On the 'Unique' Structure of the Heliosphere during the Recent Solar Minimum: Unipolar Streamers

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Predictive Science
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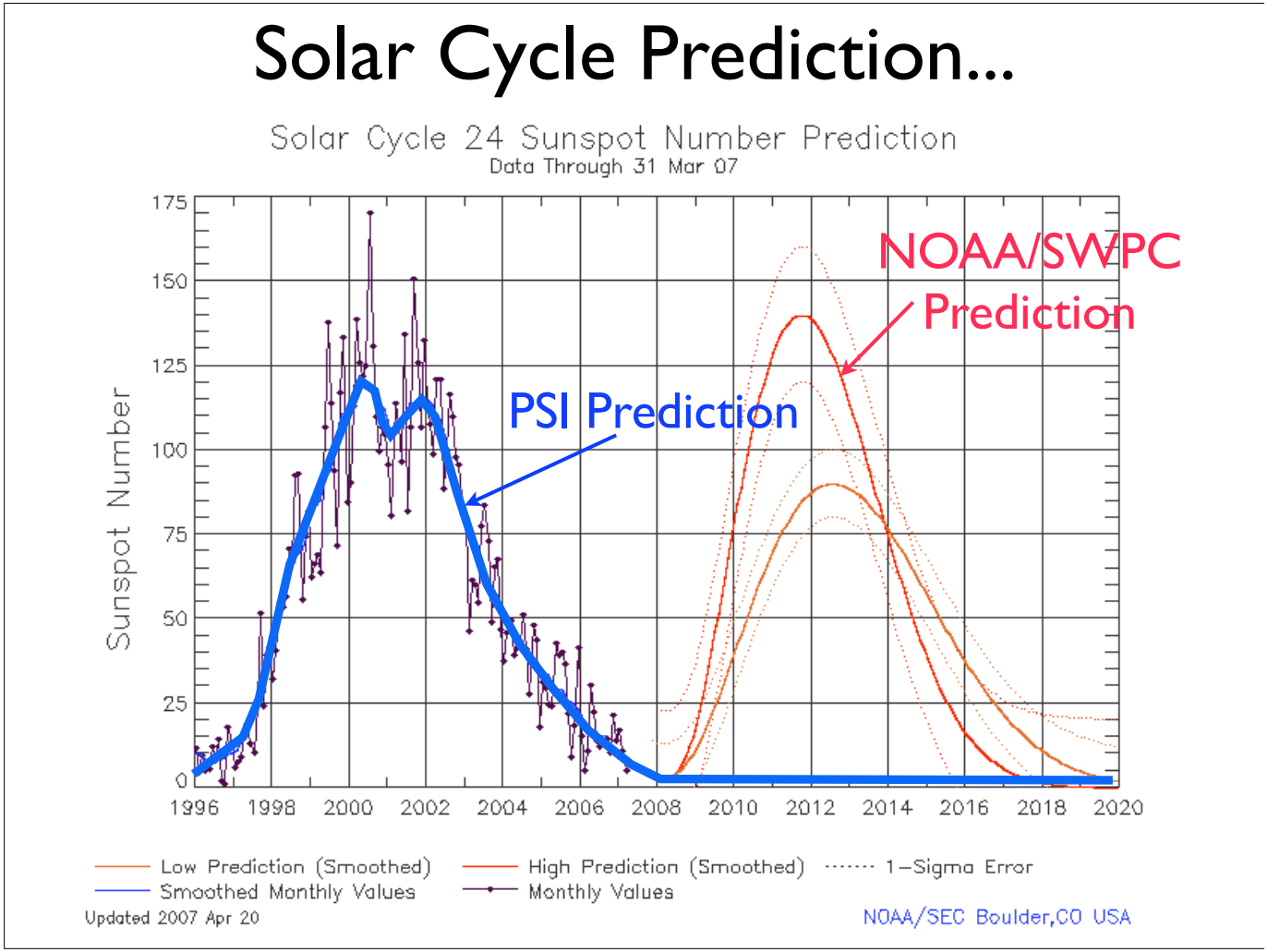
PSI's Prediction of Solar Cycle 24



Overview of the talk

- Review some of the 'unique' features of the recent solar minimum;
- Overview of the modeling approach;
- Unipolar Streamers:
  - Unipolar and Dipolar streamers in the corona;
  - Origin of the slow and fast solar wind;
  - Model predictions of solar wind speed from unipolar streamers;
  - interplanetary signatures of unipolar streamers.
- Summary.

Some 'Unique' Properties of the Recent Solar Minimum

- Most prolonged and quiet in last century (e.g., 71% of days in 2009 were spotless);
- Photospheric flux decreased by $\sim 40\%$;
- At Ulysses (McComas et al. 2008; Smith and Balogh, 2008; Riley et al., 2010a):
  - Magnetic flux 36% lower;
  - Density 17% lower;
  - Speed constant (3% lower);
  - Dynamic pressure 22% lower;
  - Thermal pressure 25% lower;
  - Magnetic pressure 87% lower.
- At Earth (Gibson et al., 2009; Riley et al., 2010b):
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Structural Differences between the Current and Previous Solar Minimum

- More equatorial coronal holes (Kirk et al, 2009; Gibson et al., 2009);
- Ubiquitous presence of unipolar streamers;
- Elevated latitudinal extent of the HCS;
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  - Upwind model (Riley et al., 2011) - to map speed from $30R_{\odot}$ to 1 AU.

MHD Equations

$$\nabla \times \mathbf{B} = \frac{4\pi}{c}\mathbf{J}, \tag{1}$$

$$\frac{1}{c}\frac{\partial \mathbf{B}}{\partial t} = -\nabla \times \mathbf{E}, \tag{2}$$

$$\mathbf{E} + \frac{\mathbf{v} \times \mathbf{B}}{c} = \eta \mathbf{J}, \tag{3}$$

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \mathbf{v}) = 0, \tag{4}$$

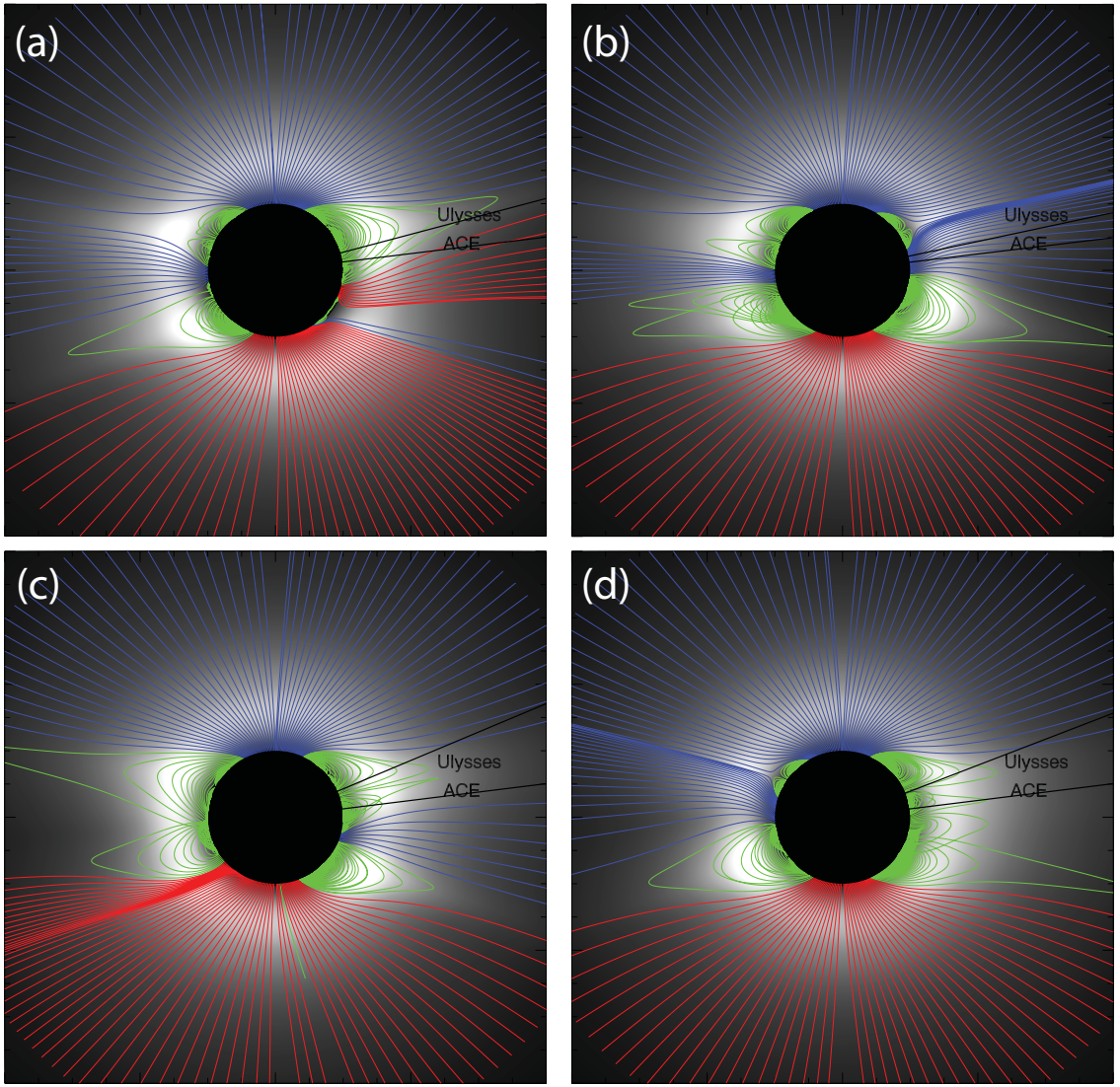
$$\rho \left(\frac{\partial \mathbf{v}}{\partial t} + \mathbf{v} \cdot \nabla \mathbf{v} \right) = \frac{1}{c}\mathbf{J} \times \mathbf{B} - \nabla p + \rho \mathbf{g} + \nabla \cdot (\nu \rho \nabla \mathbf{v}), \tag{5}$$

$$\frac{\partial p}{\partial t} + \nabla \cdot (p\mathbf{v}) = (\gamma - 1)(-p \nabla \cdot \mathbf{v} + S). \tag{6}$$

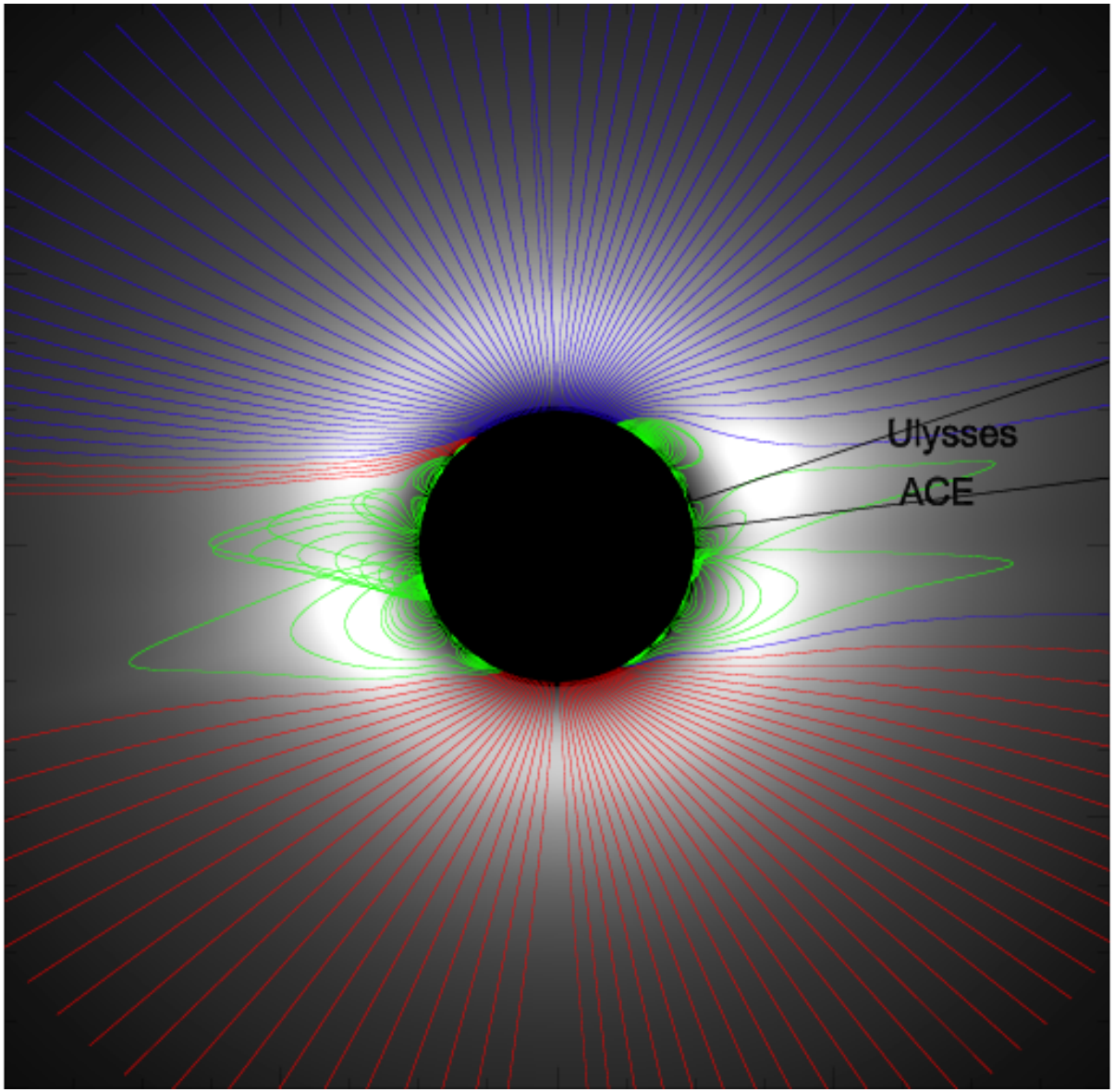
Main Features of MHD Model

- Time-dependent, resistive MHD;
- Incorporate observed photospheric magnetic field;
- Modeling region separated into two components: Corona and heliosphere;
- Physics: (hopefully) the essential energy transport processes are included (a turbulence approach is under development);
- Non-uniform, structured meshes;
- 3D finite difference;
- Implicit and semi-implicit time differencing;
- F95, MPI, multi-OS, Dynamic mesh allocation, restarts, post-processing tools.

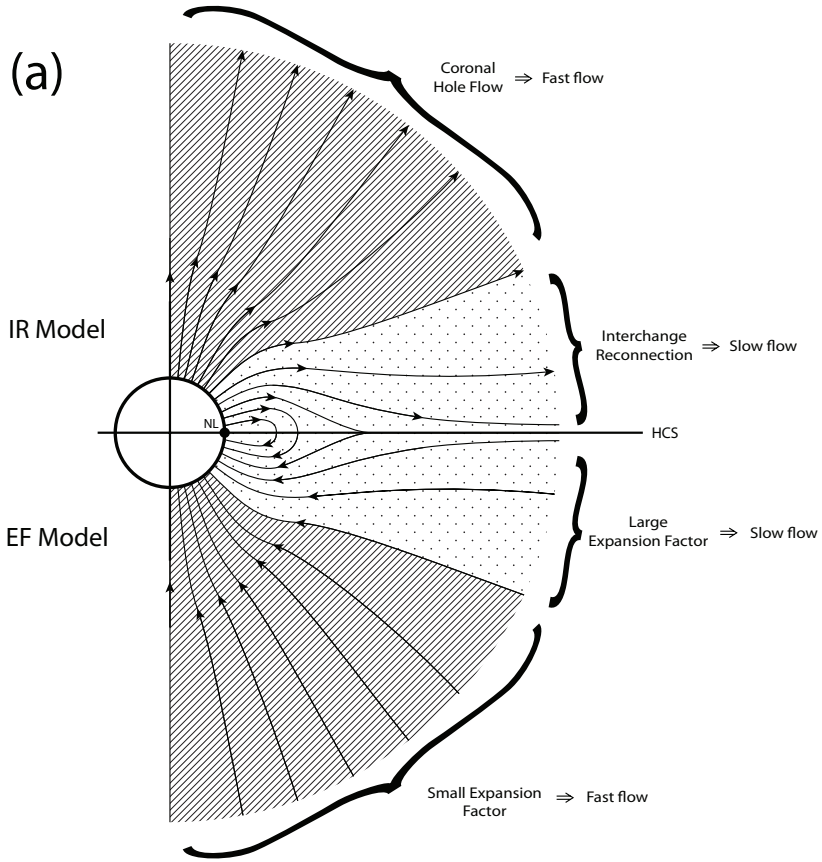
Unipolar and Dipolar Streamers during CR 2060



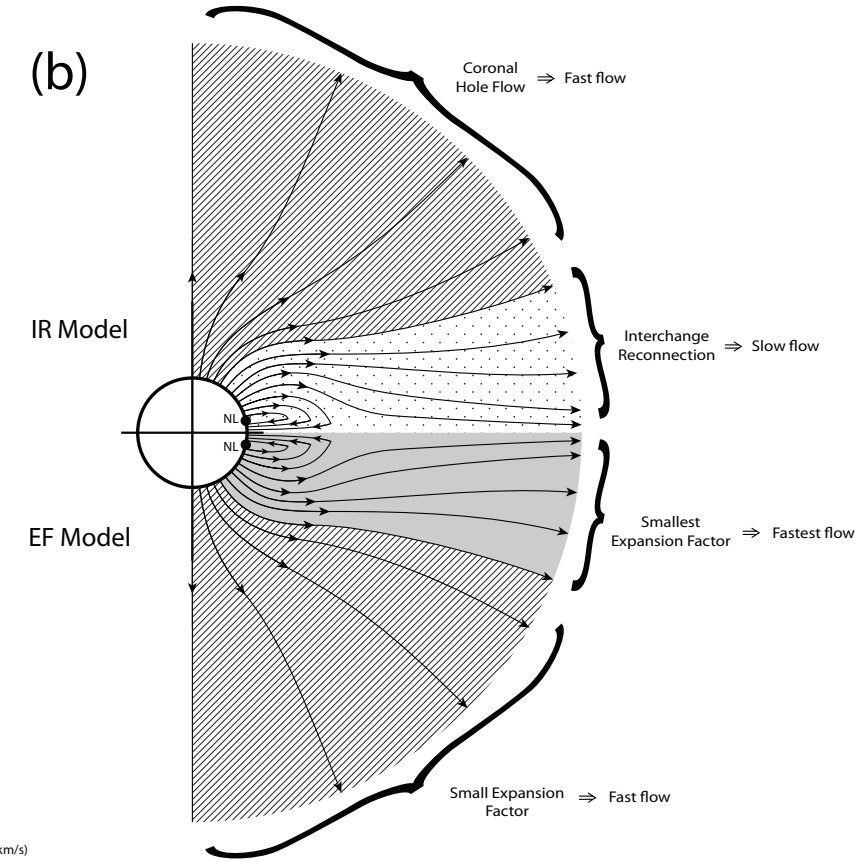
pB and Magnetic Field lines for CR 2060



Two Basic ideas for the origin of Solar Wind Associated with Streamers: Expansion Factor (EF) and Interchange Reconnection (IR) models



Dipolar Streamer



Unipolar Streamer

Two Empirical Models Encapsulating EF and IR Ideas

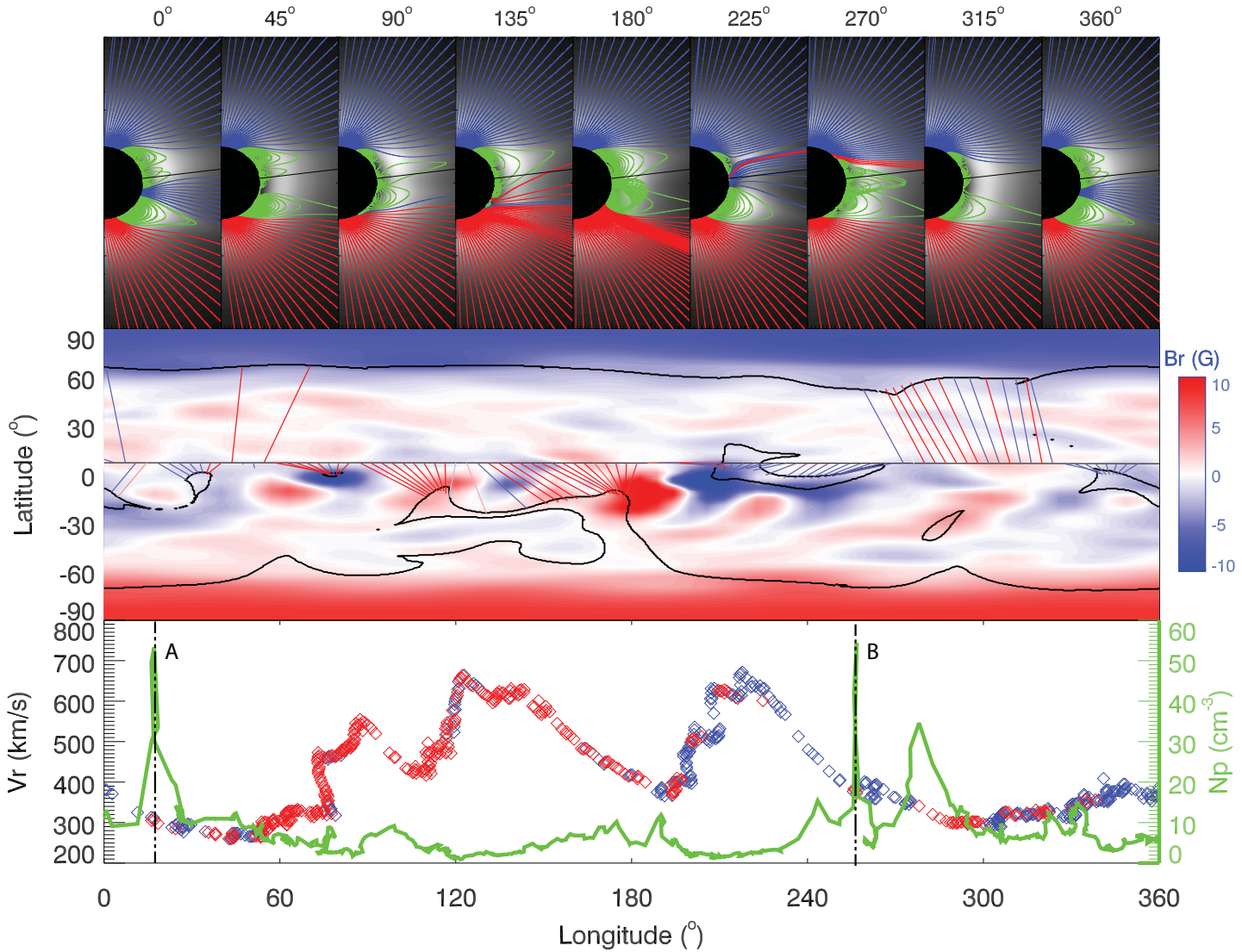
- Wang-Sheeley:

$$V_{WS}(f_s) = V_{slow} + \frac{V_{fast}}{(f_s)^{\alpha}} \tag{1}$$

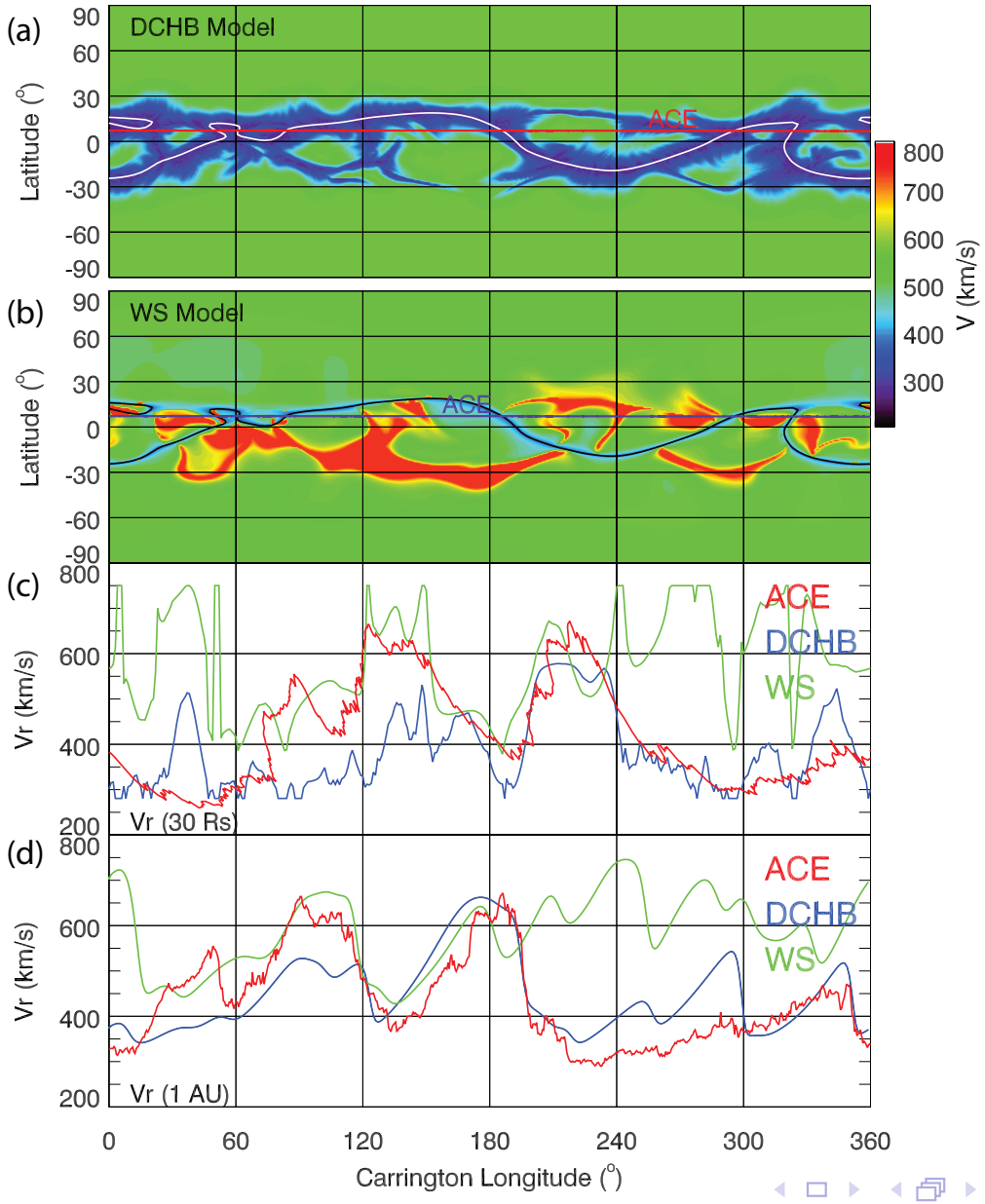
- "Distance from the Coronal Hole Boundary" (DCHB):

$$V_{DCHB}(d) = V_{slow} + \frac{1}{2}\left(V_{fast} - V_{slow}\right)\left(1 + \tanh\left(\frac{d-\alpha}{w}\right)\right) \tag{2}$$

Connecting Coronal Unipolar Streamer Structure with *in-situ* Measurements



WS and DCHB Model Predictions for CR 2060



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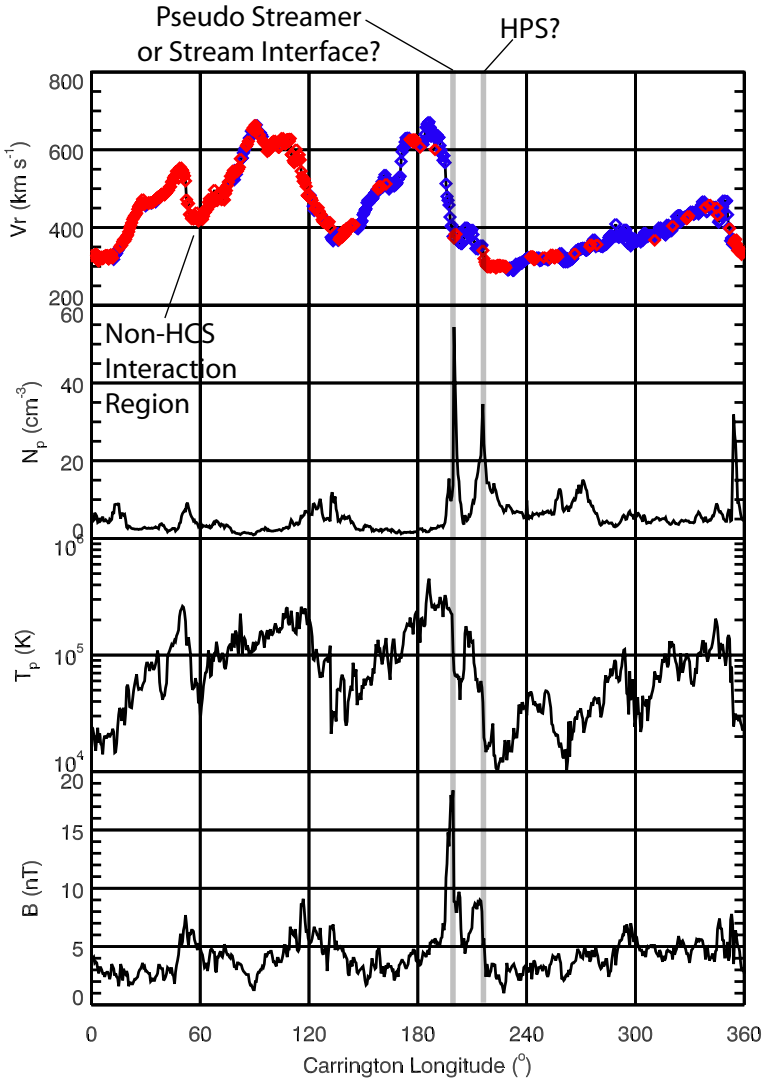
- Their conclusion: Unipolar streamers should produce very fast solar wind.

Wang et al. (2010)'s Identification of a Unipolar (Pseudo) Streamer during CR 2060



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- At least some non-HCS interaction regions (Neugebauer et al., 2004) are associated with unipolar streamers.
- Future work would include detailed case, and statistical studies:
  - Tracking events from the corona into the solar wind;
  - and mapping events back from the interplanetary medium to the Sun.
  - Also, more sophisticated models incorporating the EF and IR processes.

General Summary

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  - Underlying cause: Photospheric magnetic field.
- Results on the web (www.predsci.com):
  - Polytropic solutions (CR 1625 to present) at: http:/www.predsci.com/mhdweb/;
  - Higher-resolution Solutions (CR 2050 to present) at: http:/www.predsci.com/stereo/;
  - Thermodynamic solutions are being made available at: http://www.predsci.com/sdo/;
  - Runs-on-demand at the CCMC: http://ccmc.gsfc.nasa.gov.