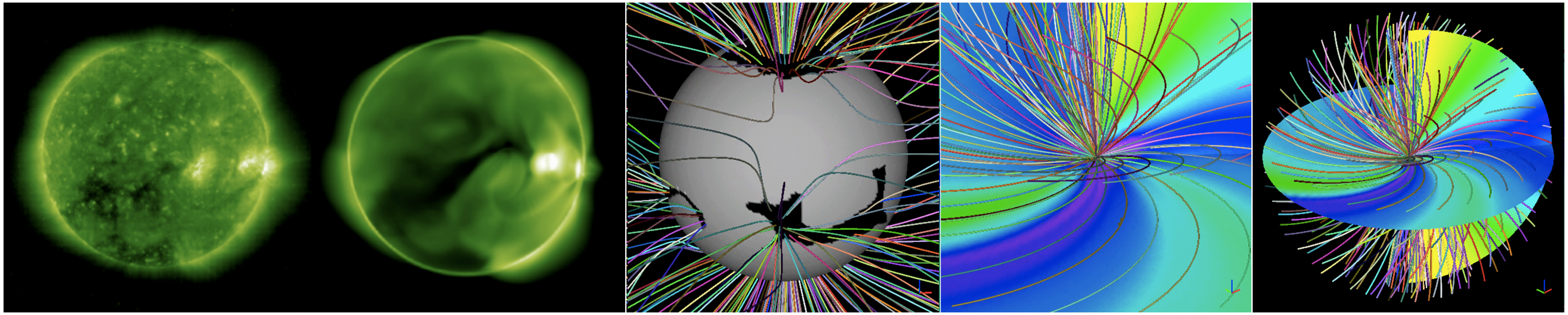
Global MHD Modeling of the Solar Corona & Solar Wind: A Comparison of Two Solar Minima*



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Introduction

- The Whole Heliosphere Interval (WHI, http://ihy2007.org/WHI/) is an international effort to characterize the 3D heliosphere at solar minimum.
  - CR2068: March 20 - April 16, 2008
- This study is patterned after the successful Whole Sun Month I campaign (WSM I, August 8 - September 10, 1996).
- This solar minimum (end of cycle 23) has significant differences from the end of cycle 22.
  - Nearly a factor of 2 decrease in the Interplanetary Magnetic Field ($|B_{IMF}|$).

Introduction (continued)

- We are studying the differences between these two solar minima by comparing MHD models for WSM I and WHI.
- There has been considerable debate about the origin of this IMF decrease.
- *Owens et al*. (2008) argue that the amount of open magnetic flux is primarily controlled by CME rates.
- This would imply that the polar fields of the sun have little to do with $|B_{IMF}|$, and quasi-steady models of the corona/solar wind cannot predict $|B_{IMF}|$.
  - This was in fact asserted by *Svalgaard & Cliver* (2007).

In Situ observations show significant differences in average solar wind properties between WSM and WHI.

Parameter	1st orbit (WSM)	3rd Orbit (WHI)	Difference (%)
V_p (km/s)*	761	739	-3
N_p*r^2 (cm^{-3})*	2.65	2.19	-17
T_p*r (10^6 K)*	2.66	2.3	-14
rho*v*r^2 ($kgm^{-2}s^{-1}$)*	3.96	3.17	-20
rho*v^2*r^2 (nPa)*	3.01	2.34	-22
P (pPa)*	9.89	7.43	-25
B_r*r^2 (nT)+	3.6	2.3	-36
N_e (cm^{-3}) #	2.43/2.65	2.06/2.09	-15/-21
T_e (core, 10^4 K) #	7/7.5	6.2/6.43	-11/-14

* McComas et al. (2008)

+ Smith and Balogh (2008)

Issautier et al. (2008)

MHD Equations
(Improved Energy Equation Model)

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

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

$$\mathbf{E} + \frac{1}{c}\mathbf{v} \times \mathbf{B} = \eta \mathbf{J}$$

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

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

$$\frac{\partial p}{\partial t} + \nabla\cdot(p\mathbf{v}) = (\gamma - 1)\left(-p\nabla\cdot\mathbf{v} - \nabla\cdot\mathbf{q} - n_e n_p Q(T) + H\right)$$

$$\gamma = 5/3$$

$$\mathbf{q} = -\kappa_\parallel \hat{\mathbf{b}}\hat{\mathbf{b}}\cdot\nabla T$$ (Close to the Sun, $r \lesssim 10R_S$)

$$\mathbf{q} = 2\alpha n_e T\,\hat{\mathbf{b}}\hat{\mathbf{b}}\cdot\mathbf{v}/(\gamma - 1)$$ (Far from the Sun, $r \gtrsim 10R_S$)

+ WKB equations for Alfvén wave pressure p_w evolution

An empirically-based heating function reproduces emission measurements relatively well.

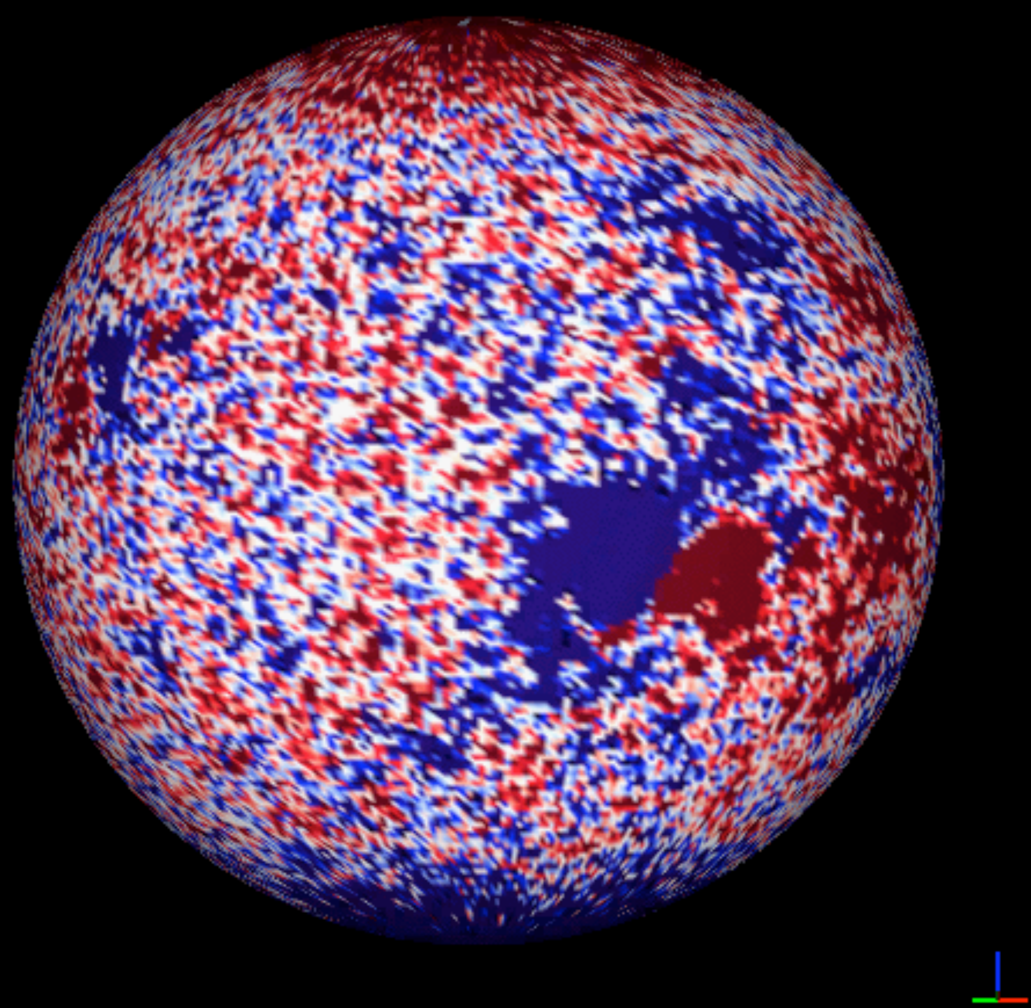
$$
\begin{aligned}
H_{\mathrm{ch}} &= H_{\mathrm{exp}} + H_{\mathrm{QS}} + H_{\mathrm{AR}}, \\
H_{\mathrm{QS}} &= H^0_{\mathrm{QS}} f(r) \frac{B_t^2}{B(|B_r| + B_r^c)}, \\
H_{\mathrm{AR}} &= H^0_{\mathrm{AR}} g(B) \left(\frac{B}{B_0}\right)^{1.2},
\end{aligned}
$$

$$H_{\mathrm{exp}} = H_0 \exp -(r - R_\odot)/\lambda_0,$$

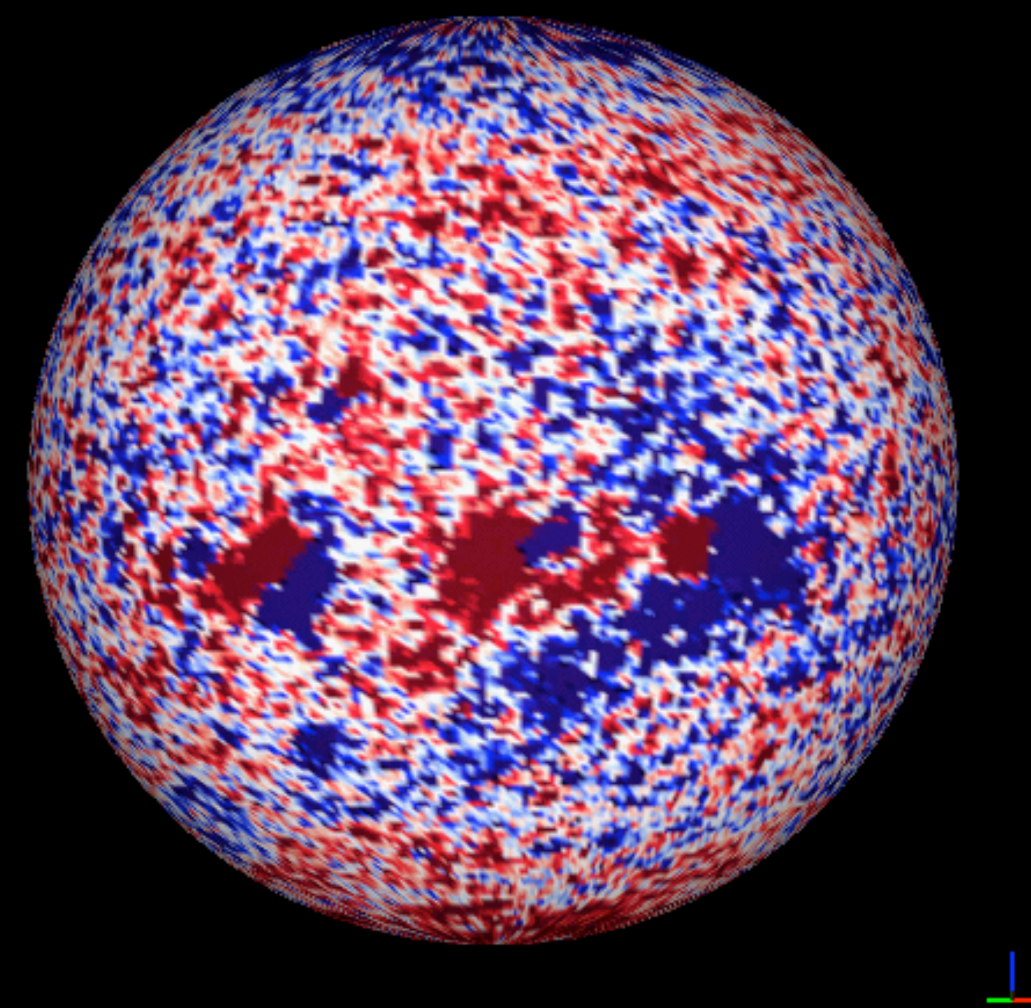
$$
\begin{aligned}
f(r) &= \frac{1}{2}\left(1 + \tanh \frac{1.7 - r/R_\odot}{0.1}\right) \exp\left(-\frac{r/R_\odot - 1}{0.2}\right), \\
g(B) &= \frac{1}{2}\left(1 + \tanh \frac{B - 18.1}{3.97}\right),
\end{aligned}
$$

Lionello et al. (2009) shows comparisons for different heating specifications

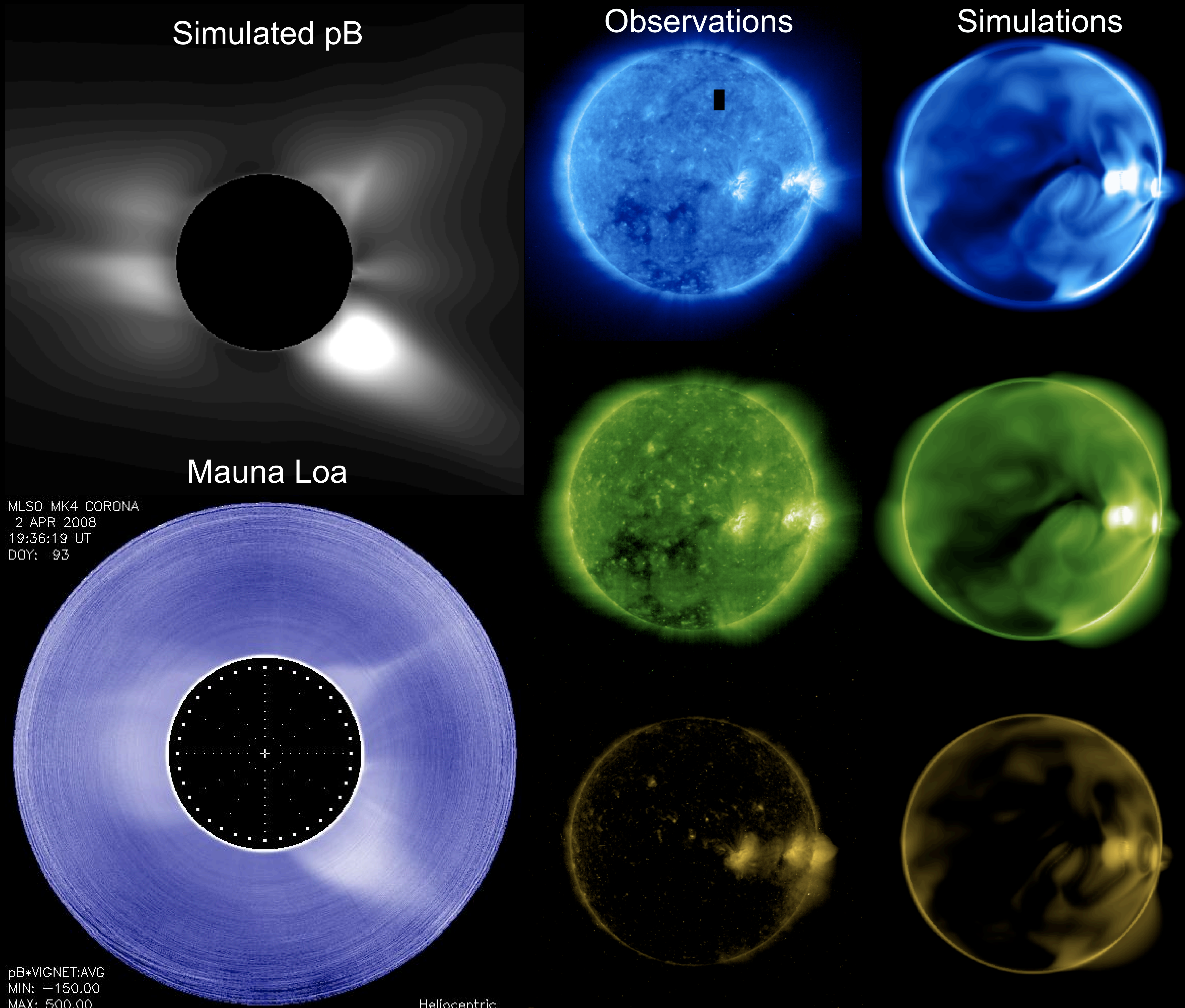
Comparison of CR1913 (WSM I) and CR2068 (WHI)



CR1913

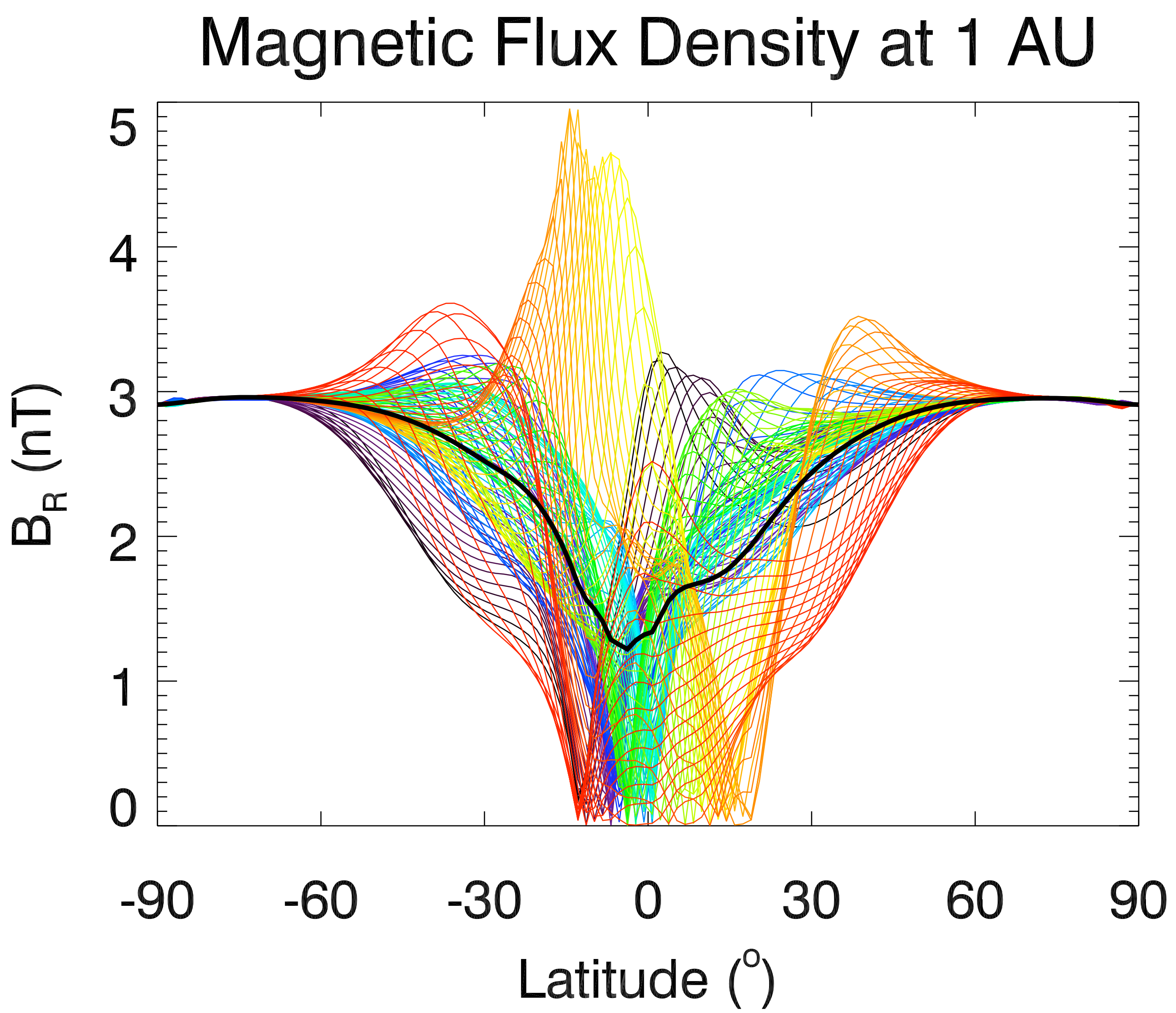


CR2068

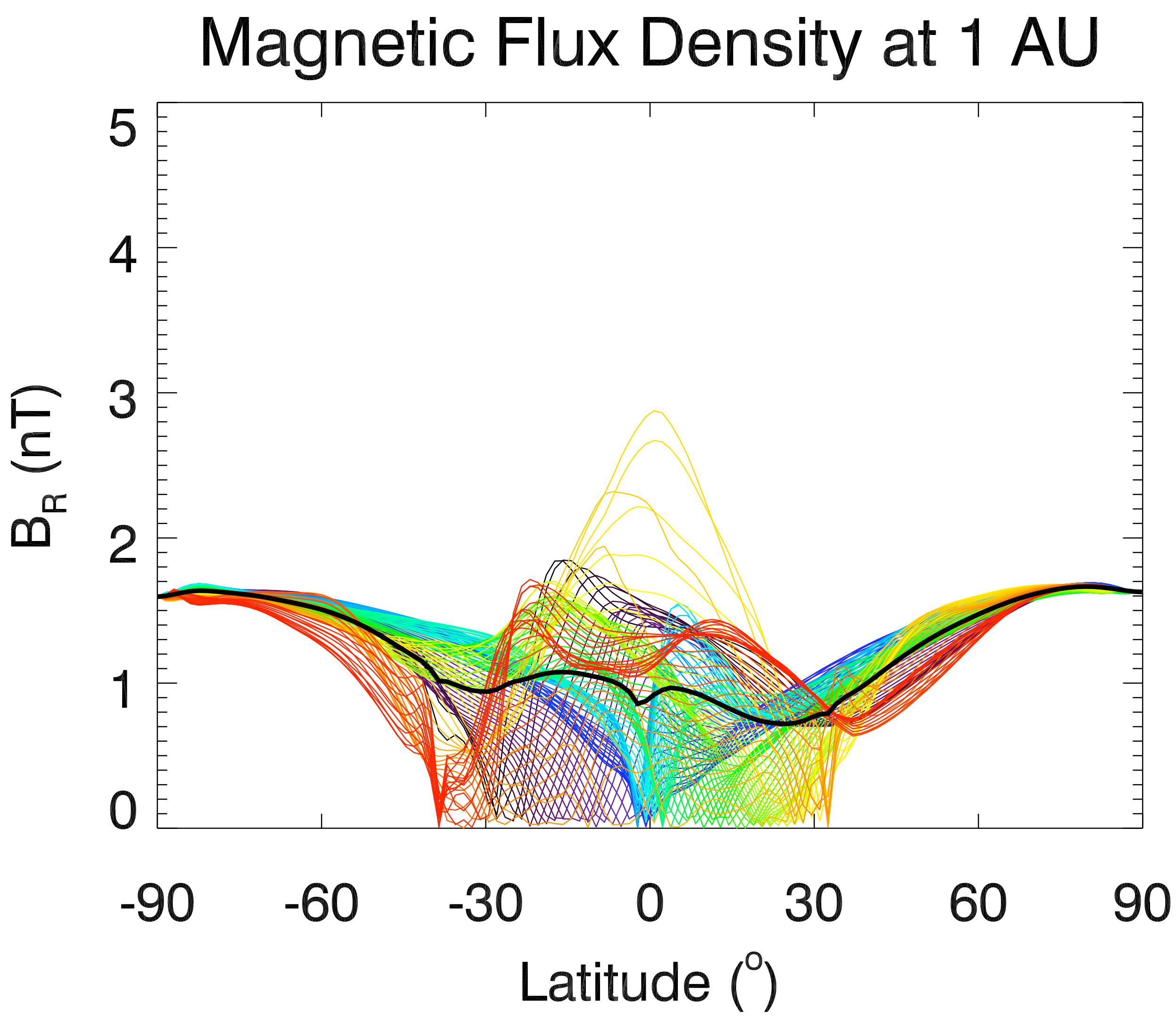

Simulated pB
Observations
Simulations
Mauna Loa
MLSO MK4 CORONA
2 APR 2008
19:36:19 UT
DOY: 93
pB*VIGNET:AVG
MIN: −150.00
MAX: 500.00
Heliocentric

Model results of the radial magnetic field at 1 AU are broadly consistent with observations.

CR 1913



CR 2068



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The global MHD model shows a significant difference in B_r between WSM and WHI, close to the observed difference. The change in density is not reproduced.

Parameter	CR1913 (WSM) N/S pole	CR2068 (WHI) N/S Pole	Difference (%)	Observed Difference (%)
V_p (km/s)	731/722	704/719	-3	-3
N_p (cm^{-3})	2.17/2.24	2.38/1.99	-1	-17
B_r (nT)	2.91/2.91	1.63/1.59	-45	-36

Summary

- We have developed thermodynamic MHD simulations for the WHI (CR2068, 3/20/08 - 4/16/08) and WSM I (CR1913, 8/8/96 - 9/10/96) time periods.
- We have previously reported on WSM I (most recent paper is *Lionello et al*. 2009).
- The simulation for WHI shows agreement with many aspects of the observations; it also shows some differences.
  - These are preliminary results
- $|B_{IMF}|$ is significantly reduced in this solar minimum compared to the previous, in agreement with observations.
- Polar fields on the sun *are* important
  - Caution: comparison of just 2 rotations
- Reminder: You can obtain polytropic MHD solutions for STEREO at **http://www.predsci.com/stereo/**

Extra Slides

An Empirically-based heating function reproduces emission measurements relatively well.

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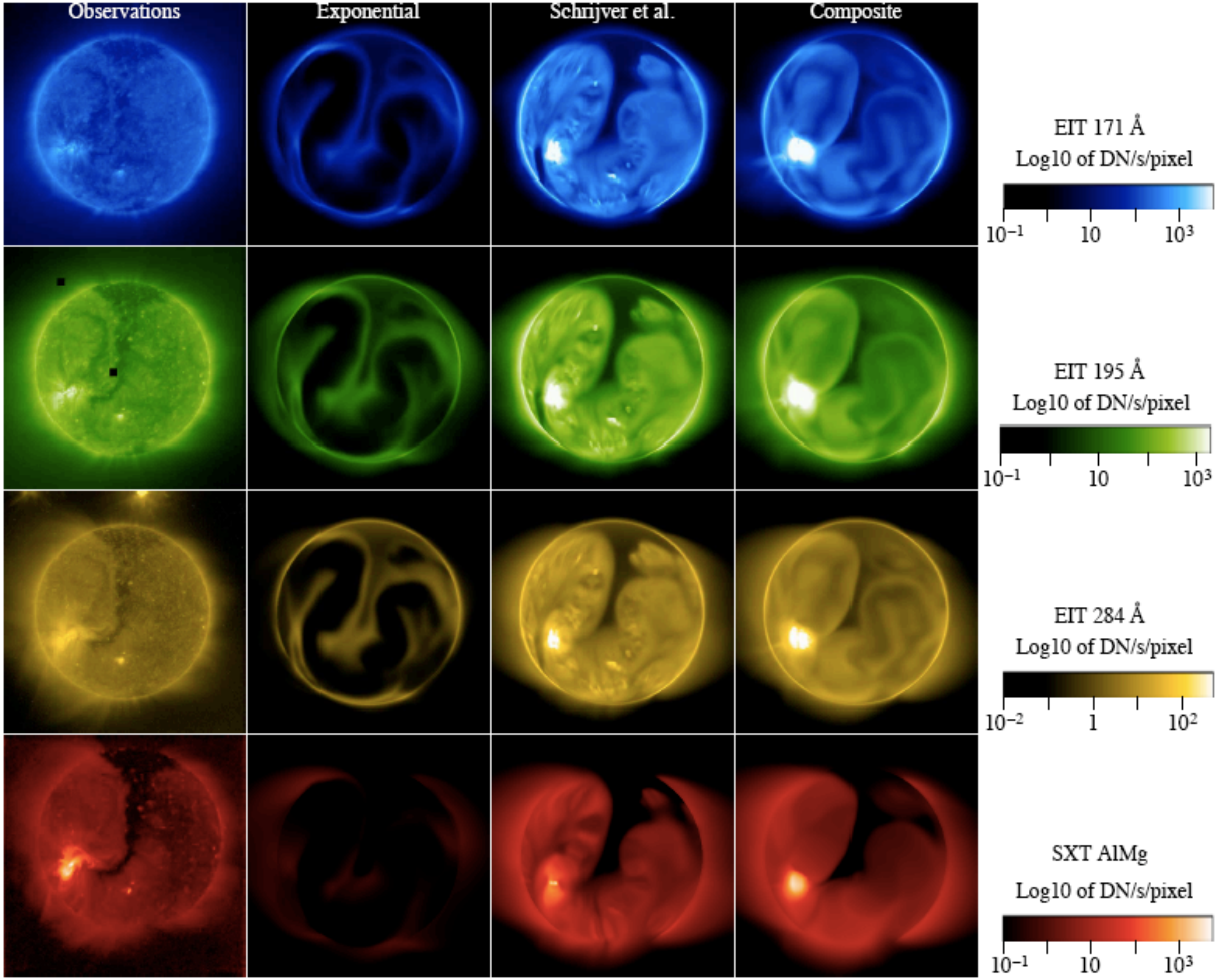
$$

Comparison of Heating Models: August 1996



Comparison of Heating Models: August 1996 equatorial cut