

# Coronal Modeling and Synchronic Maps\*

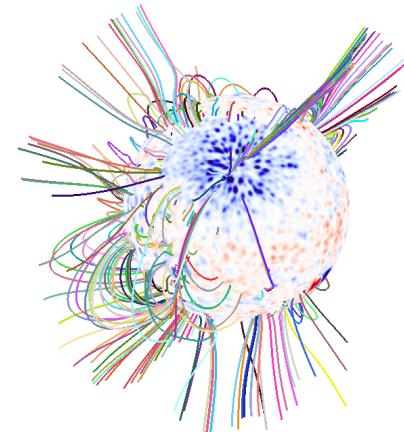
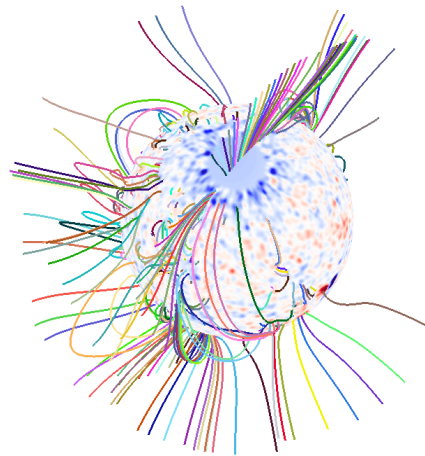
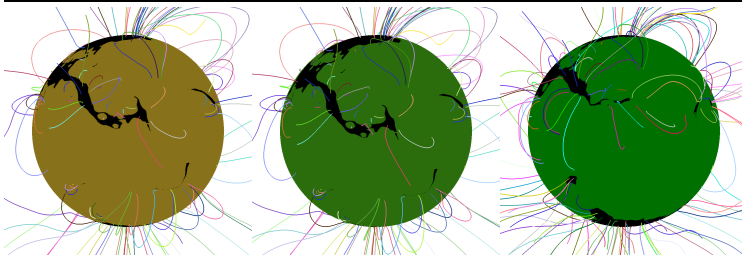
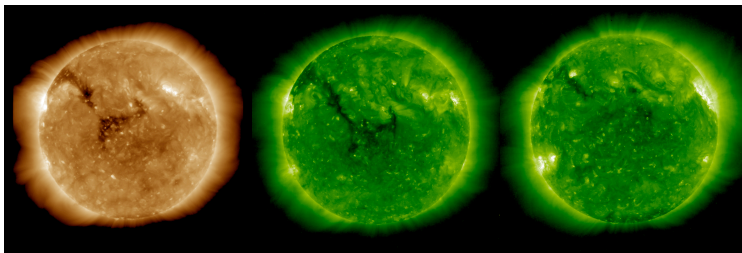
Jon A. Linker, Roberto Lionello, Zoran Mikic, Pete Riley,  
and Cooper Downs

*Predictive Science, Inc. (PSI), San Diego, CA 92121*

<http://www.predsci.com>

Carl Henney and Charles N. Arge

*Space Vehicles Directorate, Air Force Research Laboratory, Kirtland AFB, NM 87117*



\*Research Supported by NASA, NSF and AFOSR



Predictive Science, Inc.

# Introduction

- Coronal models typically rely on so-called “synoptic” magnetic maps to derive boundary conditions for these models
  - Maps are built up from line-of-sight (LOS) magnetograms taken over a solar rotation
  - Really “diachronic” not synoptic
- Two well-known problems:
  - Sun’s magnetic flux is always evolving, but synoptic map data can be as much as 27 days old
  - The LOS field at the Sun's poles is poorly observed, and the polar fields in these maps are filled with a variety of interpolation/extrapolation techniques
- Photospheric flux evolution models can help to address both these issues - “synchronic” maps
- Today I focus on the evolutionary aspect



# Where We Would Like to Go: Towards A Near-Real Time Coronal Description

- We presently provide steady solutions for each Carrington Rotation, e.g. <http://www.predsci.com/hmi>
- Even at solar minimum, the corona and solar wind are always evolving in response to changes in the photospheric magnetic field
- If we observed the entire Sun's photospheric field continuously and simultaneously, we could drive MHD models with this boundary data
- Flux evolution models have a long history and have been successful in describing the photospheric field response to known flows.
- We can use these models to assimilate magnetic data (magnetograms) where the field is observed, and fill in the gaps where it is not
- Emergence of active regions in unobserved portions of the Sun can significantly change the coronal evolution - how important is this effect?
- Today I illustrate some of the concepts using potential field source-surface (PFSS) models

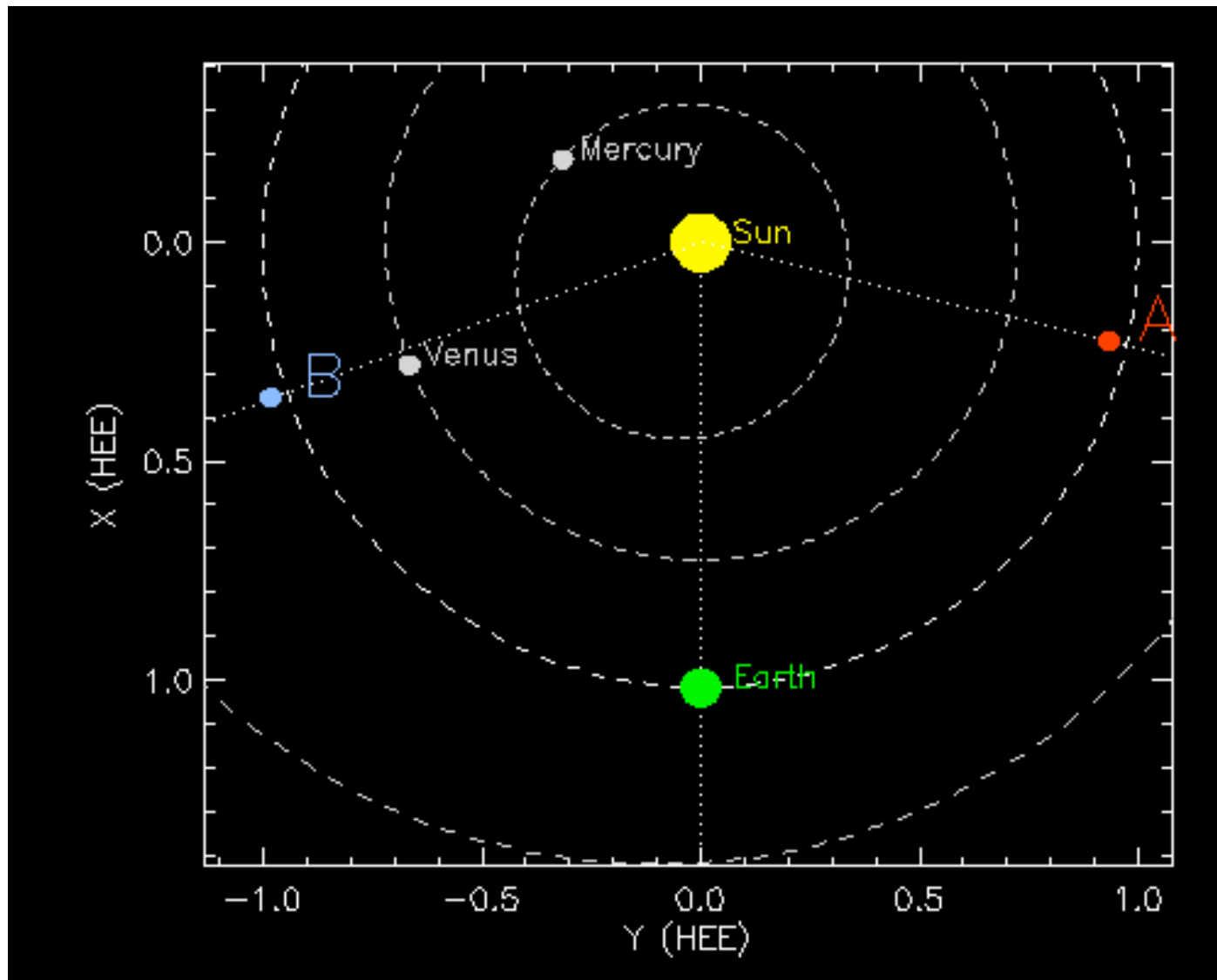


# Air Force Data Assimilative Photospheric Flux Transport (ADAPT) Model

- The ADAPT flux transport model (Arge et al. 2009) is based on Worden & Harvey (2000), which accounts for known flows in the solar photosphere:
  - Differential rotation
  - Meridional flow
  - Supergranular diffusion
  - Random flux emergence
  - Polar fields arise from long-term evolution
- ADAPT improves on the Worden&Harvey model by incorporating rigorous data assimilation methods into it.
- Present ADAPT maps are to be considered preliminary.
- Presently experimenting with the incorporation of far side images

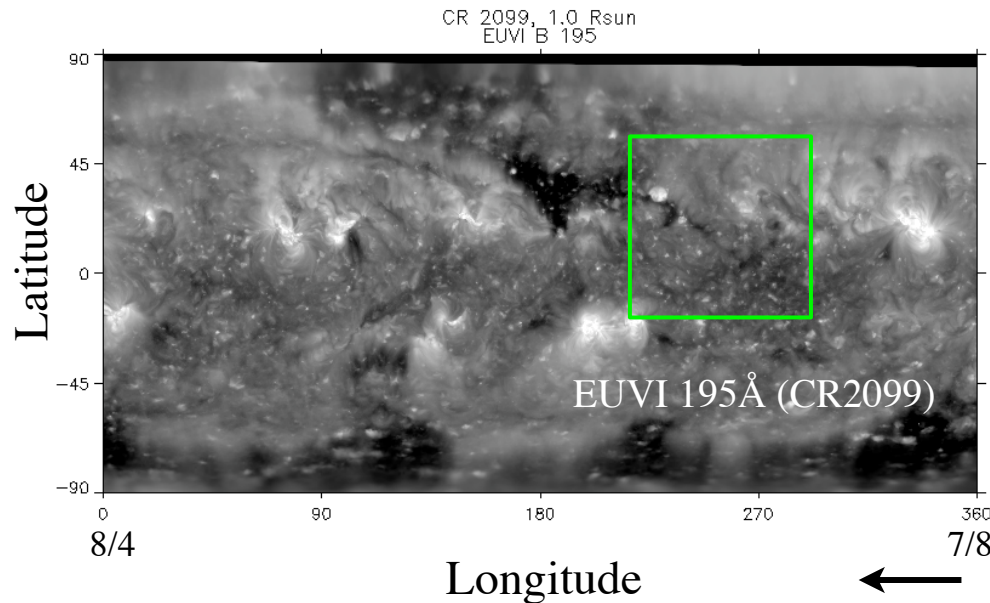


# The Positions of the STEREO Spacecraft on July 11, 2010

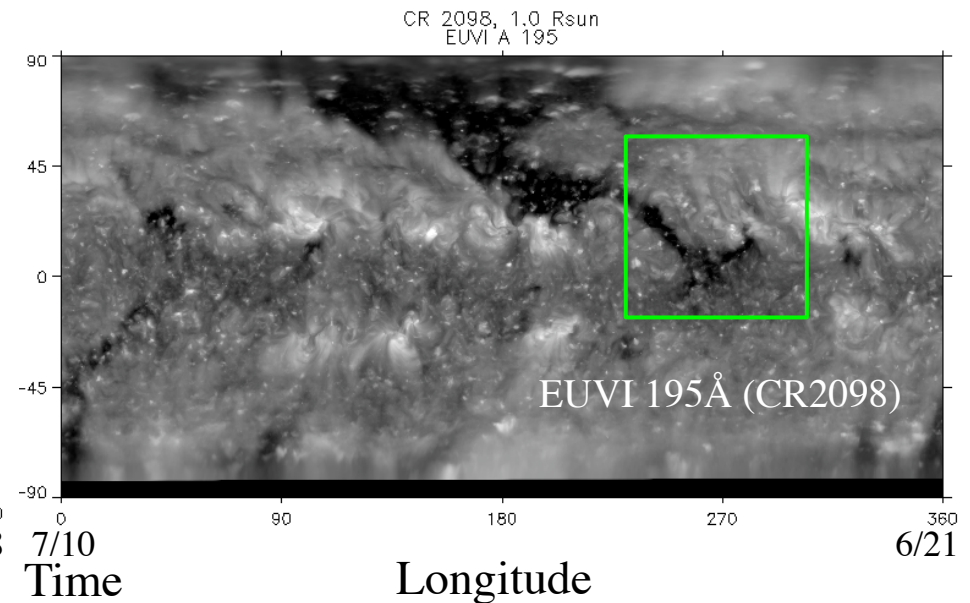


# Coronal Hole Evolution (June-July 2010)

STEREO B Synoptic: 7/8 - 8/4



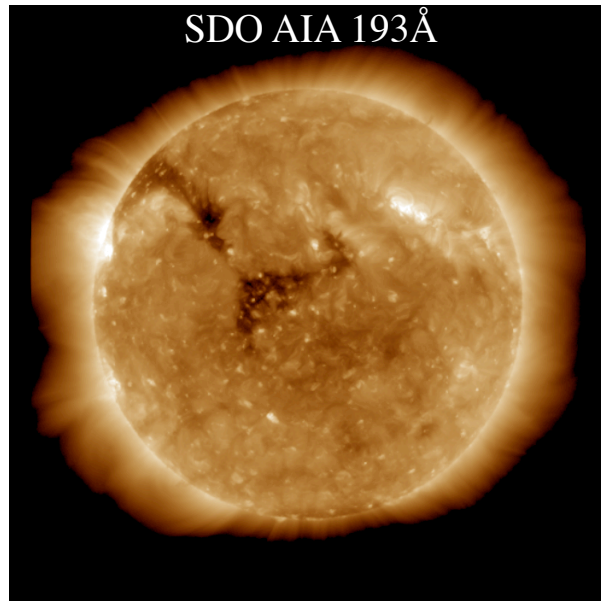
STEREO A Synoptic: 6/21 - 7/10



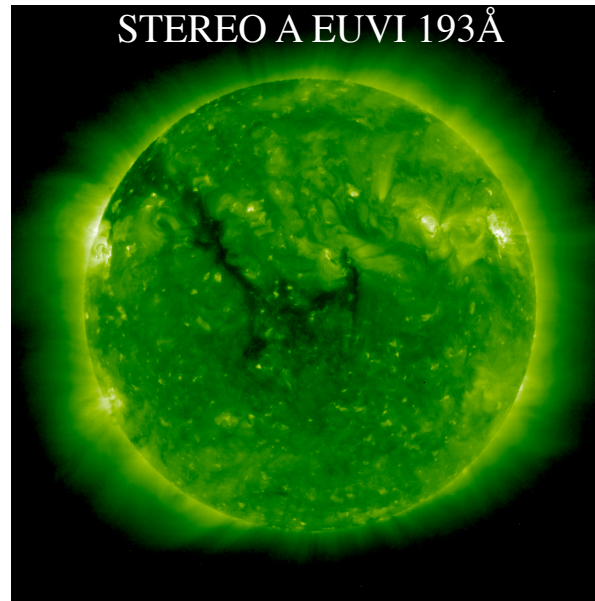
- Coronal structure is strongly influenced by magnetic flux evolution.
- This is illustrated by coronal hole evolution.
- STEREO and SDO spacecraft provide us with a global view of this evolution.
- A number of extended coronal holes were visible during this time period.
- We focus on the extension of the coronal hole near longitude 270°.



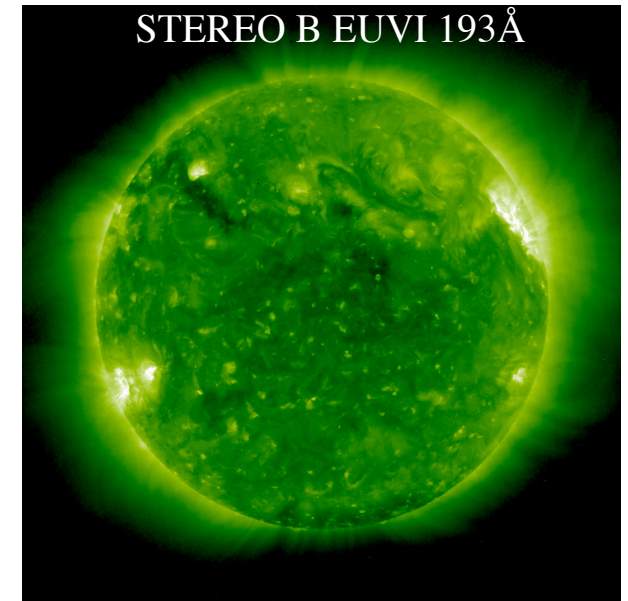
# Coronal Hole Evolution (June-July 2010)



6/22/2010, 19:59 UT



6/28/2010, 17:15 UT

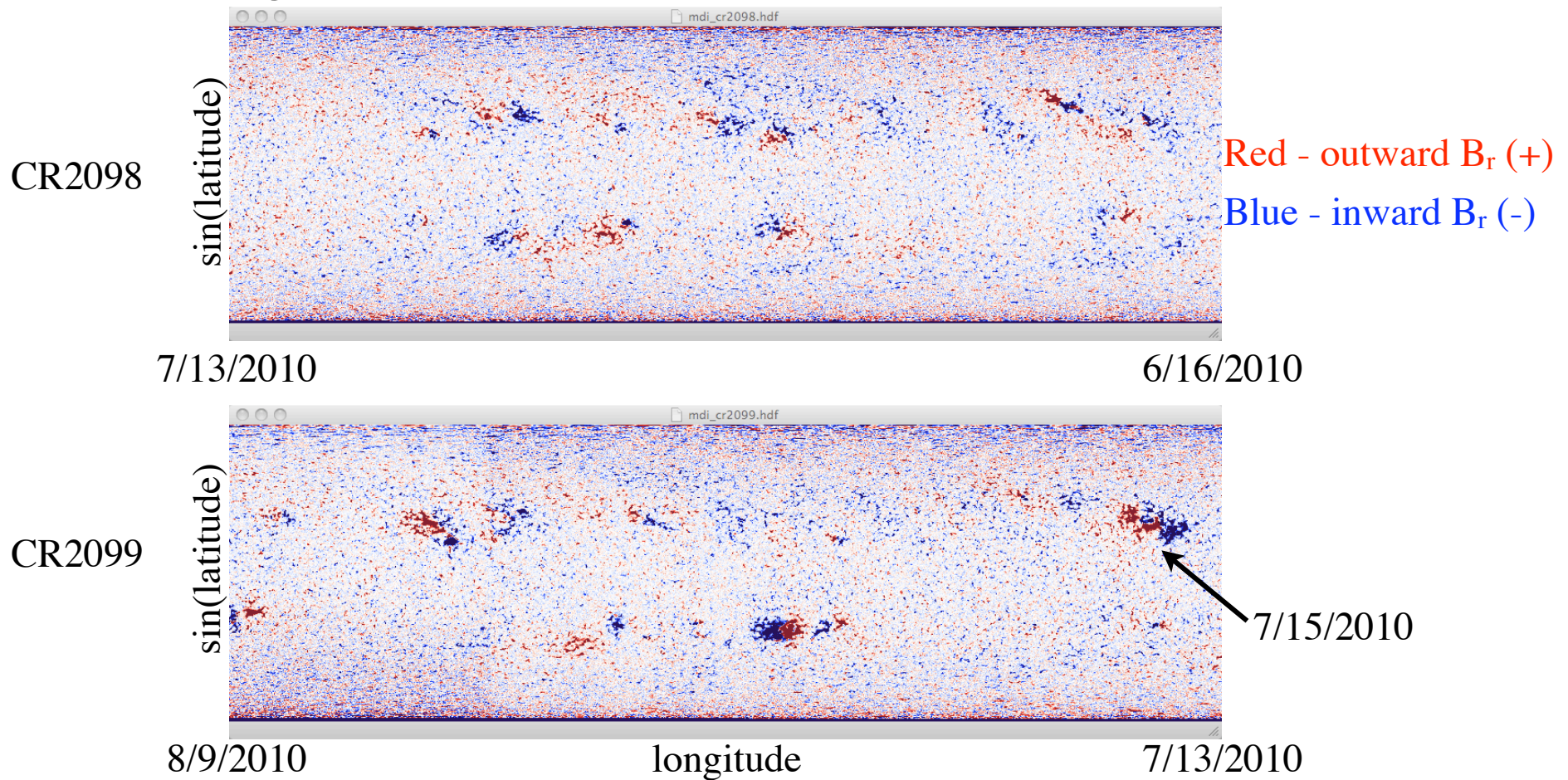


7/14 /2010, 19:41 UT

- Coronal structure is strongly influenced by magnetic flux evolution.
- This is illustrated by coronal hole evolution.
- STEREO and SDO spacecraft provide us with a global view of this evolution.
- A number of extended coronal holes were visible during this time period.
- We focus on the extension of the coronal hole near longitude 270°.



# Magnetic Field Evolution (CR2098-CR2099)

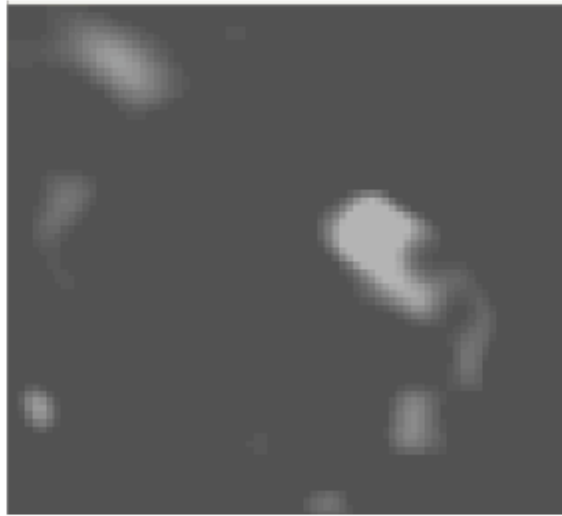


- SOHO/MDI synoptic maps for CR2098 and CR2099 are shown.
- Note the new active region complex in CR2099 at  $\sim 338^\circ$  longitude.
- When did this AR actually emerge?

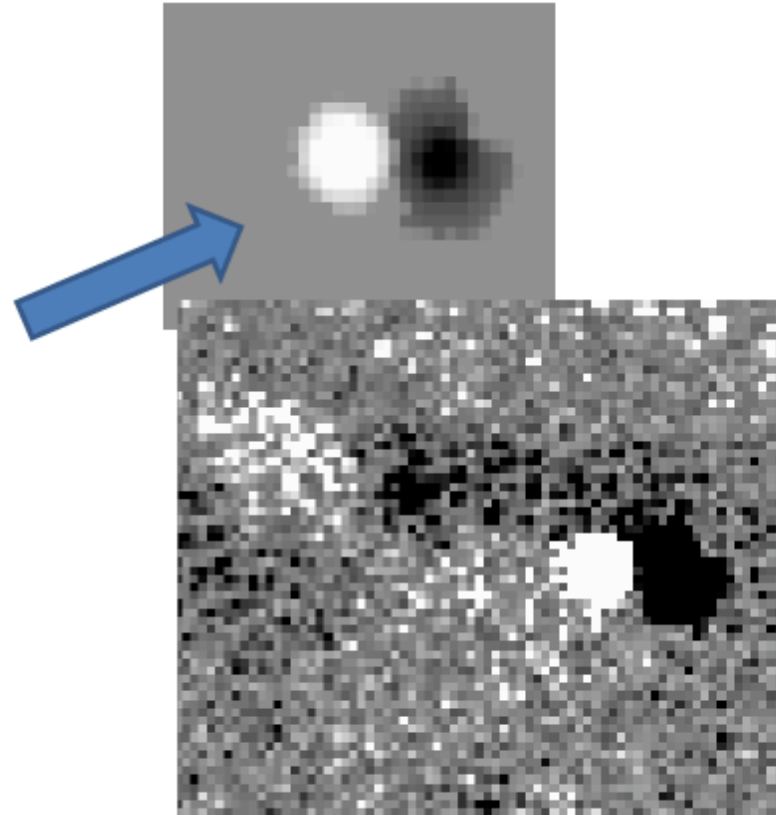




# Far Side Imaging - July 1, 2010



Far-side signal (July 1, 2010)  
(NSO GONG)



New estimation merged w/ ADAPT map

- Active regions on the far side of the Sun can be detected with helioseismology
- Field strength can be estimated
- Polarity must be guessed - use Hale and Joy rules

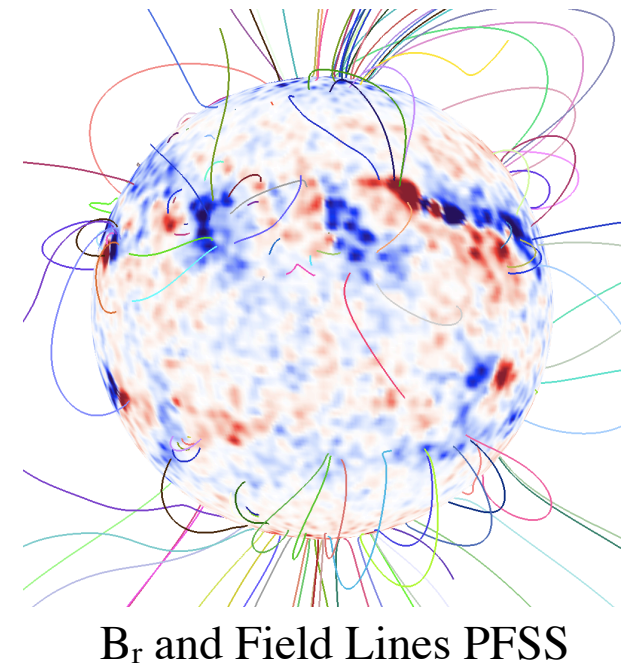
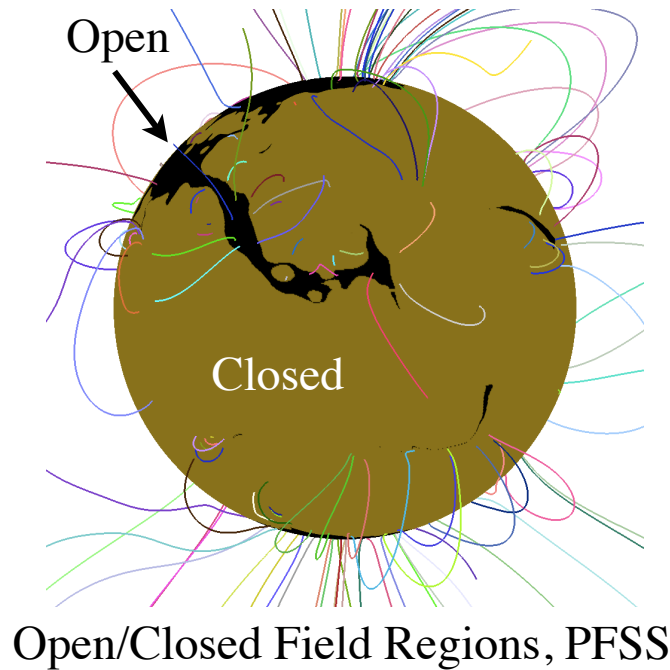
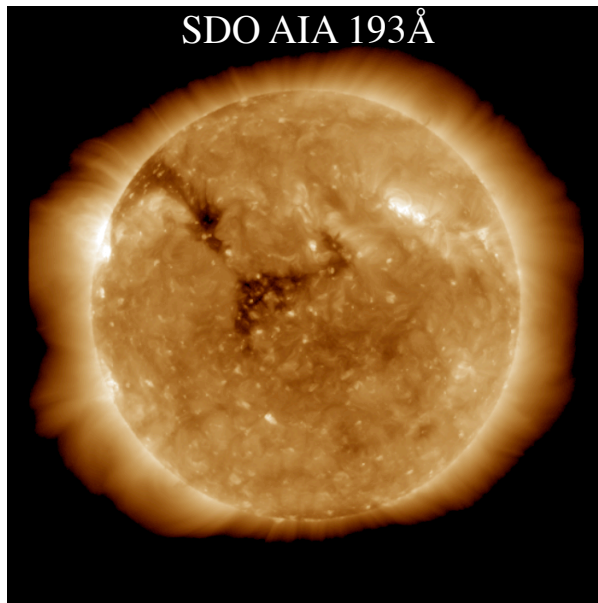


# Comparison of Photospheric B Approximations

- Maps from ADAPT are approximations of the state of the photospheric magnetic flux at a given time
- We consider 4 different maps and examine the coronal structure they predict using source-surface models:
  - An ADAPT flux evolved map for 6/23/2010
  - An ADAPT flux evolved map for 7/7/2010, standard evolution
  - An ADAPT flux evolved map for 7/7/2010, new active region inserted based on GONG far side image
  - An ADAPT flux evolved map for 7/7/2010, new active region inserted but with leading and trailing polarities reversed



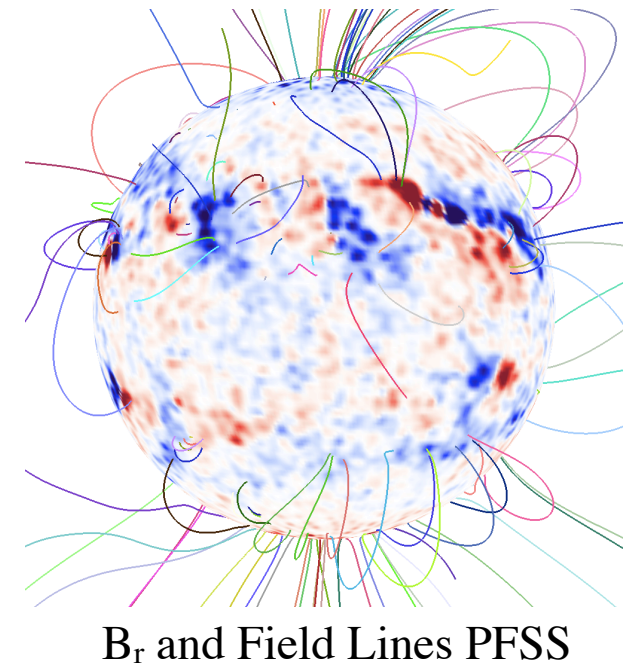
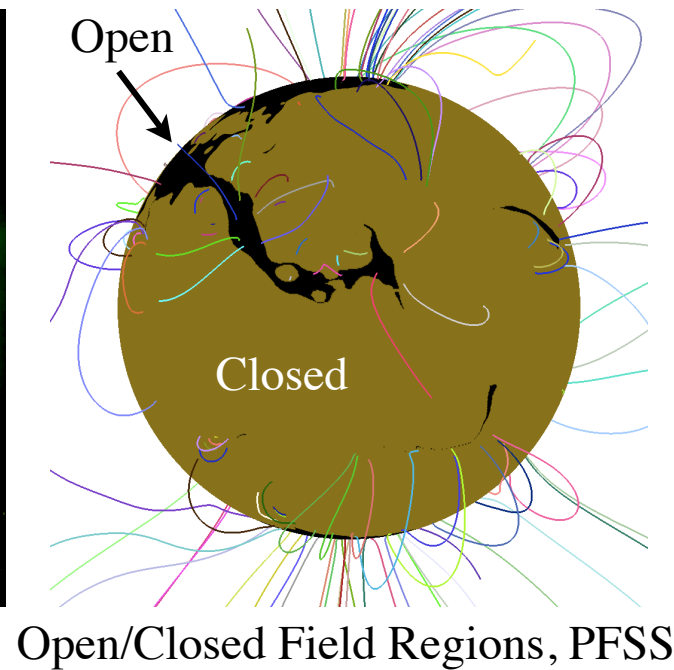
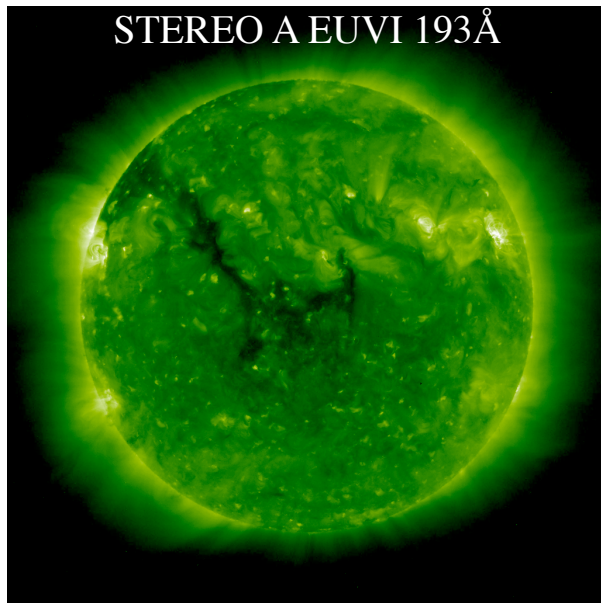
# Coronal Hole Comparison (PFSS solution for 6/23/2012)



- PFSS solution using ADAPT flux-evolved map to 6/23, no further evolution
- PFSS coronal holes agree reasonably well with those observed by SDO on 6/23 and STEREO A on 6/28



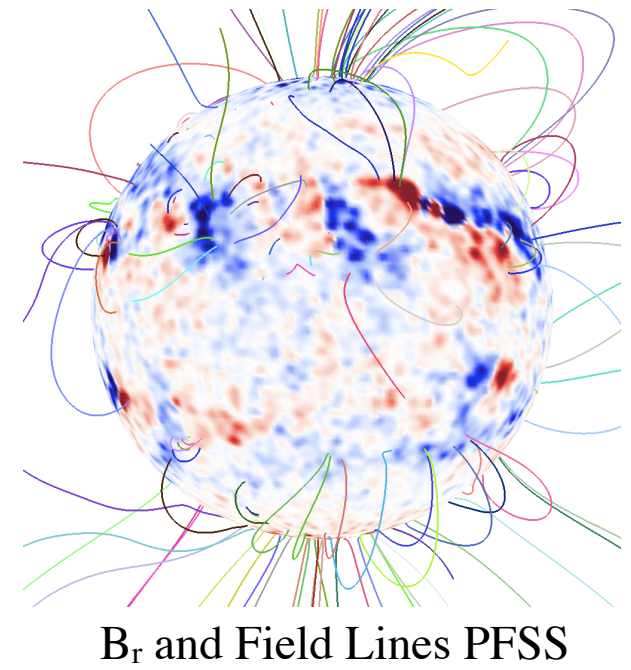
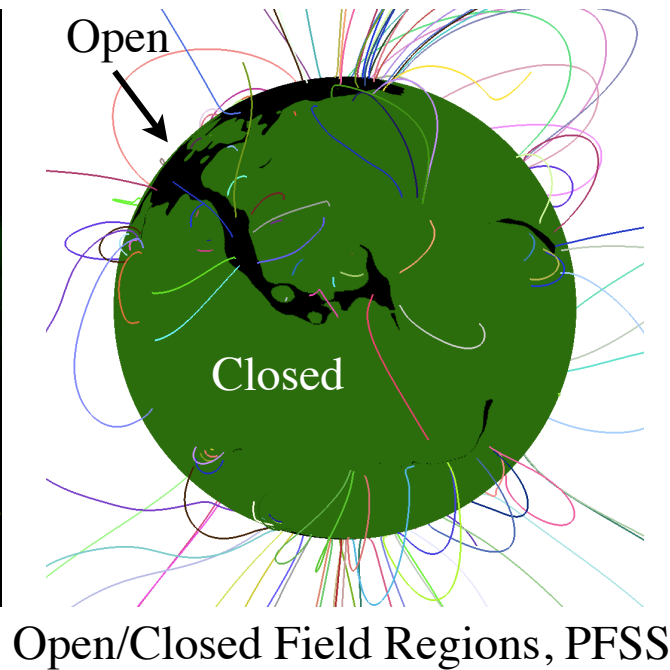
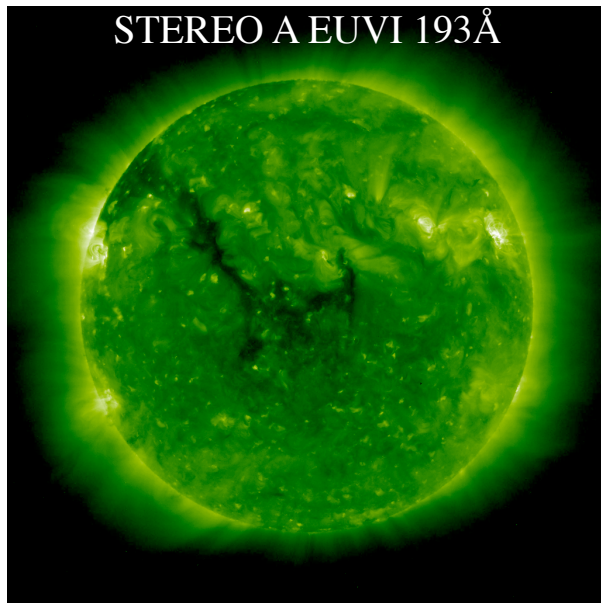
# Coronal Hole Comparison (PFSS solution for 6/23/2012)



- PFSS solution using ADAPT flux-evolved map to 6/23, no further evolution
- PFSS coronal holes agree reasonably well with those observed by SDO on 6/23 and STEREO A on 6/28



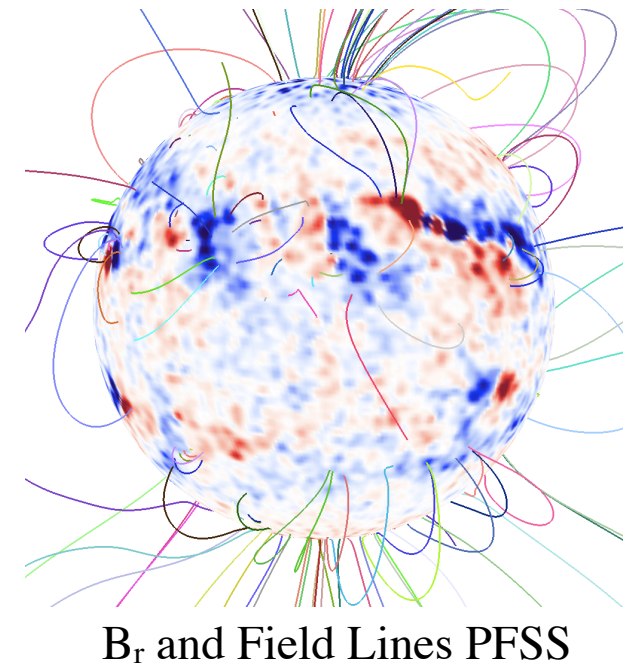
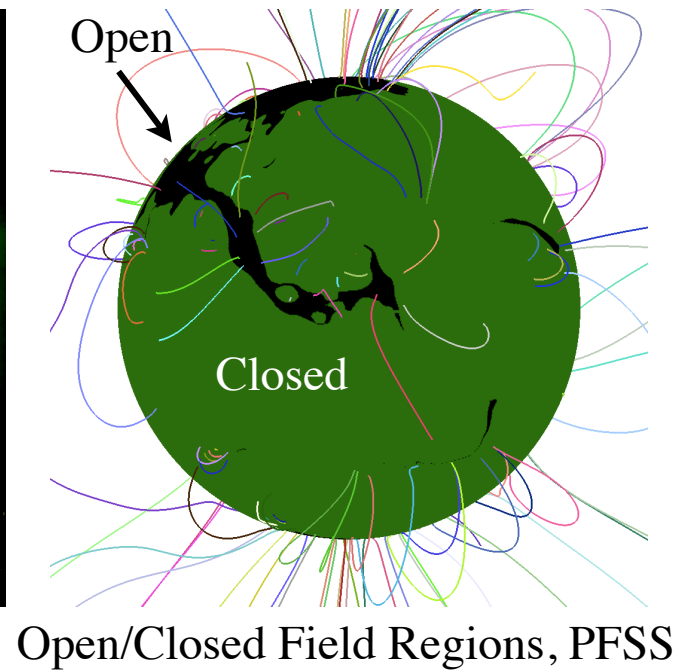
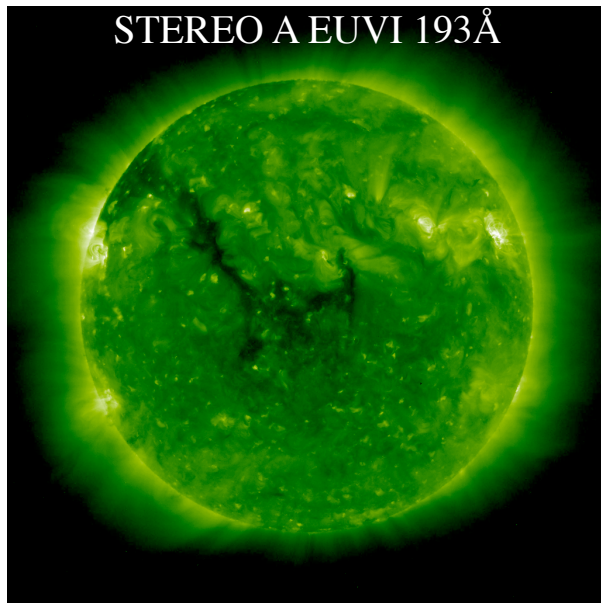
# Coronal Hole Comparison (PFSS solution for 6/23/2012)



- PFSS solution using ADAPT flux-evolved map to 6/23, no further evolution
- PFSS coronal holes agree reasonably well with those observed by SDO on 6/23 and STEREO A on 6/28



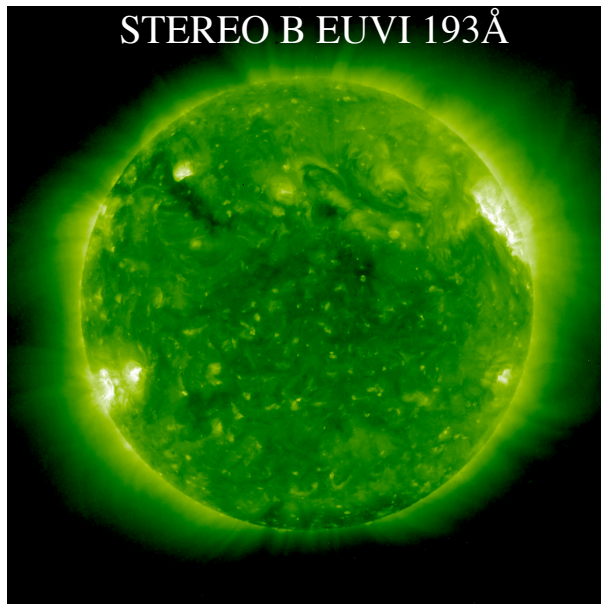
# Coronal Hole Comparison (PFSS solution for 6/23/2012)



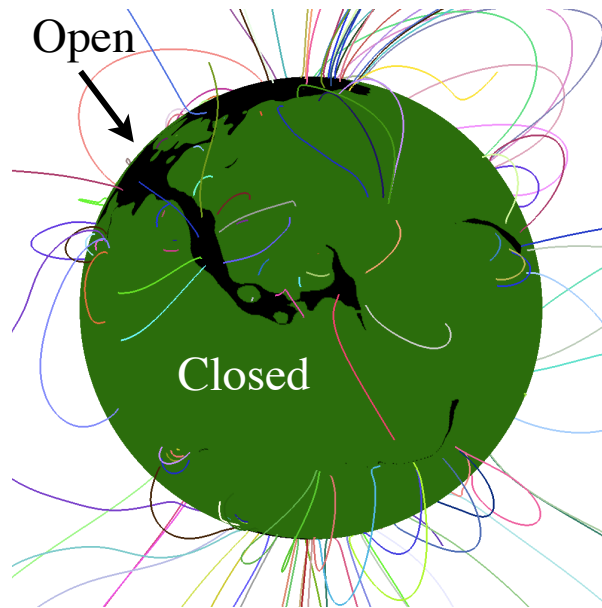
- PFSS solution using ADAPT flux-evolved map to 6/23, no further evolution
- PFSS coronal holes agree reasonably well with those observed by SDO on 6/23 and STEREO A on 6/28



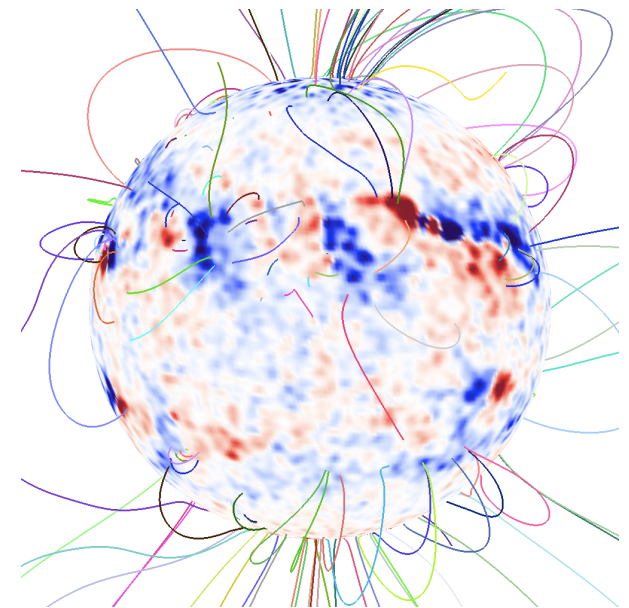
# Coronal Hole Comparison (PFSS solution for 6/23/2012)



7/14 /2010, 19:41 UT



Open/Closed Field Regions, PFSS

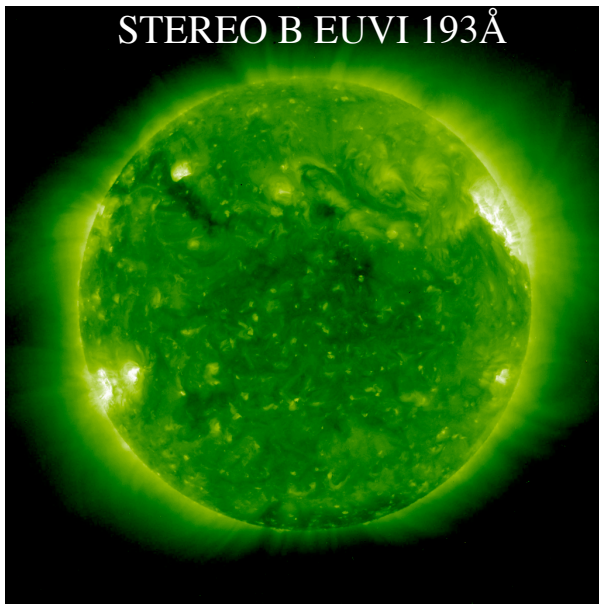


$B_r$  and Field Lines PFSS

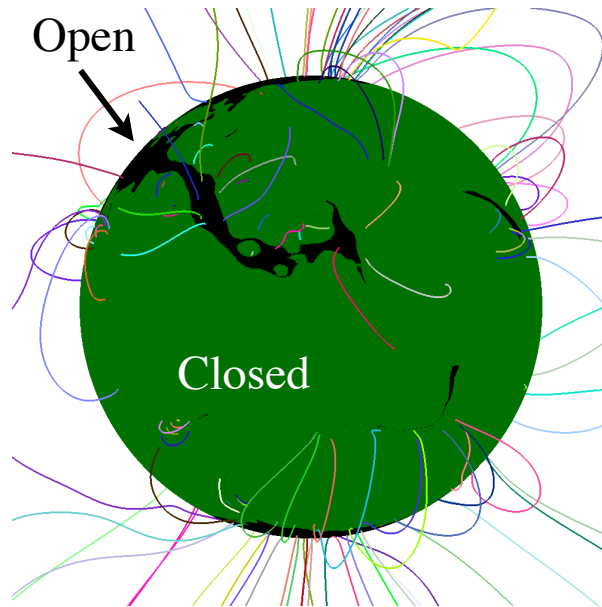
- PFSS solution using ADAPT flux-evolved map to 6/23, no further evolution
- PFSS coronal holes agree reasonably well with those observed by SDO on 6/23 and STEREO A on 6/28



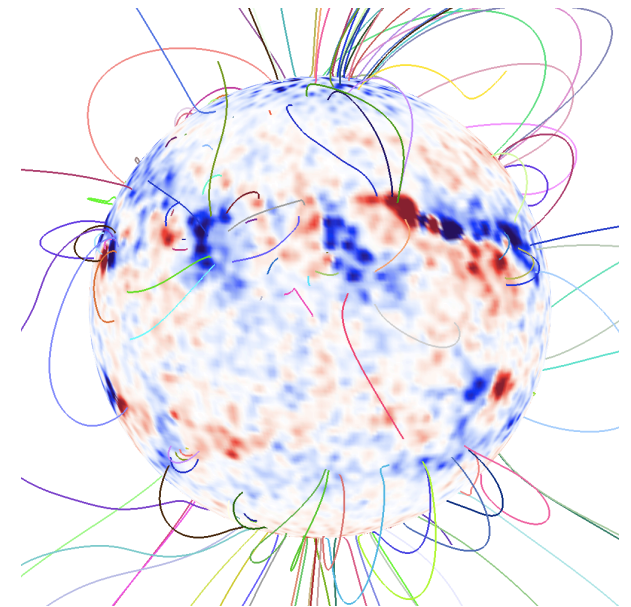
# Coronal Hole Comparison (PFSS solution for 6/23/2012)



7/14 /2010, 19:41 UT



Open/Closed Field Regions, PFSS



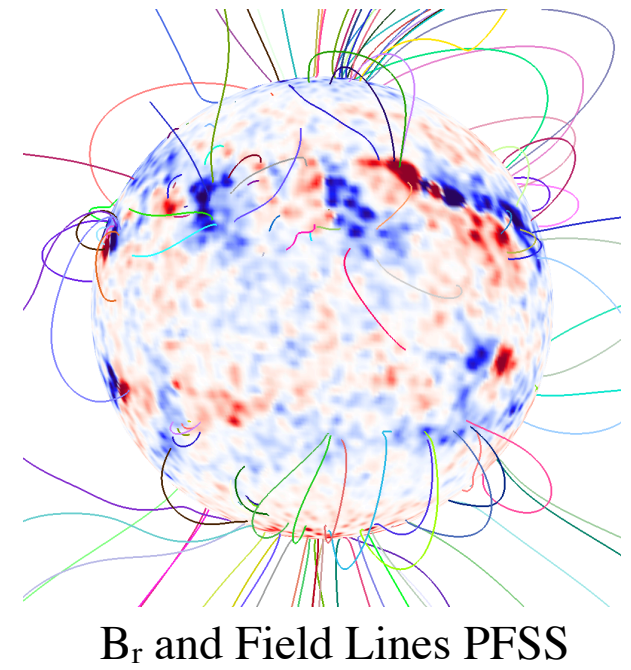
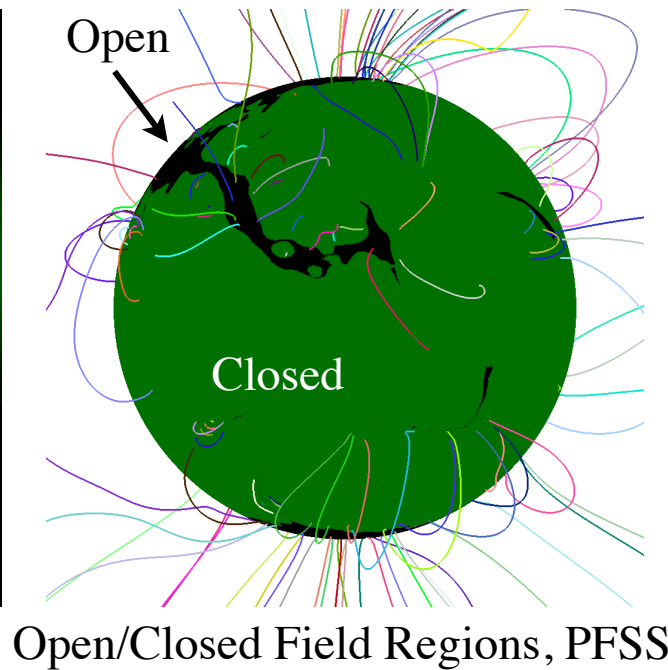
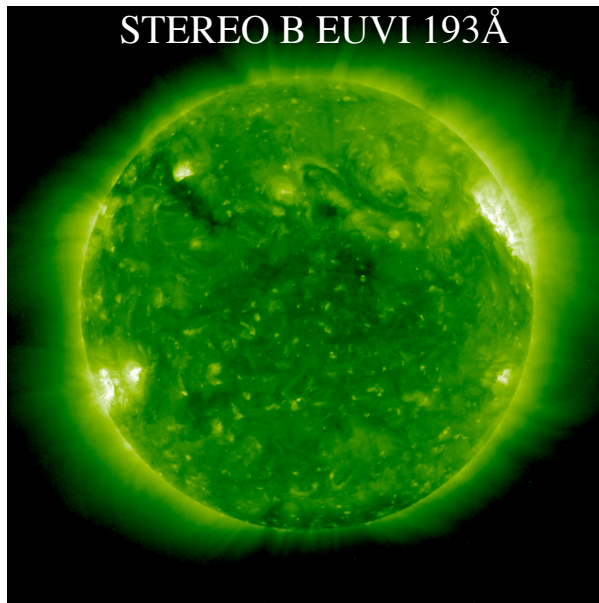
B<sub>r</sub> and Field Lines PFSS

- PFSS solution using ADAPT flux-evolved map to 6/23, no further evolution
- PFSS coronal holes agree reasonably well with those observed by SDO on 6/23 and STEREO A on 6/28





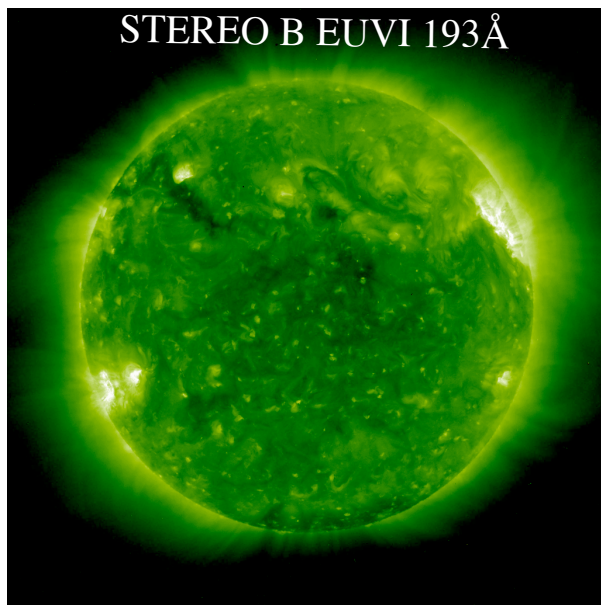
# Coronal Hole Comparison (PFSS solution for 6/23/2012)



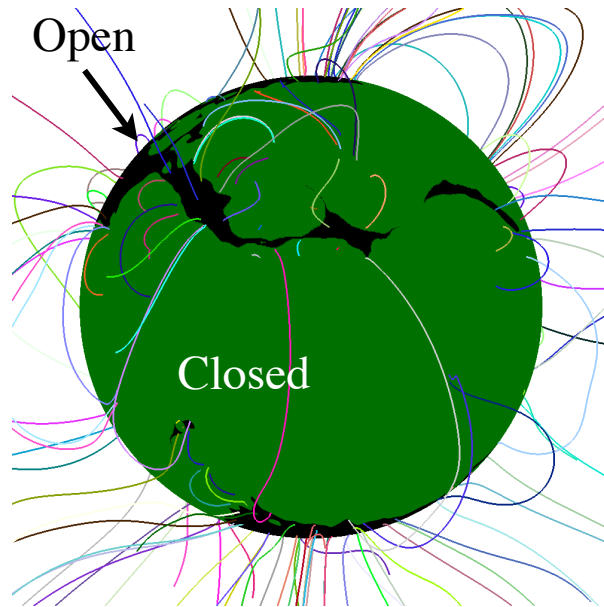
- PFSS solution using ADAPT flux-evolved map to 6/23, no further evolution
- PFSS coronal holes agree reasonably well with those observed by SDO on 6/23 and STEREO A on 6/28
- They do not agree well on with STEREO B observations on 7/14 (after the active region emerged on the far side)



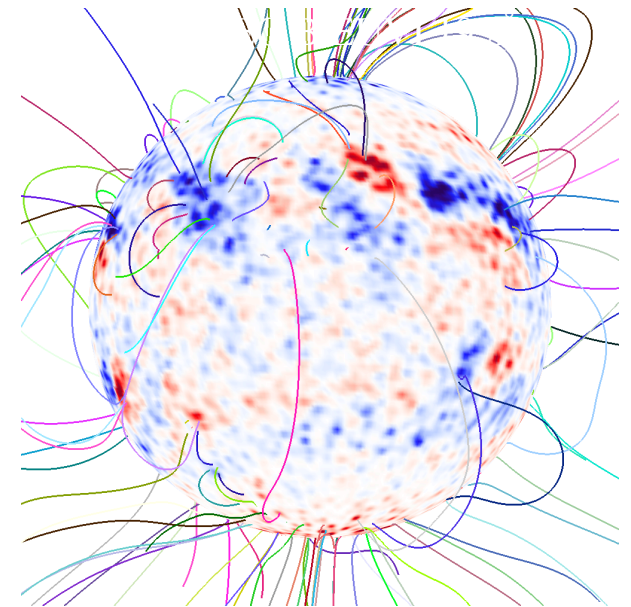
# Coronal Hole Comparison: Flux-evolved map without AR



7/14 /2010, 19:41 UT



Open/Closed Field Regions, PFSS

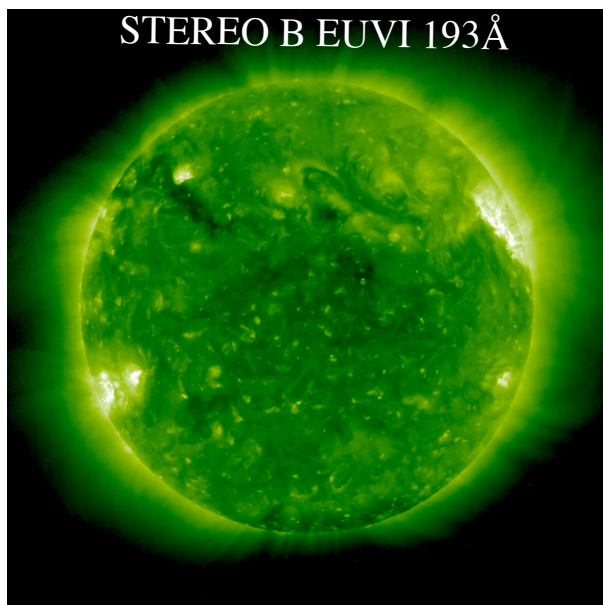


Br and Field Lines PFSS

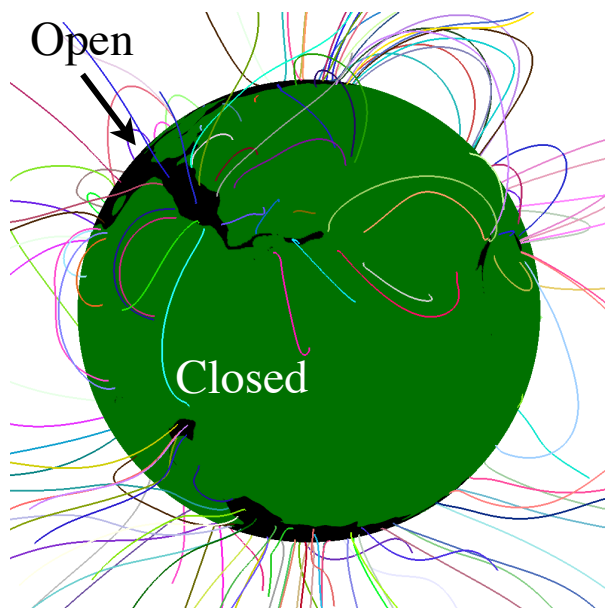
- PFSS solution using ADAPT with standard flux evolution to 7/7/2010.
- New active region is not present in the map.
- Still not very good agreement between the modeled coronal holes and the STEREO B observation



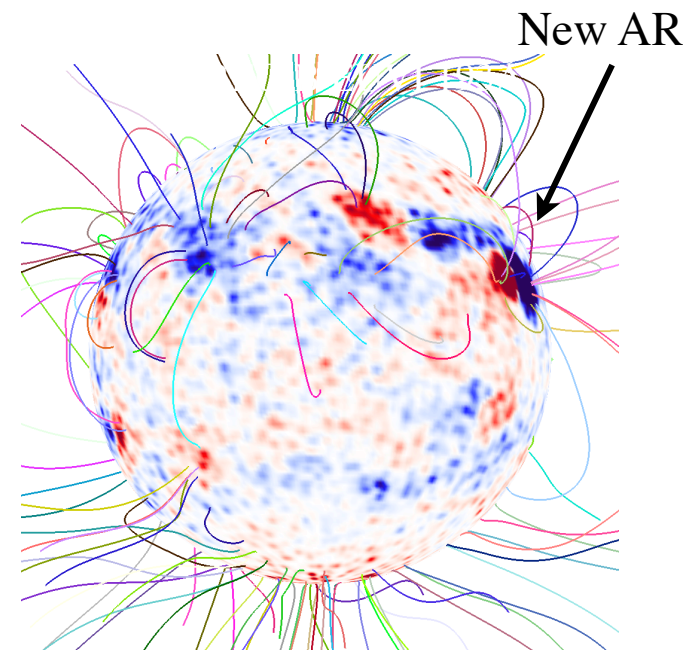
# Coronal Hole Comparison: Flux-evolved map with AR



7/14 /2010, 19:41 UT



Open/Closed Field Regions, PFSS

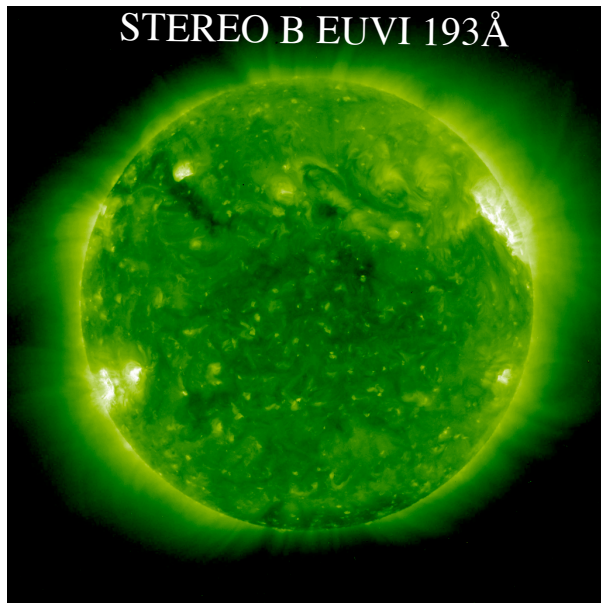


Br and Field Lines PFSS

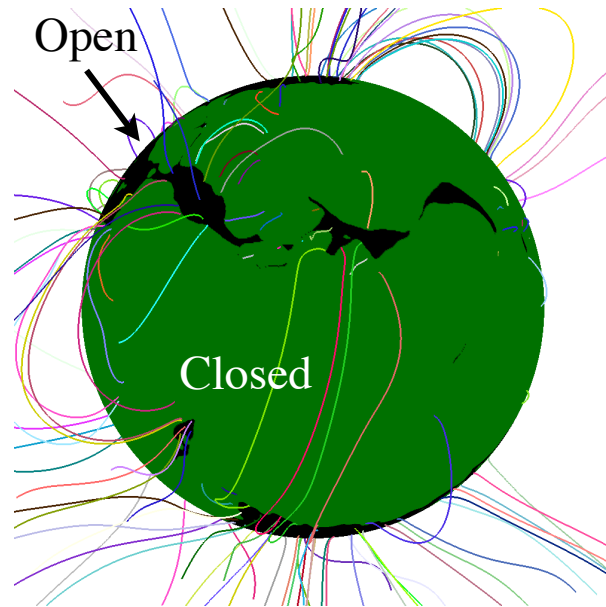
- PFSS solution using ADAPT with the far side active region assimilated into the map on 7/1.
- Map evolved with flux evolution to 7/7/2010.
- Noticeable change in the modeled coronal holes that agrees better with the observations



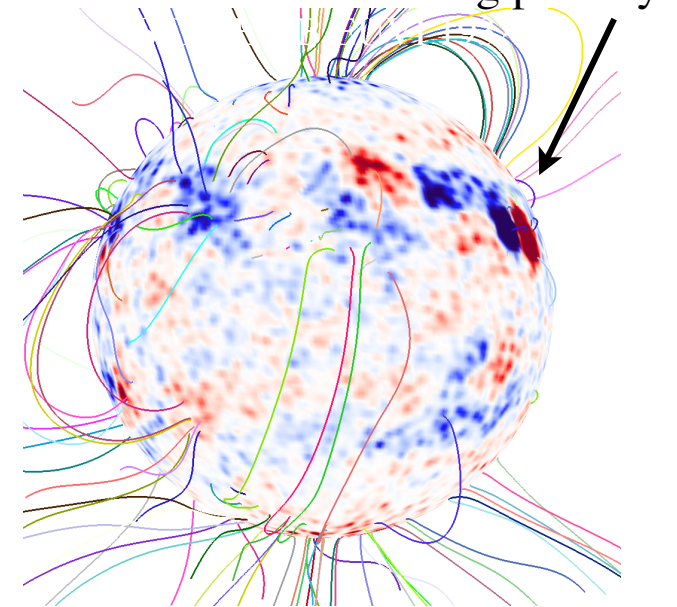
# What Happens if we get the Polarity Wrong?



7/14 /2010, 19:41 UT



Open/Closed Field Regions, PFSS



Br and Field Lines PFSS

- PFSS solution using ADAPT with the far side active region assimilated into the map on 7/1.
- Leading/trailing polarity reversed relative to previous case (and what was eventually observed)
- String of modeled coronal holes appear that don't agree that well with observations



# Summary

- Connecting solar and heliospheric observations ultimately requires a time-dependent coronal description.
- Flux evolution models that assimilate photospheric fields are a promising technique for driving time-dependent MHD models.
- Active region emergence on the unobserved portions of the Sun can significantly affect coronal structure.
- We have demonstrated that incorporating active regions estimated from far-side acoustic imaging can improve models of coronal structure.
- Magnetograms from a mission like Solar Orbiter, or an eventual L5 mission, could provide even more reliable data for predicting coronal structure.

