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MHD simulation of the evolution of the solar corona around August 1st 2010 using the HMI solar magnetic field data

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abstract

We will report results of the MHD simulation of the solar corona and solar wind using the HMI magnetic field data, especially focusing on a simulated eruption of a coronal streamer that reasonably corresponds to a large-scale coronal events observed on August 1, 2010.

The pre-event coronal situation is prepared through the time-relaxation MHD simulation using the synoptic map data of the solar surface magnetic field for a period of the Carrington Rotation 2098. Then, the observation-based global magnetic field evolutions from CR 2098 to 2099 are introduced in the simulation by means of a boundary model we recently developed, which allows to trace numerically the sub-Alfvenic MHD responses of the corona.

The simulated coronal features include the formation of the two twisted coronal magnetic field structures along the magnetically inversion lines at the lowermost corona (coinciding the two observed filaments at west-north part of the solar disk, seen on July 31) and the large-scale outward motions and decay of the closed-field streamer above the two twisted-field regions.

Our MHD simulation model did not include the triggering event directly, and our simulations were done in somewhat low resolution in space. However, the reasonable successes in reproducing coronal features relating a specific event in a well-known manner (using the synoptic map format data and the MHD simulation model) shows that the new dataset from HMI will be useful for the models, such as the MHD and the potential field models, as the previous dataset by SOHO/MDI.

Introduction

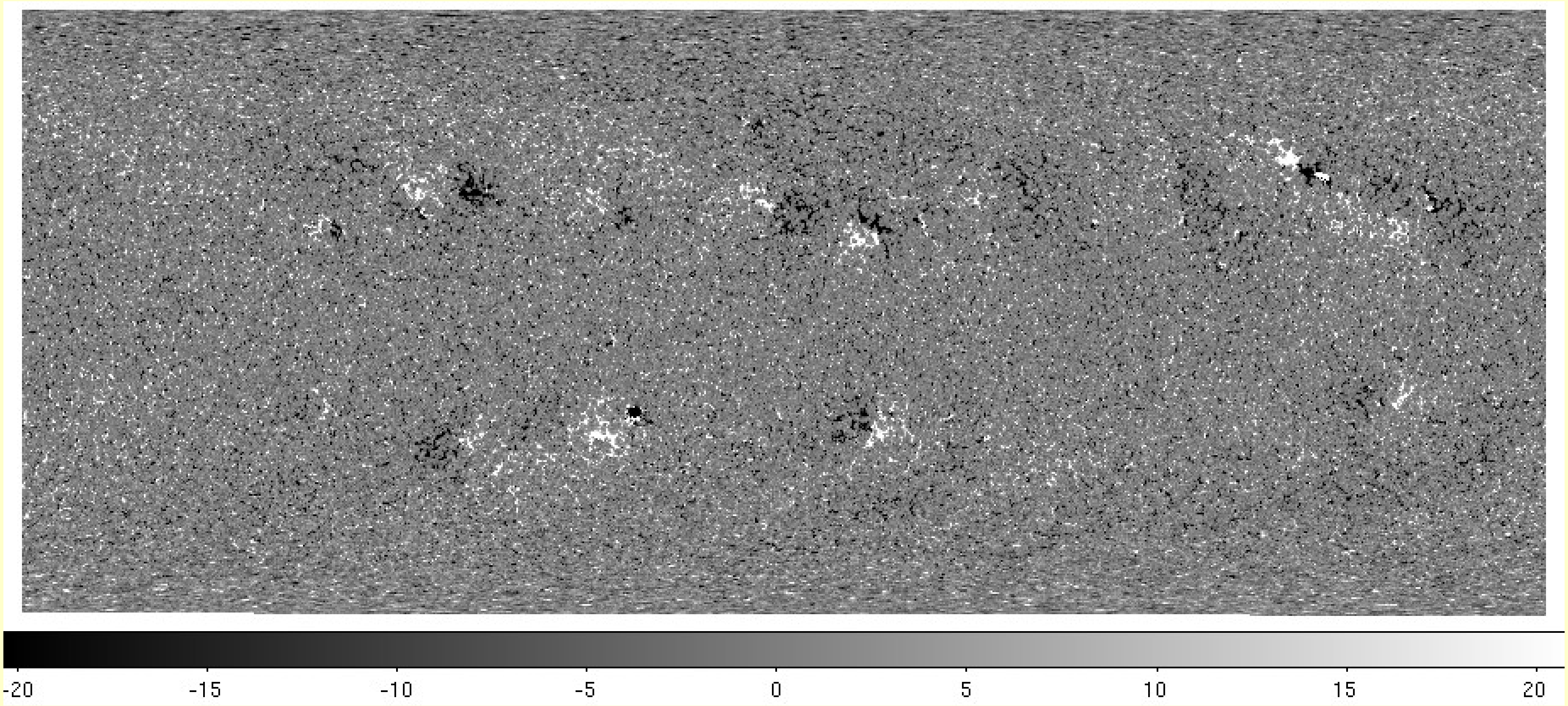
- We used the preliminary version of SDO/HMI synoptic maps for CR2098 and CR 2099. The two maps are used to set up the boundary time-evolutions driving the corona simulated.

- The synoptic maps from HMI are of preliminary ones; formal version will be available soon.

- Our model (1) introduces the time-evolution of Br at the inner simulation boundary sphere, (2) satisfies the divergence-free condition of magnetic field in the computation domain, (3) satisfies the characteristics properties of MHD hyperbolic system on the inner boundary, (4) derives the full-MHD responses of the global corona to the large-scale (low spatial resolution) variations of the solar surface magnetic field.

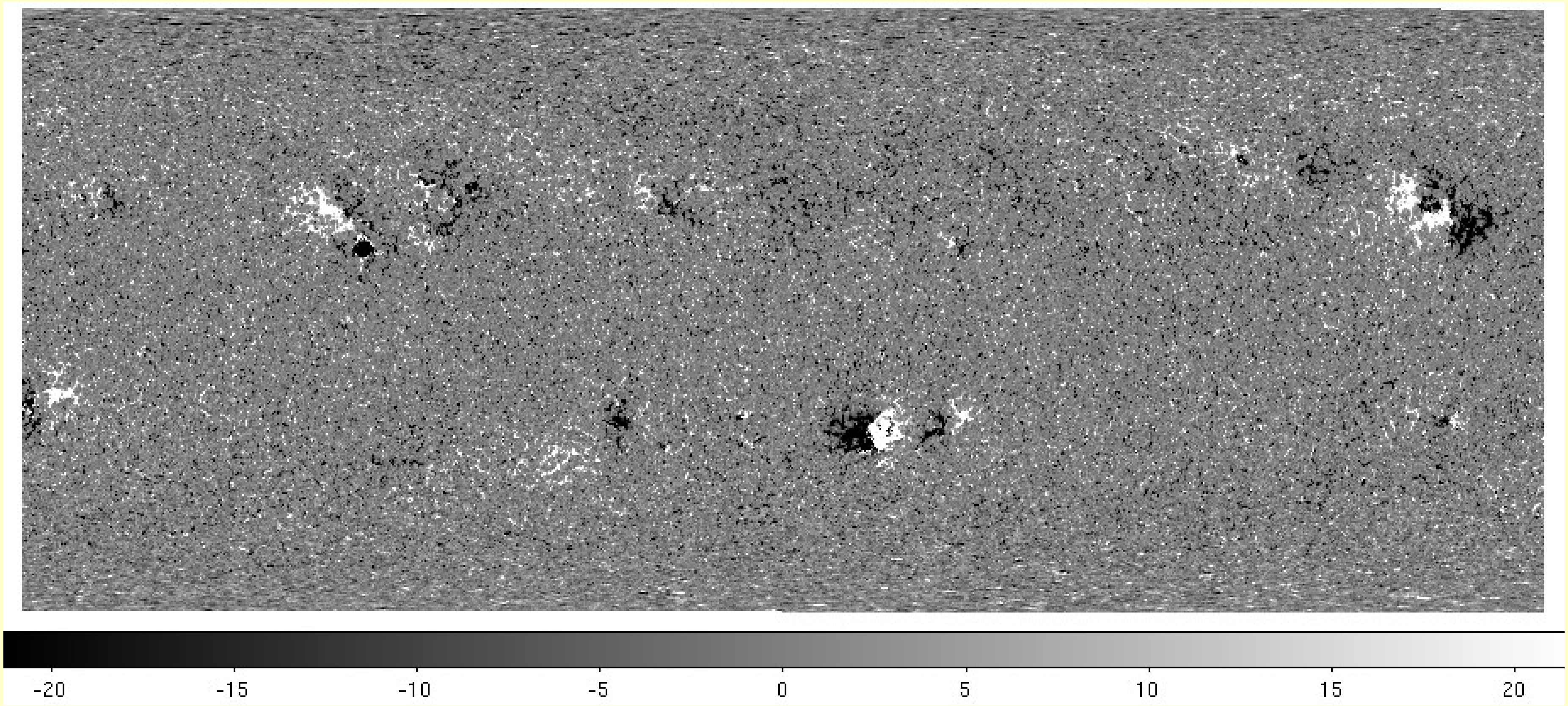
Data: SDO/HMI magnetogram, LoS

CR2098



Data: SDO/HMI magnetogram, LoS

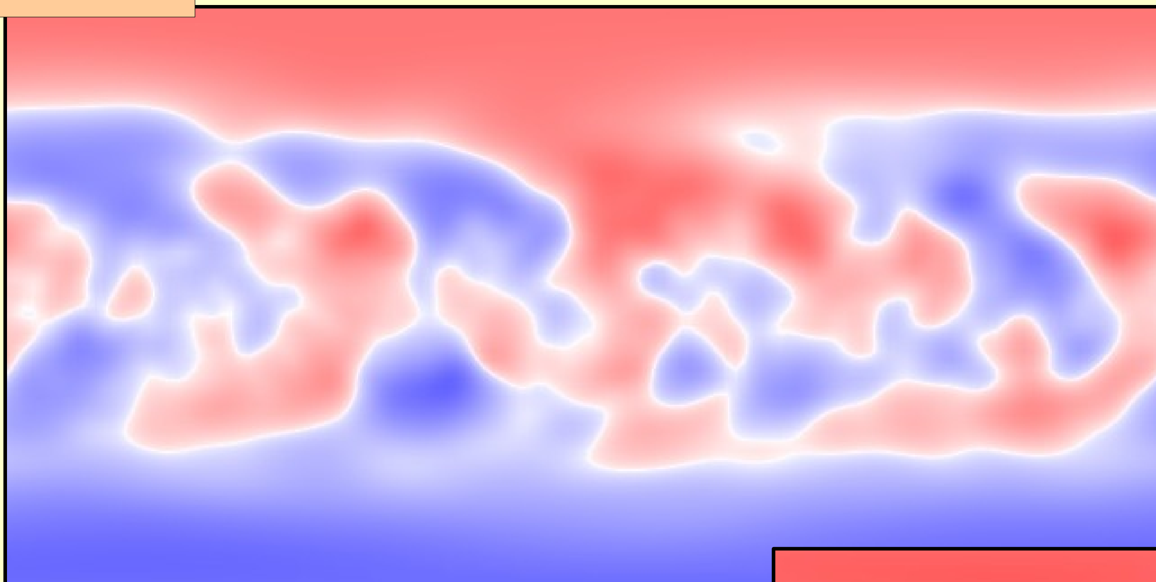
CR2099



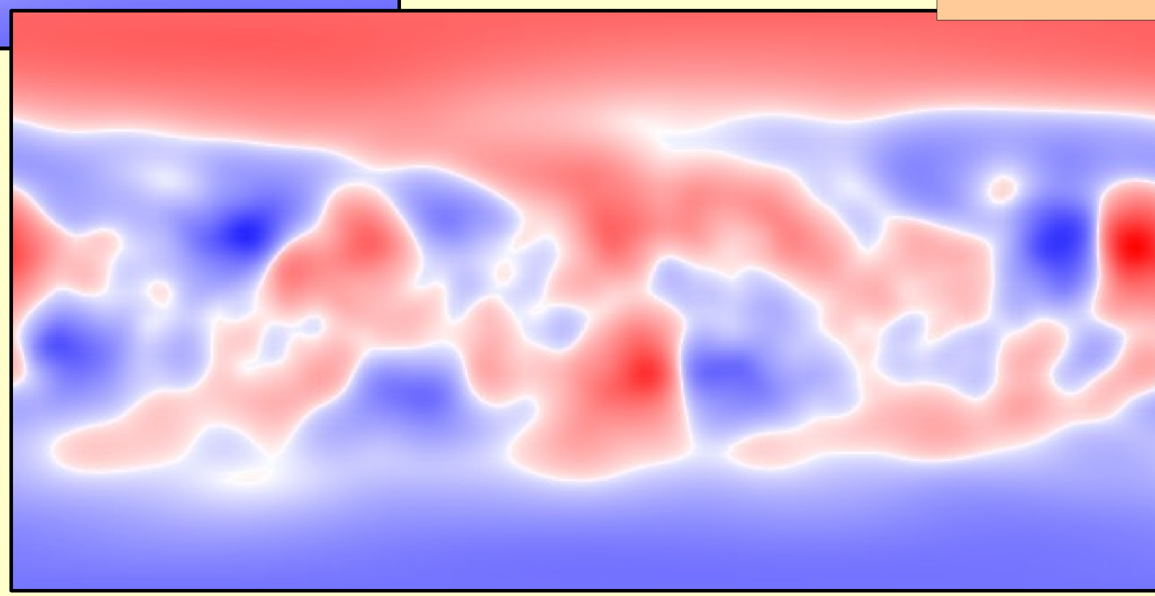
Truncated at ~ +/- 20 Gauss

Smoothed maps

CR2098



CR2099



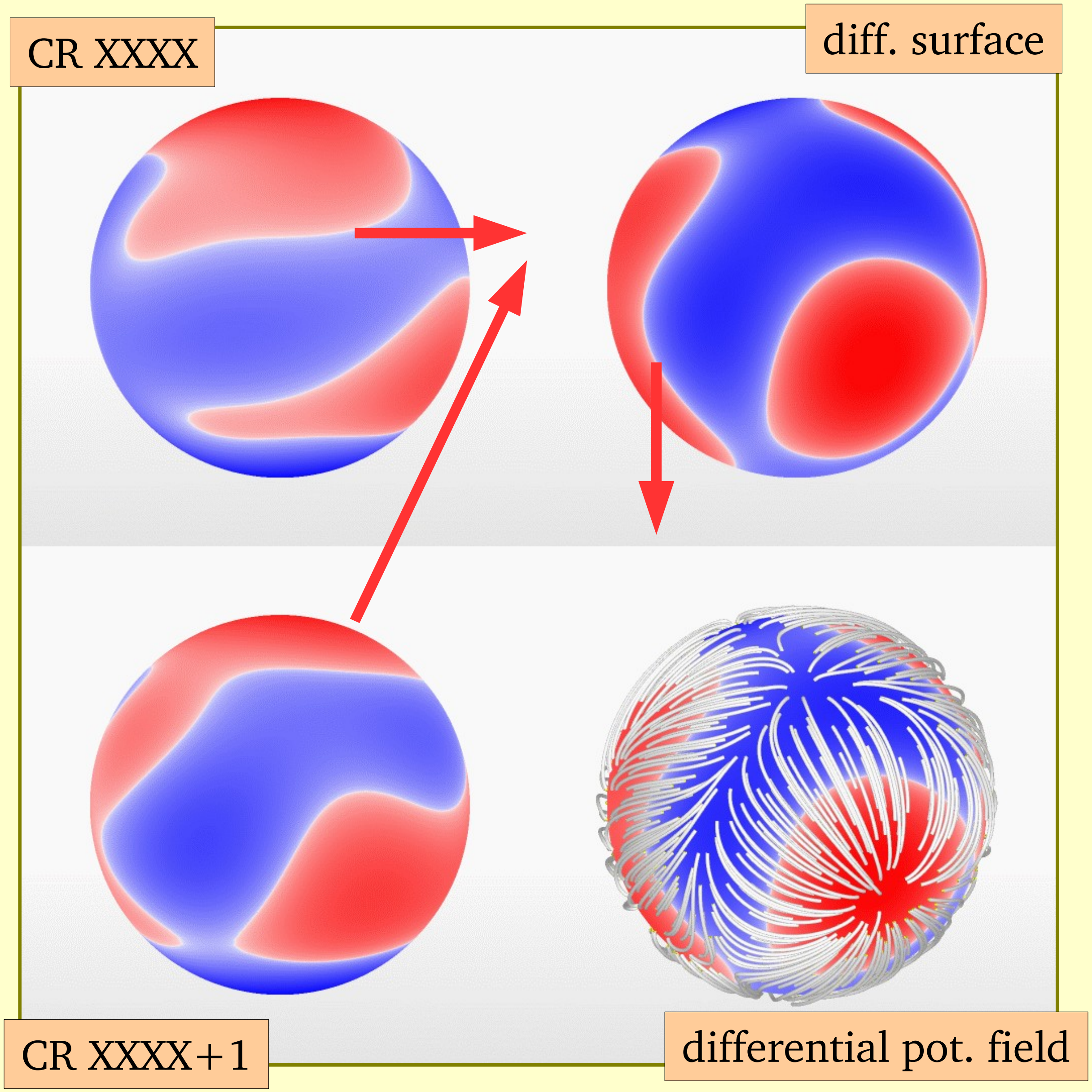
Truncated at ~ +/- 7 Gauss

MHD code

- solves the time-dependent three-dimensional nonlinear MHD system.
- has the boundary surface treatment, based on the concept of the projected normal characteristics (Nakagawa,Y., 1980 ; Han,S. Wu,S.T., and Dryer,M., 1988 ; Hayashi,K., 2005)
- includes the boundary layer model (Hayashi,K., 2006~2008), in which the temporal variation, *dB/dt,* is imposed, keeping the divergence-free condition, in conjunction with the projected normal characteristic method satisfying the hyperbolic system of the MHD equations.
- is written in Fortran 77/90 with OpenMP and in part MPI for parallelism.

$$
\begin{aligned}
\frac{\partial \varrho}{\partial t} &= -\nabla \cdot (\varrho \boldsymbol{v}) \\
\frac{\partial (\varrho \boldsymbol{v})}{\partial t} &= -\nabla \left(P + \varrho \boldsymbol{v} : \boldsymbol{v}\right) + \frac{1}{4\pi} \nabla \left[\boldsymbol{B} : \boldsymbol{B} - \frac{1}{2} B^2 \mathbf{I}\right] \\
&+ \varrho \left(\boldsymbol{g} + (\boldsymbol{\Omega} \times \boldsymbol{r}) \times \boldsymbol{\Omega} + 2\,\boldsymbol{v} \times \boldsymbol{\Omega}\right) \\
\frac{\partial \boldsymbol{B}}{\partial t} &= -\nabla \cdot (\boldsymbol{v} : \boldsymbol{B} - \boldsymbol{B} : \boldsymbol{v}) \\
\frac{\partial}{\partial t}\left[\frac{1}{2}\varrho v^2 + \frac{P}{\gamma - 1} + \frac{1}{8\pi} B^2\right] &= -\nabla \cdot \left[\left(\frac{1}{2}\varrho v^2 + \frac{\gamma P}{\gamma - 1}\right) \cdot \boldsymbol{v} - \frac{1}{4\pi} (\boldsymbol{v} \times \boldsymbol{B}) \times \boldsymbol{B}\right] \\
&+ \varrho \boldsymbol{v} \cdot \left[\boldsymbol{g} + (\boldsymbol{\Omega} \times \boldsymbol{r}) \times \boldsymbol{\Omega}\right]
\end{aligned}
$$

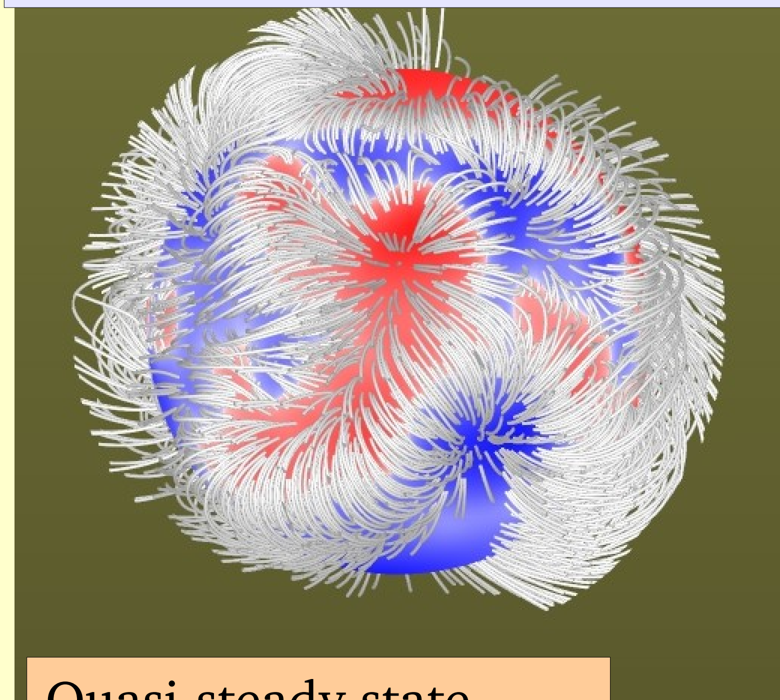
Three-dim. differential potential field



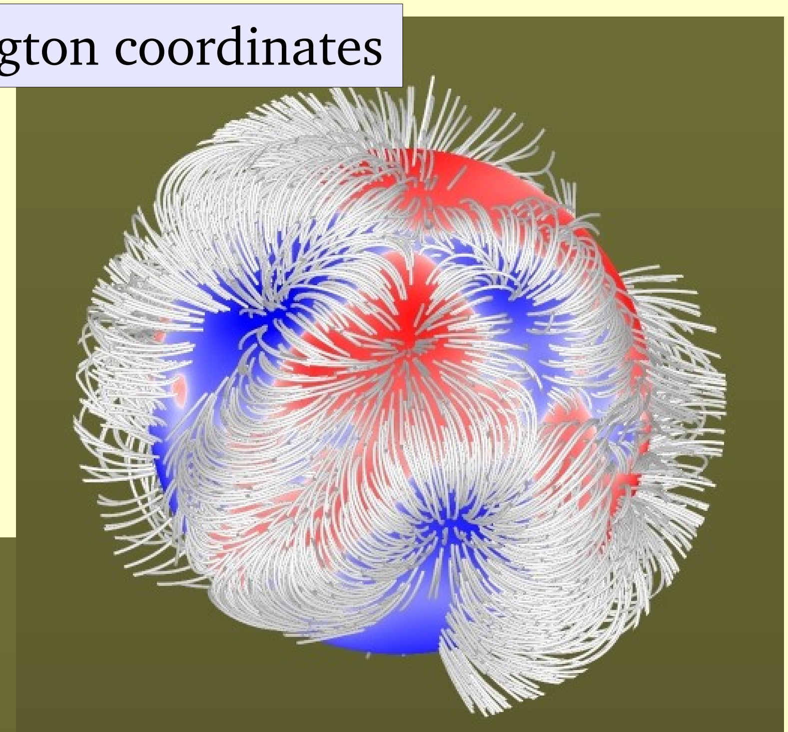
The temporal evolution of the boundary magnetic field is made by imposing the differential potential field confined at the lower corona. We set the “thickness” of such confined potential field to be 0.1 solar radii. The spatial resolutions are of 2.7 degree (using raw data map) or about 20 degree (using up to 7-th term of the spherical harmonic polynomial)

Field lines at the lower corona

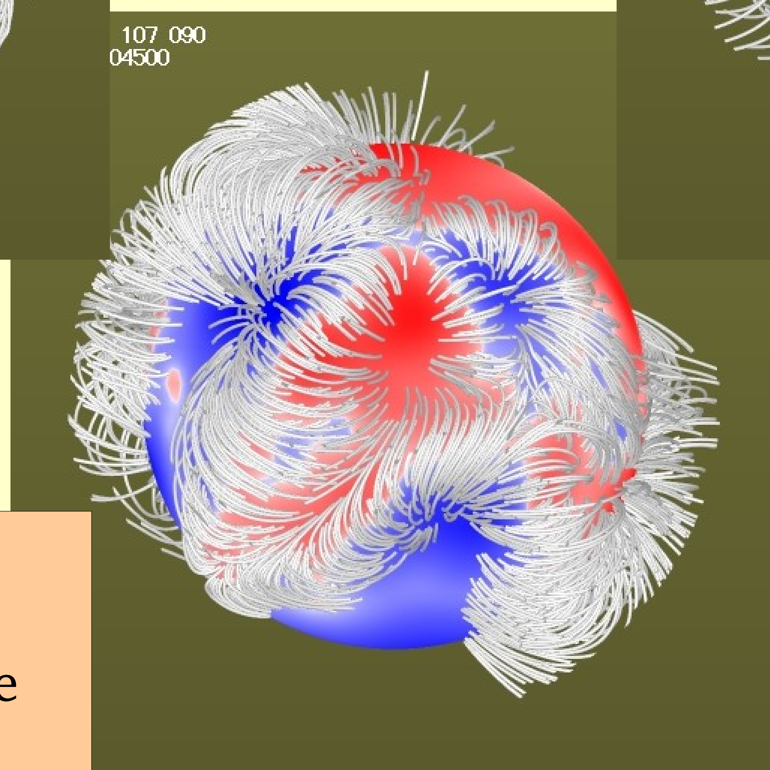
Viewed from Earth's position on August 1st, in Carrington coordinates



Quasi-steady state
with syn. map CR 2098

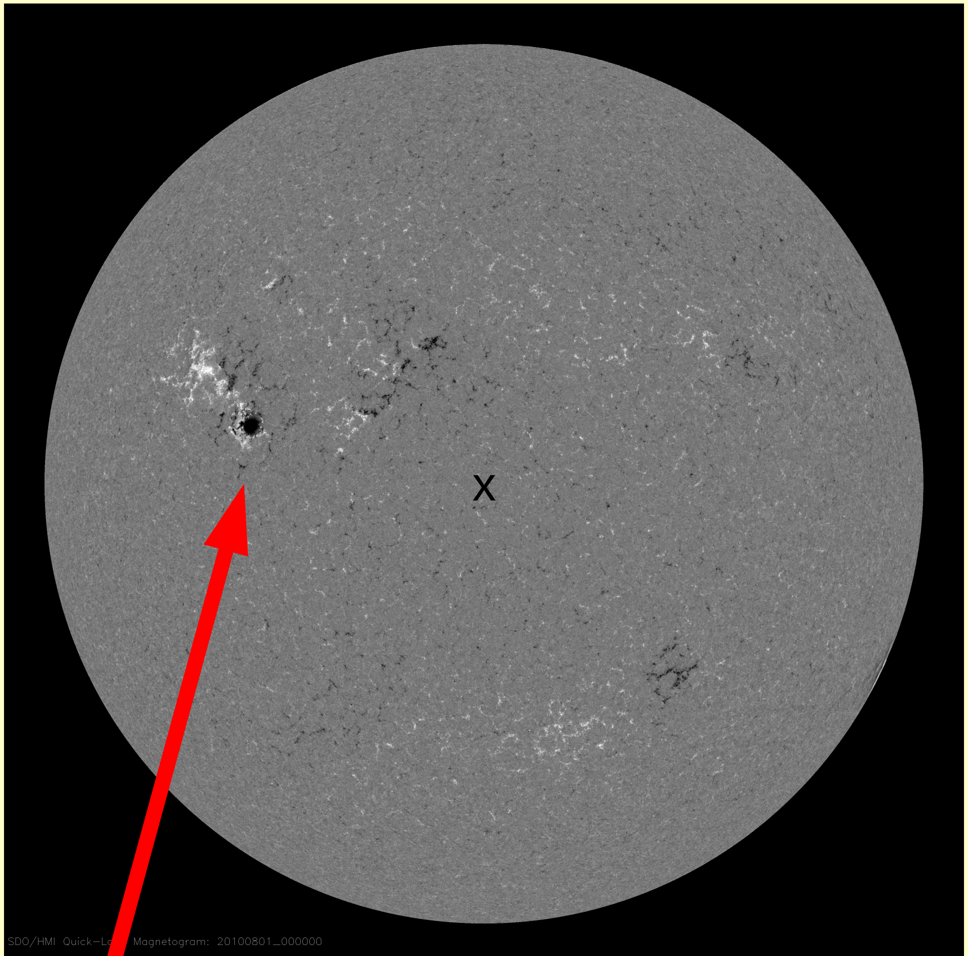


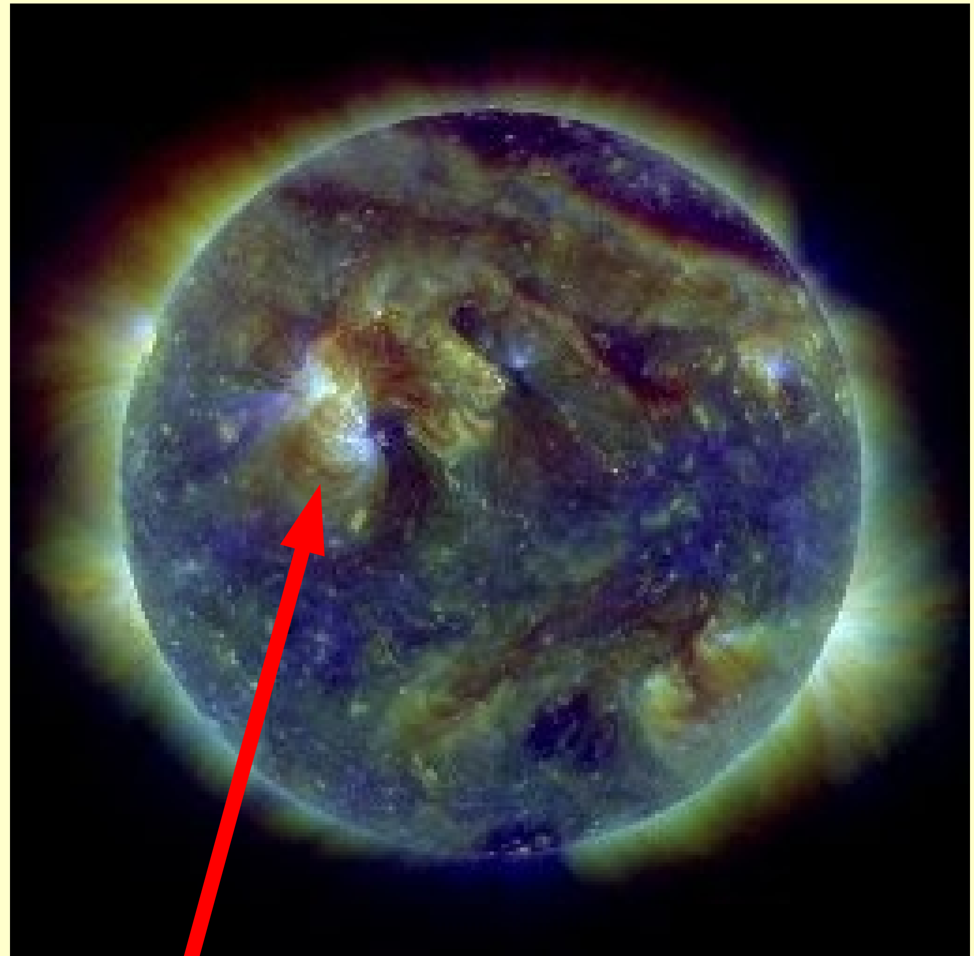
Quasi-steady state
with syn. map CR 2099



Simulated state at a time corresponding to CR2099, starting with the steady state at CR2098

Observations on August 01, 2010



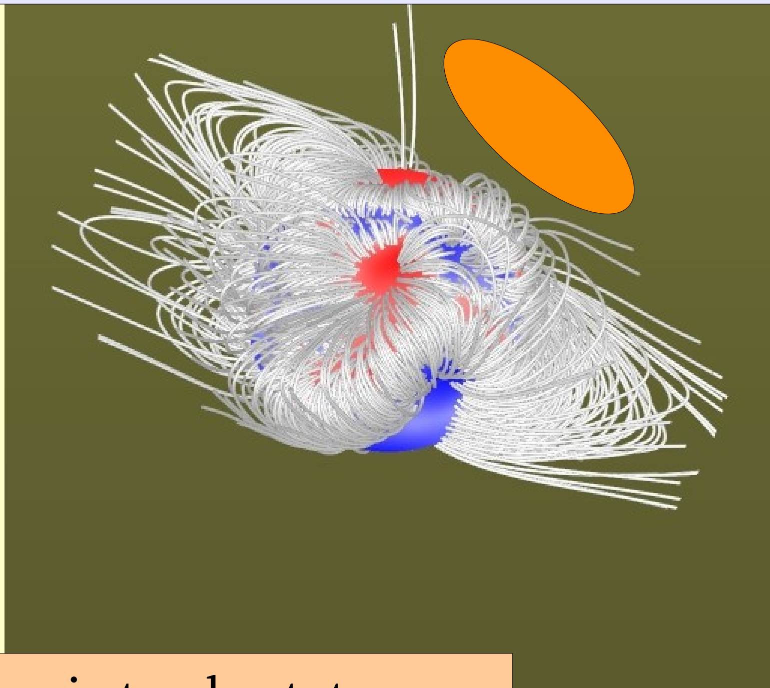


AR11092

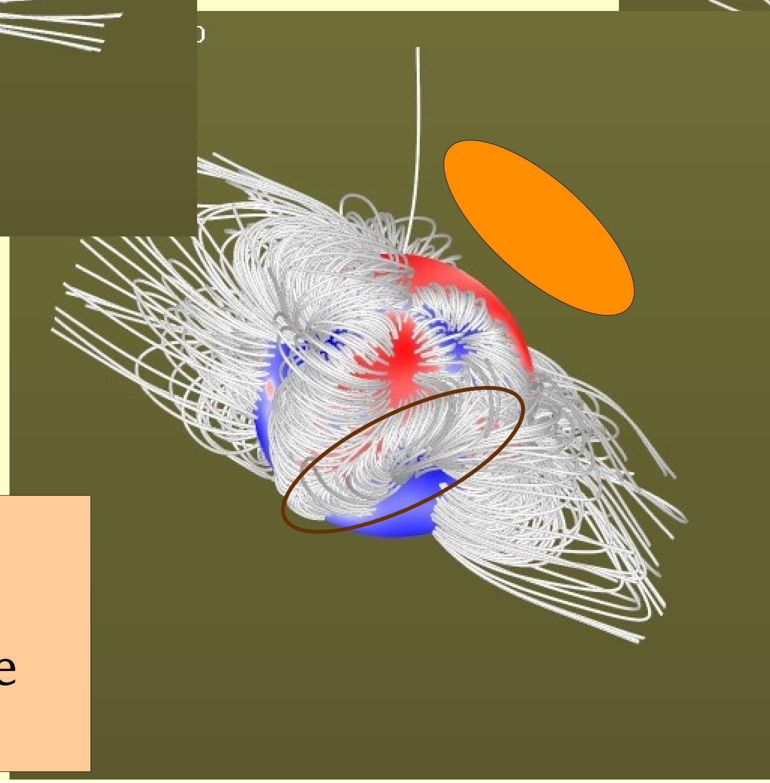
211/193/171
The Sun Today/LMSAL

Coronal magnetic structures

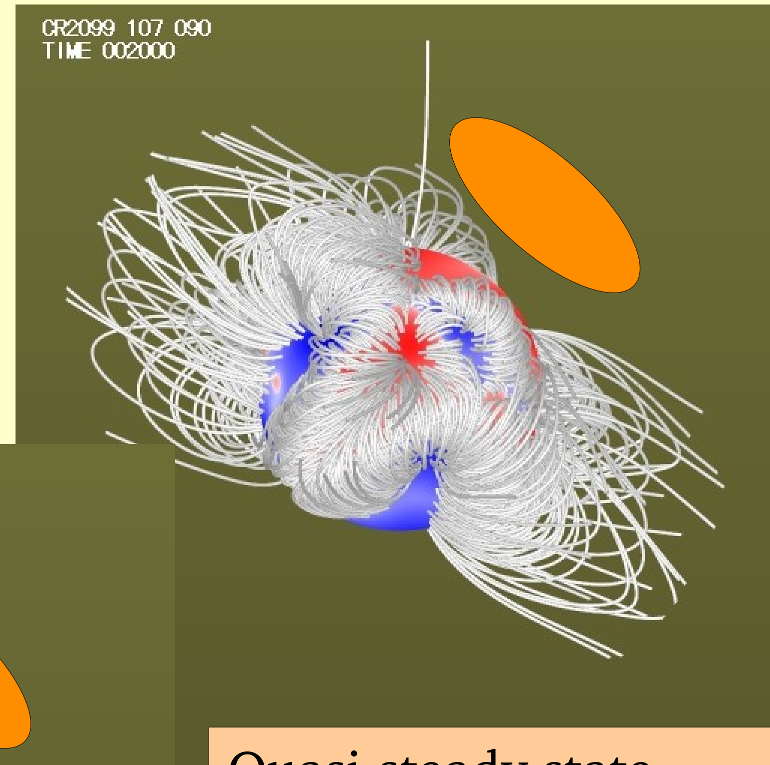
Viewed from Earth's position on August 1st, in Carrington coordinates



Quasi-steady state
with syn. map CR 2098

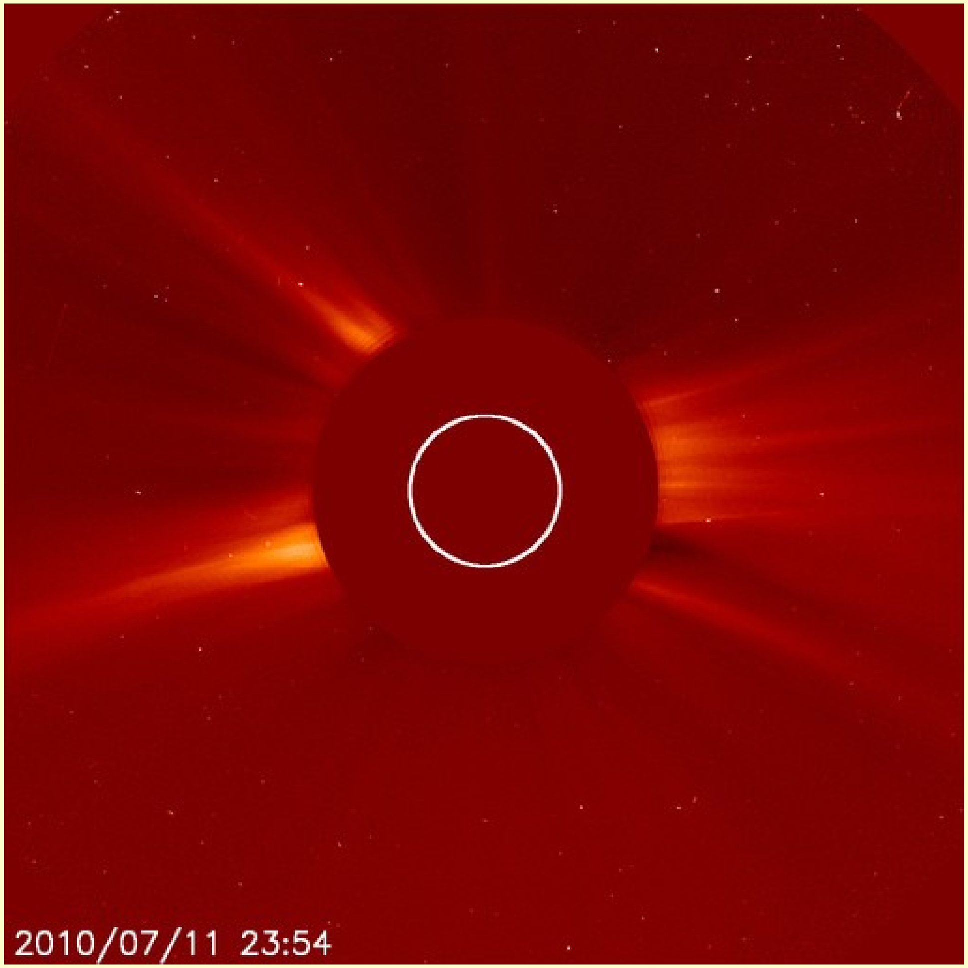


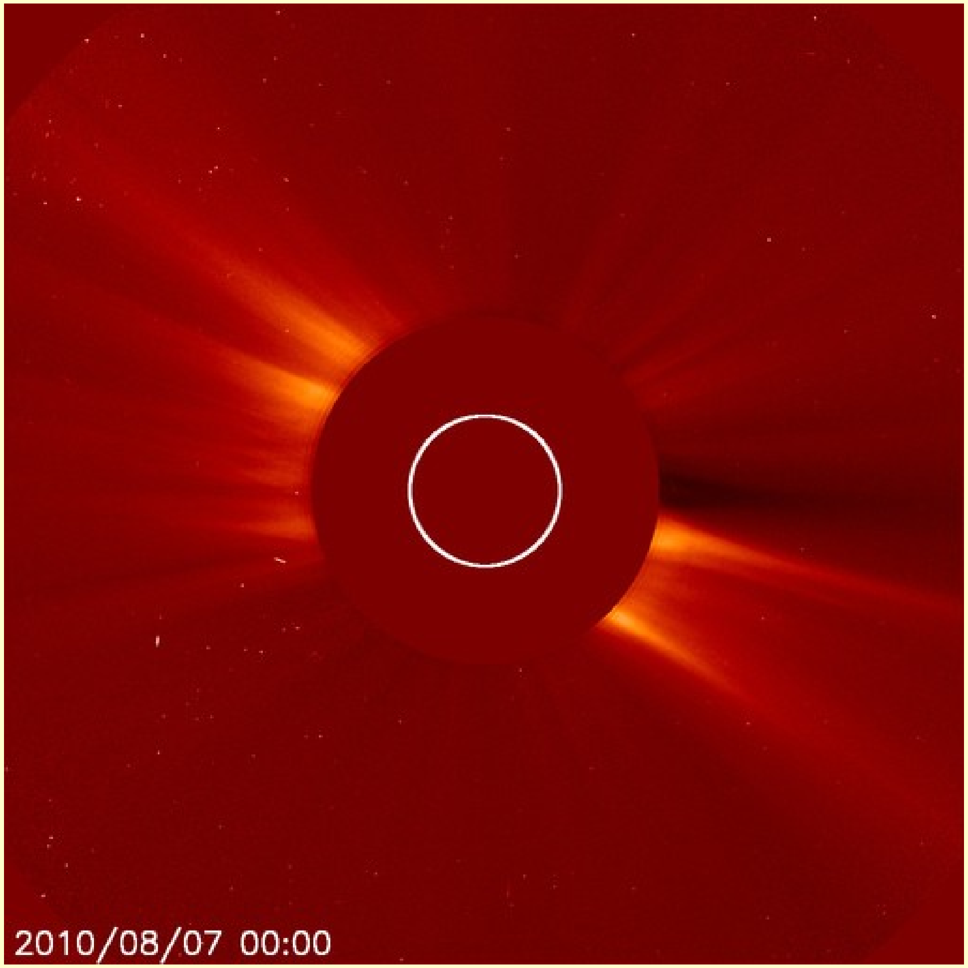
Simulated state at a time
corresponding to CR2099,
starting with the steady state
at CR2098



Quasi-steady state
with syn. map CR 2099

Corona (seen ~90 dgr. east)

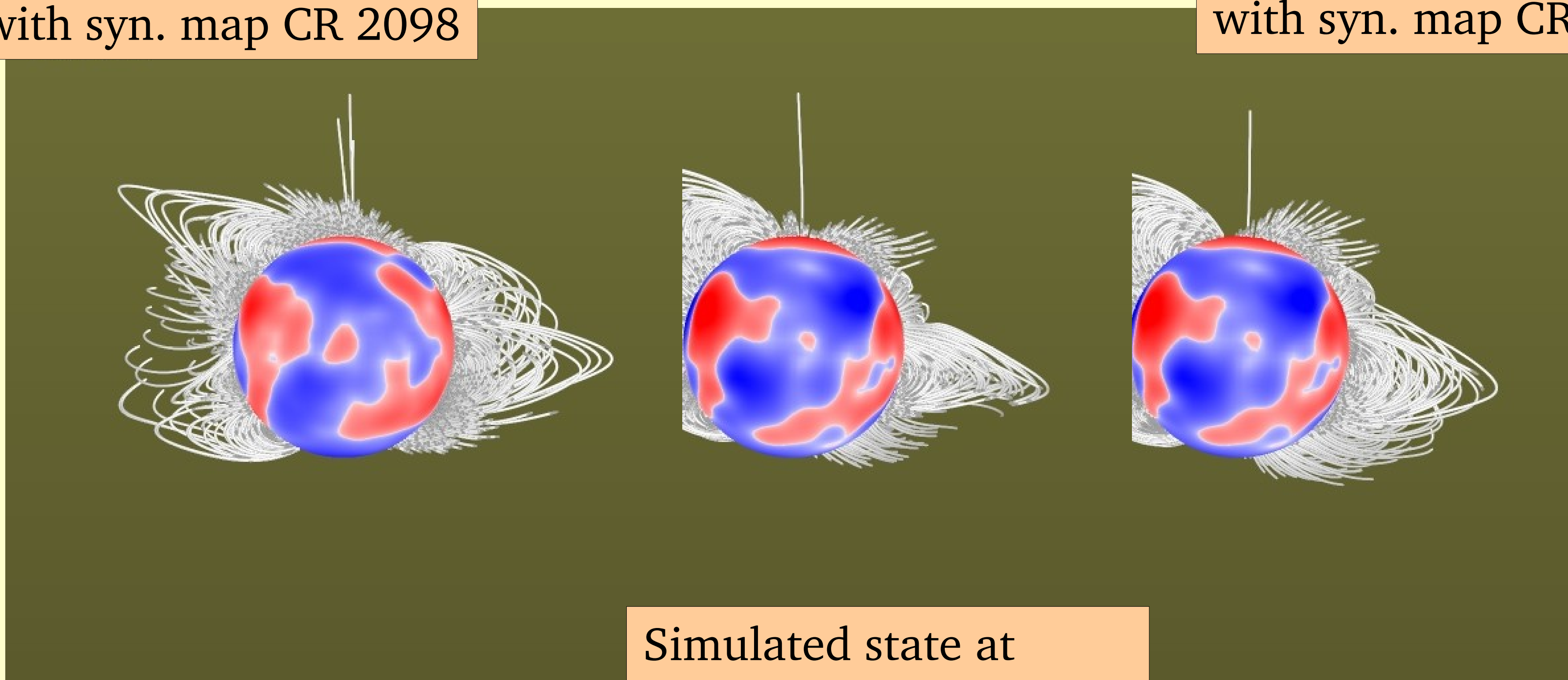




Closed-field streamer

Quasi-steady state
with syn. map CR 2098

Quasi-steady state
with syn. map CR 2099

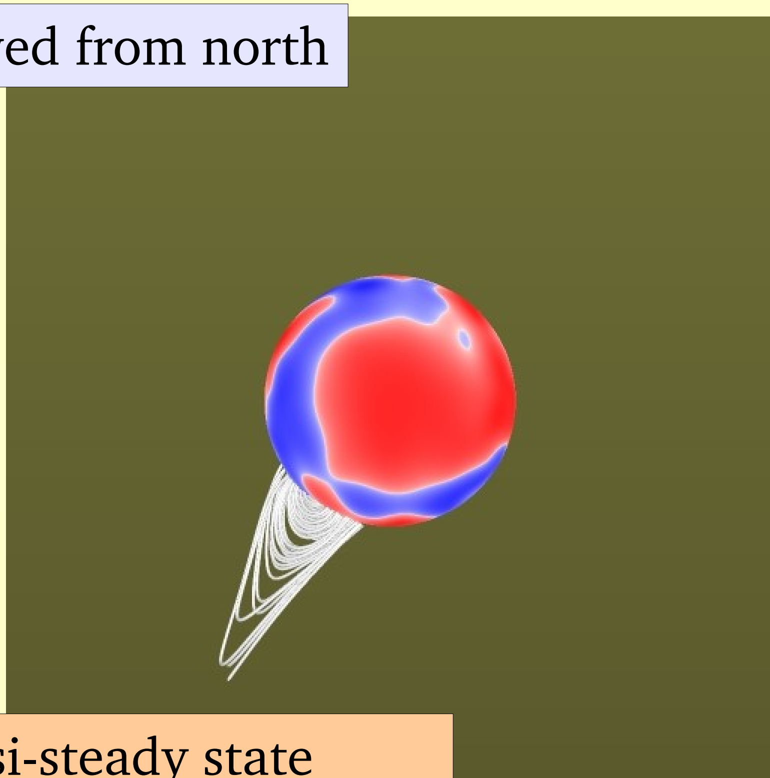


Simulated state at
a time corresponding to
CR2099, starting with
steady state at CR2098

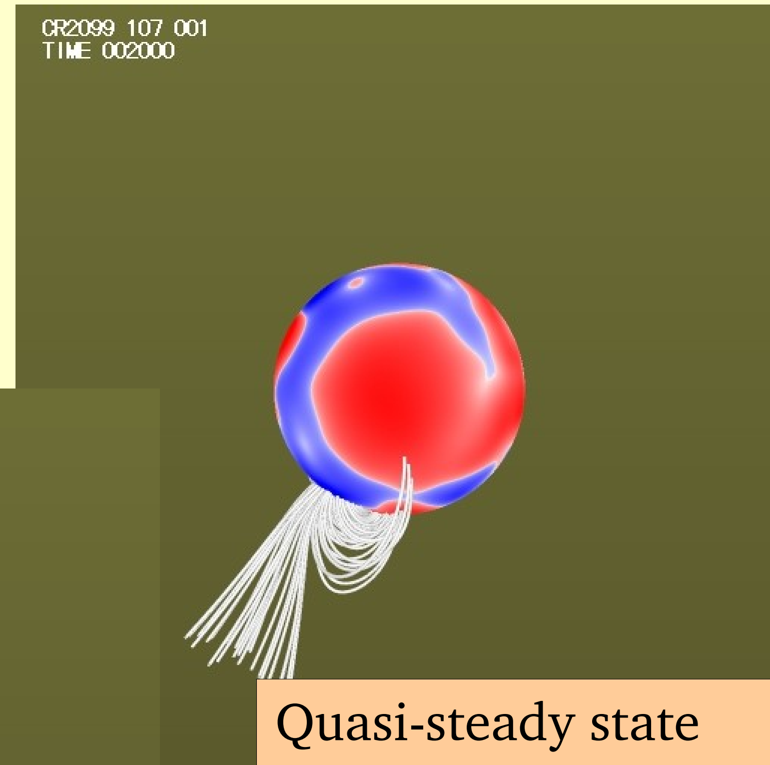
Viewed from a point, approximately 90 degree east from
Earth's position on August 1st, in Carrington coordinates

Mag. Connecting from/to AR11092

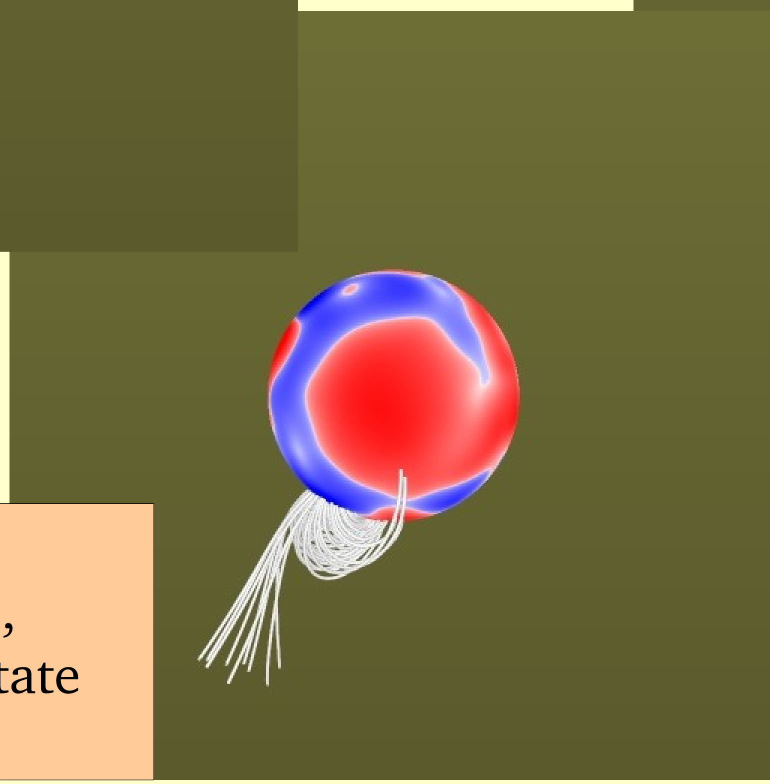
Viewed from north



Quasi-steady state
with syn. map CR 2098



Quasi-steady state
with syn. map CR 2099

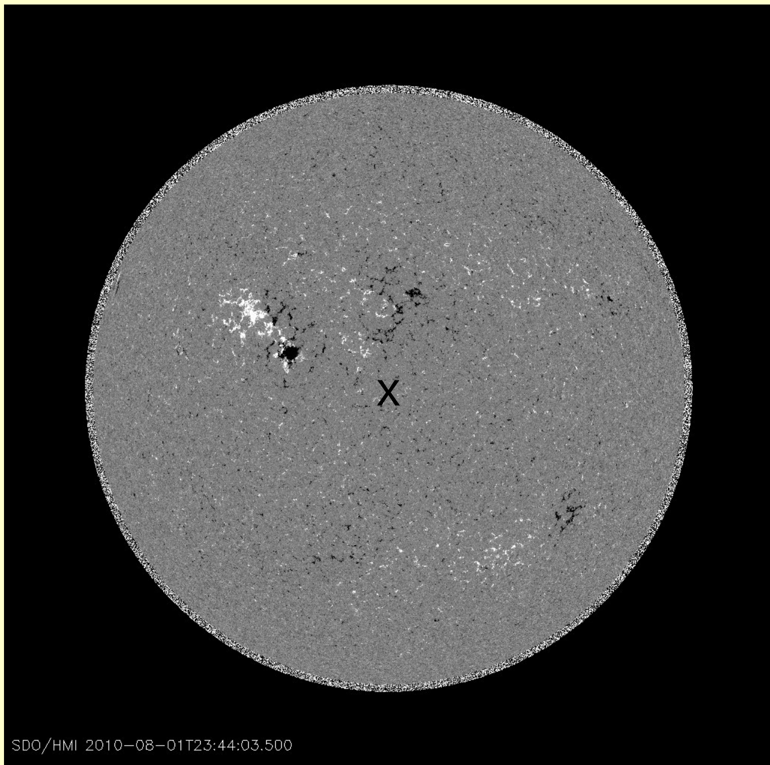


Simulated state at a time
corresponding to CR2099,
starting with the steady state
at CR2098

summary

- We used two synoptic maps for two consecutive Carrington Rotation periods, CR 2098, and 2099, in this simulation study. The maps we used were made in the preliminary, test data processing.
- A model we had developed is used in order to achieve time-varying boundary *Br* that fully matches the measurement maps at the two instances of the observation. The divergence-free condition is preserved.
- Simulation results with both the time-varying and fixed *Br* were carried out. Variations of coronal magnetic field topology were well be traced, with the models and the HMI data.

- The official version of the HMI synoptic maps will be soon available; the calibrated definitive ones will be regularly generated on one-per-CR basis, and the preliminary daily-updated one will be generated on 1～4/day basis. Other formats such as the synchronic frame will be regularly produced.



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- MHD simulations for

rotation (e.g. Lionello e
plasma motions derived
Mac ; Yeates
coronal changes respon
motion.