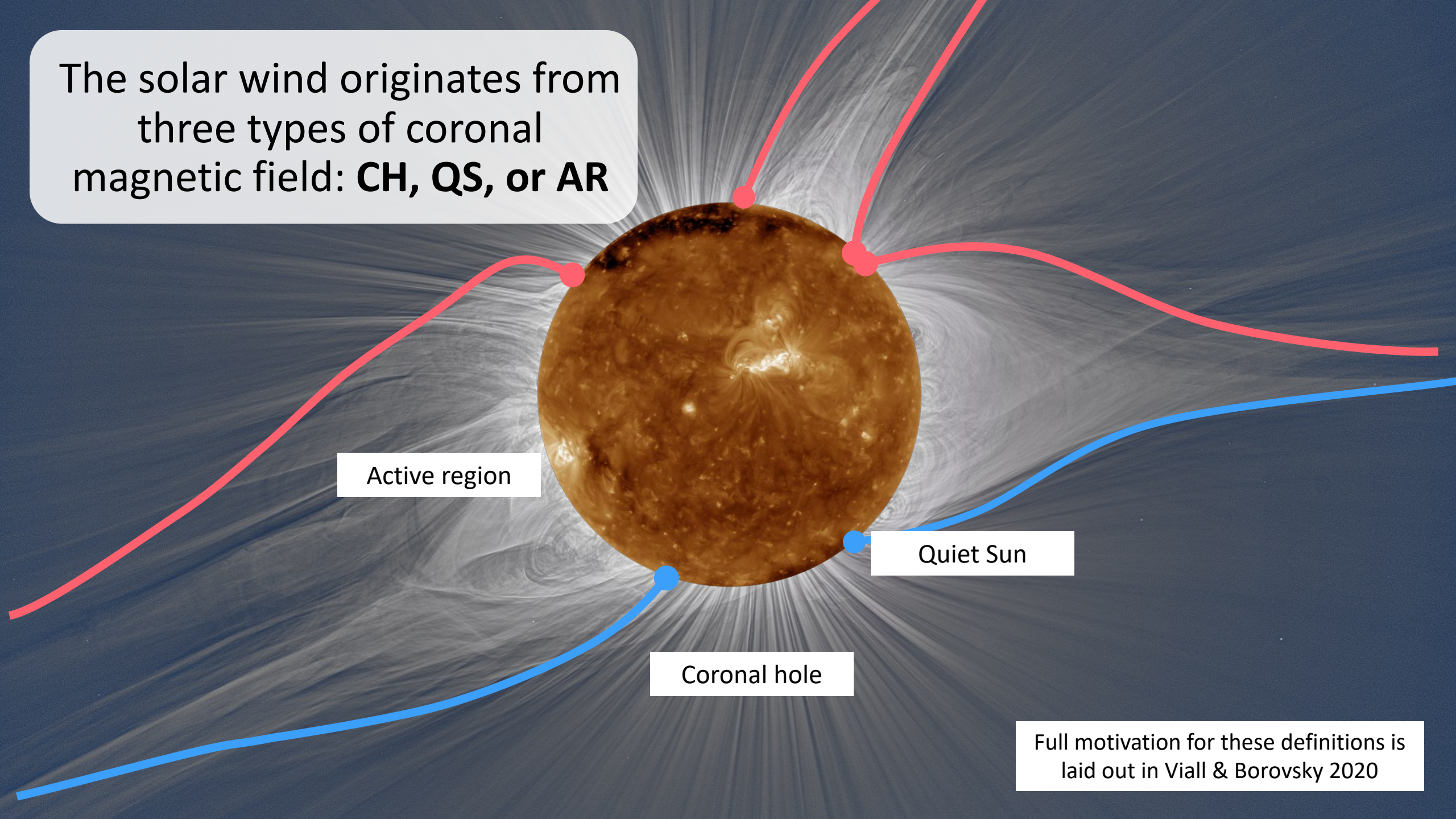
Characterizing the L1 in situ observed solar wind originating from differing source regions identified by ADAPT-WSA

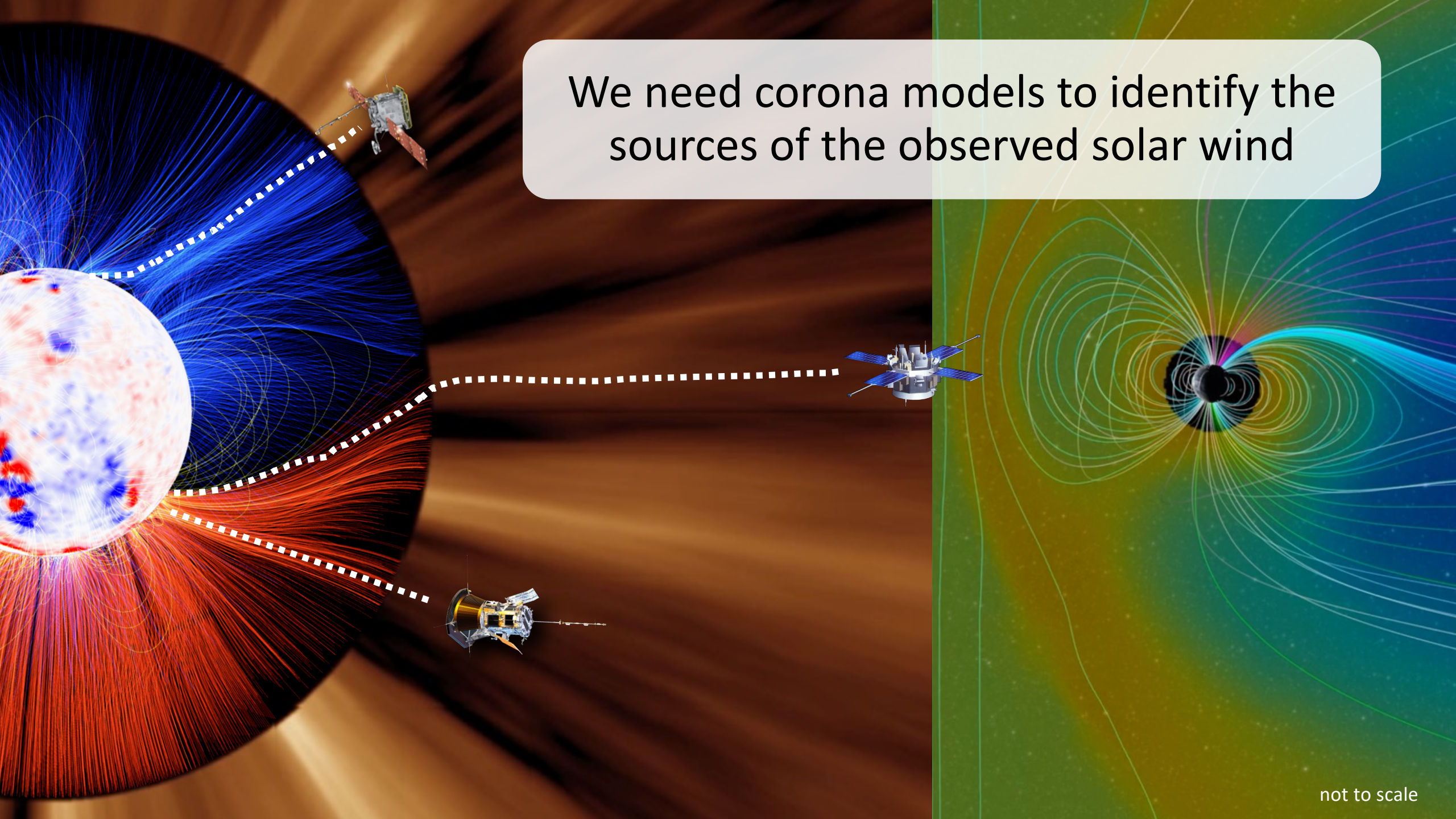
Samantha Wallace

Nicholeen Viall, C.N. Arge

The solar wind originates from three types of coronal magnetic field: **CH, QS, or AR**

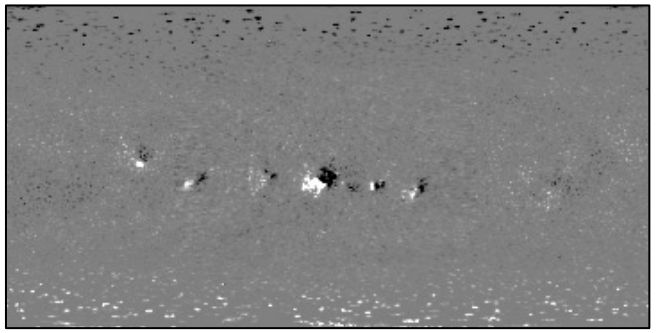


Full motivation for these definitions is laid out in Viall & Borovsky 2020


We need corona models to identify the sources of the observed solar wind
not to scale

The ADAPT-WSA model

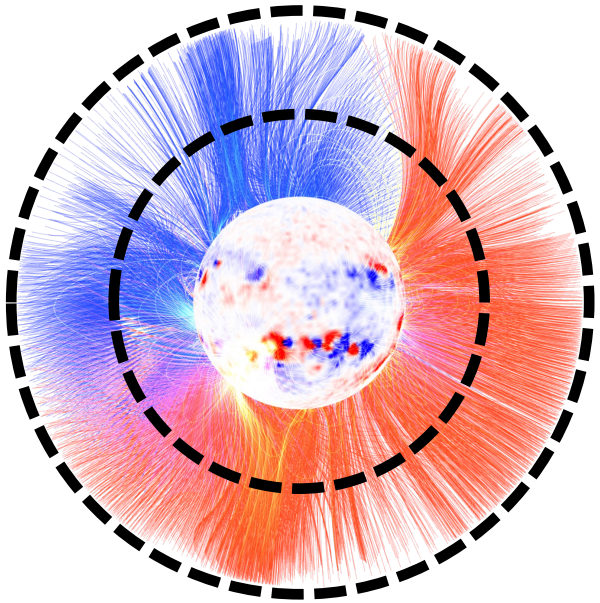
Input: ADAPT
(ensemble of 12 maps)



Arge+ 2010, 2011, 2013, Hickmann+ 2015

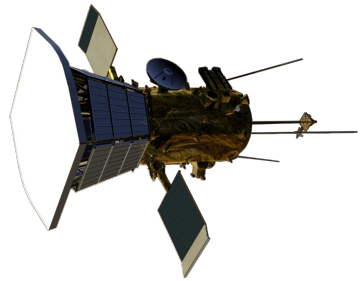
Derived from magnetograms
provided by
HMI, GONG, VSM etc.

WSA
PFSS + SCS



Arge and Pizzo 2000, Arge+ 2003, 2004

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

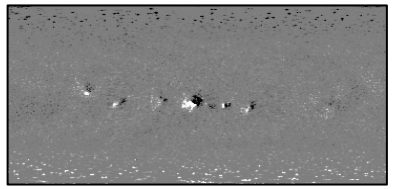


Air Force Data Assimilative Photospheric Flux Transport (ADAPT) model

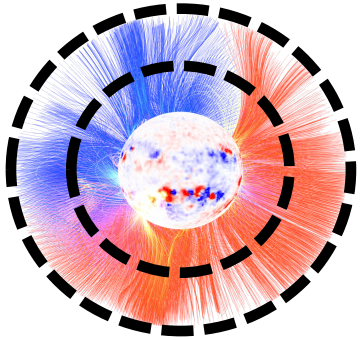
Wang-Sheeley-Arge (WSA) model

The ADAPT-WSA model

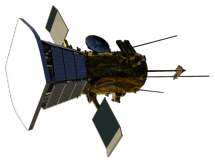
Input: ADAPT



WSA



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

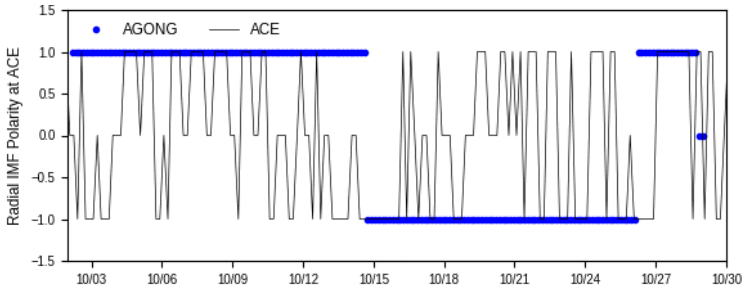


OUTPUT:

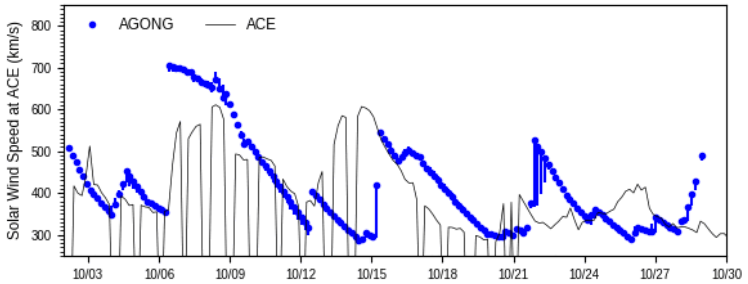
12 solutions of the global corona field, spacecraft magnetic connectivity, and solar wind

for one moment in time

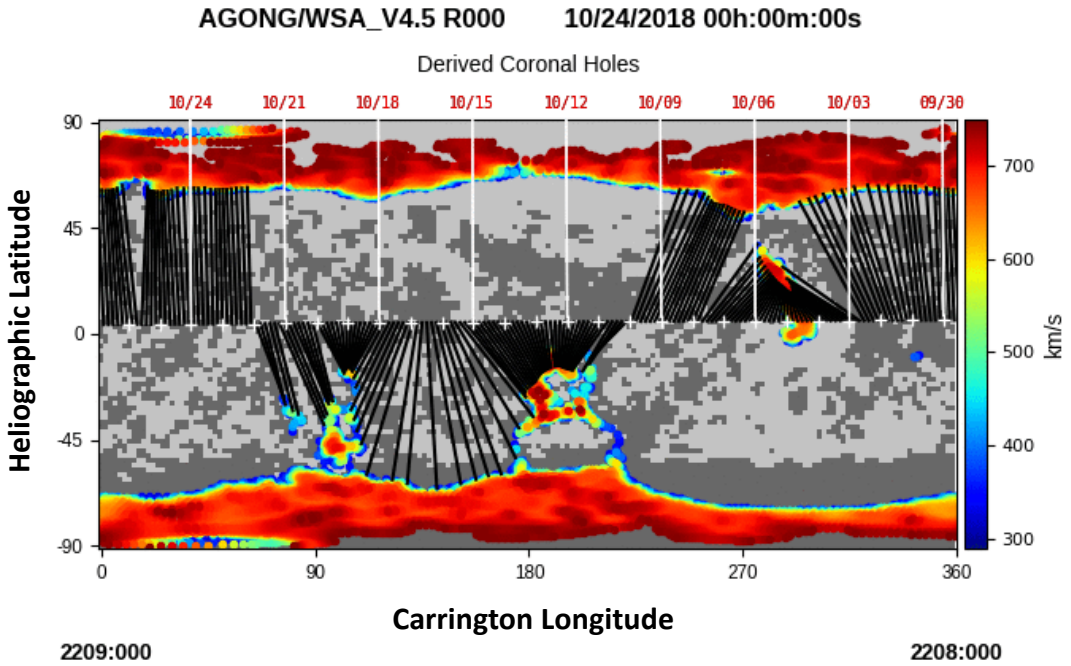
IMF Polarity



Solar wind speed (km/s)



Date



Science Questions

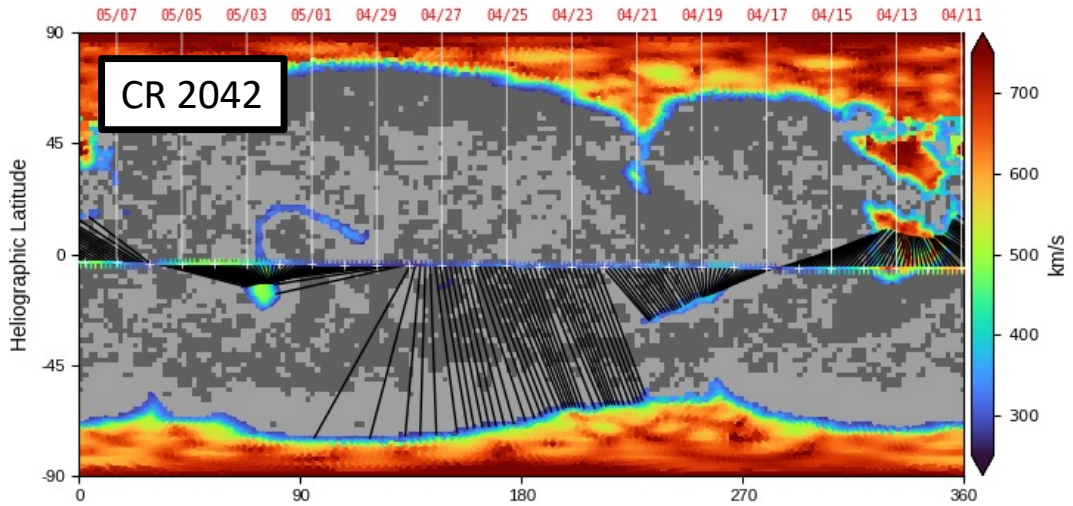
What are the defining in situ properties of solar wind originating from CHs, QS, and ARs?

> Are there even defining properties? Is solar wind formation driven more by larger structure it originated from (e.g. helmet vs. pseudostreamer, continuous vs. intermittently open)?

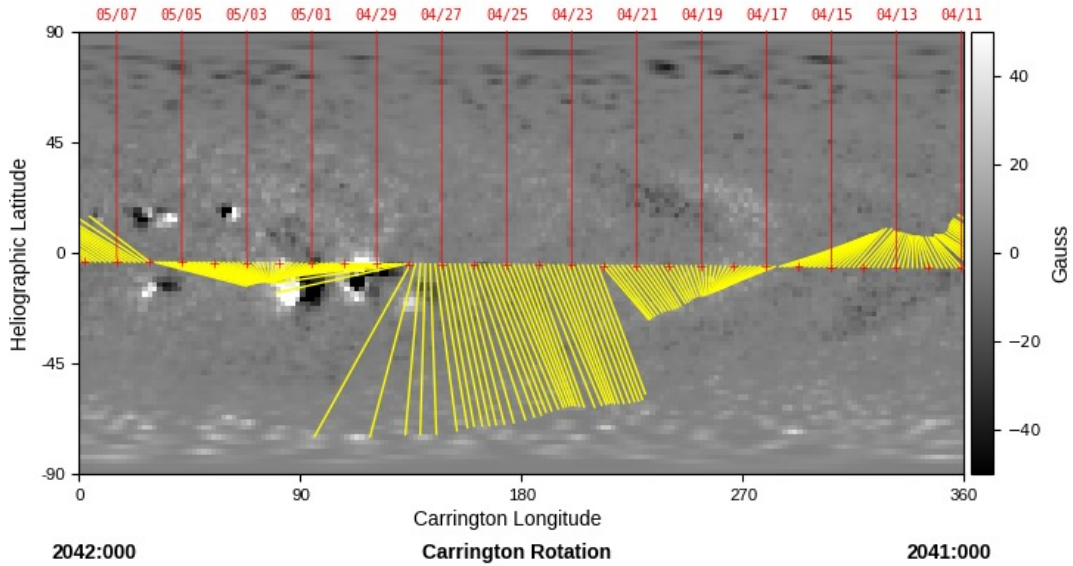
What do the in situ properties unique to each source region tell us about how the solar wind is formed?

Methodology

WSA coronal holes - Sources of solar wind observed at ACE/L1

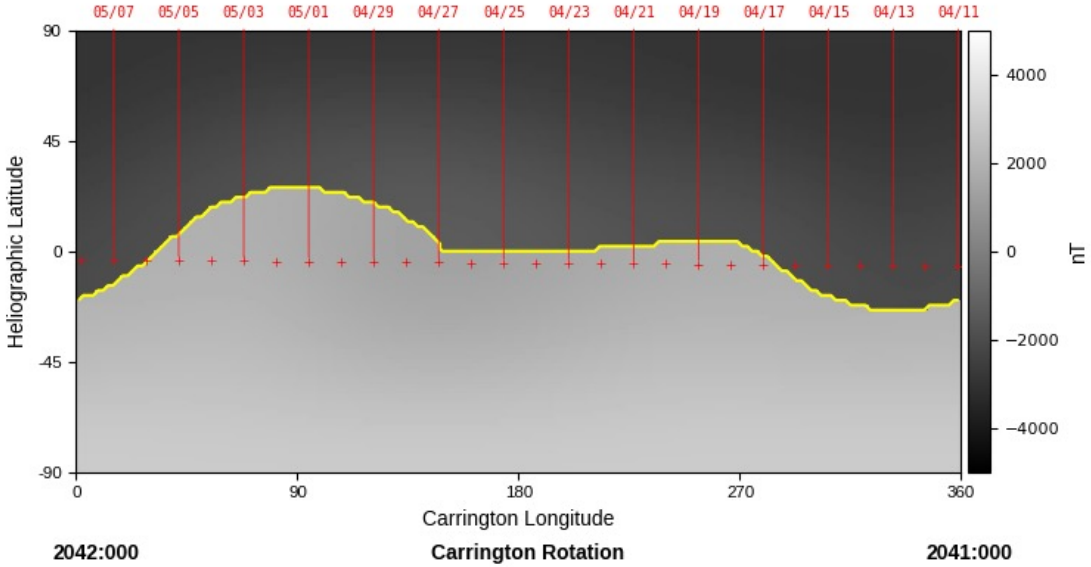


Sources of solar wind at Sun's surface (1 R_s)

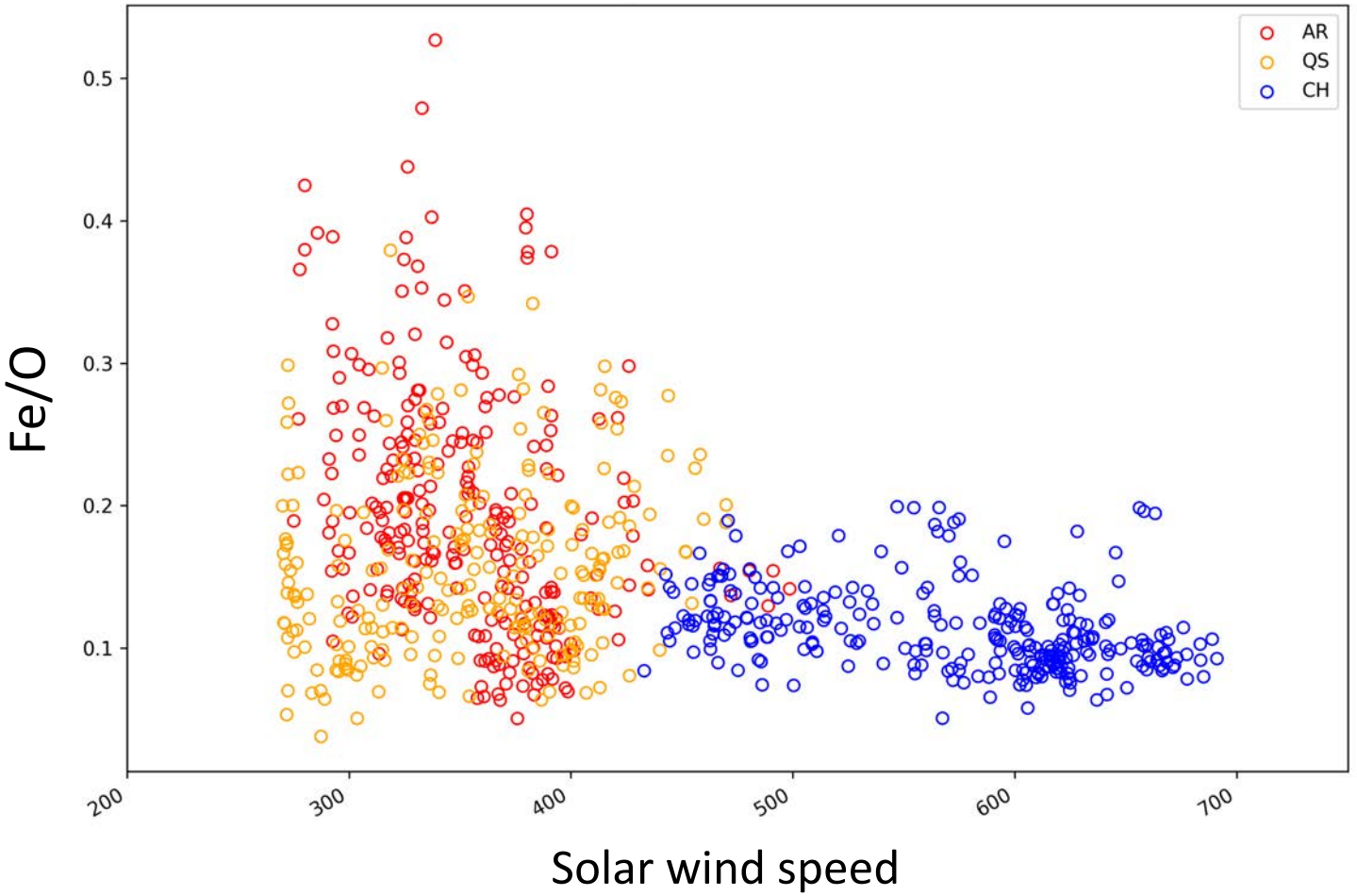


- Derive L1 connectivity to 1 R_s with ADAPT-WSA for 2 Carrington Rotations
  - CR 2042: April/May 2006, lower activity
  - CR 2109: April/May 2011, higher activity
- SW of **coronal hole** origin: DCHB > 2.5, B_{ph} < 20 G
- **Quiet Sun:** DCHB < 2.5, B_{ph} < 20 G
- **Active region:** DCHB < 2.5, B_{ph} > 20 G

Coronal Field at 5 R_s

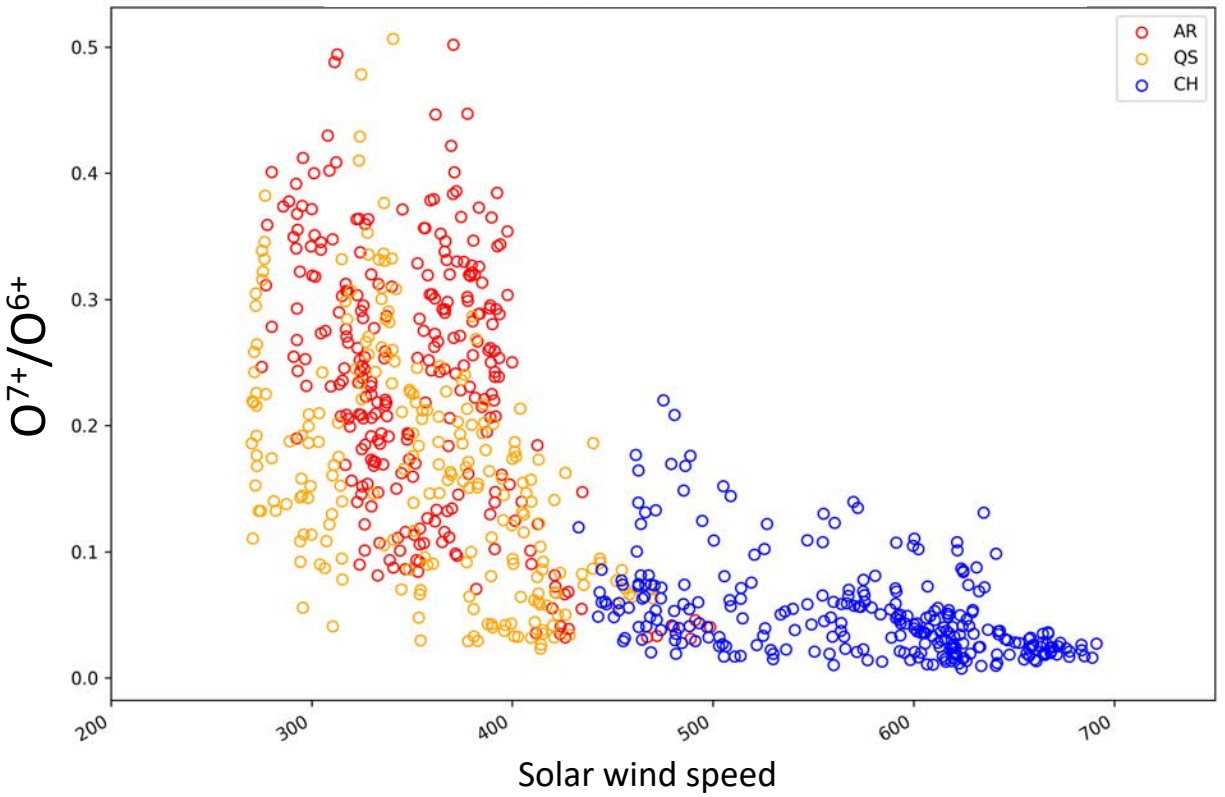


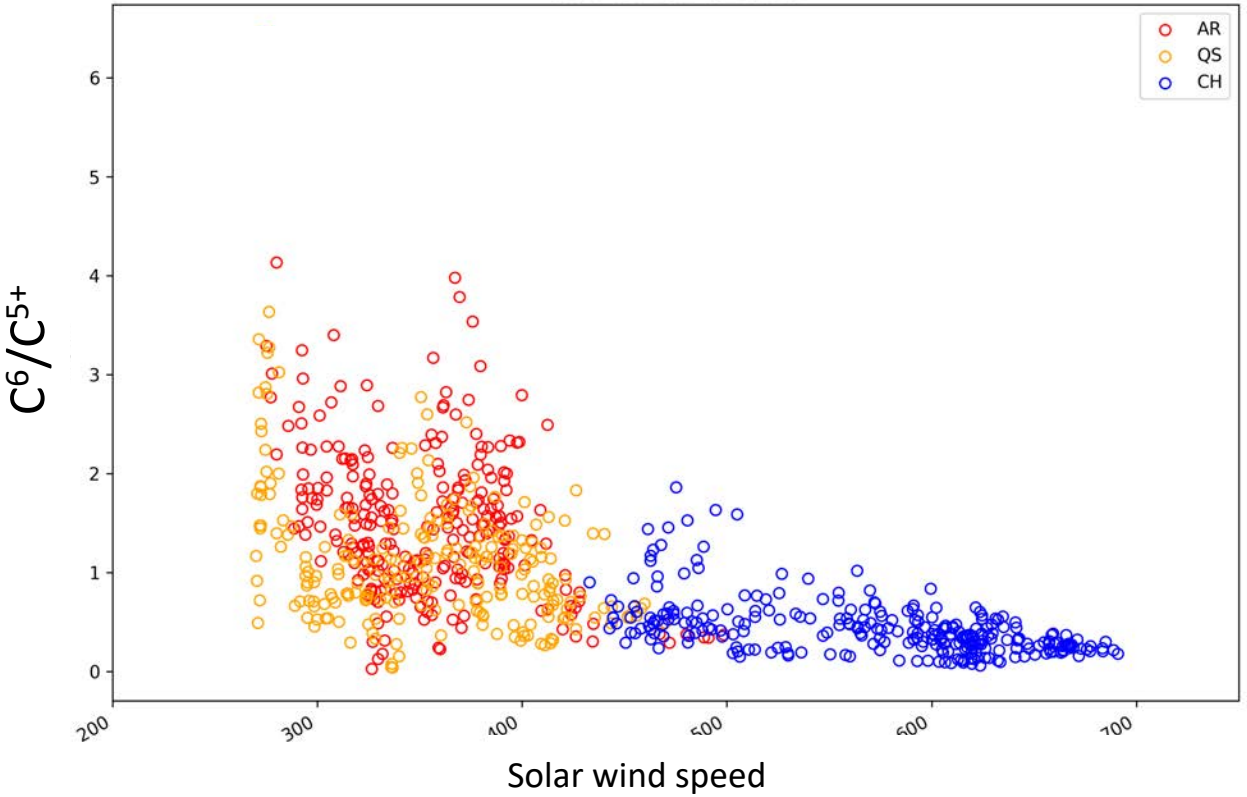
Average Fe/O composition (FIP enhancement) strongly linked to source region. Most variation from strongest magnetic field regions.



Fe/O	avg	std	min	max
AR	0.19	0.09	0.05	0.53
QS	0.16	0.06	0.04	0.38
CH	0.11	0.03	0.05	0.20

Charge state ratios linked to source region. Distinction more lies between open-closed boundary and continuously open field.

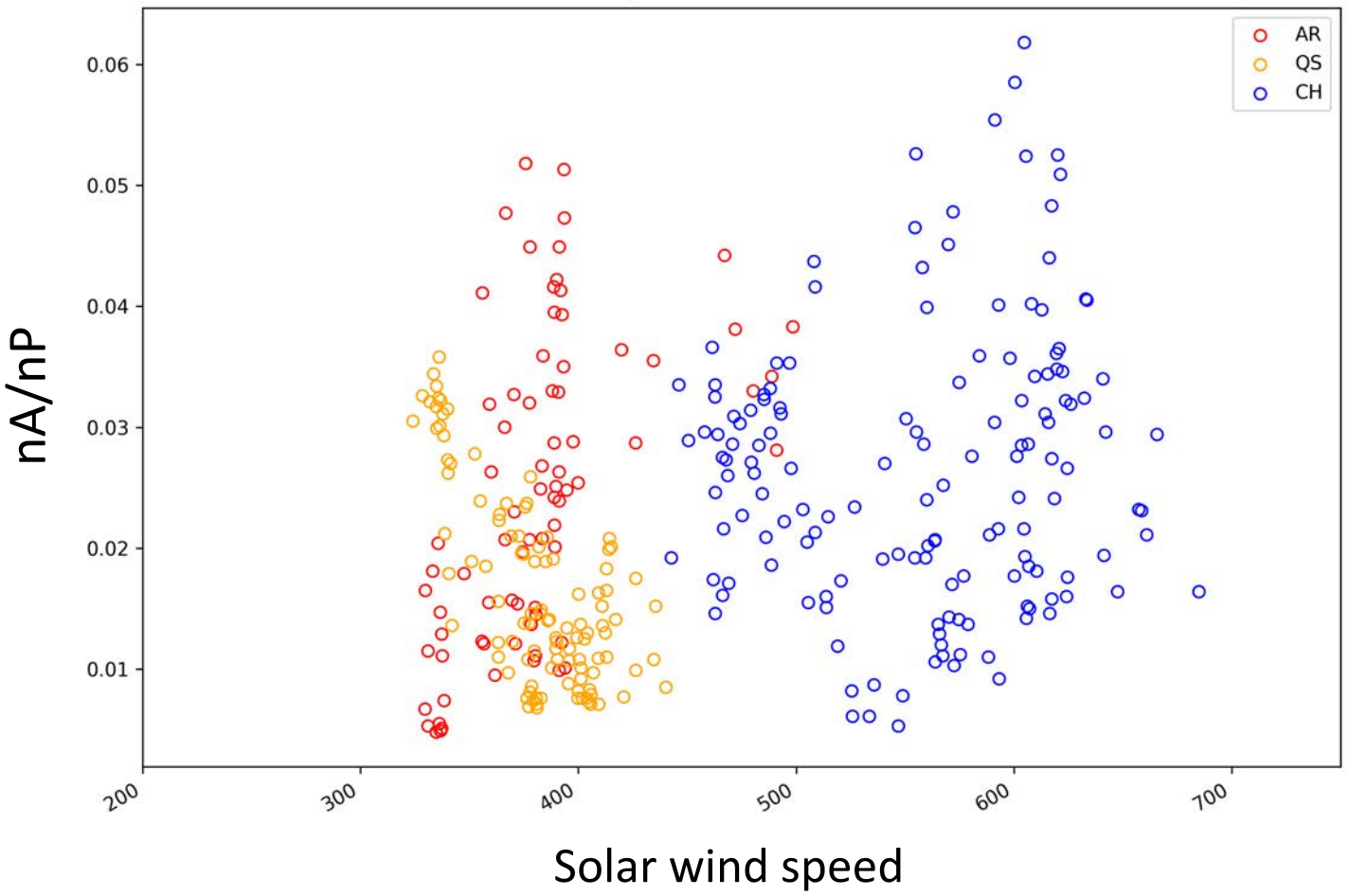




O^{7+}/O^{6+}	avg	std	min	max
AR	0.24	0.10	0.03	0.50
QS	0.17	0.09	0.02	0.51
CH	0.05	0.04	0.01	0.22

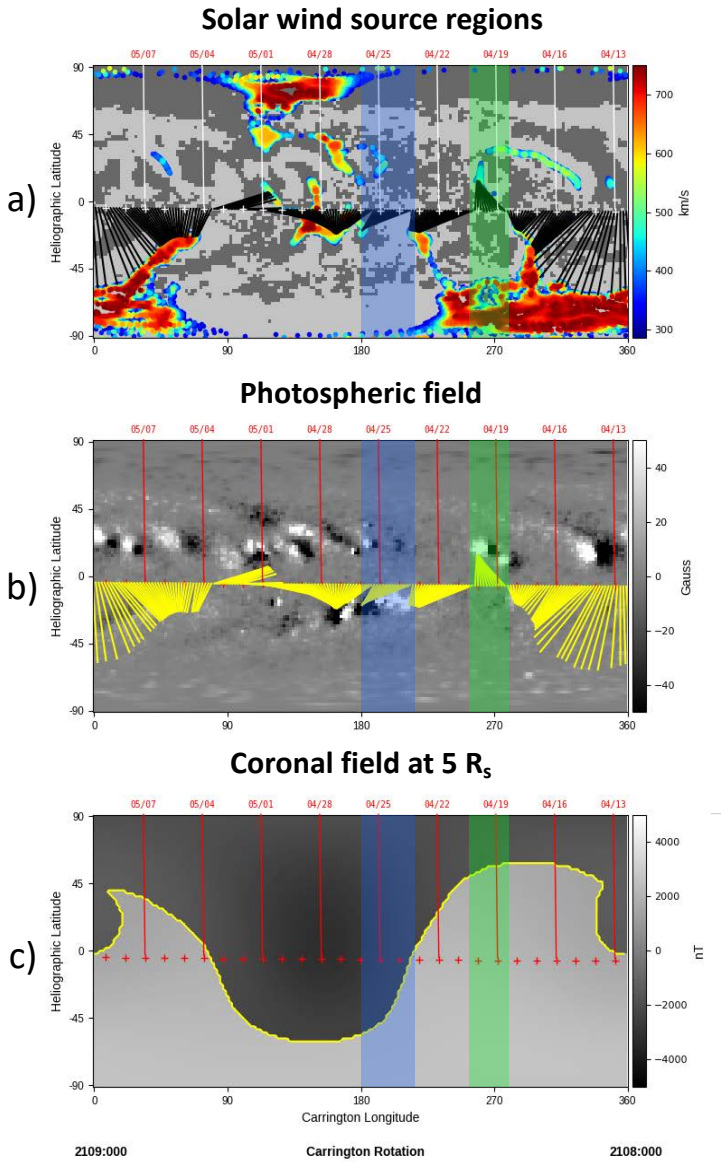
C^{6+}/C^{5+}	avg	std	min	max
AR	1.49	0.73	0.02	4.1
QS	1.13	0.73	0.04	3.9
CH	0.44	0.28	0.06	1.86

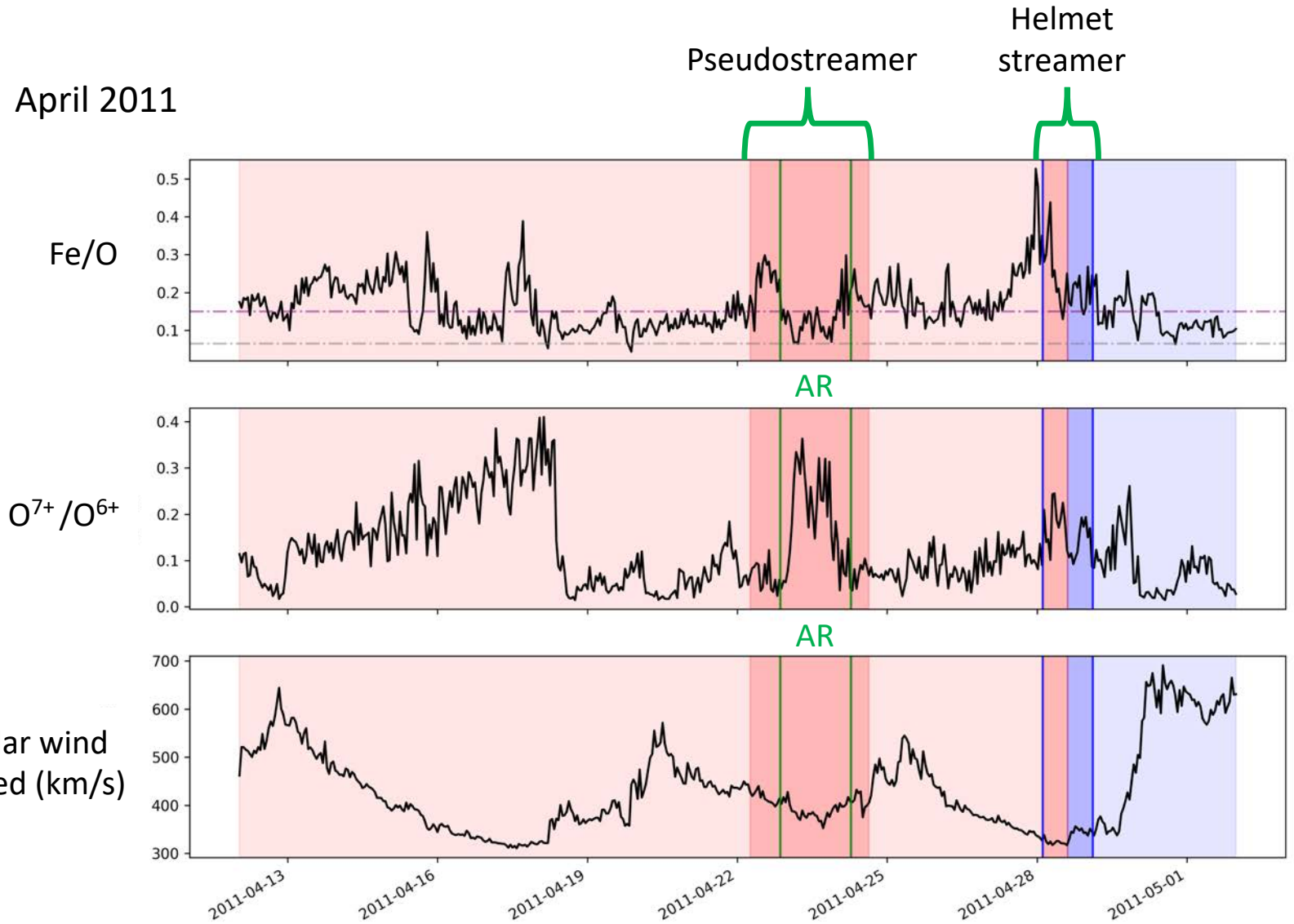
Average alpha to proton ratio and variation independent of source region?



nA/nP (%)	avg	std	min	max
AR	2.5	1.3	0.5	5.2
QS	1.7	0.8	0.7	3.6
CH	2.6	1.1	0.5	6.2

Solar wind from coronal streamers varies based on the presence or absence of active region





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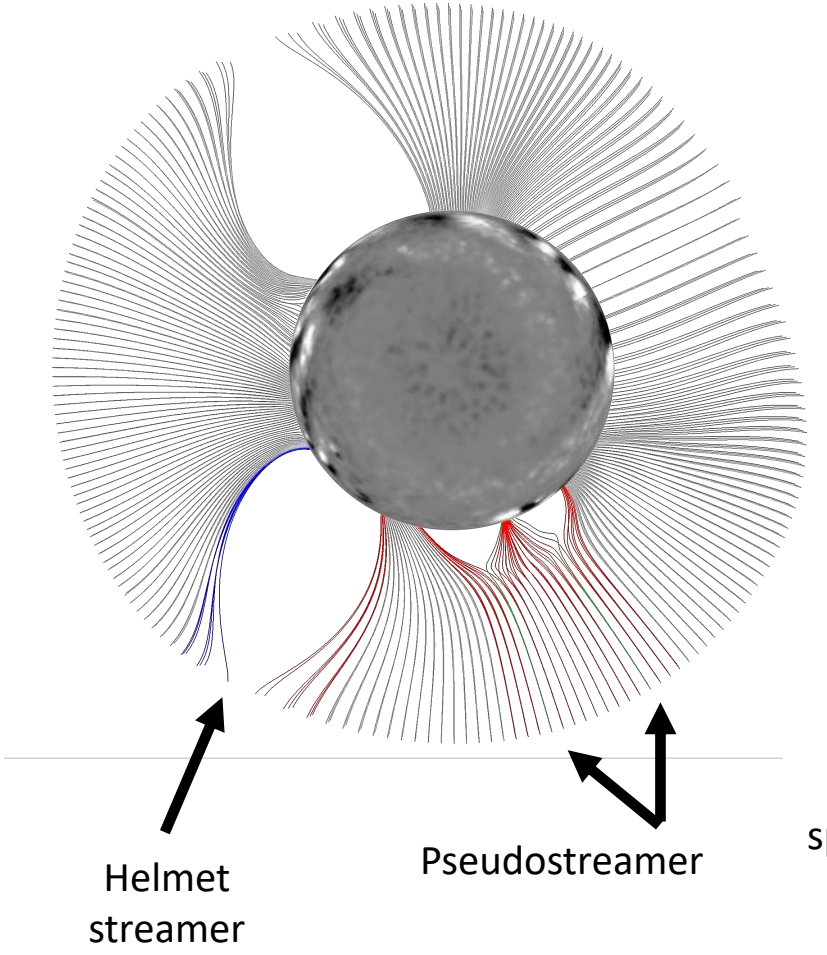
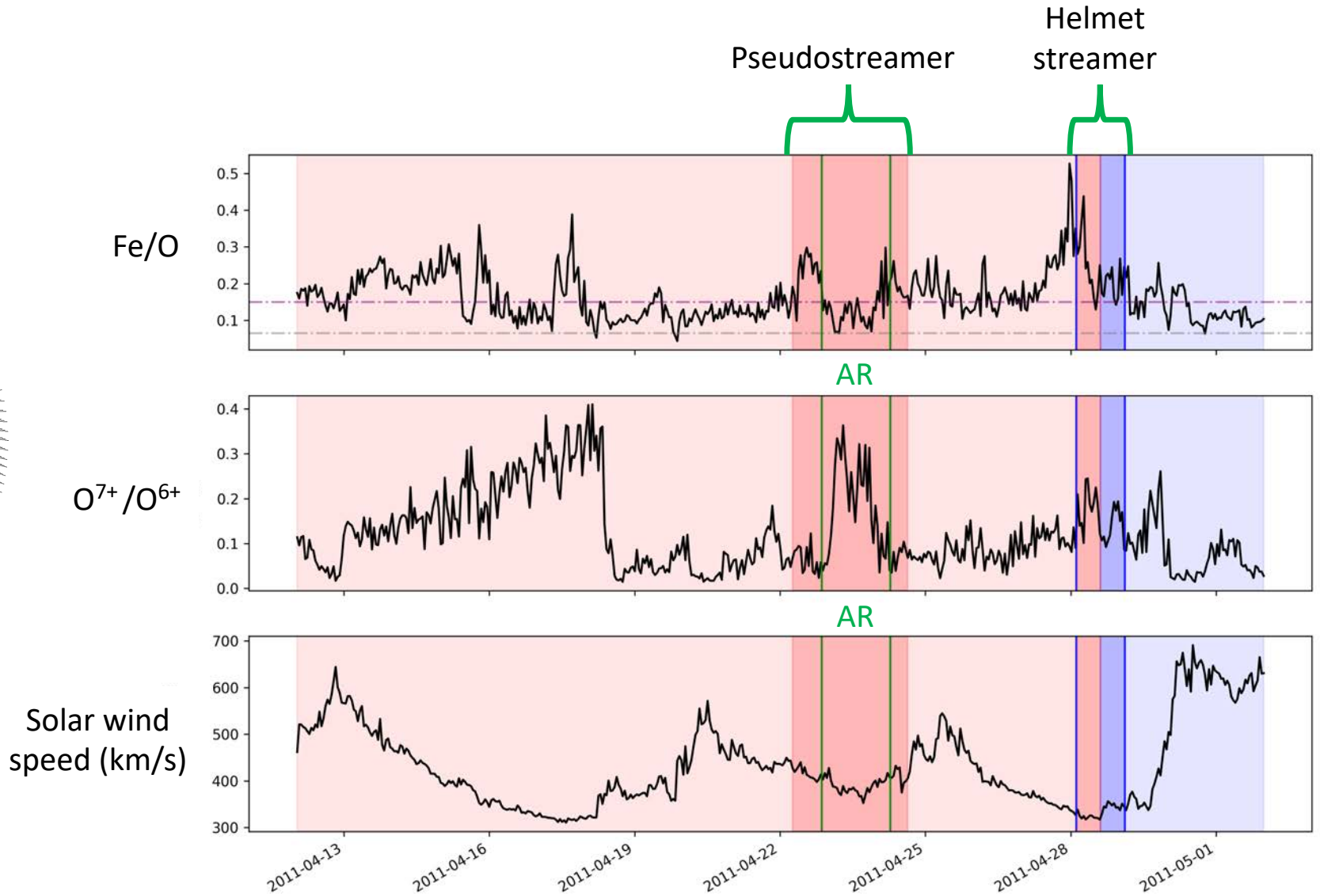
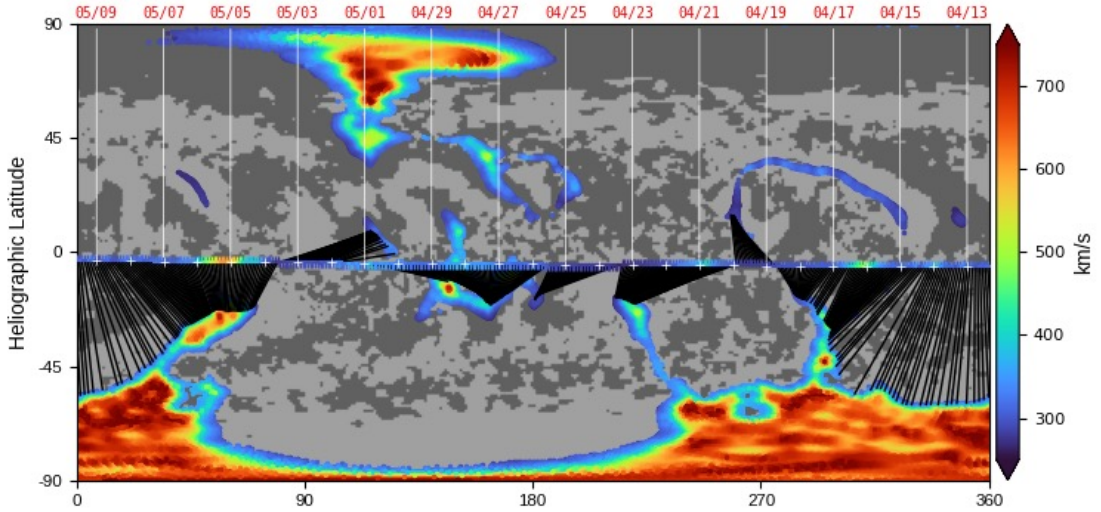


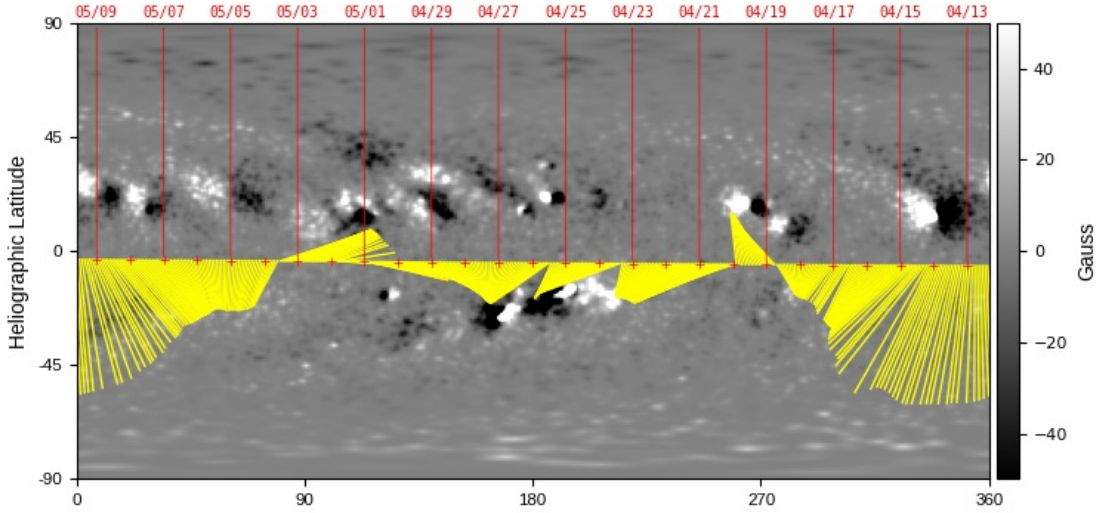


The S-web is now a standard output product of the WSA model!

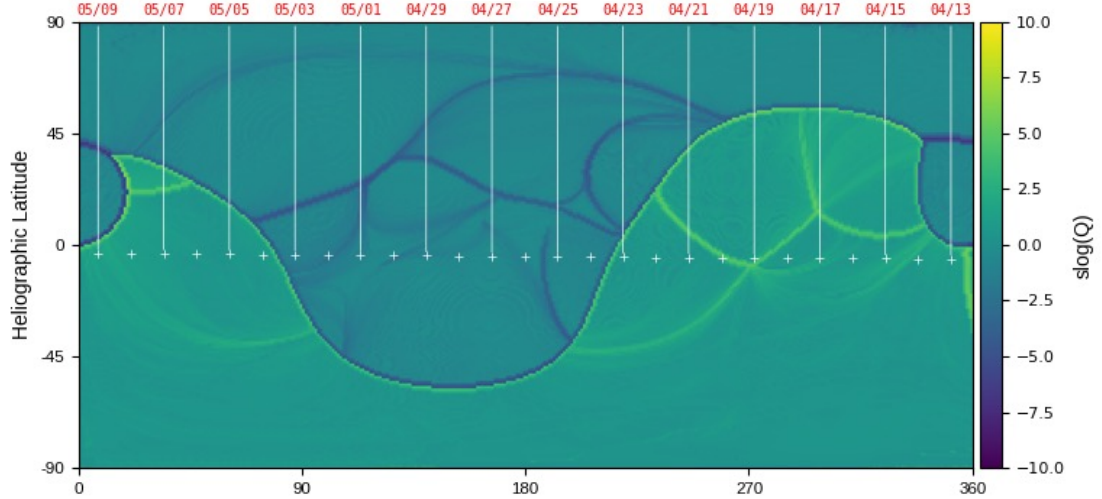
WSA coronal holes
Sources of solar wind observed at ACE/L1



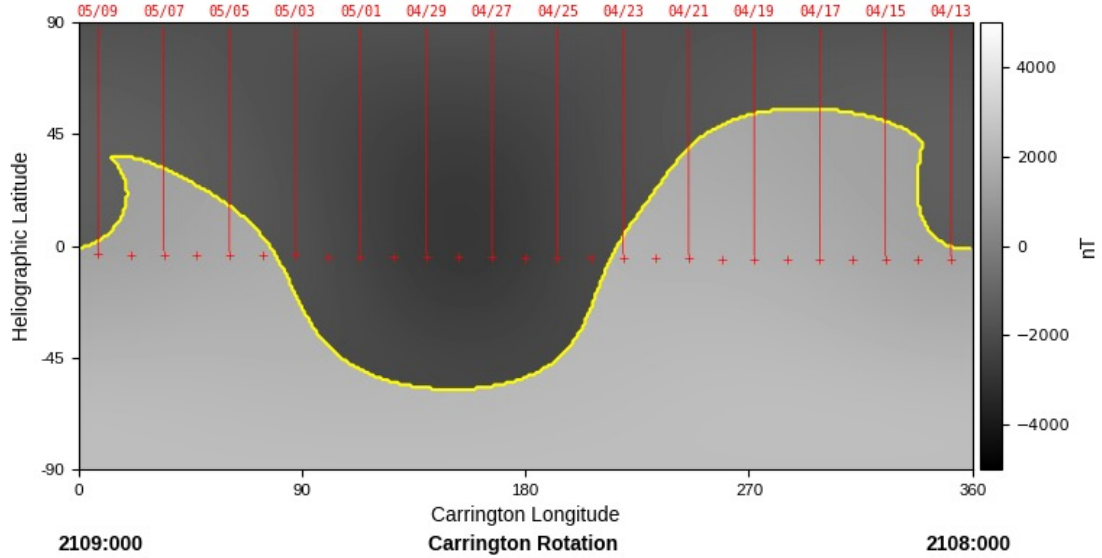
Sources of solar wind at Sun's surface (1 R_s)



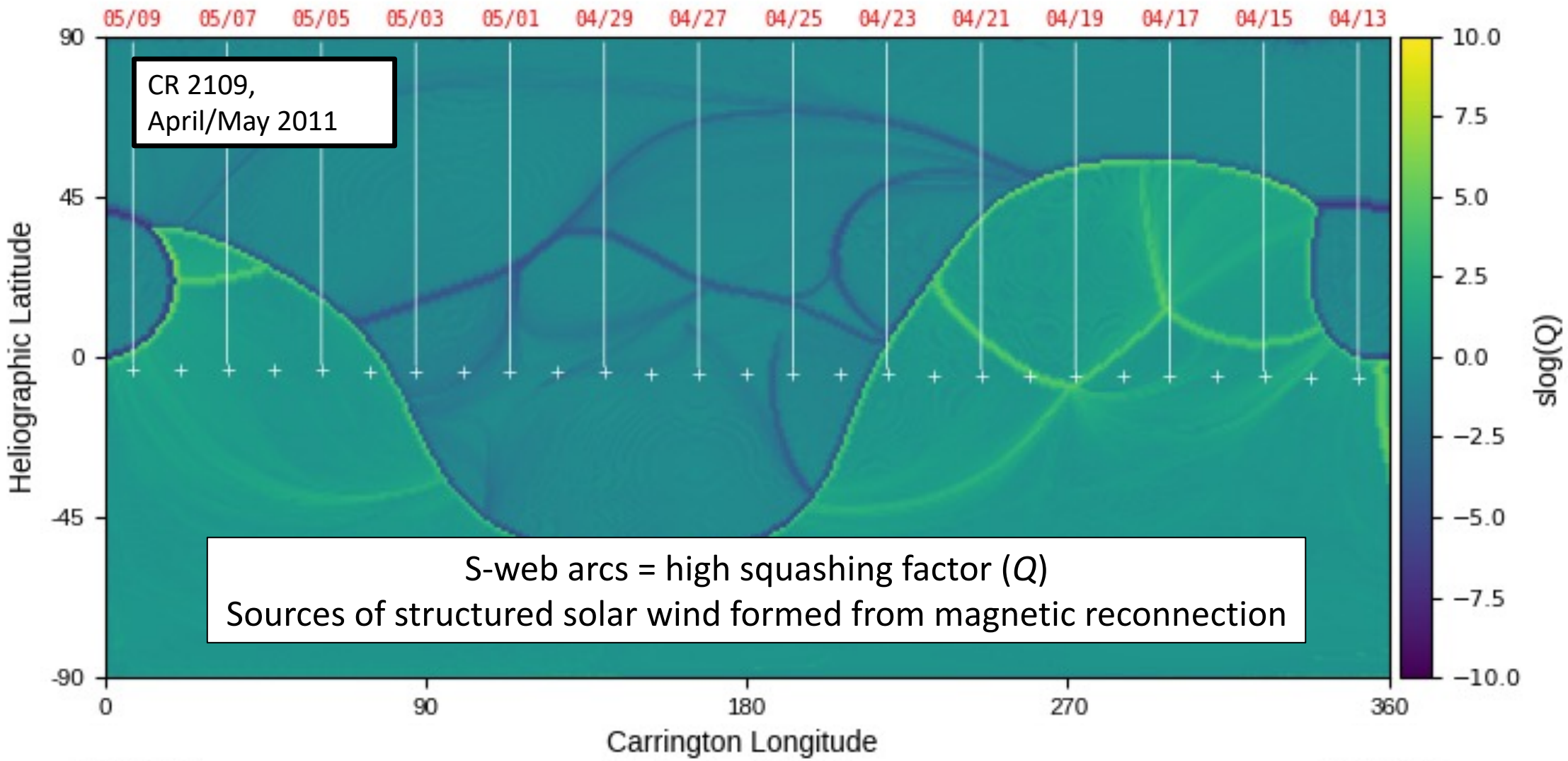
S-web



Coronal Field at 5 R_s



WSA is the only community tool that can quantify the value of *Q* related to in situ solar wind measurements, revealing when the observed SW originates from magnetic open-closed boundary



Solar source regions with high *Q* correspond to slow, hot solar wind with corresponding changes in composition at L1.

CR 2109,
April/May 2011

B_r polarity

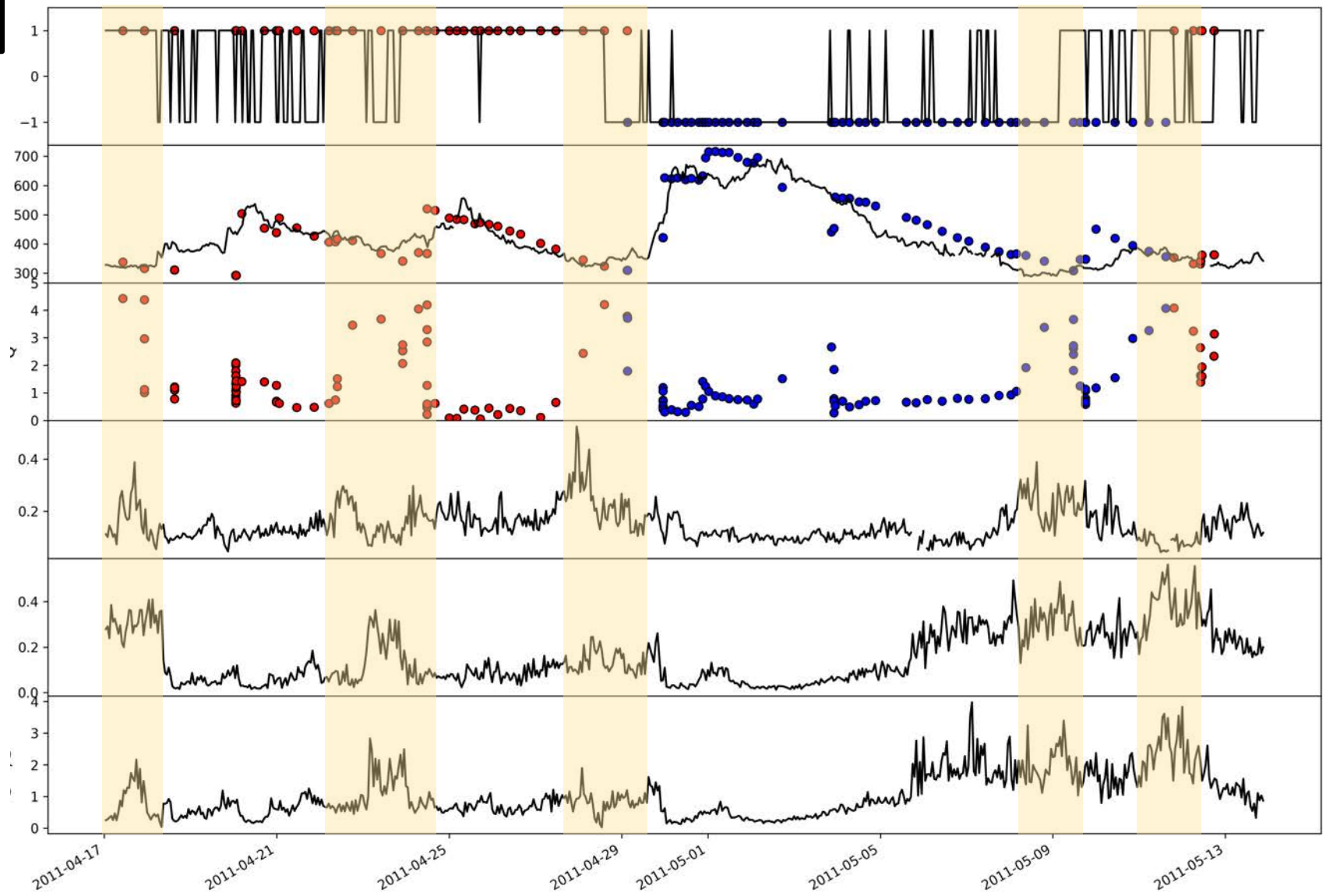
Solar wind speed (km/s)

Squashing factor (*Q*)

Fe/O composition

O^{7+}/O^{6+} (related to *T*)

C^{6+}/C^{5+} (related to *T*)

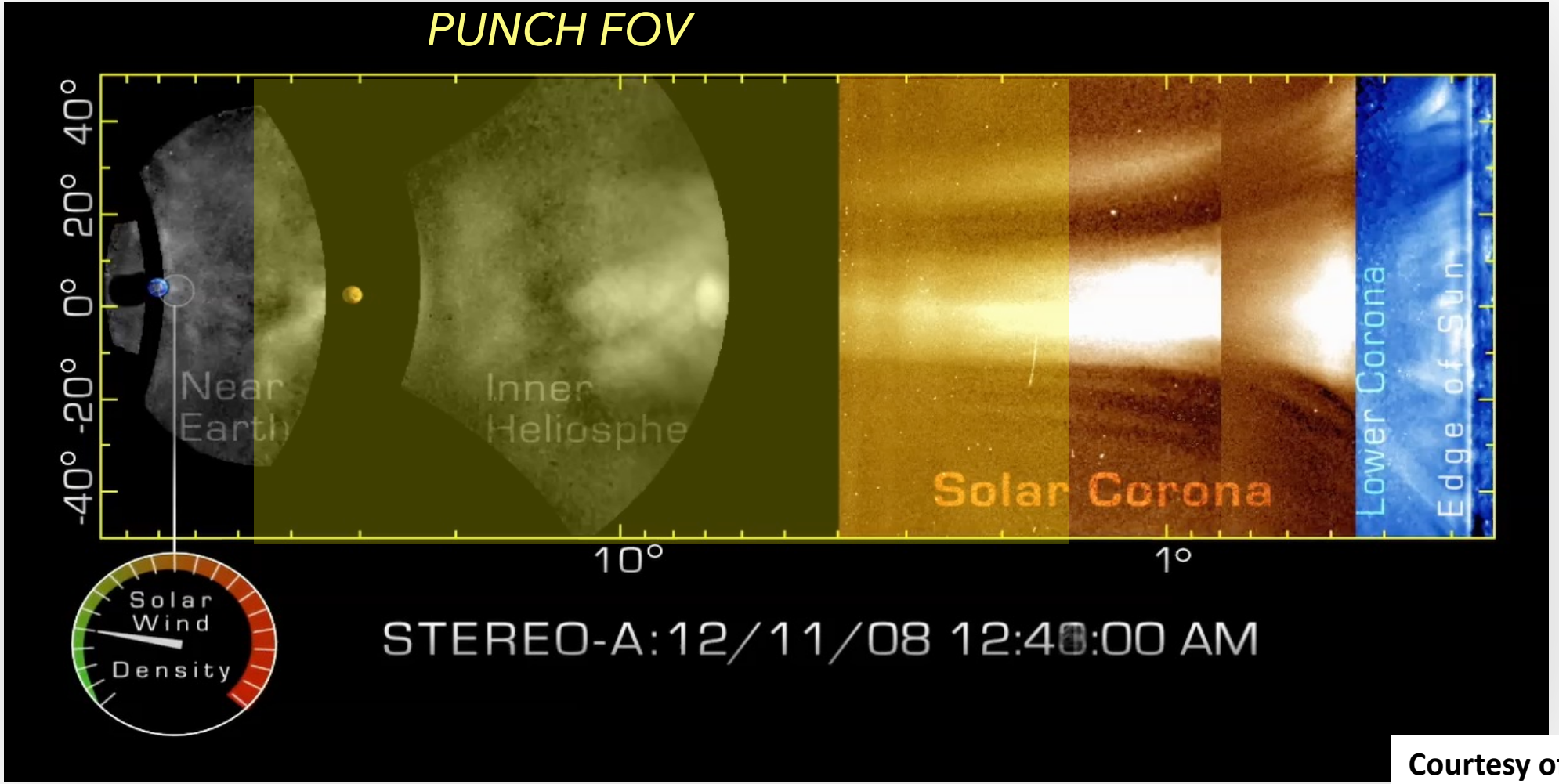


WSA model = color pos/neg B field

ACE obs = black

Wallace et al., in prep

ADAPT-WSA can help interpret PUNCH inner heliosphere observations (and any corresponding in situ measurements) based on the model-derived low coronal magnetic field and S-web.

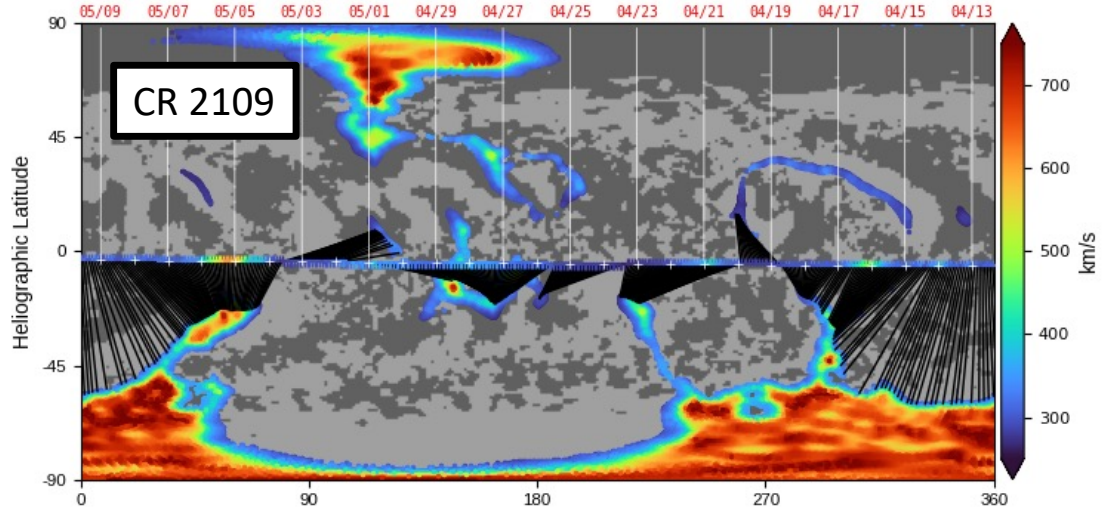


Courtesy of Craig DeForest

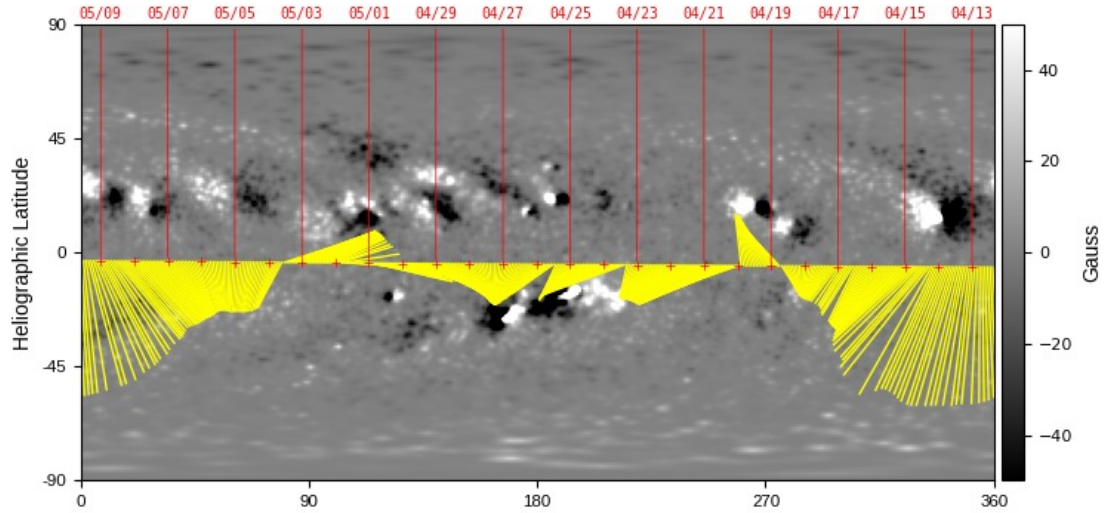
Backup slides

Methodology

WSA coronal holes - Sources of solar wind observed at ACE/L1



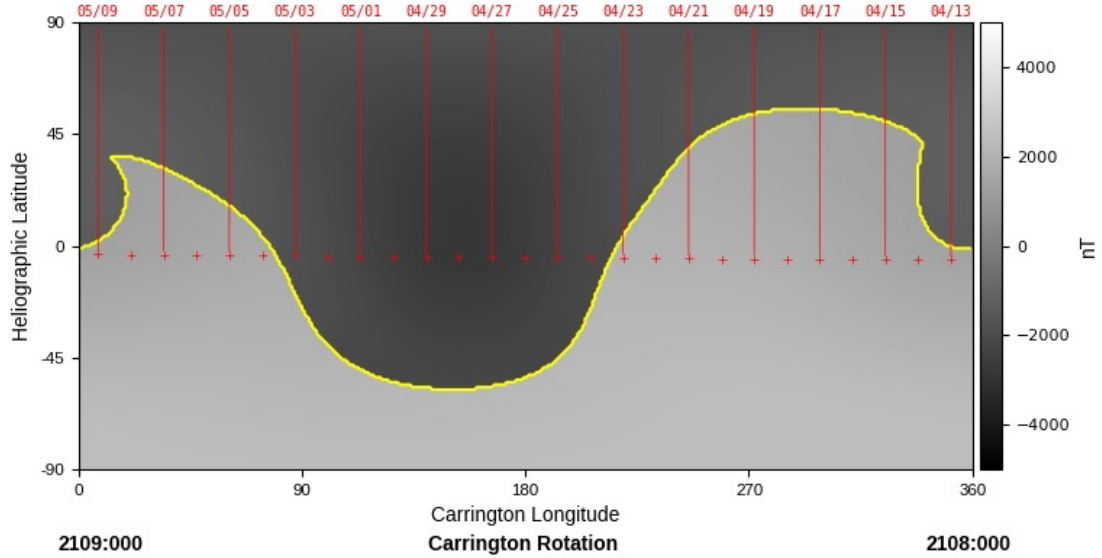
Sources of solar wind at Sun's surface (1 R_s)



Corrections were made for periods in which open-closed boundary solar wind was influenced by an AR.

Not possible to detect with footpoint connectivity criteria alone, or by any automated filtering of model parameters

Coronal Field at 5 R_s



Results/Discussion

What are the defining in situ properties of solar wind originating from CHs, QS, and ARs?

- Charge States
- Fe/O / FIP enhancement most closely follows source region
- alpha to proton ratio
- Appears to be dependence of local source region within coronal streamers

What do the in situ properties unique to each source region tell us about how the solar wind is formed?

More to do:

- Run truly quiet period, more rigorous comparison of min vs max periods to determine cycle dependence.
- Wind data for alpha to proton
- Conduct similar statistics for HS vs PS (independent of underlying source region)

What: Two ISFM teams have worked together to derive the S-web with WSA magnetic field lines, and integrate this as a tool into the model.

Scientific motivation: The solar magnetic open-closed boundary (revealed by the S-web) is a source of ambient solar wind structures that drive magnetospheric dynamics. Our tool can identify when the observed solar wind originates from this location.

Results: We have related Earth impacting solar wind structure and variability observed at L1 to its solar origin – the magnetic open-closed boundary.

We can now provide this output to the heliophysics community via our team or the CCMC

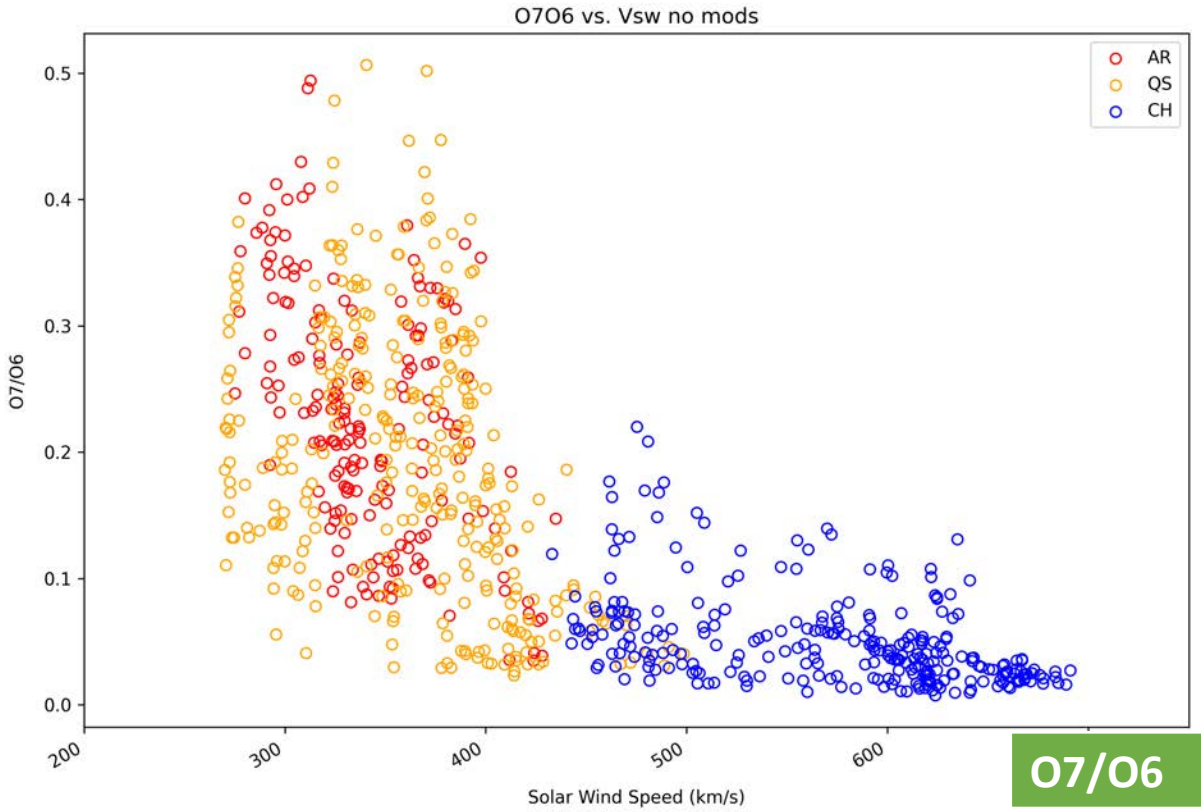
Research applications:

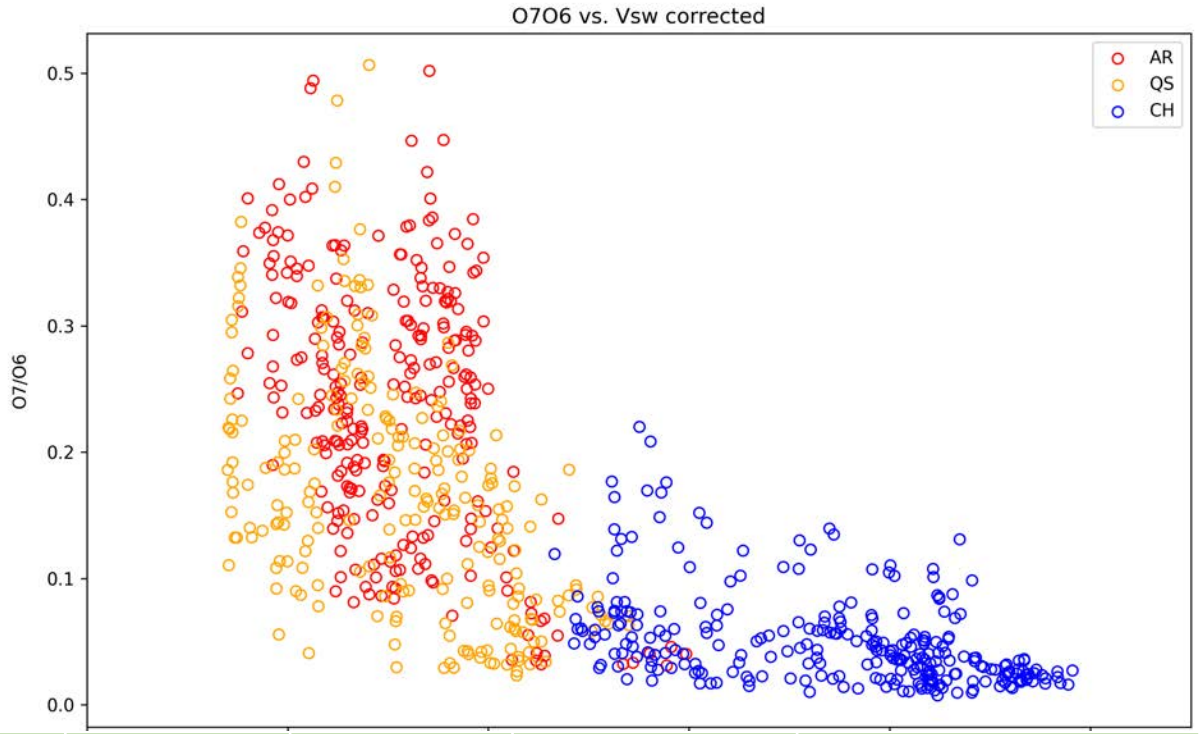
- Understanding solar wind formation, characterizing the solar wind from specific sources
- Statistically quantifying which sources produce geoeffective solar wind and how much of the time

Long term operational application: Using WSA model-derived parameters to *forecast* when and in what ways the ambient solar wind will be geoeffective.

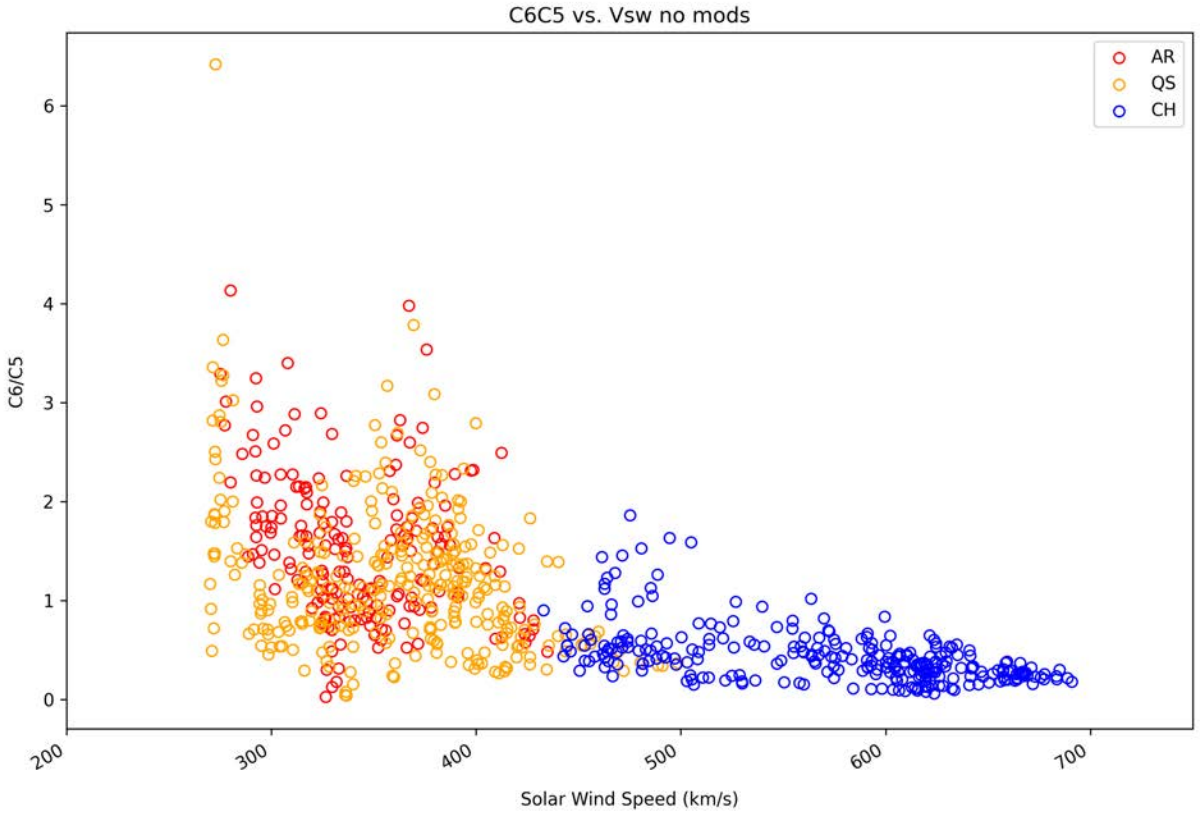
The solar wind originates from three types of coronal magnetic field: active region, quiet Sun, or coronal hole

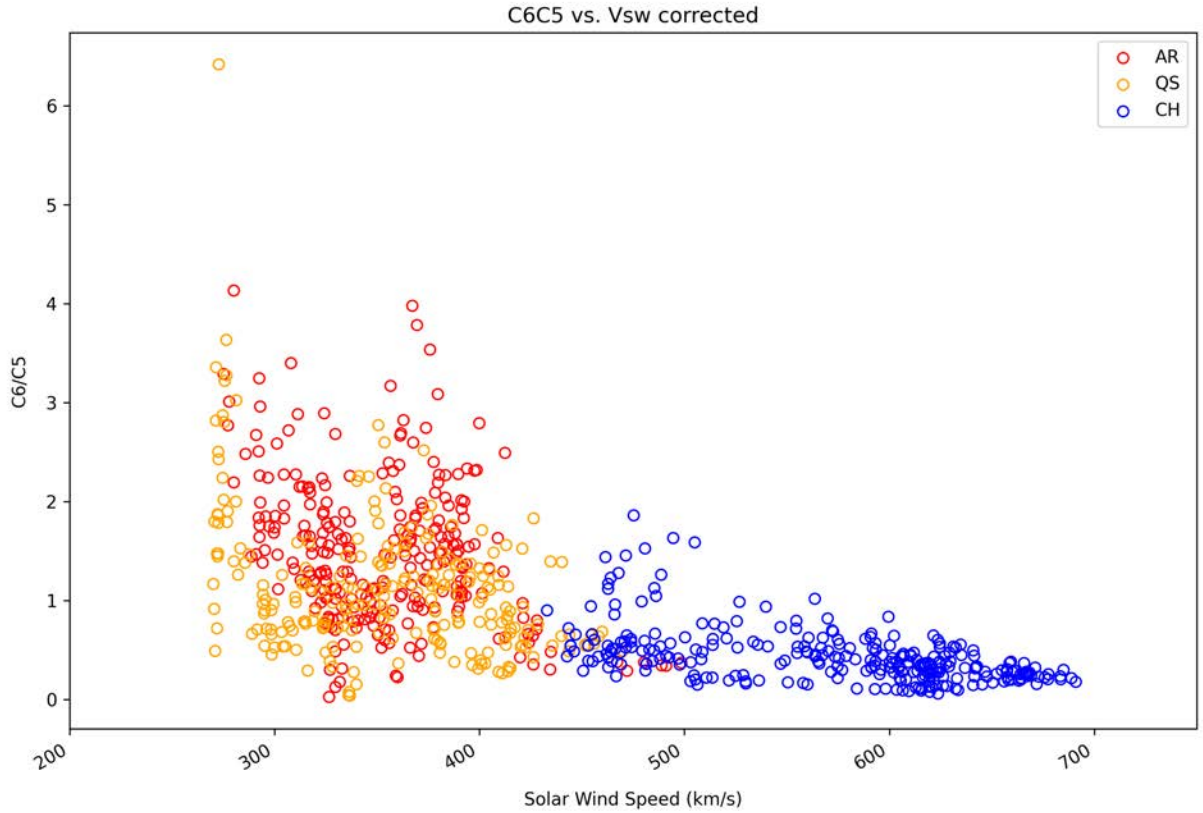
The solar wind originates from three types of coronal magnetic field: active region, quiet Sun, or coronal hole



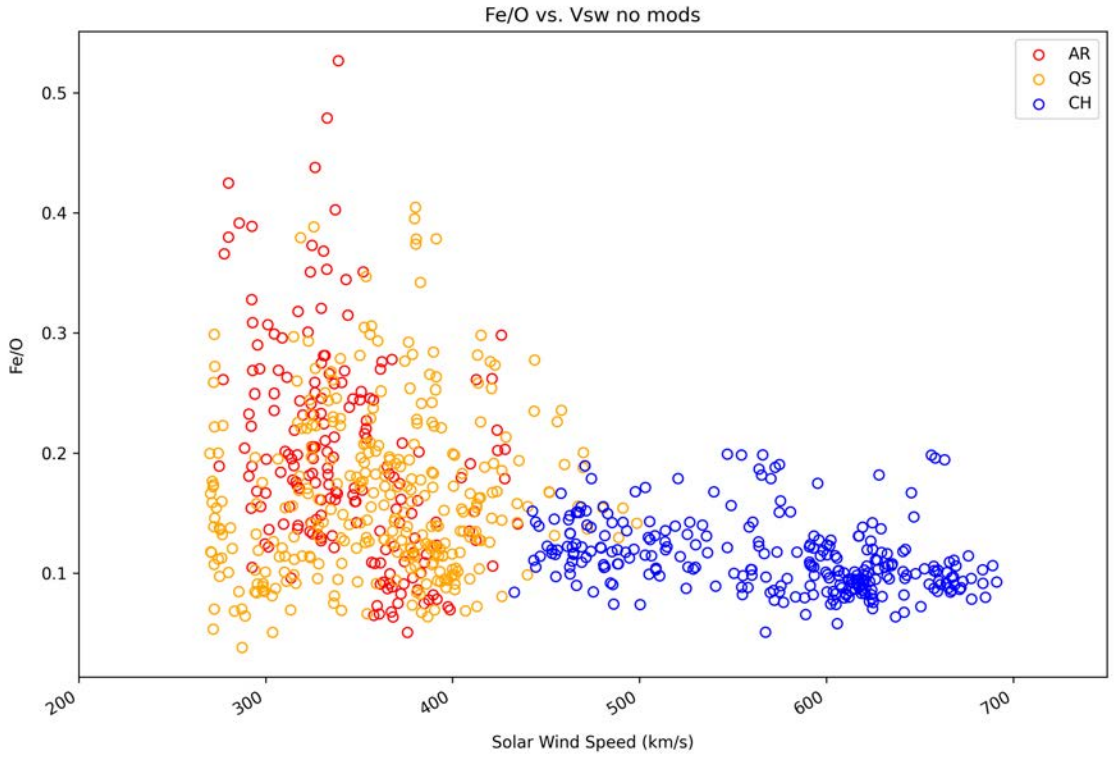


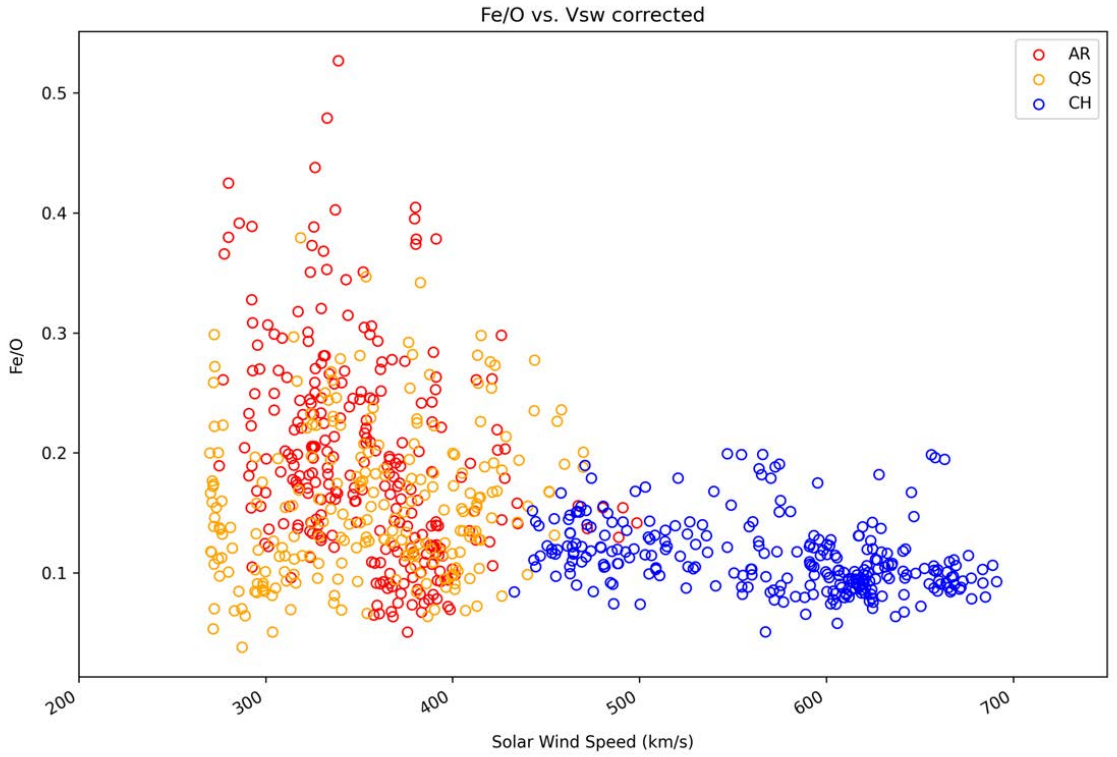
O7/O6	avg	std	min	max
AR	0.238738	0.101408	0.031032	0.50178
QS	0.165386	0.094623	0.023123	0.50646
CH	0.051094	0.03757	0.007356	0.21997



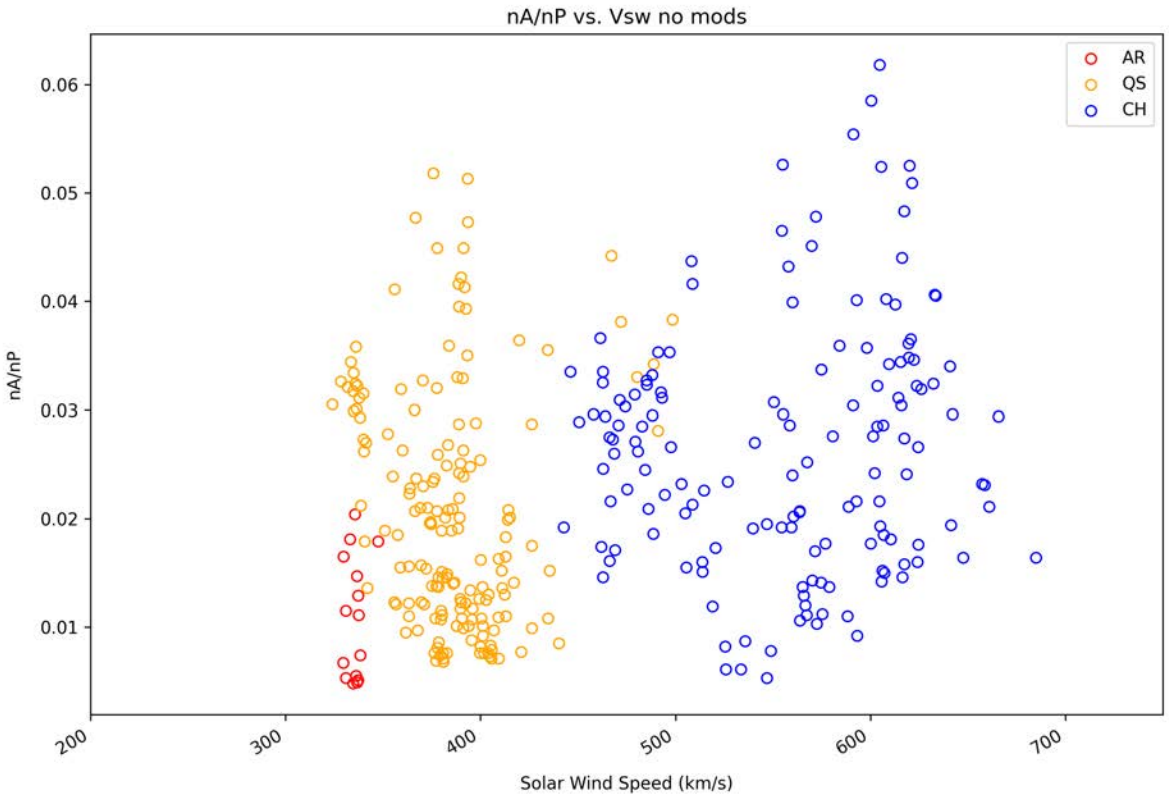


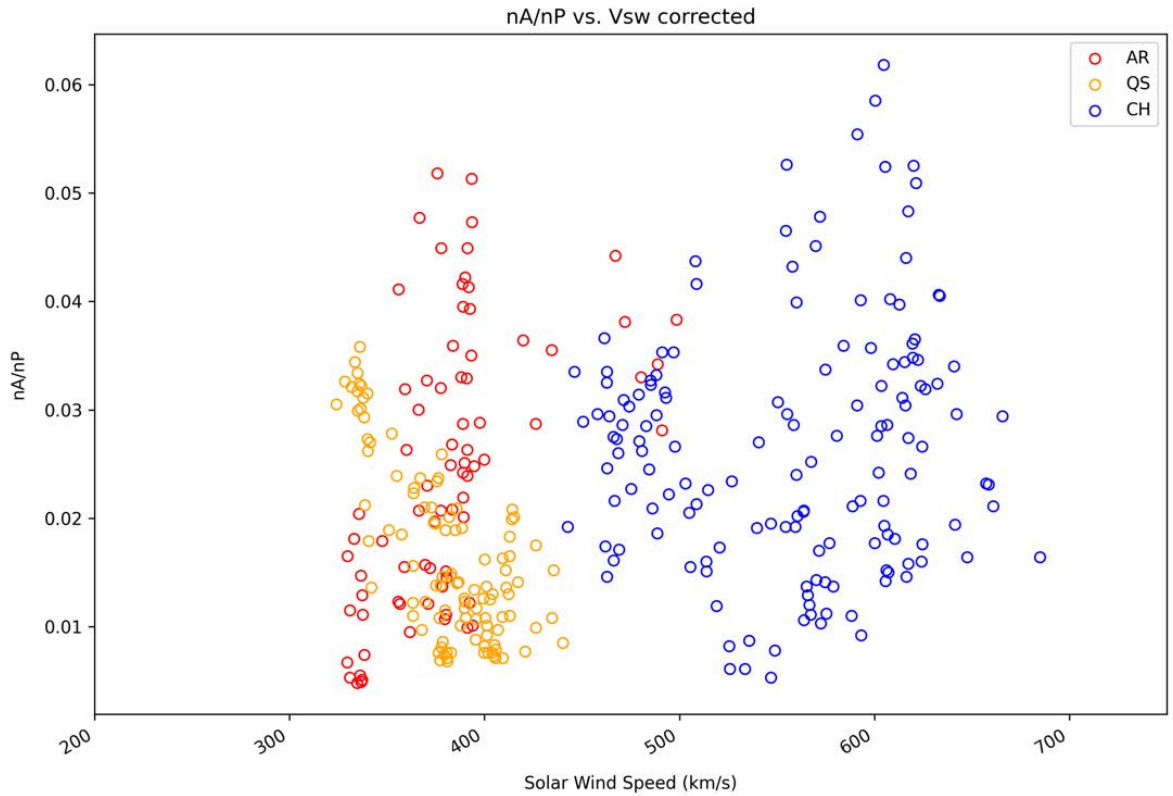
C6/C5	avg	std	min	max
AR	1.493854	0.729994	0.024021	4.1304





Fe/O	avg	std	min	max
AR	0.192749	0.086306	0.050475	0.52687


nA/nP vs. Vsw no mods
AR
QS
CH
0.06
0.05
0.04
0.03
0.02
0.01
nA/nP
200
300
400
500
600
700
Solar Wind Speed (km/s)


nA/nP vs. Vsw corrected
AR
QS
CH
0.06
0.05
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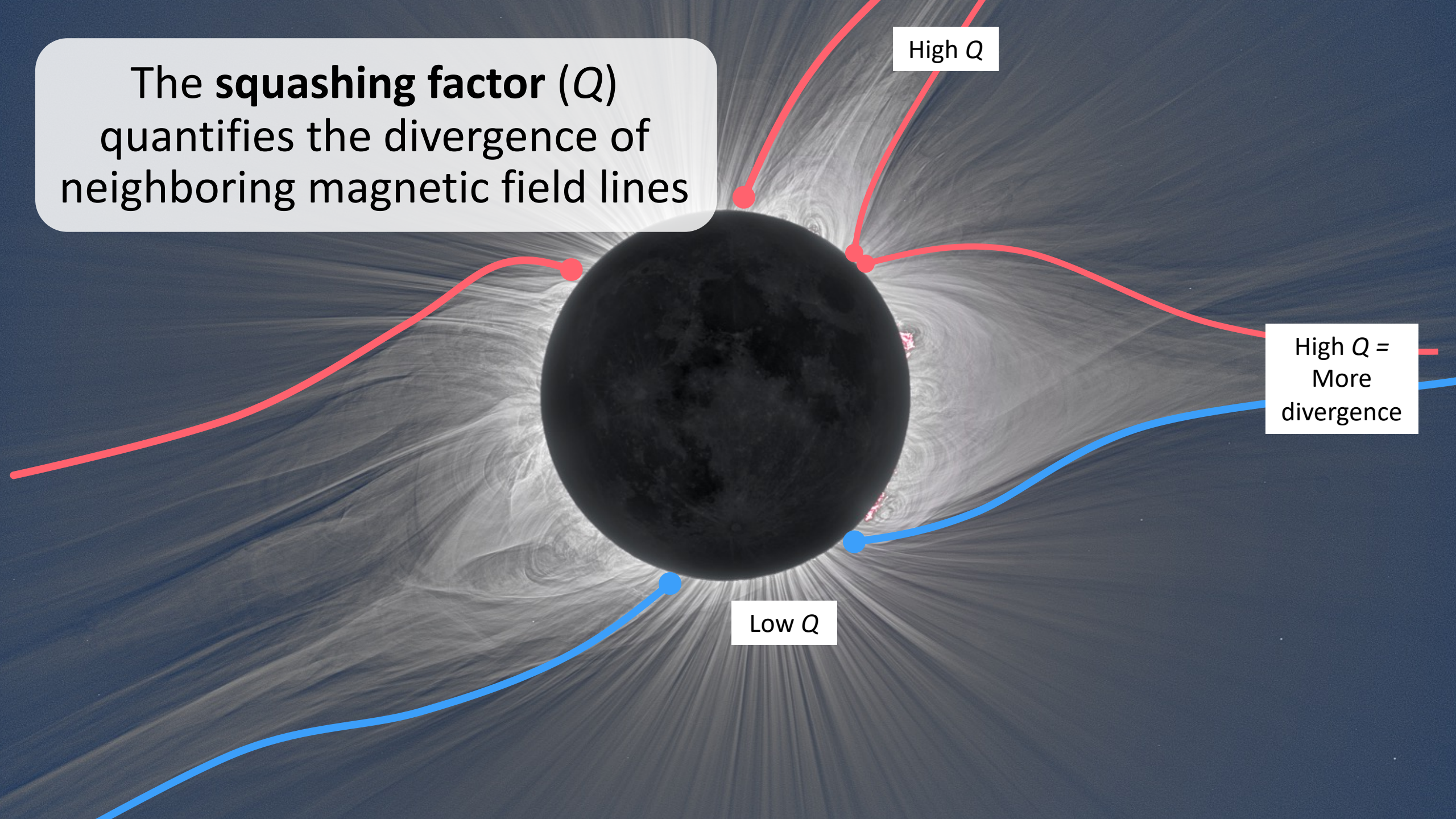
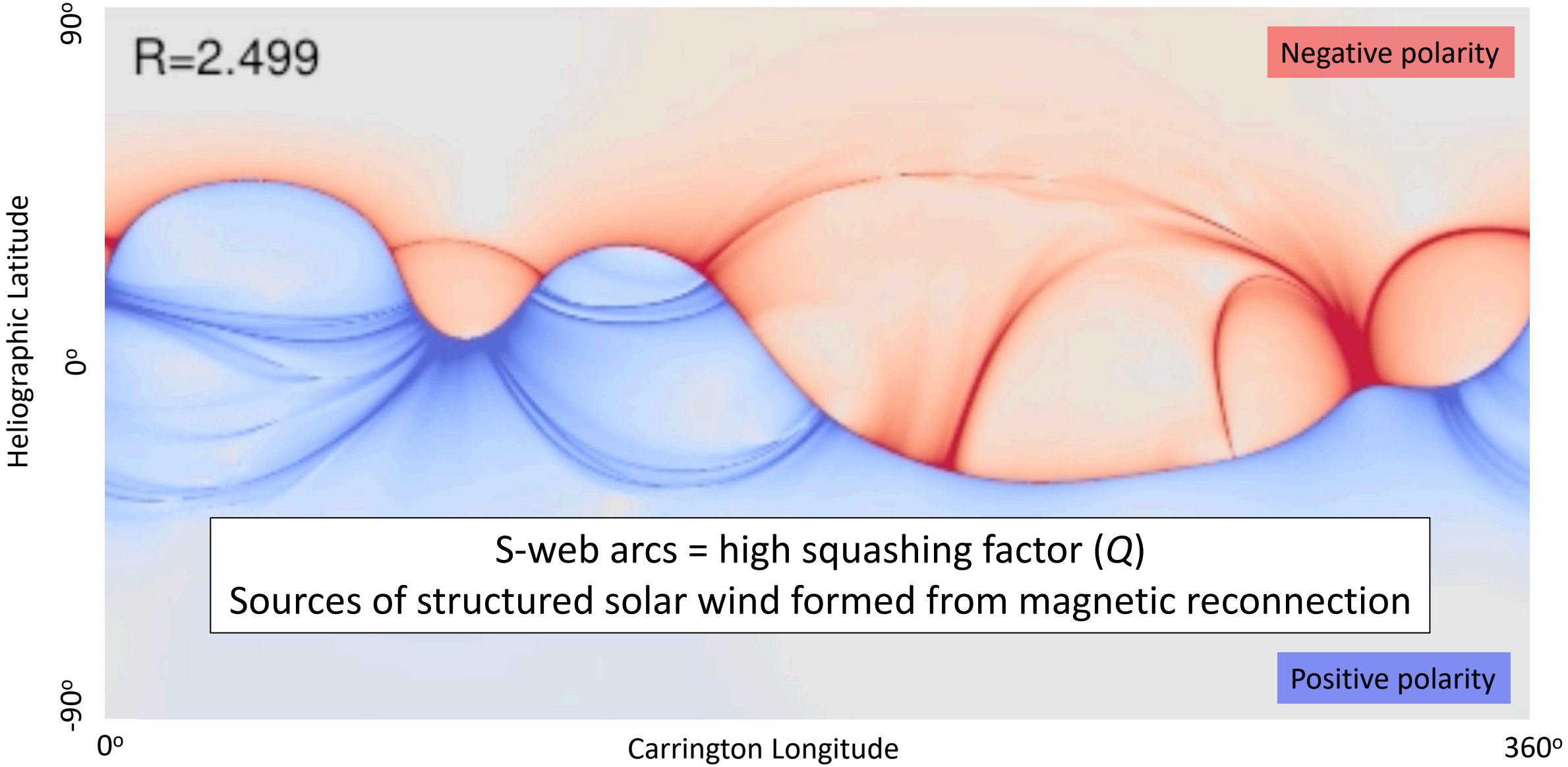
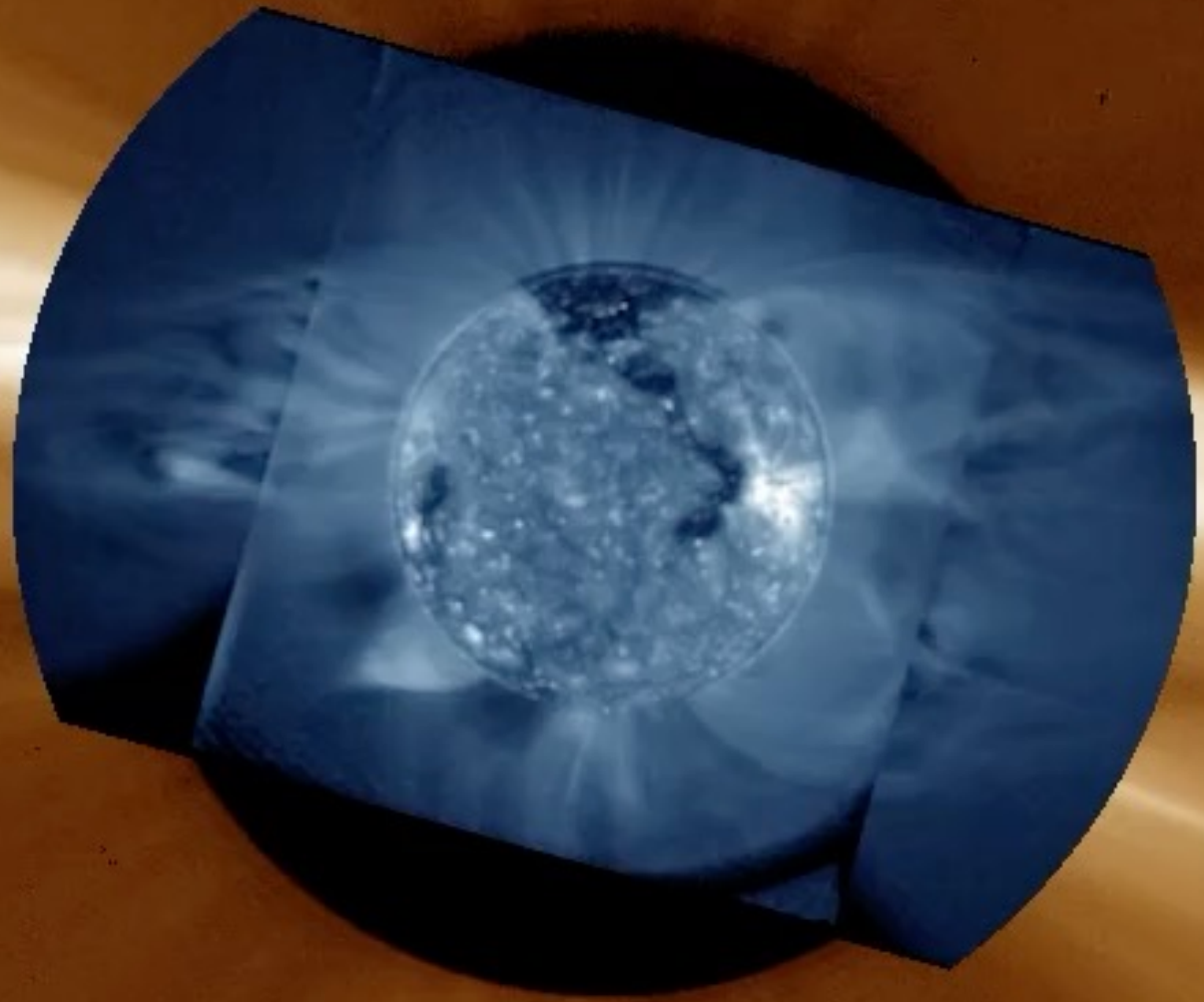
Solar Wind Speed (km/s)


The **squashing factor** (*Q*) quantifies the divergence of neighboring magnetic field lines
High *Q*
High *Q* = More divergence
Low *Q*

The coronal separatrix-web (S-web) reveals where the magnetic open-closed boundary maps to in the heliosphere



The ambient solar wind is formed by dynamics in the corona, and is highly structured at mesoscales.



Seaton et al., 2021