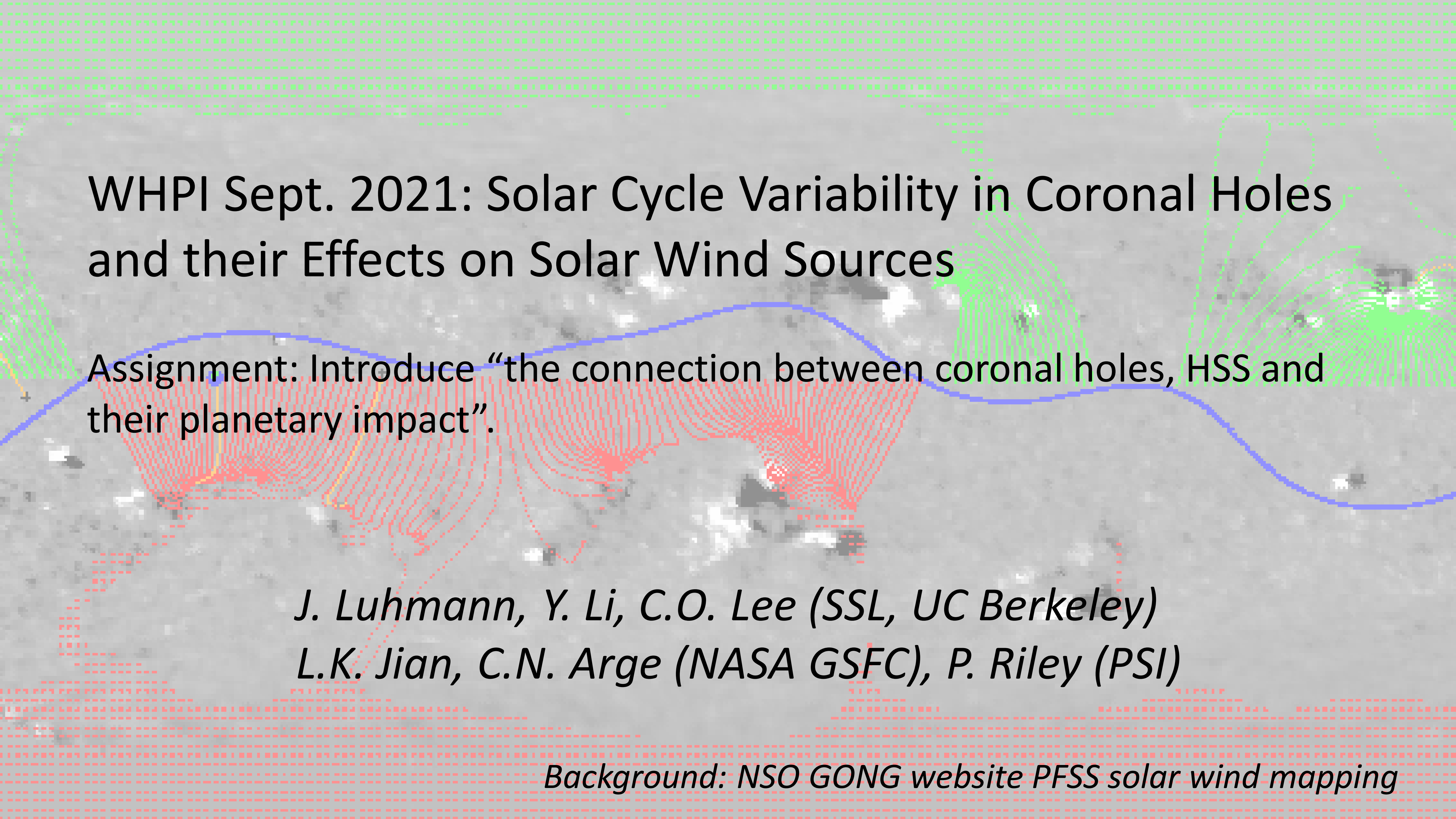

WHPI Sept. 2021: Solar Cycle Variability in Coronal Holes and their Effects on Solar Wind Sources

Assignment: Introduce “the connection between coronal holes, HSS and their planetary impact”.

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L.K. Jian, C.N. Arge (NASA GSFC), P. Riley (PSI)

Background: NSO GONG website PFSS solar wind mapping

The solar wind time series contains much information about how coronal structure evolves through the solar cycle, and how different cycles compare. The challenge is to interpret what Is observed in the ecliptic - which provides a limited view. HSSs and SIRs/CIRs are prominent (and geoeffective) features whose behavior can be traced to their global coronal origins.

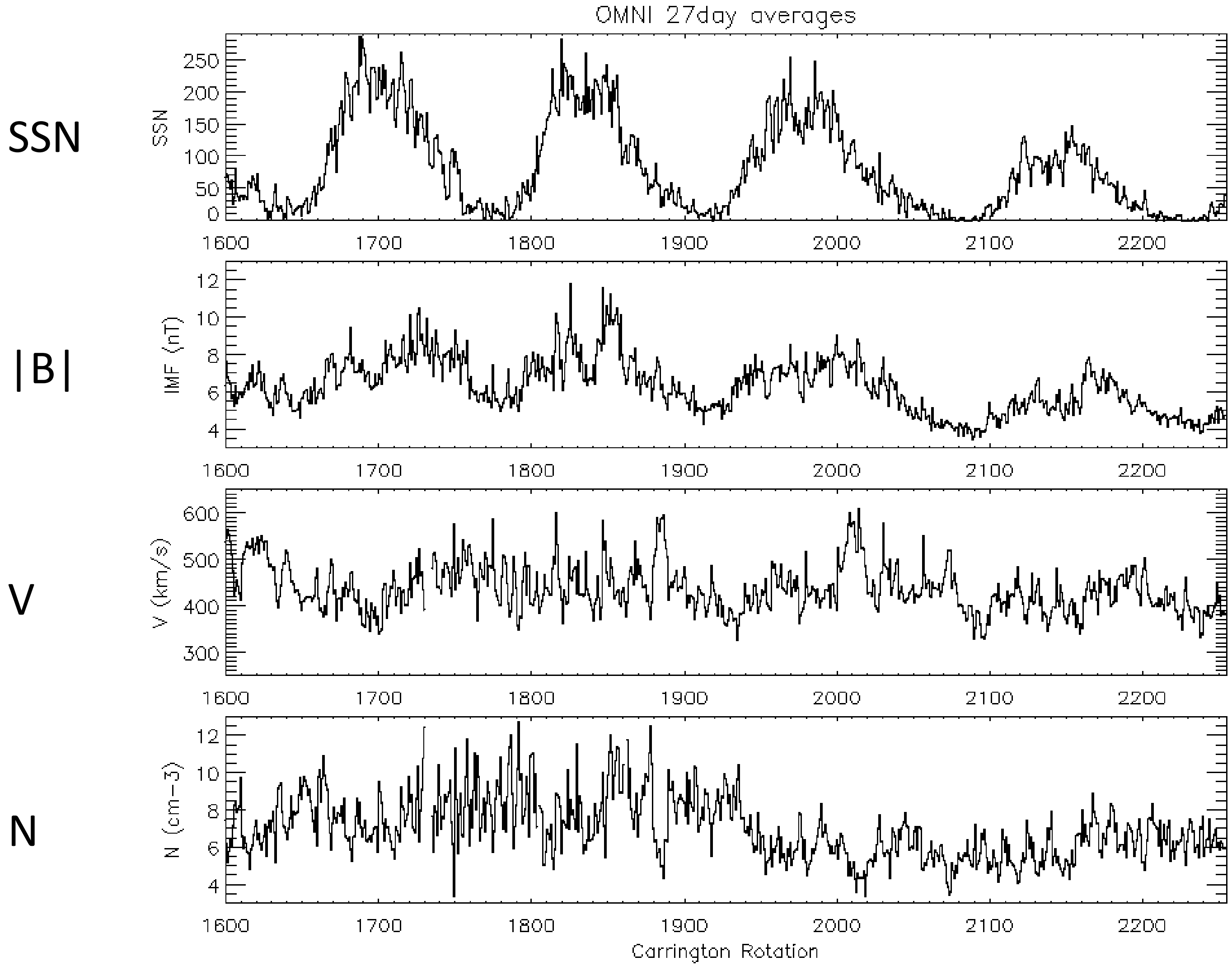
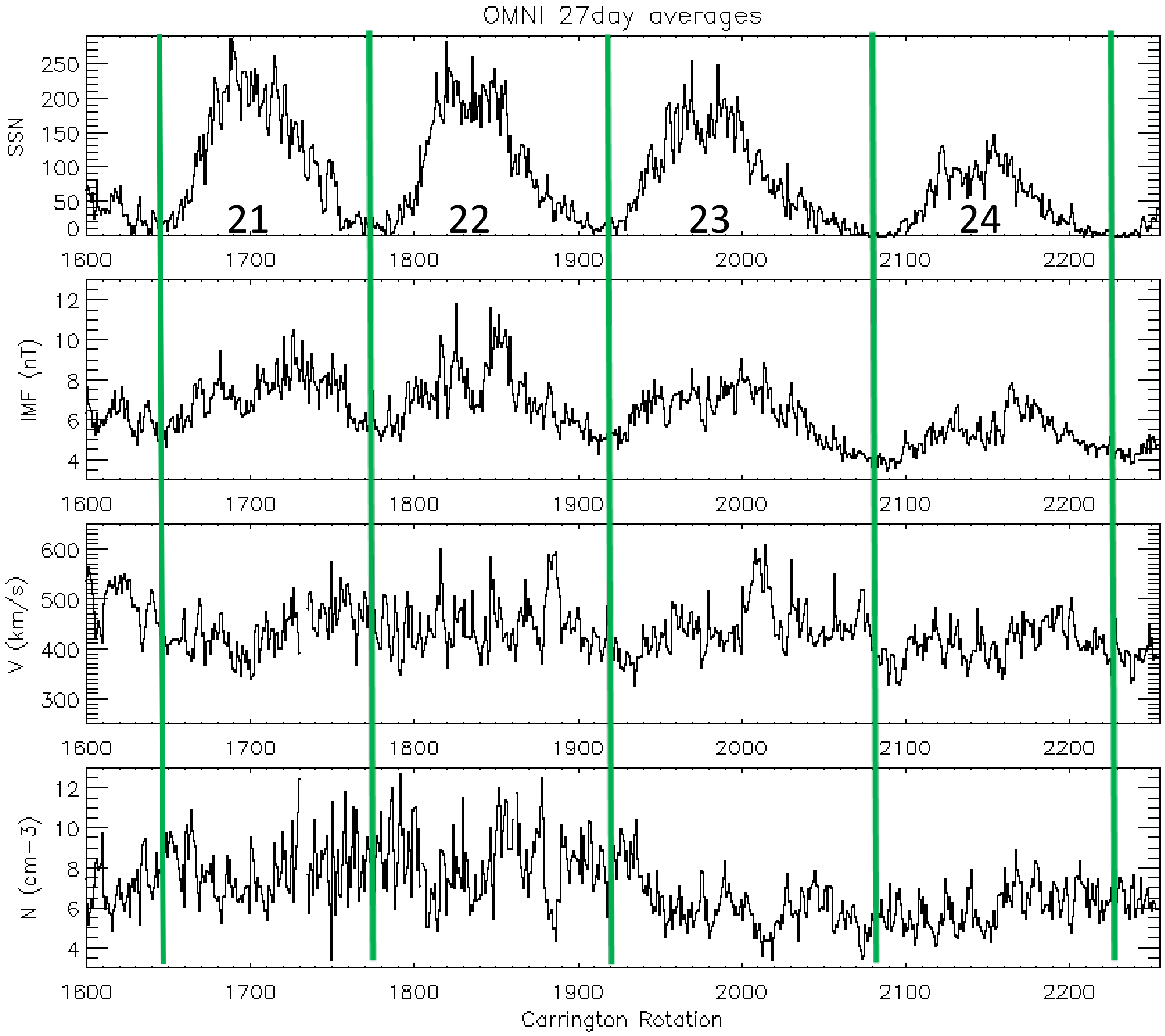


Figure from Yan Li

We use a time proxy 'Carrington Time' that is convenient for studies where solar rotation is a main organizing influence.



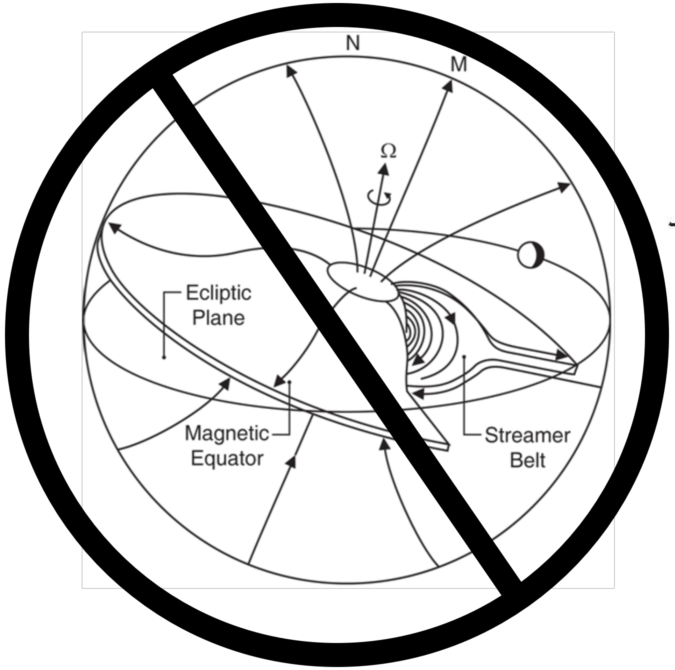
Starts for Cycles

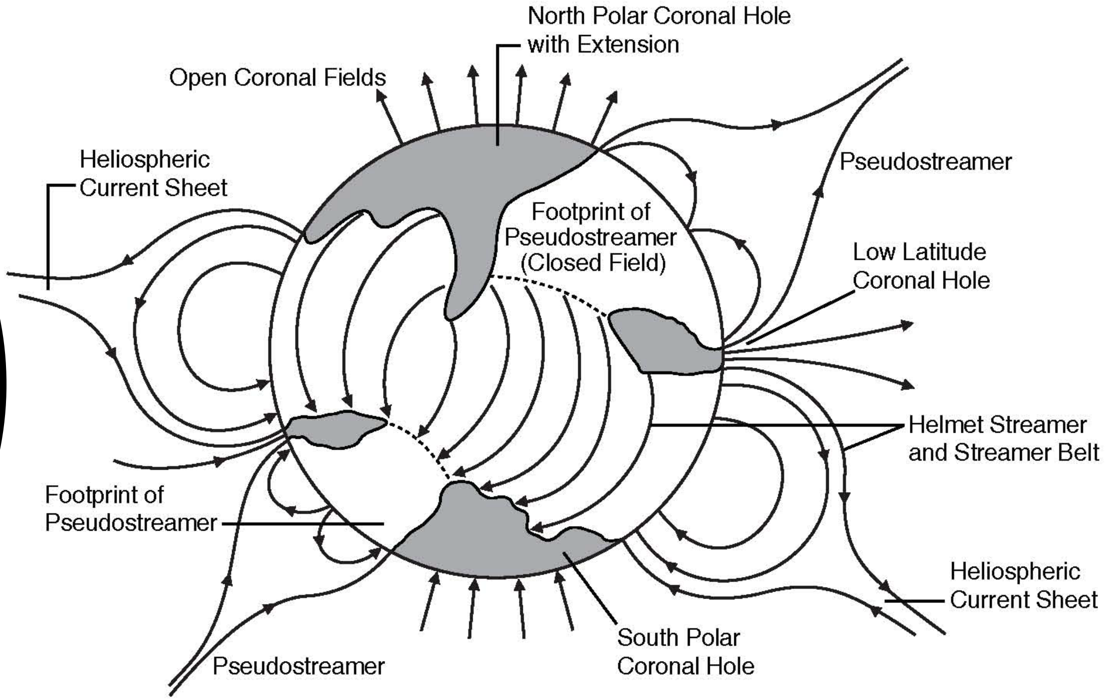
21: CR1639 (3/1976)
22: CR1780 (9/1986)
23: CR1913 (8/1996)
24: CR2078 (12/2008)
25: CR2225 (12/2019)

Sources of the 'ambient' solar wind include:

1. PCHs (Polar Coronal Holes)
2. PCH extensions
3. Mid-Low latitude CHs
4. Helmet streamer and Pseudostreamer stalks and boundaries**

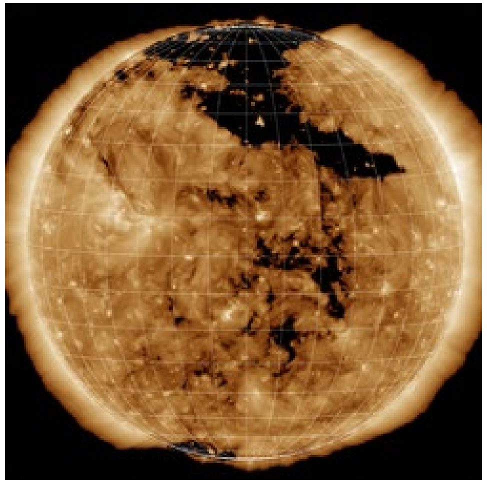
** including *transients currently not part of most models*

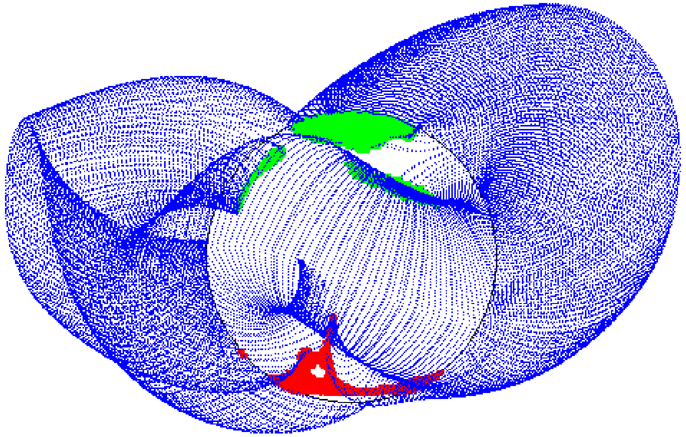


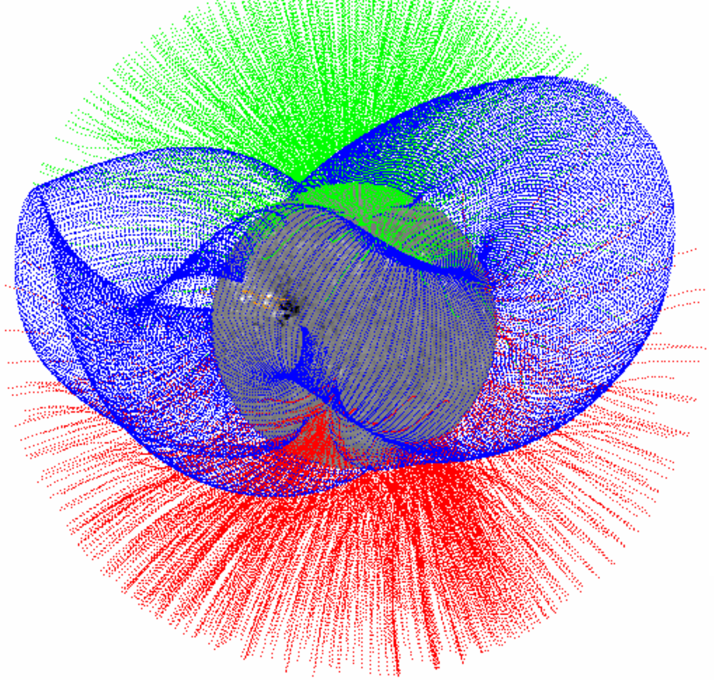


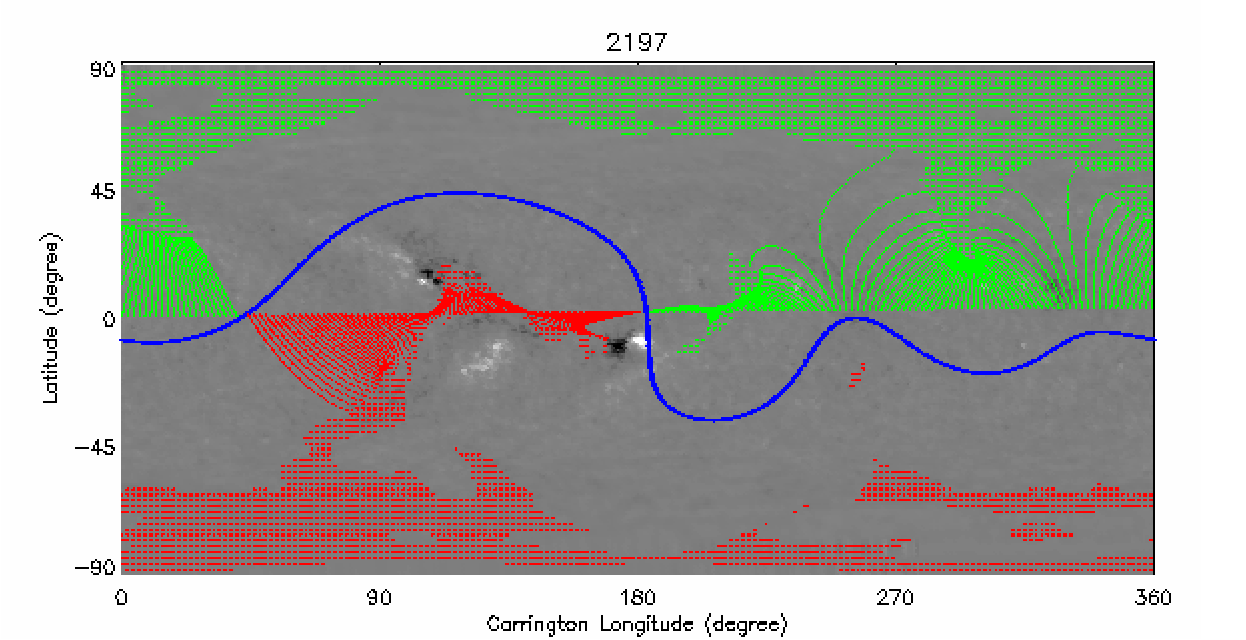
Luhmann et al., Proc. IAU 286, 2012

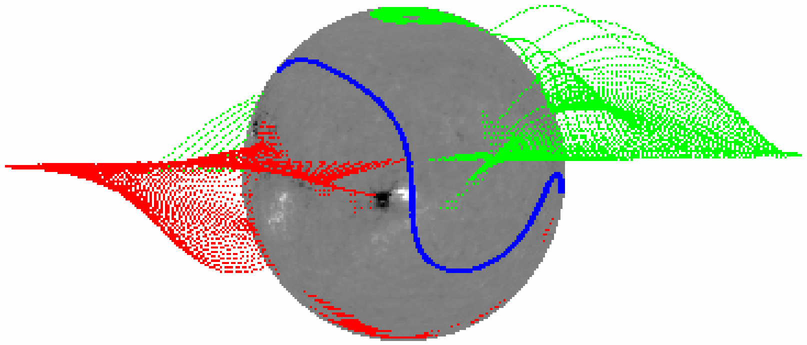
PFSS models enable first-order source mappings and visualizations of at least the quasi-steady CH contributions and stream boundaries









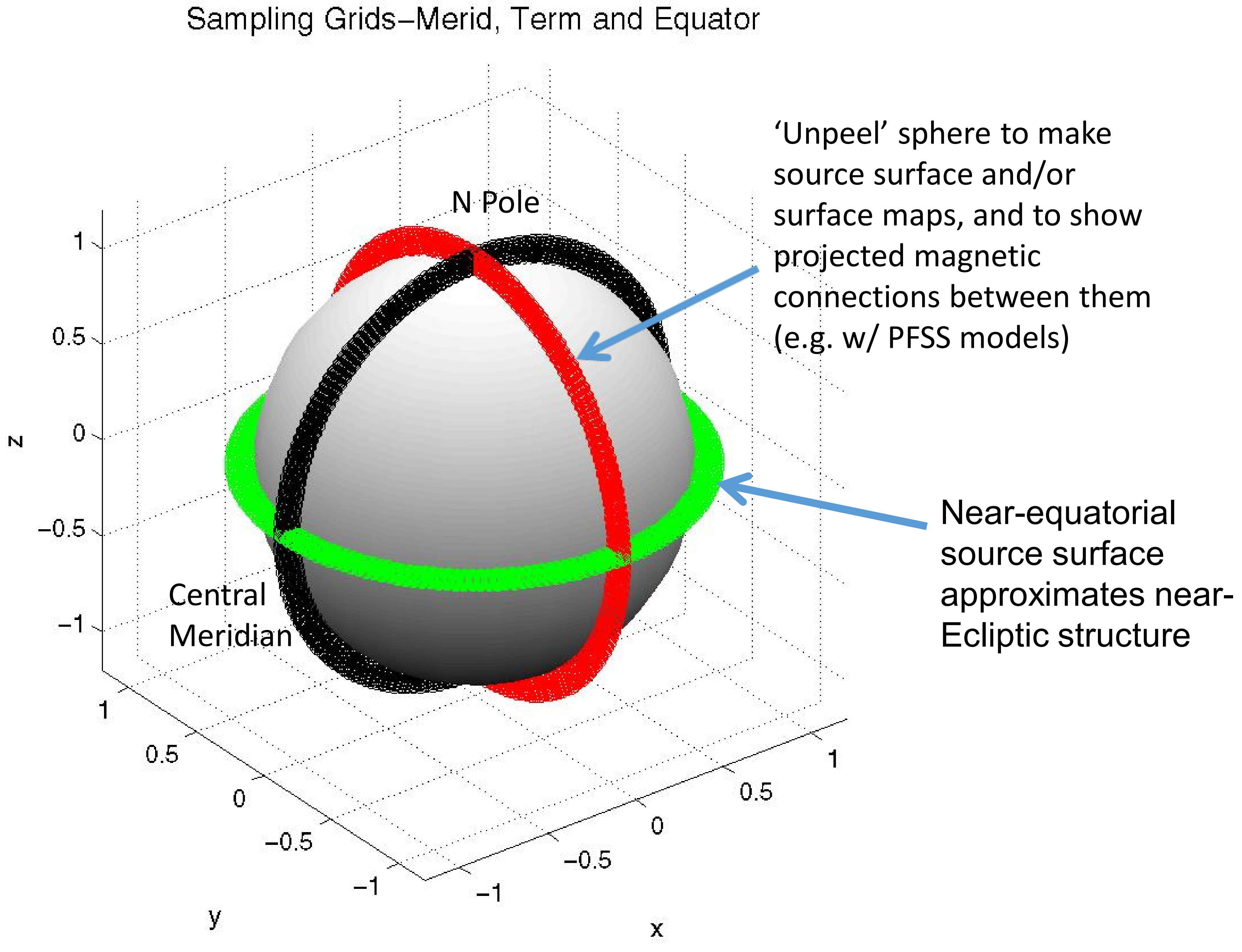


AIA EUV image, NSO GONG PFSS plots

Two Ways to visualize the 3D, rotating, evolving conditions are:

1) 'Timelines' of sequential, merged synoptic maps (latitude vs CR 'time' (long.) plots),

2) Contours of In-situ parameter time series stacked in sequential CR - length intervals (CR longitude vs CR 'time')



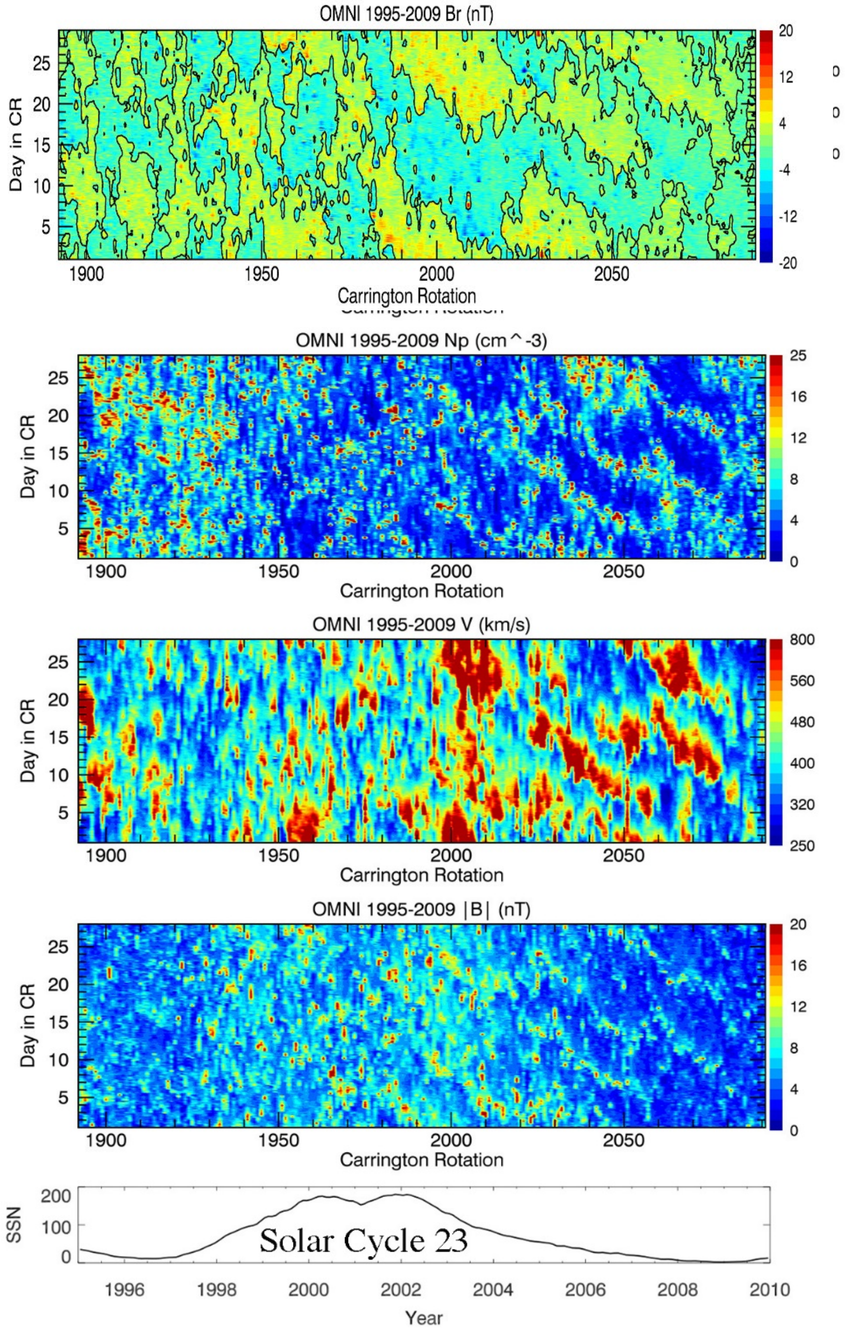
Example: OMNI data in CR day (long.) vs CR time form showing solar wind structure for cycles 23 and 24

Br

N

V

|B|



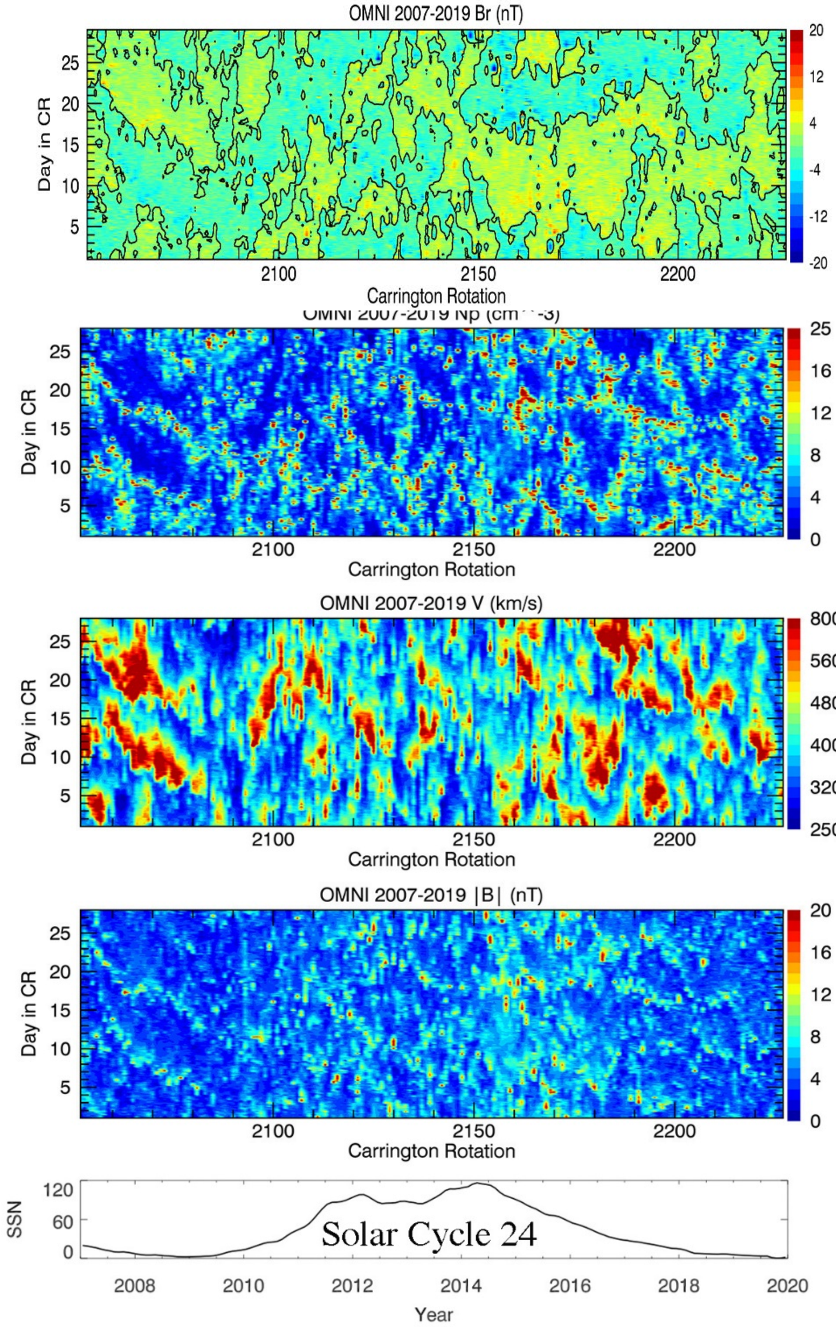
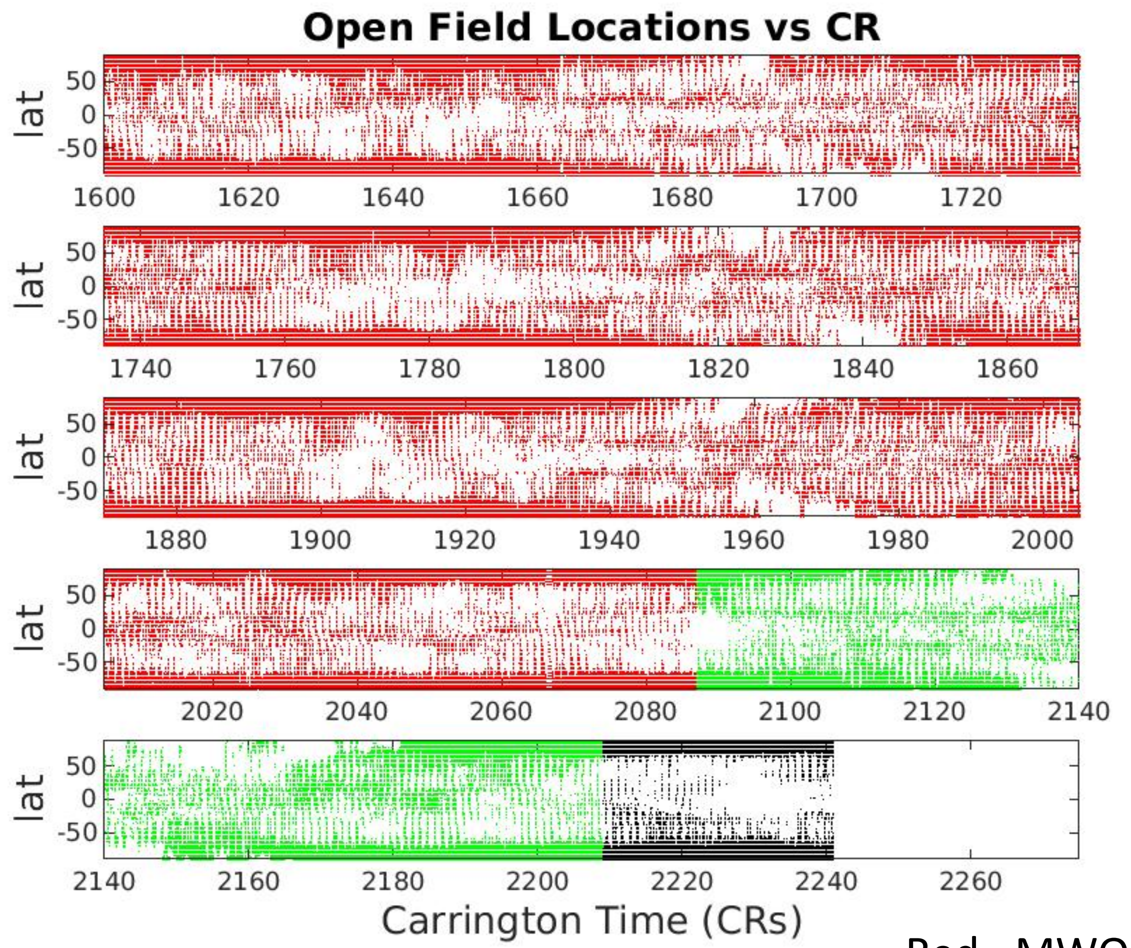


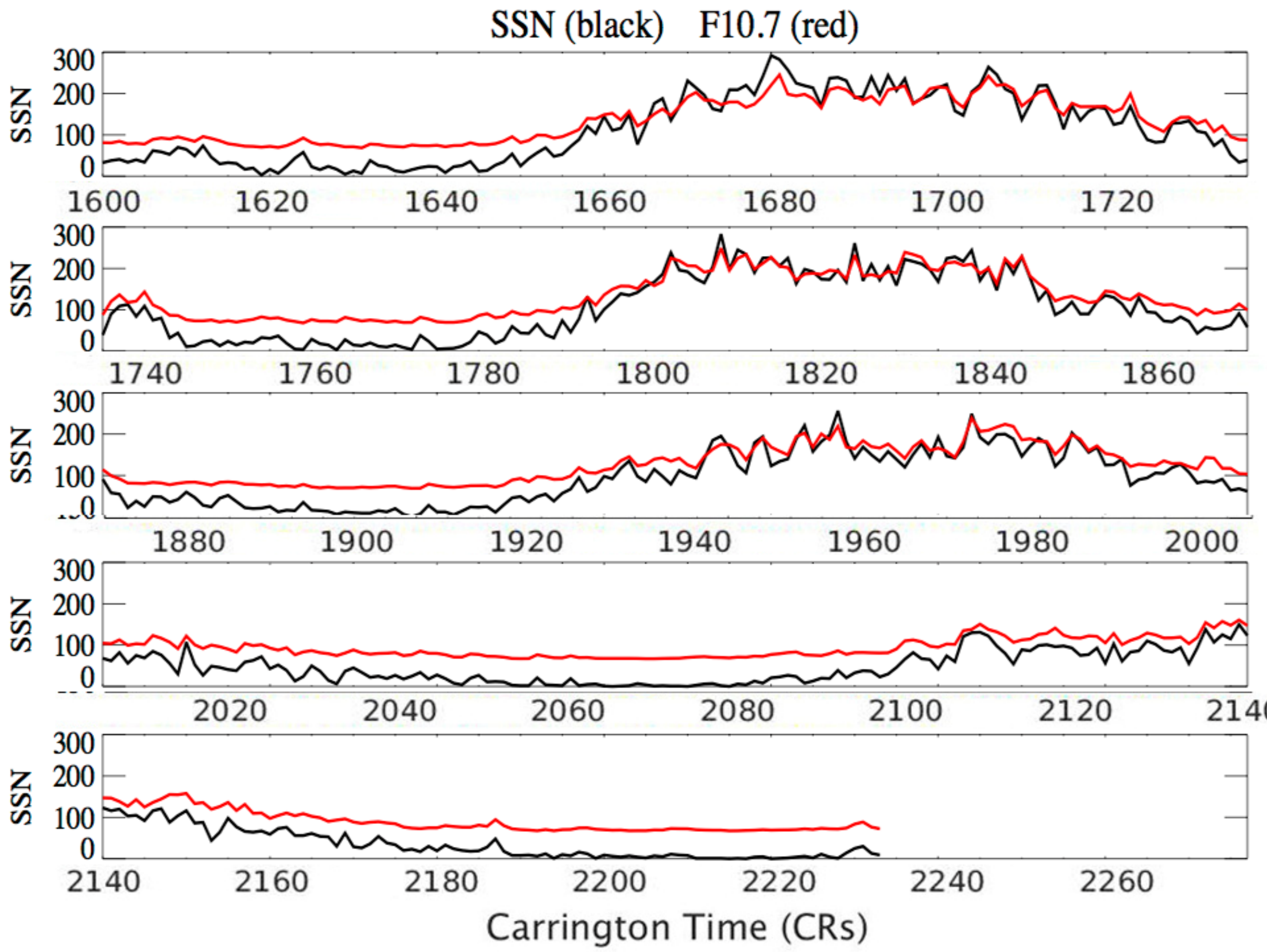
Figure: Yan Li

Example: Latitude vs. CR 'time' plots of modeled coronal holes for 4+ solar cycles-

PFSS Model Open Field Footpoint Maps



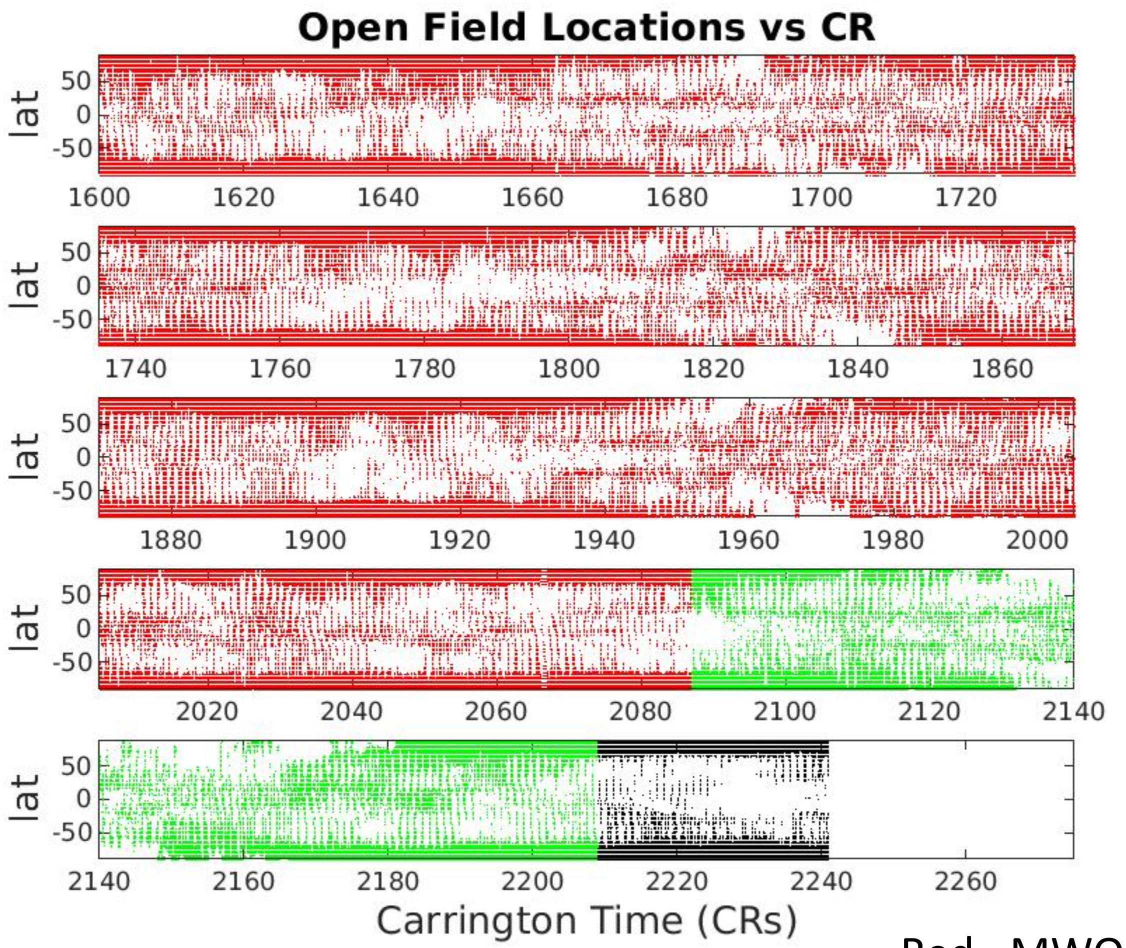
OMNI SSN and F10.7



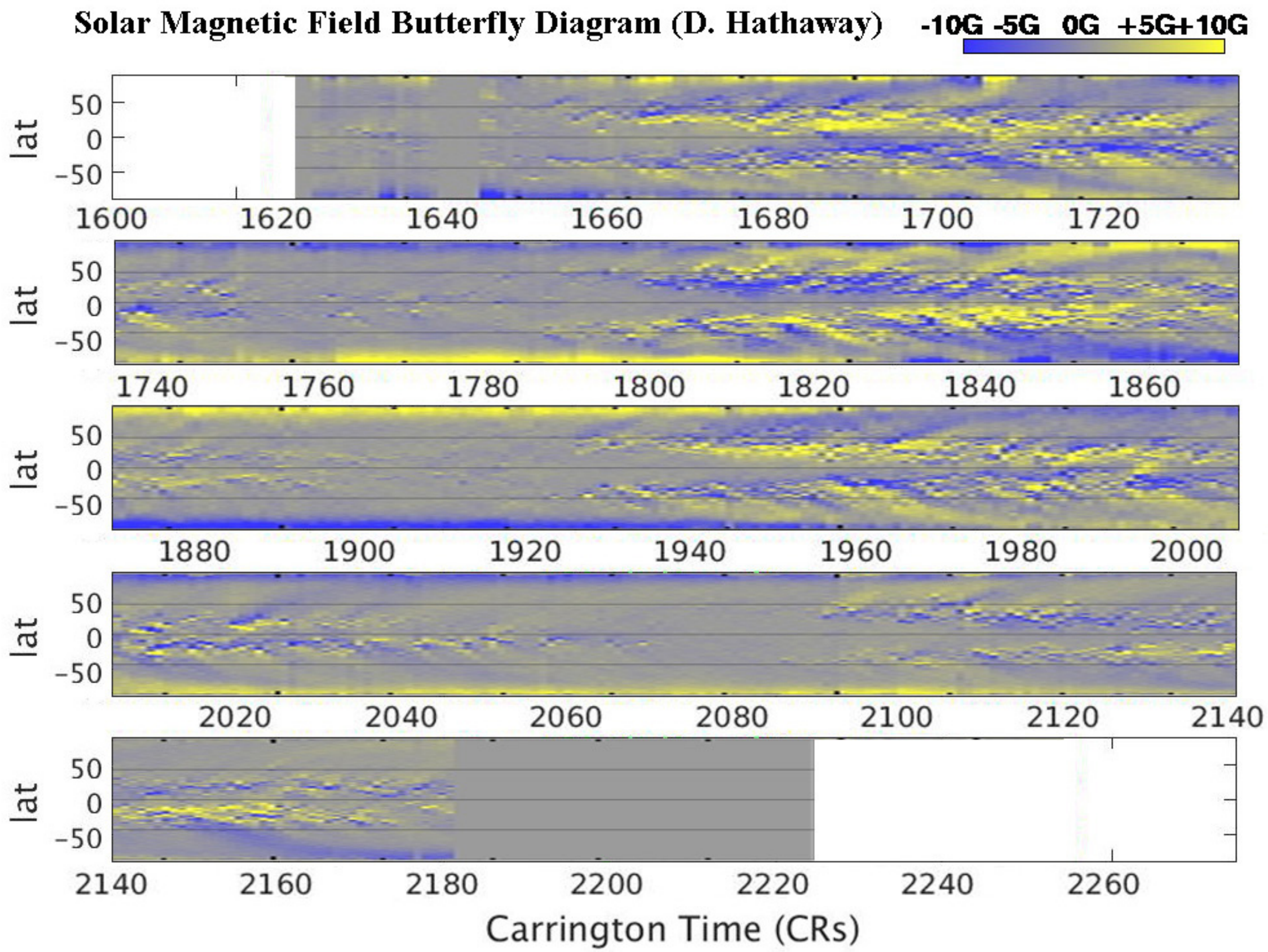
Red =MWO
Green=GONG-STEREO era
Black=GONG-PSP/SolO era

Example: Latitude vs. CR 'time' plots of modeled coronal holes for 4+ solar cycles-

PFSS Model Open Field Footpoint Maps



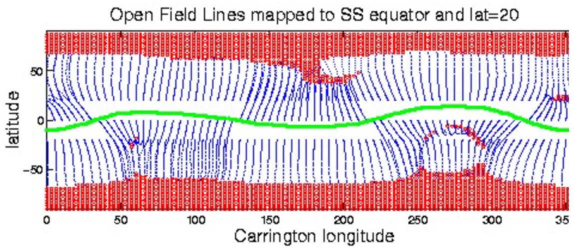
Longitudinally Averaged Surface Field Polarity



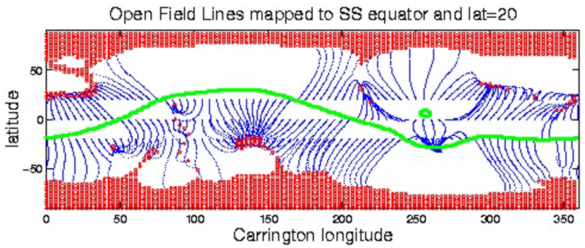
Red =MWO
Green=GONG-STEREO era
Black=GONG-PSP/SolO era

PFSS fields (+polarity) mapping from the source surface equator to the photosphere, superposed on the overall CH/open field picture suggest where the ecliptic solar wind and IMF comes from vs time.

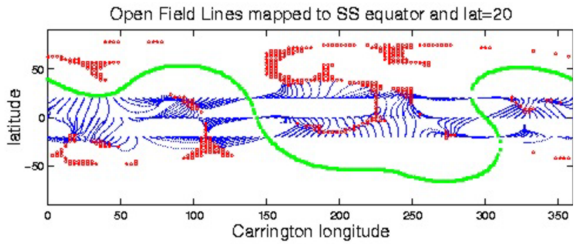
'polar'



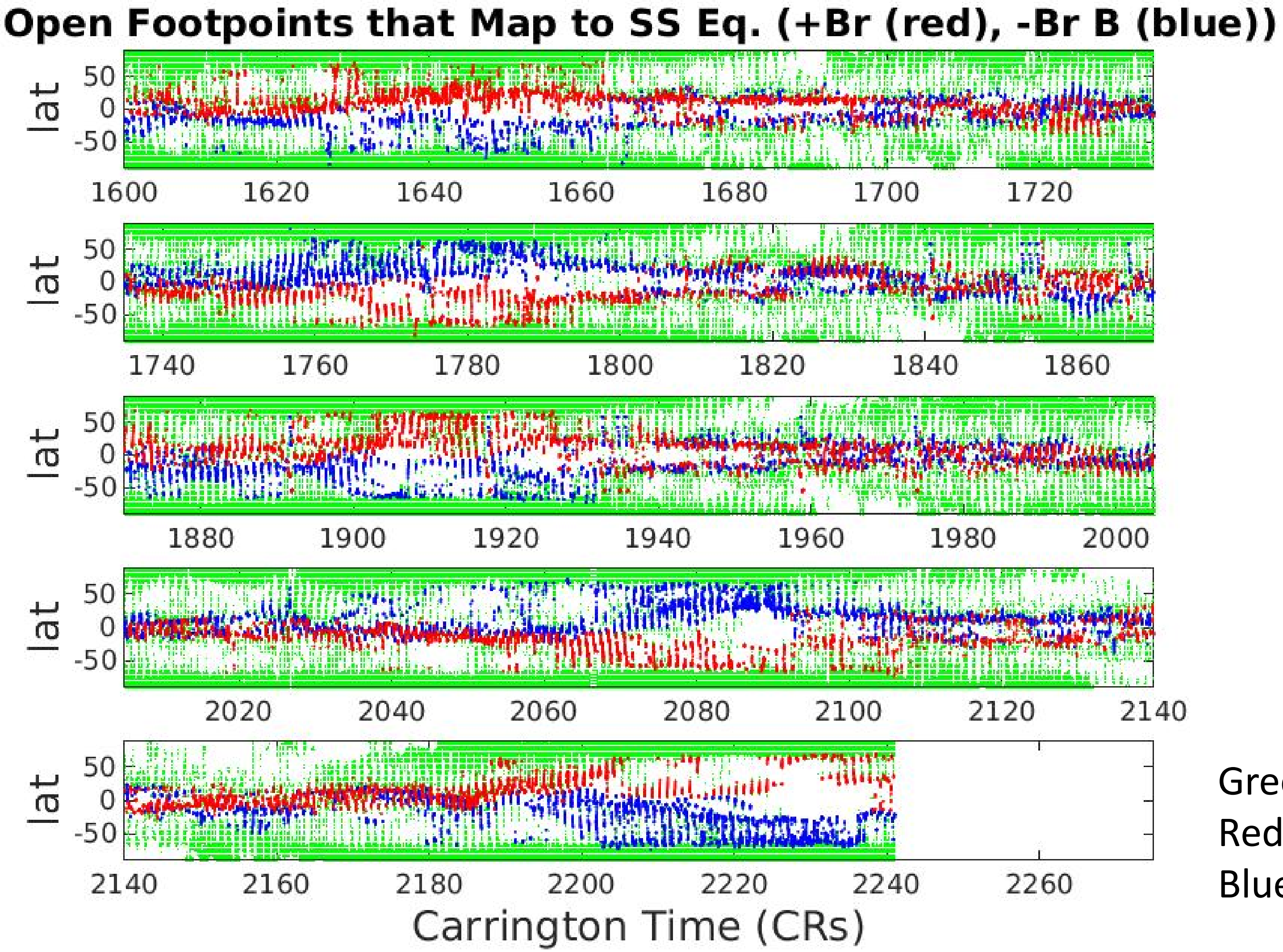
'mix'



'active'

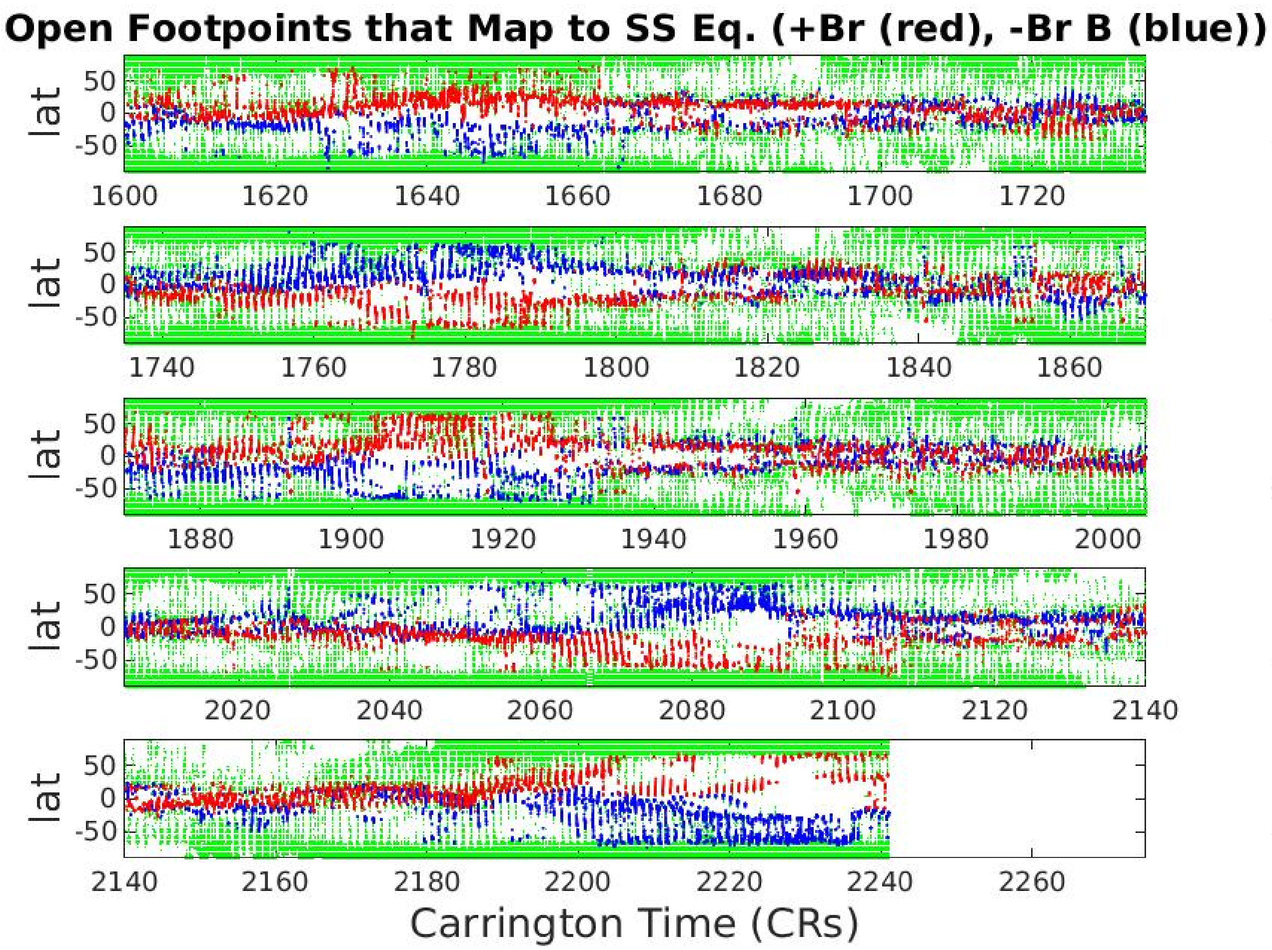


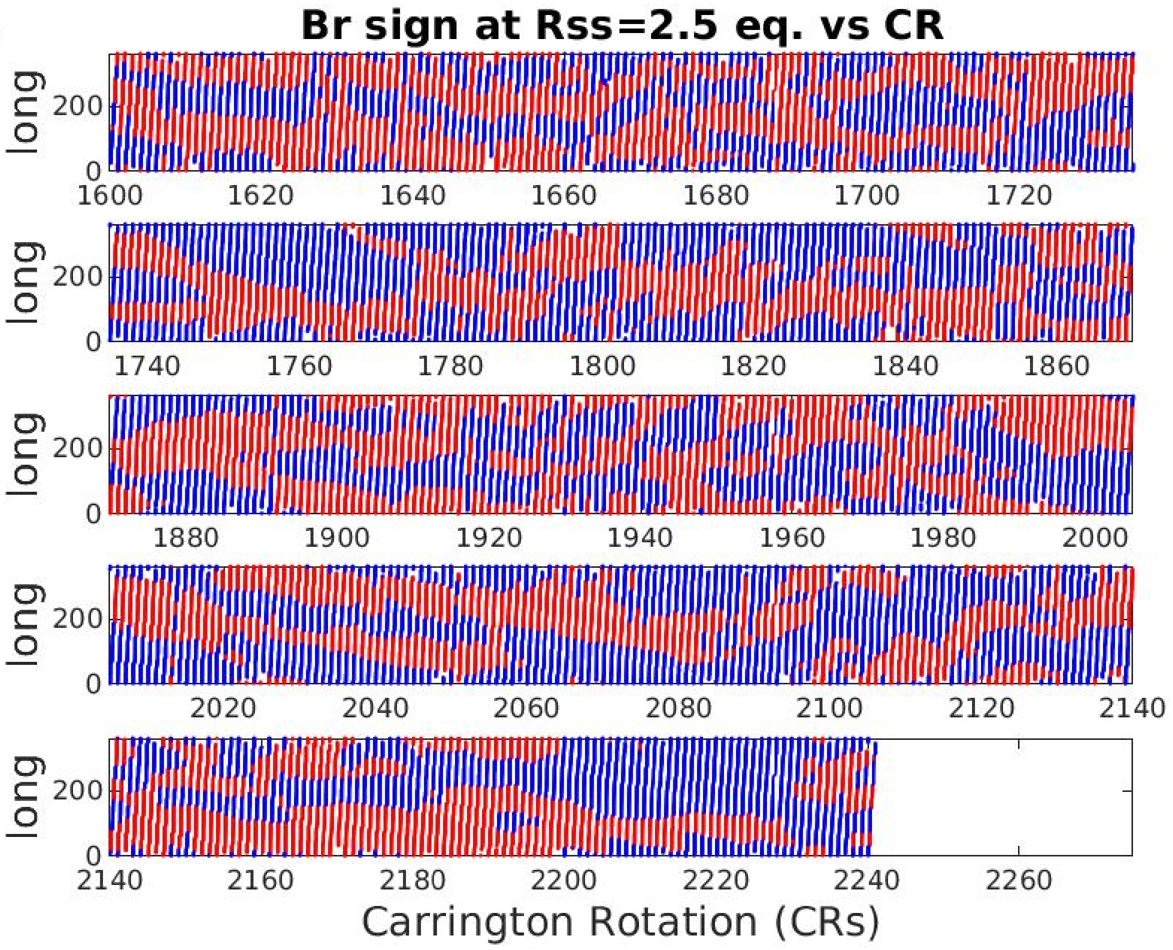
(Luhmann et al., JGR, 2002)



Green =CHs
Red + eq. field
Blue- -eq. field

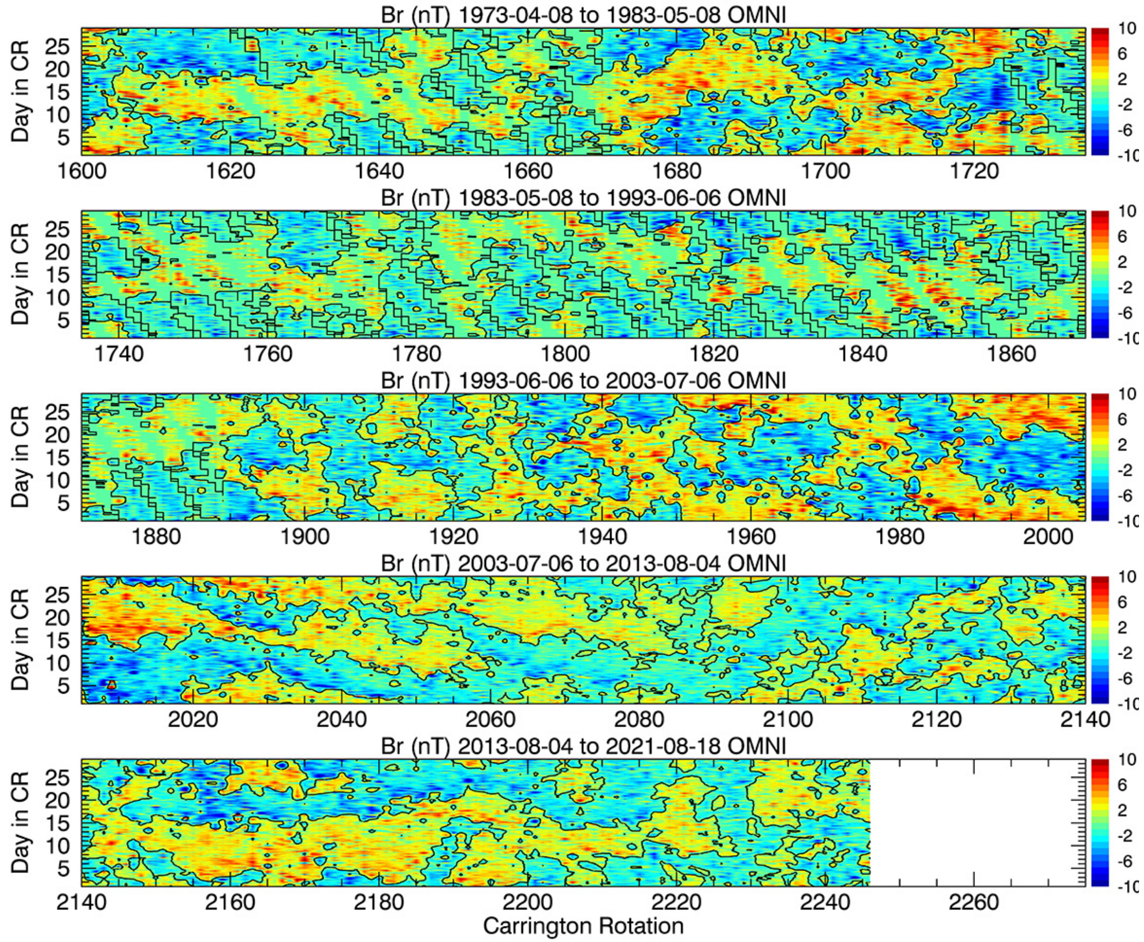
The footpoint fields can be mapped to the source surface equator to interpret L1 IMF origins



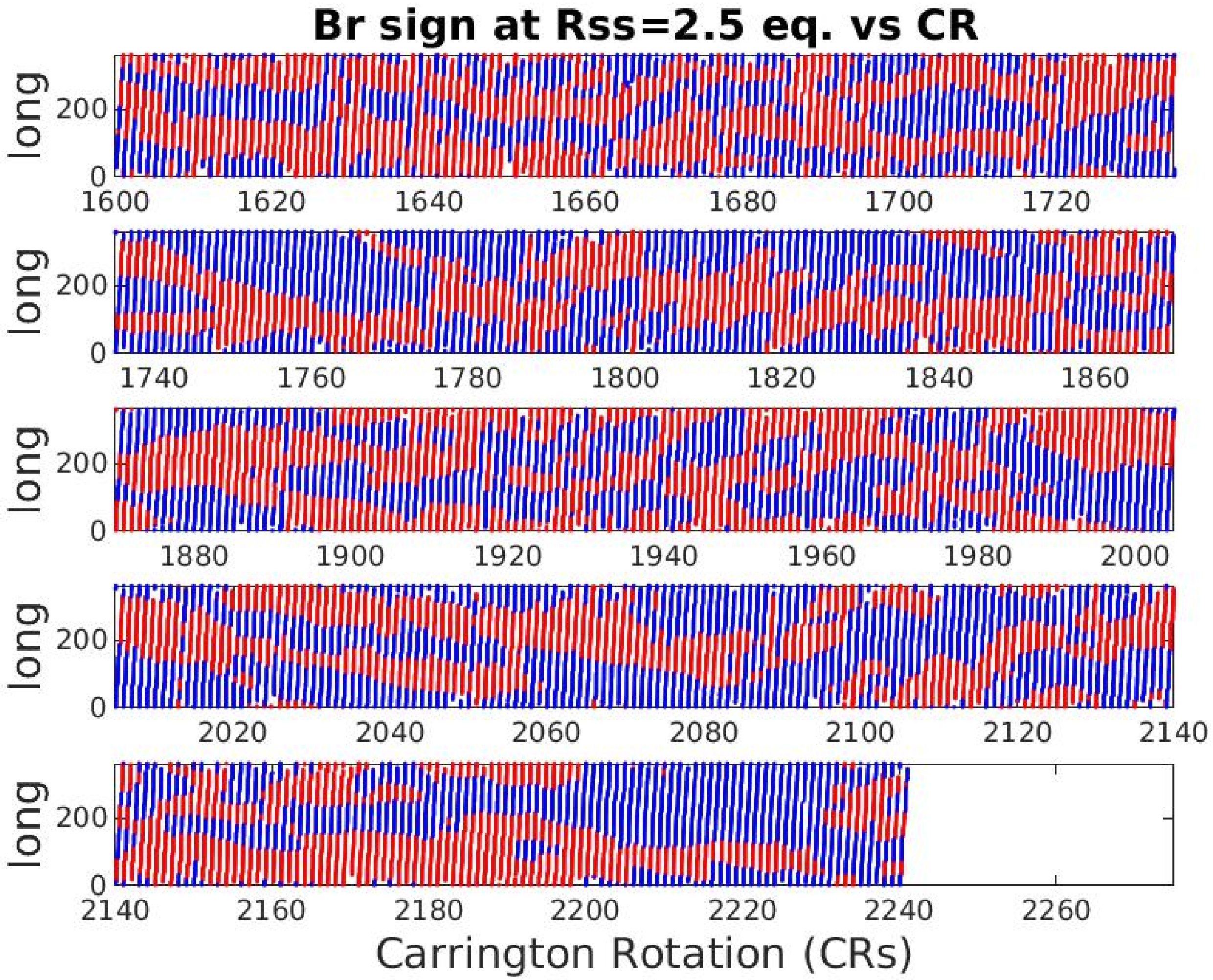


PFSS Open Fields + SS Eq. Polarity Mappings → PFSS Source Surface Eq. Field Polarity

Omni L1 Br for comparison

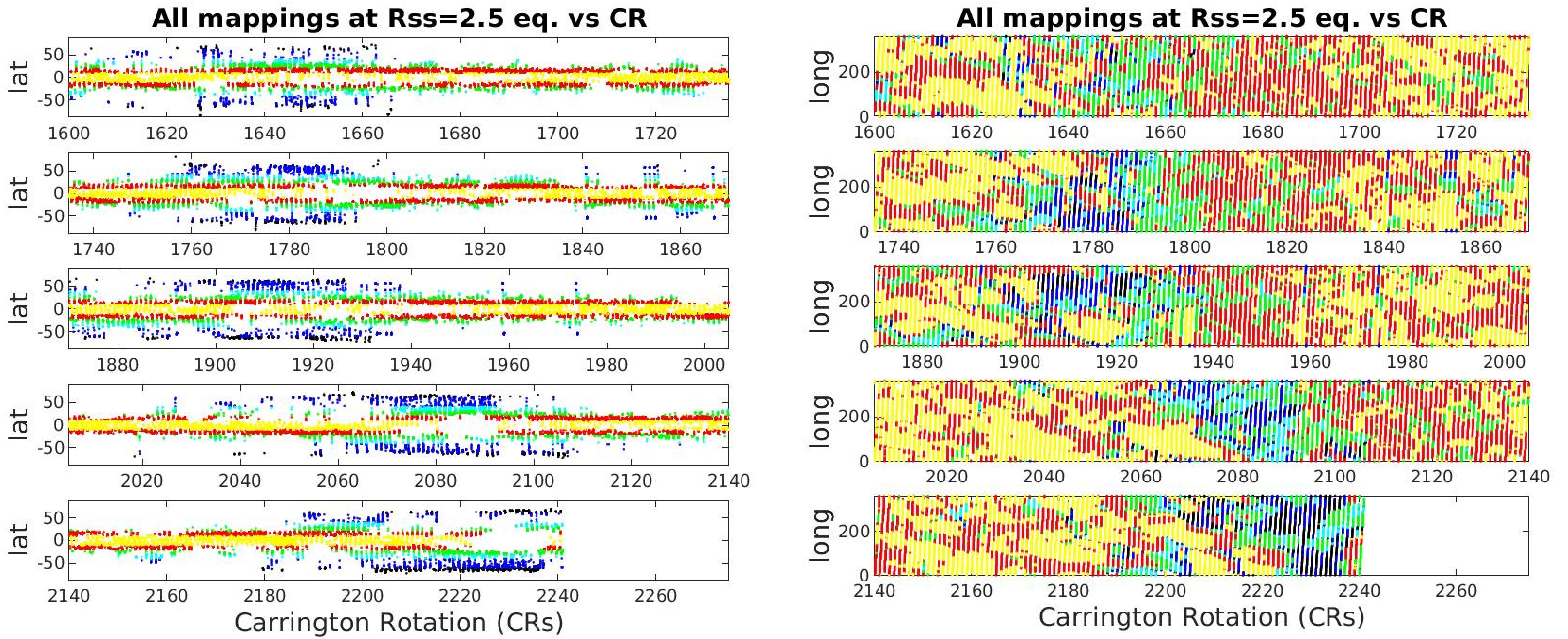


PFSS Source Surface Field Polarity



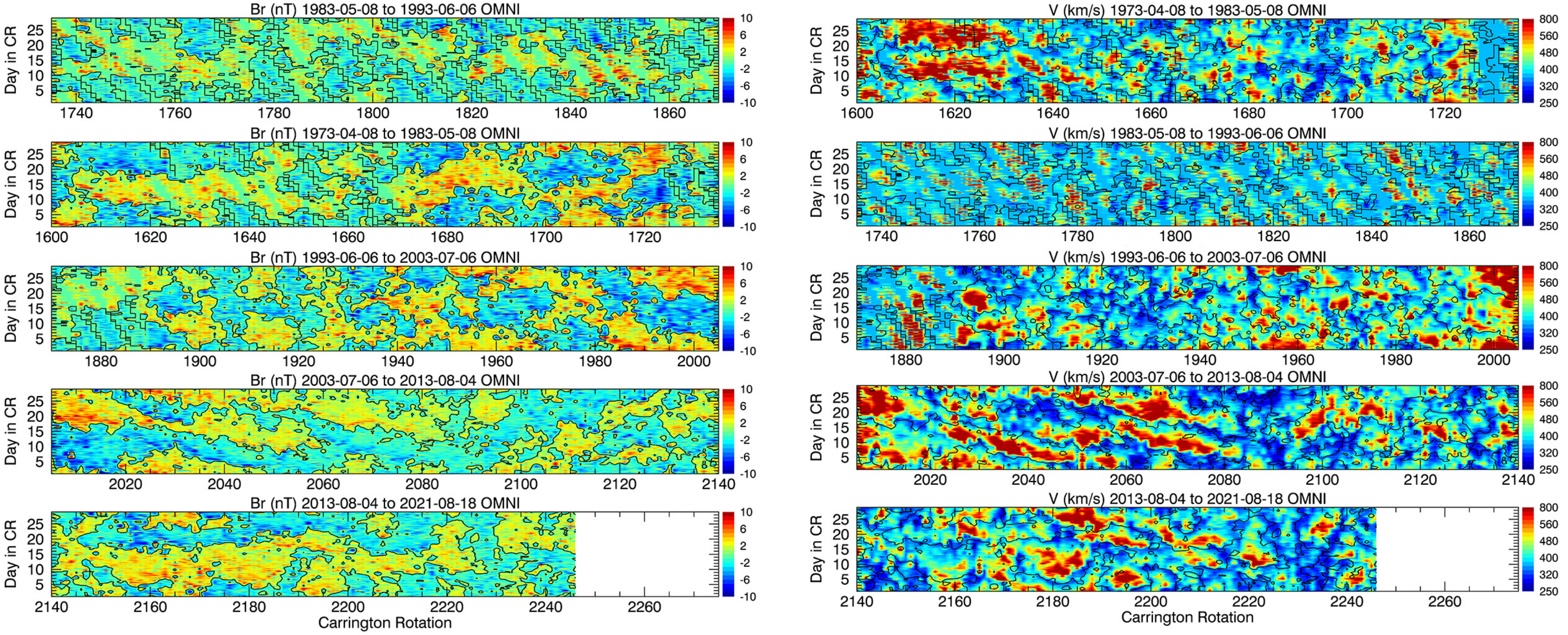
Note: No adjustment was made here for Sun-to-L1 transit times or radial evolution

The Footpoints Colored by Latitude - and these Source Surface Equator Locations where they map, suggest how/where CHs at different latitudes contribute vs time



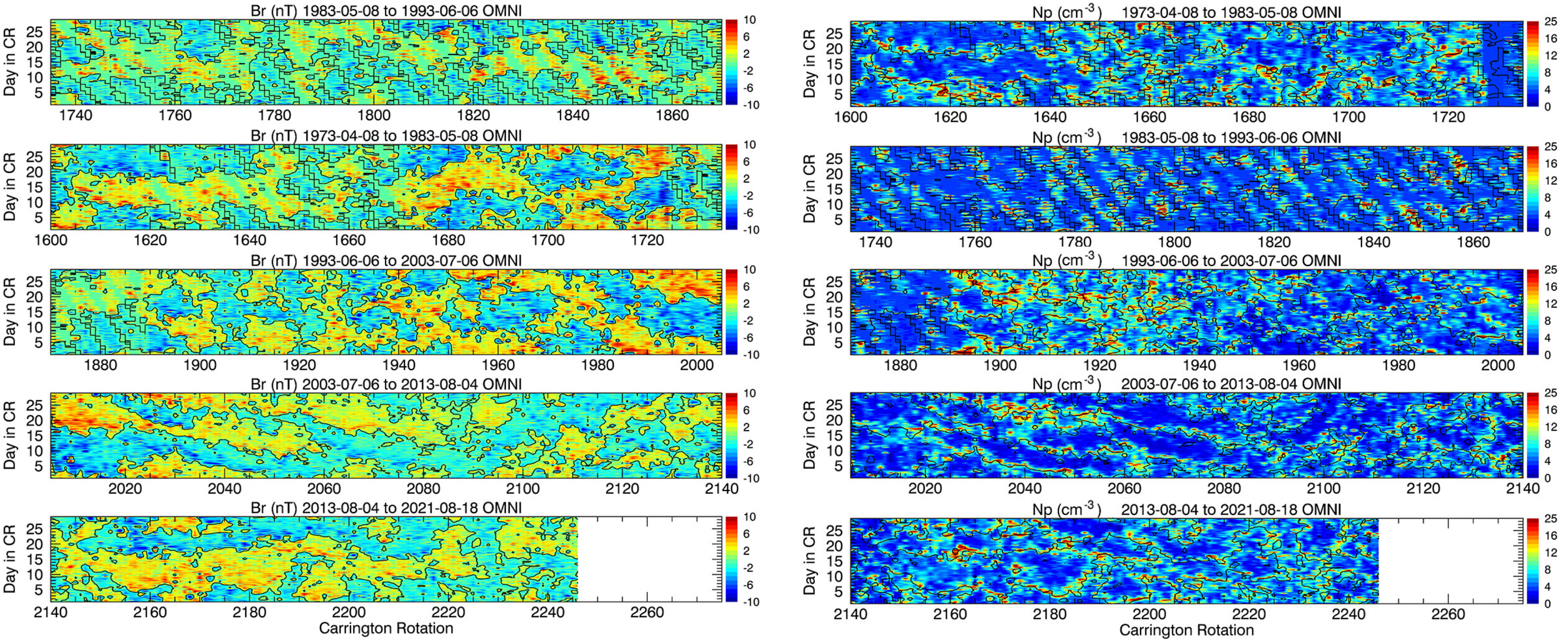
Y=0-10 deg lat, R=10-20, G=20-30, C=30-40, Blu=40-60, Blk=60-90

These OMNI plots for polarity and V show how IMF polarity patterns relate to sometimes long-lived HSS features (left: Br, right: V counterpart)



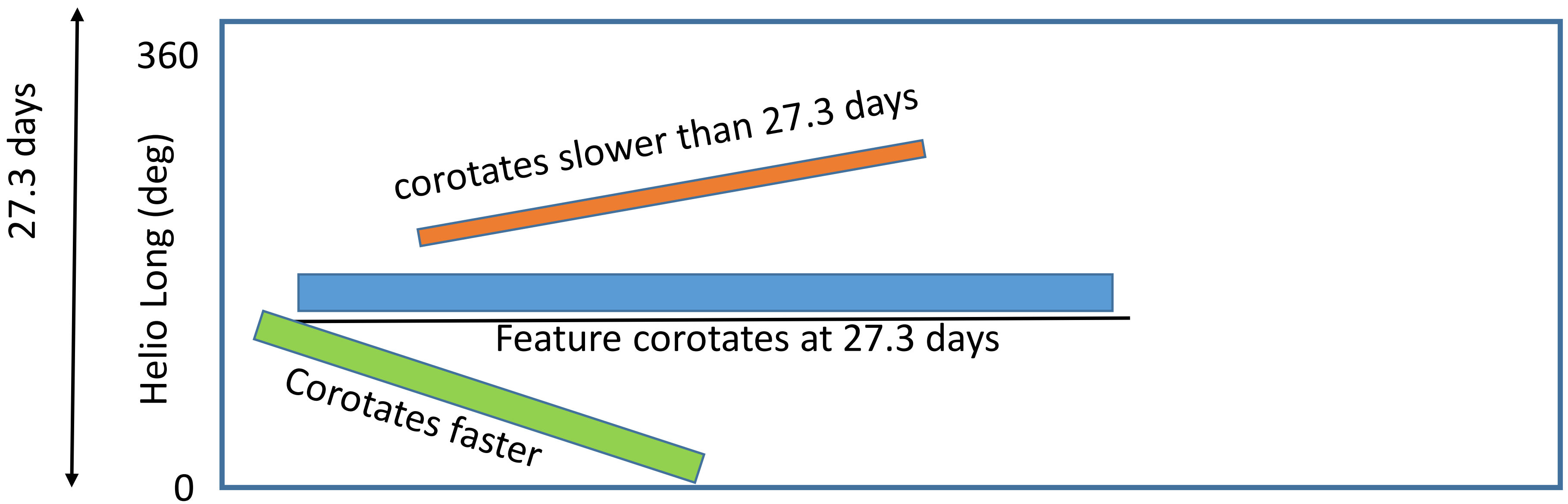
Note: the assumed CR duration for these plots is the standard 27.3 days

This also applies to the patterns of observed density compressions



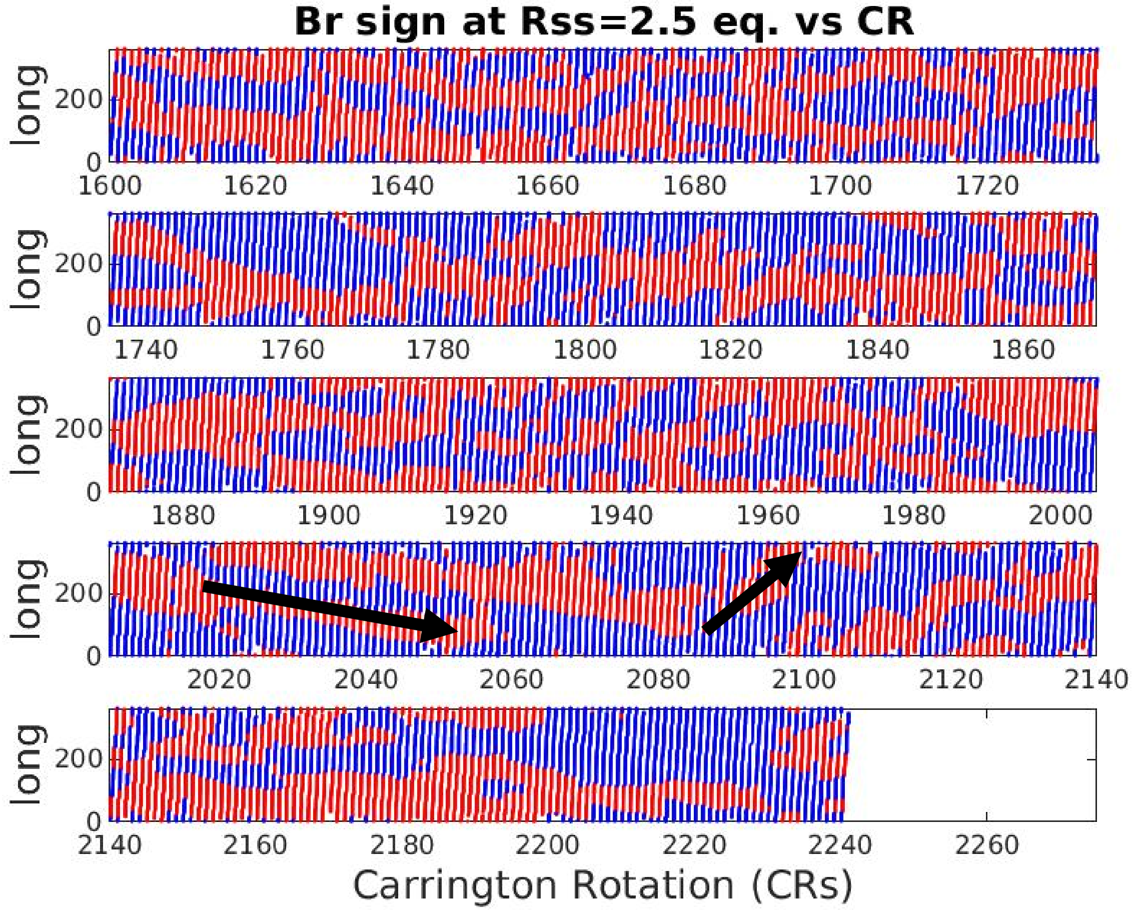
Note: the assumed CR duration for these plots is the standard 27.3 days

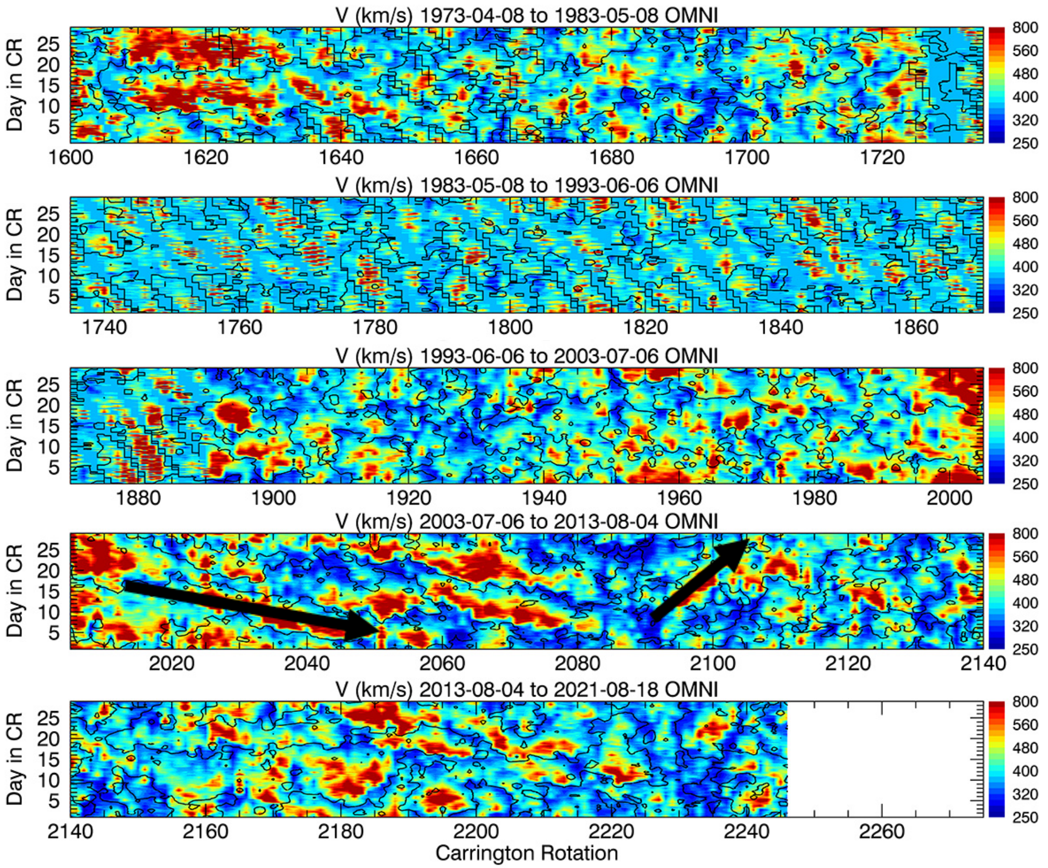
The pattern trends hint at the coronal origins of different solar wind features, expected from the rigid rotation of some CHs, and differential rotation of others.



e.g. apparent ‘corotation’ rates of different HSSs and CIRs can differ by days

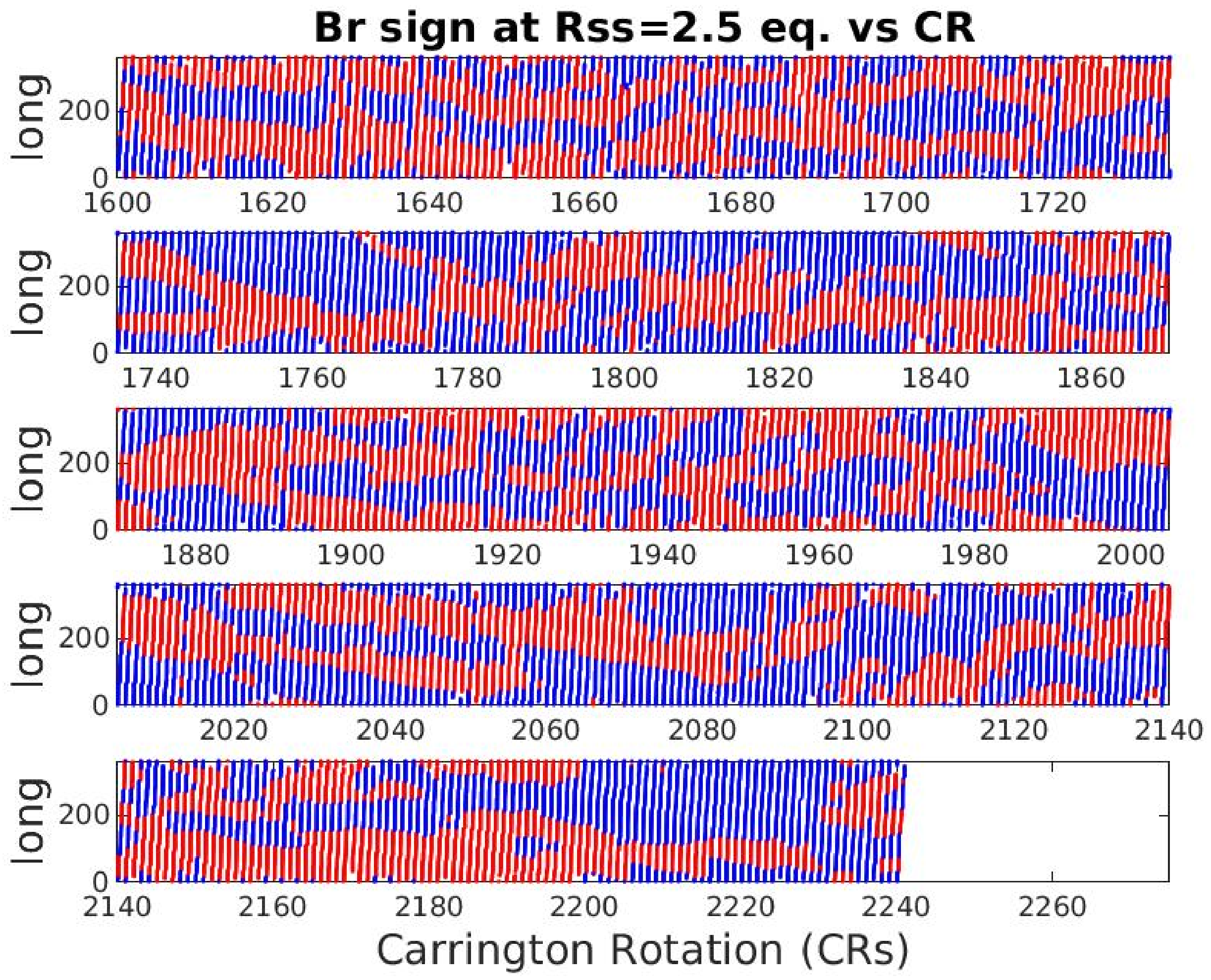
These trends can sometimes be useful as a simple way of forecasting the return of a particular HSS and/or CIR

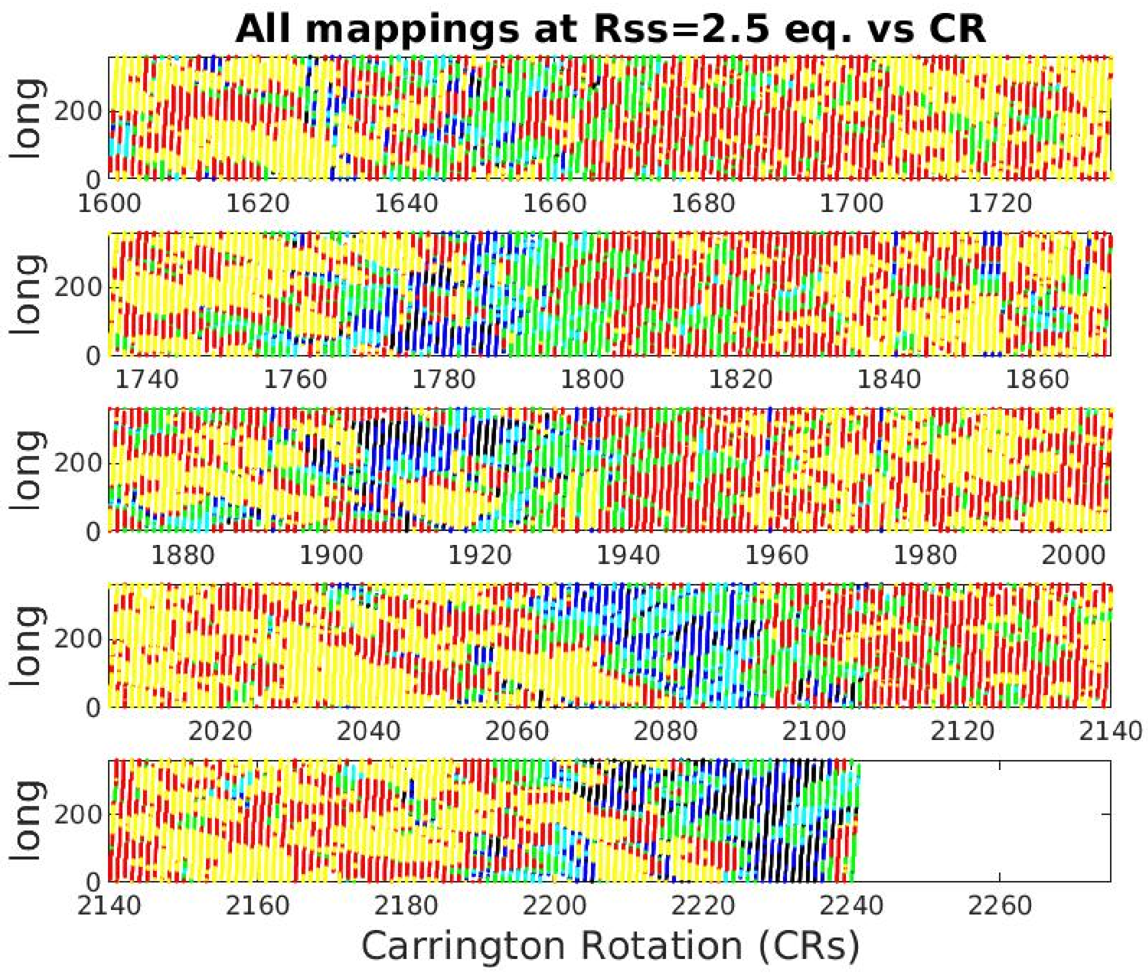




Notably, some of these features seem to persist for many years

At the same time, the approximate timing of exposure to low vs. mid-high latitude coronal holes and HCS crossings can be obtained





What have we learned?

-HSS and CIR structure and recurrence trends significantly differ from cycle to cycle, and with cycle phase, related to each cycle's distinctive solar field evolution. These features can outlast the lifetimes of individual CHs, with some appearing to endure for many years.

-Regular PFSS models using synoptic data provide useful first-order pictures of the coronal origins of the HSSs and CIRs. They provide global 'situational awareness' that allows us to track coronal and solar wind structure evolution over each cycle.

-Further improvements (e.g. via ADAPT + farside and solar polar field corrections to the magnetic field maps used in these models), and extensions (e.g. 1 AU extrapolations with ENLIL, Euphoria, CORHEL, etc.) can both enhance recurrence forecasts and increase our understanding of how solar cycle differences affect L1 solar wind conditions. We can also ask deeper questions about the influences of interacting flows from CH with different rotation styles, as the solar wind moves out into the heliosphere.