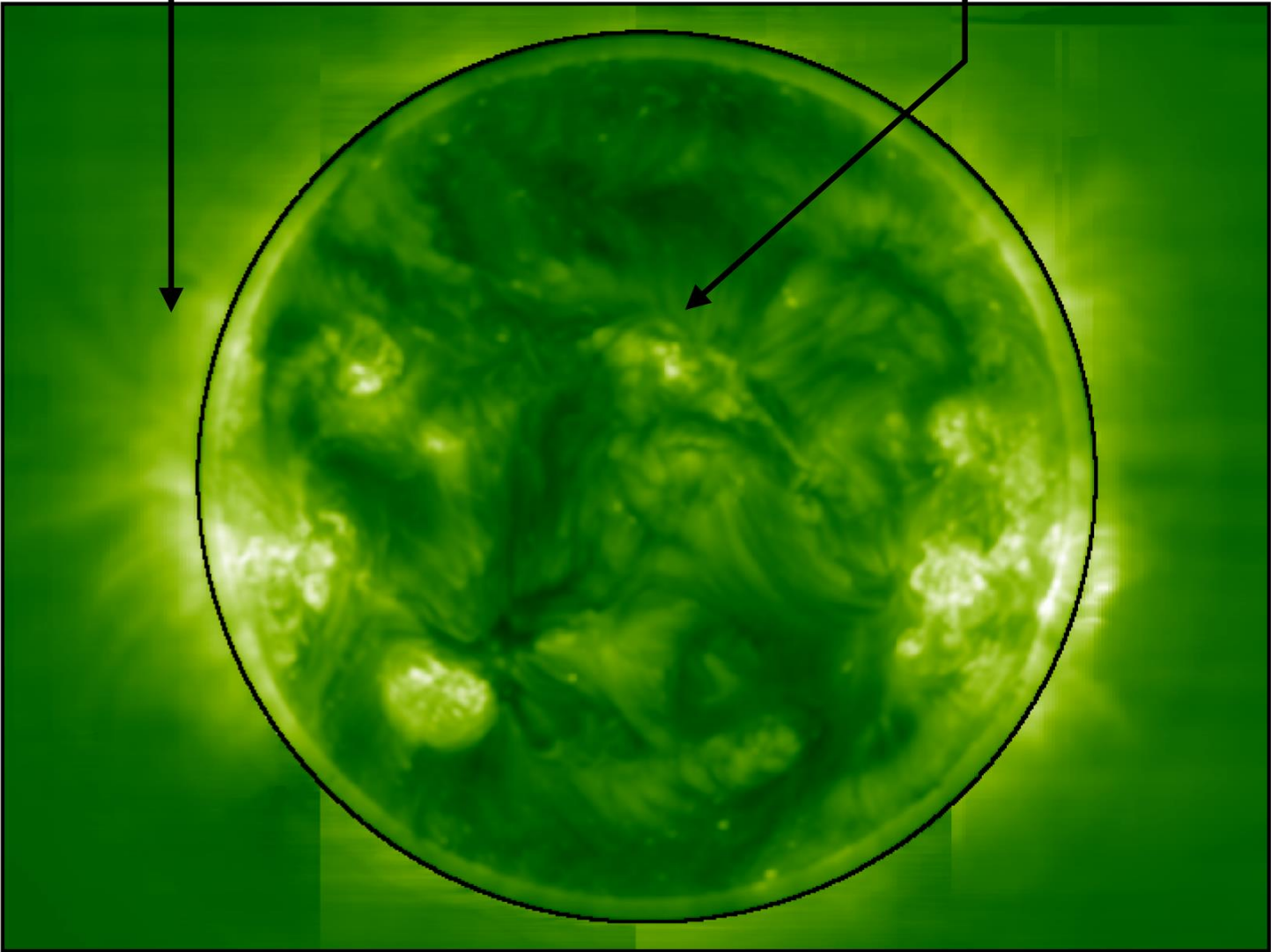


**Aditya-L1**  
**VELC 5303**  
*1.05-1.5 Solar Radius*



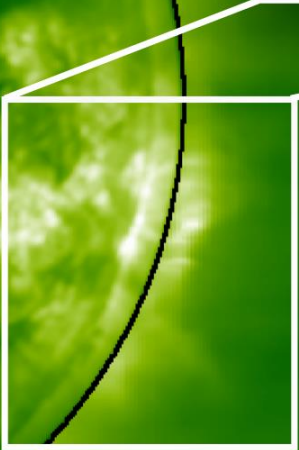
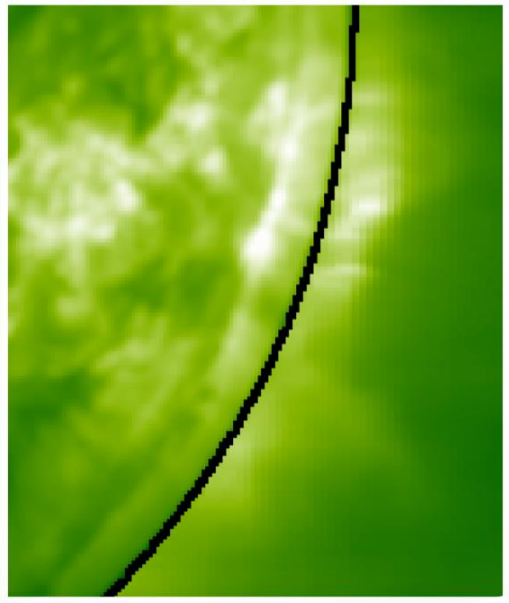
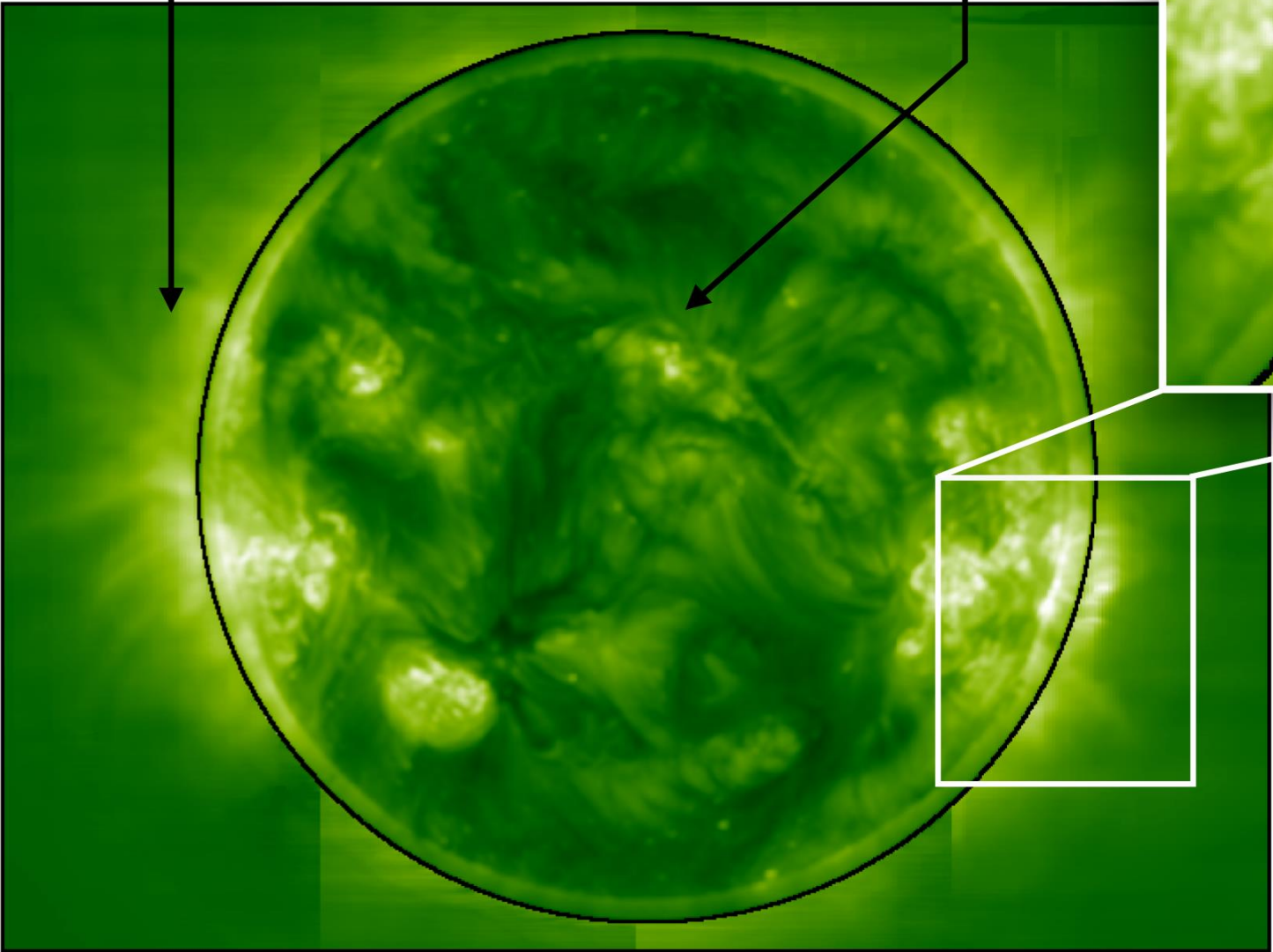
**Aditya-L1**  
**VELC 5303**  
*1.05-1.5 Solar Radius*

**SDO**  
**AIA 211**  
*0-1.05 Solar Radius*

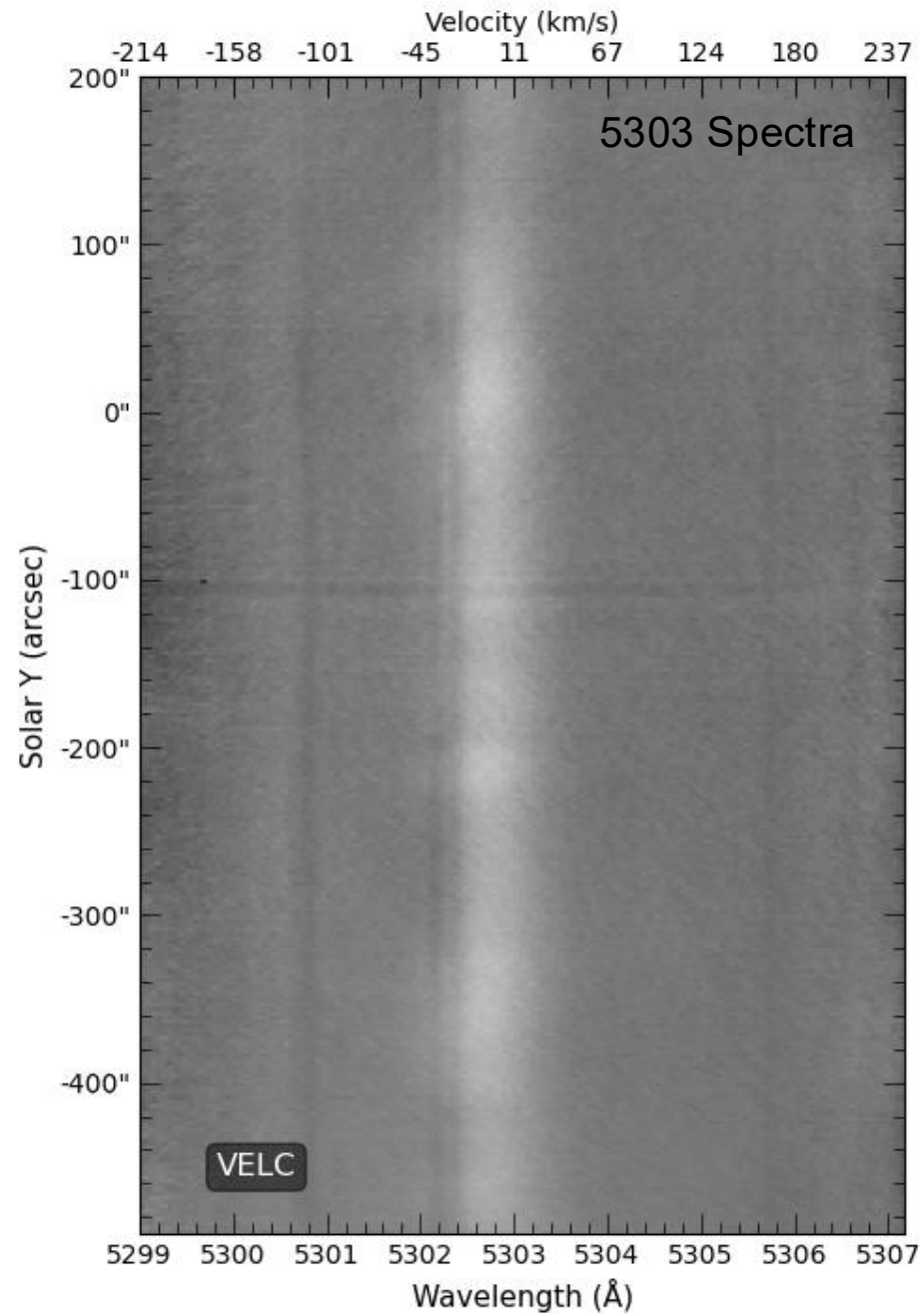
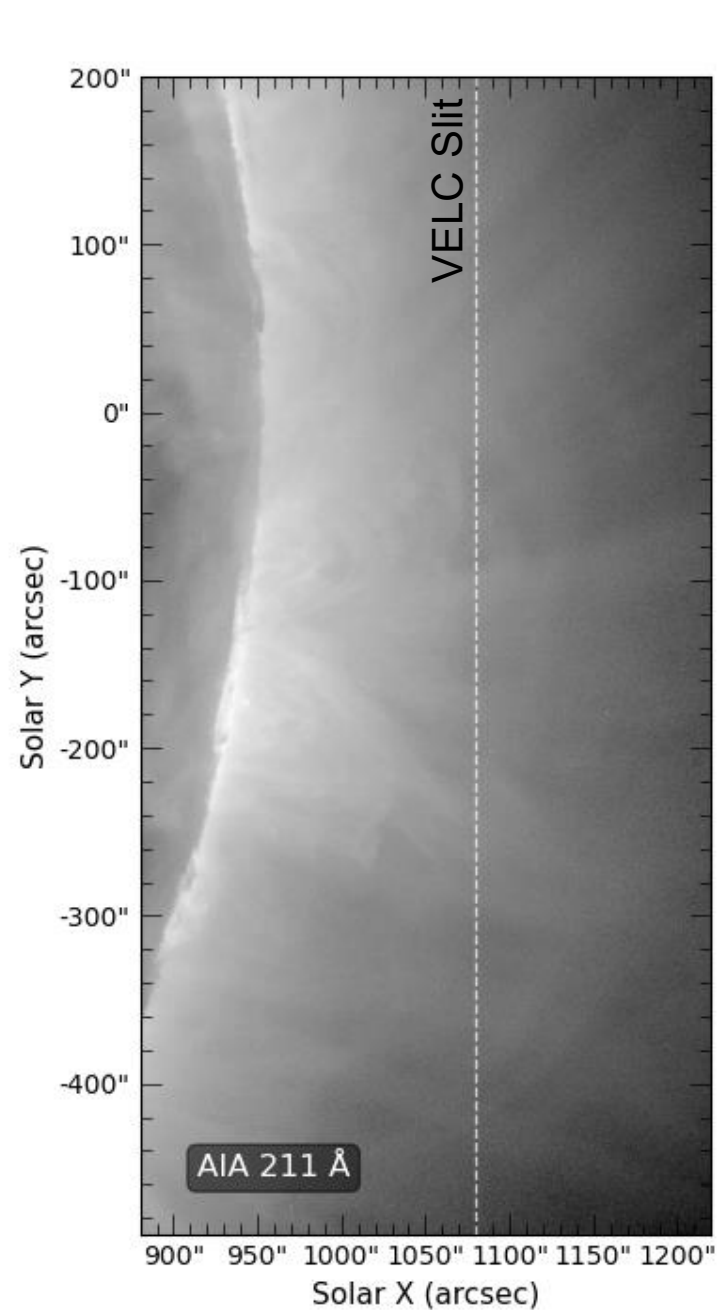


**Aditya-L1**  
**VELC 5303**  
*1.05-1.5 Solar Radius*

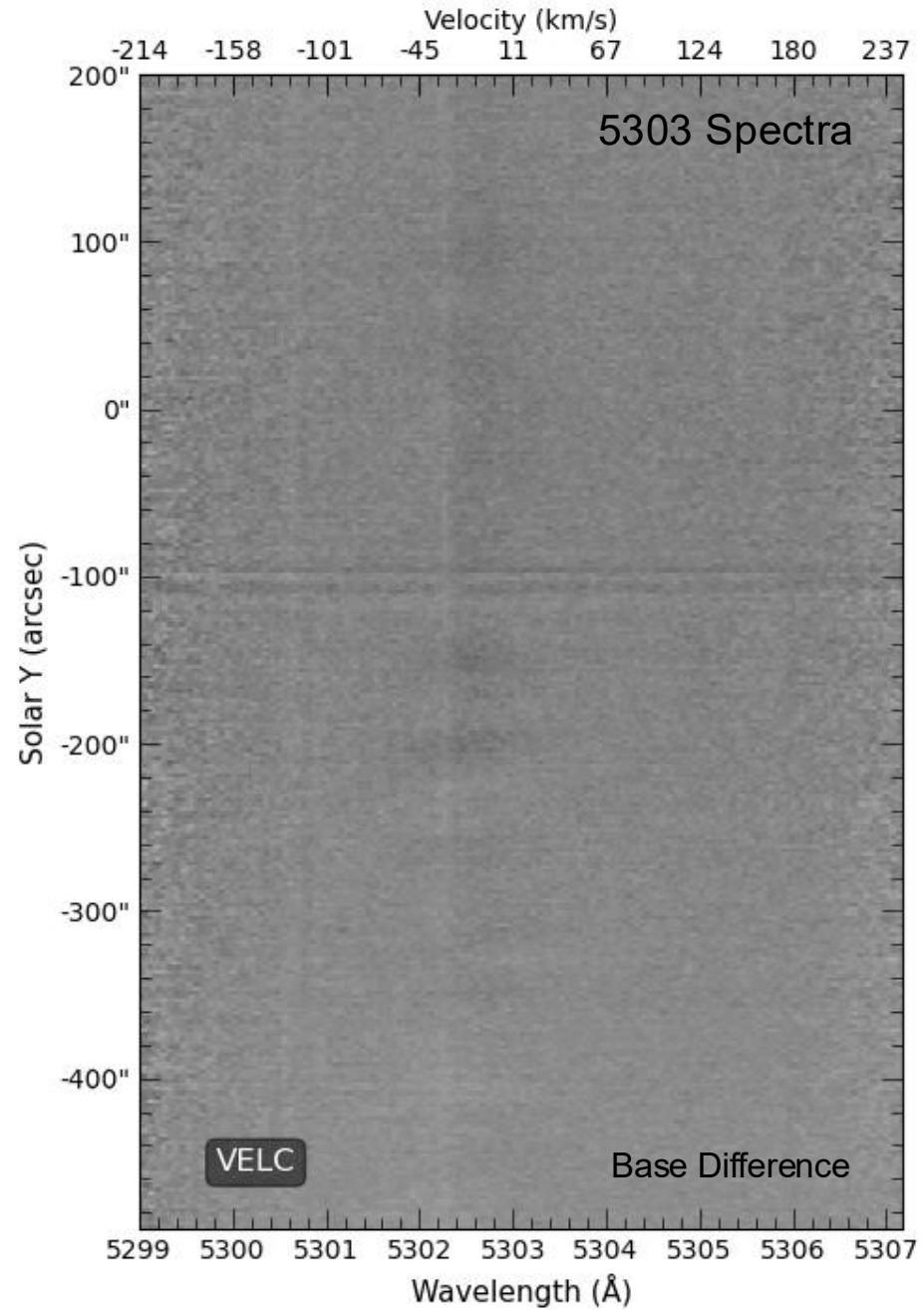
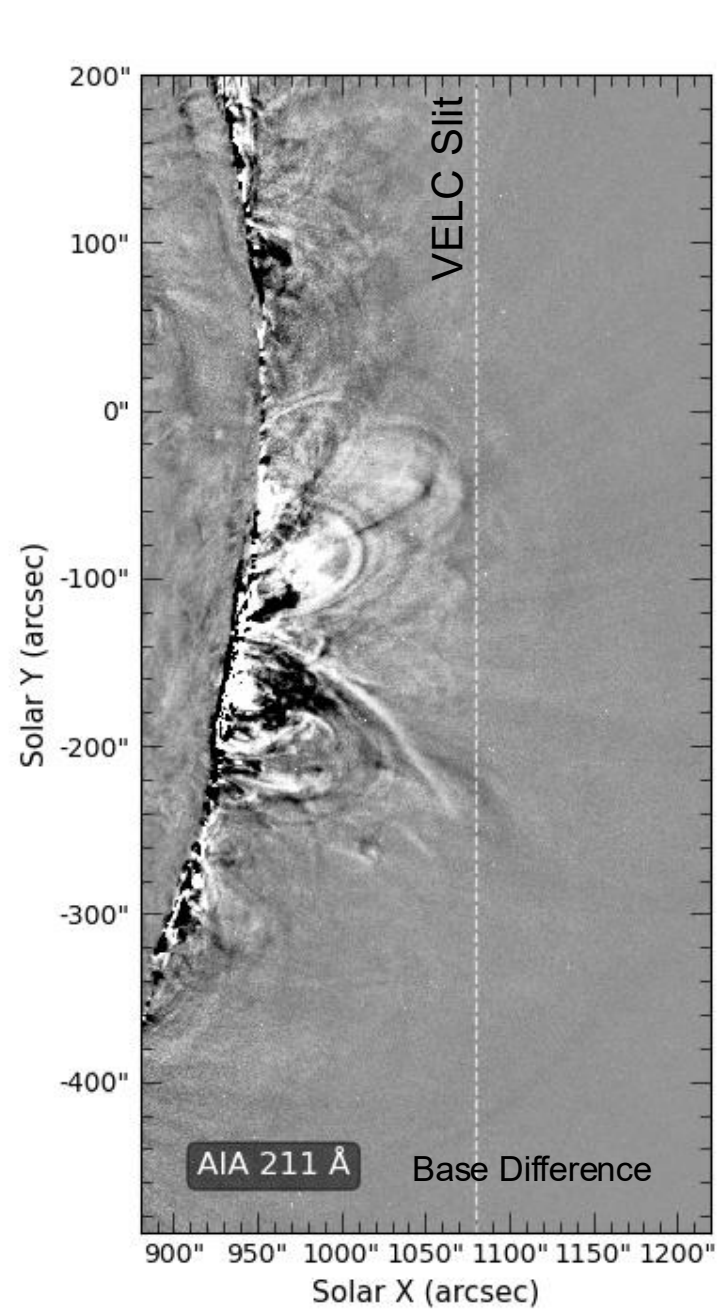
**SDO**  
**AIA 211**  
*0-1.05 Solar Radius*



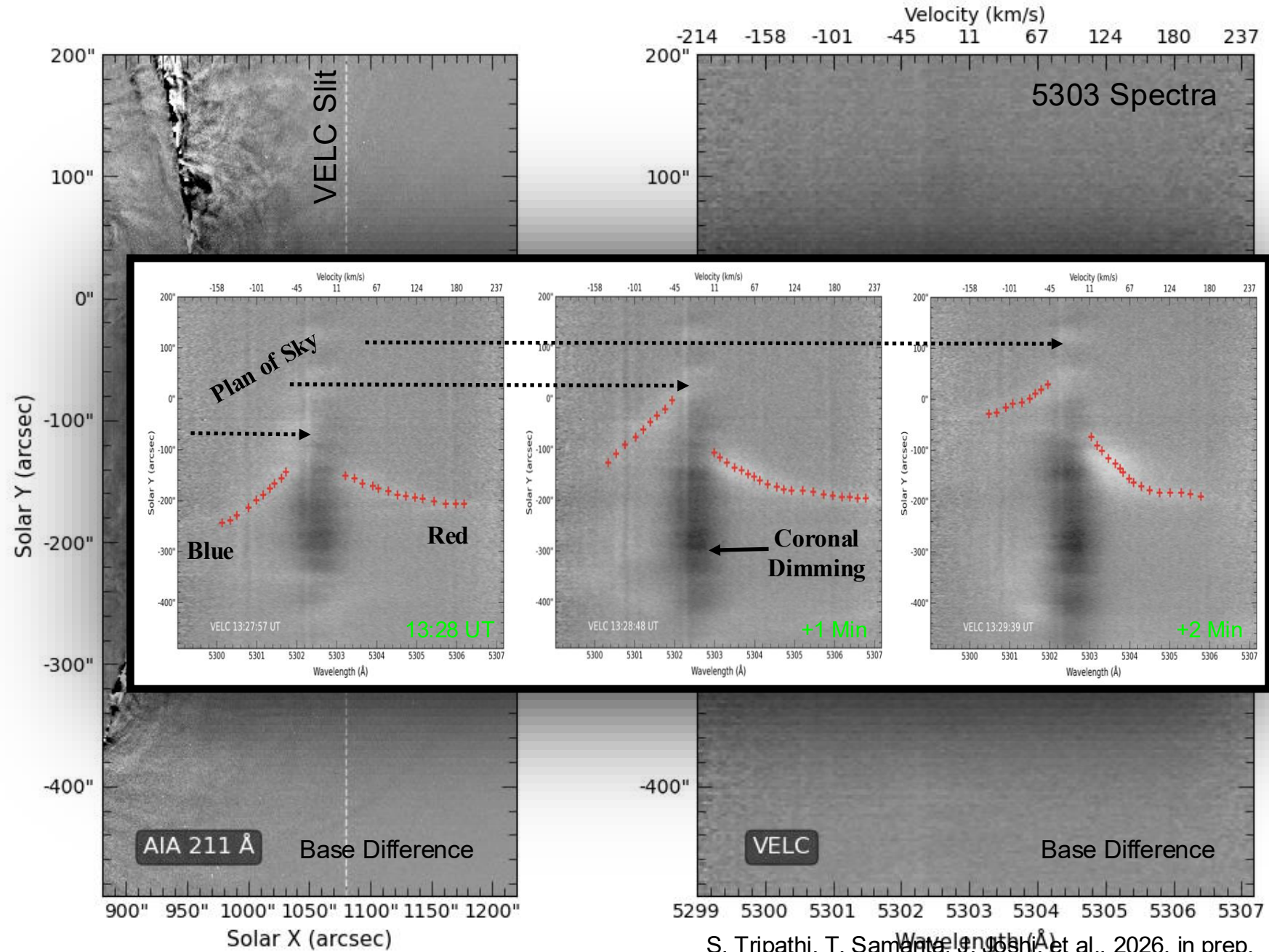
# Sit-and-Stare CME observation



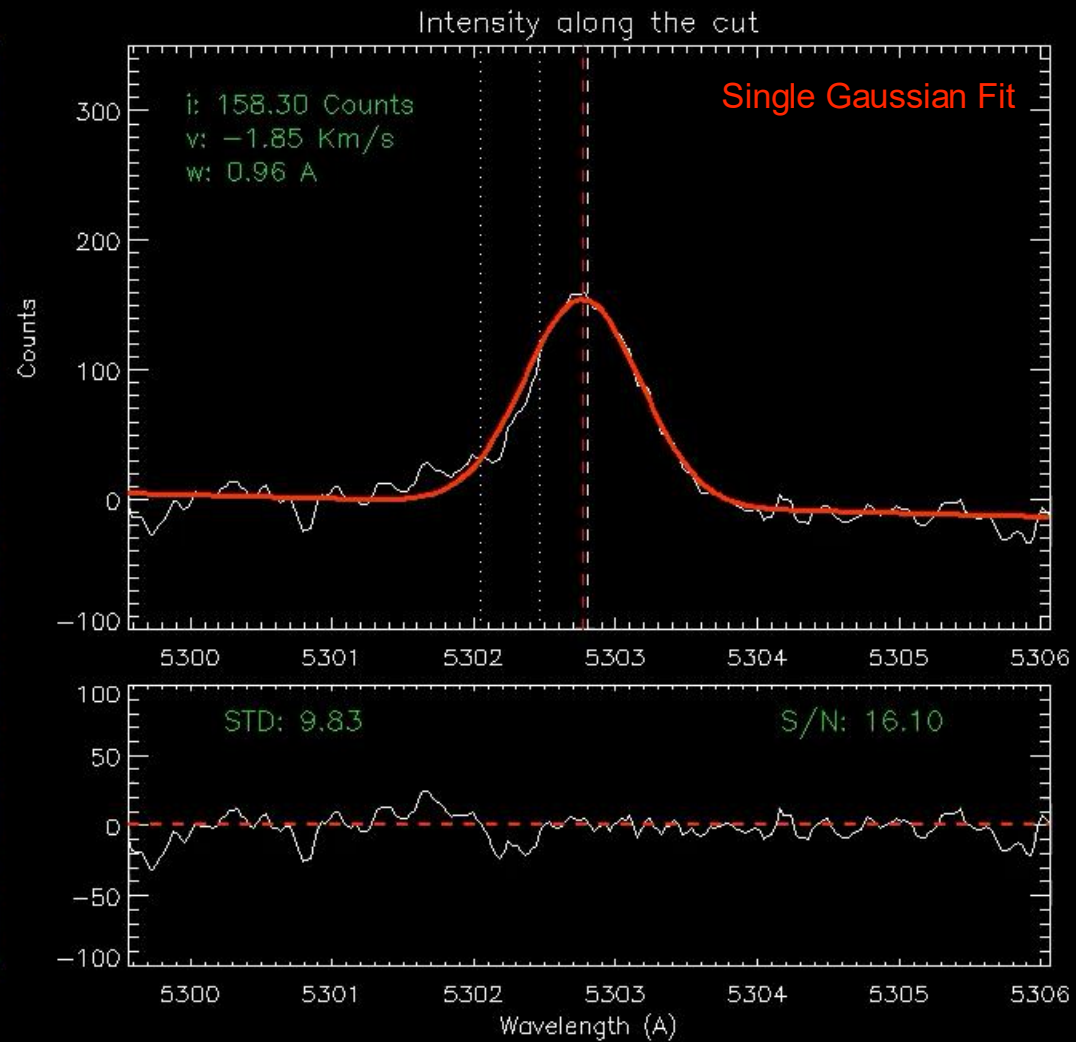
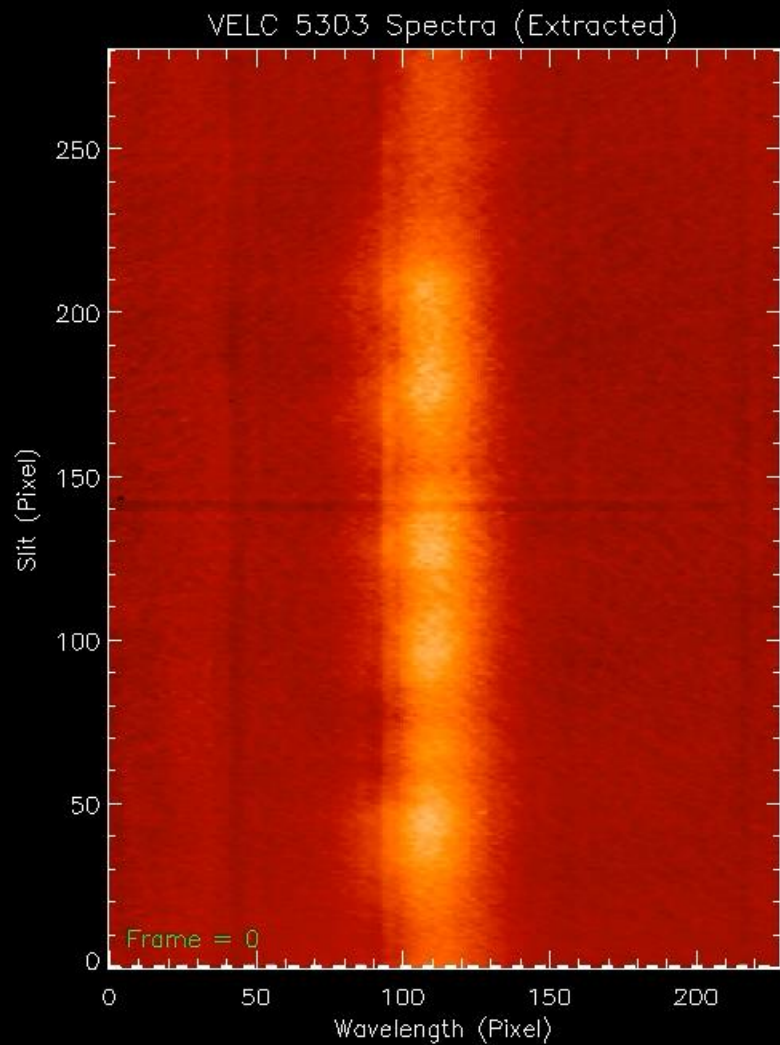
# 3D CME Dynamics

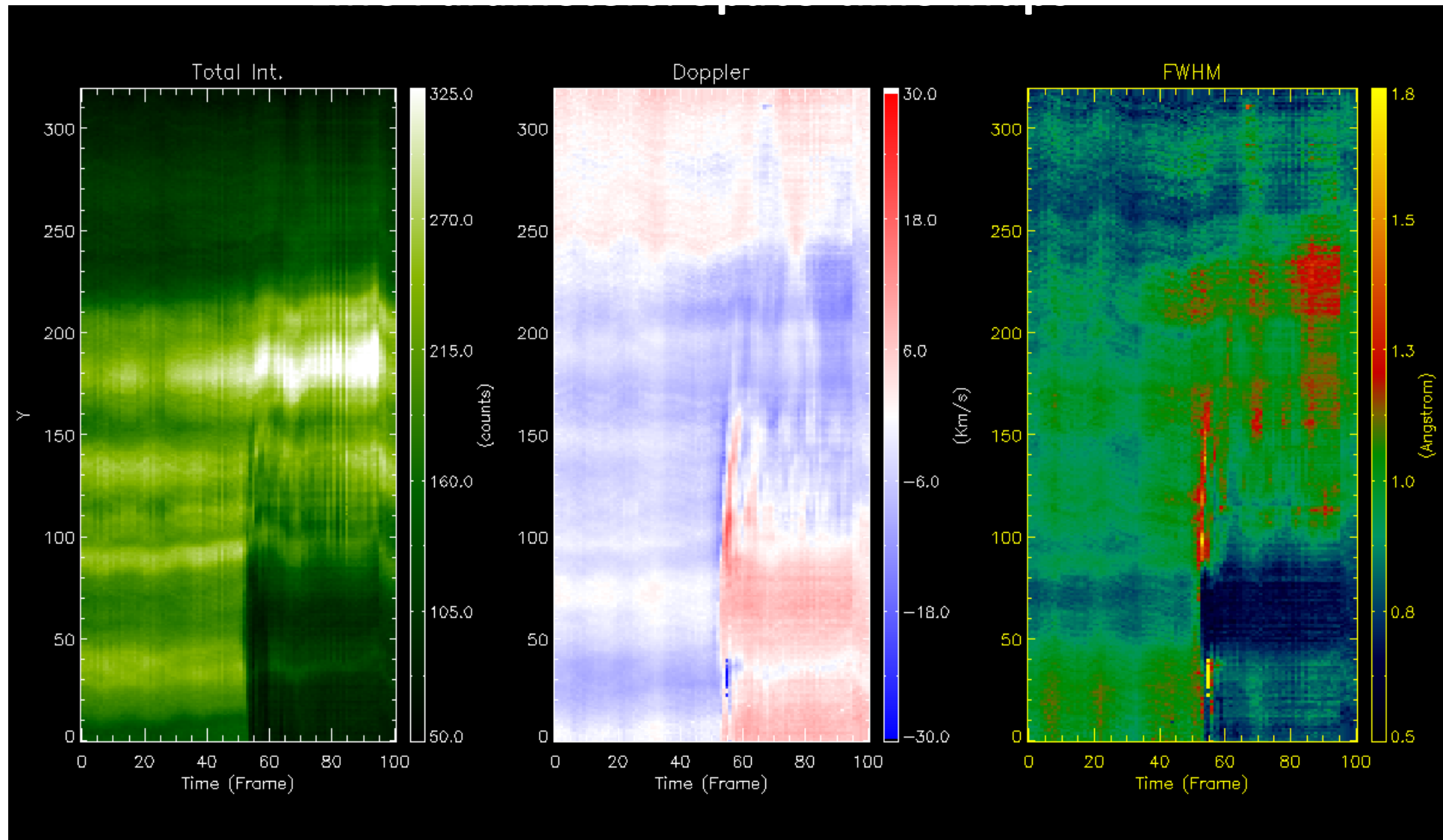


# 3D CME Dynamics

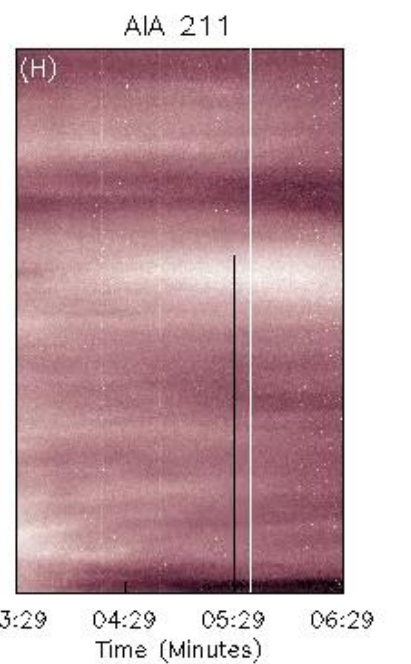
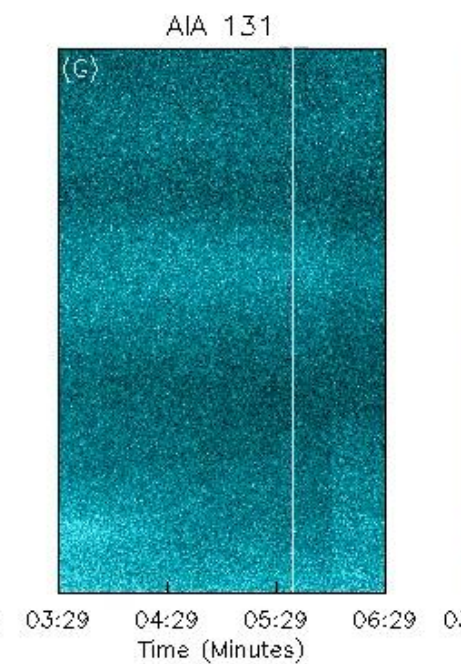
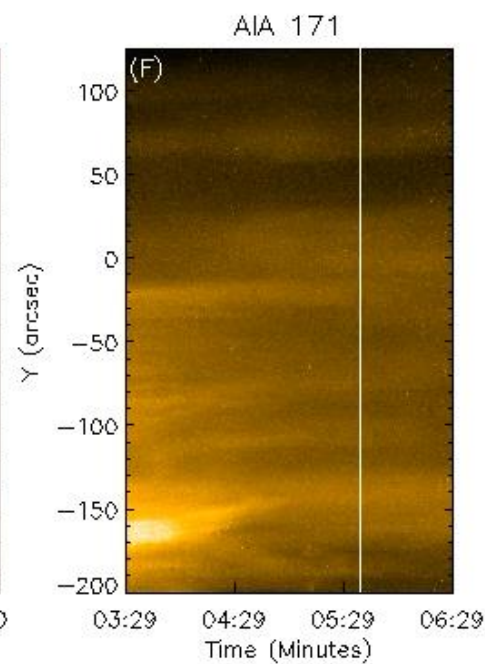
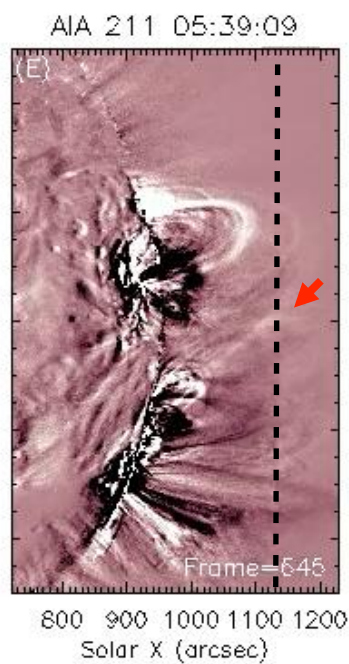
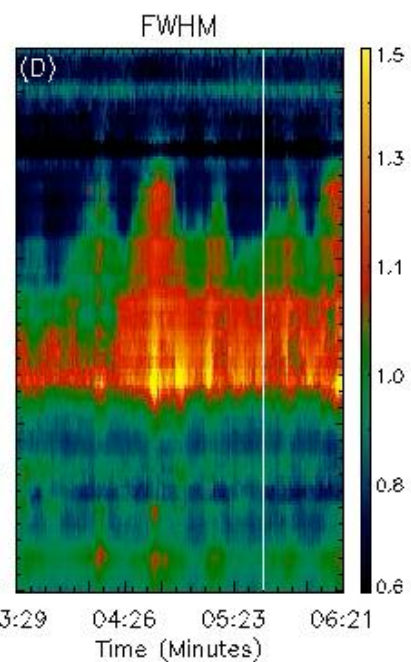
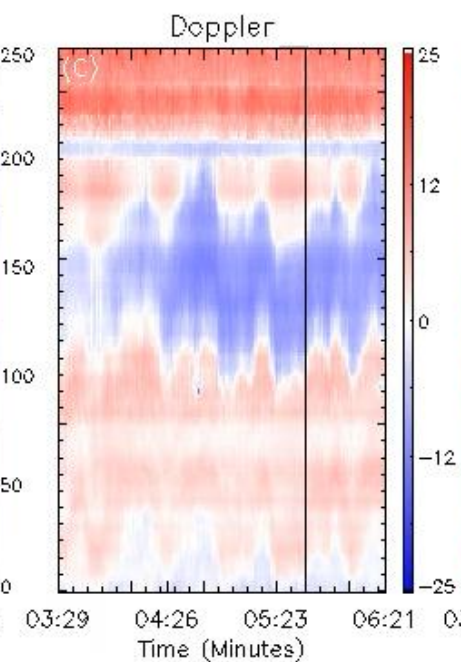
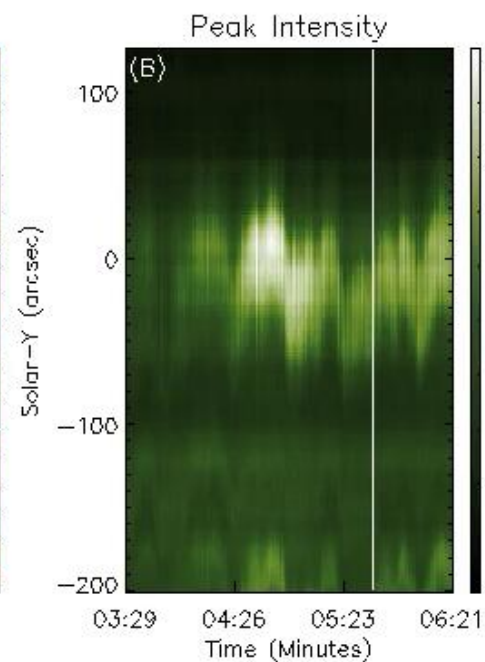
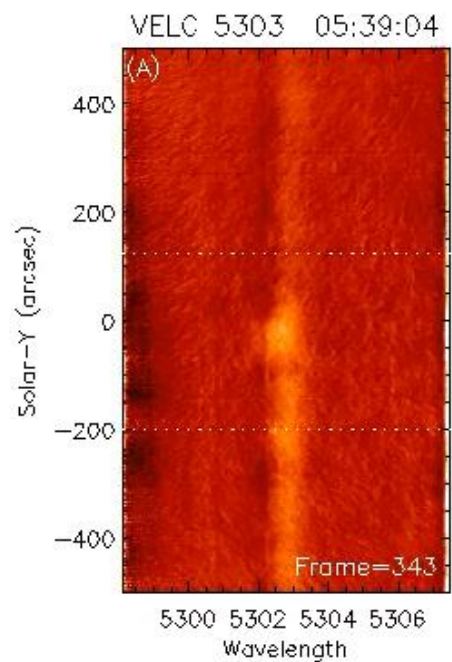


# Spectral Fit





**Data Available: July 2024 onward**  
**(~2 raster/ day, ~2 sit-and-stare@10 Hrs)**

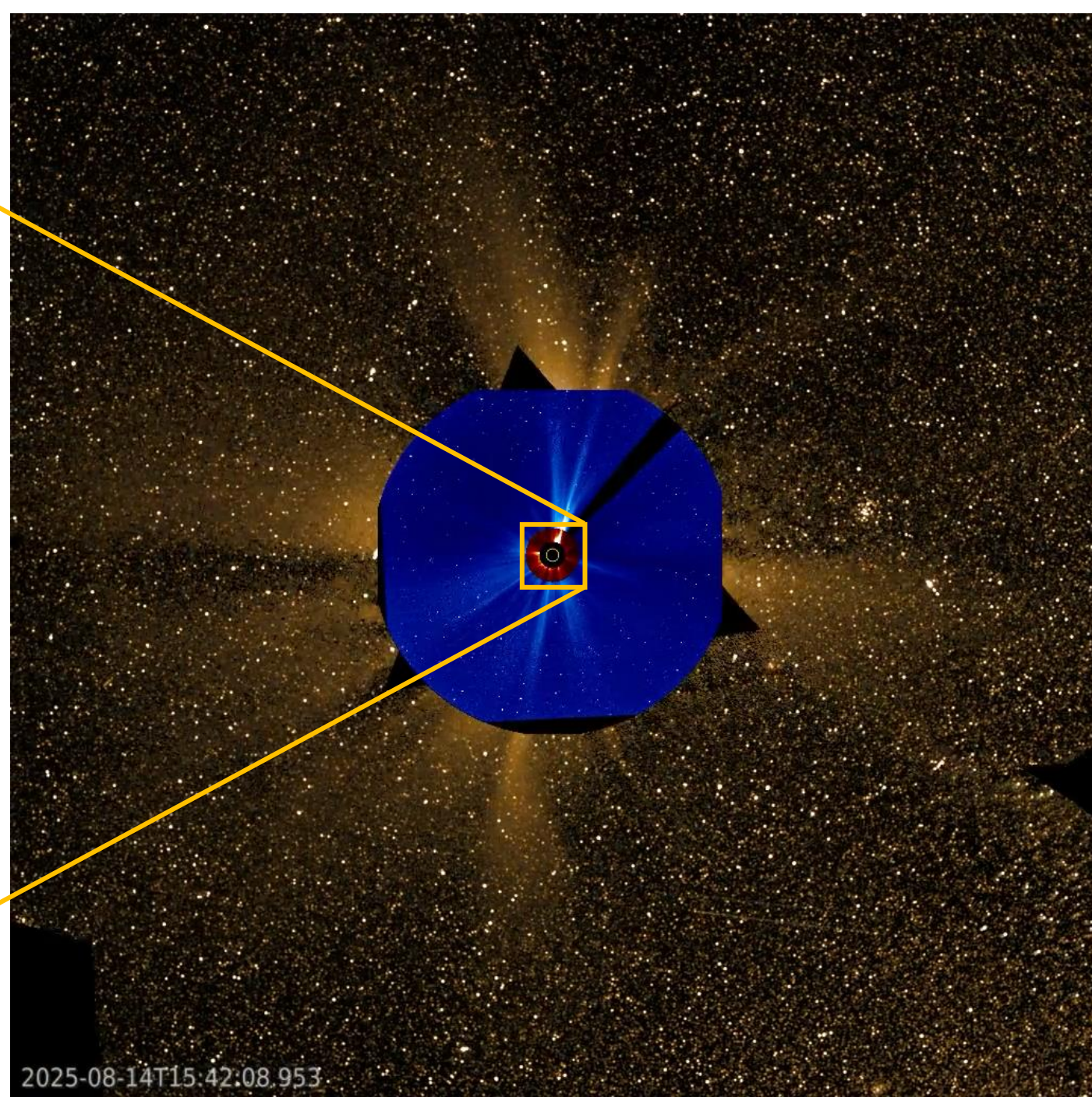
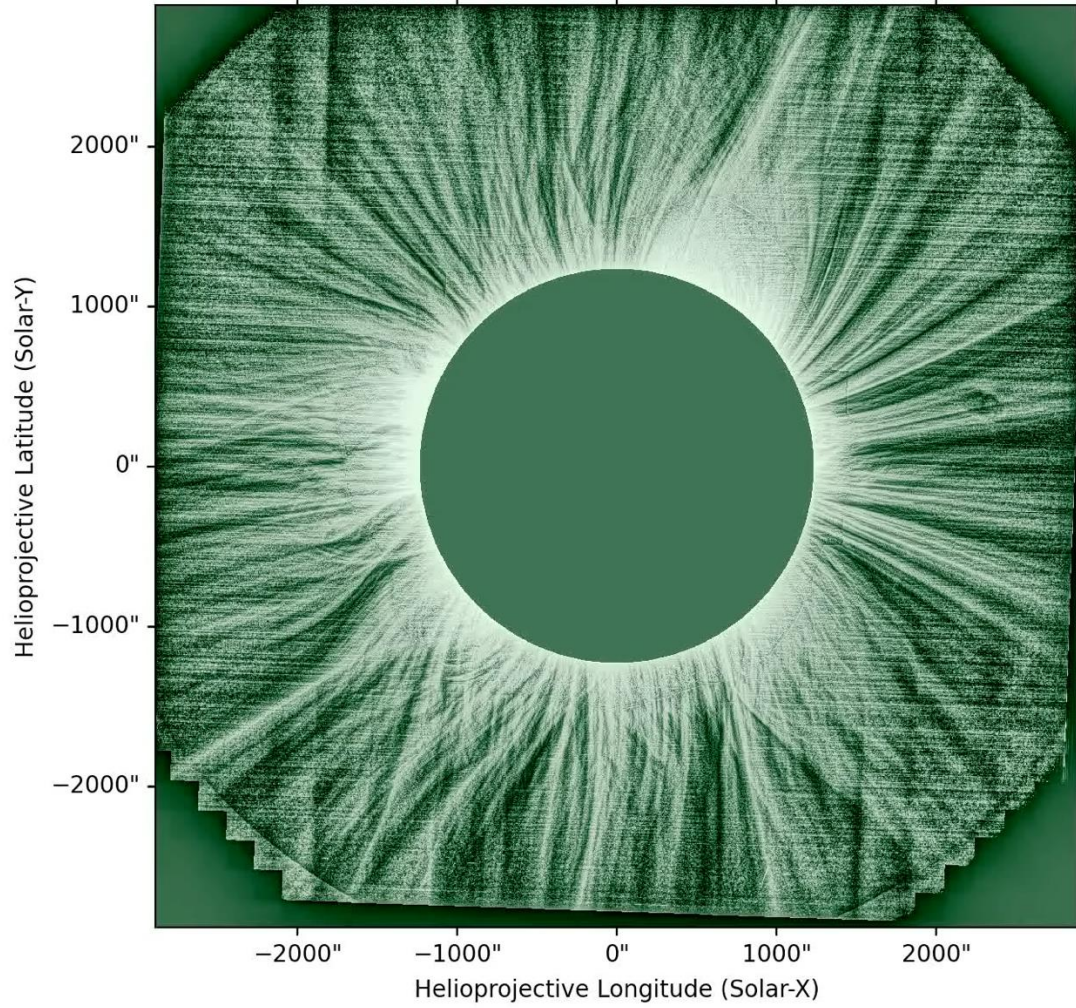


**VELC 5303**

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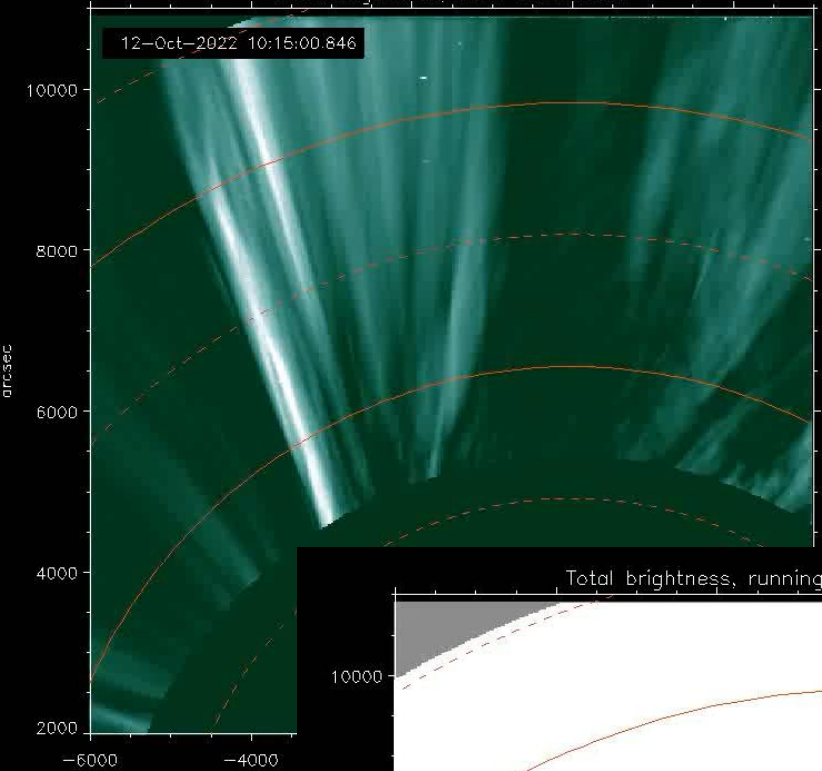
# Way forward .....

WOW-enhanced ASPIICS ( $r > 1.30 R_{\odot}$ )  
aspiics\_bt\_l3\_134080050002\_20250814T063312.fits

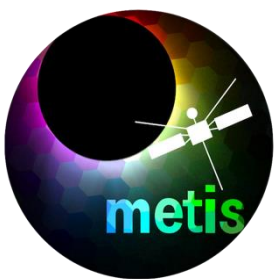
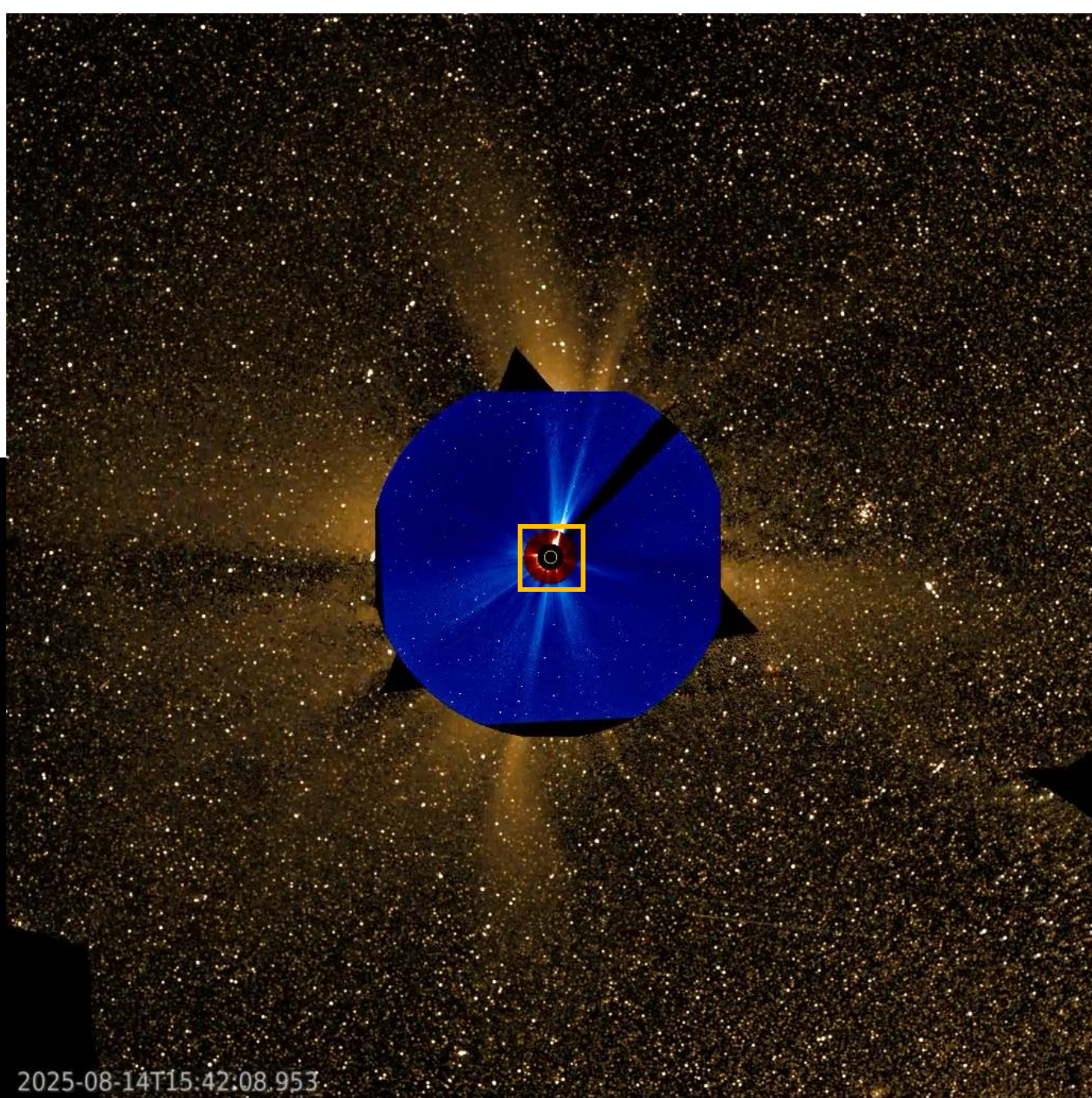
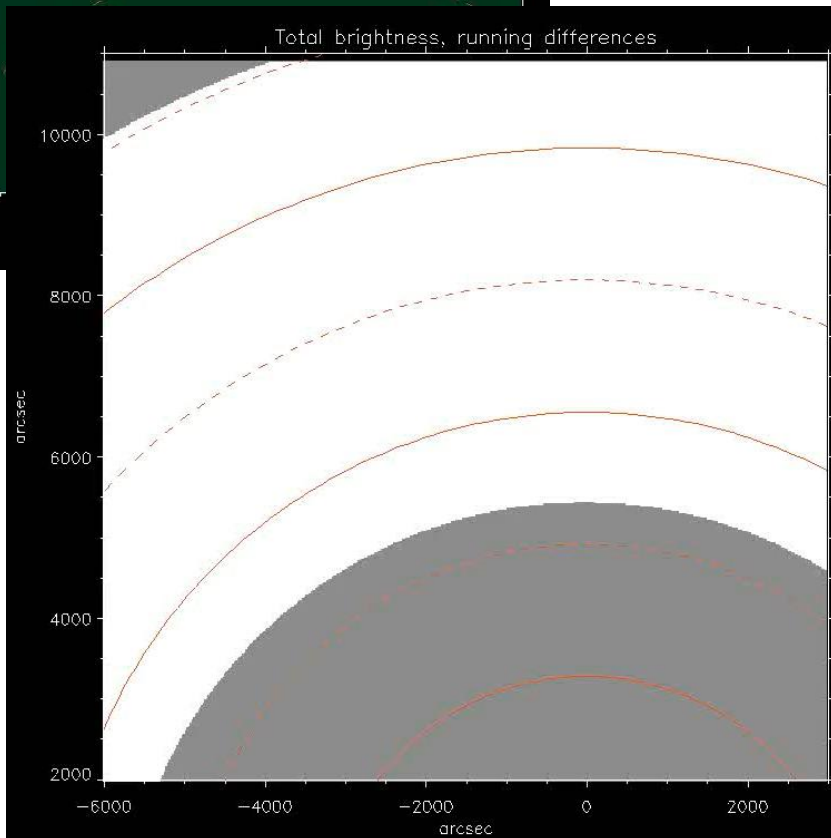


Credit: Arpit K. Shrivastav

Total brightness, base differences

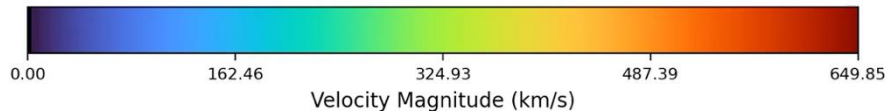
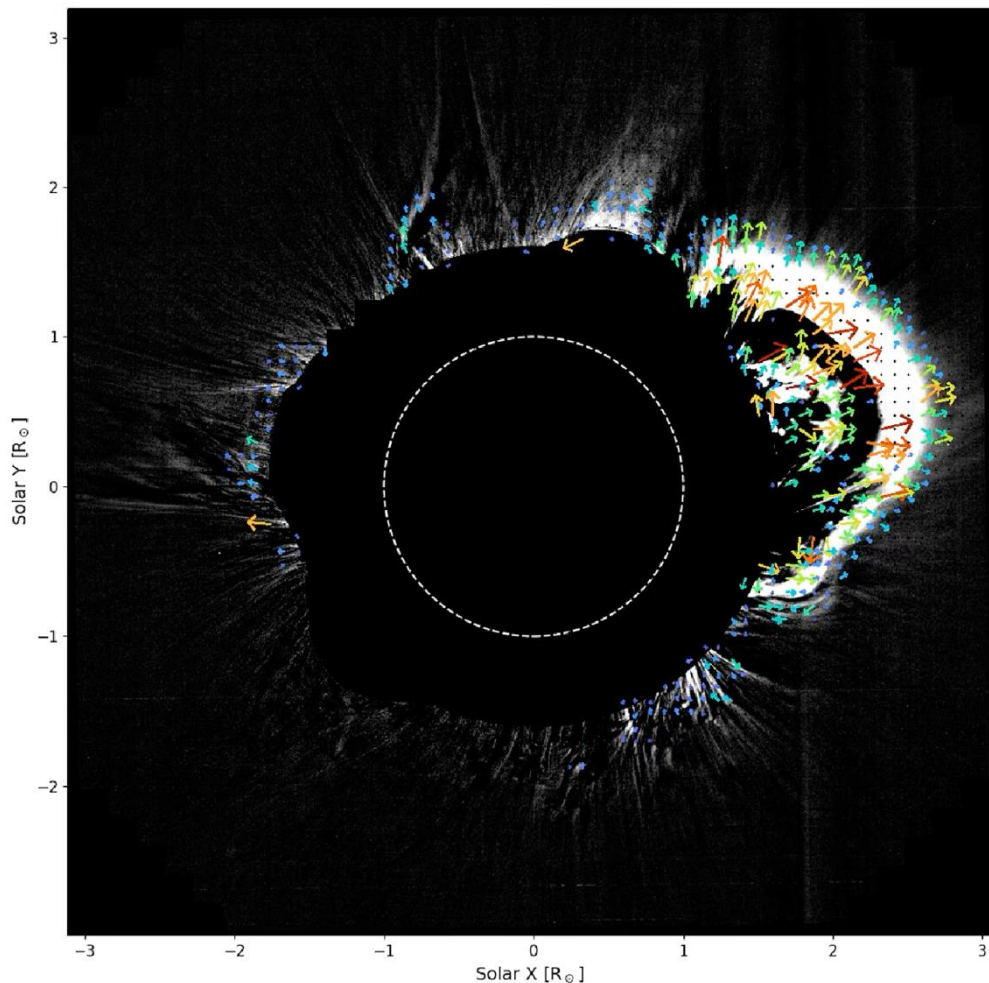


Total brightness, running differences

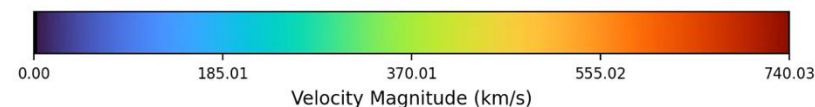
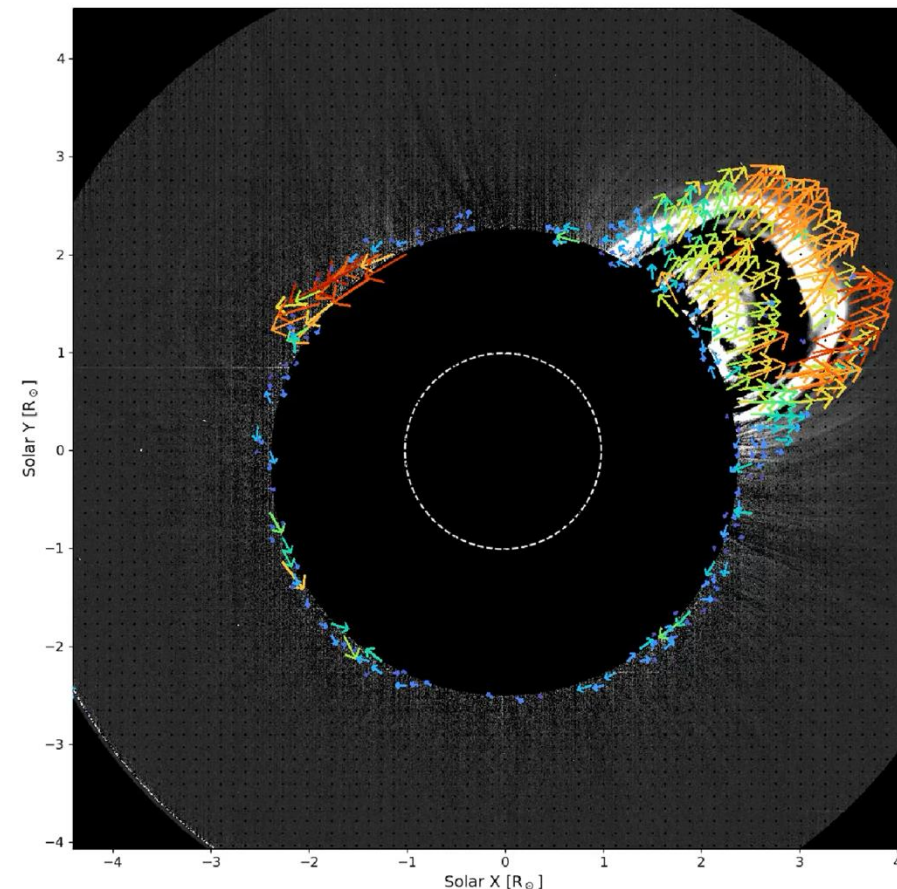


# Kinematics of flows and CMEs in the middle corona : Optical flow

PROBA3 WB Frame 0117  
2025-07-16 17:35:37 UT



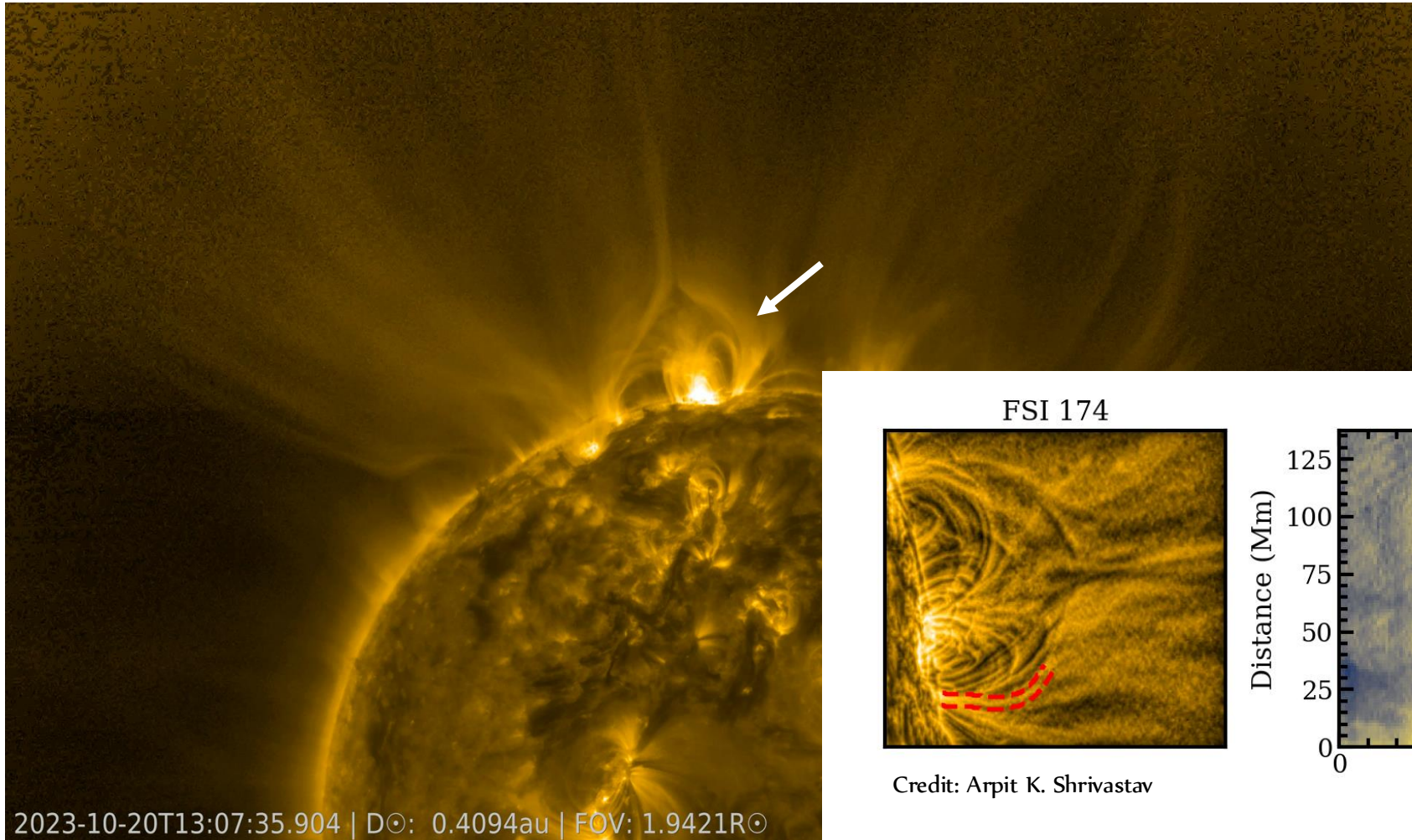
METIS TB Frame 0105  
2024-04-16 08:39:19 UT



- Optical flow is used to detect the bright outflows including CMEs.
- It can also be used to make flow maps of the middle corona.
- Can capture both outflows and inflows.

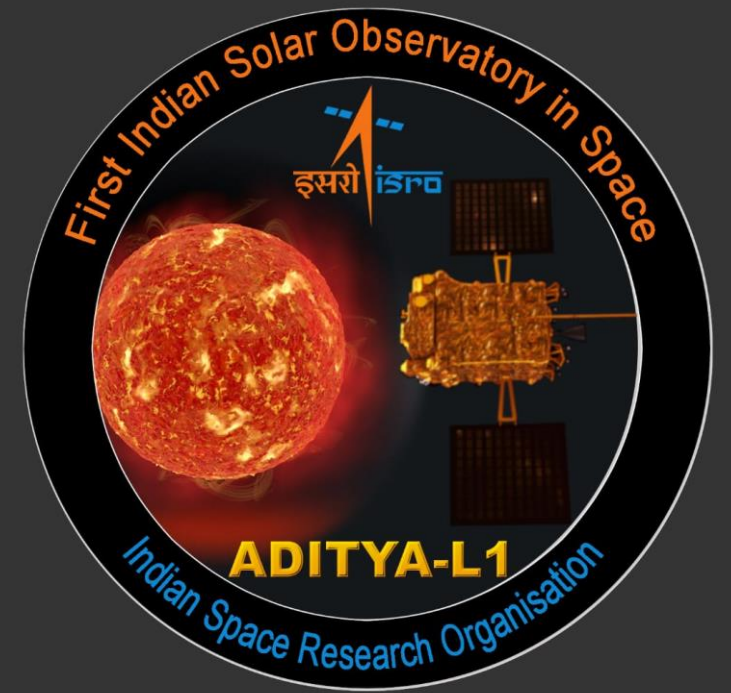
Das, Pant et al, 2026, in prep.

# Solar wind outflows connection



The interactions between open and closed fields can also be quantified by the convergence of open and closed fields over time, which can be captured by the time-distance diagrams

More on these outflows will be shown in talk by Arpit K Shrivastav soon...



**THANK YOU!**



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