

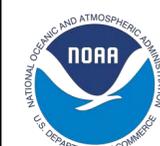
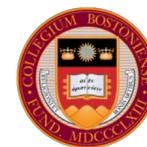
# Polarimeter to UNify the Corona and Heliosphere: revealing how our star's atmosphere becomes the solar wind



C.E. DeForest, S.E. Gibson,  
and the *PUNCH* team



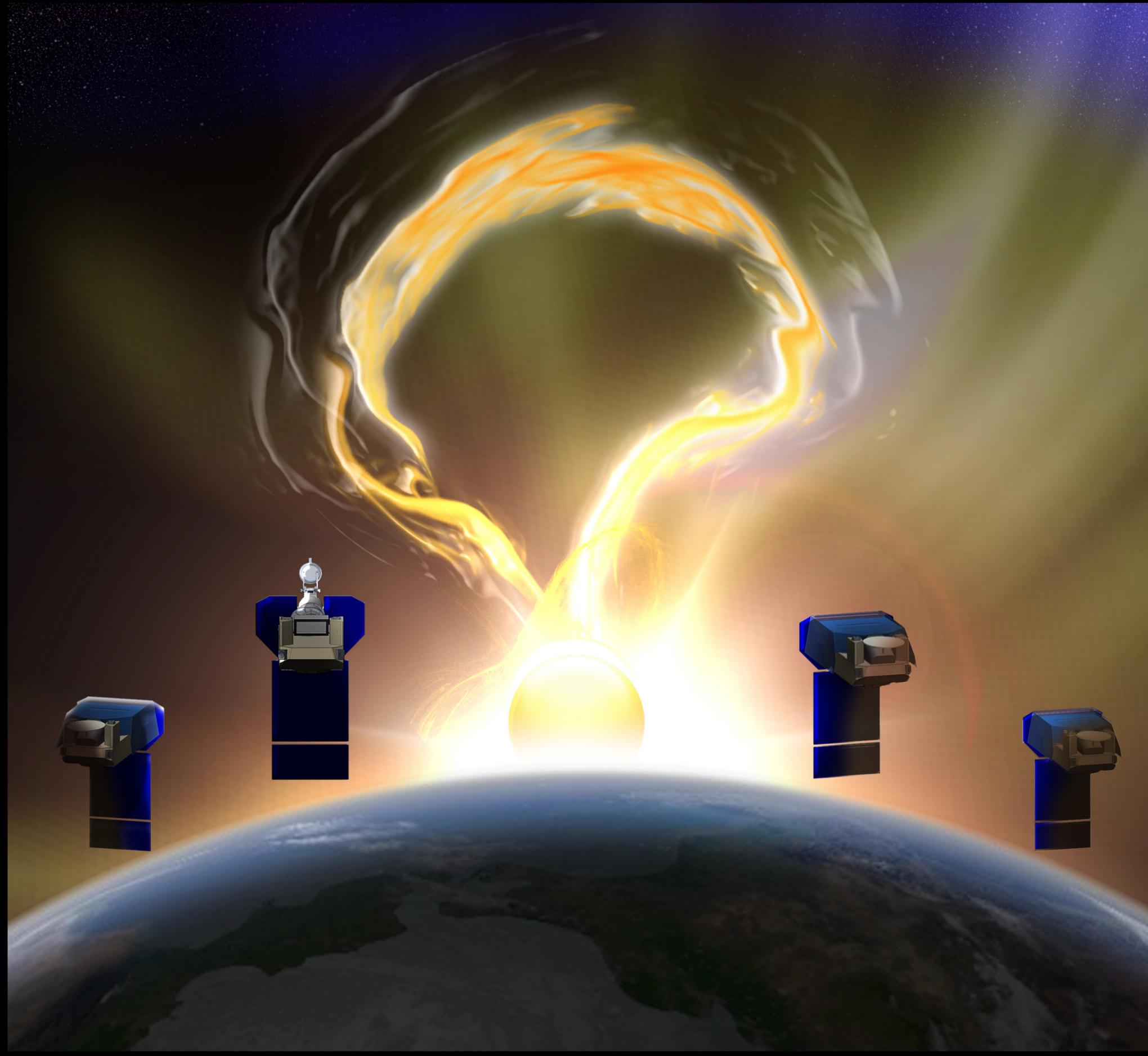
*Into the Red Dragon's Lair: 4-in-1 Workshop Tackling  
Outstanding Problems in Heliophysics and Space Weather  
Cardiff, 7-Dec-2017*





## What is PUNCH?

- Mission: Polarimeter to UNify the Corona and Heliosphere
- Approach: direct, 3-D imaging of the transition from corona to heliosphere
- Measurement: polarized photometry of Thomson-scattered visible light





# PUNCH Mission Structure

- Four LEO smallsats
- One compact coronagraph
- Three wide-field cameras
- Synchronized operation
- Rapid deep-field imaging
- Polarization for 3D inversion

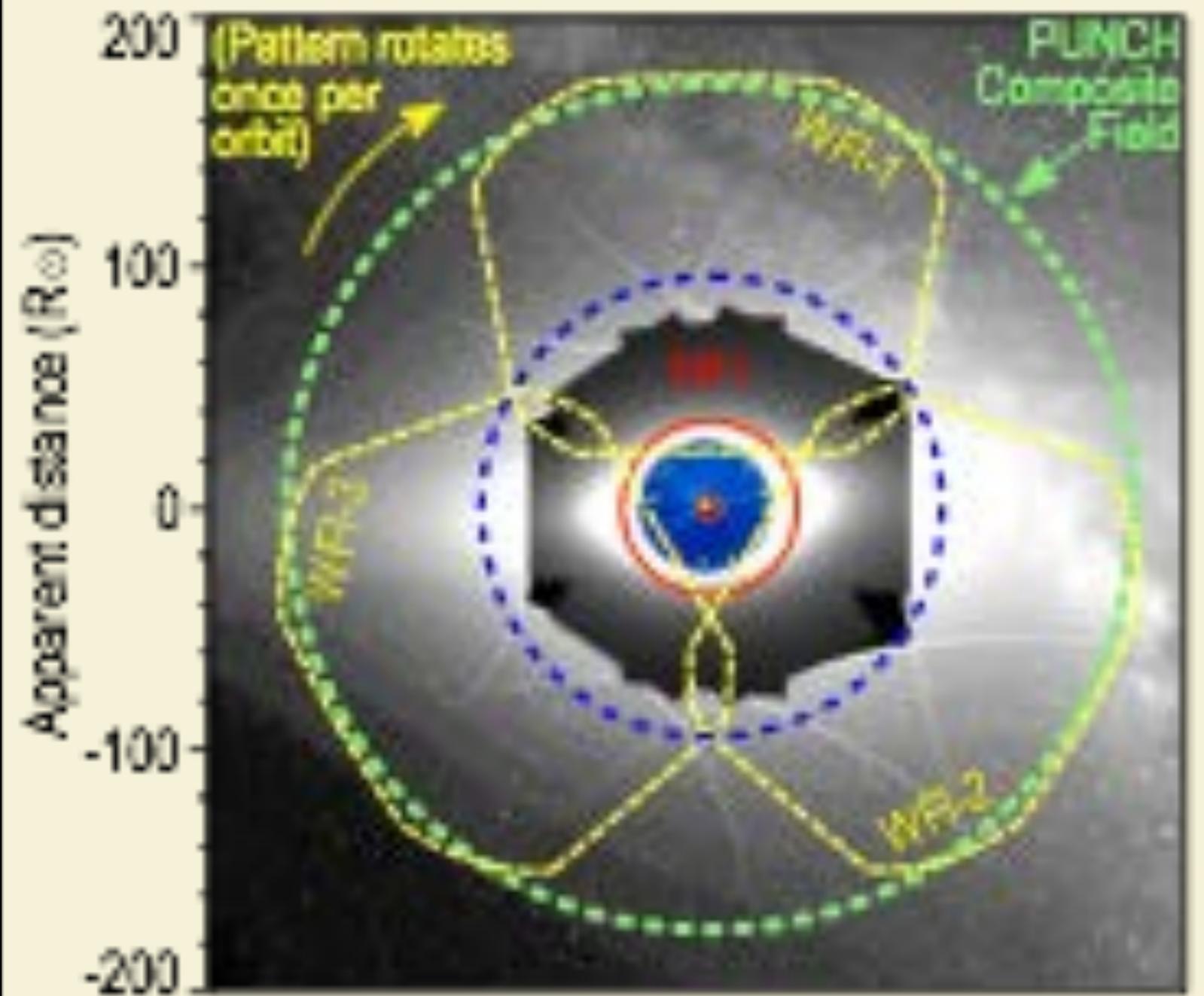




# PUNCH observing strategy

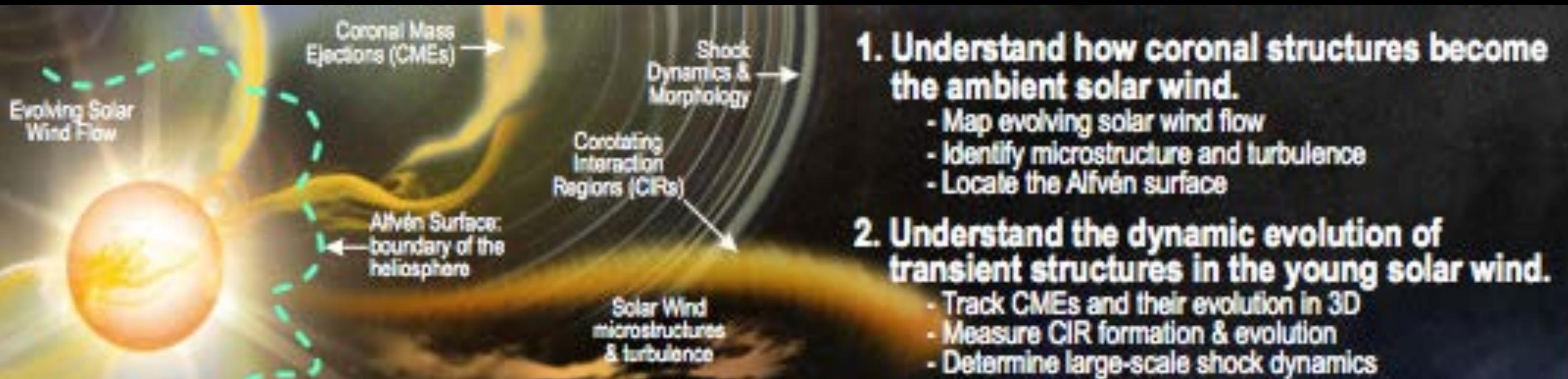
- Sun-synchronous twilight LEO
- Cameras are synchronized & matched in wavelength.
- pB & B measurements: 4-min cadence

- PUNCH observes continuously at 4-min. cadence.
- NFI covers  $6R_{\odot}$ - $32R_{\odot}$  (Red circles: inner/outer).
- WFI covers  $20R_{\odot}$ - $180R_{\odot}$  in 3 parts (Yellow dash trefoil).
- PUNCH images continuously inside  $80R_{\odot}$  (Blue dots).
- PUNCH produces 3 full mosaics per orbit, outside  $80R_{\odot}$ .

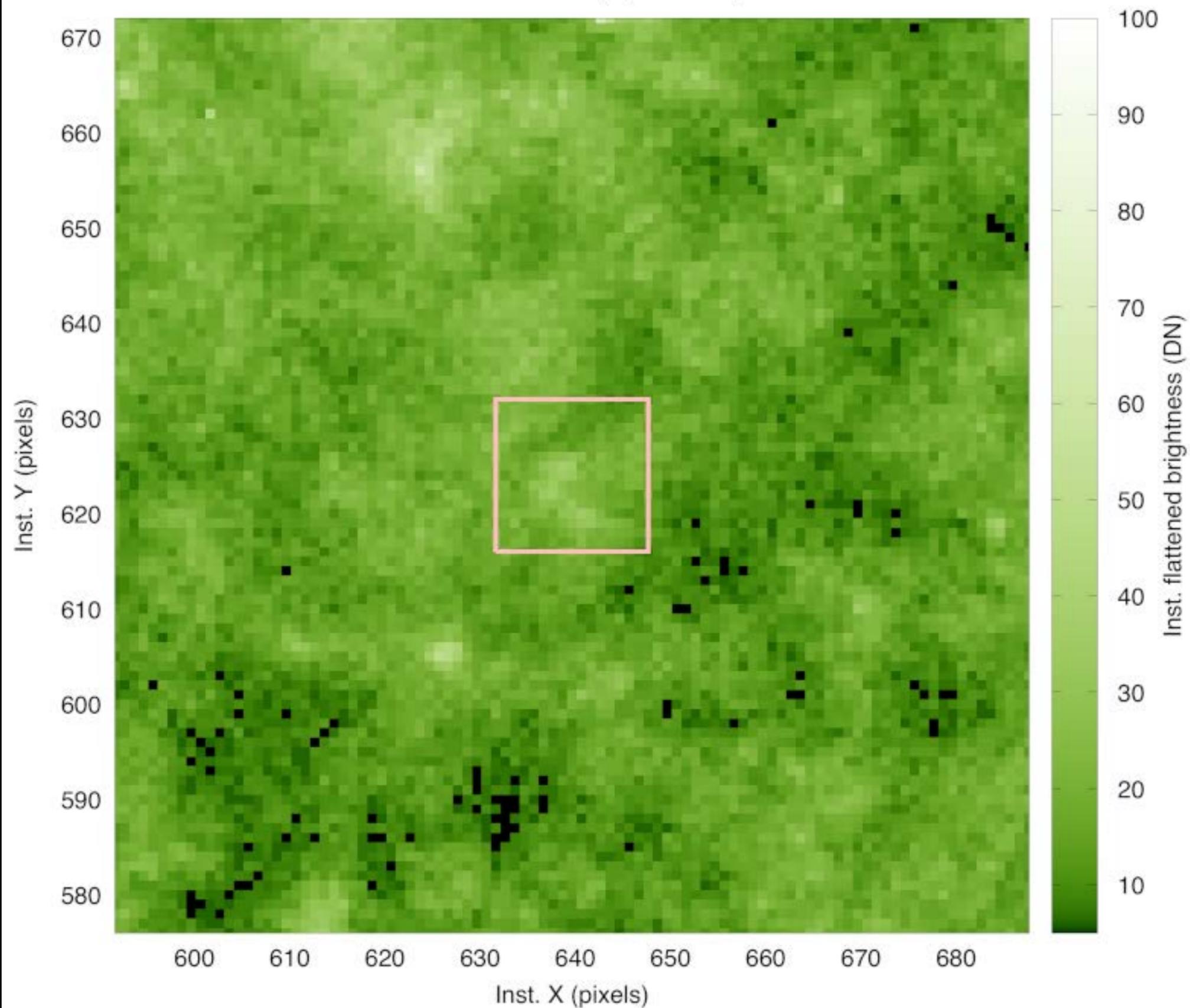




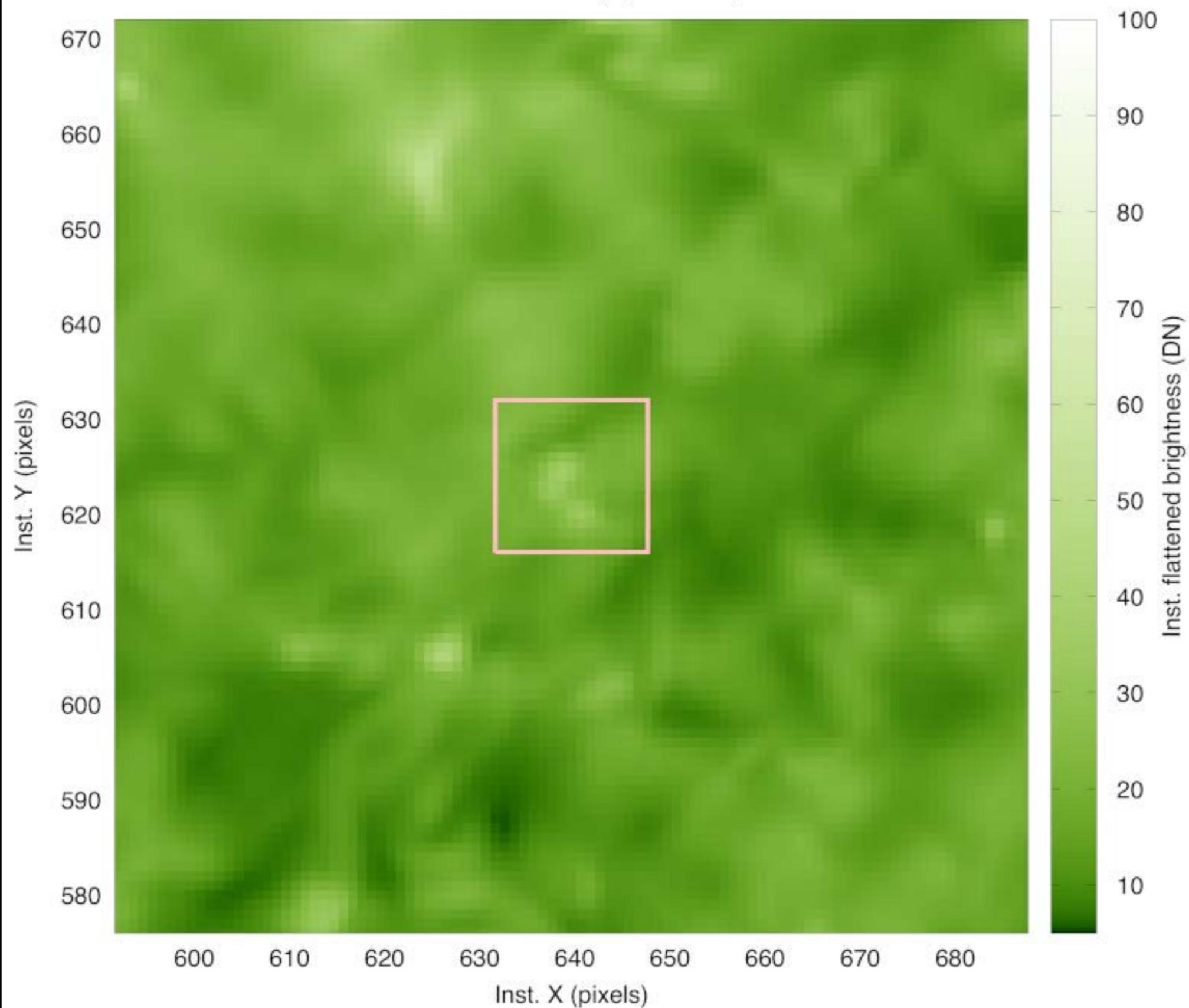
# PUNCH science objectives



SUVI 131A Closeup (Quiet Sun)



SUVI 131A Closeup (Quiet Sun)

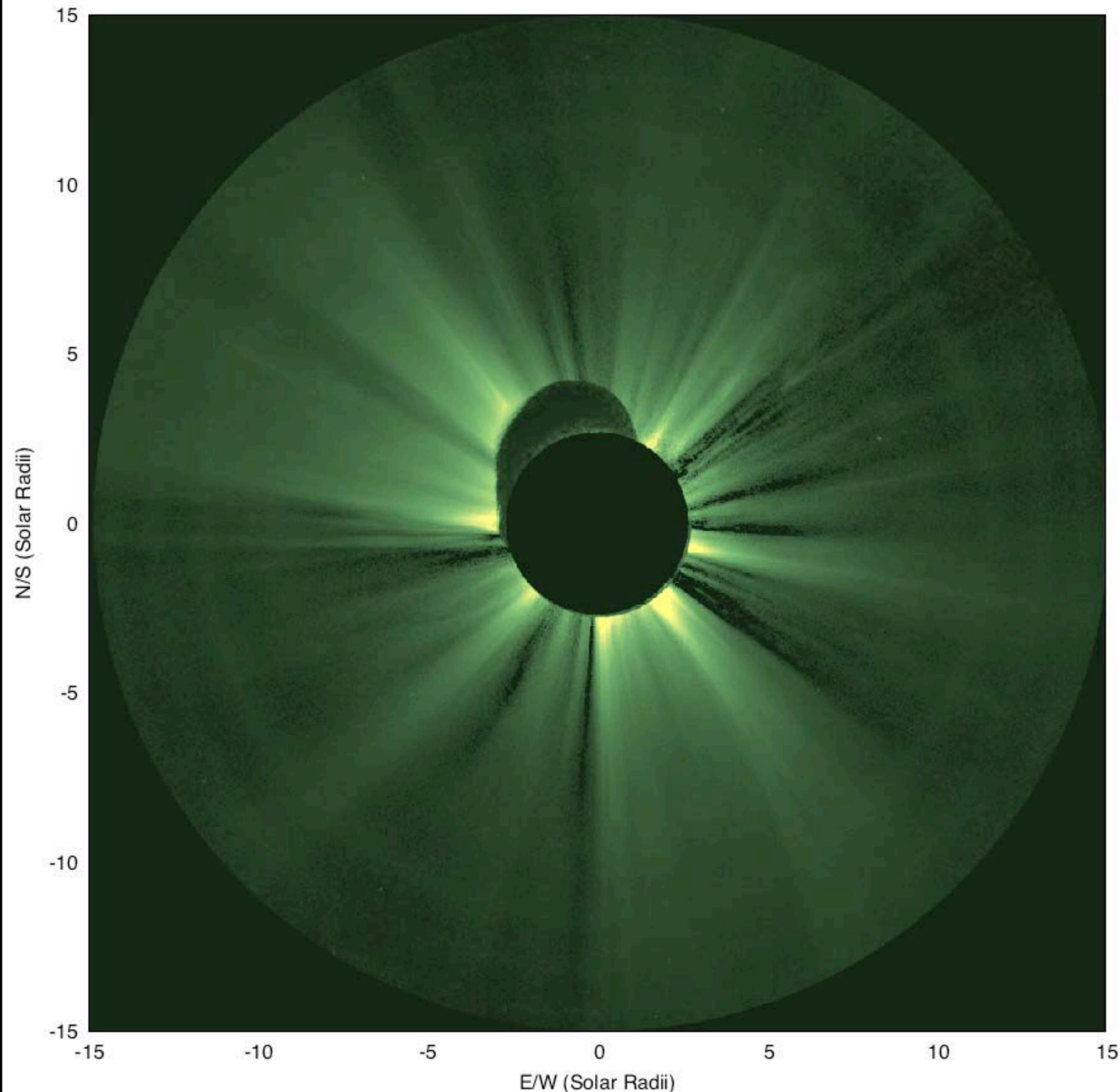




# The importance of deep-field imaging

- There is an interplay between noise level and effective spatial resolution.
- All coronagraphs flown to date have been noise-limited.
- The 2014 COR2 deep campaign revealed very fine structure throughout the solar corona.
- PUNCH has 10x-30x improved sensitivity over SECCHI (synoptic).

L2: 2014-04-14T00:06:00.008

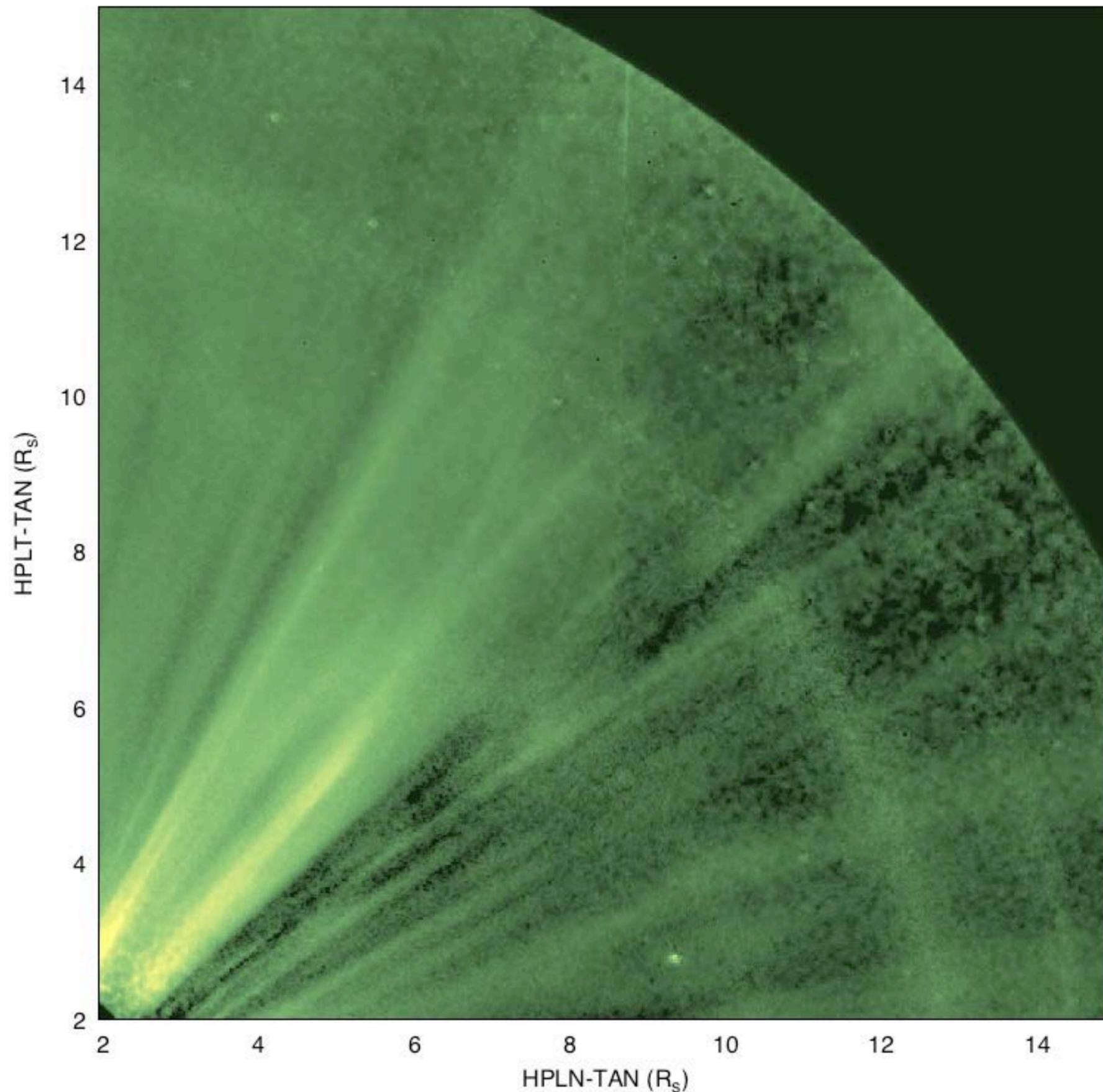




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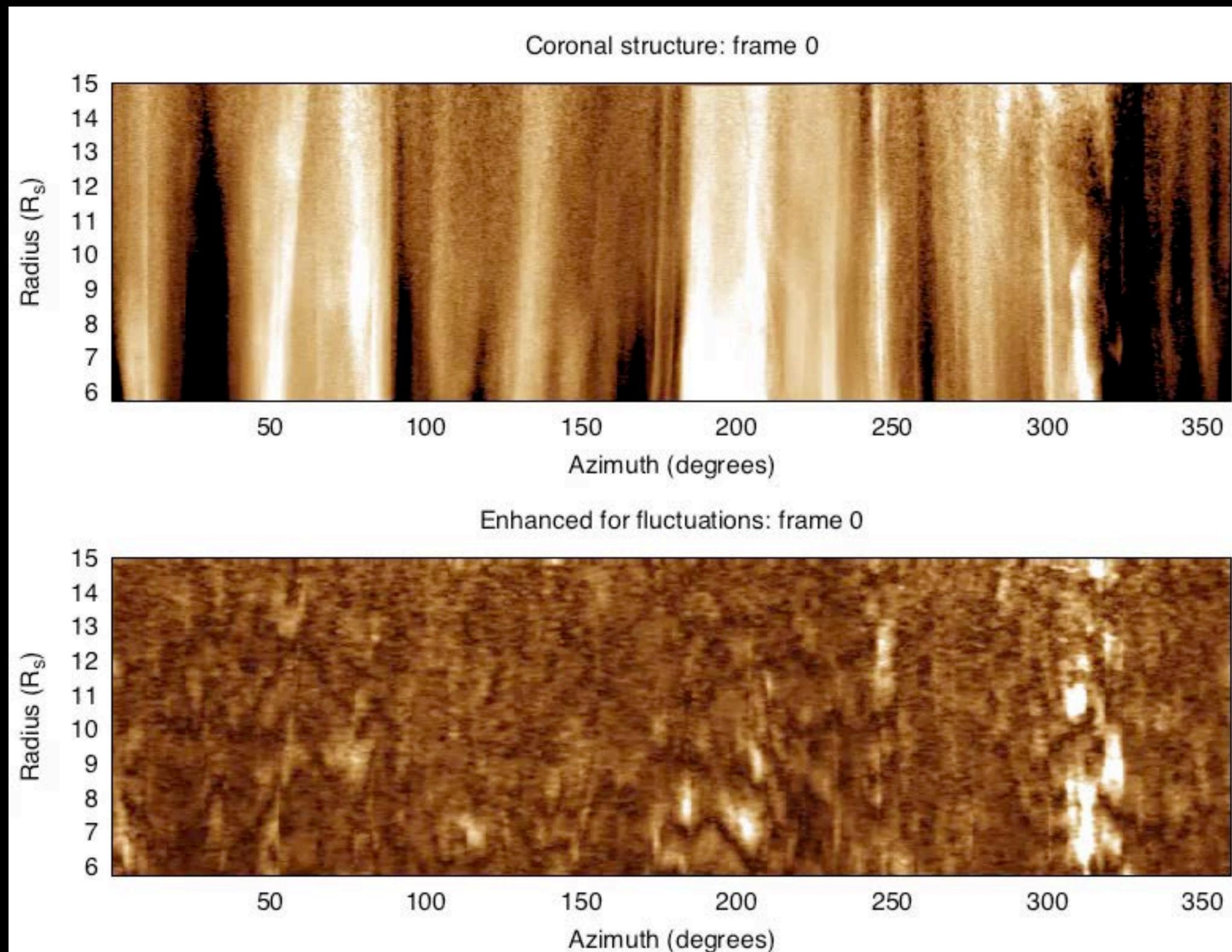
COR2 L2: 2014-04-14T00:46:00.015 (radial filtered)





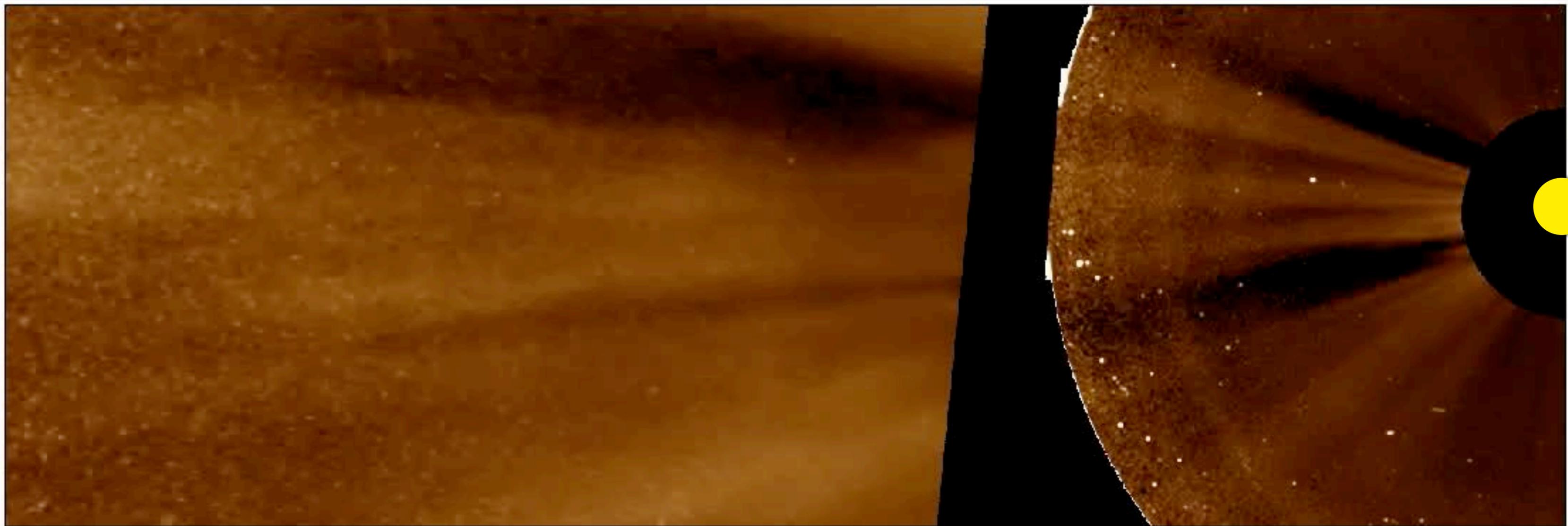
# Tracing solar wind flow with universal small features

- Deep photometry and post-processing reveal universal unsteady “blobby” streams that trace the wind flow.
- Ulysses produced the first global wind speed maps, once every 4.5 years.
- PUNCH images will yield global wind acceleration maps, once every few hours.
- L5: Ground truth for space weather “ambient background” models (!)





# Shifting dynamics: corona to solar wind



Isotropic/unstructured blobs  
with weak, fading radial  
structure

$\beta=1$   
surface?

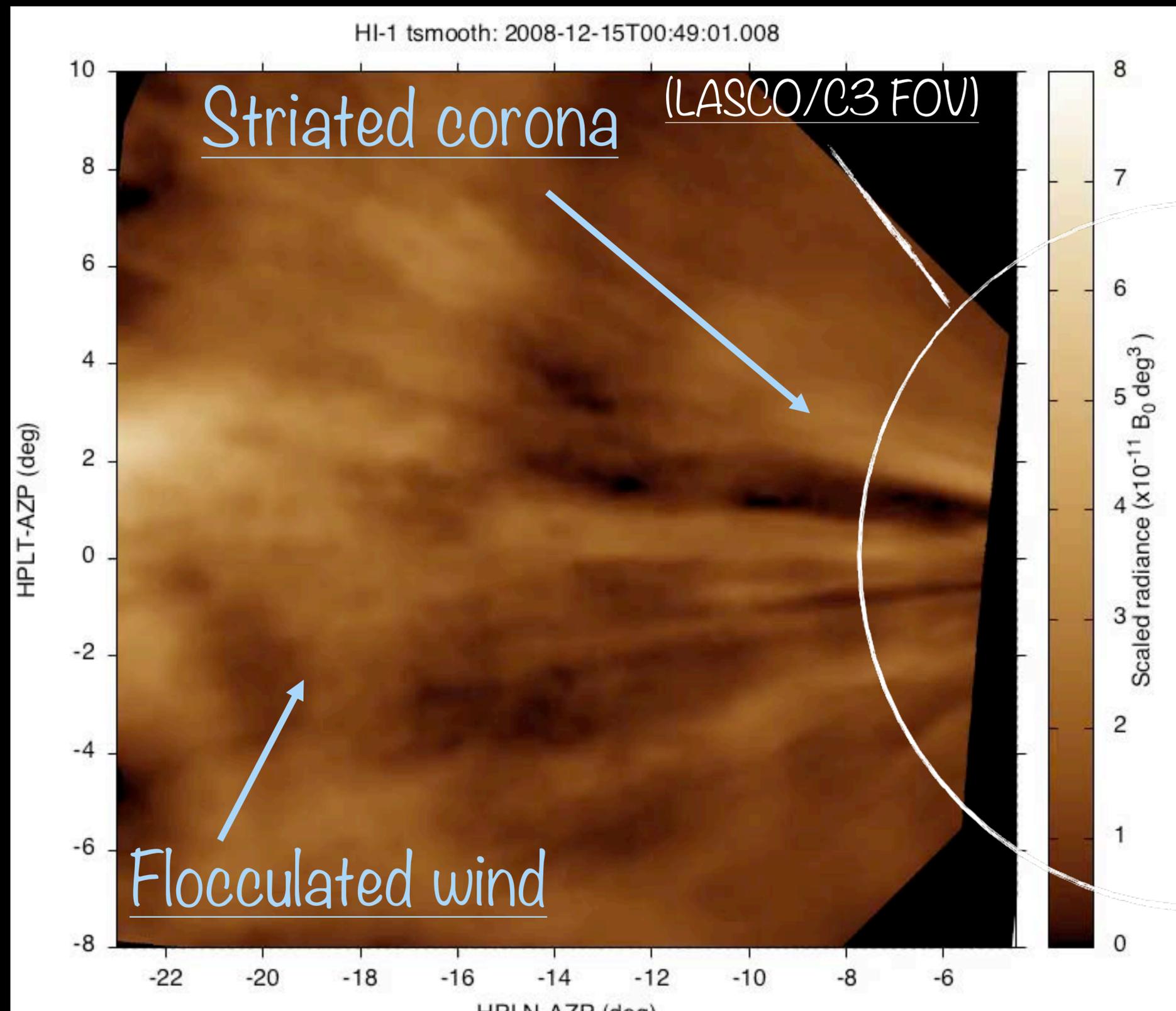
Alfvén  
surface?

Striated/structured corona  
with small flowing blobs &  
puffs



# Shifting dynamics: corona to solar wind

- Between 20-80 Rs, the coronal striae fade.
- “Flocculae” fade in, forming a nearly isotropic visual field.
- Onset of quasi-hydrodynamic turbulence? Isotropization of coronal turbulence?
- L5: Track turbulence and compare to in-situ events at Earth: unique propagation science





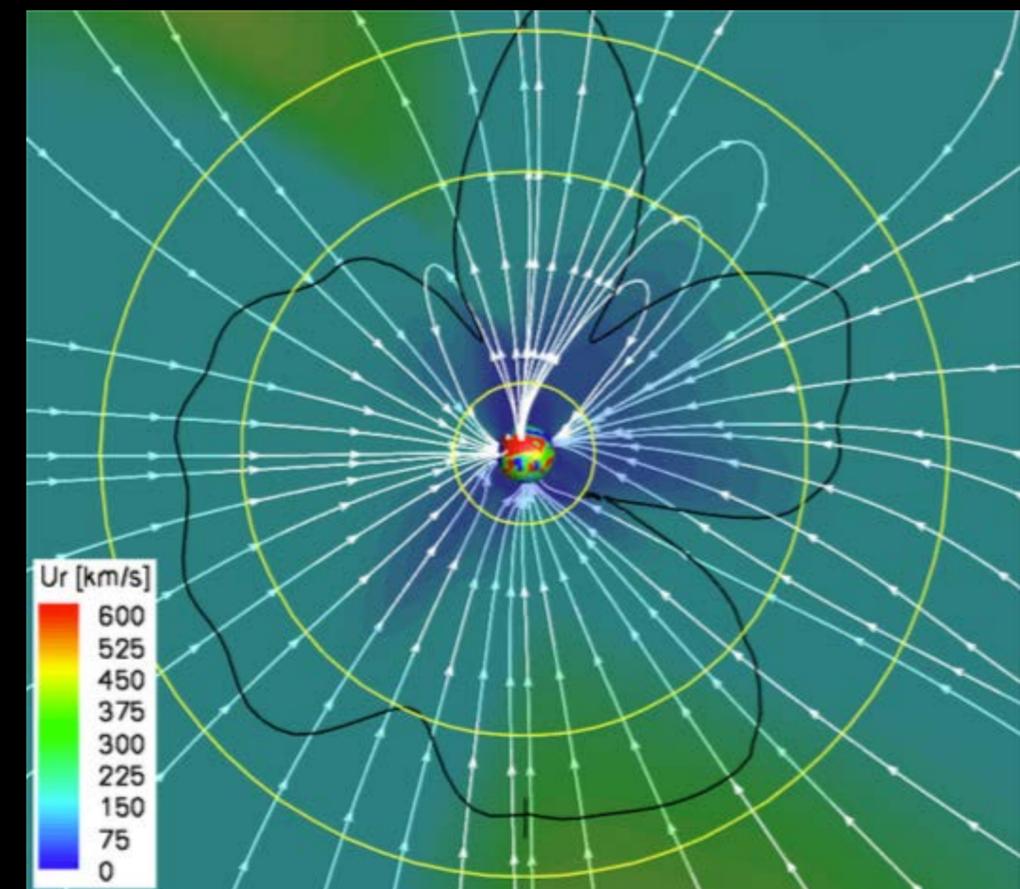
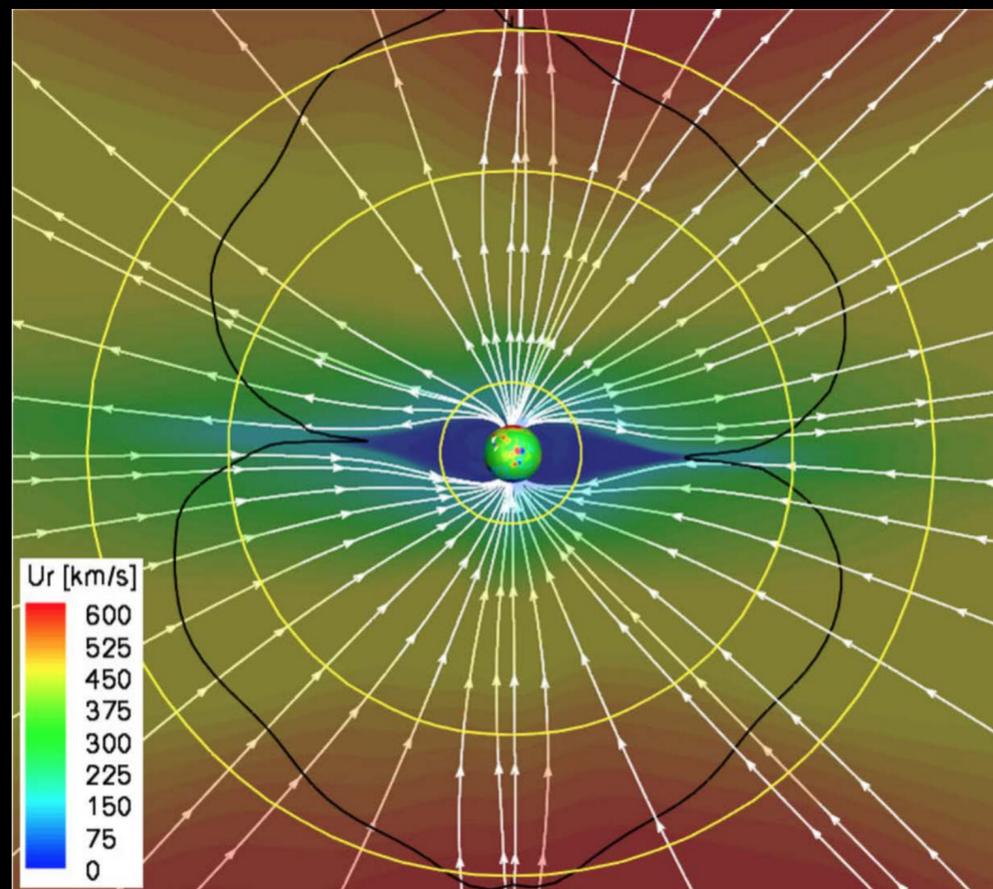
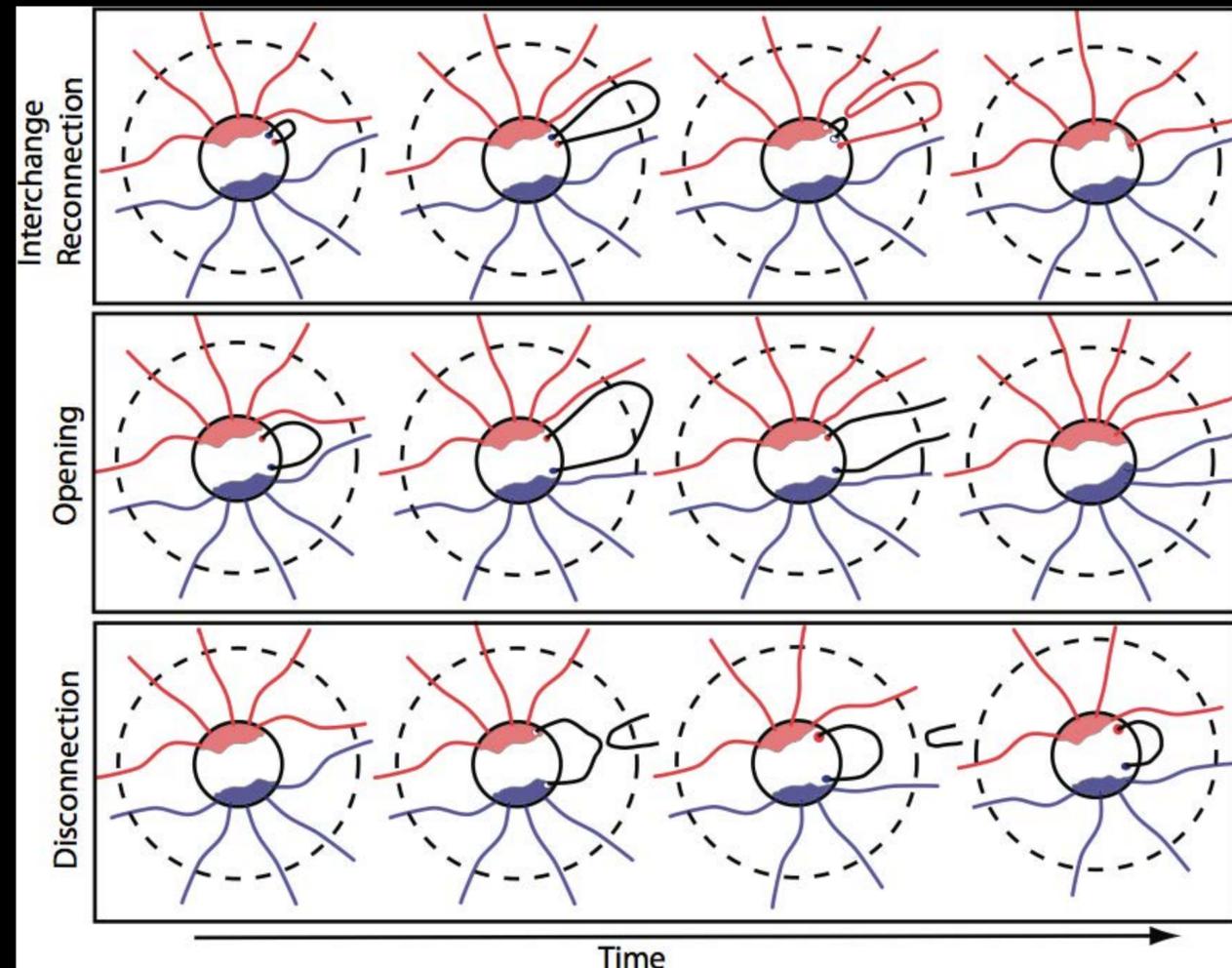
# The Alfvén surface: final unexplored boundary in the heliosphere

*The Alfvén surface is the true “source surface” for the corona and IMF.*

*The Alfvén surface is complex and changes with magnetic topology (Sim.: Cohen 2015)*

**Solar minimum**

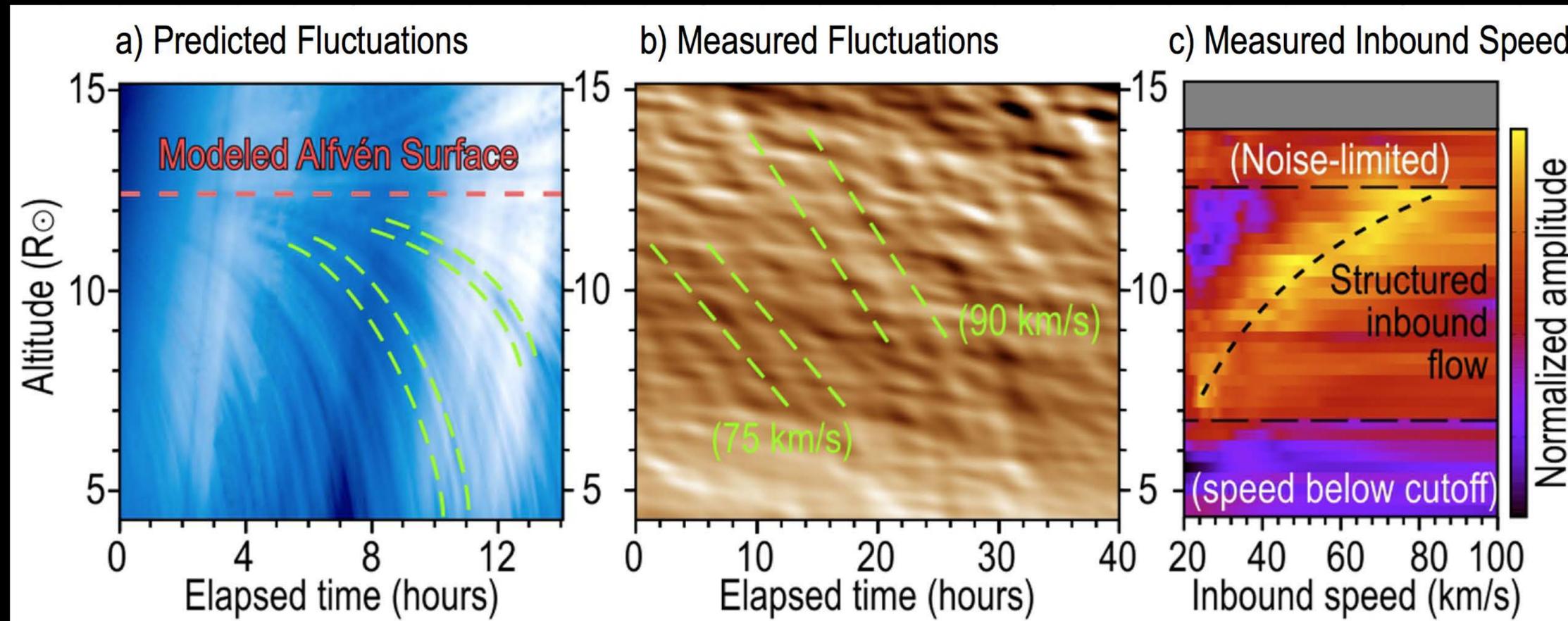
**Solar maximum**



With inbound fluctuation analysis, PUNCH will map the shifting Alfvén surface.



# Inbound fluctuations identify the Alfvén surface



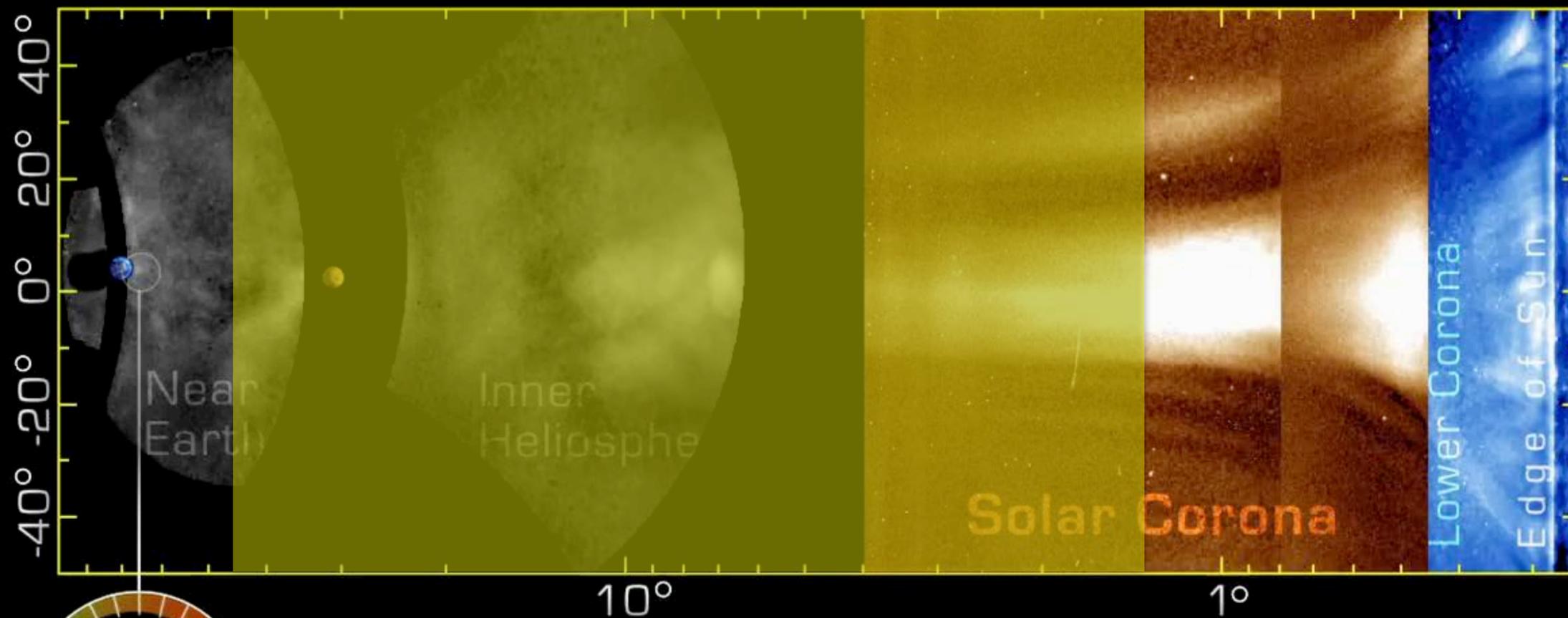
- COR2 synoptic observations reveal faint inbound features at all azimuths
- Features are consistent with jets, not waves — but still constrain the surface
- Current measurements are noise-limited and FOV-limited.
- PUNCH measurements will identify the Alfvén surface and its motion.



# Tracking CMEs through the heliosphere

- This is the central aspect of space weather science
- PUNCH uses polarimetry to track even halo CMEs in 3-D.
- PUNCH observes CME substructure and evolution enroute through the heliosphere.

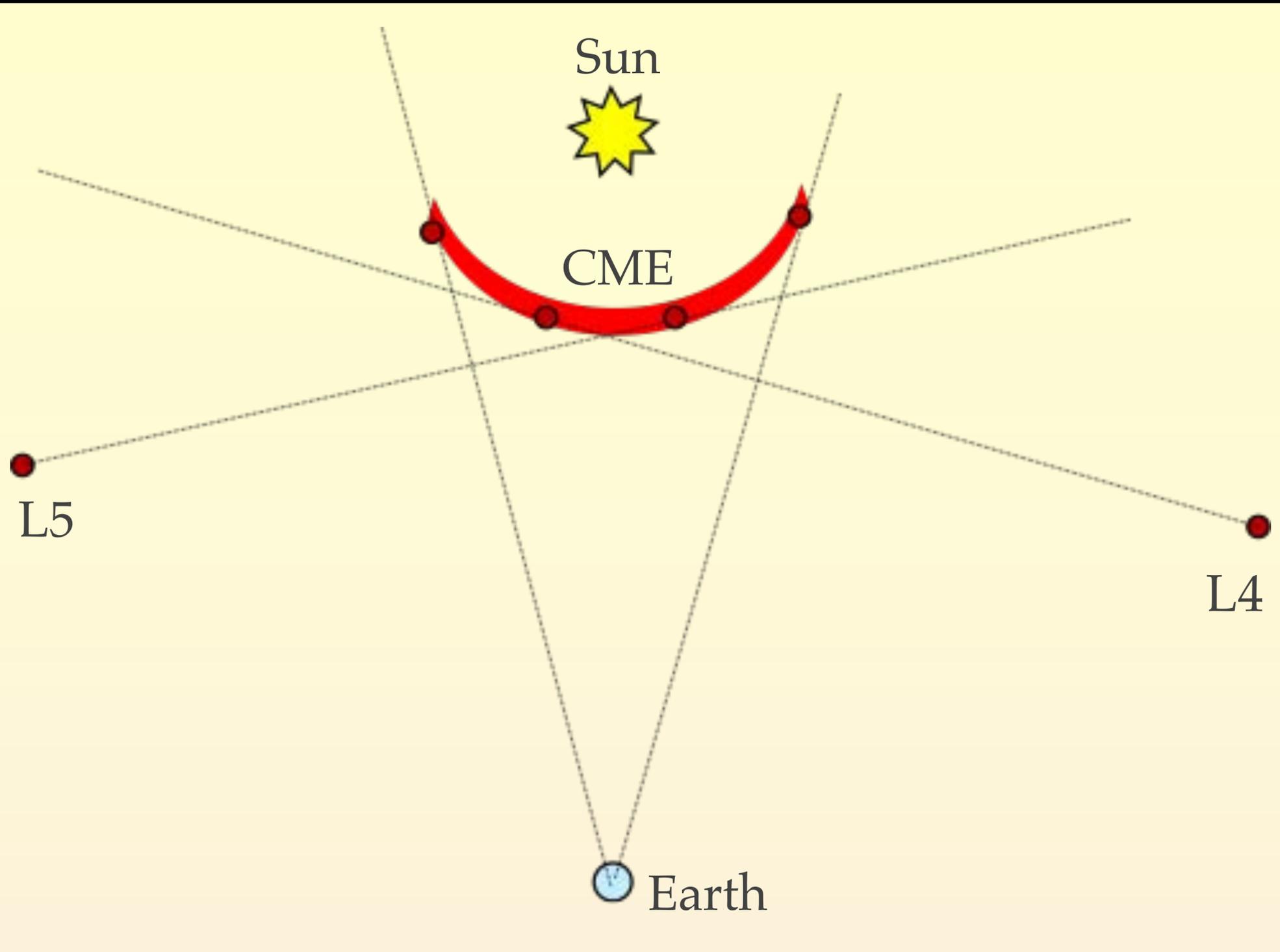
(PUNCH FOV)



STEREO-A: 12/11/08 12:40:00 AM



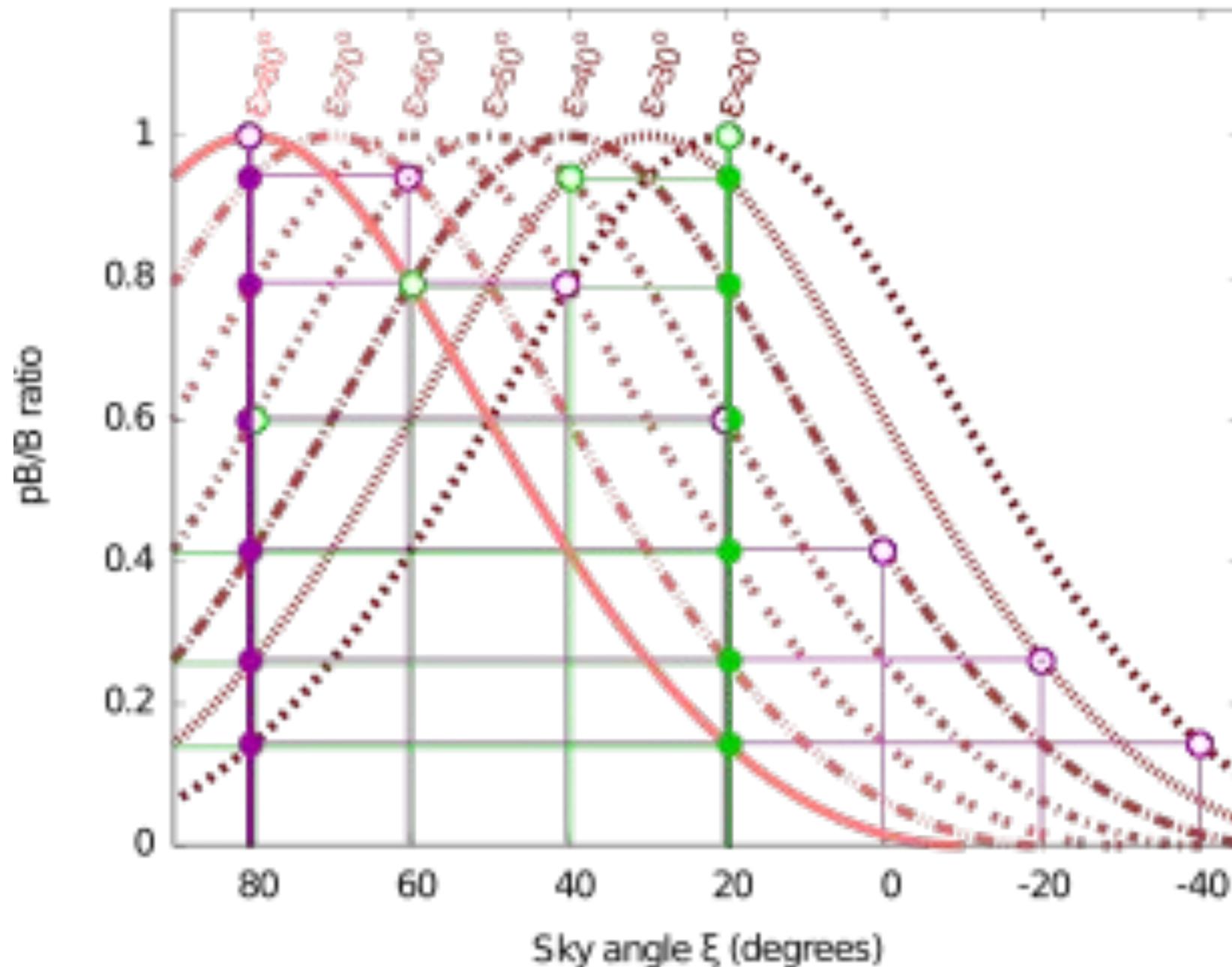
# Polarimetry overcomes the limits of stereoscopy



- Different lines of sight give different locations for the “front” of a shock or CME, spoiling stereoscopy.
- CME shape couples to inferred location and speed.
- Polarimetry overcomes this by using only one line of sight.



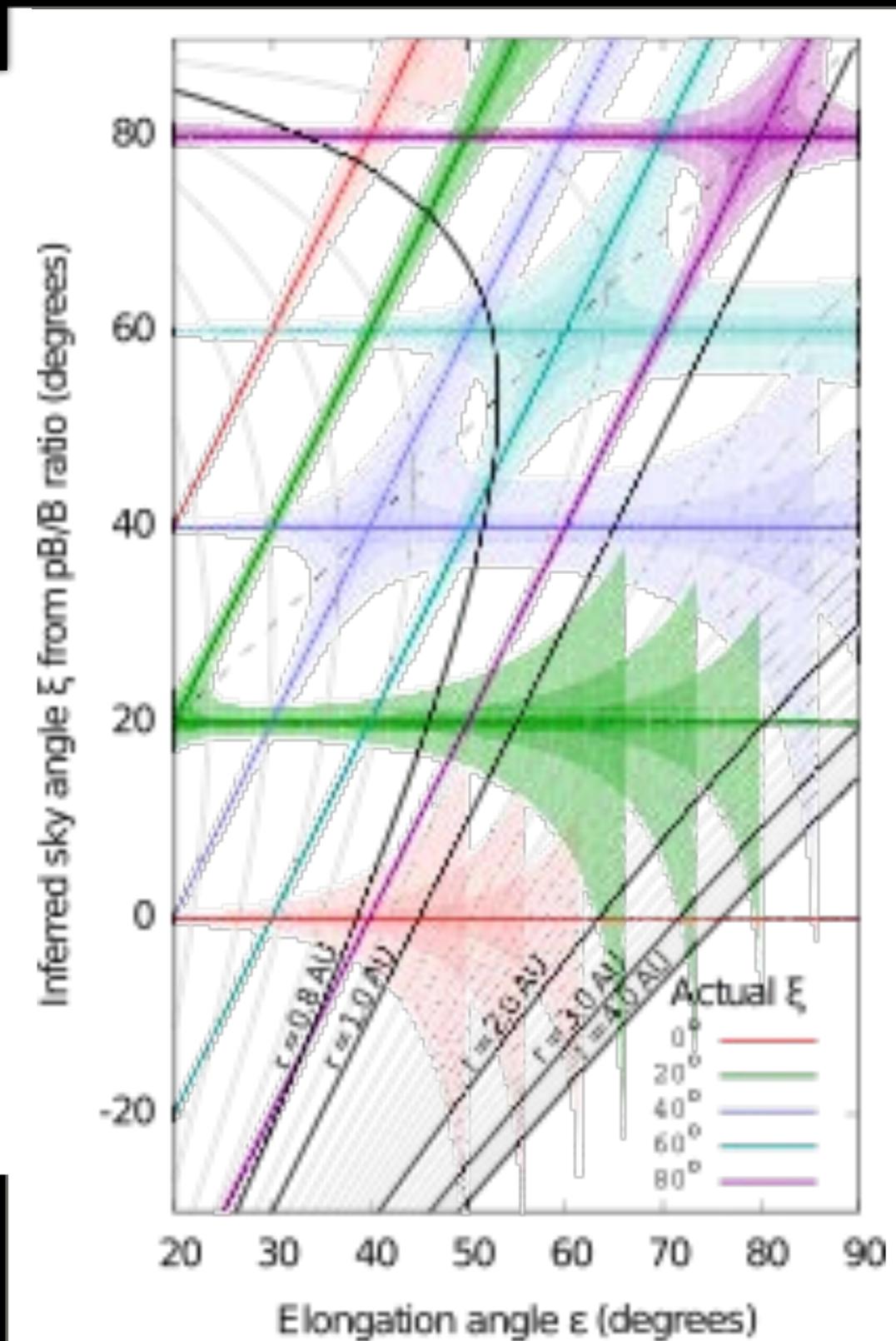
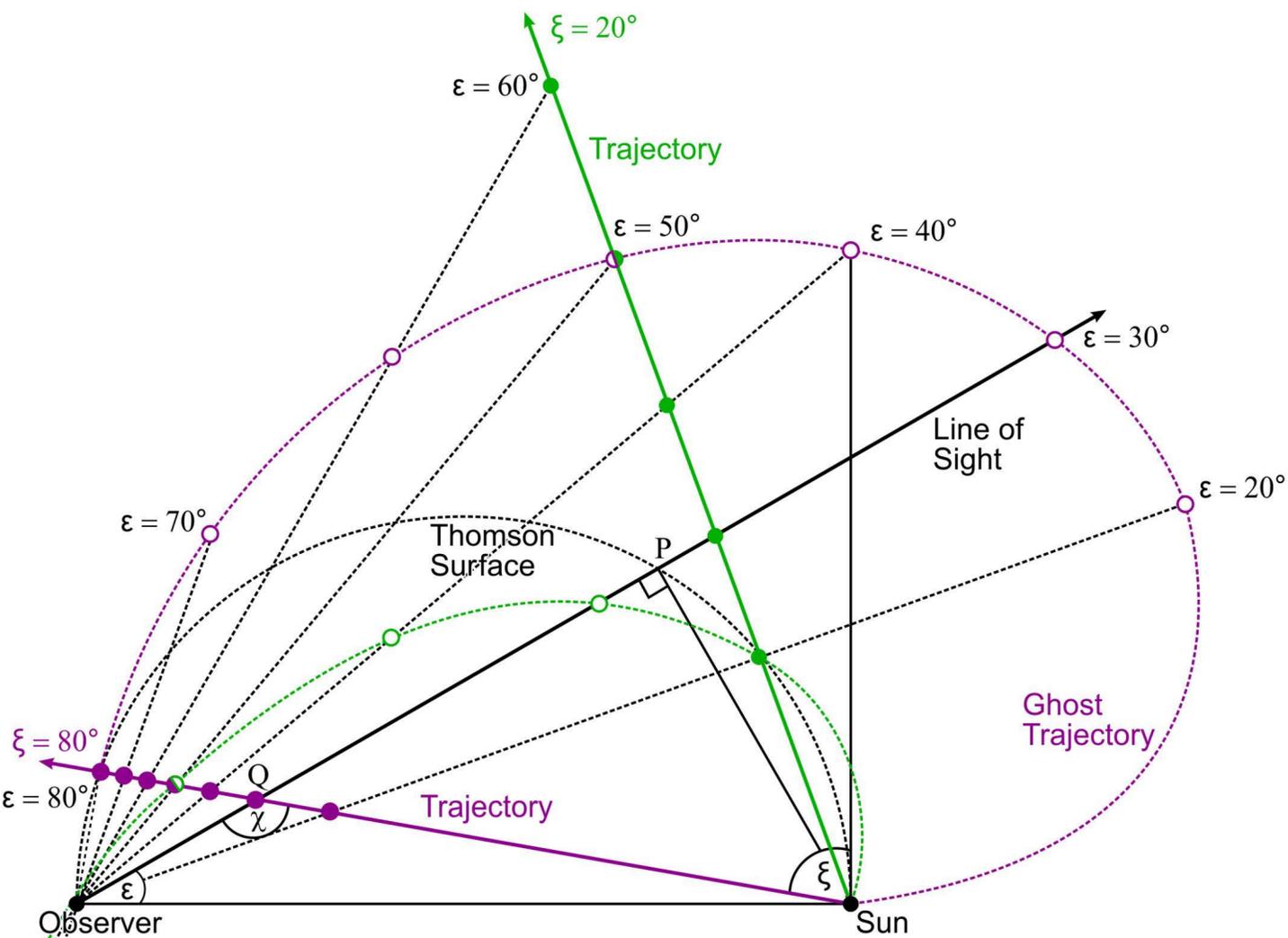
# 3-D location from polarimetry



- pB is “Stokes Q” in a solar-centric coordinate system.
- B is “Stokes I”.
- Thomson scattering physics: pB is positive-definite.
- pB/B ratio yields scattering angle.



# 3-D location from polarimetry

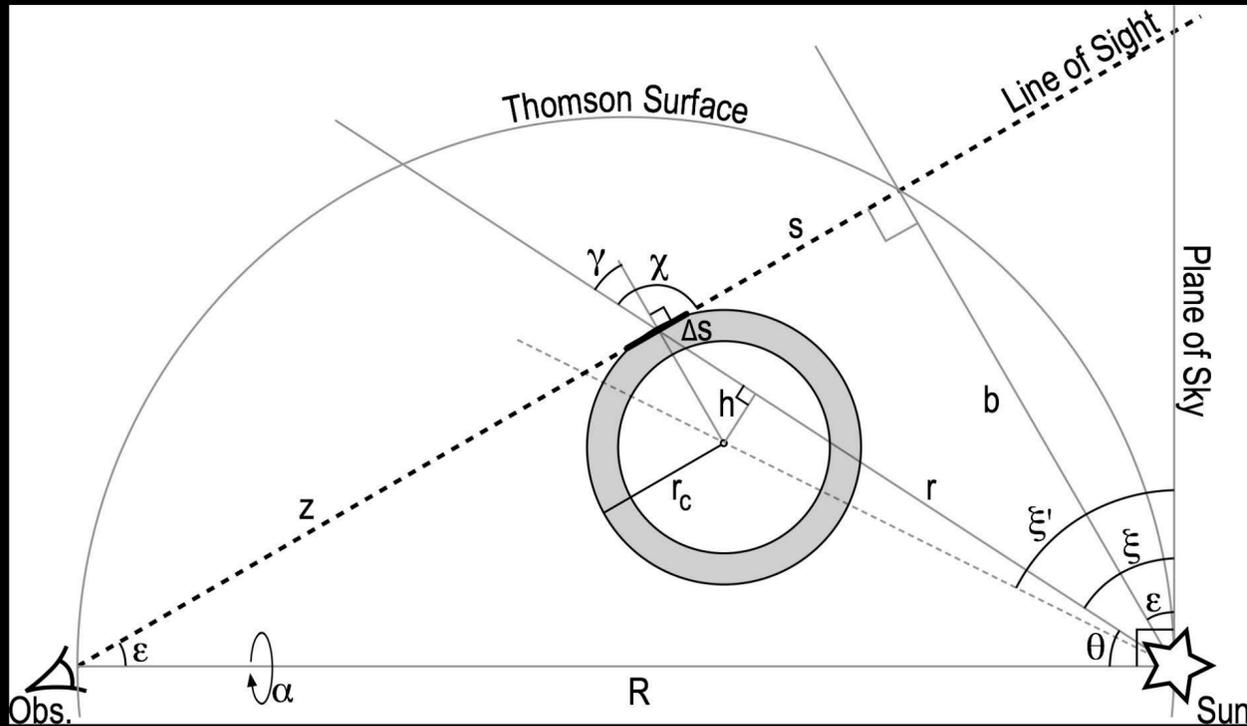


- Small features can be found via analytic inversion.
- Error propagation is well understood.

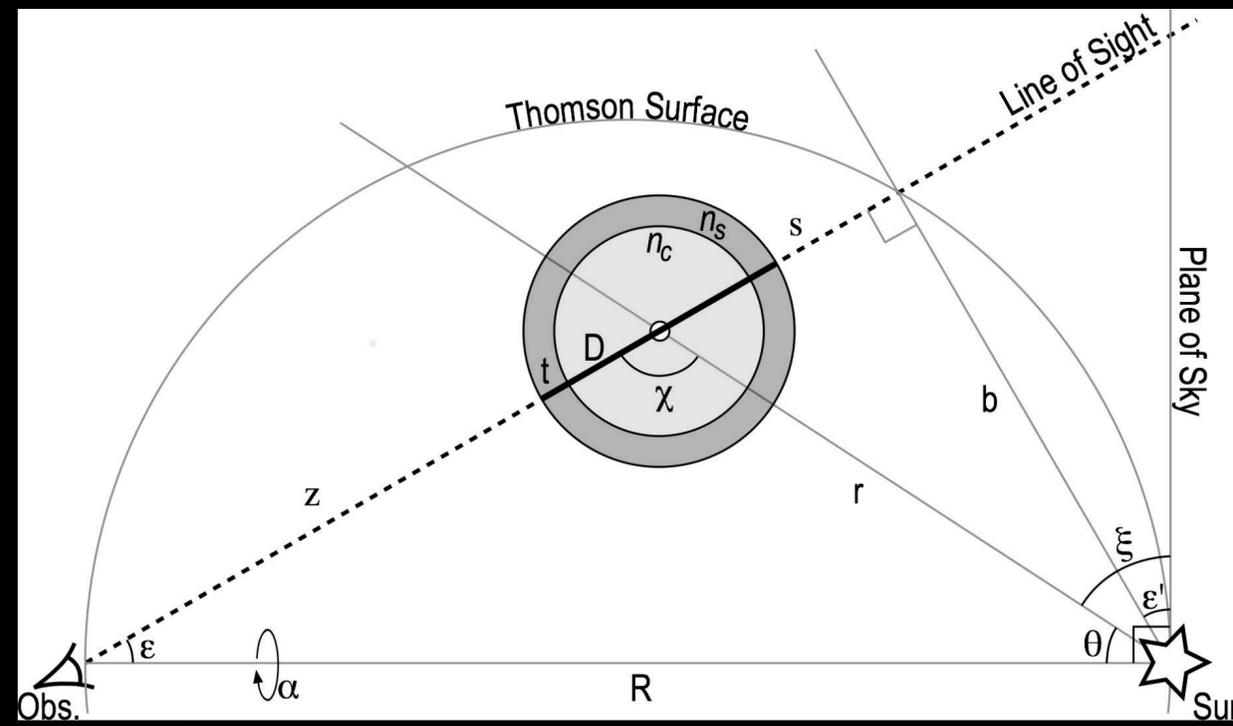
- Curvature of the Alfvén surface breaks the front/back symmetry.



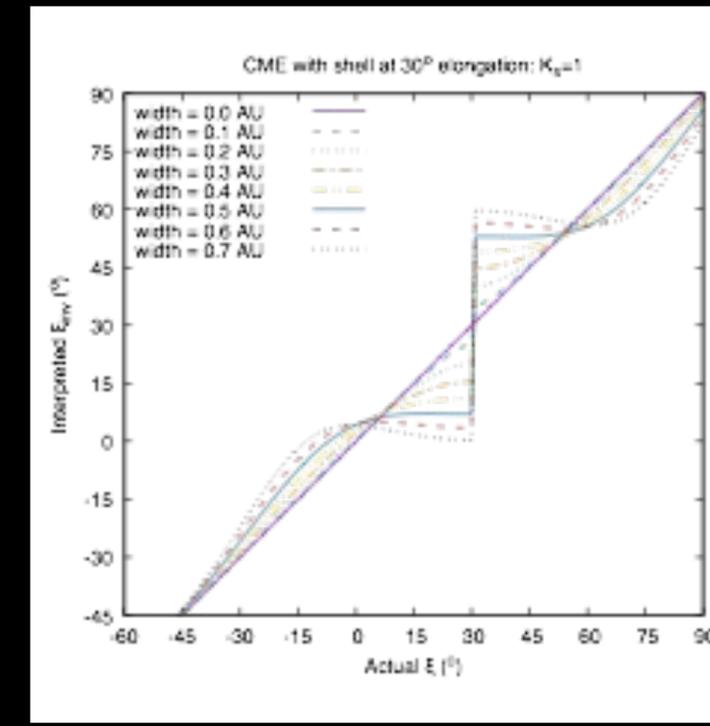
# Location of bulk CMEs: trickier but understood



**Small-angle formula applies at the leading edge.**



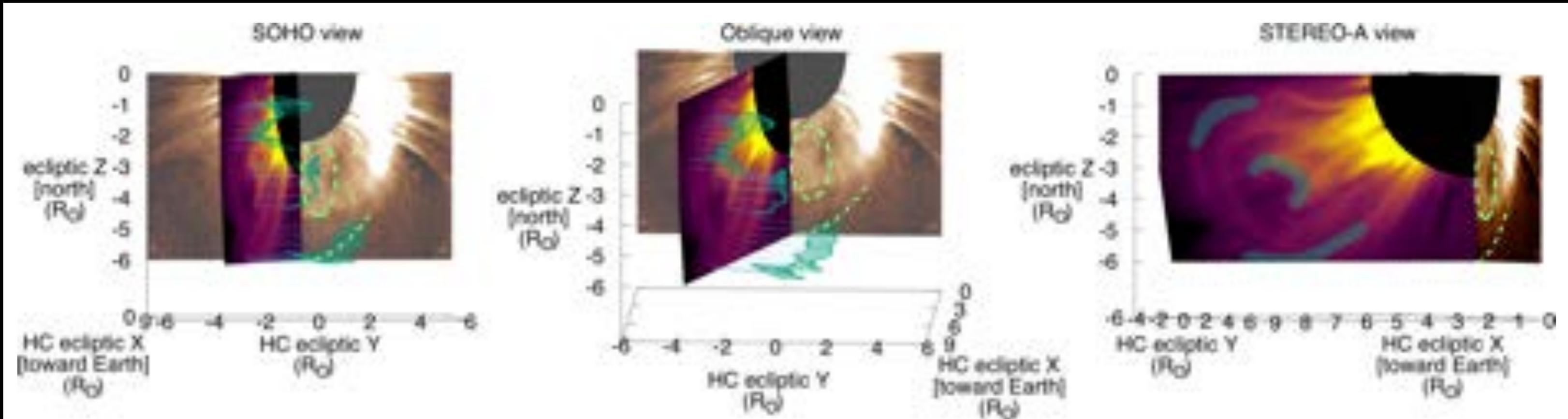
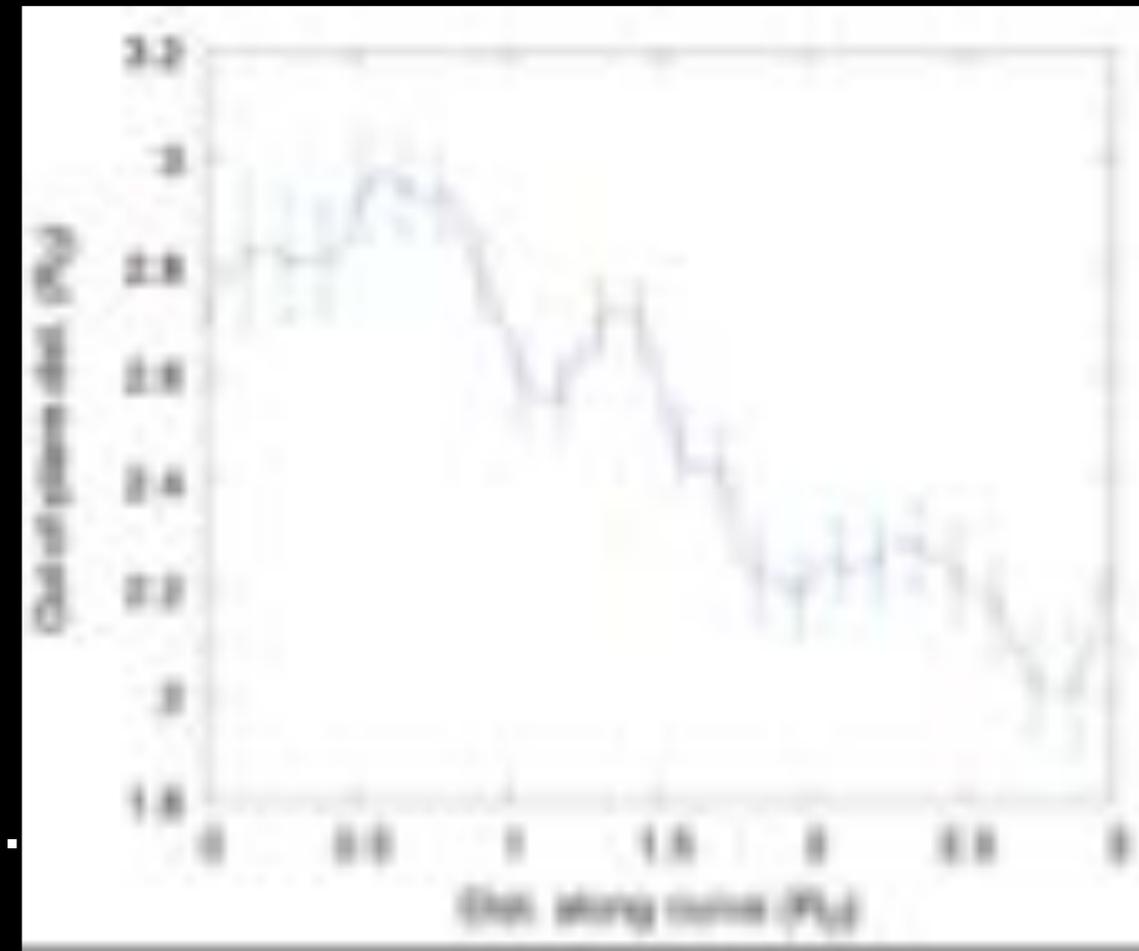
**Correction is required for a bulk structure.**





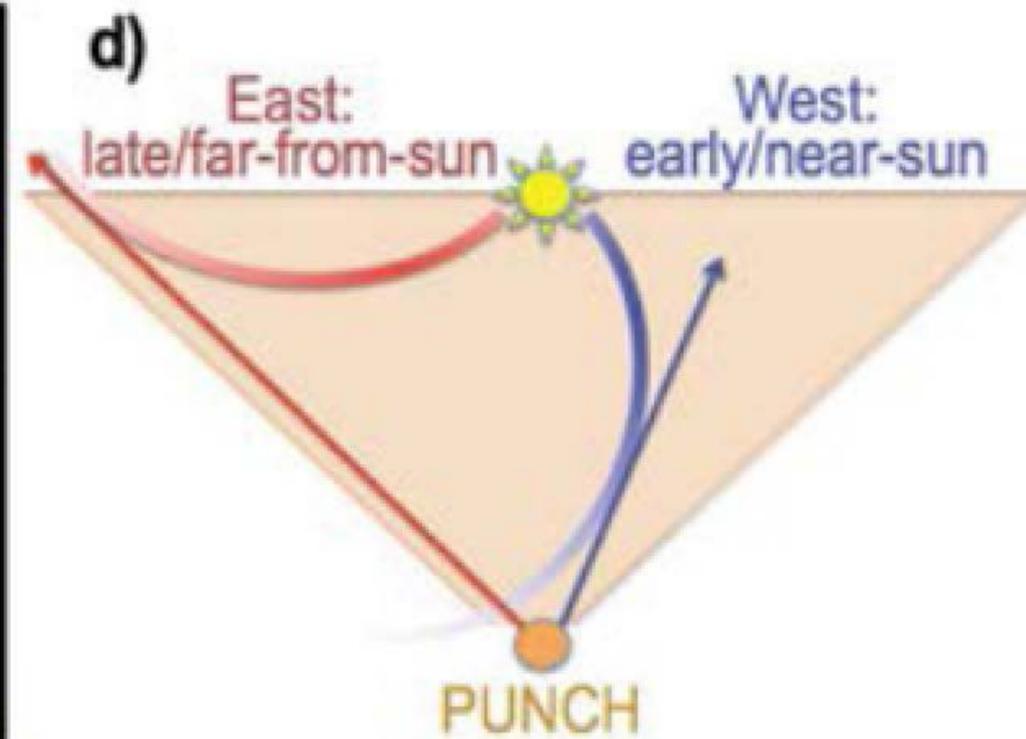
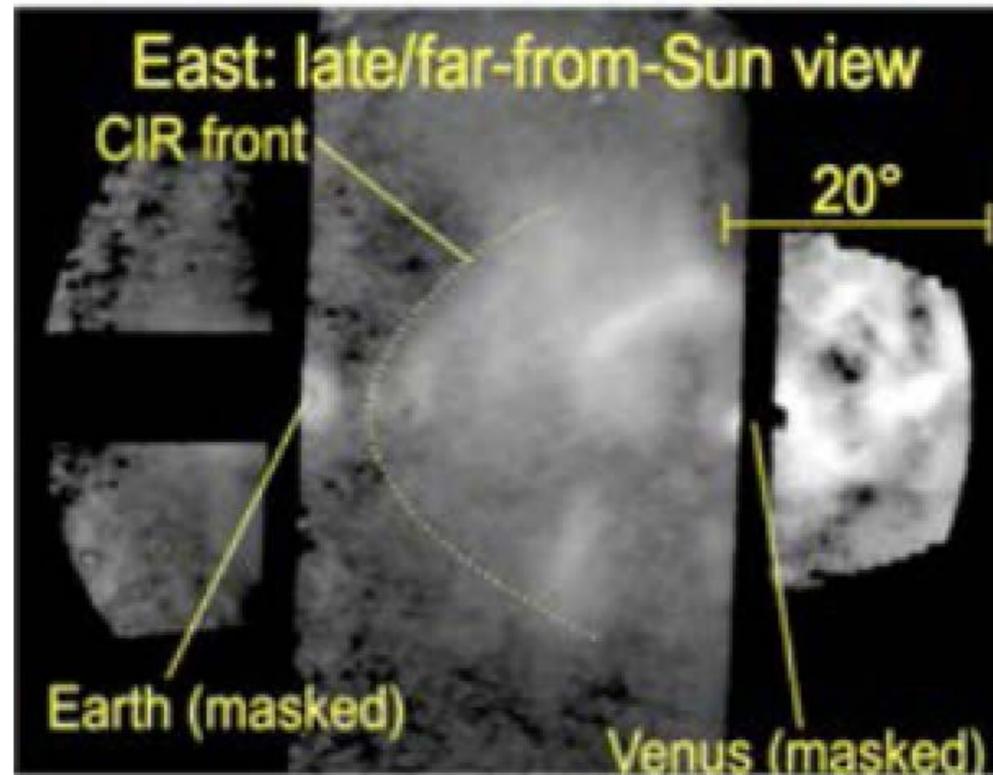
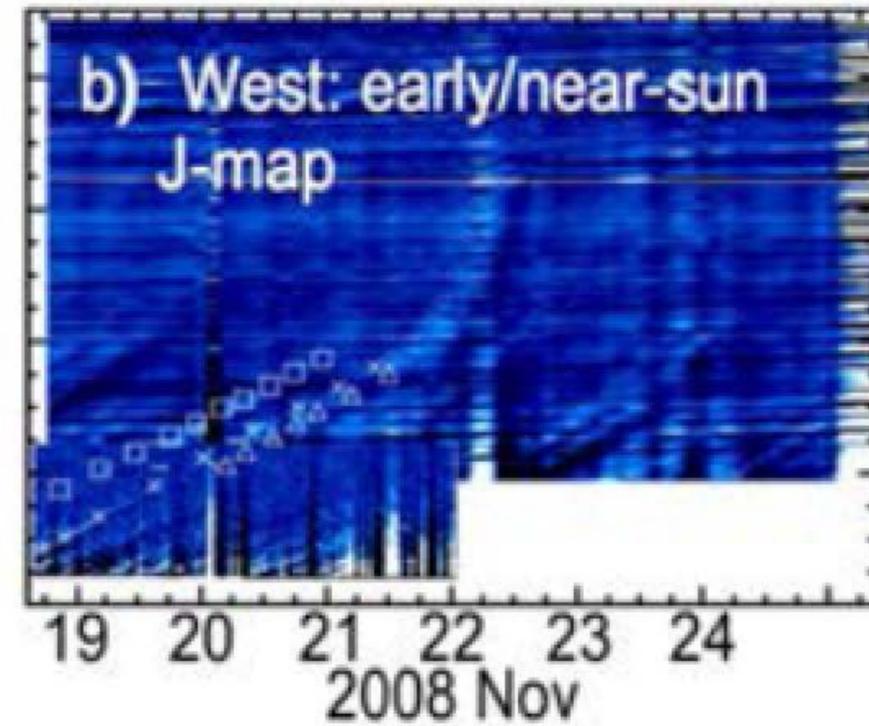
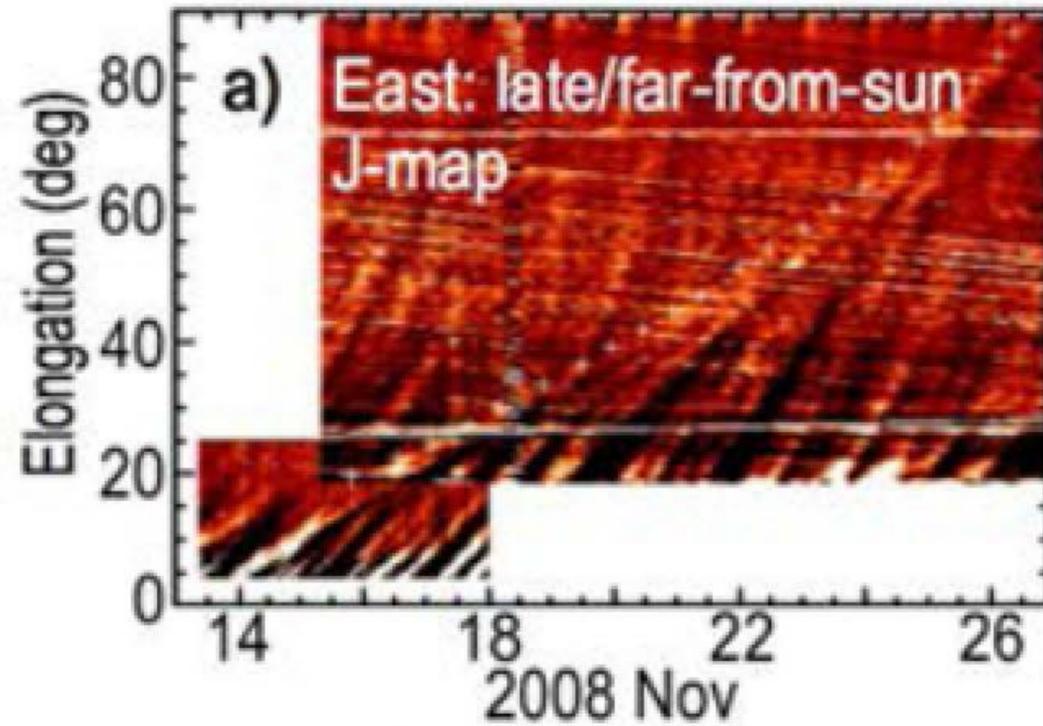
# 3-D Structure of CMEs

- CME envelopes are bubbles (Crifo et al. 1983) with complex internal structure (Tousey 1973).
- COR2 measurements reveal chirality via pB/B.
- PUNCH will follow evolution (CME-ICME) w/ 10x lower noise.
- L5: chirality helps predict leading-edge Bz from solar features.





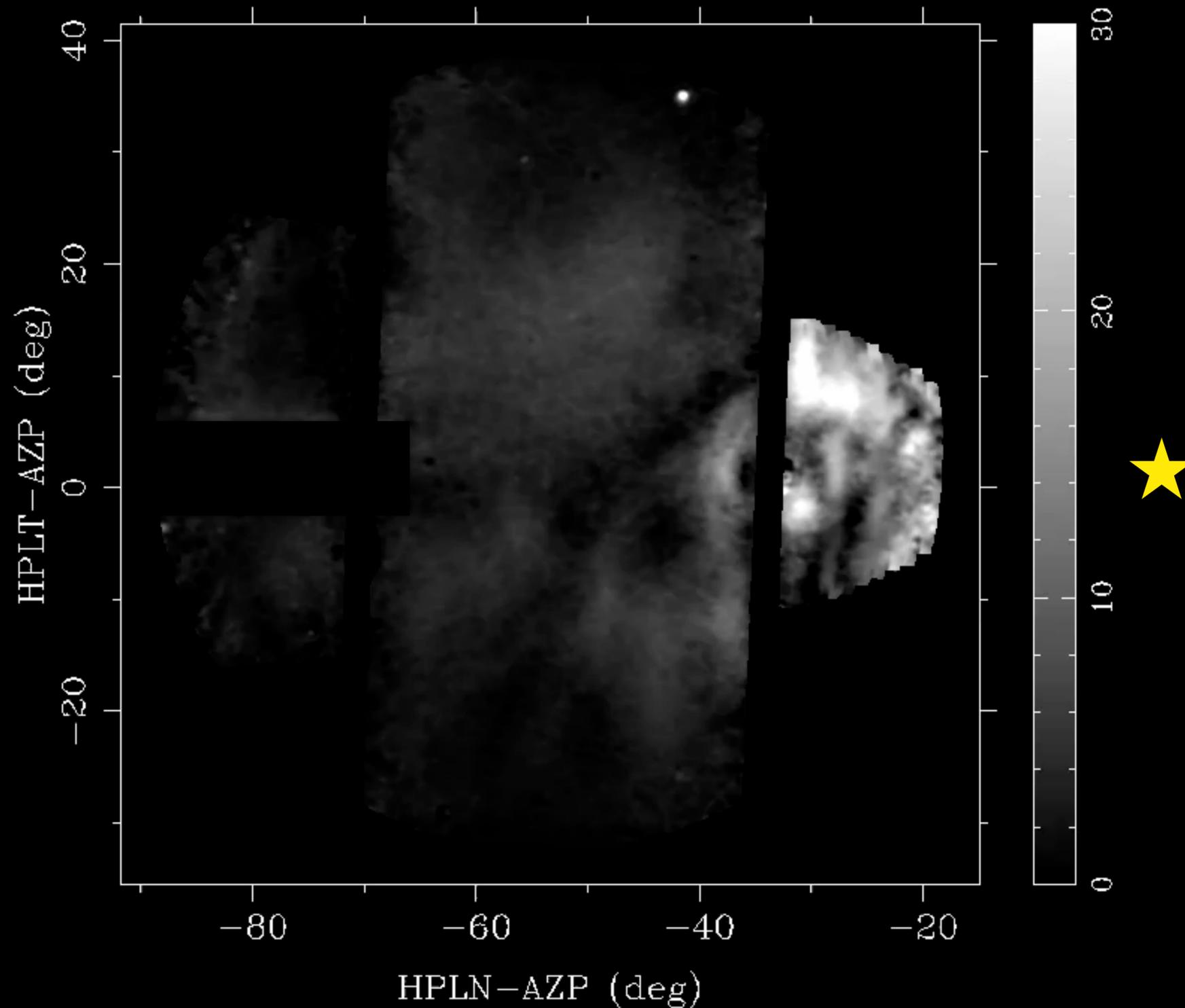
# A 3-D understanding of interplanetary CIRs





# A 3-D understanding of interplanetary CIRs

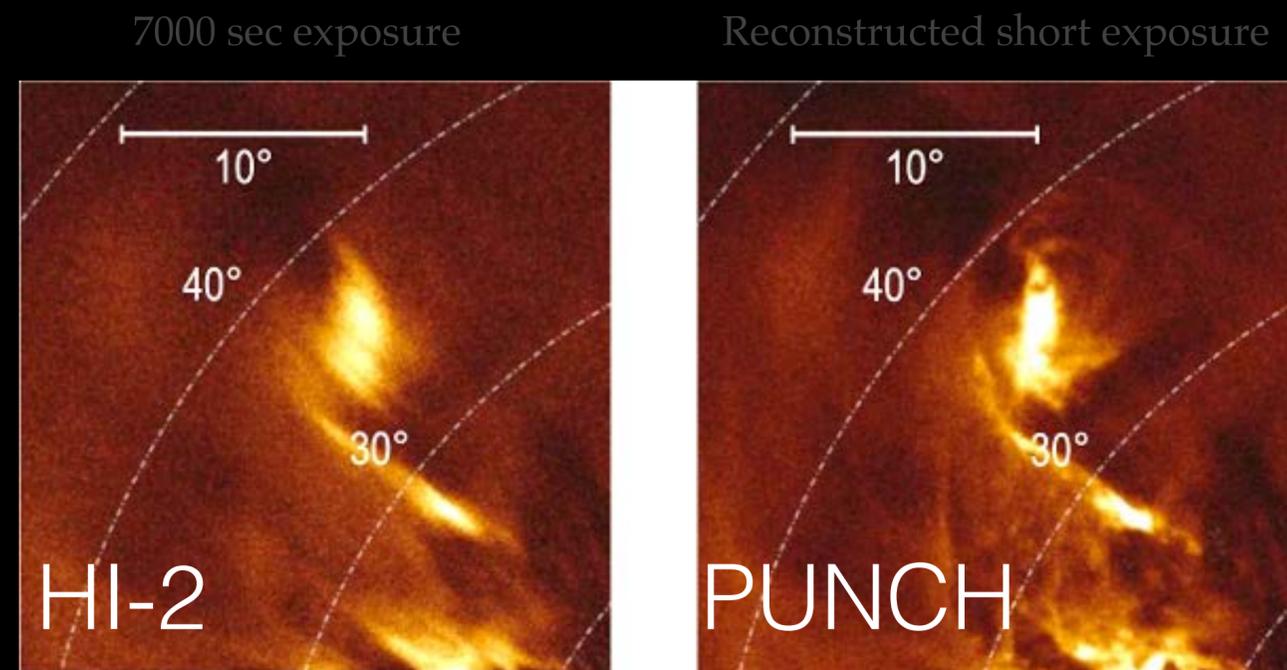
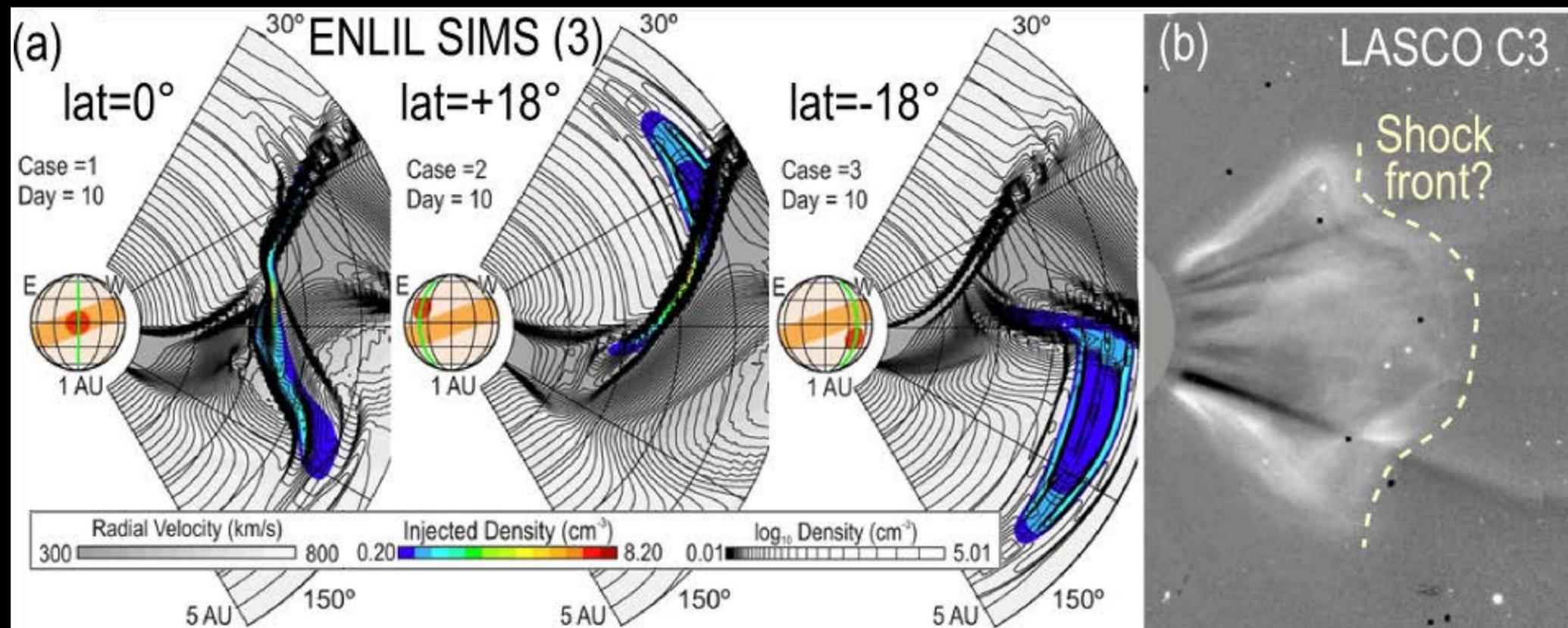
HI-2A clean ( $\times 10^{-17} B_0$ ) 2008-12-26 06:58





# High resolution shock imaging

- CME and CIR shocks are structured by the medium through which they travel.
- Instabilities and local evolution make shock fronts complex, affecting SEP acceleration.
- These effects are only indirectly to in-situ probes, but directly visible to PUNCH.
- L5: Preserve high spatial resolution to understand and predict effects of Earth-directed shocks





# Summary

- *PUNCH* is a SMEX to **unify understanding of the corona and heliosphere**.
- *PUNCH* collects **rapid, high resolution, polarized images** in white light.
- *PUNCH* is **10x more sensitive** than prior instruments.
- *PUNCH* generates **wind flow maps** every few hours.
- *PUNCH* performs **3-D imaging** of space weather relevant features, to improve space weather predictions.
- Status: competitive Phase A; downselect Spring 2019
- Launch: 2022