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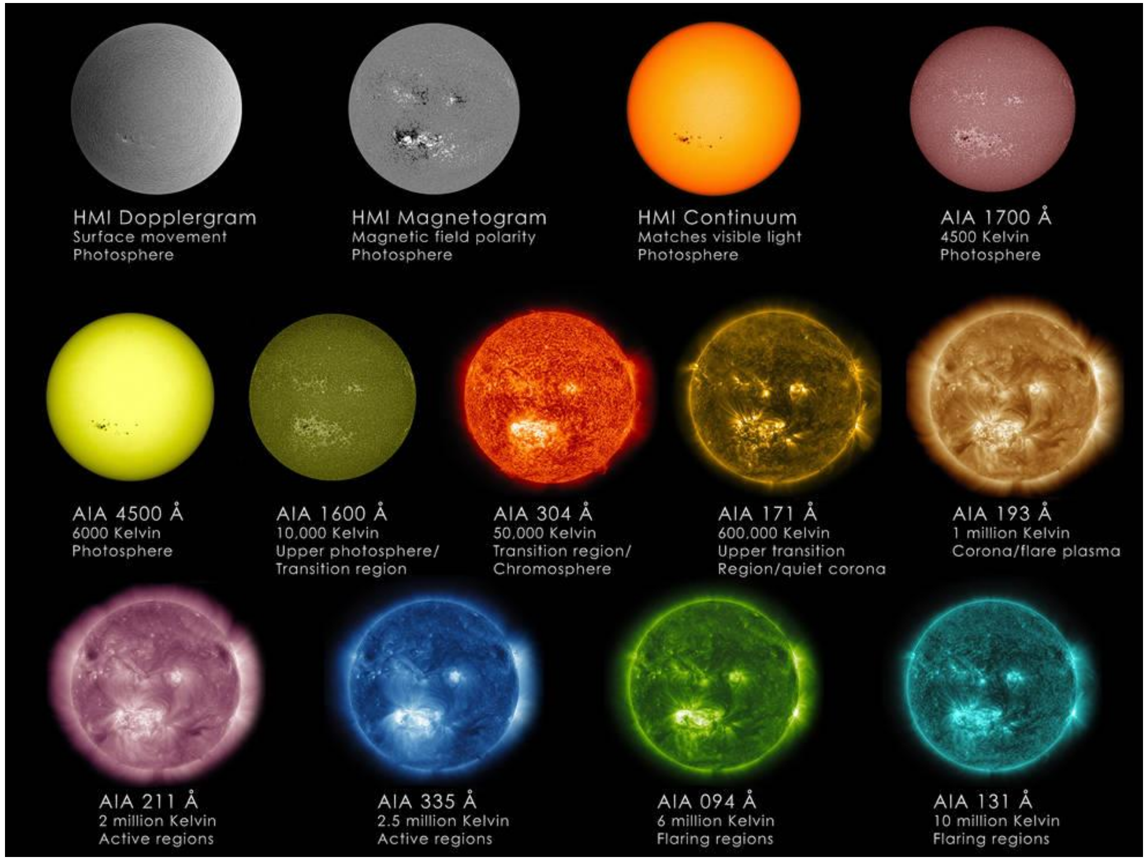
PUNCH Mission Scientist
Chair of the Solar Physics Division of the American Astronomical Society

Aurora in Iceland, April 19, 2025

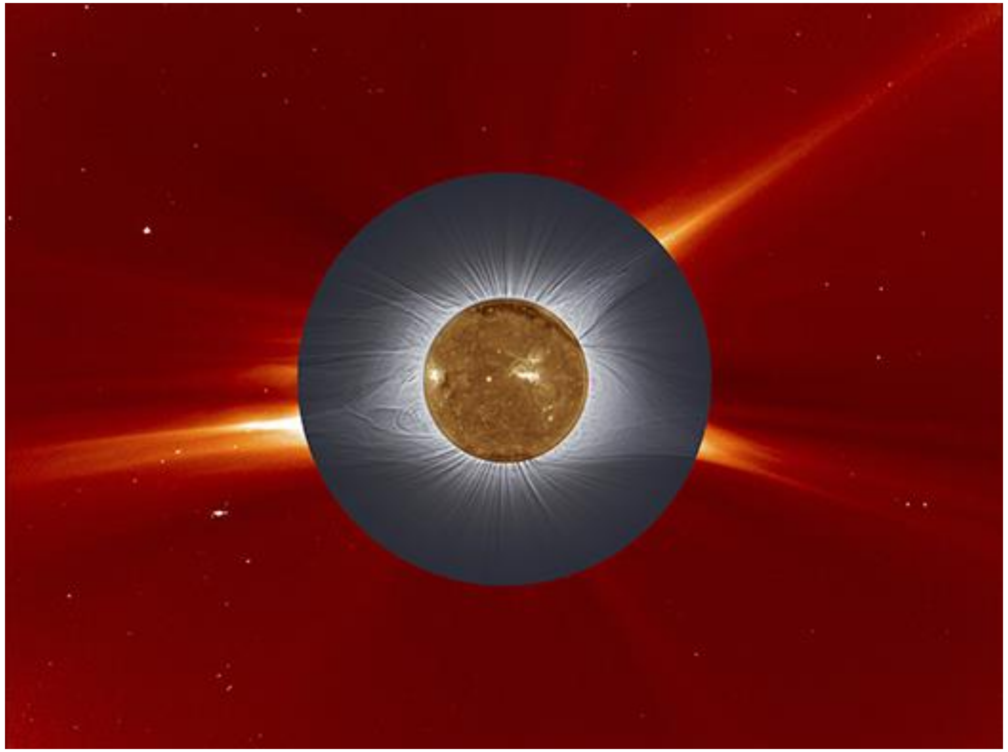

Aurora in Iceland, April 19, 2025

Solar corona during the 2017 total solar eclipse from Oregon

The Sun and heliosphere is a system-of-systems. Physical connectivity within and between the systems usually crosses observational boundaries.



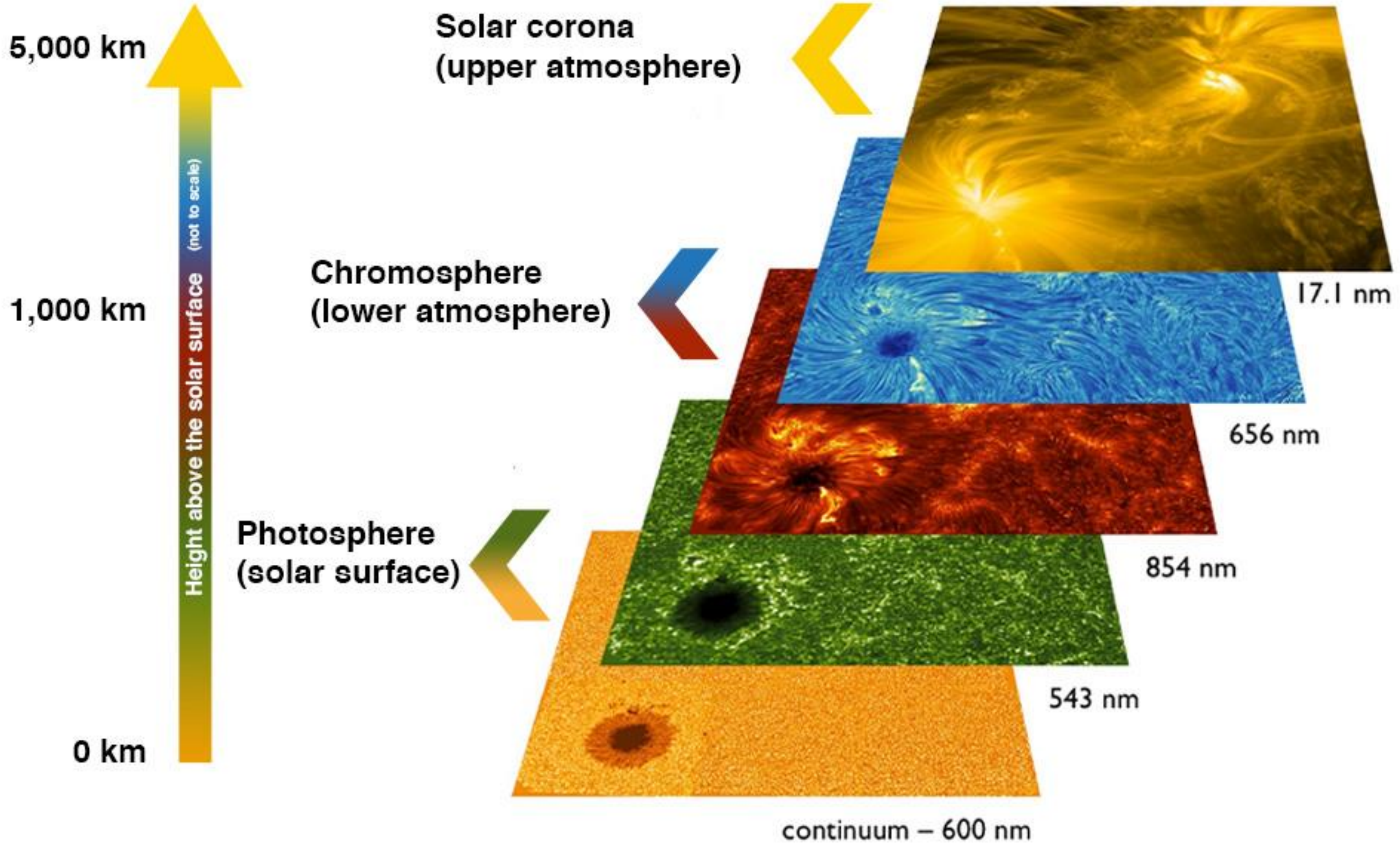
SDO images show the photosphere and lower solar atmosphere



Composite eclipse images between an EUV image from GOES-16/SUVI at 19.5 nm (corresponding to Fe XI/XII emission at about 1.5 MK) and an image from the LASCO C2 coronagraph, occulting up to 2.5 solar radii revealing the connection between structures in the extended corona and the source regions on the solar disk. (eclipse: Jay Pasachoff, Vojtech Rušin, Roman Vanúr, and the Williams College Eclipse Expedition team).

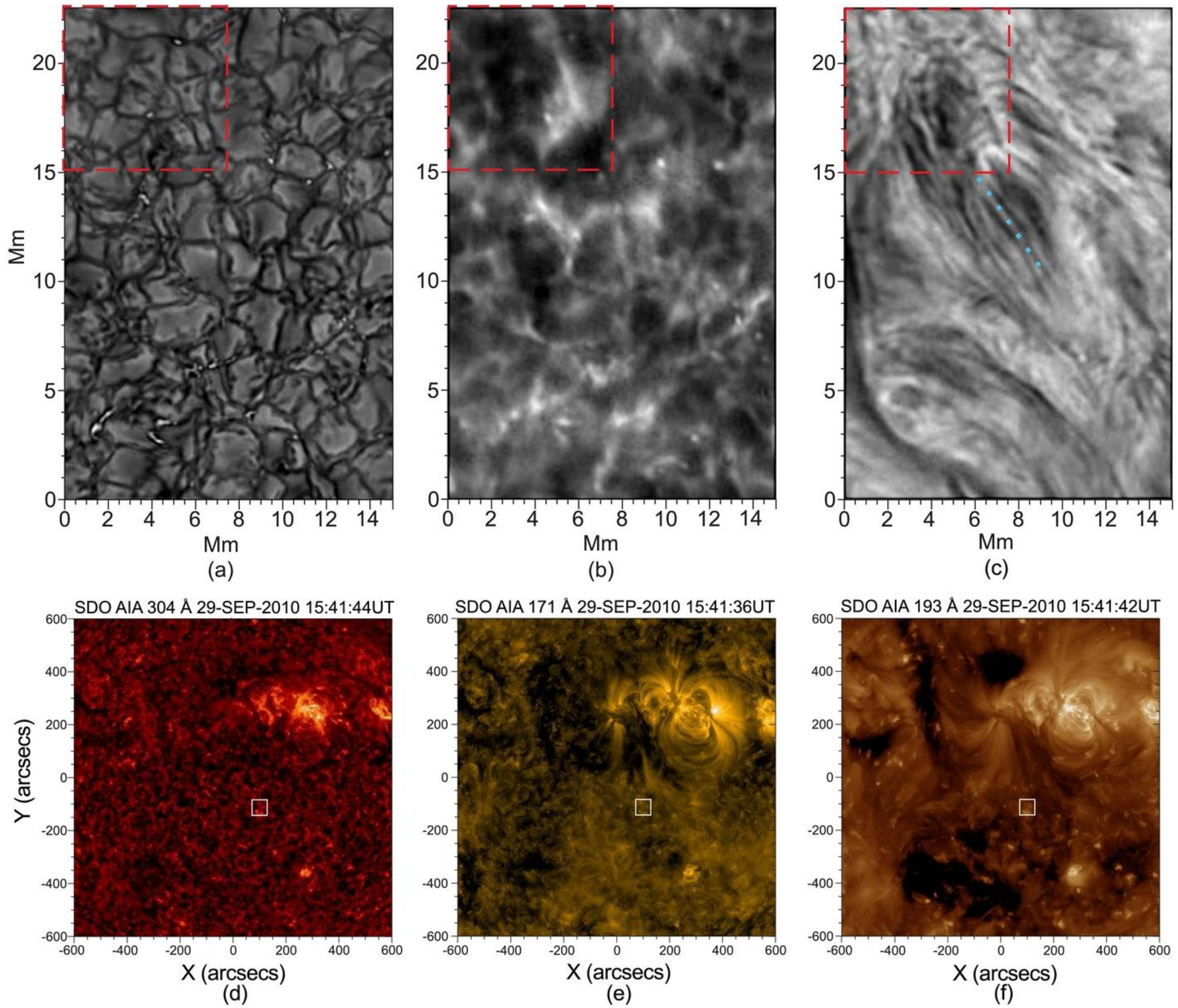
Each of the SIH (solar inner heliosphere) systems is measured in different ways with different tools (e.g. in situ versus remote; wavelengths span radio- gamma; optically thin versus optically thick emission). Each system is dominated by different physical processes.

System-of-Systems Observations of a Sunspot



Series of images representing the view of a sunspot at different layers in the solar atmosphere. Layers include the photosphere (yellow, green), and the chromosphere (red, blue), all of which were taken with the IBIS instrument on NSF's Dunn Solar Telescope. The corona is represented as the topmost layer, with an image taken from NASA's Solar Dynamic's Observatory AIA imager. NSO/AURA/NSF & NASA/SDO

System-of-Systems Observations of quiet Sun



Citation R. J. Morton *et al* 2013 *ApJ* **768** 17

We have observations of microscales in the photosphere, but not in the corona.

Region of the quiet solar atmosphere as observed by ROSA.

(a) *G*-band image showing a 15 × 23 Mm^2 sub-region of the ROSA field of view. Collections of magnetic bright points are clearly visible in the intergranule lanes.

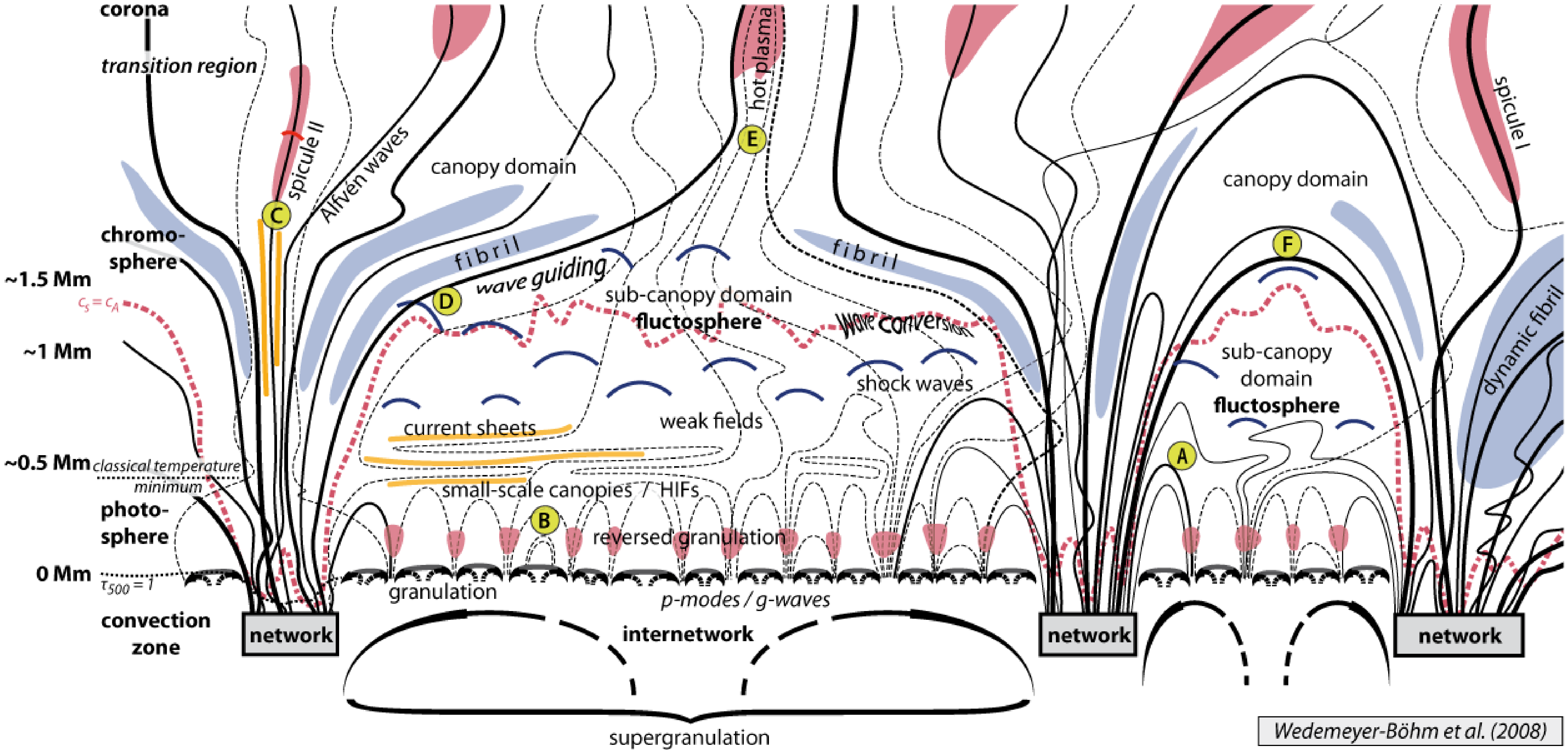
(b) Ca K image of the lower chromosphere.

(c) Hα core image of the mid to upper chromosphere.

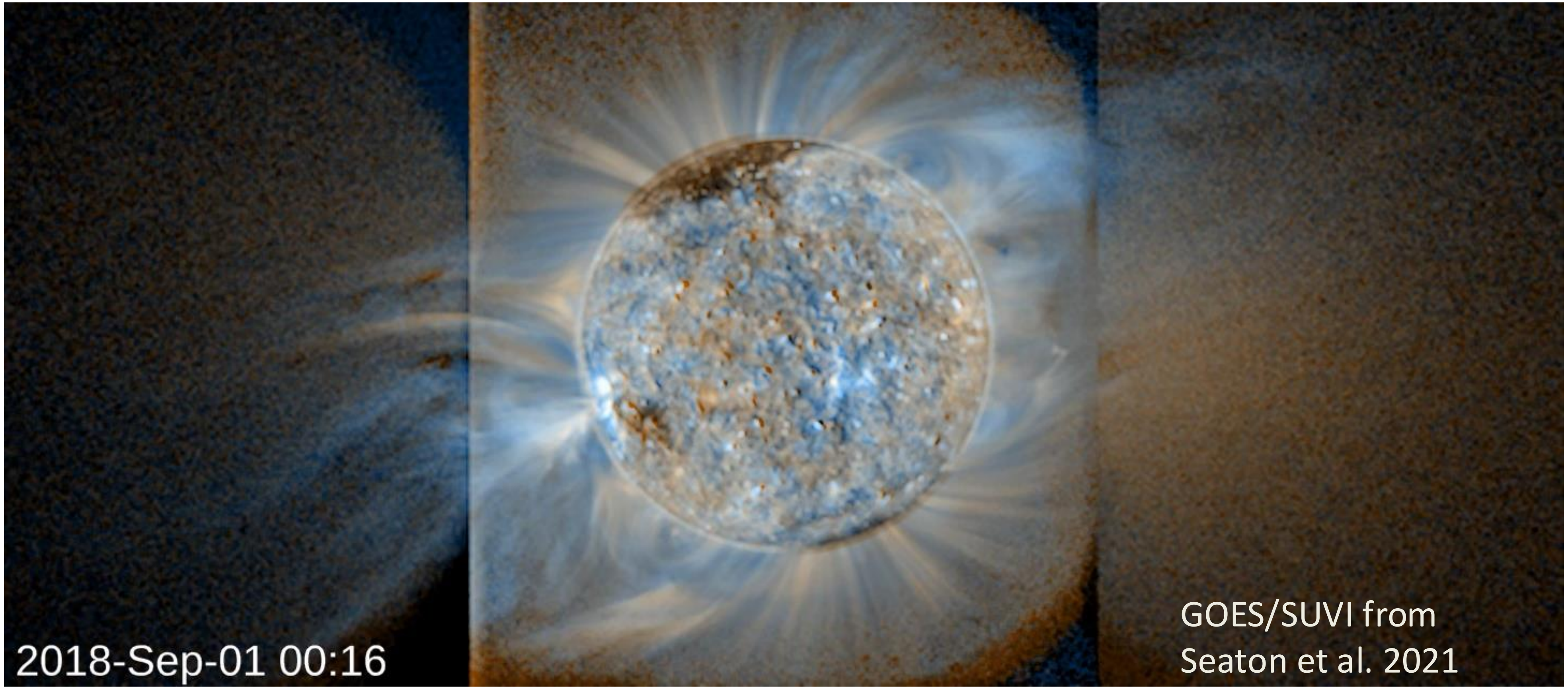
The bottom row displays images of the upper solar atmosphere observed by *SDO*/AIA. The panels show (d) 304 Å, (e) 171 Å, and (f) 193 Å filters.

The white boxes in AIA highlight the region which ROSA observed.

The 3D, time dependent connection between the photosphere, through the chromosphere and transition region into the corona is a dynamic, cross-scale, cross-system physics problem with enormous complexity.



The 3D, time dependent connection from low to mid corona into the solar wind is a dynamic, cross-scale, cross-system physics problem with enormous complexity.



GOES/SUVI from
Seaton et al. 2021

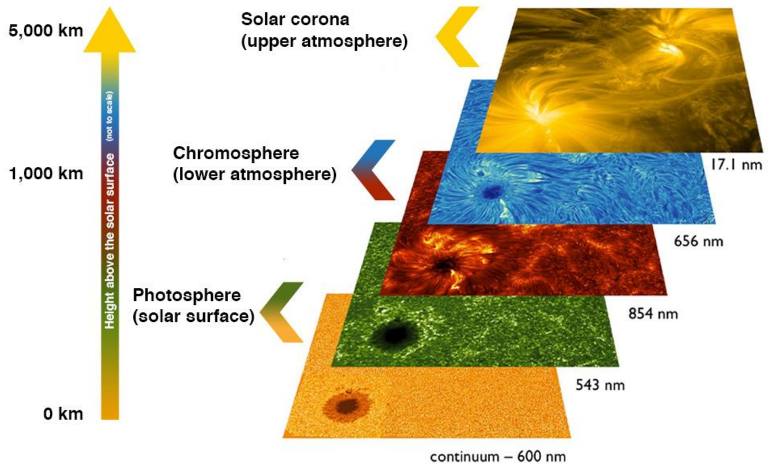
Low and mid corona are coupled to solar wind through thermal conduction and magnetic fields, yet they are vastly different physical regimes:

- Mixed of closed, non radial complex magnetic field -> (mostly) all open, radial magnetic field
- Collisional -> collisionless plasma
- Beta
- Sound and Alfven speeds

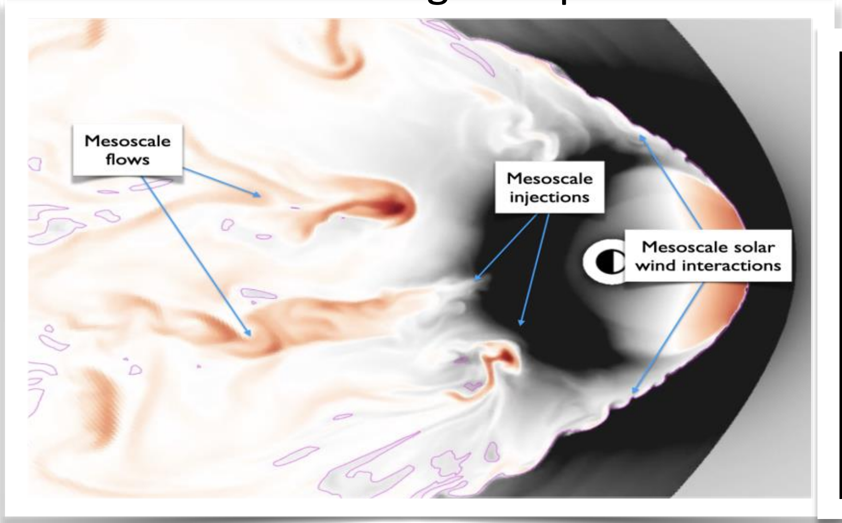
Solar Example of System-of-Systems

Geospace Examples of System-of-Systems

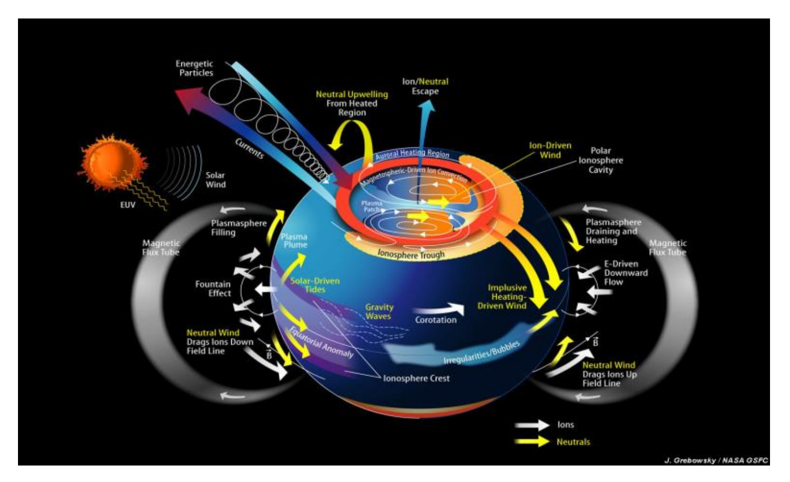
Sunspot



Magnetosphere

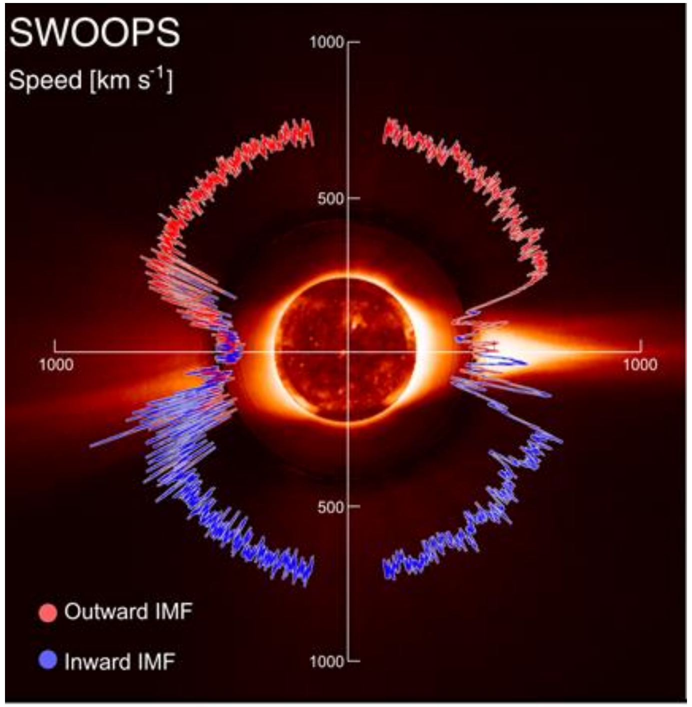


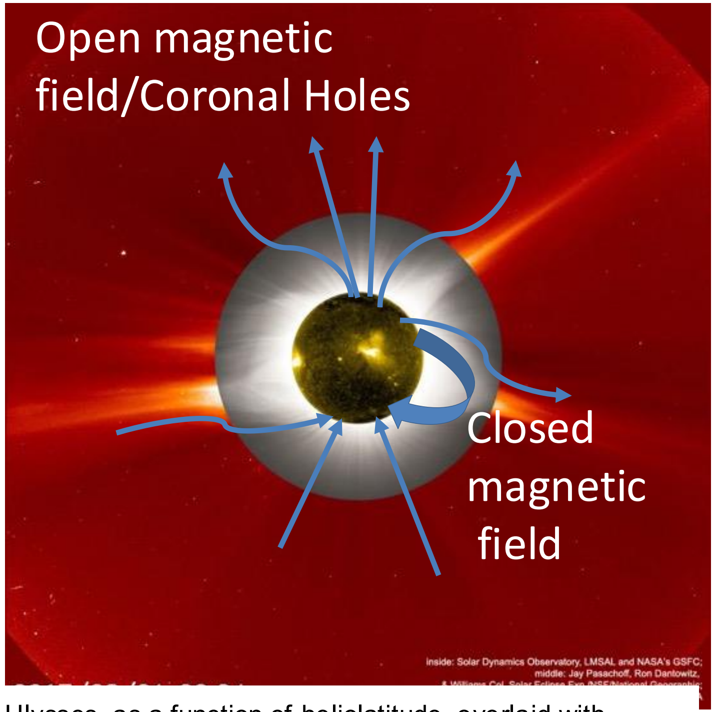
ITM

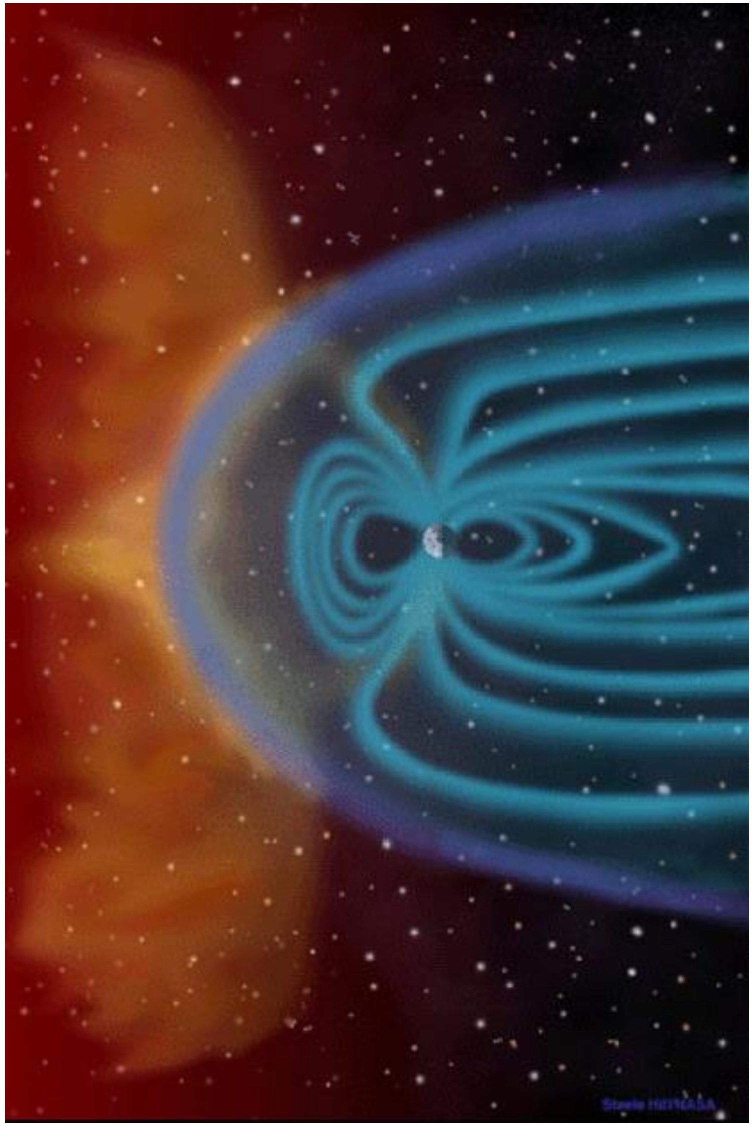


- All of Heliophysics is now in an era where the important outstanding questions require a system-of system approach: questions that are cross-scale, cross-system and cross-physics in nature.
- This requires multi-mission, modeling and mission-ground-based coordination.
- This is true for **ALL** of the sub disciplines of Heliophysics: Solar, interplanetary medium, magnetosphere, ITM

How does the solar atmosphere create the solar wind and Heliosphere? How do the resulting structures drive Geospace?



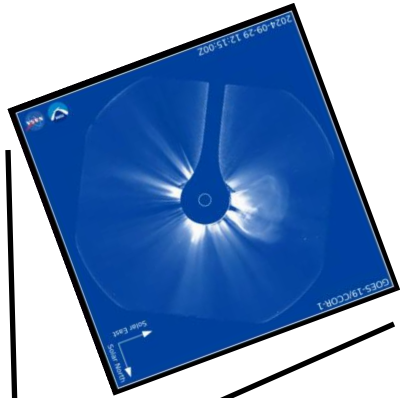


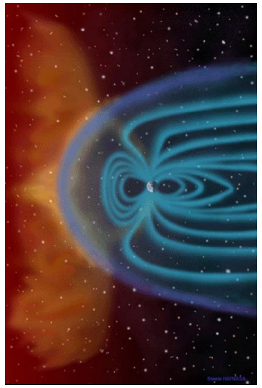


Left: Solar wind speed and magnetic polarity measured by Ulysses, as a function of heliolatitude, overlaid with images from EIT, the HAO Mauna Loa coronagraph, and LASCO C2 coronagraph. Credit: McComas et al., GRL, 1998, 25, 1.

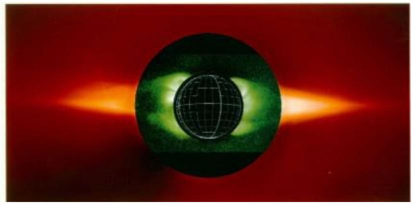
Right*: Inside:* Solar Dynamics Observatory, LMSAL and NASA's GSFC;
Middle: Jay Pasachoff, Ron Dantowitz, and the Williams College Solar Eclipse Expedition/NSF/National Geographic; *Outside:* LASCO from NRL on SOHO from ESA. Credit: Astronomy Picture of the Day.

The Heliosphere is Enormous; Accomplishing Revolutionary Science Results Requires a Unified Framework that Captures System-of-Systems and Cross-scale dynamics





93 million miles, several days and a whole lot of physical processes



Earth

This complex chain requires the critical mass of experts under a common science vision

Solar wind formation can be broken down into three general steps associated with the time history of the solar wind plasma. Crucially, when the plasma is released through reconnection, the physical process that energize the plasma in the high corona is not the same as that which energized the plasma in the low corona.

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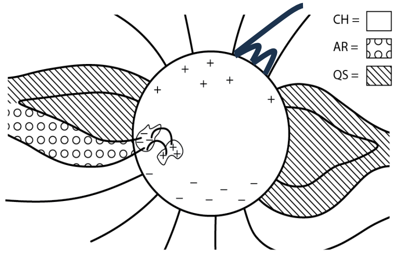
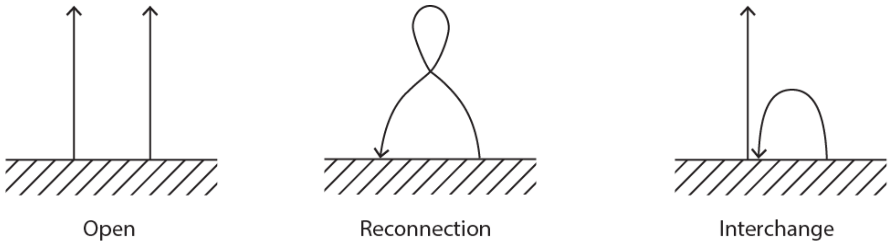


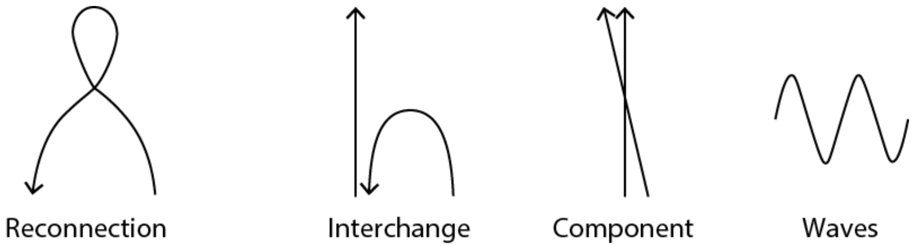
Heating/energization in the low corona

Step 2 Release



Energization **<u>and/or</u>** mass release in the low through middle corona

Step 3 Acceleration



Energization middle corona and outwards

Viall & Borovsky 2020, "Nine Outstanding Questions of Solar Wind Physics", JGR, Grand Challenges in the Earth and Space Sciences

Theme 1: The formation of the solar wind
(1): From where on the Sun does the solar wind originate? 'the coronal heating problem'
(2): How is the solar wind released?
(3): How is the solar wind accelerated?
Theme 2: Interpreting observations of solar wind parcels
(4): What determines the heavy-ion elemental abundances, the ionic charge states, and the alpha/proton density ratios in the solar wind? (And what do they tell us about the Sun?)
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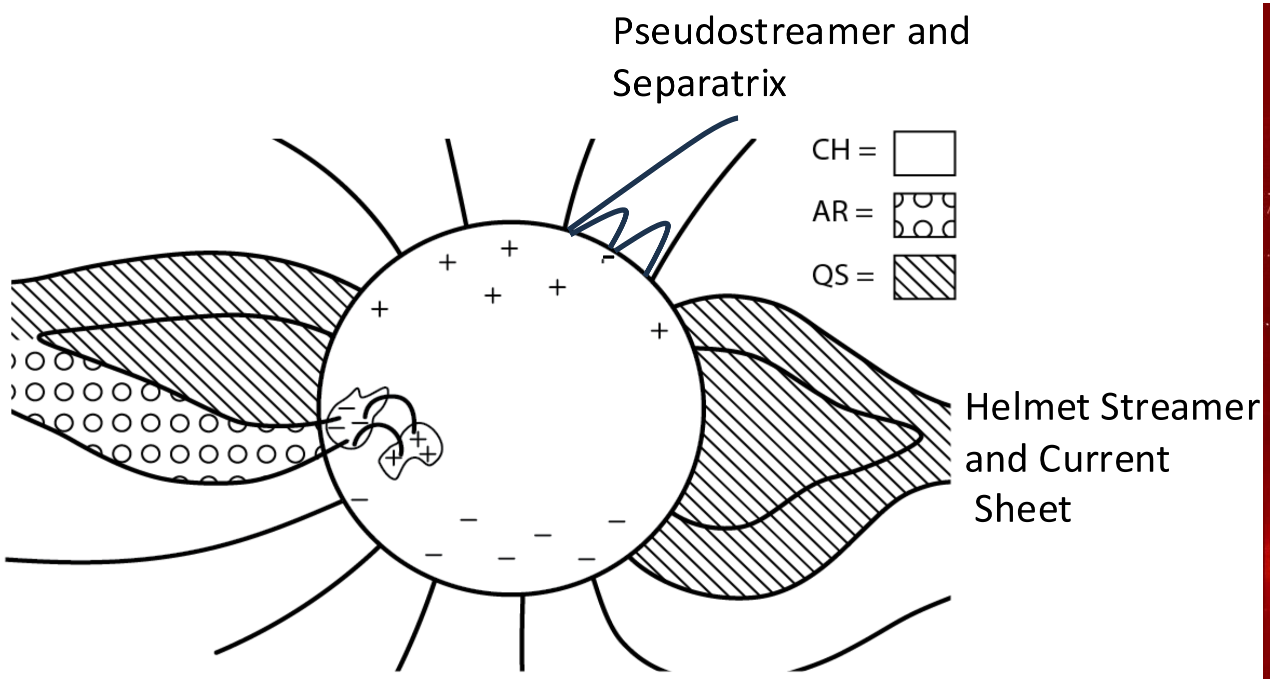
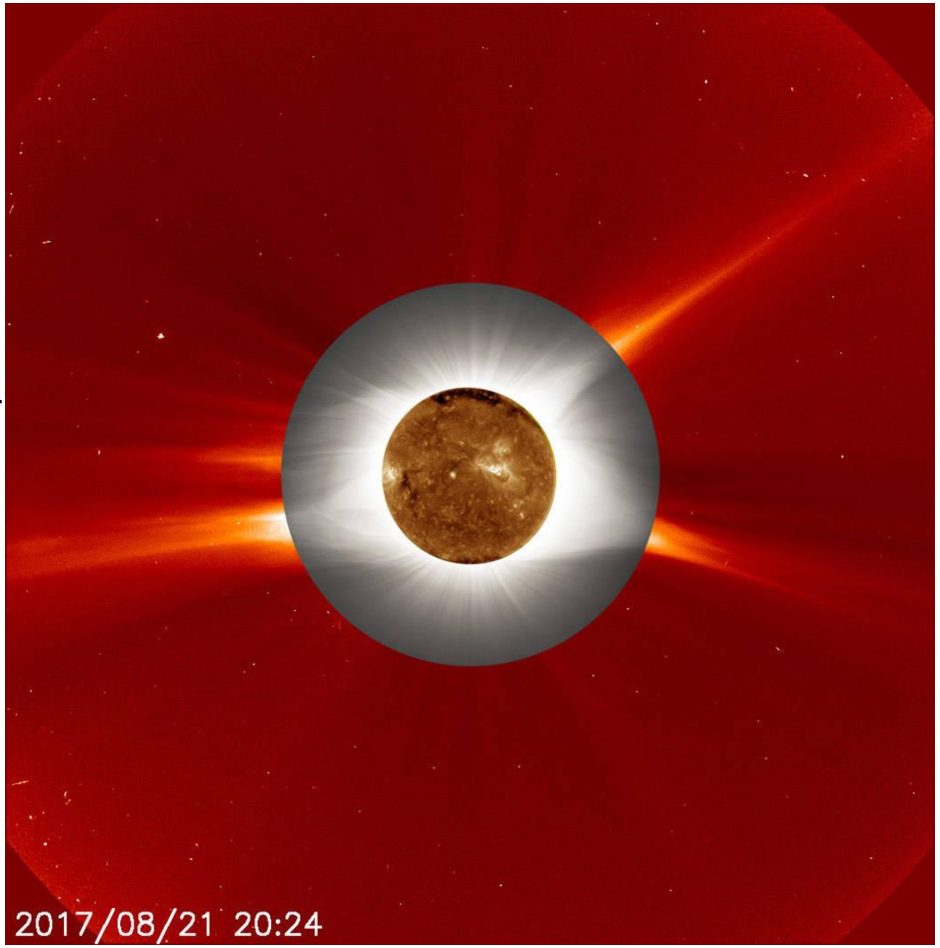
Theme 3: Physical mechanisms operating on solar wind formation and evolution
(6): What is the Origin of the Alfvénic Fluctuations in the Solar Wind?
(7): How is solar-wind turbulence driven, what are its dynamics, and how is it dissipated?
(8): How do the kinetic distribution functions of the solar wind evolve?
(9): What are the roles of solar wind structure and turbulence on the transport of energetic particles in the heliosphere?

Viall & Borovsky 2020, "Nine Outstanding Questions of Solar Wind Physics", JGR, Grand Challenges in the Earth and Space Sciences

Q1 From where on the Sun does the solar wind originate? (The energization in the low atmosphere; the coronal heating problem)

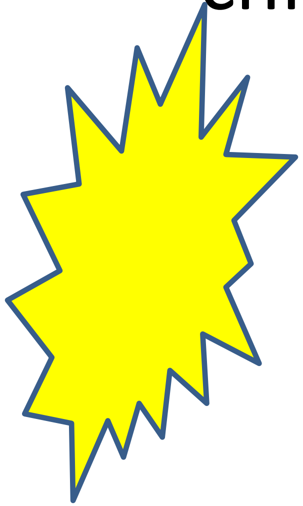


Different parts of the Sun are heated differently (dependent on magnetic field), and thus are comprised of plasma of different temperatures, densities, the relative abundance of elements with low first ionization potential: the solar wind from each will be different



Innermost image: NASA/SDO
Ground-based eclipse image: Jay Pasachoff, Ron Dantowitz, Christian Lockwood and the Williams College Eclipse Expedition/NSF/National Geographic
Outer image: ESA/NASA/SOHO

The solar coronal heating problem: energization of the chromosphere, transition region and low corona.

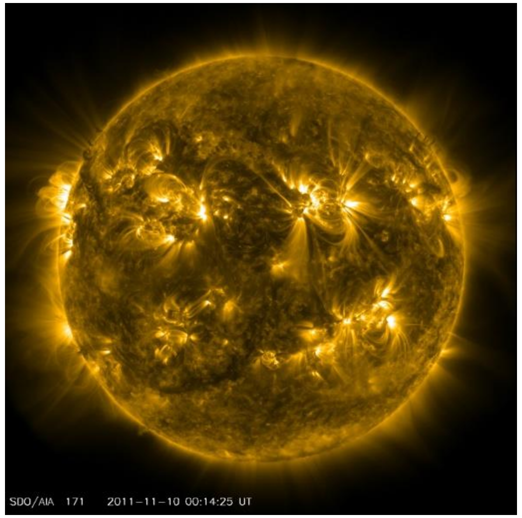


Energy release in the corona

Individual heating events (nanoflares) are not currently observable because they are
a) below instrument resolution
b) below instrument sensitivity
c) there will be many along a given line of sight.

Giant black box

Corona, transition region and chromosphere are fundamentally connected through magnetic fields and thermal conduction; rapidly smooths out temperature gradients, wiping out spatial information of the energy deposition.

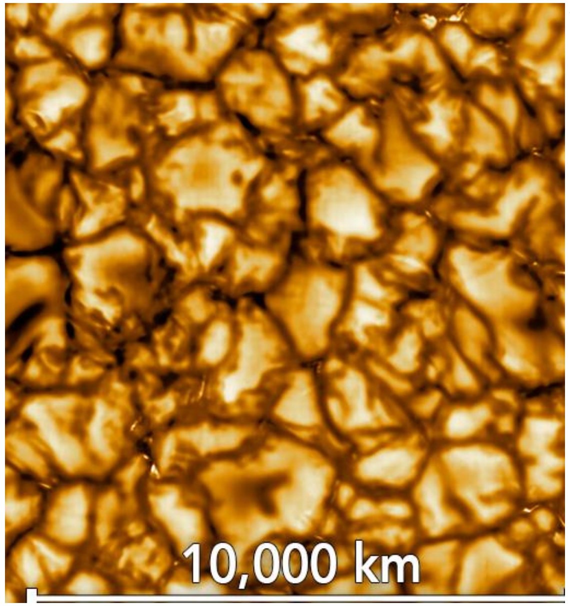


Spectral lines and EUV images

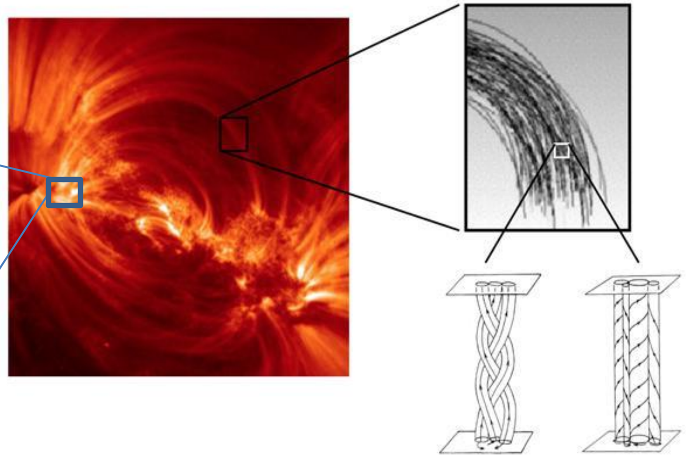
Thermal emission long after the energy release

Viall, De Moortel et al. 2021, ‘The Heating of the Solar Corona’ in Solar Physics and the Solar Wind

Magnetic Reconnection in the Solar Corona: we have observations of the photospheric driver but not of the microscale coronal energy release



DKIST image of granulation in the photosphere



- SDO/AIA ‘loops’ – width of at least a couple of Mm – are comprised of subresolution flux tubes.

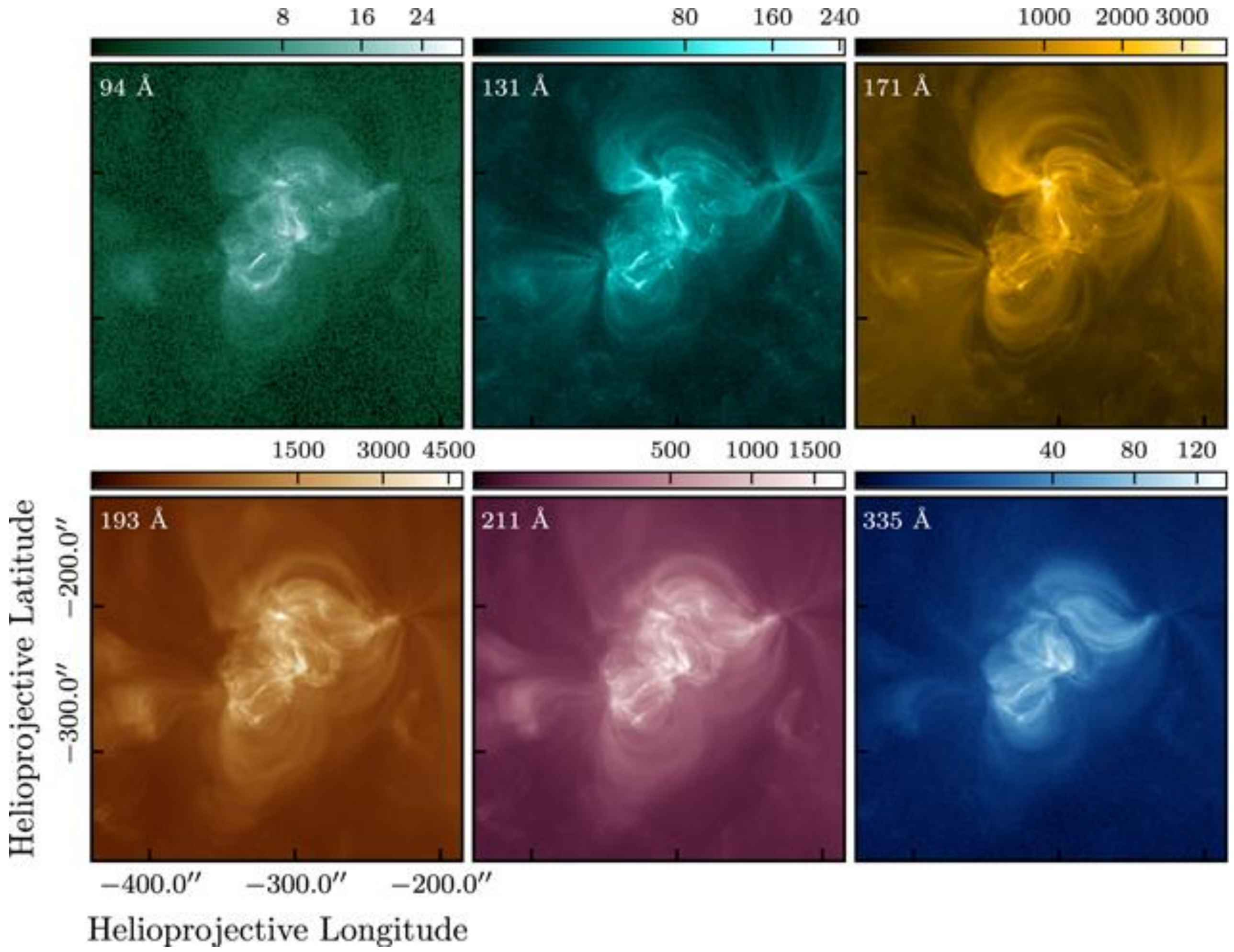
- Extrapolating from the flux concentrations in the photospheric driving to the corona implies 100,000 coronal current sheets and magnetic flux tubes in a single active region. We have good resolution of the photospheric driving, but resulting coronal nanoflares are well below resolution.

- We can’t answer: ‘what is the onset of reconnection?’ The answer requires at least 6 orders of magnitude coverage. The mesoscale response in the corona is observed: coronal loops (spatial-mesoscale) and reheating timescales ~1000s (temporal-mesoscale). We are guessing at the cross-system and cross-scale coupling.

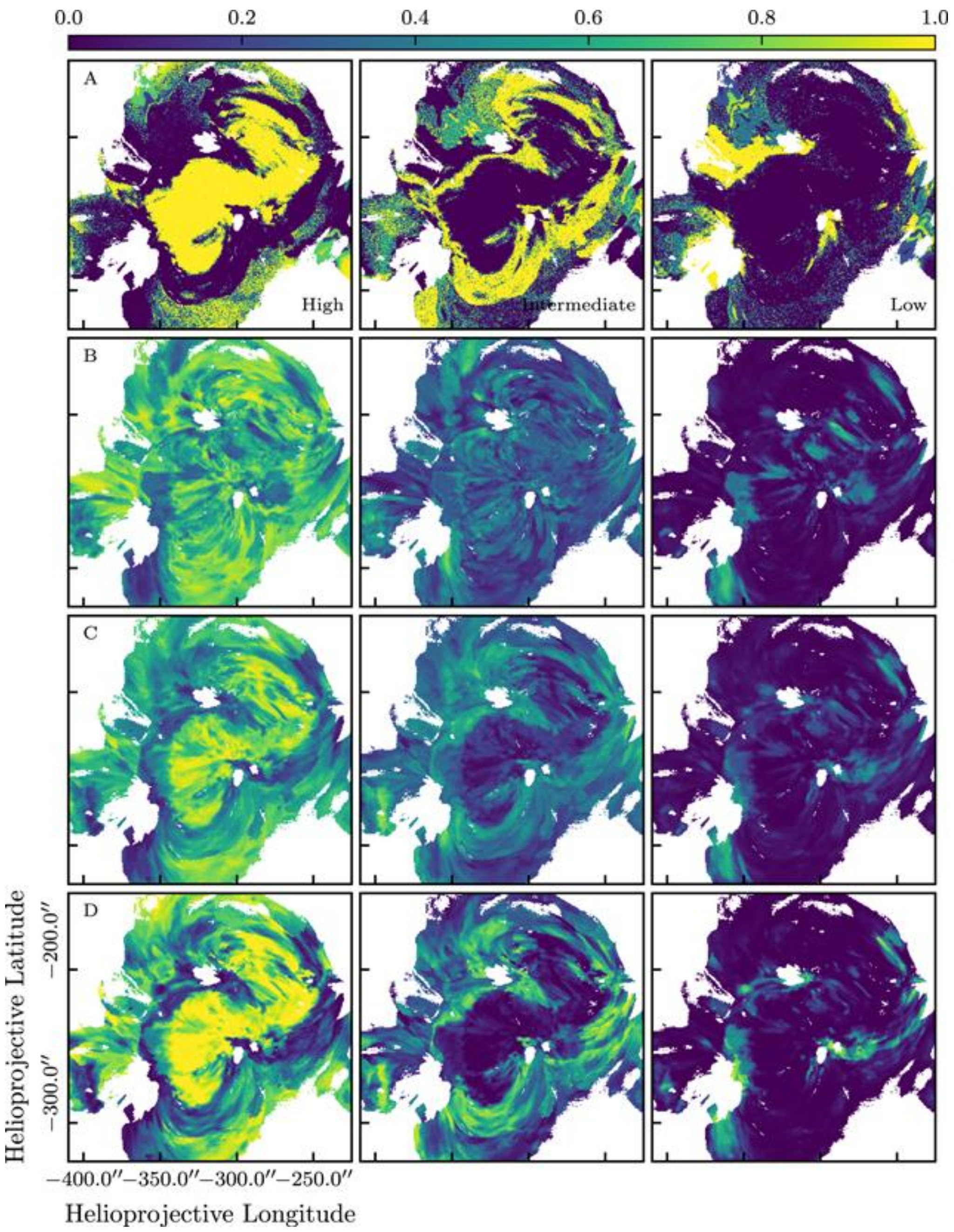
What can we do today?

Determine which set of coronal heating parameters best reproduces the observables.

- Coronal heating parameter: heating frequency per flux tube (high/intermediate/low defined relative to the cooling time)
- SDO/AIA per pixel differential emission measure slope, the peak temperature of the differential emission measure, and time lags and cross correlation values of those time lags
- Random forest classification model on forward modeled observables



Barnes *et al* 2021 *ApJ* **919** 132



Barnes *et al* 2021 *ApJ* **919** 132

Table 1
The Four Different Combinations of Emission Measure Slope, Peak Temperature, Time Lag, and Maximum Cross-correlation

Case	Parameters	p	Error	High	Inter.	Low
A	a, $T_{\rm peak}$	2	0.25	0.469	0.353	0.178
B	τ_{AB}, $\mathcal{C}_{AB}$	30	0.03	0.829	0.116	0.054
C	a, $T_{\rm peak}$, τ_{AB}, $\mathcal{C}_{AB}$	32	0.02	0.744	0.224	0.033
D	Top 10 features from Table 2	10	0.05	0.683	0.261	0.056

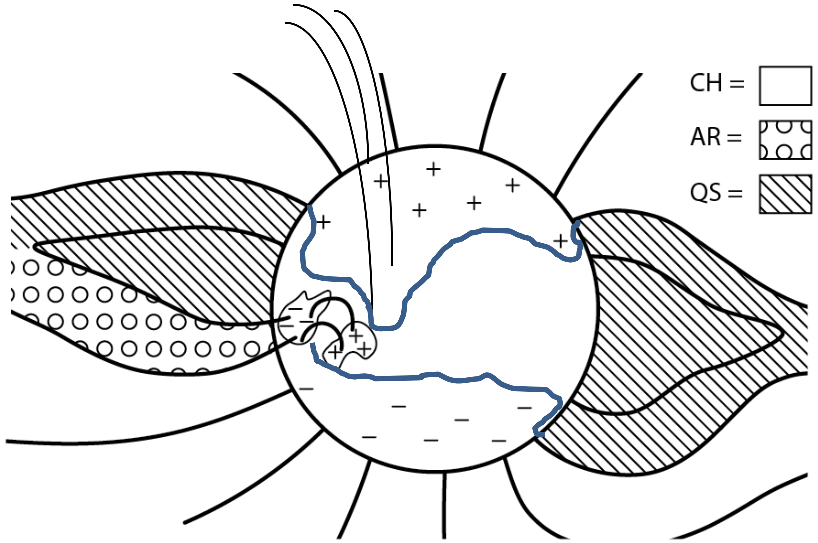
Notes. The third column lists the total number of features used in the classification. The fourth column gives the misclassification error as evaluated on $X_{\rm test}$, $Y_{\rm test}$. The fifth, sixth, and seventh columns show the percentage of pixels labeled as high-, intermediate-, and low-frequency heating, respectively.

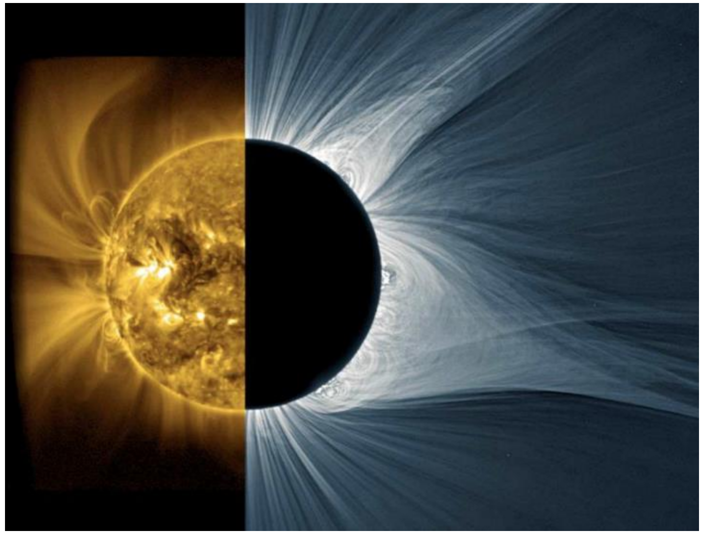
Figure 7. Classification **probability** for each pixel in the observed active region. The rows denote the different cases in Table 1 and the columns correspond to the different heating frequency classes. Note that summing over all heating probabilities in each row gives 1 in every pixel.

'We find that high-frequency heating dominates in the inner core of the active region while intermediate-frequency dominates closer to the periphery of the active region. '

In most pixels, low-frequency heating, is not needed to explain the observed diagnostics.

From where on the Sun does the solar wind originate? Connecting solar wind to the solar source.





Models used for mapping connectivity and source equate coronal hole with static open field lines, do not account for closed-field reconnection and solar wind release; requires human interpretation

-Are AR part of the streamer or is it all QS?

-Is the 'coronal hole' really an AR periphery?

-Proxies for dynamics and reconnection-released wind: S-web, coronal hole boundary distance, distance from HCS

Solar wind formation can be broken down into three general steps associated with the time history of the solar wind plasma. Crucially, when the plasma is released through reconnection, the physical process that energize the plasma in the high corona is not the same as that which energized the plasma in the low corona.

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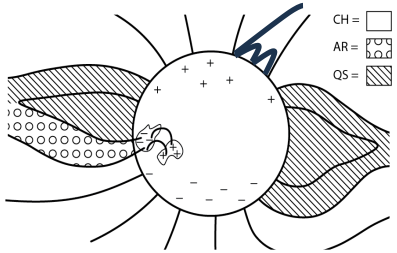
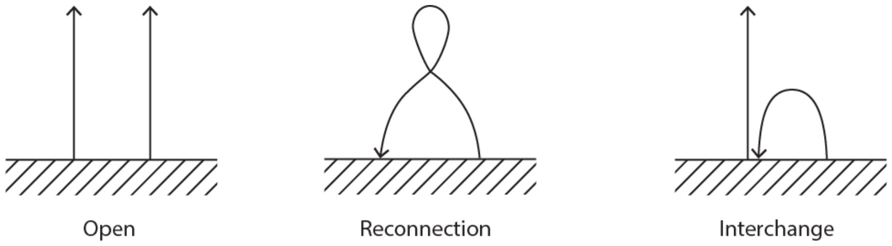


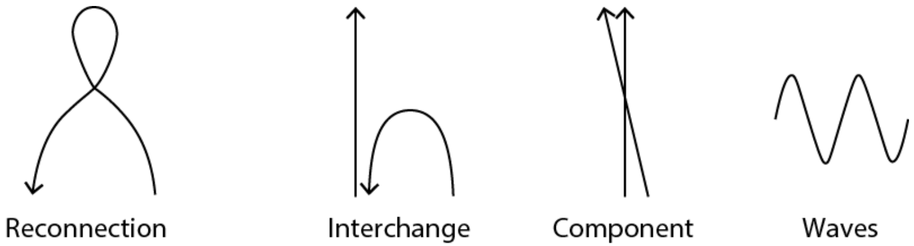
Heating/energization in the low corona

Step 2 Release



Energization **and/or** mass release in the low through middle corona

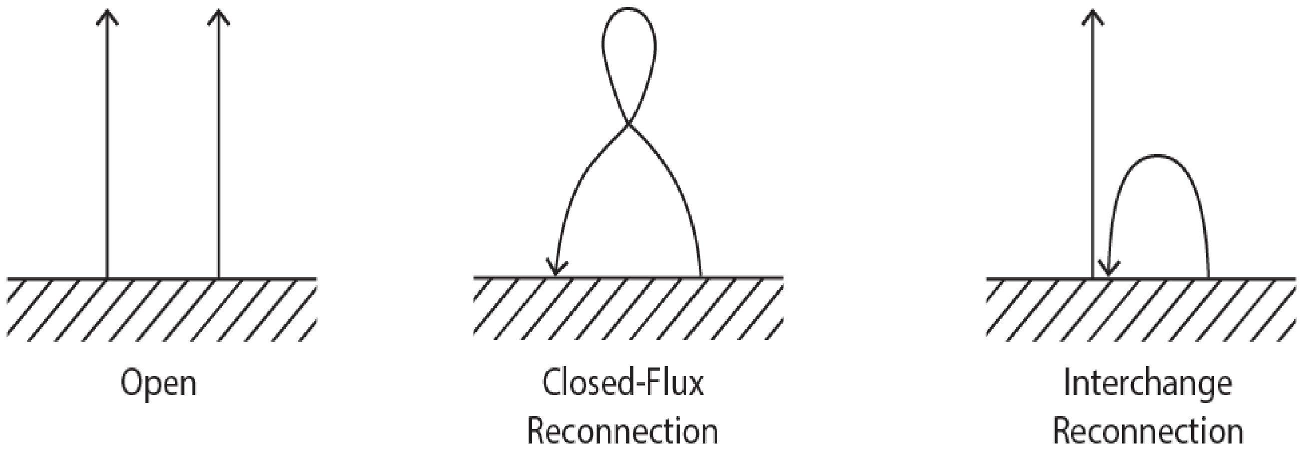
Step 3 Acceleration



Energization middle corona and outwards

Viall & Borovsky 2020, “Nine Outstanding Questions of Solar Wind Physics”, JGR, Grand Challenges in the Earth and Space Sciences

Q2 How is the solar wind released?



- The plasma may already be on open fields, or it may be on closed-fields, requiring one (or more) reconnection events for it to be released into the solar wind.
- Reconnection produces magnetic and plasma structures in the solar wind
- The reconnection may (e.g. coronal hole jets and jetlets) or may not (e.g. helmet streamer blobs) be energetically important.

Solar wind formation can be broken down into three general steps associated with the time history of the solar wind plasma. Crucially, when the plasma is released through reconnection, the physical process that energize the plasma in the high corona is not the same as that which energized the plasma in the low corona.

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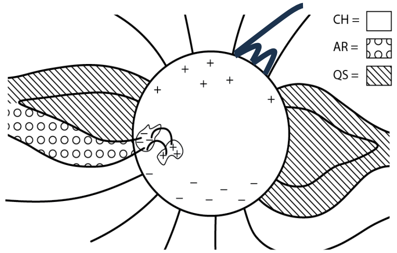

Heating/energization in the low corona

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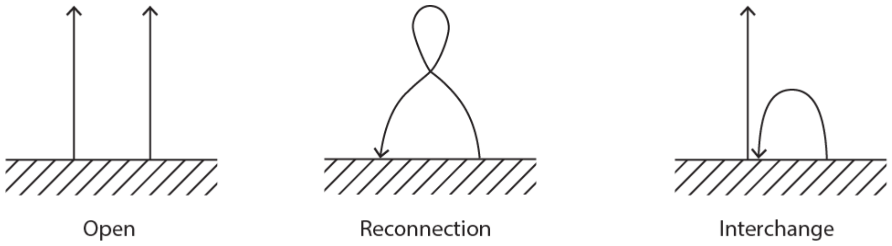

Energization **<u>and/or</u>** mass release in the low through middle corona

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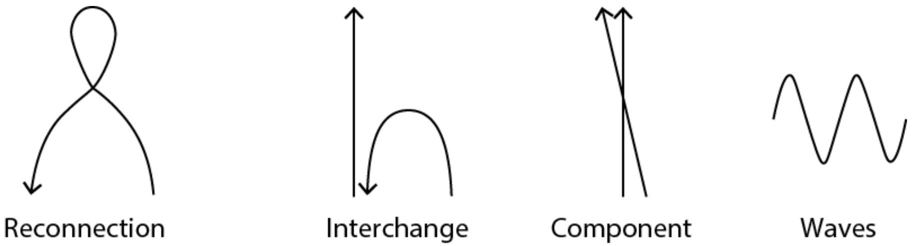
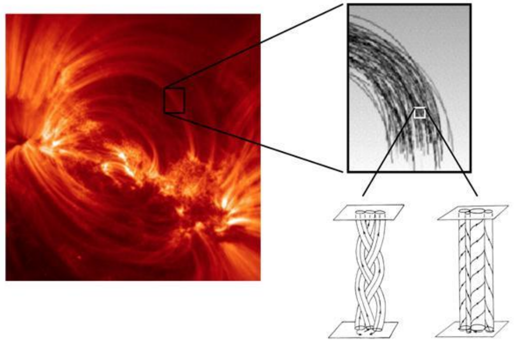


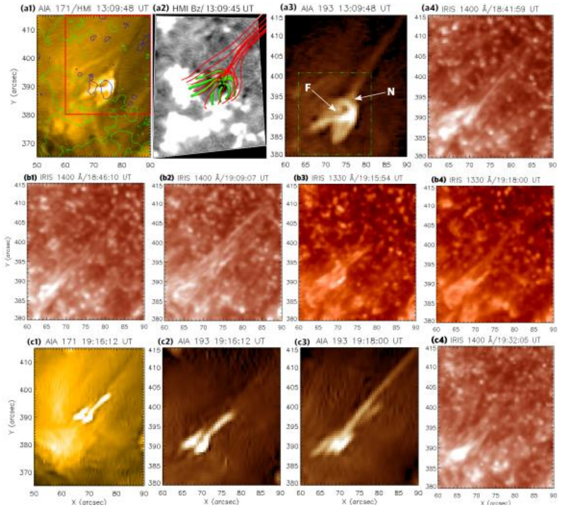
Energization middle corona and outwards

Viall & Borovsky 2020, “Nine Outstanding Questions of Solar Wind Physics”, JGR, Grand Challenges in the Earth and Space Sciences

Magnetic Reconnection in the Solar Corona: Enormous Range of Conditions and Consequences

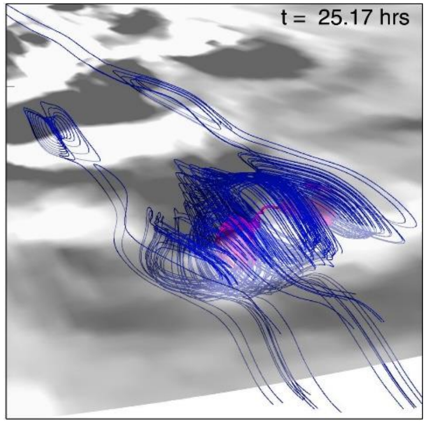
Coronal Heating: Nanoflares





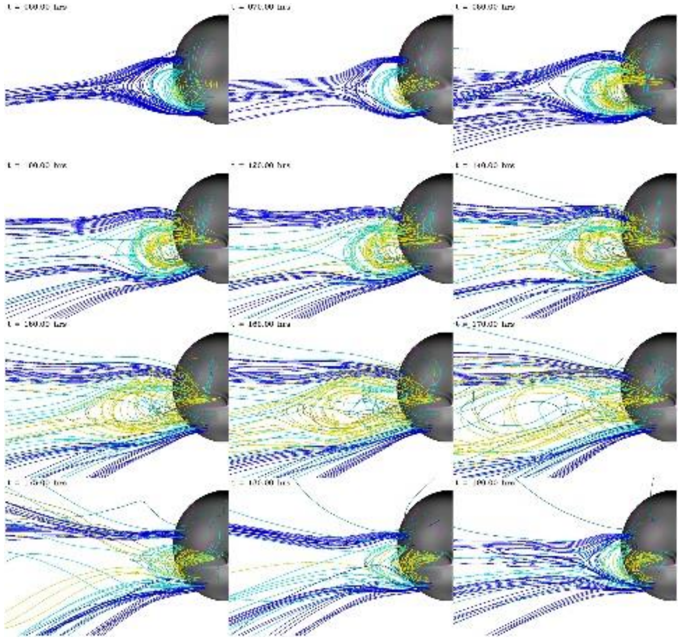
Raouafi, Panesar, Kumar, etc. many observation in SDO and IRIS of jetlets

Solar Wind Release: Helmet Streamer Blobs



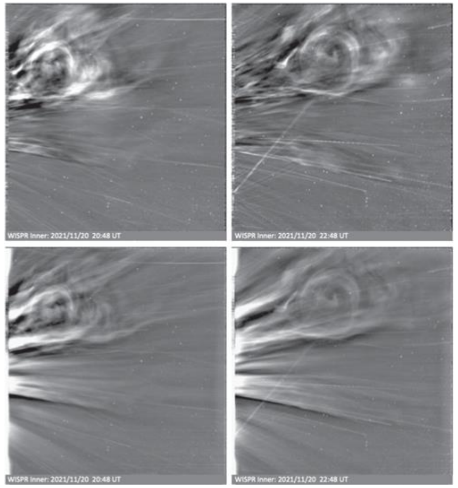
Sheeley et al.
Higginson et al.

Stealth CMEs



Lynch et al. 2016
Palmerio et al.

Large Flares and CMEs

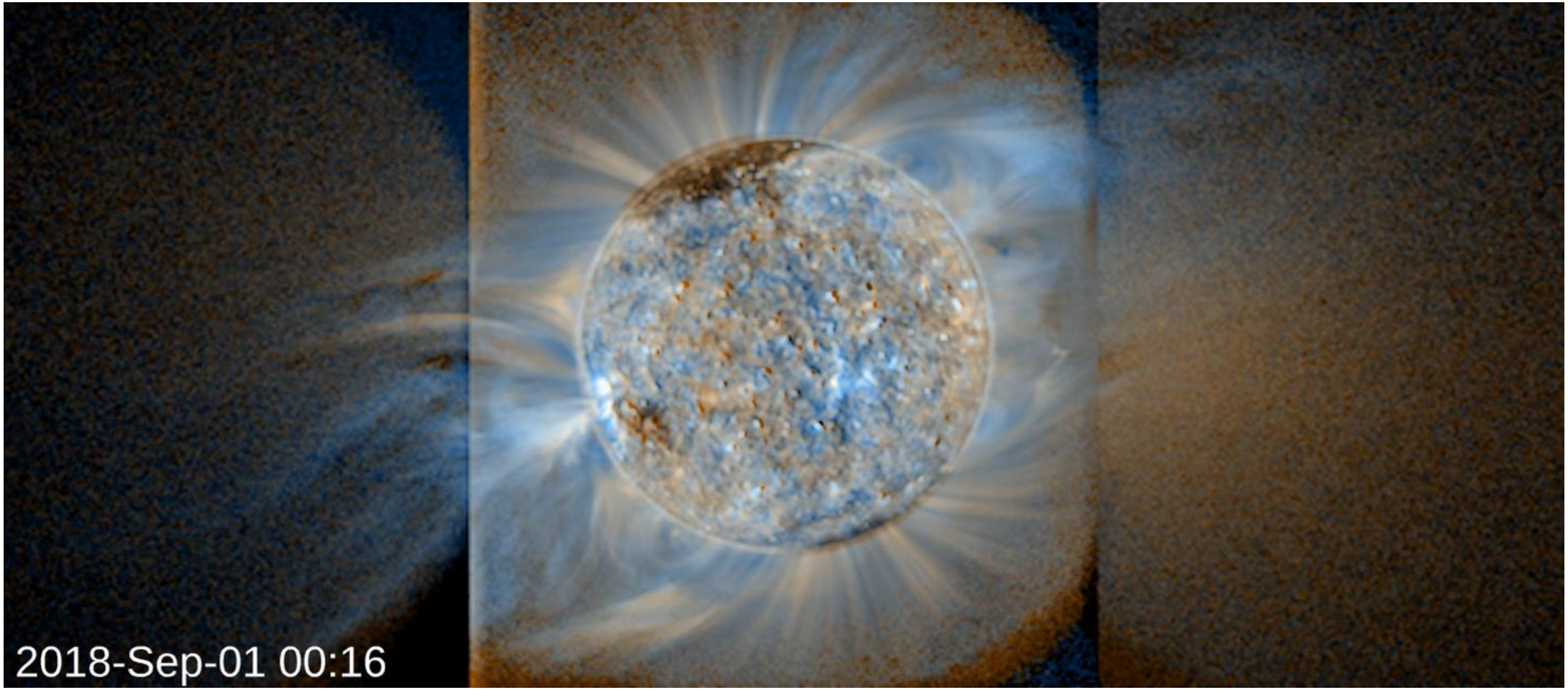


Howard et al. 2022
PSP/WISPR CME

All examples of coronal reconnection, but there are enormous differences in:

- Magnetic topology - component reconnection; interchange reconnection; anemone; antiparallel
- Energy injection – small-scale flux emergence, AR-scale flux emergence, foot point mixing/shear on granular scales, foot point mixing/shear on super granular scales, shear from differential rotation…
- Energy released - spans nine (at least) orders of magnitude
- Mass released into the heliosphere – zero (closed-closed reconnection), 10^8 kg (Raouafi 2023 jetlets), up through 10^13 kg (CMEs)

Middle Corona is Highly Structured in Density and Temperature



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(1): From where on the Sun does the solar wind originate?
(2): How is the solar wind released?
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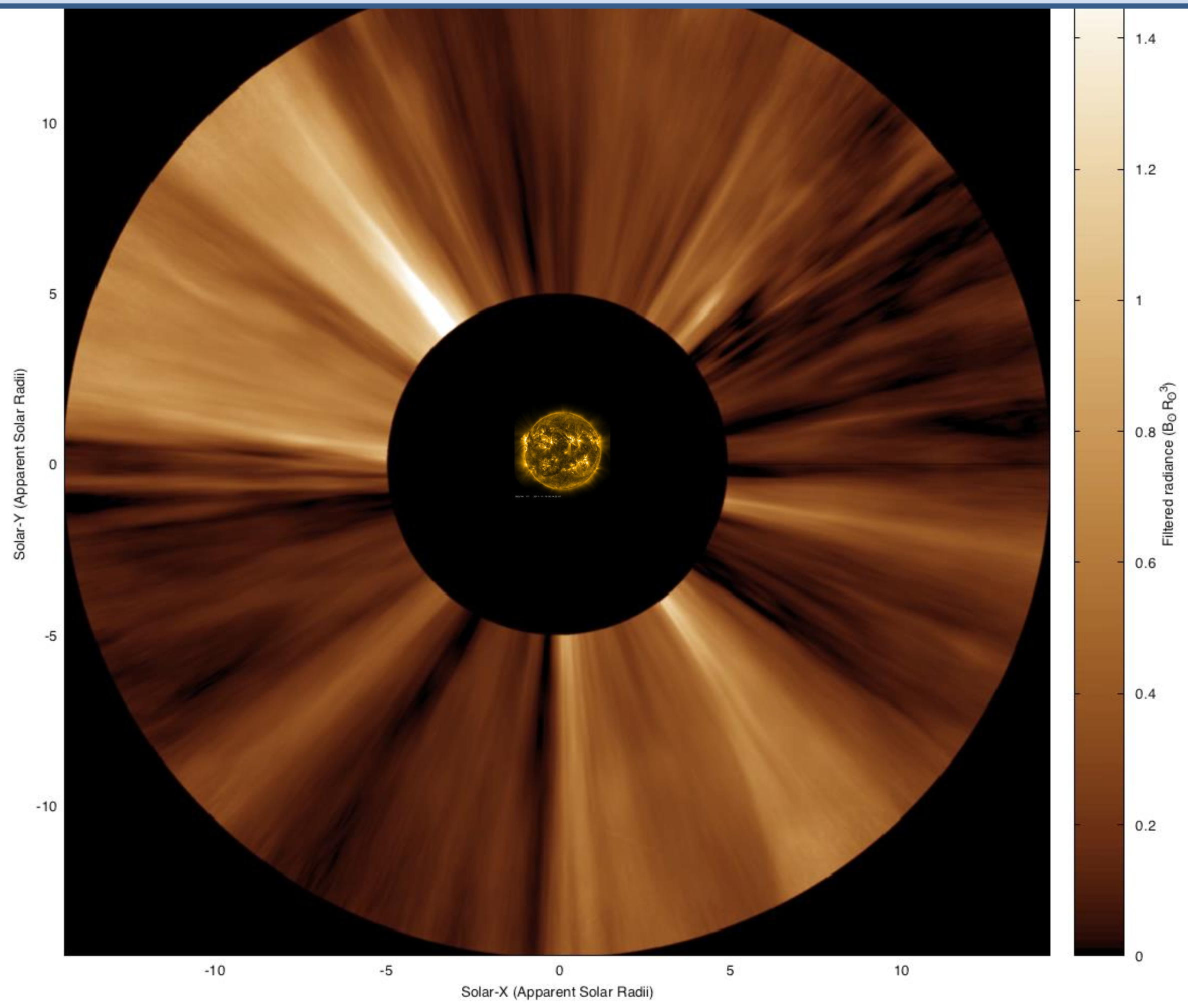
(8): How do the kinetic distribution functions of the solar wind evolve?
(9): What are the roles of solar wind structure and turbulence on the transport of energetic particles in the heliosphere?

How does the solar atmosphere create the solar wind and Heliosphere? How do the resulting structures drive Geospace?

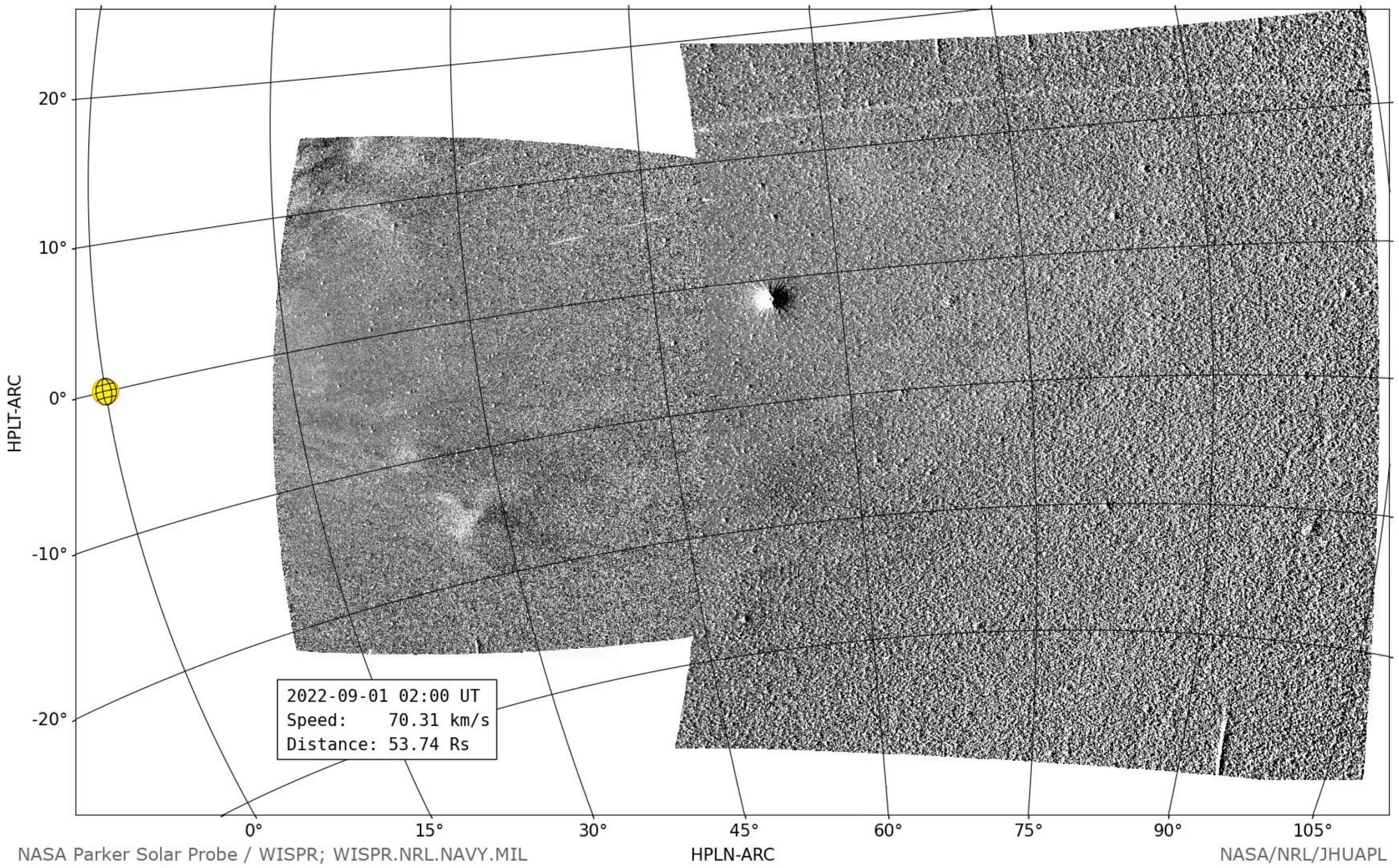


The ground state of space weather:

the dynamic connection between the Sun, the Heliosphere, and Geospace that occurs even during so-called "quiet" times.

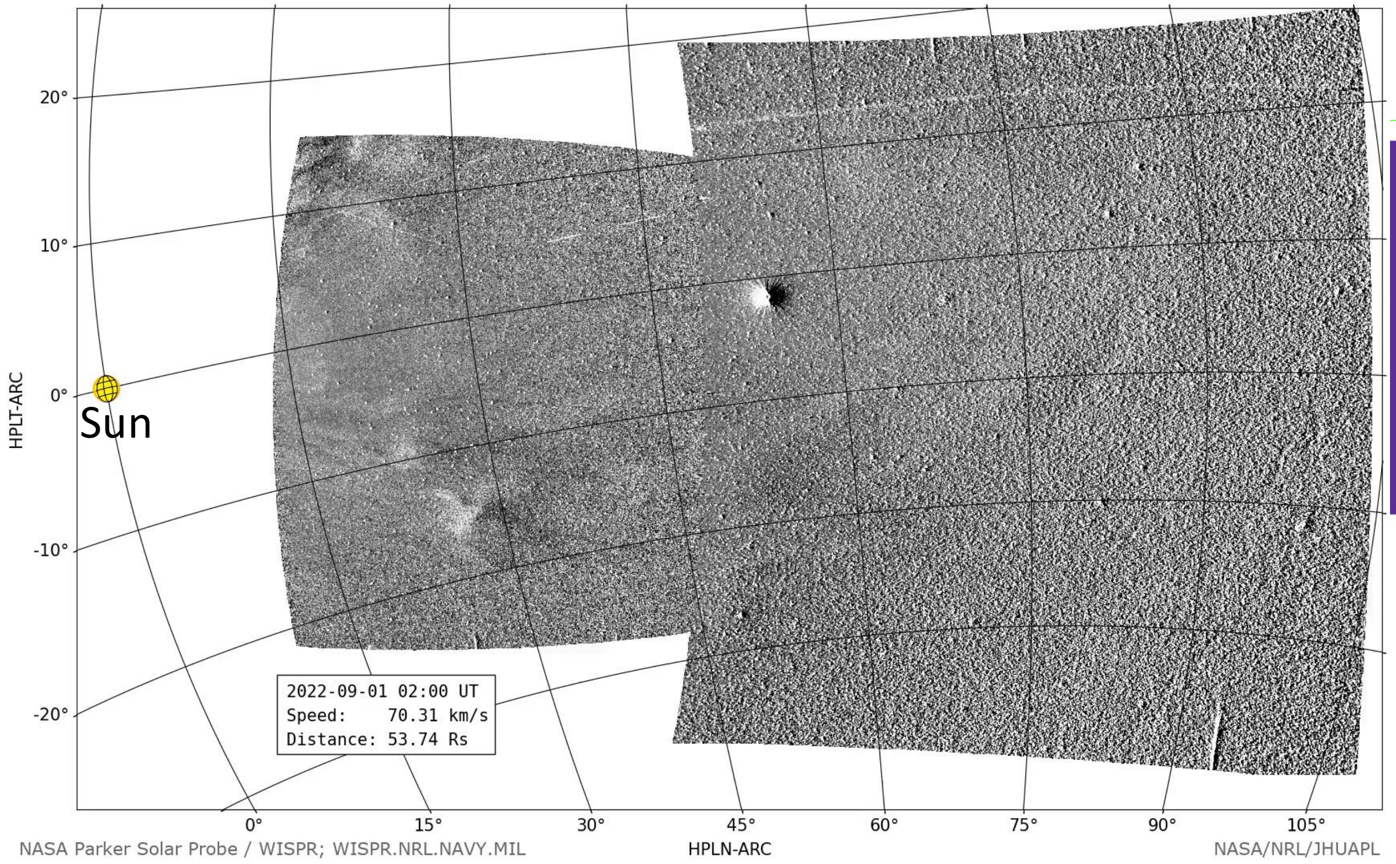
Special high resolution, deep field STEREO COR2 campaign, DeForest et al. 2018, shows that the solar wind density is highly dynamic at its formation; Fourier analysis reveals periodic density structure

The Solar Wind and CMEs are comprised of mesoscale structure



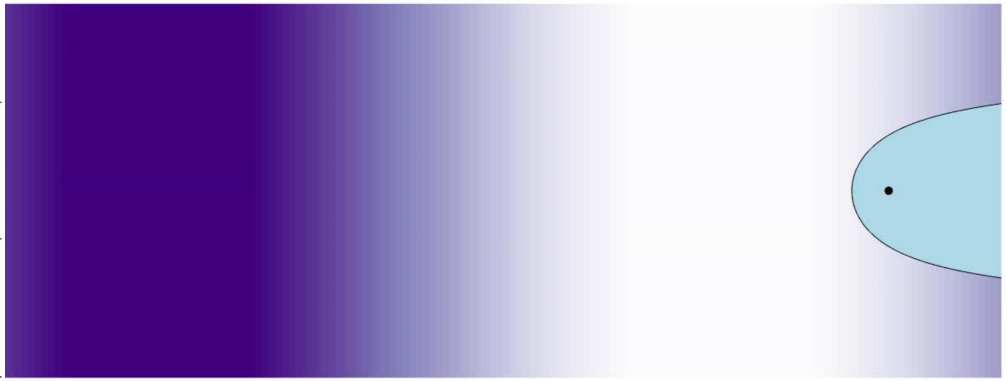
WISPR full-field observations from the thirteenth PSP Mission Encounter (2022-09-01 - 2022-09-11), processed via the LW Algorithm developed by Dr. Stenborg (JHUAPL) and detailed in Appendix A of *Howard et al. 2022* (ApJ, 936, id.43. DOI 10.3847/1538-4357/ac7ff5).

The solar wind is comprised of mesoscale structures as a direct result of how the solar wind is formed; many solar wind mesoscale structures survive to 1 AU and drive dynamics in Geospace



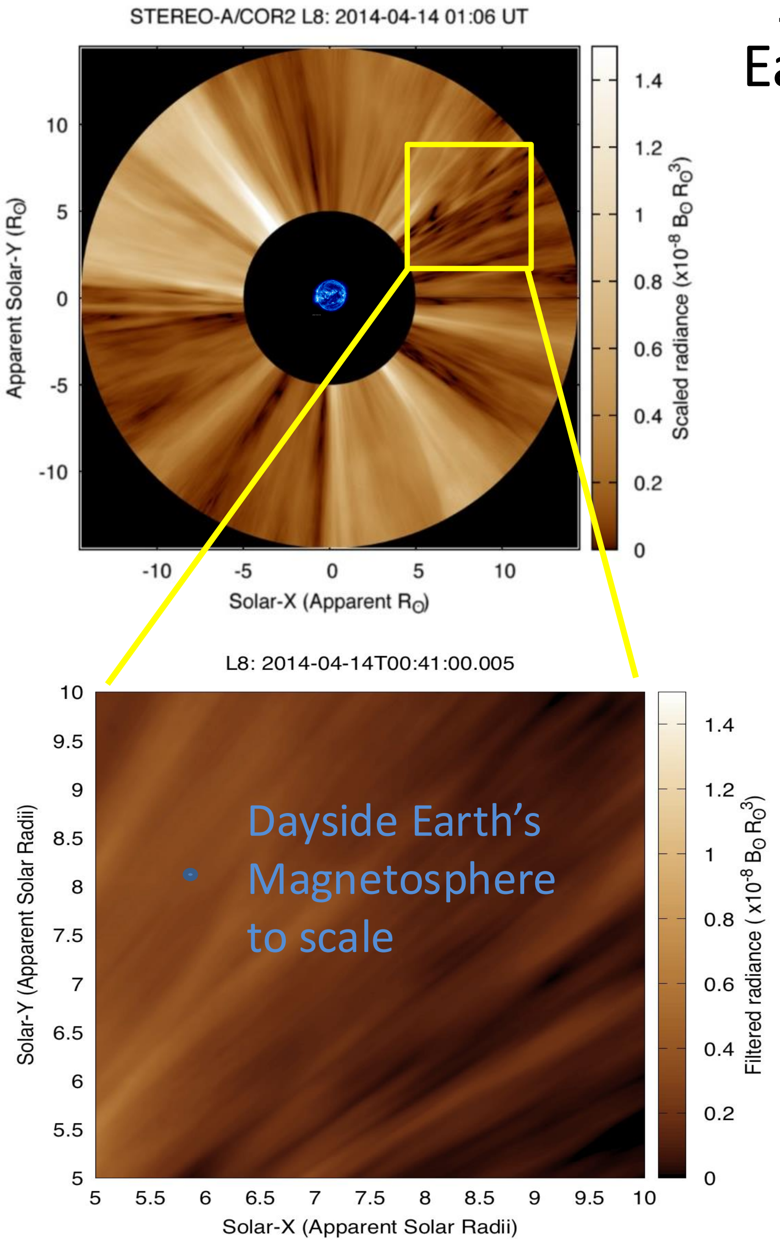
Parker Solar Probe WISPR images of solar wind density show the newly formed solar wind is filled with mesoscale density structures (smaller than CMEs, larger than kinetic); this is also the background that large events propagate through.

Representation of solar wind driving Earth's Magnetosphere



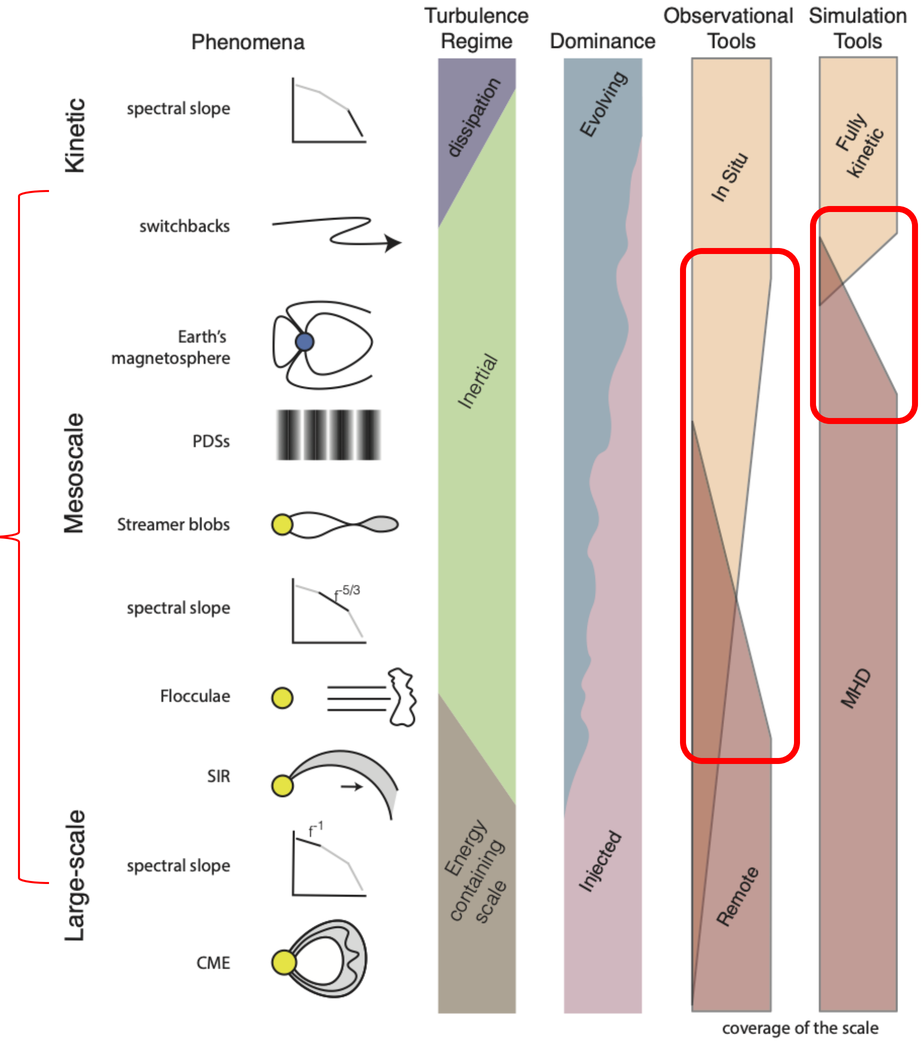
Mesoscale solar wind density structures are often periodic (hours to minutes, or ~0.2-5 mHz). They cause a periodic 'forced breathing' in the magnetosphere, driving ultra low frequency (ULF) waves, radiation belt dynamics and particle precipitation into Earth's atmosphere.

mesoscale solar wind structures: they are large compared to Earth's magnetosphere, thus are important drivers of Geospace.



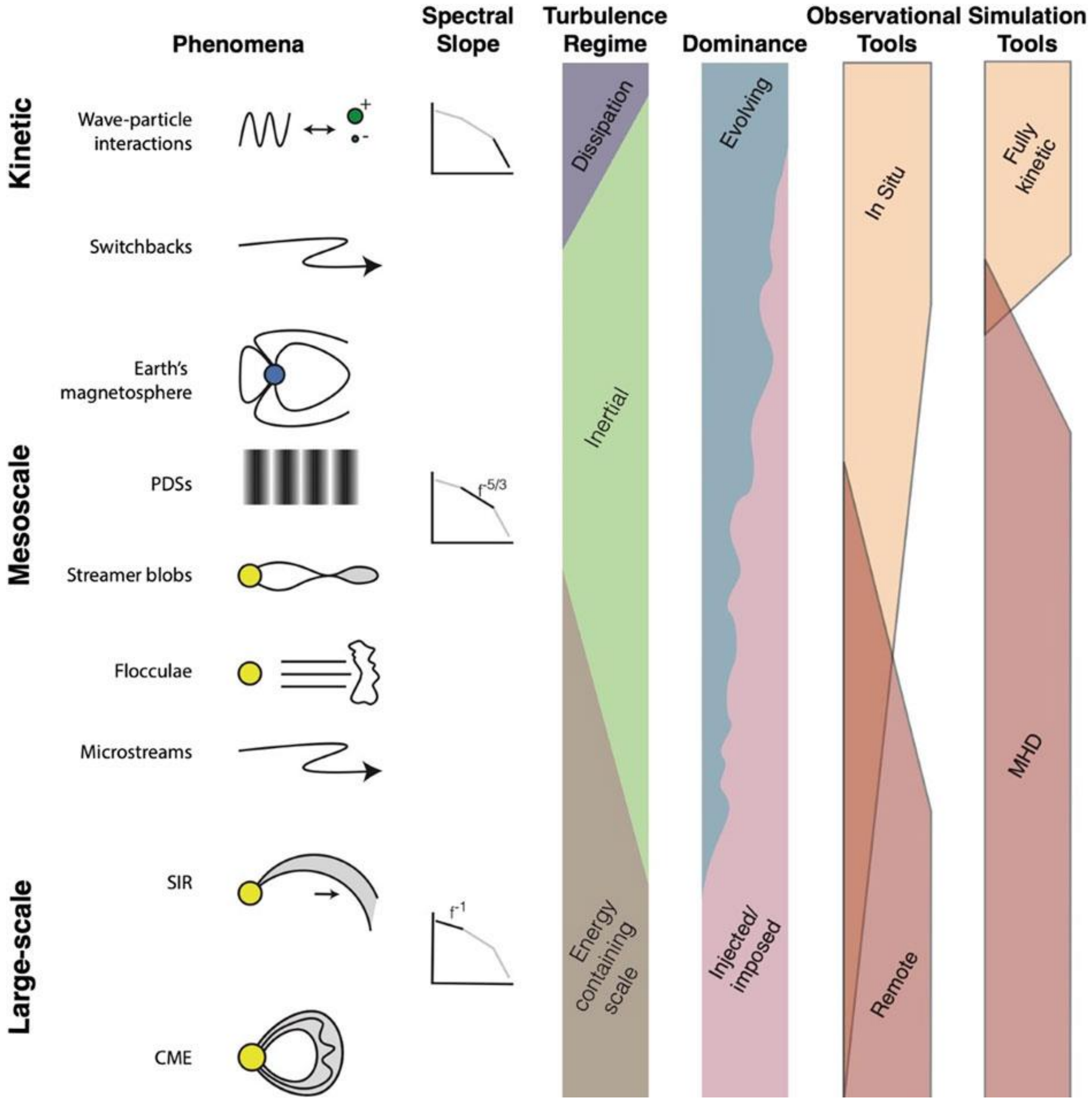
DeForest et al. 2018

Spans ~ **8 orders of magnitude** in the inner heliosphere



Observations and Simulations are missing the Mesoscales

Viall, DeForest, and Kepko, 2021



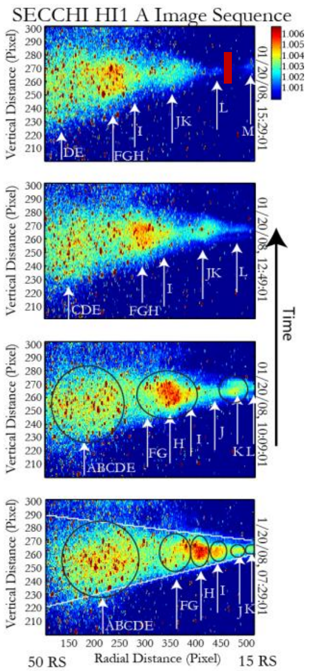
- Large scale structures in the solar wind are all imposed (spatial structure) or injected (time dynamics) from the Sun
- Kinetic scale structures are all due to evolution and processing en route, and begin at the dissipation scales
- Mesoscales are between Large and kinetic scales, and are created by both evolution en route and also directly imposed/injected
- Mesoscales span a multiple-decade size range: at 1 AU in the approximate spatial range of ~5–10,000 Mm and temporal range of 10 s–7 hrs.

Viall, DeForest and Kepko, Mesoscale Structure in the Solar Wind
Front. Astron. Space Sci., 25 August 2021 | https://doi.org/10.3389/fspas.2021.735034

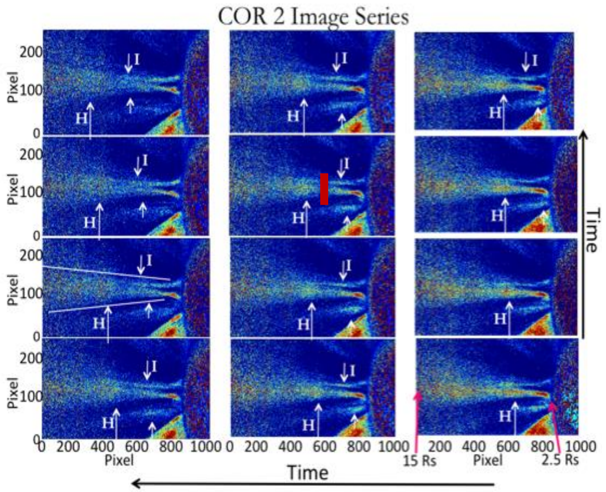
Example where we (mostly) know the answers to Q1, Q2, Q3, and Q5

- Periodic Density structures

Periodic density structures are a type of solar wind mesoscale structure observed throughout the inner Heliosphere formed by Separatrix-web (S-web) reconnection

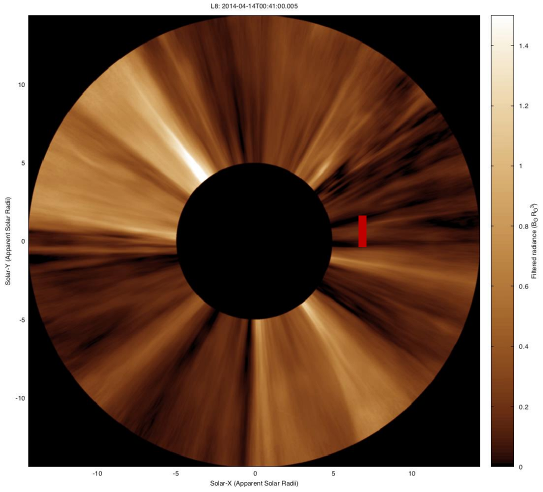


Viall et al. 2010

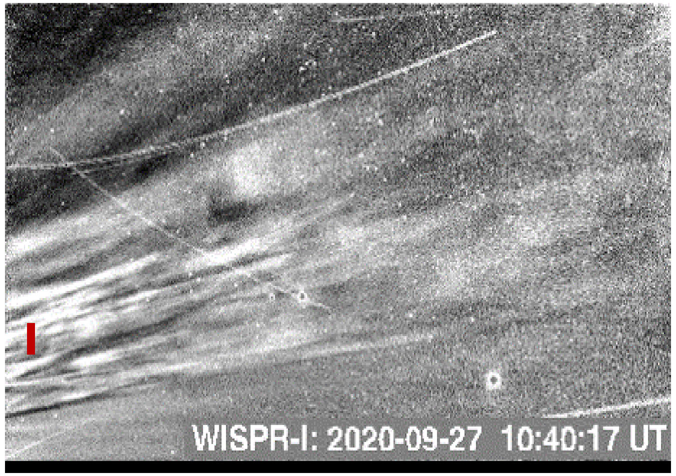


Viall & Vourlidas 2015

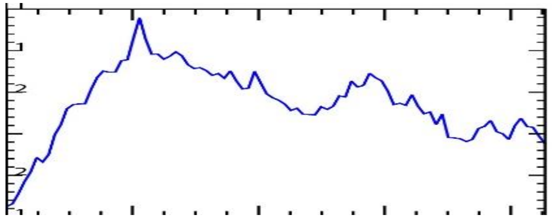
COR 2



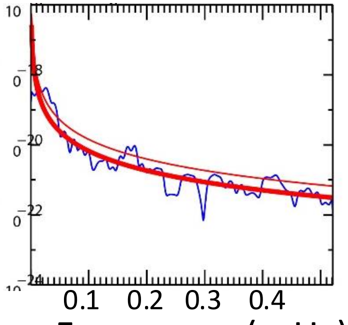
DeForest et al. 2018



Viall et al. in prep



24-hour WISPR intensity time series from pixel slit near inner edge

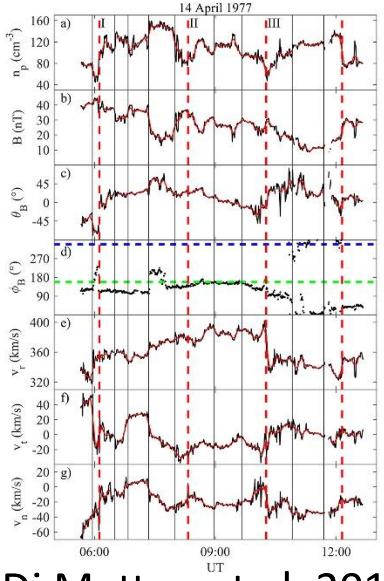


Frequency (mHz)

- Observed **remotely in white light between 2.5 and 50 solar radii**
- Trains of density enhancements spaced periodically (defined with Fourier analysis); intensity time series from pixel slits
- Frequencies of ~0.1-5.0 mHz (a couple of hours to 3 minutes)
- Structures advect with the solar wind flow, radial length scales of 100s Mm- 1000s Mm

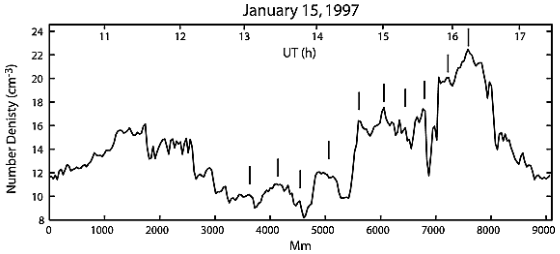
Periodic density structures are a type of solar wind mesoscale structure observed throughout the inner Heliosphere formed by (S-web) reconnection

Helios



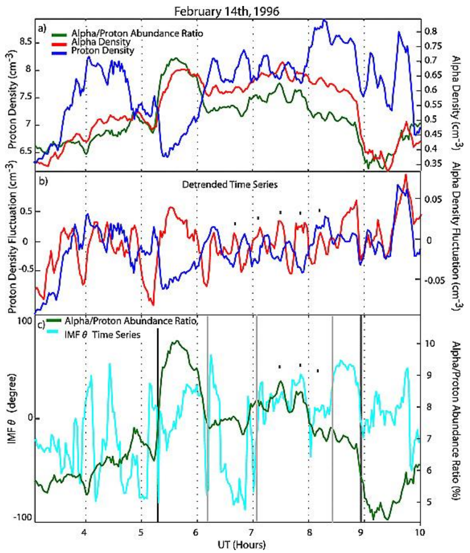
Di Matteo et al. 2019

Wind



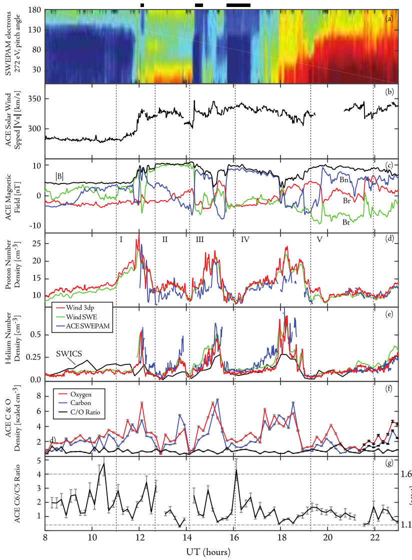
Viall et al. 2008

Wind



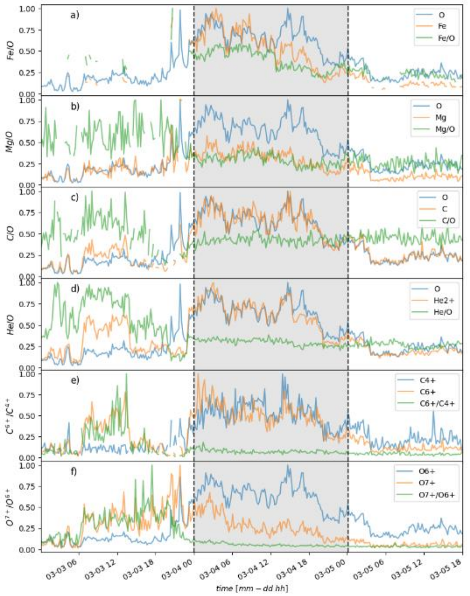
Viall, Spence & Kasper 2009

ACE and Wind



Kepko et al. 2016

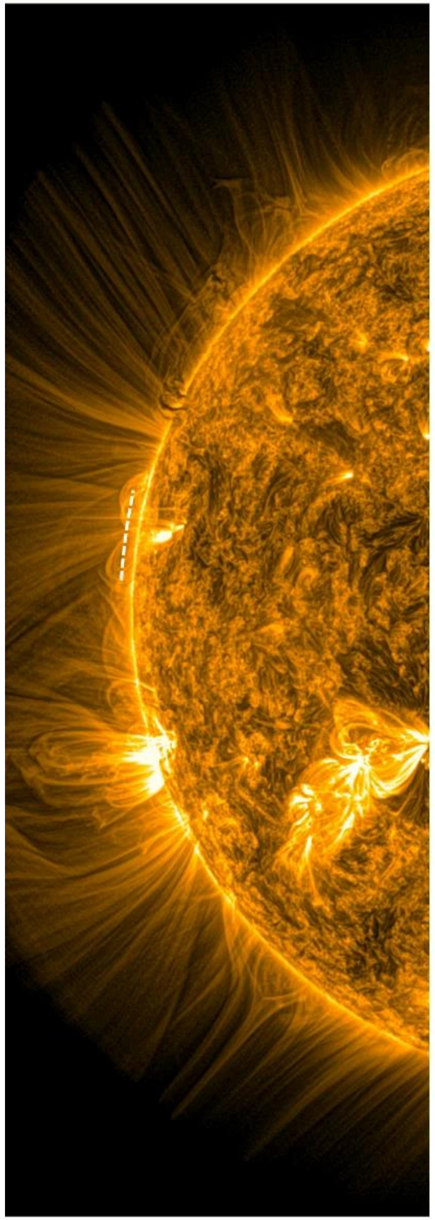
ACE

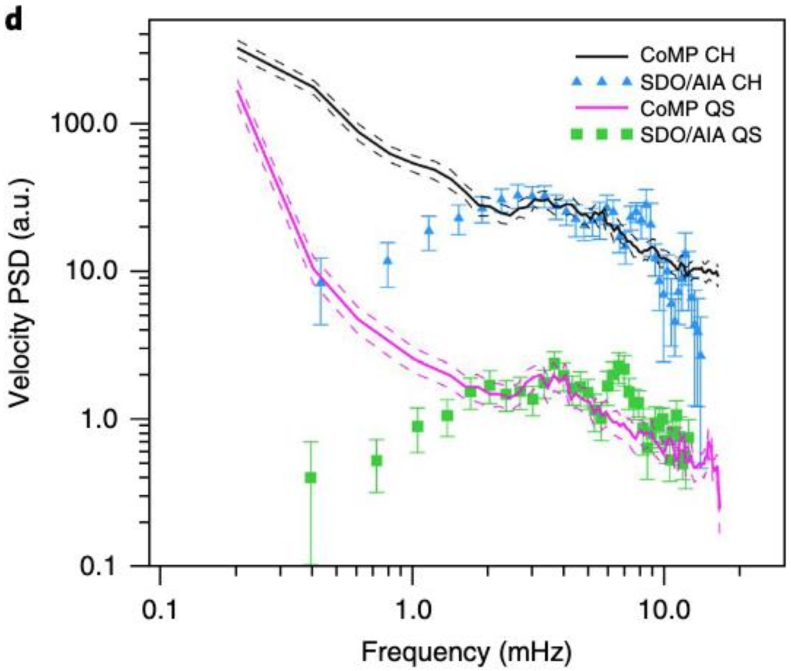


Gershkovich et al. 2022

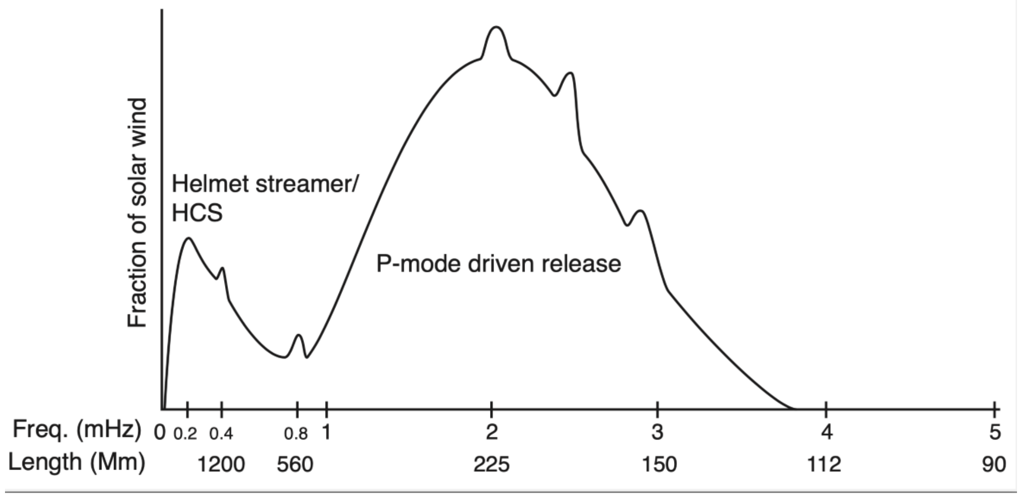
- Observed **<u>in situ between 0.3 and 1.0 AU</u>**
- Trains of density enhancements spaced periodically (defined with Fourier analysis)
- Frequencies of ~0.1-5 mHz (a couple of hours to 3 minutes)
- Structures advect with the solar wind flow, radial length scales of 100s Mm- 1000s Mm
- Often multiple embedded periodicities
- Composition changes (alpha/proton, charge state, FIP, Sulfur/Oxygen…) confirm that periodic density structures are created in the solar corona and survive to at least 1 AU
- Associated magnetic field variations confirm structure interpretation (e.g. often flux ropes, PBS) and rules out propagating waves or wavey HCS

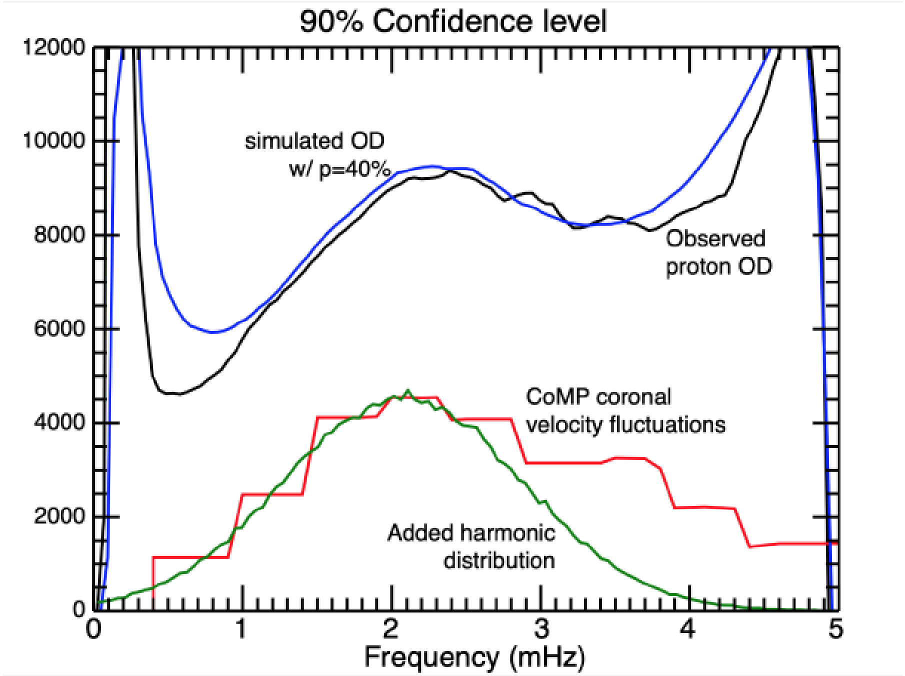
a





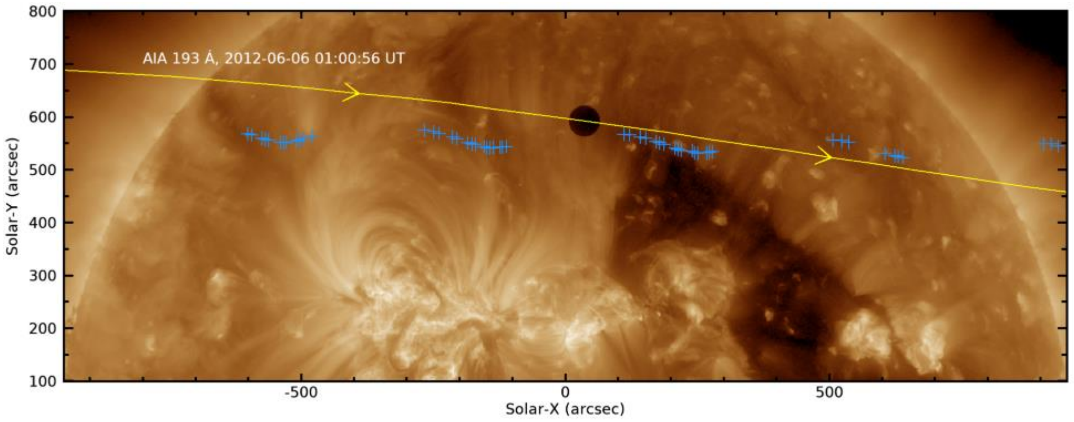
Morton et al, 2019

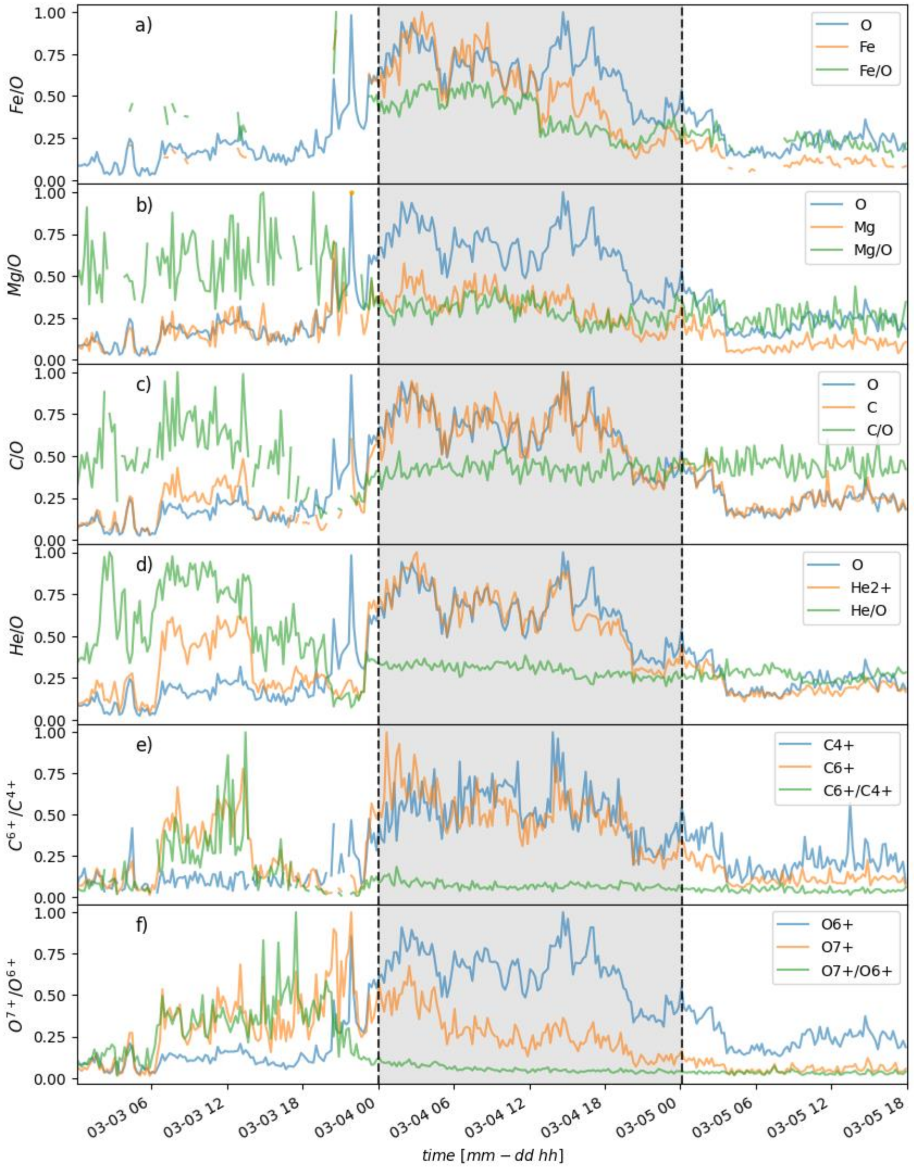




Kepko, Viall and DiMatteo, 2024

Event 1: Elemental abundances links in situ solar wind periodic mesoscale structures to their source in the corona





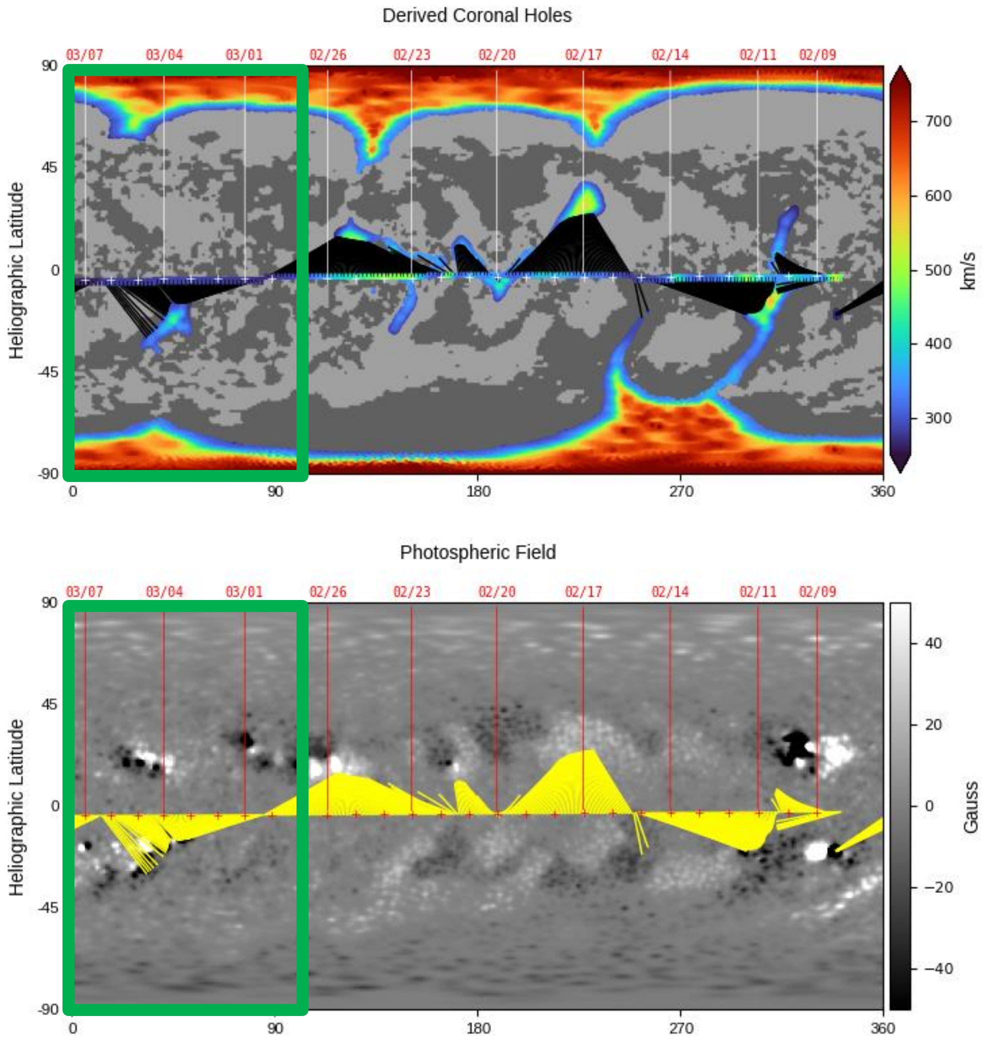
Young and Viall (ApJ, 2022) used the Venus transit to quantify the scattered light (noise) and determined the conditions when it is possible to measure the elemental abundances in and around coronal holes.
Analysis tools open source at github pryoung/papers/2022 venus

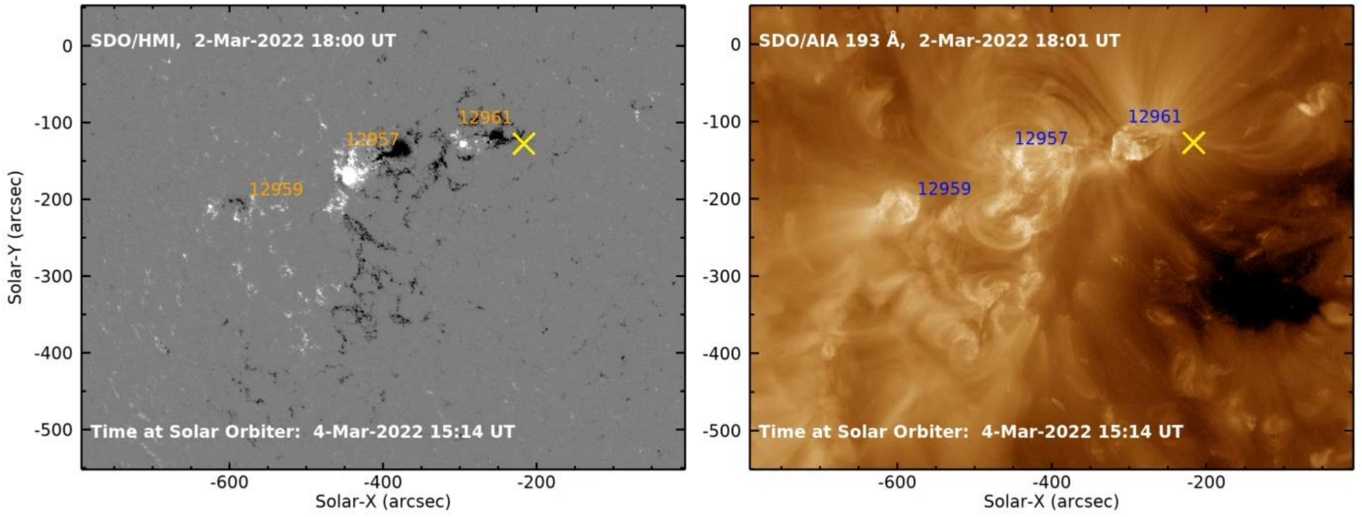
Gershkovich, Lepri, Viall, Kepko and DiMatteo, (ApJ, 2022) shows that mesoscale periodic structures observed at ACE (L1) exhibit elemental abundance changes, linking Earth-impacting solar wind structures to solar source and solar wind formation

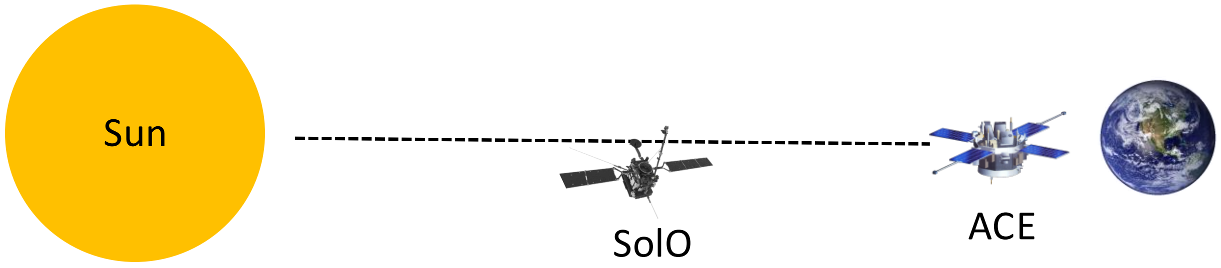
Gershkovich, Lepri, Viall, Kepko and DiMatteo, (Solar Physics, 2023) extended the analysis to 14 years of ACE data. Found 90 min, and a half hour to be characteristic periodicity of mesoscale periodic elemental abundance variations

Extending to Solar Orbiter data now

Event 2: Solar Orbiter SEWP+ ADAPT-WSA link remote coronal FIP bias measurements from SolO with that observed in situ at SolO and ACE





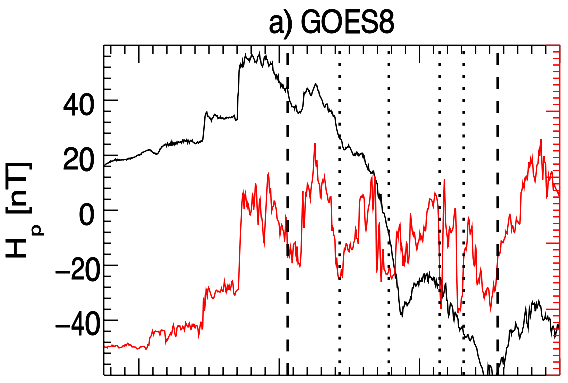


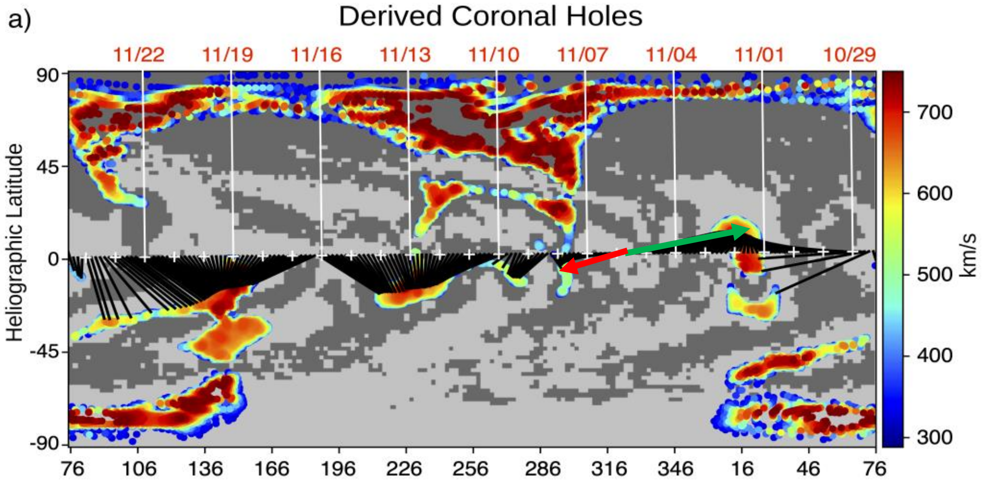
Wallace, Zambrana-Prado, Gershkovich, Viall, Kucera, Young, Lepri, Yardley, in prep

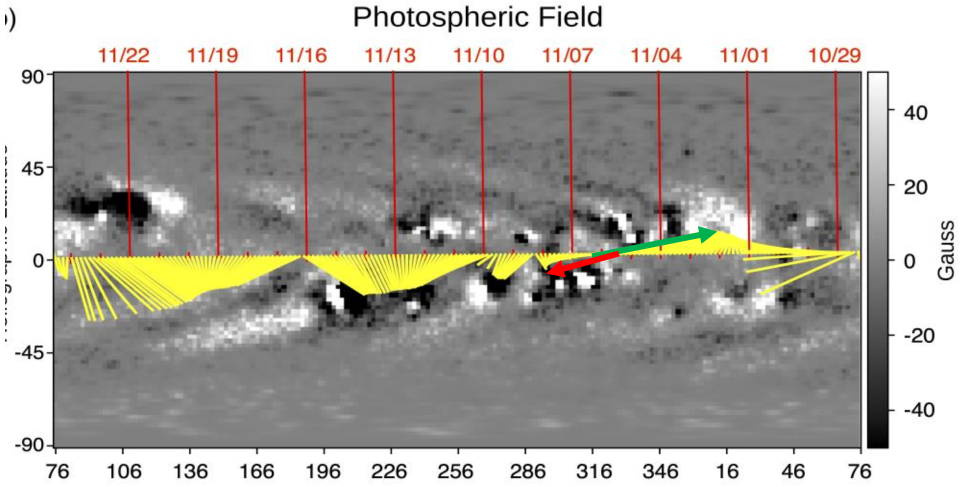
***SolO*:SPICE rasters:** March 3-6, 2022 (at the Sun)

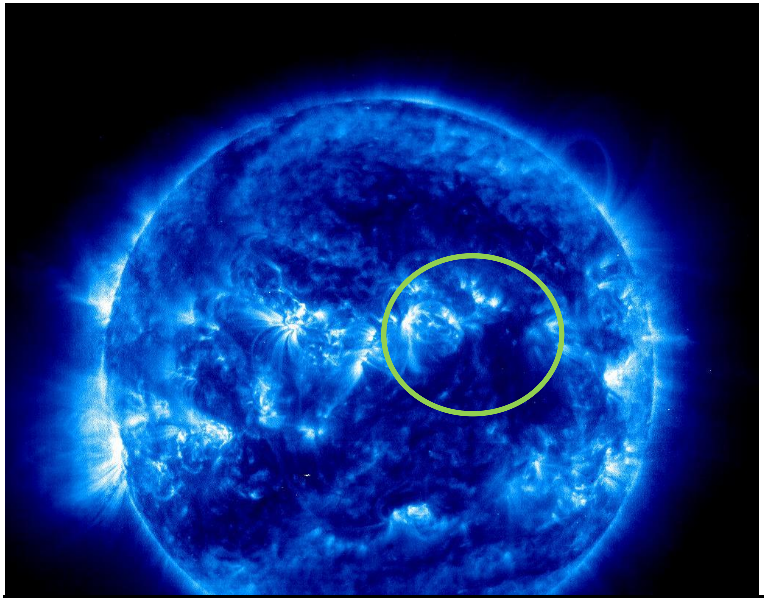
***SolO*:HIS in situ solar wind measurements:** March 4-8, 2022 (at 0.54 AU)

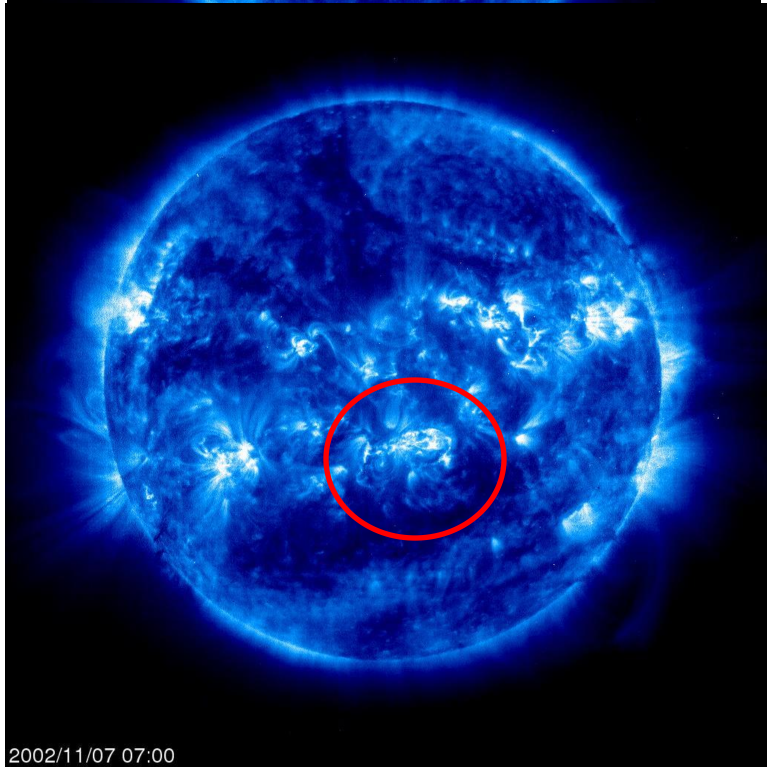
Event 3: GOES+ Wind +ADAPT-WSA link remote coronal active region observed in SDO









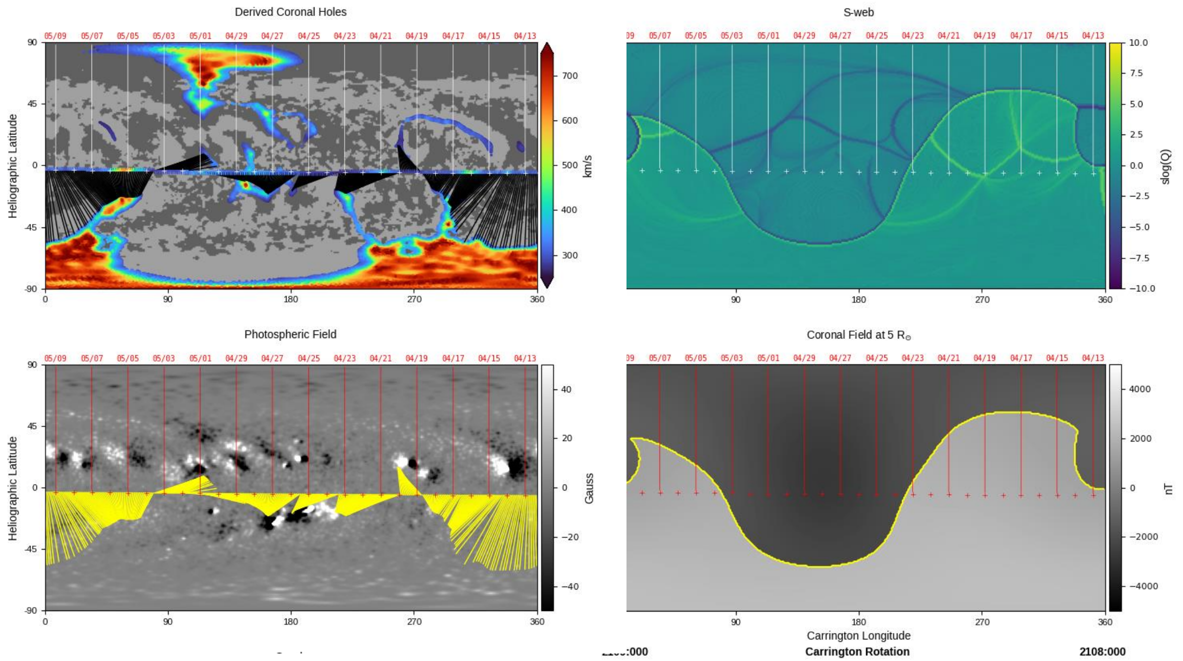


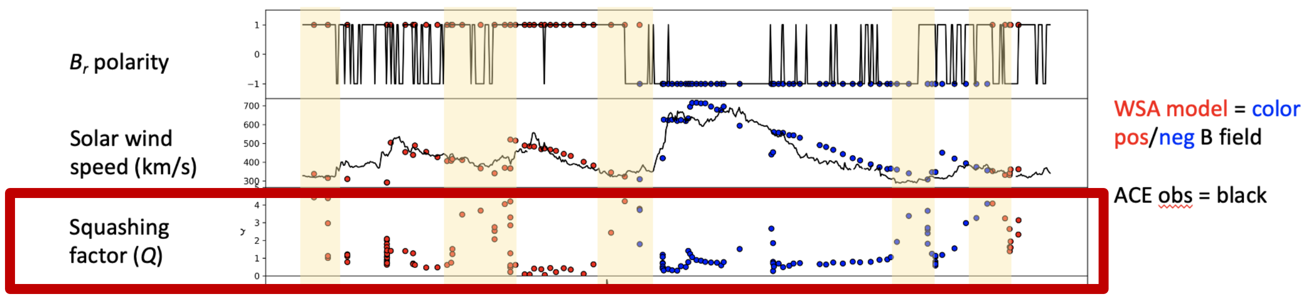
- The solar wind with periodic density structures came from large, decayed AR (green); multipolar AR (red) doesn't make solar wind periodic density structures (that survive to 1 AU)
- Applied to PSP backside of the Sun (Wallace et al. 2022)
- We are the beta testers for a wide variety of science use cases for WSA, and help define the needed model tools

In collaboration with Arge's ISFM; WSA-ADAPT

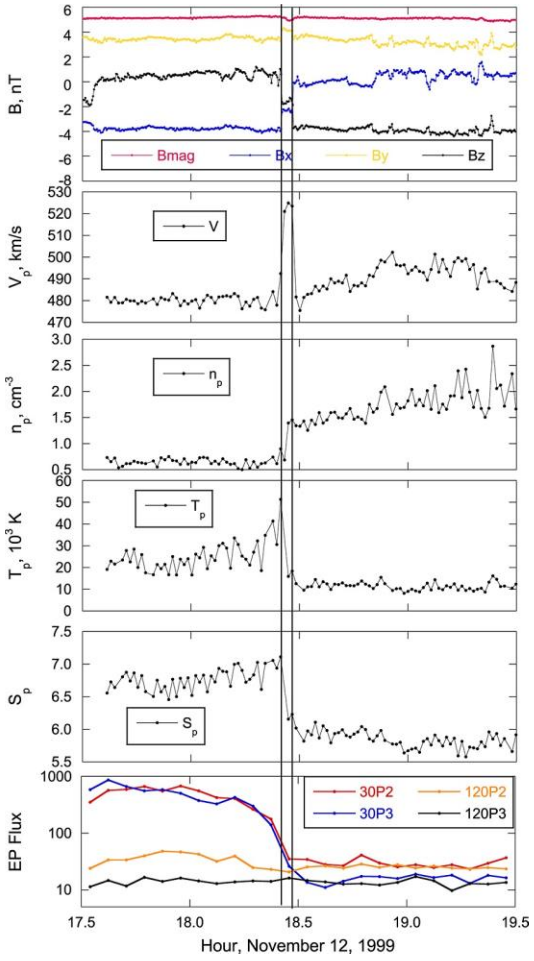
Data-driven Spacecraft Connection Studies Using WSA

- Successfully implemented a squashing-factor (Q) calculation within the WSA framework Used to identify connections to pseudostreamers specifically
  – Can plot squashing factor connectivity as an in situ quantity!
- Provided beta-testing of this feature with science use cases



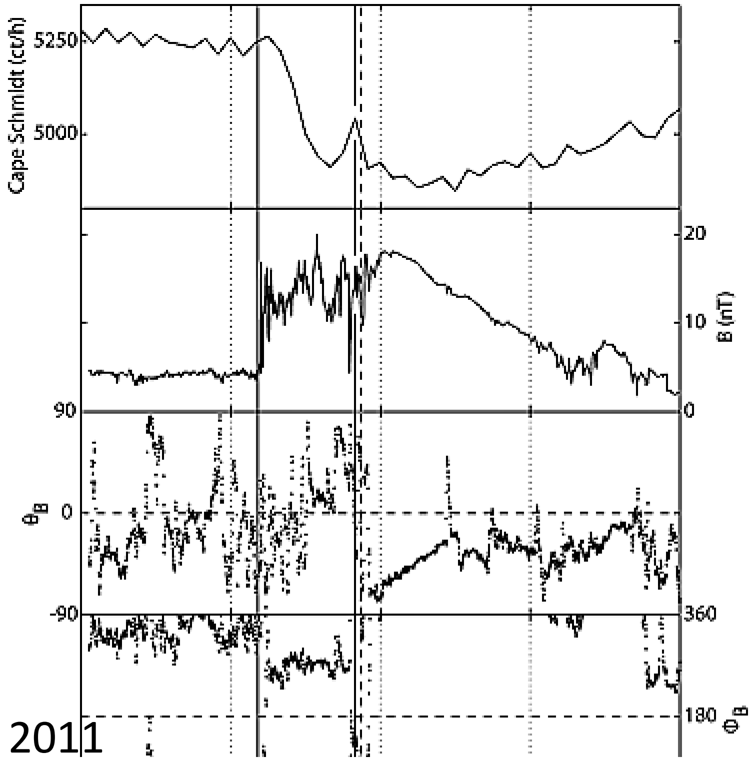


Mesoscale Structures within the Solar Wind and CMEs affect Energetic Particles



Neugebauer, J. Giacalone 2015

'This study examines the probable sources of sharp changes in the flux of energetic particles (EPs) in the solar wind… occur at significant changes in the plasma and magnetic field in the solar wind. Those changes are consistent with crossing preexisting tangential discontinuities or flux tube boundaries'

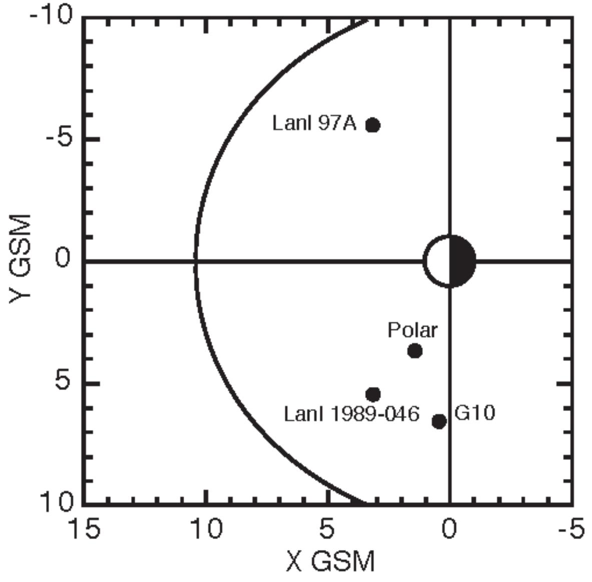


Jordan et al. 2011

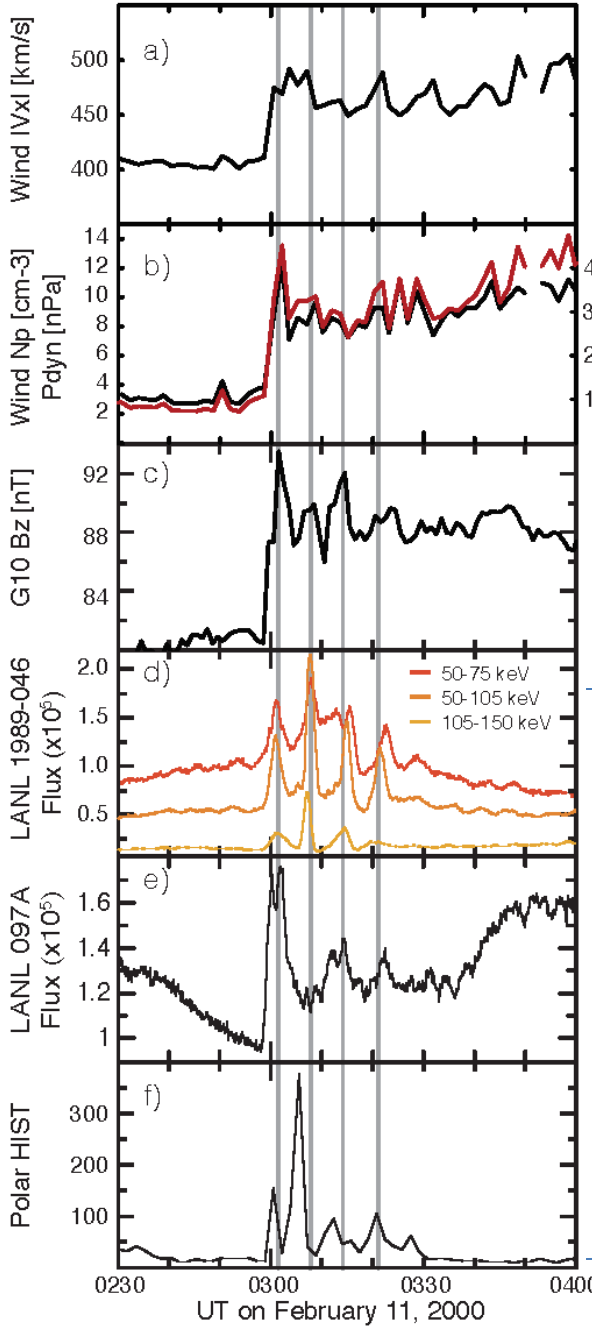
We conclude that the traditional model of FDs as having one or two steps should be discarded. We also conclude that generally ignored small-scale interplanetary magnetic field structure can contribute to the observed variety of FD profiles.

Small shock followed by periodic density structures. The periodic density structures (not the shock itself) drive ULF waves and particle precipitation from the radiation belt into Earth's atmosphere.

See new paper by Katsavarias et al. 2025 for a comprehensive statistics!



~8 min (2 mHz)

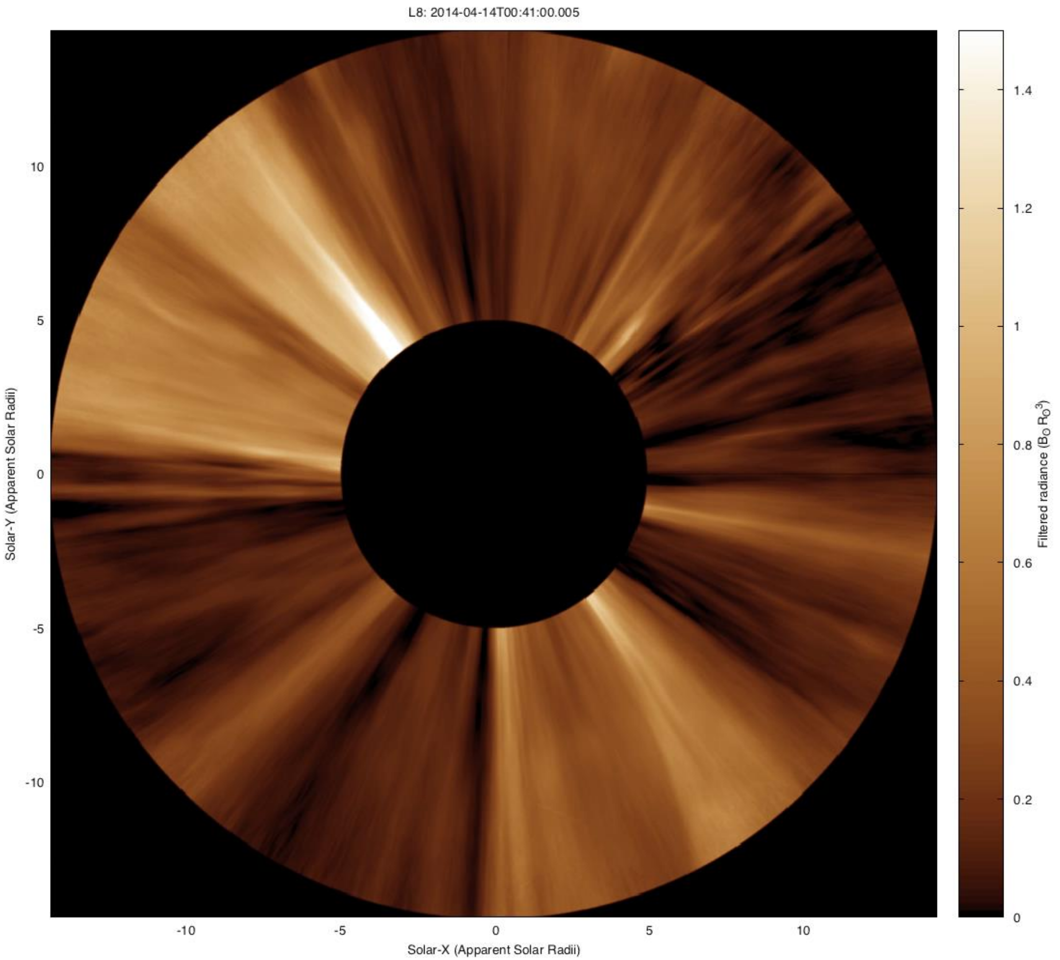


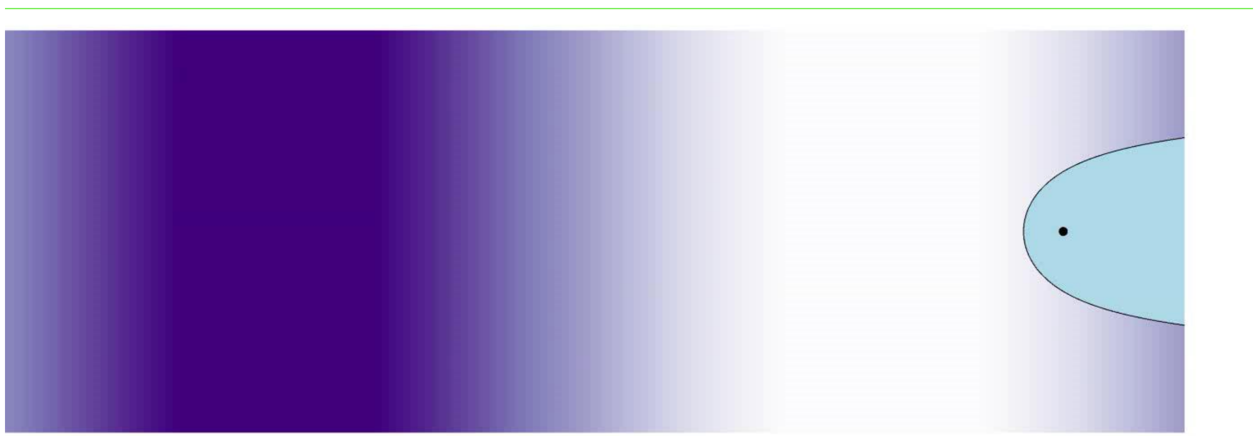
Solar Wind

Magnetosphere

Radiation Belt

Kepko & Viall 2019


L8: 2014-04-14T00:41:00.005
Solar-Y (Apparent Solar Radii)
Solar-X (Apparent Solar Radii)
Filtered radiance ($B_O R_O^3$)
10
5
0
-5
-10
1.4
1.2
1
0.8
0.6
0.4
0.2
0



Upcoming Missions

PUNCH and SPHEREx Integrated on Payload Adaptor

SPHEREx Spacecraft

NFI Spacecraft

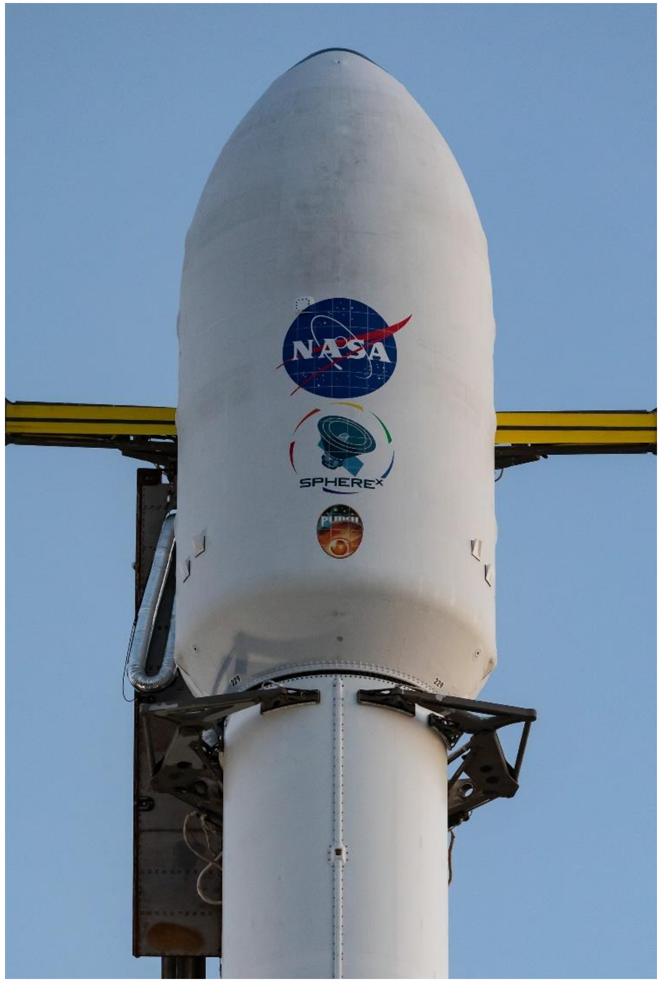
WFI-1 Spacecraft

Falcon 9 Fairing

WFI-2 Spacecraft

PUNCH Successfully Launched March 11, 2025

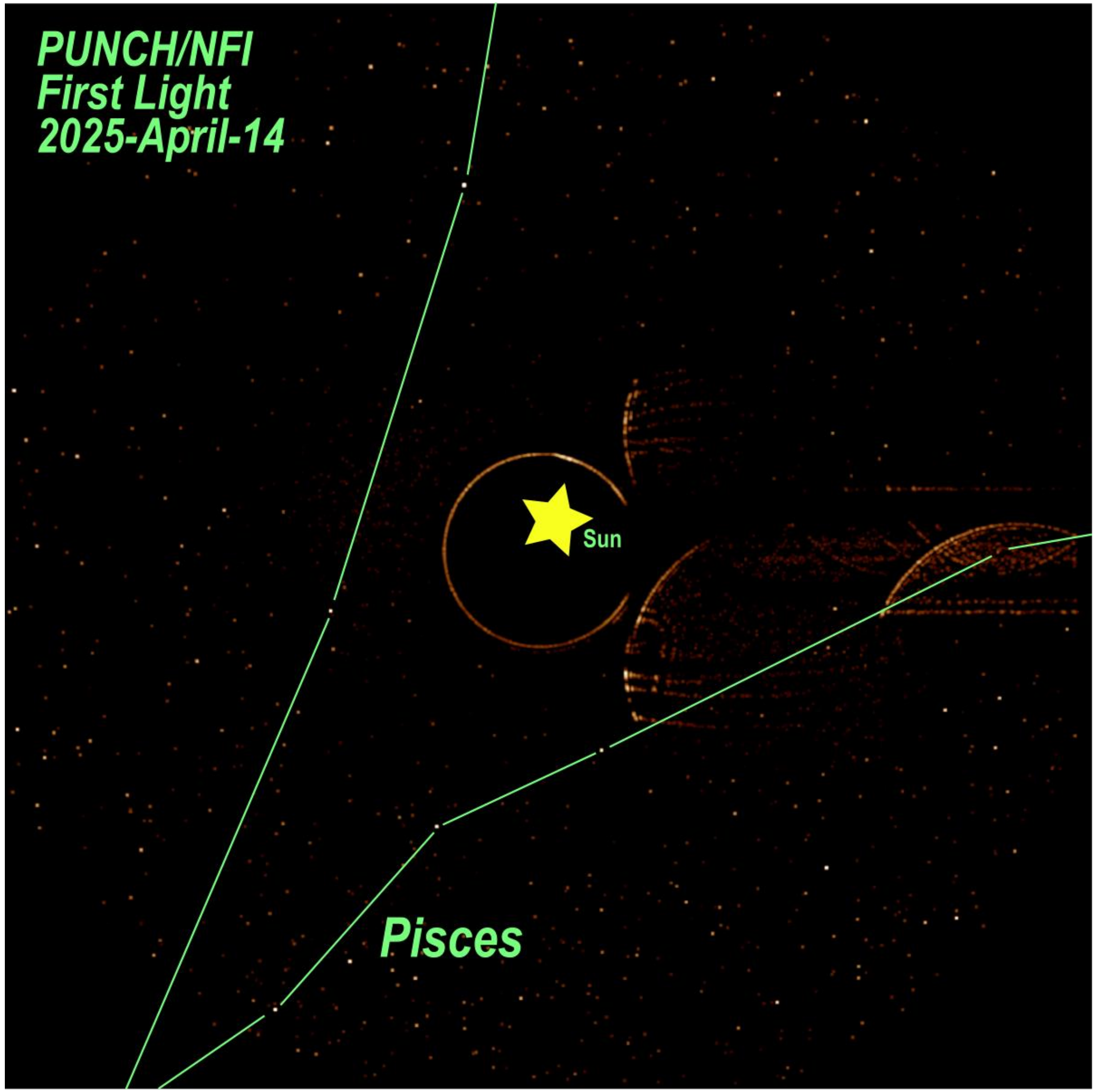
https://www.youtube.com/watch?v=BqBUQoPW0Aw&t=5342s

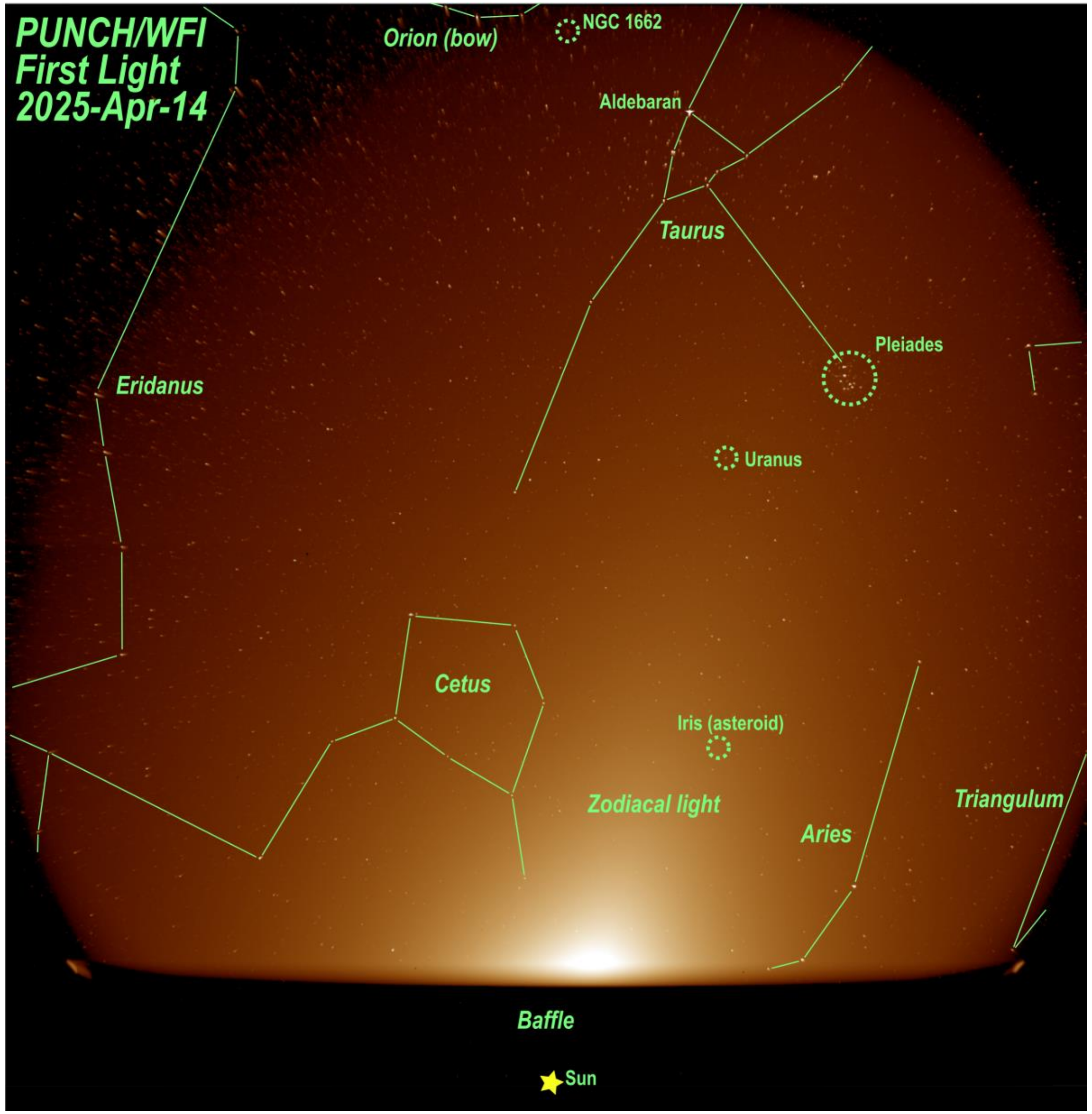


PUNCH Launched!

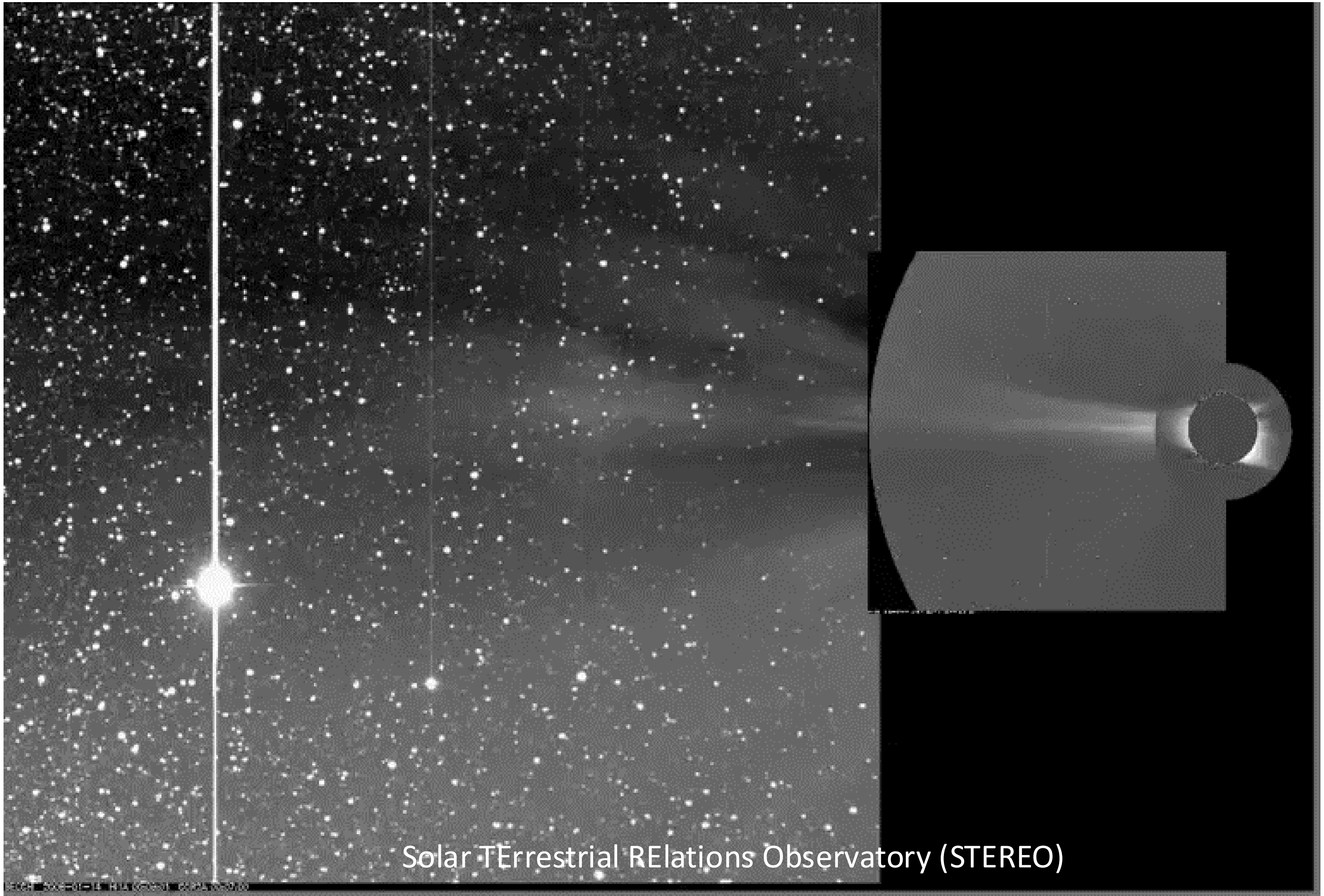
PUNCH launched successfully on March 11, 2025 from VSFB as a rideshare with SPHEREx
Coronagraph and heliospheric imagers measure electron density and speed in the corona and inner heliosphere (6 – 180 Solar radii).

PUNCH successfully completed spacecraft commissioning and opened its instrument doors to capture "first light"





PUNCH is the next-generation mission of imagers to image the Corona and Solar Wind Density (Thomson scattered white light)



WHAT IS THE PUNCH SMALL EXPLORER MISSION?

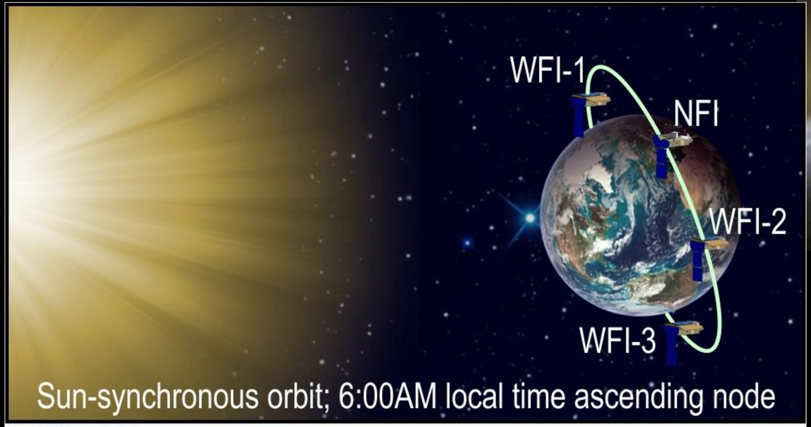
Scientific Driver: Understanding how the corona gives rise to the heliosphere and solar wind

Approach: direct, continuous, 3D imaging of the entire outer corona and inner heliosphere

Measurement: polarized images of Thomson-scattered light

Mission structure:

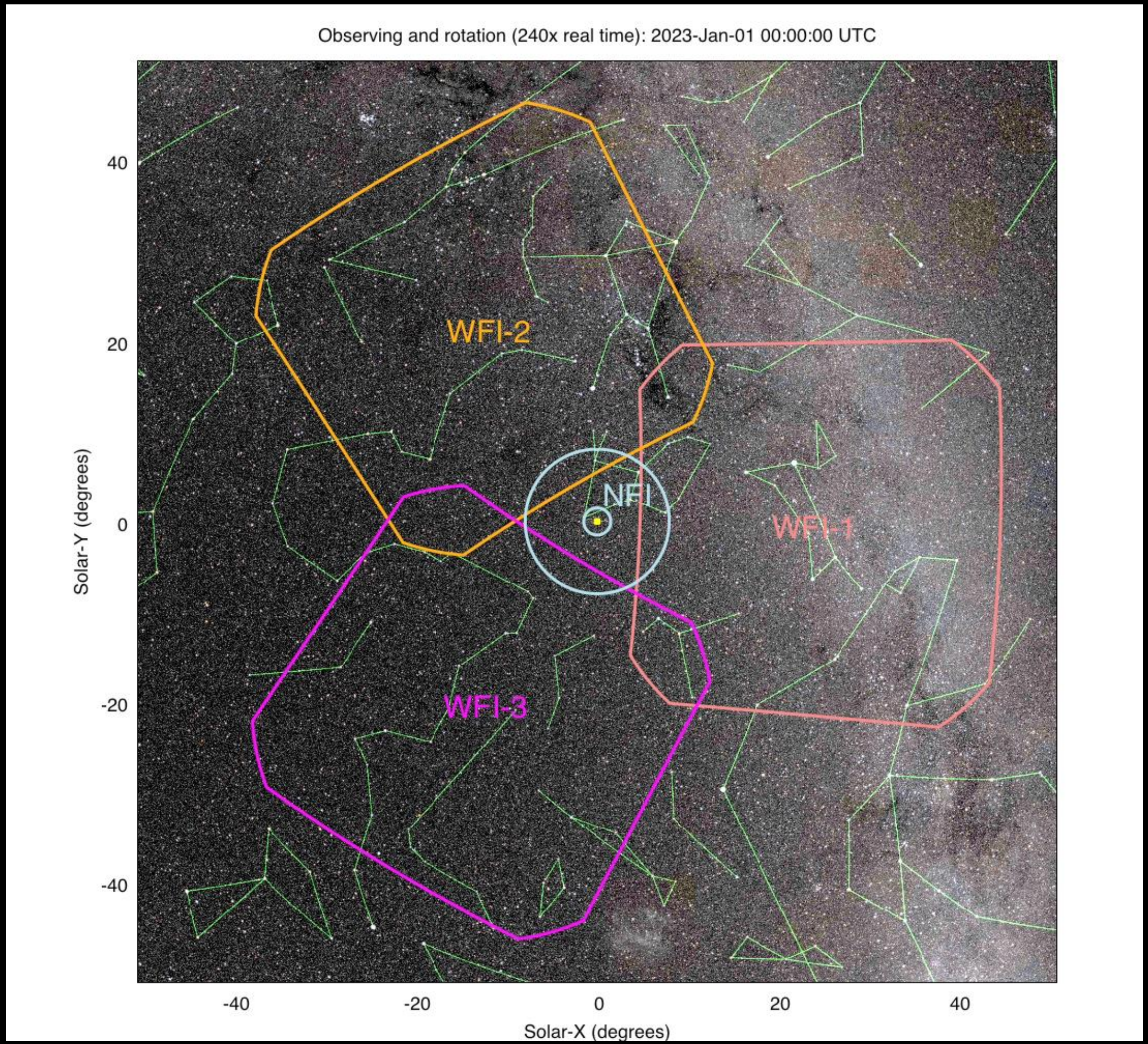
- four synchronous smallsats
- 620km sun-synch LEO
- two year duration

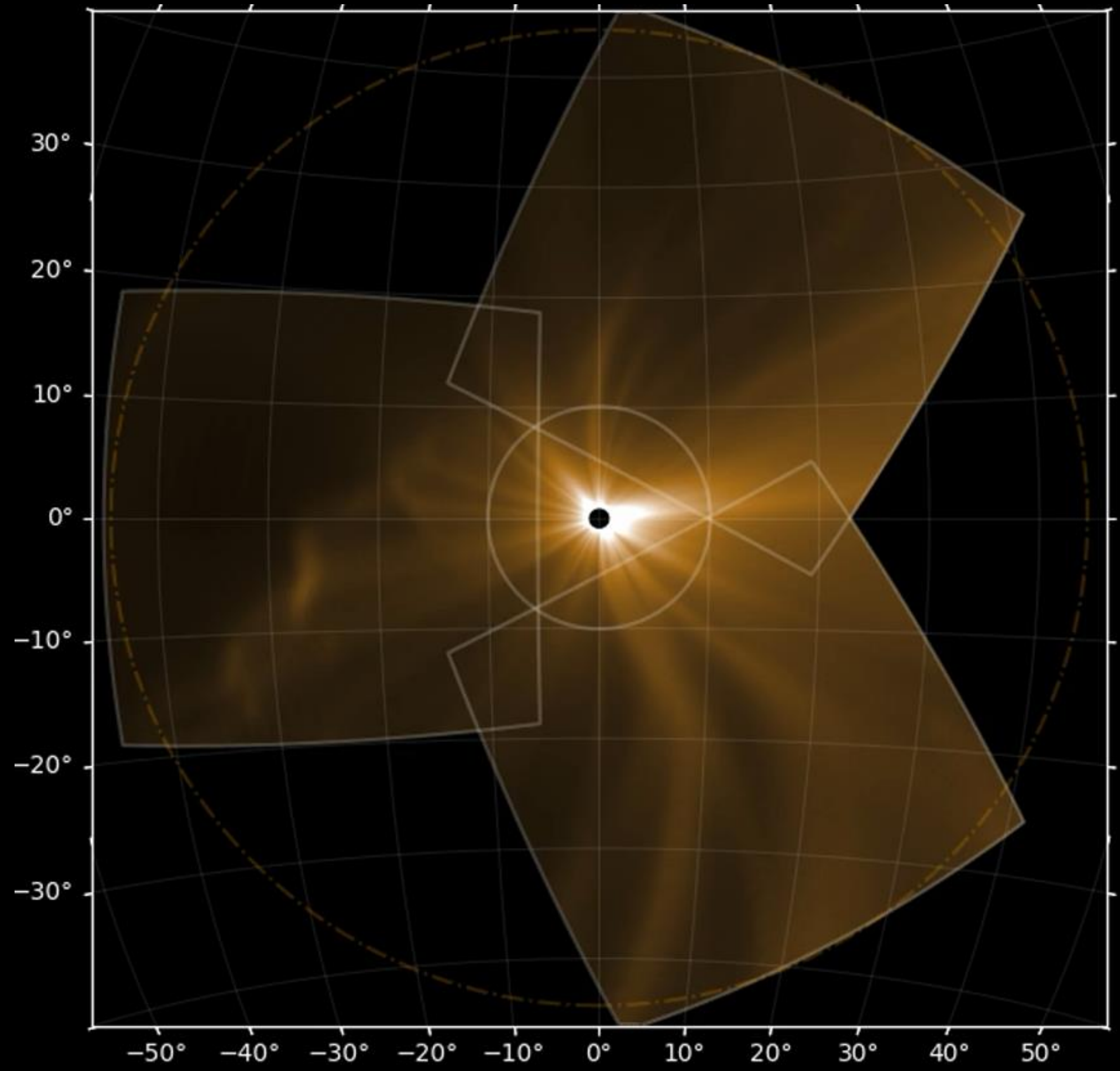


Sun-synchronous orbit; 6:00AM local time ascending node

TA009813-B-PUNCH

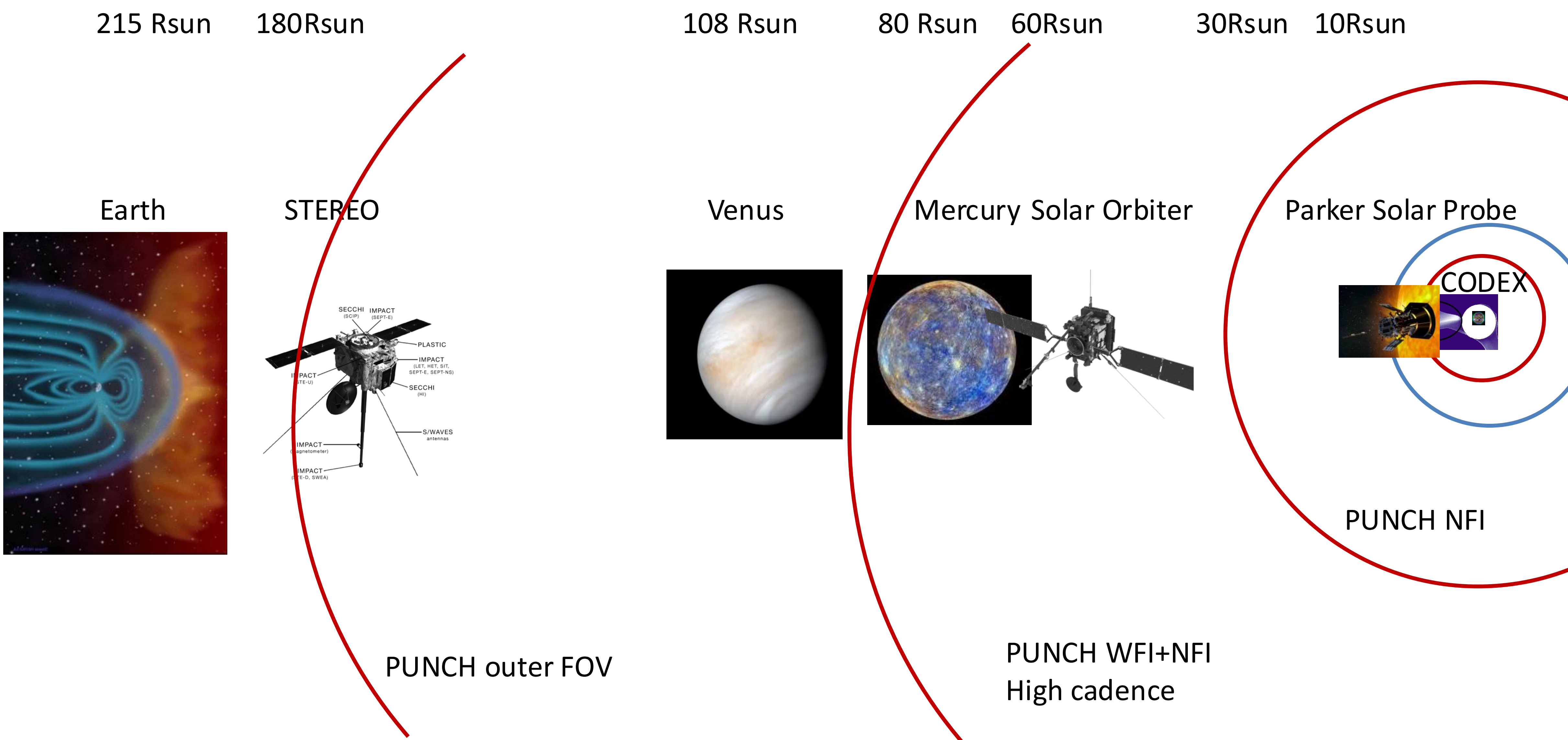
PUNCH: 4 spacecraft form a single "virtual instrument"





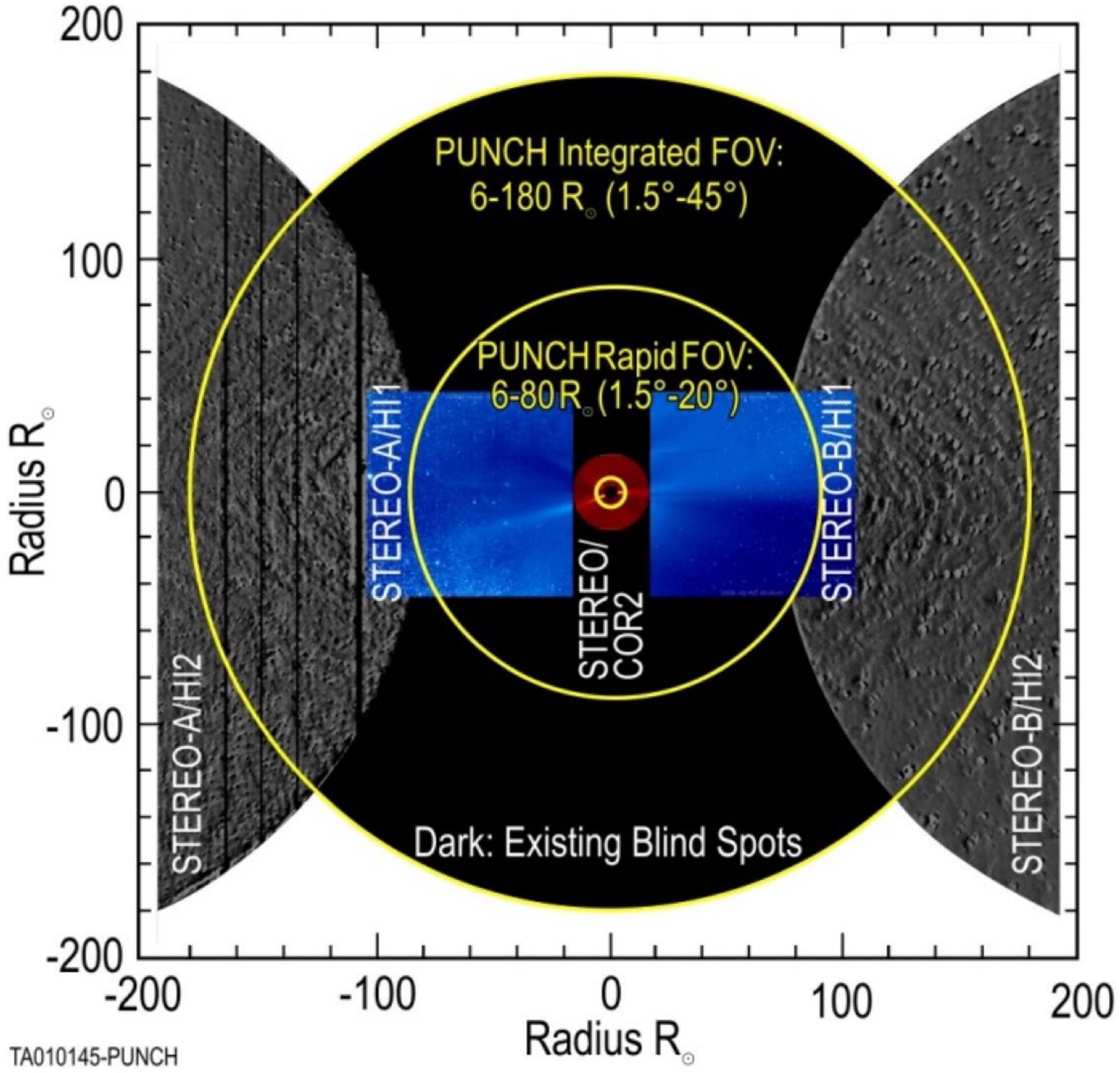
- Each flash: complete white light polarization sequence
- Green circle: 4-min cadence coverage inside ~80 solar radii
- CME tracking is analogous to hurricane tracking

PUNCH UNifies the Heliophysics Systems Observatory (and Decadal recommended ‘Integrated Heliosystems Laboratory’) by providing the global context of the inner Heliosphere, simultaneously resolving the mesoscales to reveal the physics of cross-scale coupling and evolution.



PUNCH's FOV fills this entire picture from the 2017 total solar eclipse from Oregon

PUNCH greatly extends remote sensing temporal/spatial resolution and coverage, and will measure in polarized light (3D localization) to answer PUNCH's objectives



Objective 1. Understand how coronal structures become the ambient solar wind.

1A – What is the global solar wind flow

1B – What is the source and evolution of mesoscale solar wind structure and turbulence

1C – Determine the Alfven Zone

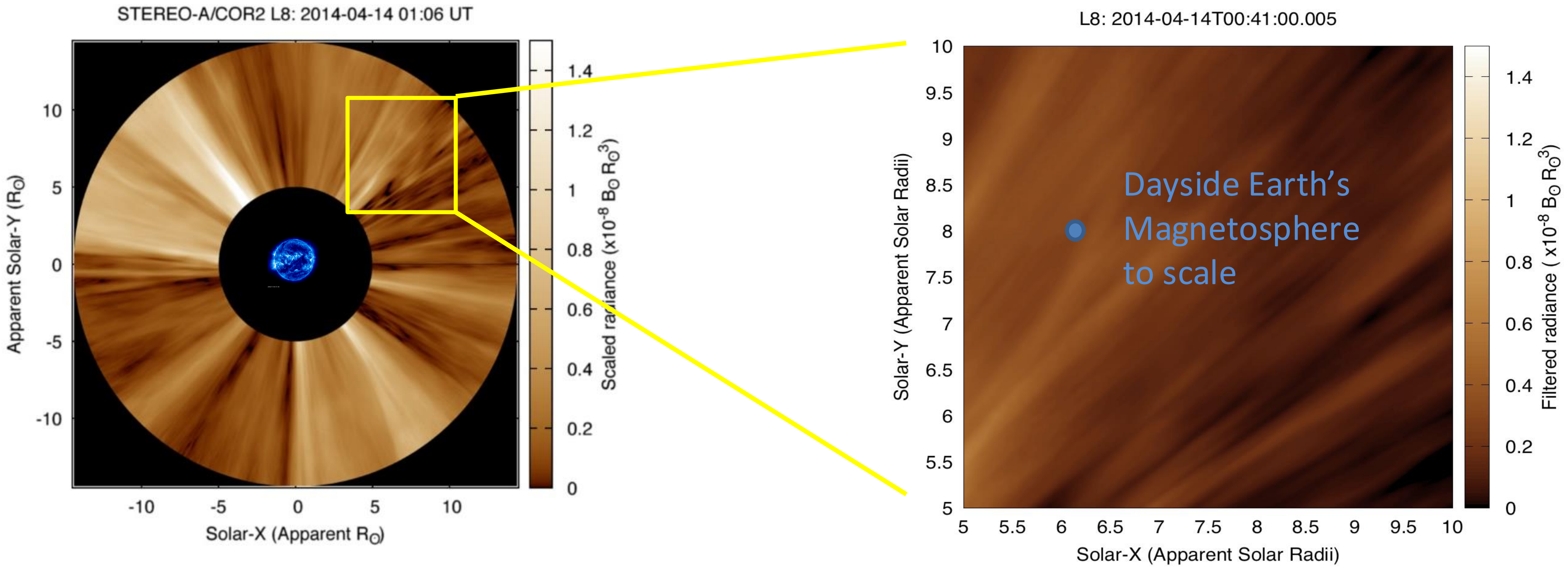
Objective 2. Understand the evolution of transient structures (such as CMEs) in the young solar wind.

2A – What is the 3D Structure, Evolution, and Trajectory of CMEs?

2B – What are the 3D Structure, Evolution, and Dynamics of SIRs?

2C – What are the 3D Structure and Dynamics of Shocks?

The Sun produces large space weather events, and highly structured solar wind that comprises the ground state of space weather



This STEREO Cor 2 deep field campaign (imaging electron density) shows solar wind filled with mesoscale structures at its formation. Physical understanding of mesoscale structure within the solar wind and larger space weather events is important for:

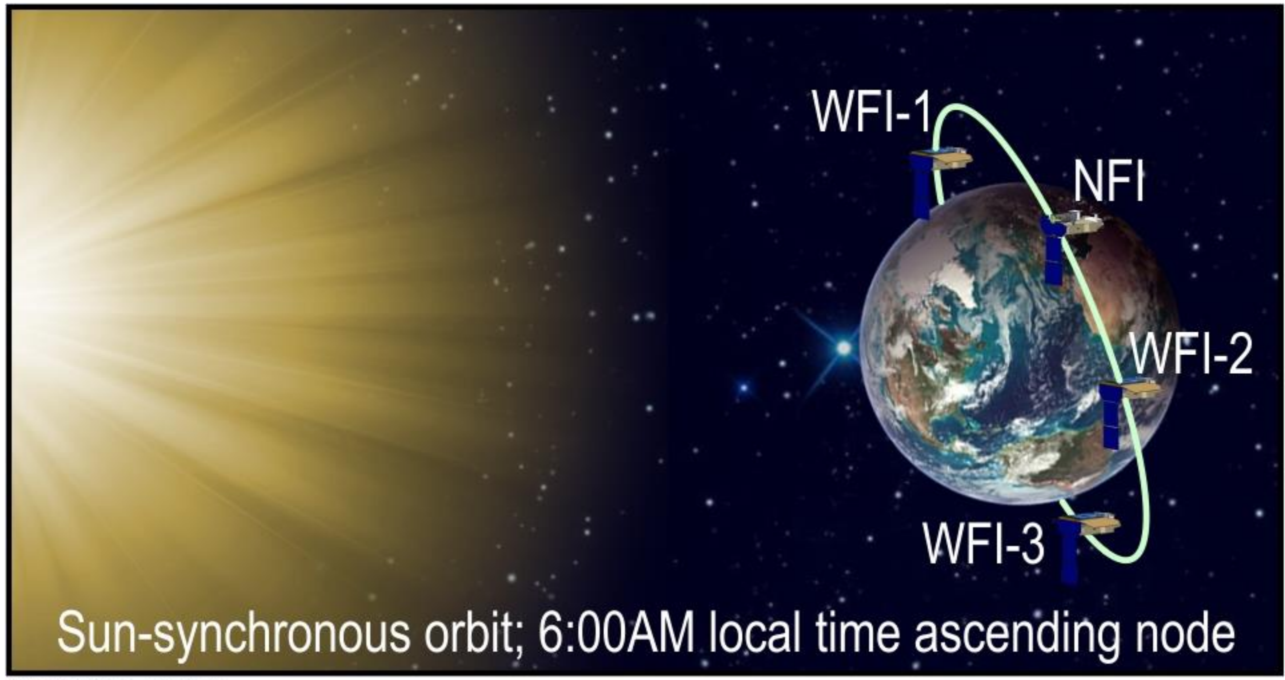
- Understanding how the Sun forms the solar wind and the heliosphere
- Providing critical insight into where and how kinetic energy becomes available to drive a turbulent cascade
- Understanding the ground state of space weather: the solar wind variability impacting Earth's magnetosphere and other inner planets on a daily basis. There are no quiet days on the Sun or in the Heliosphere.

Additional Science PUNCH Provides:

- Heliophysics: global context for all inner heliosphere missions, e.g. Parker Solar Probe and Solar Obiter; space weather via QuickPUNCH; geospace high altitude aurora to compare with EZIE and TRACERs.

-Astrophysics: most comprehensive polarimetric starmap to date; exoplanet hunting via lightcurves.

-Planetary physics: comet tail formation & evolution; solar system dust cycle & dust dynamics; vulcanoid searches.



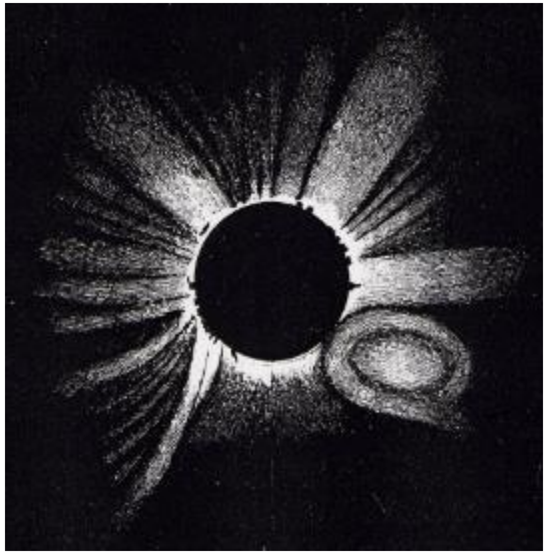
TA009813-B-PUNCH

PUNCH's Ancient and Modern Sun Watching outreach Theme:
Humanity has been 'sun watchers' for Millennia for survival. With modern technology and humanity's expansion into outer space (astronauts and spacecraft) Heliophysics is more important than ever! It is crucial that we study the Sun and its effects throughout the heliosphere.

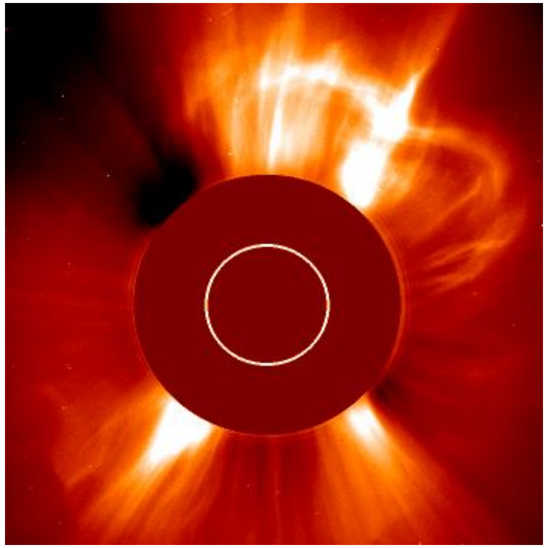
Human renderings of an active solar corona through time?: Ancient rock art, Hand drawing, and a NASA spacecraft image. PUNCH Outreach will leverage the connection among:

1) the Chacoan observation of the 1097 total solar eclipse at a time of high solar activity (solar maximum ~1098)
2) the opportunity modern people have to observe the total solar eclipses
3) the milestones and discoveries of NASA heliophysics missions

Ancestral Puebloan petroglyph in Chaco Canyon, interpreted to depict the **1097** total solar eclipse. Are the curlicues due to a CME*? Solar maximum~1098.



An **1860** drawing of a total solar eclipse from Spain (G. Tempel). Distortions of the striations were rendered in other drawings. A CME*?

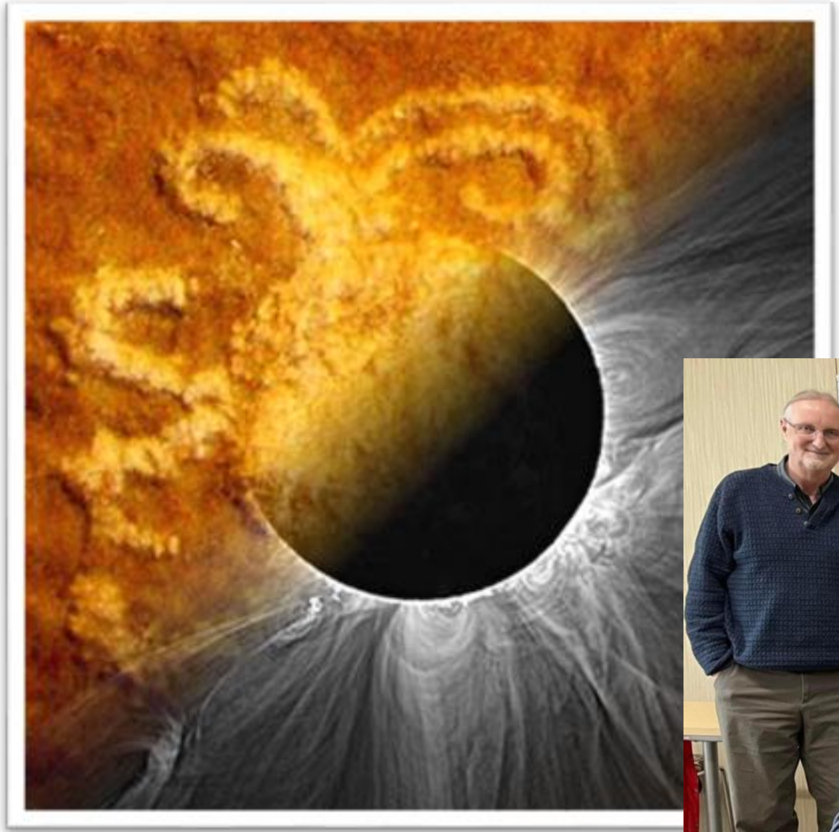


2005 coronagraph image from the NASA SOHO spacecraft with a CME* in progress. The white circle defines the solar disk.

cherilynn.morrow@gmail.com

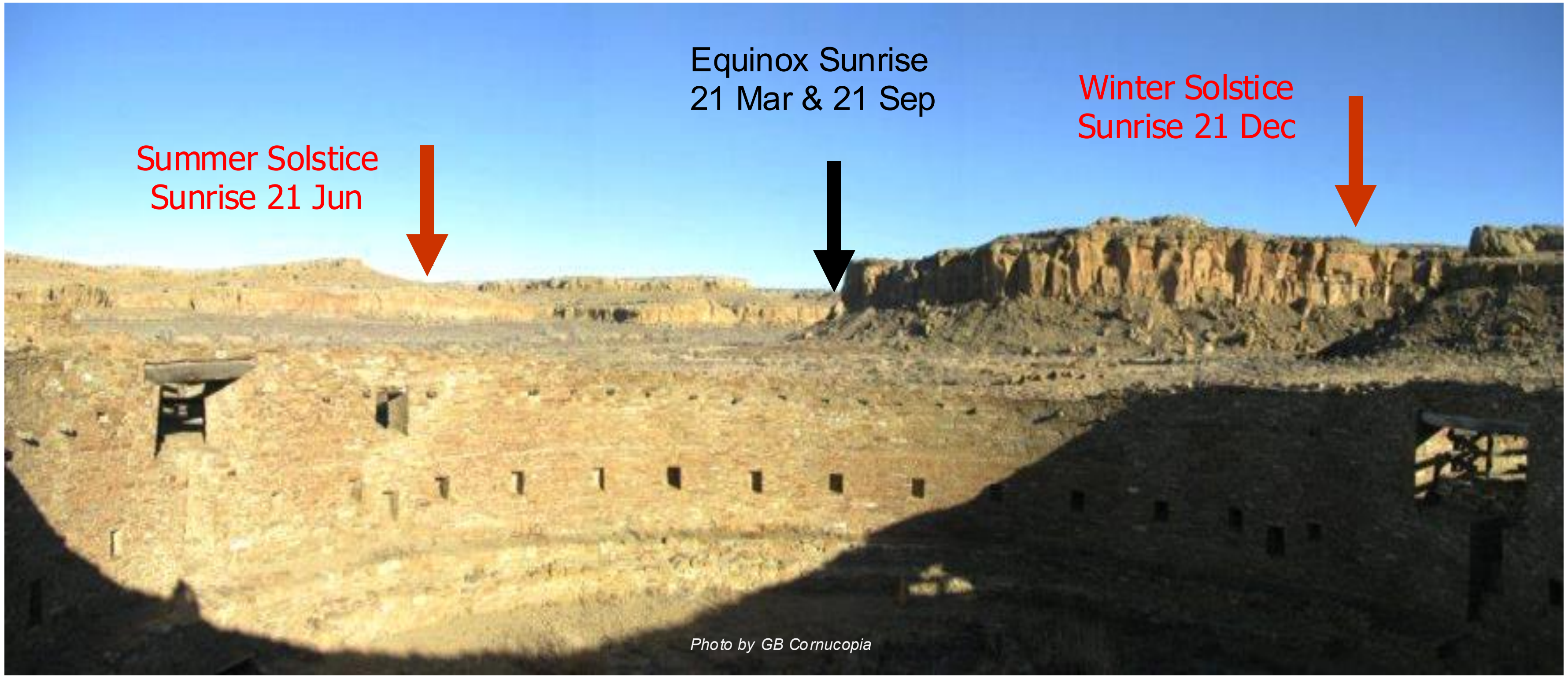
Dr. Cherilynn Morrow

PUNCH Outreach – Great for the public! Great for Girl Scouts!



Ancient & Modern Sun Watching Theme
Outreach icon for the [PUNCH Website]

Chaco Canyon is a focal point for the PUNCH Outreach *Ancient & Modern Sun-Watching* Theme



Where would the Sun rise on your birthday?

Sunrise photos taken looking over
Patapsco State Park, Maryland

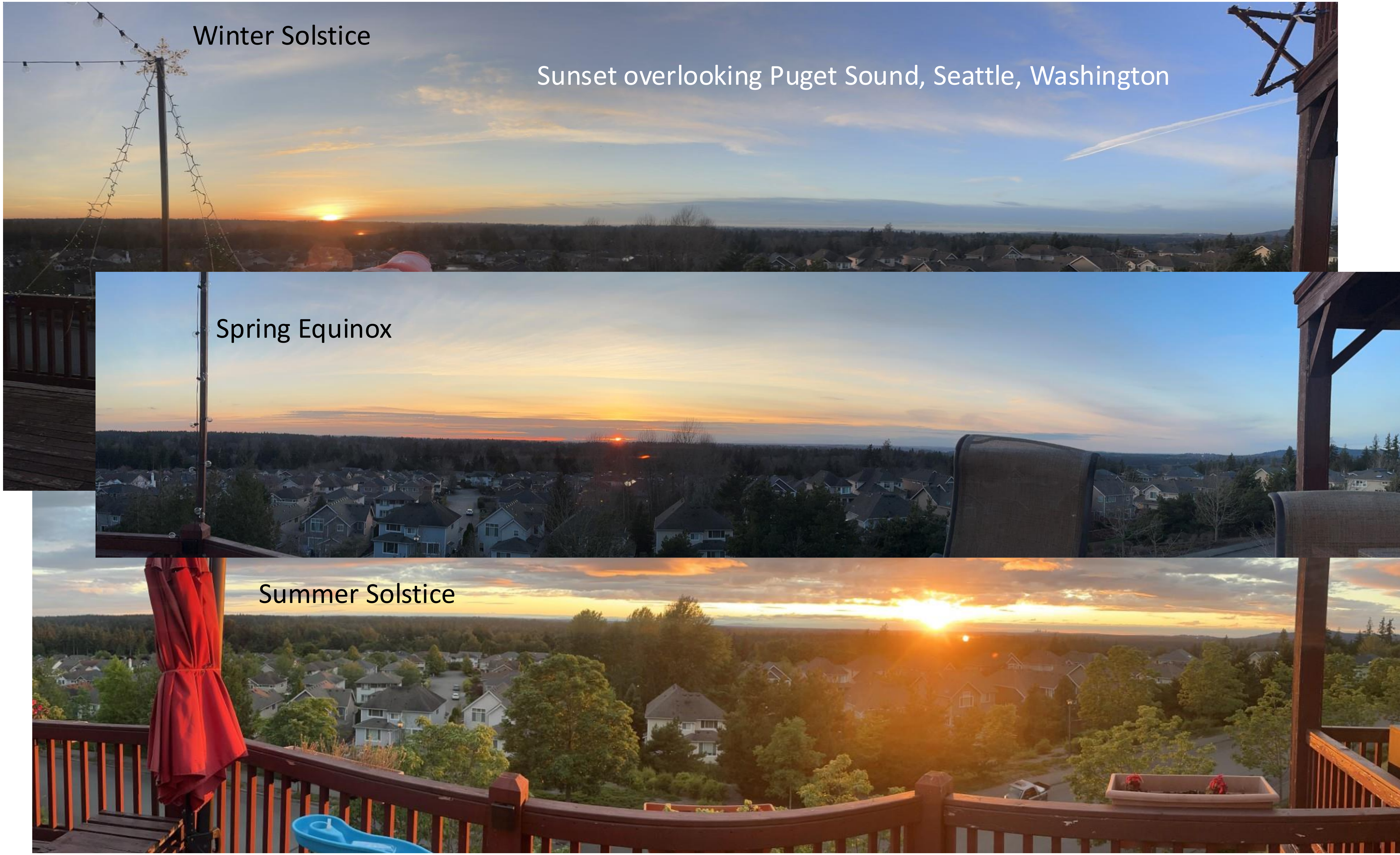
Winter Solstice

Spring Equinox

Summer Solstice

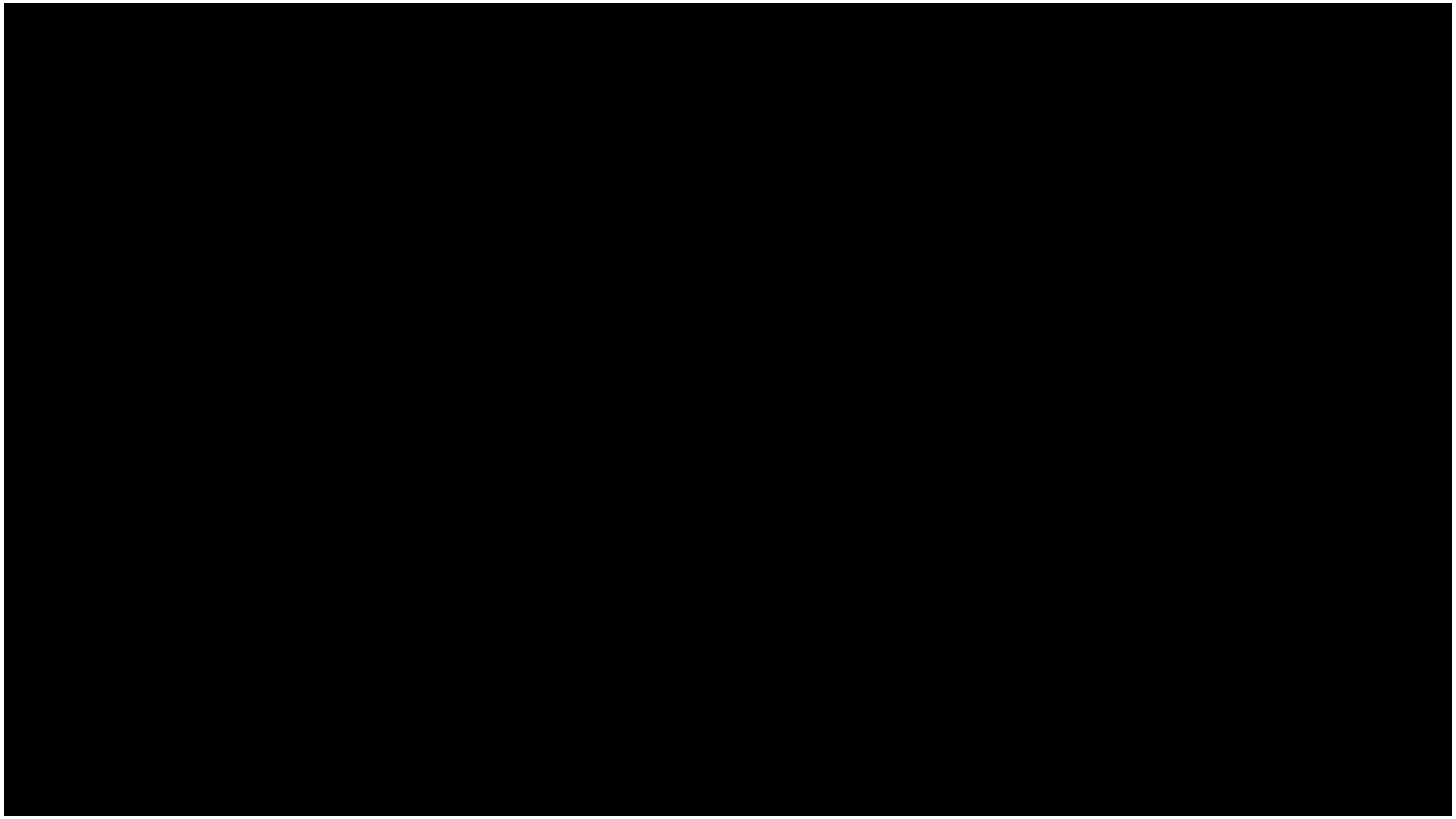
Fall Equinox

Winter Solstice


Winter Solstice
Sunset overlooking Puget Sound, Seattle, Washington
Spring Equinox
Summer Solstice

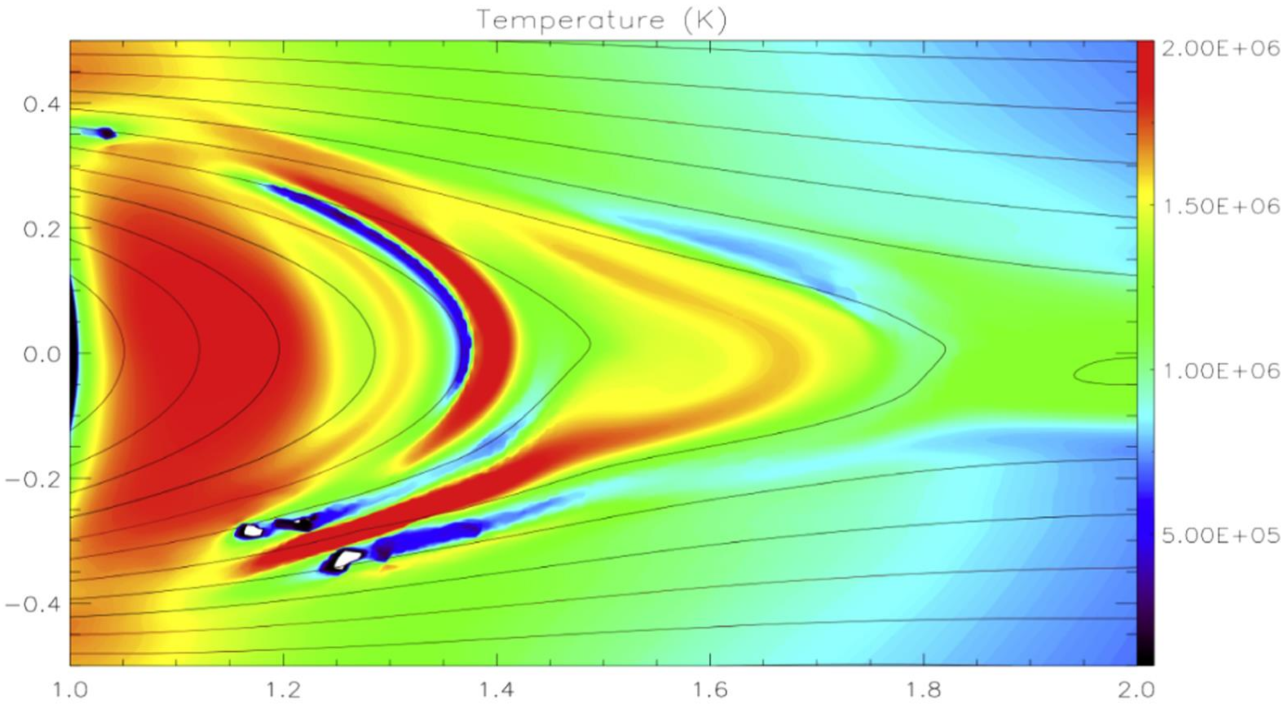
CODEX

- The COronal Diagnostic EXperiment (CODEX) is a coronagraph which will fly on the International Space Station this fall.
- CODEX is developed by NASA’s Goddard Space Flight Center (GSFC) and the Korea Astronomy and Space Science Institute (KASI).
- Imaging coronagraph observes polarized brightness images using 10 nm bandpass filters at 393.5, 405.0, 398.7 and 423.4 nm, and a broadband filter (380-430 nm).



CODEX launched November 4, 2024.
Coronagraph measures the electron density, temperature, and speed in the corona (~2.5 – 10 Solar radii).

When coronal loop plasma is released into the solar wind, how much hotter are those solar wind structures compared to the open-field wind? How much energization is from the reconnection itself?



Schlenker, Antiochos, MacNeice, Mason, 2021

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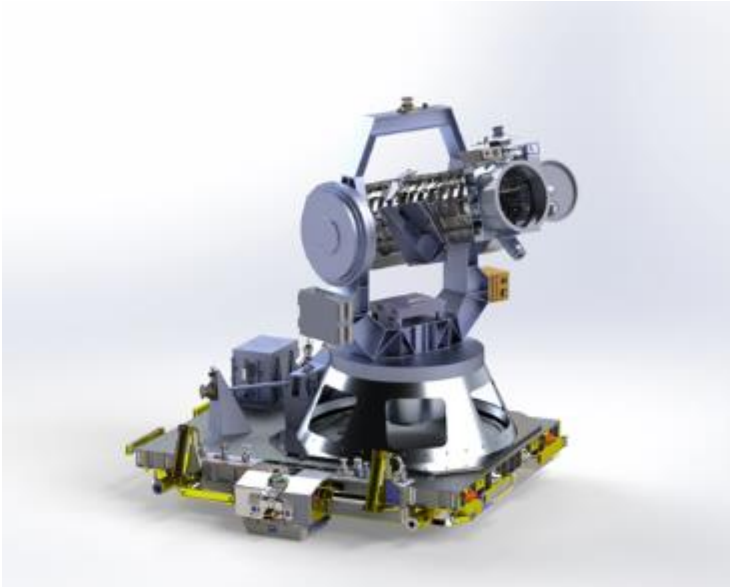
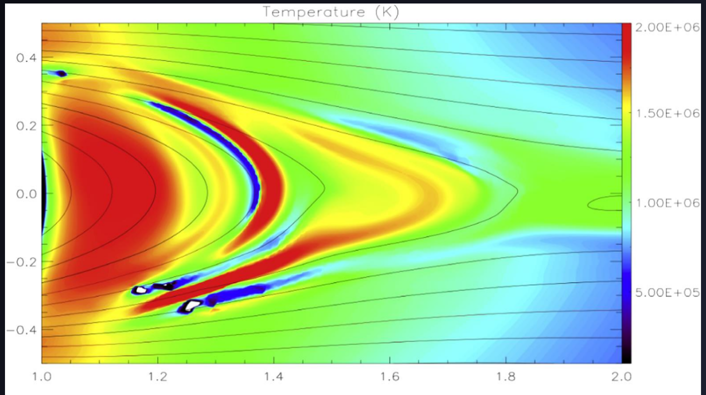


National Aeronautics and Space Administration

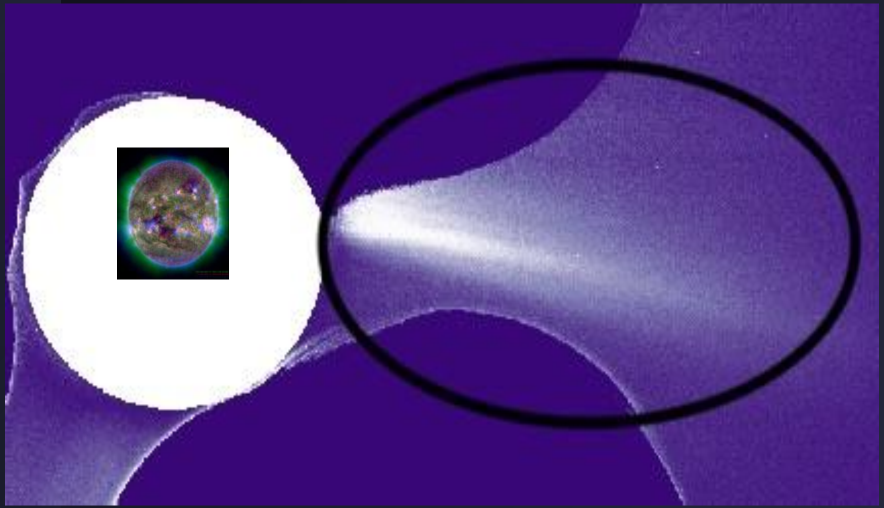
CODEX

Exploring the solar wind acceleration region…

- NASA's CODEX observes the Sun's outer atmosphere, the corona, to test fundamental theories of solar wind formation and provide crucial constraints on predictive models of the solar wind.
- CODEX is an imaging solar coronagraph that produces images of the coronal electron temperature and radial speed as it transitions to solar wind.
- CODEX will determine 1) the low coronal source of different types of solar wind streams 2) how much solar wind plasma is released through magnetic reconnection of closed magnetic fields, and 3) the amount of energization and acceleration of the plasma as a function of height through the middle and upper corona.
- Operating on the International Space Station since November 2024.



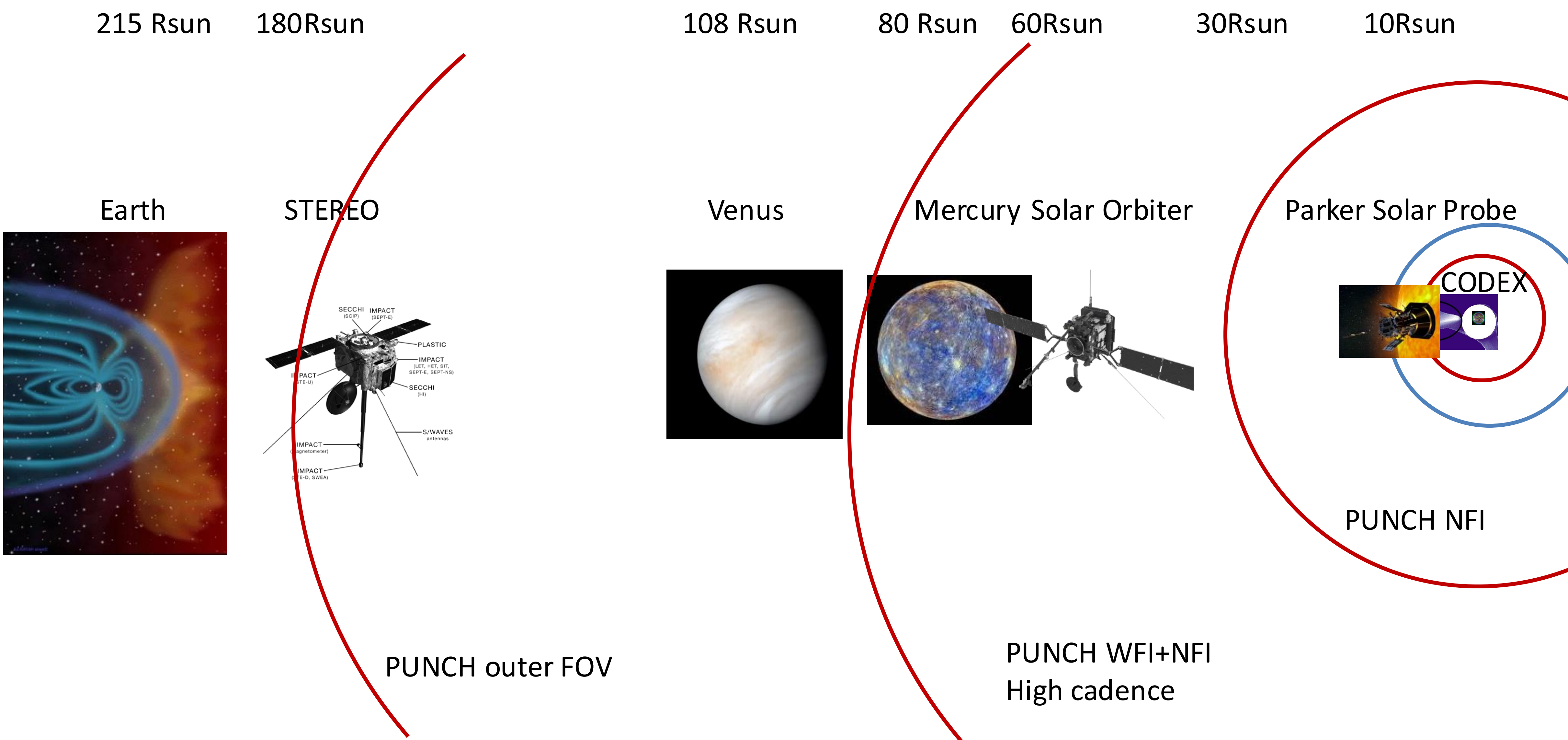
Schlenker et al. 2021 coronal simulation predicts CODEX will see 4x temperature variations



NASA's CODEX Partnerships

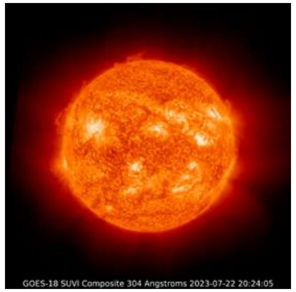
- Partnership with KASI, KASA, and INAF
- Innovative, "high contrast" coronagraph

PUNCH UNifies the Heliophysics Systems Observatory (and Decadal recommended 'Integrated Heliosystems Laboratory') by providing the global context of the inner Heliosphere, simultaneously resolving the mesoscales to reveal the physics of cross-scale coupling and evolution.

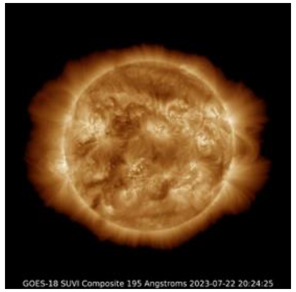


JEDI Overview

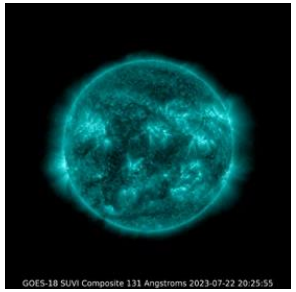
SWOC (Space Weather Operational Coronal Imager)
(3 Channels - Full disk images out to 3 $R_\odot$)



He II/Fe XVI 30.4/33.5 nm
8×10^4/6×10^6 K



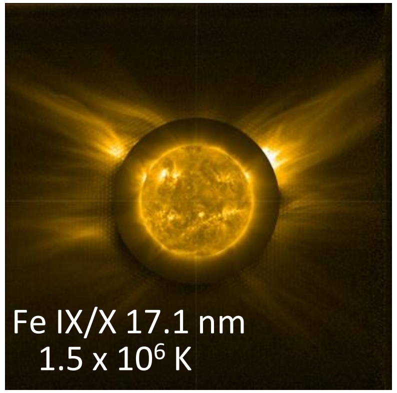
Fe XII 19.5 nm
1.5×10^6 K

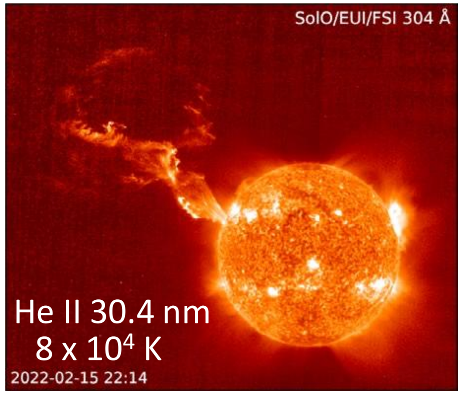


Fe VIII/XX 13.3 nm
1×10^6/1×10^7 K

SWOC is based on Solar Orbiter EUI/HRI & PROBA-2/SWAP heritage demonstrating high resolution EUV disk imaging in multiple passbands.

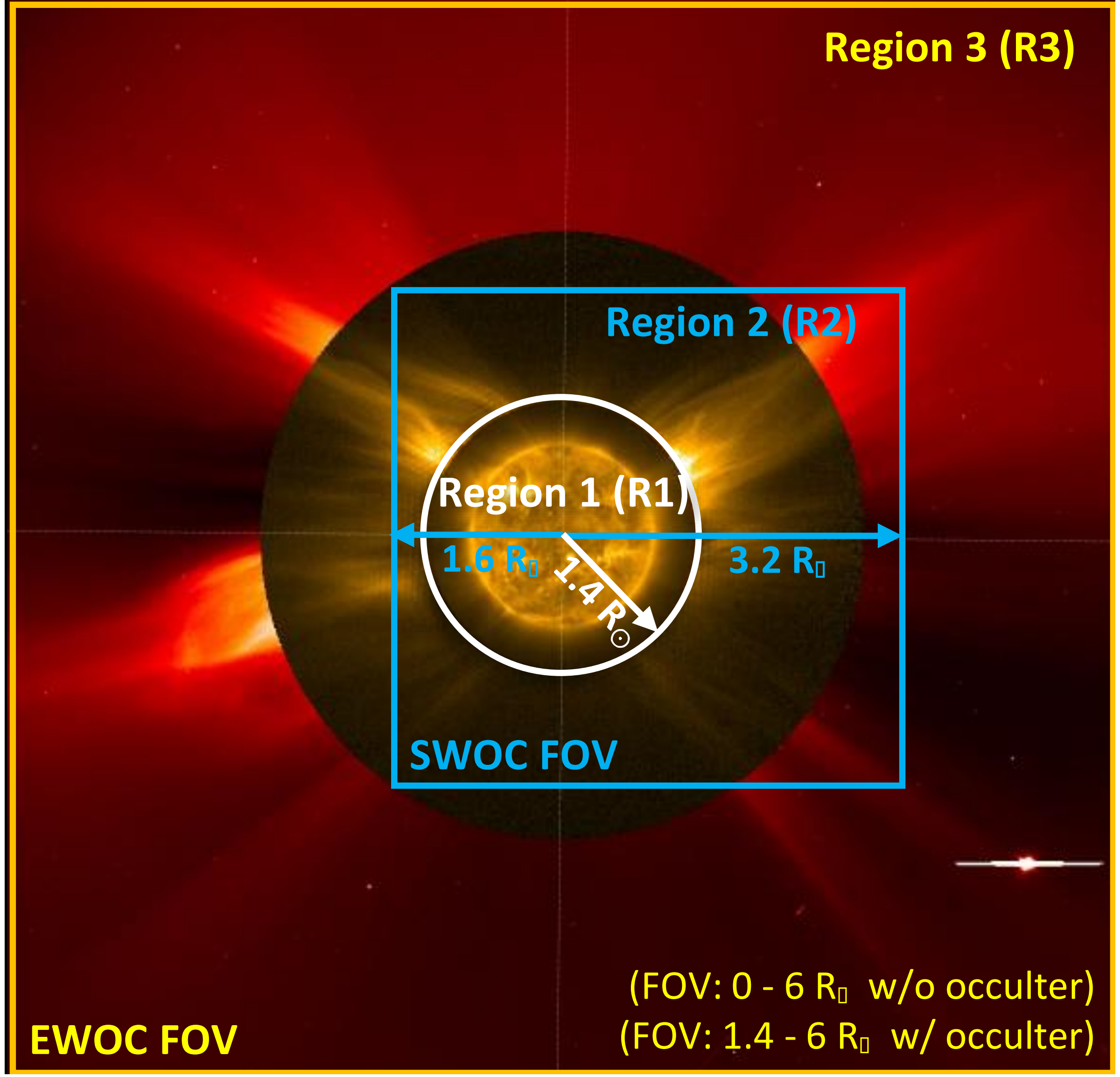
EWOC (Enhanced Wide-angle Observations of the Corona)
(2 Channels – Full disk & Occulted coronal images out to 6 $R_\odot$)





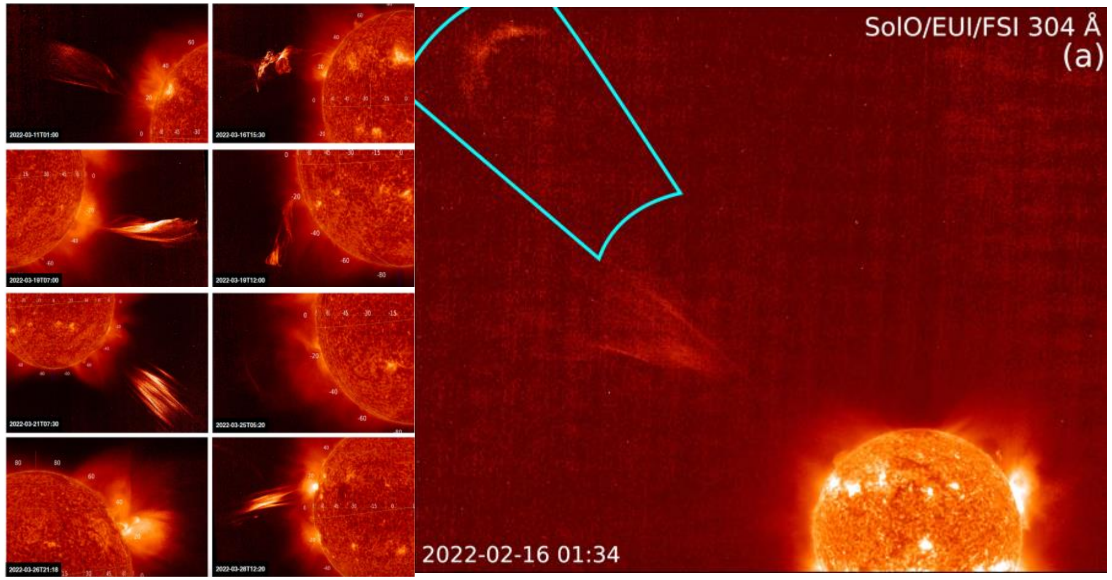
EWOC is based on Solar Orbiter EUI/FSI heritage demonstrating solar wind structures such as coronal streamers, CMEs and other dynamic activity is visible in EUV through the middle corona out to 6 solar radii.

JEDI Instrument Fields-of-View

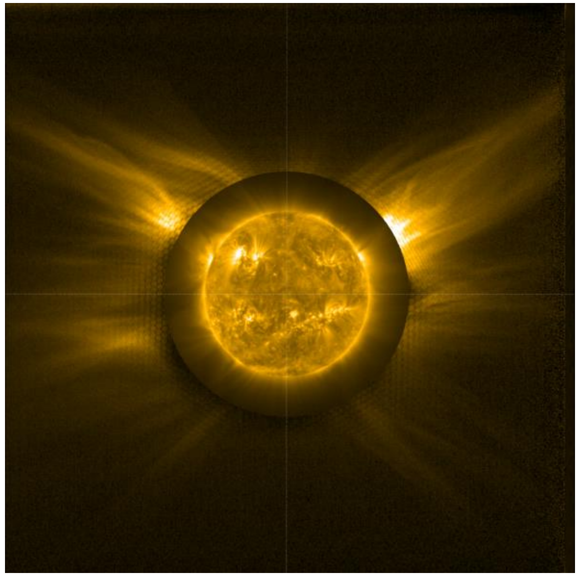


The ground state of space weather

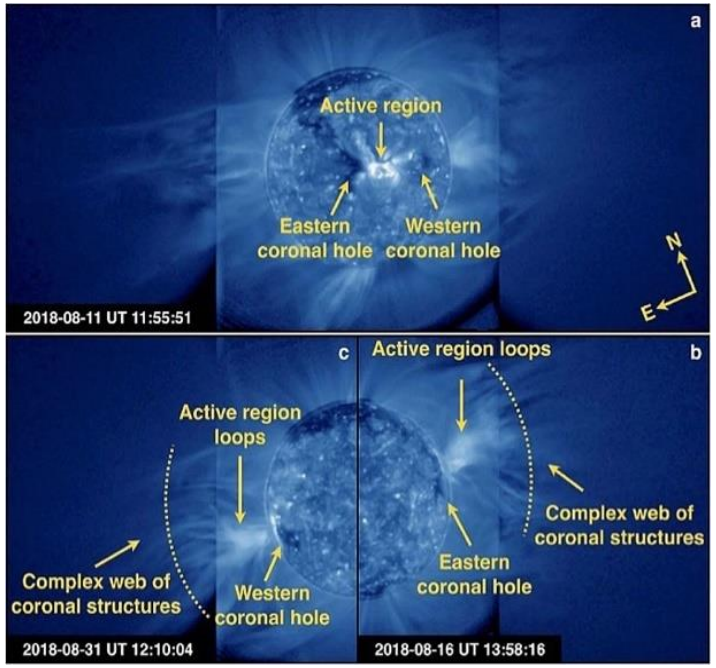
From L5, JEDI will capture all Earth-directed space weather events, from the large space weather i.e. coronal mass ejections (CME), proto-stream interaction regions (SIR), and flares, through the ground state of space weather, i.e. solar wind structures.



SoLO EUI 30.4 nm images capture a prominence eruption low in the corona and high above the limb, demonstrating the importance of measuring CMEs and prominences through the Middle Corona for determining their structure, dynamics, implied magnetic field, and trajectory.



SoLO EUI 17.1 nm images show that the combination of full disk and extended coronal fields of view link low coronal structure with streamer morphology



(Chitta et al. 2023) shows a reconnection event at an S-web corridor in EUV releasing solar wind structures.

JEDI'S FOV, SPATIAL RESOLUTION, TEMPERATURE COVERAGE, AND MEASUREMENT CADENCE WILL MAKE OBSERVATIONS THROUGH THE MIDDLE CORONA STANDARD AND ROUTINE AND WILL TACKLE: HOW MUCH OF THE CLOSED CORONA IS INVOLVED IN MAKING SOLAR WIND STRUCTURES?

Upcoming missions will image the formation and evolution of the ground state of space weather and the large space weather events, coupling the mesoscale with the global context.