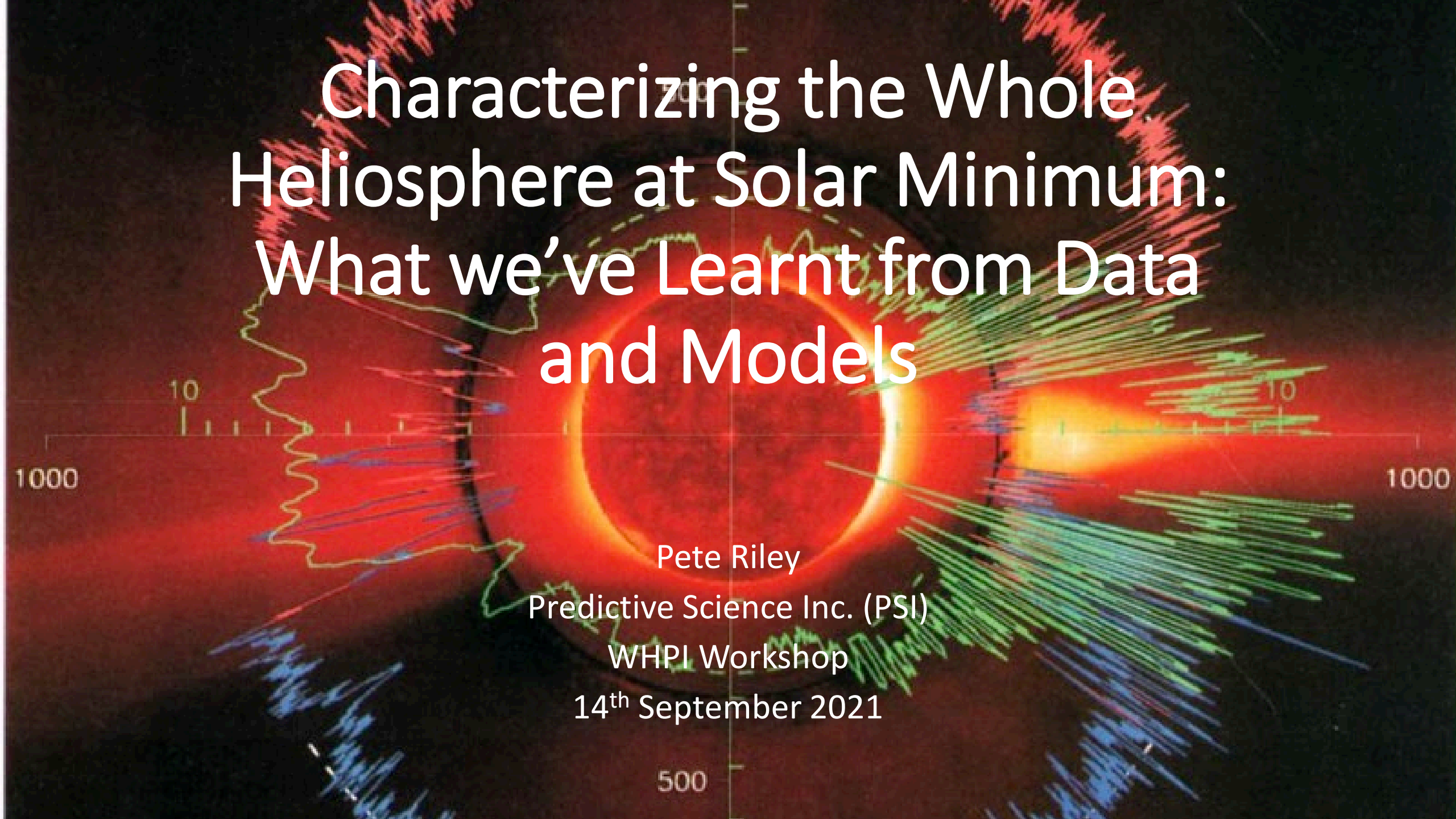
Characterizing the Whole Heliosphere at Solar Minimum: What we've Learnt from Data and Models



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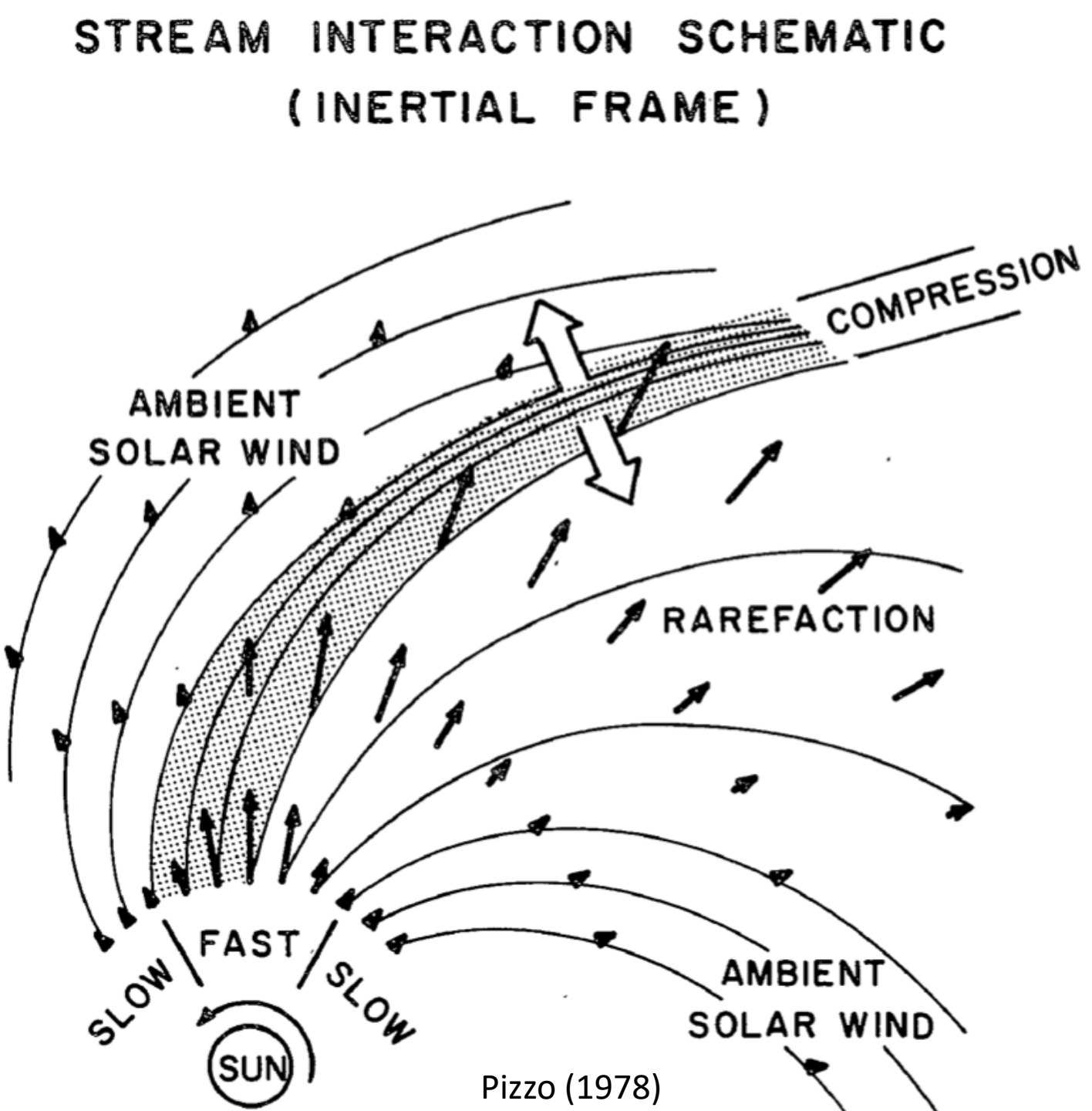
Predictive Science Inc. (PSI)
WHPI Workshop
14th September 2021

Overview

- Basic properties of the large-scale heliosphere at, and around solar minimum (<1992)
- Insight from missions and models:
  - Ulysses (1992 - 2008)
  - PSP (2018 – present)
- Characterizing different Solar Minima
- Planetary responses to the quiescent Sun
- Summary and Future Opportunities

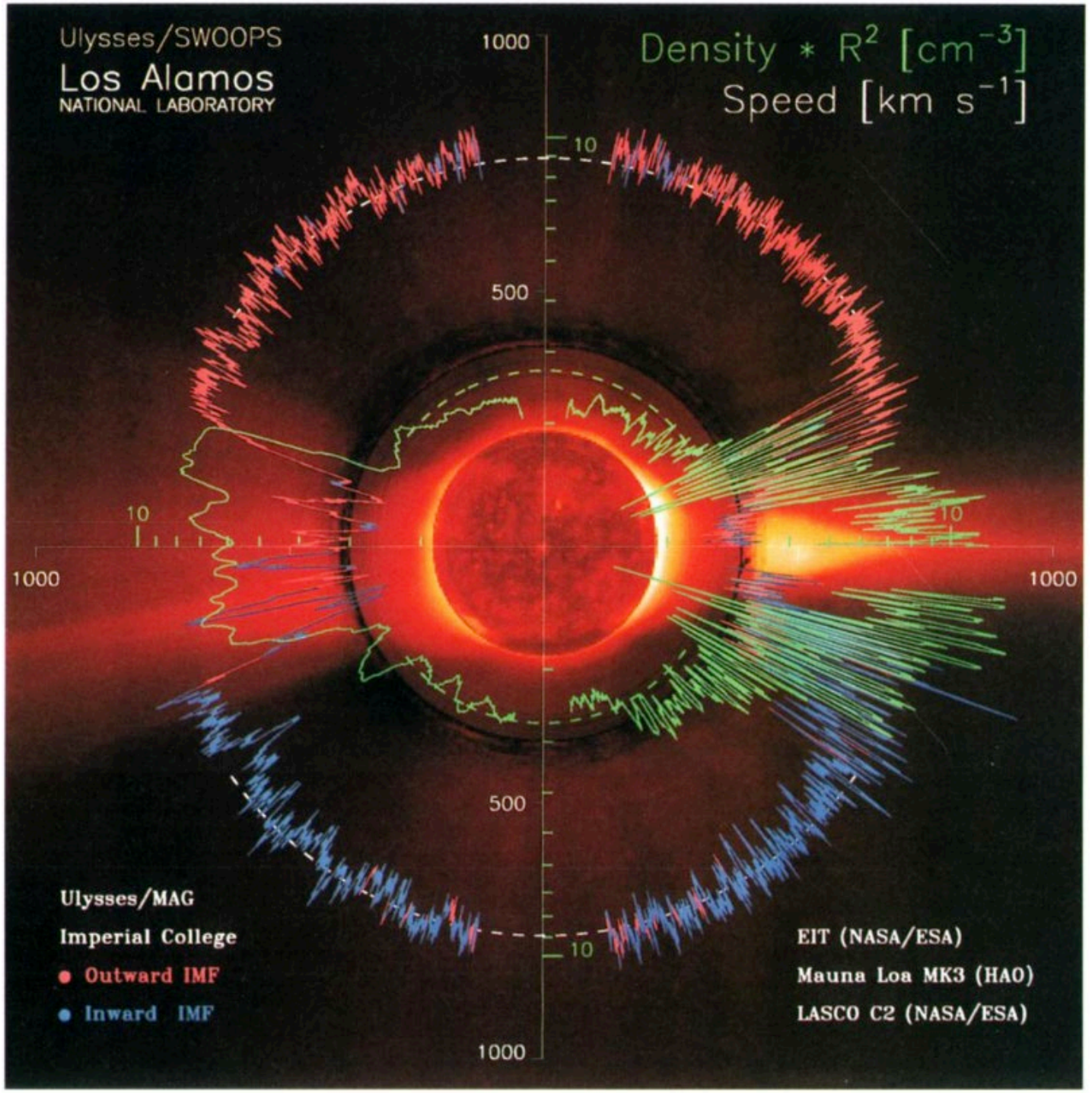
Before Ulysses: The 2-D Heliosphere

- 2-D picture of the global heliosphere
  - Orientations of CIRs and their F/R shocks
  - Development of shocks
  - Detailed analysis of stream interfaces
  - General properties of the heliospheric current sheet
  - Modeling by Pizzo (late ‘70’s and early ‘80’s) foretold 3-D structure that Ulysses would observe

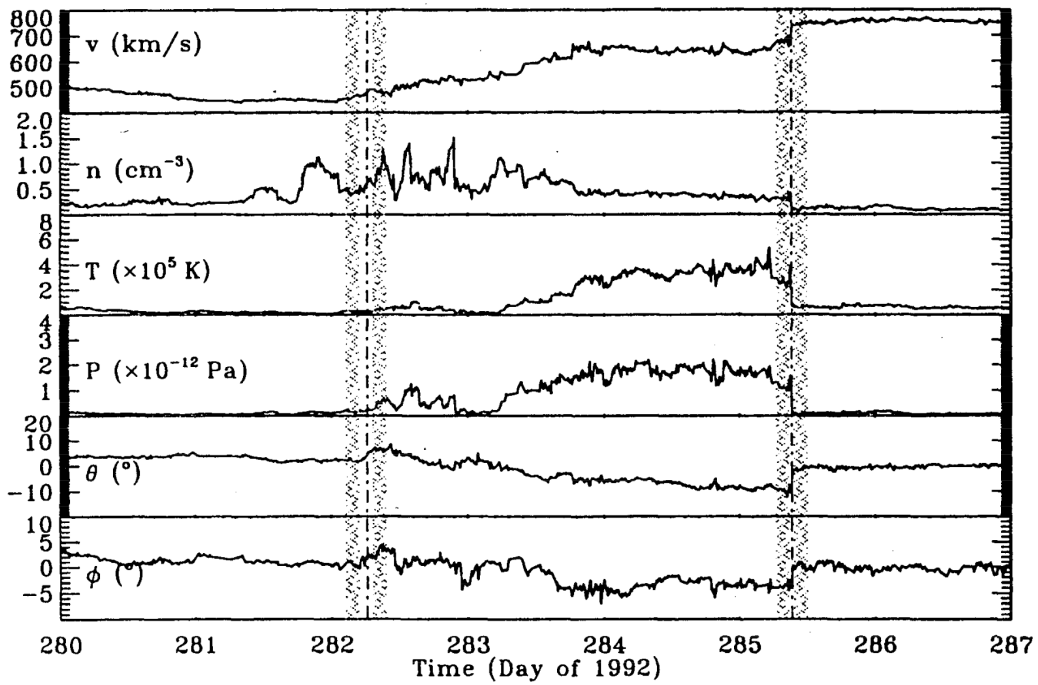


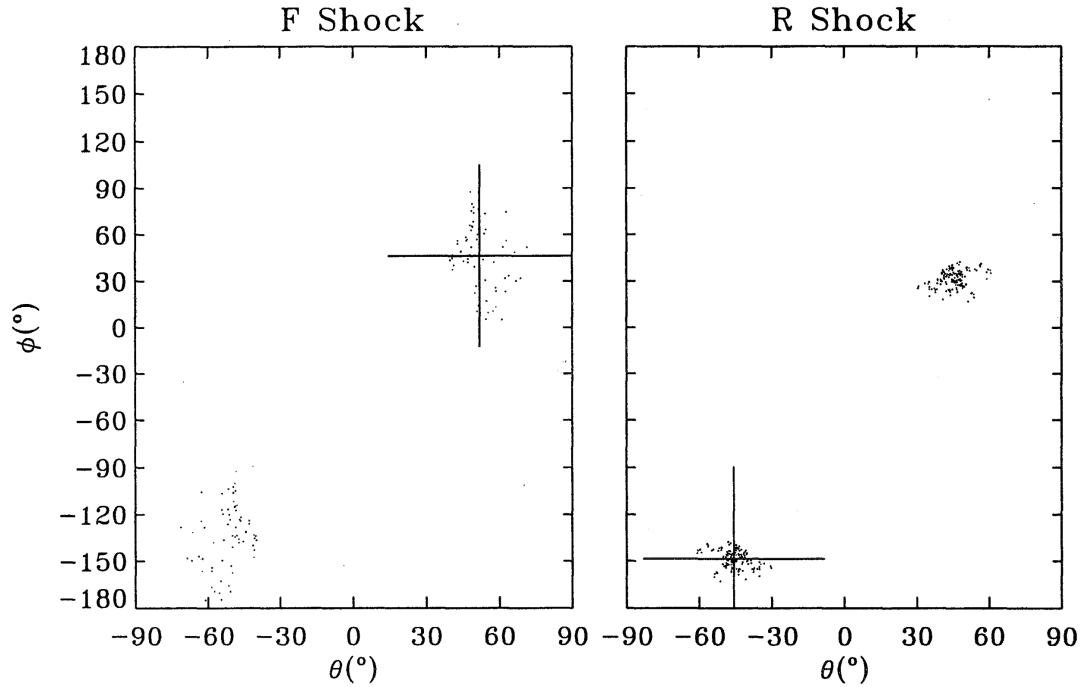
Pizzo (1978)

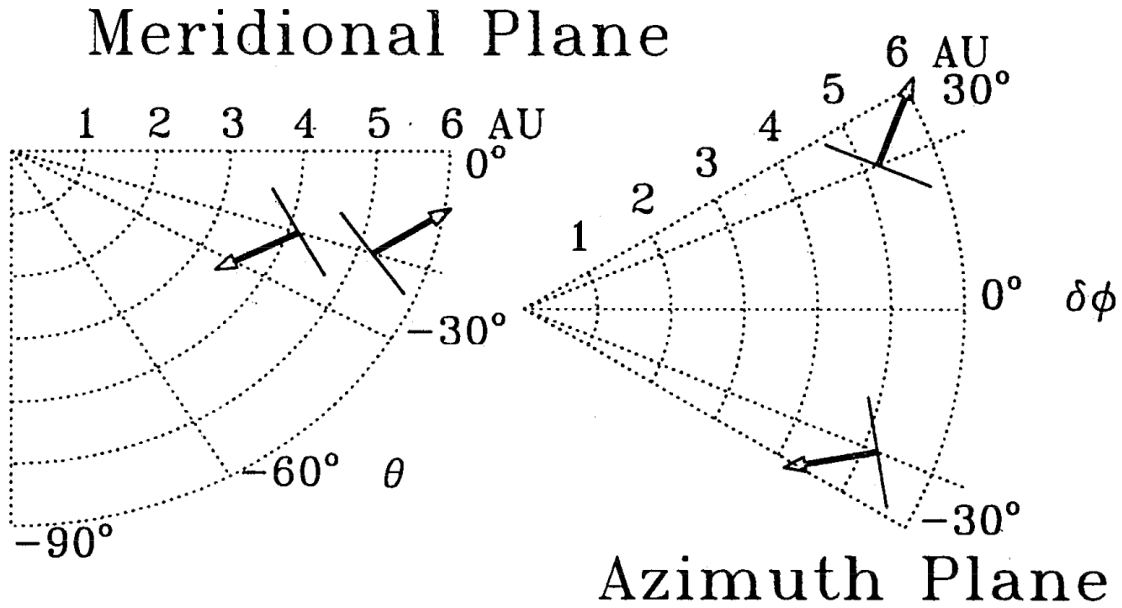
After Ulysses: The 3-D Heliosphere

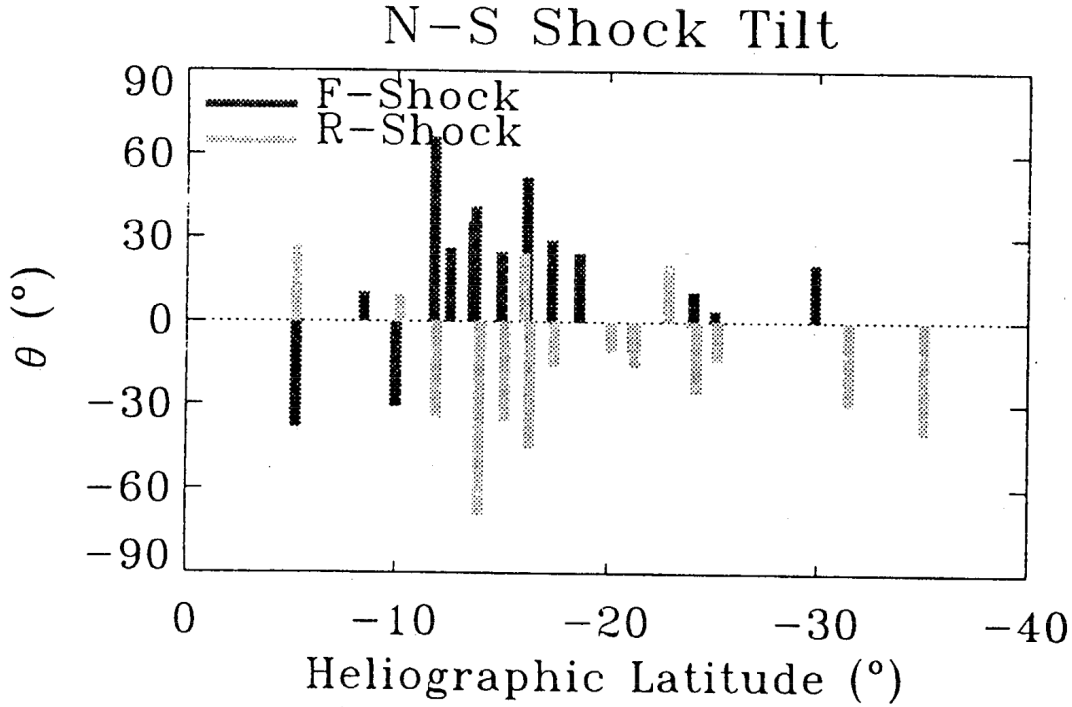


McComas et al. (1998; 2003)

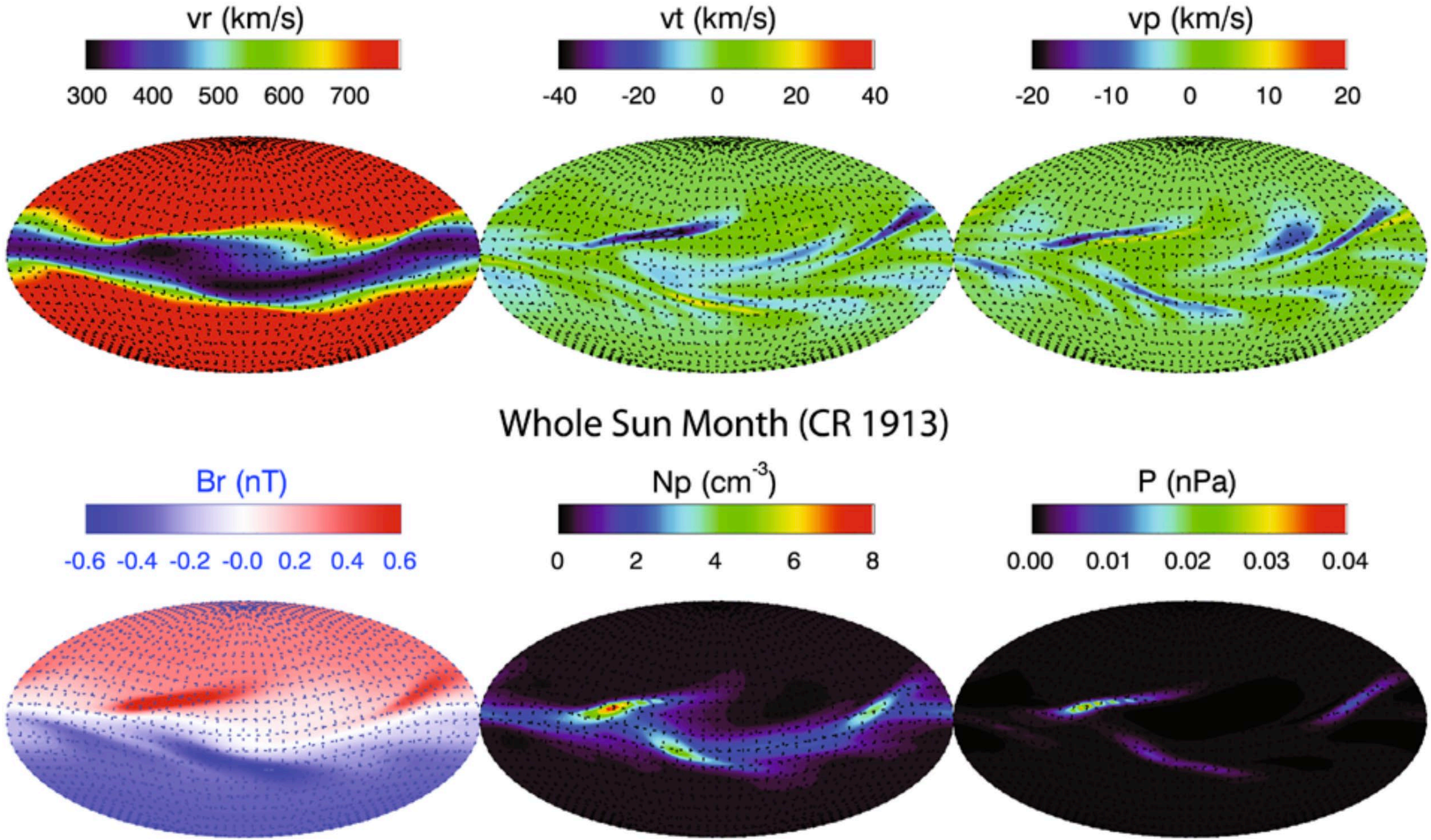


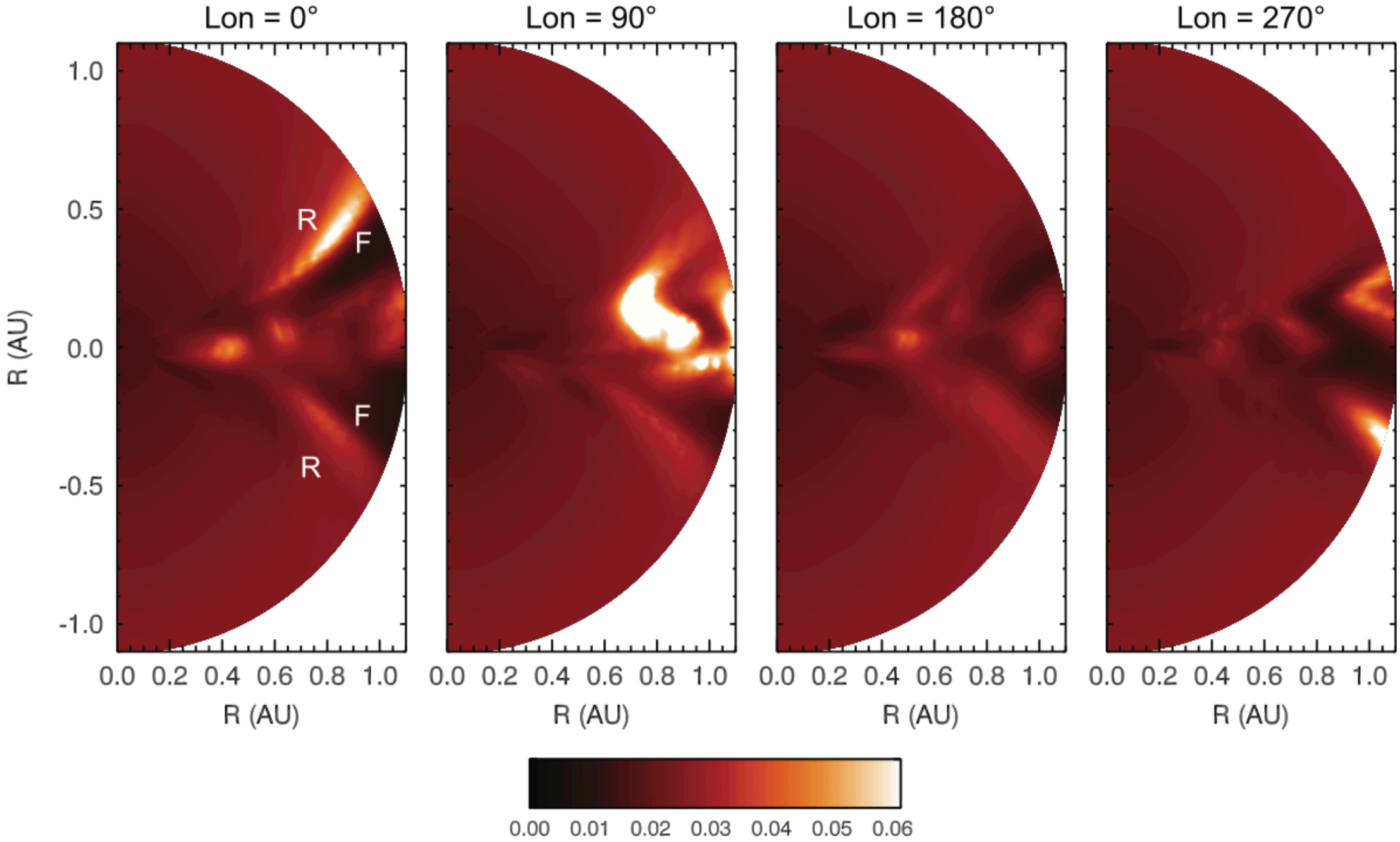


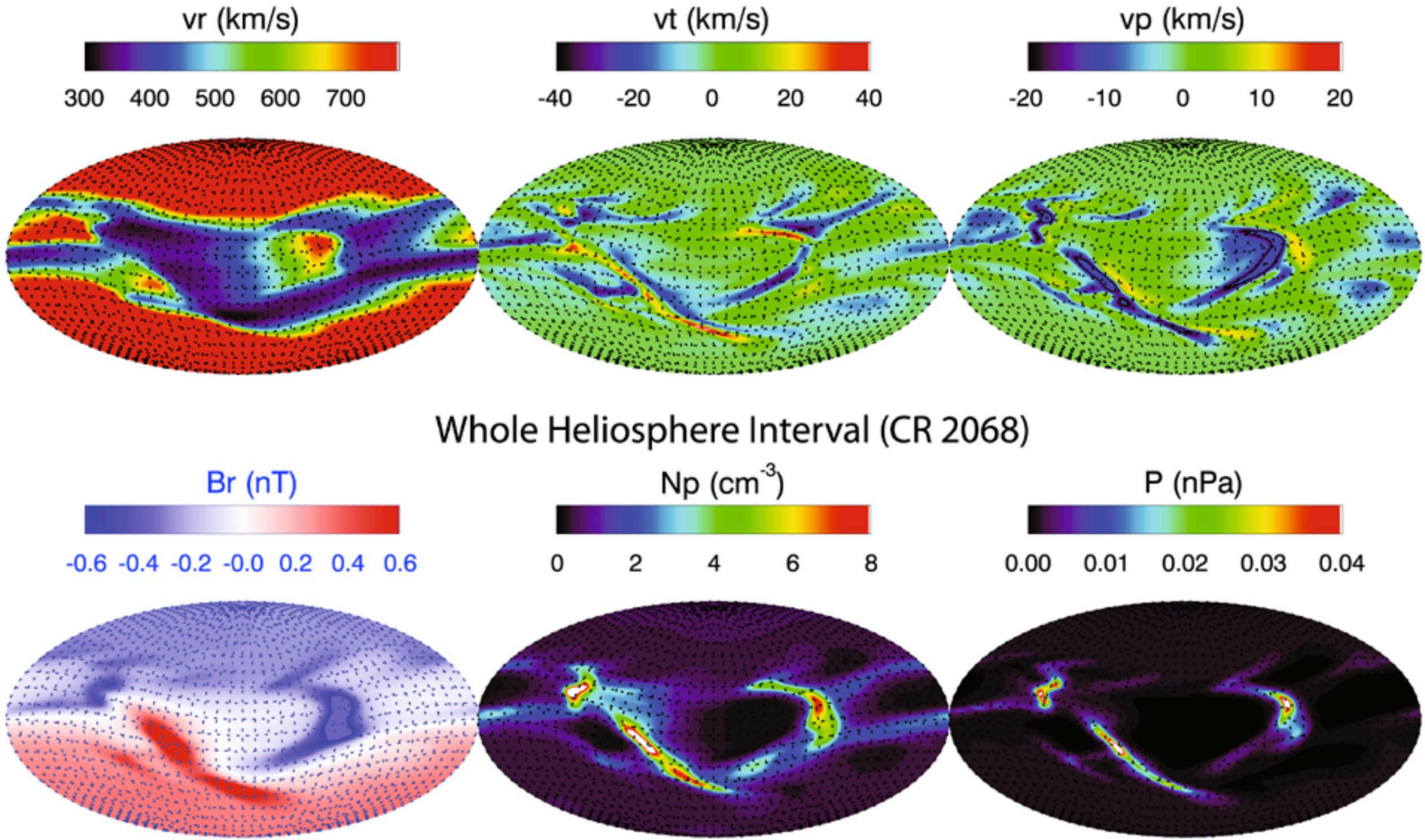


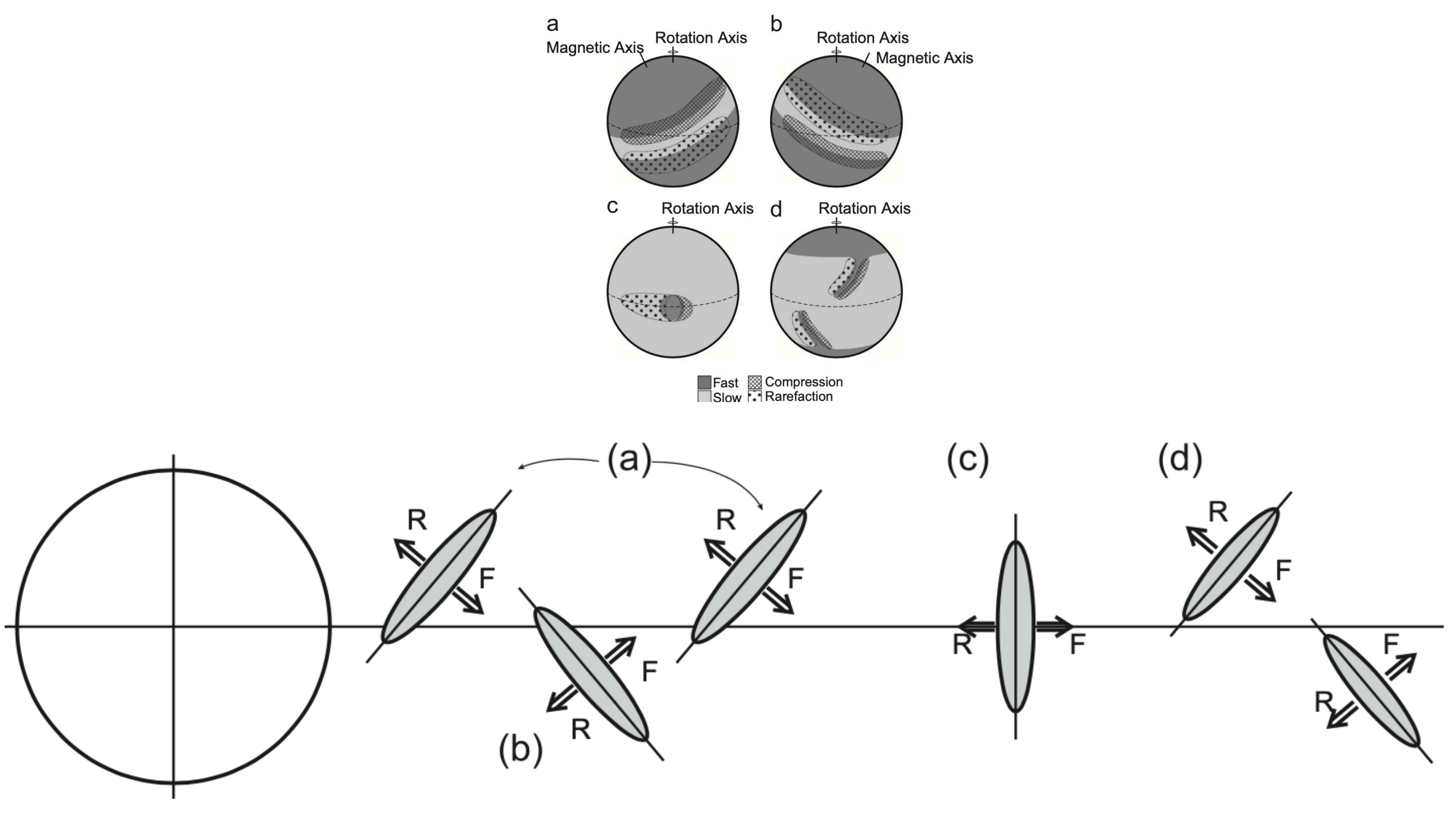


Riley et al. (1996)

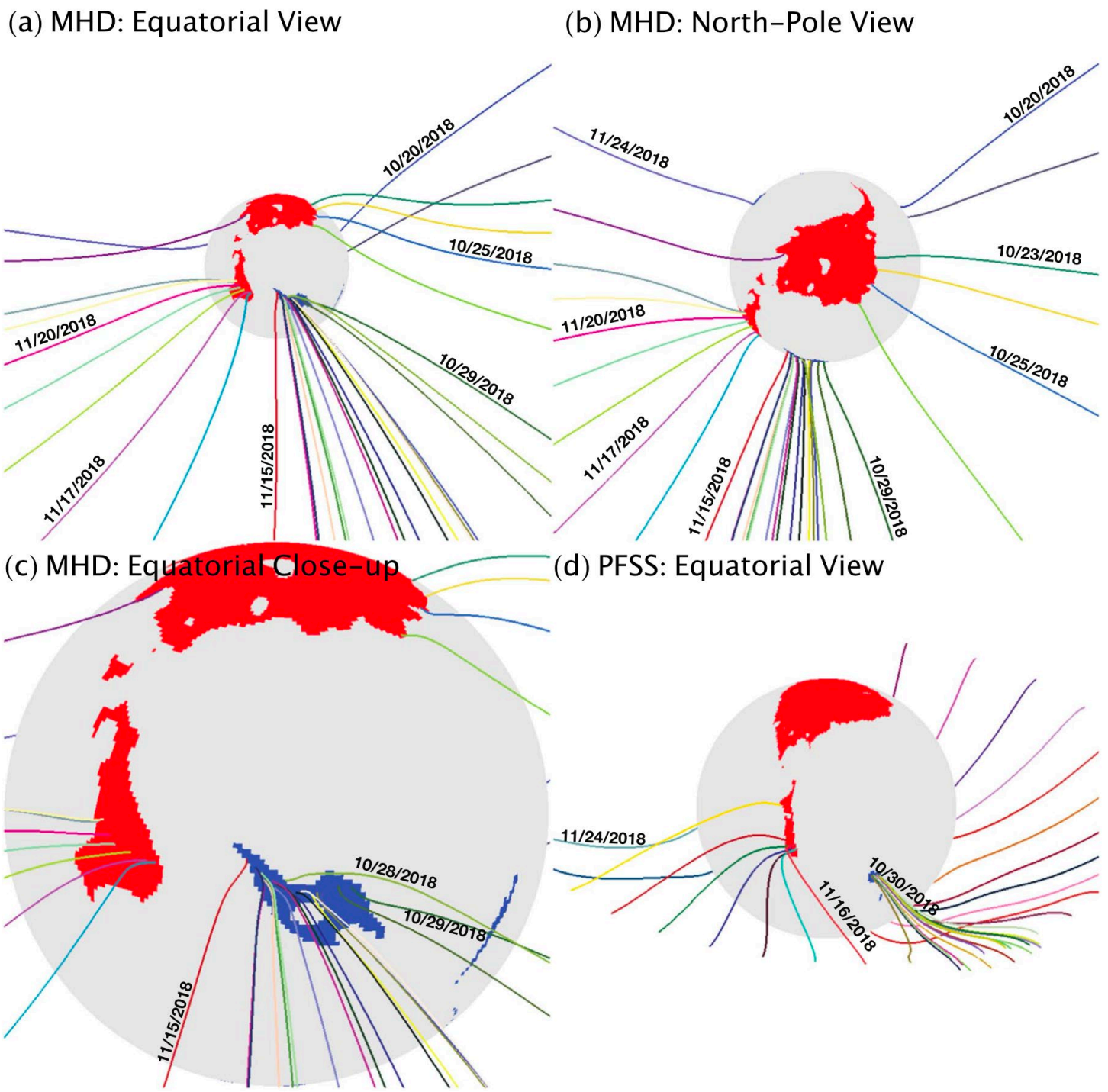

vr (km/s)
300 400 500 600 700
vt (km/s)
-40 -20 0 20 40
vp (km/s)
-20 -10 0 10 20
Whole Sun Month (CR 1913)
Br (nT)
-0.6 -0.4 -0.2 -0.0 0.2 0.4 0.6
Np (cm-3)
0 2 4 6 8
P (nPa)
0.00 0.01 0.02 0.03 0.04


Lon = 0°
Lon = 90°
Lon = 180°
Lon = 270°
R
F
F
R
1.0
0.5
0.0
-0.5
-1.0
R (AU)
0.0 0.2 0.4 0.6 0.8 1.0
R (AU)
0.00 0.01 0.02 0.03 0.04 0.05 0.06


vr (km/s)
300 400 500 600 700
vt (km/s)
-40 -20 0 20 40
vp (km/s)
-20 -10 0 10 20
Whole Heliosphere Interval (CR 2068)
Br (nT)
-0.6 -0.4 -0.2 -0.0 0.2 0.4 0.6
Np (cm-3)
0 2 4 6 8
P (nPa)
0.00 0.01 0.02 0.03 0.04

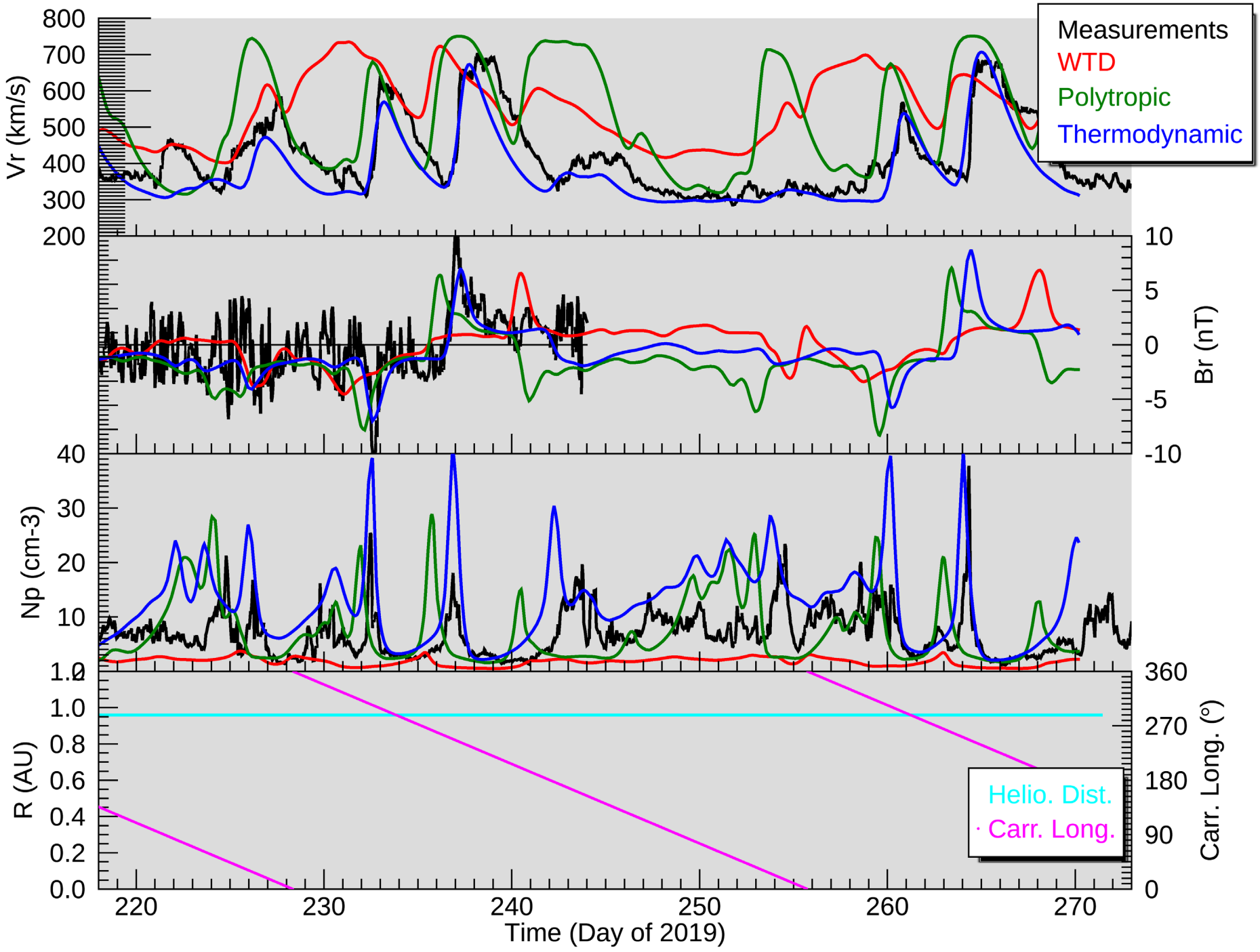

a
Magnetic Axis
Rotation Axis
b
Rotation Axis
Magnetic Axis
c
Rotation Axis
d
Rotation Axis
Fast
Slow
Compression
Rarefaction
(a)
(b)
(c)
(d)
R
F

The PSP View

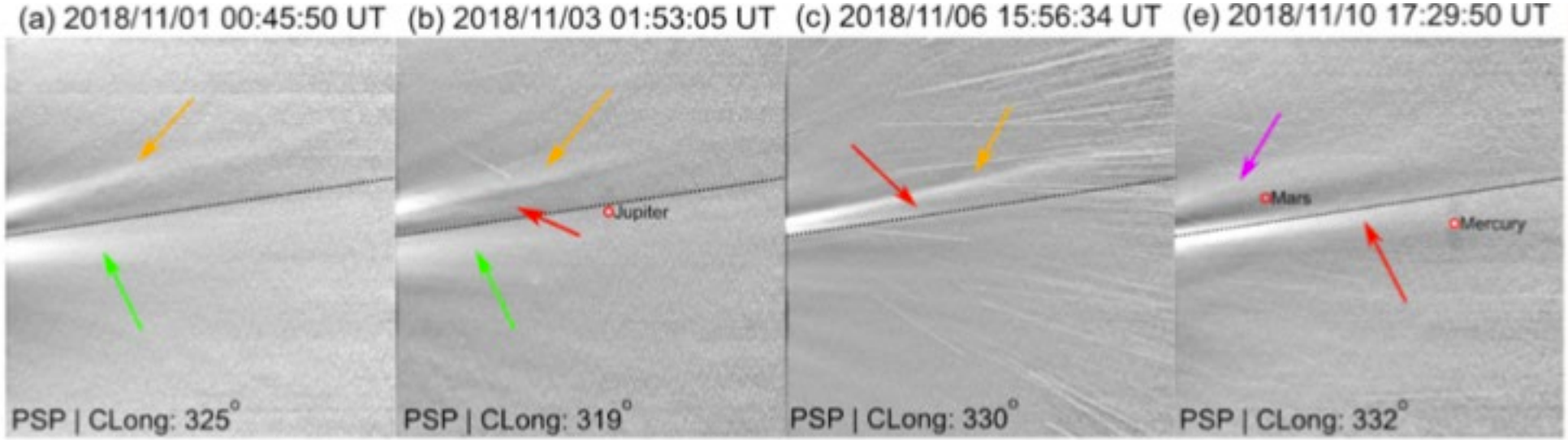


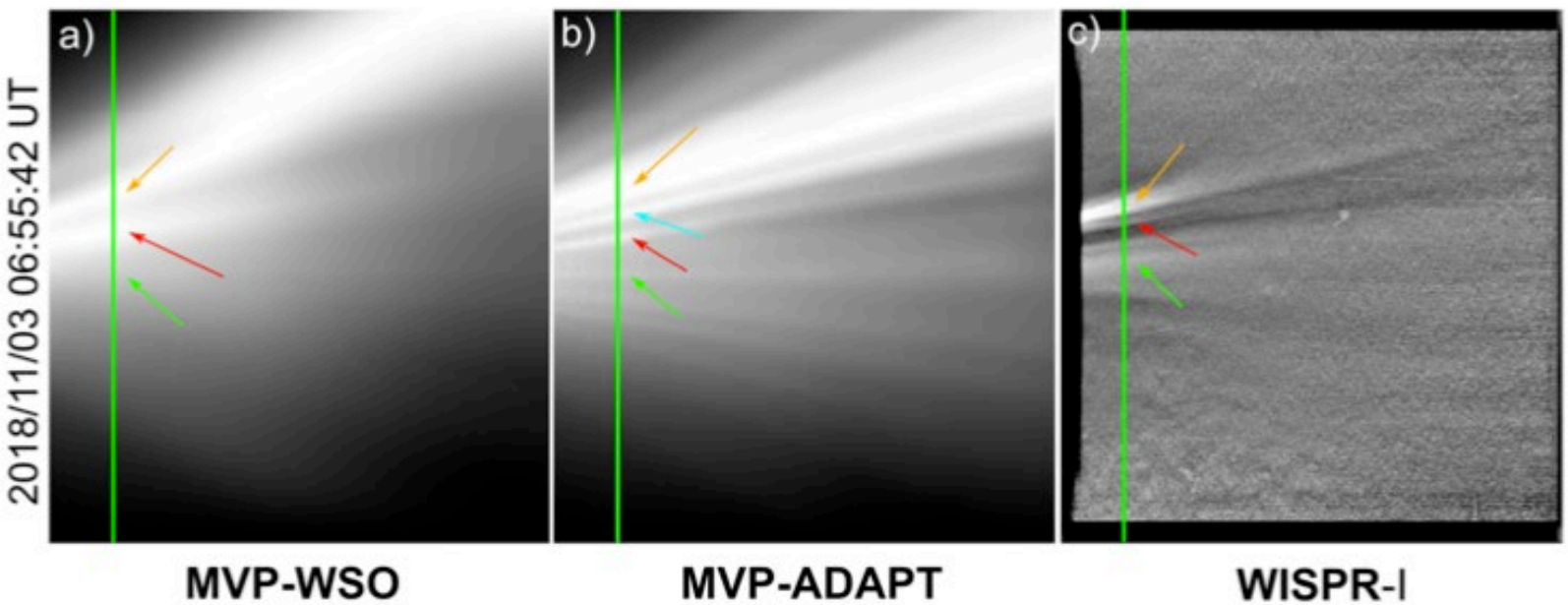
Riley et al. (2019)

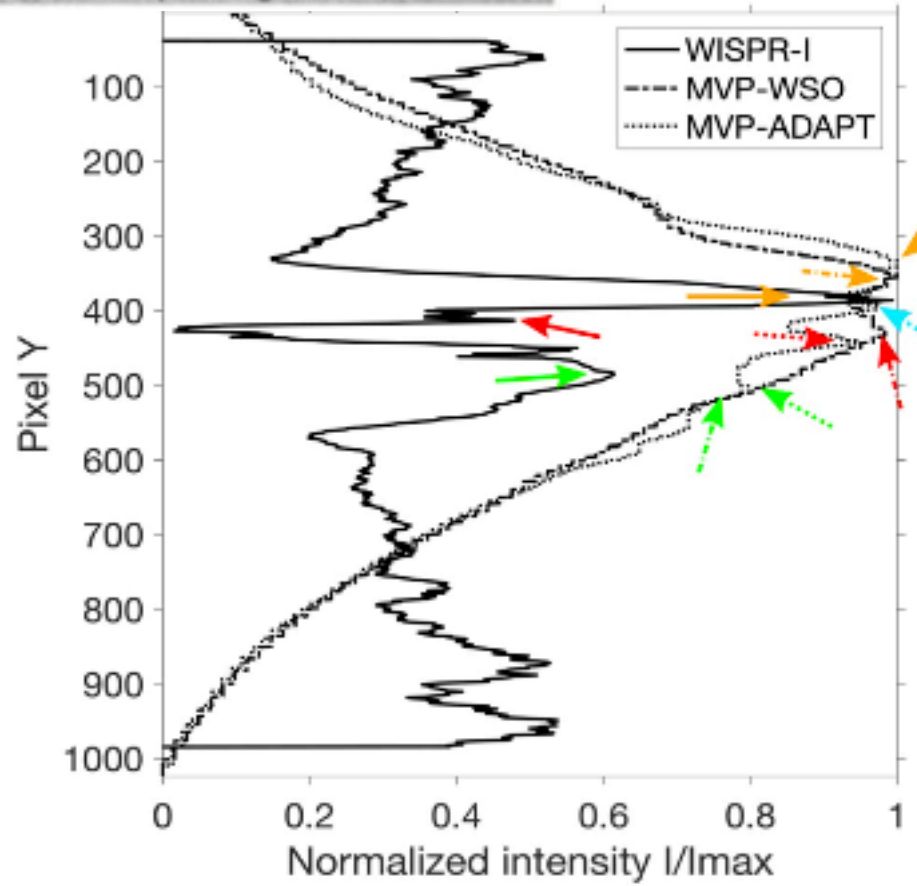
P3: Comparison with Stereo-A measurements



Riley et al. (2021)

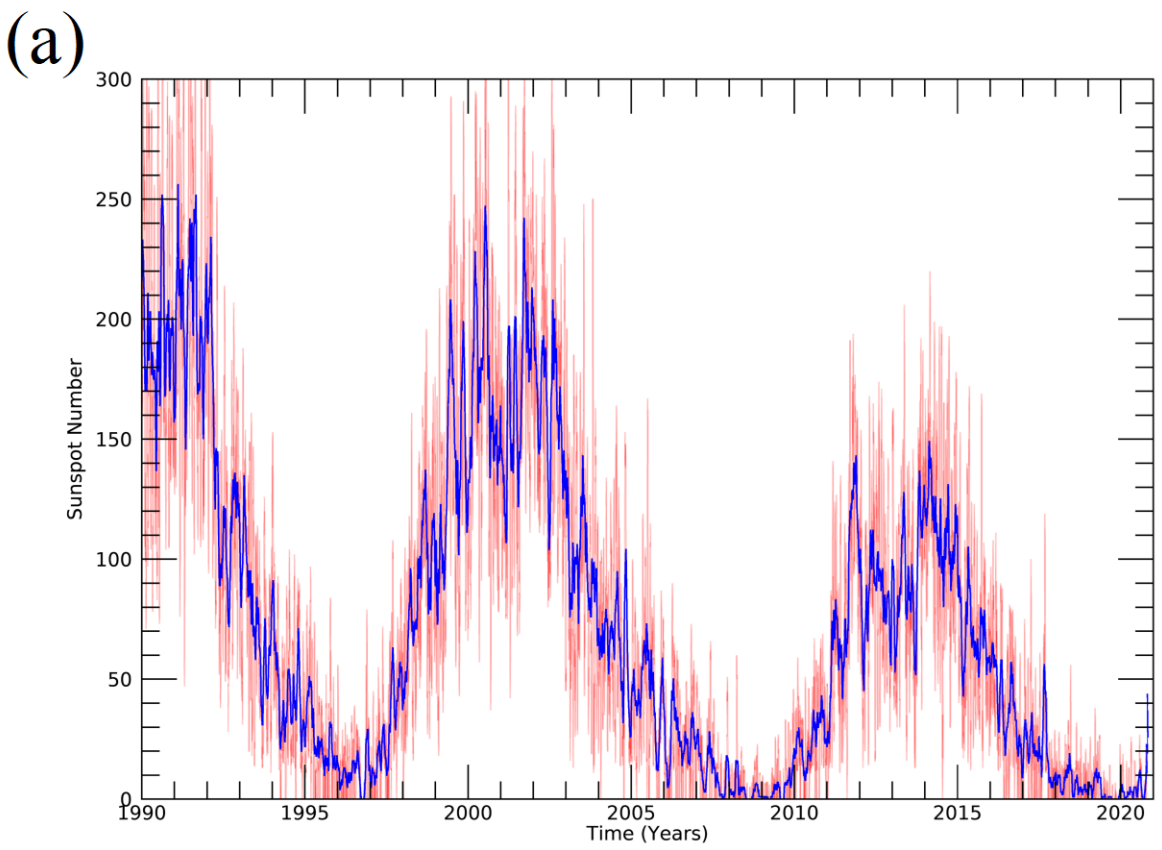


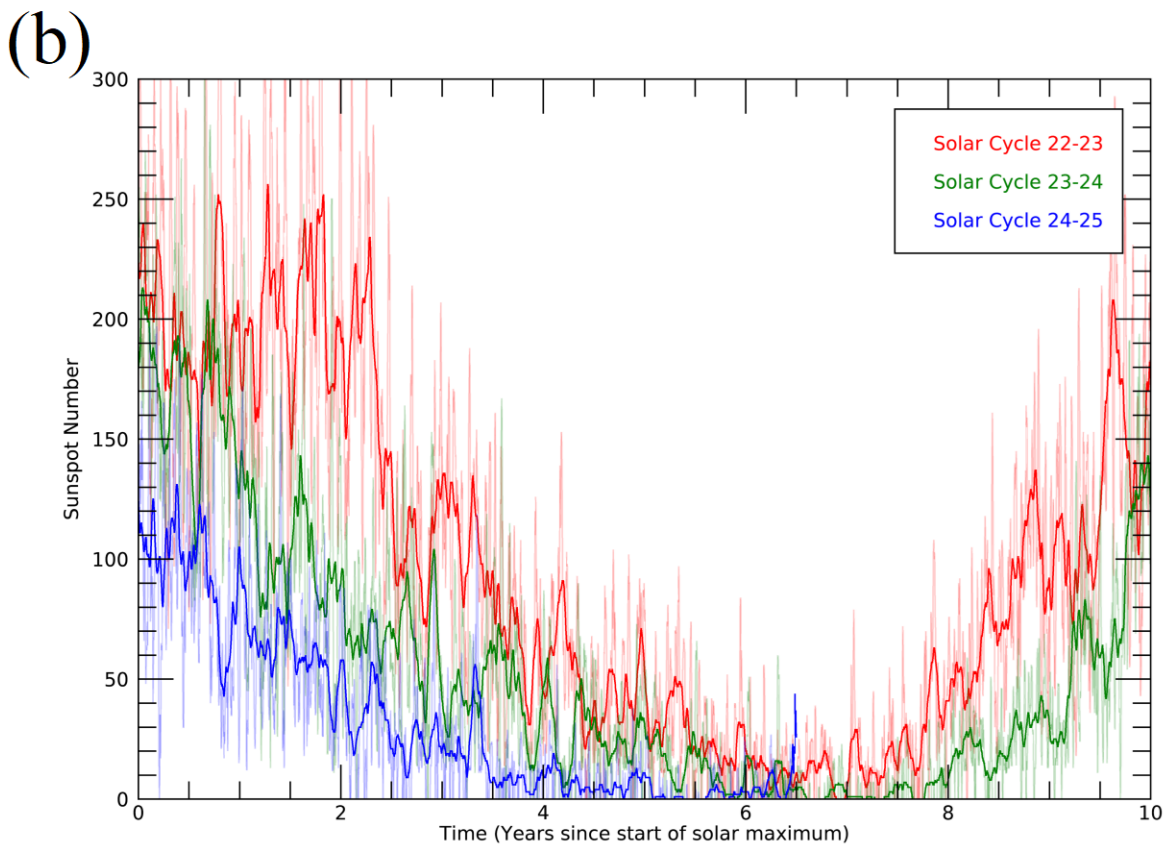




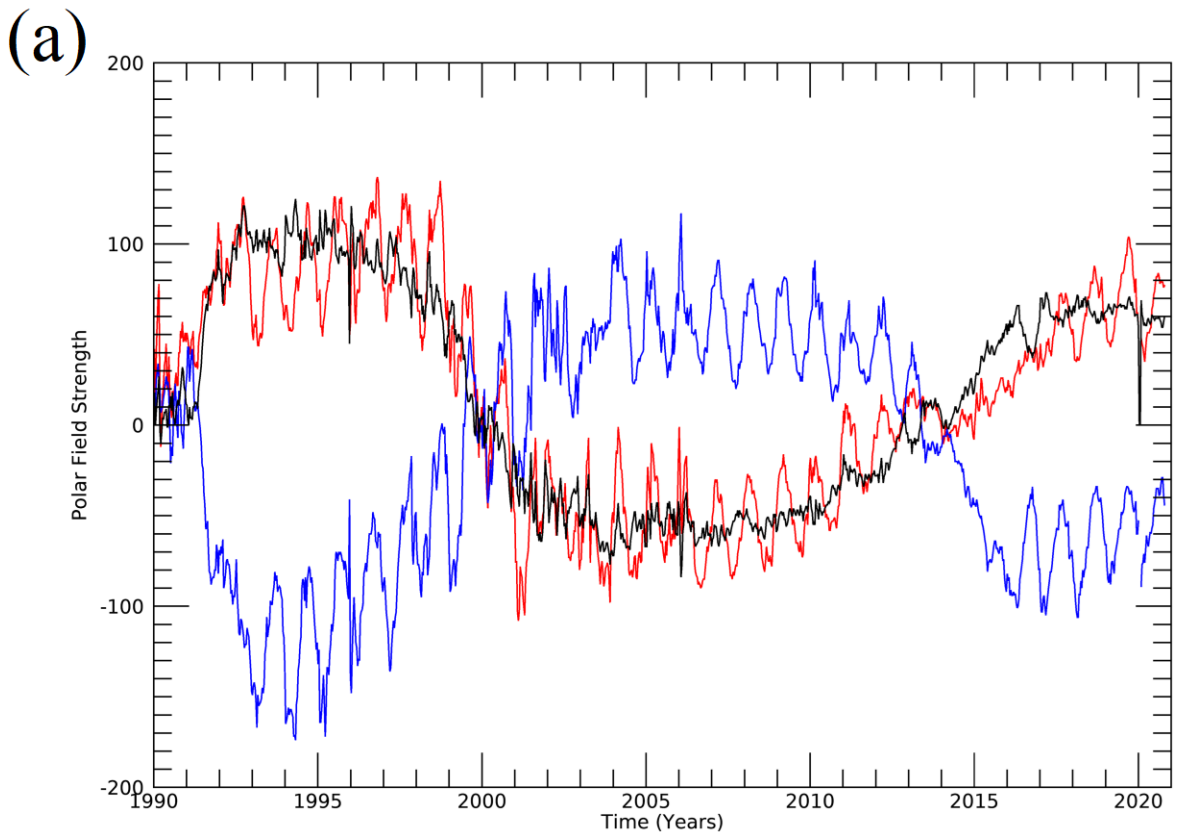
Poirier et al. (2020)

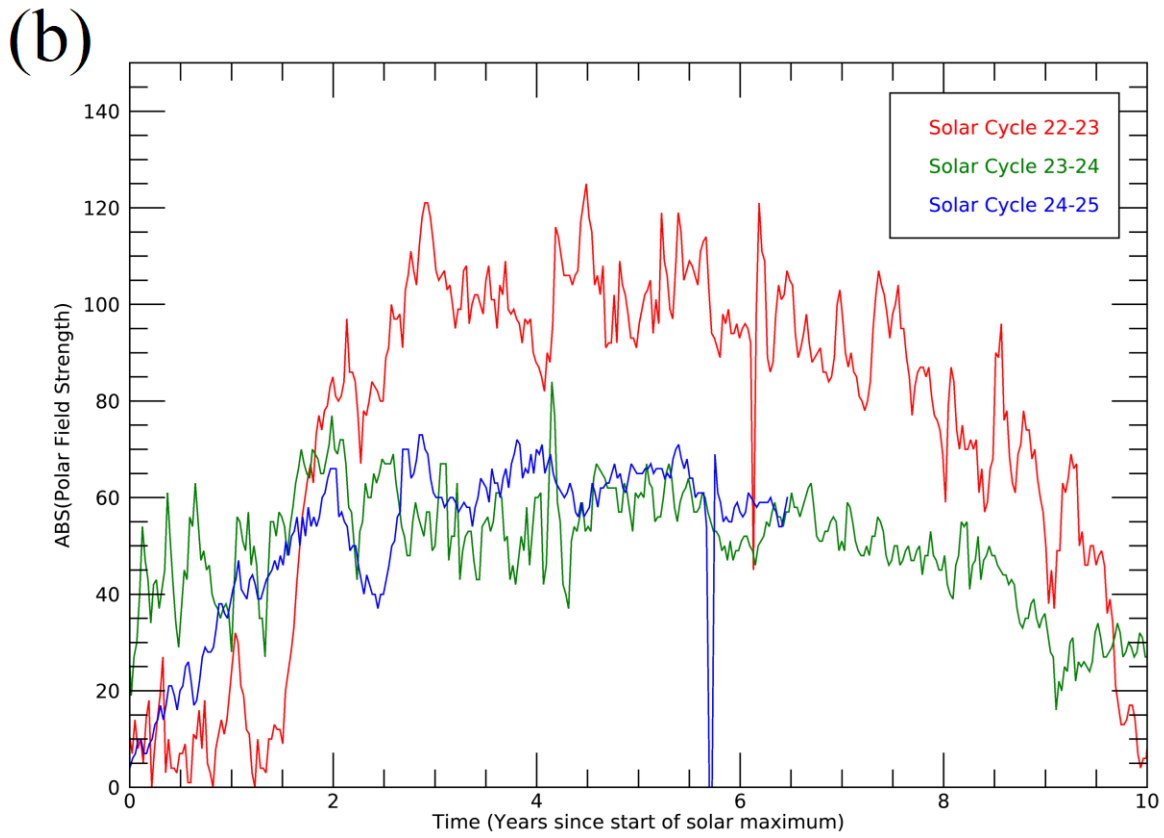
Comparing Solar Minima: Sunspot Number



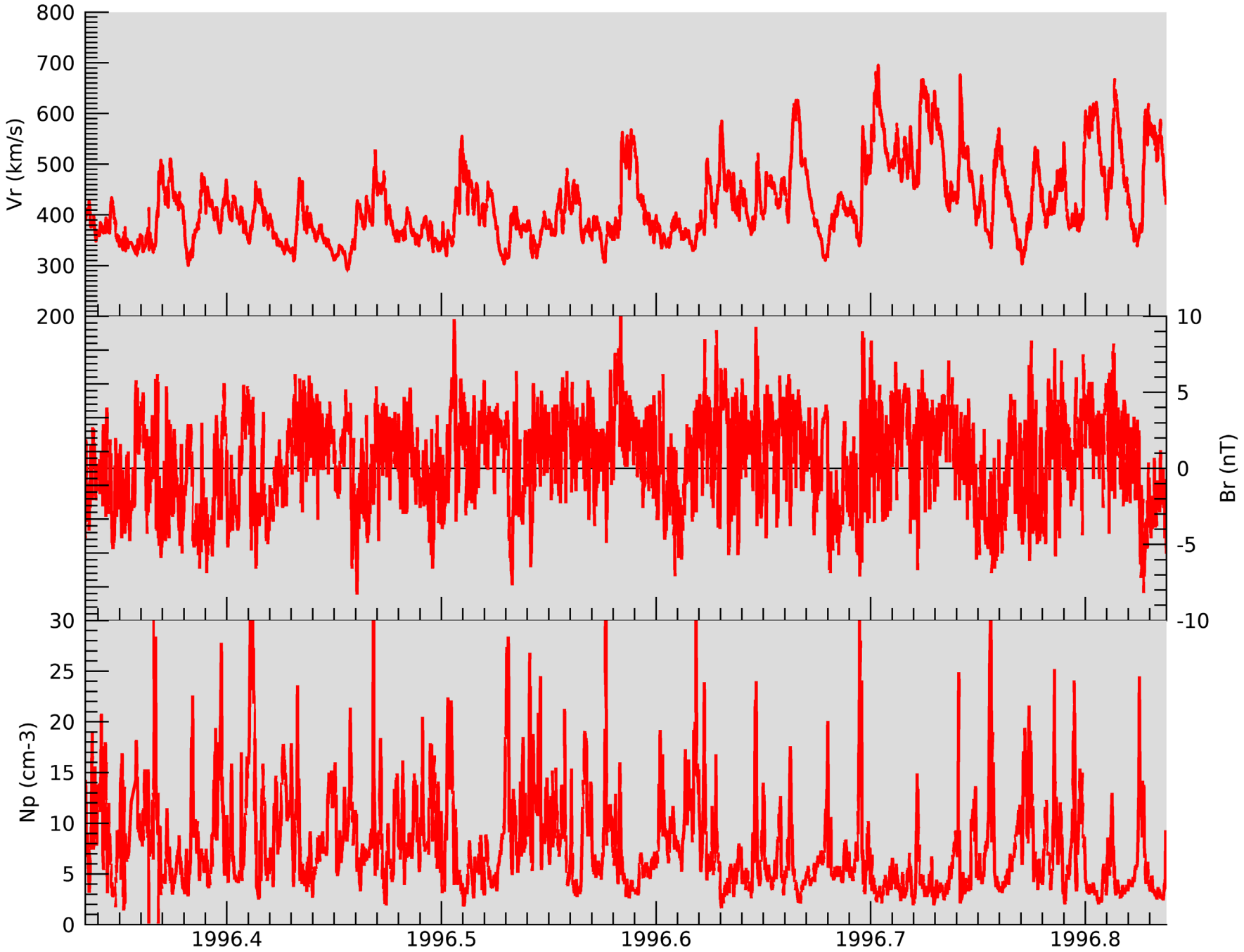


Comparing Solar Minima: Polar Field Strength

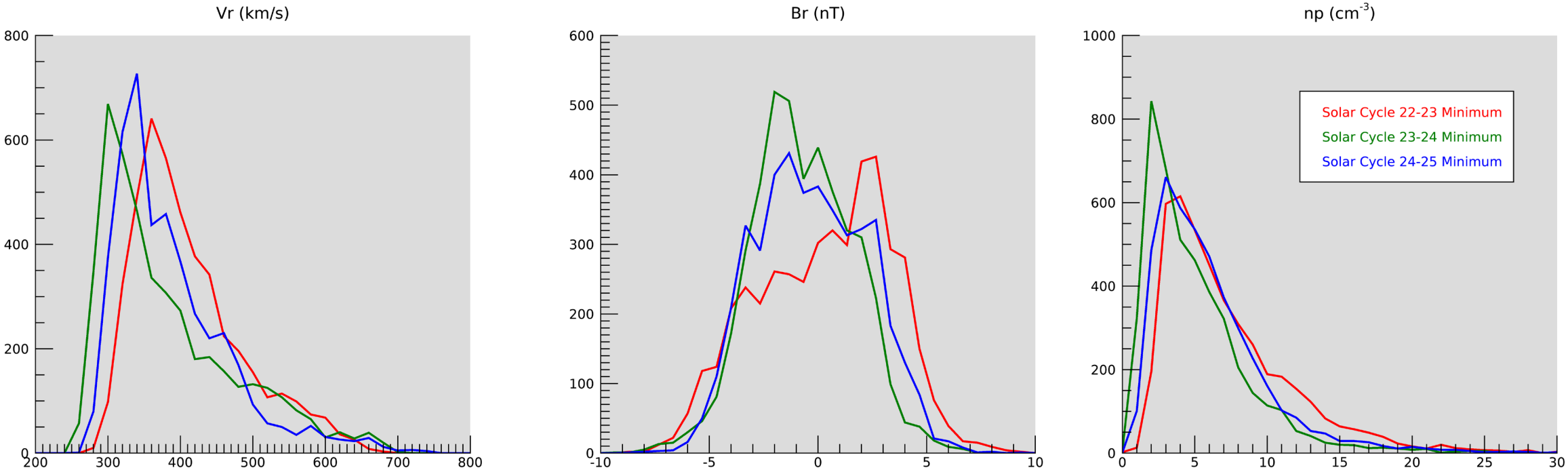




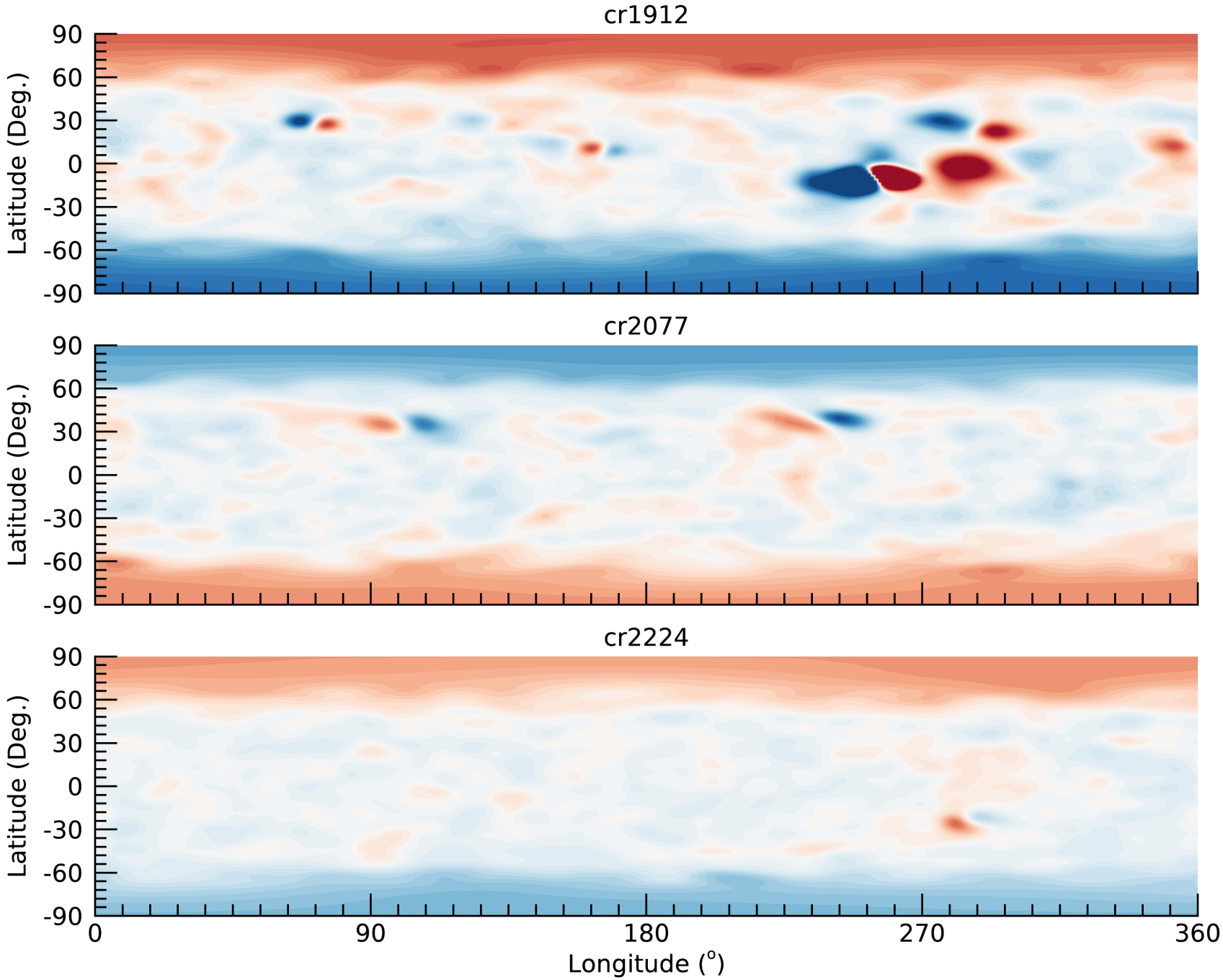
Solar Wind Conditions for 22/23 Minimum



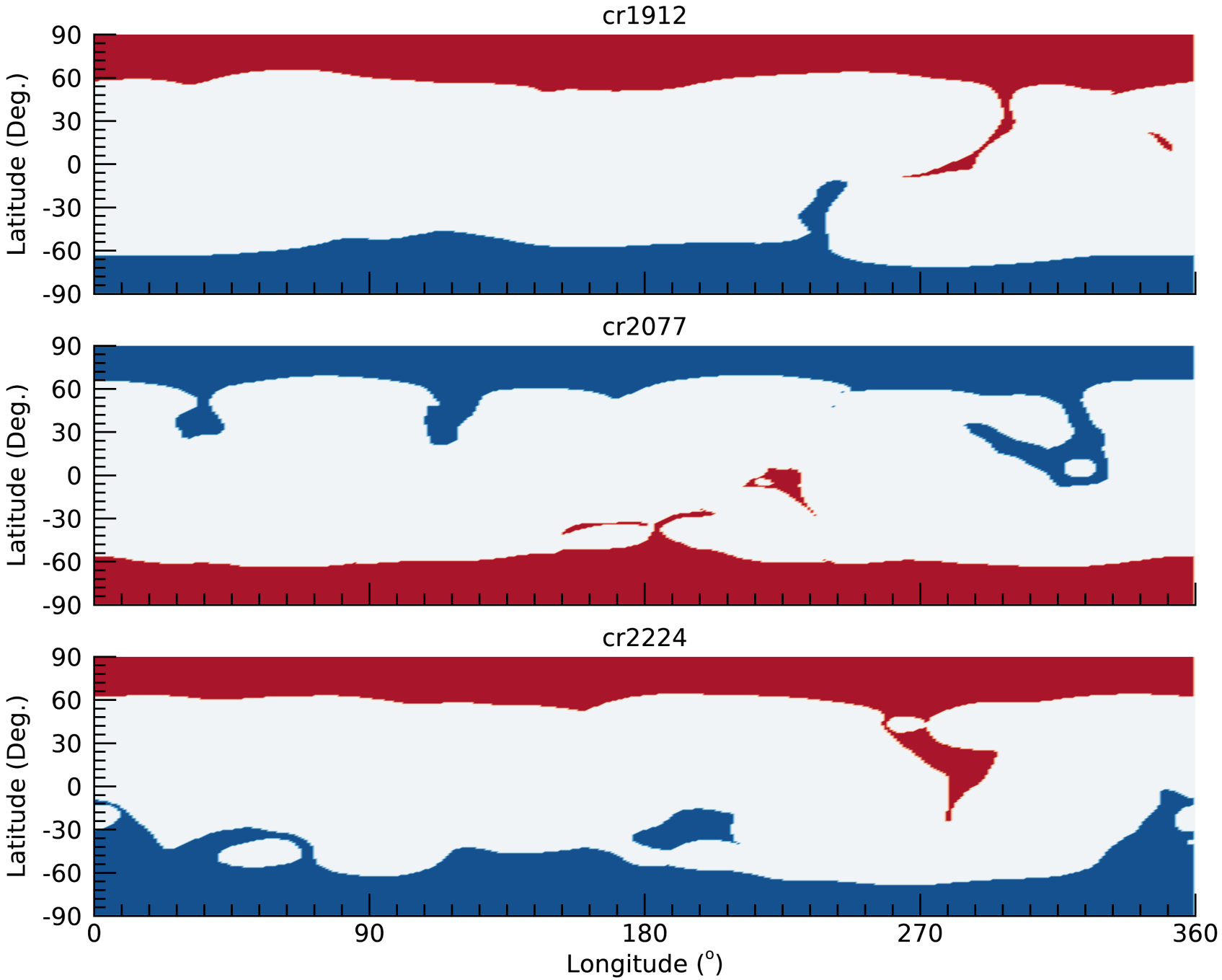
Histograms of Observed Solar Wind Properties

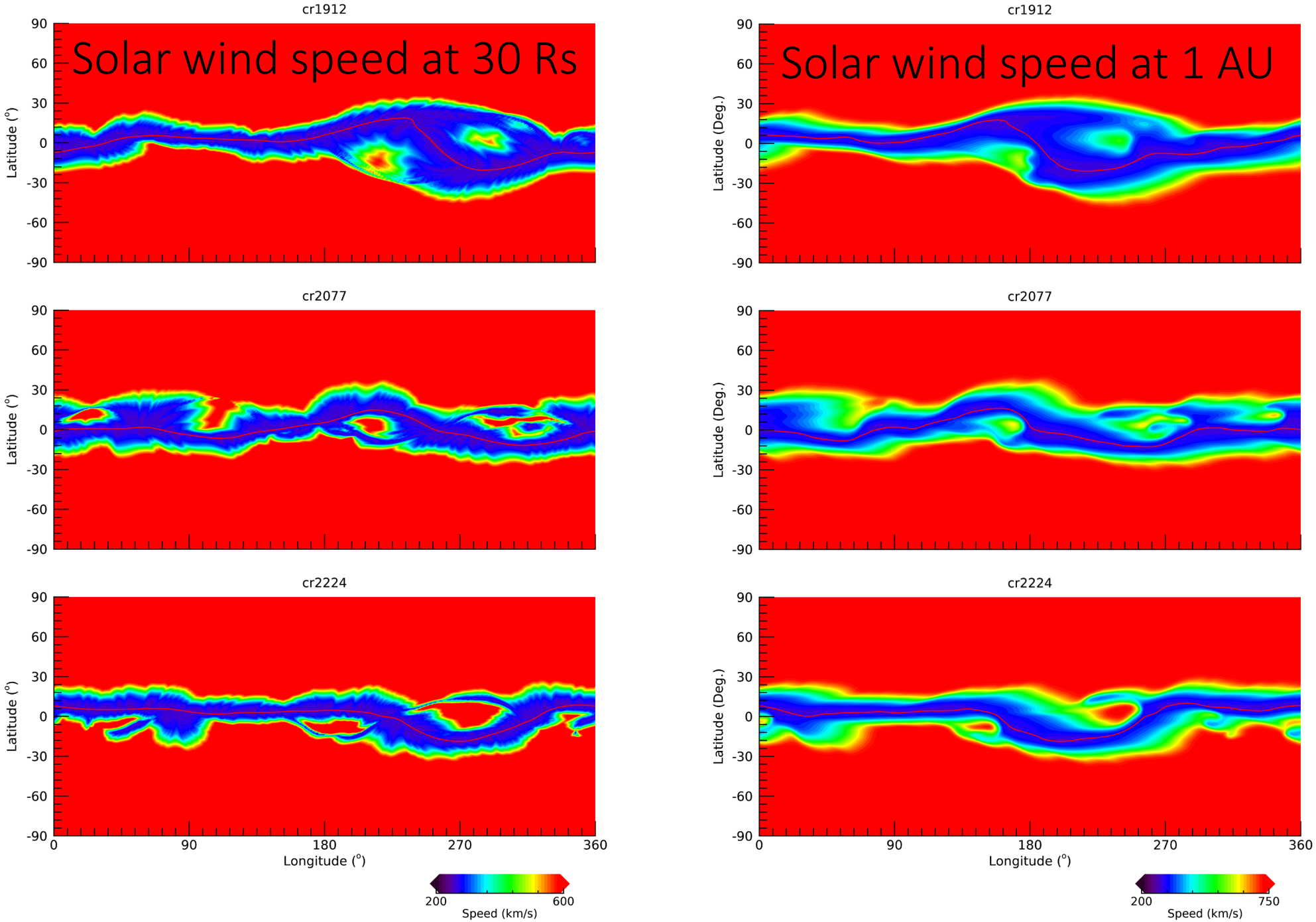


Boundary Conditions

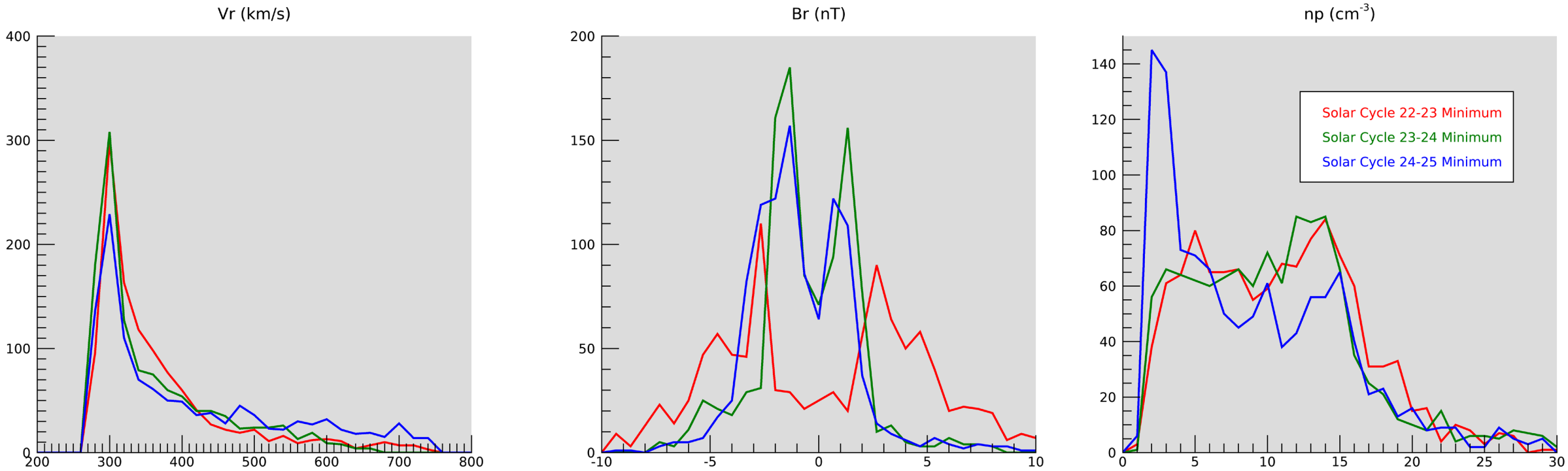


Coronal Holes

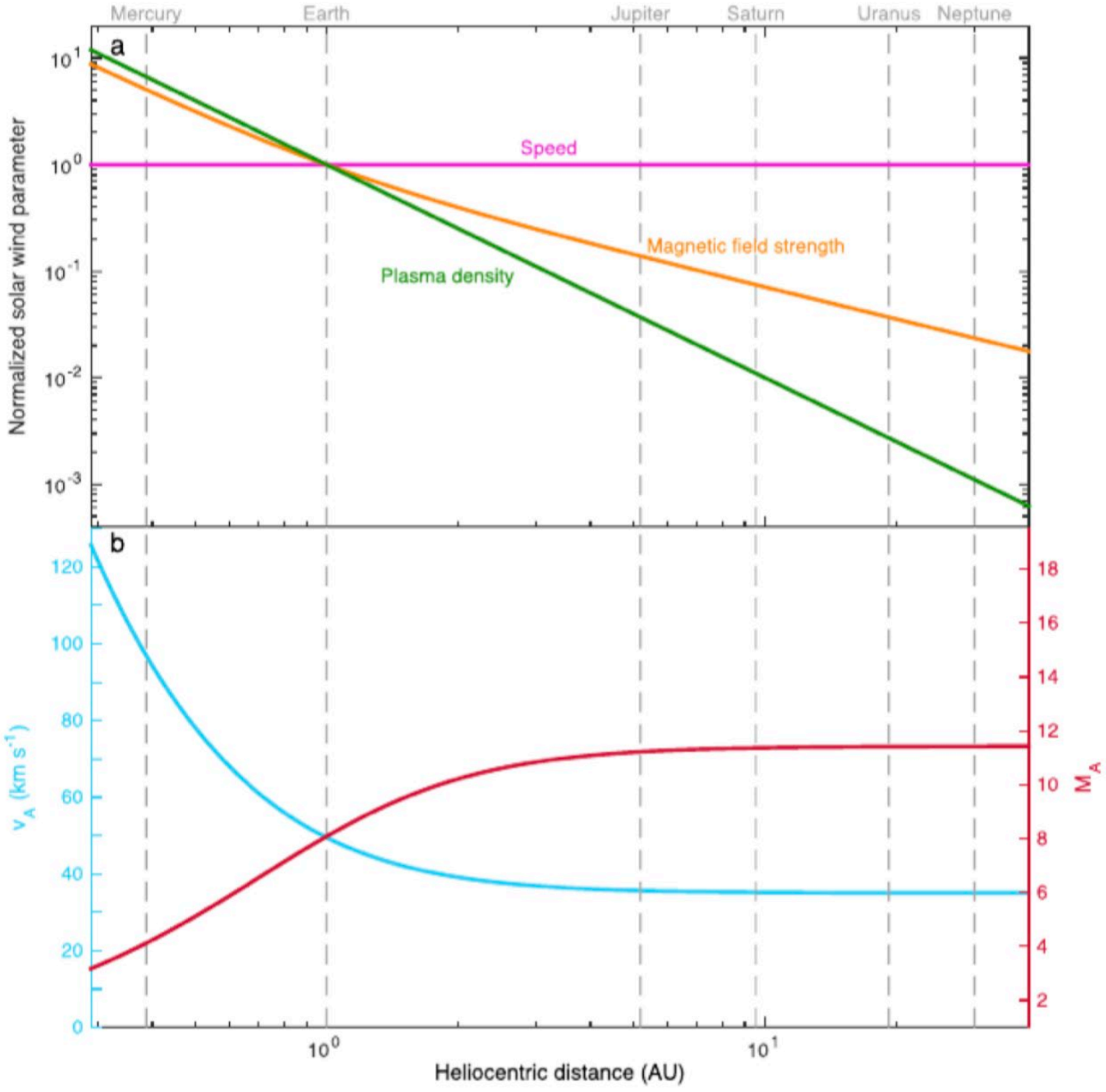



cr1912
Solar wind speed at 30 Rs
cr1912
Solar wind speed at 1 AU
cr2077
cr2077
cr2224
cr2224
Latitude (°)
Latitude (Deg.)
90
60
30
0
-30
-60
-90
0
90
180
270
360
Longitude (°)
200
600
Speed (km/s)
200
750
Speed (km/s)

Histograms of Modeled Solar Wind Properties

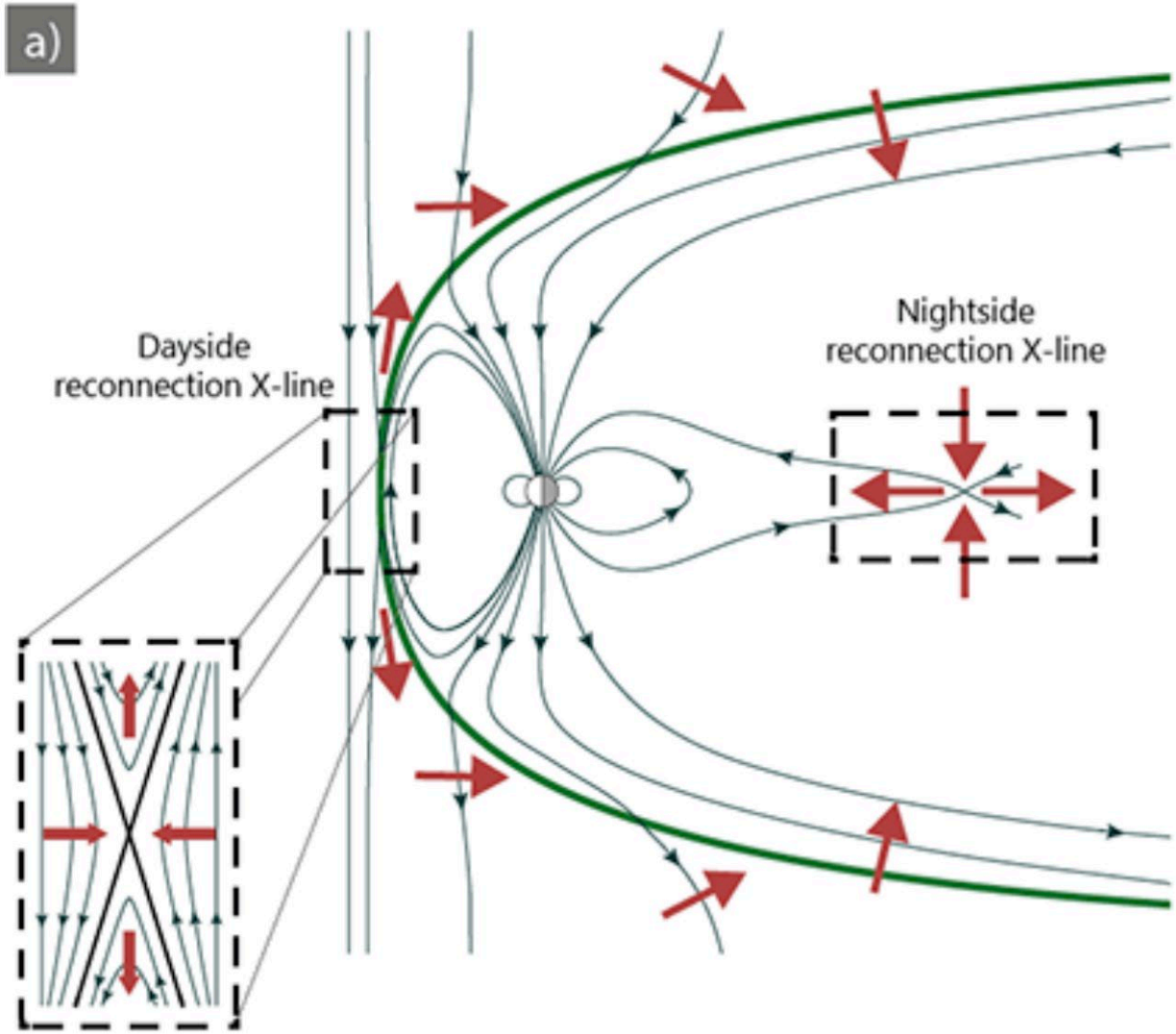


Planetary responses to the quiescent Sun: The role of the solar wind

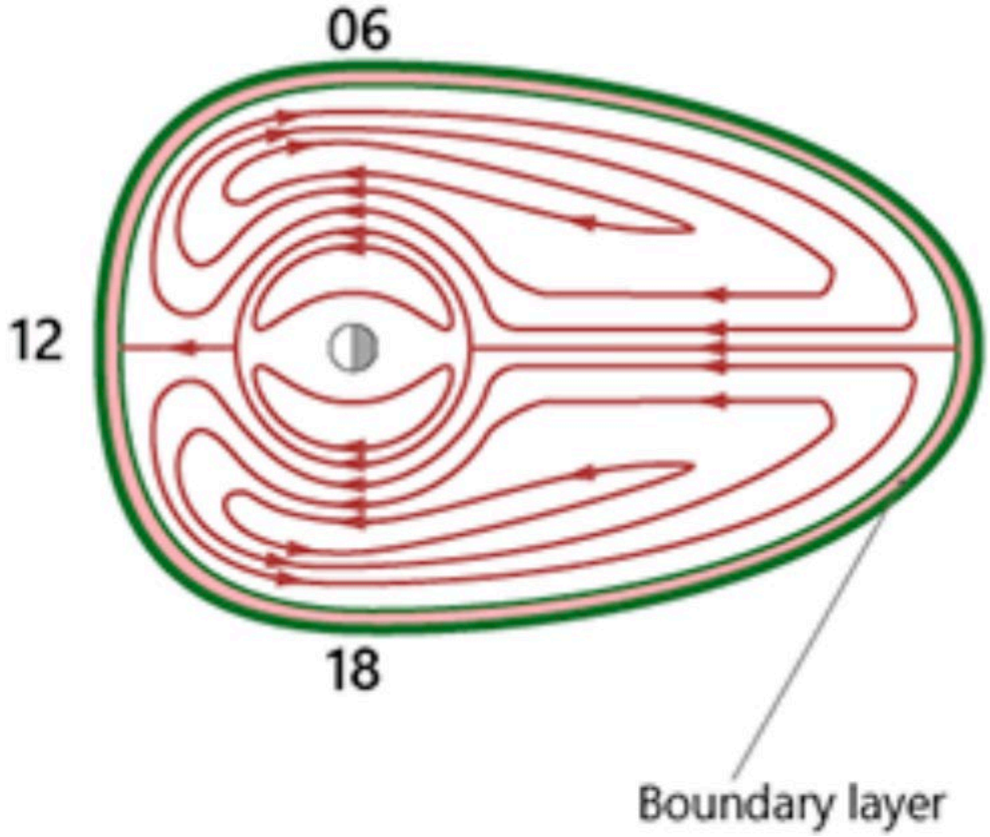


Masters (2018)

Dungey (Reconnection) Model

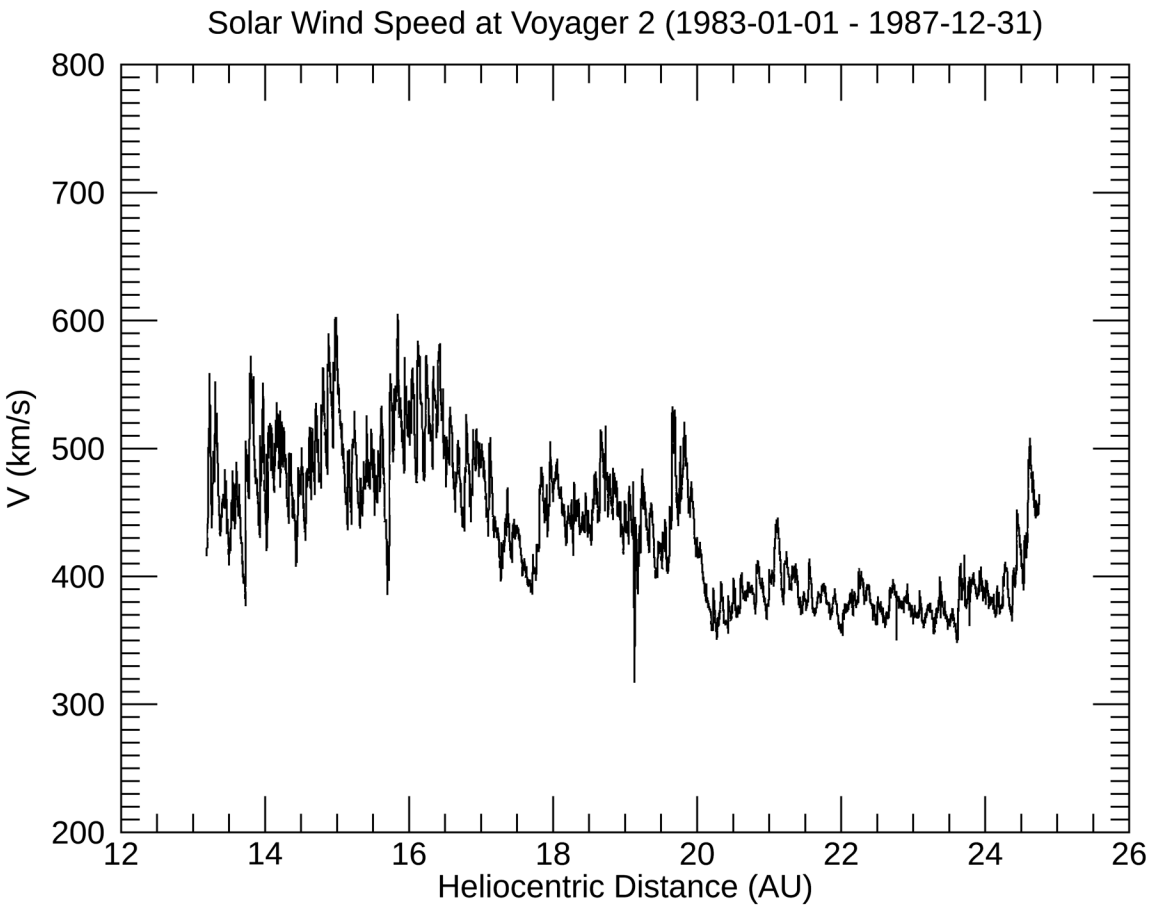


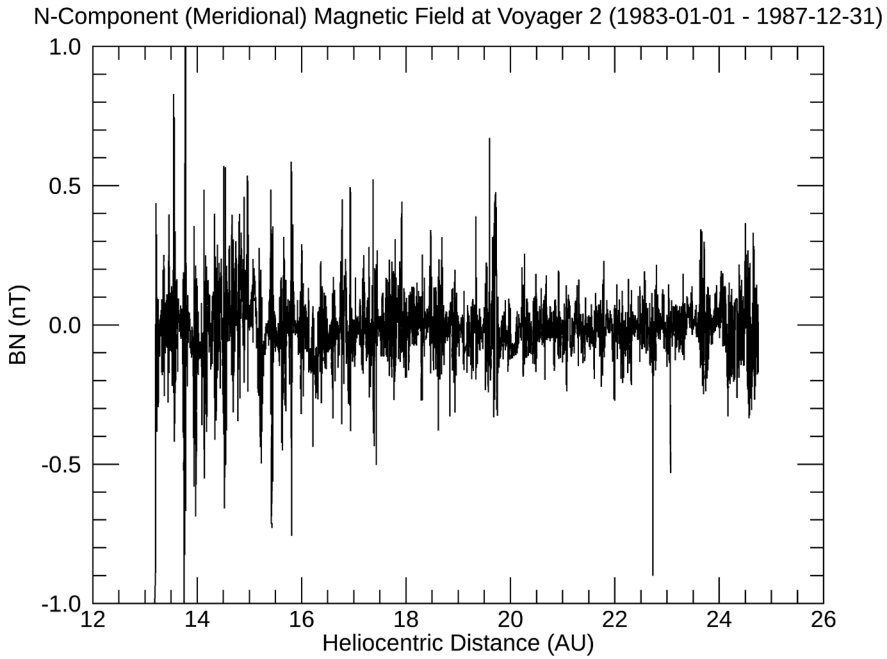
Axford and Hines (Viscous interaction) Model

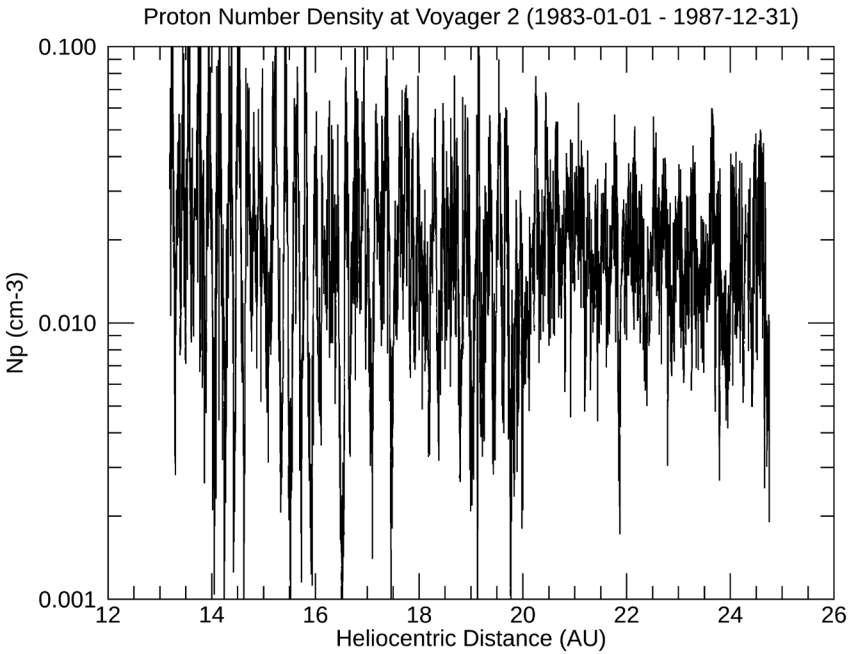


Arridge (2020)

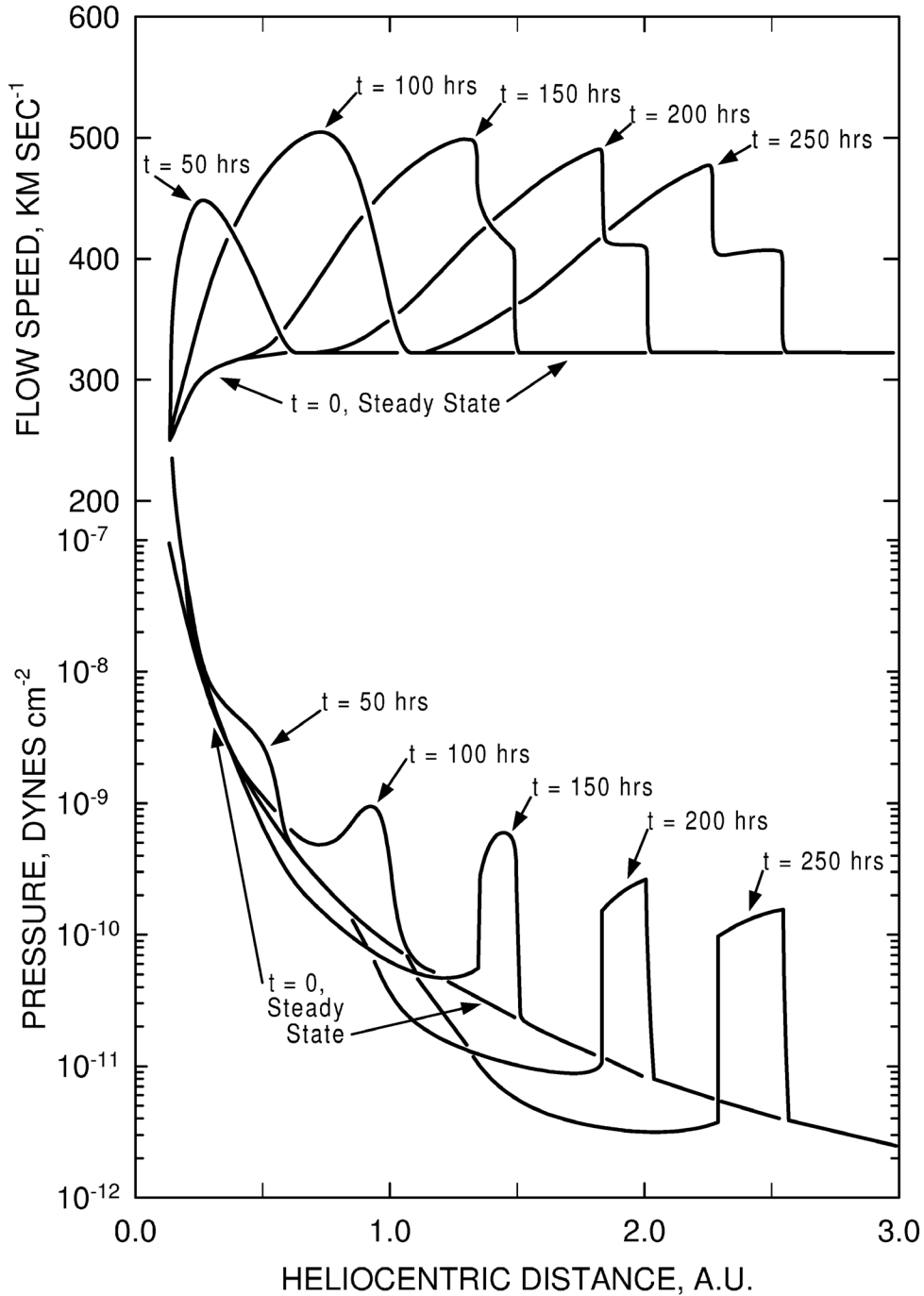
Planetary responses to the quiescent Sun: The role of the solar wind





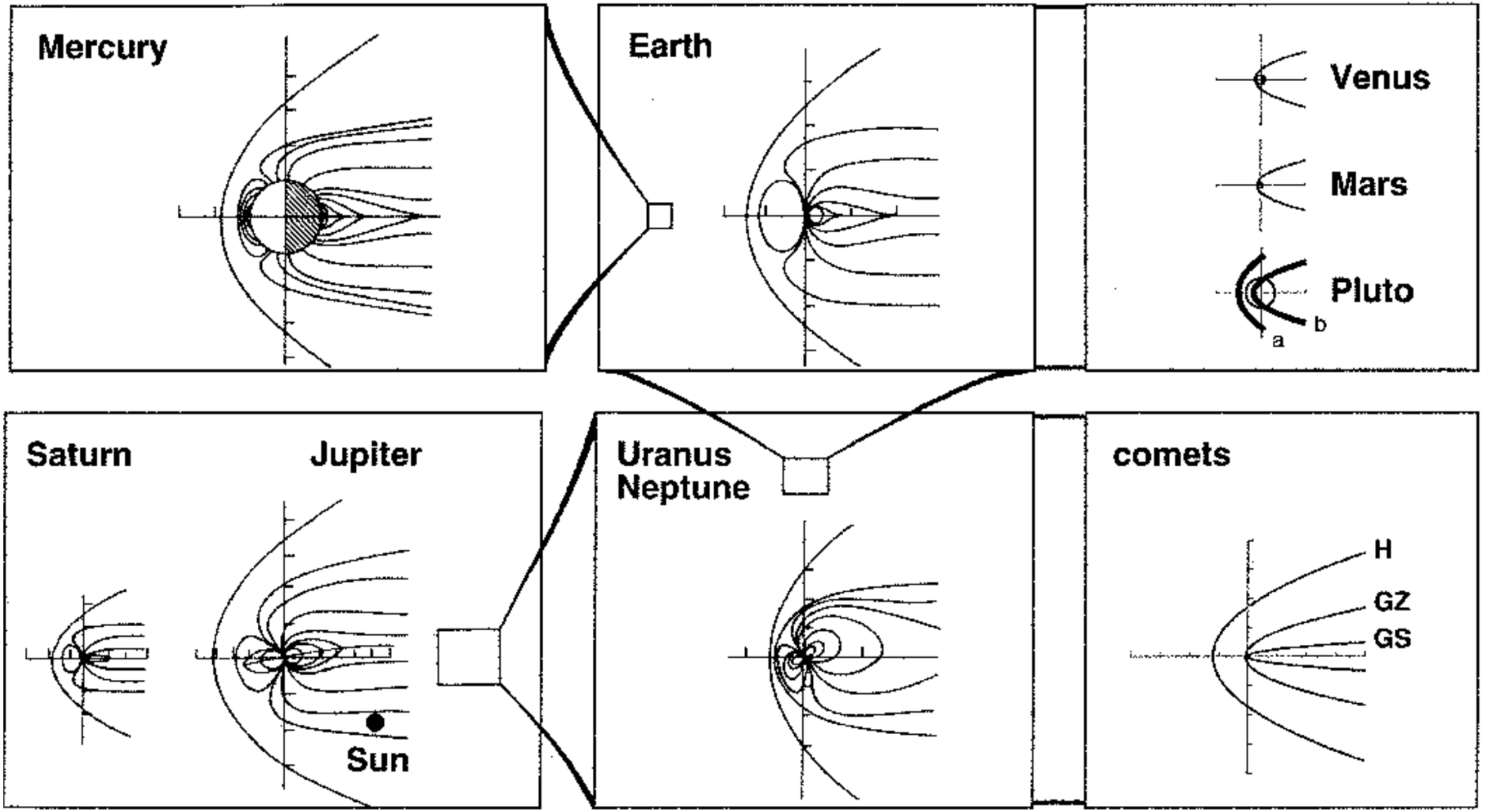


- Models confirm evolution of stream structure
  - F/R shocks form bounding compression
  - Stream amplitudes are strongly damped



Gosling et al. (2007)

Planetary responses to the quiescent Sun: The role of the planet



Kivelson & Russell (1995)

Summary

- Model results provide a global context for interpreting *in-situ* measurements
  - 3-D structure and properties captured by models
- Comparing Solar Minima:
  - Solar indices (SSN and Polar Field Strength) suggest a continual slide into deeper minimum conditions, but:
  - Statistical properties of the solar wind during most recent minimum (24/25) are midway between the 22/23 (1996) and 23/24 (2008) minima.
  - Structurally, the 2008 and 2019 minima are different from 1996 minimum (e.g., pseudo-streamers, equatorial CHs).
- Planetary response to solar wind depends on:
  - Properties of solar wind (location of planet)
  - Properties of the planet

Future Opportunities / Questions

- New Missions:
  - Coupling SolO's unique dataset with global MHD models
    - Adding PHI magnetograms into modeling pipeline
- Old Missions:
  - We can still learn from STEREO, Ulysses, Helios datasets
- How does the large-scale structure of the heliosphere respond to secular changes in the structure of the solar corona?
  - Larger/smaller solar cycle?
  - Grand minimum?