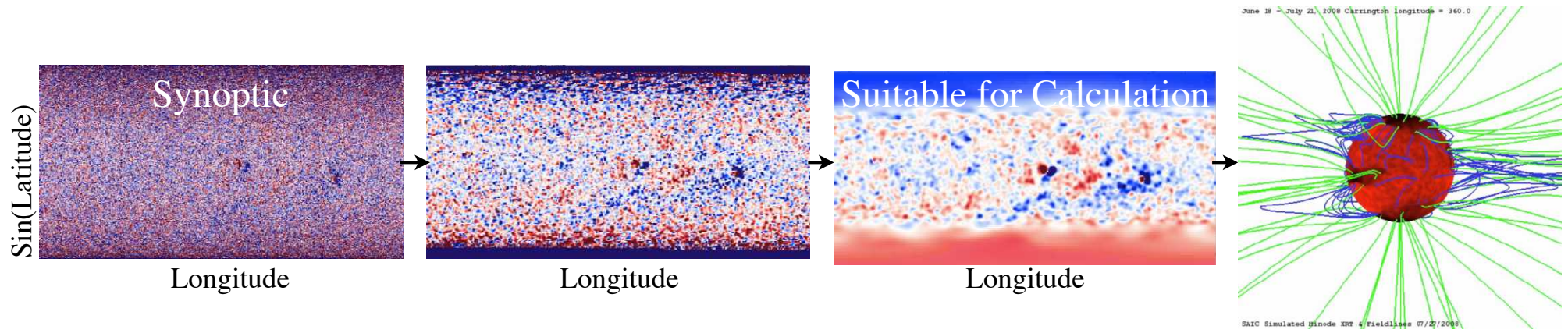


# Global Coronal Modeling With Magnetic Maps



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# Coronal Modeling & Magnetic Maps

- The coronal magnetic field is of paramount importance in solar & heliospheric physics
- We require models of the magnetic field for both research and operational purposes
  - Location of fast wind streams, heliospheric current sheet location, field connectivity to the earth
  - Magnetic structure, coronal and solar wind parameters
  - Ambient state for models of CMEs, shock arrival
- The principle input to coronal/solar wind models are global maps of the magnetic field, usually at the photosphere
- Models range from potential field to MHD with varying levels of complexity.
- Today I will review how maps are used in calculations, and describe some results from the SHINE workshop



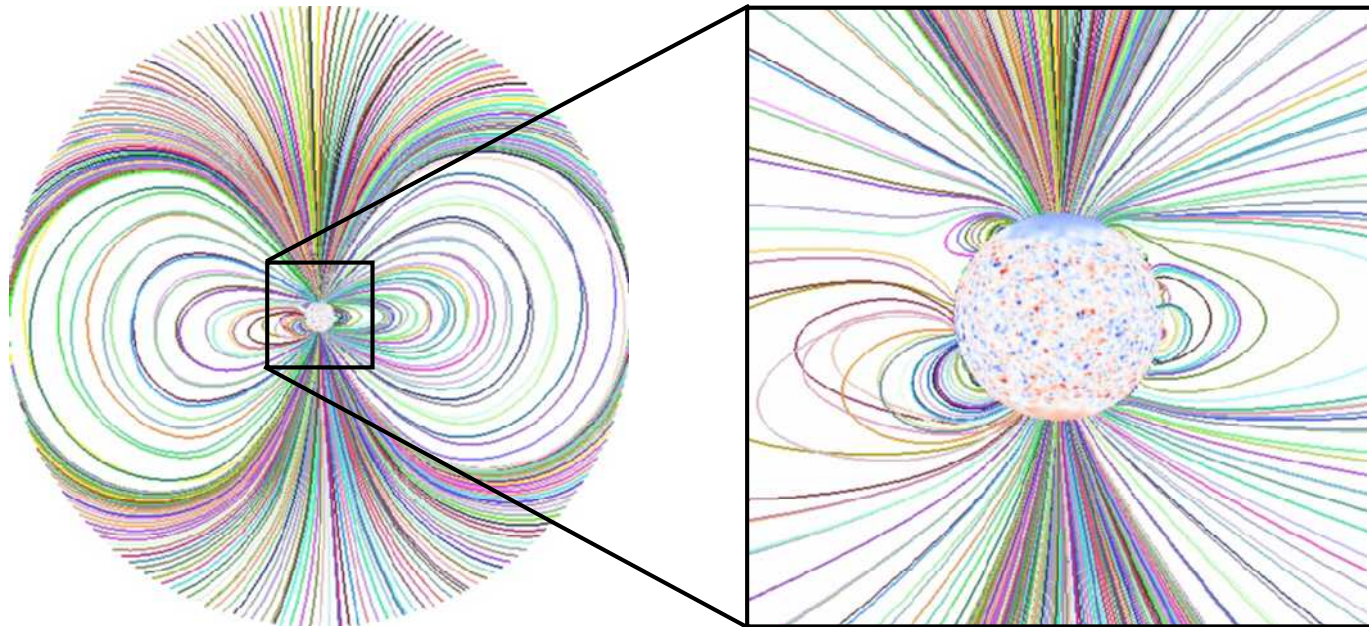
# How are Maps Used?

- Boundary conditions:
  - A map of  $B_r$  at the solar surface (can also use  $B_{LOS}$ )
- Potential field/empirical solar wind: Solve Laplace's equation
  - WSA or DCHB specification to predict speed
  - Calibration dependence: Field structure, open/closed boundaries don't depend directly on  $|B|$ , estimates of open flux do
- MHD calculations:
  - Start from potential field and spherically symmetric solar wind solution
  - Solve MHD equations in time and relax to steady-state
  - Calibration dependence (Polytropic MHD):  $V_A$  depends directly on  $|B|$
  - Thermodynamic MHD: Heating model, acceleration model also depend on  $|B|$
- *The more sophisticated the model, the more sensitive it is to  $B$  calibration*



# How are Maps Used? (continued)

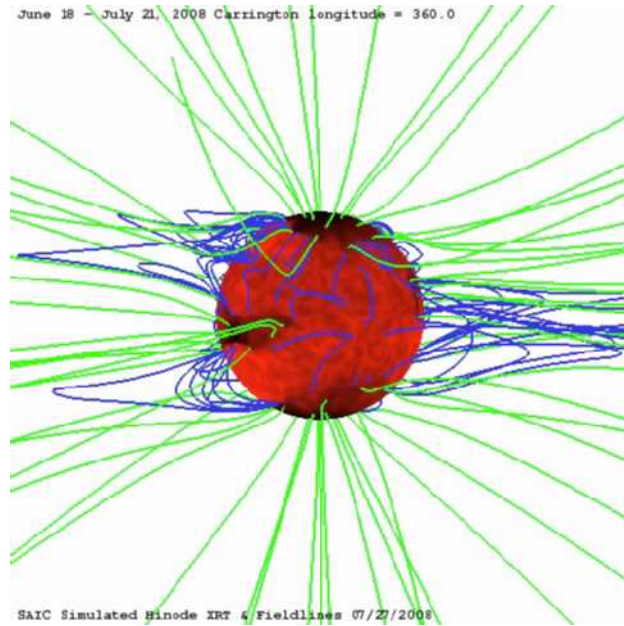
- 3D MHD calculations: Solution integrated in time to  $\sim$ steady state



Magnetic Field Lines  
Coronal Domain

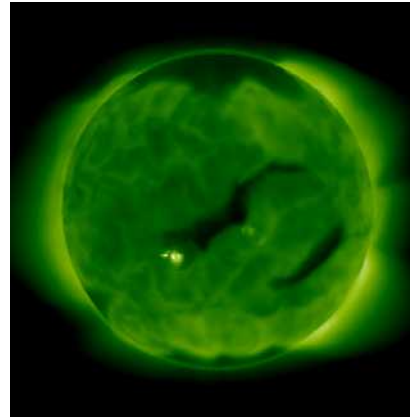
# How are Maps Used? (continued)

- 3D MHD calculations: Solution integrated in time to  $\sim$ steady state
- Solution has open/closed regions - these can be compared in emission and white light

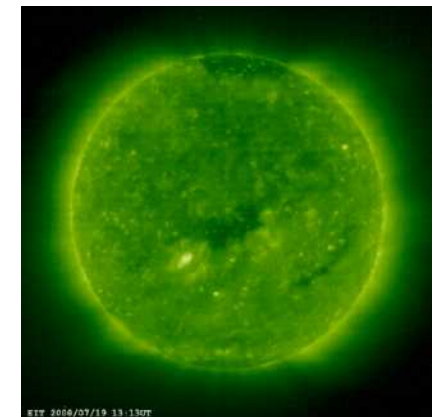


Magnetic Field Lines  
&  
Simulated Hinode XRT

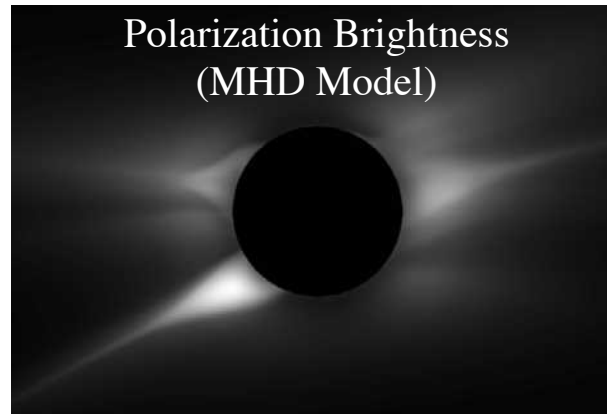
Simulated EIT 195Å



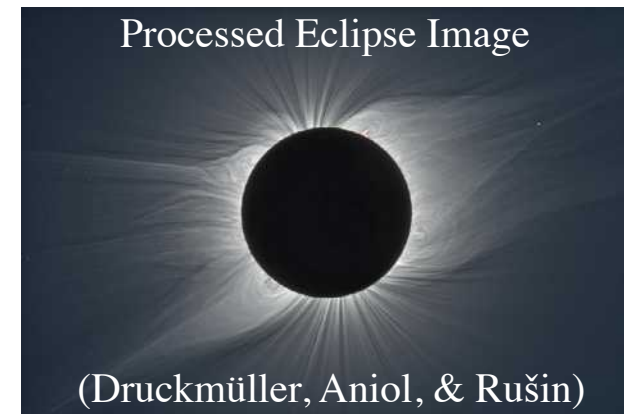
EIT 195Å



Polarization Brightness  
(MHD Model)

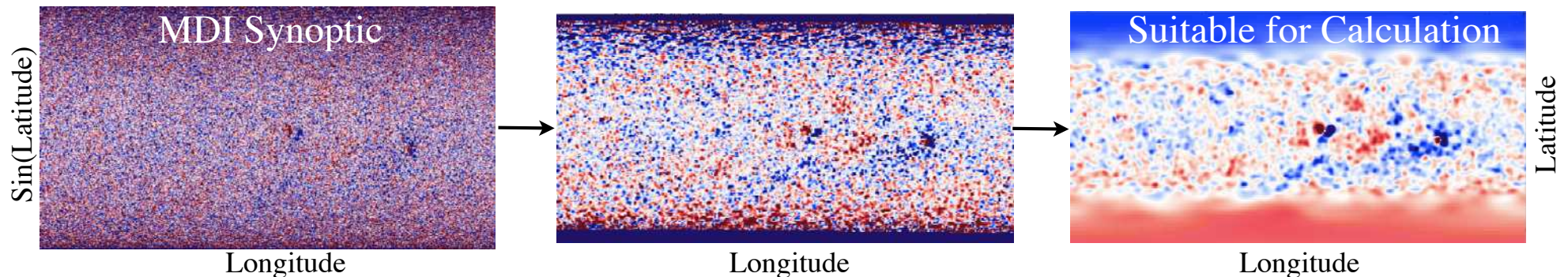


Processed Eclipse Image



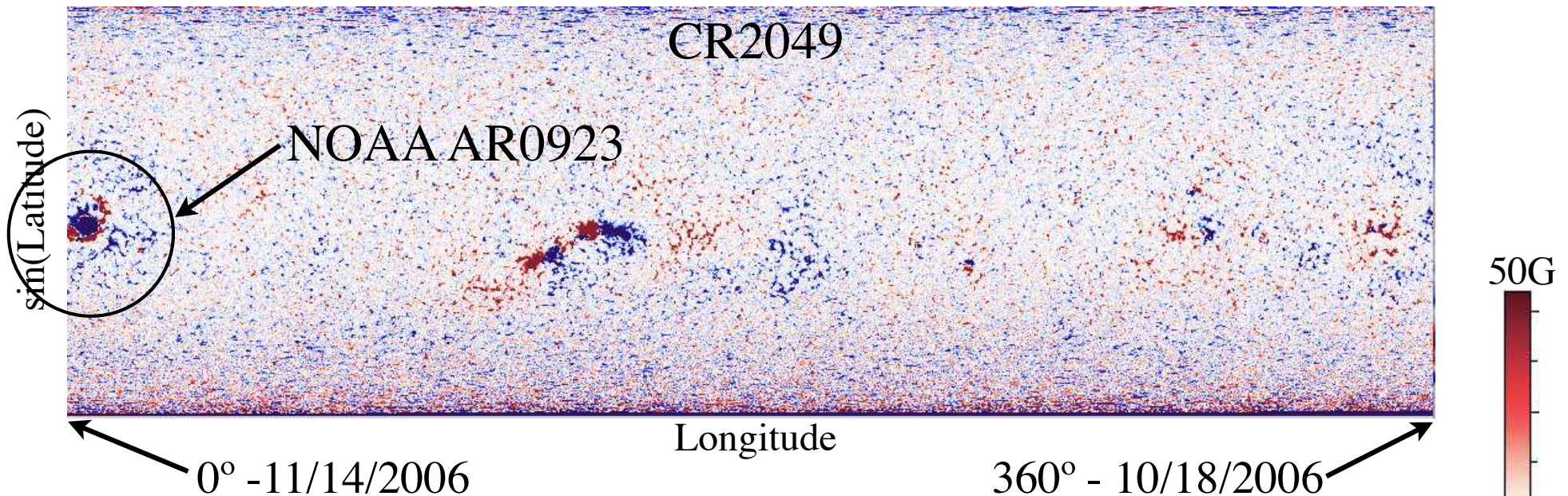
# Steps For Processing a Map

- Download map from Observatory, or build from individual magnetograms.
- Infer radial field from  $B_{LOS}$  (often performed by Observatory).
- Interpolate to desired mesh, fill poles.
- Smooth based on available resolution.
- Balance magnetic flux



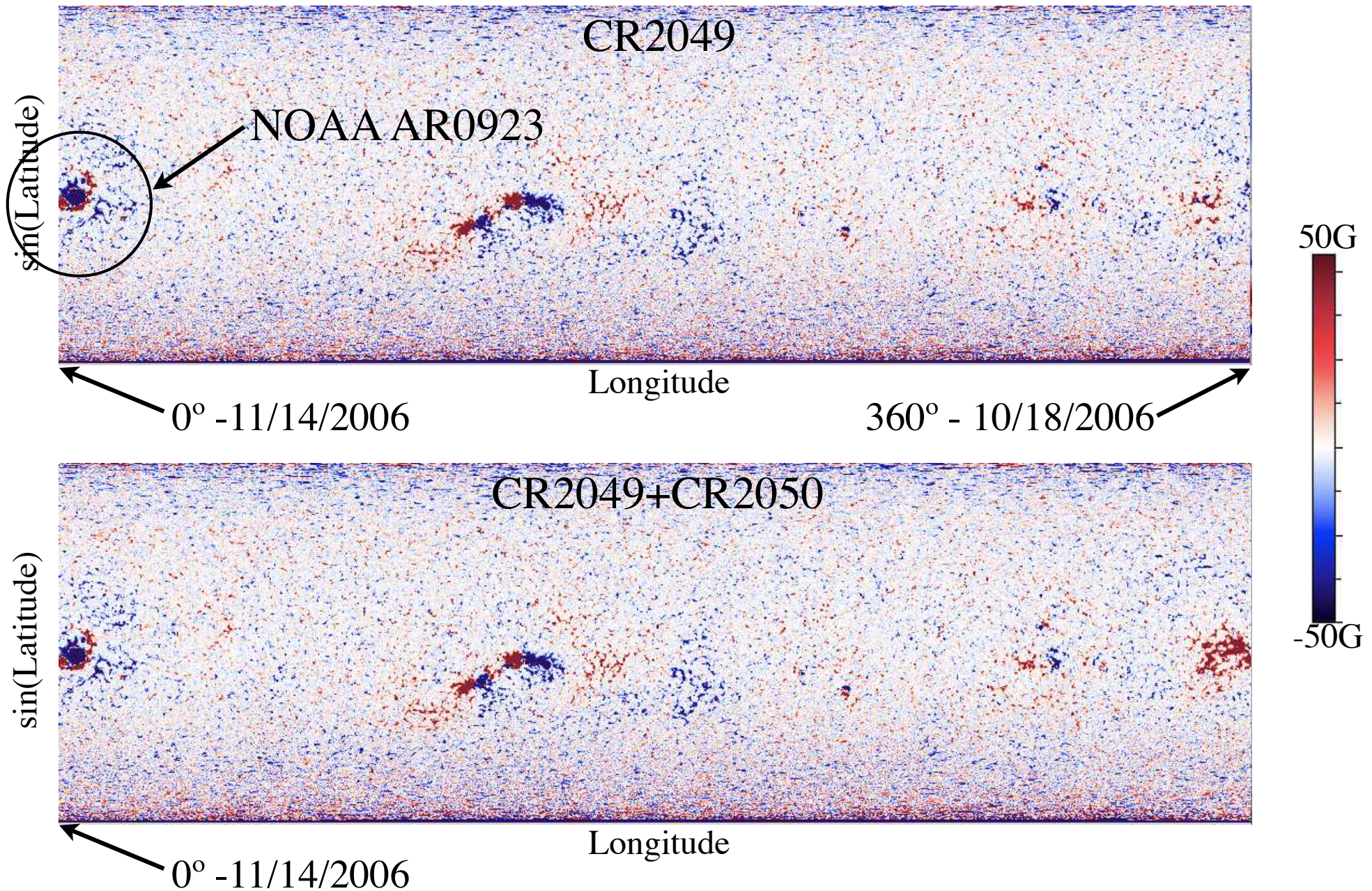
- In practice, there are many assumptions/difficulties in using this data:
  - Quantitative disagreements between observatories
  - Data is built up over a rotation, but the photospheric field is always evolving (somewhat mitigated by flux transport models)
  - The polar fields are poorly observed

# What Can Go Wrong? Example - Flux Balance



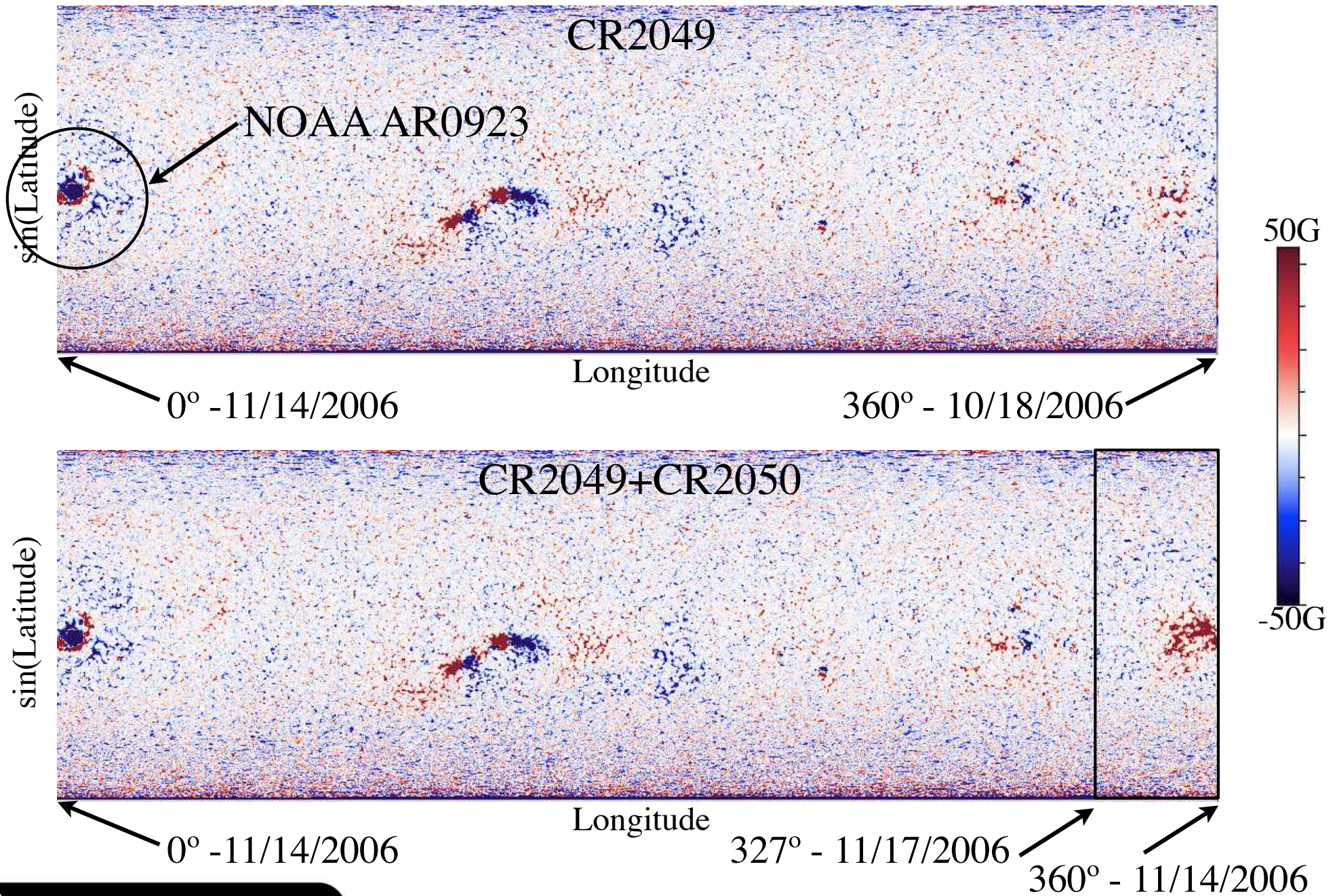
- Carrington Rotation 2049 - partially observed active region
- Leading (negative) polarity observed of AR0923
- Flux imbalance is  $\sim 30\%$ . Contrast with CR2050  $\sim 5\%$ .
- This problem can occur frequently with daily updated maps or “blind” pasting of new map into flux evolution model

# What Can Go Wrong? Example - Flux Balance

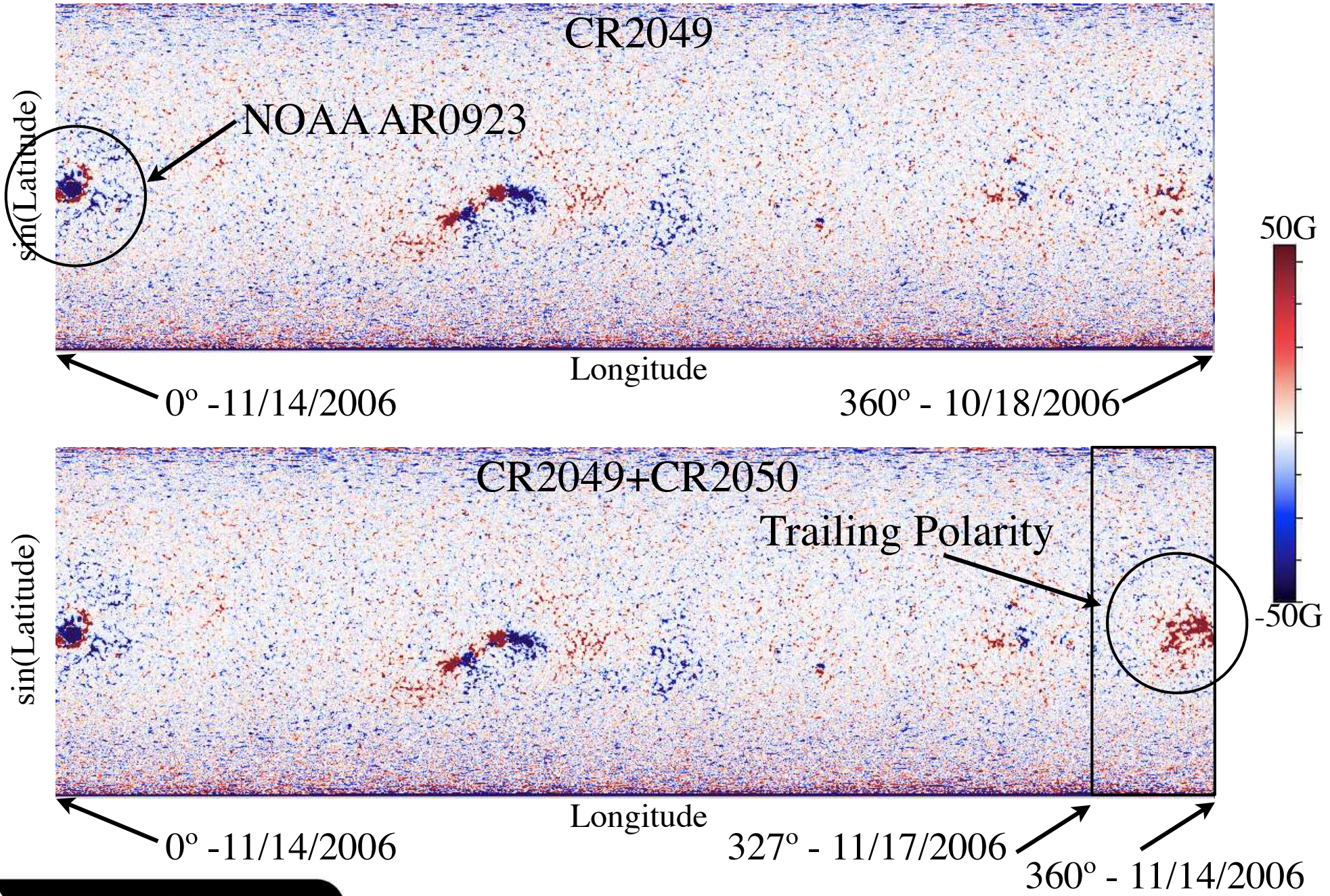




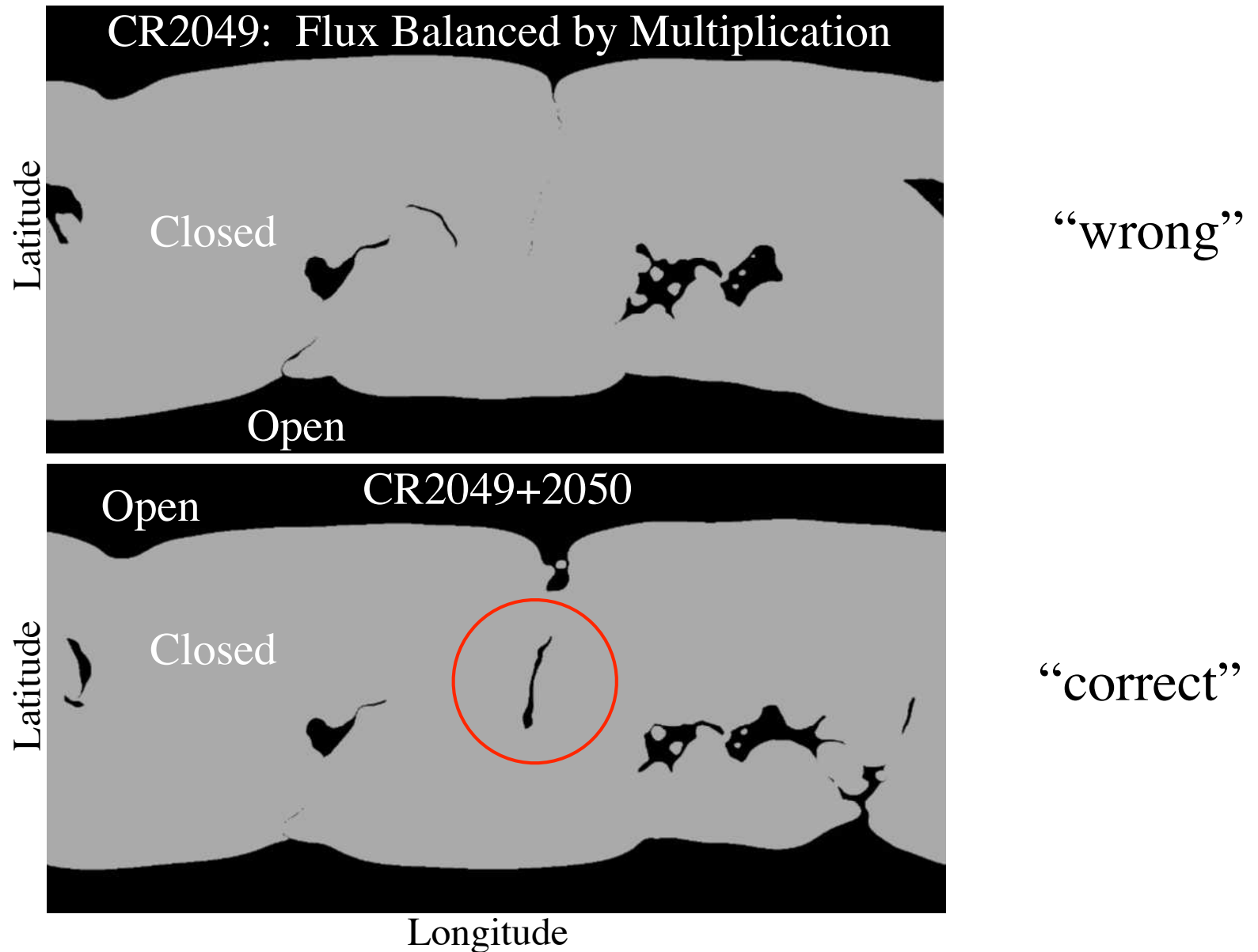
# What Can Go Wrong? Example - Flux Balance



# What Can Go Wrong? Example - Flux Balance



# After Correcting Unbalanced Flux: Open Field Regions (Source-Surface Models)

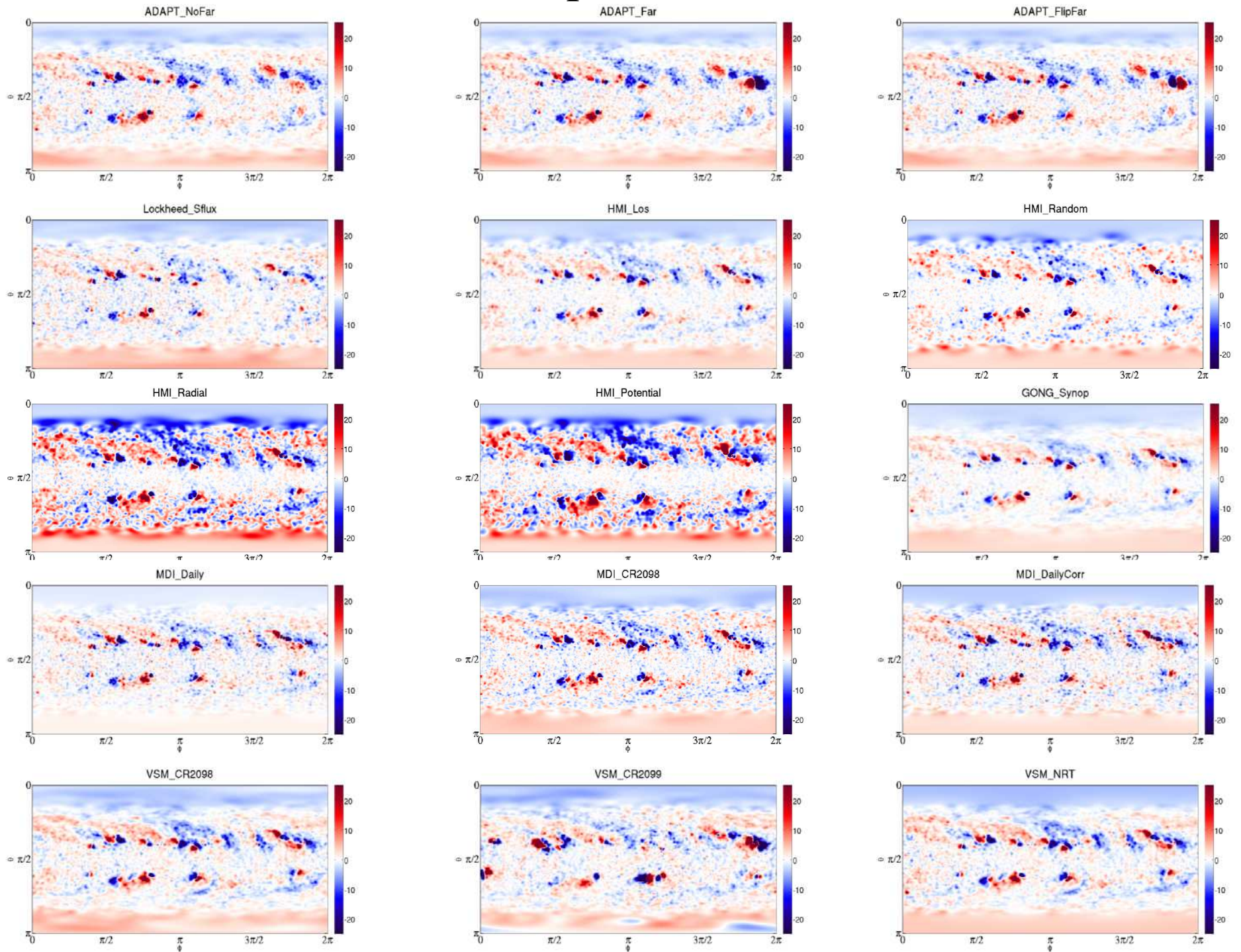


Open field regions are altered significantly, even far from the AR

# SHINE 2016 Maps Session

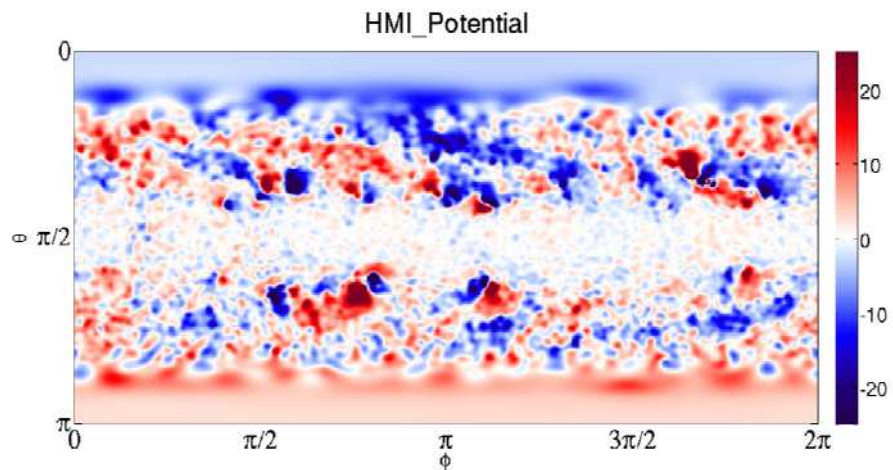
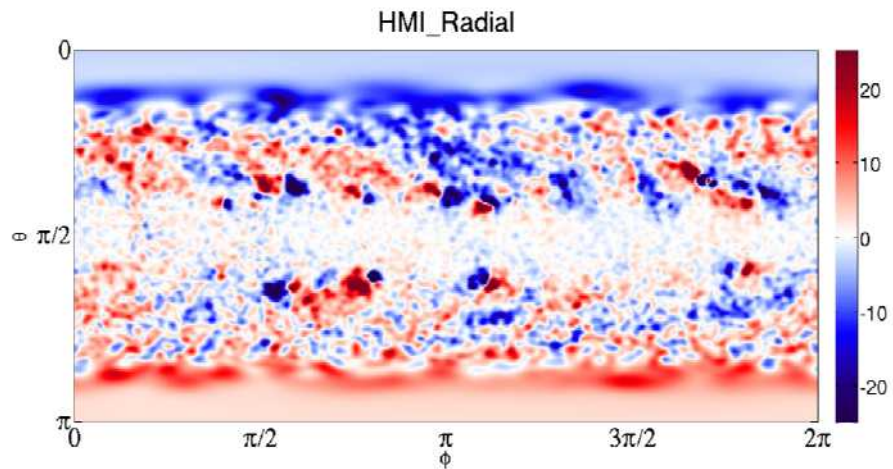
- Earlier work has shown that maps agree qualitatively, but not quantitatively (e.g. Riley et al. 2014).
- Goals:
  - Compare different techniques for generating global solar magnetic field maps
  - Understand how “poor” maps affect coronal and solar wind model results.
- The session was devoted to a “challenge event” - selected with sufficient lead time for participants to produce results prior to the workshop
  - A single date and time was selected: 20 UT on July 8th 2010
  - Map makers provided maps, and modelers provide output using the maps

# Br Maps (Processed)

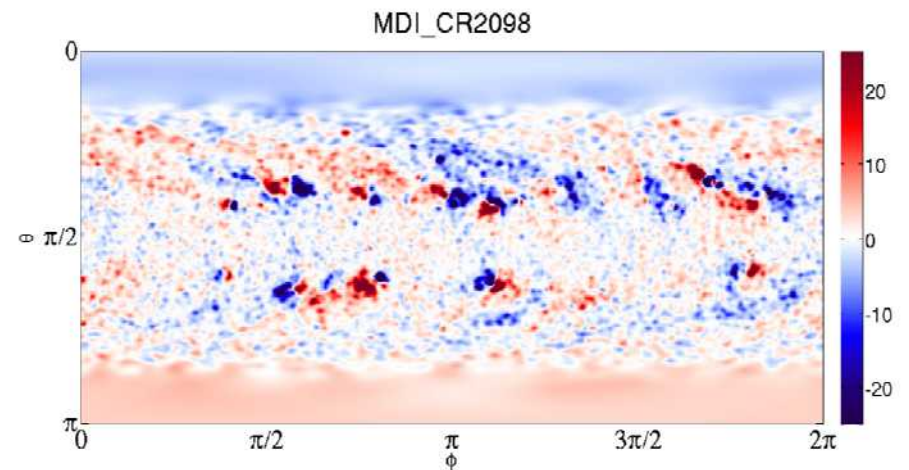
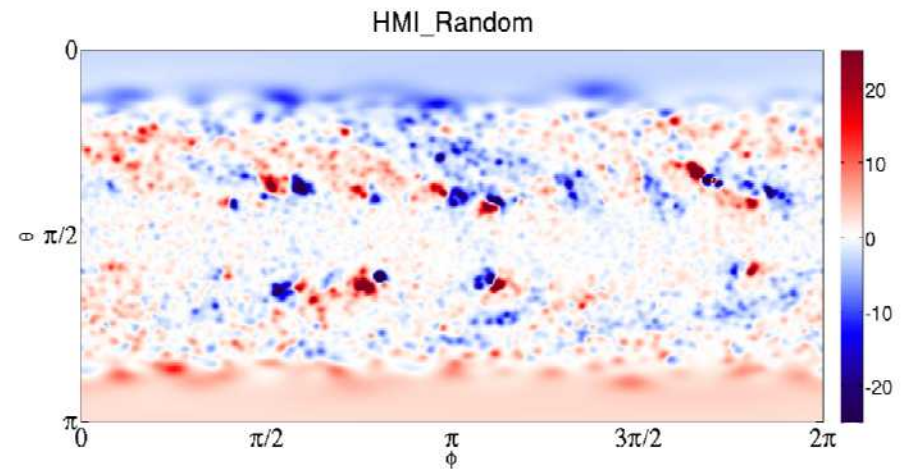


# Br Maps (Processed)

These maps look different:



As compared to these:

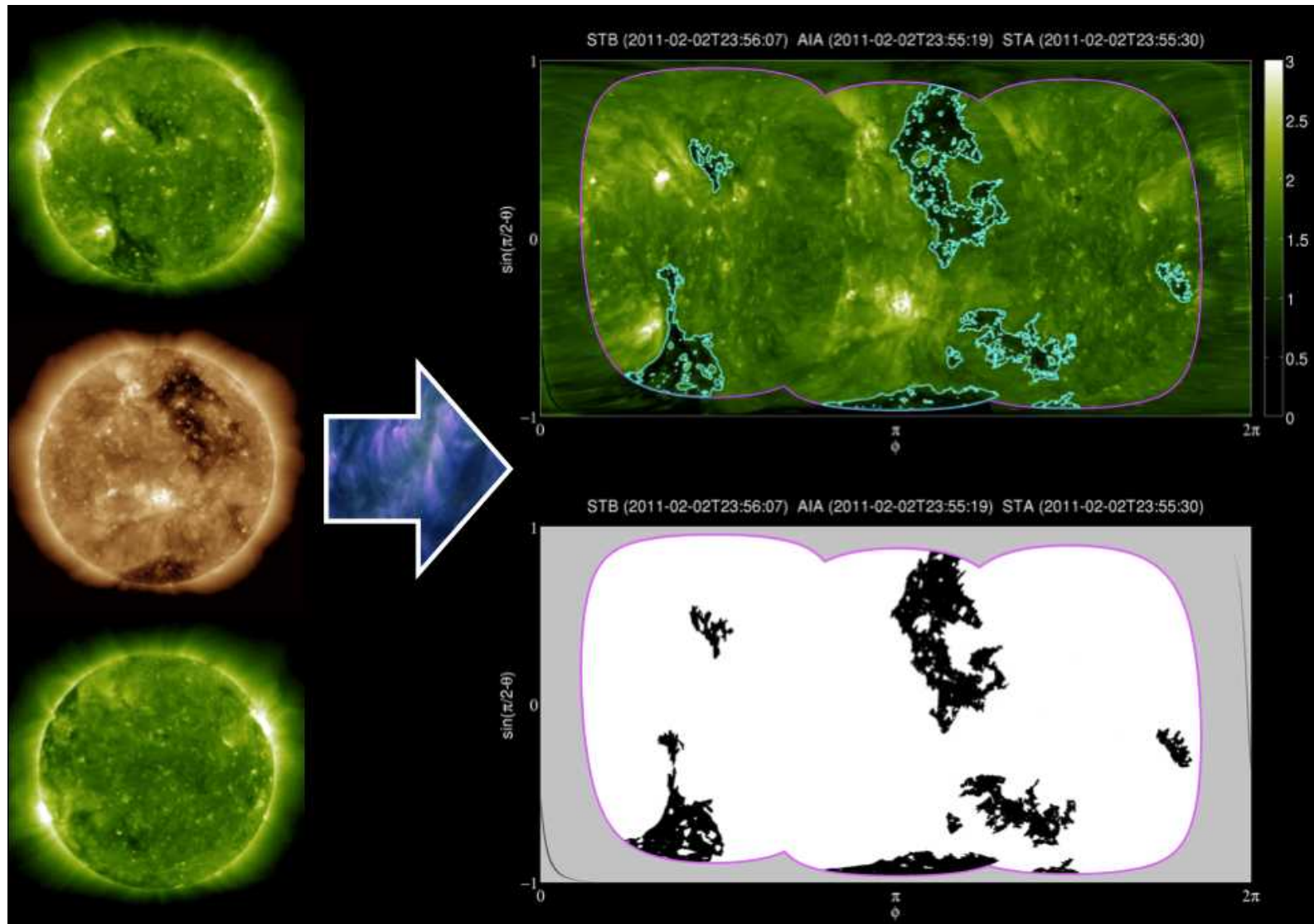


# What Basic Quantities Should We Compare?

- Magnetic field models predict open field regions
  - Emission observations indicate likely open fields, but the exact correspondence is unknown
- Models predict the location of the heliospheric current sheet (HCS)
  - testable from *in situ* spacecraft data, but difficult to quantify
- Models predict how much open flux should be in the heliosphere
- Ulysses observations:
  - $B_r$  is nearly uniform in latitude away from the HCS
  - We can use 1 AU measurements to estimate open magnetic flux (e.g. Owens et al. 2008)
- Open flux and open field regions together are a powerful constraint

# Constructing Time-Dependent Coronal Hole Maps (Caplan, Downs, Linker, ApJ 2016)

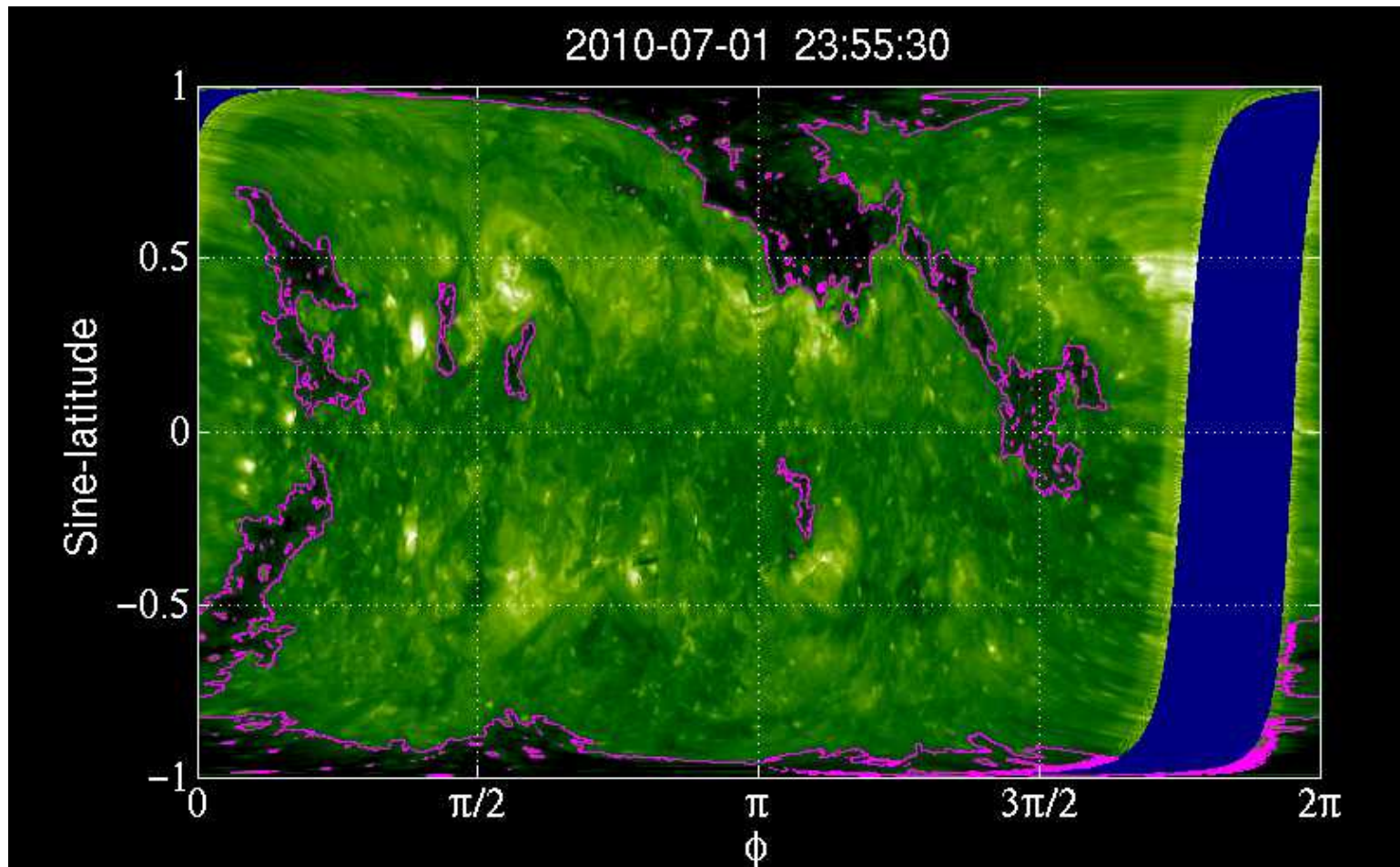
- **Basic Idea:** Use heterogeneous, multi-point EUV imaging data from SDO/AIA and the twin STEREO spacecraft to build instantaneous full-sun maps of coronal holes. Available at [www.predsci.com/CHD](http://www.predsci.com/CHD)





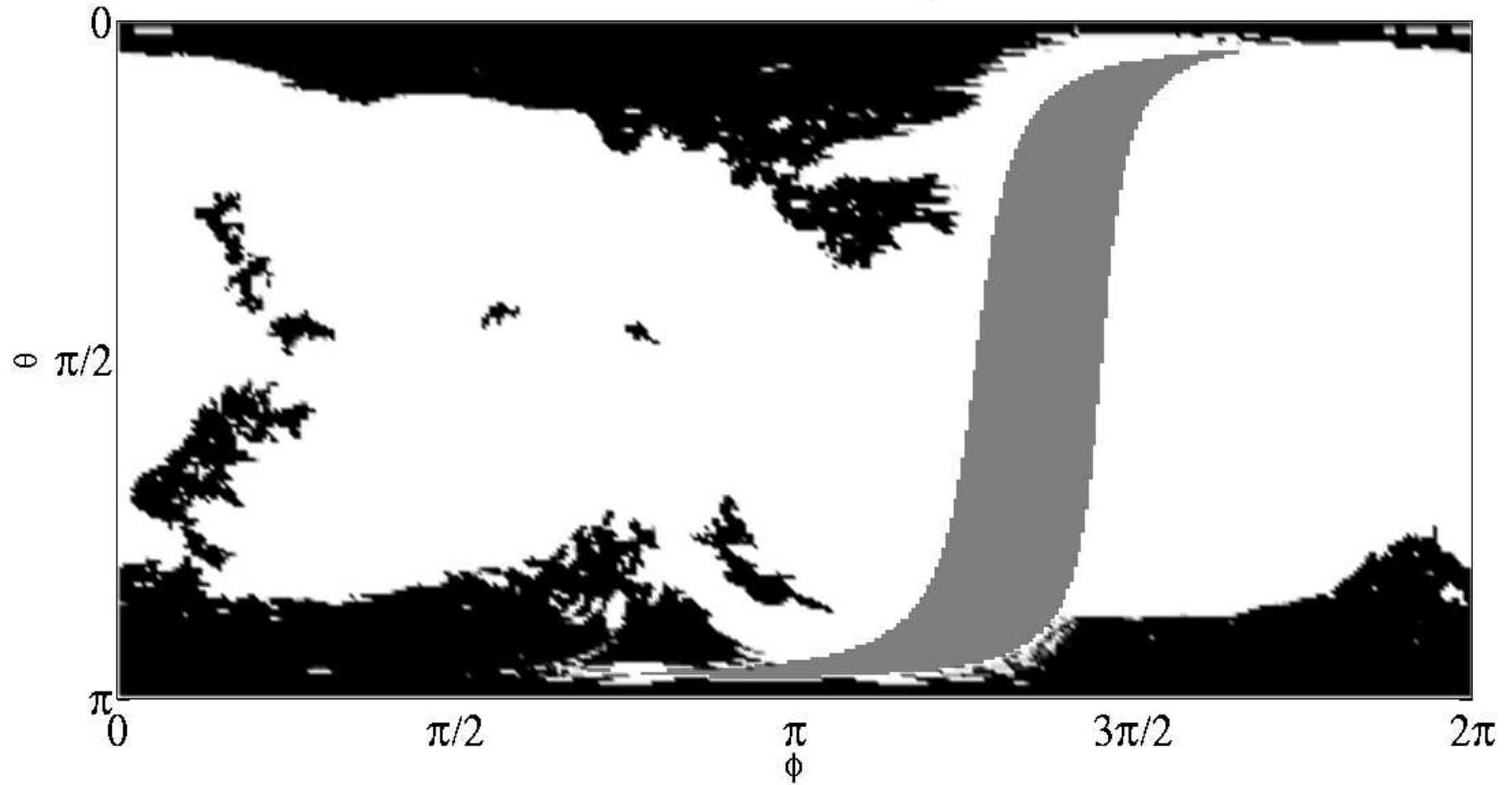
# Coronal Holes - July 2010

- A number of extended/equatorial coronal holes were present

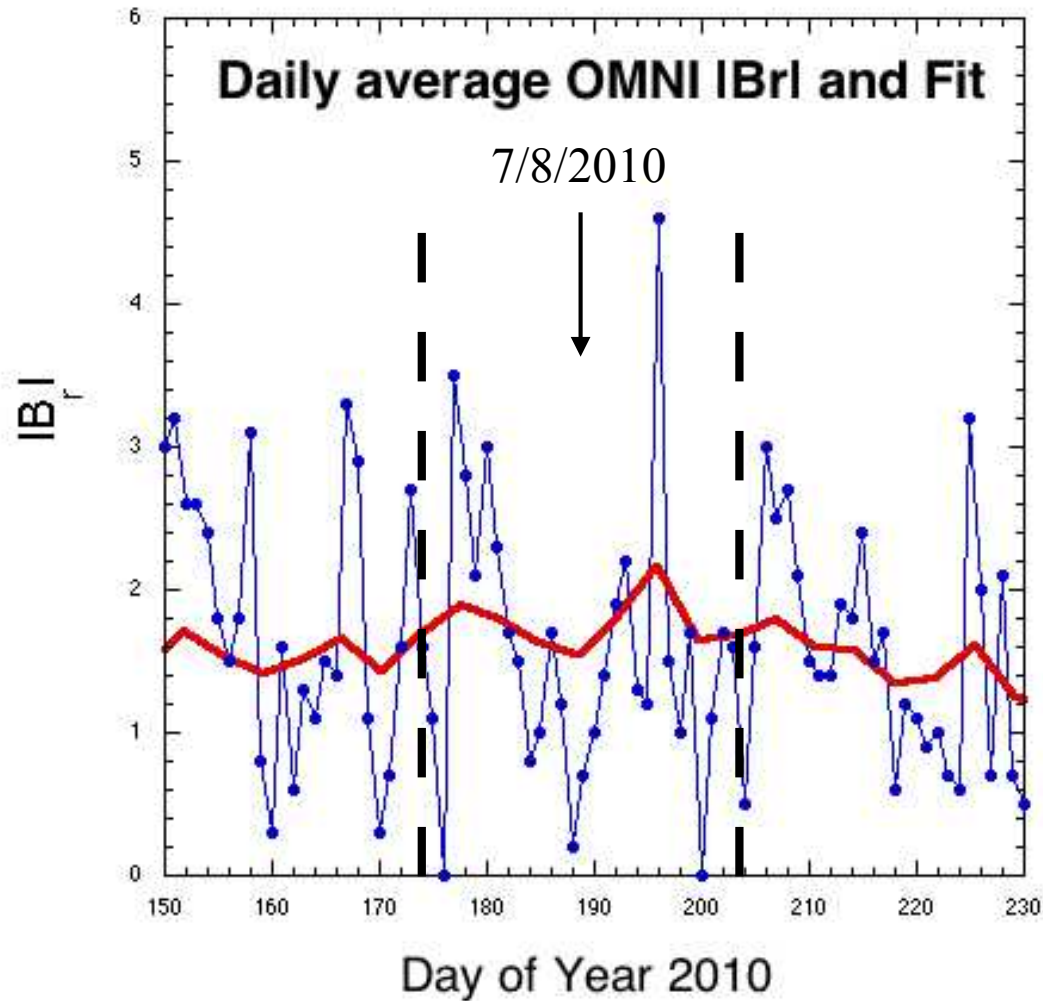


# Coronal Hole Map Inferred for Observations 07/08/2010

Observed CHM Interpolated

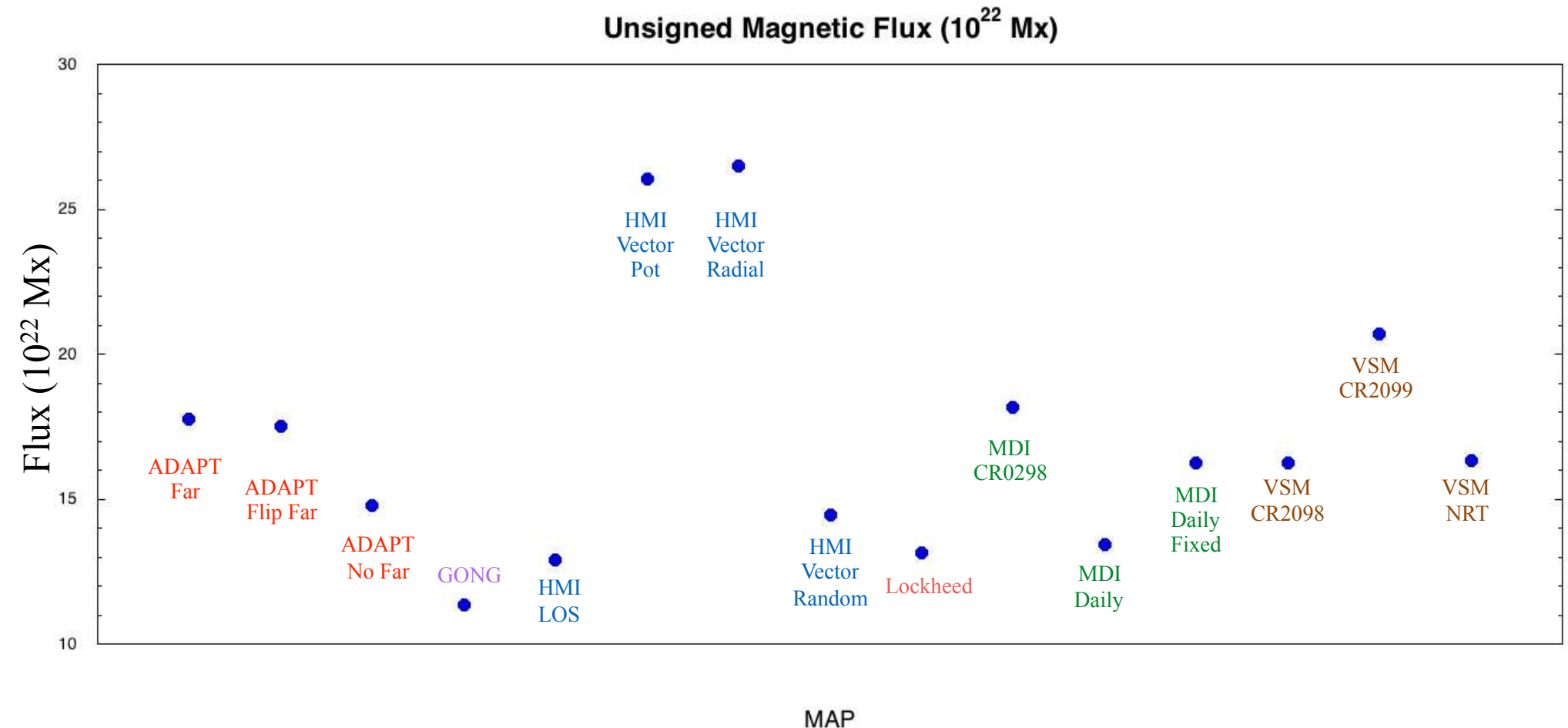


# Open Flux at 1 AU



Range of fit: 1.6-2.2 nT

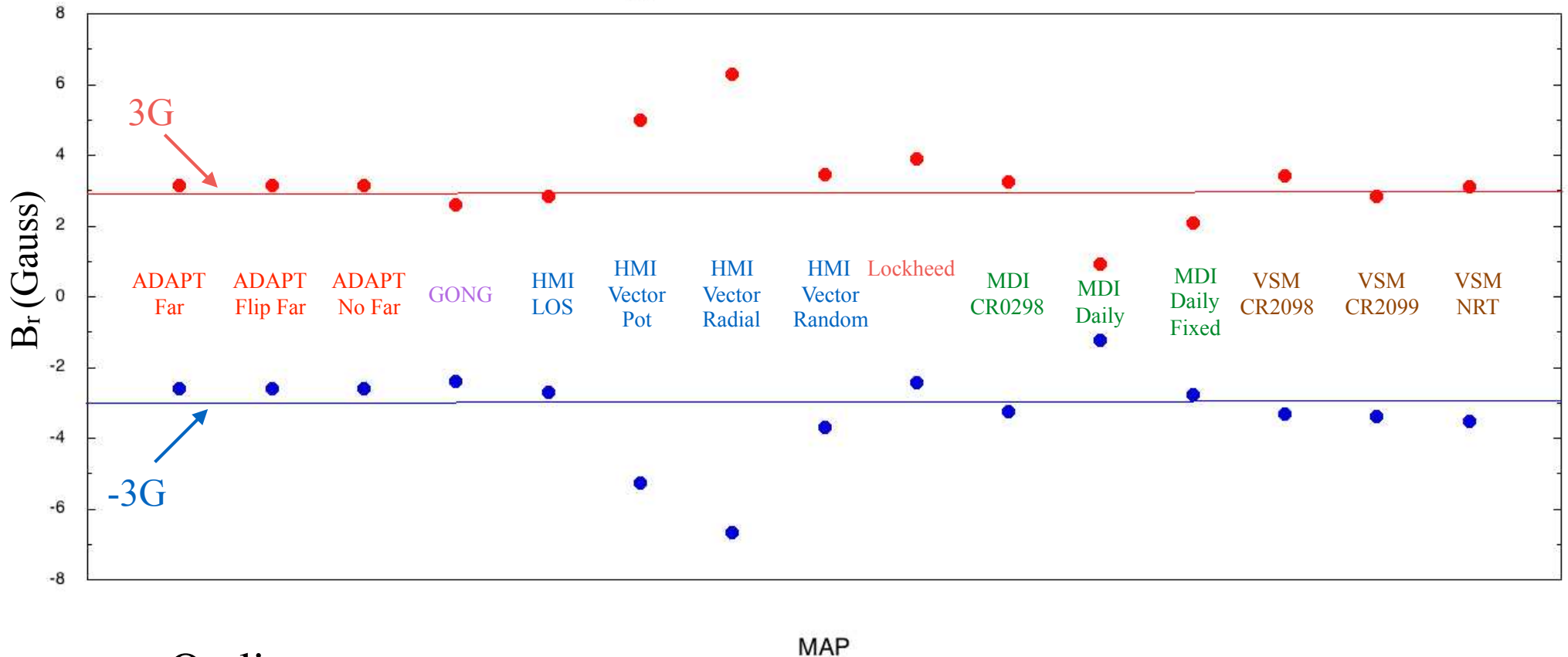
# Results - Magnetic Fluxes



- Outliers: HMI Vector - potential & radial ambiguity resolution

# Results - Polar Fields

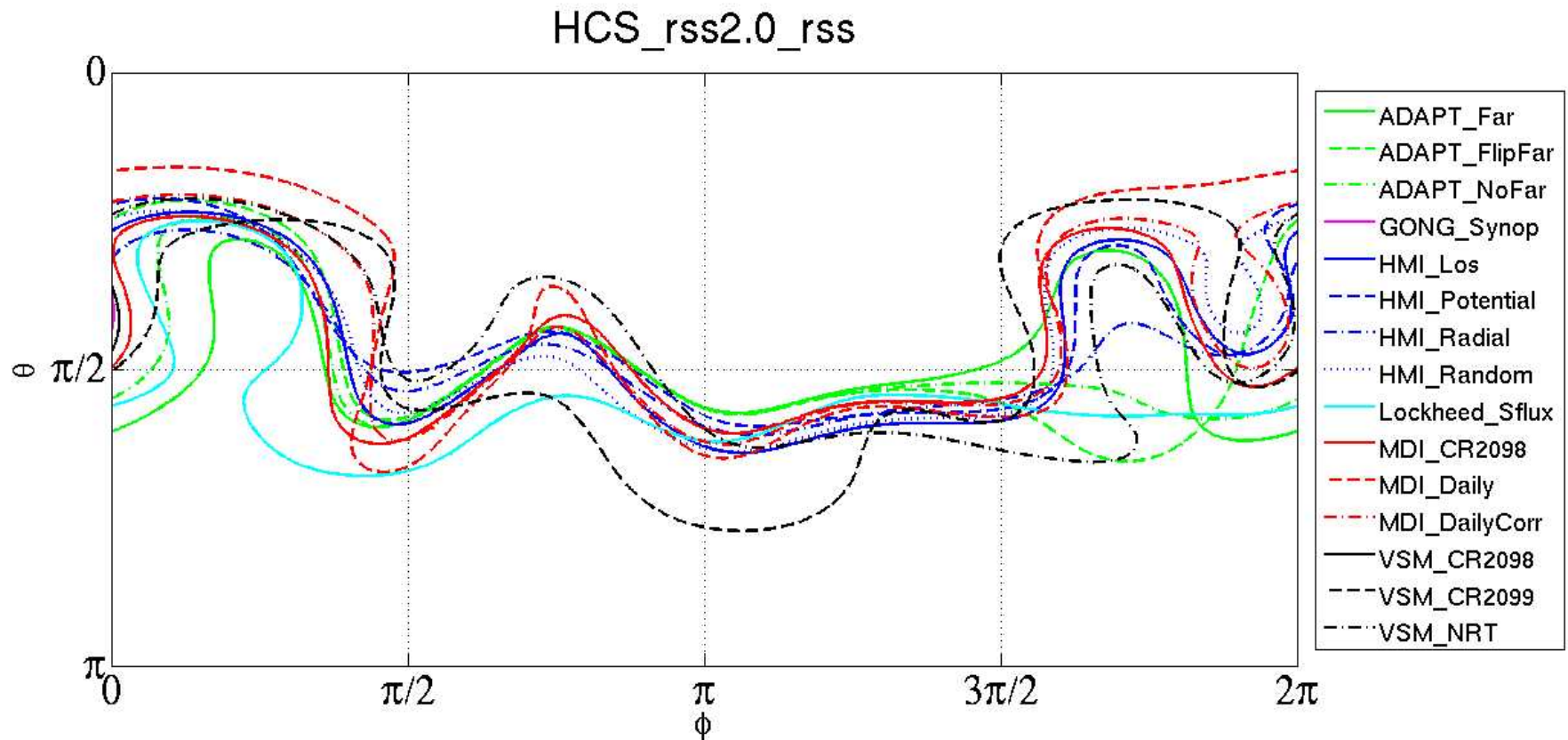
Average Polar Field Above 65° Latitude



- Outliers:

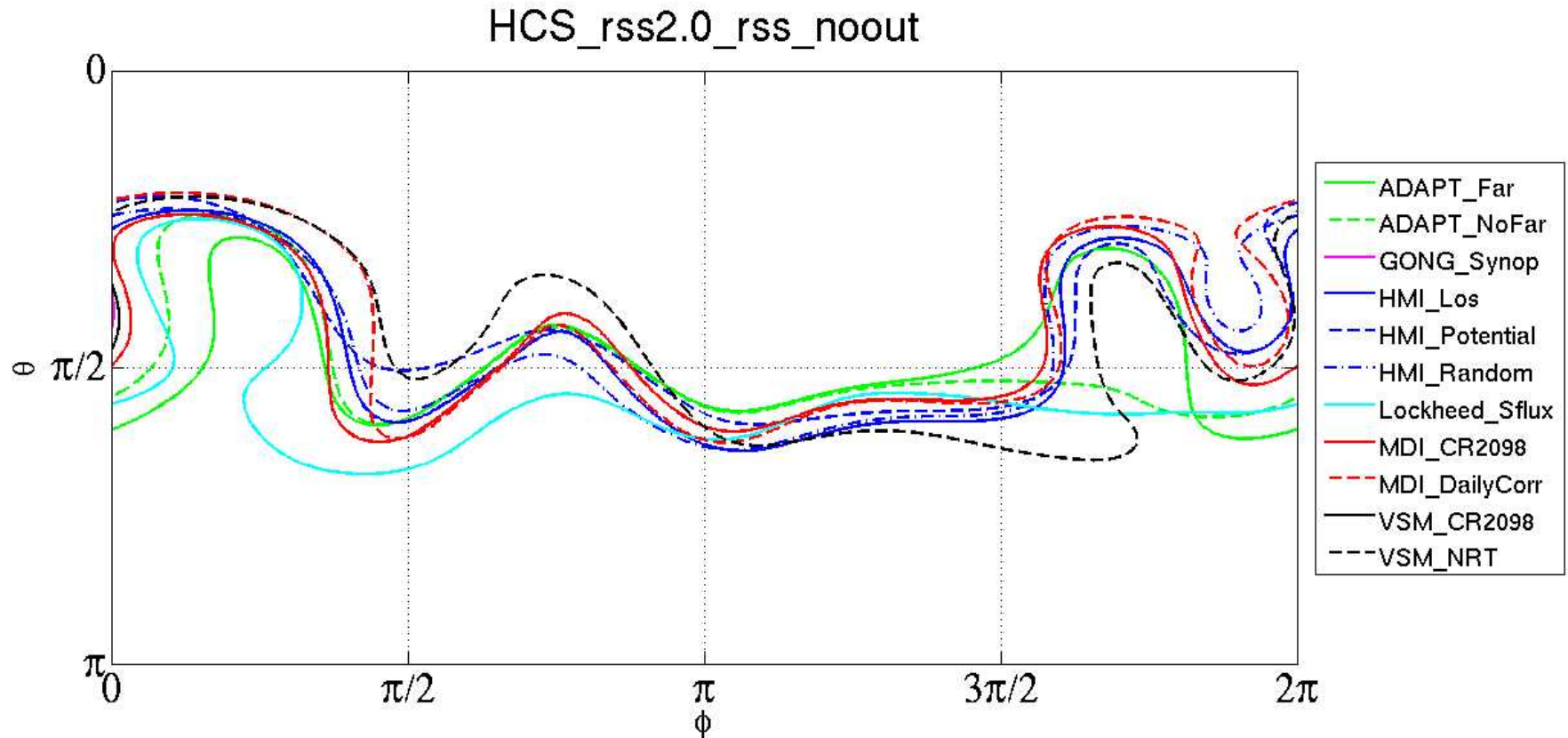
- HMI Vector - potential & radial ambiguity resolution
- MDI Daily (low value) - wasn't converted to radial

# Results - Heliospheric Current Sheet



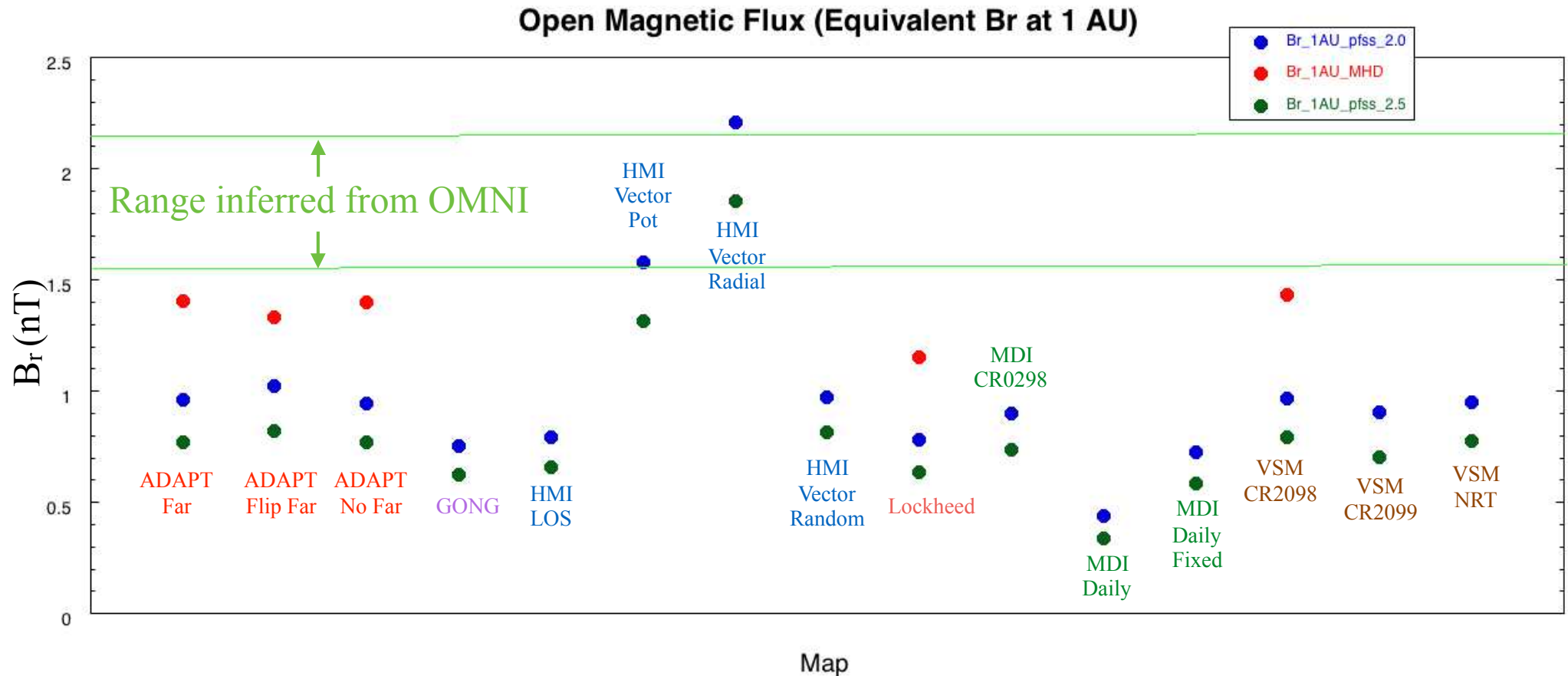
- Outliers: VSM CR2099, MDI Daily (uncorrected), HMI Radial, ADAPT Flip Far

# Results - Heliospheric Current Sheet



- Outliers Removed

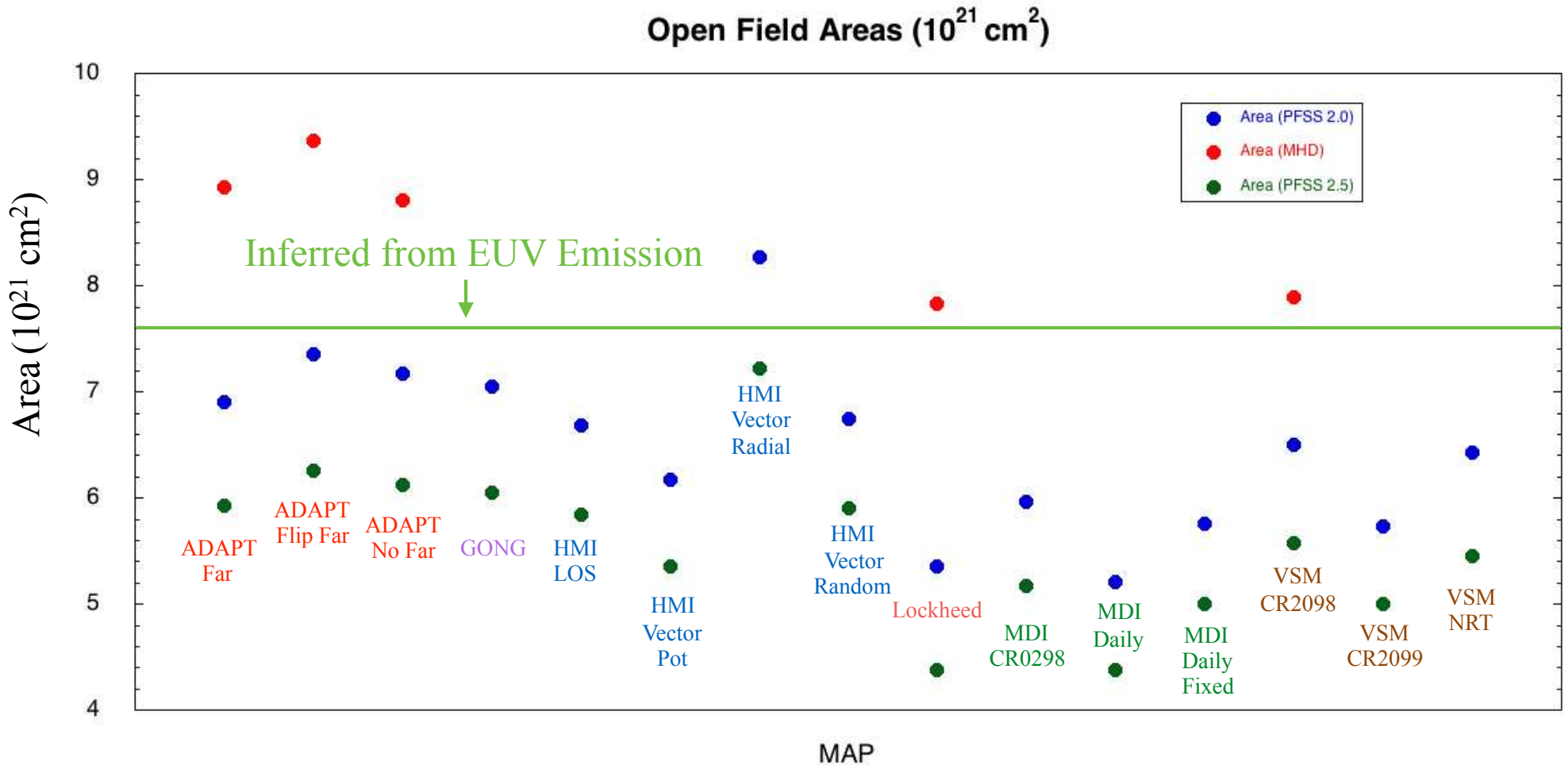
# Results - Open Magnetic Flux



- HMI Vector (Potential/Radial) - highest values, but these maps are suspect
- MHD values (red) are next highest - but coronal hole areas are large



# Results - Open Field Areas

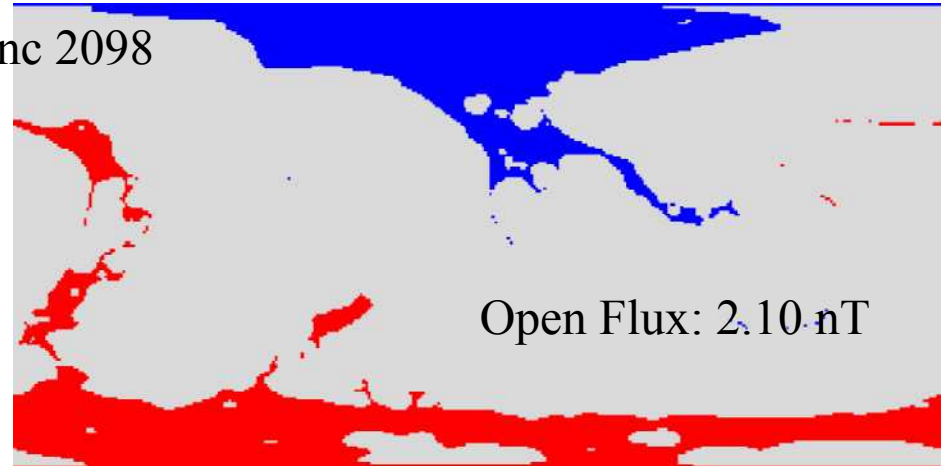
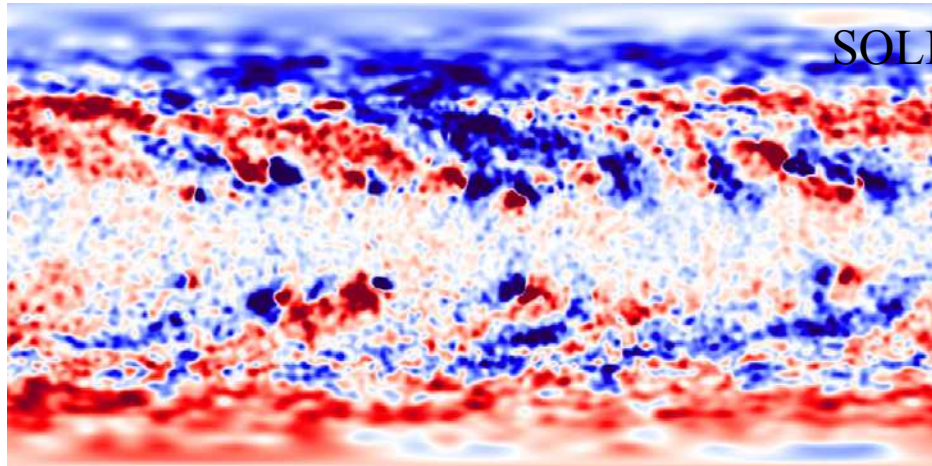
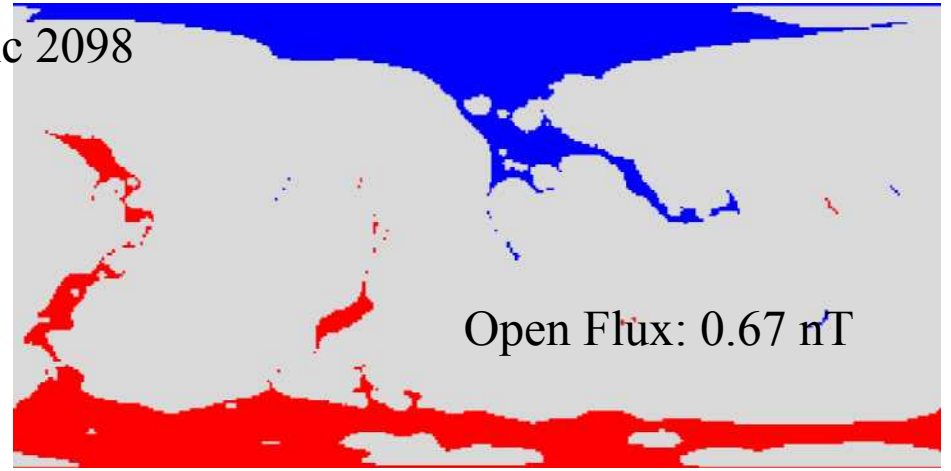
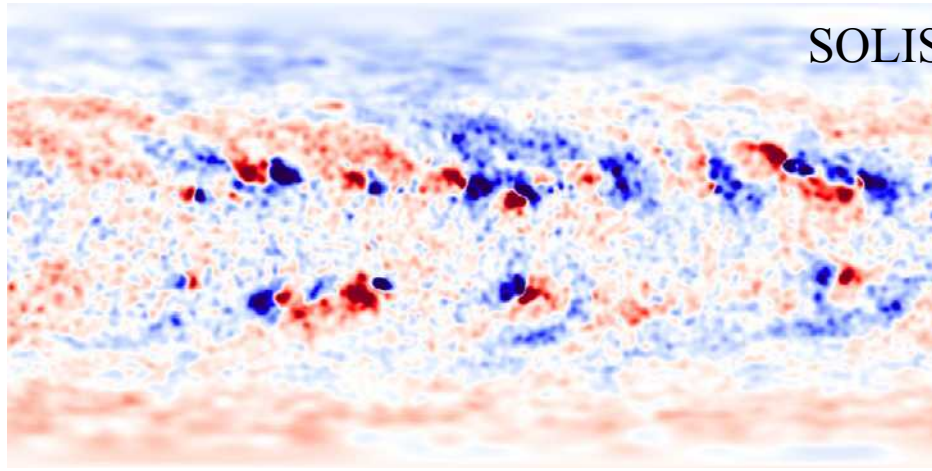
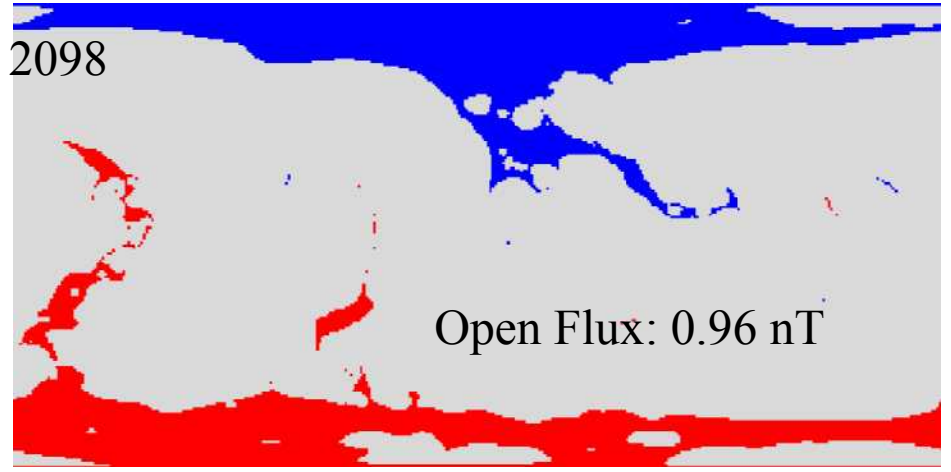
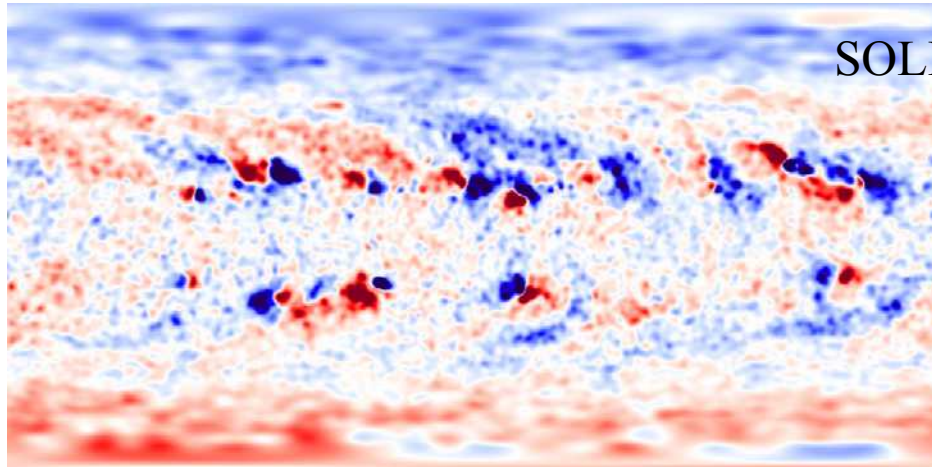


- MHD values (red) are generally highest - opening related to heating model

# Summary

- For this time period, the models generally underestimate the open magnetic flux inferred from *in situ* measurements
- The models that are closest to the *in situ* values have open field areas that are larger than that inferred from emission images
- These results are consistent with earlier studies we have performed
- Vector synoptic maps:
  - Magnetic flux may be greater
  - Can we obtain better estimates of the polar fields?
  - Vector fields are difficult to measure away from active regions. Is it better to combine LOS and vector data to build a map?
  - To use the transverse field, noise level must be low enough that  $J_r$  is meaningful
- PSI MHD results available for each Carrington rotation available at:
  - [www.predsci.com/hmi/](http://www.predsci.com/hmi/) [www.predsci.com/stereo/](http://www.predsci.com/stereo/) [www.predsci.com/mhdweb/](http://www.predsci.com/mhdweb/)
  - Runs on demand at CCMC: <http://ccmc.gsfc.nasa.gov>

# Br & CH Maps



# Br & CH Maps

