

# Leveraging an Alignment of PUNCH, CODEX, ASPIICS and Metis to Reveal the Outflow and Acceleration of the Solar Wind

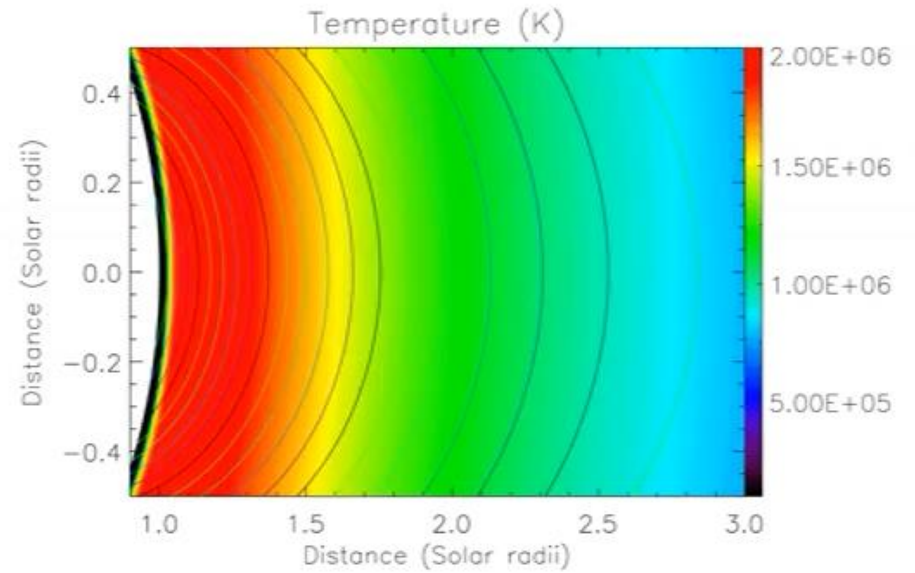
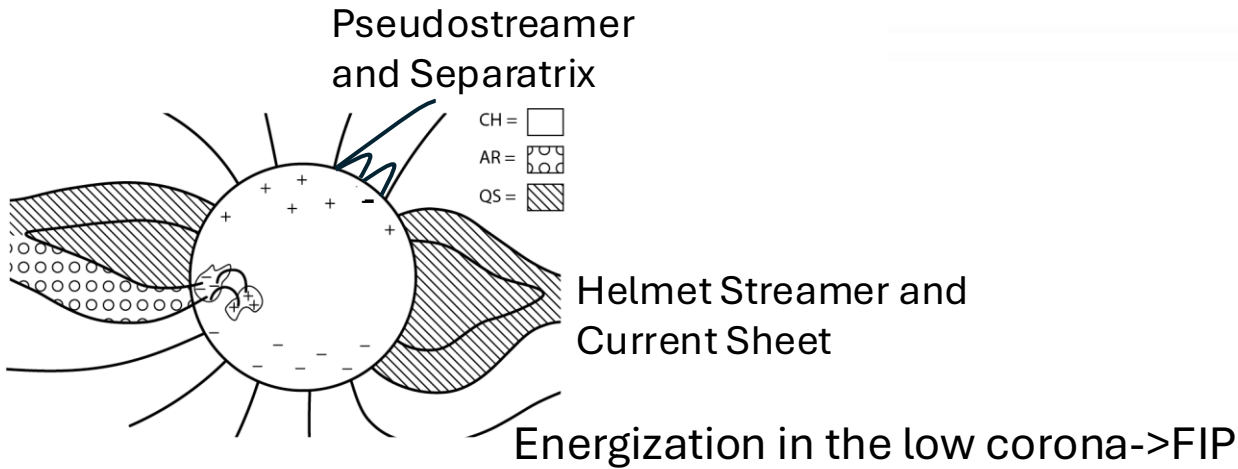
Nicholeen Viall, Heliophysicist, NASA Goddard Space Flight Center  
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Thanks to the competed HISFM program, Samantha Wallace; the CODEX team, Jeff Newmark, Shanwlee Sow Mondal, Yeon-Han Kim; the PUNCH team, Raphael Attie; the Metis team, Silvano Fineschi; the ASPIICS team Andrei Zhukov

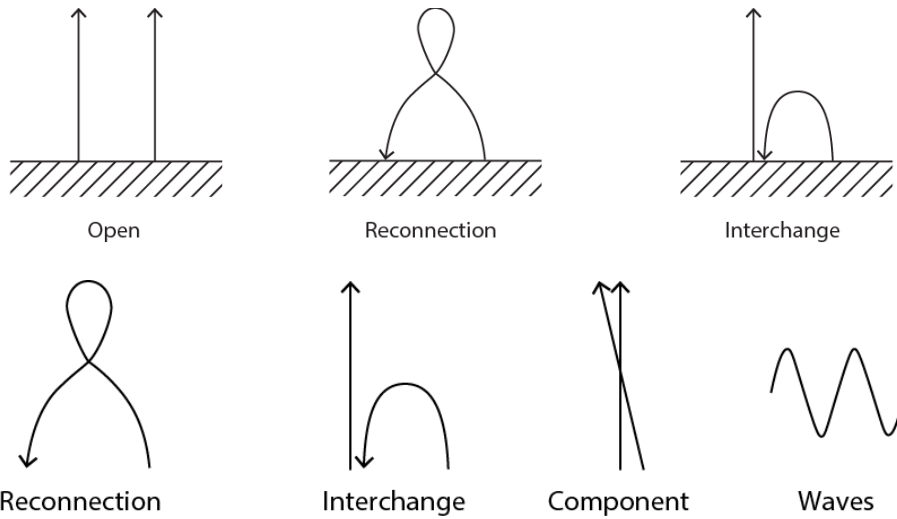
Common Science of PUNCH, CODEX, ASPIICS and  
Metis: Mesoscale Solar Wind Density Structures and  
the Ground State of Space Weather

Solar wind formation is highly complex and there are many types of wind. Understanding the complexity requires considering the time history of the plasma.

Time: 0.0 hr Frame: 0000 Iteration: 000000

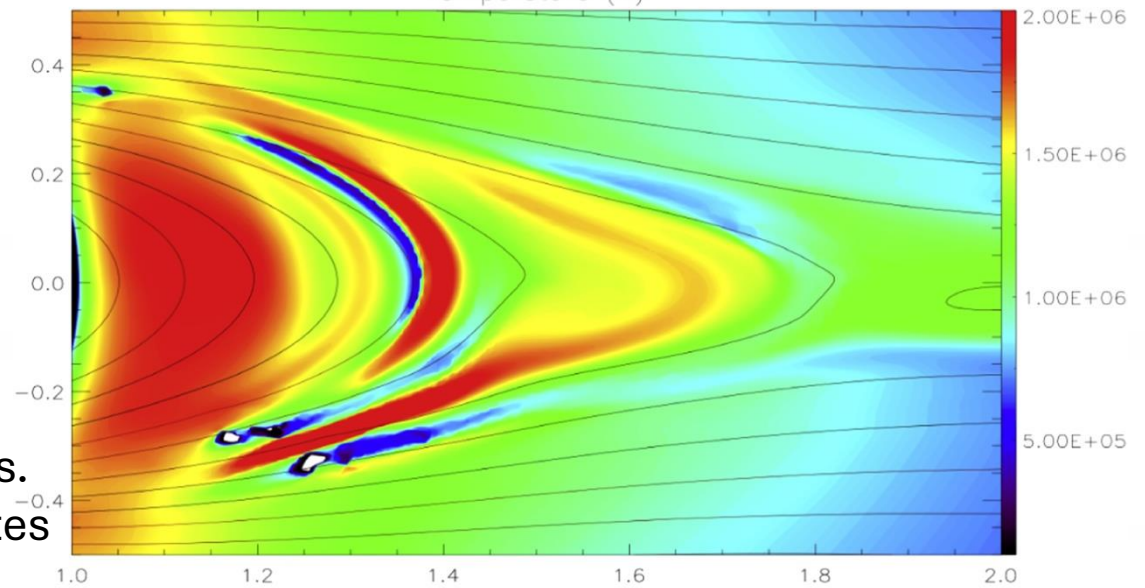


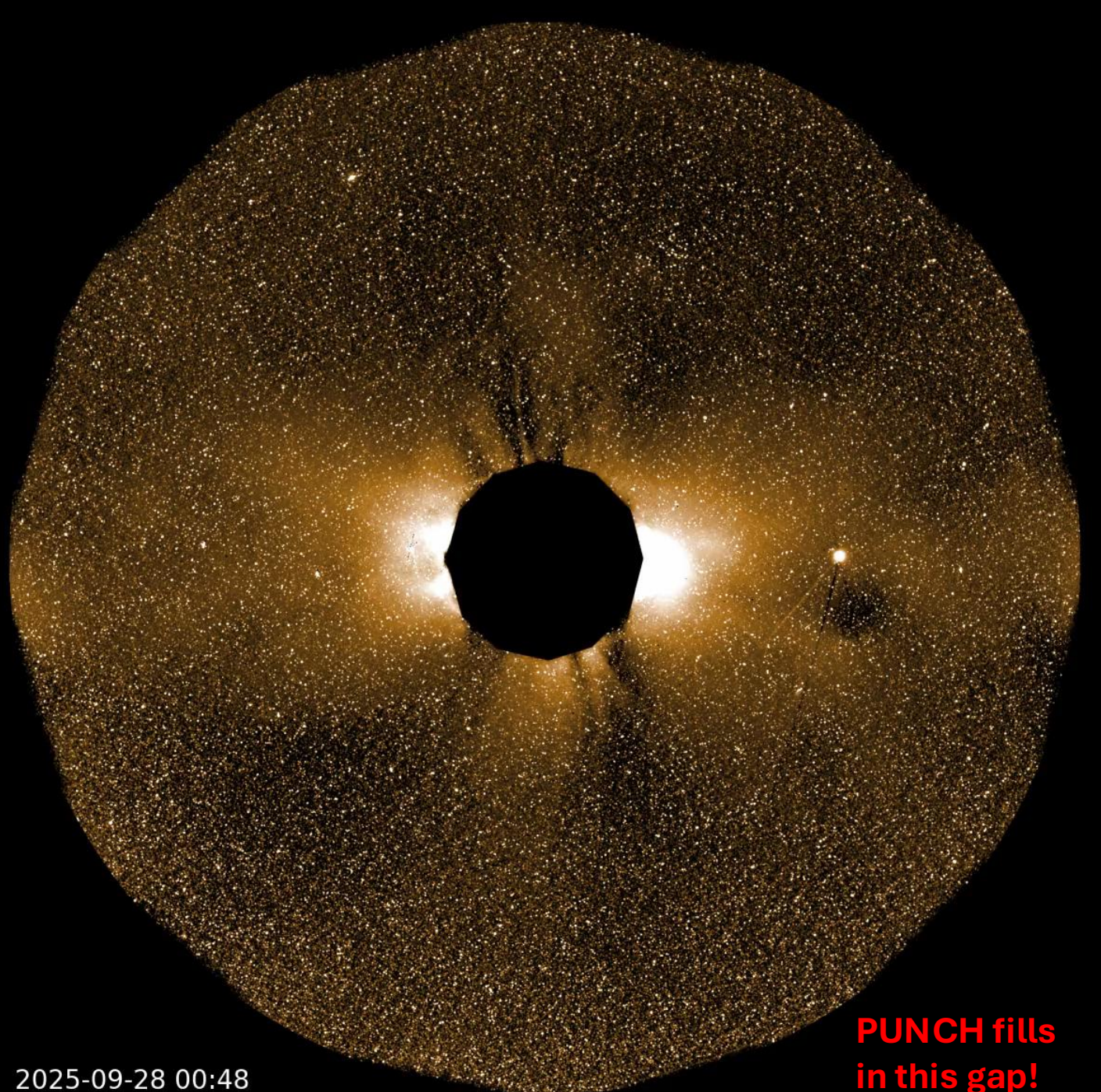
Schlenker, Antiochos, MacNeice, Mason, 2021



Energization **and/or** mass release in the low through middle corona. ->FIP

Energization middle corona and outwards. ->Sp and charge states



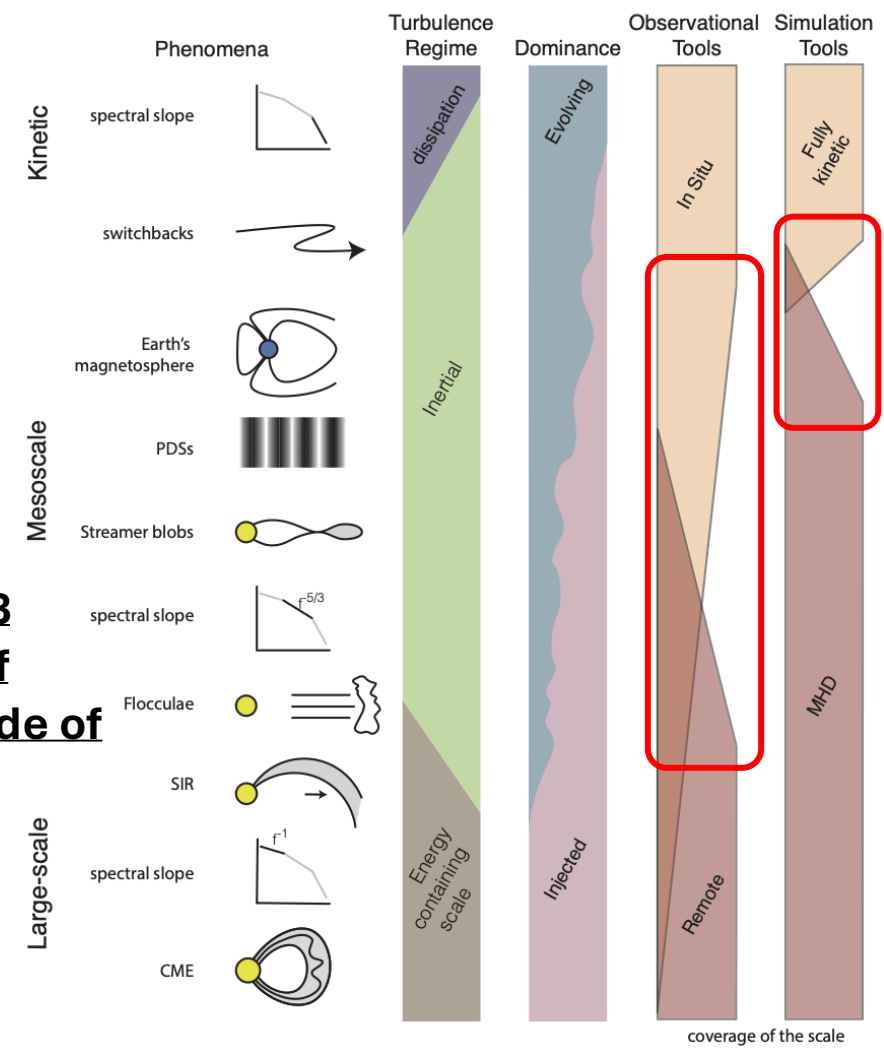


2025-09-28 00:48

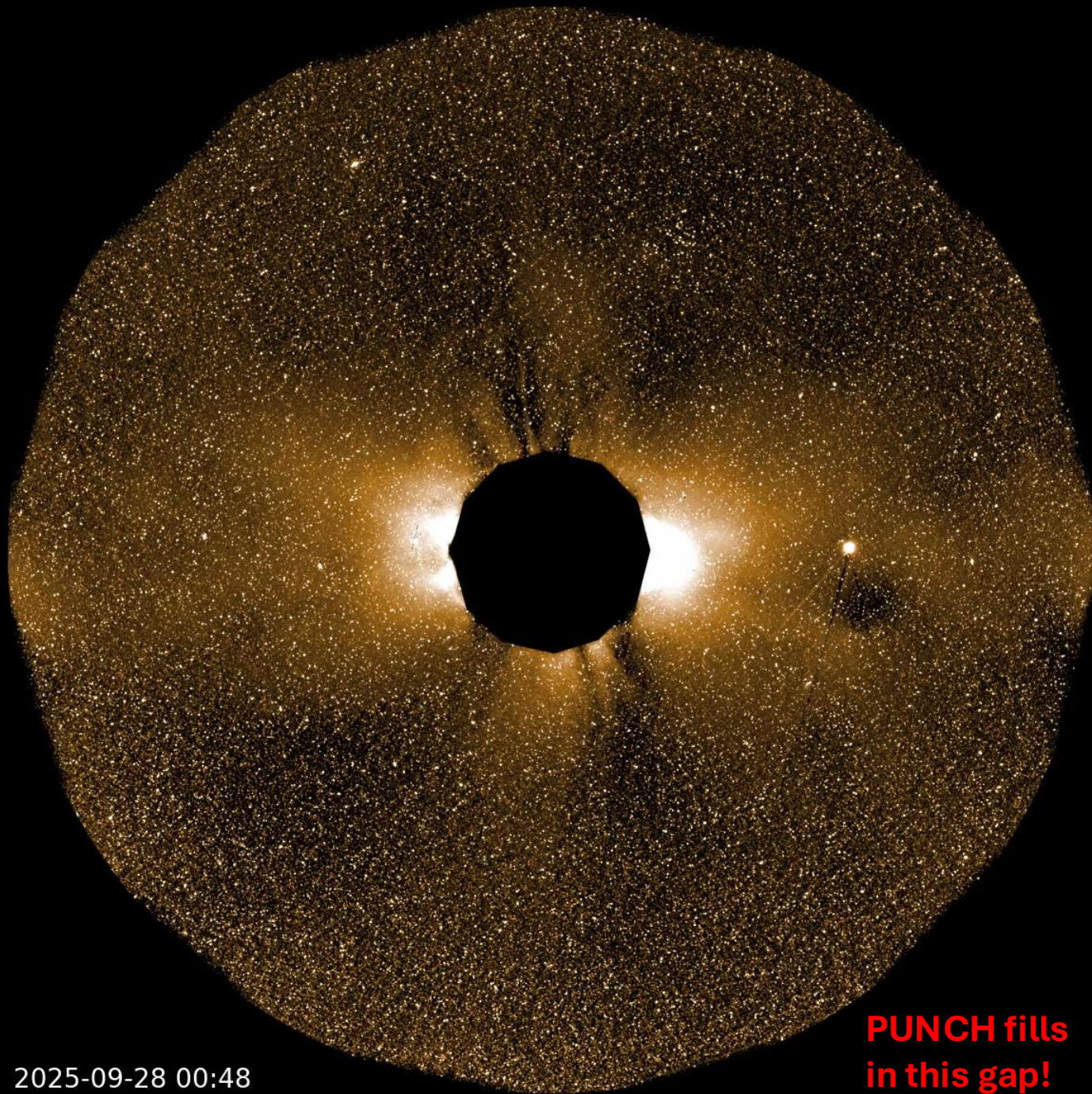
**PUNCH fills in this gap!**

**Mesoscale solar wind structures:**  
they are tiny compared to the inner heliosphere and most imagers

**PUNCH spans ~ 3 orders of magnitude of scales**



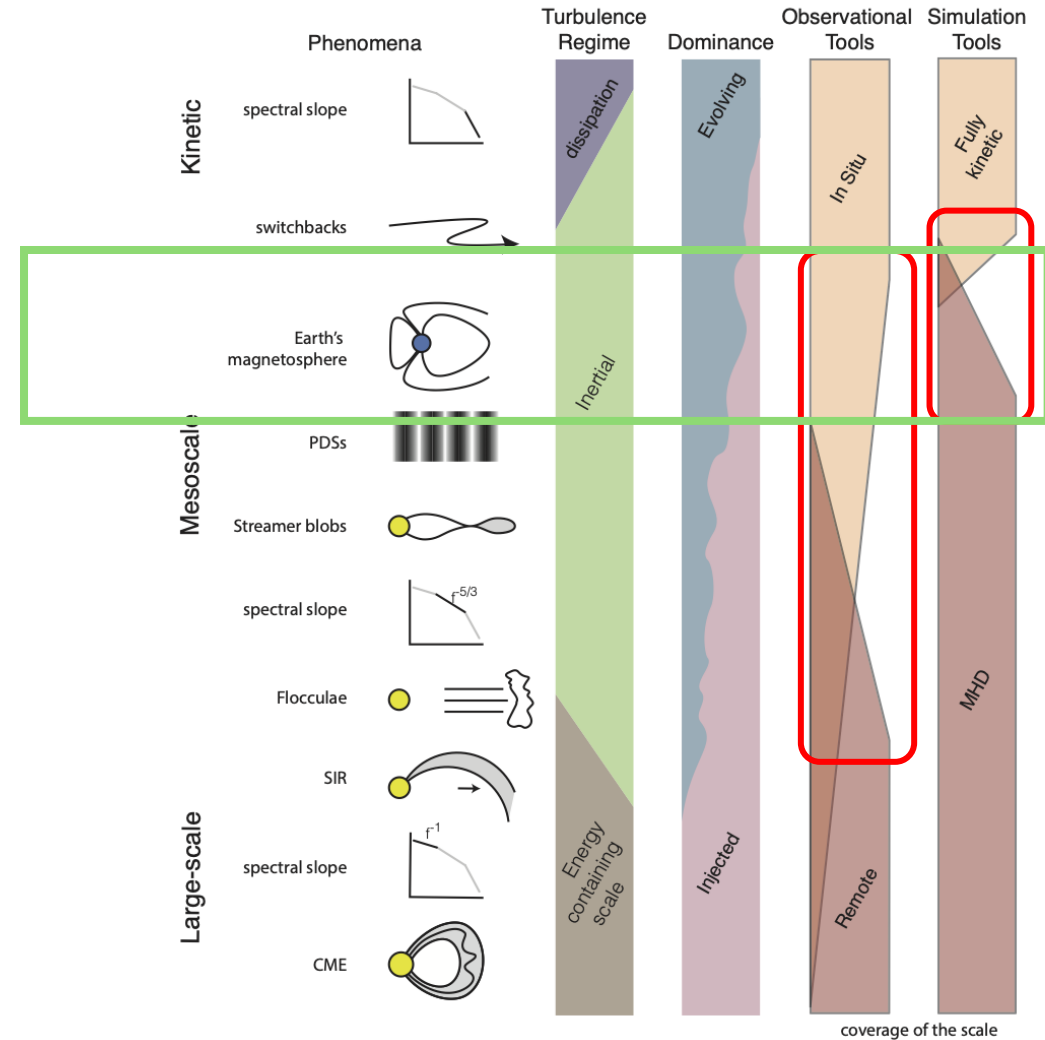
Viall, DeForest, and Kepko, 2021



2025-09-28 00:48

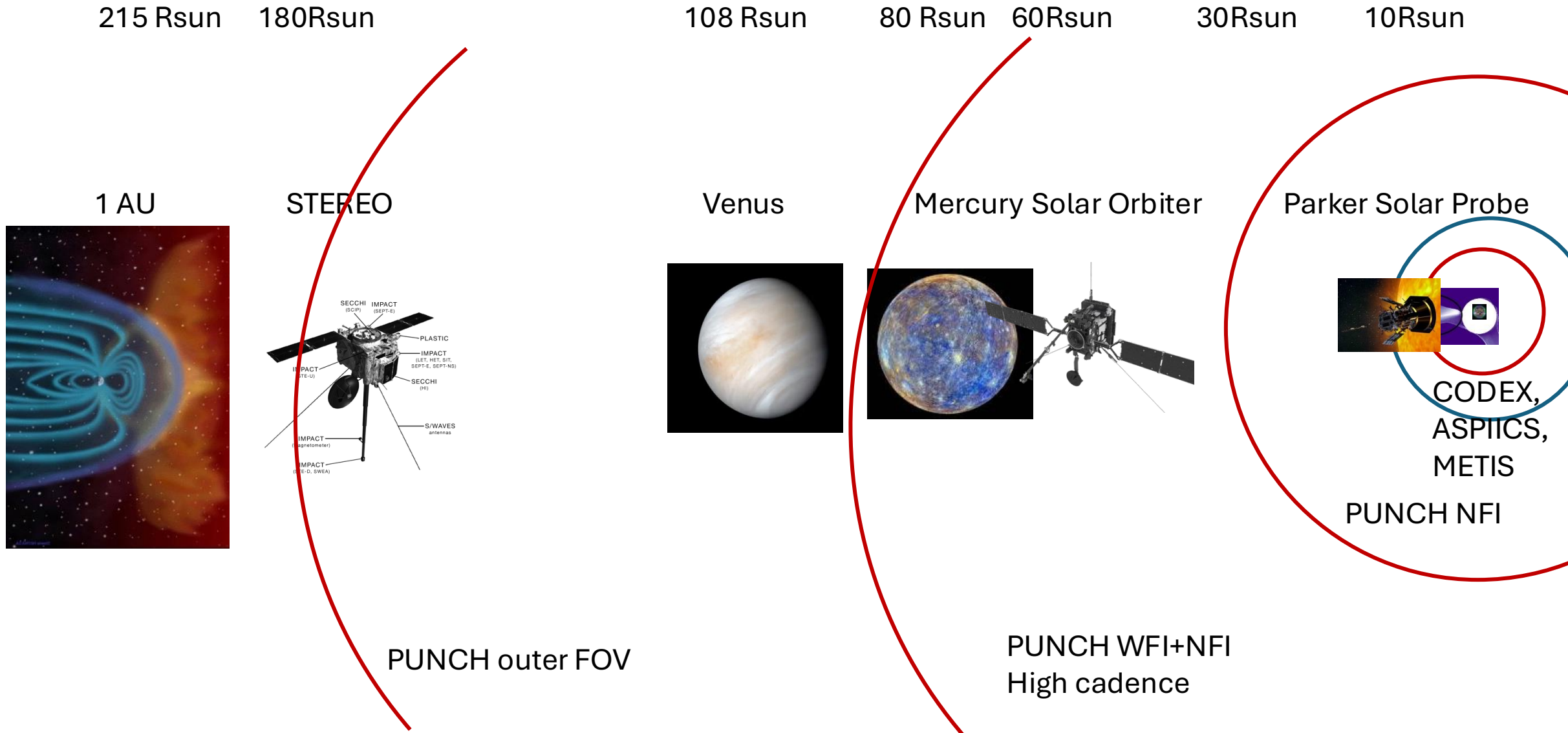
**PUNCH fills in this gap!**

**Mesoscale solar wind structures:** comprise the ground state of space weather  
Punch images them!

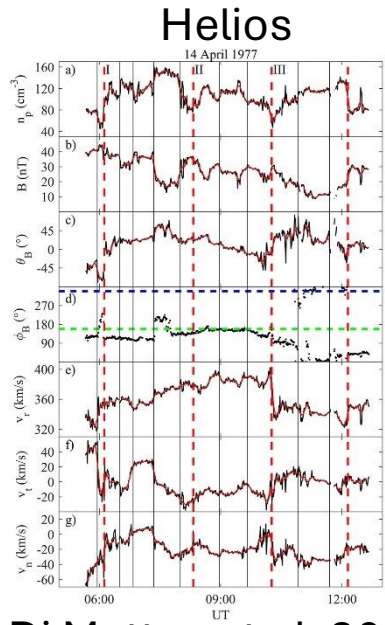


Viall, DeForest, and Kepko, 2021

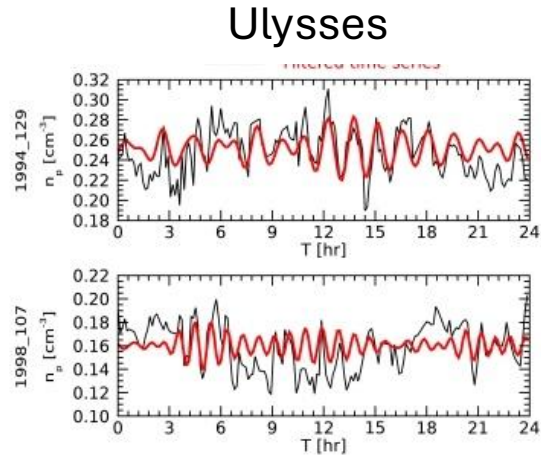
PUNCH UNifies NASA's Heliophysics Systems Observatory by providing the global context of the inner Heliosphere, simultaneously resolving the mesoscales to reveal the physics of cross-scale coupling and evolution and the ground state of space weather-> **PUNCH CONNECTS!**



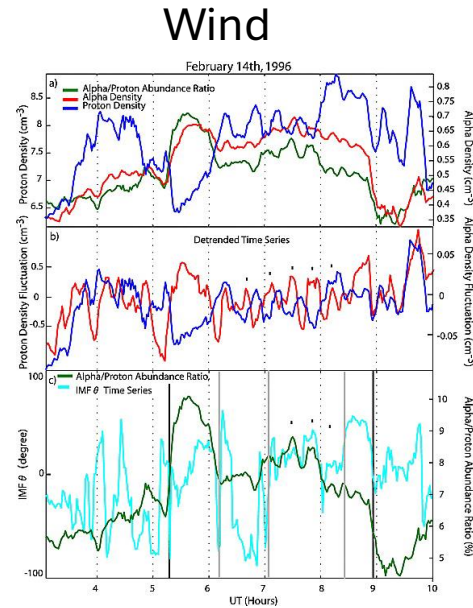
Periodic density structures are a type of Mesoscale Structure that PUNCH, CODEX, ASPIICS, and METIS see. Formed in the corona through periodic driven reconnection (S-web/jets/jetlets)



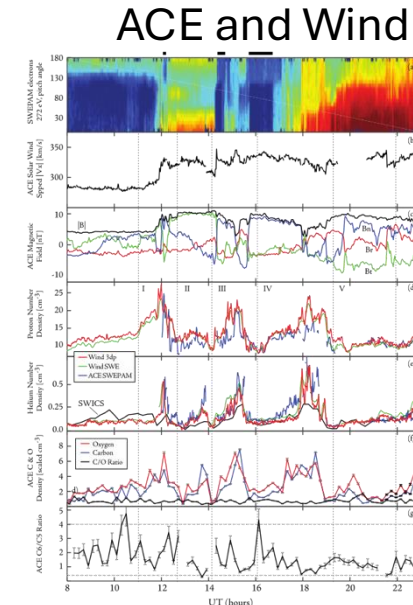
Di Matteo et al. 2019



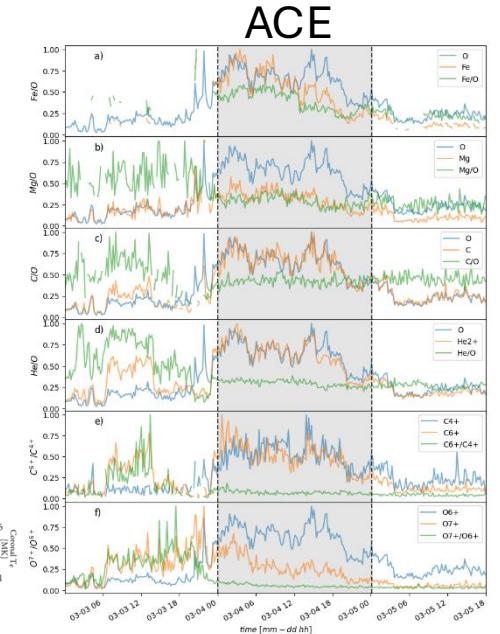
Randol, Viall, DiMatteo & Kepko 2026



Viall, Spence & Kasper 2009



Kepko et al. 2016



Gershkovich et al. 2022, 2023

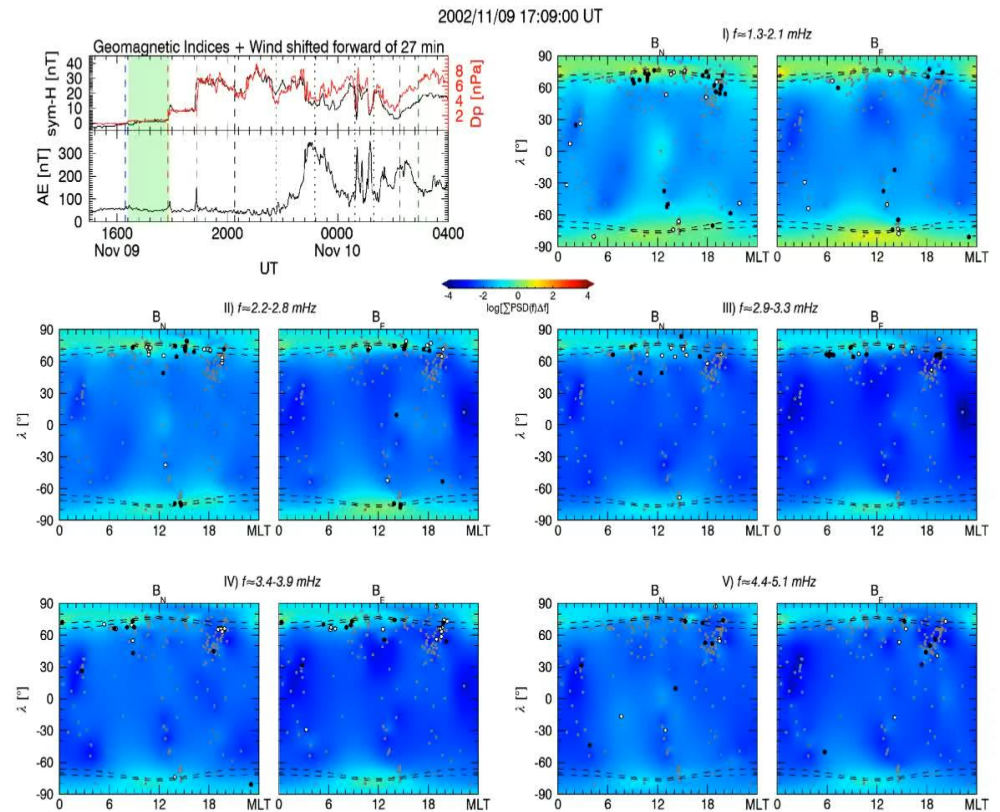
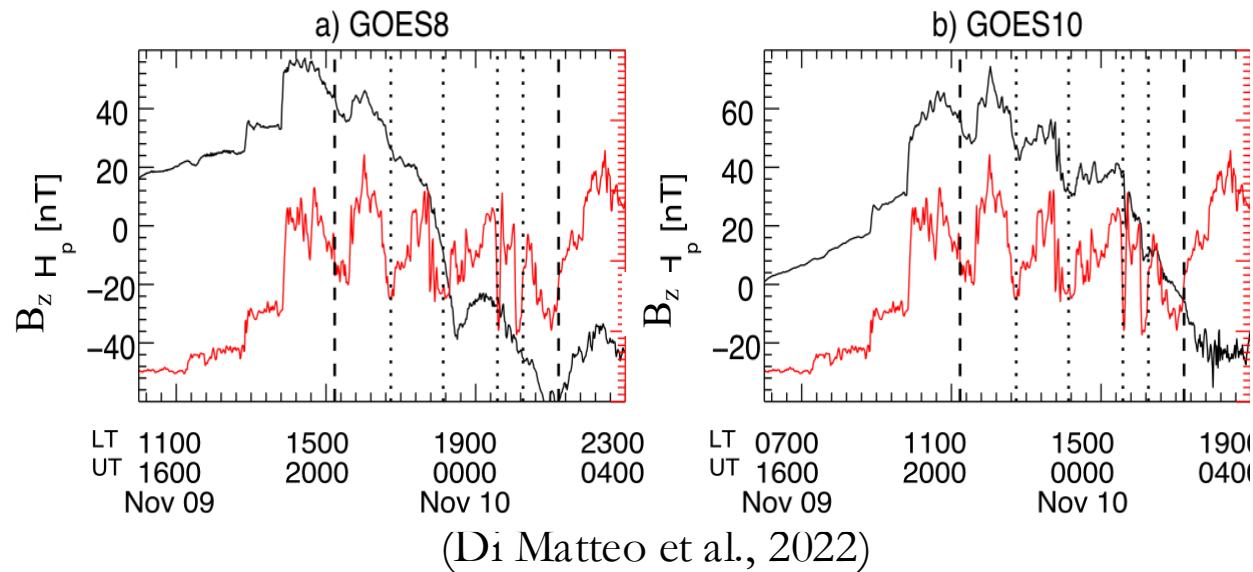
- Trains of density enhancements spaced periodically (MTM Fourier analysis + red noise null hypothesis –IDL and Python open source and in the PUNCHBOWL).
- (at least) Two populations of frequencies.  $\sim 0.1-1.0$ , and  $\sim 1.0-5.0$  mHz.
- Composition changes (alpha/proton, charge state, FIP, Sulfur/Oxygen, Proton Specific Entropy...)
- Associated magnetic field variations confirm structure interpretation (e.g. often flux ropes, PBS) and rules out locally propagating waves or wavy HCS. ‘they are in a relaxed state’.

**PUNCH, APIICS, METIS, CODEX have unique spatial coverages, cadences (Nyquist), physically measured quantity**

# Periodic density structures directly drive global magnetospheric fluctuations

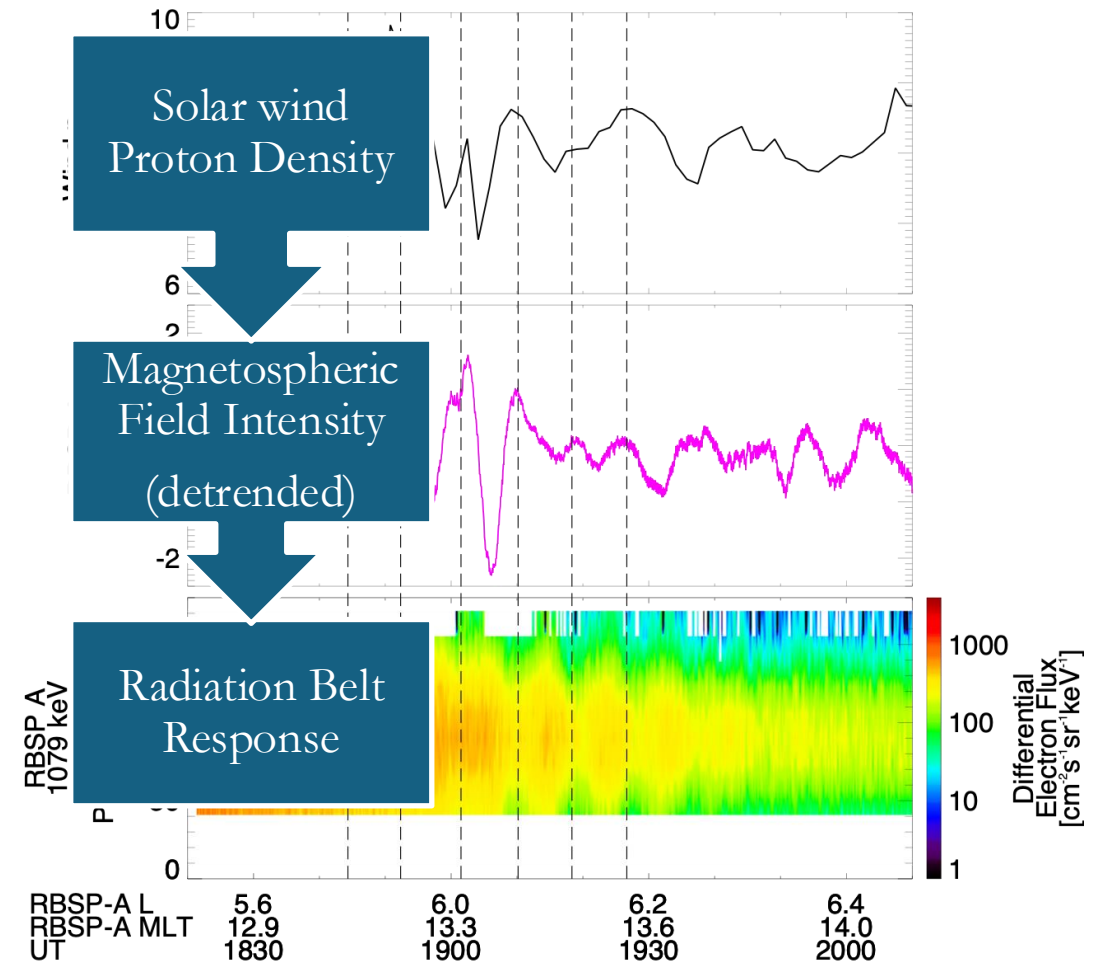
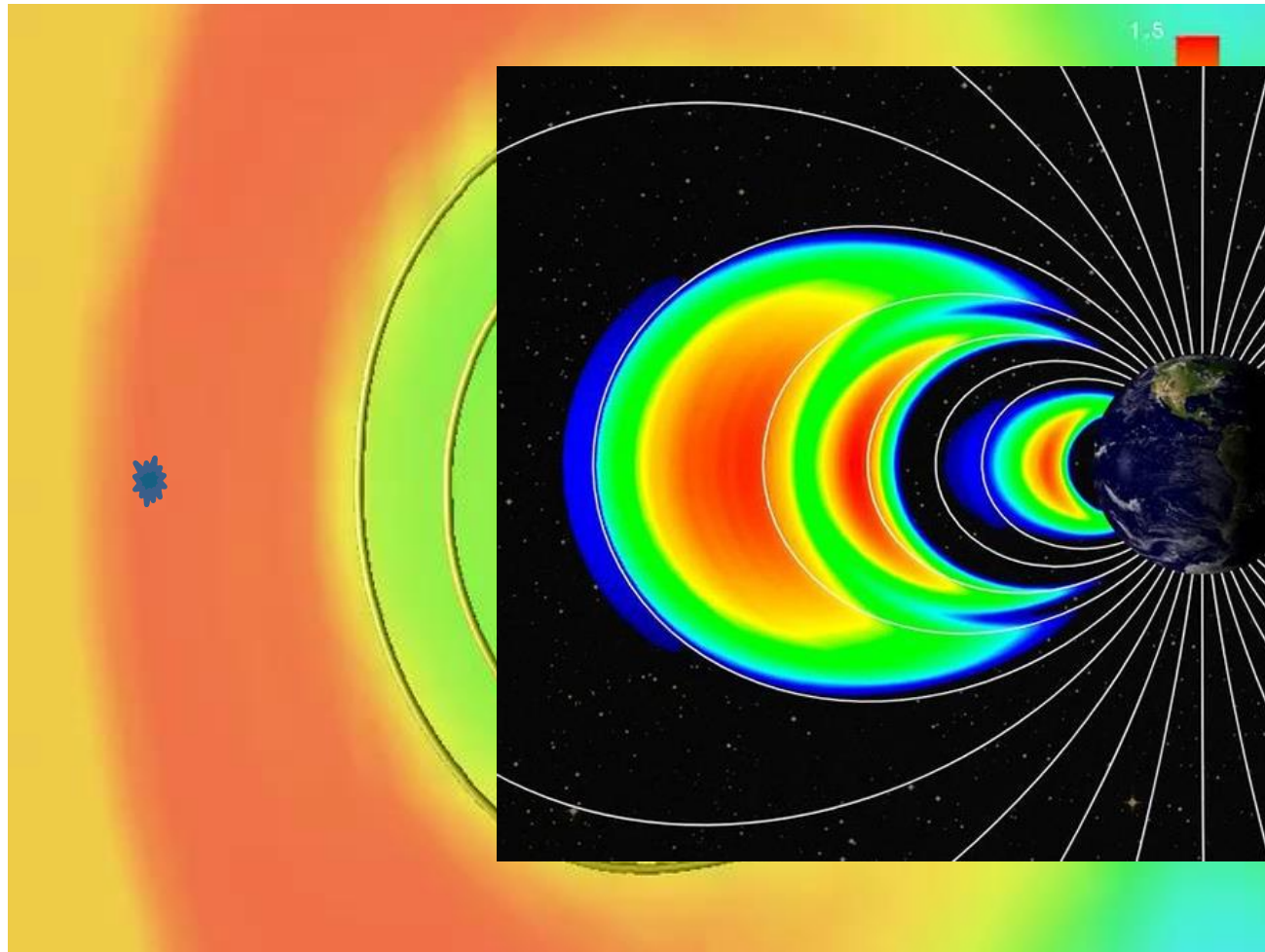
**Red** – proton density at L1 (shifted forward of  $\approx 25$  min)

**Black** - magnetic field at the geostationary orbit

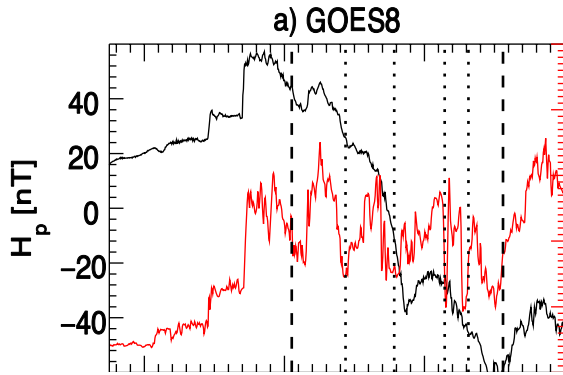


Qualitative global map of the power observed in ground magnetometers between  $\approx 2.2$  and  $\approx 2.8$  mHz shows the global ULF waves (black dots) directly driven by solar wind periodic density structures

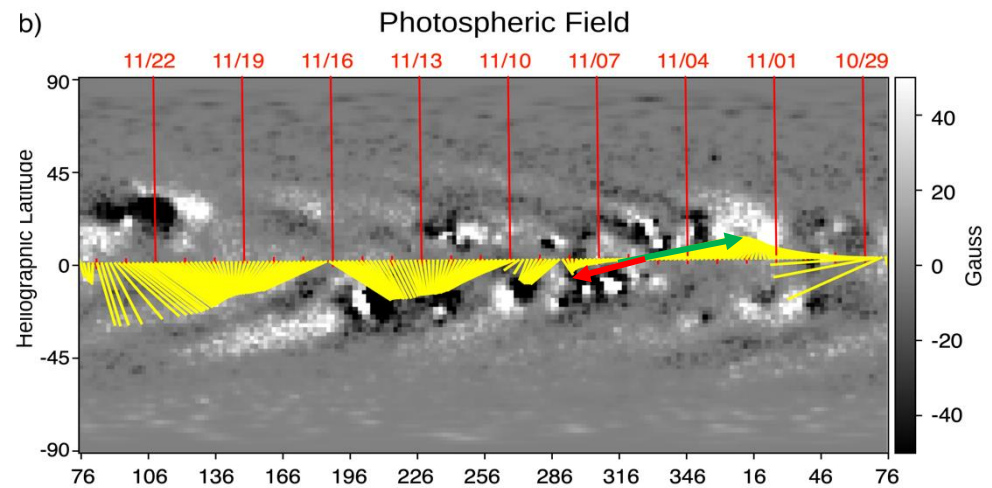
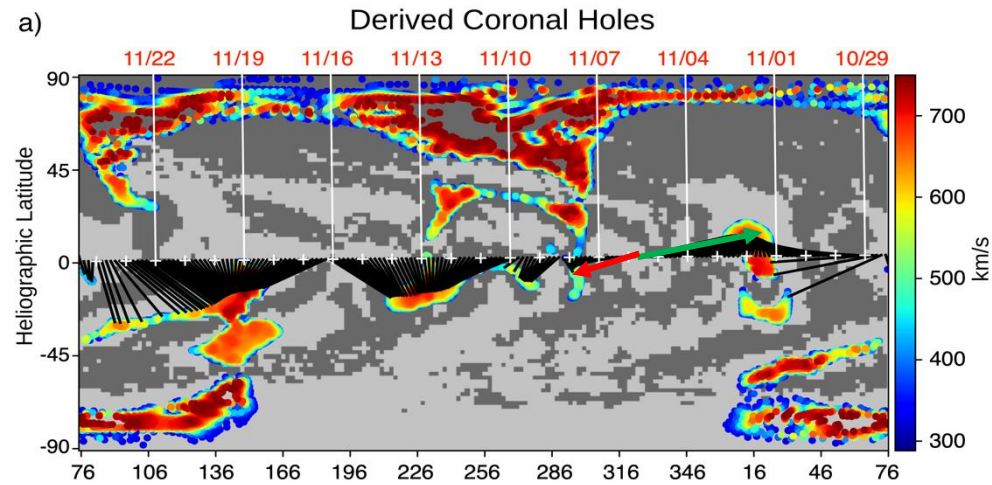
# Ground state of space weather: The Sun creates Periodic Density Structures, which drive ULF waves in the magnetosphere, which causes RELATIVISTIC particles to precipitate from radiation belts into Earth's atmosphere



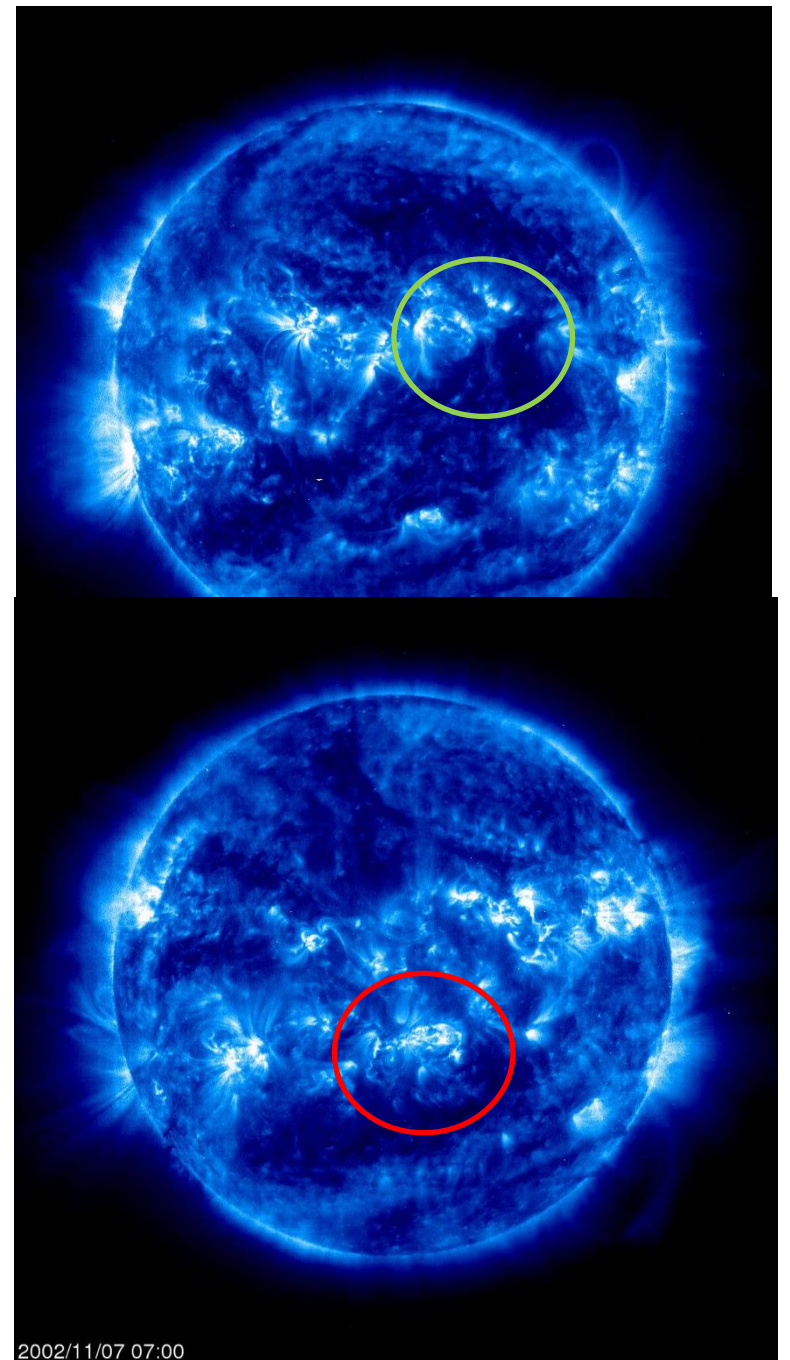
# GOES+ Wind +ADAPT-WSA link remote coronal active region observed in SDO



- The solar wind with periodic density structures came from large, decayed AR (green); newly emerged multipolar AR (red) doesn't make solar wind periodic density structures (that survive to 1 AU). DiMatteo et al. 2022.



WSA-ADAPT



# Planning of August 2025

15 August 2025

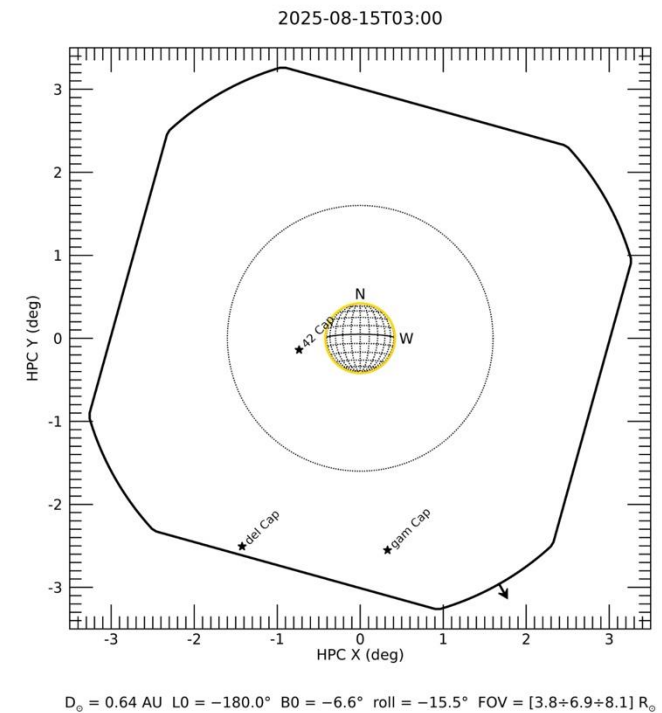
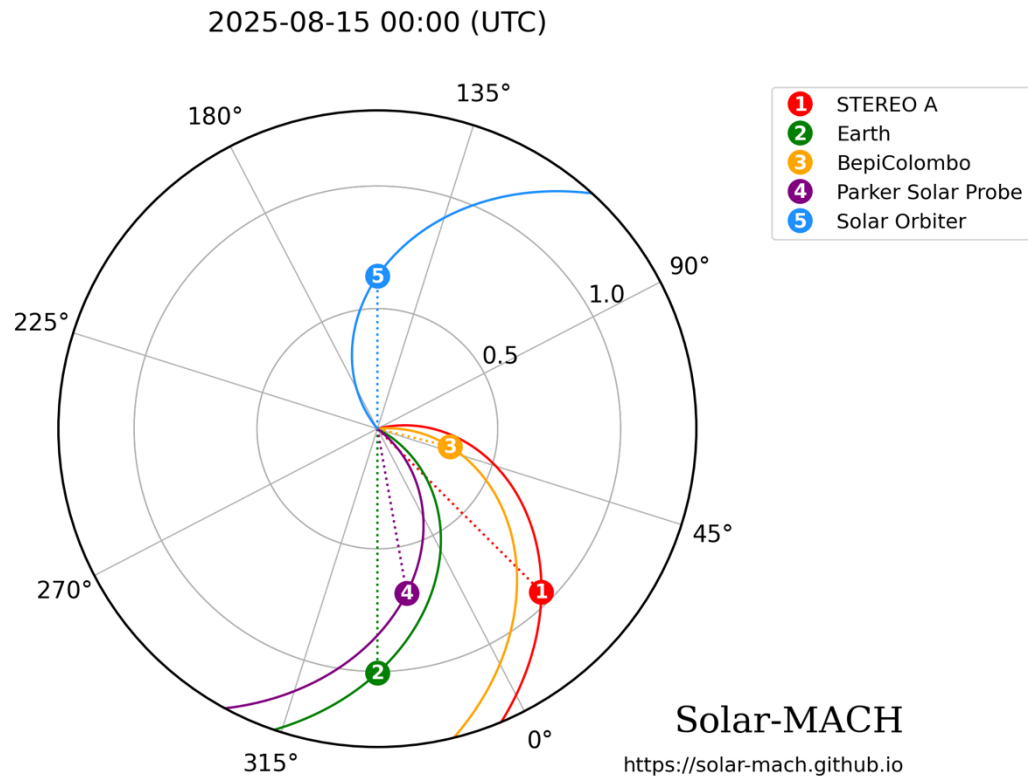
Solar Orbiter – Earth : superior conjunction

SoO @0.63 au, 7° from the ecliptic

Metis FOV: 3.8-6.9 R<sub>sun</sub>

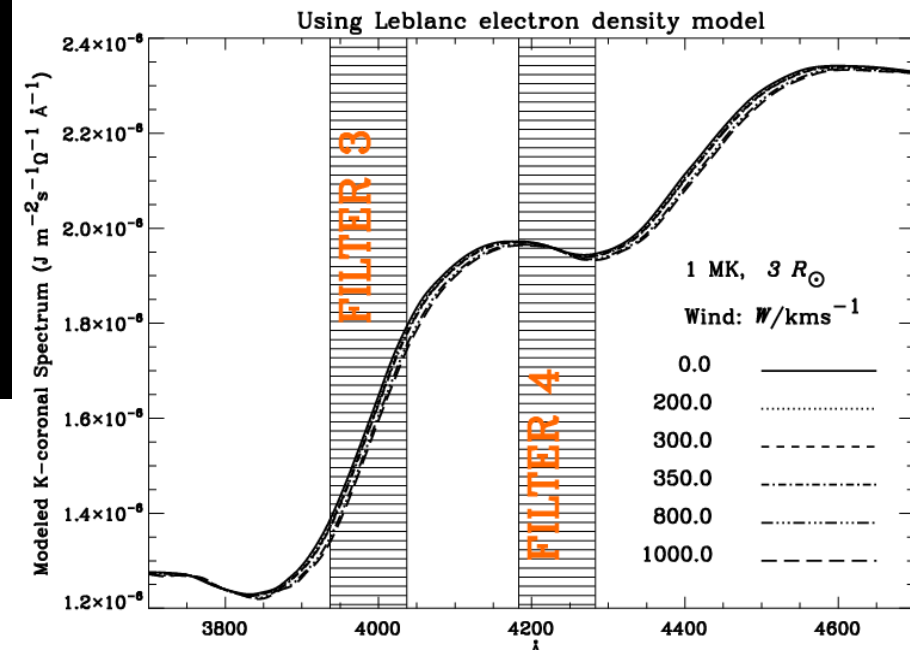
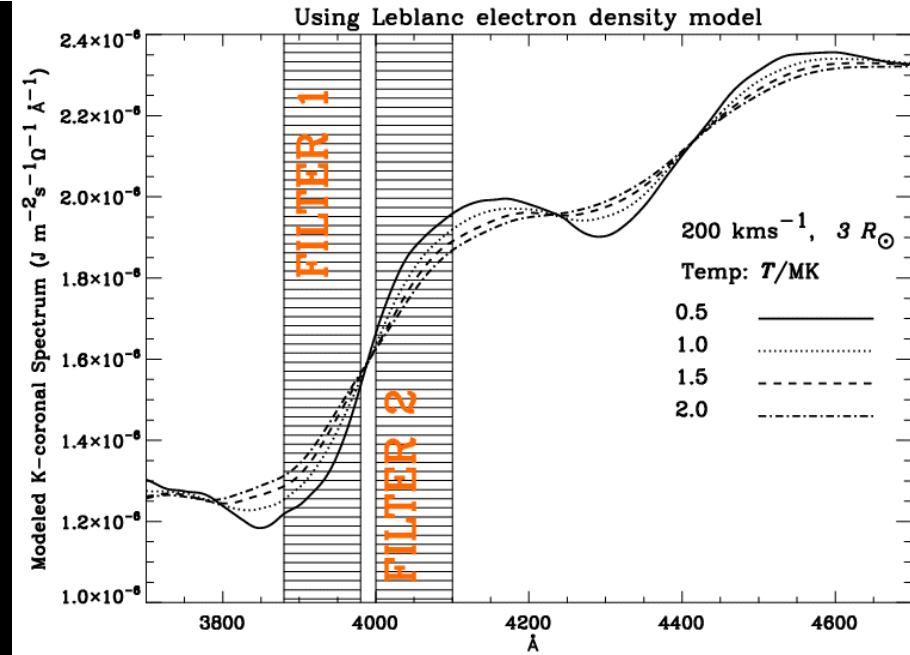
Metis Observing Programs : Synoptic (1 pB + 1 UV; cadence 1800 s; binning 4x4) +  
Synoptic (1 pB + 1 UV; cadence 120 s; binning 2x2)

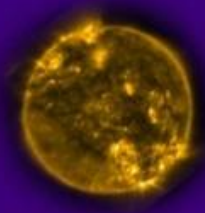
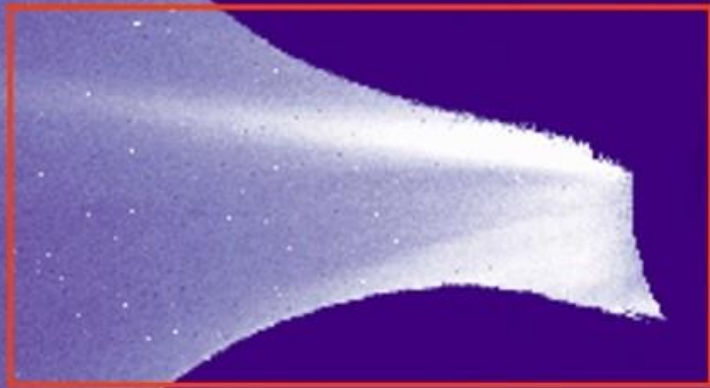
ASPIICS Observing Program : CME Watch, WBF every 30s (3 exposures) +  
all filters every 5 min





- CODEX is a next-generation solar coronagraph that combines, for the first time, simultaneous measurements of density, temperature, and velocity of the electrons in corona, testing fundamental theories of solar wind formation.
- CODEX is an international partnership: NASA Goddard Space Flight Center leads the scientific and technical breakthroughs, supplemented with expertise from the Naval Research Laboratory (NRL), the Korea Astronomy and Space Science Institute (KASI), and National Institute for Astrophysics (INAF-OATo).



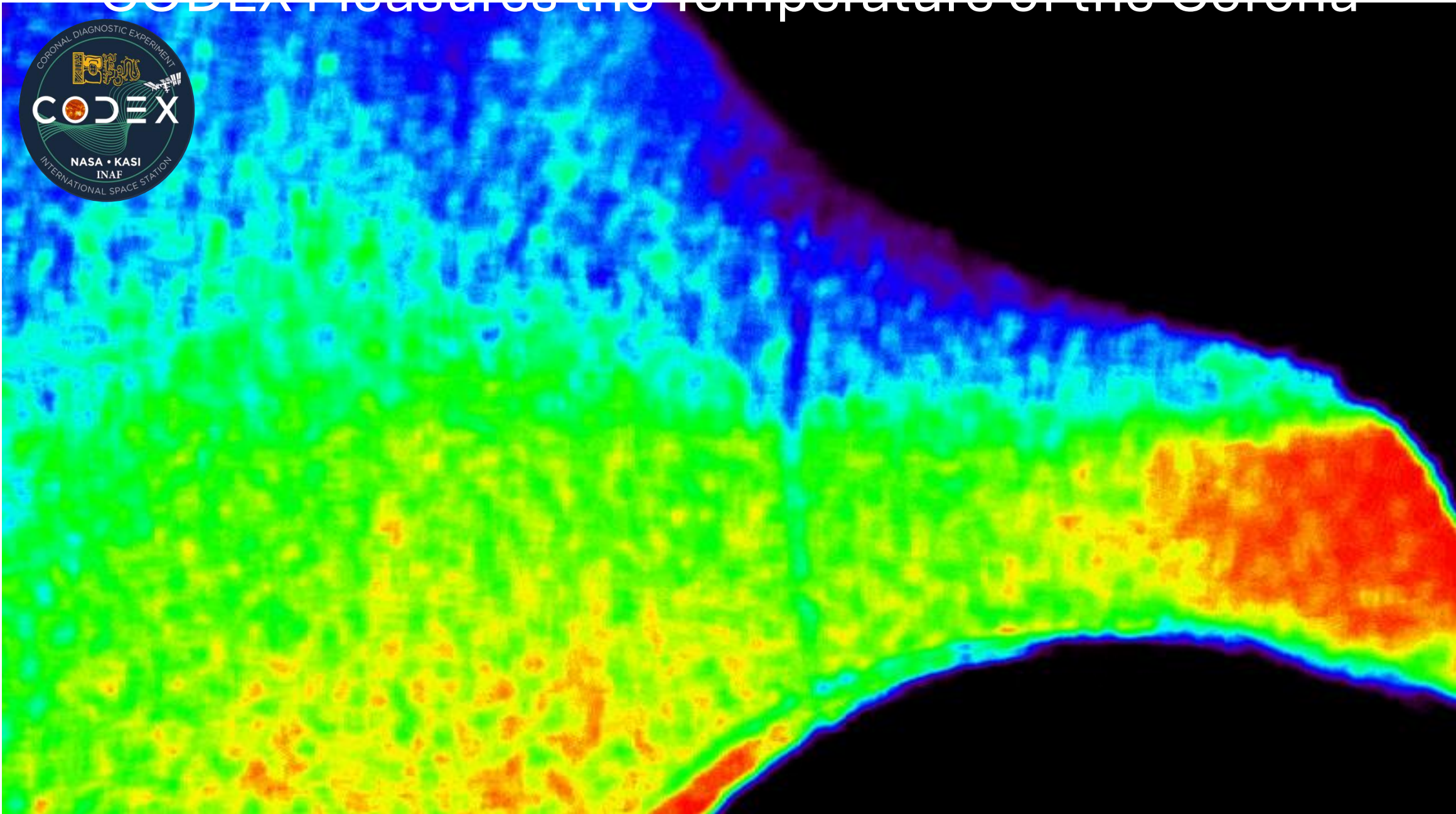


Sun

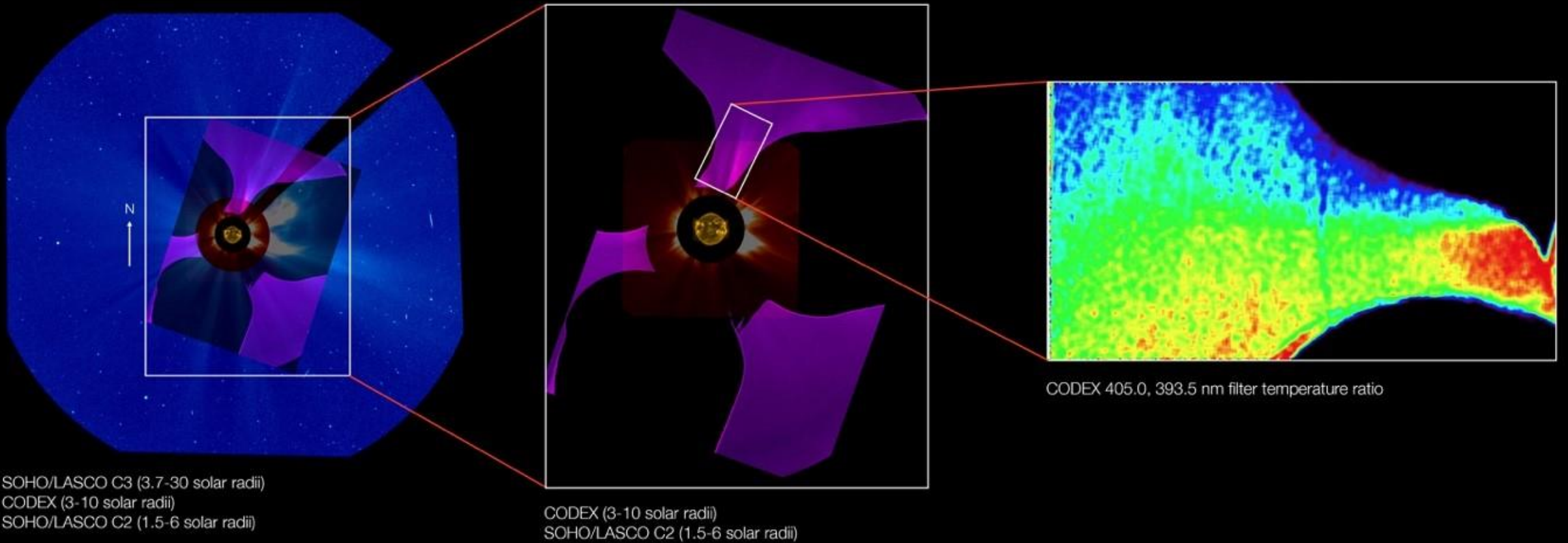
coronal streamers

*The location and size of the Sun in this image are approximate.*

# CODEX measures the temperature of the corona



# CODEX links structure on the Sun with the solar wind



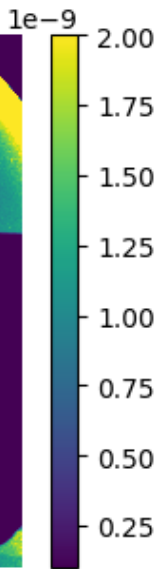
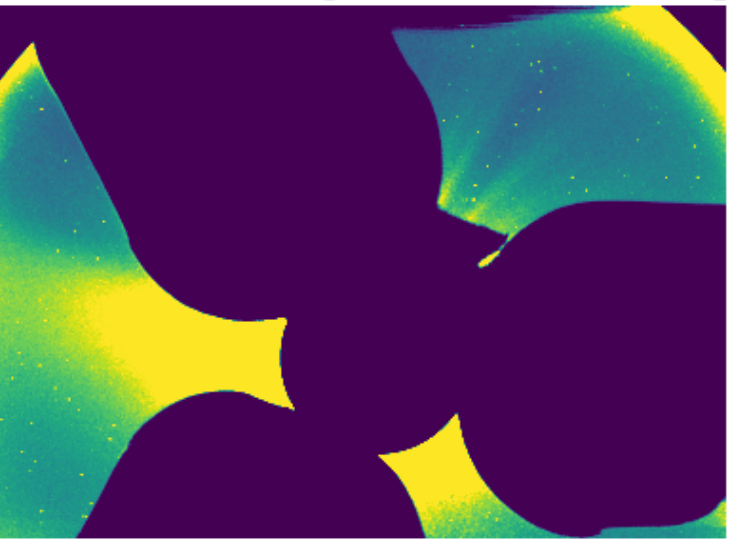
*Image location and size comparisons are approximate.*

**Observation Time**

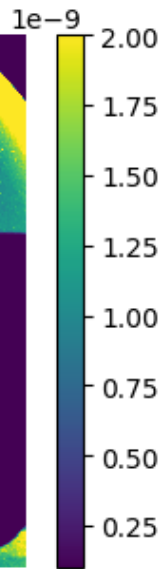
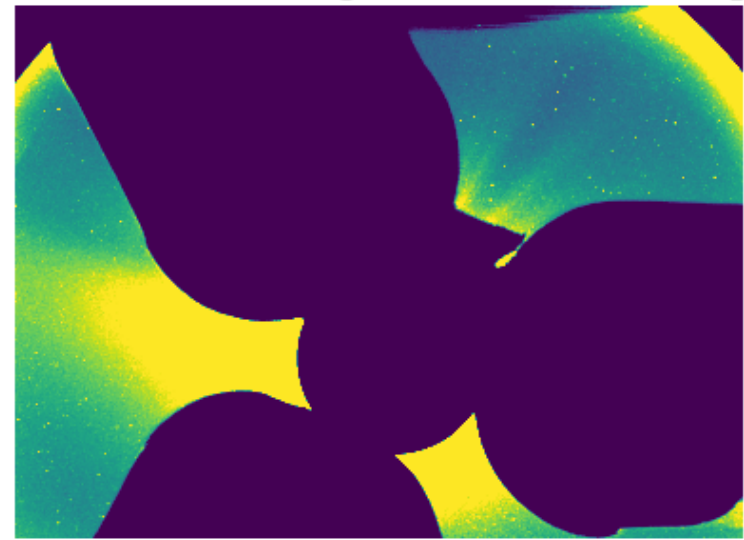
**T1: 2025-08-15 01:44:27.143932**

**T2: 2025-08-15 01:59:26.406788**

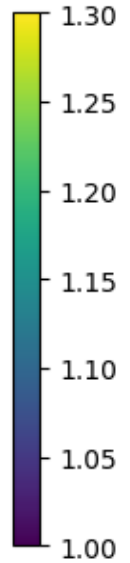
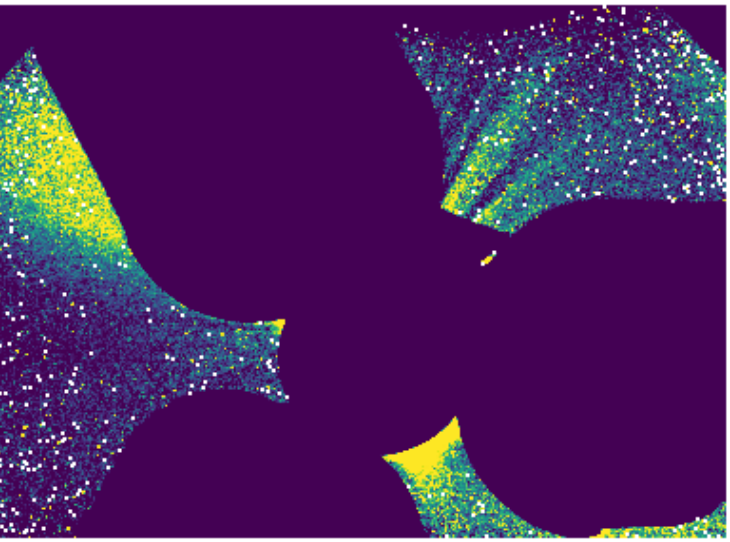
Total brightness (T1)



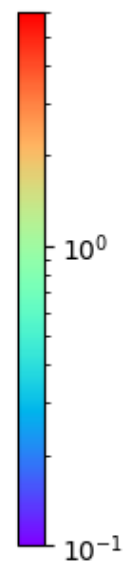
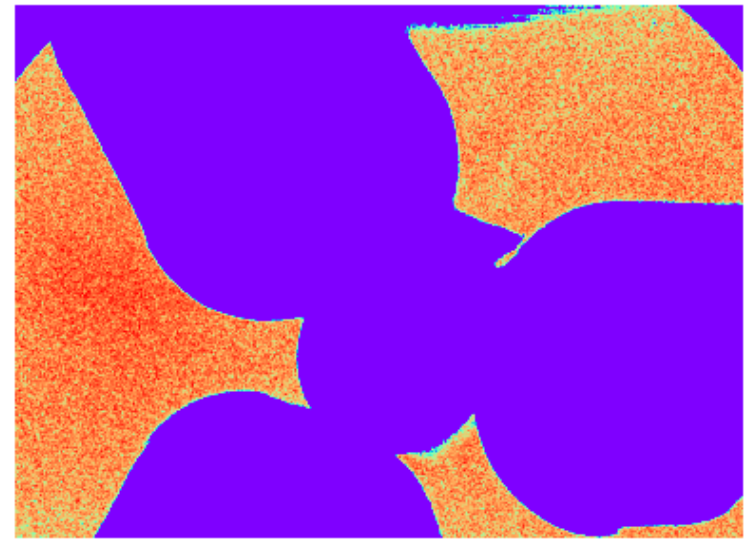
Total brightness (T2)



Ratio = T2/T1



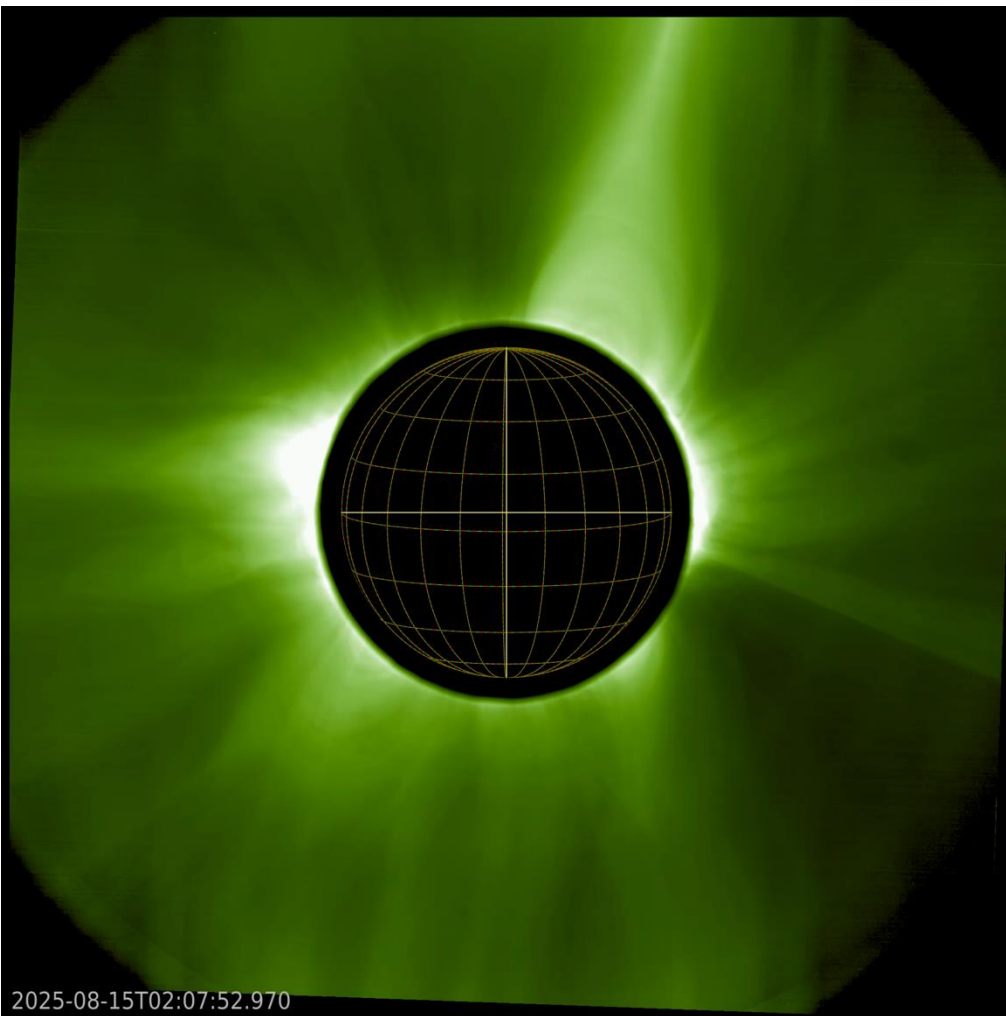
Tmp (MK)



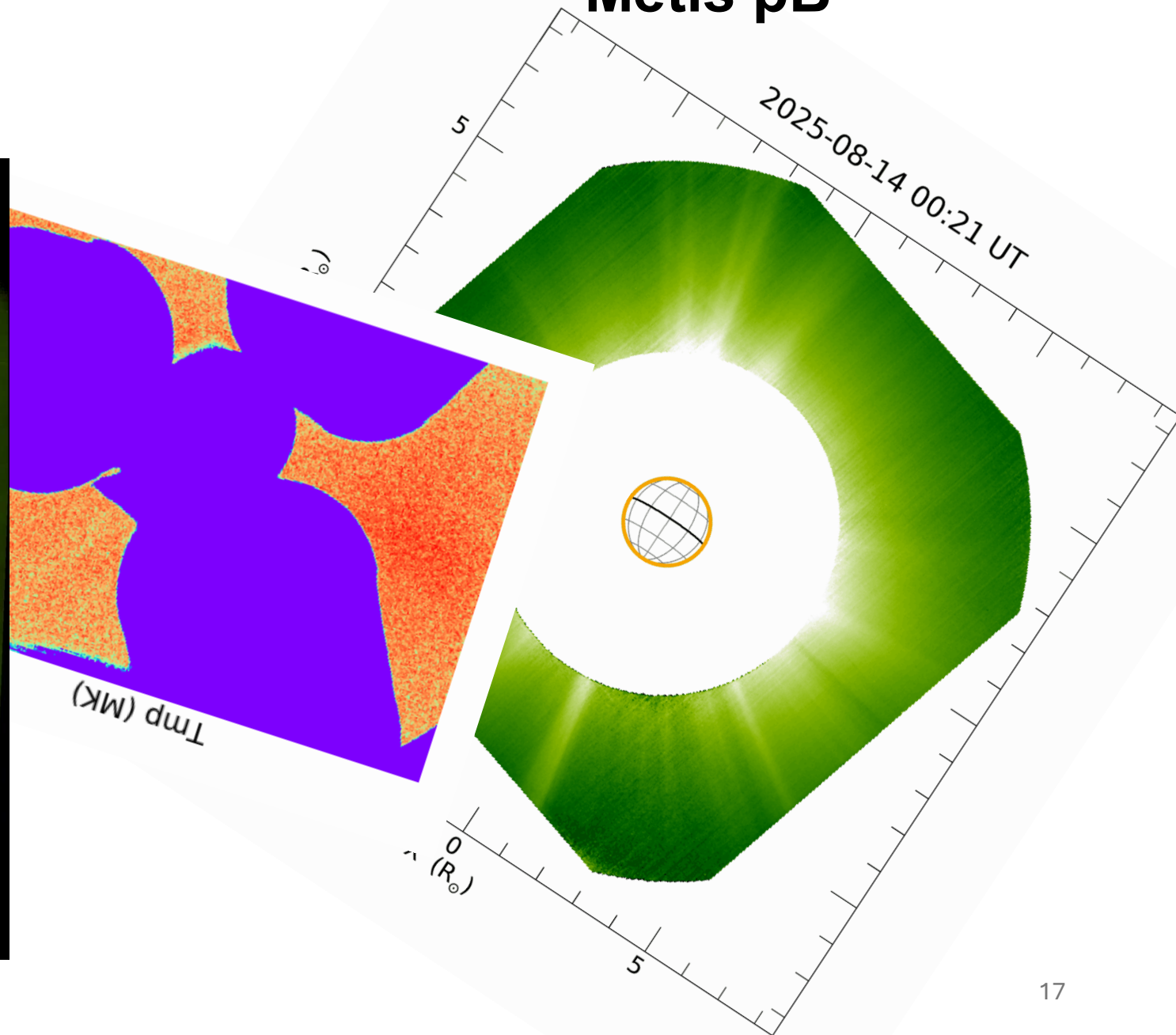
Even without summing images, there is sufficient SNR in this streamer to measure temperature (~1.2 MK)

# ASPIICS wideband

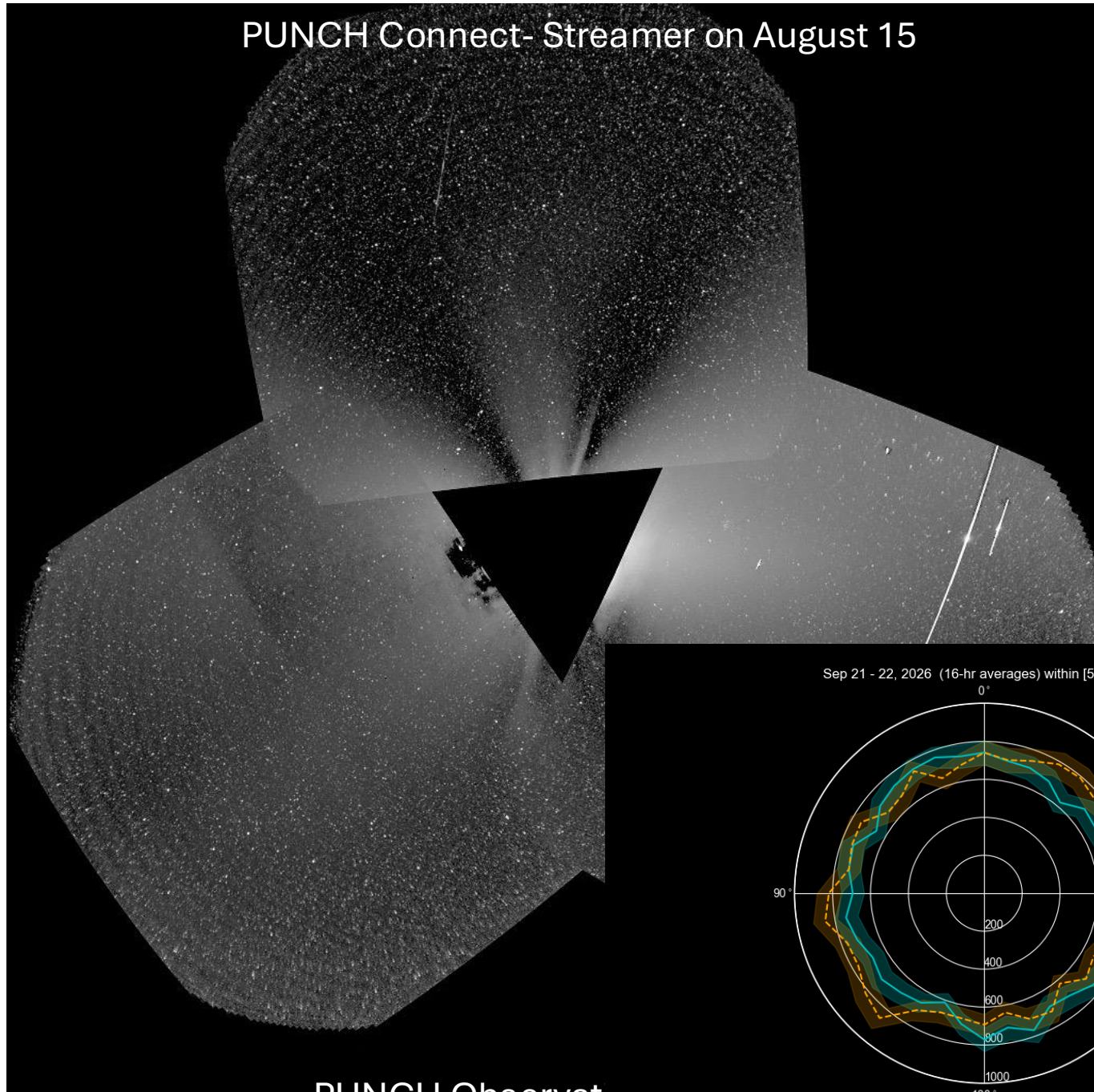
(L2)(MGN filter)



# Metis pB

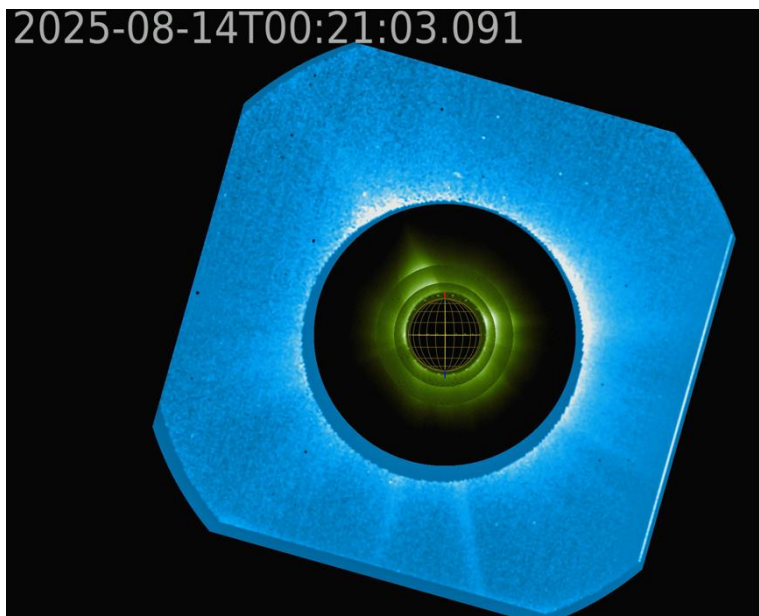


PUNCH Connect- Streamer on August 15

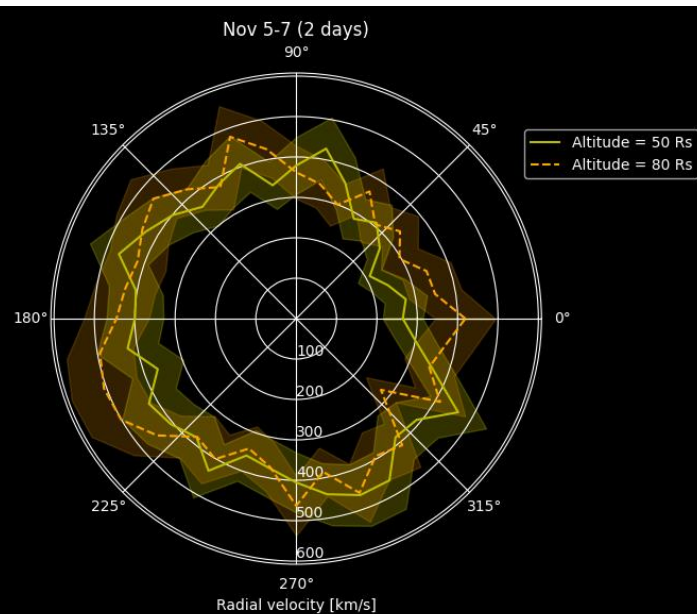
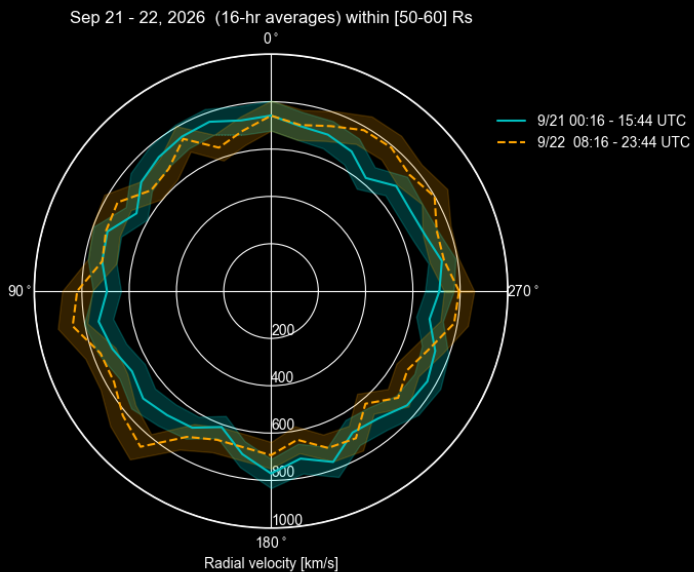


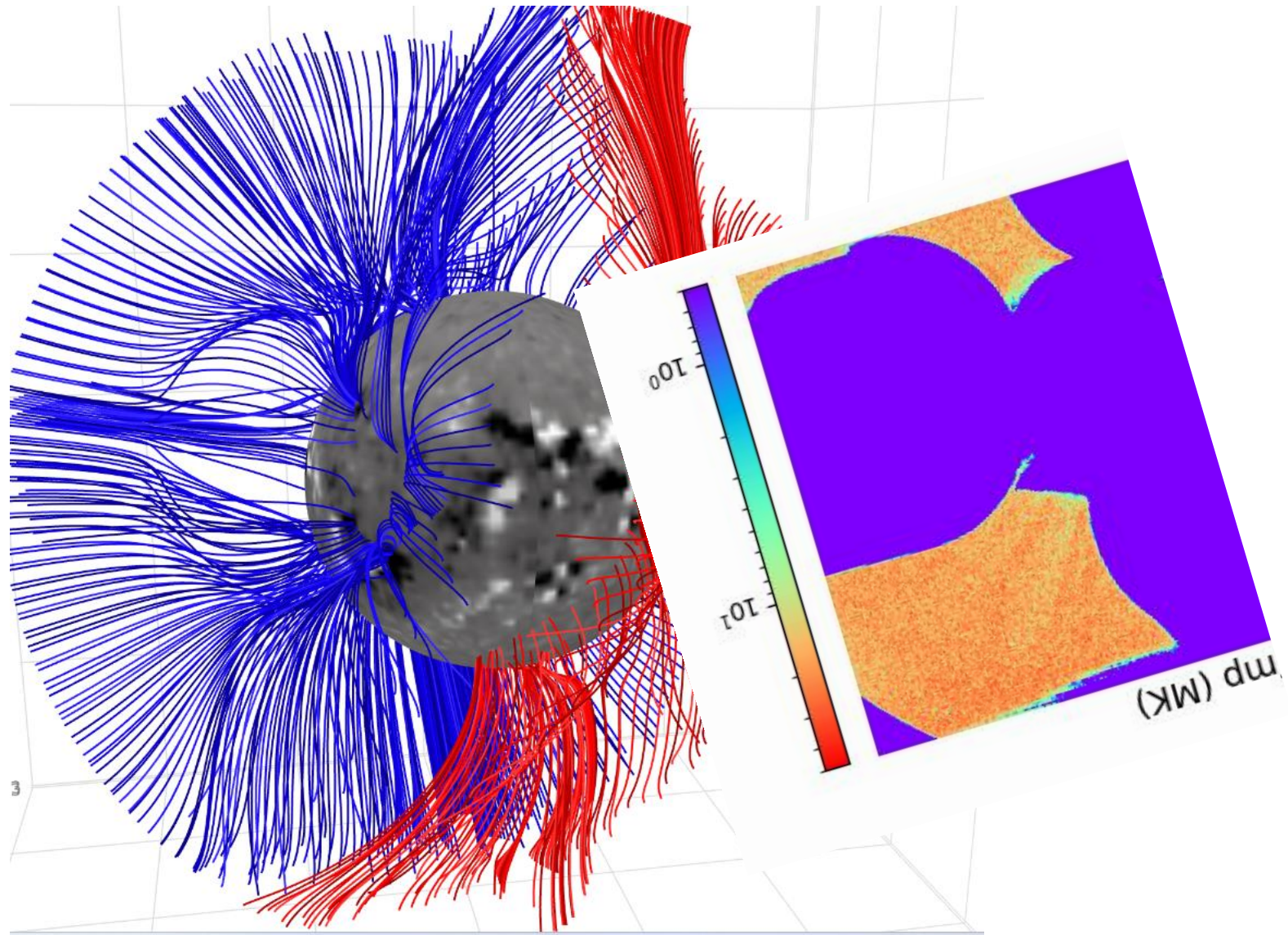
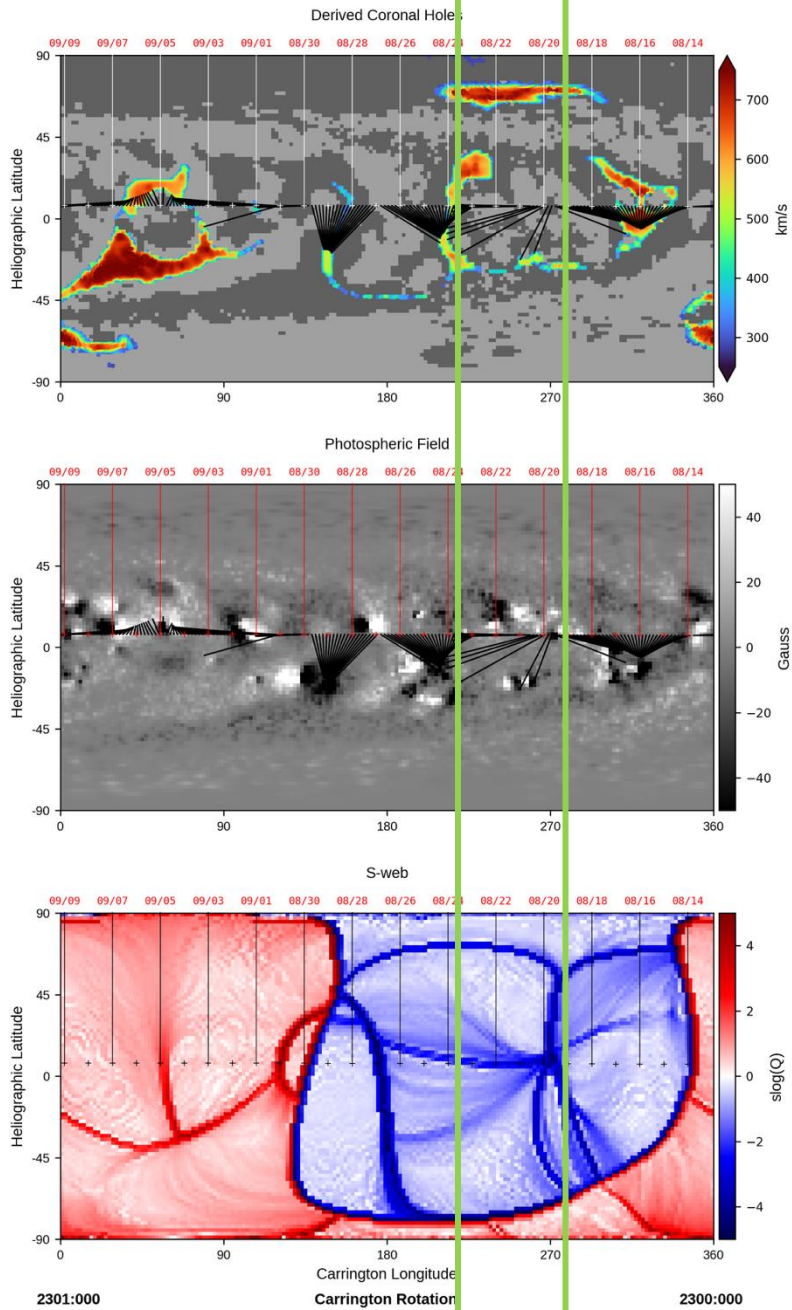
Work in progress: Convert Metis UV into flows

2025-08-14T00:21:03.091



Work in progress: Apply PUNCH flows to Aug15

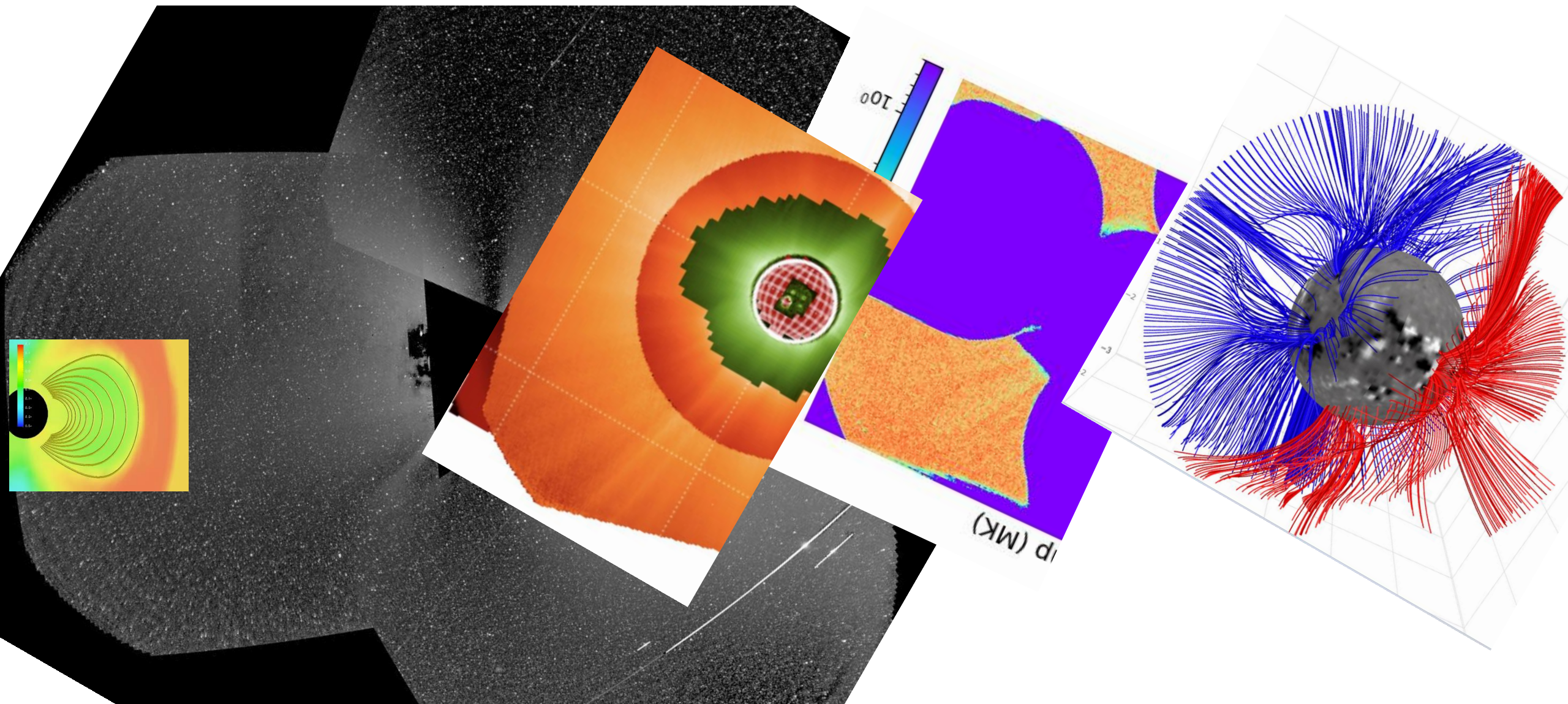




Latest modeling advances allow physical understanding of magnetic sources that progresses beyond pseudostreamer/streamer

PUNCH +LASCO+Metis+ASPIICS+CODEX+WSA/S-web

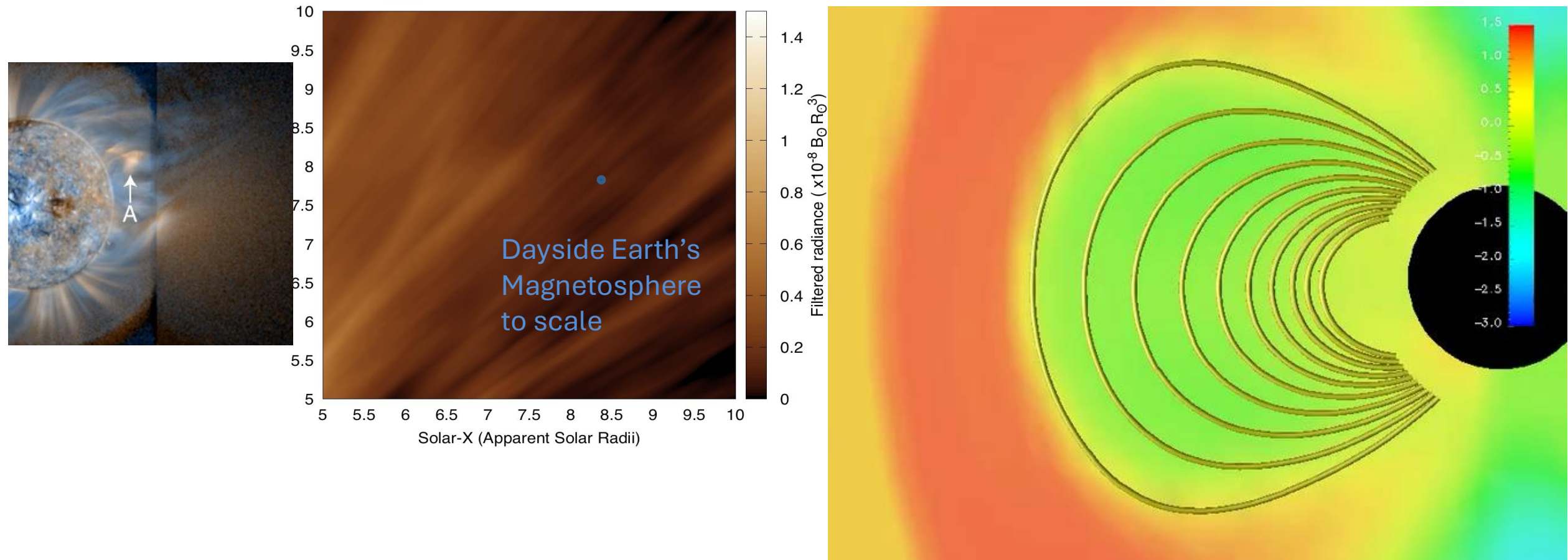
= solar wind speed, temperature, source region and connect the Sun to the inner heliosphere to Geospace and ground state of space weather



- extra

The details of the coronal heating and solar wind release create different types of solar wind structures; mesoscale solar wind structures are fundamental to the ground state of space weather, driving daily dynamics in geospace.

L8: 2014-04-14T00:41:00.005



- Metis observed August 15 (01:20 - 07:20 UTC), and between 21:00 UTC on August 15 and 03:00 on August 16.

ASPIICS observation window (02:27–07:12 UT).

**Observation Time: 2025-07-30 01:39:40**

