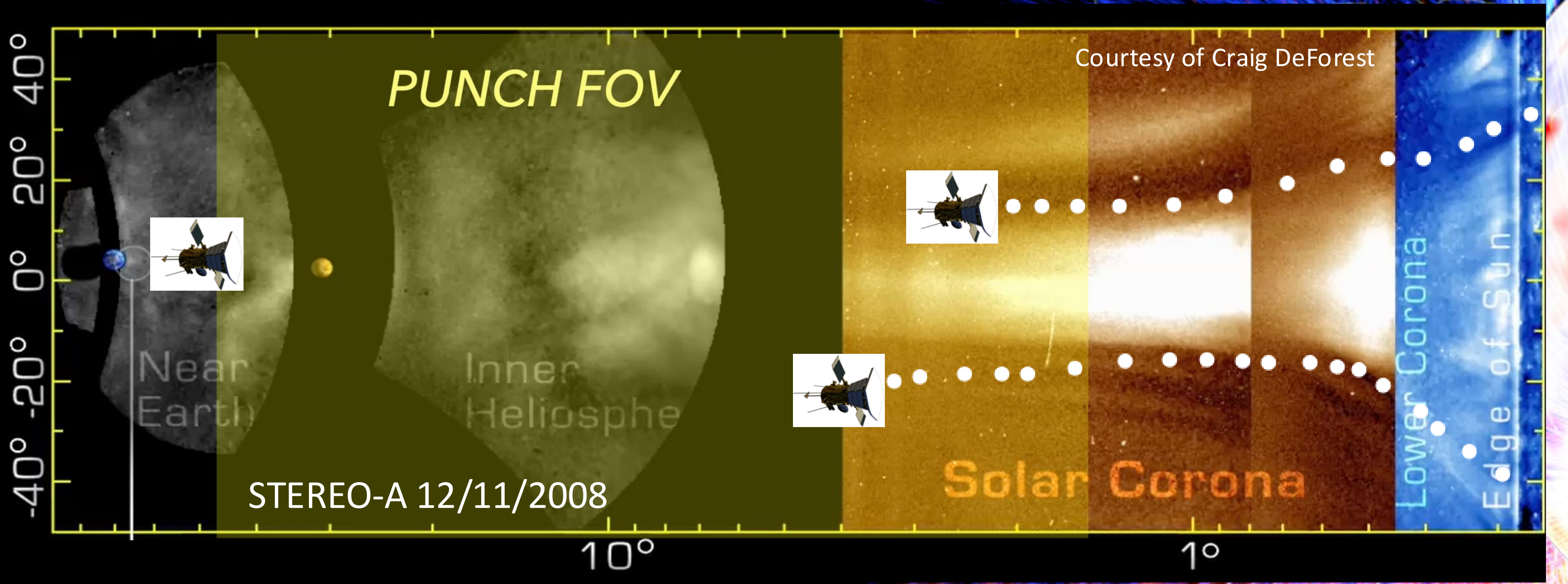
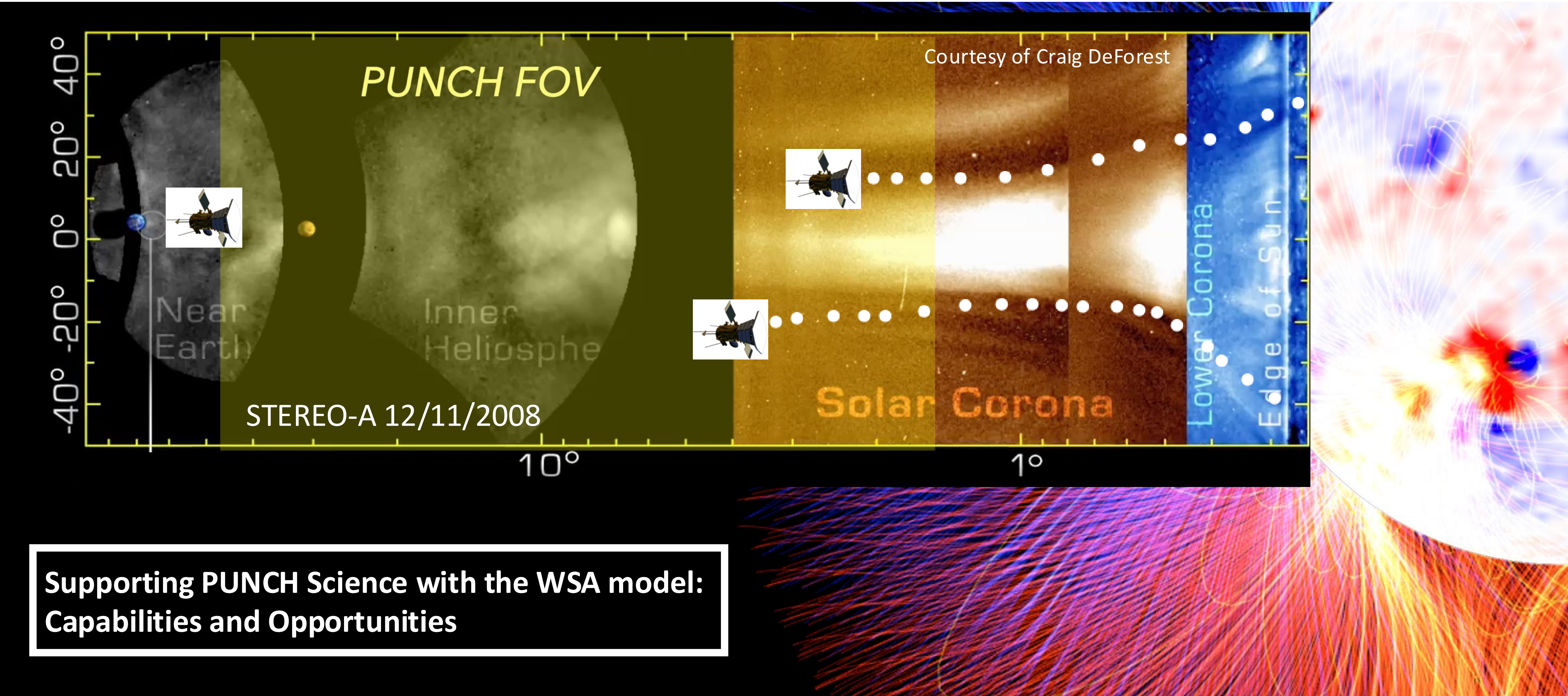
Supporting PUNCH Science with the WSA model: Capabilities and Opportunities



Samantha Wallace

PUNCH 7 – May 6th, 2026

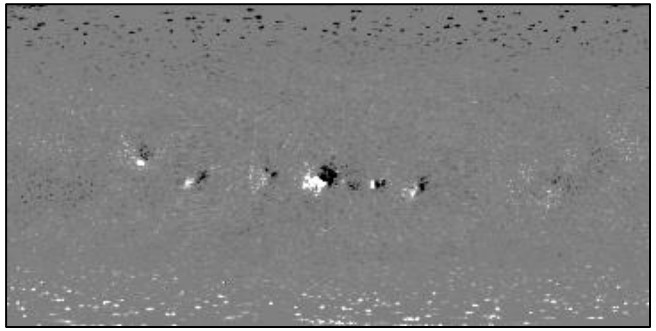
WSA provides the **coronal and heliospheric context** and the **in situ connection** necessary to advance PUNCH science objectives.



Supporting PUNCH Science with the WSA model: Capabilities and Opportunities

The ADAPT-WSA model

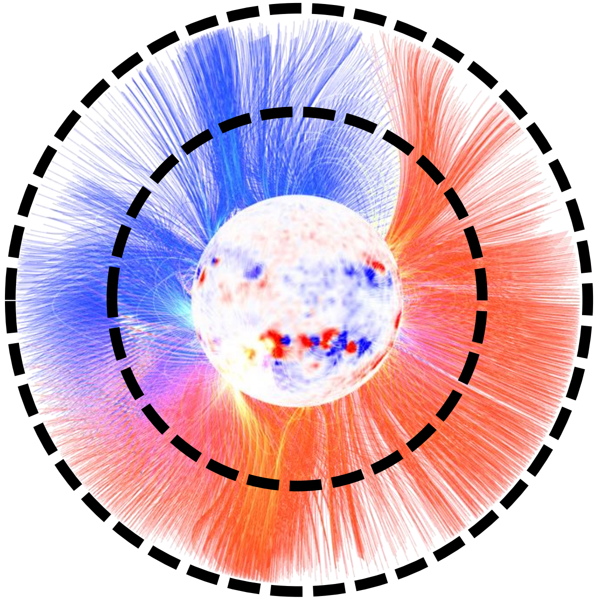
Input: ADAPT
(ensemble of 12 maps)



Arge+ 2010, 2011, 2013, Hickmann+ 2015

Derived from magnetograms provided by HMI, GONG, VSM etc.

WSA
PFSS + SCS



Arge and Pizzo 2000, Arge+ 2003, 2004

$$V(f_s, \theta_b) = 285 + \frac{625}{(1+f_s)^{2/9}}\left\{1.0 - 0.8e^{-\left(\theta_b/2\right)^2}\right\}^3$$

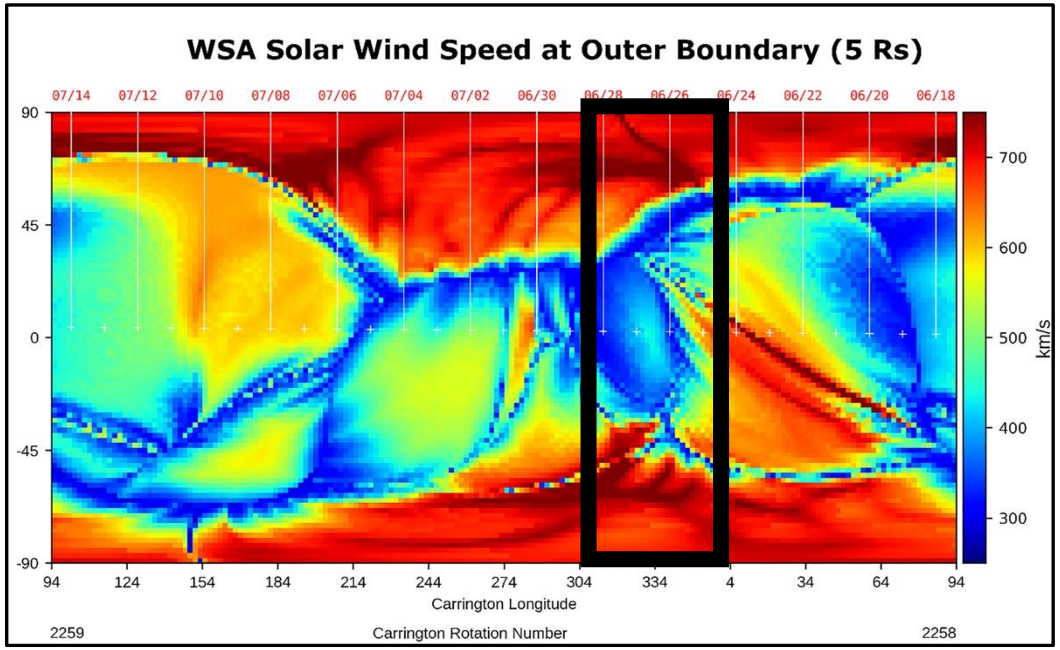
Air Force Data Assimilative Photospheric Flux Transport (ADAPT) model

Wang-Sheeley-Arge (WSA) model

1A/1B: Global solar wind outflow and mesostructures

WSA output provides the context needed for PUNCH to identify true fast solar wind source regions, even when PUNCH LOS brightness is dominated and obscured by denser slow wind.

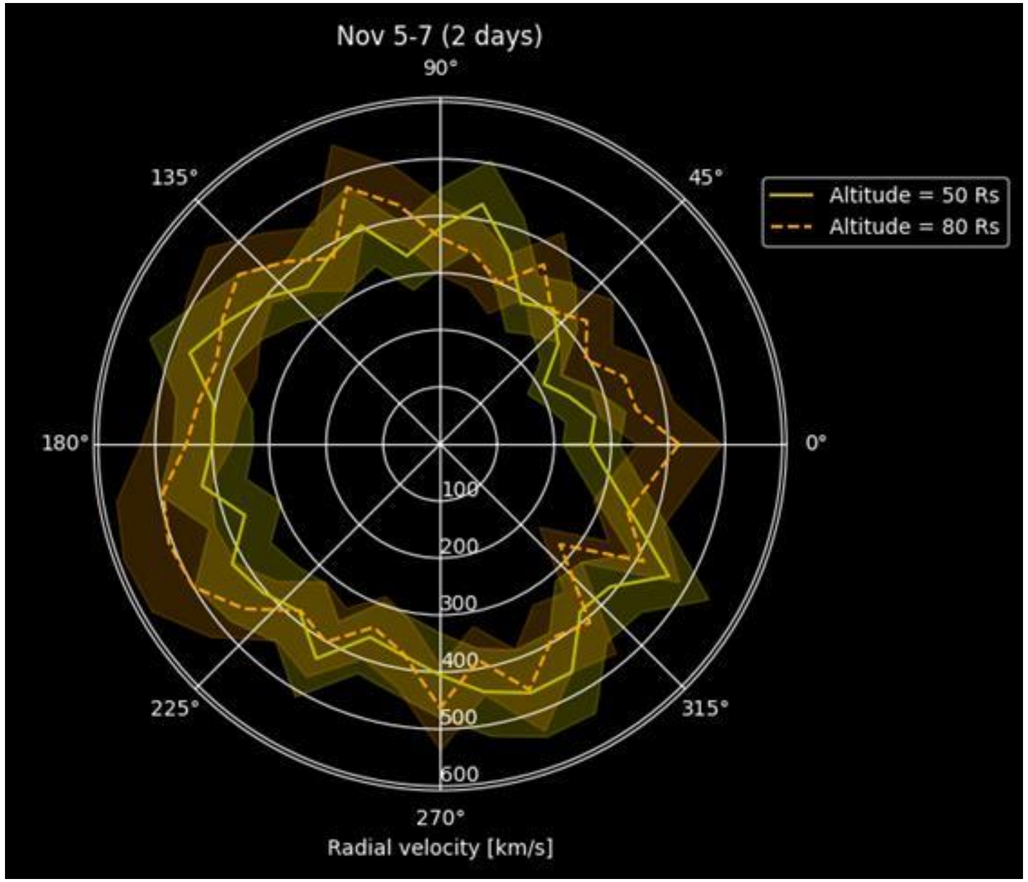
WSA terminal ("1 AU") solar wind speed



…and 3D density cubes in the works with WSA-FORWARD

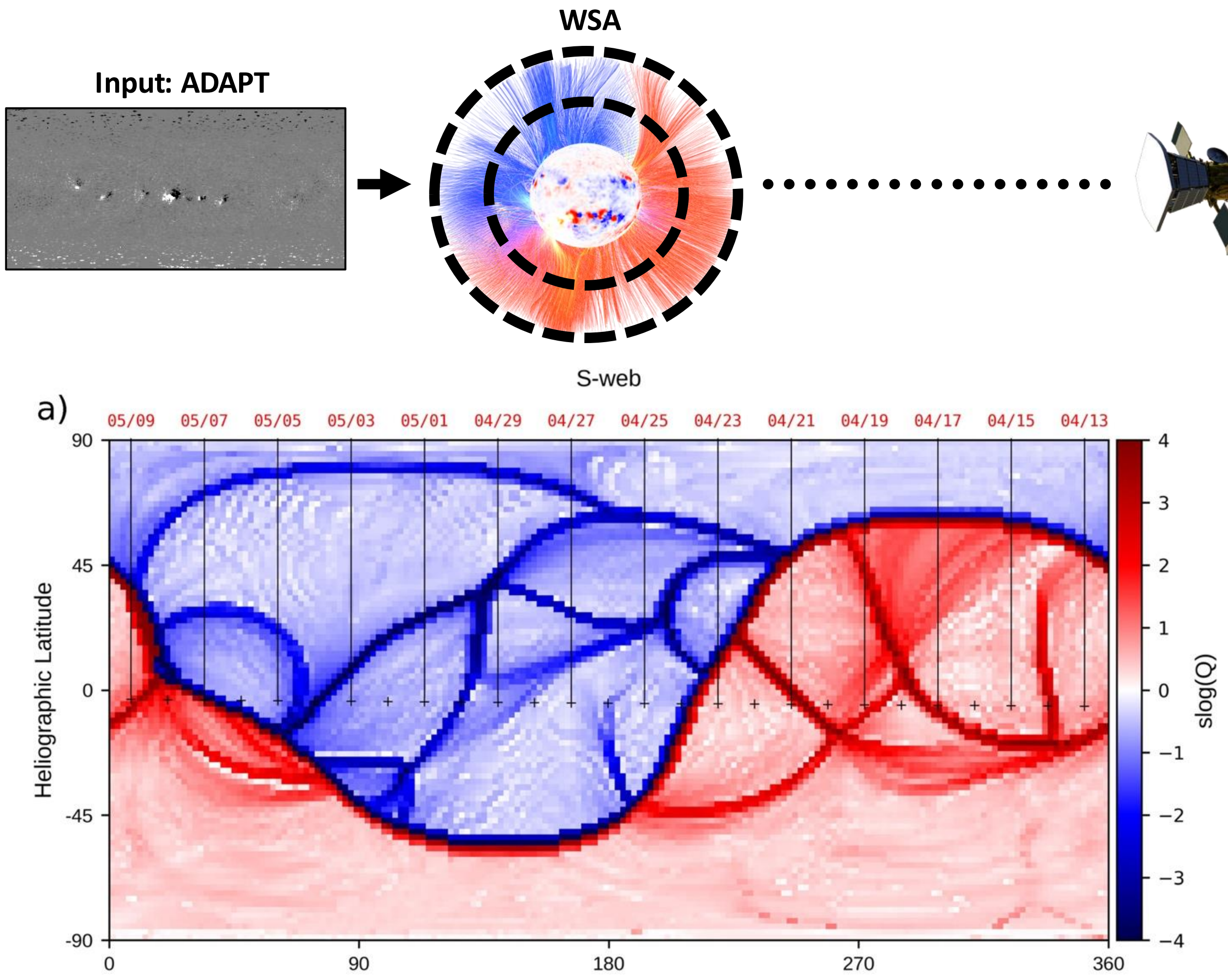
(Alison Farrish, Sarah Gibson, et al)

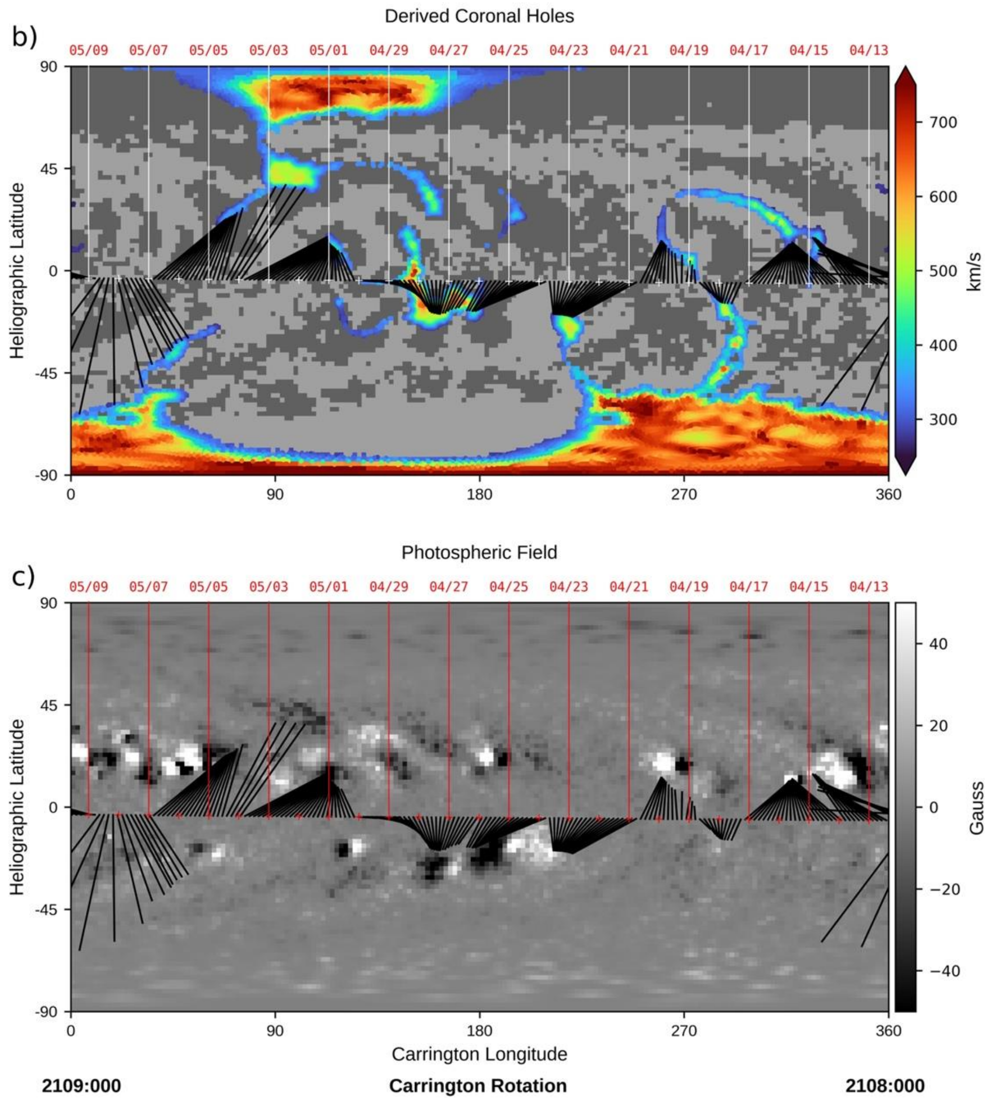
PUNCH flow map
Solar wind speed as a function of latitude



Flow maps generated by Raphael Attie

WSA now routinely derives the S-web, enabling a direct link between solar wind measurements and the complex coronal magnetic topologies at their source.





Wallace, Higginson, Simpson, Viall, Wyper, & Arge, 2025
JGR Space Physics

What does the S-web reveal?

- The SLs and QSLs that form due to the topological mapping of the coronal field, both **near to and far from the HCS.**
- The sources of **coronal dynamics, magnetic reconnection, and structured solar wind.**
- **The connections** between seemingly separate flux systems at the photosphere.
- Low $|\log(Q)|$ reveals coronal hole expansion at a given R_s, and the spatial extent of the resulting solar wind outflow.

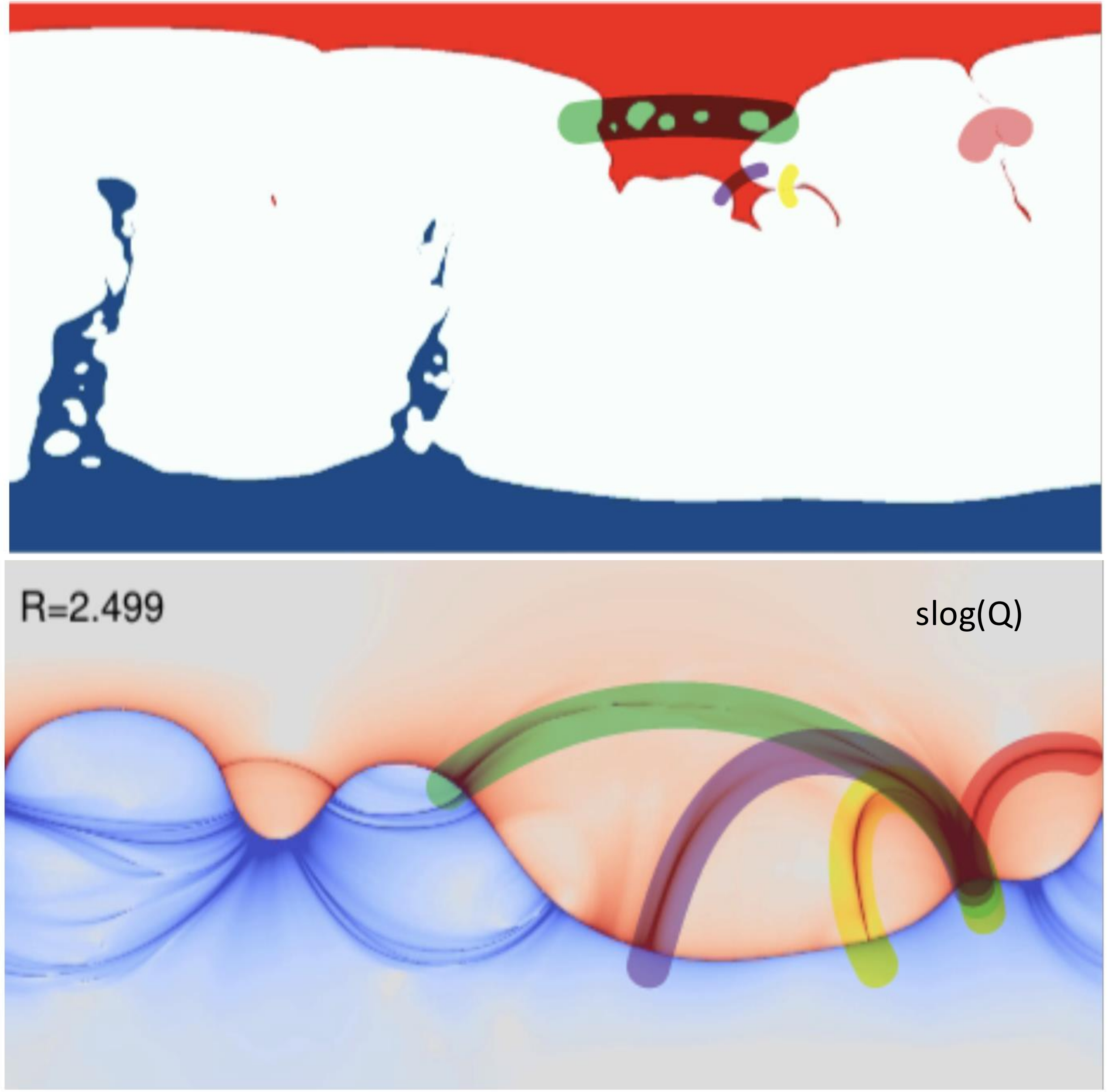
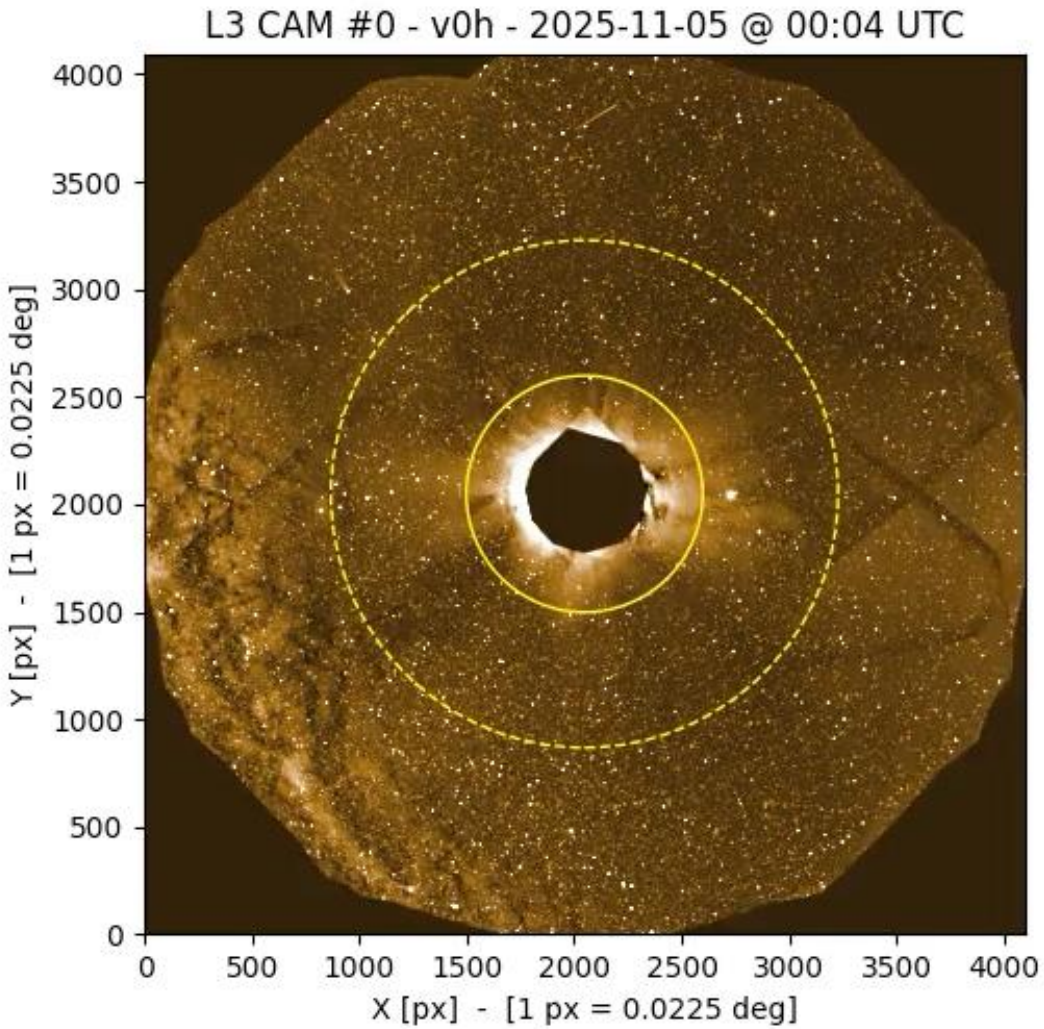
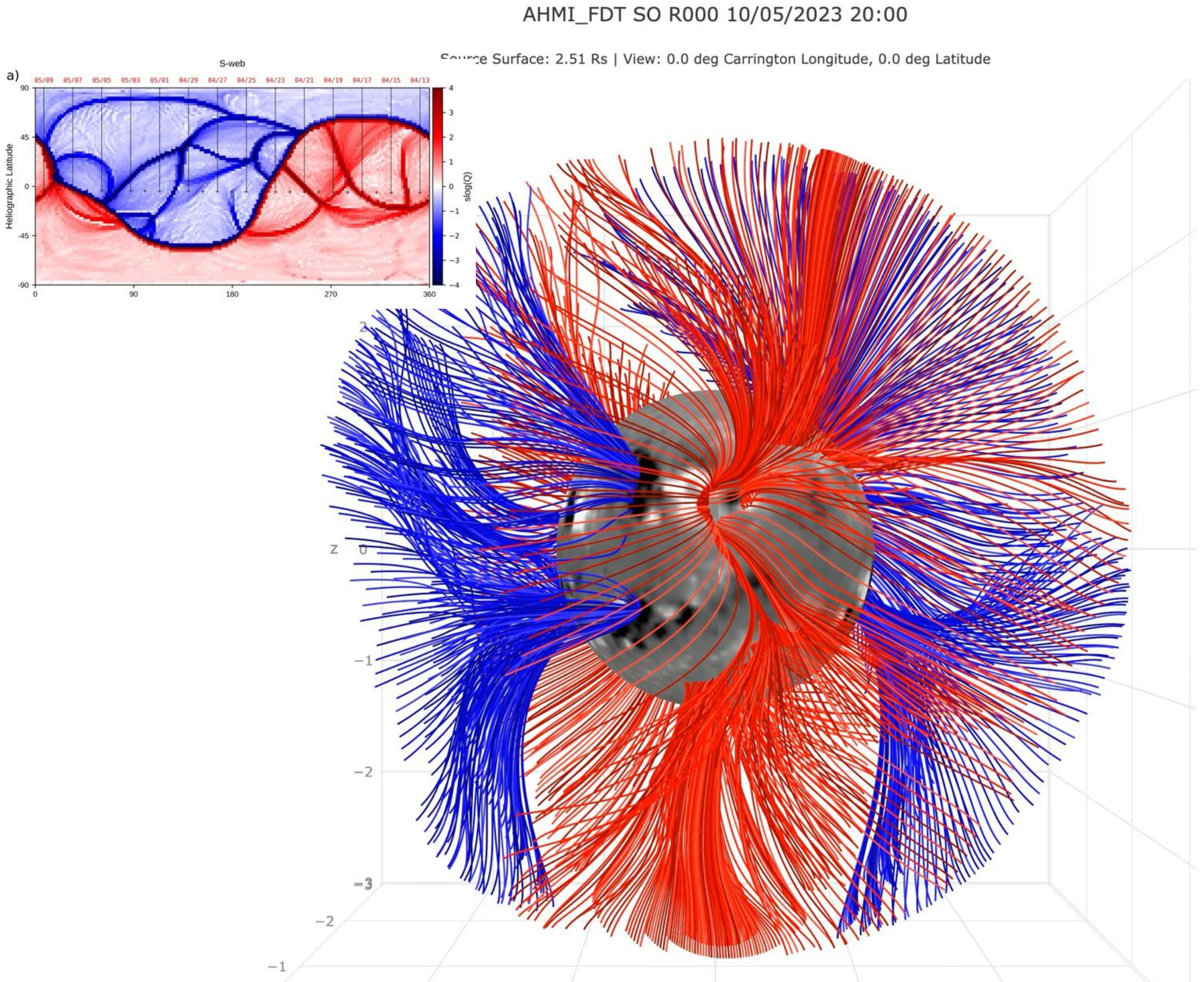


Figure courtesy of Aleida Higginson

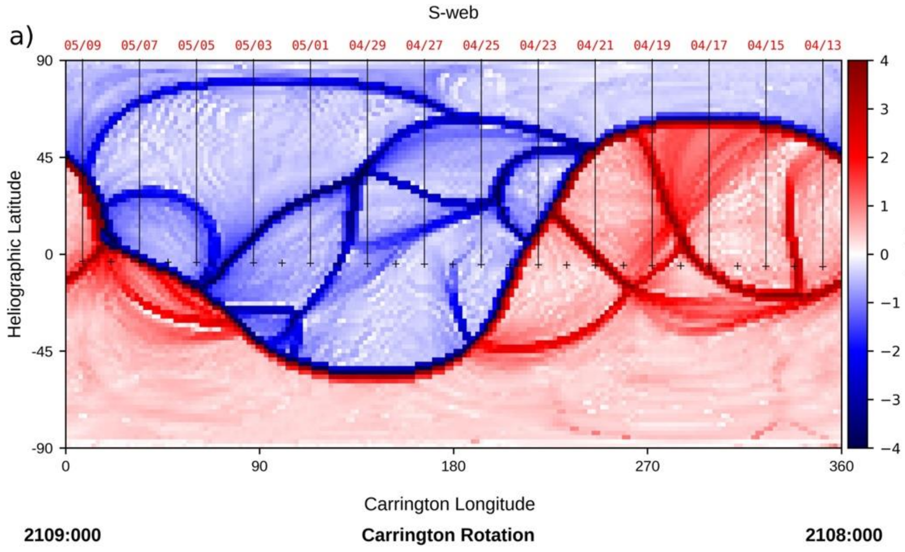
Rendering the S-web in 3D reveals the complex coronal structures and multiple source regions contributing solar wind along the line of sight.

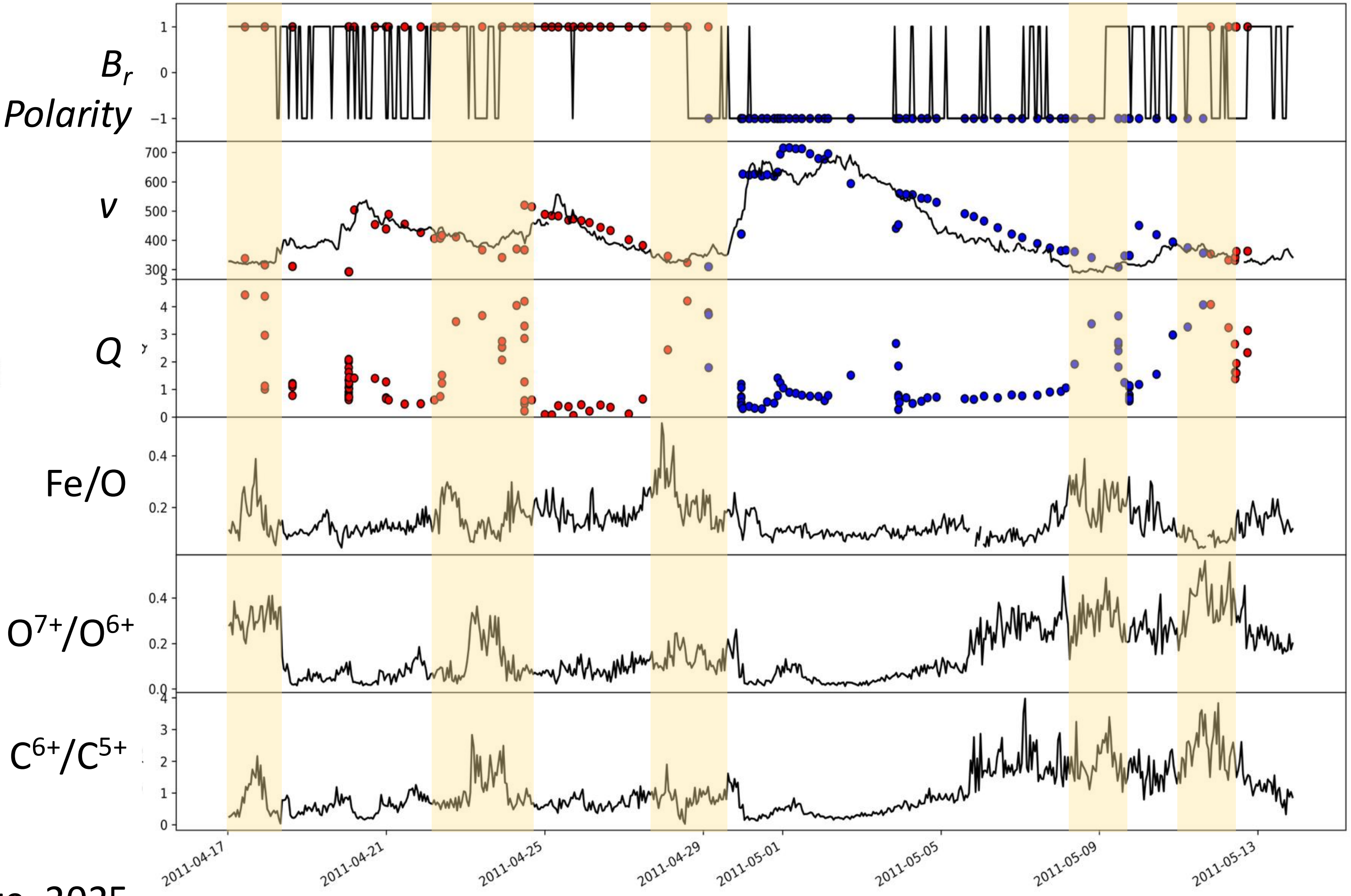




Software developed by Jaime Landeros, UCSD

In situ connection: Solar source regions with **high log(Q)** correspond to slow, hot solar wind with **enhanced and variable FIP and charge states at L1.**

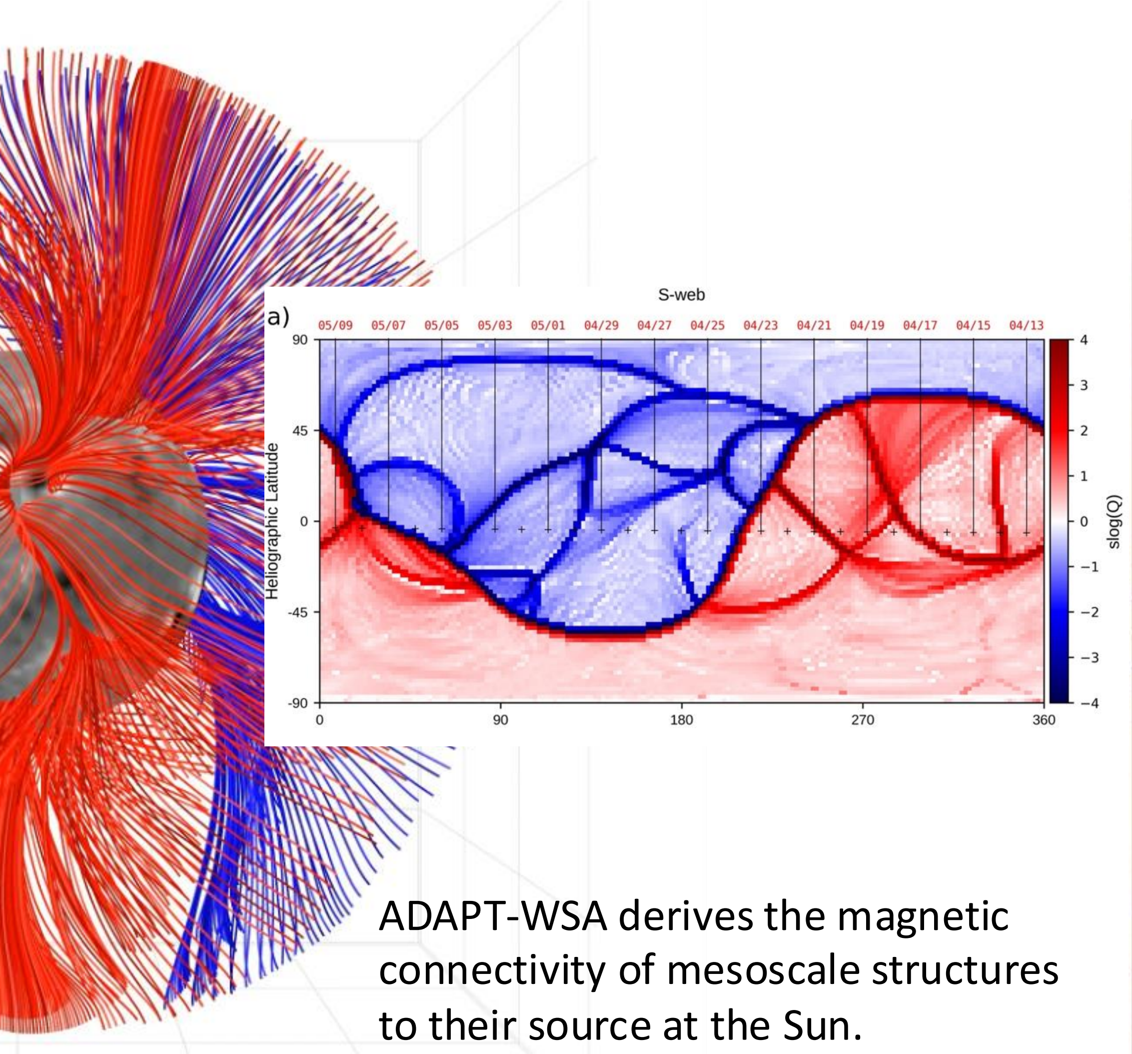




Wallace, Higginson, Simpson, Viall, Wyper, & Arge, 2025
JGR Space Physics

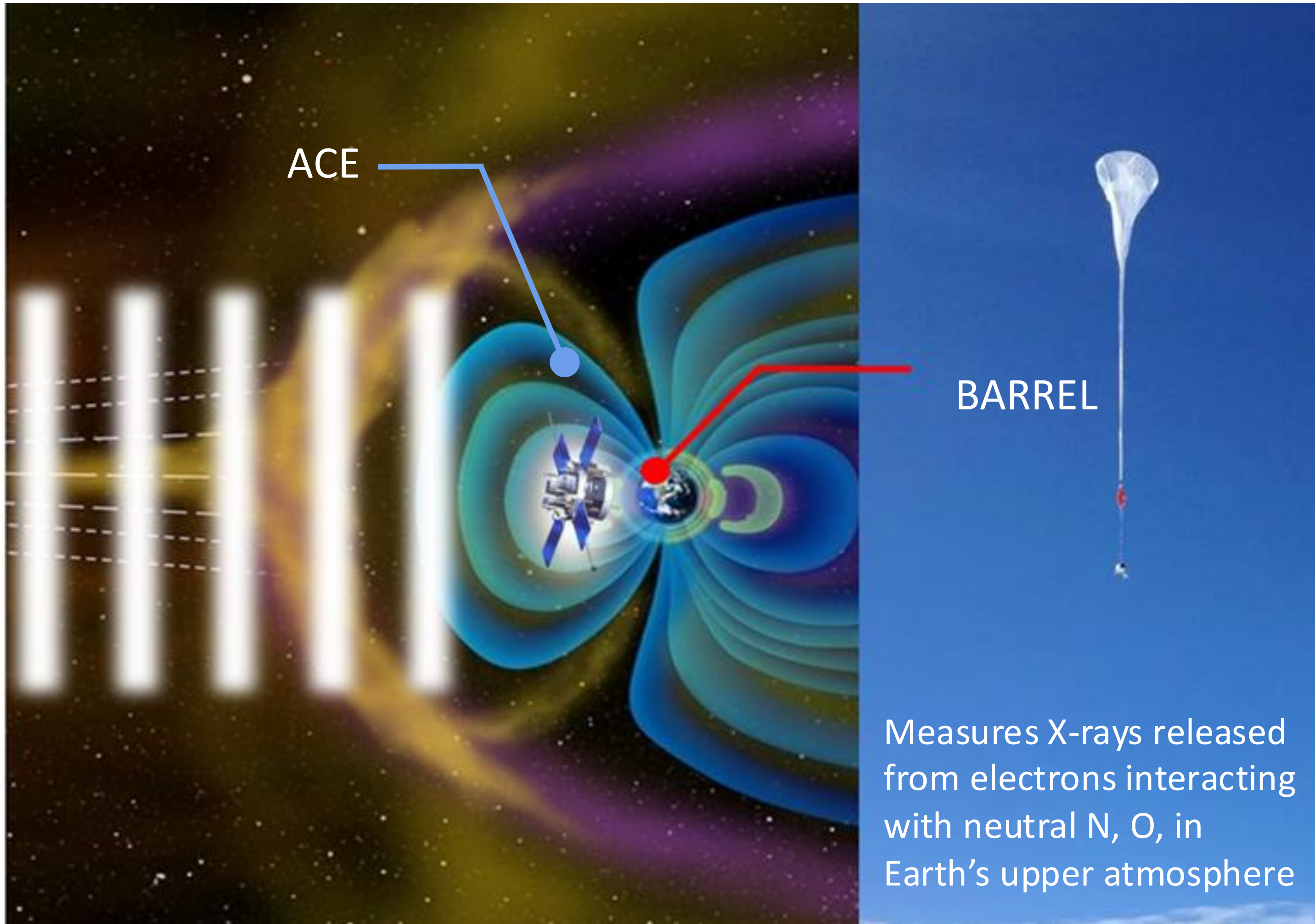
Characterizing the aspects of solar wind formation that produce geoeffective mesoscale solar wind.

Periodic density structures responsible for radiation belt depletion preferentially originate from the S-web!



ADAPT-WSA derives the magnetic connectivity of mesoscale structures to their source at the Sun.

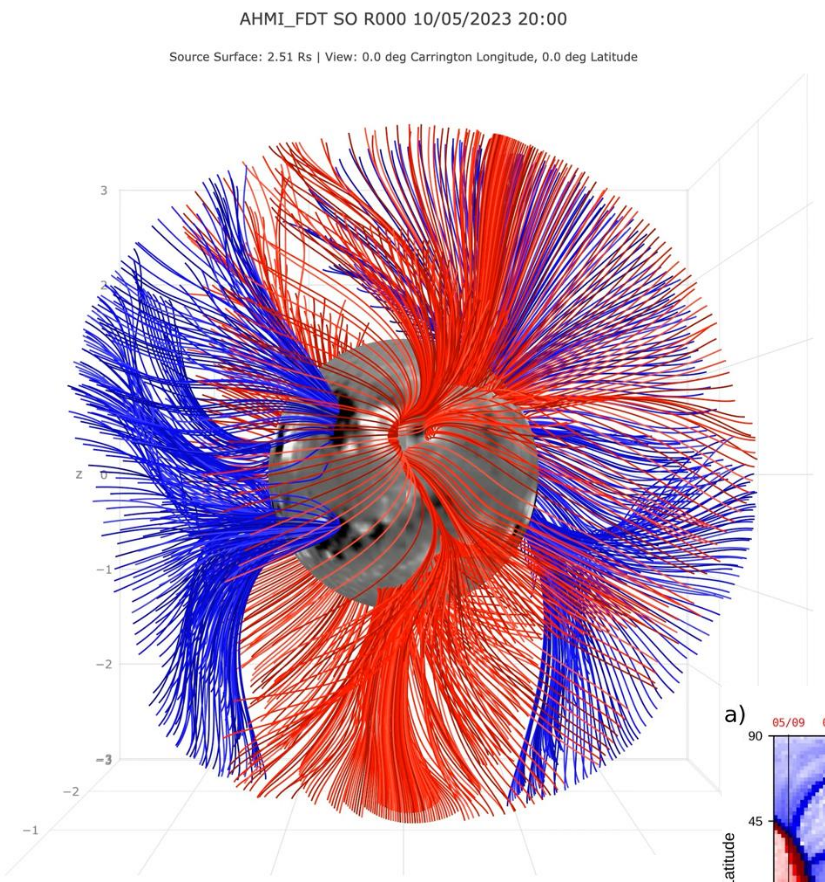
Gratton, Wallace, Viall, Di Matteo (in prep)

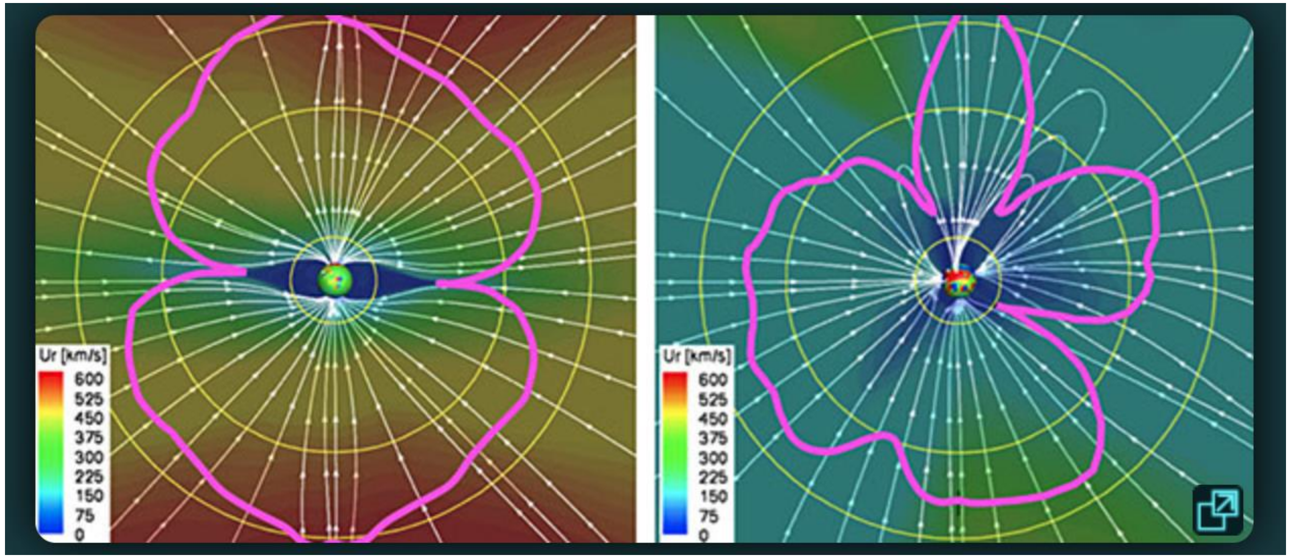


Measures X-rays released from electrons interacting with neutral N, O, in Earth's upper atmosphere

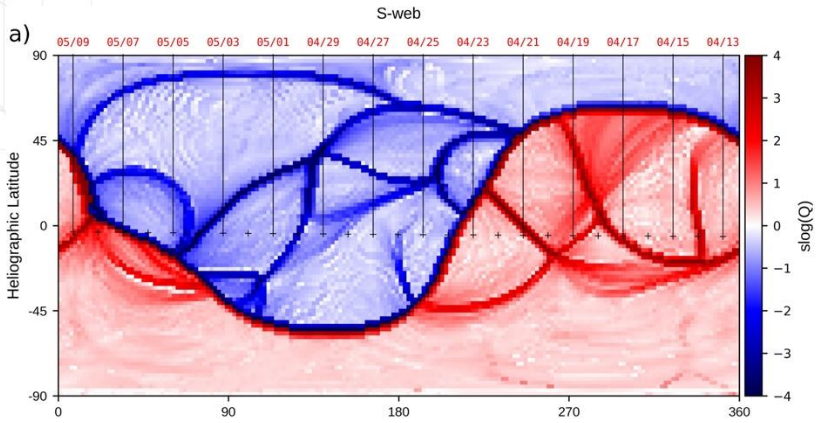
1C: Alfven Zone: Boundary of the Heliosphere

Does the Alfven zone morphology correlate with the 3D S-web topology?





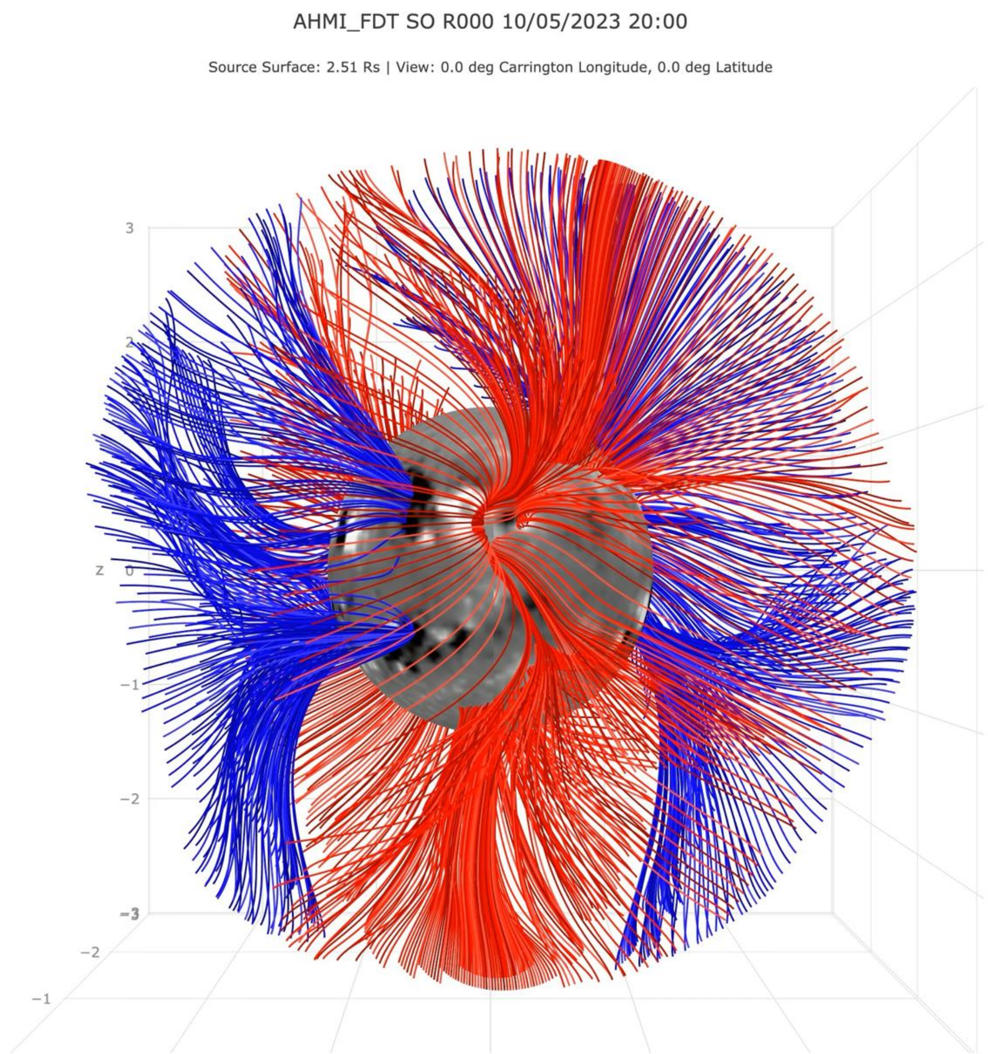
Cohen, 2015

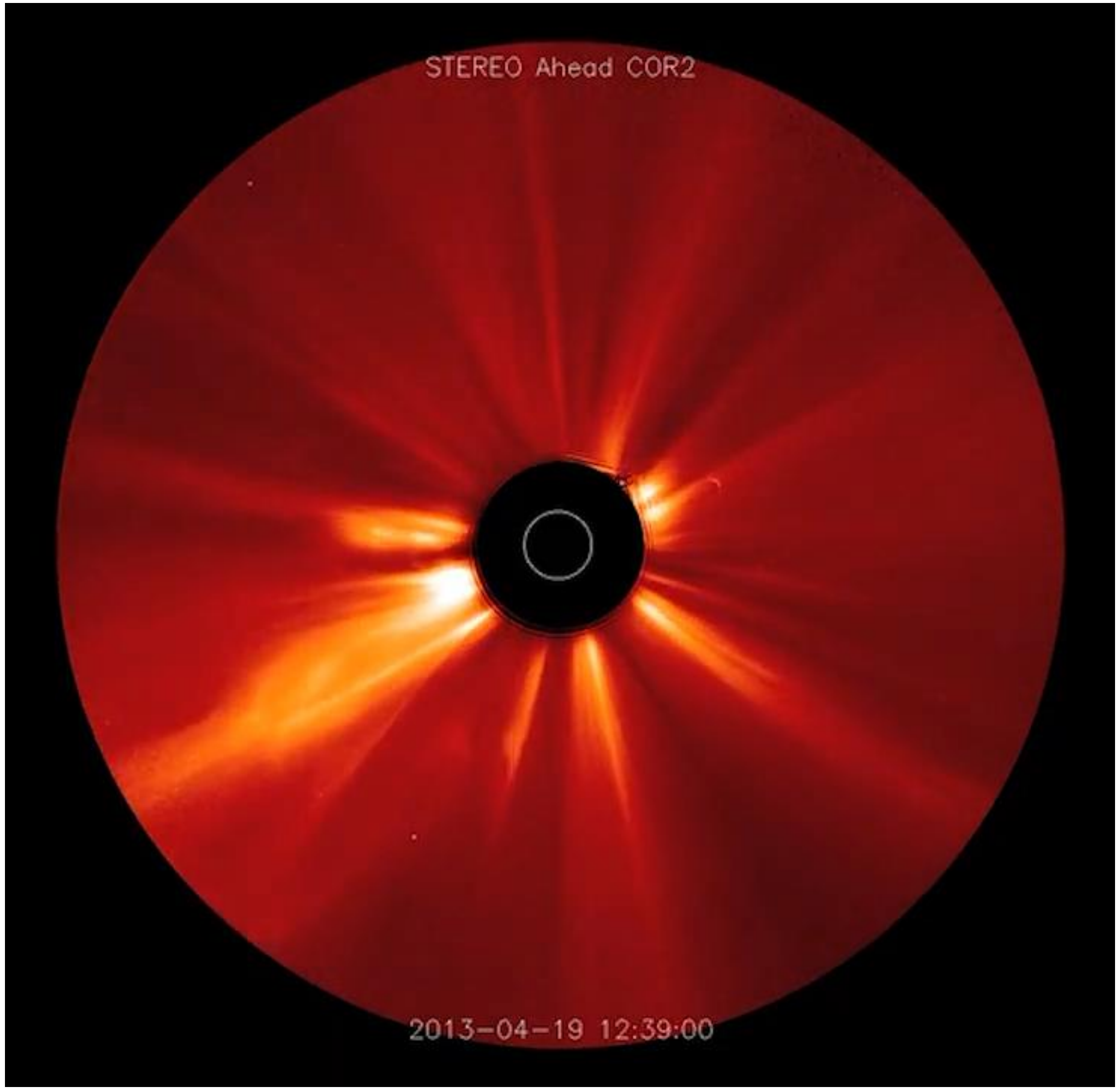


Objective 2:
Determine how transient structures evolve in the young solar wind.

2A: CME 3D Trajectory, Structure, and Evolution:

WSA can help characterize the global conditions through which transient structures propagate.

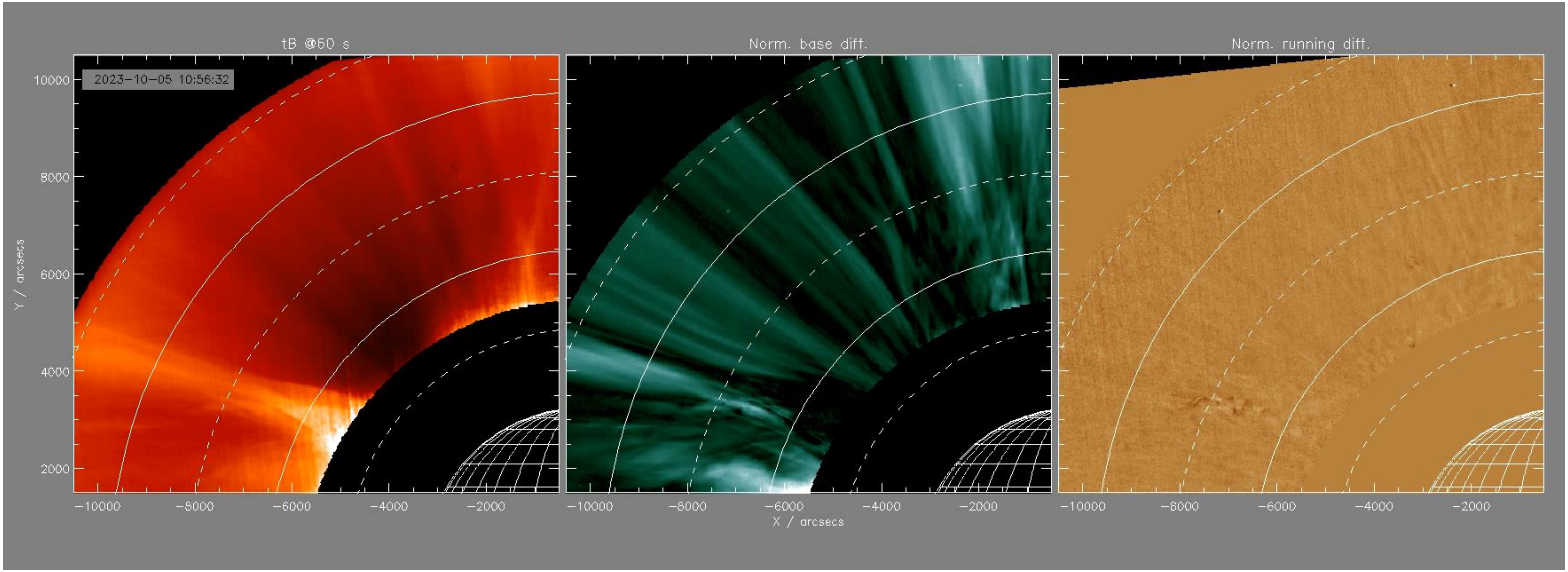




Example: Deriving the sources of high-latitude coronal downflows observed at SO/METIS, before and after a CME

October 5th, 2023

Andretta et al., in prep

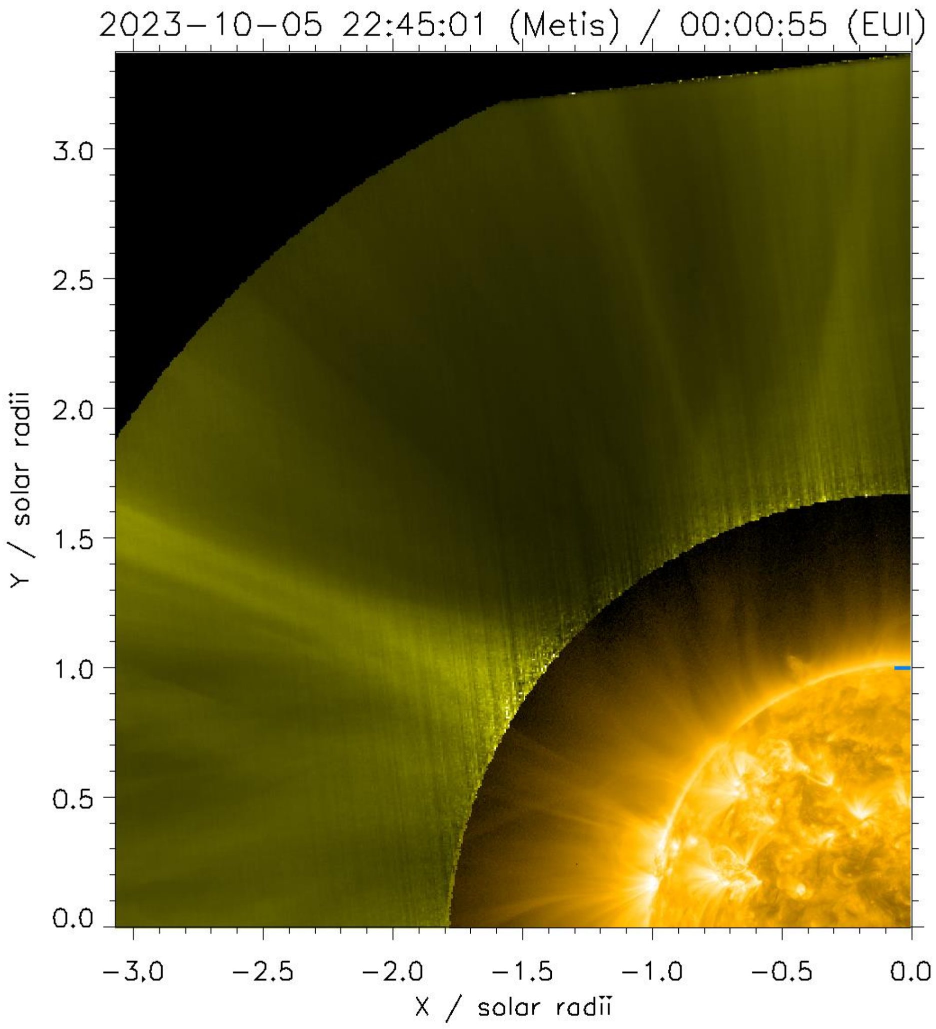


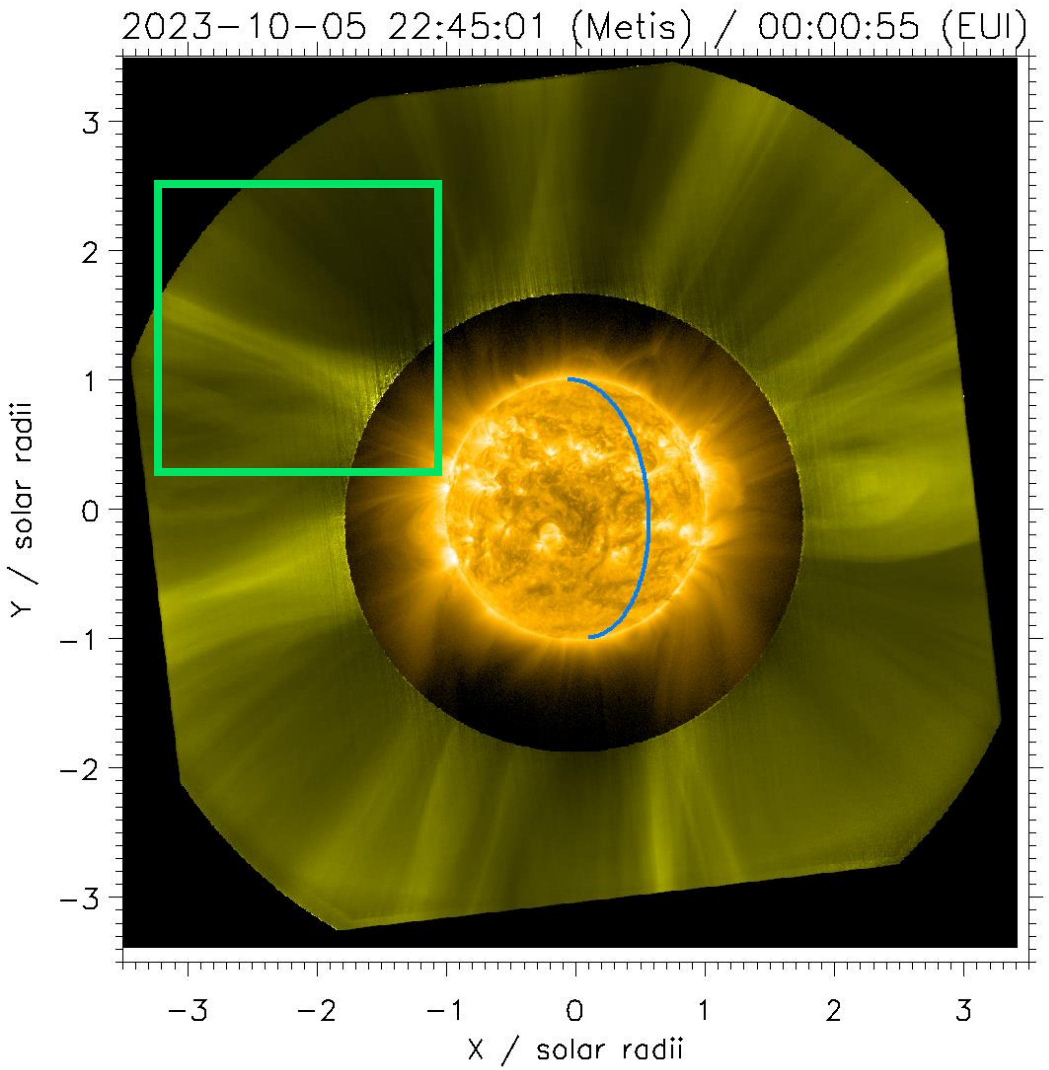
Coronal downflows: Dynamic and intermittent release of plasma associated with the streamer belt, as the counterpart to outward propagating streamer blobs, formed by magnetic reconnection

Downflows observed at high latitudes! Is that a pseudostreamer?

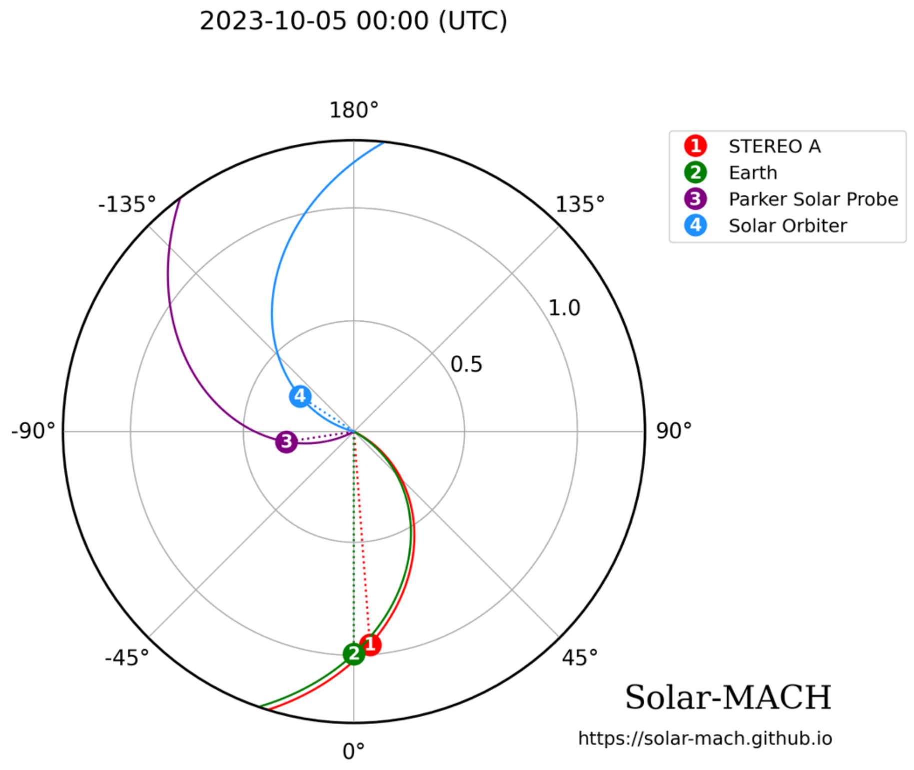
October 5th, 2023

Andretta et al., in prep

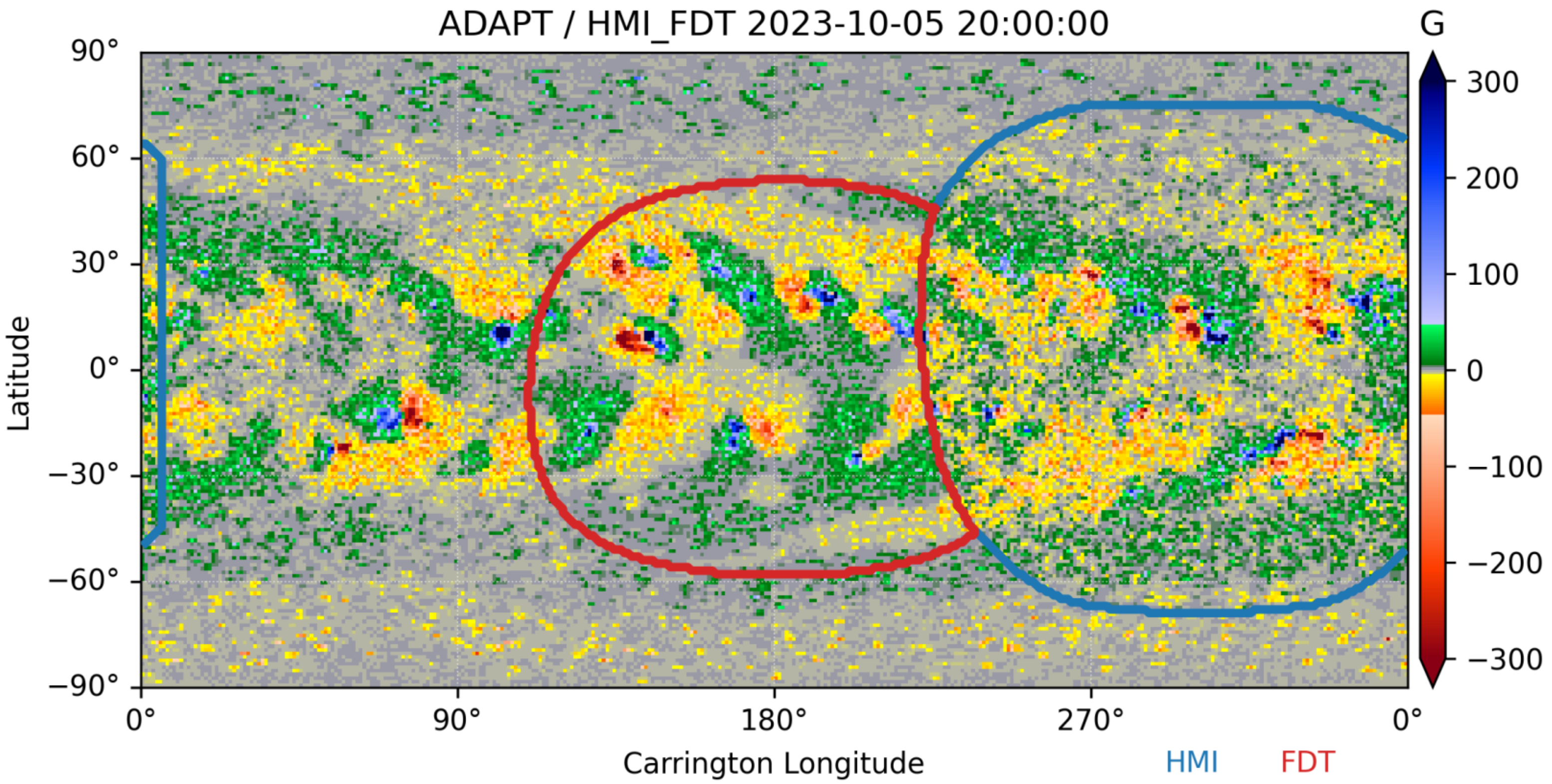




The location of spacecraft for this event are ideal for incorporating SO/PHI data into ADAPT global photospheric maps



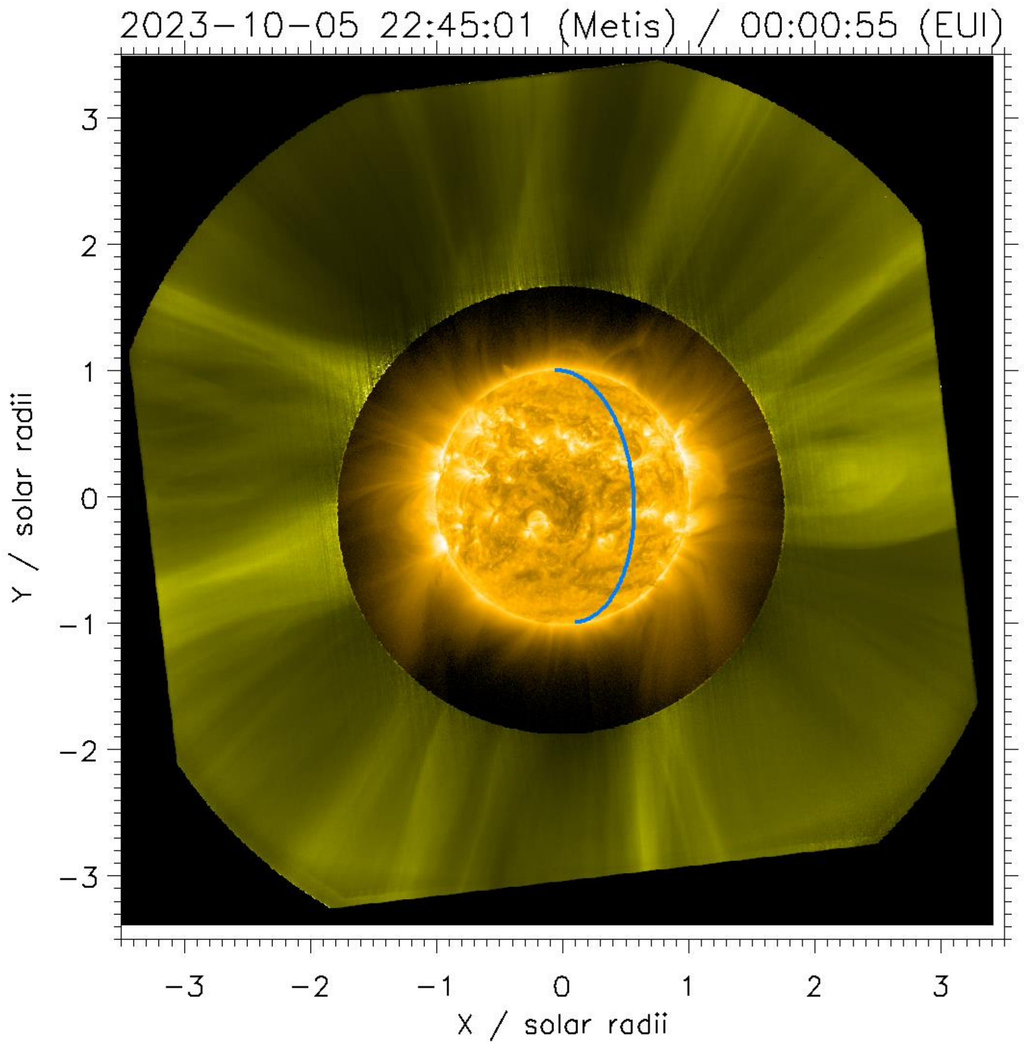
SolO located at 0.29 au, 123° longitudinal separation from Earth

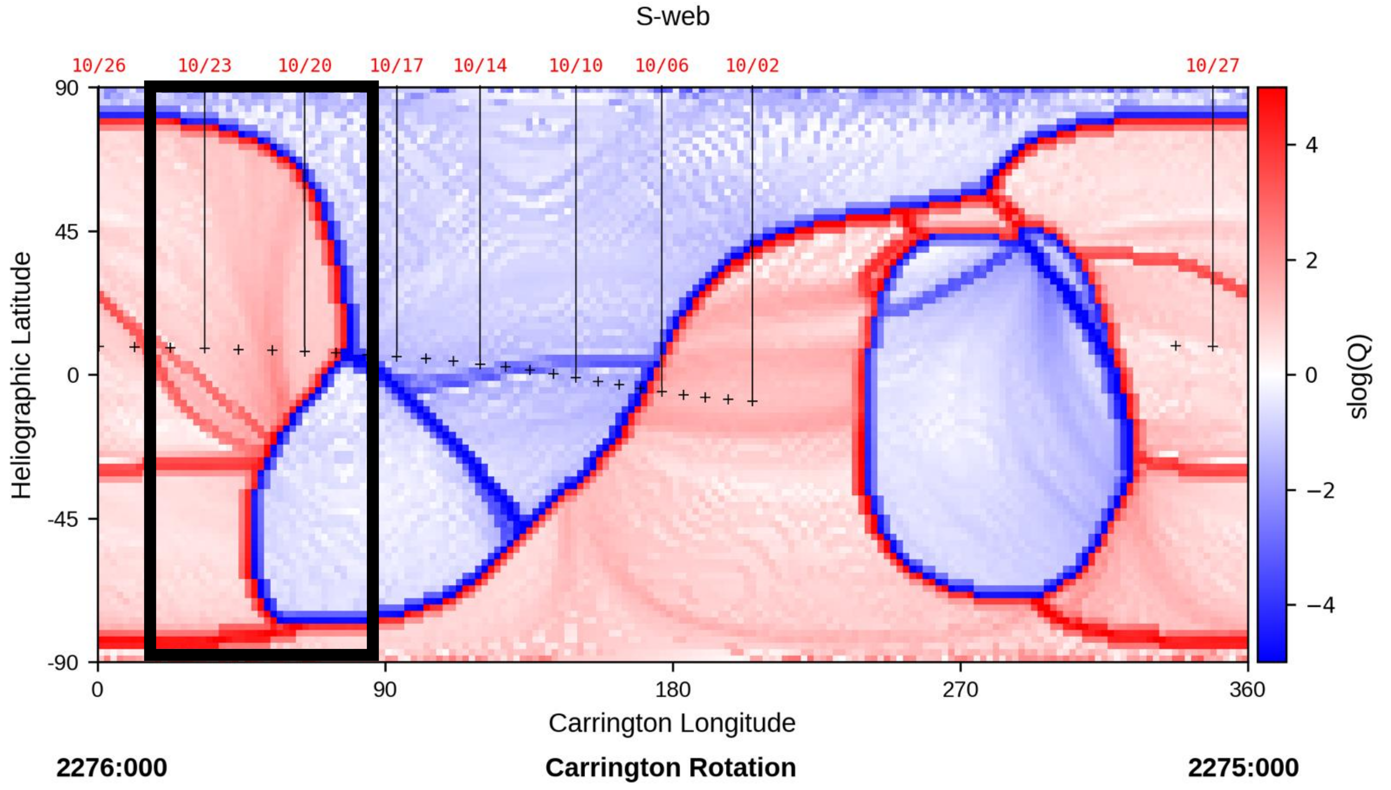


ADAPT SDO/HMI + far-side SolO/PHI-FDT

Schonfeld et al., in prep

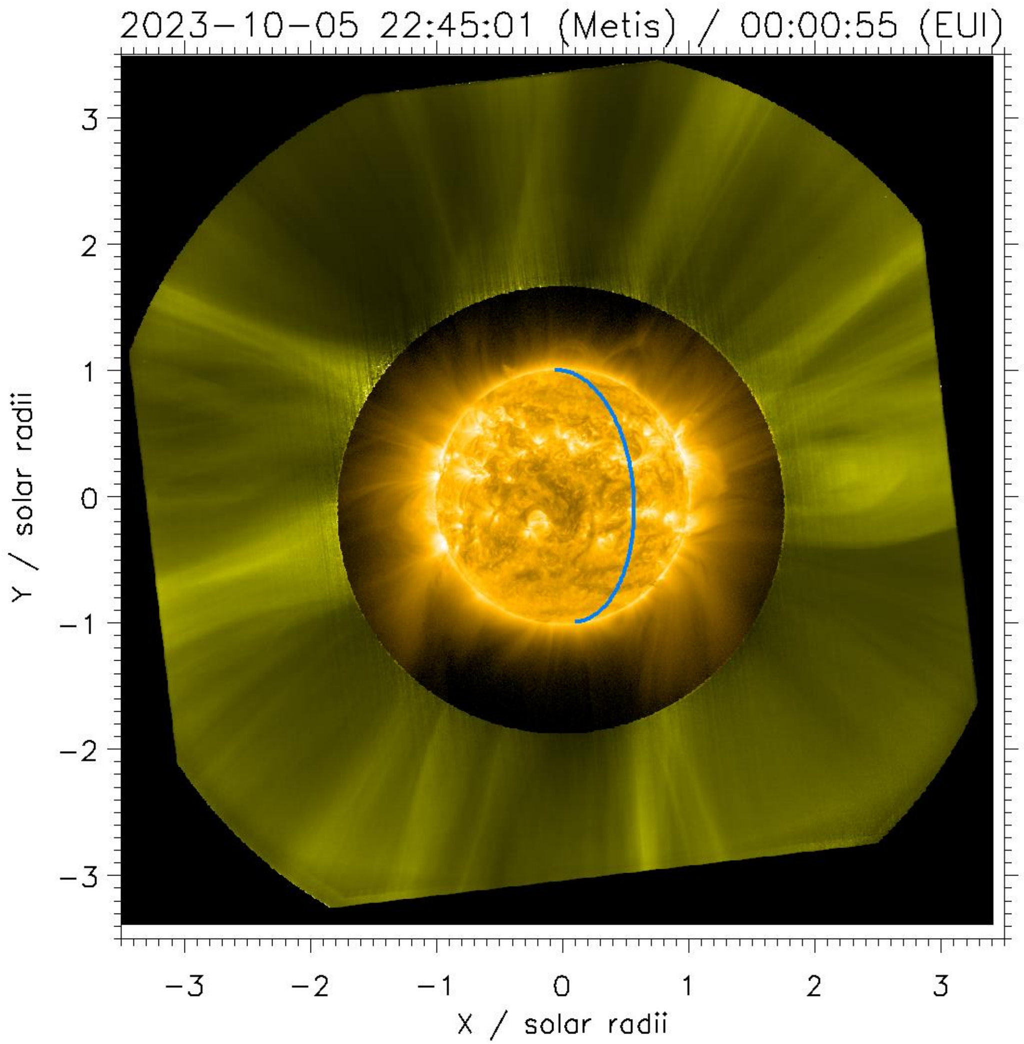
Downflows observed in SO/METIS originating from HCS inclined to high latitudes!

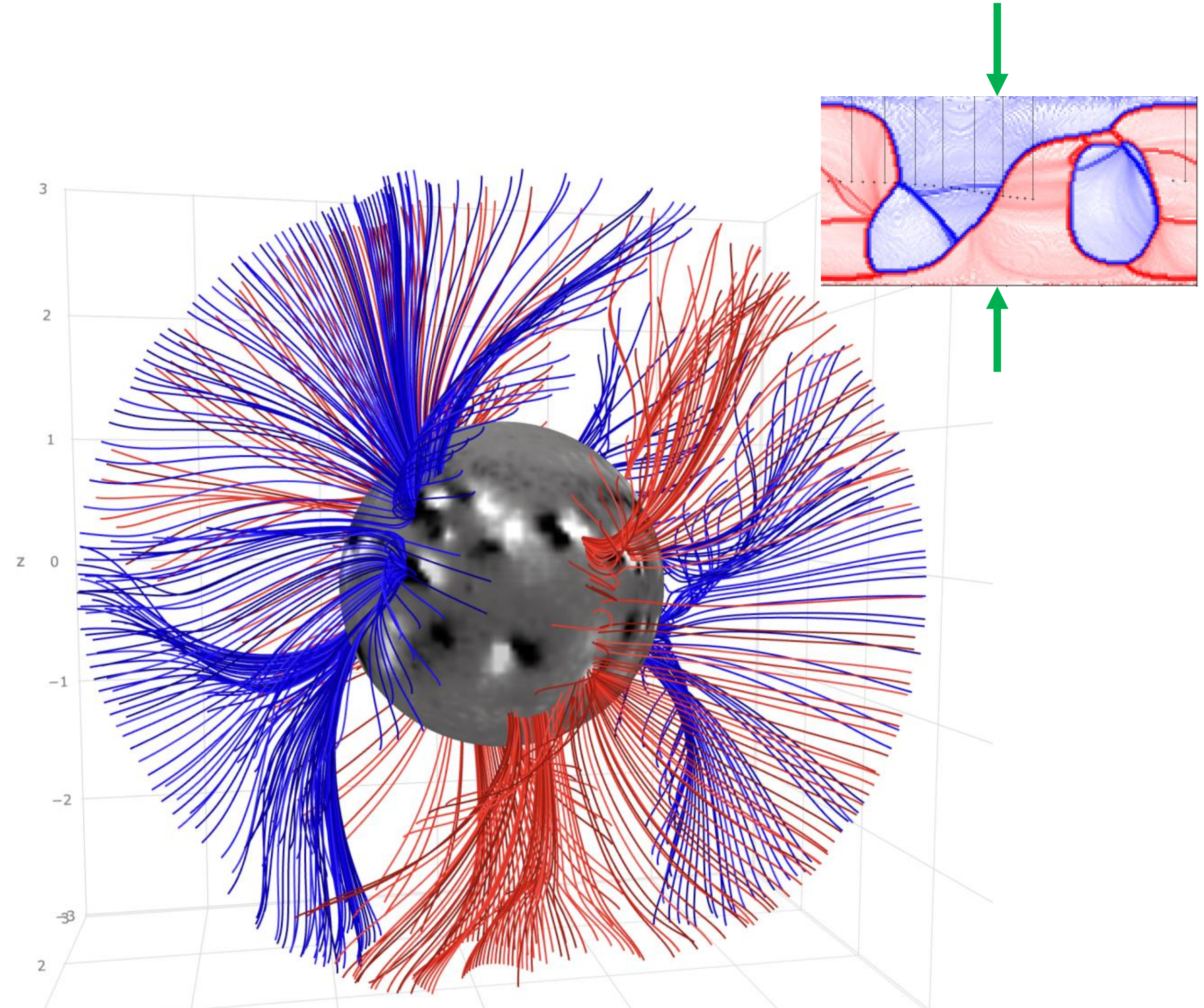




Andretta et al., in prep

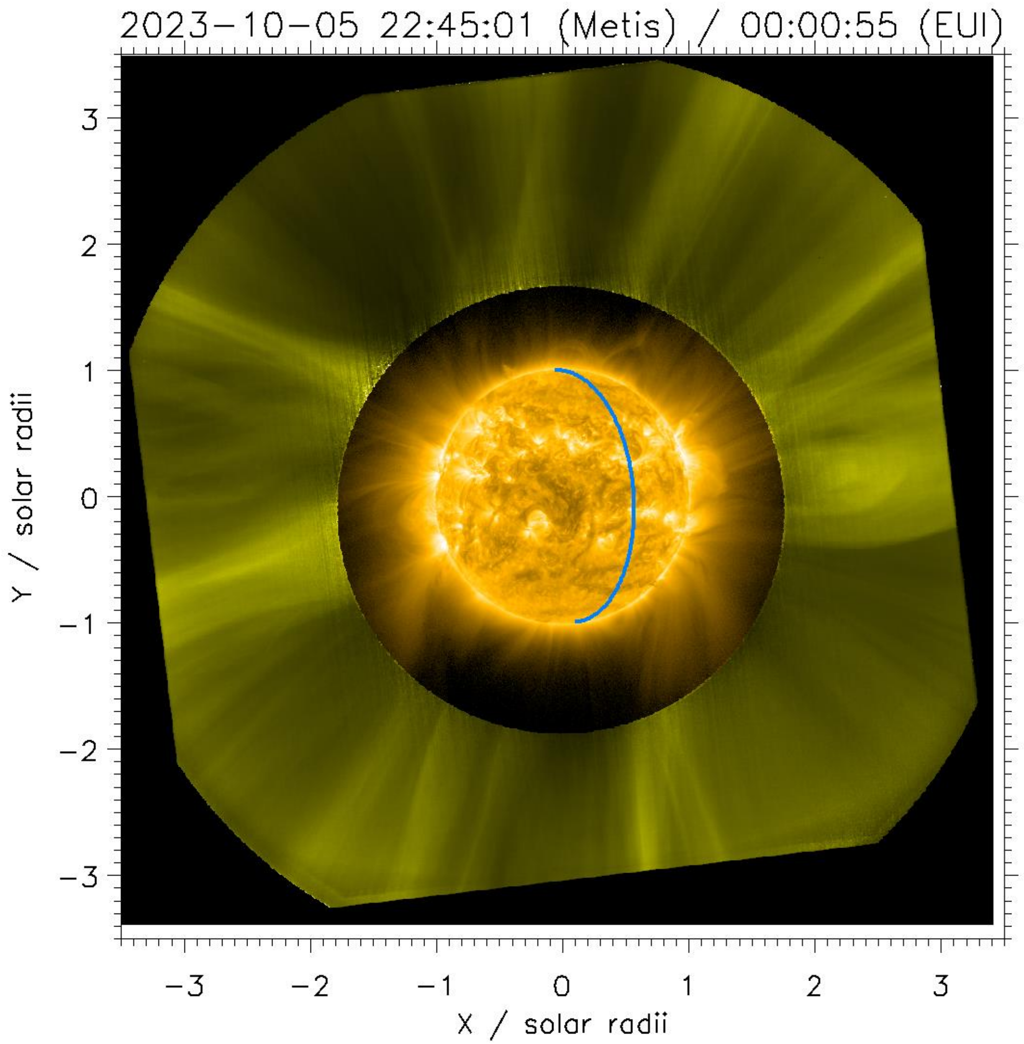
3D S-web aligned with FOV of SO/EUI and METIS (half the sampling rate)

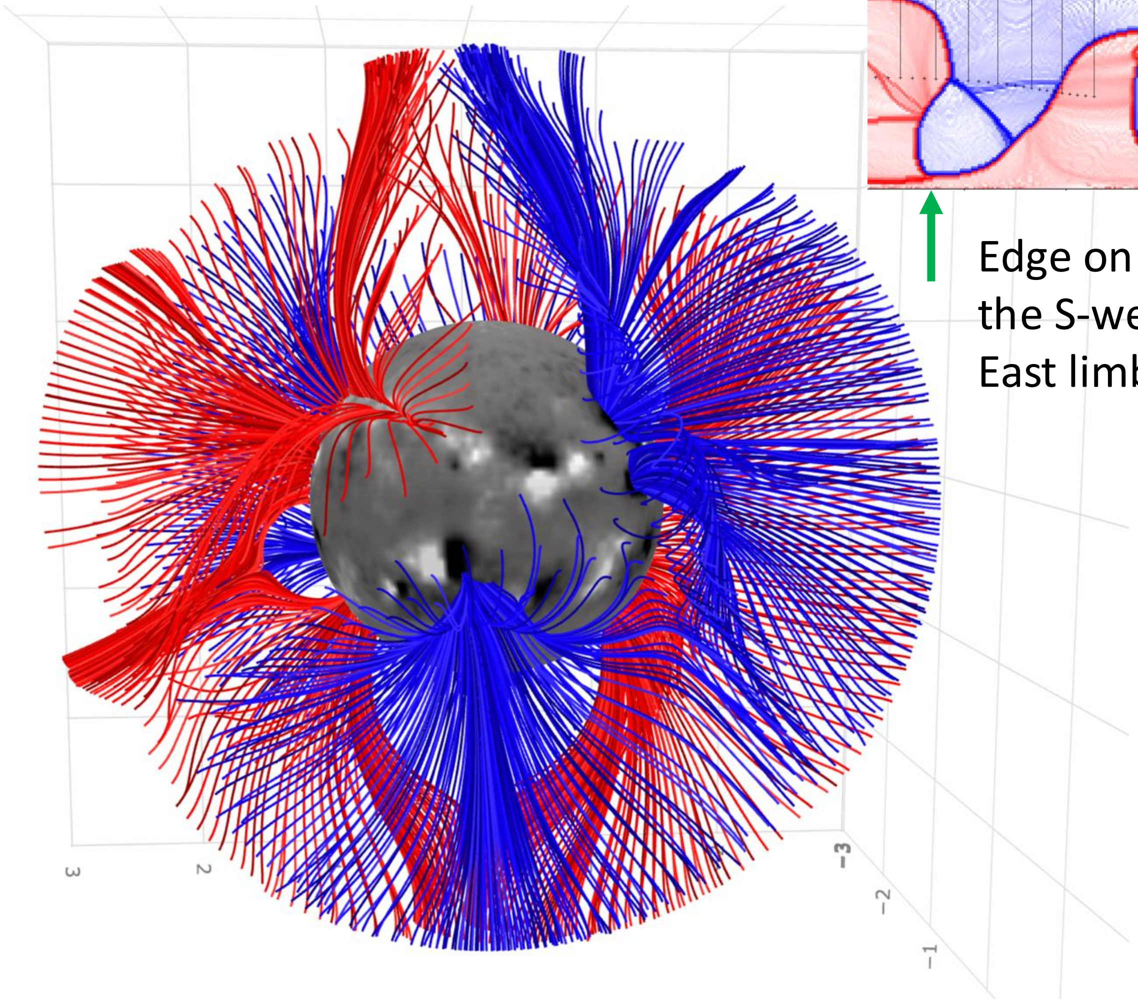


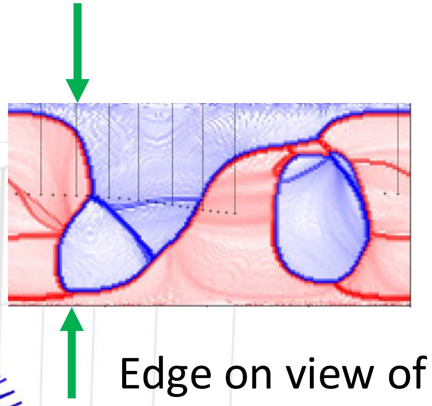


“3D S-web” = all field lines with log(Q)>3

We are beyond the days of pseudostreamer vs. helmet streamer…
The 3D, time-dependent corona is inherently complex.



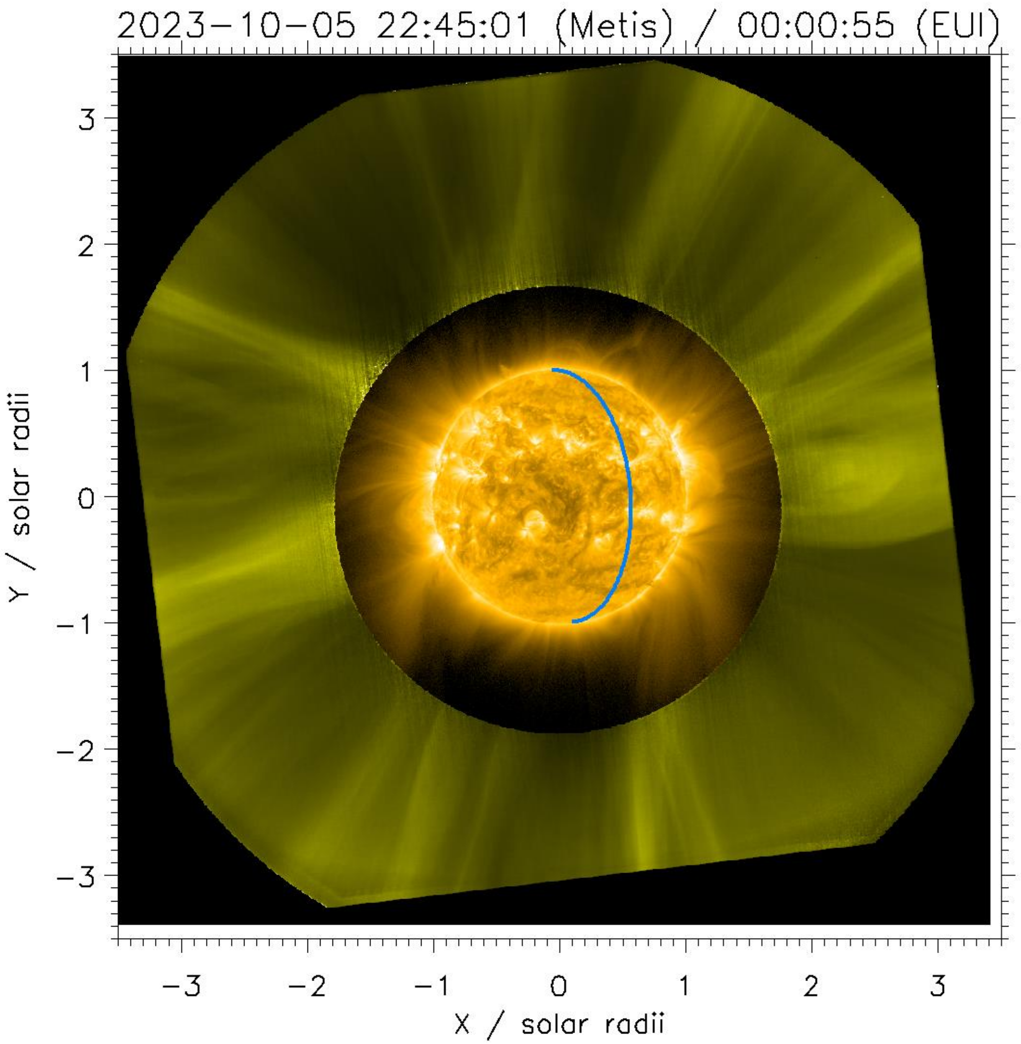


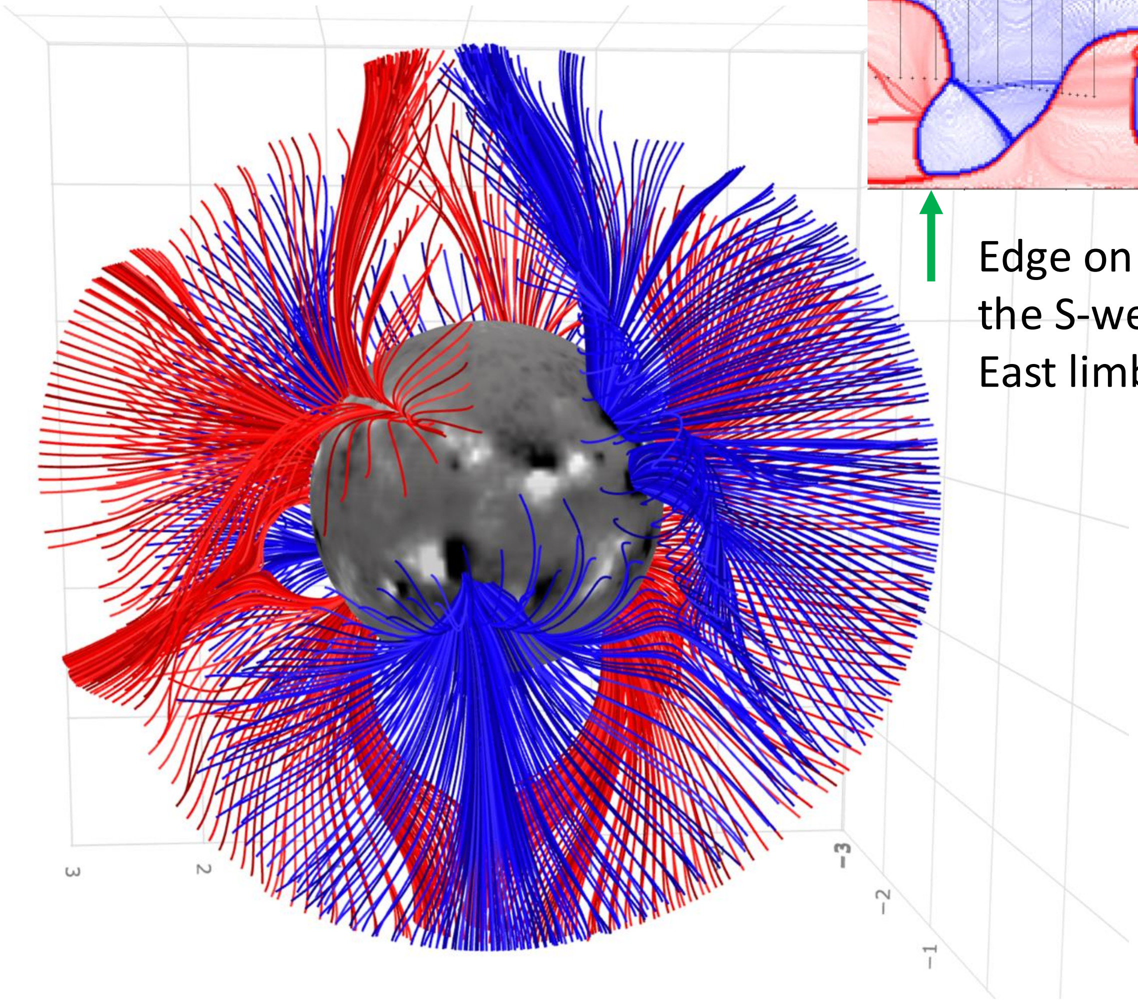


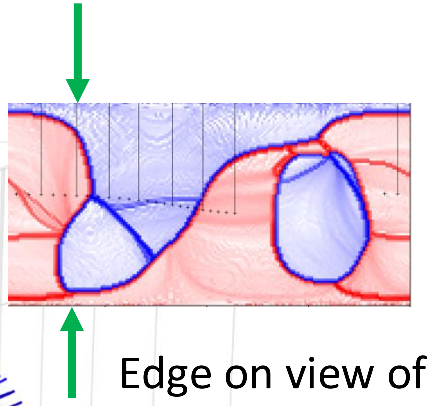
Edge on view of the S-web at the East limb

"3D S-web" = all field lines with log(Q)>3

PUNCH observations, interpreted in the context of WSA output, will help relate observed heliospheric structure to the underlying coronal magnetic topology at the source.







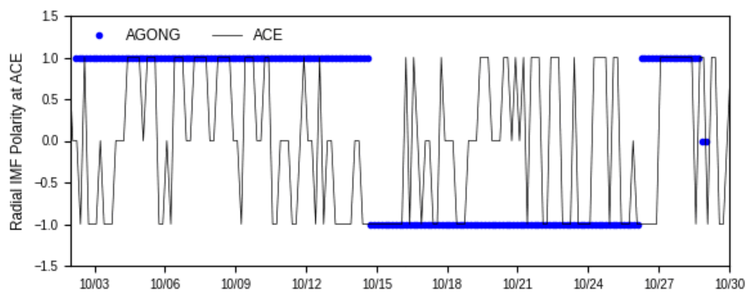
Edge on view of the S-web at the East limb

“3D S-web” = all field lines with log(Q)>3

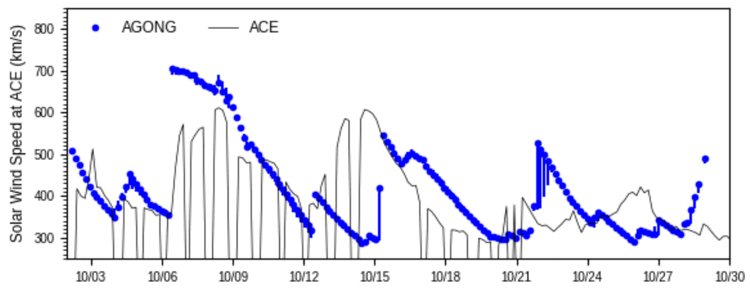
2B: CIR Formation and 3D Dynamics:

WSA-Enlil routinely identifies CIRs, fast/slow stream interfaces, and can help identify these interfaces in PUNCH observations to support studies into their formation.

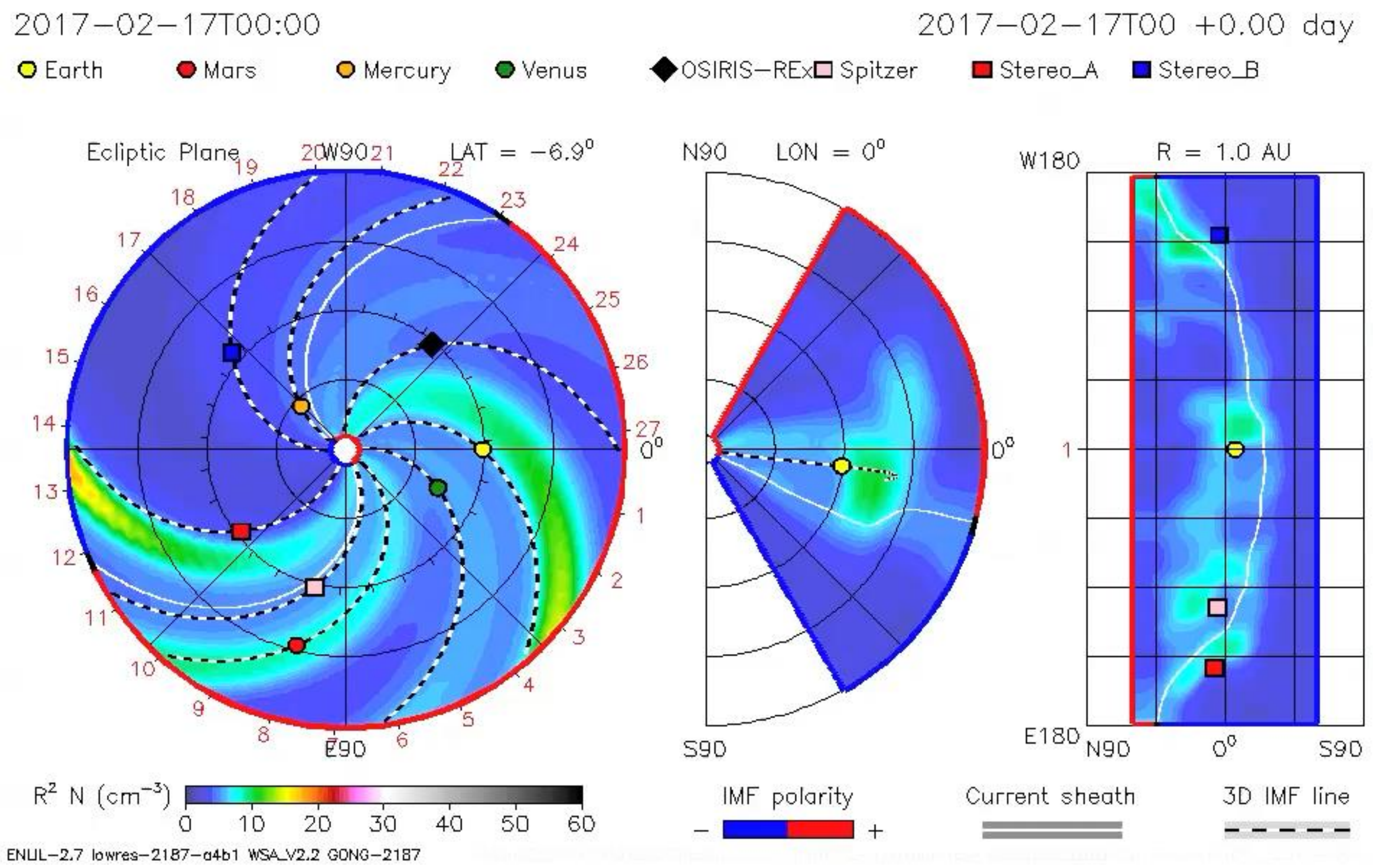
IMF Polarity



Solar wind speed (km/s)

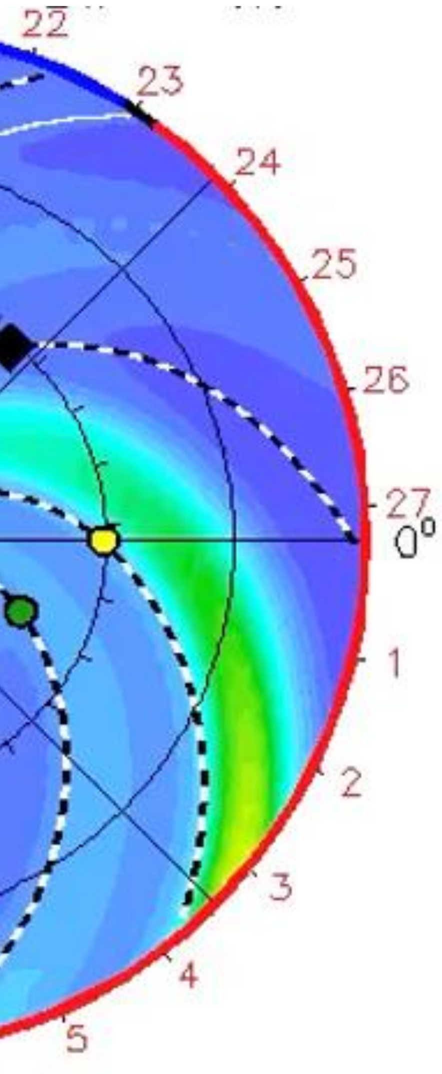


Date

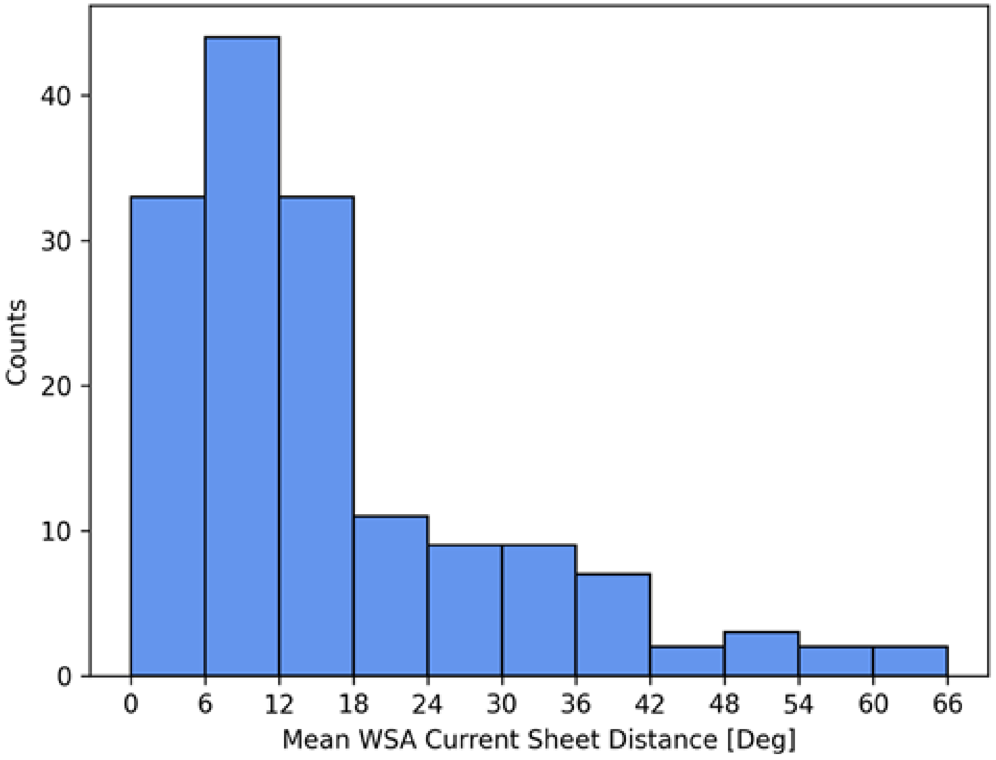


Characterizing the aspects of solar wind formation that produce geoeffective mesoscale solar wind.

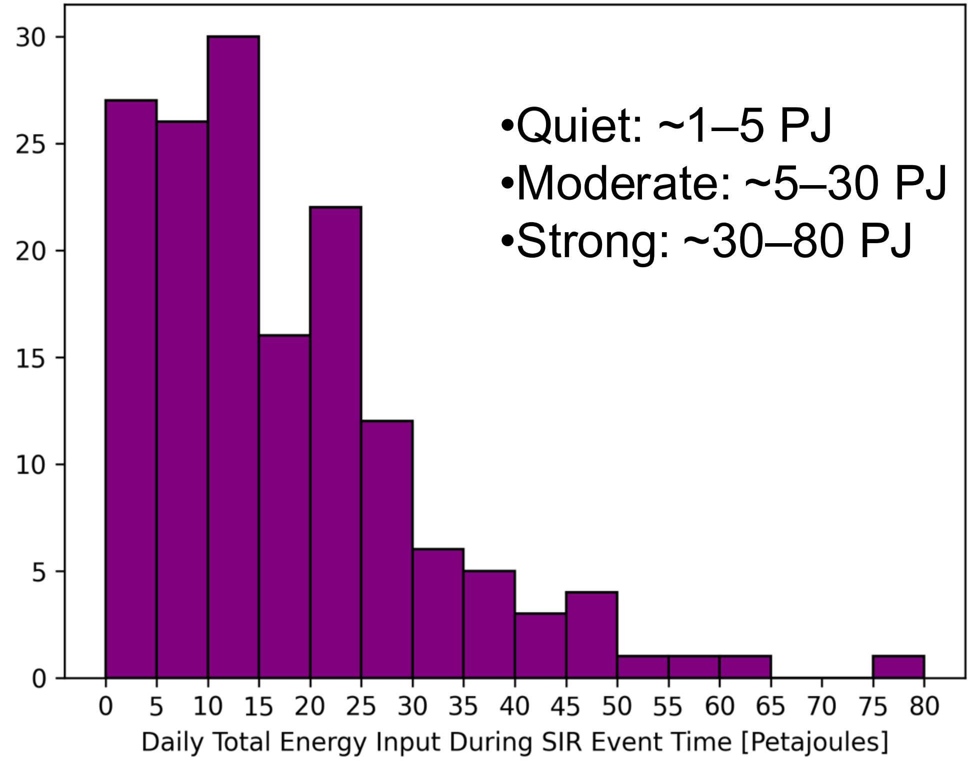
SIRs in isolation of CMEs studied over 30 years drive moderate to strong activity in Earth's magnetosphere, and can originate from S-web arcs far from HCS!



Spacecraft separation from the HCS

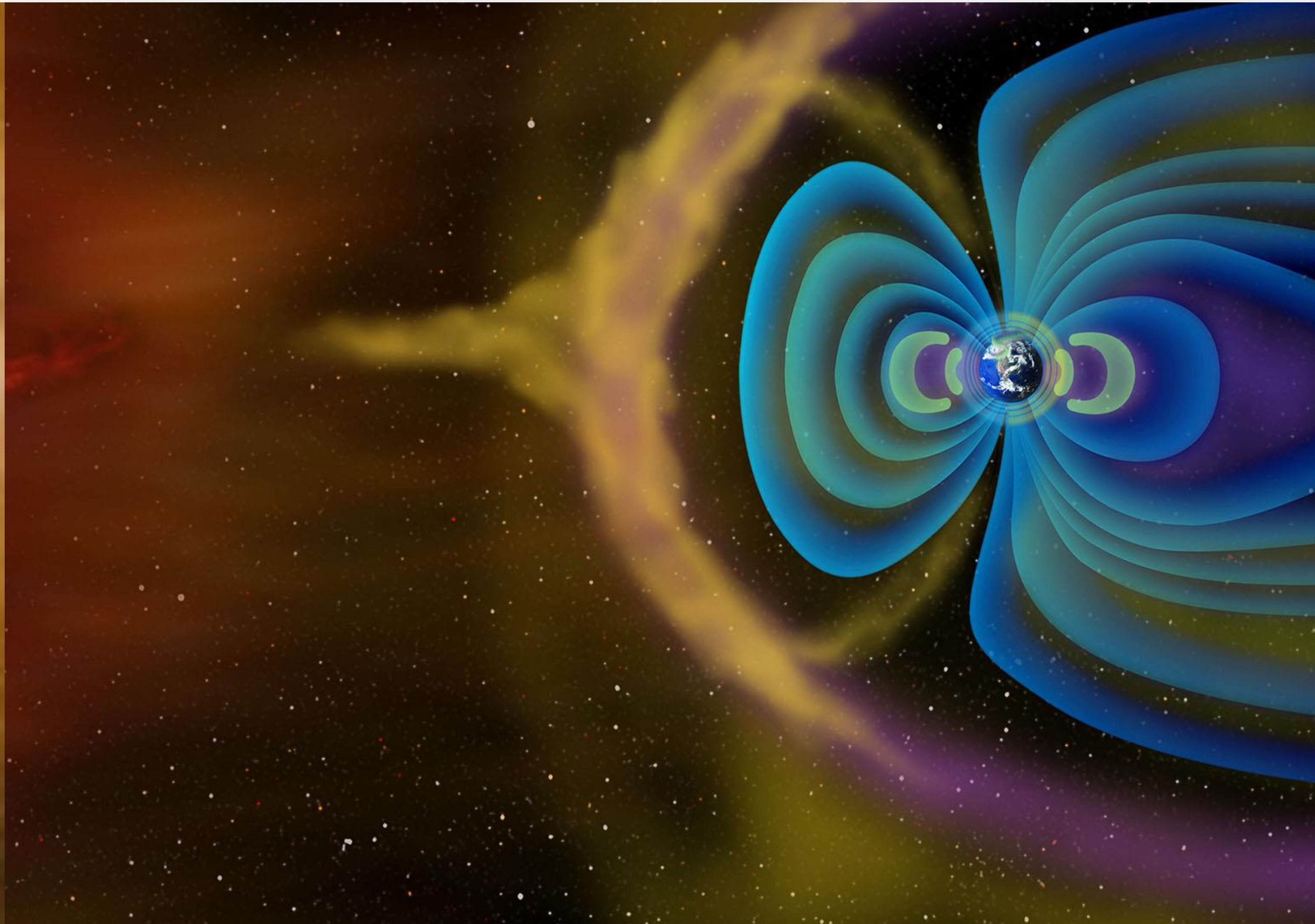


Daily total integrated energy input into the magnetosphere



Helgerson, Wallace, Viall, Kepko, Di Matteo (in prep)

By combining PUNCH remote imaging of SIRs with WSA capabilities, we can connect their solar origins to geospace responses.



WSA can support 4.5 out of 6 PUNCH science objectives

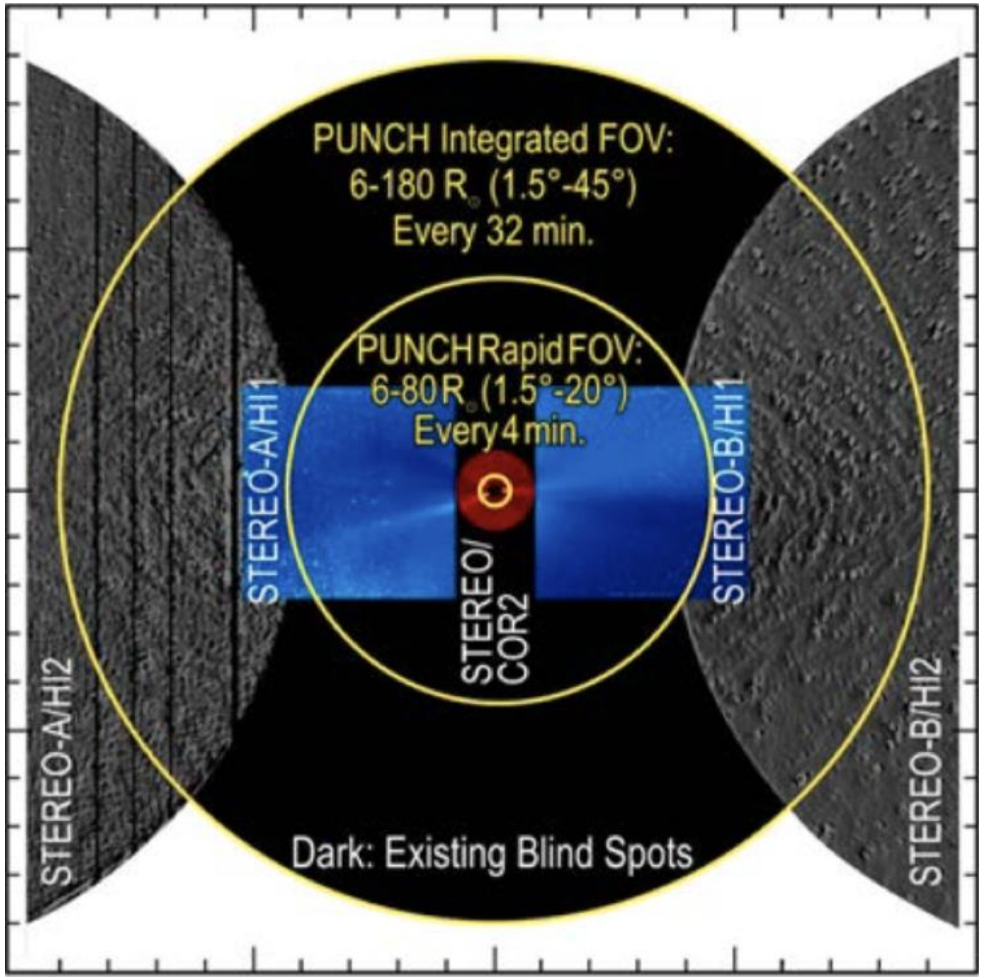
PUNCH science goal: to determine the cross-scale physical processes that unify the solar corona with the rest of the solar system environment (the heliosphere).

Objective 1: Ambient Solar Wind

- 1A: Global solar wind flow
- 1B: Solar wind mesostructures ~~and turbulence~~
- 1C: Alfvén Zone: Boundary of the Heliosphere

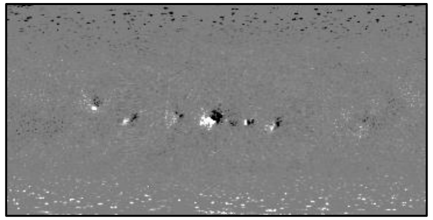
Objective 2: Dynamic Solar Wind

- 2A: CME 3D Trajectory, Structure, and Evolution
- 2B: CIR Formation and 3D Dynamics
- ~~2C: Shock 3D Dynamics & Morphology~~

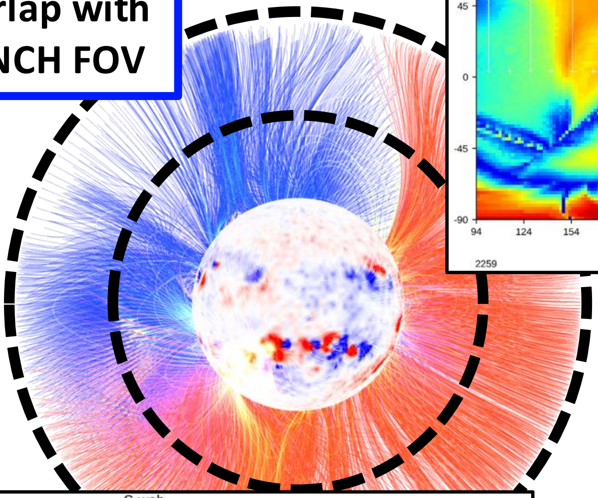


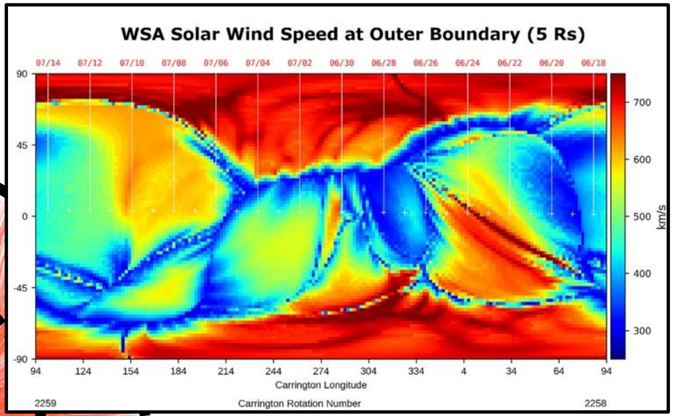
WSA provides the **coronal and heliospheric context** and the **in situ connection** necessary to advance PUNCH science objectives.

ADAPT+far-side data!



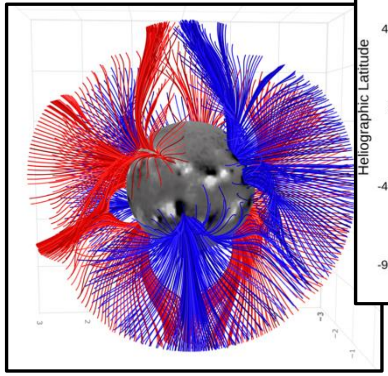
SCS model to overlap with PUNCH FOV

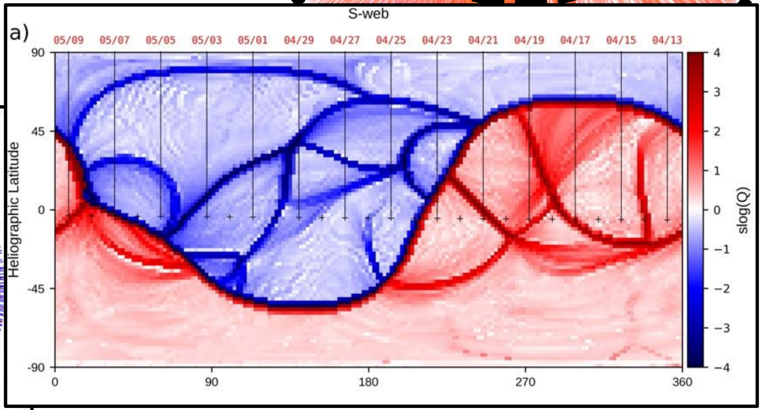


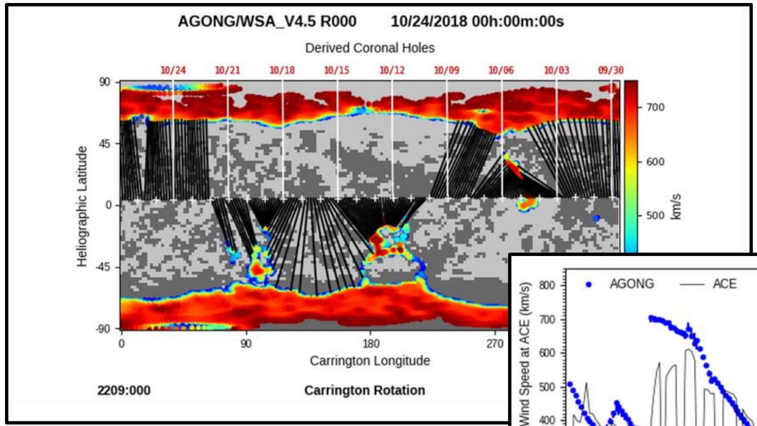


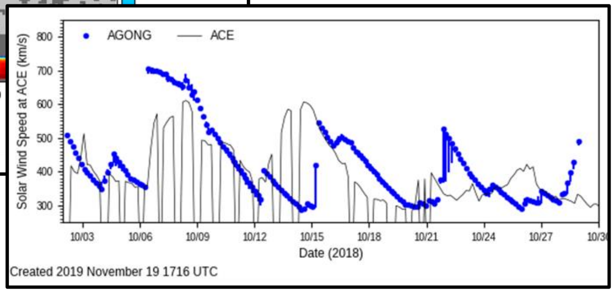
Global maps of terminal SW speed

S-web







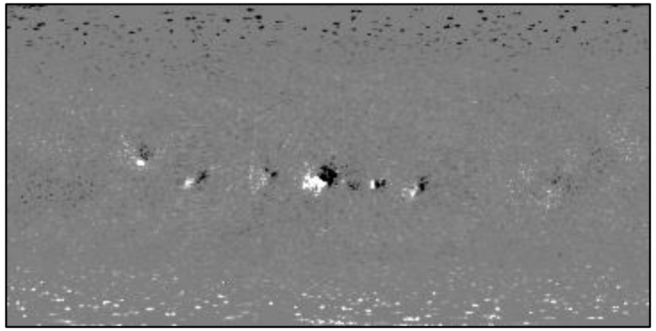


In-situ connection
Additional validation with empirically derived SW speed

Extra slides

The ADAPT-WSA model

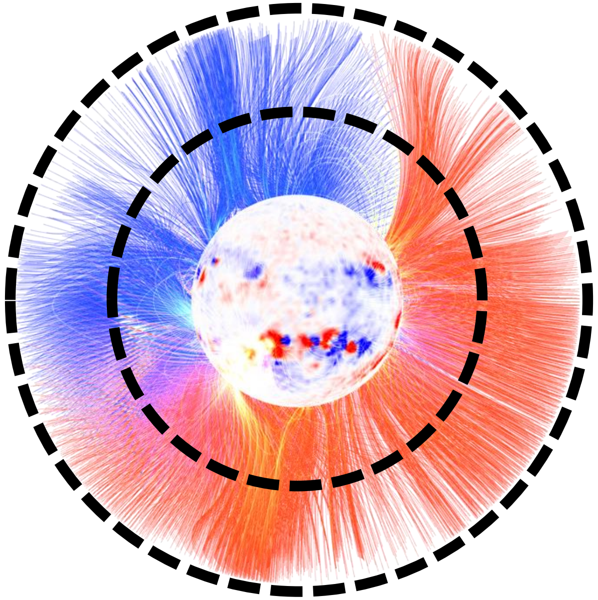
Input: ADAPT
(ensemble of 12 maps)



Arge+ 2010, 2011, 2013, Hickmann+ 2015

Derived from magnetograms
provided by
HMI, GONG, VSM etc.

WSA
PFSS + SCS



Arge and Pizzo 2000, Arge+ 2003, 2004

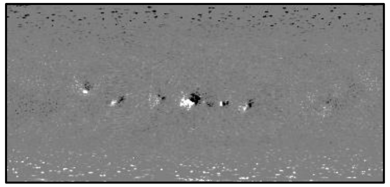
$$V(f_s, \theta_b) = 285 + \frac{625}{(1 + f_s)^{2/9}} \left\{ 1.0 - 0.8 e^{-\left(\theta_b / 2\right)^2} \right\}^3$$

Air Force Data Assimilative Photospheric Flux Transport (ADAPT) model

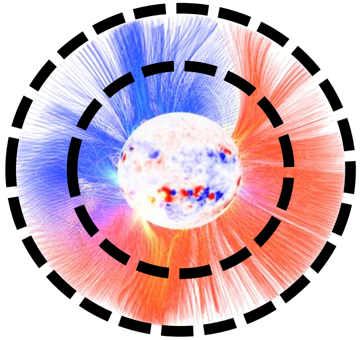
Wang-Sheeley-Arge (WSA) model

The ADAPT-WSA model

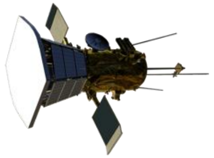
Input: ADAPT



WSA

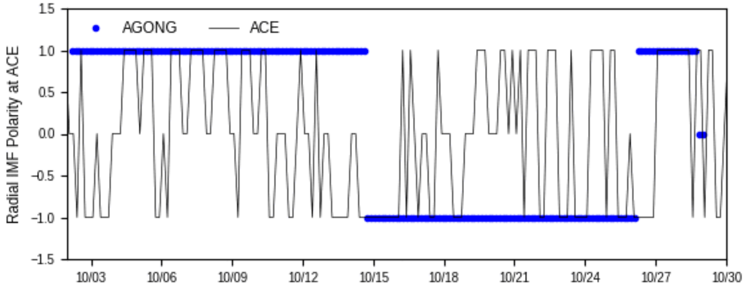


$$V(f_s,\theta_b) = 285 + \frac{625}{(1+f_s)^{2/9}}\left\{1.0 - 0.8e^{-\left(\theta_b/2\right)^2}\right\}^3$$

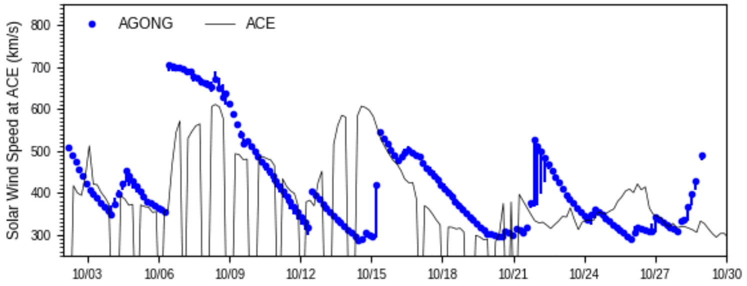


OUTPUT:
12 solutions of the global corona field, spacecraft magnetic connectivity, and solar wind
for one moment in time

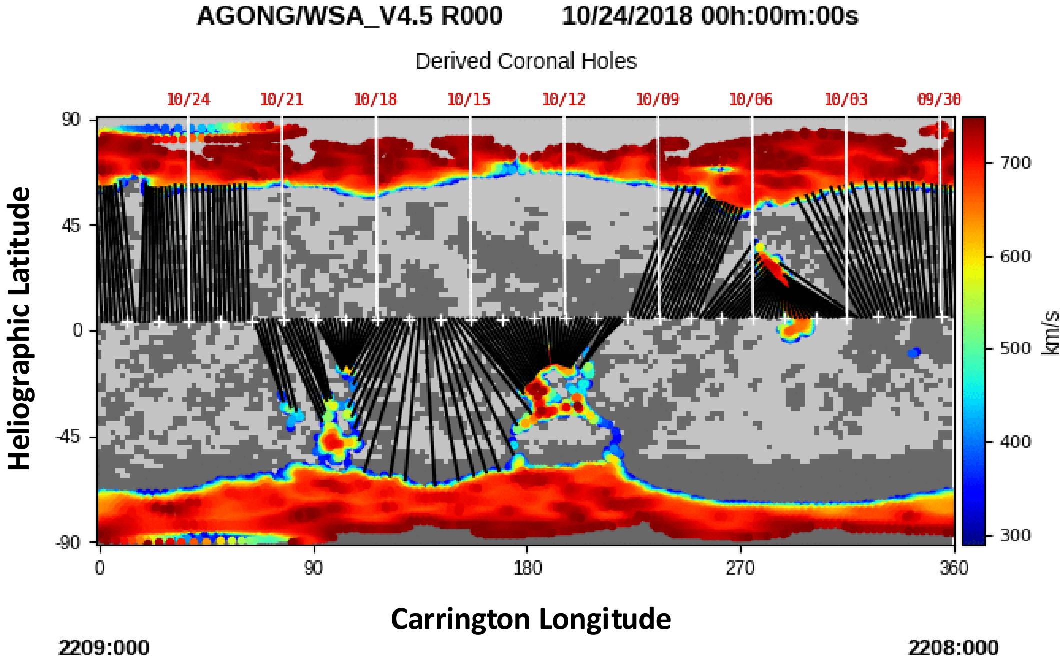
IMF Polarity



Solar wind speed (km/s)

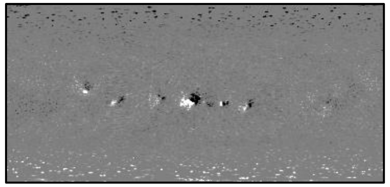


Date

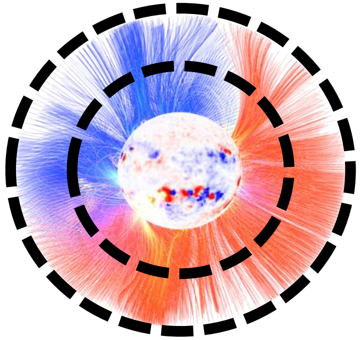


The ADAPT-WSA model

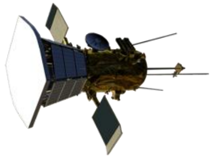
Input: ADAPT



WSA

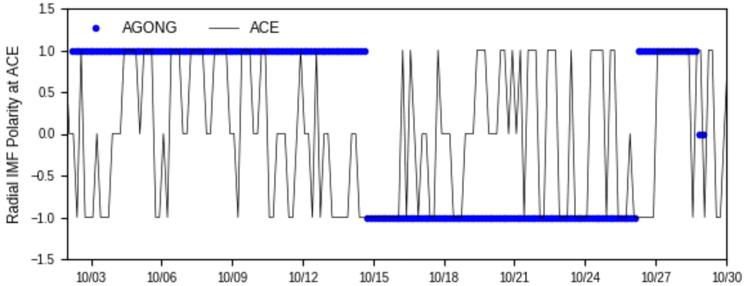


$$V(f_s, \theta_b) = 285 + \frac{625}{(1+f_s)^{2/9}} \left\{ 1.0 - 0.8 e^{-\left(\theta_b/2\right)^2} \right\}^3$$

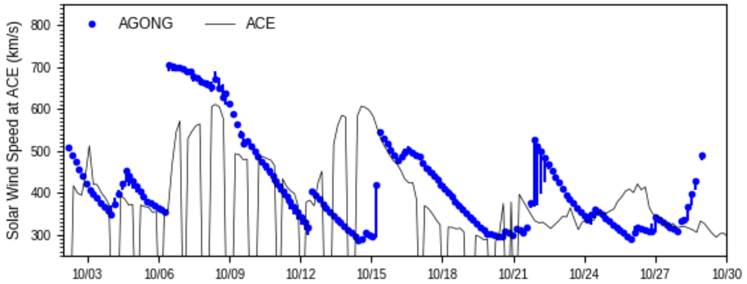


OUTPUT:
12 solutions of the global corona field, spacecraft magnetic connectivity, and solar wind
for one moment in time

IMF Polarity

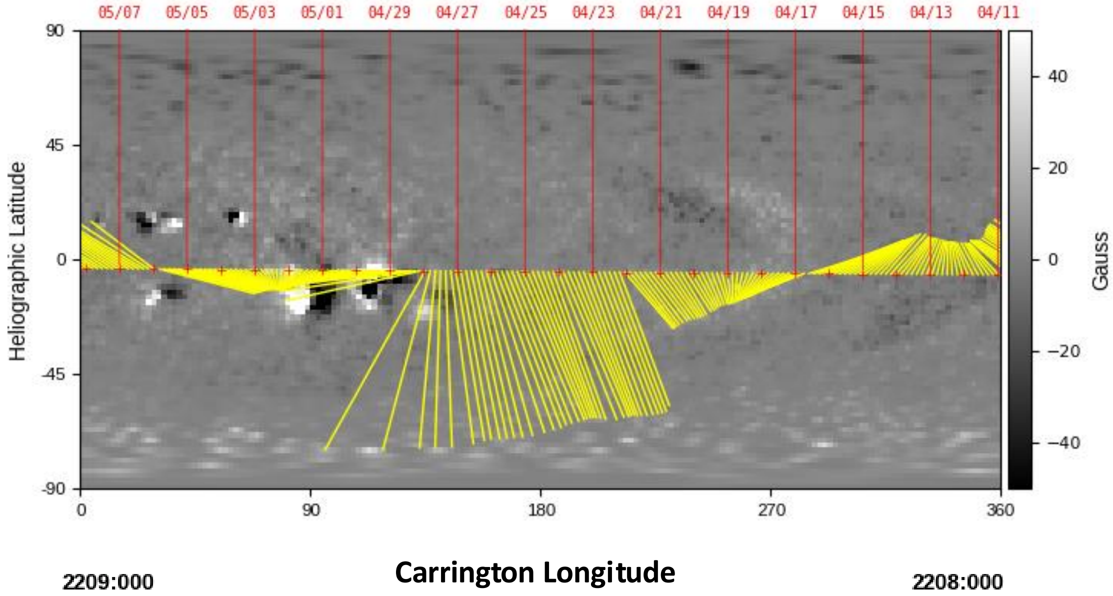


Solar wind speed (km/s)

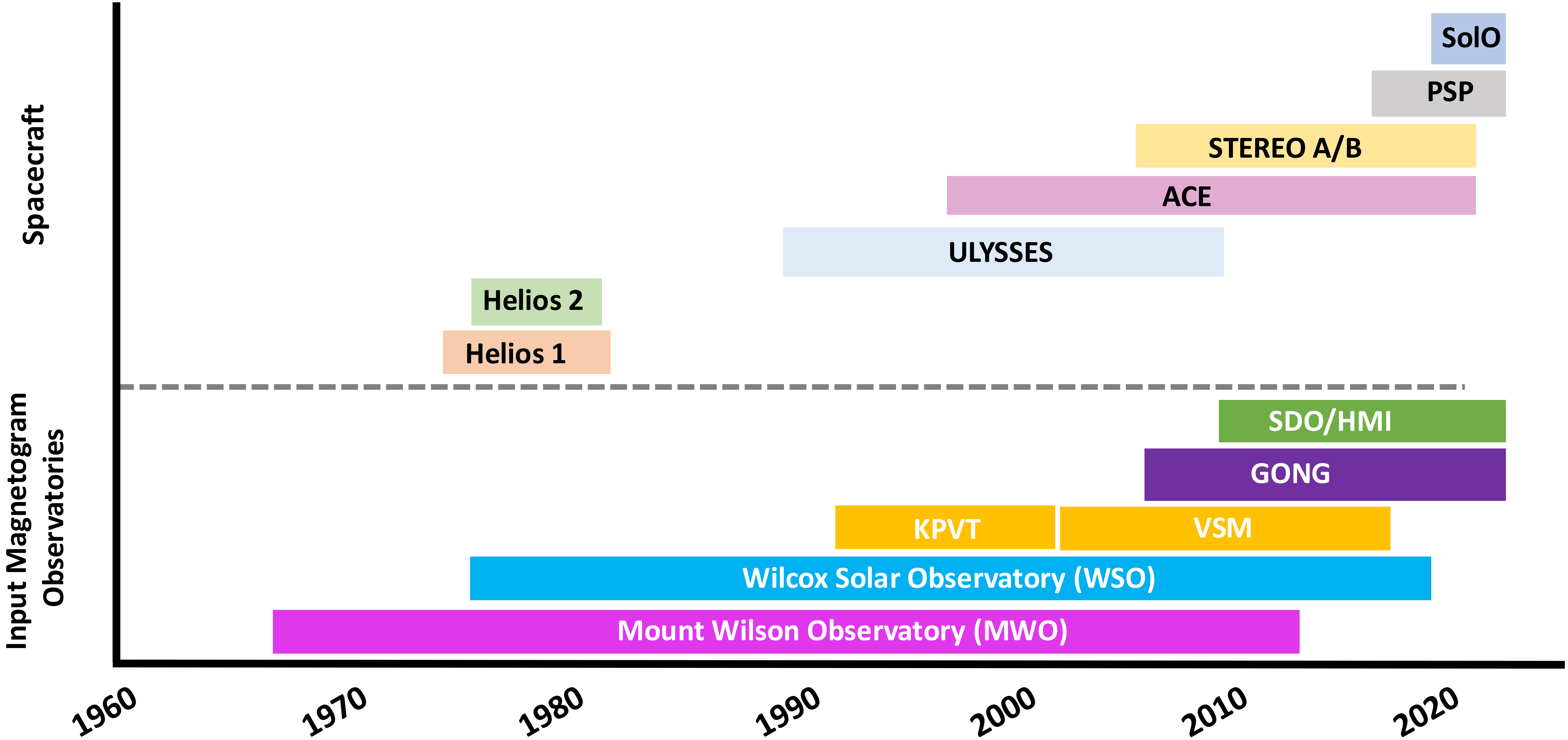


Date

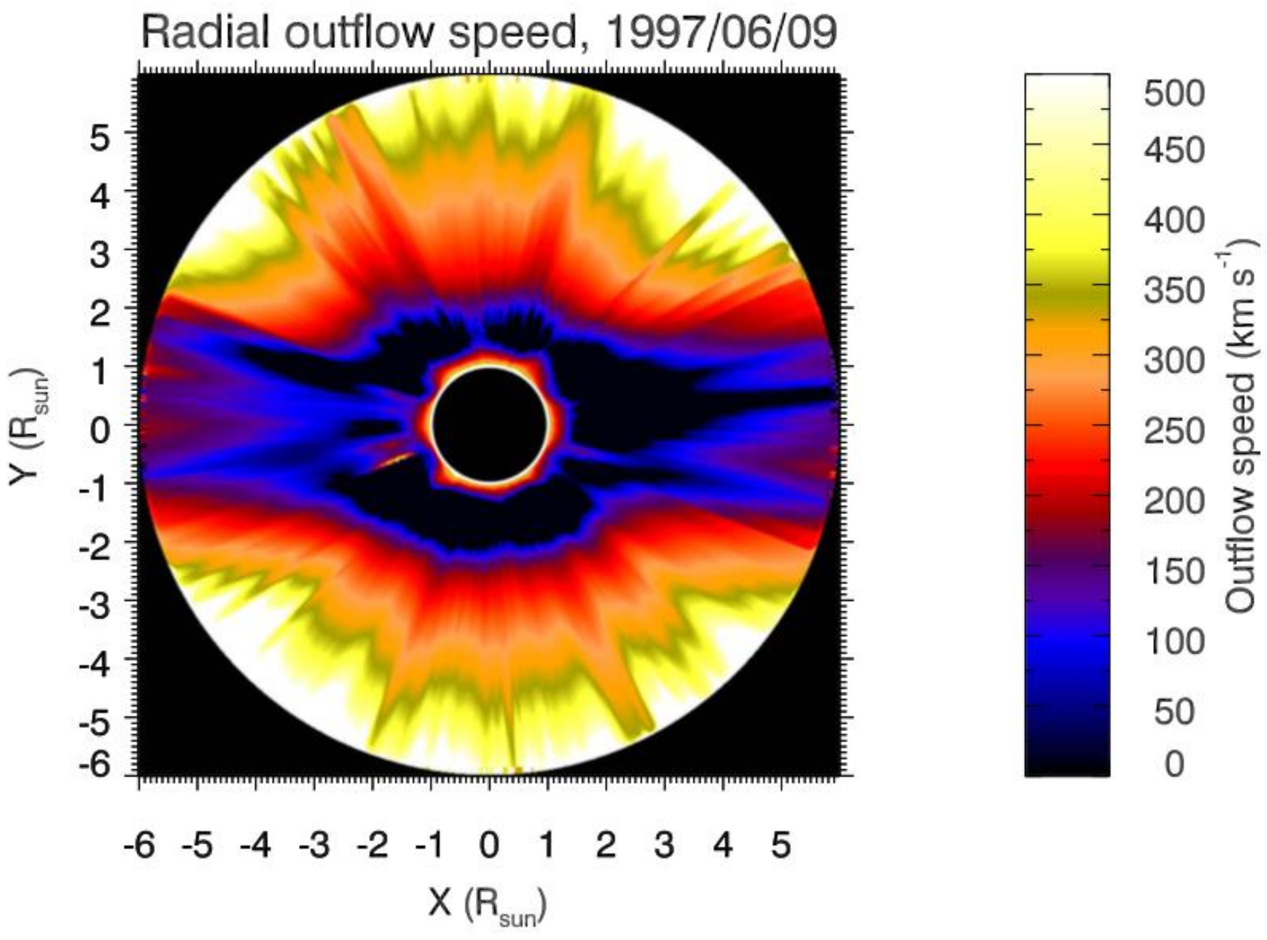
Sources of solar wind at Sun's surface (1 R_s)

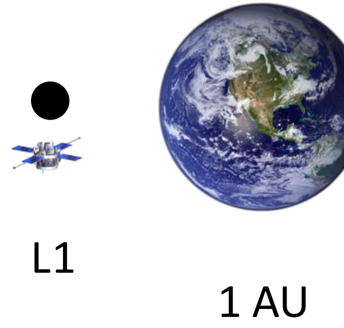


WSA can derive the coronal magnetic field and source regions of the solar wind using over 50+ years of ground and space-based observations



Using ADAPT-WSA, global maps of solar radial outflow speed derived with the Doppler dimming technique (~2 – 5 $R_{\odot}$), and in-situ solar wind measurements to obtain acceleration profiles for solar wind emerging from specific source regions.





not to scale

Casti, M., Arge, C.N., Bemporad, A., Pinto, R.F. and Henney, C.J., 2023. A New Method Linking the Solar Wind Speed to the Coronal Magnetic Field. ApJ, 949(2), p.42.

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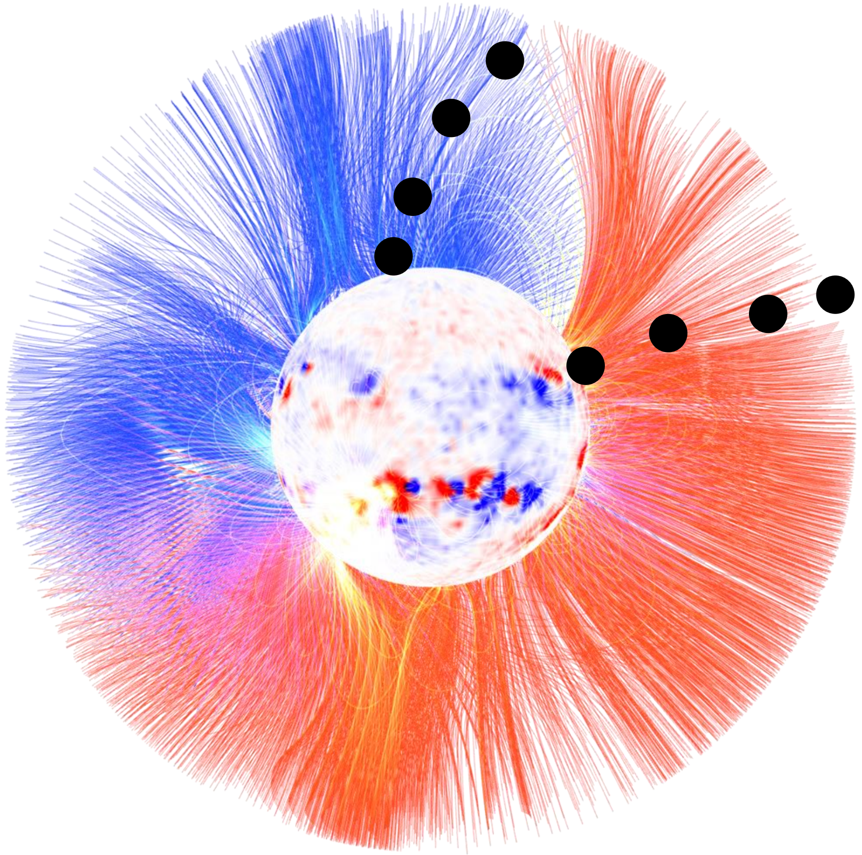
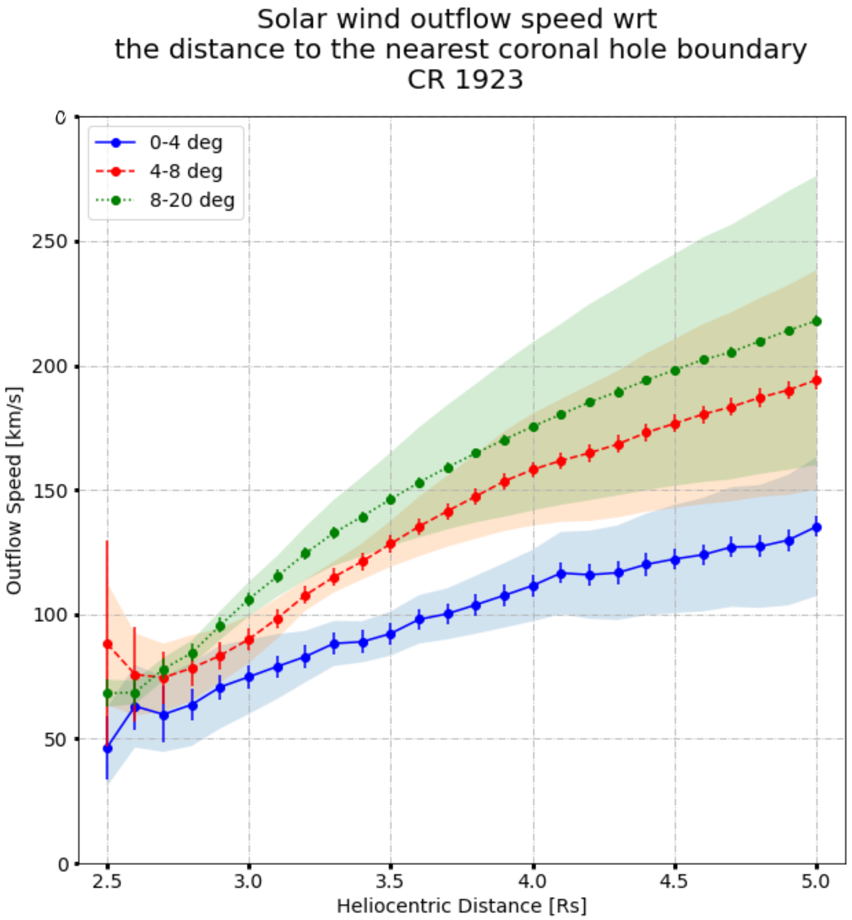


Coronal field at 5 Rs

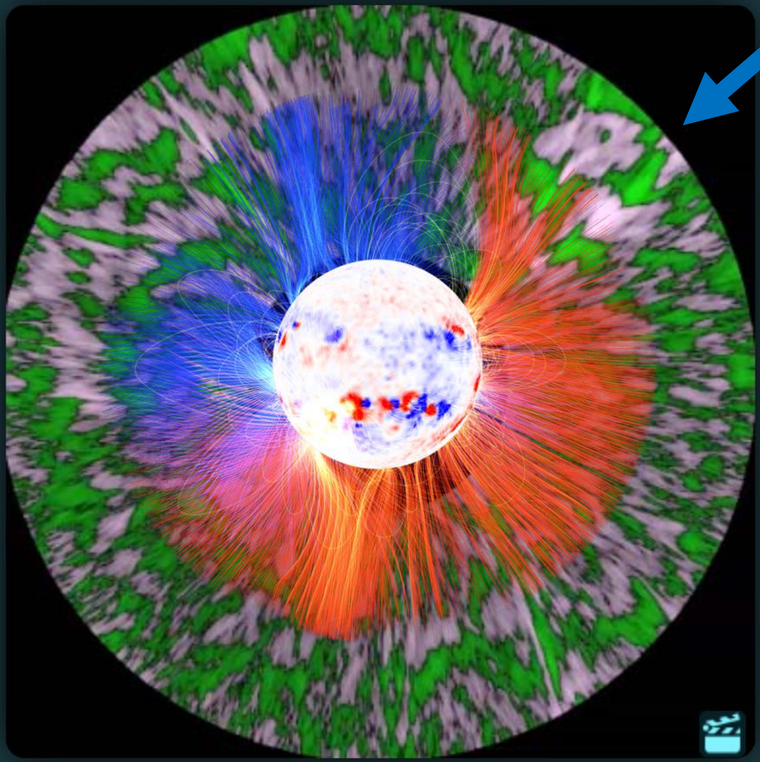


Casti, M., Arge, C.N., Bemporad, A., Pinto, R.F. and Henney, C.J., 2023. A New Method Linking the Solar Wind Speed to the Coronal Magnetic Field. ApJ, 949(2), p.42.

With PUNCH, we can derive SW acceleration profiles more routinely, tracking how the solar wind accelerates from a specific source, through the corona, to in situ spacecraft.

Objective 1: Ambient Solar Wind

1A: Global Evolving Solar Wind



DeForest et al. 2018

ADAPT-WSA global coronal field will overlap with PUNCH observations due to combined PFSS+SCS model solution!

Science Working Group 1A Planned Activities

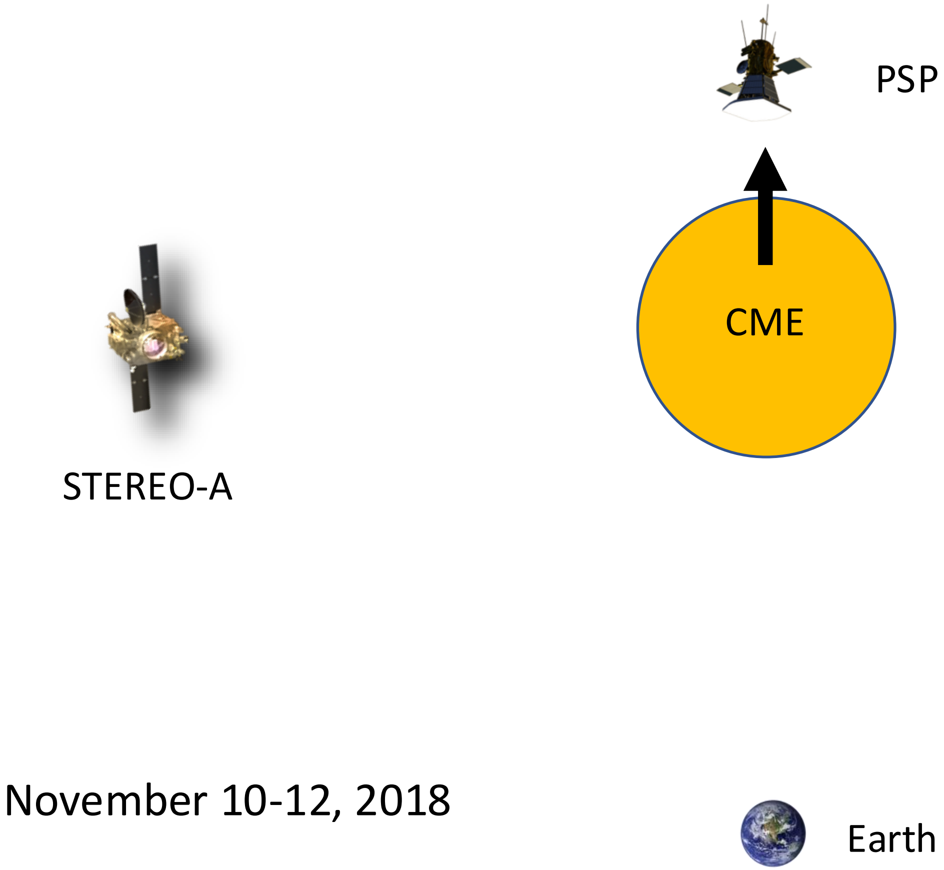
Working group 1A members

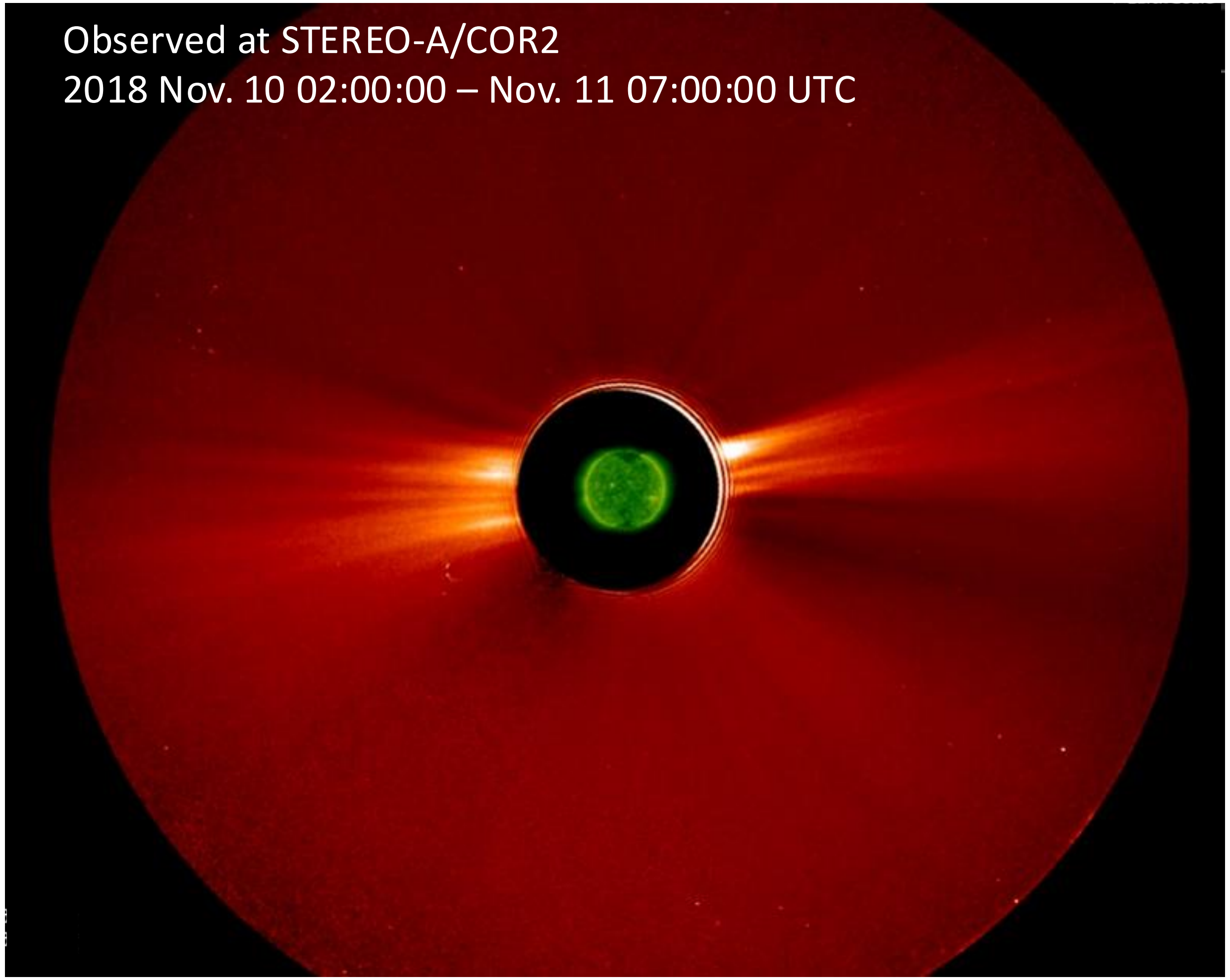
- Measure time-dependent solar wind flow from the outer corona to the inner heliosphere.
- Identify the changing flow boundaries between solar wind streams in the corona and heliosphere.
- Determine large-scale flow context necessary to relate coronal structure to in-situ measurements, and to provide ground-truth verification for global simulations.
- Characterize the global solar wind conditions through which transient structures propagate.

Characterizing first CME observed at Parker Solar Probe

Combining modeling efforts with remote and in situ observations

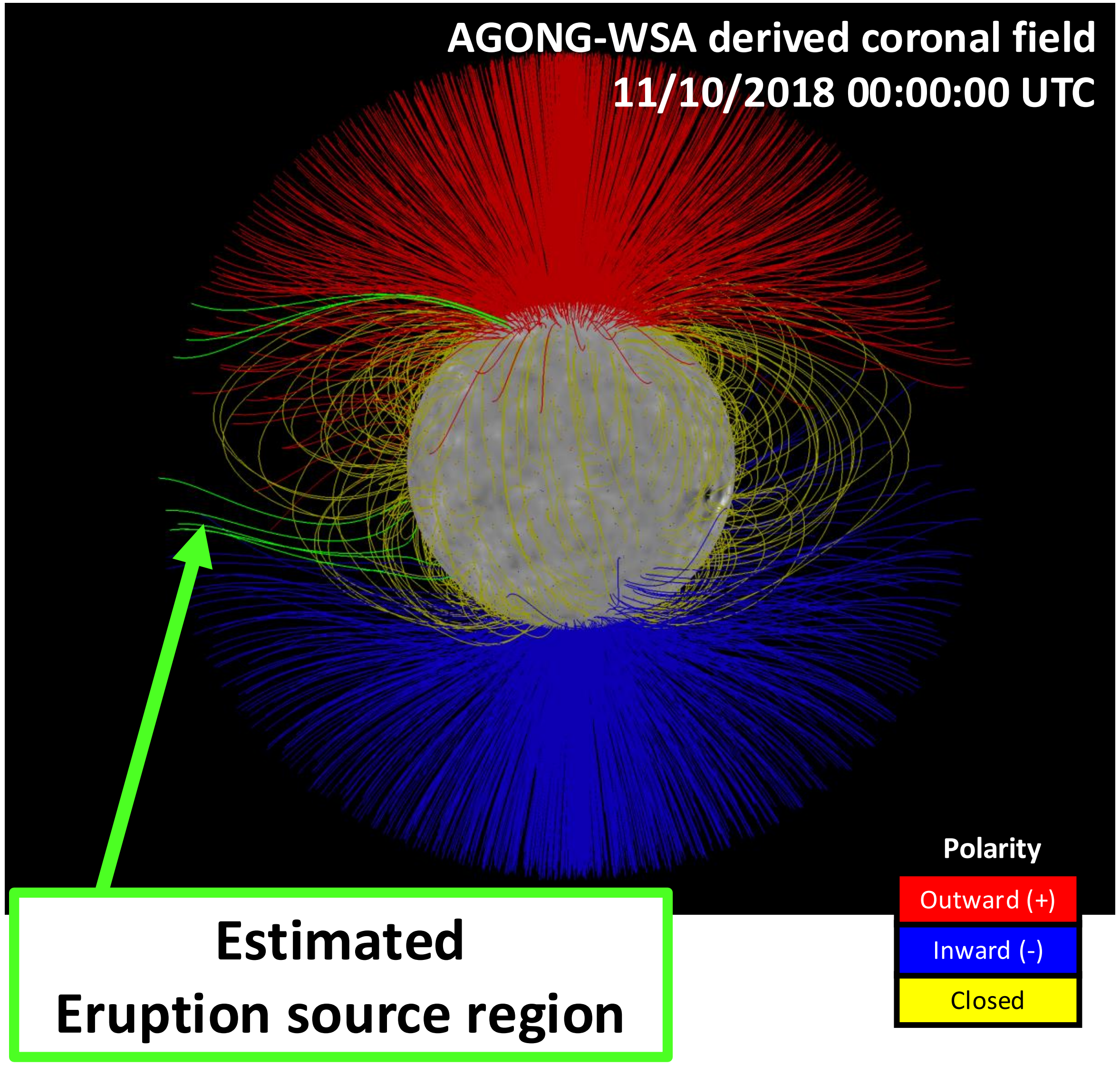
2A: CME 3D Trajectory, Structure, and Evolution

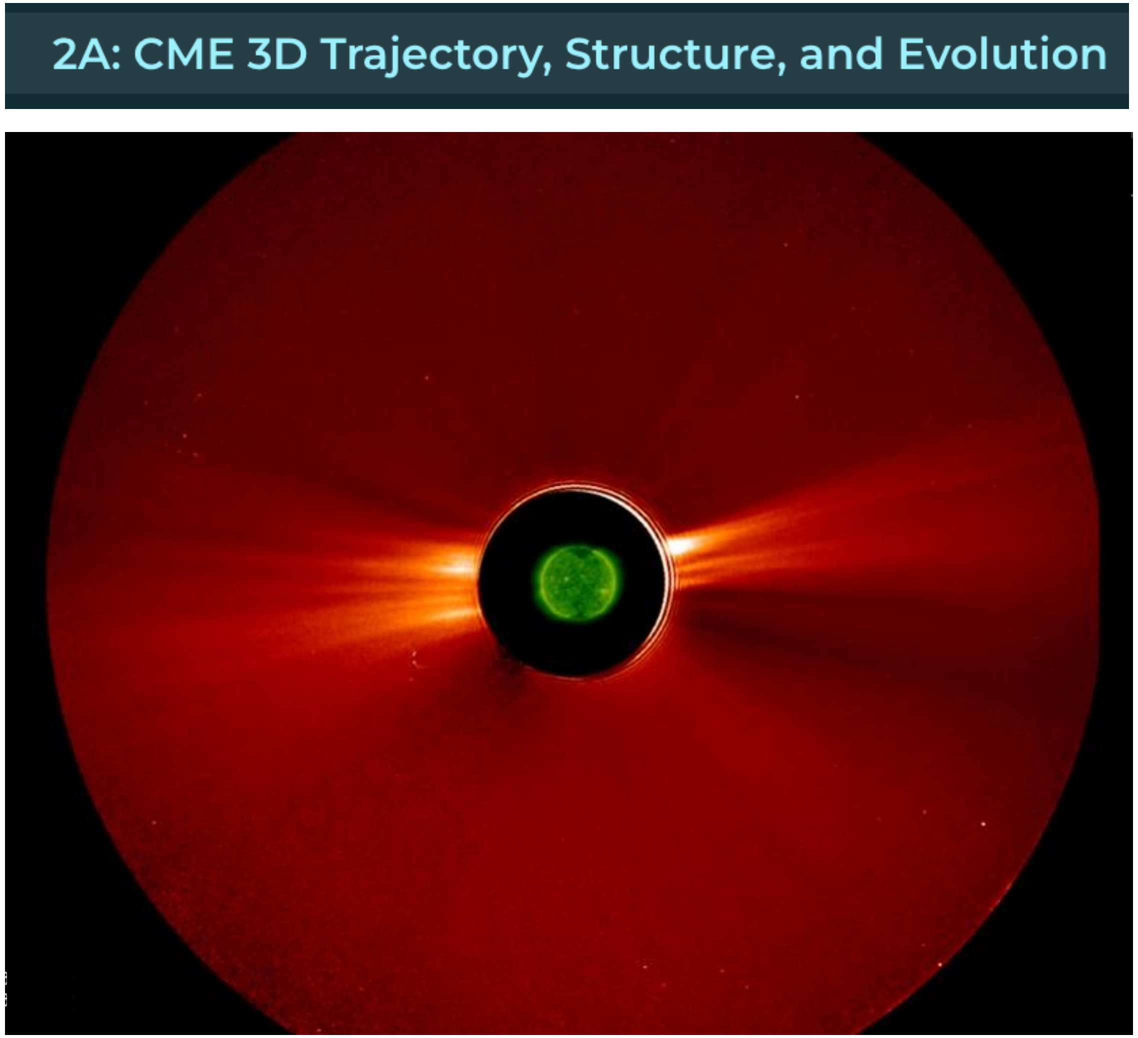




Korreck et al., 2020, *ApJS*, Vol. 246 Issue 2
Nieves-Chinchilla et al., 2020, *ApJS*, Vol. 246 Issue 2

ADAPT-WSA modeling of source region confirms CME is a streamer blowout in *PSP* Enc. 1

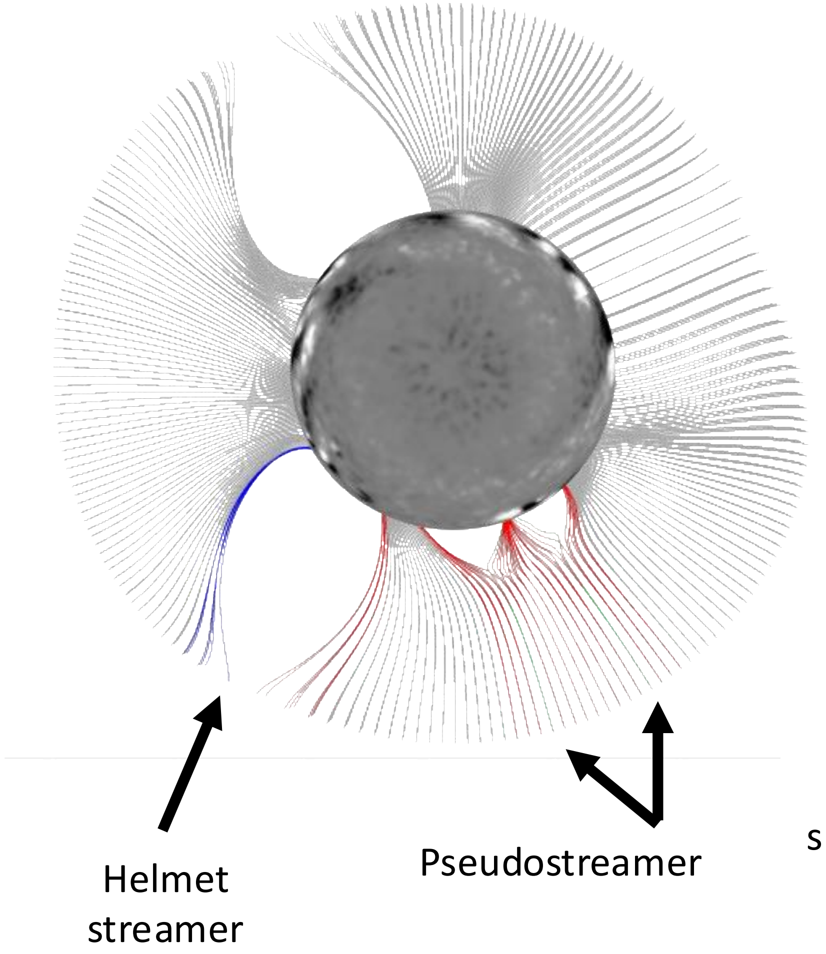


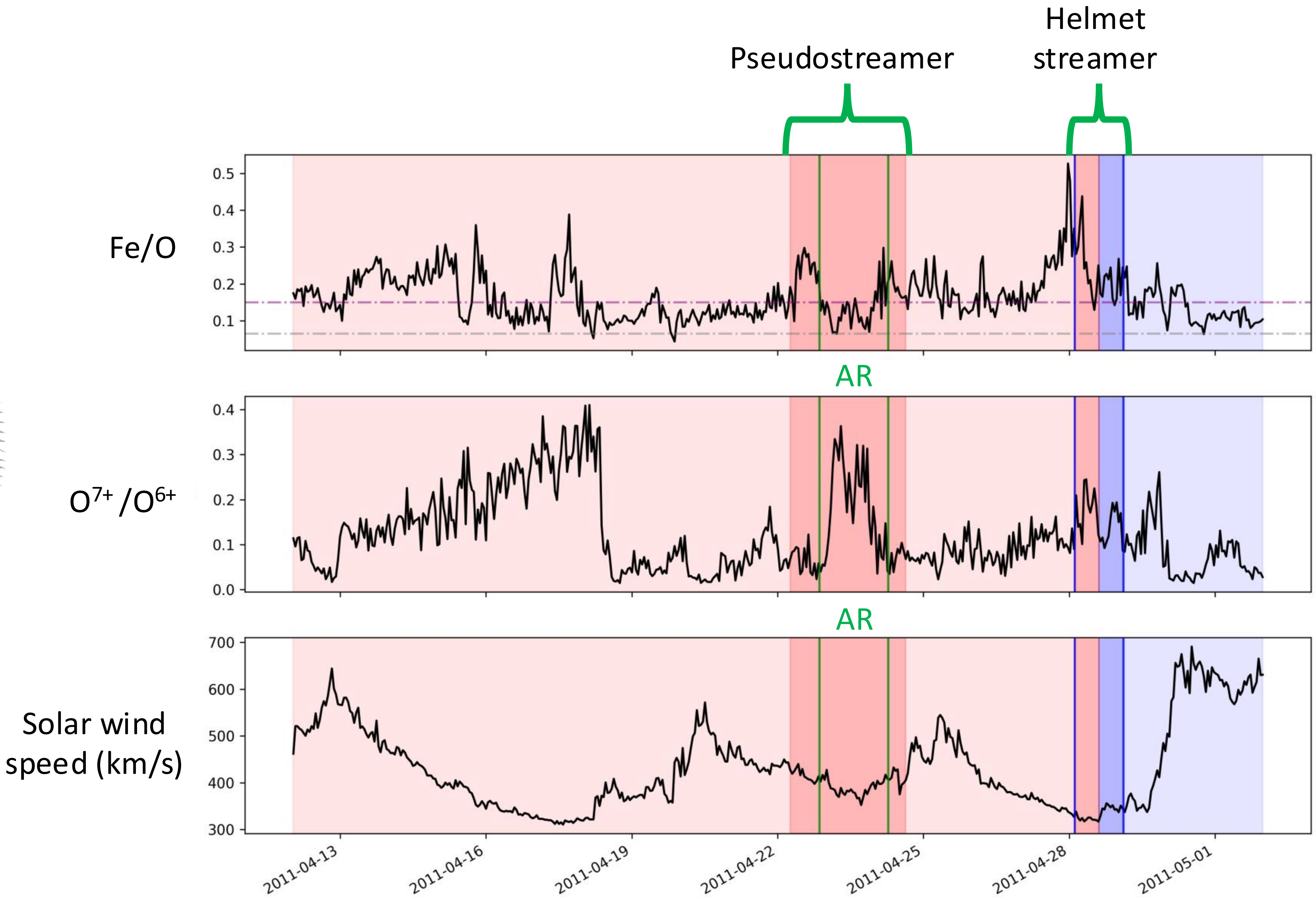


Korreck et al., 2020, *ApJS*, Vol. 246 Issue 2
Nieves-Chinchilla et al., 2020, *ApJS*, Vol. 246 Issue 2

Investigating solar wind formation by characterizing SW properties from specific sources

Solar wind variability from coronal streamers directly related to spacecraft connectivity changes between different solar wind sources

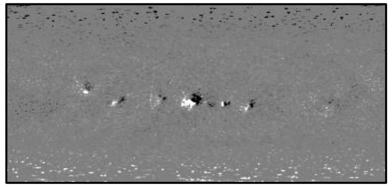




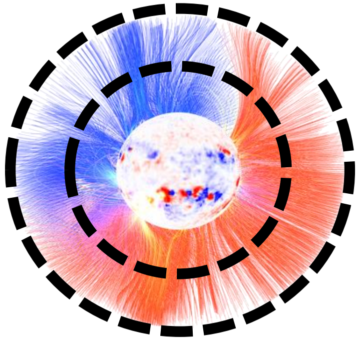
Why WSA?

- Well-vetted, regularly maintained, modernized, computationally efficient code.
- Multi-solar cycle investigations possible due to compatibility with older input magnetograms and spacecraft data (e.g. MWO, Helios)
- Coupled PFSS-SCS model.
- Estimate uncertainty via ensemble of global, instantaneous solutions of the coronal field when coupled with ADAPT.
- Validation of model output/realizations with B_r *and* empirically-derived speed.

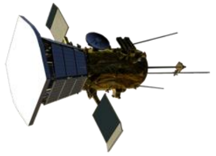
Input: ADAPT

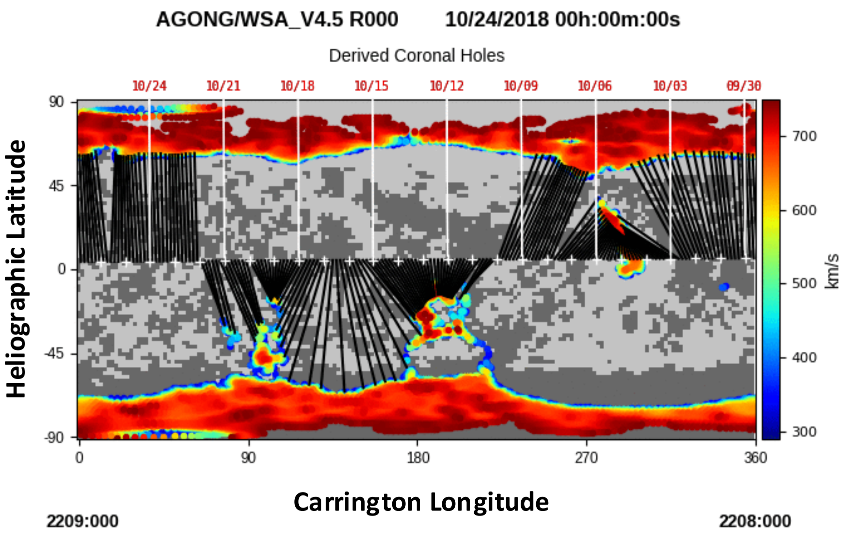


WSA



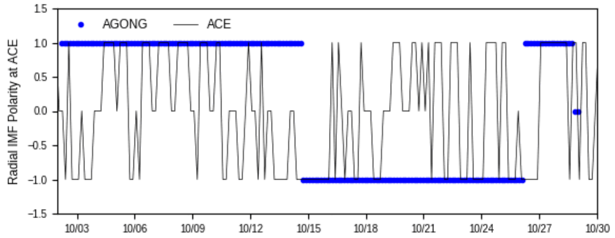
$$V(f_s,\theta_b) = 285 + \frac{625}{(1+f_s)^{2/9}}\left\{1.0 - 0.8e^{-(\theta_b/2)^2}\right\}^3$$



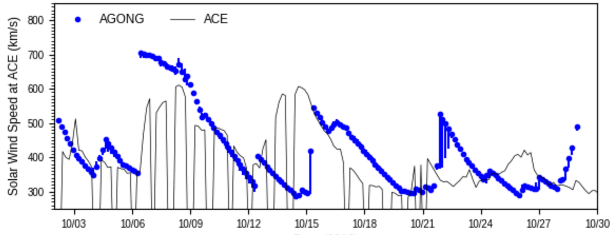


Carrington Longitude

IMF Polarity



Solar wind speed (km/s)

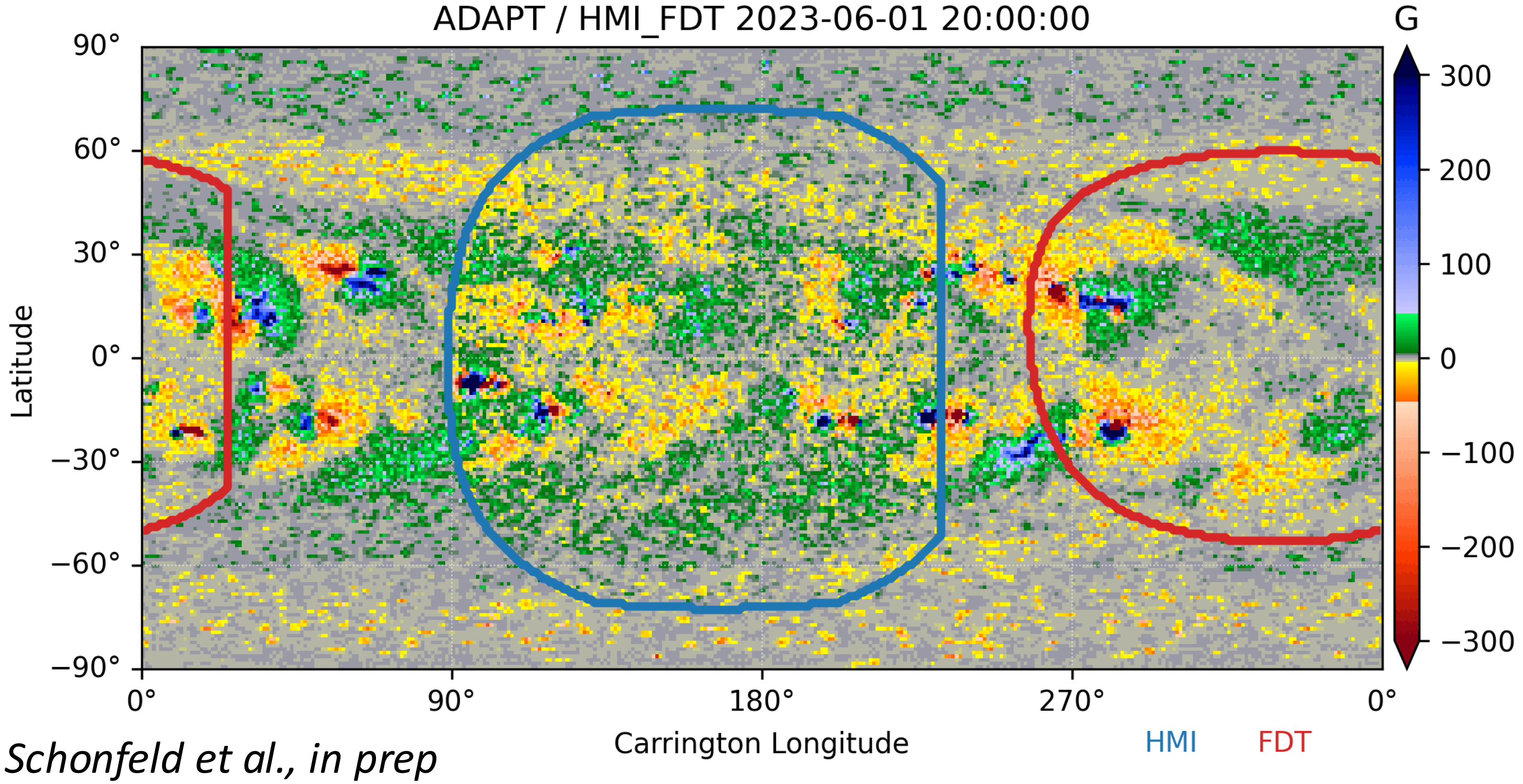


Date

****Many tools in place to characterize the formation of the solar wind observed at various spacecraft****

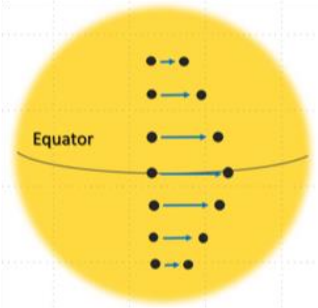
- Global maps of S-web connectivity
- Quantitatively relating in situ measurements to *Q, fs, DCHB, source region distance from HCS*, etc.
- Output available via CCMC, or WSA team

Creating a **global and synchronic** photospheric magnetic field map: Assimilating SO/PHI-FDT and SDO/HMI data into the ADAPT model

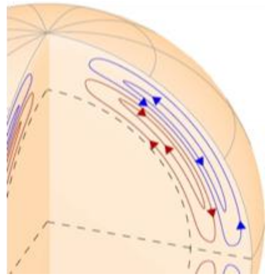


Schonfeld et al., in prep

ADAPT utilizes flux transport modeling to account for solar time-dependent effects:

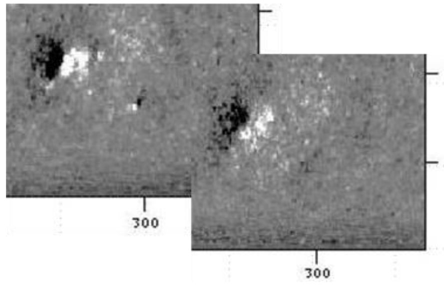


Differential Rotation

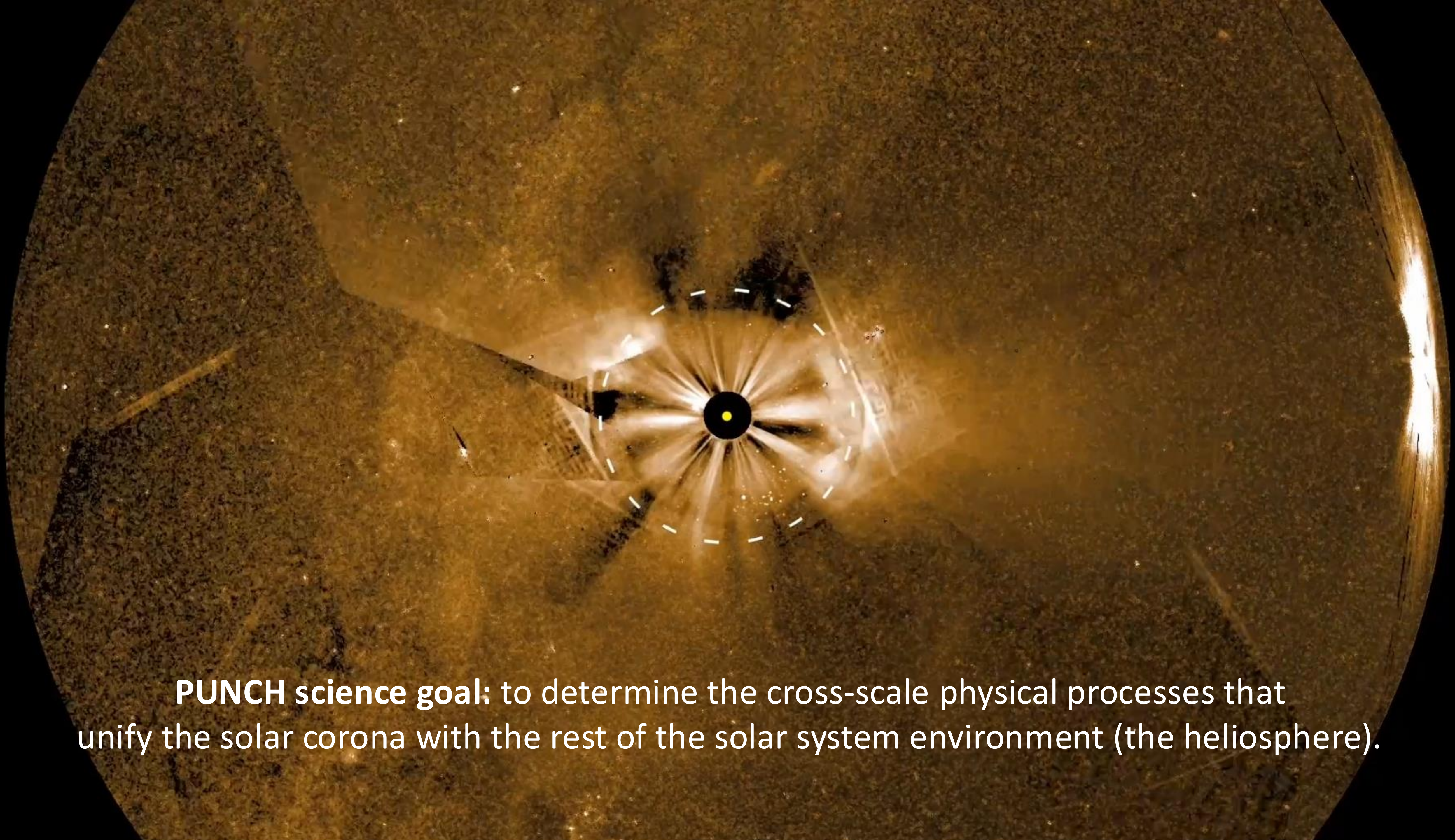


Meridional Flows

Supergranulation, random flux emergence



ADAPT is an ensemble model, producing 12 realizations of the photospheric flux distribution, providing an estimate in the uncertainty.



PUNCH science goal: to determine the cross-scale physical processes that unify the solar corona with the rest of the solar system environment (the heliosphere).

Generating 3D coronal density data cubes

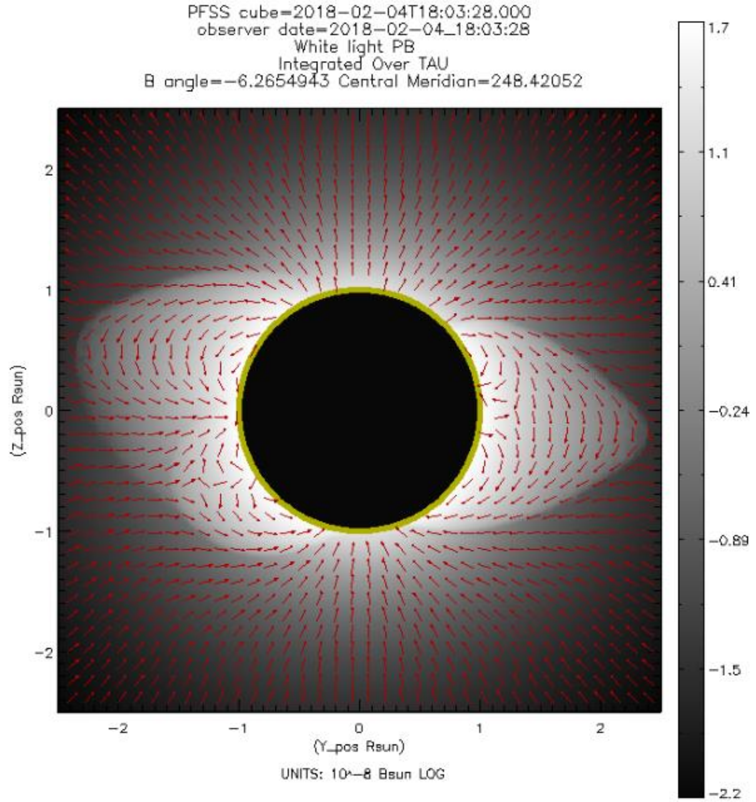
Adding an empirical electron density specification capability to the model

- Approach: Integrating WSA with the HAO FORWARD model
- FORWARD generates white light images of the Sun based on the magnetic field configuration generated by a coronal model and empirical density functions
- WSA will make use of these empirical density functions to generate 3D coronal density data cubes

WSA-FORWARD will generate:

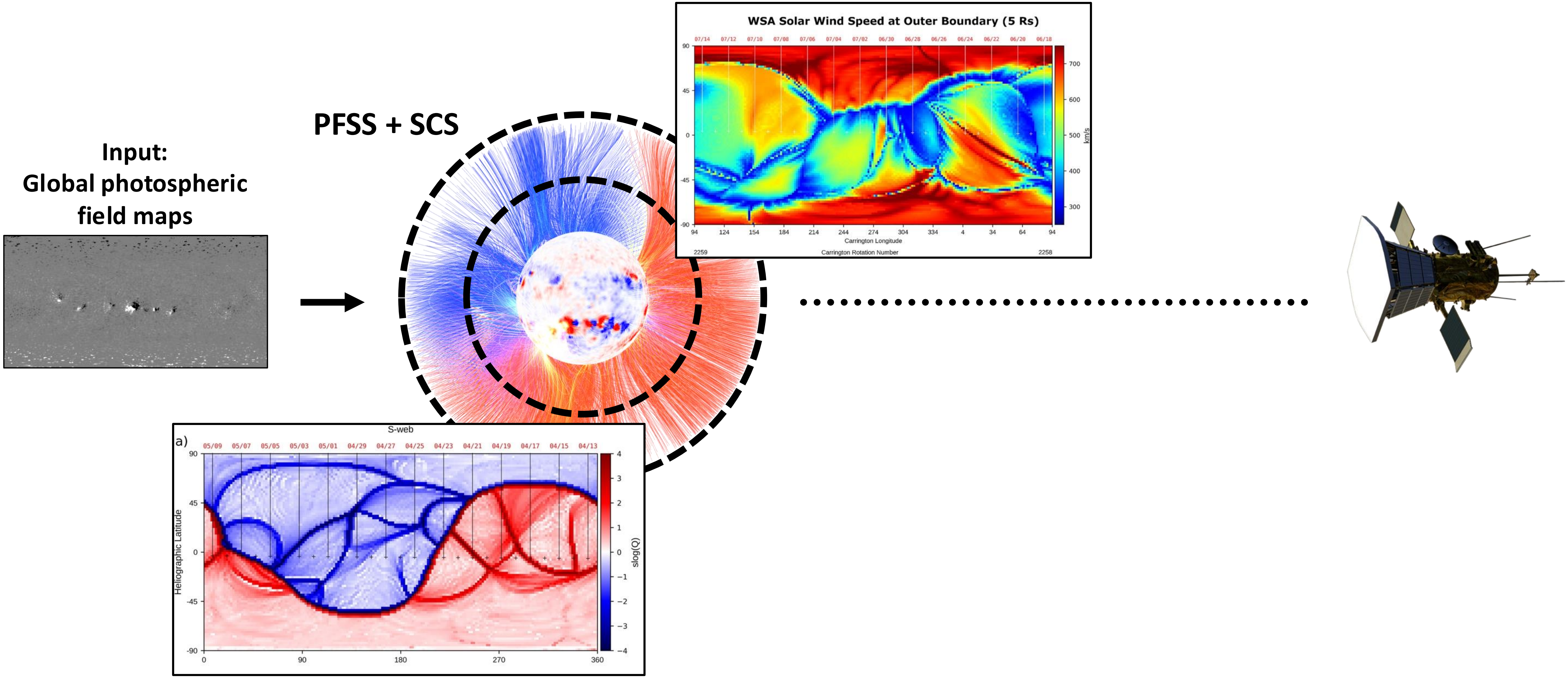
- White light (plane of the sky) images of the Sun
- 3D coronal e- density cubes
- These model products will be made available to public!

FORWARD Model



Courtesy Sarah Gibson, HAO

WSA provides the **coronal and heliospheric context** and the **in situ connection** necessary to advance PUNCH science objectives.



WSA provides the **coronal and heliospheric context** and the **in situ connection** necessary to advance PUNCH science objectives.