Understanding the Unique Features of the Recent Solar Minimum using a Global MHD Model of the Corona and Heliosphere

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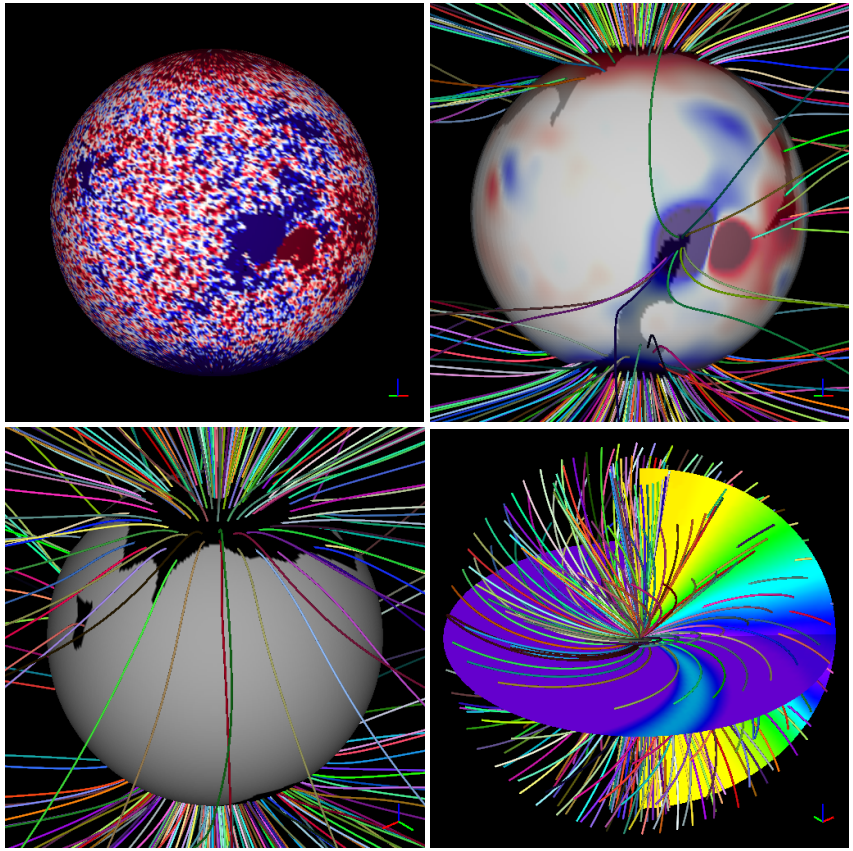
San Diego, California.



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Kona, Hawaii
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Outline

- Summary of the MHD modeling approach
- Overview of the observations
- Comparison of model results and observations for CR 1913 (WSM) and 2068 (WHI)
- Summary

Summary of MHD Approach: The equations

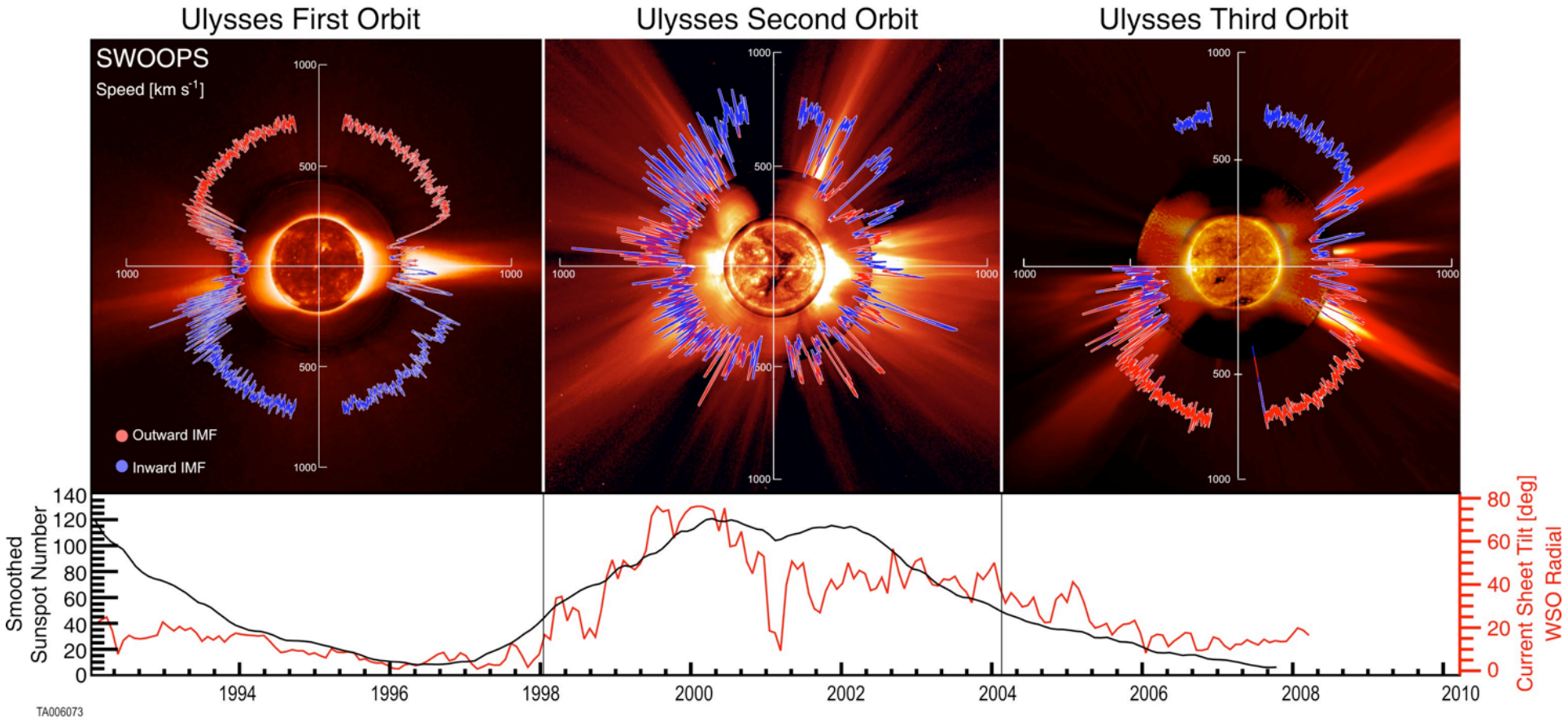
$$
\begin{aligned}
\nabla \times \mathbf{B} &= \frac{4\pi}{c}\mathbf{J}, \\
\nabla \times \mathbf{E} &= -\frac{1}{c}\frac{\partial \mathbf{B}}{\partial t}, \\
\mathbf{E} + \frac{\mathbf{v} \times \mathbf{B}}{c} &= \eta \mathbf{J}, \\
\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \mathbf{v}) &= 0, \\
\frac{1}{\gamma - 1}\left(\frac{\partial T}{\partial t} + \mathbf{v} \cdot \nabla T\right) &= -T\nabla \cdot \mathbf{v} + \frac{m}{k\rho}S \\
\rho\left(\frac{\partial \mathbf{v}}{\partial t} + \mathbf{v} \cdot \nabla \mathbf{v}\right) &= \frac{1}{c}\mathbf{J} \times \mathbf{B} - \nabla(p + p_w) + \rho \mathbf{g} + \nabla \cdot (\nu \rho \nabla \mathbf{v}), \\
S &= (-\nabla \cdot \mathbf{q} - n_e n_p Q(T) + H_{\rm ch}),
\end{aligned}
$$

$$
\mathbf{q} = \begin{cases} -\kappa_0 T^{5/2} \hat{\mathbf{b}}\hat{\mathbf{b}} \cdot \nabla T & \text{if } R_\odot \leq r \lesssim 10 R_\odot \\ \alpha n_e k T \mathbf{v} & \text{if } r \gtrsim 10 R_\odot \end{cases},
$$

Summary of MHD Approach: Main Features

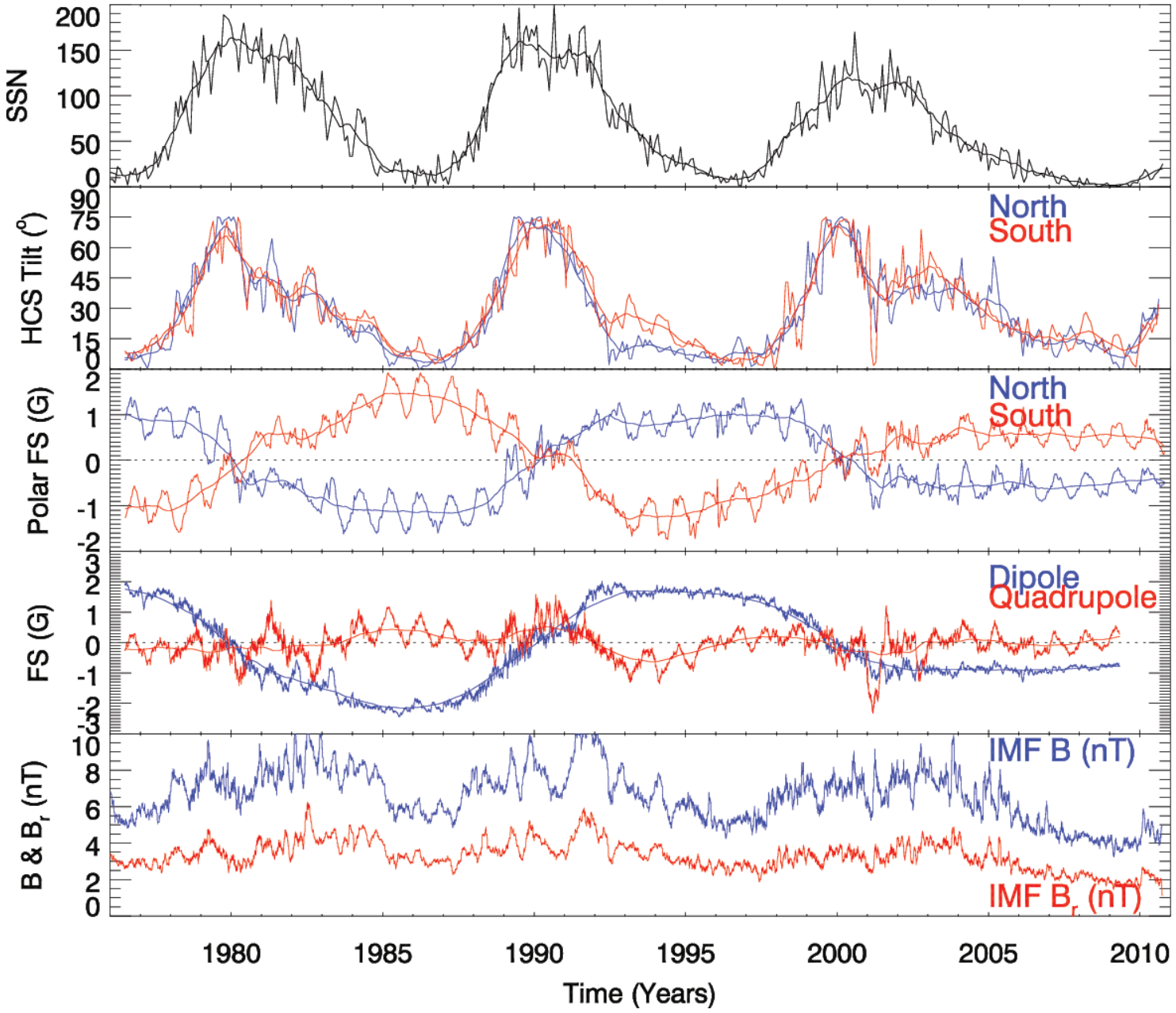
- Time-dependent, resistive MHD
- Incorporate observed photospheric magnetic field
- Modeling region separated into two components: Corona and heliosphere
- Physics: Essential energy transport processes included, empirically-based coronal heating profiles, Alfvén wave pressure
- Non-uniform meshes
- 3D finite difference
- Implicit and semi-implicit time differencing
- F95, MPI, multi-OS, Dynamic mesh allocation, restarts, post-processing tools.

A 3-D View of the Heliosphere from Ulysses



McComas et al. (2008)

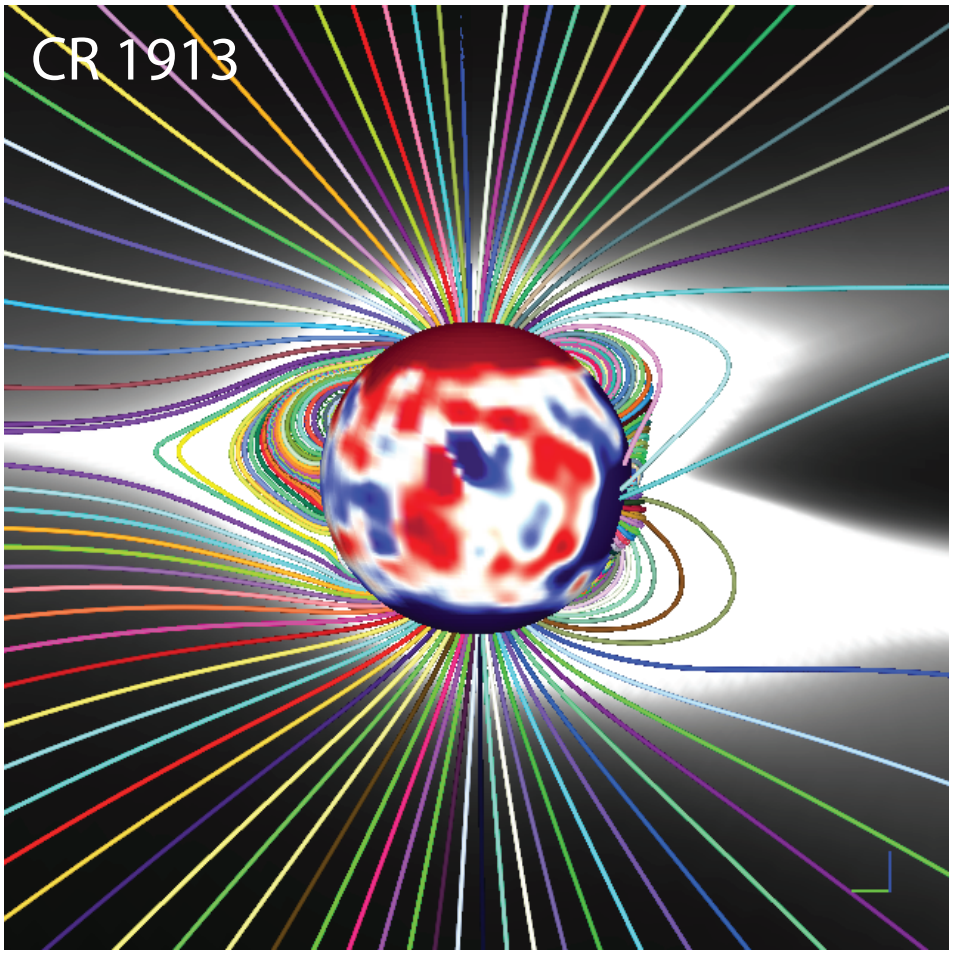
Solar cycle evolution of some key parameters

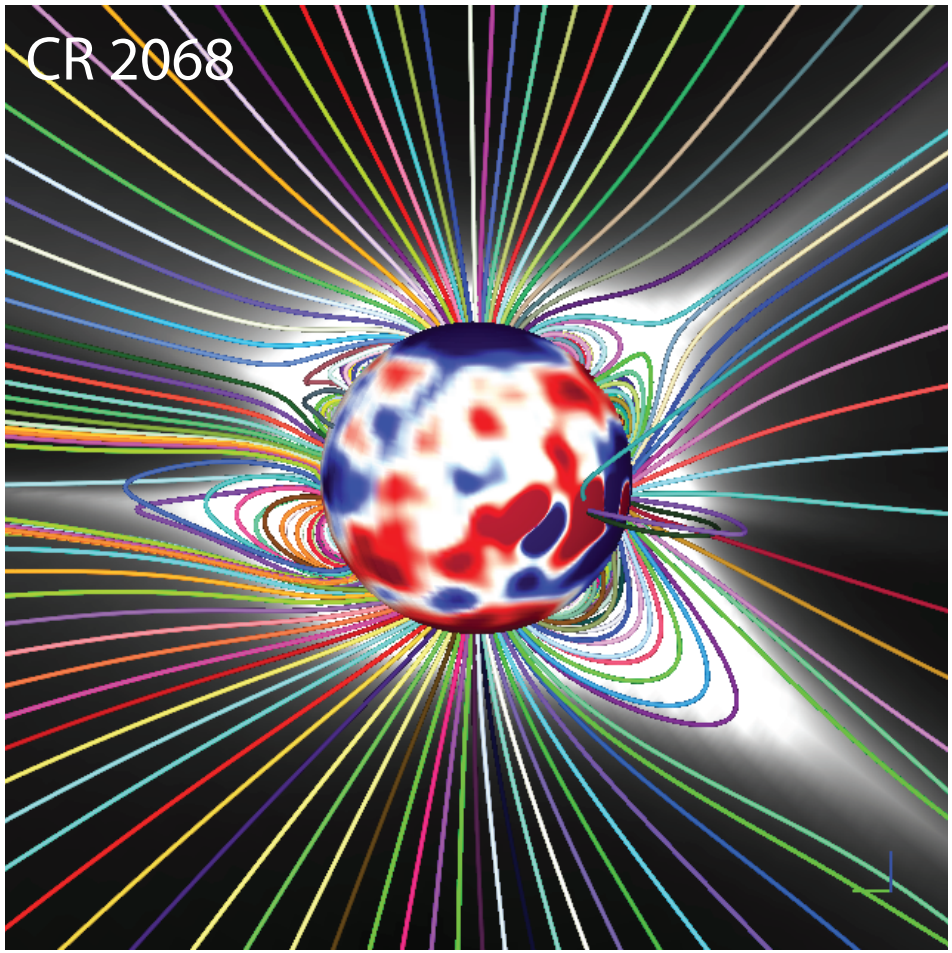


Structural Differences between the Current and Previous Solar Minimum

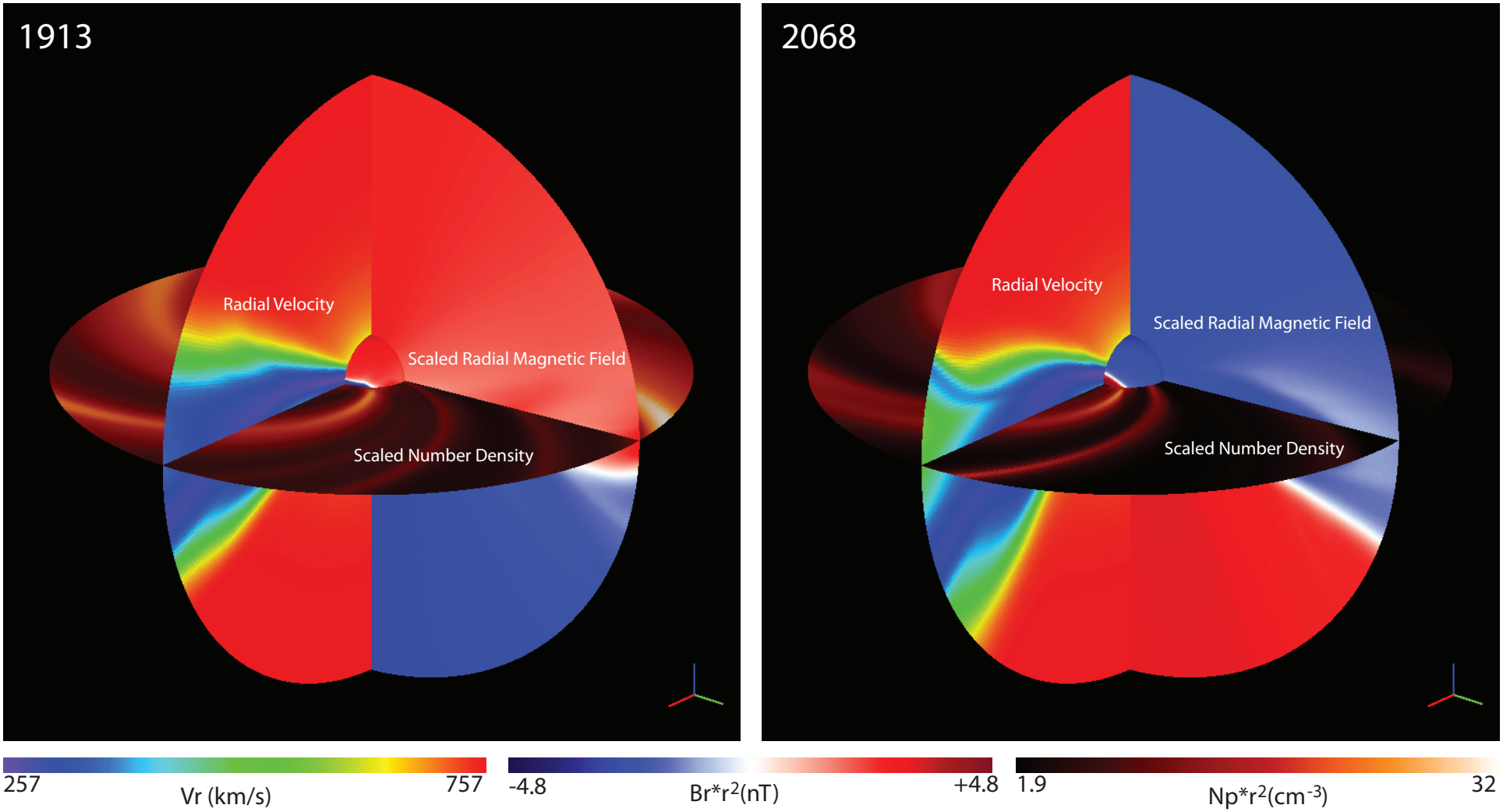
- Coronal streamer structure is different:
  - Pseudostreamers (*Wang et al.,* 2007)
- Coronal Holes:
  - Smaller (*Kirk et al.,* 2009)
  - More equatorial holes (*Gibson et al.,* 2009)
- Solar wind streams
  - Stronger
  - Longer in duration
  - More recurrent (*Gibson et al.,* 2009)

Comparison of WSM and WHI intervals: The corona

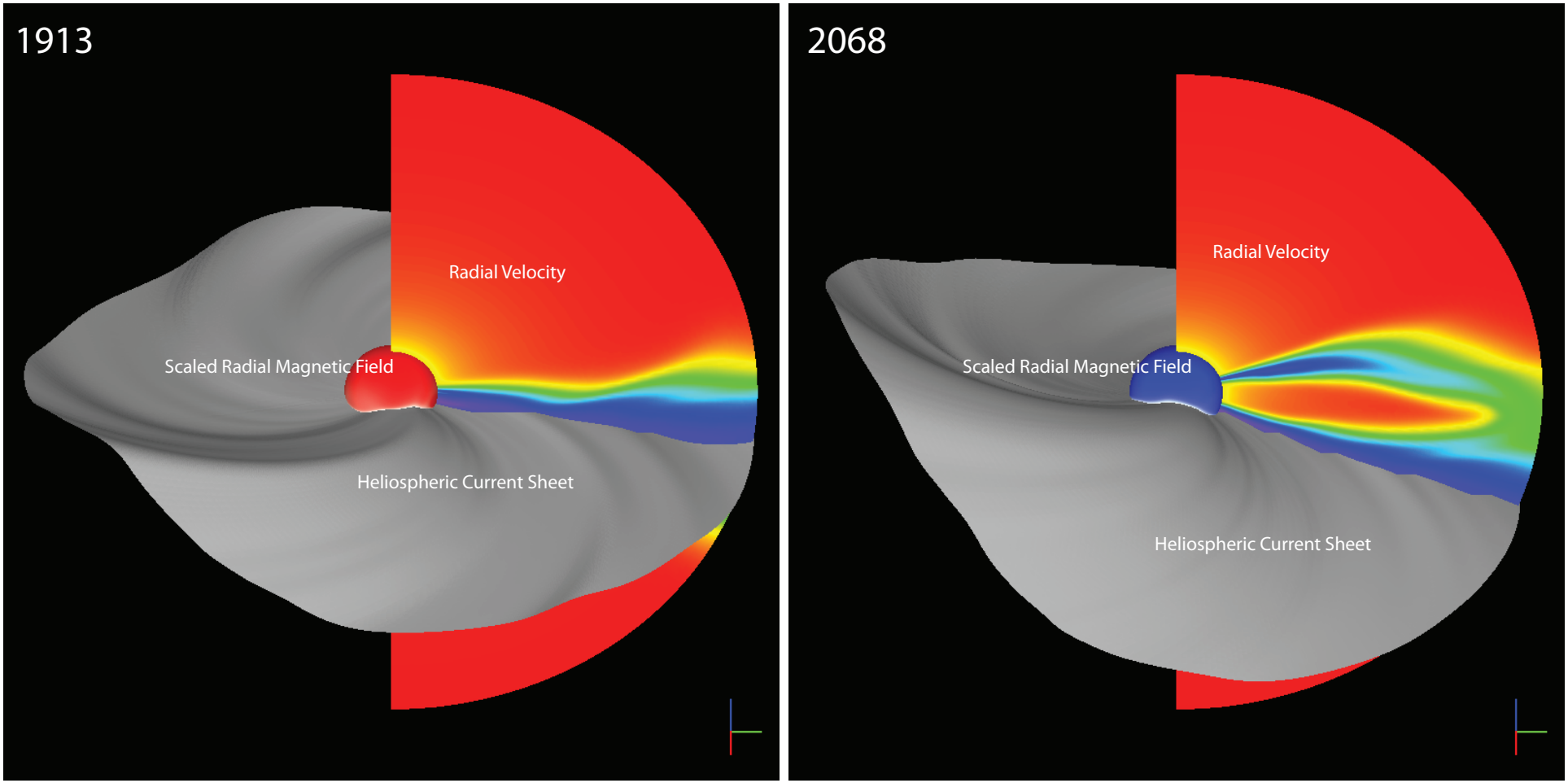


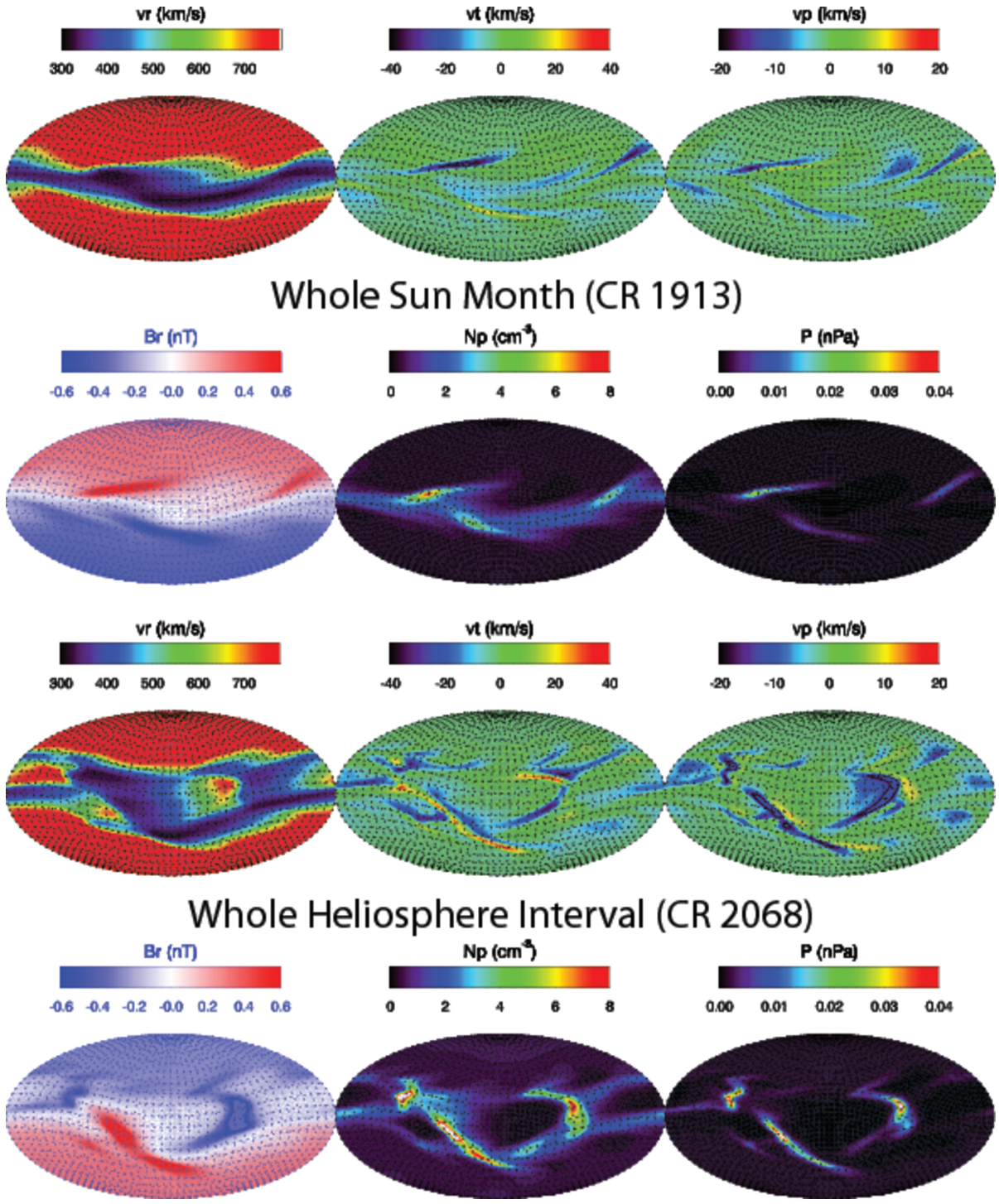


Comparison of WSM and WHI intervals: The heliosphere

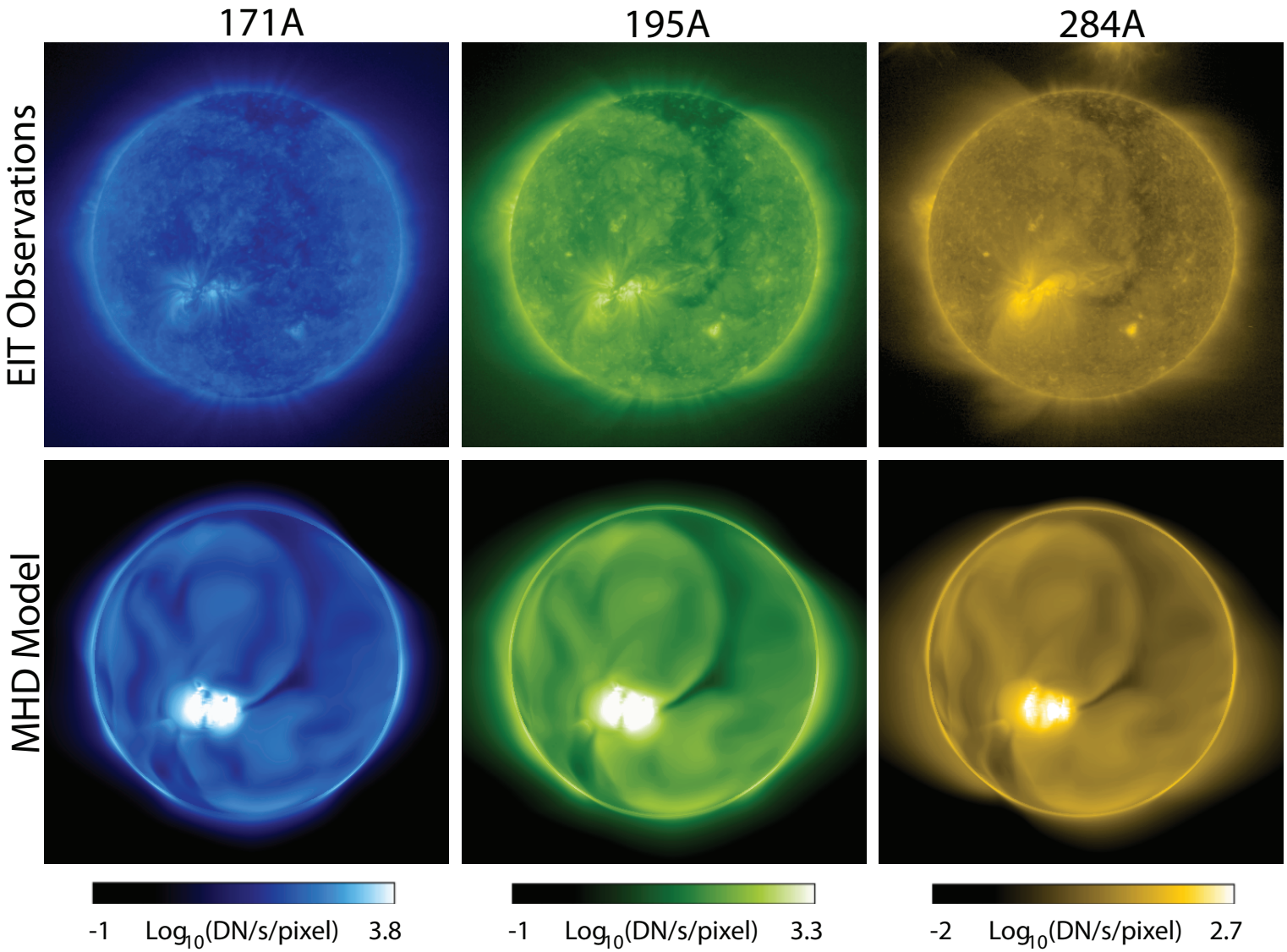


Comparison of WSM and WHI intervals: The heliosphere

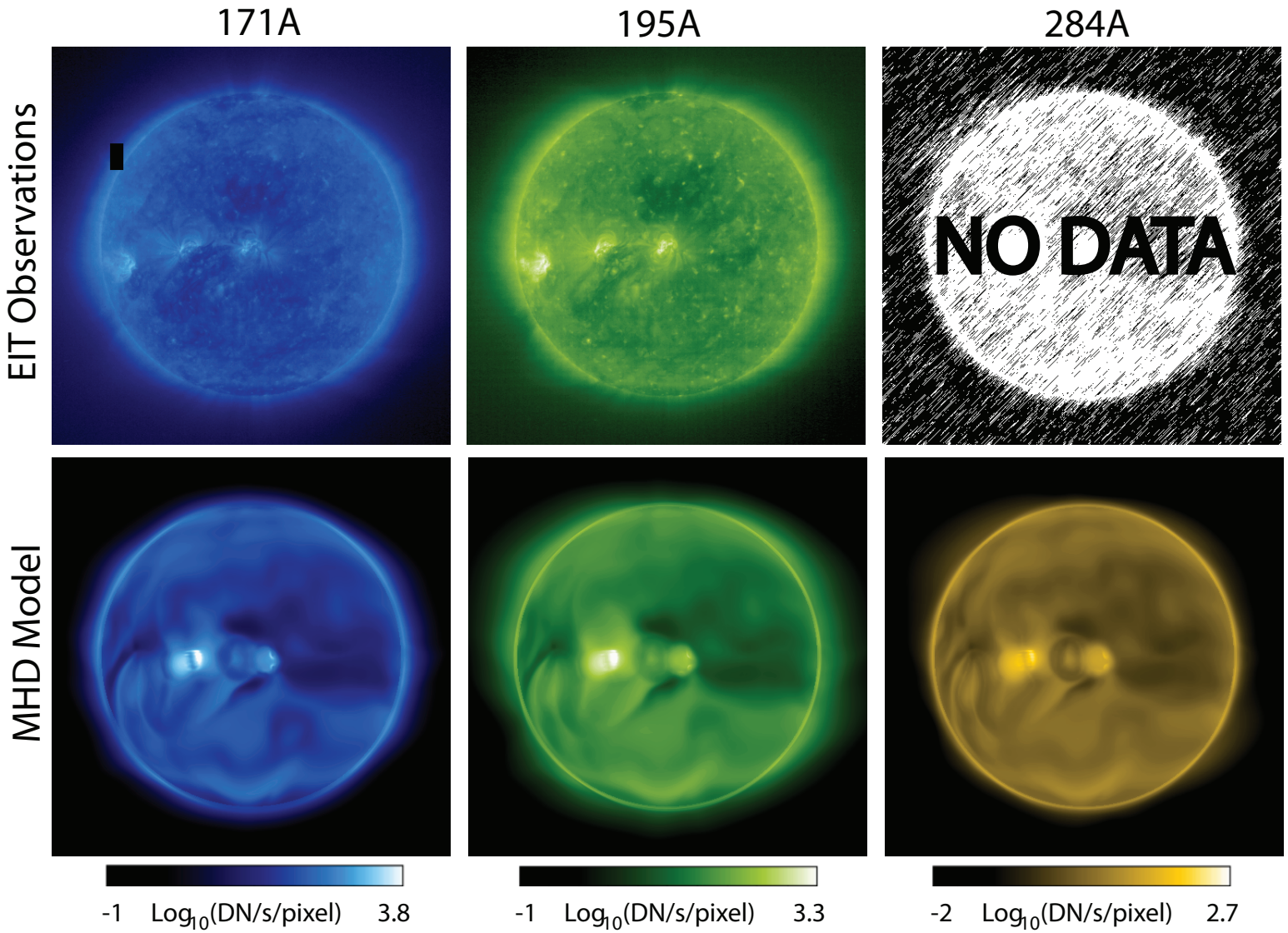



vr (km/s)
300 400 500 600 700
vt (km/s)
-40 -20 0 20 40
vp (km/s)
-20 -10 0 10 20
Whole Sun Month (CR 1913)
Br (nT)
-0.6 -0.4 -0.2 -0.0 0.2 0.4 0.6
Np (cm-3)
0 2 4 6 8
P (nPa)
0.00 0.01 0.02 0.03 0.04
vr (km/s)
300 400 500 600 700
vt (km/s)
-40 -20 0 20 40
vp (km/s)
-20 -10 0 10 20
Whole Heliosphere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

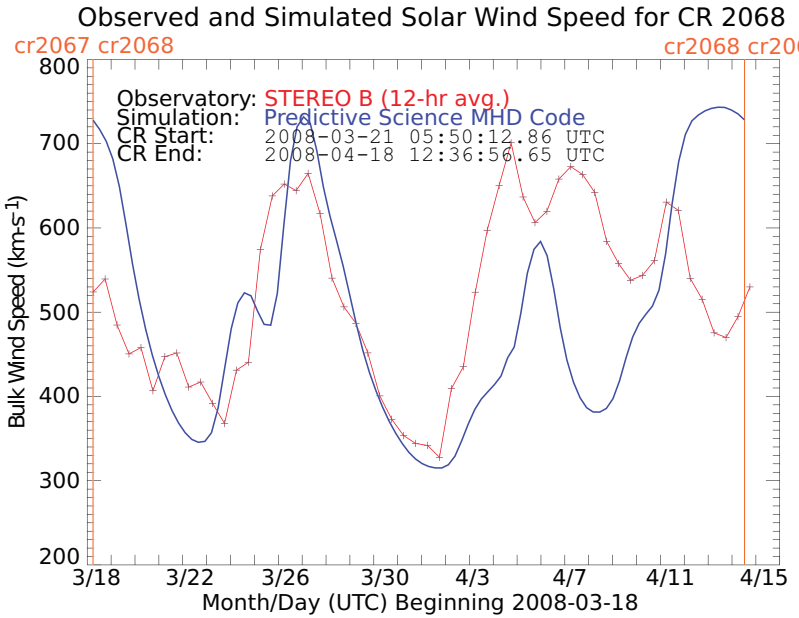
Comparison of model results remote sensing observations CR 1913

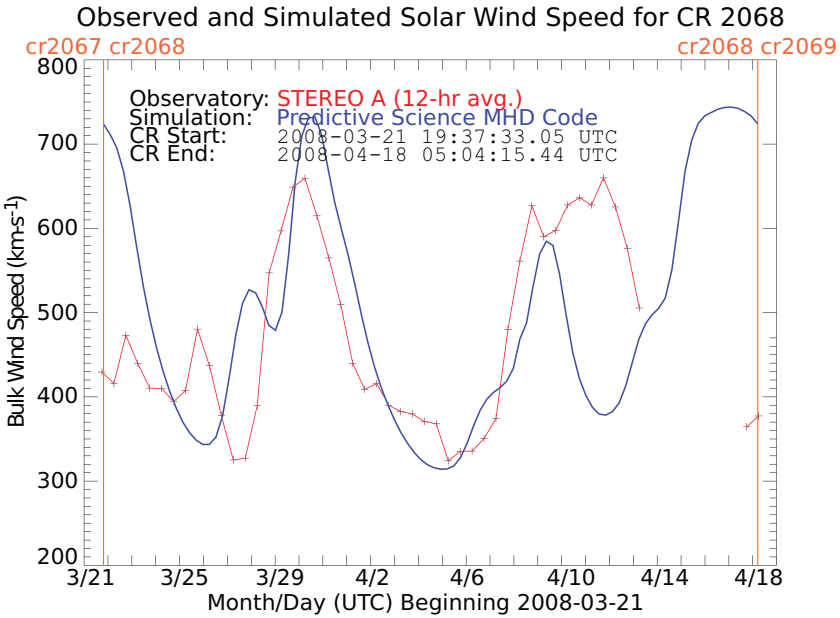


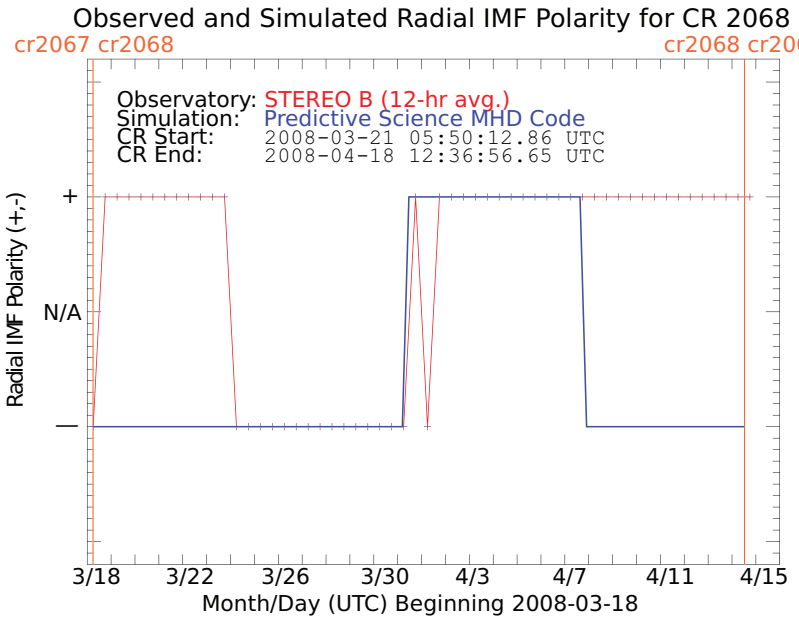
Comparison of model results remote sensing observations
CR 2068

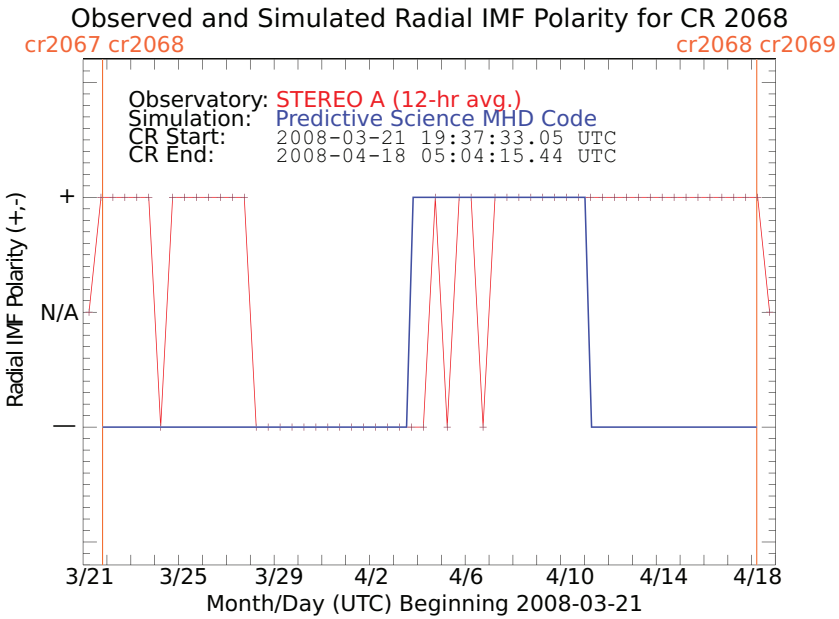


Comparison of model results with in-situ measurements

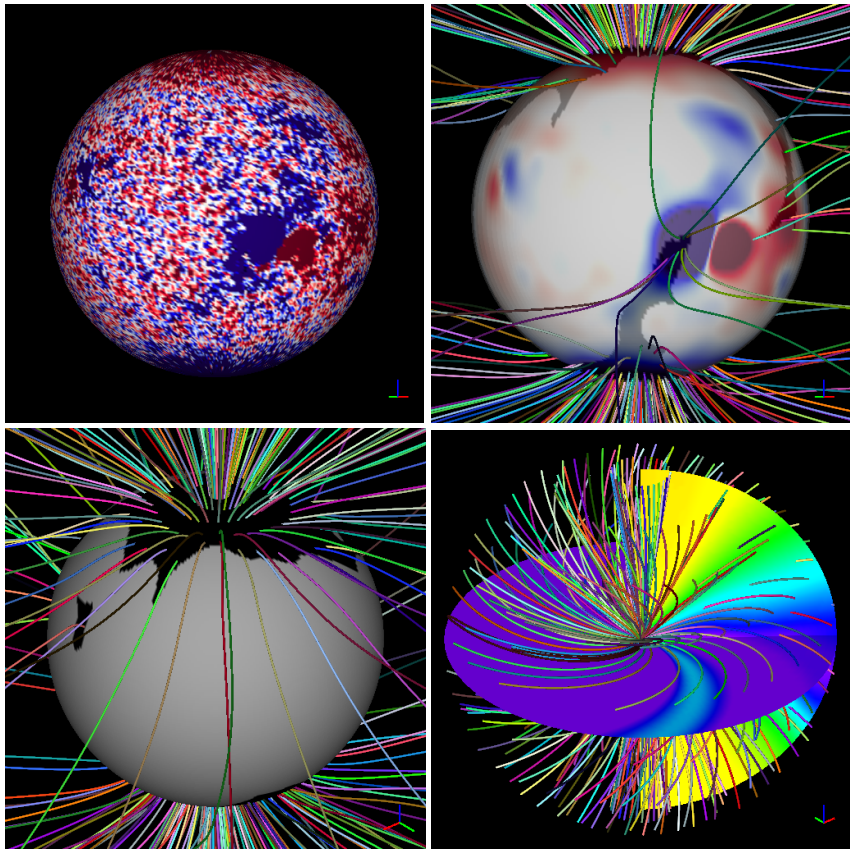








Summary



- The thermodynamic MHD model allows us to investigate both coronal and heliospheric structure in more detail:
  - Quantitative emission comparisons
  - Direct comparisons with in-situ measurements
  - Model results broadly consistent with observations
- Comparison of WSM with WHI:
  - Two intervals have markedly different structure
  - WHI wind is more complex than WSM
  - Underlying cause: Photospheric magnetic field
  - Outstanding issues: e.g., pseudostreamers, missing flux?
- Results on the web:
  - Polytropic solutions are currently available at: http:/www.predsci.com/stereo/
  - The thermodynamic solutions shown here will be made available in the near future.