Corona and Inner Heliosphere for the Whole Heliosphere Interval

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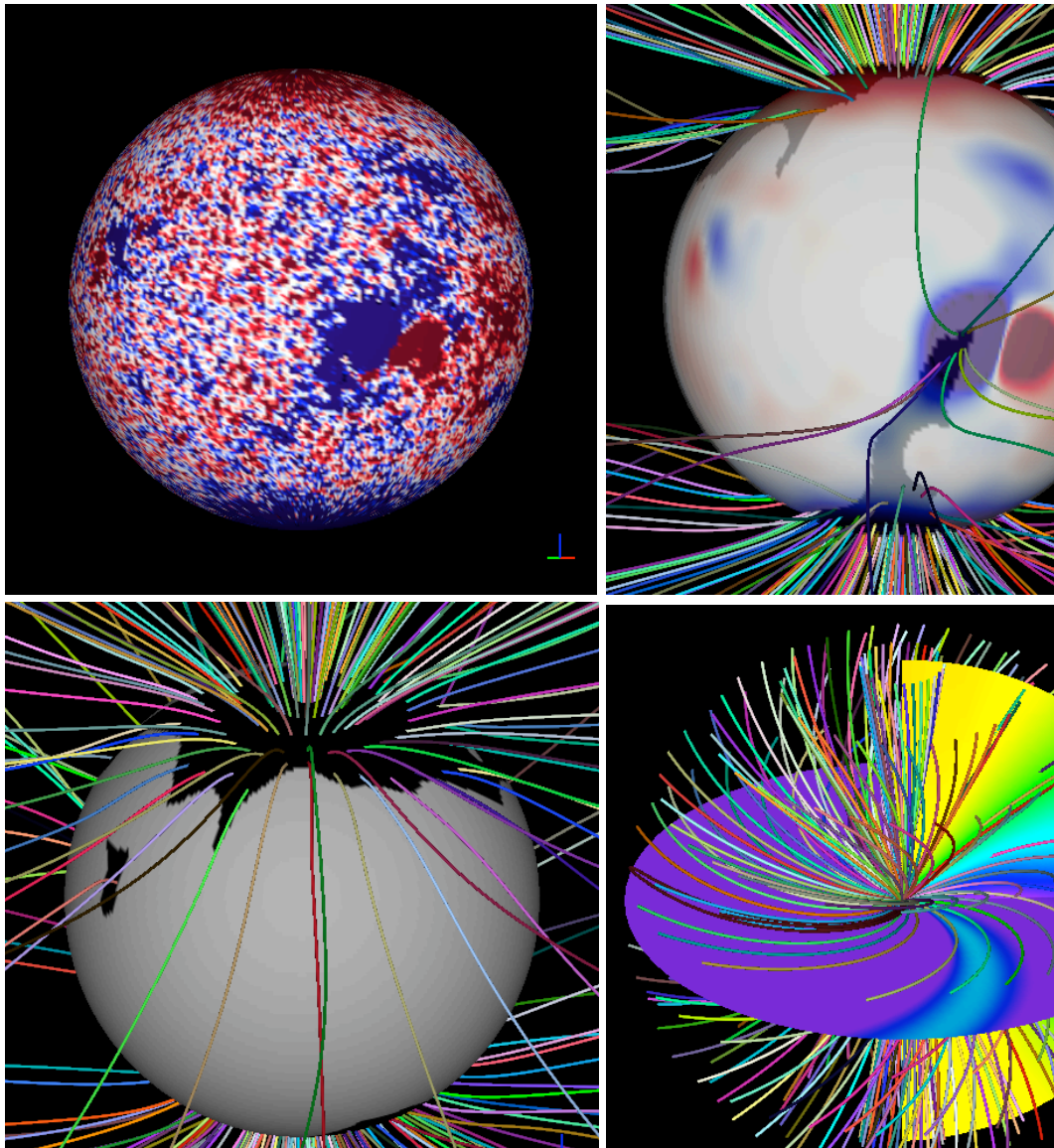


IAU, XXVII GENERAL ASSEMBLY

Rio de Janeiro, Brazil
August 12th, 2009

Overview

- The MHD Model
- Coronal and heliospheric properties of WHI and a comparison with WSM
  - Observations and model results
  - Properties of the polar solar wind
  - Heliospheric structure from WSM to WHI
- Summary

cludes energy transport processe

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

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

roperties of coronal heating, while evading th
question of what actually heats the corona

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

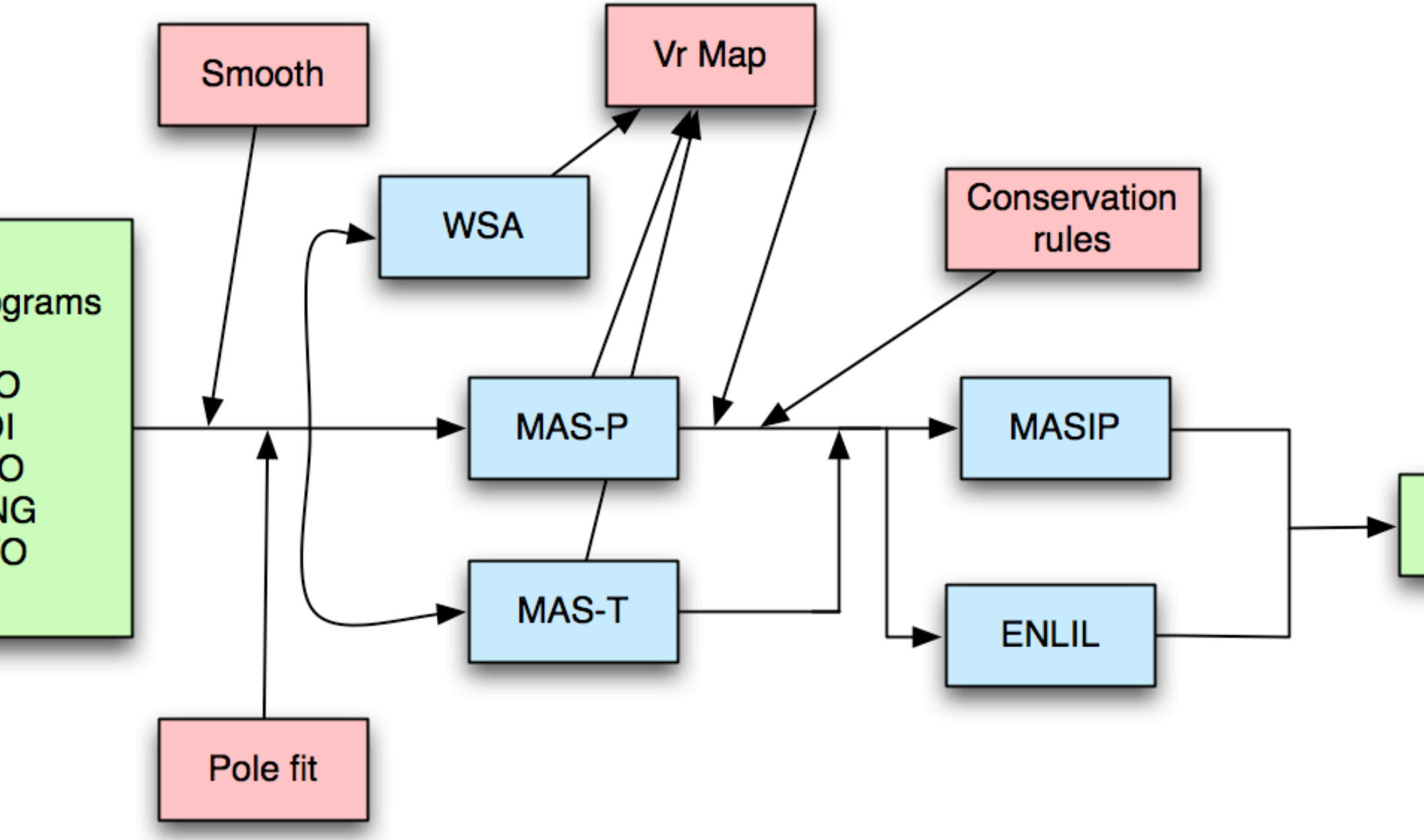
$$
H_{\rm exp} = H_0 \exp -(r - R_\odot)/\lambda_0,
$$

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

Main Features of Model

- Time-dependent, resistive MHD
- Incorporates observed photospheric magnetic field
- Non-uniform meshes
- 3D finite difference
- Implicit and semi-implicit time differencing
- F95, MPI, multi-OS, Dynamic mesh allocation, restarts, post-processing tools.
- Comprehensive physics incorporated: e.g., energy transport (radiation, parallel thermal conduction, heating, and Alfven waves),

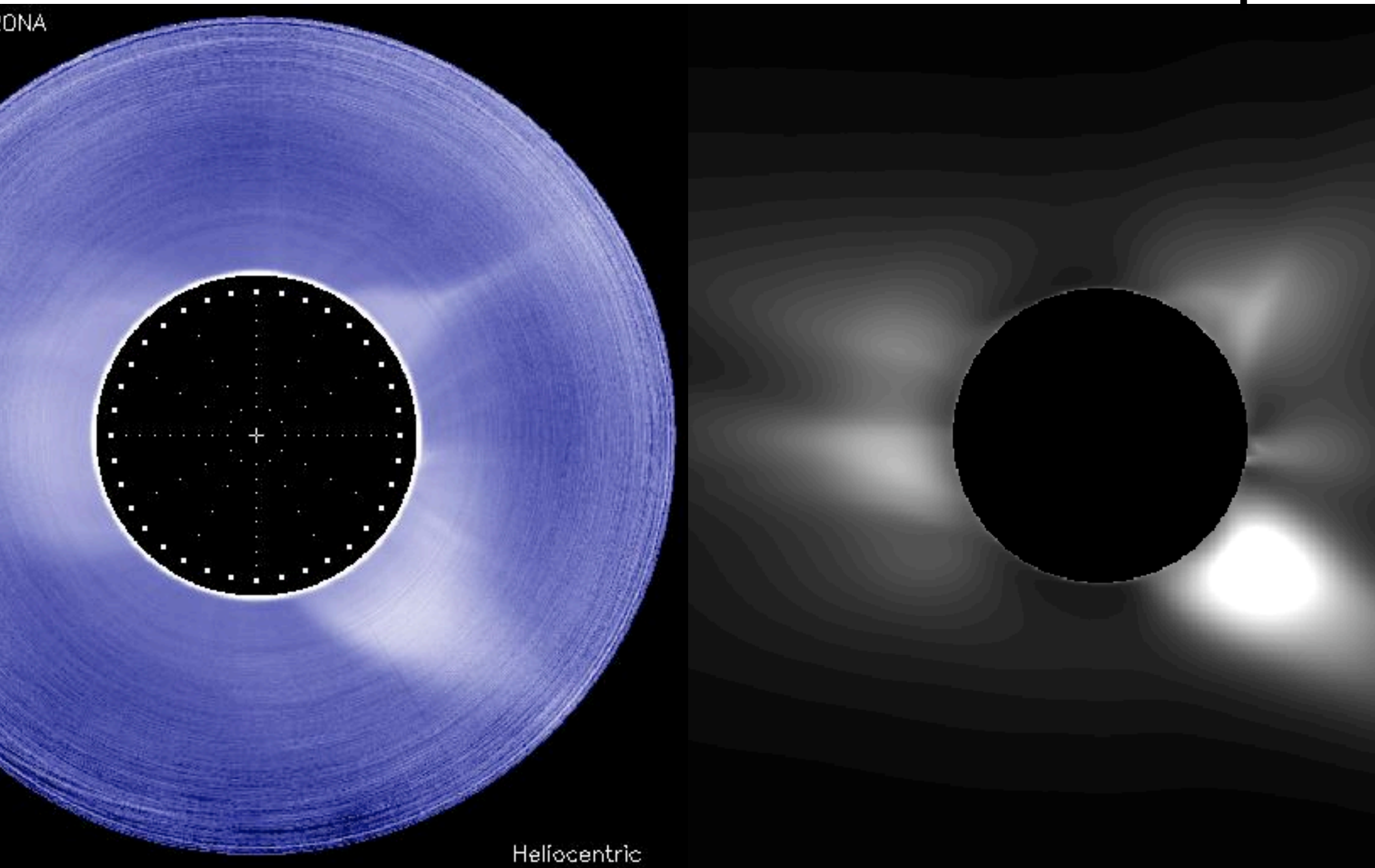
onstructed in a number of ways



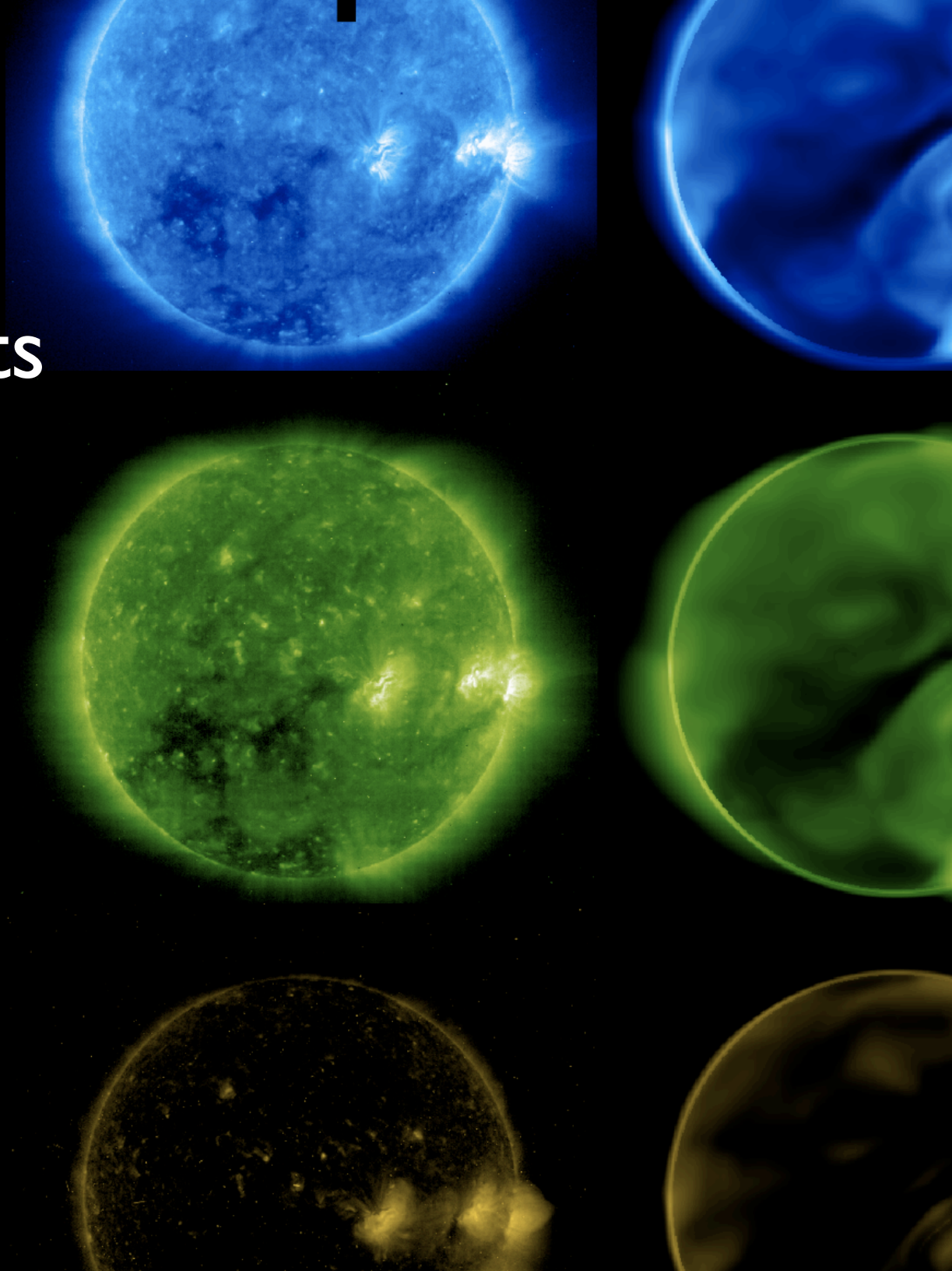
Streamers

Mauna Loa

Simulated pB



nderstanding the
Observations:
ssion Measurements

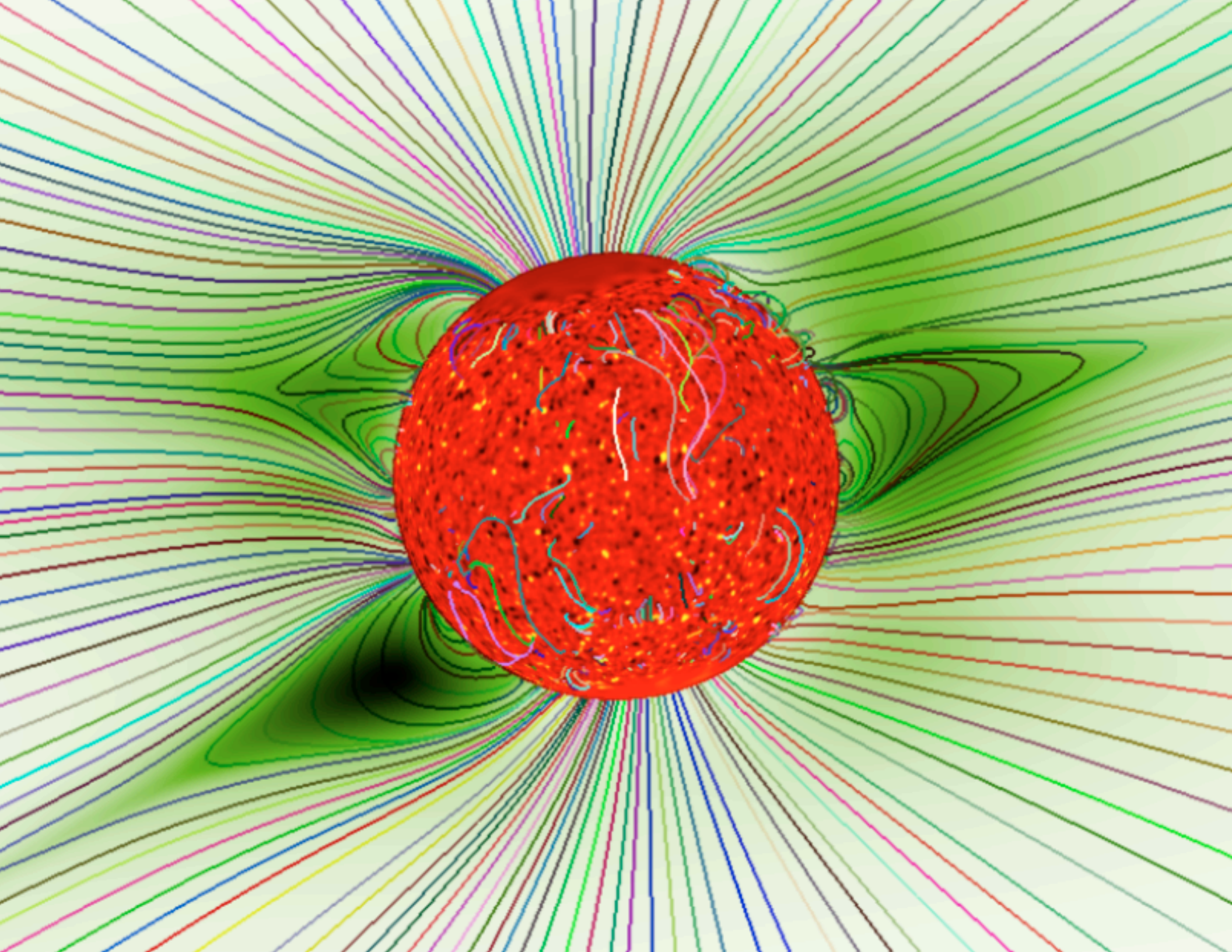


Unique Properties of 2007-2009 (and the Current Solar Minimum in general)

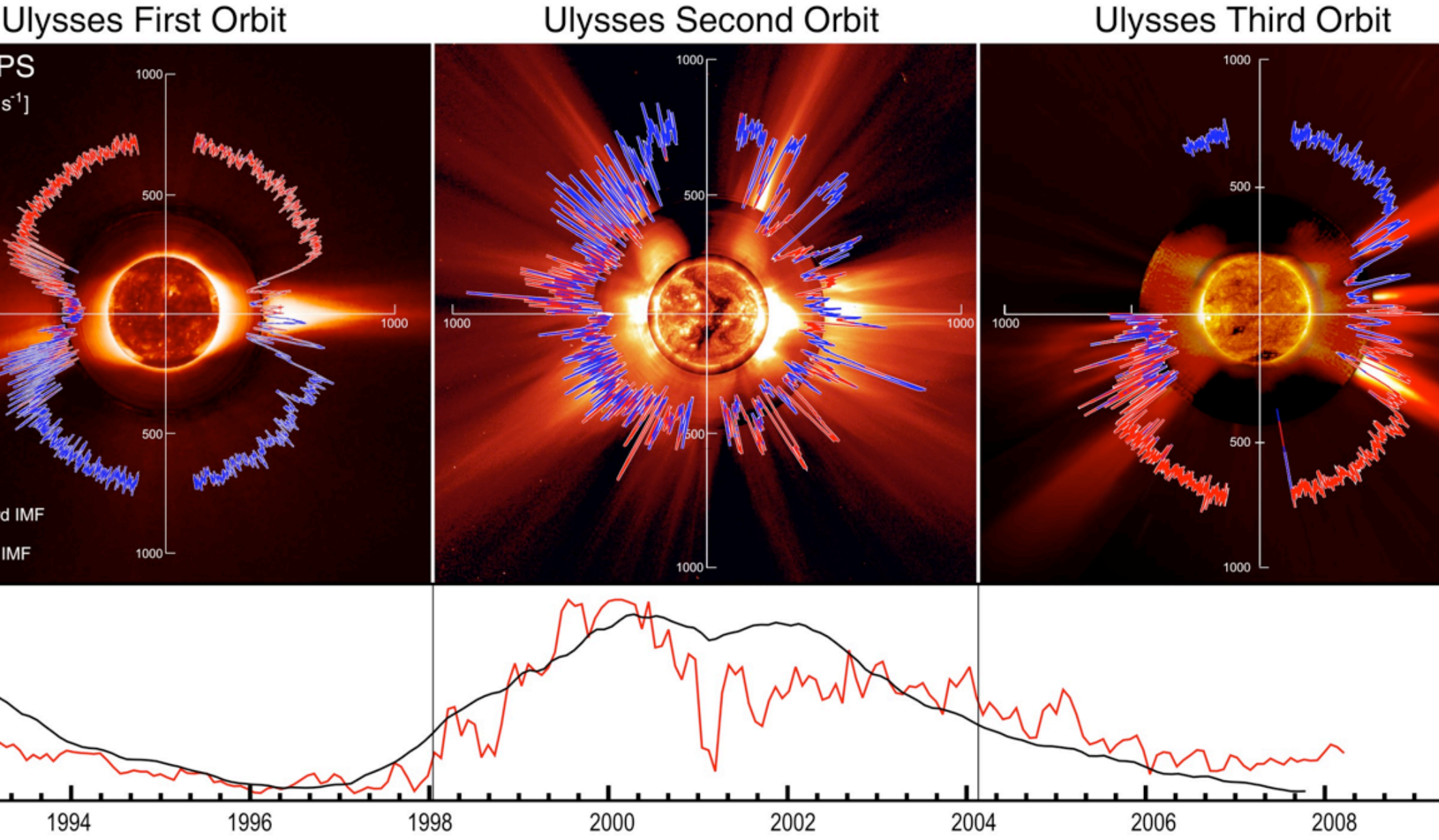
- Solar Parameters:
  - Polar fields are weaker (*Svalgaard et al.,* 2007)
  - Tilt of current sheet larger
- Interplanetary Parameters:
  - IMF is lower (*Smith and Balogh,* 2008)
  - Plasma density is lower (*McComas et al.,* 2008*; Issautier et al.,* 2008)
  - Temperature is lower (*McComas et al.,* 2008*; Issautier et al.,* 2008)
  - Dynamic pressure is lower (*McComas et al.,* 2008)

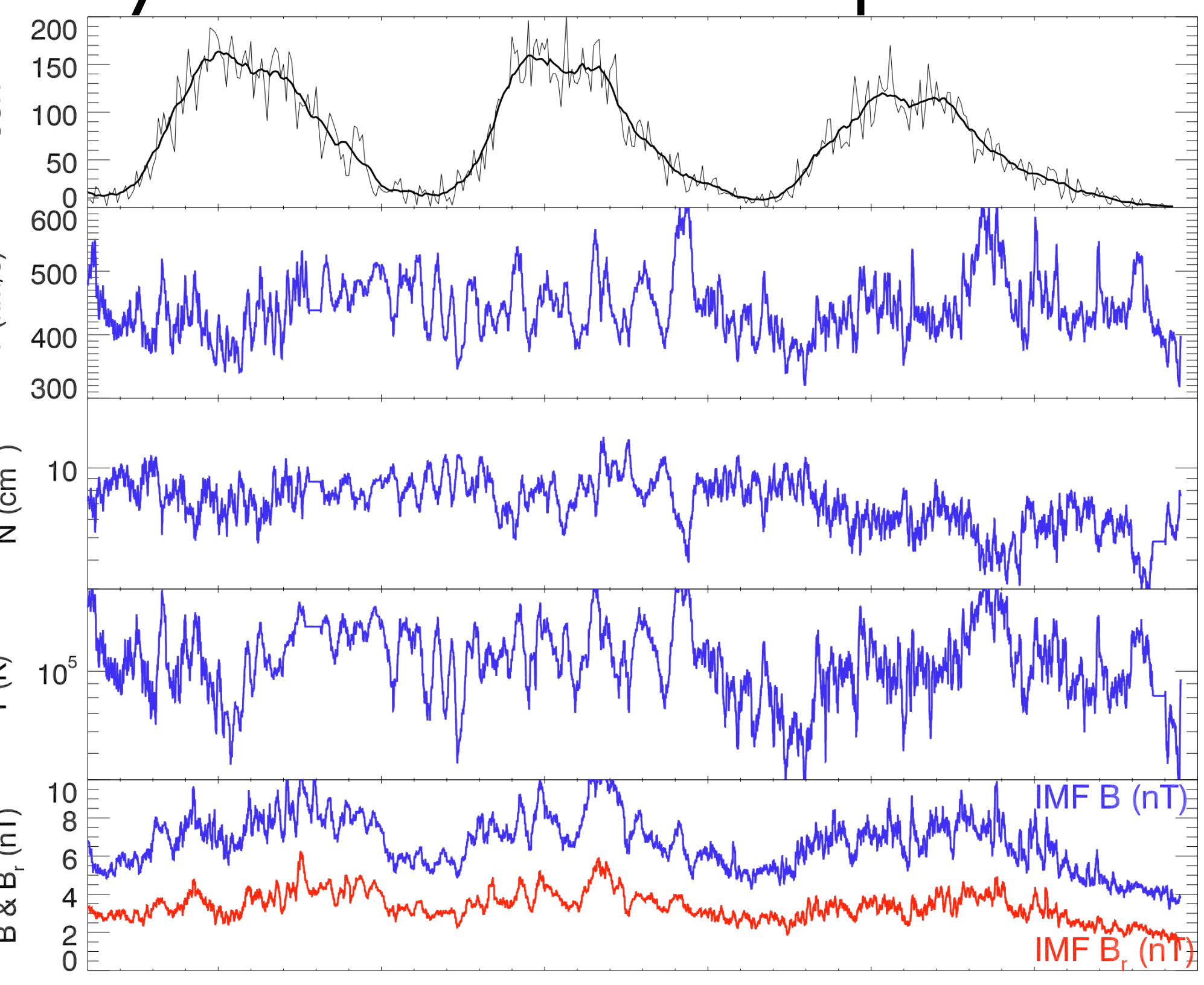
HI (and Current and Previous Sol
Minimum in general)

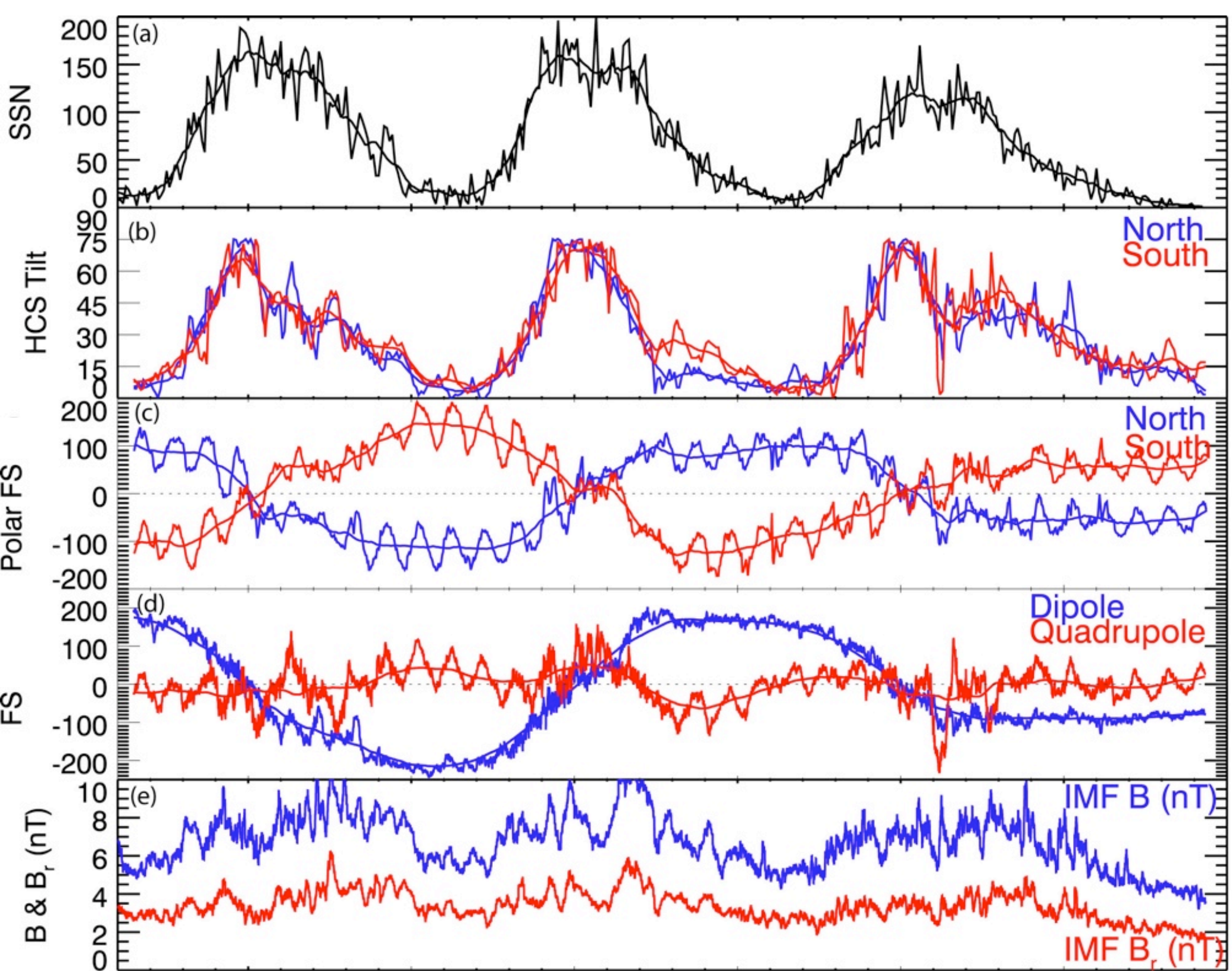
- Coronal streamer structure is different:
  - Pseudostreamers (*Wang et al.,* 2007)
- Coronal Holes:
  - Smaller (*Kirk et al.,* 2009)
  - More equatorial holes (*Gibson et al.,* 2009)
- Solar wind streams
  - Stronger
  - Longer in duration



3-D View of the Heliosphere from Ulyss




200
150
100
50
0
600
500
400
300
10
10^5
10
8
6
4
2
0
N (cm)
B & B_r (nT)
IMF B (nT)
IMF B_r (nT)

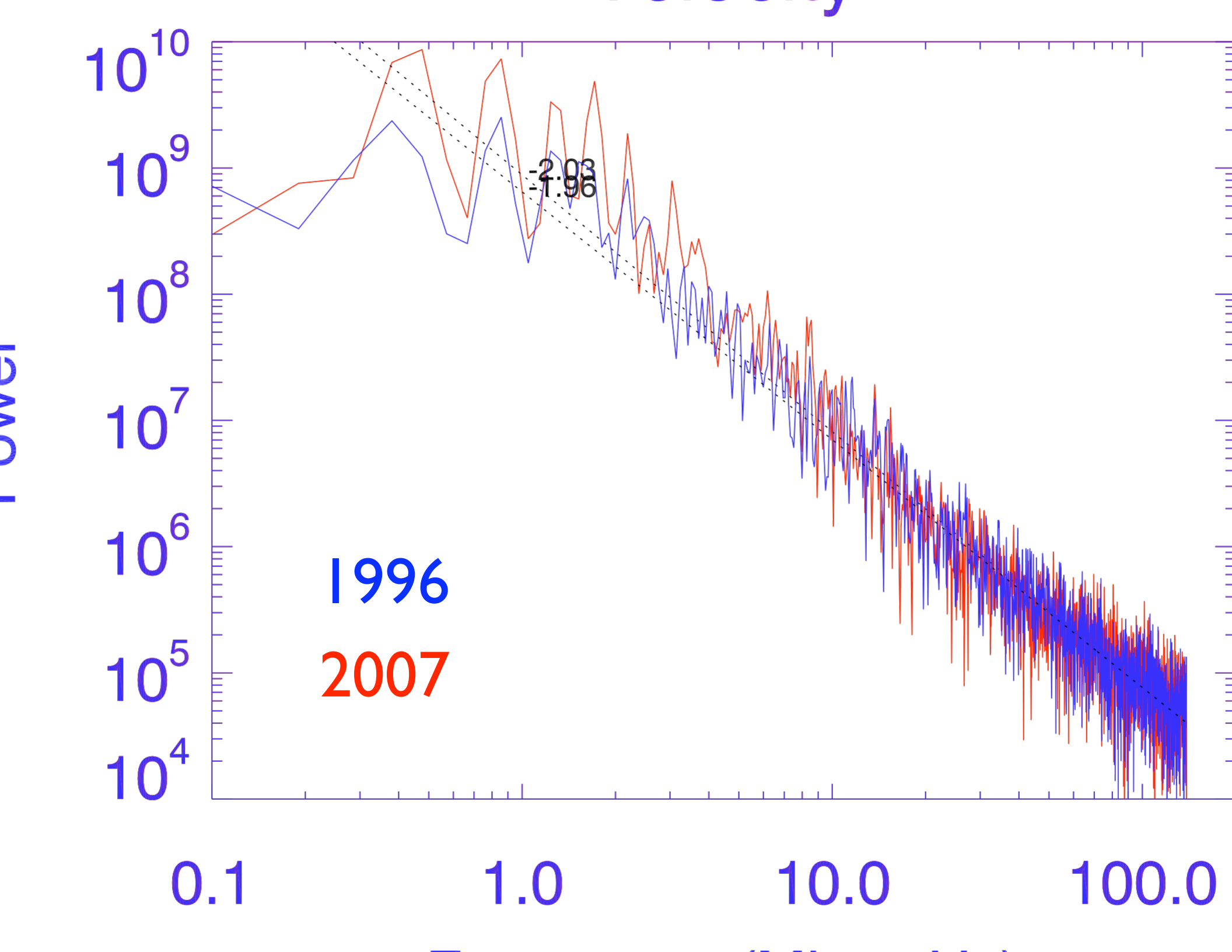

(a)
SSN
200
150
100
50
0
(b)
HCS Tilt
90
75
60
45
30
15
0
North
South
(c)
Polar FS
200
100
0
-100
-200
North
South
(d)
FS
200
100
0
-100
-200
Dipole
Quadrupole
(e)
B & B$_r$ (nT)
10
8
6
4
2
0
IMF B (nT)
IMF B$_r$ (nT)

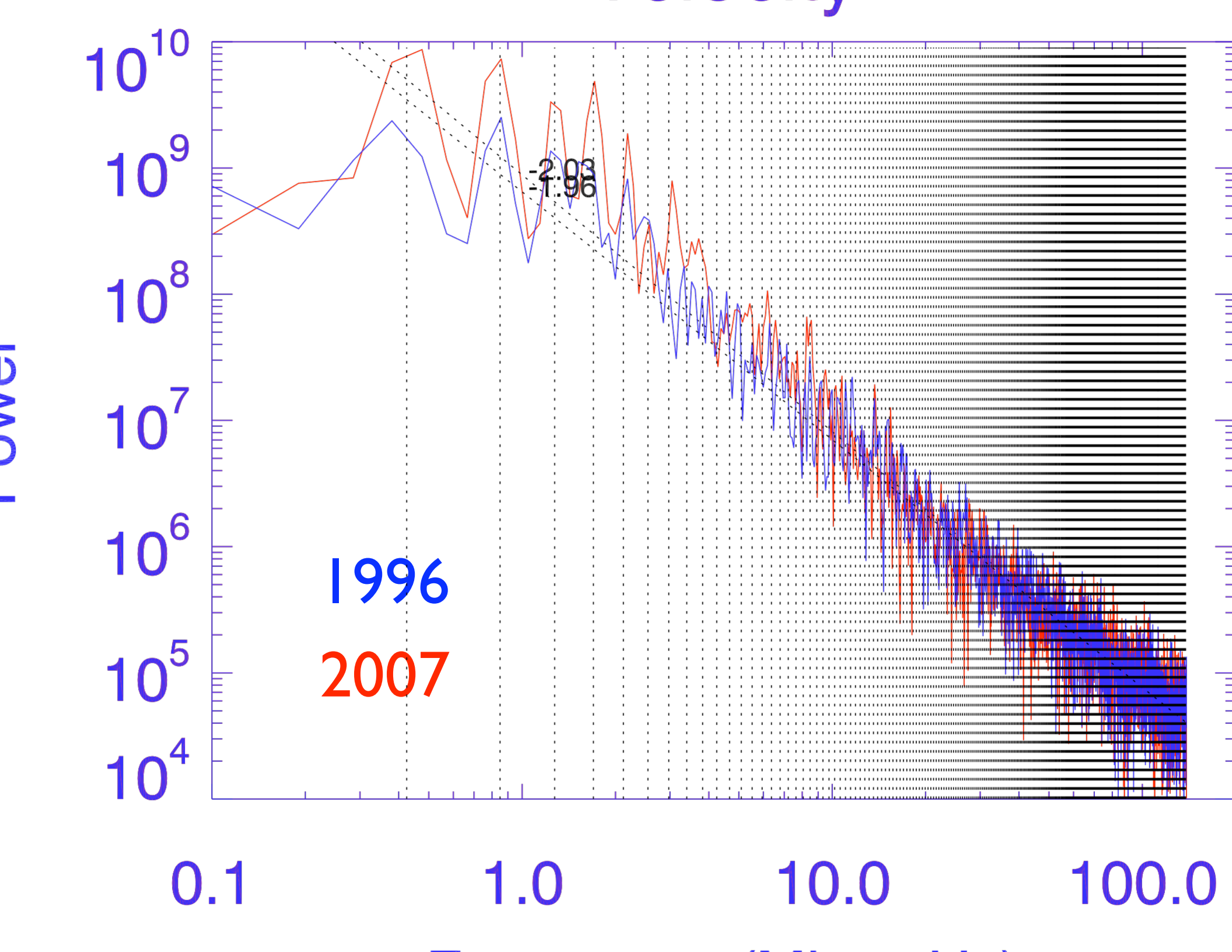
In-situ observations show significant differences
age solar wind properties between WSM and

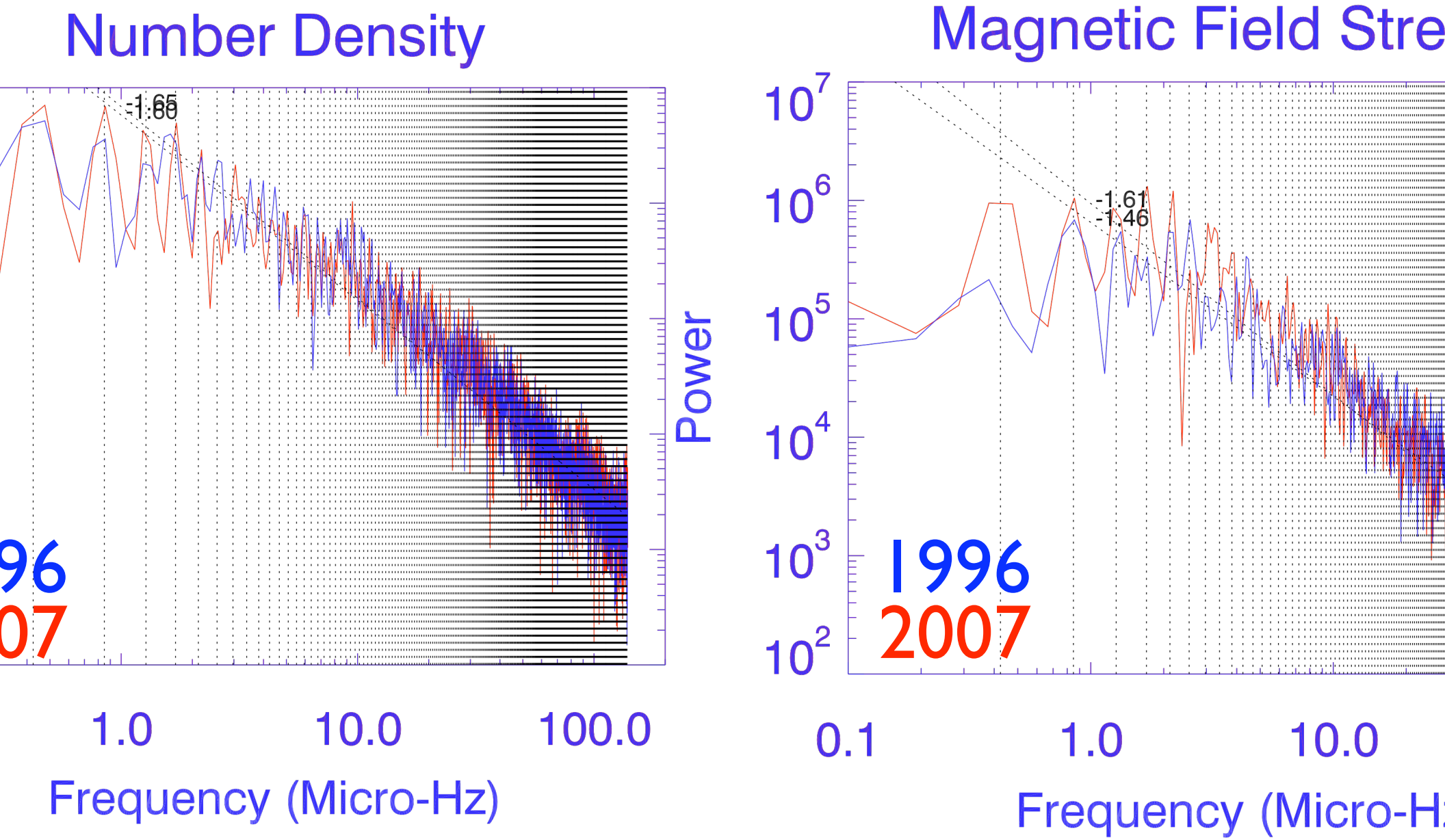
neter	1st orbit (WSM)	3rd Orbit (WHI)	Difference (
n/s)*	761	739	-3
(cm^{-3})*	2.65	2.19	-17
10^6 K)*	2.66	2.3	-14
r^2 (kgm^{-2}s^{-1})	3.96	3.17	-20
^{2}*r^2 (nPa)*	3.01	2.34	-22
a)*	9.89	7.43	-25
nT)$^+$	3.6	2.3	-36
n $^{-3}$) #	2.43/2.65	2.06/2.09	-15/-21
re, 10^4 K) #	7/7.5	6.2/6.43	-11/-14

erage solar wind properties between WSM and WH
some of which match the observed trends!

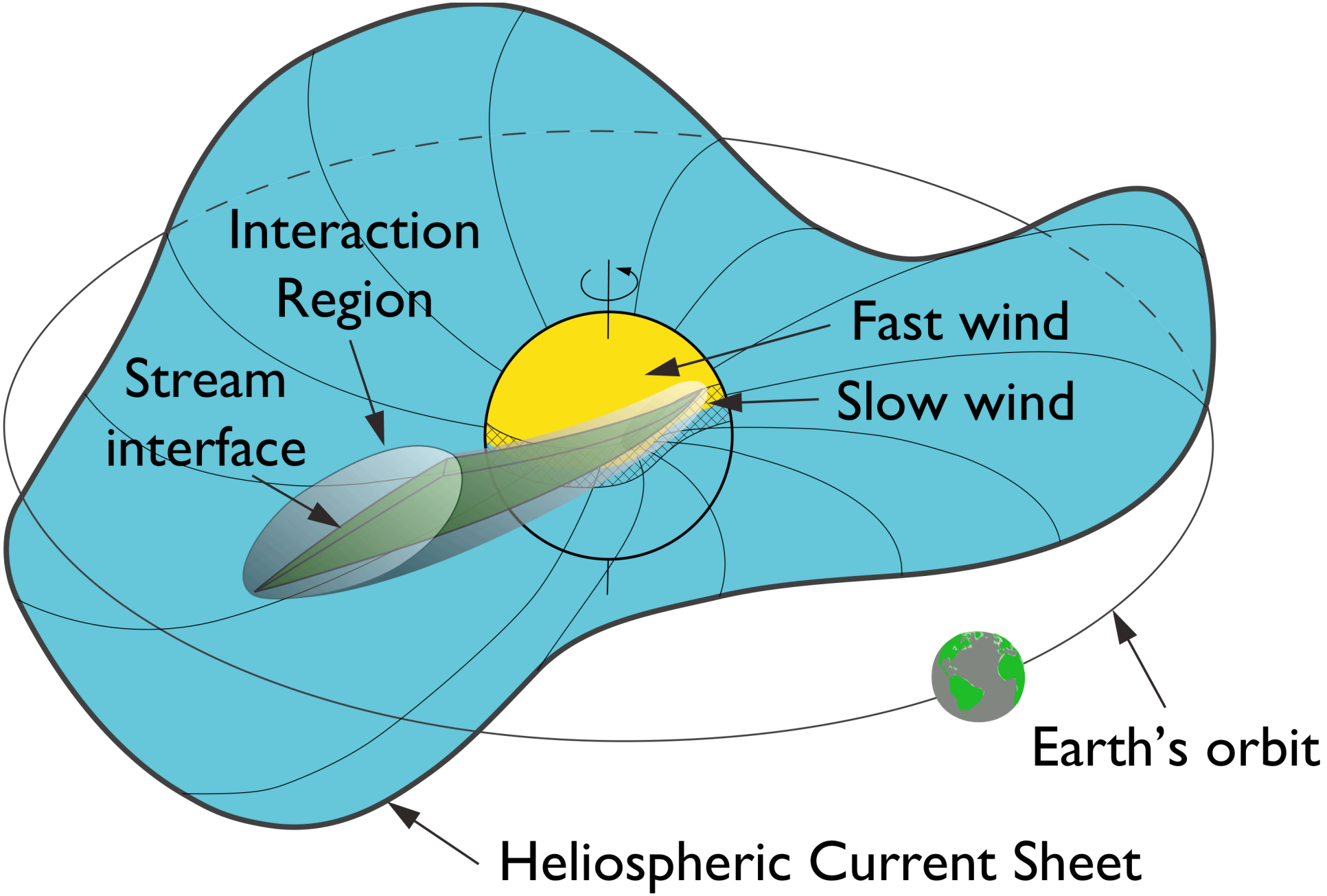
meter	CR1913 (WSM) N/S pole	CR2068 (WHI) N/S Pole	Difference (%)	Observ Differenc
m/s)	731/722	704/719	-3	-3
m^{-3})	2.17/2.24	2.38/1.99	-1	-17
T)	2.91/2.91	1.63/1.59	-45	-36
Flux (nT)	2.95	1.40	-53	N/A
Factor	8.39/8.66	6.92/7.34	-20	N/A


10^{10}
10^{9}
10^{8}
10^{7}
10^{6}
10^{5}
10^{4}
-2.03
-1.96
1996
2007
0.1
1.0
10.0
100.0


10^{10}
10^{9}
10^{8}
10^{7}
10^{6}
10^{5}
10^{4}
-2.03
-1.96
1996
2007
0.1
1.0
10.0
100.0


Number Density
-1.65
-1.60
96
07
Power
1.0
10.0
100.0
Frequency (Micro-Hz)
Magnetic Field Stre
10^7
10^6
10^5
10^4
10^3
10^2
-1.61
-1.46
1996
2007
0.1
1.0
10.0
Frequency (Micro-H

structure


Interaction
Region
Stream
interface
Fast wind
Slow wind
Earth's orbit
Heliospheric Current Sheet

CIR Formation
Three Dimensio

sion

Fast

Slow

on

Fast

Solar Maximu

Declining Phase

rom
ite side

Rotation axis

Magnetic axis

Fast

Slow

Compression

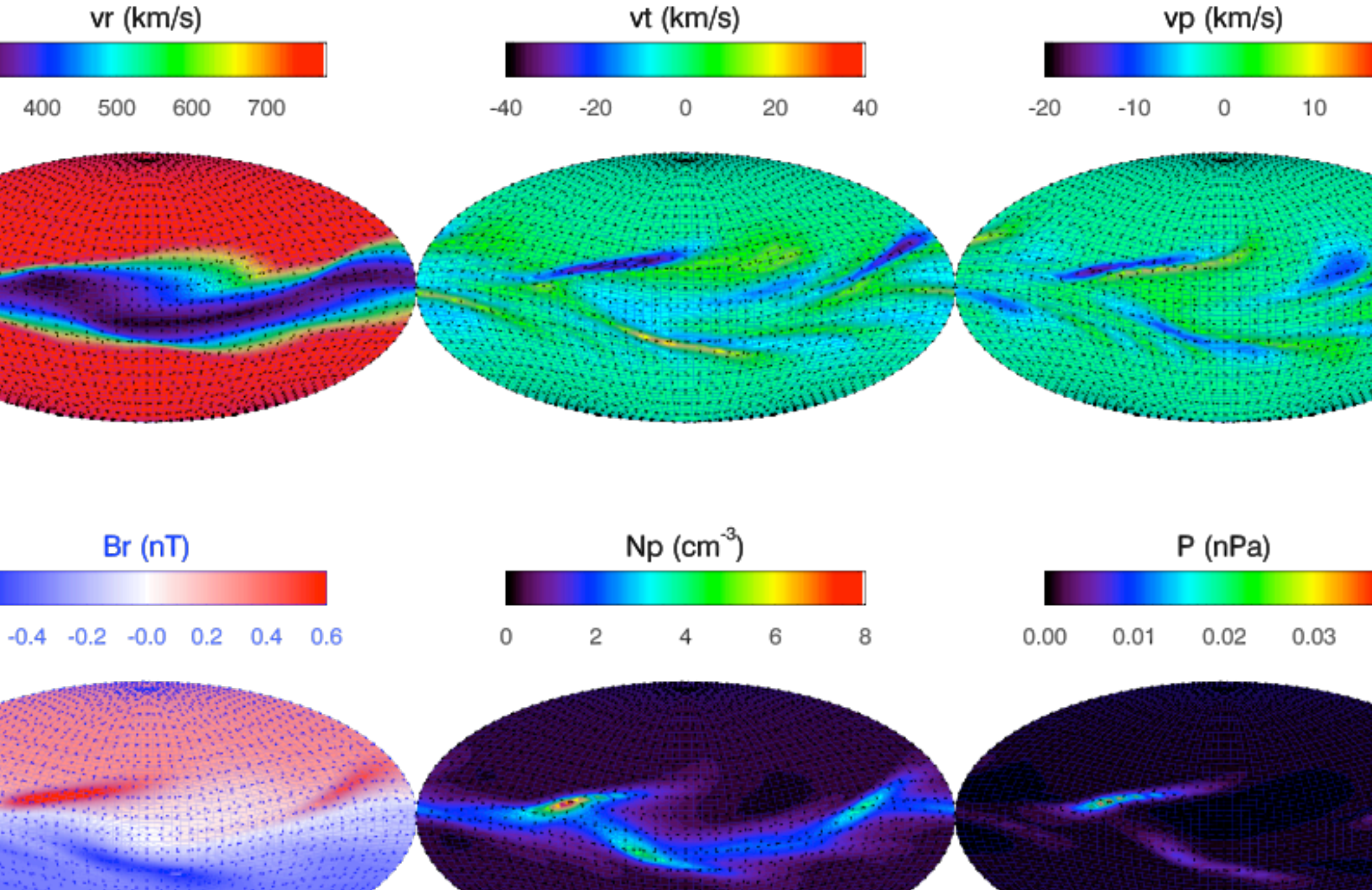
Rarefaction

Rotation a

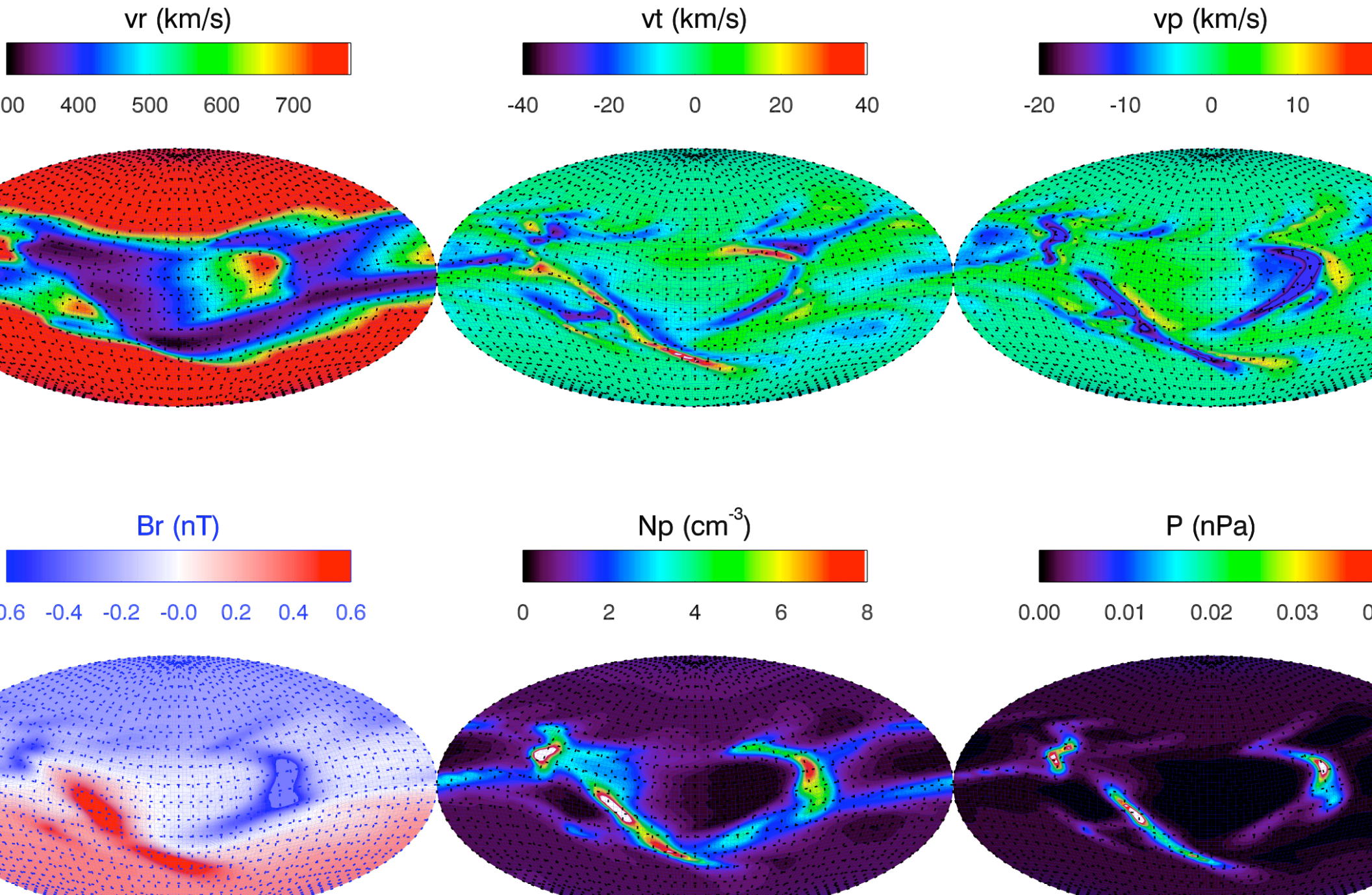
Slow

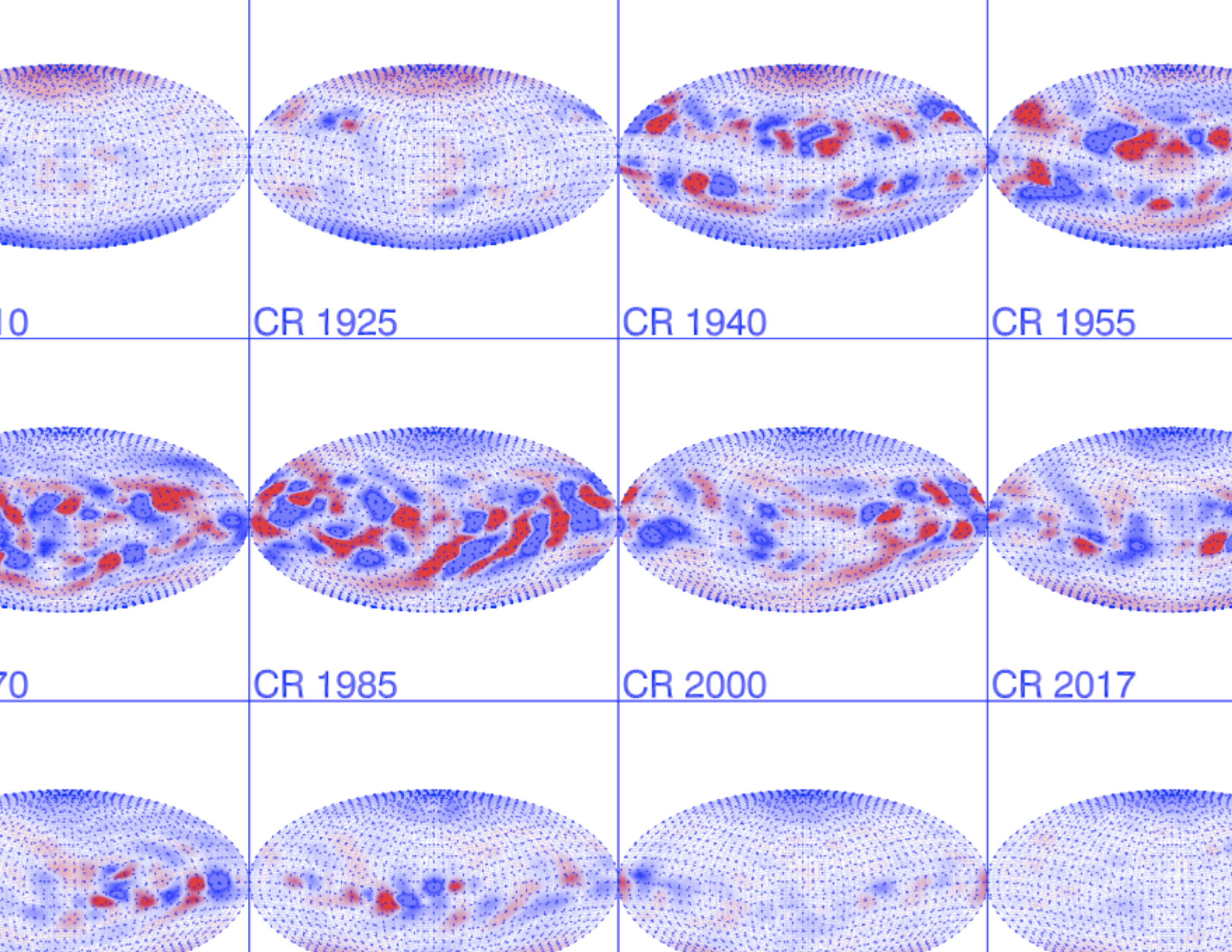
Fast

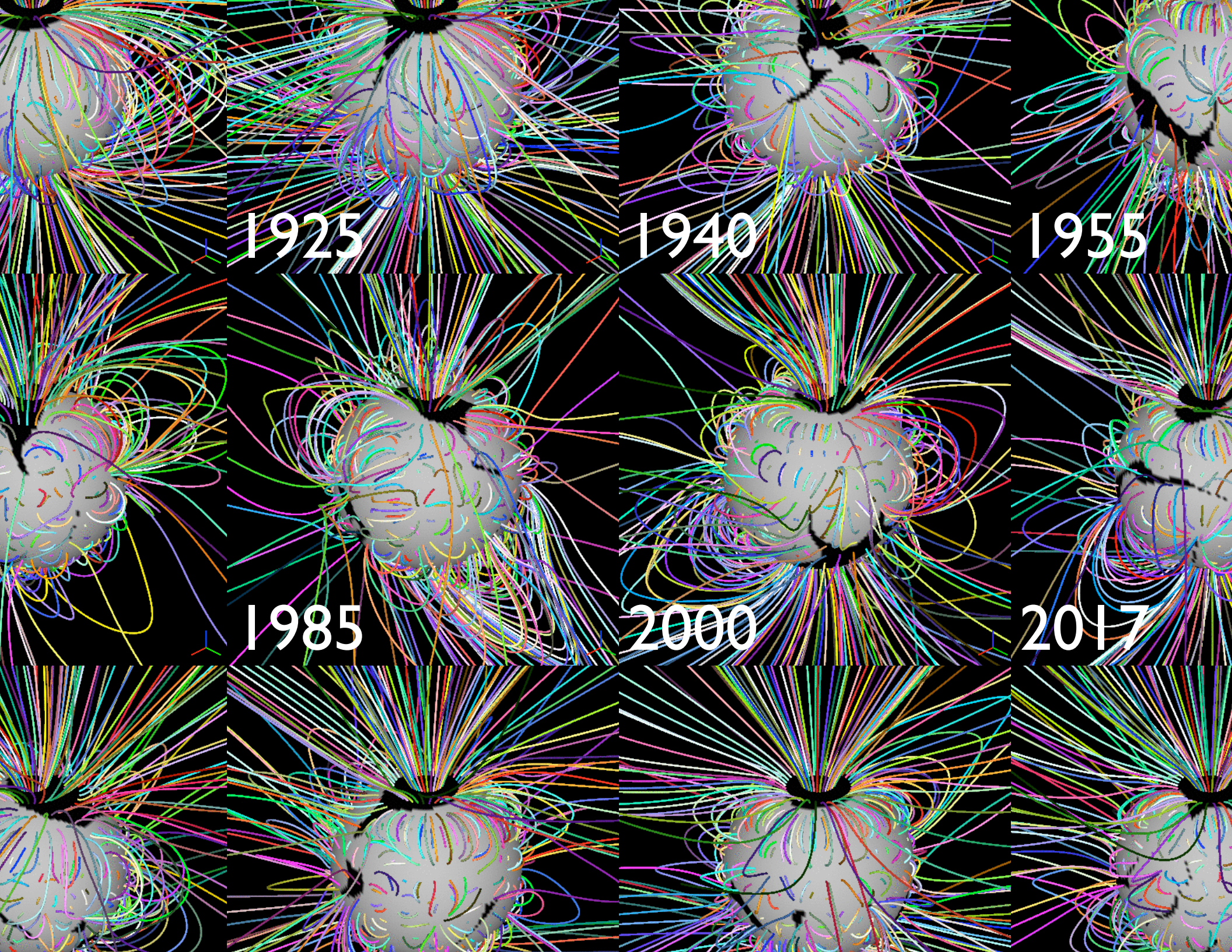
AU for 1913(WSM, Aug/Sept 19

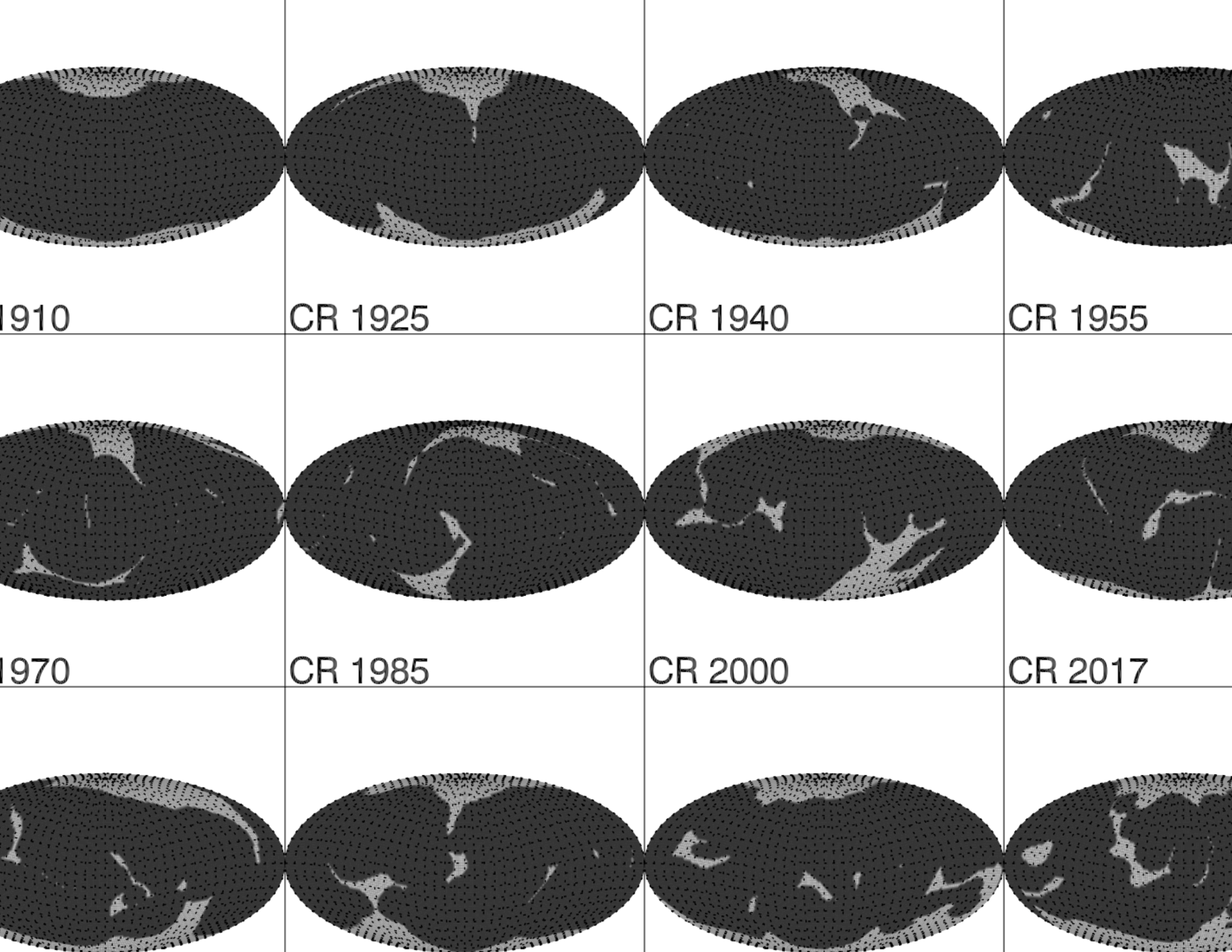


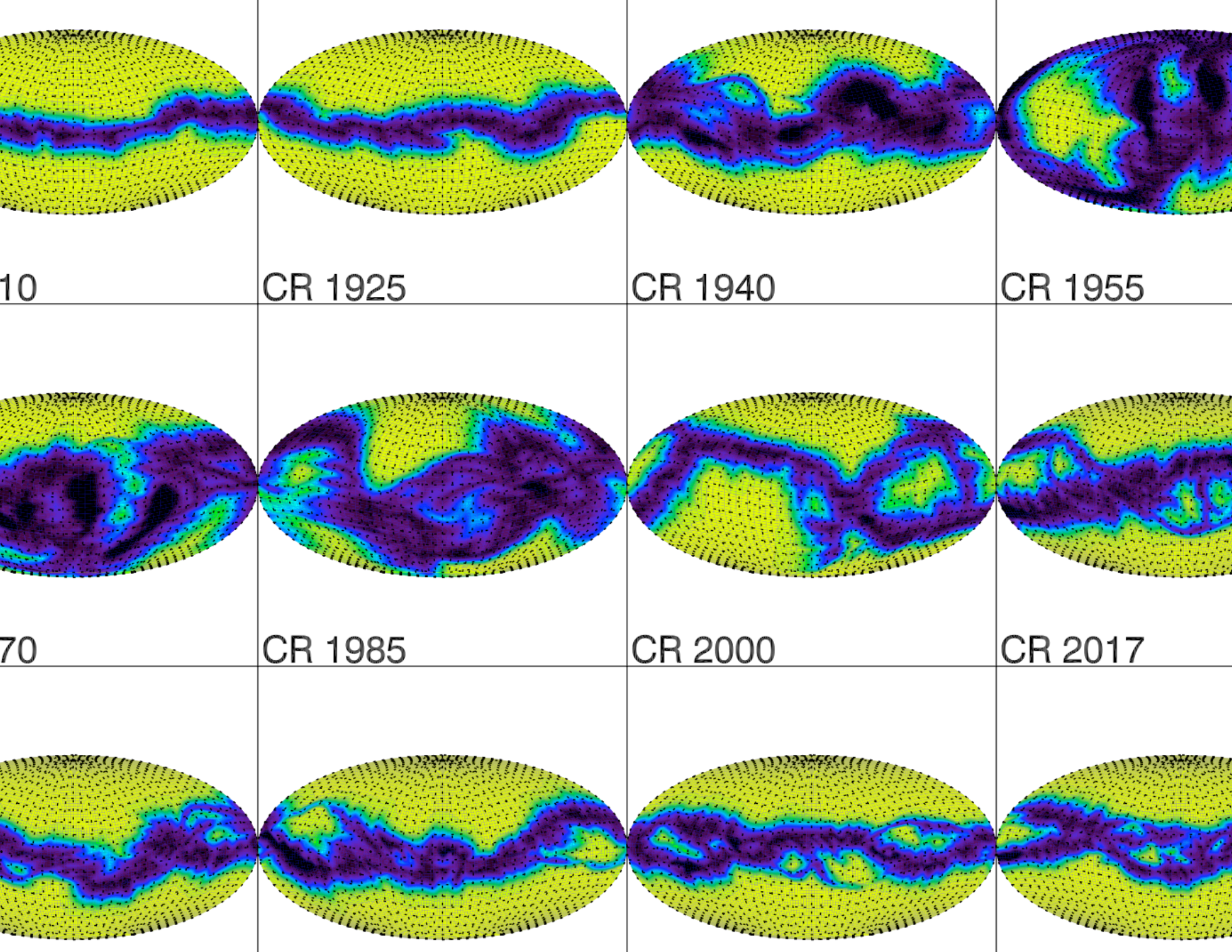
AU for 2068 (WHI, Mar/Apr 20

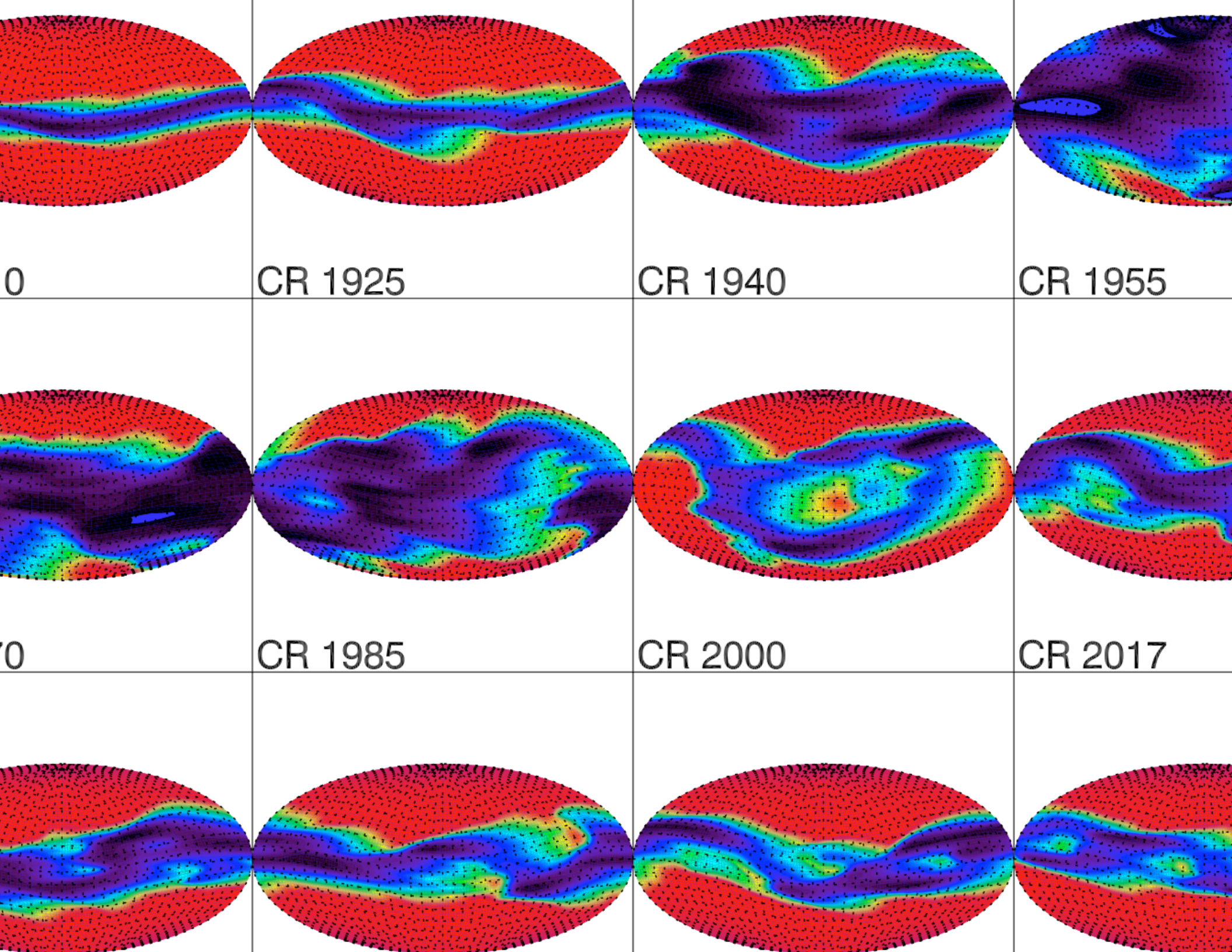


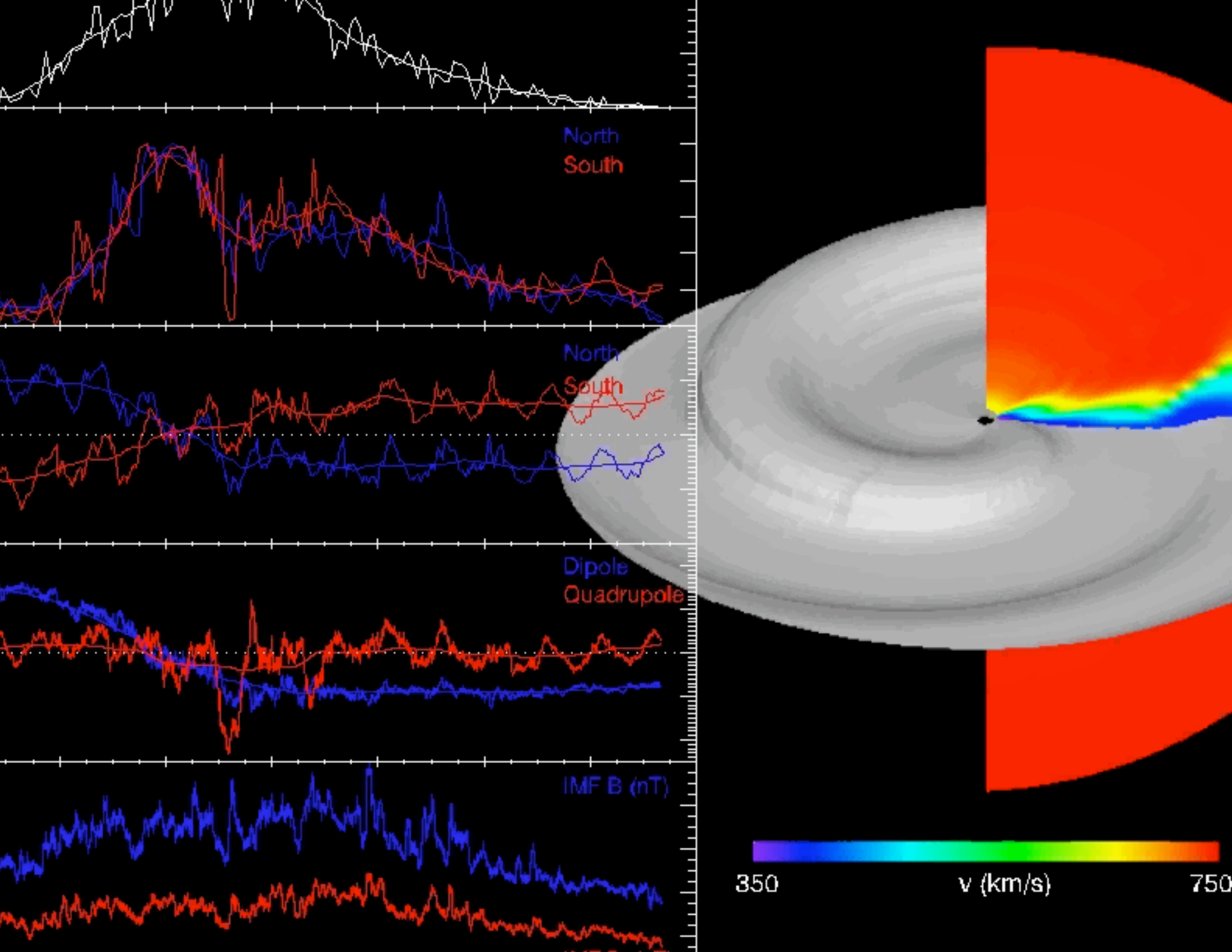

10
CR 1925
CR 1940
CR 1955
70
CR 1985
CR 2000
CR 2017


1925
1940
1955
1985
2000
2017

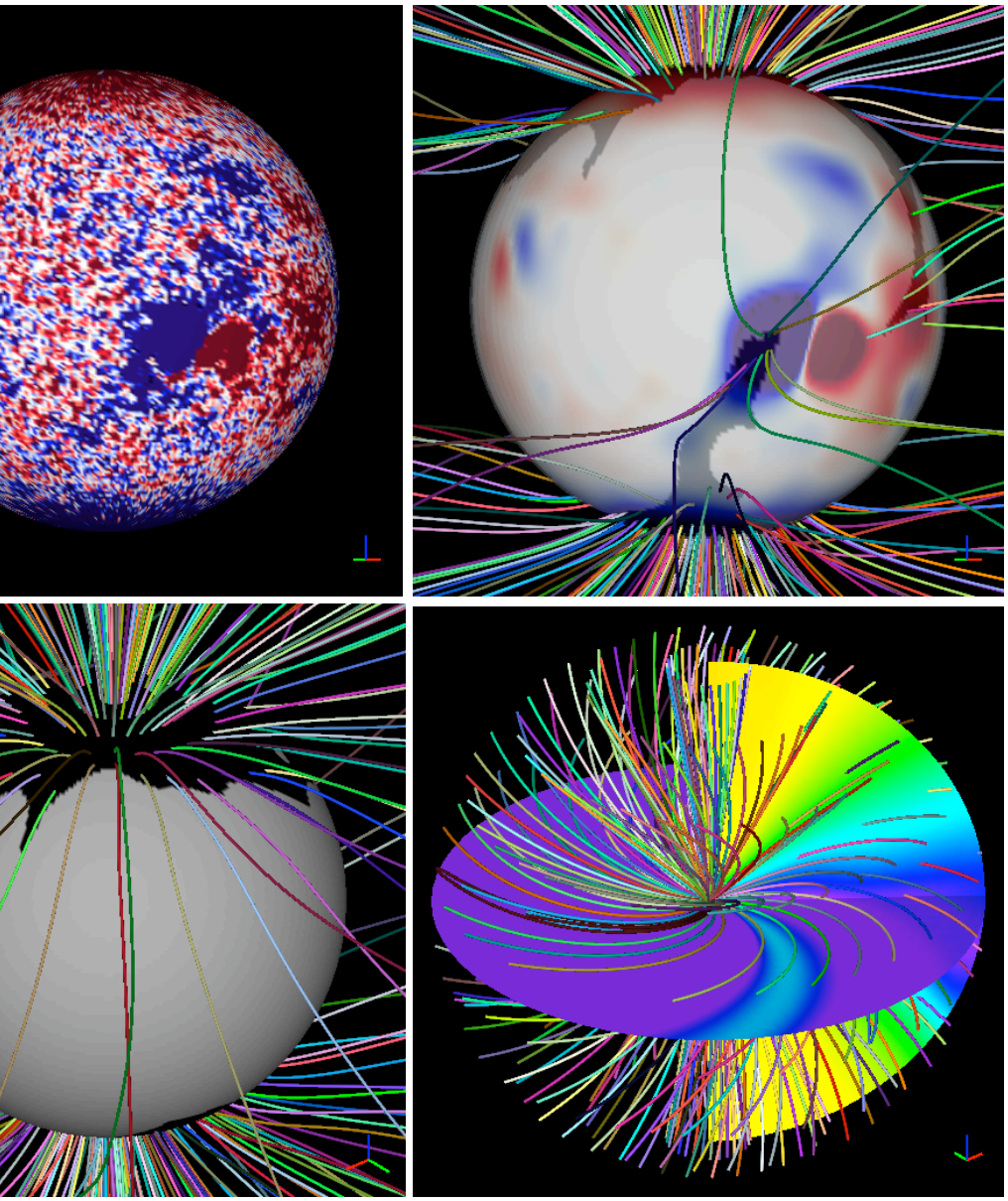

1910
CR 1925
CR 1940
CR 1955
1970
CR 1985
CR 2000
CR 2017


10
CR 1925
CR 1940
CR 1955
70
CR 1985
CR 2000
CR 2017


0
CR 1925
CR 1940
CR 1955
0
CR 1985
CR 2000
CR 2017


North
South
North
South
Dipole
Quadrupole
IMF B (nT)
350
v (km/s)
750

Summary



allows us to investigate both co
and heliospheric structure in mo
detail:

- Quantitative emission comparisons
- Direct comparisons with in situ meas

- Comparison of WSM with WHI
  - Two intervals have markedly differen
    given the ~11.5-year separation
  - WHI wind is much ‘weaker’ but more
    than WSM
  - Model results broadly consistent wit
    observations

- Results on the web:
  - Polytropic solutions are currently availab
    http:/www.predsci.com/stereo/
  - The thermodynamic solutions shown he
    made available in the near future.