Connecting the Middle Corona

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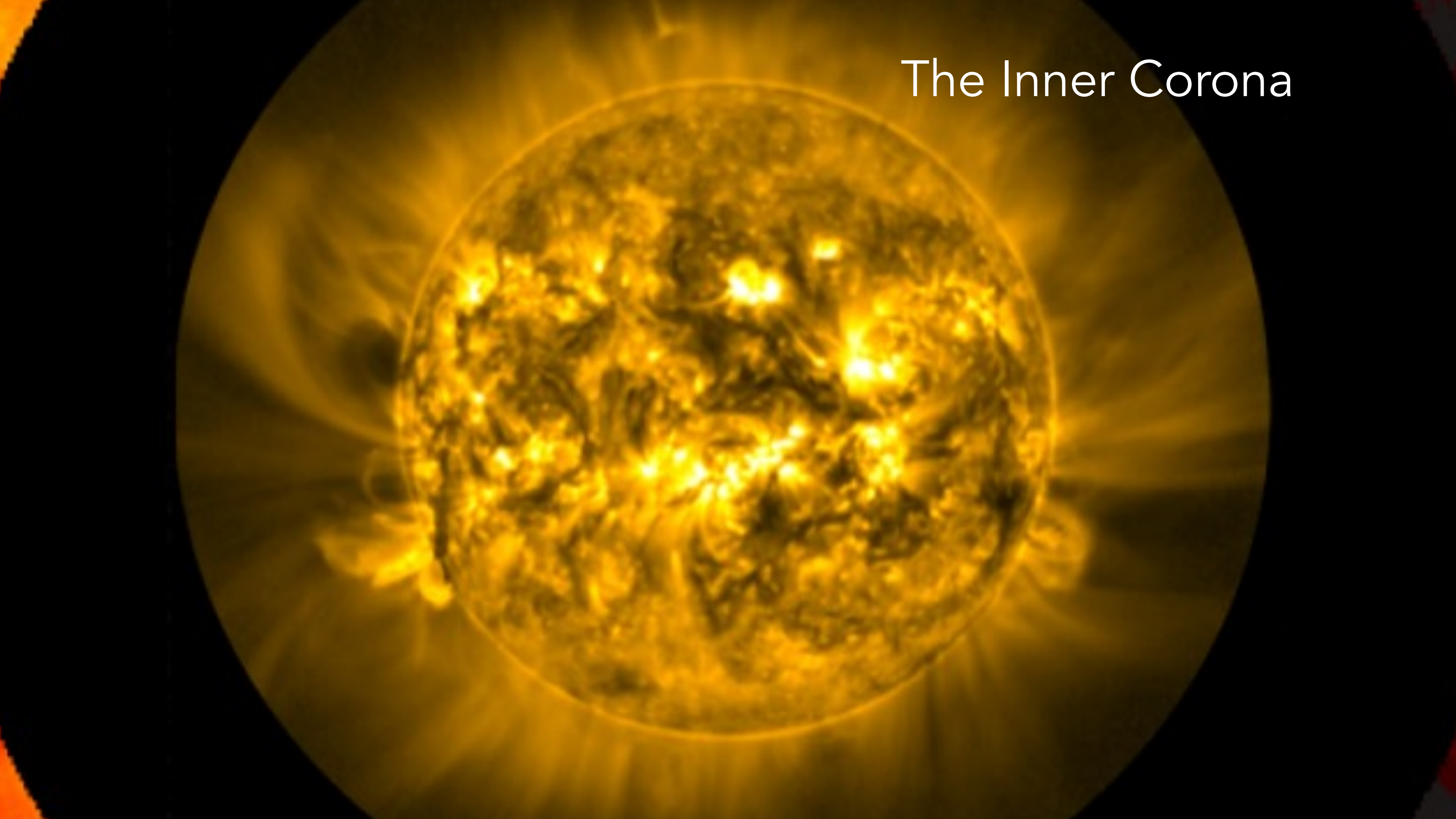
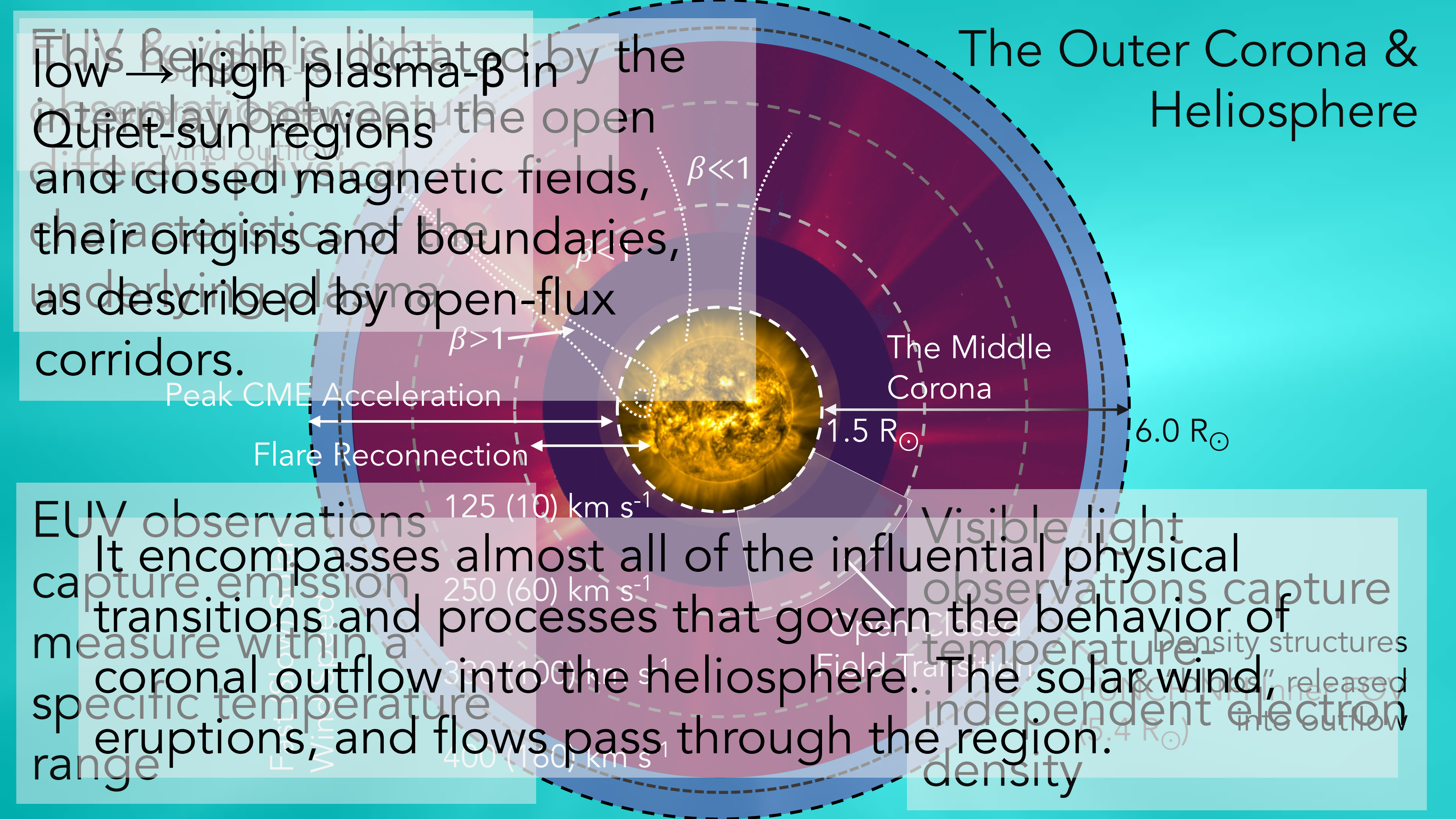
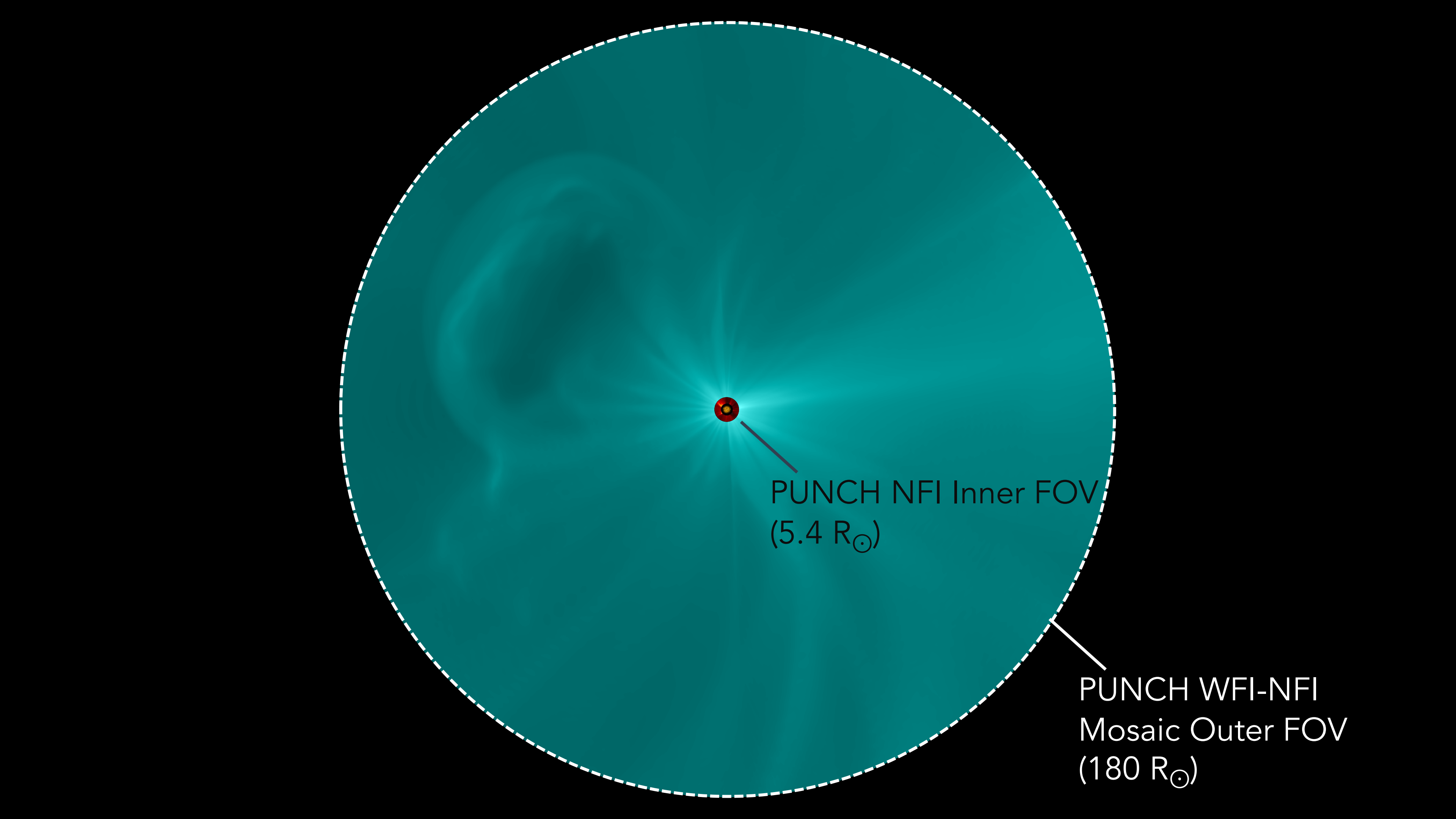
What & Where is the Middle Corona?

The Inner Corona





The Outer Corona & Heliosphere
This height is dictated by the
interplay between the open
low → high plasma-β in
Quiet-sun regions
and closed magnetic fields,
their origins and boundaries,
as described by open-flux
corridors.
EUV & visible light
observations capture
different physical
characteristics of the
underlying plasma
wind outflow
β≪1
β<1
β>1
The Middle
Corona
1.5 R⊙
6.0 R⊙
Peak CME Acceleration
Flare Reconnection
125 (10) km s-1
250 (60) km s-1
320 (100) km s-1
400 (160) km s-1
Open-Closed
Field Transition
Density structures
released
into outflow
(5.4 R⊙)
EUV observations
capture emission
measure within a
specific temperature
range
Visible light
observations capture
temperature-
independent electron
density
It encompasses almost all of the influential physical
transitions and processes that govern the behavior of
coronal outflow into the heliosphere. The solar wind,
eruptions, and flows pass through the region.


PUNCH NFI Inner FOV
(5.4 R⊙)
PUNCH WFI-NFI
Mosaic Outer FOV
(180 R⊙)

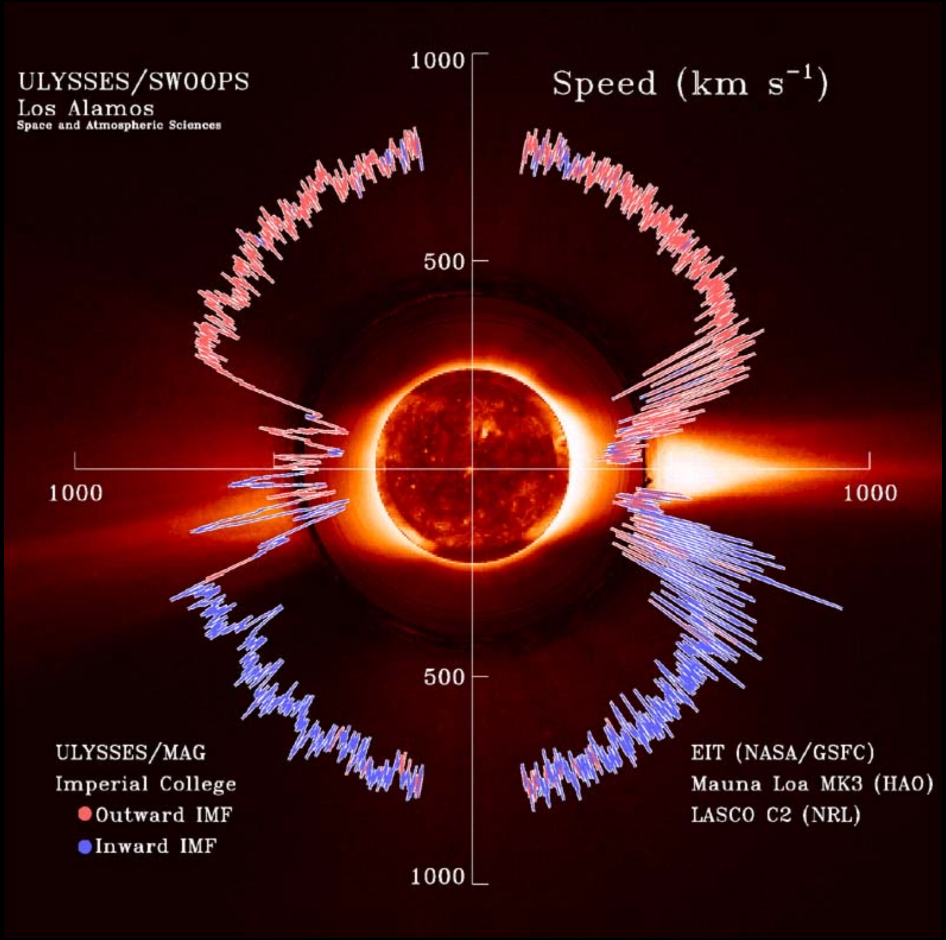
Why is the region important for PUNCH?

Fast and slow solar wind

Originally thought to originate beyond 10 $R_\odot$, now closer.

Fast wind
- Interiors of (polar) coronal holes
- Speed > 500 km s^{-1}
- Less variable
- Photospheric compositions

Slow wind
- Associated with (ecliptic) streamer belt
- Speed generally < 500 km s^{-1}
- More variable and structured
- Coronal compositions
- *What's the source?*



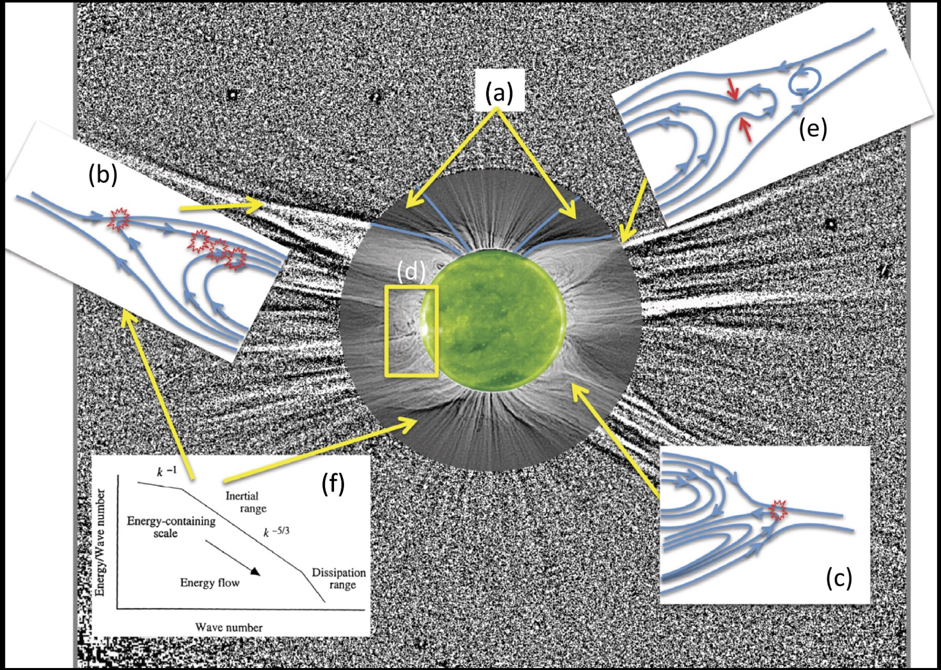
McComas et al. (1998), GRL, 25, 1

(Multiple) Sources of slow solar wind

Super-radial expansion of open fields adjacent to helmet streamers

Interchange reconnection in helmet streamers

MHD wave turbulence along open fields



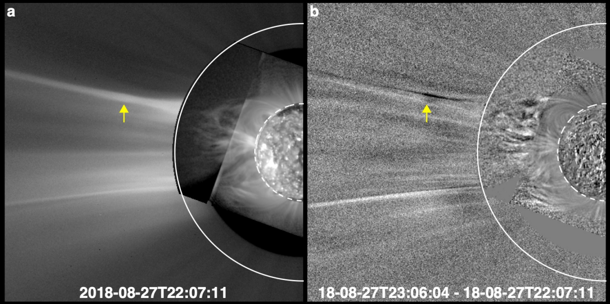
Closed loop reconnection

Interchange reconnection in pseudo-streamers

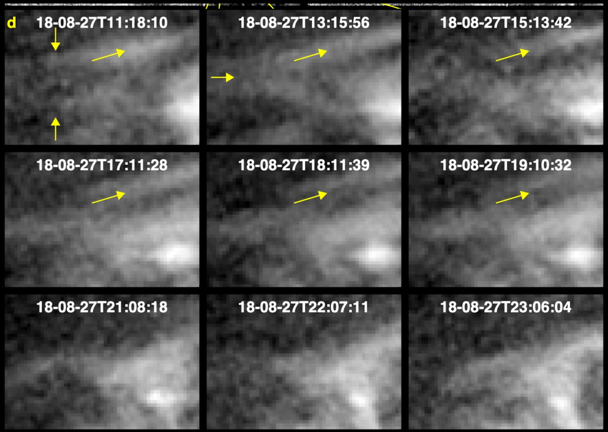
Abbo et al. (2016), SSR, 201, 55 - Wang et al. (2007), ApJ, 660, 882. (Courtesy P. Chitta)

Persistent emergence of solar wind streams

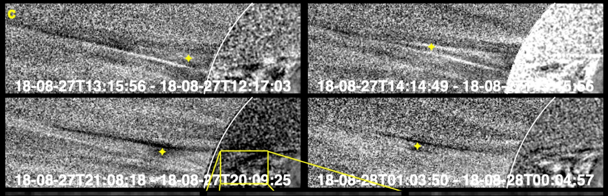
Chitta et al. (2022) studied the persistent emergence of slow solar wind streams over the coronal web throughout the inner and middle corona regions using SUVI and LASCO observations.



Connection through the inner, middle & extended solar corona (arrow points to a solar wind stream).

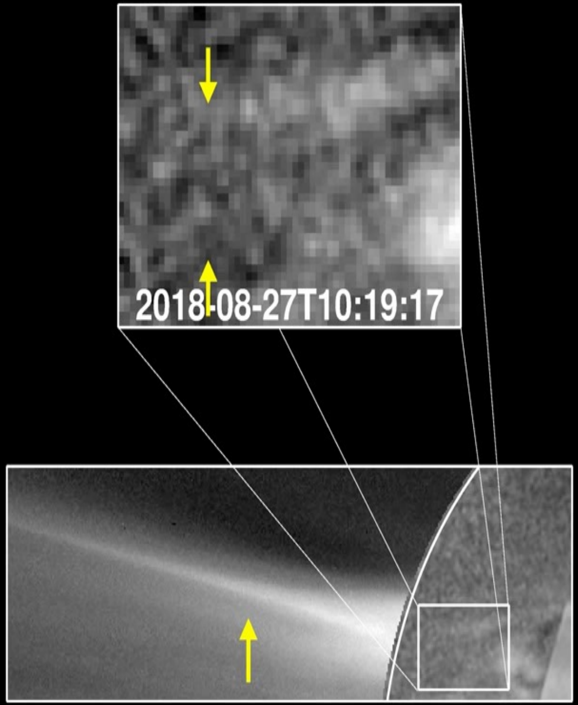


Interacting & reconnecting middle-coronal structures underlying the solar wind streams.



Solar wind streams emerging from the middle corona.

Persistent emergence of solar wind streams



Chitta et al. (2022)

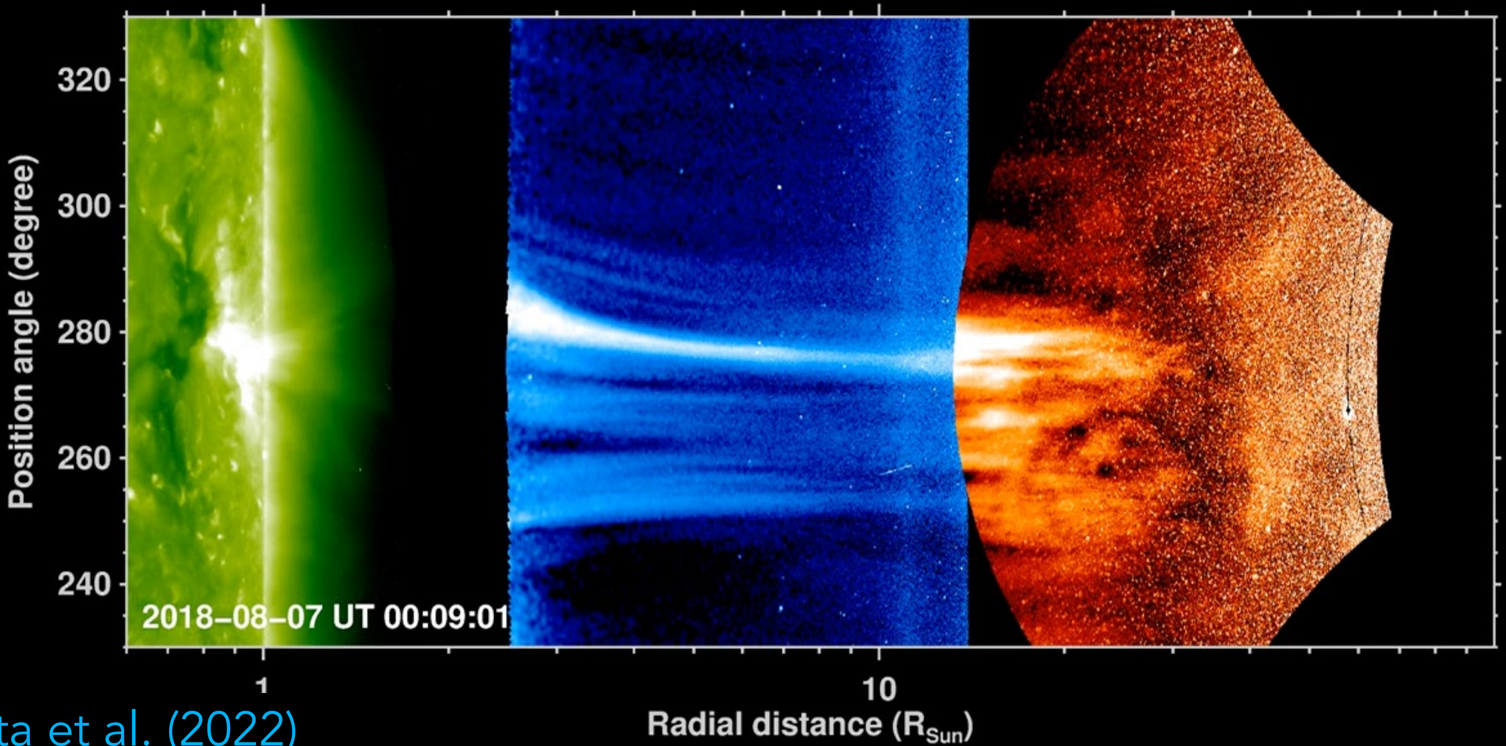
One such example zooming into this region.

The movie shows plasma jets escaping the Sun.

Chitta et al found that these jets emerged in the middle corona when a pair of coronal web structures interact and reconnect.

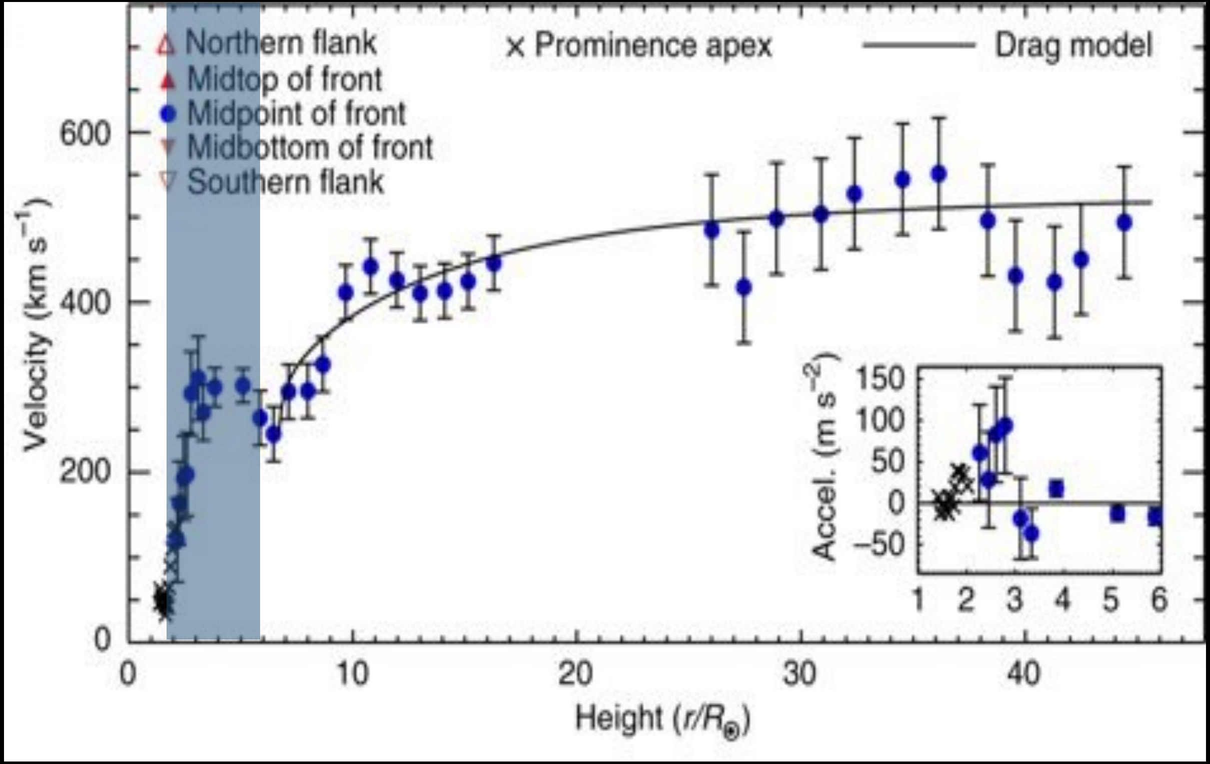
This process is continuous.

Heliospheric Connections: Dynamic evolution of the coronal web extended into the inner heliosphere



Chitta et al. (2022)

CME Acceleration



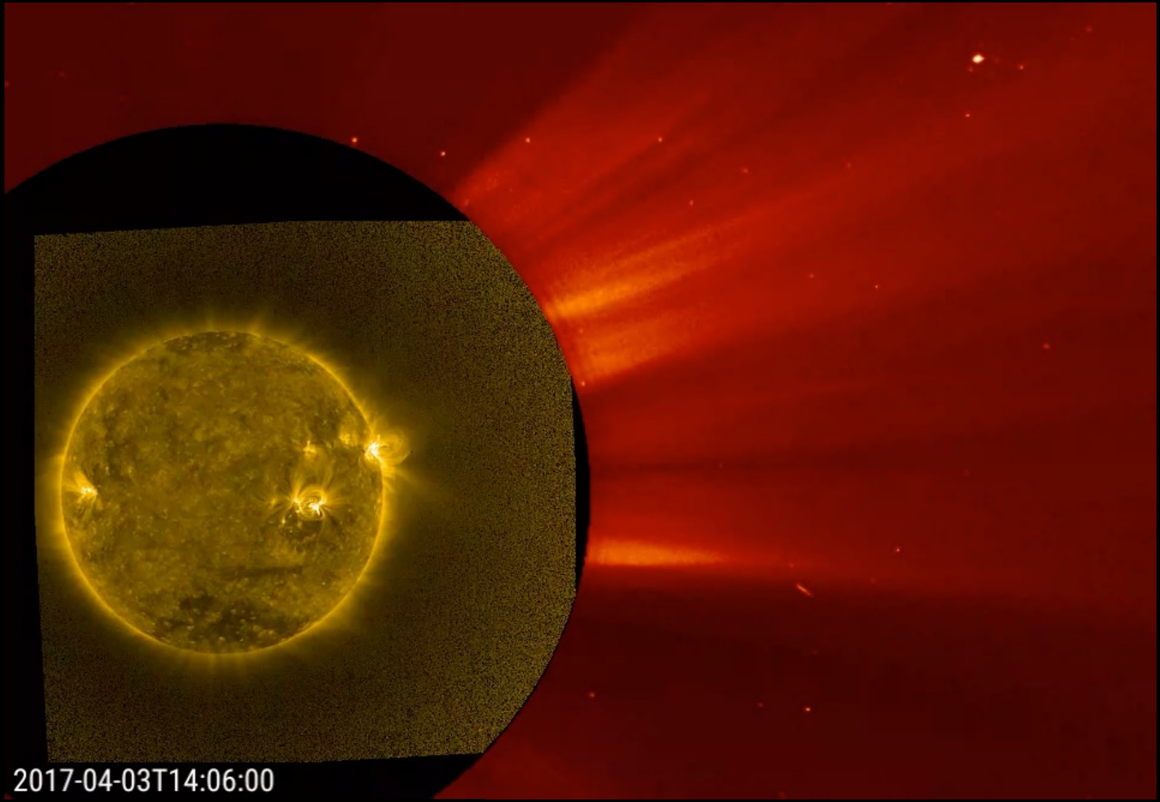
Beyond their impulsive drivers, eruptions are mainly influenced by the background corona/solar wind (e.g. Schrijver et al., 2008; Mierla et al., 2013), especially in the dense inner- and middle-coronal regions.

Byrne et al. (2010)

CME Acceleration & Initial Shock Formation

Sieyra et al. (2020) showed CMEs deflections often occur in the inner or middle corona, during their acceleration phase.

The velocity and width of the CMEs become constant at heights around $\approx 3R_{\odot}$ (Majumdar et al. (2020); Thernisien, Vourlidas, Howard, 2009).



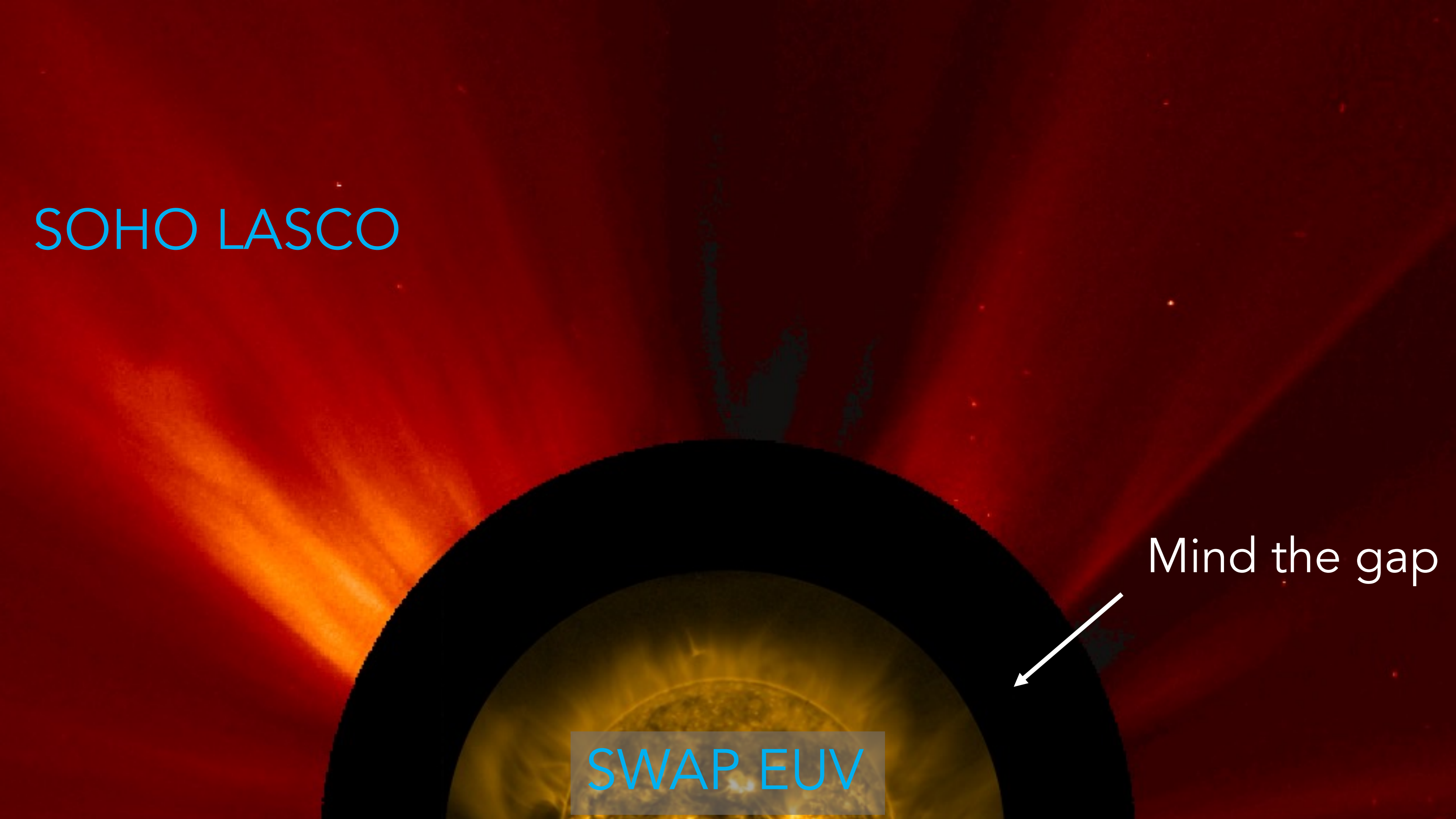
O'Hara et al. (2019)

Heliospheric Connections - Representative middle-corona properties in fast and slow solar-wind regions.

Symbol	1.5 $R_\odot$ Fast	1.5 $R_\odot$ Slow	6.0 $R_\odot$ Fast	6.0 $R_\odot$ Slow	Units: Definition
n_e[a]	1×10^{12}	7×10^{12}	6×10^{9}	3×10^{10}	m^{-3}: electron no. density
$T_{p,\parallel}$[b]	1.6	2.0	1.9	0.85	MK: proton $\parallel$ temperature
$T_{p,\perp}$[b]	2.0	2.6	—	1.1	MK: proton $\perp$ temperature
T_e[c]	1.4	1.8	0.8	—	MK: electron temperature
$T_{O,\parallel}$[d]	2	> 1	60	> 5	MK: oxygen $\parallel$ temperature
$T_{O,\perp}$[d]	10	20	200	20	MK: oxygen $\perp$ temperature
V_{SW}[e]	> 100	< 25	550	150	$km\,s^{-1}$: outflow speed
He/H[f]	—	8%	—	—	— : helium/hydrogen ratio
FIP_{bias}[g]	$1.5-2.5$	$4-6$	—	—	— : elemental composition compared to photospheric composition
B[h]	1.3×10^{5}	7×10^{4}	4×10^{3}	4×10^{3}	nT: magnetic field
C_S	150	170	160	100	$km\,s^{-1}$: sound speed
V_A[i]	3000	600	1100	500	$km\,s^{-1}$: Alfvén speed
ω_{pe}	5.6×10^{7}	1.5×10^{8}	4.4×10^{6}	9.8×10^{6}	Hz: e^- plasma frequency
β[j]	< 0.01	≥ 0.08	< 0.1	≥ 0.04	plasma-β, P_{gas}/P_{mag}

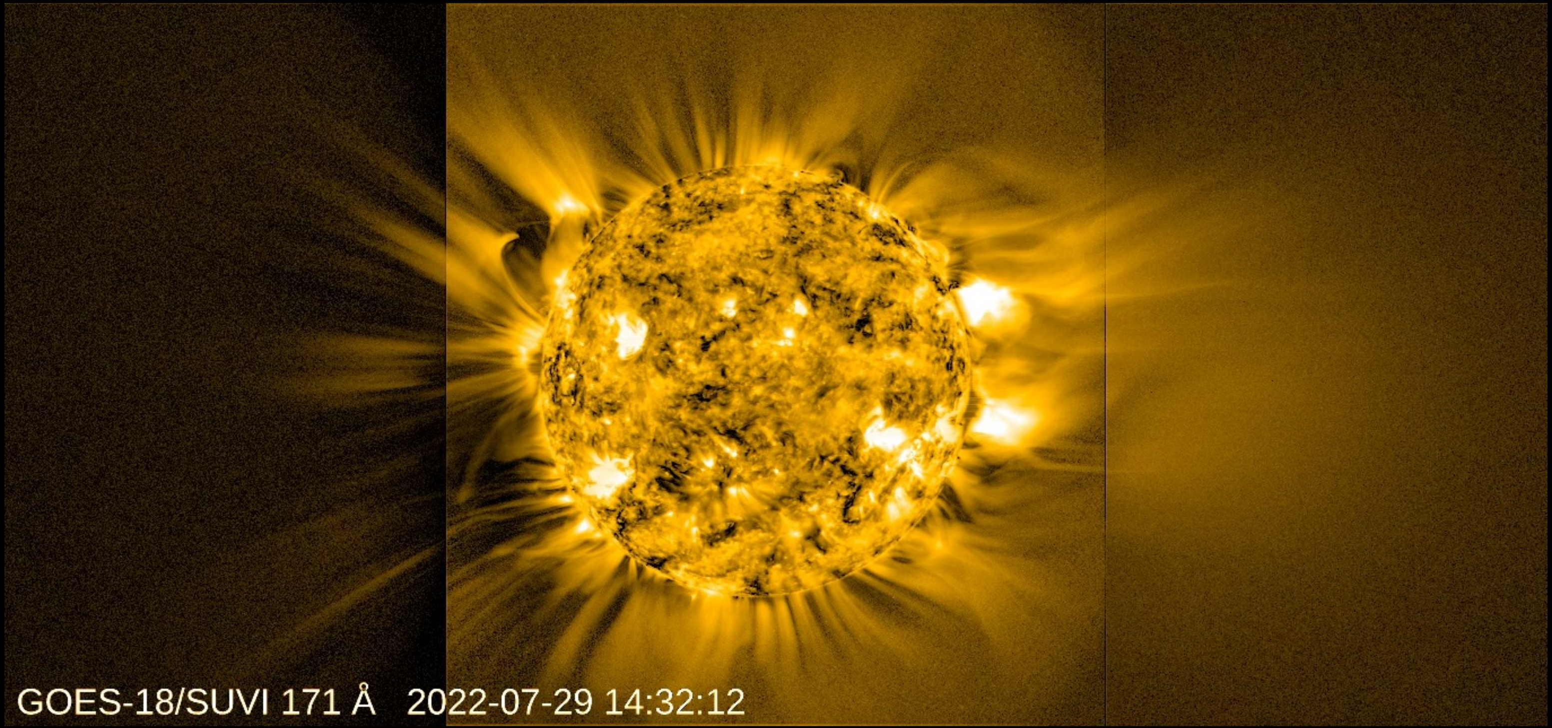
Table 2.
West et al. (2023)

How are we observing the region?


SOHO LASCO
Mind the gap
SWAP EUV

The SOLAR ULTRAVIOLET IMAGER (SUVI)

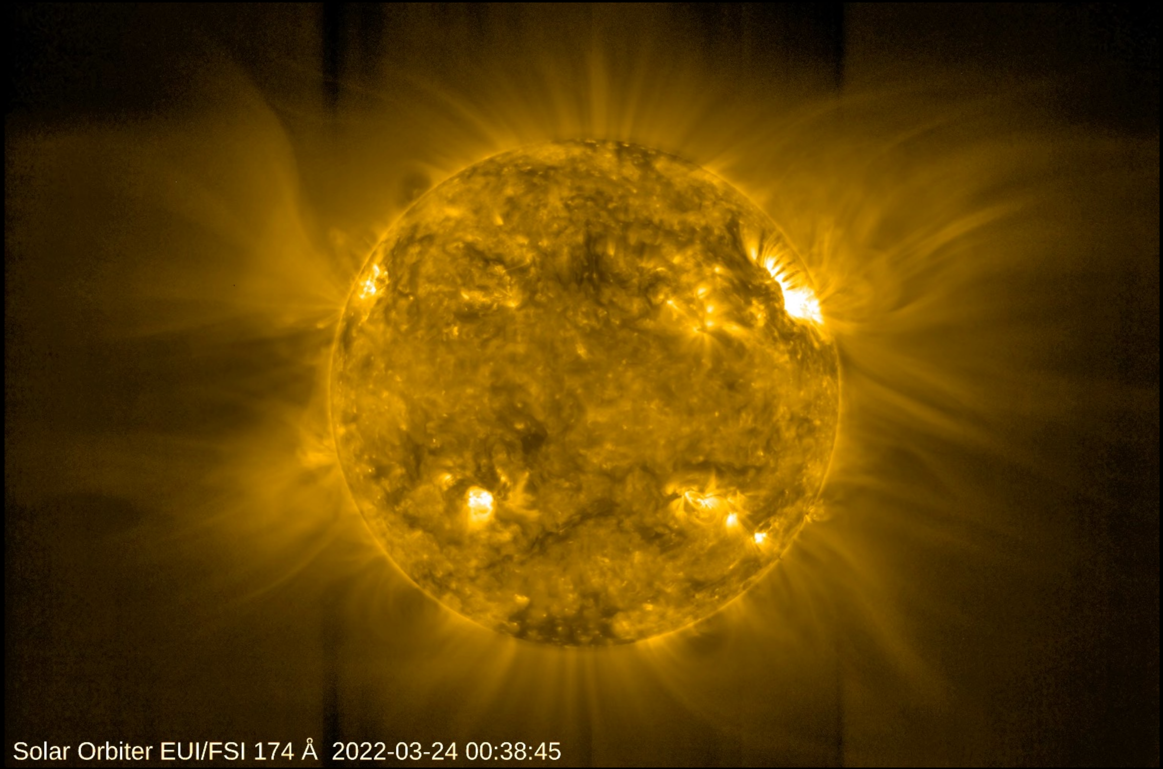
GOES-18 SUVI Campaign July 29–Aug 1 2022



Radially Filtered 171 Å Enhanced Structure

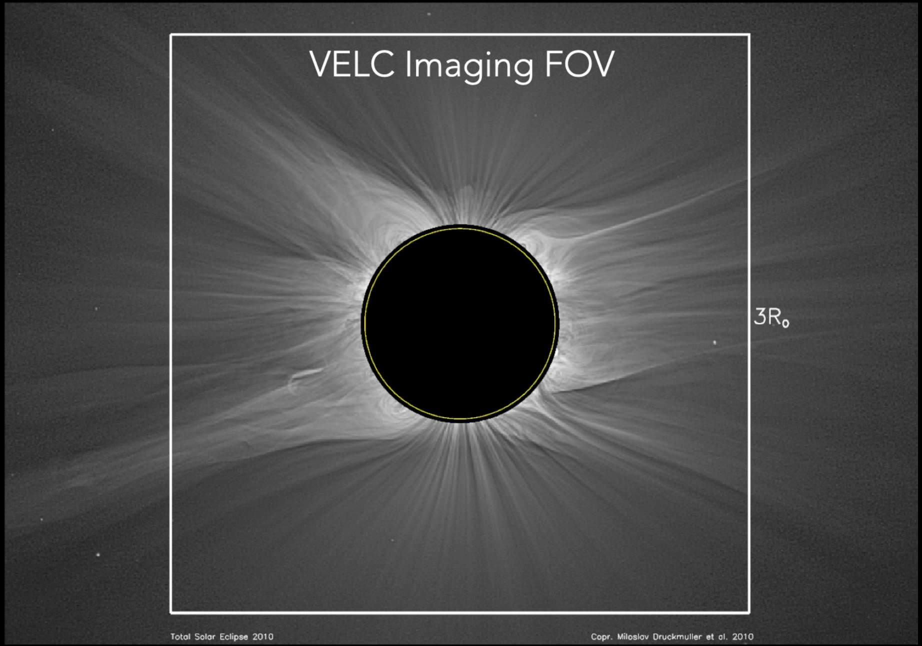
Courtesy D. Seaton

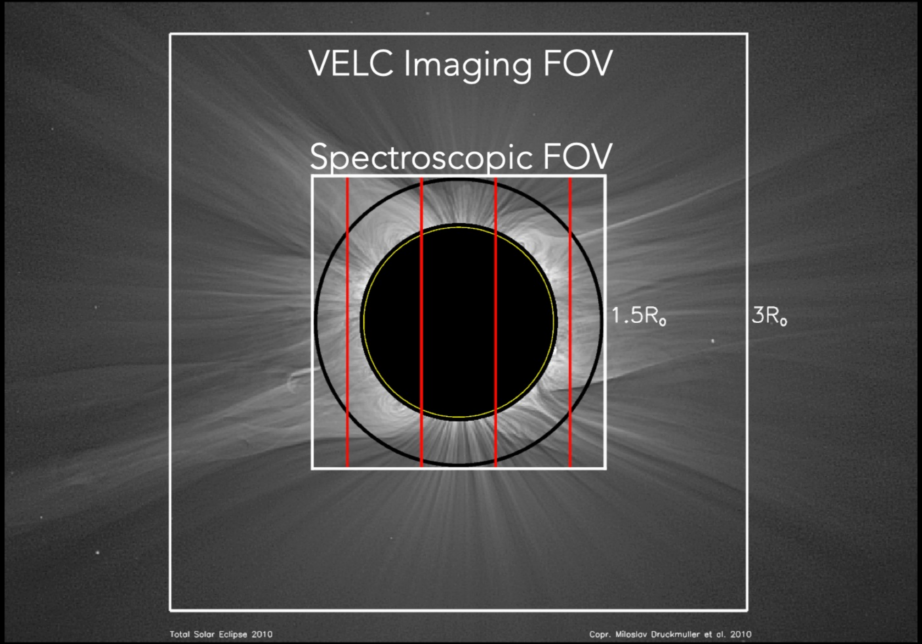
Solar Orbiter EUI Full Sun Imager (FSI)



174 & 304 Å Channels - Variable FOV depending on distance - Optional disk occulter for extreme deep imaging

Aditya L1 – VELC: Visible Emission line Coronagraph

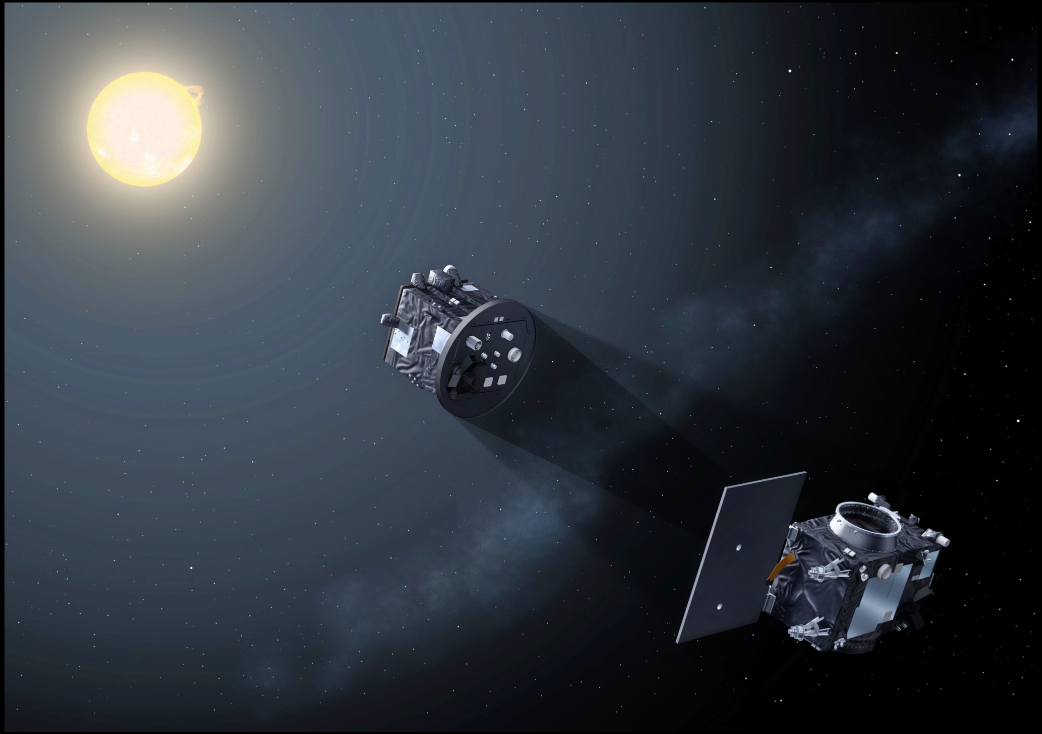


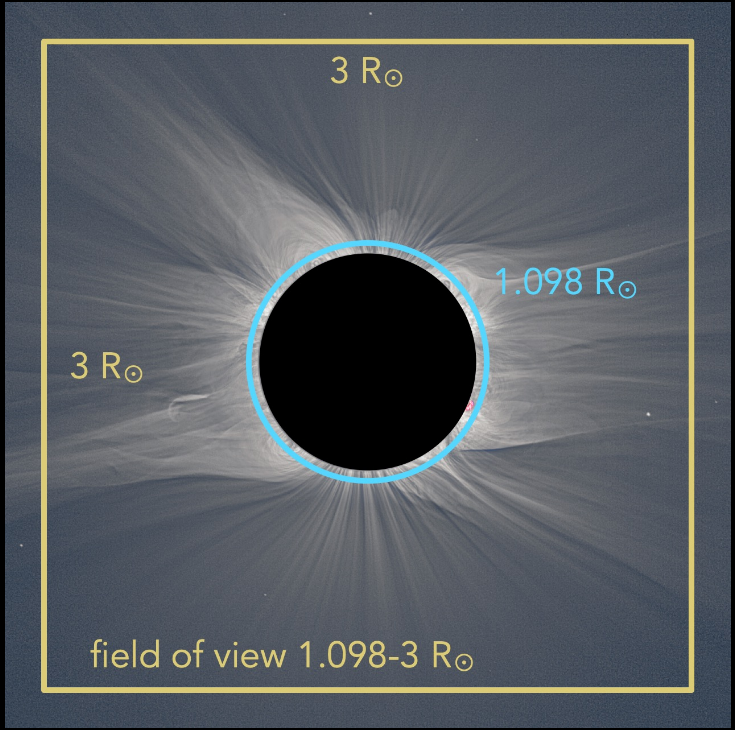


VELC payload will image the solar corona with a FOV from 1.05 to 3 $R_\odot$. VELC will simultaneously provides spectroscopic observations in the coronal emission lines and spectro-polarimetric observations in the infrared line in the FOV of 1.05 - 1.5 $R_\odot$.

Courtesy D. Banerjee

PROBA-3/ASPIICS: The Formation Flying Coronagraph

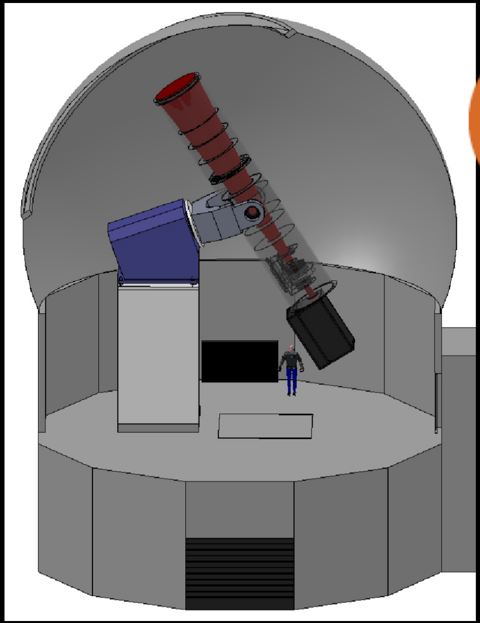




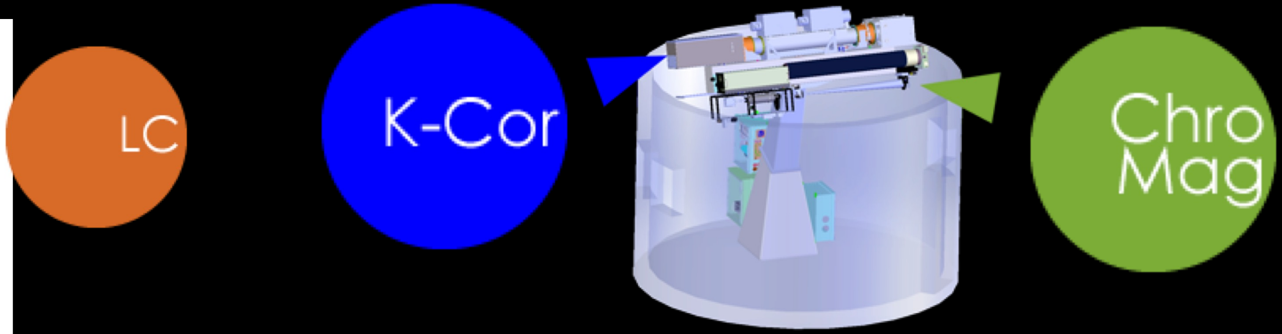
Large Coronagraph

Courtesy A. Zhukov

COSMO Coronagraph - proposed synoptic facility to measure magnetic fields and plasma properties in the large-scale solar atmosphere



Large Coronagraph

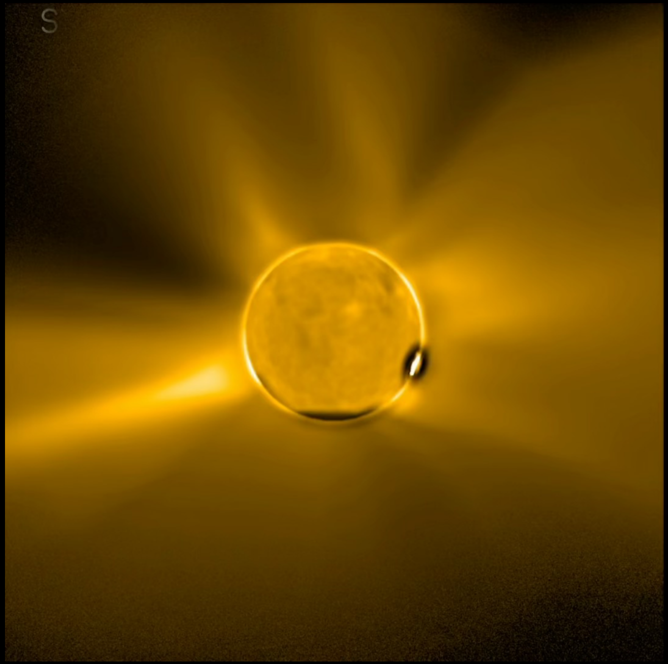


Spar Facility with K-Coronagraph and Chromospheric Imager.
Coronagraphic observations including polarimetric observations and unique magnetic diagnostics.

Courtesy S. Tomczyk

Sun's Coronal Eruption Tracker (SunCET) CubeSat

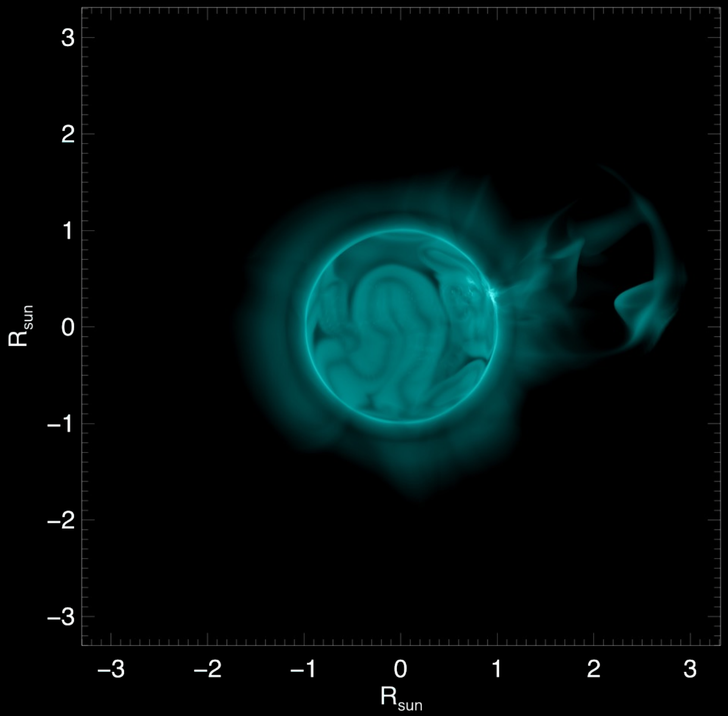
Large FOV Imager $\pm 5.34\ R_\odot \times \pm 4\ R_\odot$



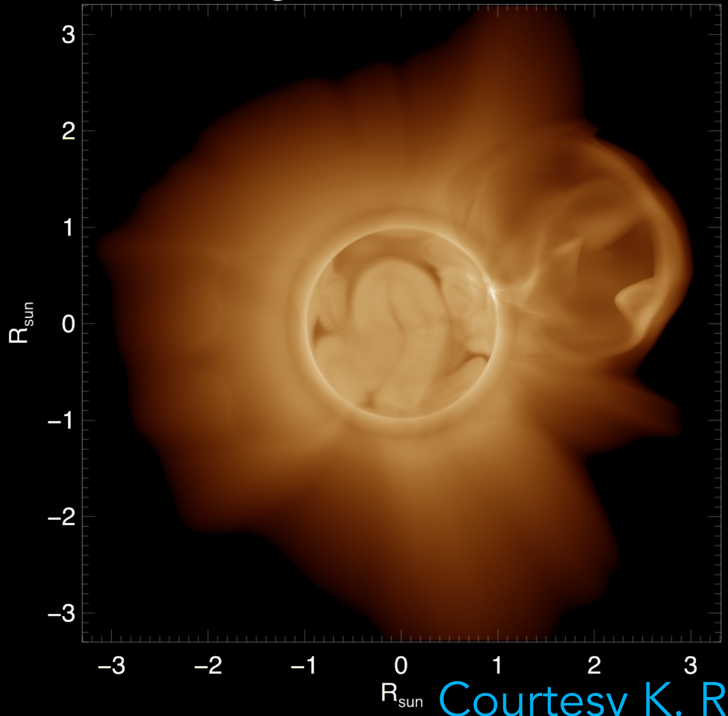
Courtesy J. Mason

EUV CME and Coronal Connectivity Observatory (ECCCO) - Imager & Spectrograph

Short channel: 126 - 148 Å

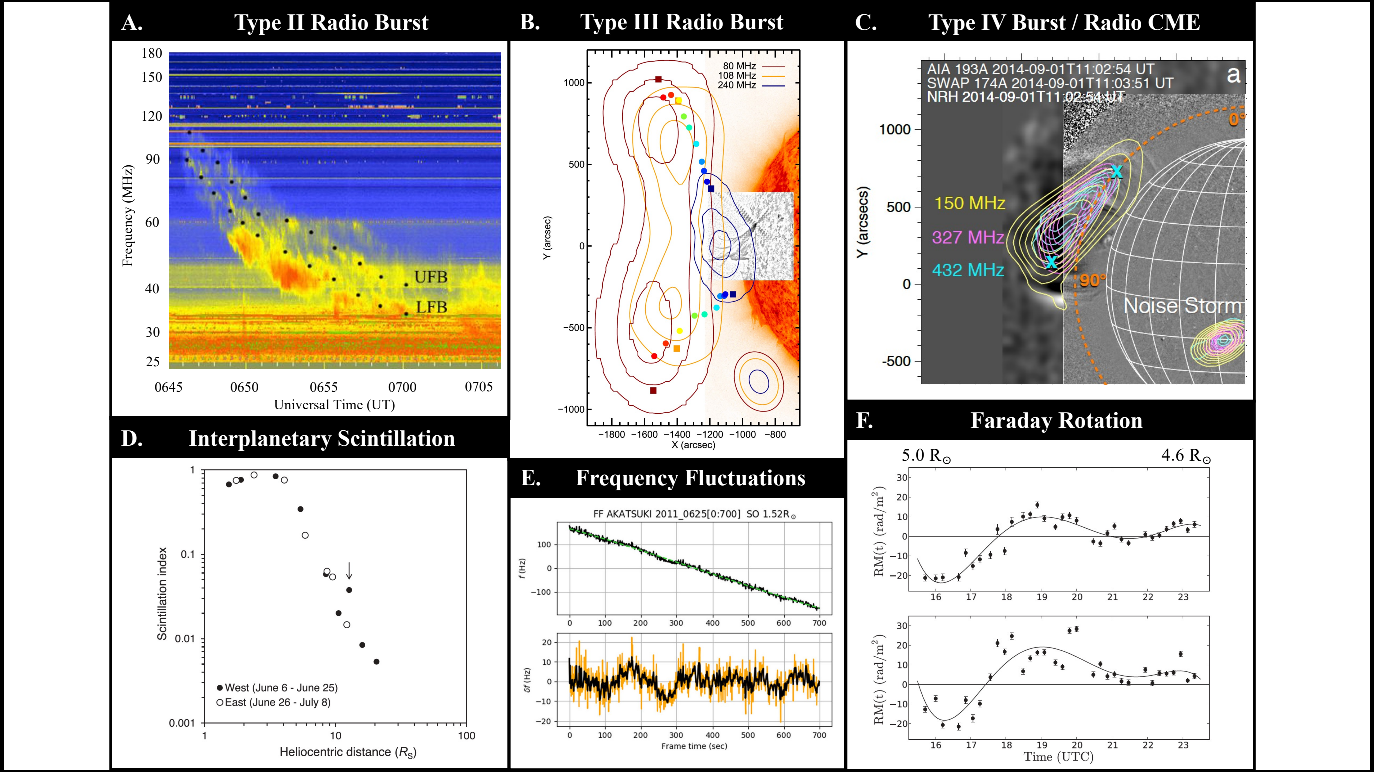


Long channel: 171 - 208 Å



Courtesy K. Reeves

Radio Observatories



West et al. (2023)

Overview of radio phenomena in the middle corona

The Middle Corona

What and where is the Middle Corona?

A region of dramatic transitions in the corona between 1.5–6 $R_\odot$.

Why is it important to PUNCH?

It's home of numerous critical processes that shape and modulate outflow.

How can we study it?

Through new techniques like wide-FOV EUV and imaging advanced coronagraphy.

How are we going to bridge the gap to PUNCH?

Numerous operating, planned, and proposed missions in the next five years.

For more information on the Middle Corona read our definitional paper:
https://link.springer.com/article/10.1007/s11207-023-02170-1

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REVIEW

Defining the Middle Corona

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Abstract
The middle corona, the region roughly spanning heliocentric distances from 1.5 to 6 solar radii, encompasses almost all of the influential physical transitions and processes that govern the behavior of coronal outflow into the heliosphere. The solar wind, eruptions, and flows pass through the region, and they are shaped by it. Importantly, the region also modulates inflow from above that can drive dynamic changes at lower heights in the inner corona. Consequently, the middle corona is essential for comprehensively connecting the corona to the heliosphere and for developing corresponding global models. Nonetheless, because it is challenging to observe, the region has been poorly studied by both major solar remote-sensing and in-situ missions and instruments, extending back to the *Solar and Heliospheric Observatory* (SOHO) era. Thanks to recent advances in instrumentation, observational processing techniques, and a realization of the importance of the region, interest in the middle corona has increased. Although the region cannot be intrinsically separated from other regions of the solar atmosphere, there has emerged a need to define the region in terms of its location and extension in the solar atmosphere, its composition, the physical transitions that it covers, and the underlying physics believed to shape the region. This article aims to define the middle corona, its physical characteristics, and give an overview of the processes that occur there.

Keywords Corona

1. Introduction

Parker (1958) showed that the hot corona cannot maintain a hydrostatic equilibrium. Instead, the pressure-gradient force exceeds gravity and produces a radial acceleration of the

Extended author information available on the last page of the article

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