

PFSS at CCMC: Suggestions for New Products

G.J.D. Petrie

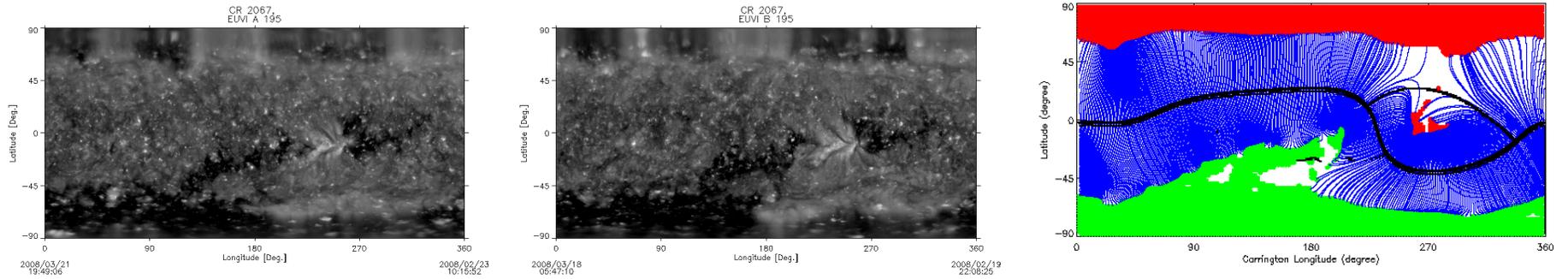
National Solar Observatory, Tucson, AZ 85719

The PFSS model is the

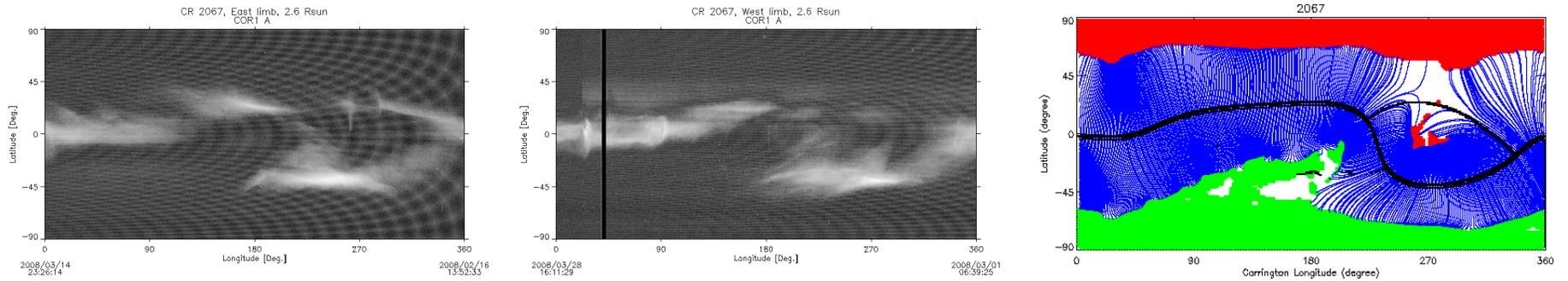
- simplest
- most widely used
- most despised

method for modeling global solar magnetic fields. But it is effective...

CR 2067: STEREO SECCHI EUVI synoptic maps compared to GONG PFSS coronal holes.



CR 2067: STEREO SECCHI COR1 synoptic maps compared to GONG PFSS streamers.



The PFSS Coronal Model

In magnetically dominated solar corona, gas pressure, gravity and plasma inertia can usually be neglected:

$$(\nabla \times \mathbf{B}) \times \mathbf{B} = 0 \Rightarrow \nabla \times \mathbf{B} = \alpha(\mathbf{x})\mathbf{B}$$

where the nonlinear force-free parameter scales as $1/L$.

For large structures $\nabla \times \mathbf{B} \approx 0$ so can use potential-field source-surface (PFSS) model (Schatten et al. 1969, Altschuler & Newkirk 1969, Hoeksema 1984, Wang & Sheeley 1992).

#



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Code written by J.G. Luhmann and Y. Li

Photospheric lower-boundary data from Wilcox Solar Observatory (1976-present)

Uses spherical harmonic coefficients direct from Wilcox

Choose rotation by dates or rotation number

Choose R_{ss} between range 1.6 - 3.25 solar radii with 2.5 the recommended value

Request a PFSS Model Run

Please complete the form below. * Indicates a required field.

Step 1: GENERATE YOUR REQUEST

Your run results will be published online *under your Run Registration Number* (FirstName_LastName_MMDDYY_ModelType_RunNumber) e.g. John_Smith_032511_SH_1.

EMAIL* how to contact you	<input type="text"/>	Enter a valid email address
FIRST NAME (GIVEN)* your given name	<input type="text"/>	Enter your given name
LAST NAME (FAMILY)* your family name	<input type="text"/>	Enter your family name
RUN NUMBER* max of 4 runs per day	<input type="text" value="choose run number for today"/>	Unless you want to overwrite it
KEYWORD/S* helps to sort and search the results of simulations	<input type="text"/>	Enter a keyword

Step 2: CHOOSE THE DATE

Harmonic Coefficient data are supplied by the Wilcox Solar Observatory. The model run submission has two (2) options:

OPTION 1

Date of interest (05/31/1976 - 10/20/2010)

year	<input type="text" value="choose year"/>
month	<input type="text" value="choose month"/>

helps to sort and search the results of simulations Enter a keyword

Step 2: CHOOSE THE DATE
 Harmonic Coefficient data are supplied by the Wilcox Solar Observatory. The model run submission has two (2) options:

OPTION 1
 Date of interest
 (05/31/1976 - 10/20/2010)

year

month

day

OPTION 2
 Carrington Rotation and
 Center Longitude (1642.315
 - 2102.135)

cr

lon

Step 3: SET THE SOURCE SURFACE RADIUS

RANGE*
 (1.60 - 3.25)
 2.5 is the nominal source
 surface

OPTIONAL: SPECIAL REQUEST
 ONLY if you require a customized simulation setup not provided by the standard submission options. Unlike the standard runs that are automatically processed, special requests are reviewed and manually modified by the CCMC staff. Please note that special requests are reviewed and manually modified by the CCMC staff and are executed only if resources are available.

JUSTIFICATION
 brief description

Code written by J.G. Luhmann and Y. Li

Photospheric lower-boundary data from Wilcox Solar Observatory (1976-present)

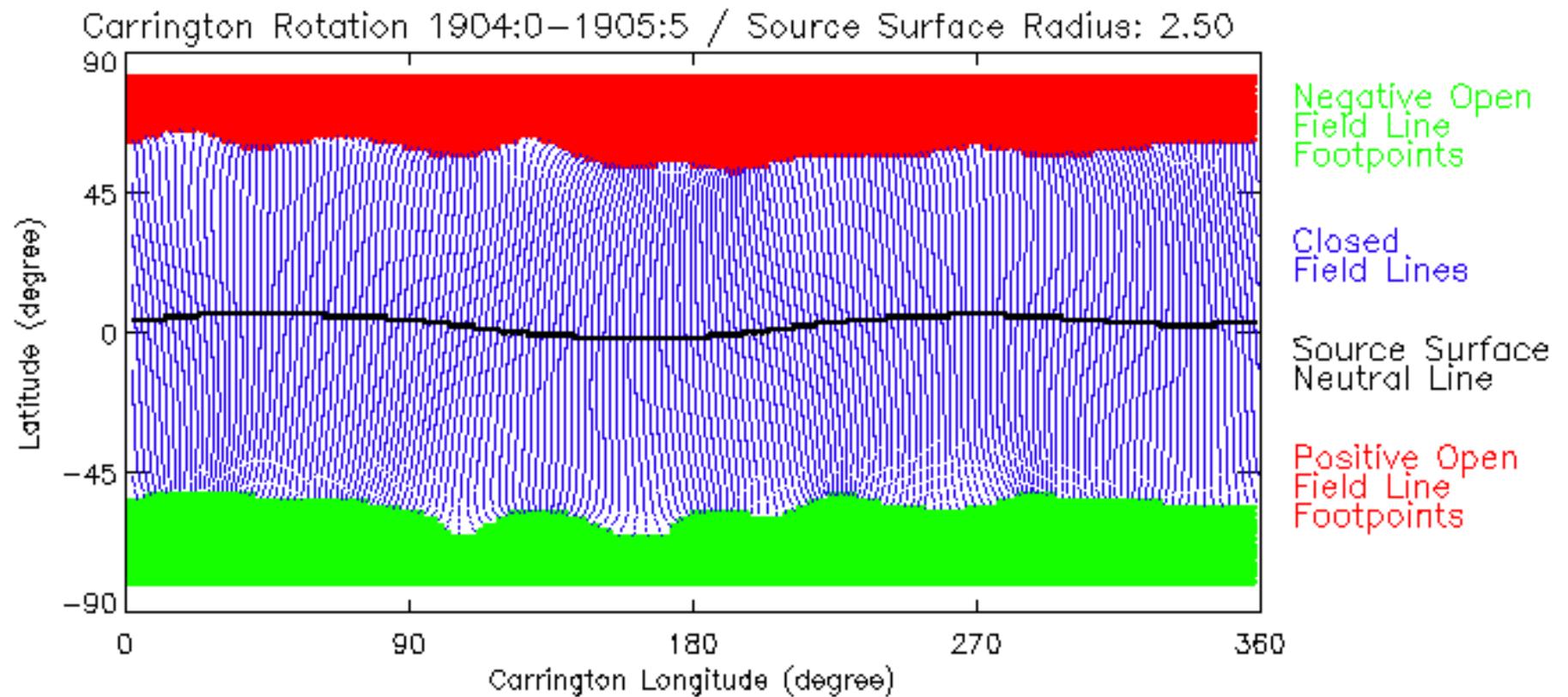
Uses spherical harmonic coefficients direct from Wilcox

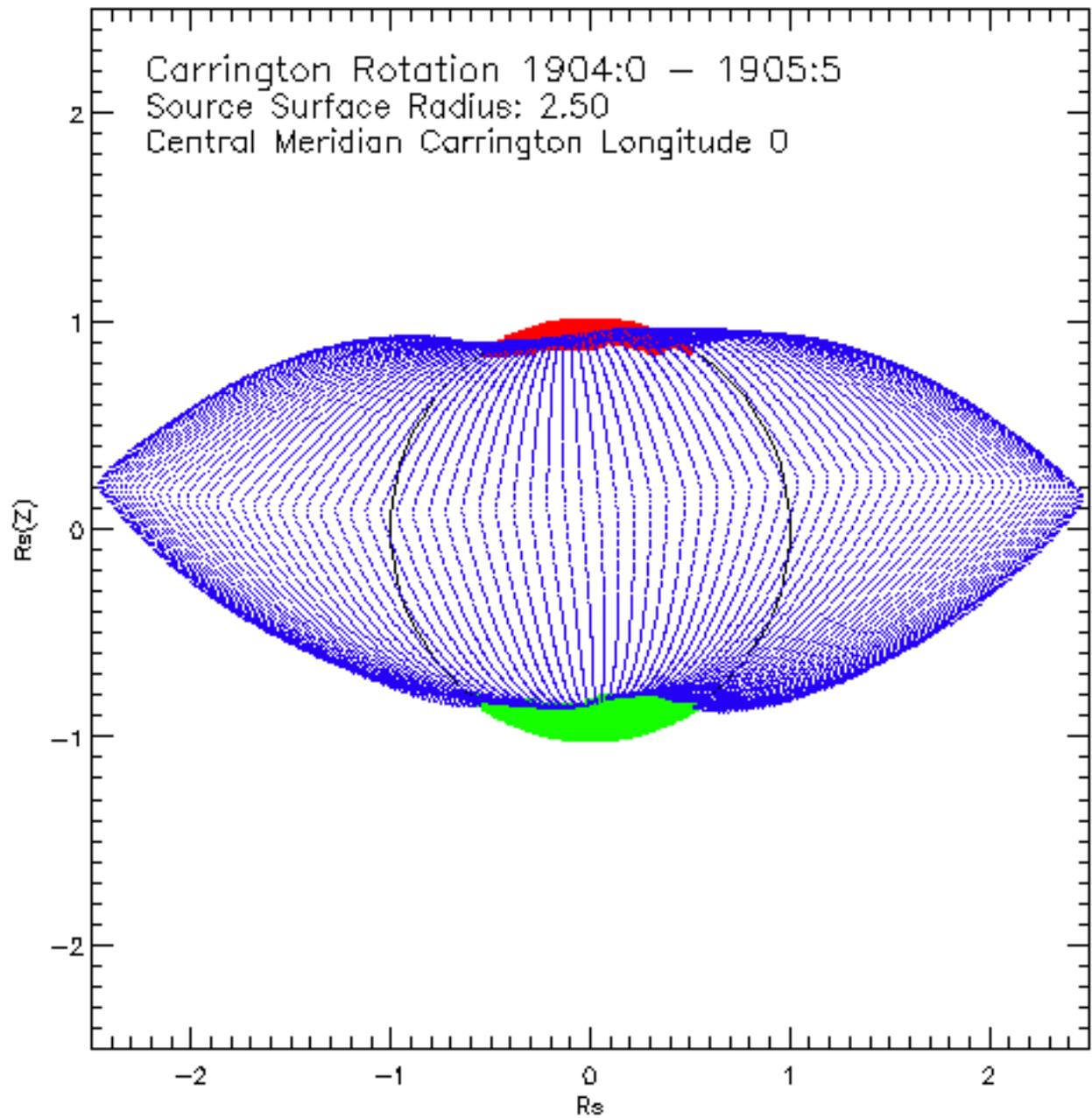
Choose rotation by dates or rotation number

Choose R_{ss} between range 1.6 - 3.25 solar radii with 2.5 the recommended value



CMCC PFSS Result





Negative Open
Field Line
Footprints

Closed
Field Lines

Positive Open
Field Line
Footprints

Other photospheric magnetographs besides WSO:

- NASA's SDO/HMI (2010) and SoHO/MDI (1996-2010)
- NSO's SOLIS (2003-) and its predecessors SPMG (1992-2003) and 512-Channel (1974-1993)
- NSO's GONG (2006-)
- Mt. Wilson Obs. (since 1960s)

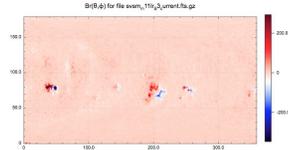
Solar Models



Tahar Amari's solar models page

A simple three steps procedure: ①

1. Choose your data set and preview



The present facility **Solar Models** allows to reconstruct online the solar coronal magnetic field from photospheric magnetograph data. The user is invited to select a data file from a server and then to compute the coronal magnetic field according to a set of models. As a first preview, this facility currently allows access to a limited number of models and data obtained with the **SOLIS** magnetograph of the NSO.

2. Configure and run your model ②

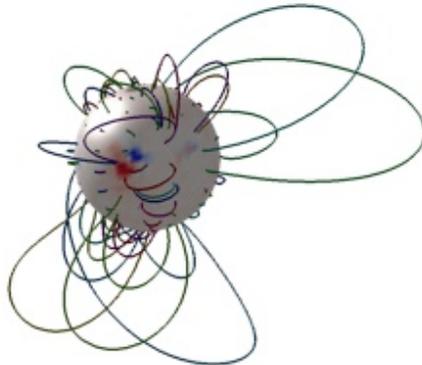
$$\nabla \times B = \alpha B$$
$$\nabla \cdot B = 0$$

As a preview all guests have access to the various models and output images for publication. Currently no file can be saved after a request is performed, but in the near future declared users having an account will be able to save and restore the files produced during previous sessions.

3. Explore your solution

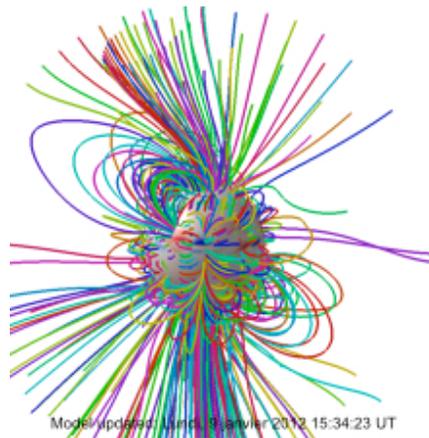
The present facility is supported by the **Centre National d'Etudes Spatiales** and represents a complementary interactive aspect of the **FROMAGE** facility.

Informations on the models and scientific background can be found on the web page of the author of this facility : **Tahar Amari** . You are welcome to send requests and comments to him.



Click to animate (wait while the movie loads ...)

Example of model computed with Carrington Rotation SOLIS data.



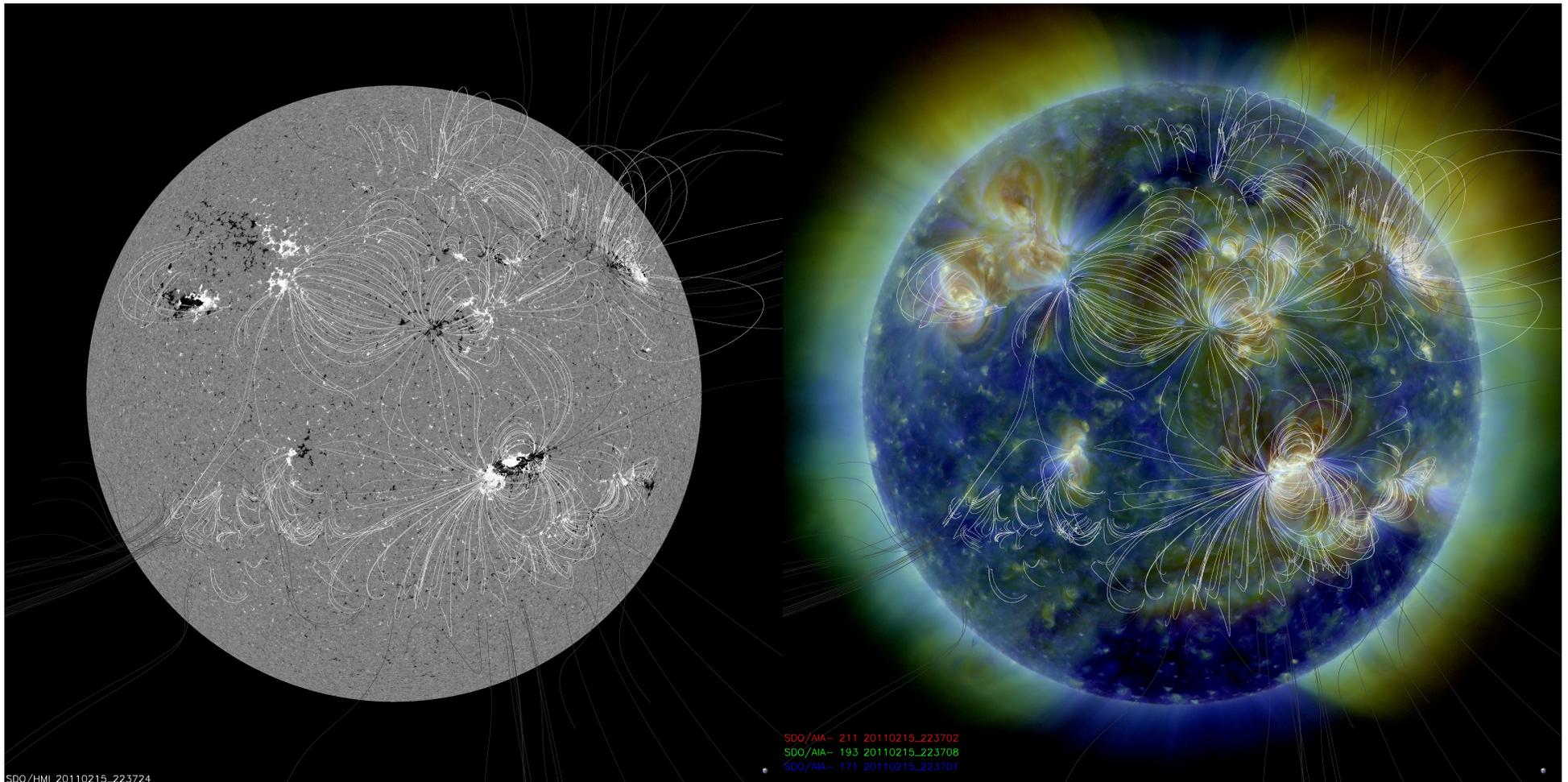
<http://solarmodels.cpht.polytechnique.fr>

The Sun Today
with **Solar Models**.

Credits: in case of use of these data or graphic outputs for scientific publications, acknowledgements would be appreciated.

Lockheed's SDO "The Sun Today" hairy ball plots
2011/02/15

<http://sdowww.lmsal.com/>



NSO/GONG

Potential-Field Source-Surface Models



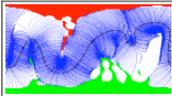
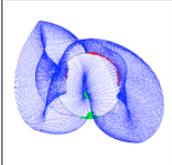
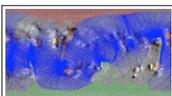
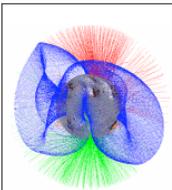
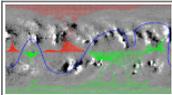
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Latest Potential-Field Source-Surface Models

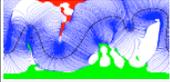
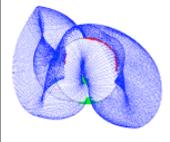
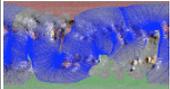
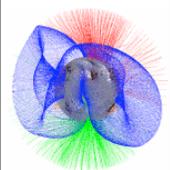
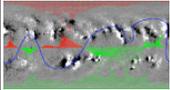
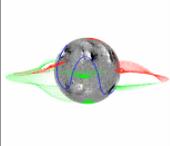
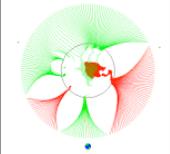
For each standard hourly synoptic magnetogram we give a potential-field source-surface model of the coronal field. To capture large-scale field structure in a model we may assume that there are no significant electric currents in the corona. We use Altschuler & Newkirk's (1969) spherical harmonic solution which includes a source surface high in the corona where the field lines are forced to be radial. This models the effect on the field of the outflowing solar wind.

The source surface is fixed at 2.5R where R is the radius of the Sun. We plot the potential fields with harmonic terms 1 to 20 for our hourly synoptic maps, omitting the monopole term. For large-scale coronal fields, expansion of the fields to order 20 is more than sufficient.

We thank Janet Luhmann, Yan Li and Xuepu Zhao for the potential-field source-surface and spherical harmonic transform codes used to develop this product.

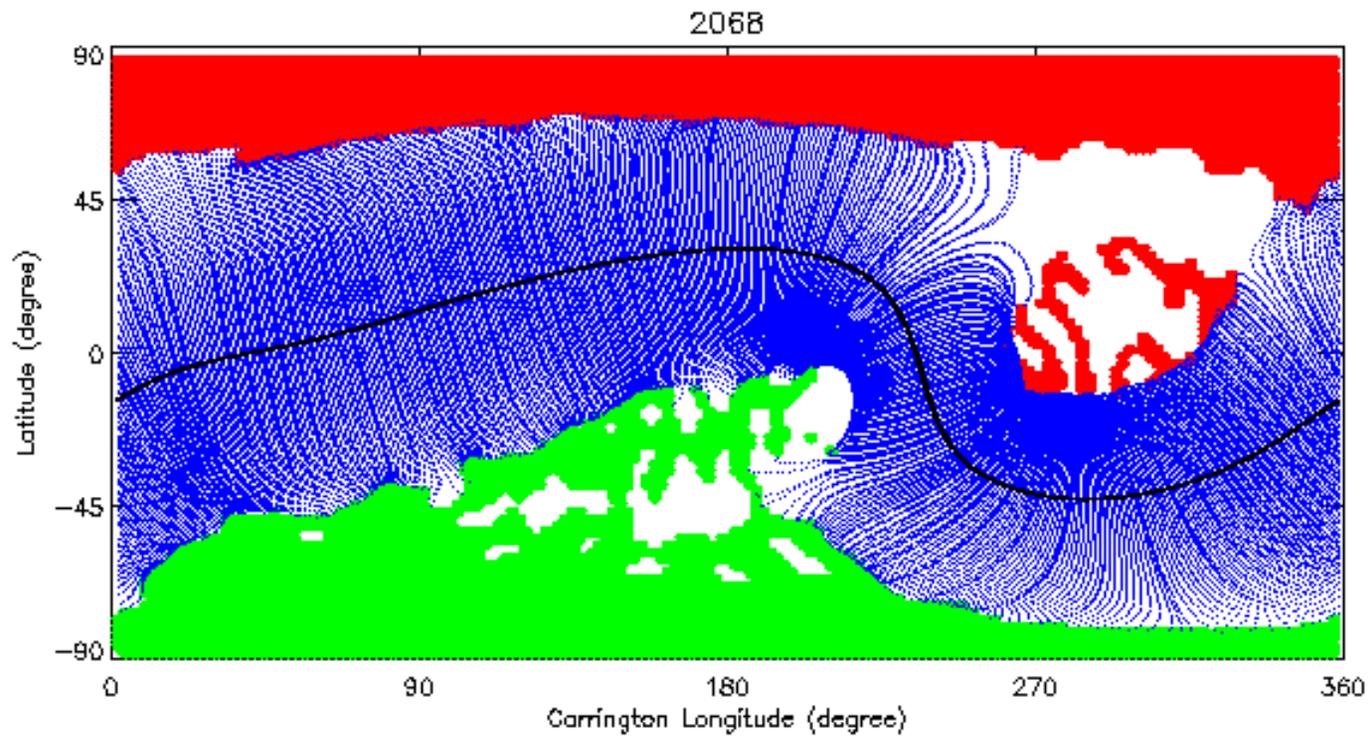
	Synoptic Coronal Hole Plot
	Line-Of-Sight Coronal Hole Plot
	Synoptic Field Plot
	Line-Of-Sight Field Plot
	Synoptic Ecliptic-Plane Field Plot
	Line-Of-Sight Ecliptic-Plane Field Plot

<http://gong.nso.edu/data/magmap/pfss.html>

	Synoptic Coronal Hole Plot
	Line-Of-Sight Coronal Hole Plot
	Synoptic Field Plot
	Line-Of-Sight Field Plot
	Synoptic Ecliptic-Plane Field Plot
	Line-Of-Sight Ecliptic-Plane Field Plot
	Top View Ecliptic-Plane Field Plot
	Simulated Line-of-Sight Views from Earth and from NASA's STEREO A & B Spacecraft

<http://gong.nso.edu/data/magmap/pfss.html>

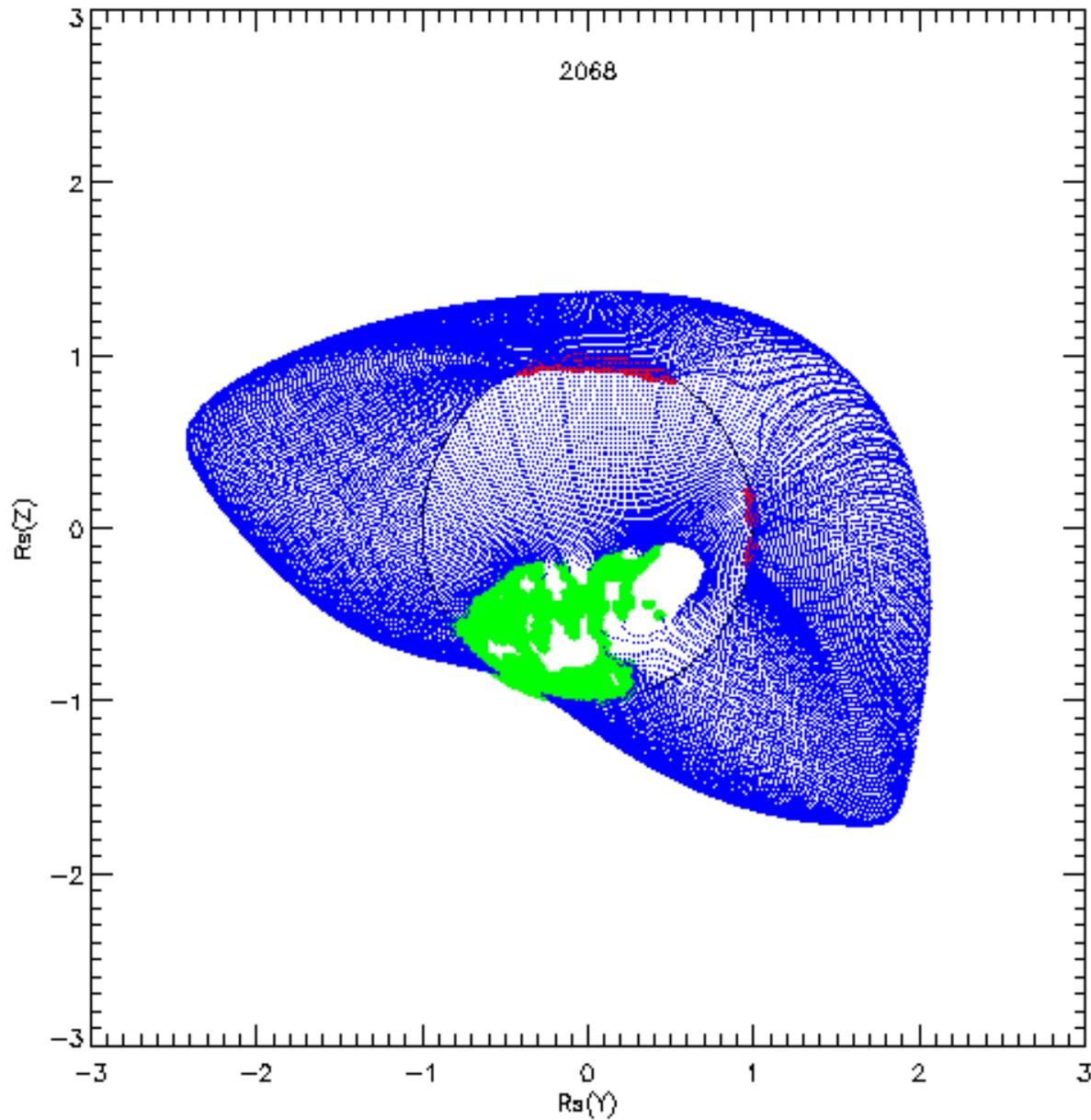
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[Pipeline Event Log](#) | [Sample Synoptic Map Keywords](#)



Synoptic coronal hole plot

green & red: positive & negative coronal holes
blue: tallest closed field lines (streamer belt)
black: neutral line

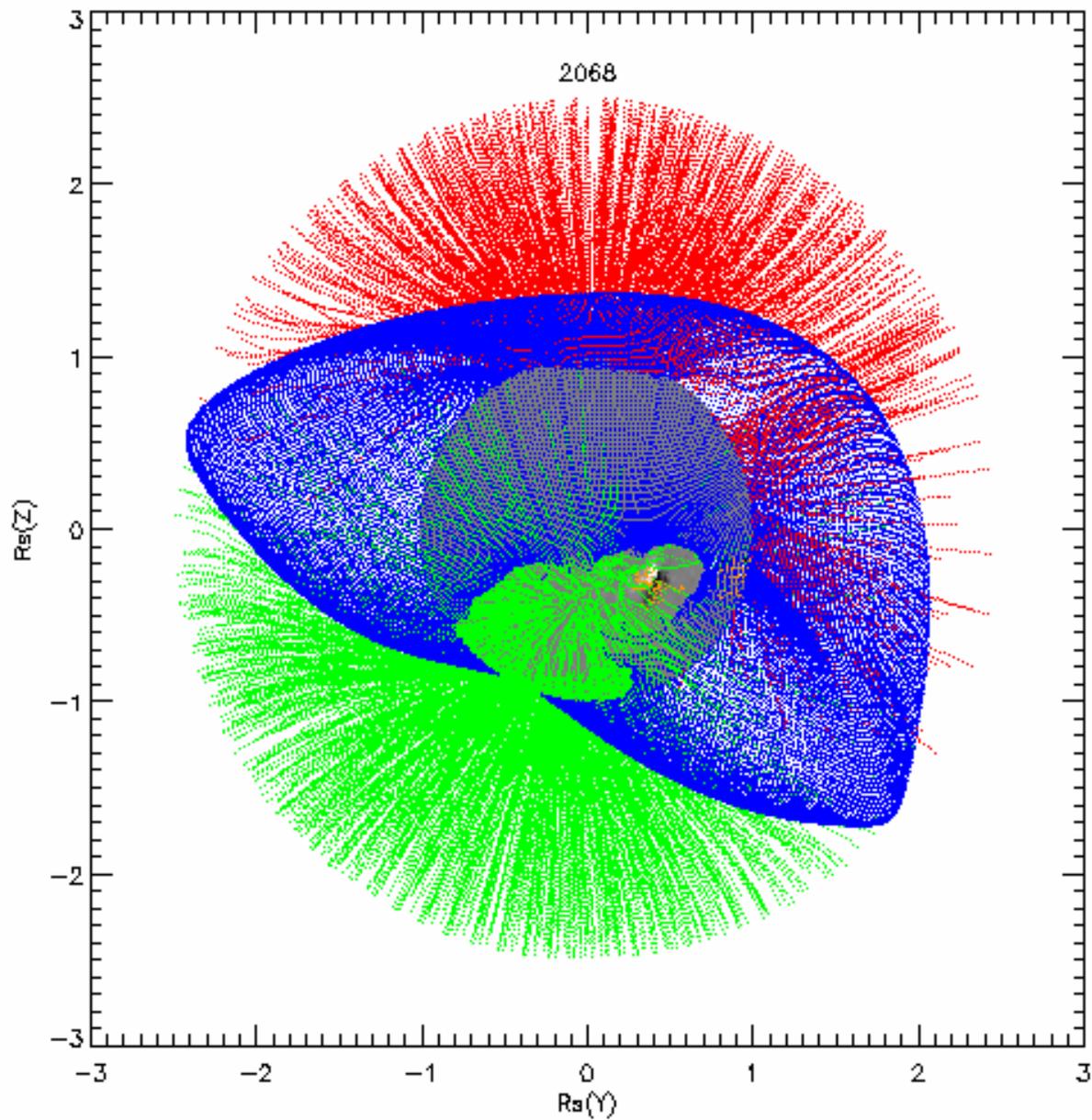
Based on code written by J.G.
Luhmann, Y. Li and X. Zhao



Spherical coronal hole plot

green & red: positive & negative coronal holes

blue: tallest closed field lines (streamer belt)



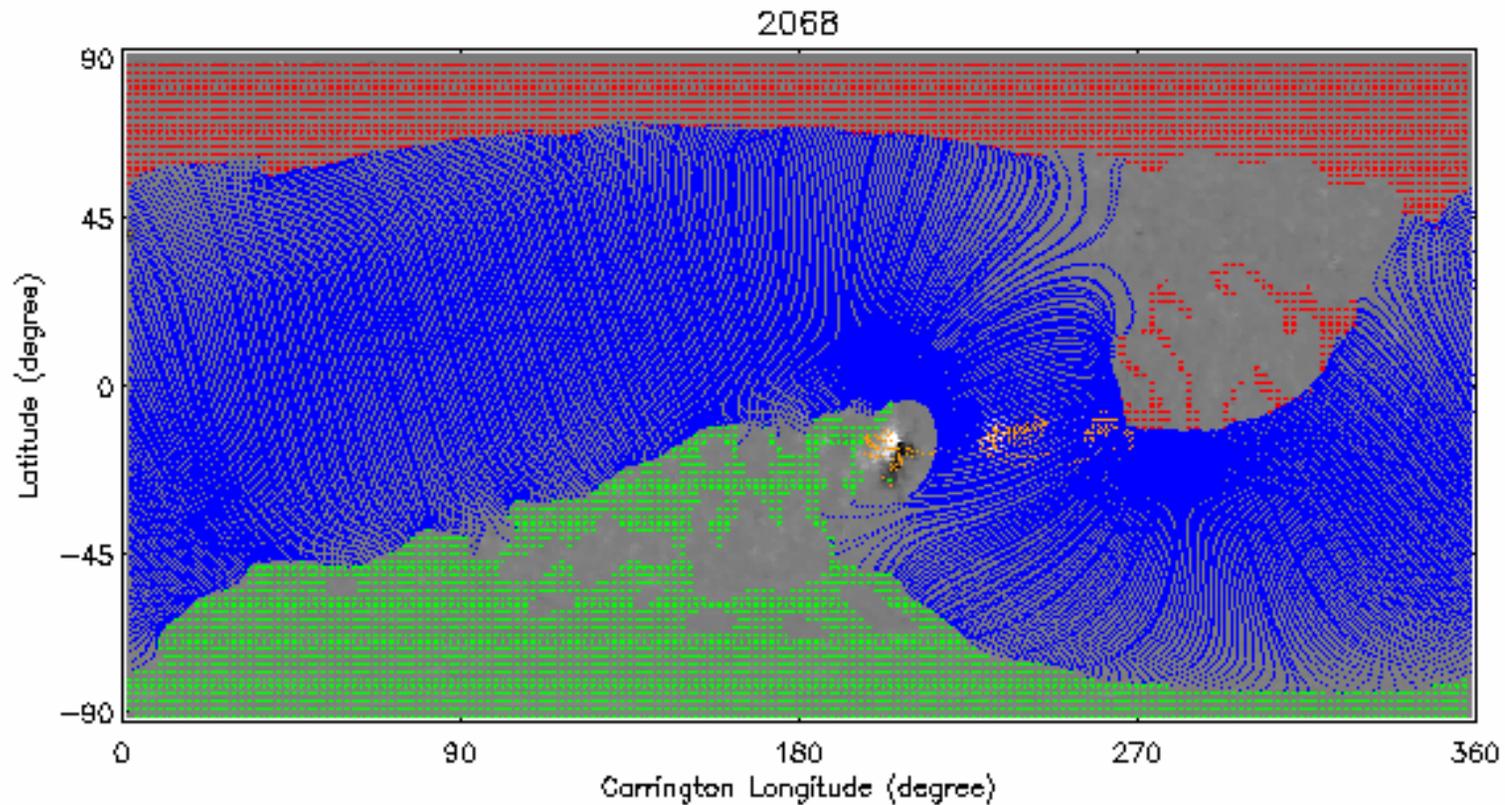
Spherical field plot

green & red: positive & negative open flux

blue: tallest closed field lines (streamer belt)

yellow: active-region

grey-scale: photospheric flux density



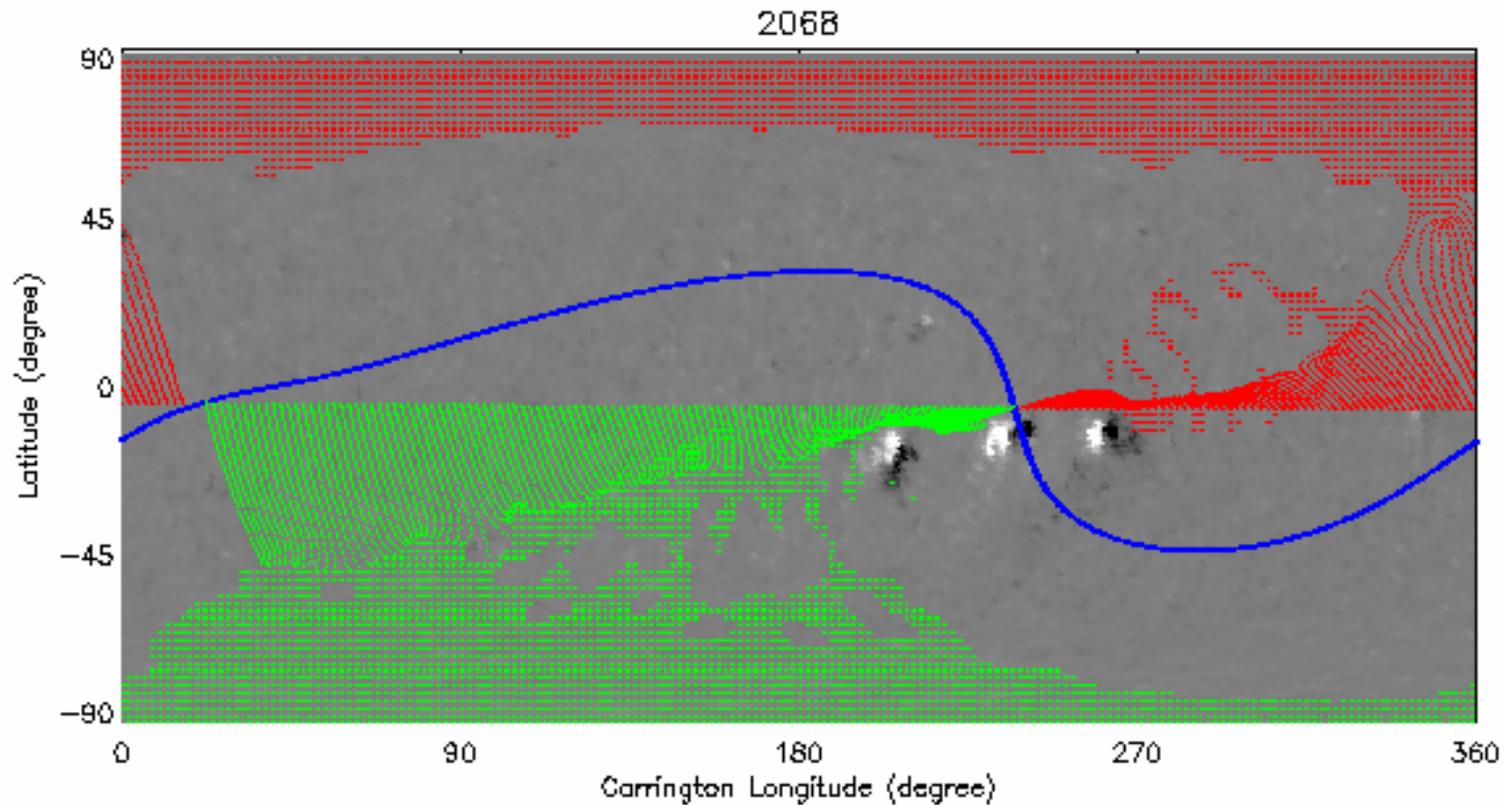
Synoptic field plot

green & red: positive & negative open flux foot-points

blue: tallest closed field lines (streamer belt)

yellow: active-region

grey-scale: photospheric flux density



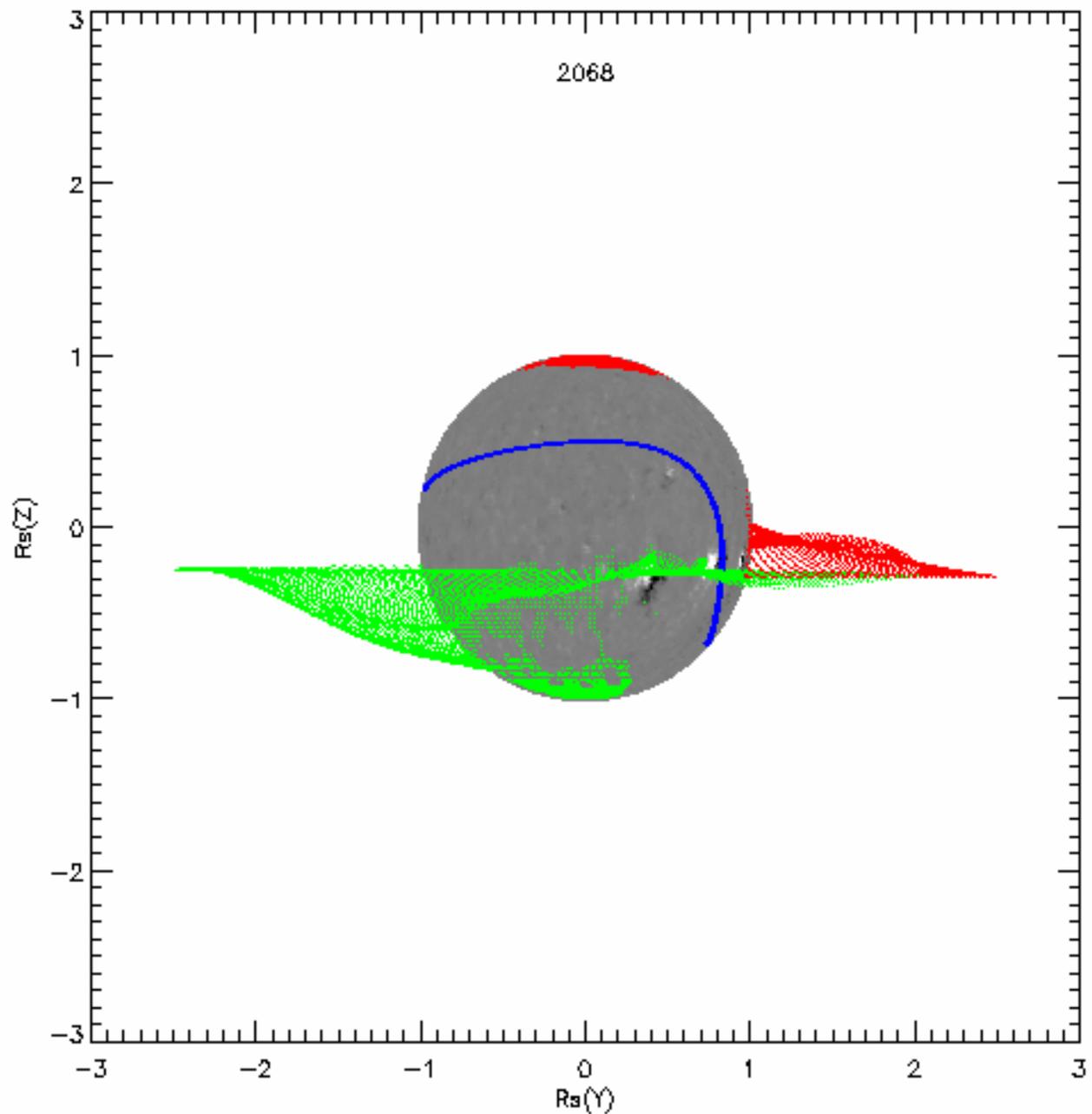
Synoptic ecliptic-plane field plot

green & red lines: positive & negative field open to the ecliptic plane.

green & red dots: positive & negative open flux foot-points

blue: neutral line

grey-scale: photospheric flux density



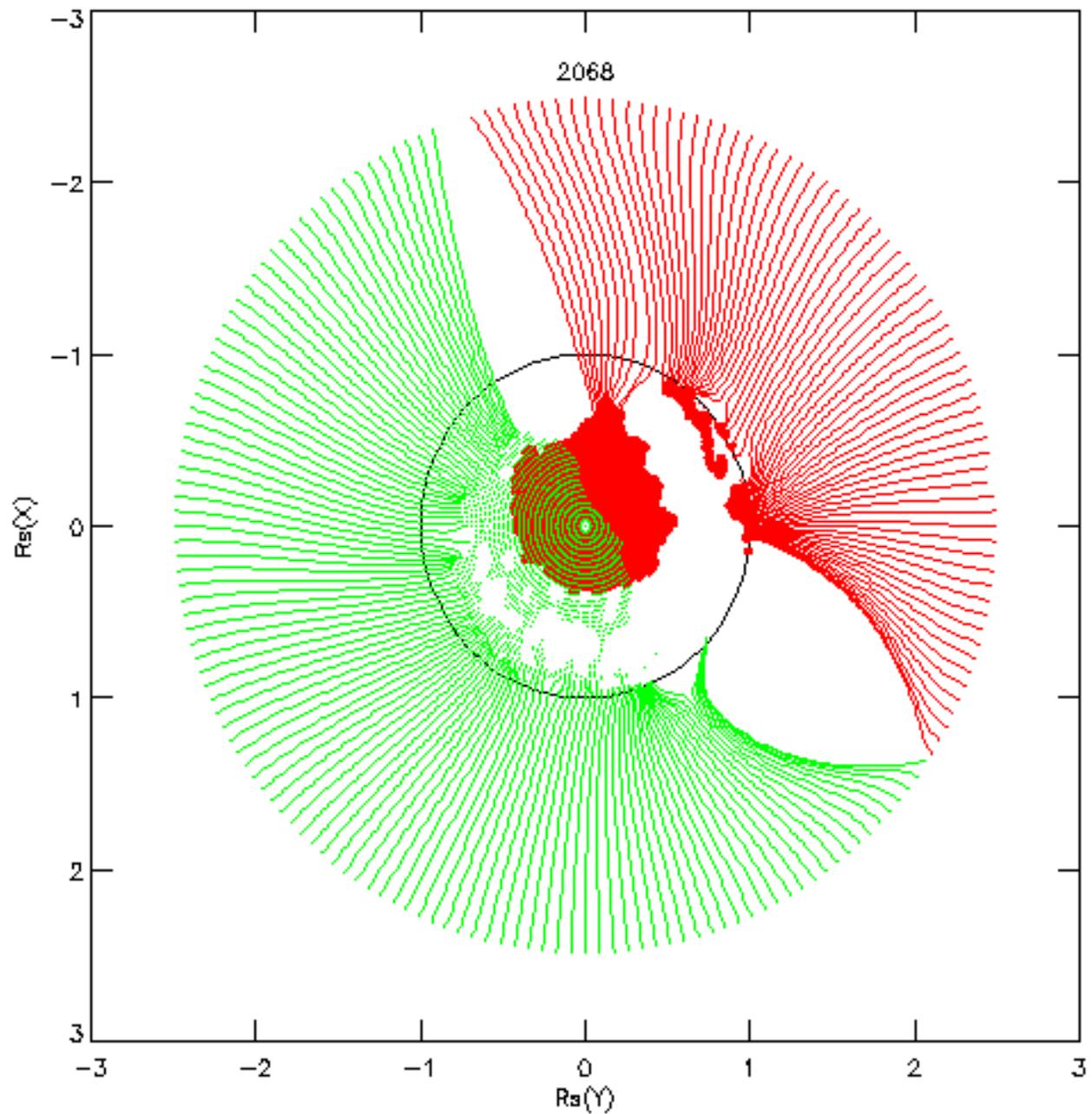
Spherical ecliptic-plane
field plot

green & red lines: positive
& negative field open to
the ecliptic plane.

green & red dots: positive
& negative open flux foot-
points

blue: neutral line

grey-scale: photospheric
flux density



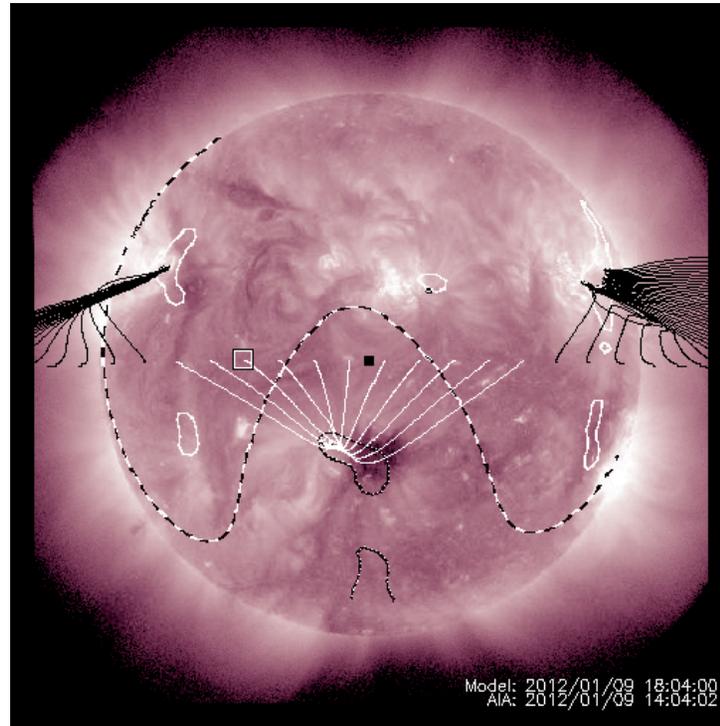
Polar-view ecliptic-plane
field plot

green & red lines: positive
& negative field open to
the ecliptic plane.

Green stripes & red
shading: positive &
negative coronal holes

Comparison of VSL model with coronal observations; views of the IMF and its origins; and diagnostic diagrams.

This web page is part of a monitor for our solar and heliospheric forecast model. The forecast (and links to model descriptions) can be accessed [here](#). Note that the links in the column to the left provide access to earlier comparisons such as the current ones shown below.



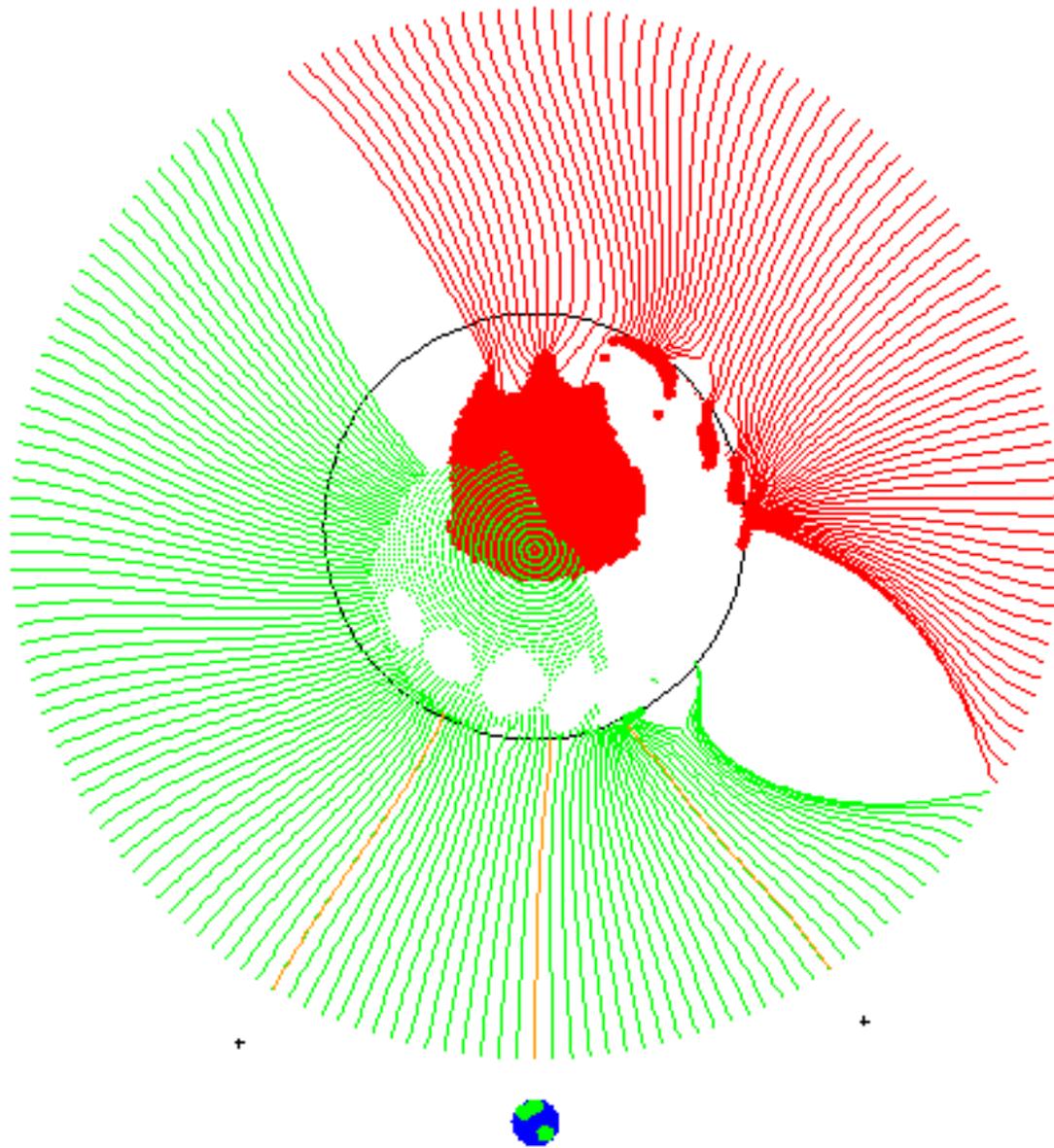
[Click here for a 2-week JAVA-script movie](#)

The image above shows a coronal image (AIA 211Å, or prior to 2010/07/21 EIT 284Å -yellow- if available, otherwise a TRACE 195Å full-disk mosaic -green- or a GOES/SXI image -red-). Onto it, the heliospheric current sheet is shown in projection onto the solar surface as a dashed black-and-white line. Coronal-hole boundaries (defined as areas that our model suggests to be open to interplanetary space) are shown as black and white contours (indicating opposite polarities of the radial field: black for outward-directed field). The image also shows the projected field lines that are at the base of the interplanetary magnetic field (showing only field lines with starting points on the visible side of the Sun). The end points of these field lines on the source surface are spaced by three degrees. The sensitivity of the field extrapolation to the value of the source-surface radius can be assessed from the image below, which shows the current sheet and coronal-hole boundaries for three source surface radii: $R_{ss}=2.5$ (green; standard value), $R_{ss}=2.0$ (red), $R_{ss}=3.0$ (blue).

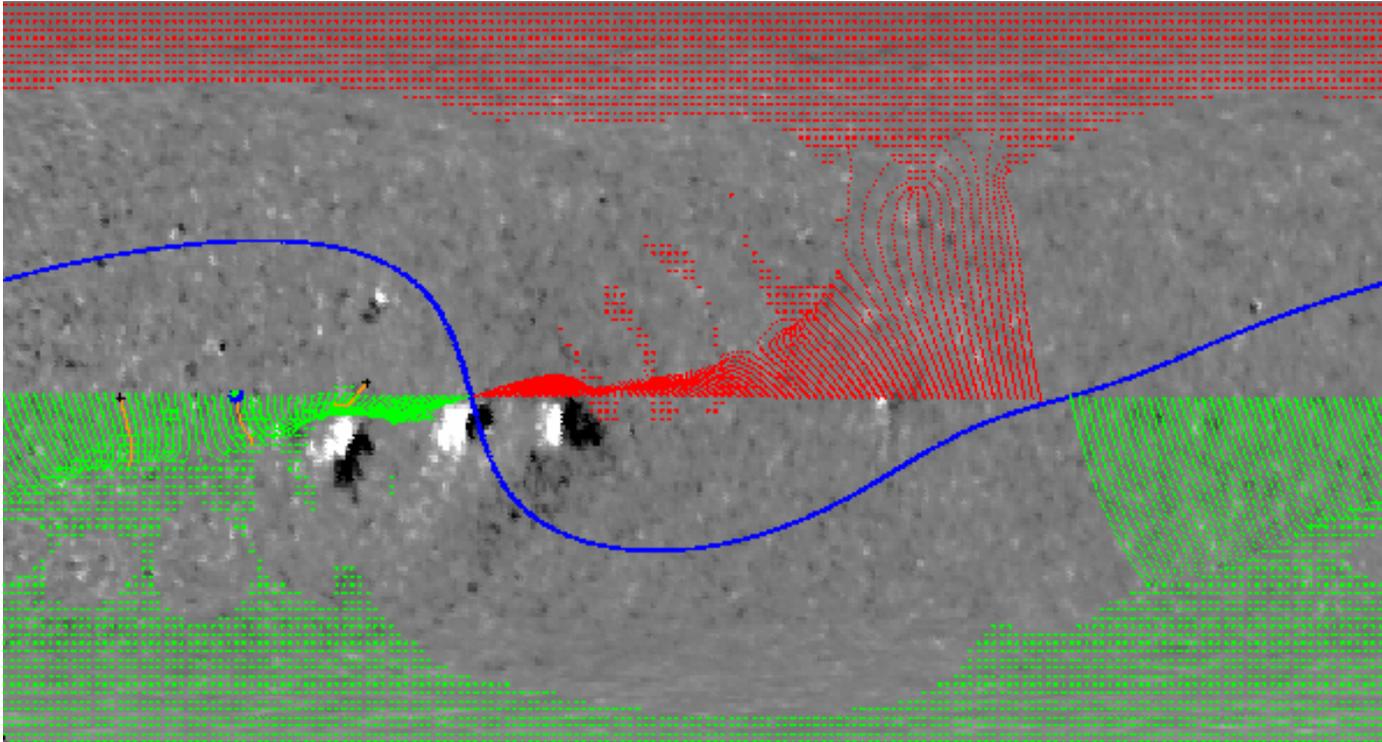
<http://www.lmsal.com/forecast>

Conclusions

- PFSS is widely used because it's simple and effective.
- CCMC could use multiple data sources beyond WSO: HMI, GONG, SOLIS.
- Could extend product range to include hairy-ball plots, elliptic-plane fields, active regions.
- Could produce composite products with, e.g., EUV or coronagraph data.

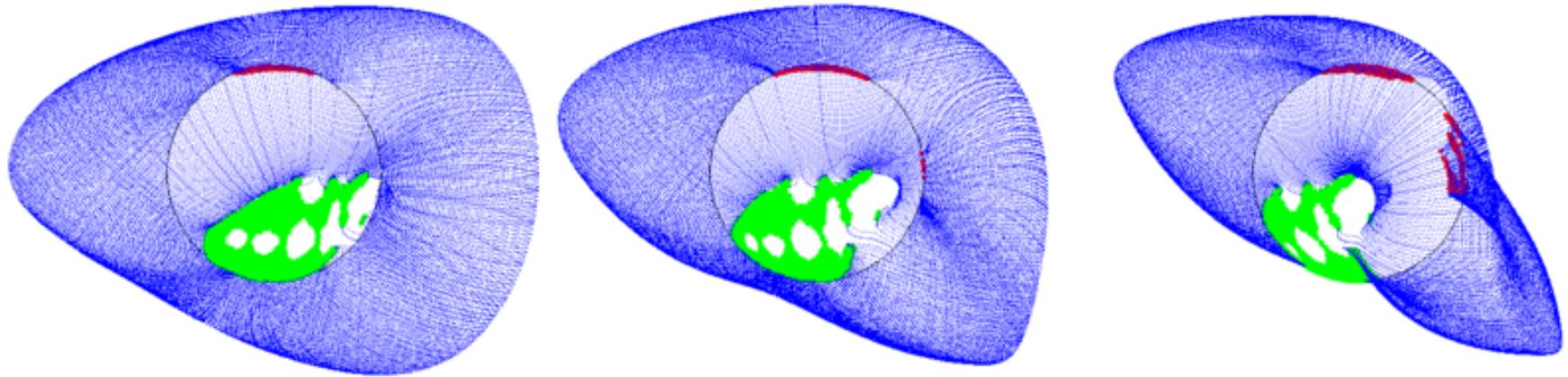


Polar-view ecliptic-plane
Field plot: The Earthward
direction is indicated by
the position of the blue
and green circle. The two
small black crosses mar
the current directions of
the two STEREO spacecraft,
A (right) and B (left). As in
The previous plot, field lines
connecting the photosphere
to the directions of Earth and
STEREO A & B at $r=2.5R$ are
plotted in yellow.



Near-real-time synoptic ecliptic field plot: the location of the sub-Earth point is shown by the small blue and green circle. The two small black crosses on each side of the sub-Earth point mark the current locations of the two STEREO spacecraft, A (right) and B (left).

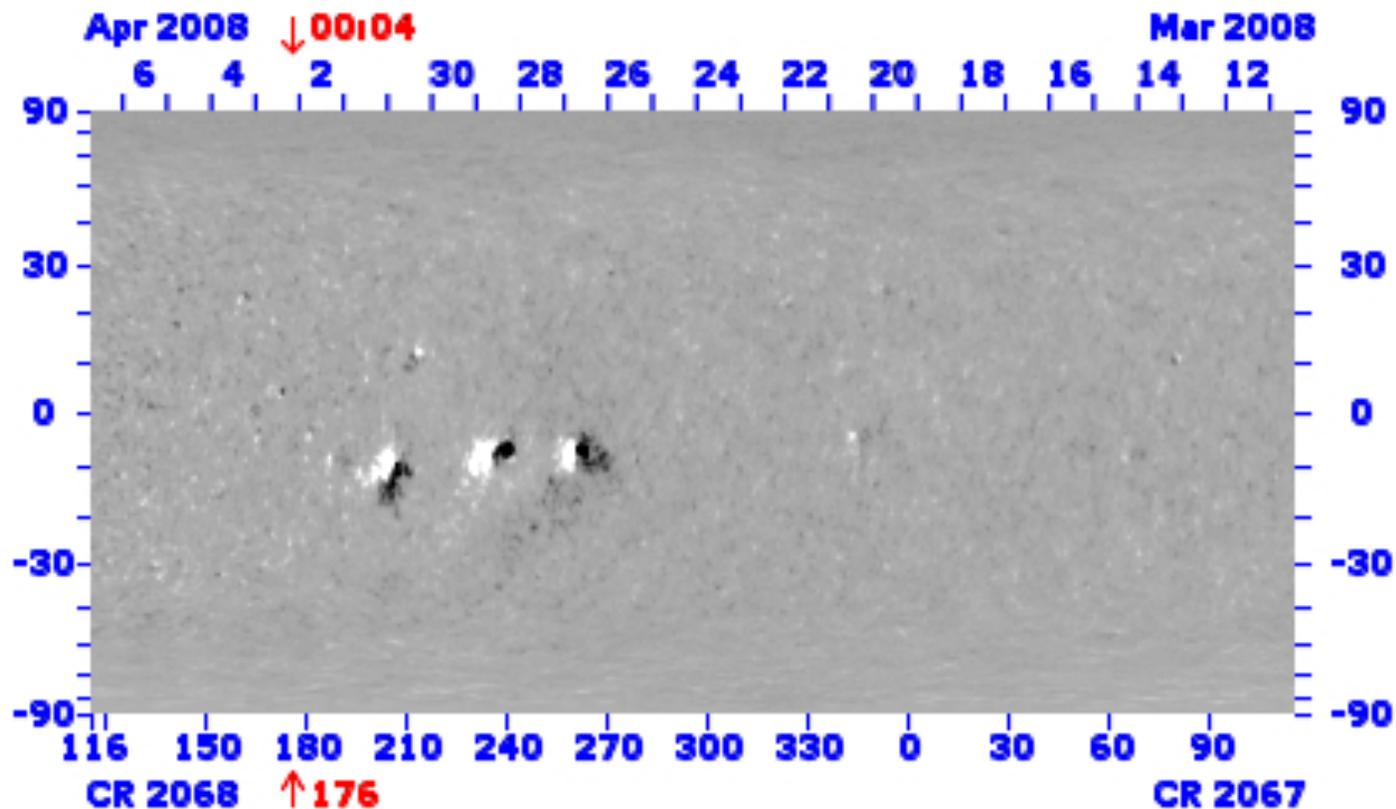
One of the three field lines drawn in yellow connects this sub-Earth point at $r=2.5R$ to the photosphere at $r=R$. The other yellow field lines connect the locations of the STEREO A & B spacecraft to the photosphere.

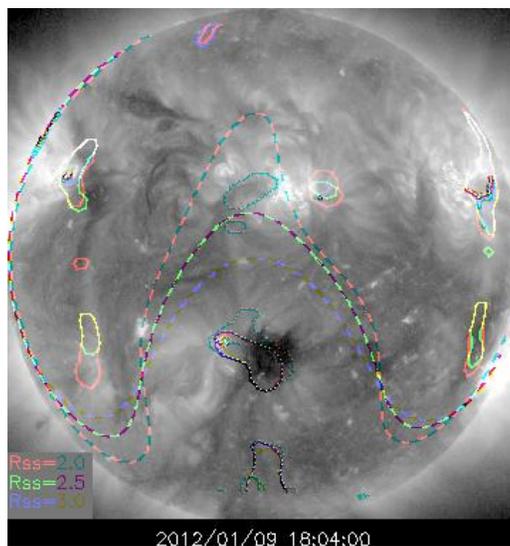


Simulated Line-of-Sight Views from Earth (middle) and from NASA's STEREO A (right) & B (left) spacecraft.

Near-real-time Magnetogram Synoptic Maps and PFSS Models

A near-real-time hourly synoptic map from the middle of CR 2068 is displayed below with arrows indicating its current time and Carrington longitude. The 60 degrees to the left (east) of these arrows are regions which have not yet crossed the central meridian.





From Wang &
Sheeley (1992)

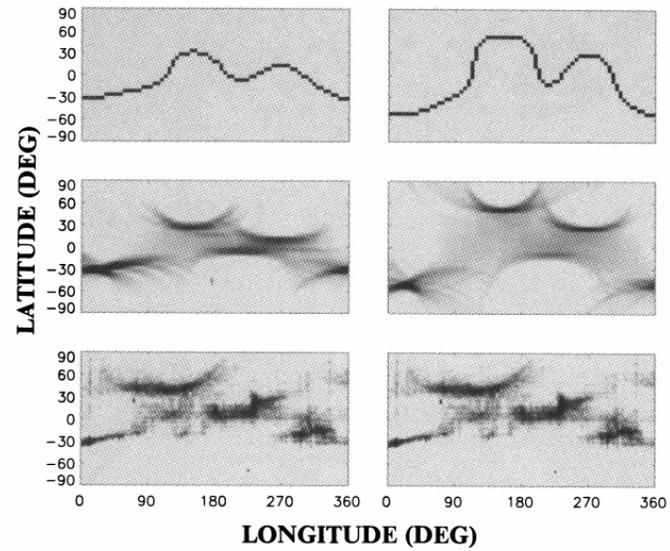


FIG. 7.—K-coronal structures for CR 1746 (1984 March). *Top panels* show the shape of the source-surface neutral line (*black*), as derived by extrapolating WSO magnetograph measurements using the radial (*left*) and line-of-sight (*right*) methods. (Alternatively, these maps indicate the angular distribution of electron density, which is assumed to be concentrated at the neutral line.) *Middle panels* show the corresponding simulated patterns of scattered intensity, with *black* indicating the brightest structures and *white* representing the regions of lowest intensity. For comparison, *bottom panels* (which are identical to each other) display the *SOLWIND* coronal intensity patterns at $r = 3.5 R_{\odot}$ during CR 1746. Here an arbitrary background intensity has been subtracted from the data and the brightest structures are again denoted by *black*.

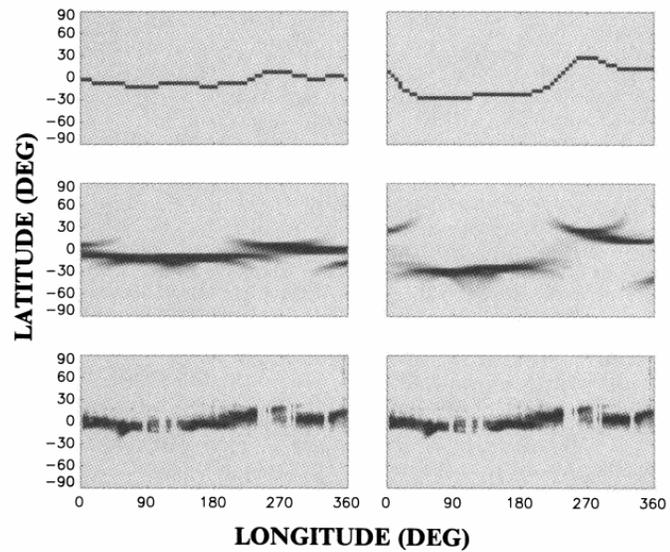
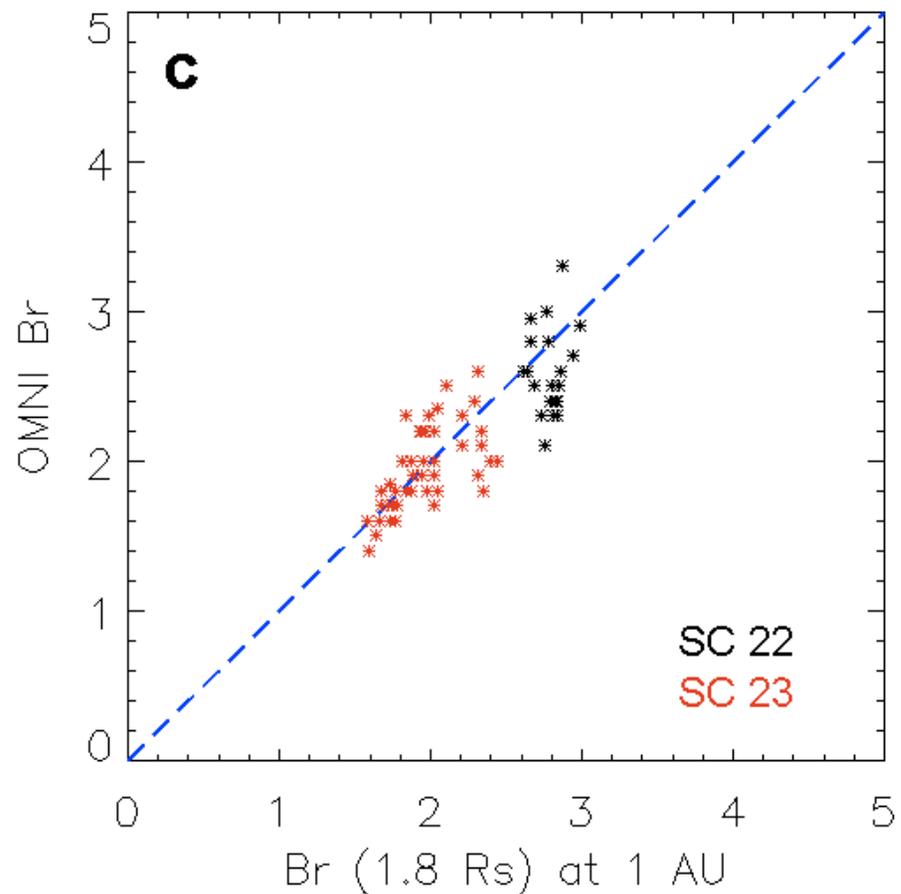
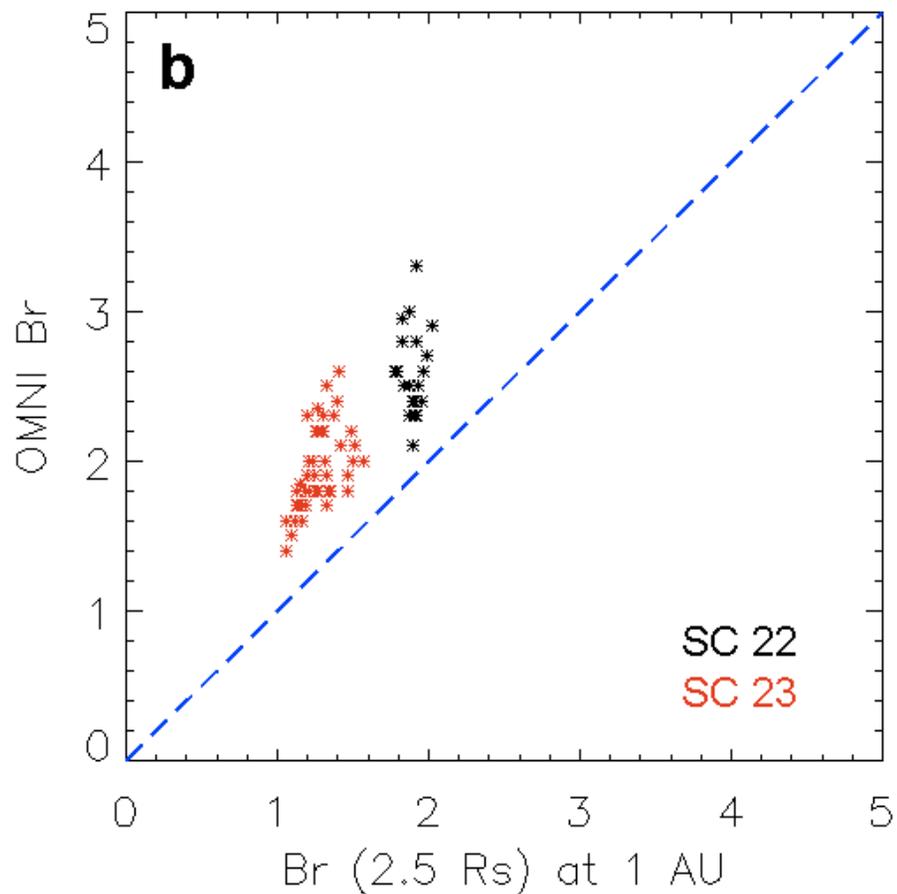


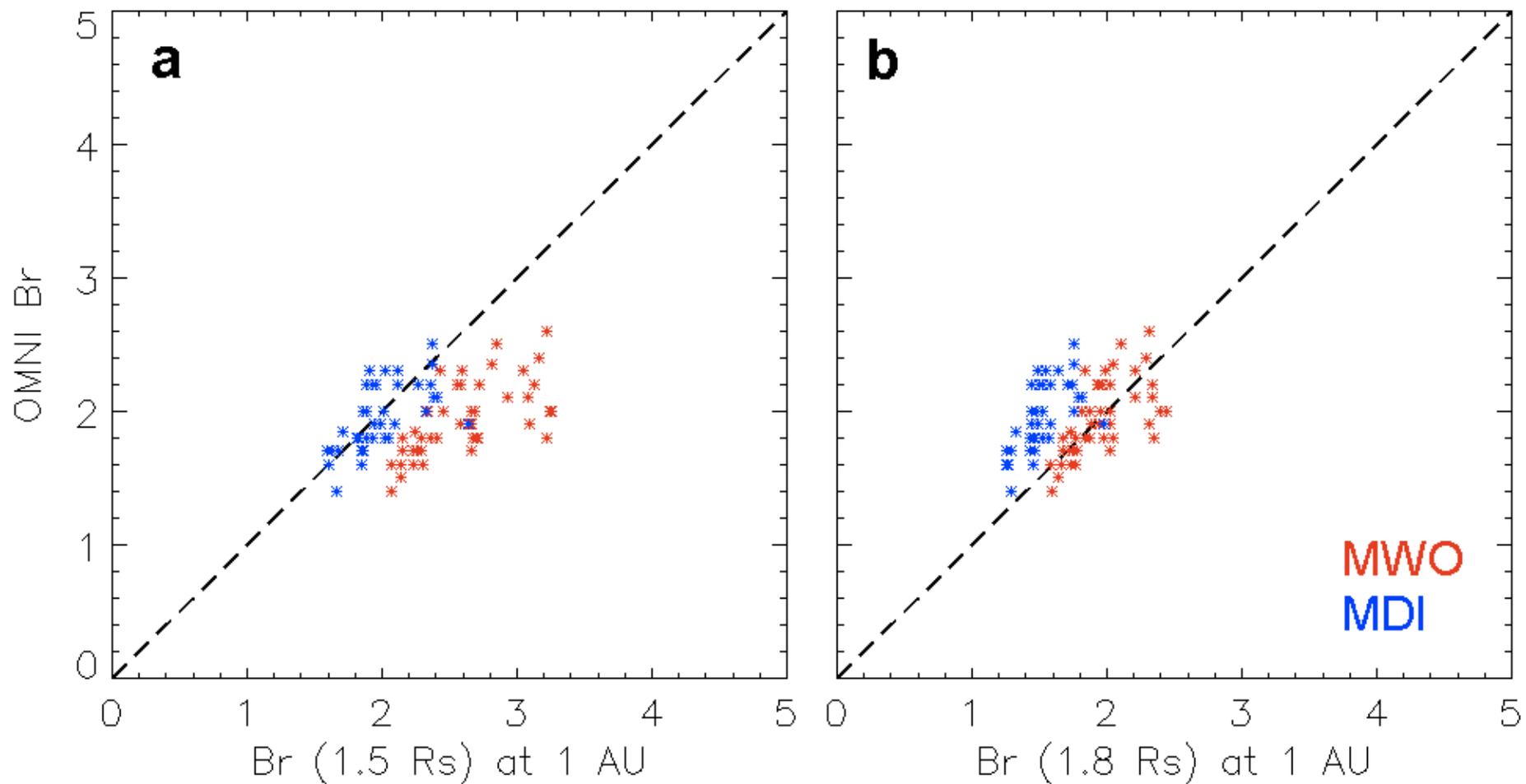
FIG. 8.—K-coronal structures for CR 1762 (1985 May). See Fig. 7 legend.

From Lee et al. (2011)

Solar Br at 1 AU



From Lee et al. (2011)



From Schatten et al. (1969)

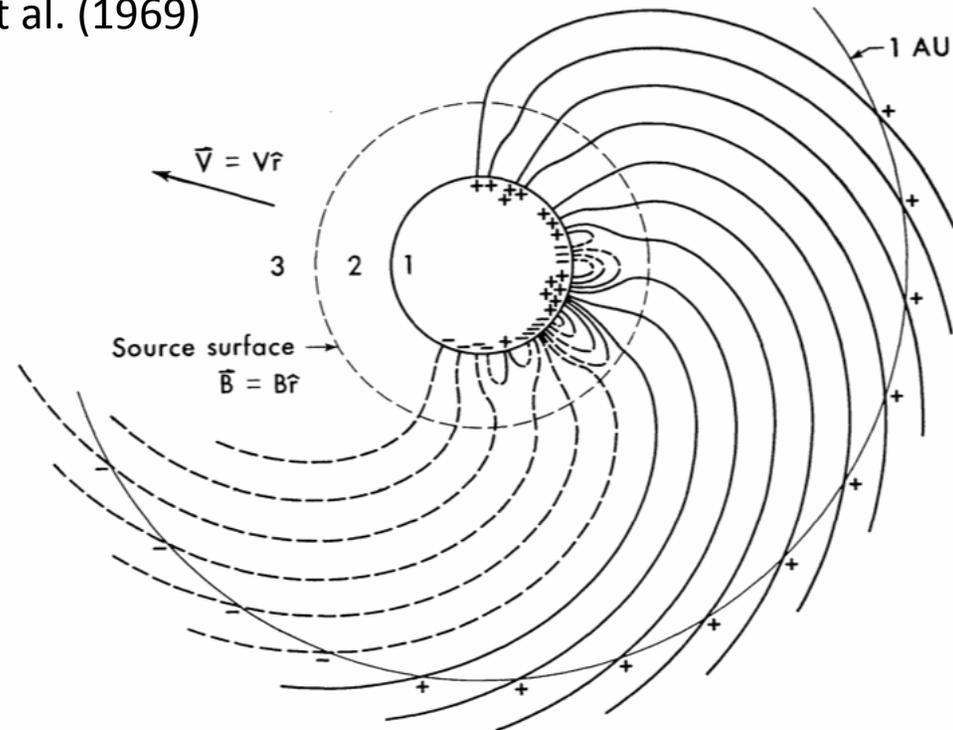
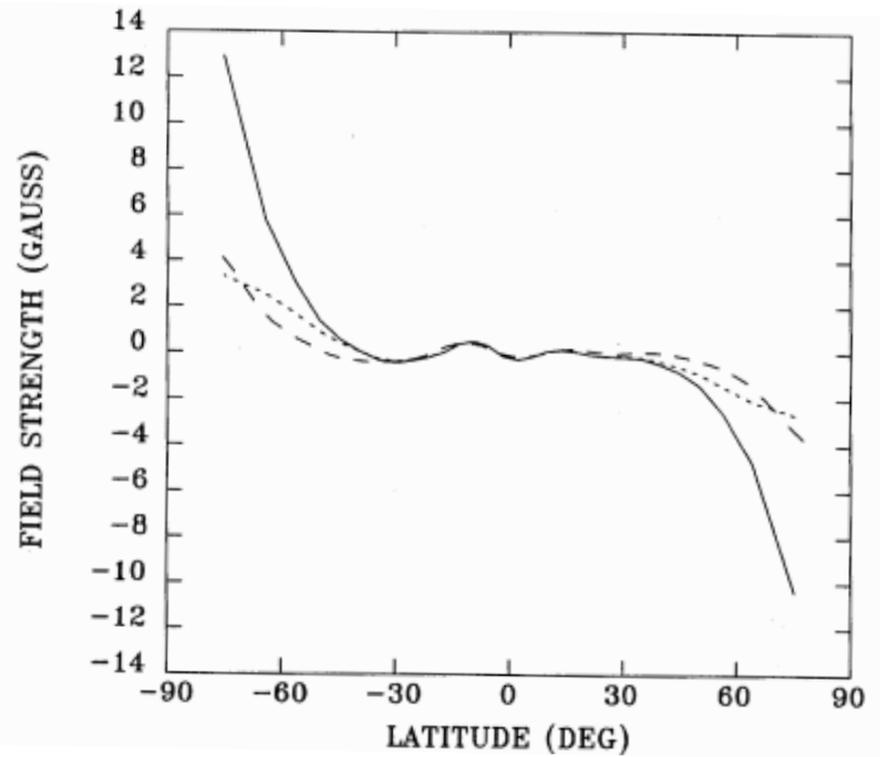


Fig. 1. Schematic representation of the source surface model. The photospheric magnetic field is measured in region 1 at Mount Wilson Observatory. Closed field lines (loops) exist in region 2. The field in this region is calculated from potential theory. Currents flowing near the source surface eliminate the transverse components of the magnetic field, and the solar wind extends the source surface magnetic field into interplanetary space. The magnetic field is then observed by spacecraft near 1 AU.

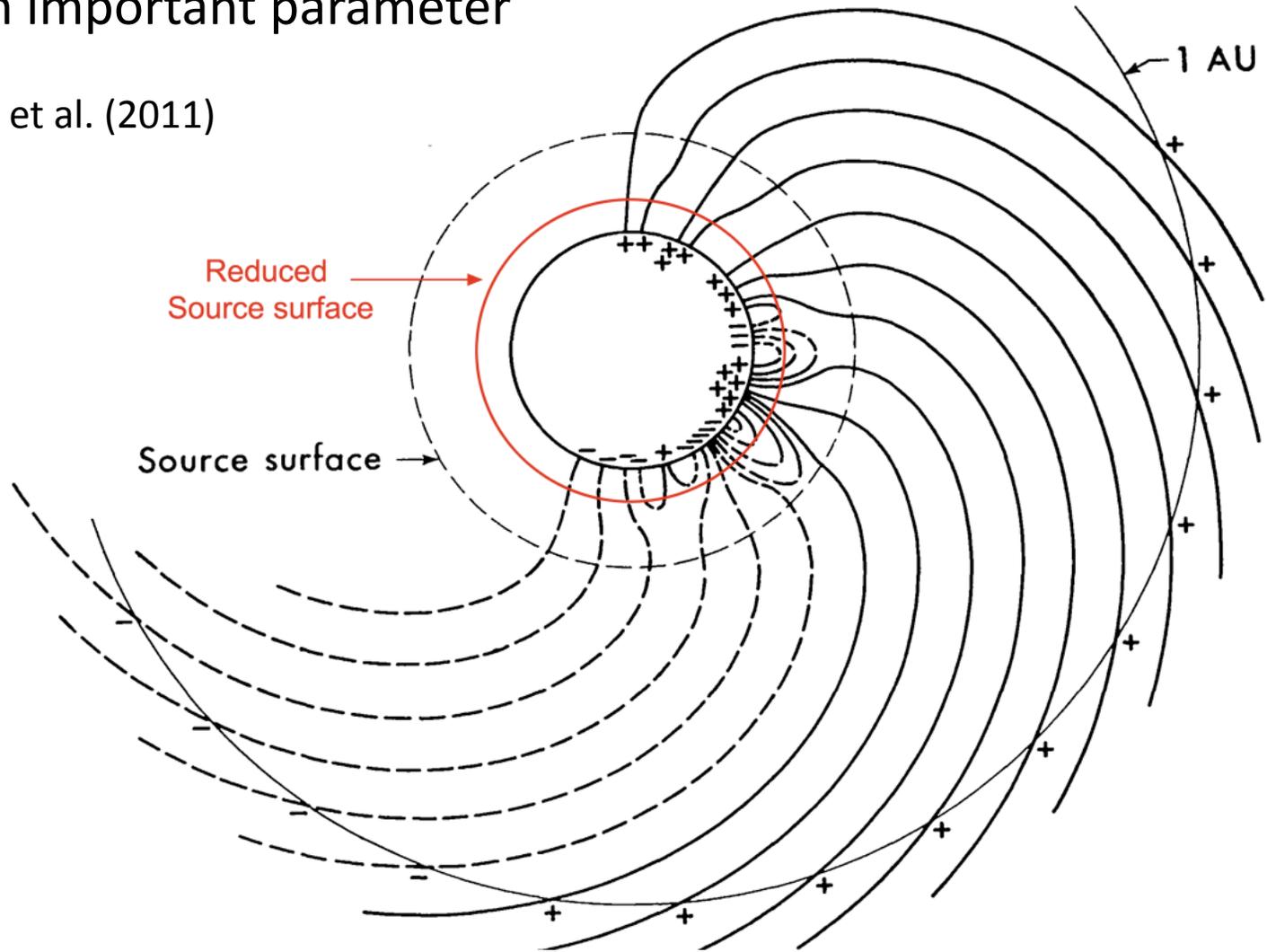
Wang & Sheeley (1992) example:
CR 1776 inferred latitudinal distribution
of B_r at the lower boundary

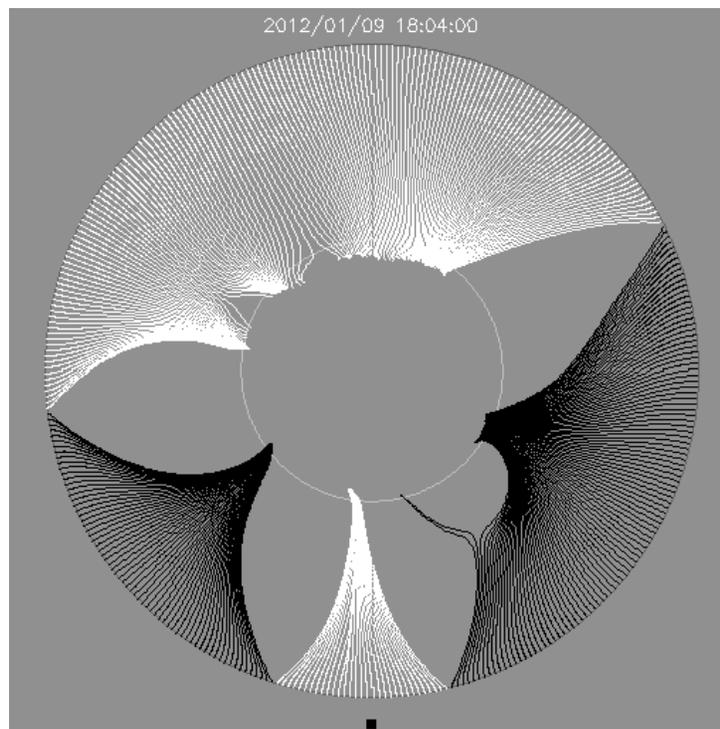
Solid curve: radial method
Long dashed curve: line-of-sight method
Dotted curve: observed line-of-sight field



R_{ss} is an important parameter

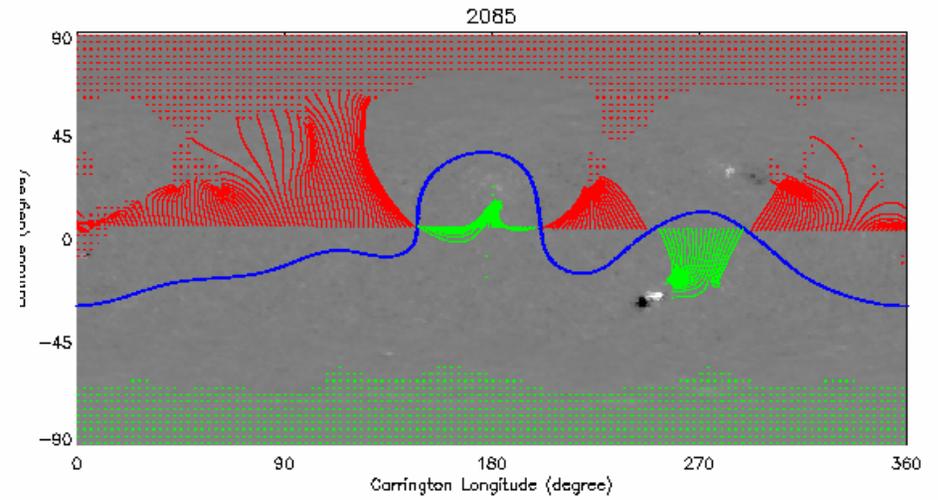
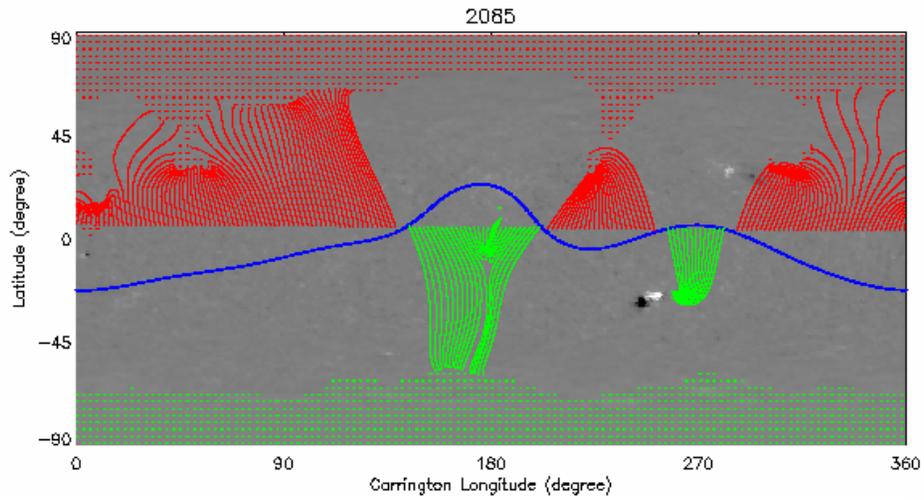
From Lee et al. (2011)





[Click here for a 2-week JAVA-script movie](#)

The above image shows a view of the field lines that connect the solar surface (inner circle) to the source surface (outer circle) at the latitude of the b -angle corresponding to the time shown at the top. That is, it shows essentially how the interplanetary magnetic field connects to the Sun. The Earth is in the direction of the small square at the bottom. The date and time are shown at the top.

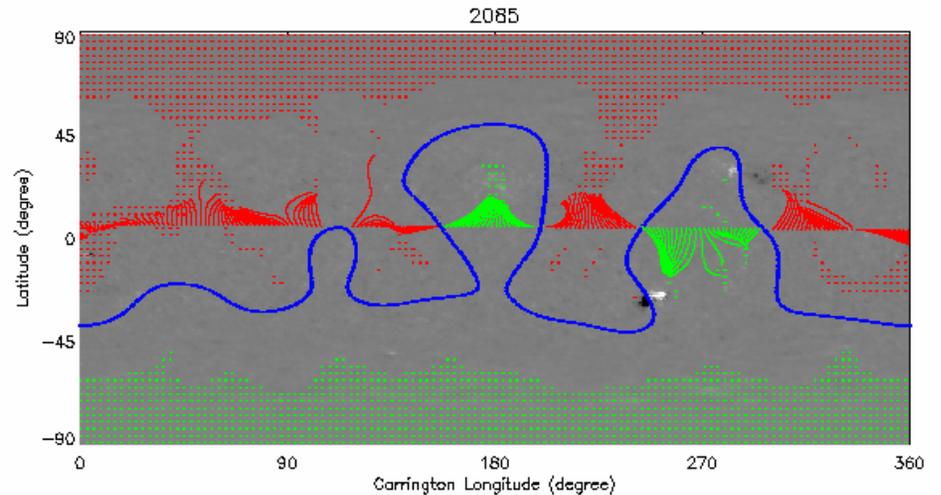


Example: GONG CR 2085

Top left: $R_{SS} = 2.5R_{sun}$

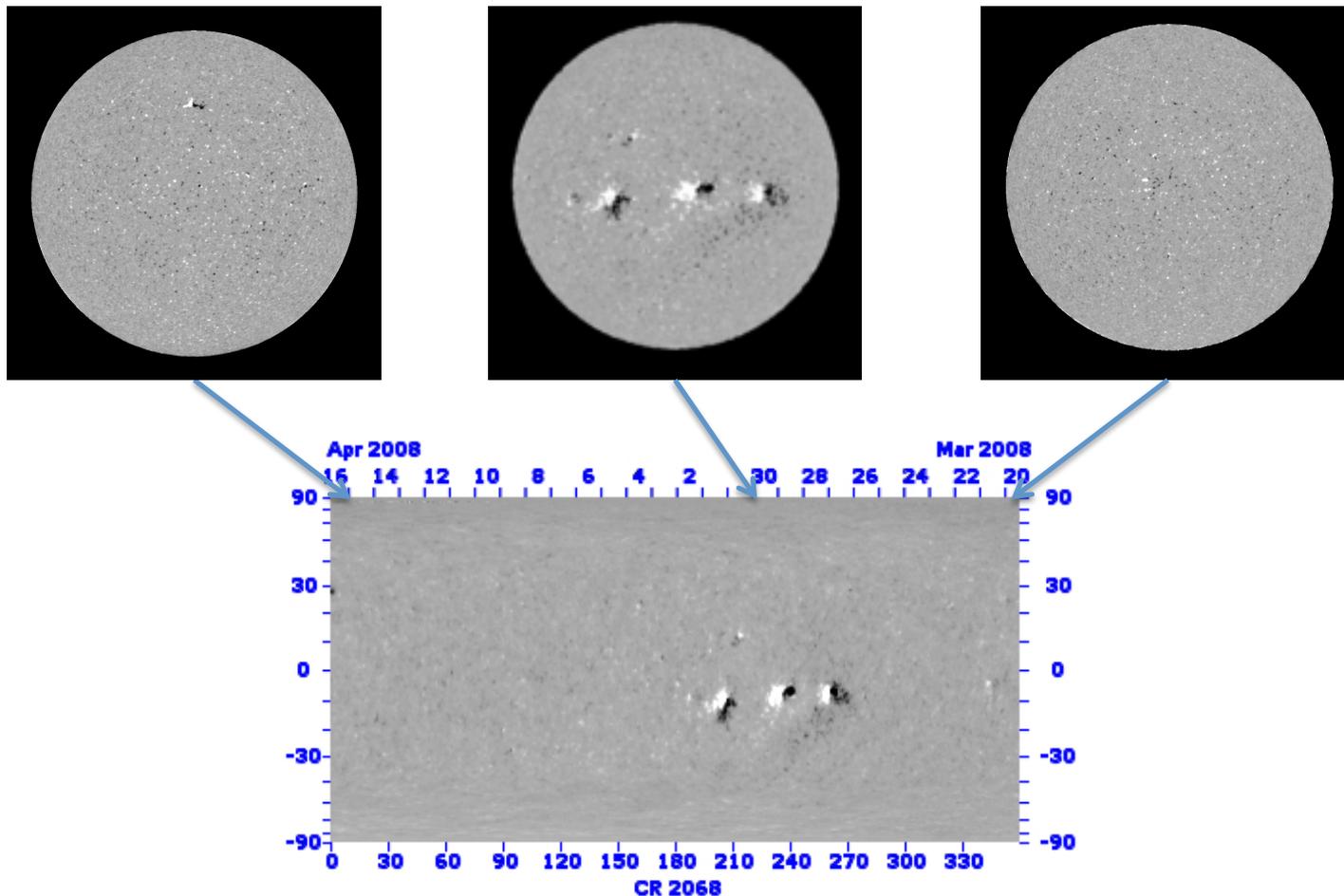
Top right: $R_{SS} = 2.0R_{sun}$

Bottom right: $R_{SS} = 1.5R_{sun}$



Magnetogram Synoptic Map for CR 2068

This image shows GONG's synoptic magnetogram for CR 2068. Three full-disk images are also shown: one from the first day of CR 2068 (right), one from the last day (left) and one from March 30th (middle) when all three active regions were clearly visible on the disk. The arrows show where the central meridian of each image appears on the synoptic map.



NSO/GONG

Integral Synoptic Maps

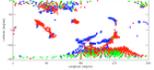
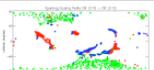
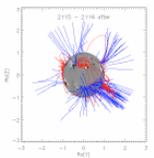
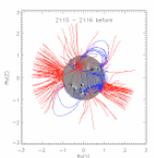
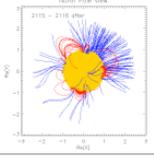
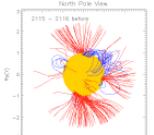
Change in Fields



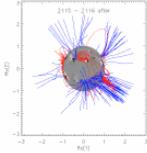
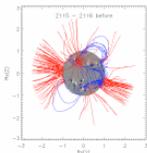
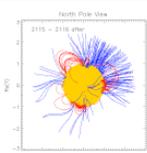
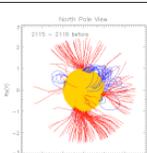
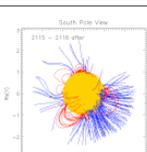
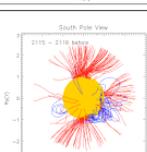
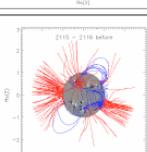
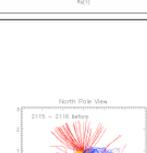
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Change in Fields

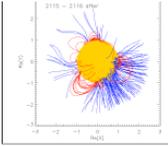
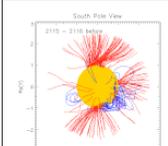
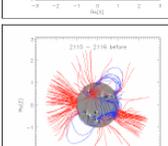
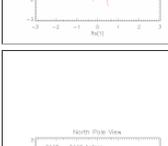
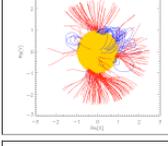
We compare PFSS models using 72 spherical harmonics based on successive magnetograms. We seek fields that are closed/open in the first model and open/closed in the second. These topological changes give a clue of the degree and location of activity in the corona. Strong flux opening to the heliosphere might have significant effects on space weather.

	Opening & Closing Fields
	Opening & Closing Strong Fields
	Opening & Closing Extrapolated Fields -- Before
	Opening & Closing Extrapolated Fields -- After
	Opening & Closing Extrapolated Fields, North View, Before
	Opening & Closing Extrapolated Fields, North View, After

<http://gong.nso.edu/data/magmap/ifch.html>

	Opening & Closing Extrapolated Fields -- Before
	Opening & Closing Extrapolated Fields -- After
	Opening & Closing Extrapolated Fields, North View, Before
	Opening & Closing Extrapolated Fields, North View, After
	Opening & Closing Extrapolated Fields, South View, Before
	Opening & Closing Extrapolated Fields, South View, After
	Animated: Opening & Closing Extrapolated Fields
	Animated: Opening & Closing Extrapolated Fields, North

<http://gong.nso.edu/data/magmap/ifch.html>

	Opening & Closing Extrapolated Fields, South View, Before
	Opening & Closing Extrapolated Fields, South View, After
	Animated: Opening & Closing Extrapolated Fields
	Animated: Opening & Closing Extrapolated Fields, North
	Animated: Opening & Closing Extrapolated Fields, South

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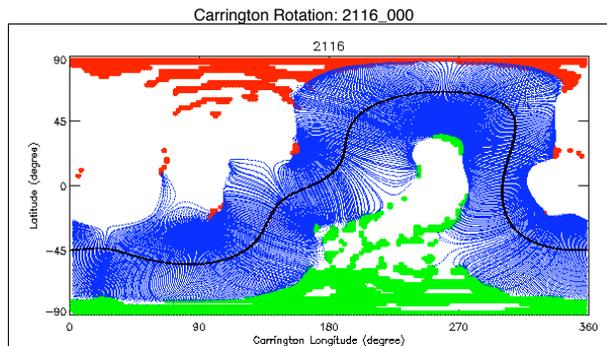
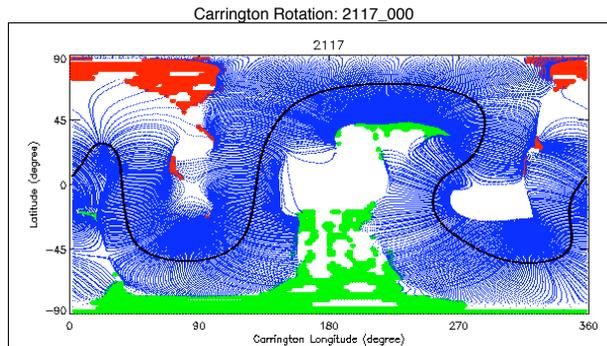
Integral CR Potential-Field Source-Surface Model



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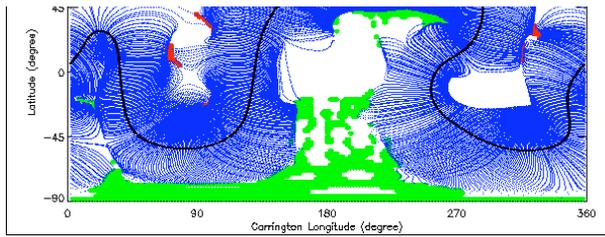
Latest Integral CR Potential-Field Source-Surface Models Synoptic Coronal Hole Plot

Integral CR Version: In these plots only the tallest closed field lines are shown. All field lines reaching $r=2.5R$ are open by assumption and so the tallest closed field lines are those with vanishing radial component just below $r=2.5R$. Such field lines separate regions of open and closed magnetic flux and are therefore a useful simple representation of the global magnetic field topology. The field lines plotted all mark boundaries between regions of open and closed field. Regions of open flux are known as coronal holes, whose footprints in the photosphere are represented here by patches of color: green denotes positive coronal holes and red negative. In the synoptic plots, the neutral line, which meanders in a quasi-sinusoidal pattern between about ± 45 degrees, is drawn in black and the sub-Earth point is indicated by a black cross.

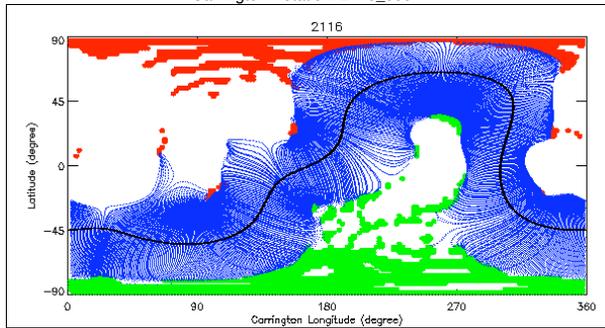


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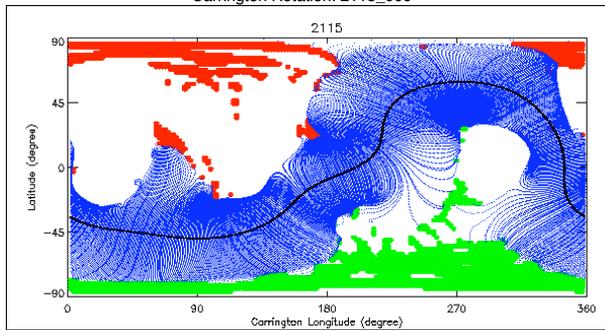
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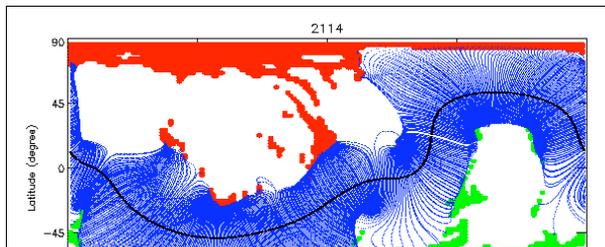
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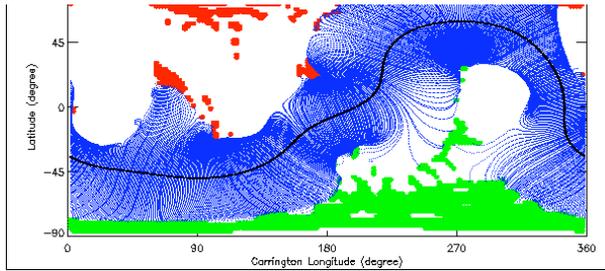
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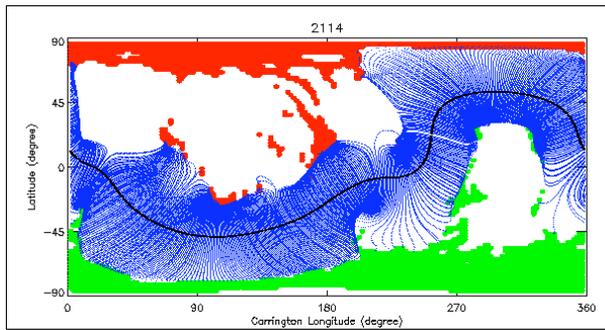
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<http://gong.nso.edu/data/magmap/fmodel.html>



Carrington Rotation: 2114_000



Carrington Rotation: 2113_000

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Integral Synoptic Maps

Potential-Field Source-Surface Models



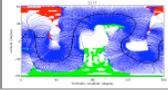
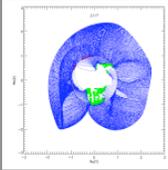
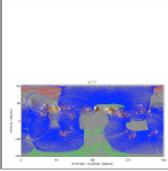
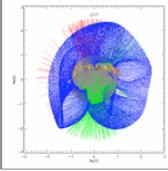
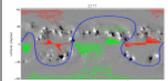
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Latest Integral Potential-Field Source-Surface Models

For each standard hourly synoptic magnetogram we give a potential-field source-surface model of the coronal field. To capture large-scale field structure in a model we may assume that there are no significant electric currents in the corona. We use Altschuler & Newkirk's (1969) spherical harmonic solution which includes a source surface high in the corona where the field lines are forced to be radial. This models the effect on the field of the outflowing solar wind.

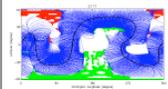
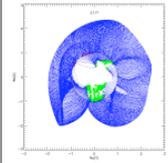
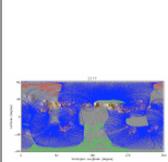
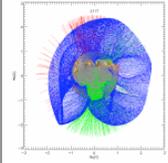
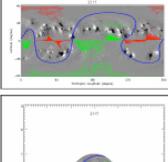
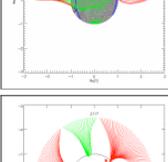
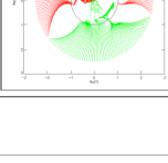
The source surface is fixed at $2.5R$ where R is the radius of the Sun. We plot the potential fields with harmonic terms 1 to 36 for our integral CR synoptic maps, omitting the monopole term. For large-scale coronal fields, expansion of the fields to order 36 is more than sufficient.

We thank Janet Luhmann, Yan Li and Xuepu Zhao for the potential-field source-surface and spherical harmonic transform codes used to develop this product.

	Synoptic Coronal Hole Plot
	Line-Of-Sight Coronal Hole Plot
	Synoptic Field Plot
	Line-Of-Sight Field Plot
	Synoptic Ecliptic-Plane Field Plot

<http://gong.nso.edu/data/magmap/ipfss.html>

ccccccc add to develop the product.

	Synoptic Coronal Hole Plot
	Line-Of-Sight Coronal Hole Plot
	Synoptic Field Plot
	Line-Of-Sight Field Plot
	Synoptic Ecliptic-Plane Field Plot
	Line-Of-Sight Ecliptic-Plane Field Plot
	Top View Ecliptic-Plane Field Plot

<http://gong.nso.edu/data/magmap/ipfss.html>

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Generate an ad hoc GONG Magnetogram movie:
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 Supported Formats: Interactive Movie, Animated GIF, MPEG, TAR File

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	Janus Movie
	Combination Standard and Janus Movie
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	Models: Line-Of-Sight Coronal Hole Plot
	Combination Synoptic Map and Synoptic Coronal Hole Plot Model
	Combination Models, Synoptic Coronal Hole Plot and Line-Of-Sight Coronal Hole Plot
	Models: Synoptic Field Plot
	Models: Line-Of-Sight Field Plot
	Models: Synoptic Ecliptic-Plane Field Plot
	Models: Line-Of-Sight Ecliptic-Plane Field Plot

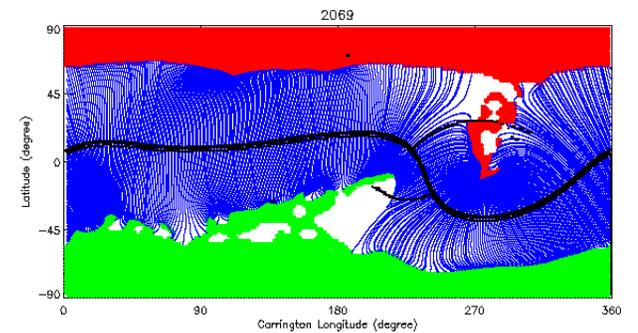
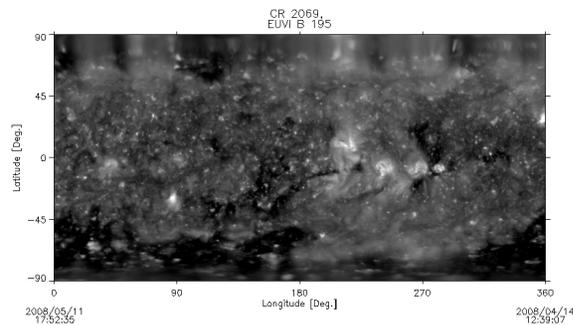
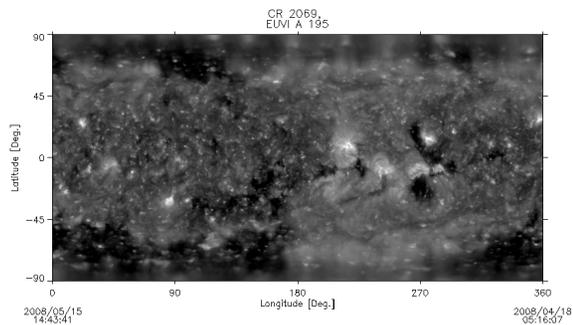
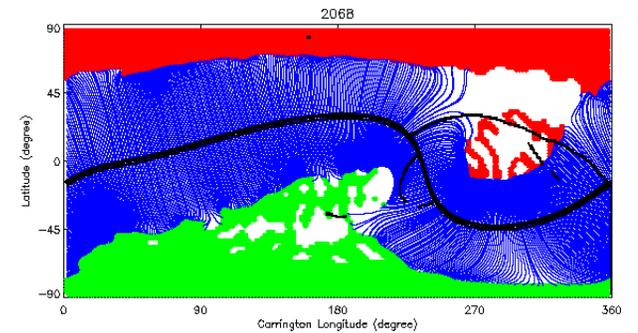
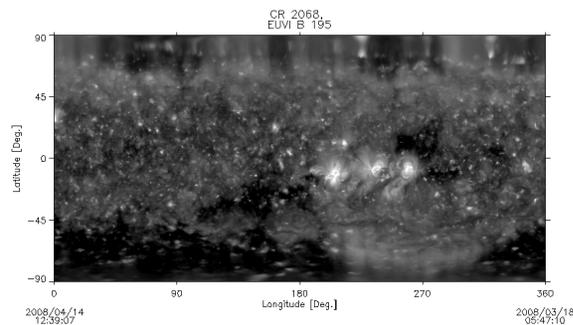
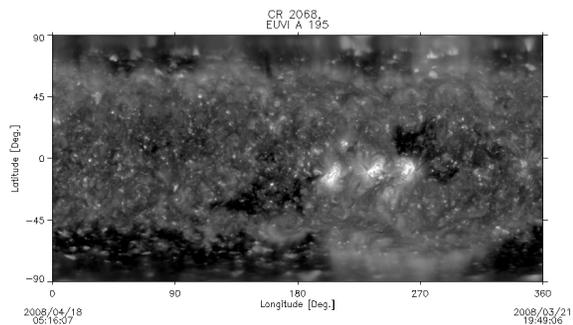
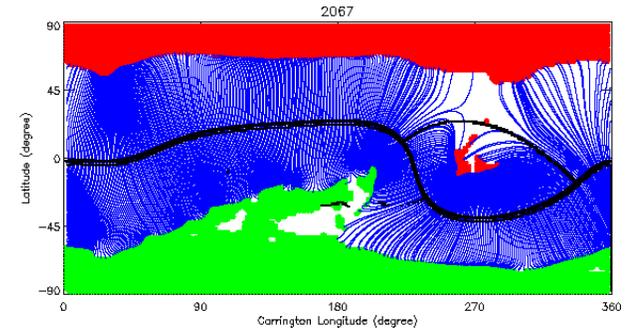
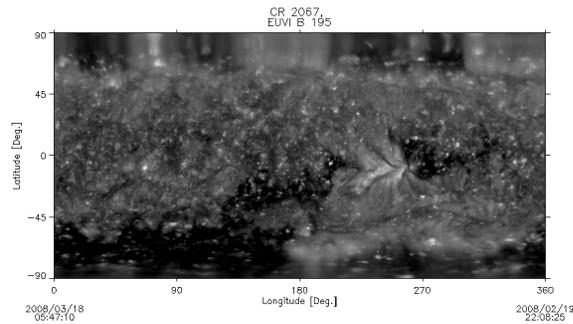
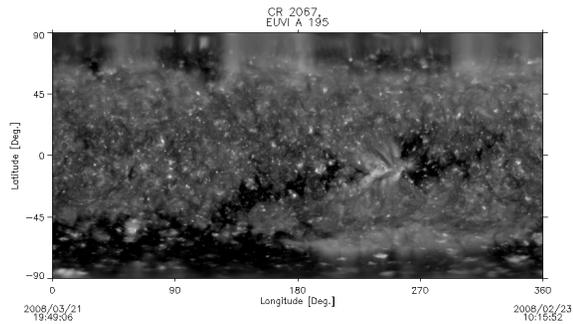
	Models: Top View Ecliptic-Plane Field Plot
	Models: Simulated Line-of-Sight Views from Earth and from NASA's STEREO A & B Spacecraft
	Integral Carrington Rotation Movie
	Models: Integral CR Synoptic Coronal Hole Plot
	Models: Integral CR Line-Of-Sight Coronal Hole Plot
	Models: Integral CR Synoptic Field Plot
	Models: Integral CR Line-Of-Sight Field Plot
	Models: Integral CR Synoptic Ecliptic-Plane Field Plot
	Models: Integral CR Line-Of-Sight Ecliptic-Plane Field Plot
	Models: Integral CR Top View Ecliptic-Plane Field Plot
	Integral CR Change In Fields: Opening & Closing Fields
	Integral CR Change In Fields: Opening & Closing Strong Fields

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CR 2067-2069: STEREO SECCHI EUVI synoptic maps compared to GONG PFSS coronal holes.



CR 2067-2069: STEREO SECCHI COR1 synoptic maps compared to GONG PFSS streamers.

