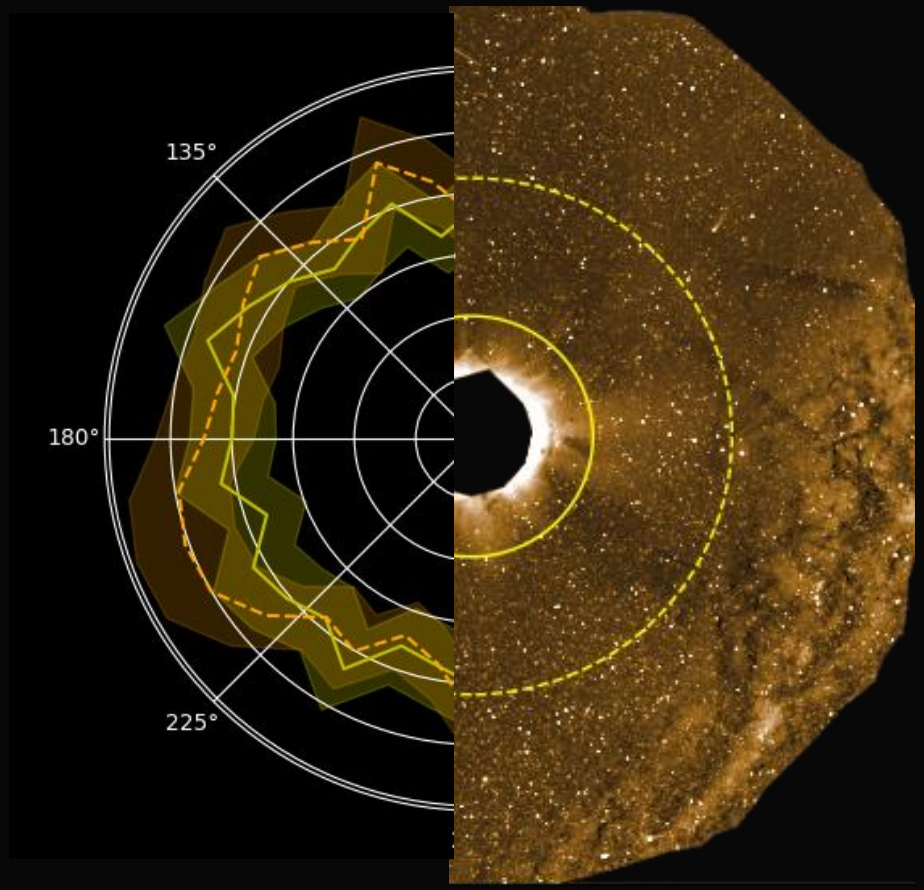
First Interplanetary Solar Wind Flow Maps series from PUNCH



Raphael Attié, Valmir Moraes Filho, Nicholeen Viall, Barbara J Thompson, Vadim Uritsky, Craig DeForest, Marcus Hughes, Chris Lowder, Heather Elliott, Maher Dayeh, Sarah Gibson, Chadi S Salem, Curt de Koning, Evangelia Samara

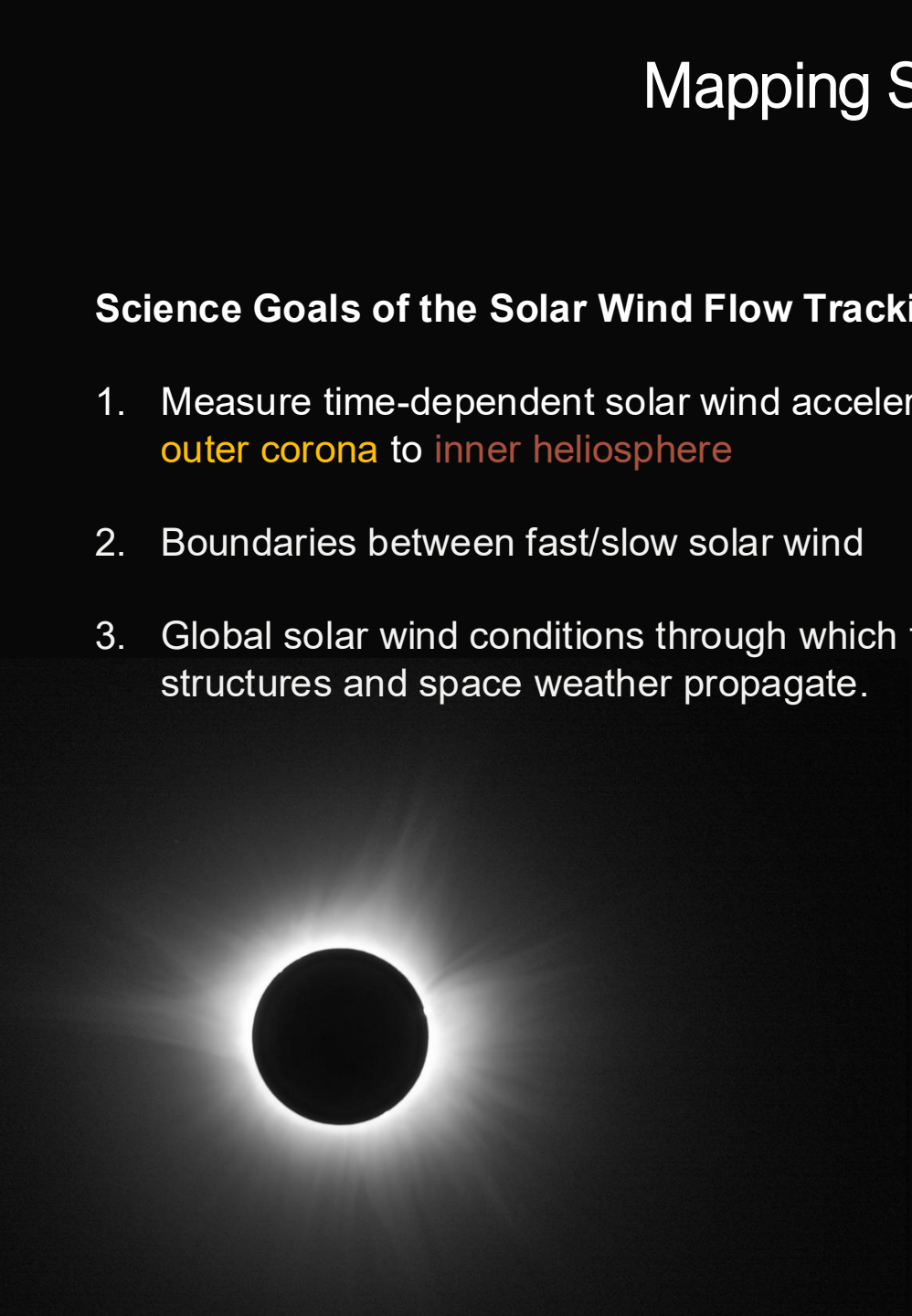
Raphael Attié. PhD
Research Assistant Professor
Lead of PUNCH WG-1A (Ambiant Solar Wind)
NASA GSFC [671] / George Mason University
rattie@gmu.edu

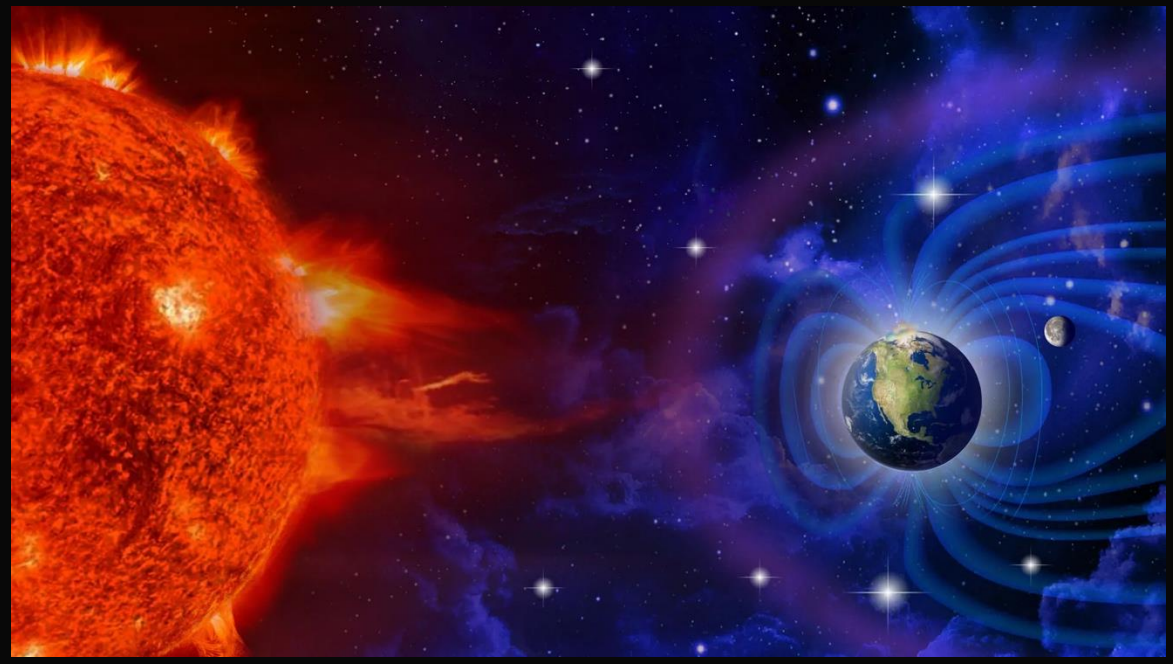
PUNCH 7, Boulder, CO – May 12, 2026

Mapping Solar Wind Flows: Why?

Science Goals of the Solar Wind Flow Tracking WG-1A

1. Measure time-dependent solar wind acceleration from outer corona to inner heliosphere
2. Boundaries between fast/slow solar wind
3. Global solar wind conditions through which transient structures and space weather propagate.



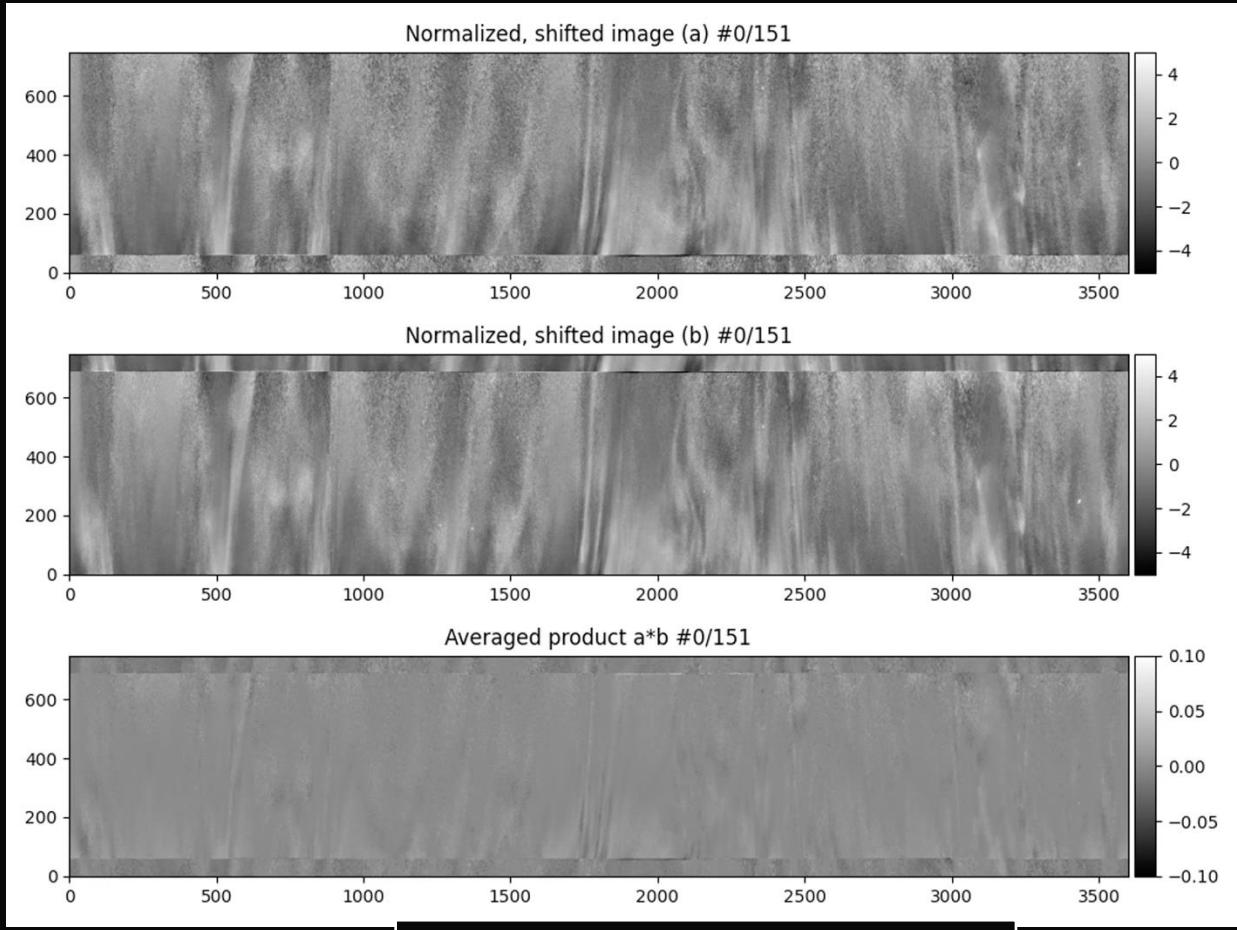


Space Weather:

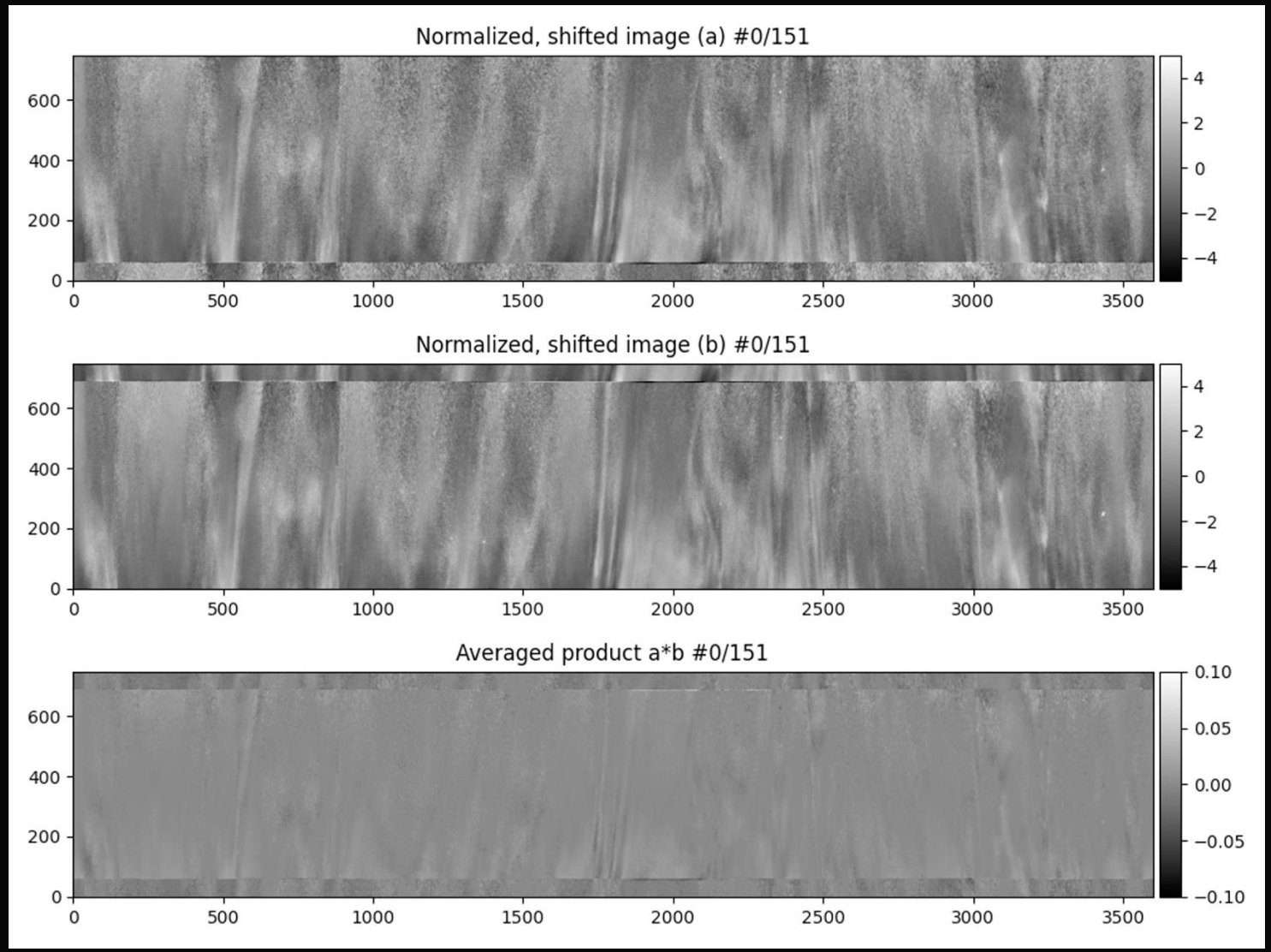
PUNCH flow maps→ data assimilation to improve prediction model

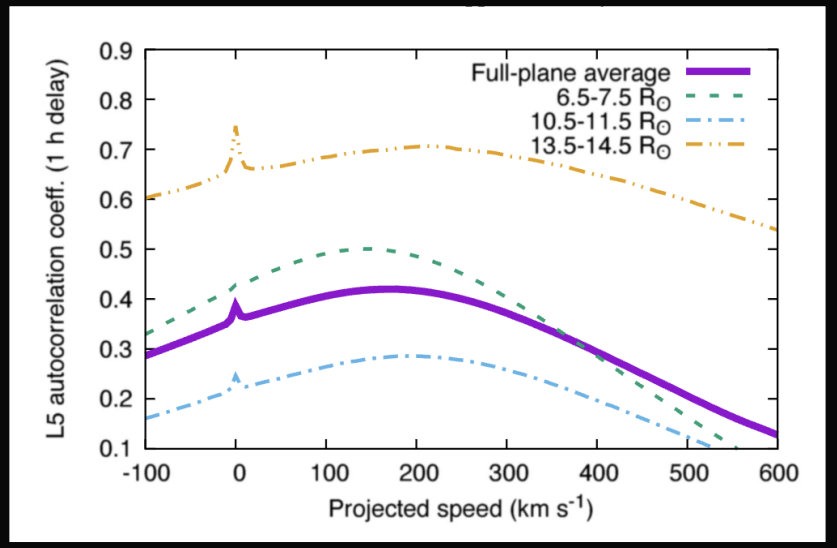
Mapping Solar Wind Flows: How?

Method 1: “Radial” correlation tracking (delivered @ PUNCH SOC)



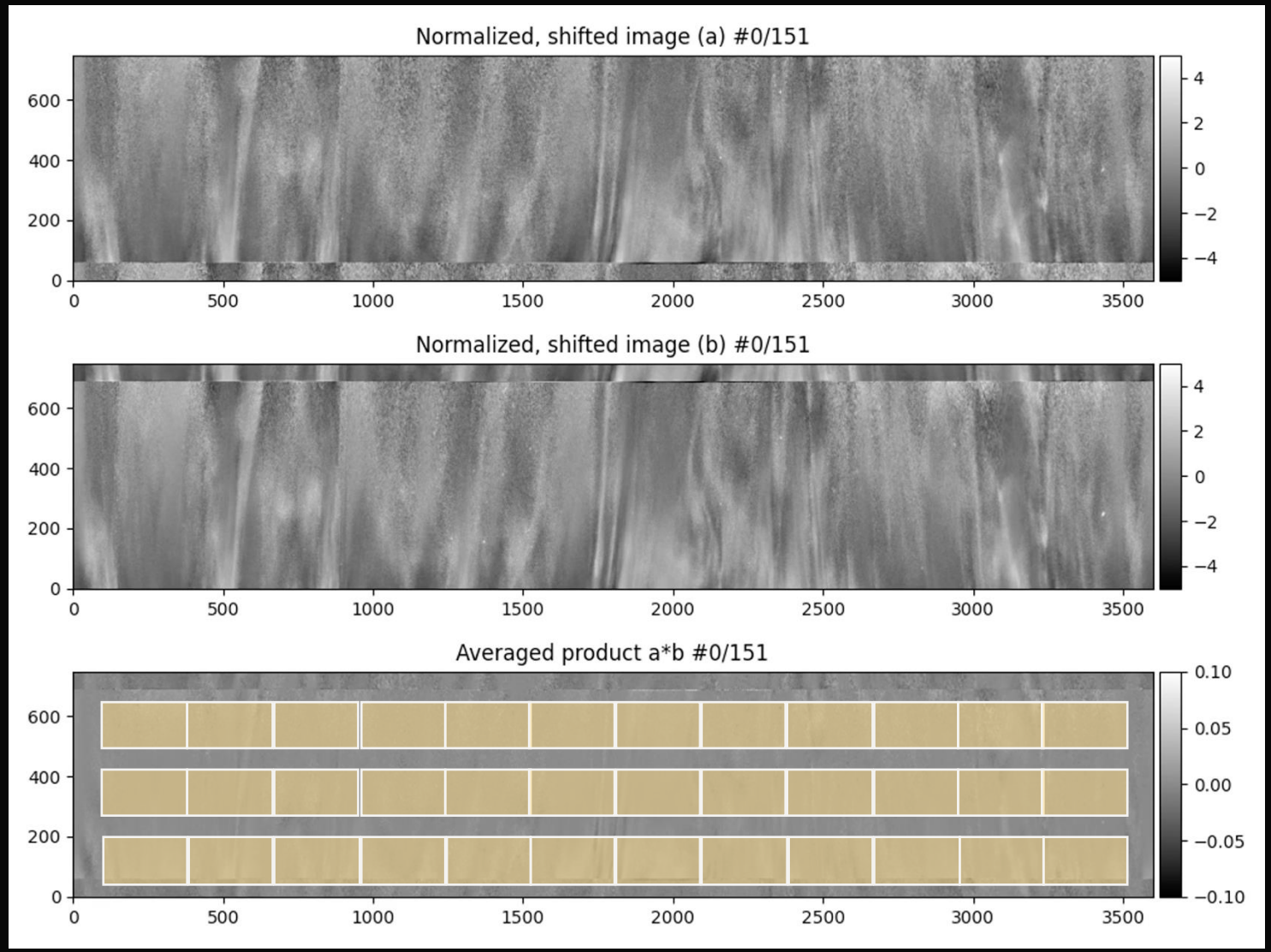
Method 1: “Radial” correlation tracking
(delivered @ PUNCH SOC)

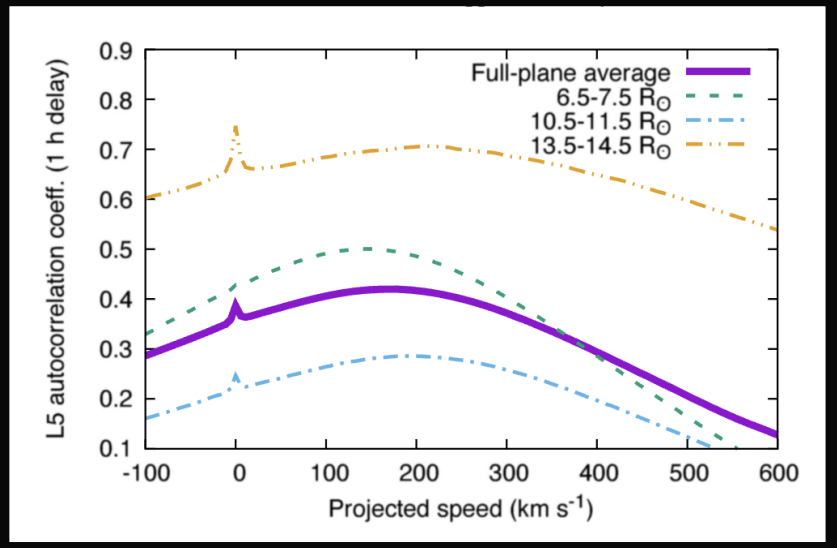




Initial method (Deforest et al. 2018) applied ”globally”, averaged over the entire FOV of STEREO/COR2 to give one number of the wind speed averaged over 3 days

Method 1: “Radial” correlation tracking
(delivered @ PUNCH SOC)



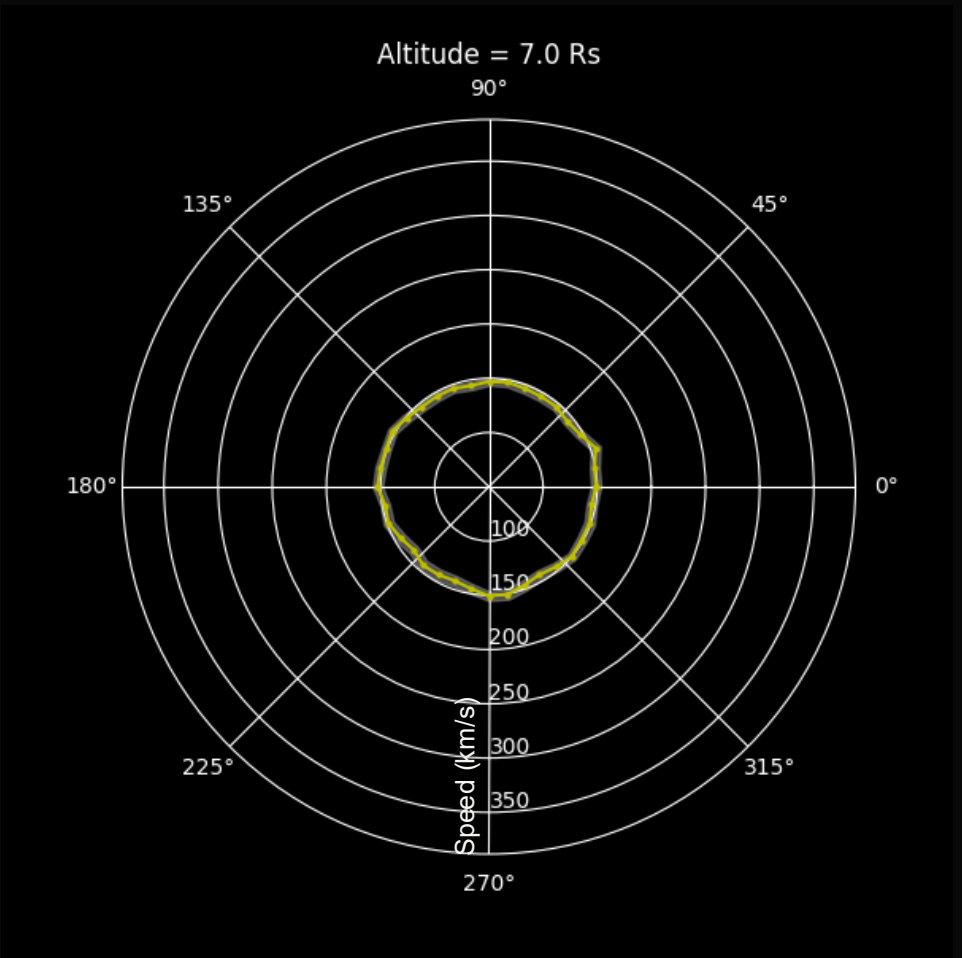


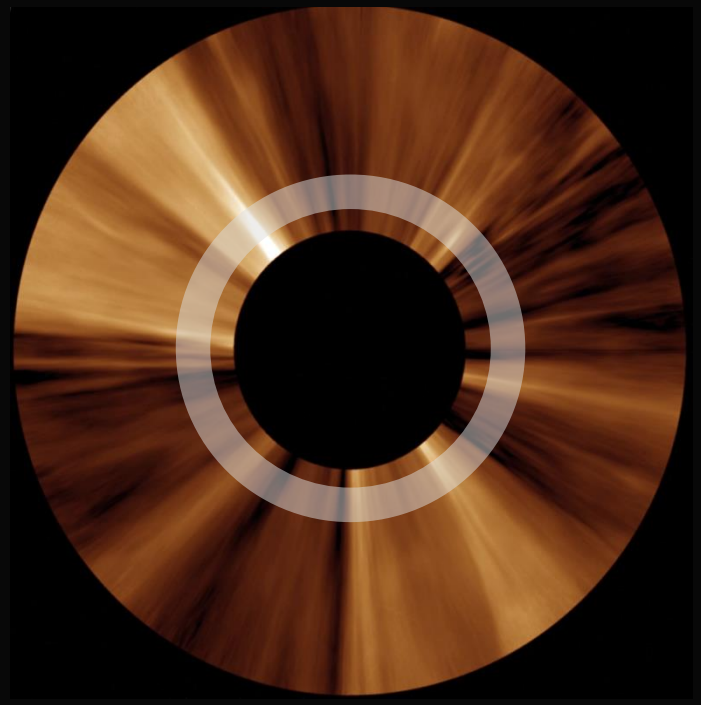
Initial method (Deforest et al. 2018) applied ”globally”, averaged over the entire FOV of STEREO/COR2 to give one number of the wind speed averaged over 3 days

For PUNCH: more granular version over smaller bins and multiple annuli

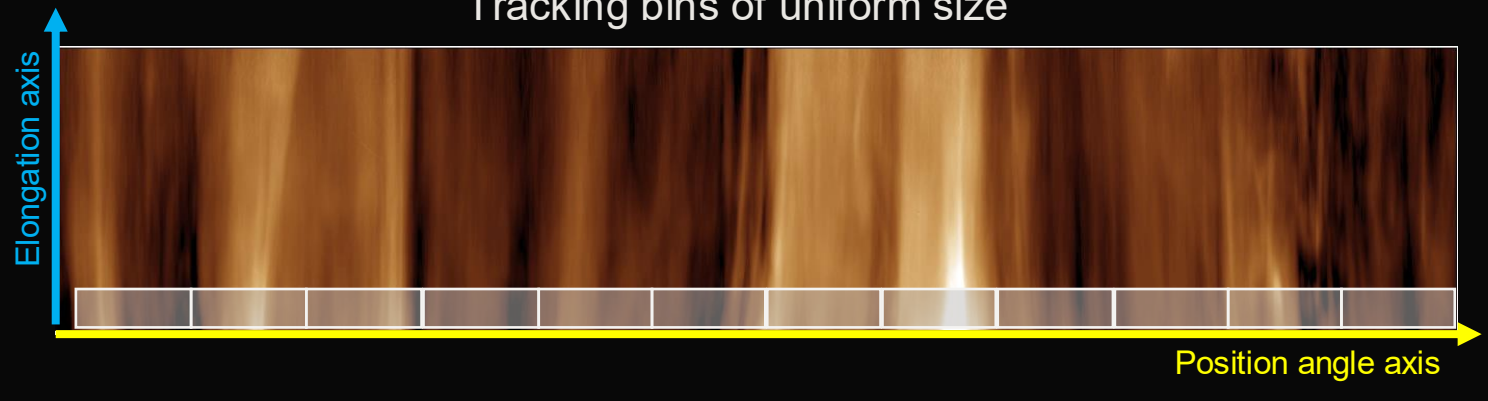
Mapping Solar Wind Flows: How?

Method 1: Radial correlation tracking



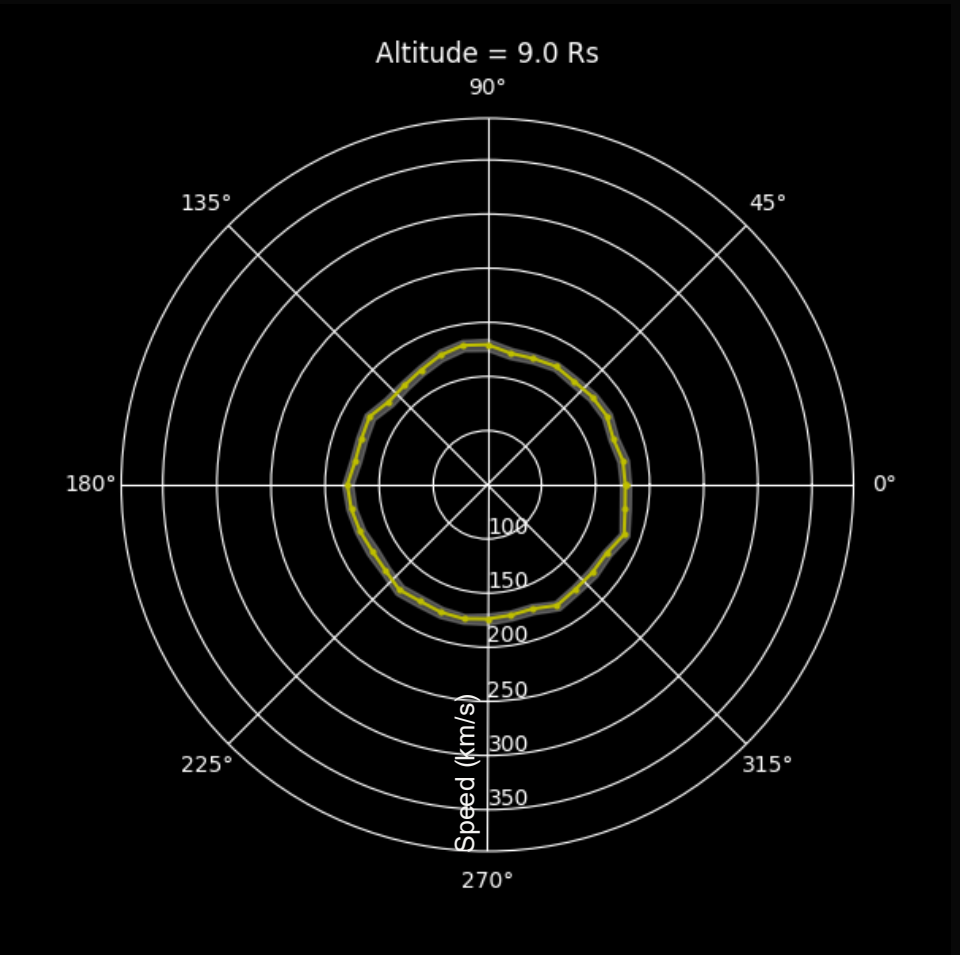


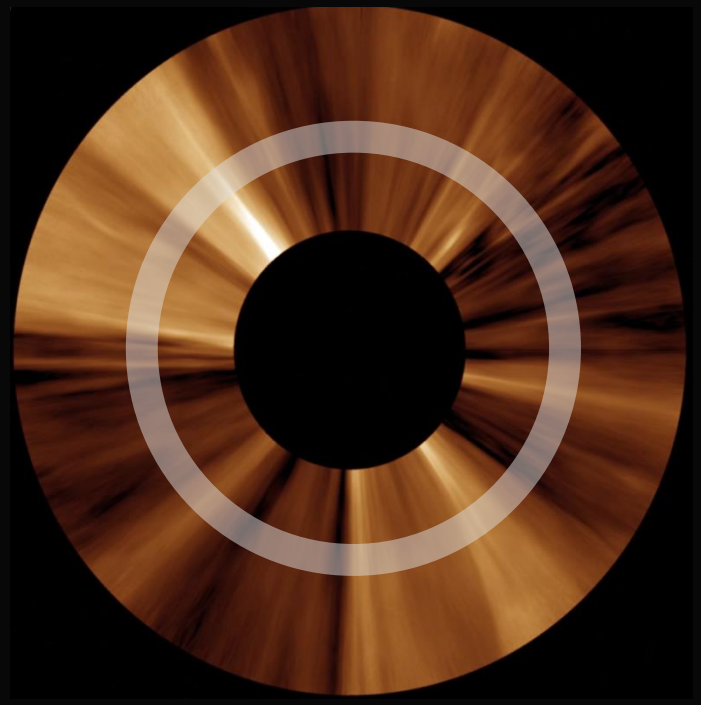
Tracking bins of uniform size



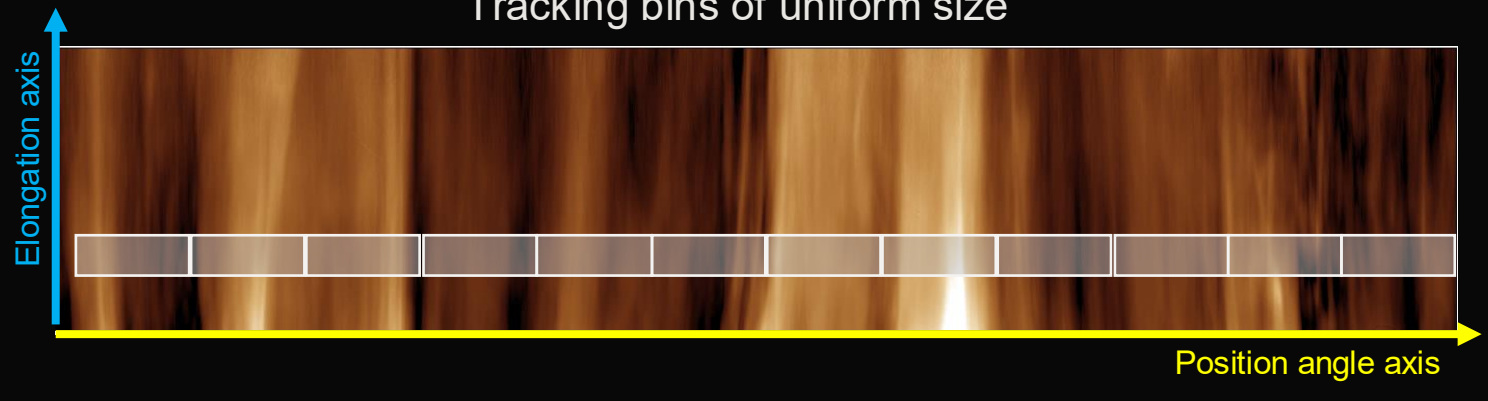
Mapping Solar Wind Flows: How?

Method 1: Radial correlation tracking



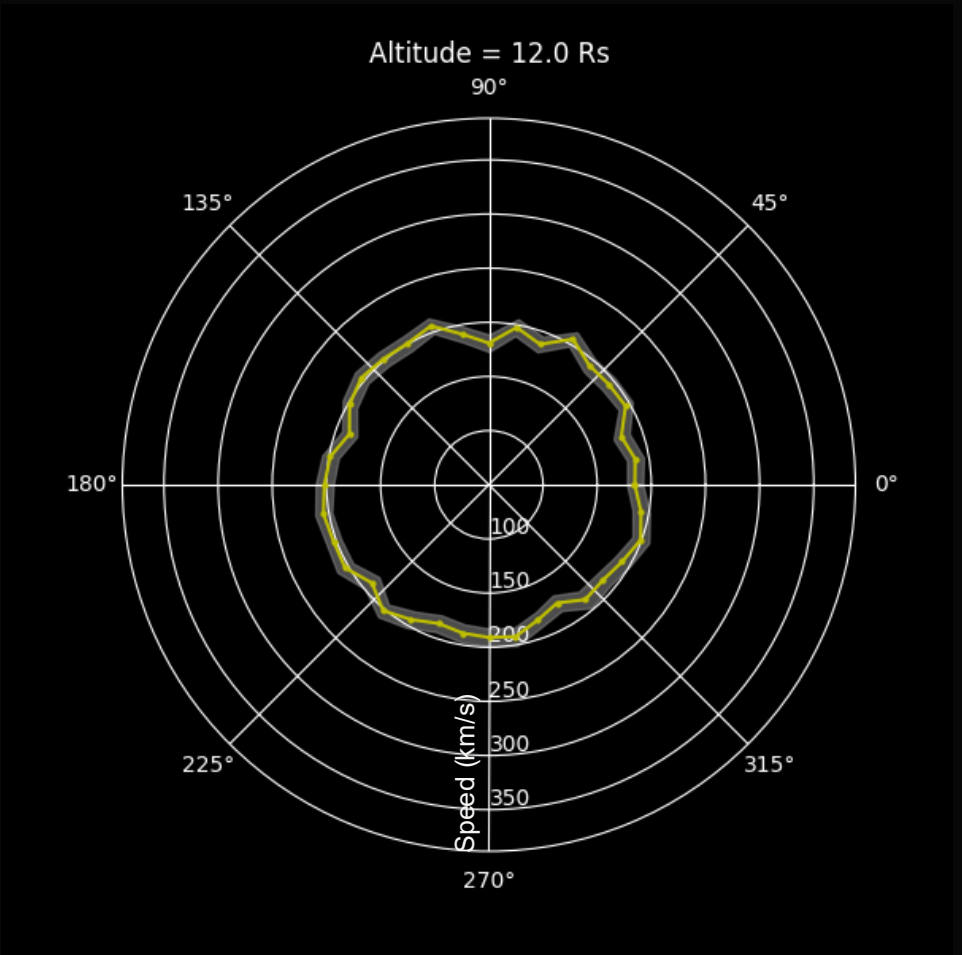


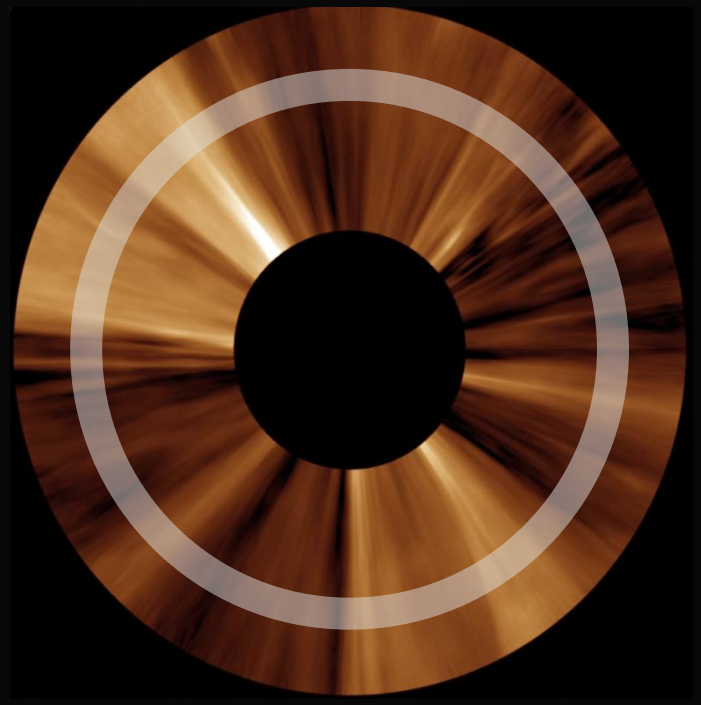
Tracking bins of uniform size

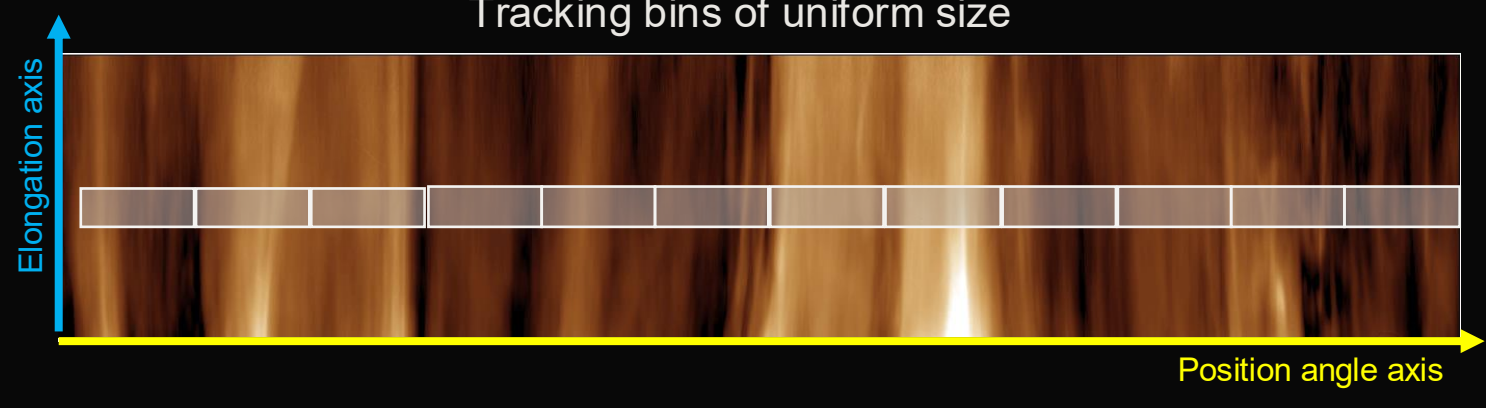


Mapping Solar Wind Flows: How?

Method 1: Radial correlation tracking

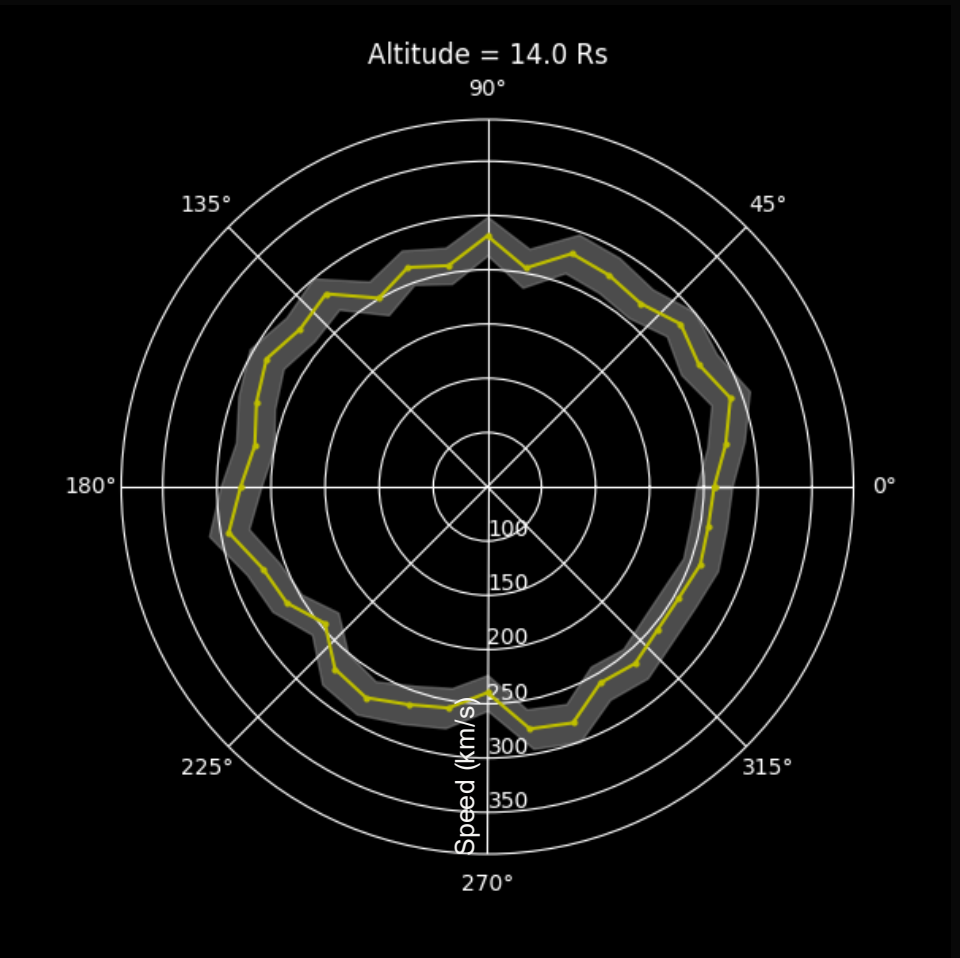


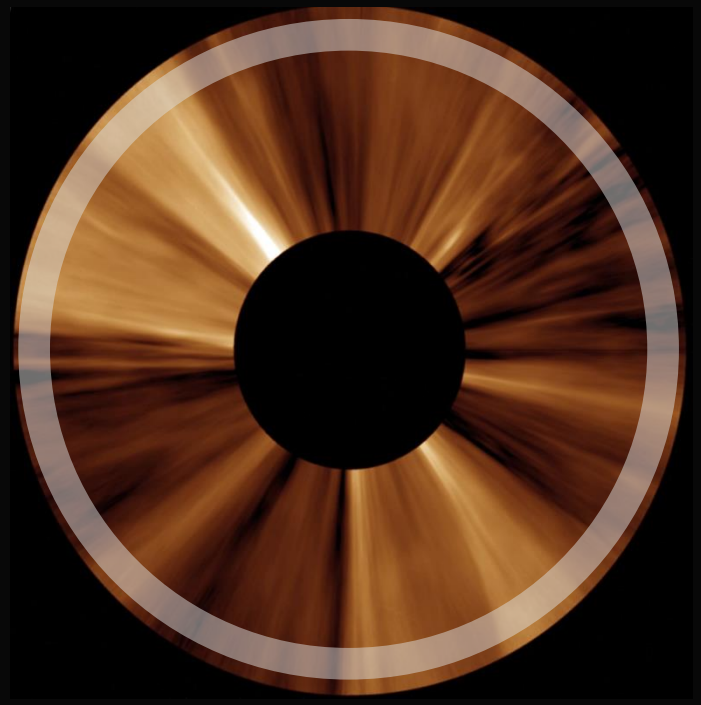


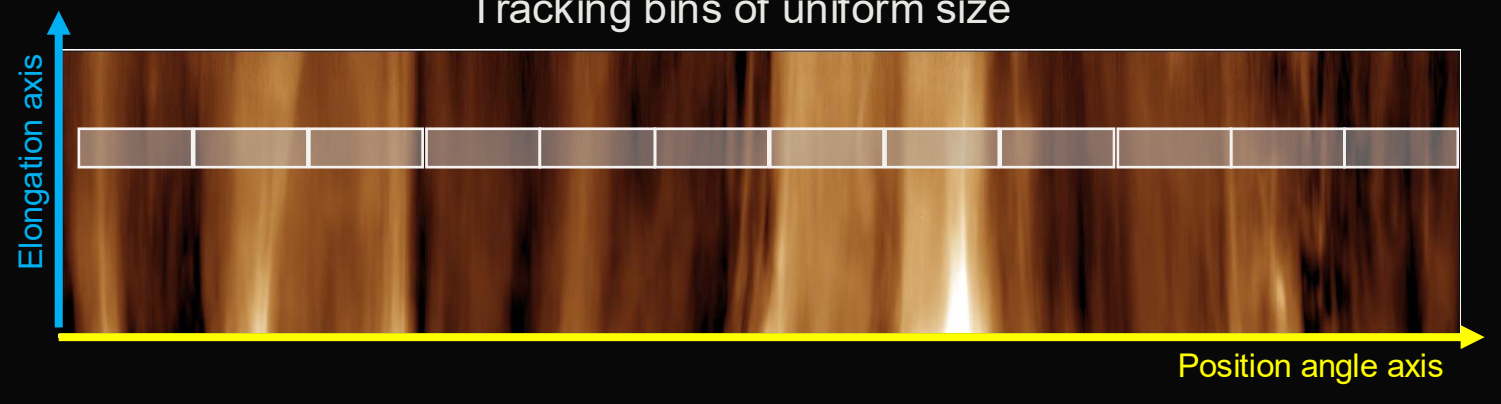


Mapping Solar Wind Flows: How?

Method 1: Radial correlation tracking

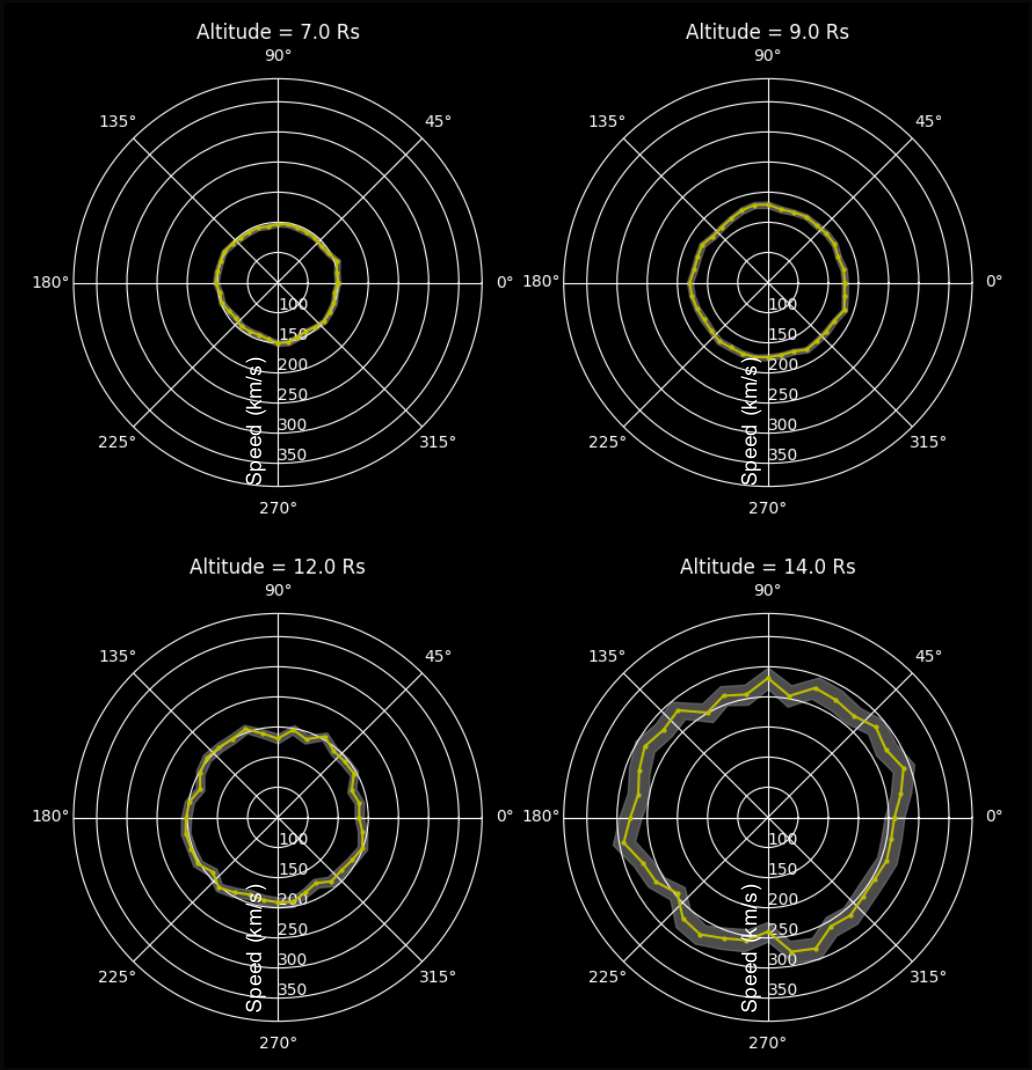


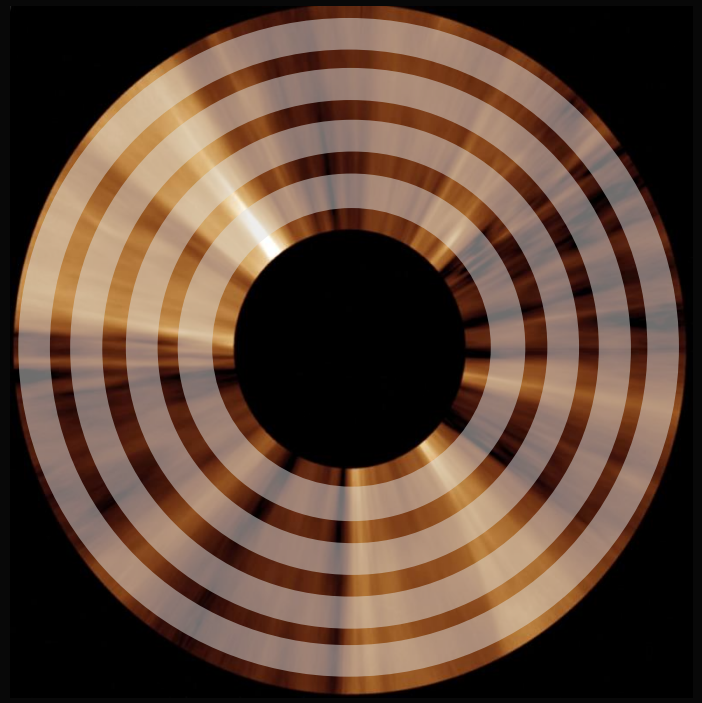




Mapping Solar Wind Flows: How?

Method 1: Radial correlation tracking

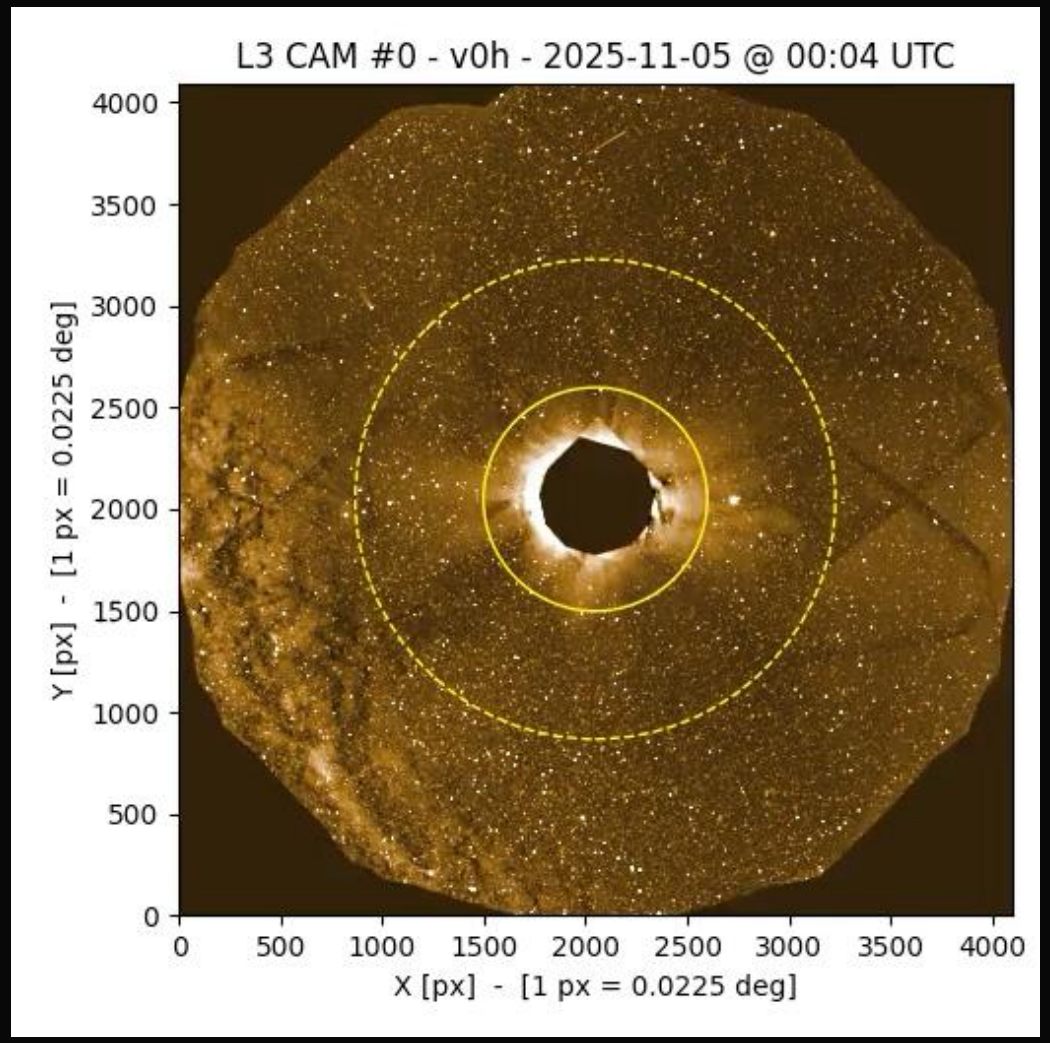


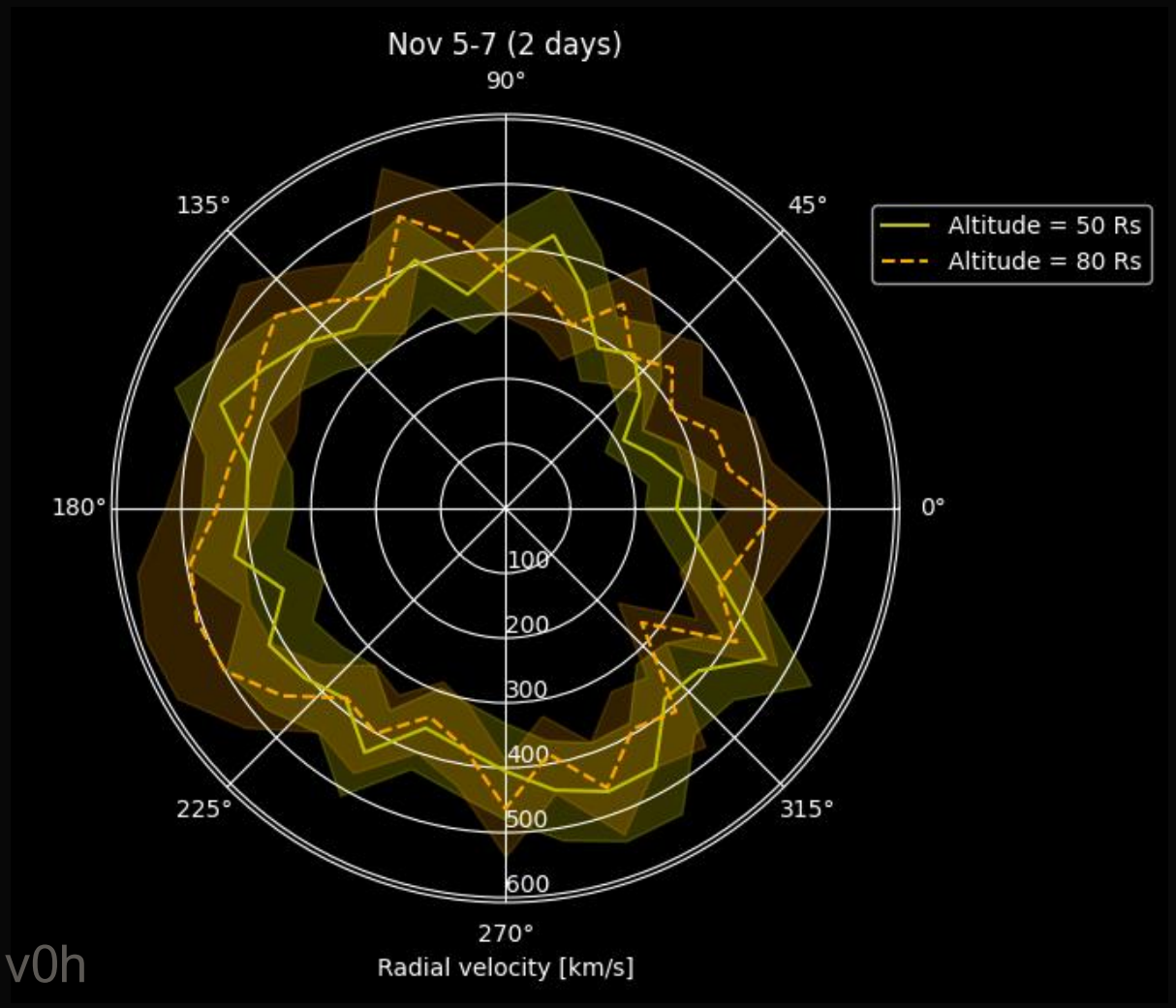


PUNCH radial flow data product:

- Every 6 hours
- At least 4 radial bins between 6 to 80 solar radii.

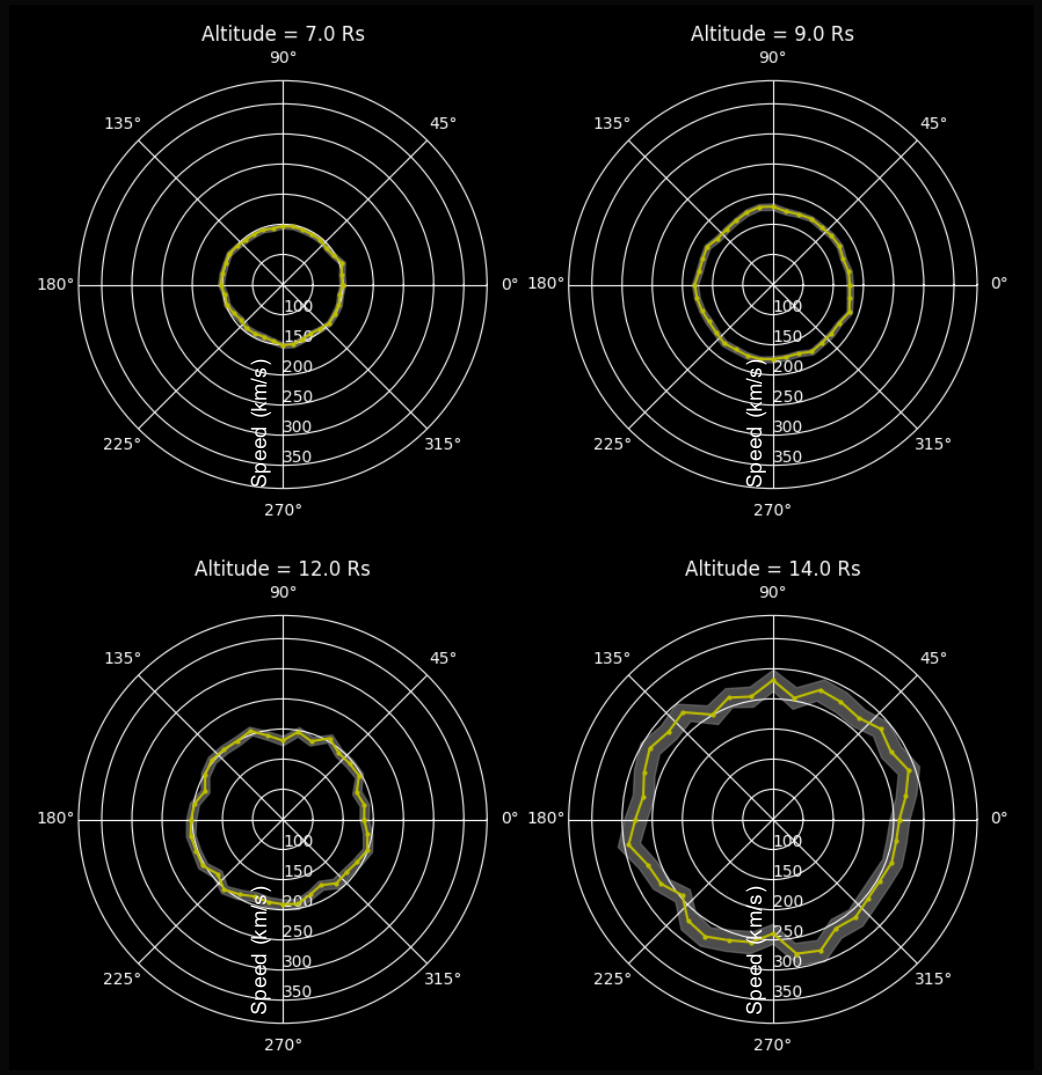
Mapping Solar Wind Flows: -> 80 Rs

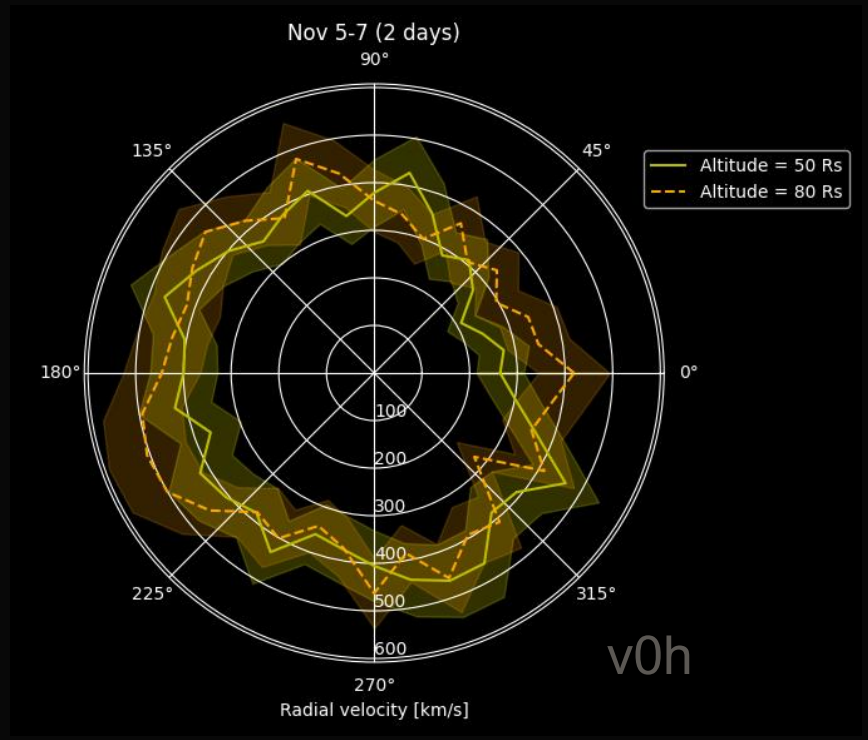




Mapping Solar Wind Flows: How?

Method 1: Radial correlation tracking





PUNCH radial flow data product:

- Every 6 hours
- At least 4 radial bins between 6 to 80 solar radii.

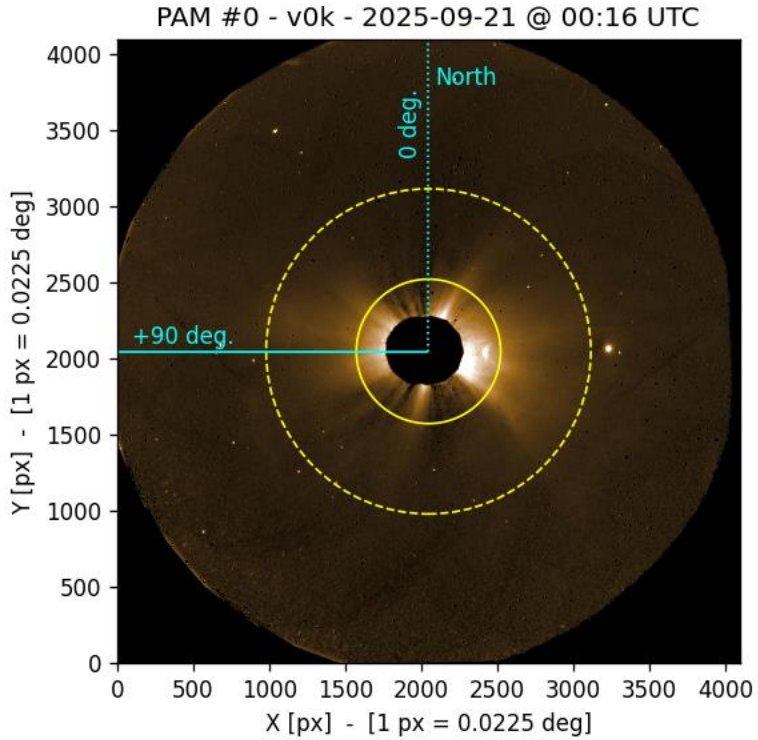
Algorithm very efficient for large-scale radial speed and accelerations, delivered by PUNCH Science Operation Center (SOC),

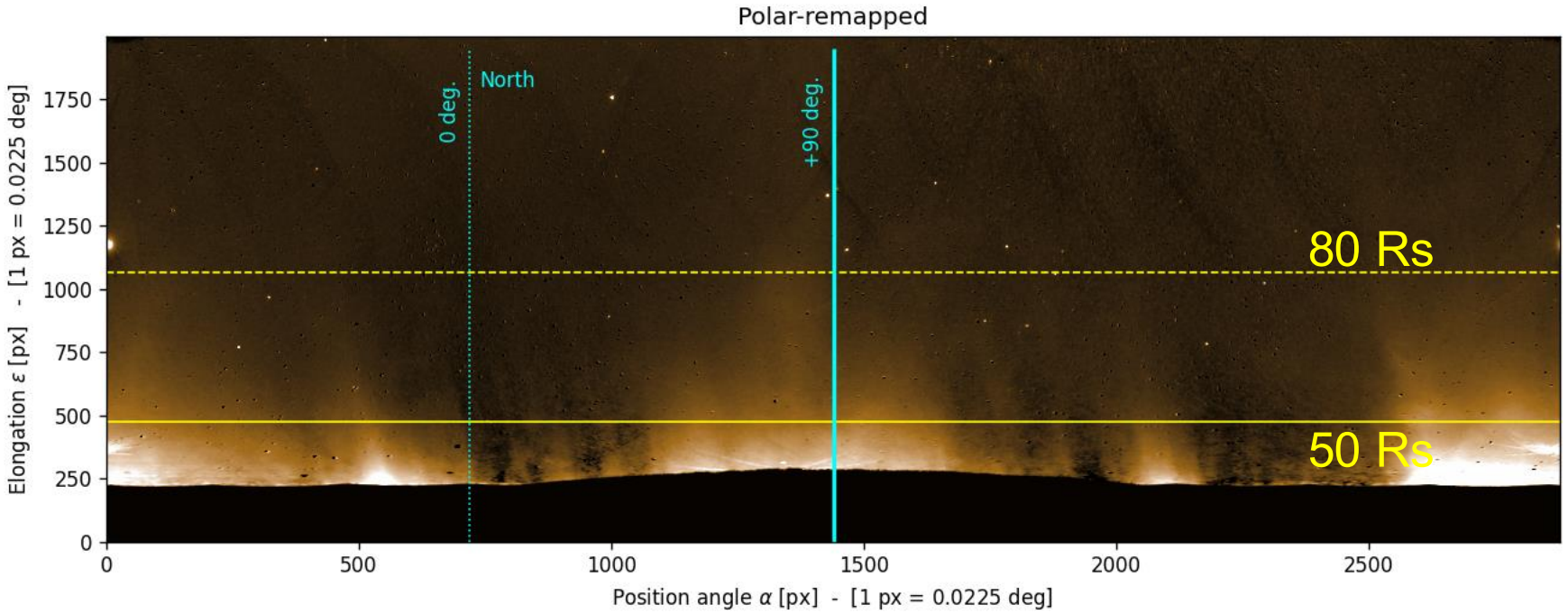
Caveats:

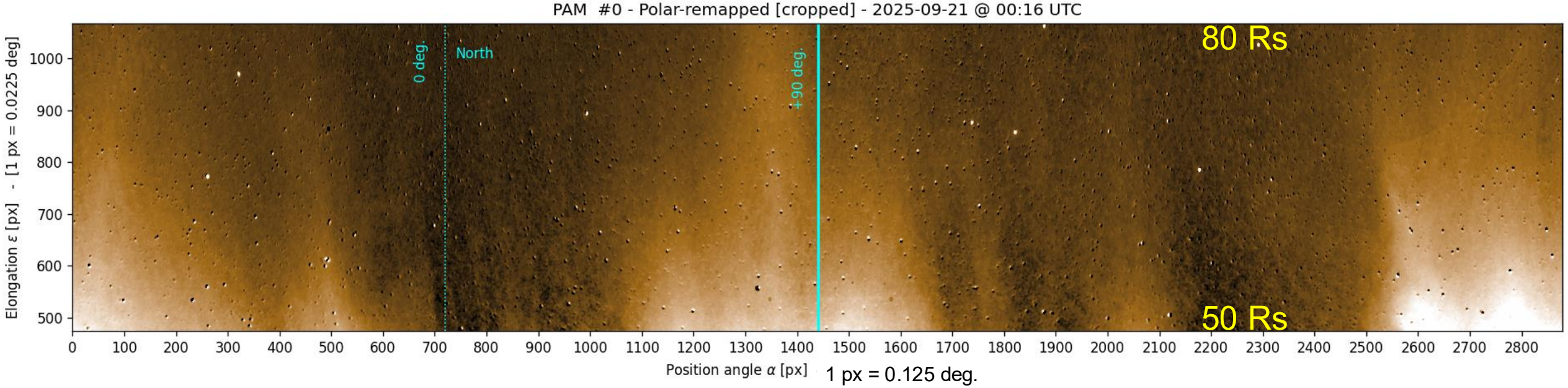
- Wind speed measured only over elongation, not strictly radial speed.
- No information about any deviation over the position angle axis
- large-scale, no access to finer mesoscale structures

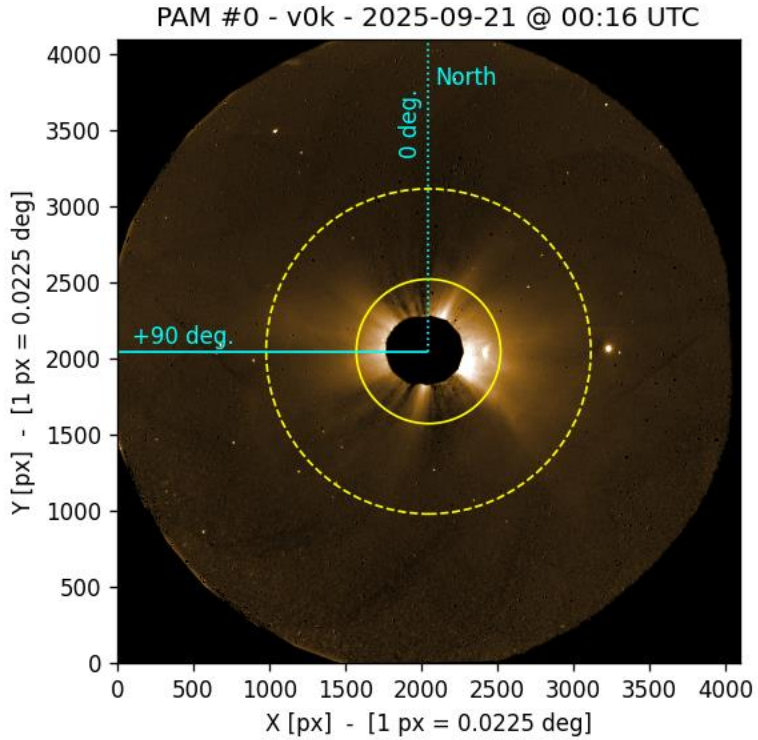
Tracking the Solar Wind with PUNCH:

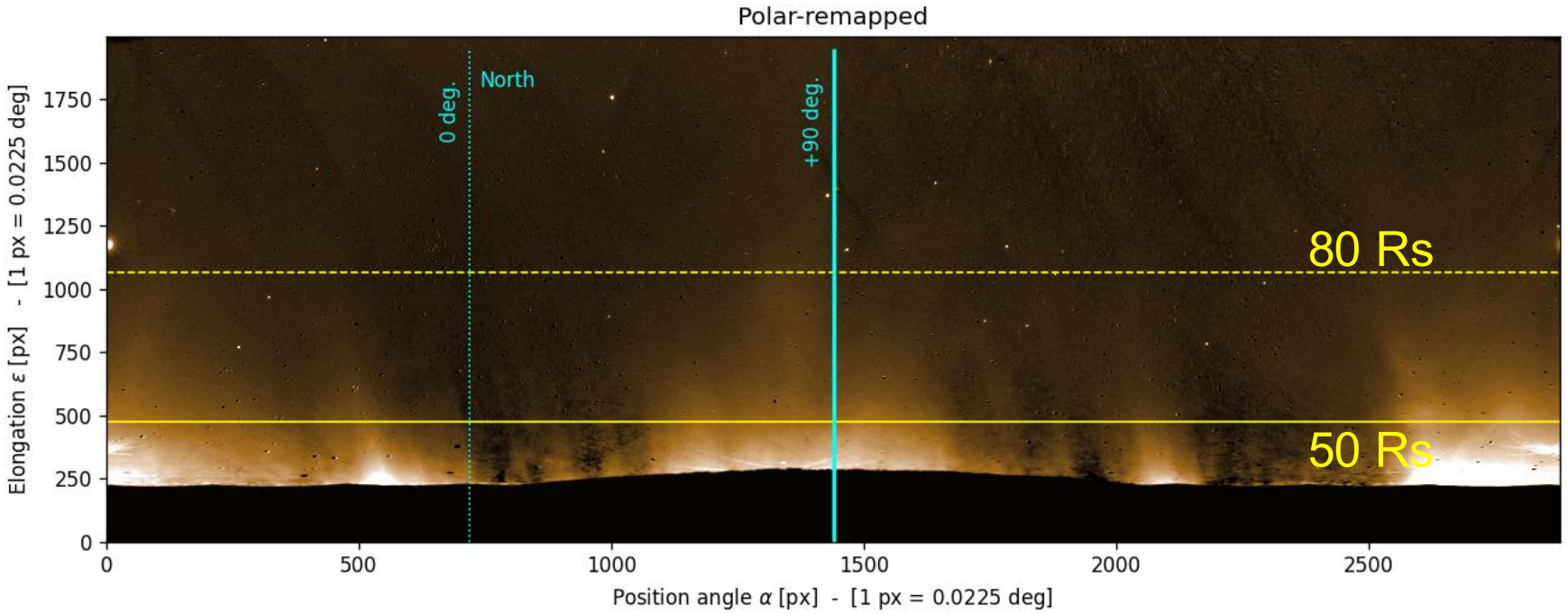
A flow of caveats

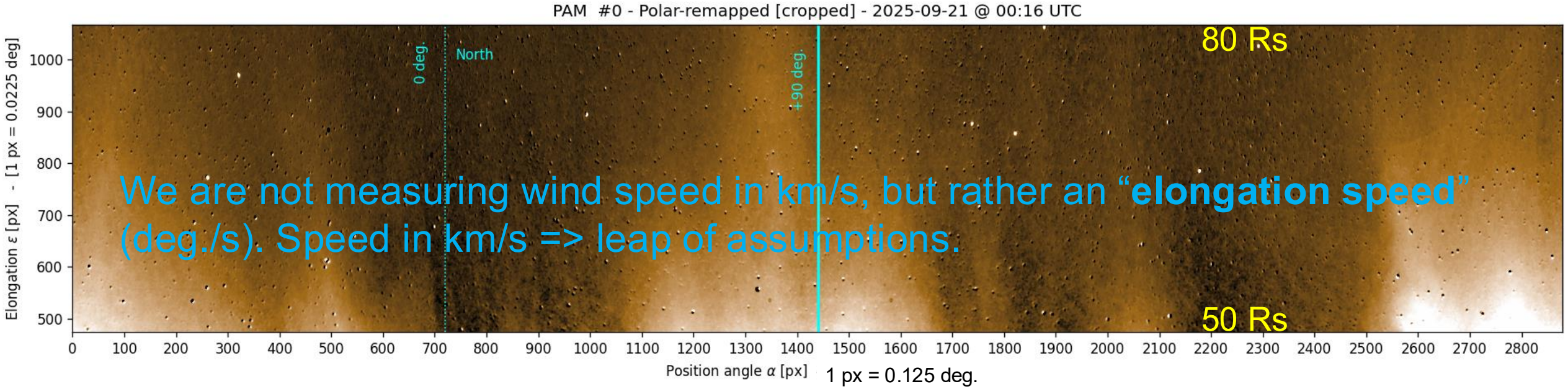

PAM #0 - v0k - 2025-09-21 @ 00:16 UTC
North
0 deg.
+90 deg.
Y [px] - [1 px = 0.0225 deg]
X [px] - [1 px = 0.0225 deg]

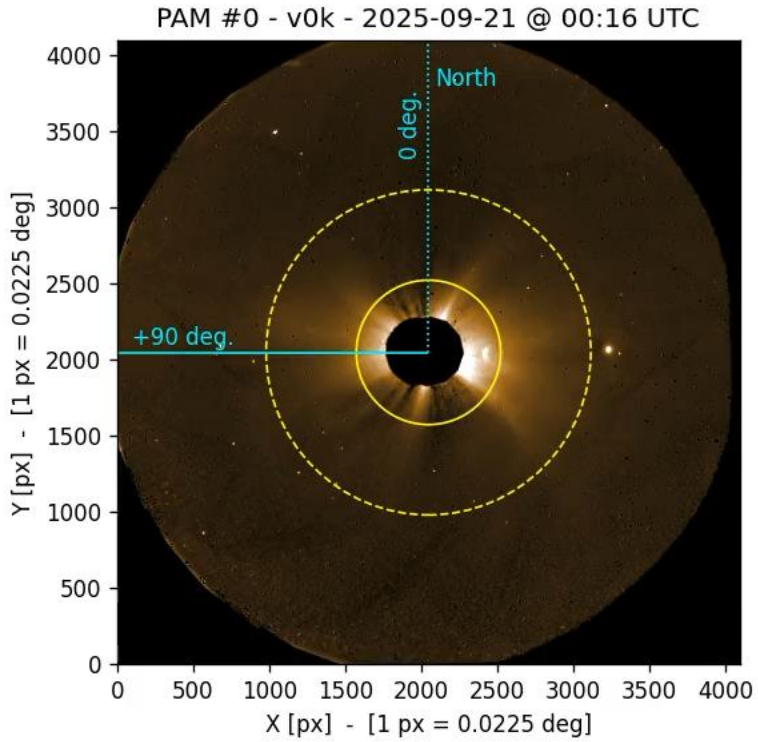

Polar-remapped
North
0 deg.
+90 deg.
80 Rs
50 Rs
Elongation ε [px] - [1 px = 0.0225 deg]
Position angle α [px] - [1 px = 0.0225 deg]

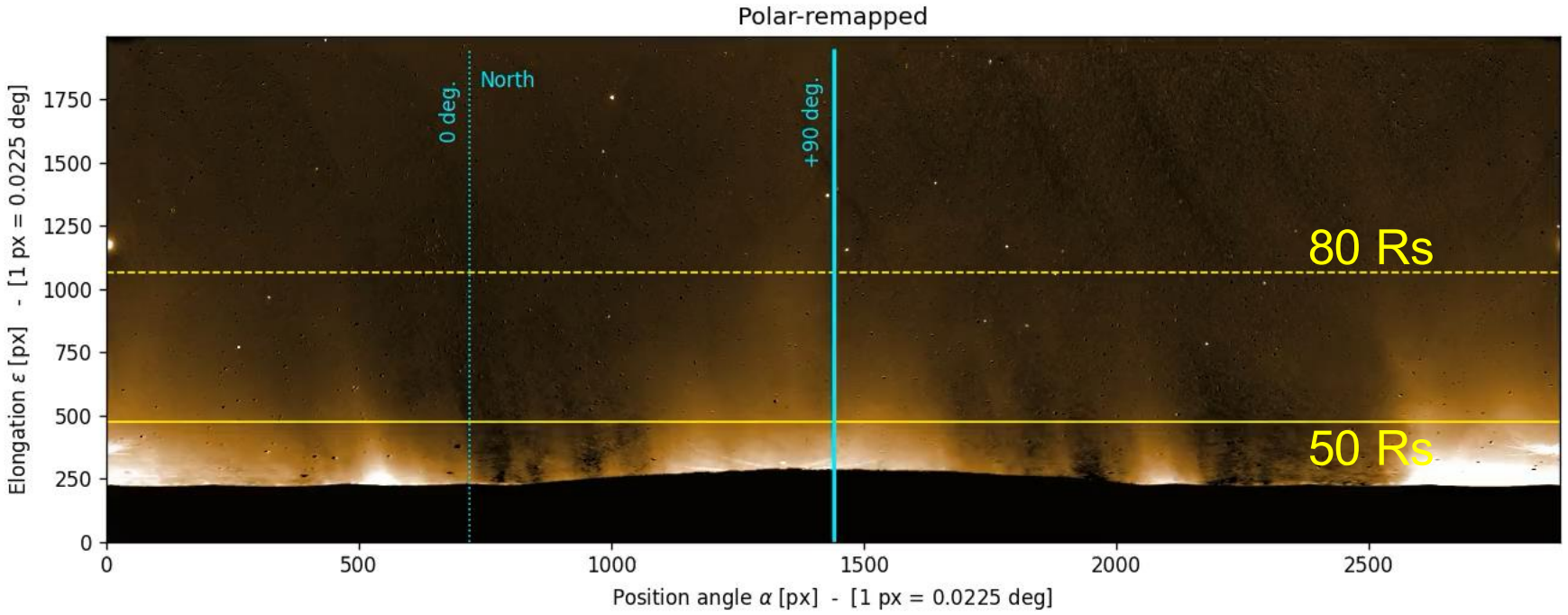

PAM #0 - Polar-remapped [cropped] - 2025-09-21 @ 00:16 UTC
North
0 deg.
+90 deg.
80 Rs
50 Rs
Elongation ε [px] - [1 px = 0.0225 deg]
Position angle α [px]
1 px = 0.125 deg.

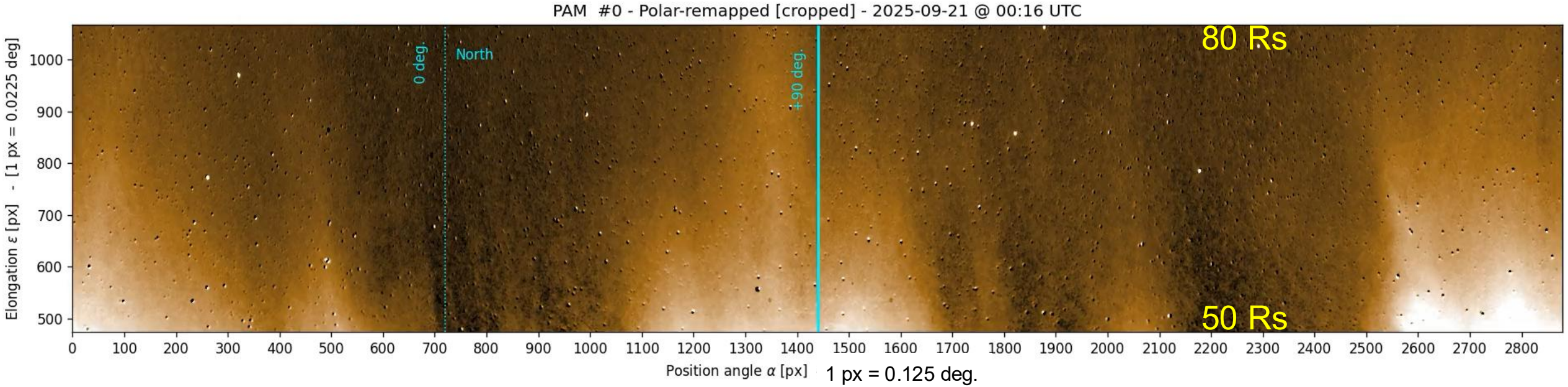

PAM #0 - v0k - 2025-09-21 @ 00:16 UTC
North
0 deg.
+90 deg.
Y [px] - [1 px = 0.0225 deg]
X [px] - [1 px = 0.0225 deg]

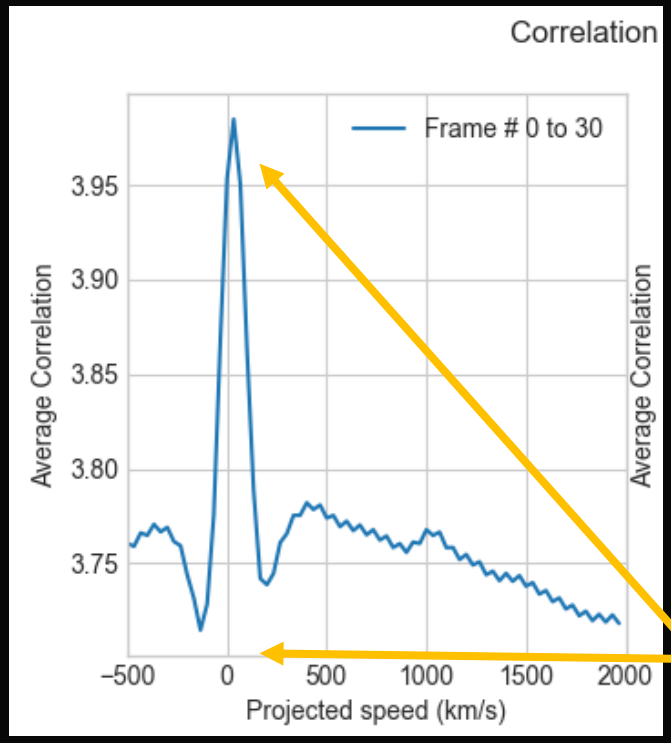

Polar-remapped
North
0 deg.
+90 deg.
80 Rs
50 Rs
Elongation ε [px] - [1 px = 0.0225 deg]
Position angle α [px] - [1 px = 0.0225 deg]


PAM #0 - Polar-remapped [cropped] - 2025-09-21 @ 00:16 UTC
North
0 deg.
+90 deg.
80 Rs
50 Rs
We are not measuring wind speed in km/s, but rather an "elongation speed" (deg./s). Speed in km/s => leap of assumptions.
Elongation ε [px] - [1 px = 0.0225 deg]
Position angle α [px]
1 px = 0.125 deg.

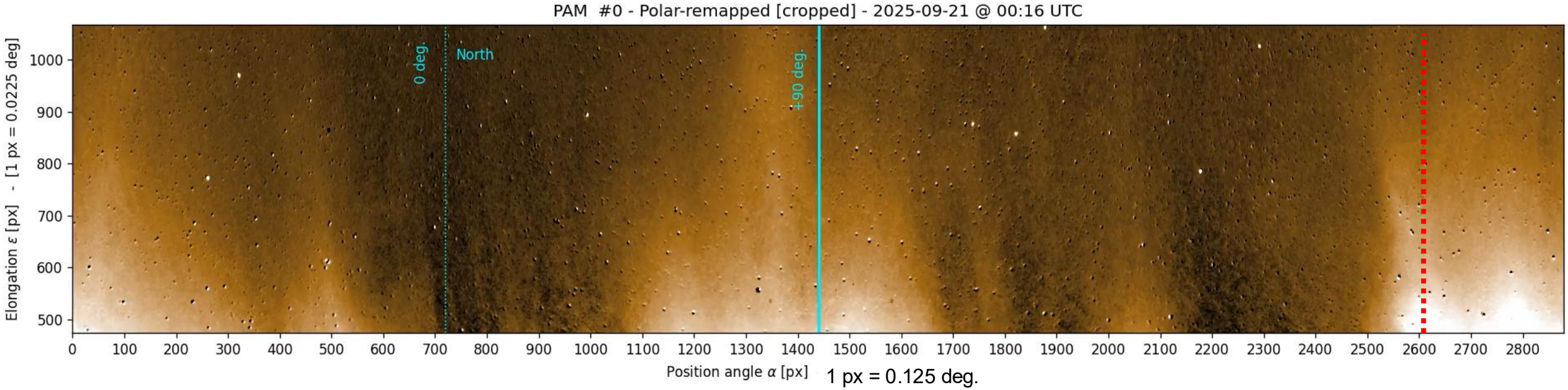

PAM #0 - v0k - 2025-09-21 @ 00:16 UTC
North
0 deg.
+90 deg.
Y [px] - [1 px = 0.0225 deg]
X [px] - [1 px = 0.0225 deg]


Polar-remapped
North
0 deg.
+90 deg.
80 Rs
50 Rs
Elongation ε [px] - [1 px = 0.0225 deg]
Position angle α [px] - [1 px = 0.0225 deg]

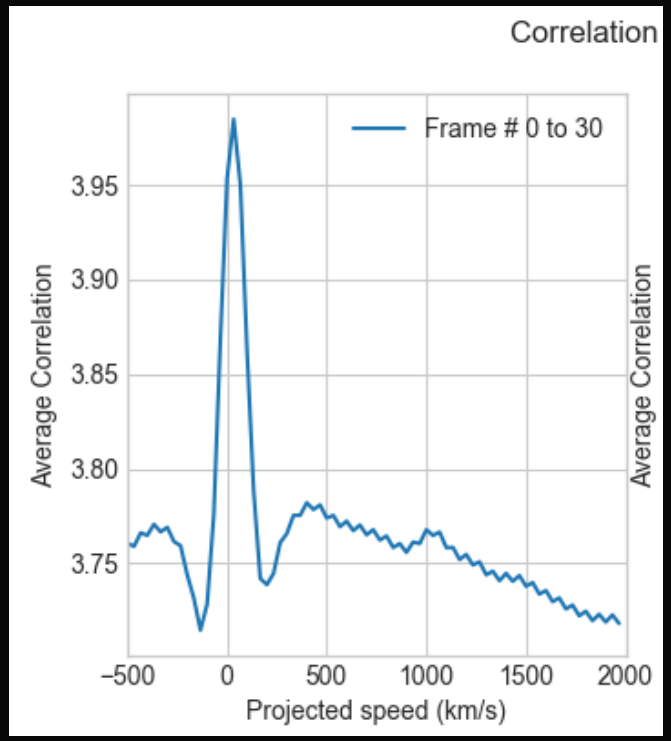

PAM #0 - Polar-remapped [cropped] - 2025-09-21 @ 00:16 UTC
North
0 deg.
+90 deg.
80 Rs
50 Rs
Elongation ε [px] - [1 px = 0.0225 deg]
Position angle α [px]
1 px = 0.125 deg.



Correlation peak at 0-px-shift from significant “static” background & star residuals



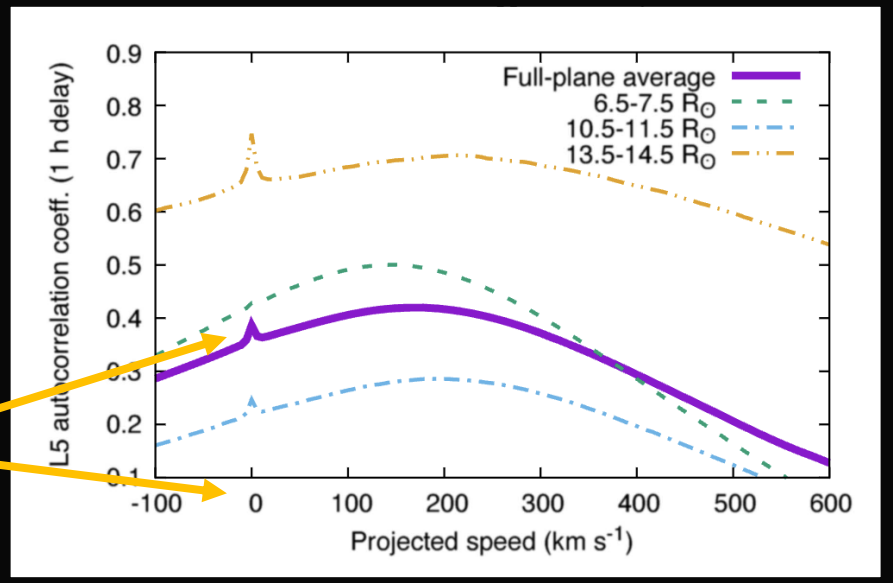
1 px = 0.125 deg.

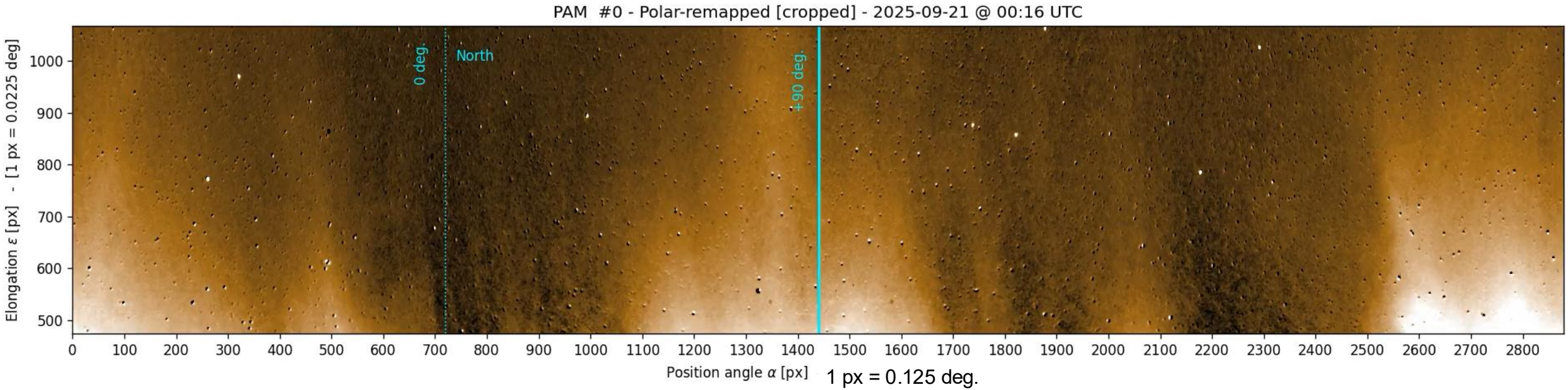


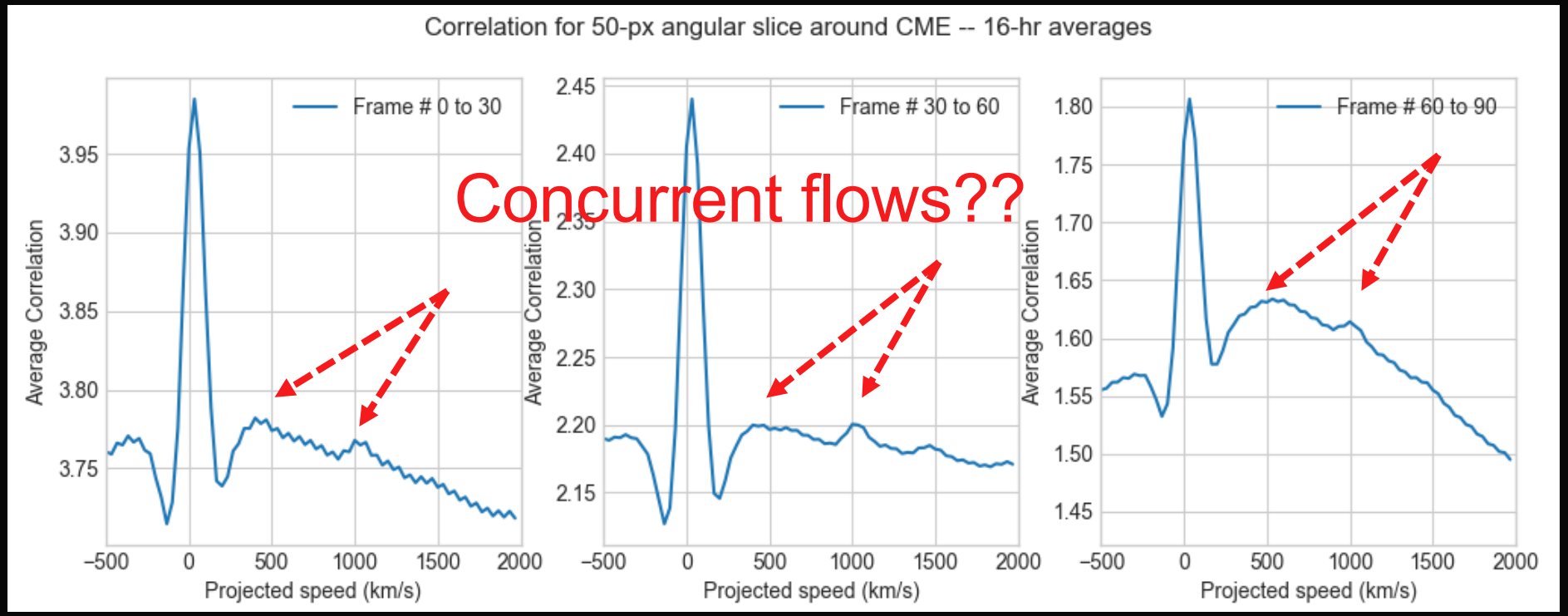
Improved calibration will facilitate disambiguating physical flows from instrumental patterns.

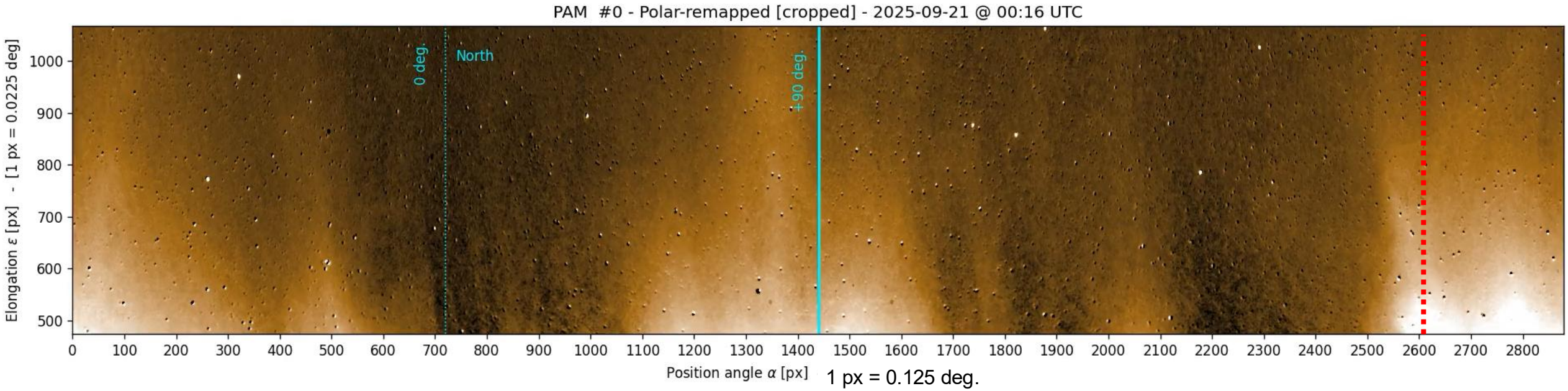
Here with COR2 (3-day average), the physical flows let a stronger correlation than the instrumental pattern

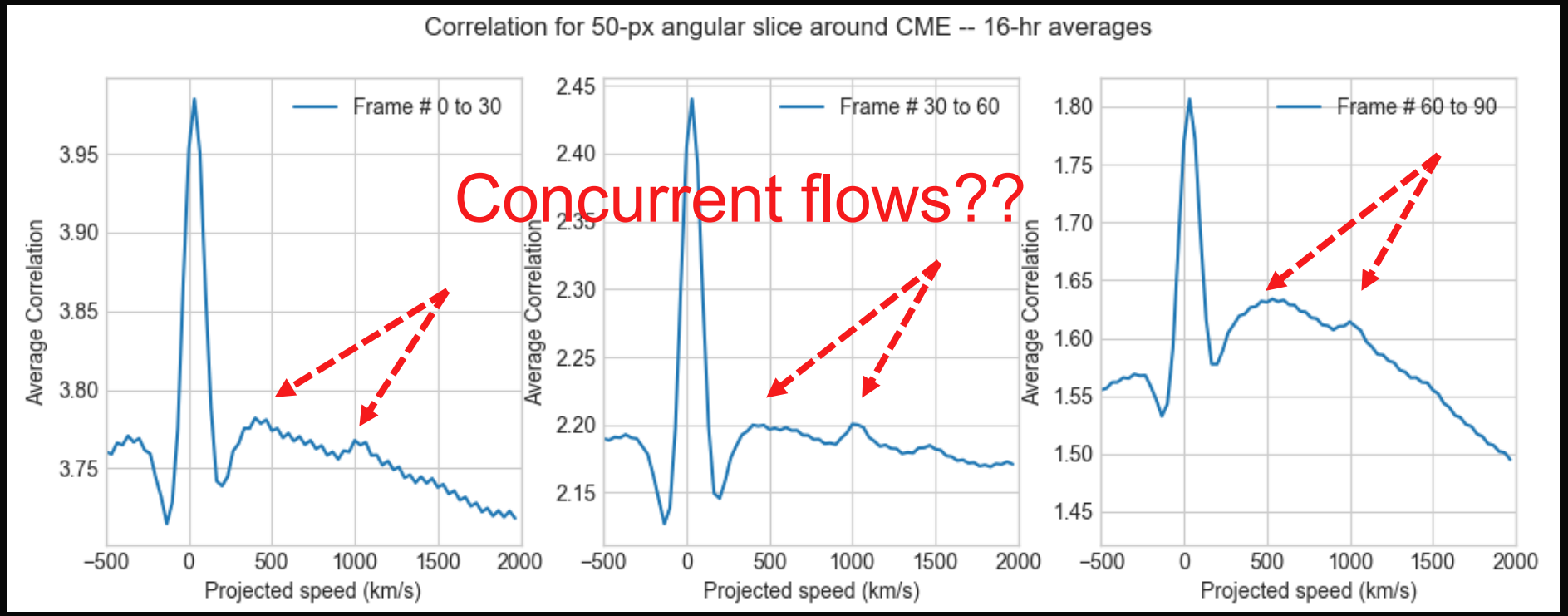
Deforest et al. 2018 (STEREO/ COR2)

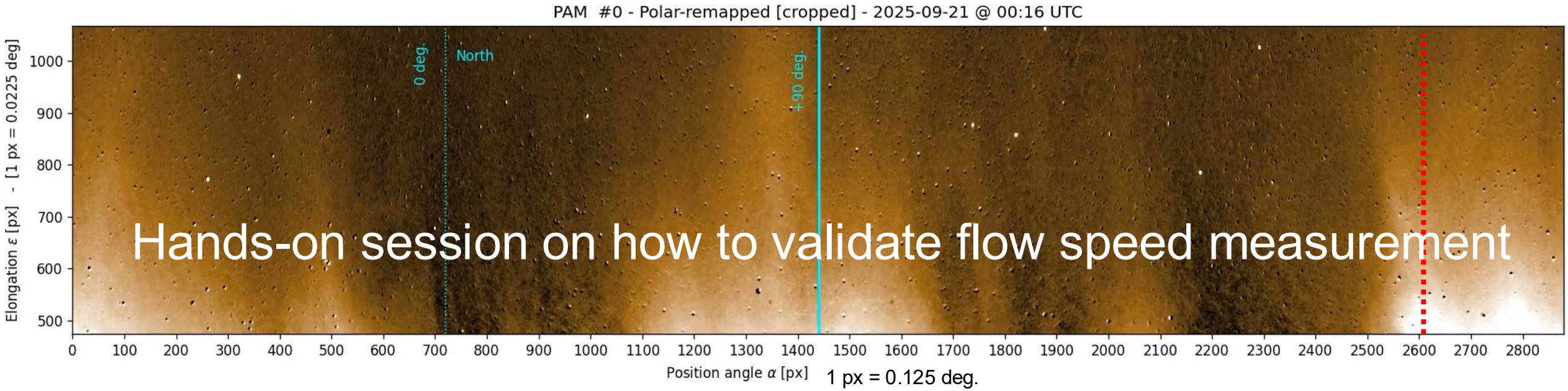





Correlation for 50-px angular slice around CME -- 16-hr averages
Frame # 0 to 30
Frame # 30 to 60
Frame # 60 to 90
Average Correlation
Projected speed (km/s)
Concurrent flows??

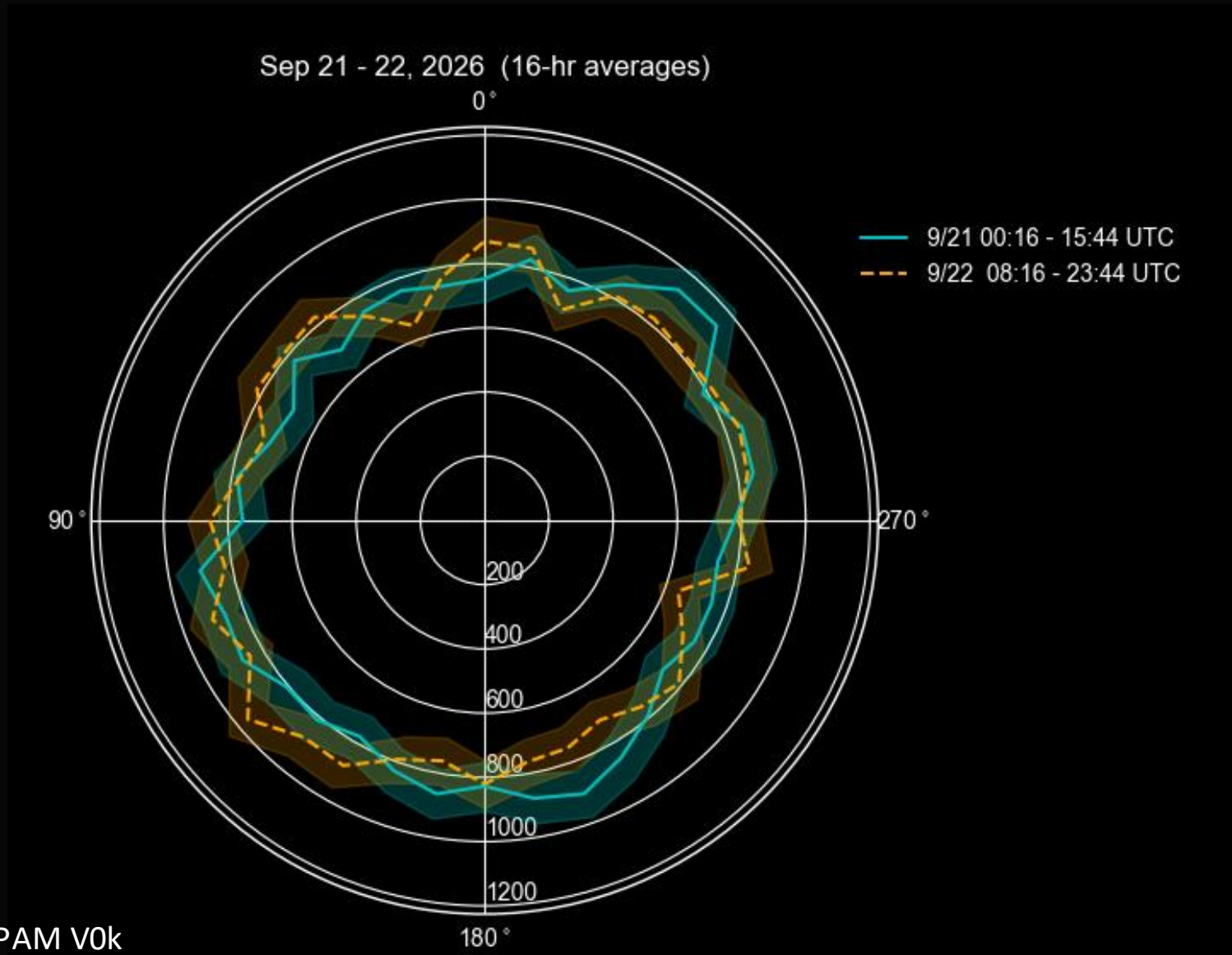

PAM #0 - Polar-remapped [cropped] - 2025-09-21 @ 00:16 UTC
0 deg.
North
+90 deg.
Elongation ε [px] - [1 px = 0.0225 deg]
Position angle α [px]
1 px = 0.125 deg.


Correlation for 50-px angular slice around CME -- 16-hr averages
Frame # 0 to 30
Frame # 30 to 60
Frame # 60 to 90
Average Correlation
Projected speed (km/s)
Concurrent flows??


PAM #0 - Polar-remapped [cropped] - 2025-09-21 @ 00:16 UTC
0 deg.
North
+90 deg.
Elongation ε [px] - [1 px = 0.0225 deg]
Position angle α [px]
1 px = 0.125 deg.
Hands-on session on how to validate flow speed measurement

Two 16-hr average flow maps showingfast solar wind stream (>600 km/s). Both flow maps are integrated between 50 – 80 Rs. These flow maps were not disambiguated from concurrent fast flows that may not be physical.

The end of the 1st flow map (cyan) is separated by 16 hours from the beginning of the 2nd flow map (orange)



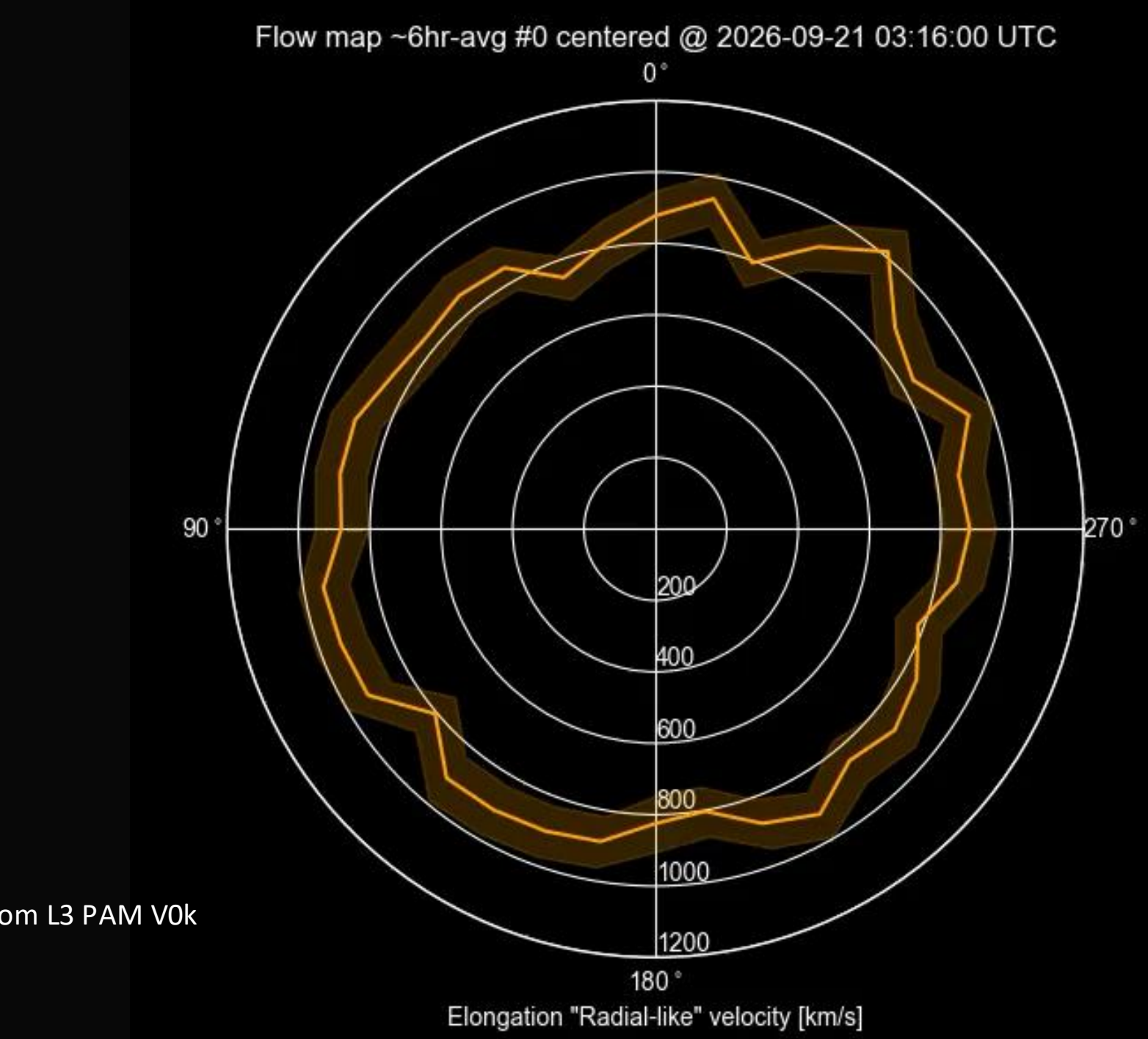
From L3 PAM V0k

Elongation “radial-like” velocity

LET’S FLOW!!!

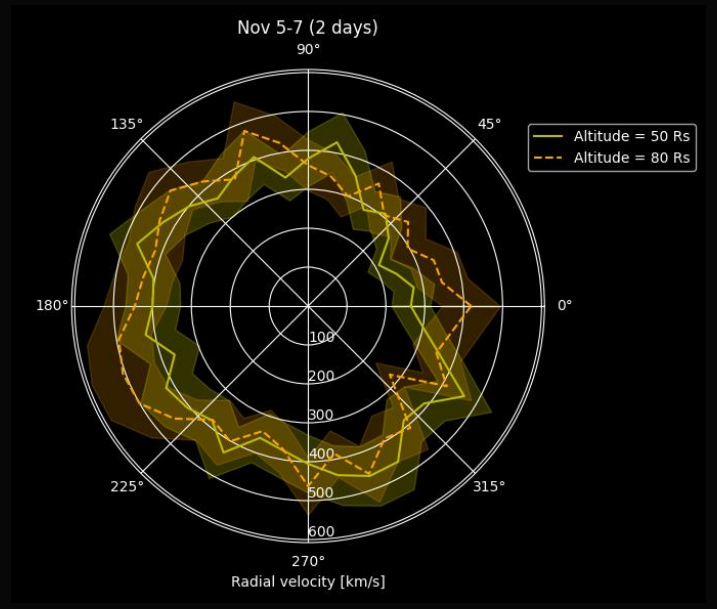
6-hr average (NASA req. YAY!)

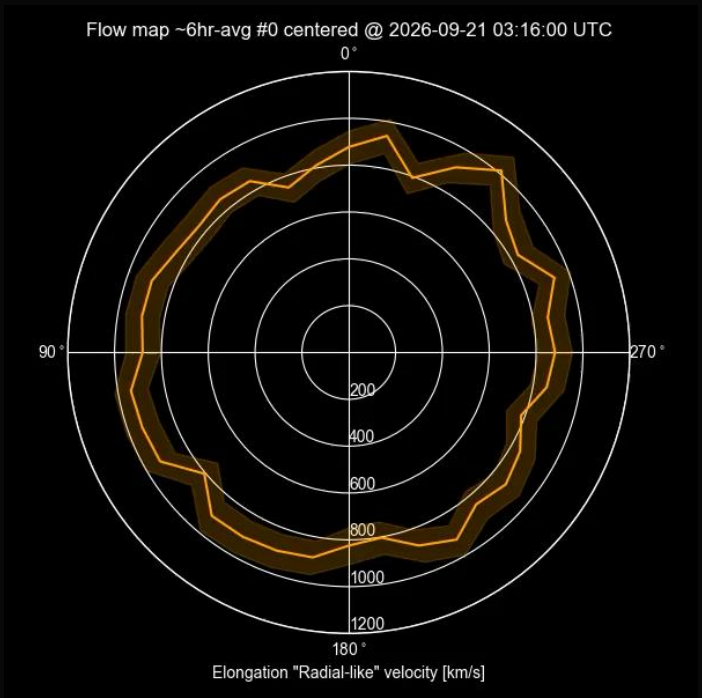
From L3 PAM V0k



Summary

- Correlation-based radial flows:
  - **@SOC: "elongation speed" [0-360 deg]** of the ambient solar wind over at least 4 different radial bins between 6 to 80 Rs, 6-hr cadence.
  - Large-scale evolution, over **elongation** axis
  - Custom flows **@user**: images -> more rings, higher radial resolution & faster cadence





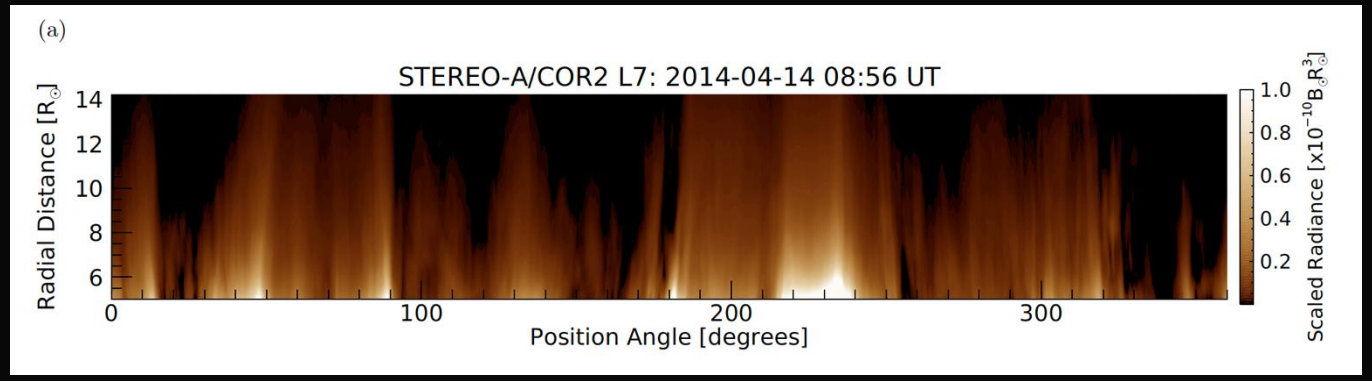
Come to the hands-on session on Wednesday PM to know the "secrets" of flow tracking!

Questions

Accuracy estimates with Flow Tracking Challenge (Valmir Moraes Filho, Vadim Uritsky)

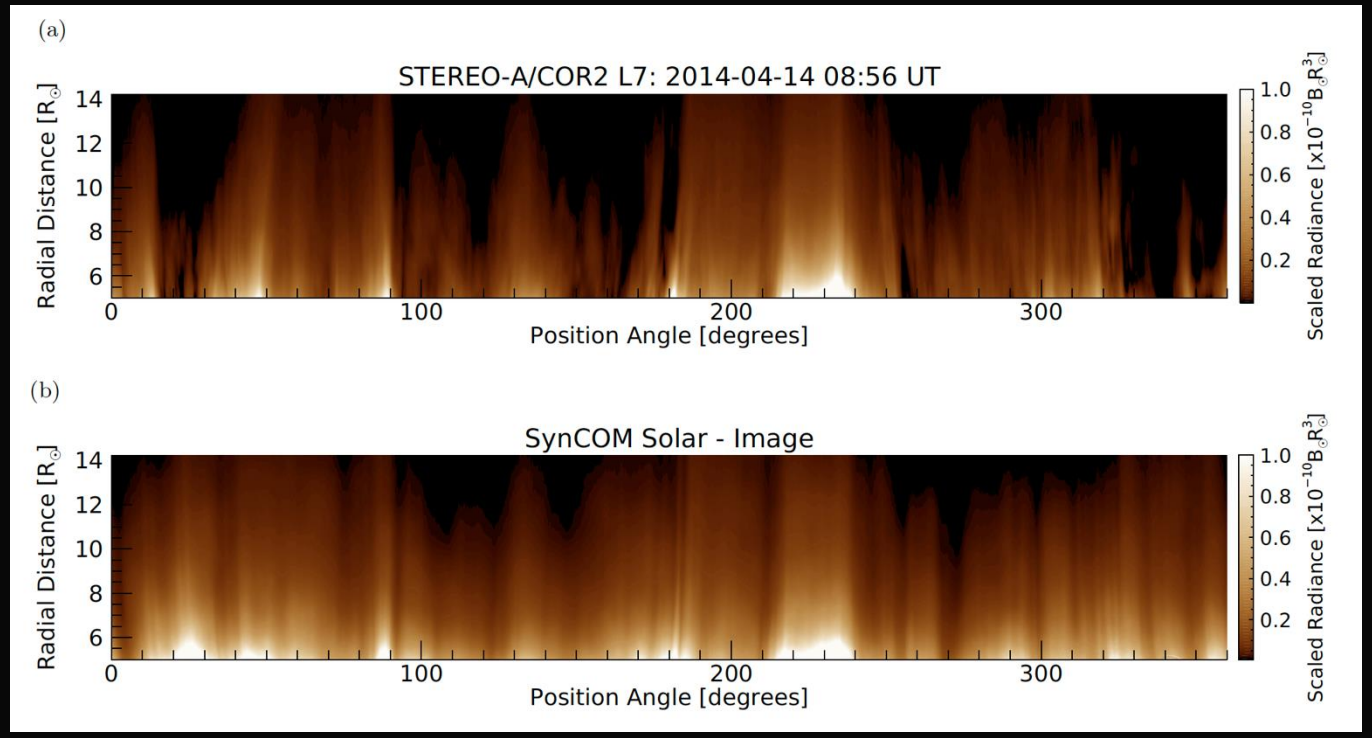
Accuracy estimates with Flow Tracking Challenge

(Moraes Filho et al., 2024) – Special thanks to Vadim Uritsky!



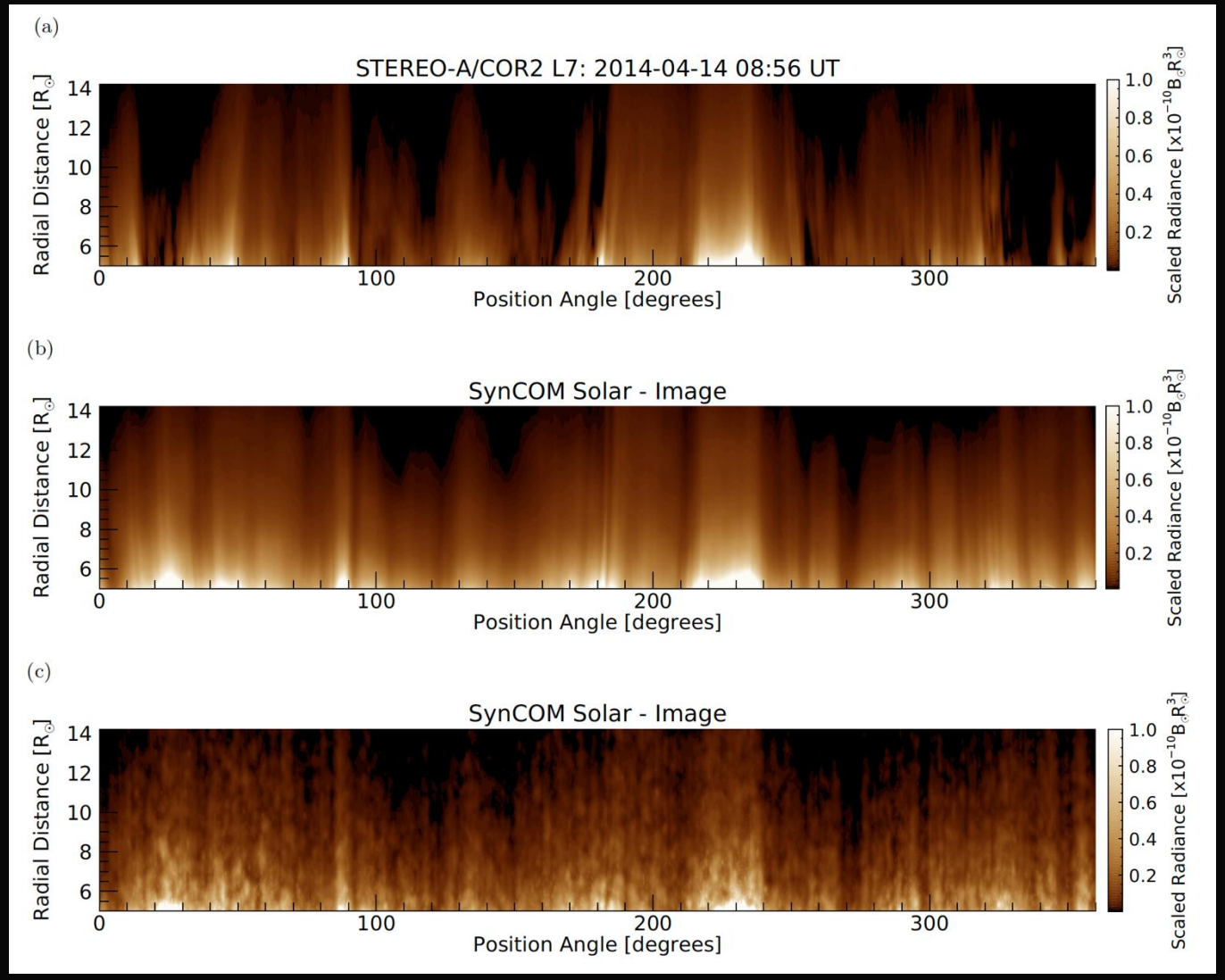
Accuracy estimates with Flow Tracking Challenge

(Moraes Filho et al., 2024) – Special thanks to Vadim Uritsky!



Accuracy estimates with Flow Tracking Challenge

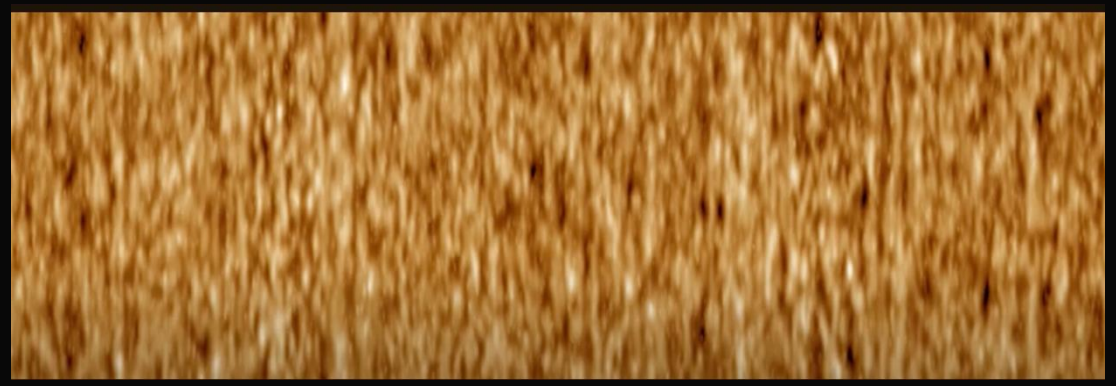
(Moraes Filho et al., 2024) – Special thanks to Vadim Uritsky!

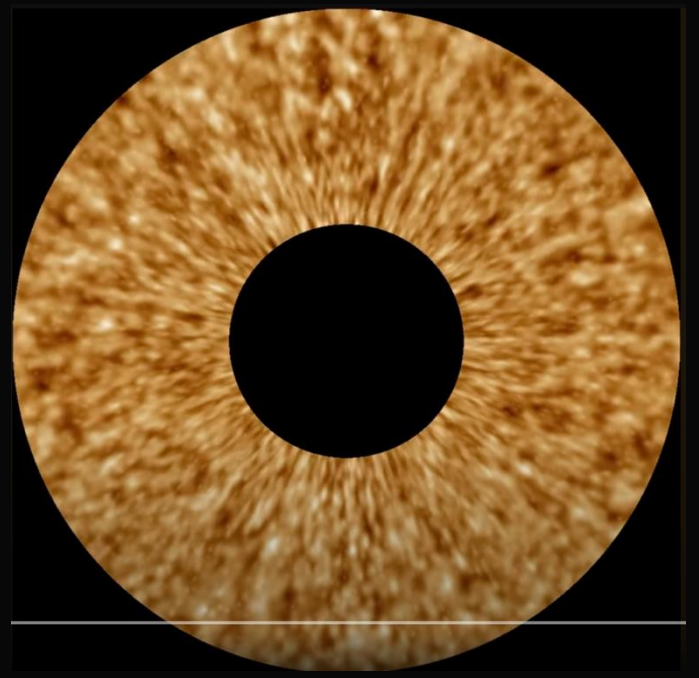


Accuracy estimates with Flow Tracking Challenge

(Moraes Filho et al., 2024) – Special thanks to Vadim Uritsky!

Synthetic realistic imagery with known “ground-truth” flows





https://youtu.be/Vmb2M6-8_pE?si=ugggWTp5iaaebFOD

https://youtu.be/cw154Po_J40?si=zlnloIxwPpHQsf7M