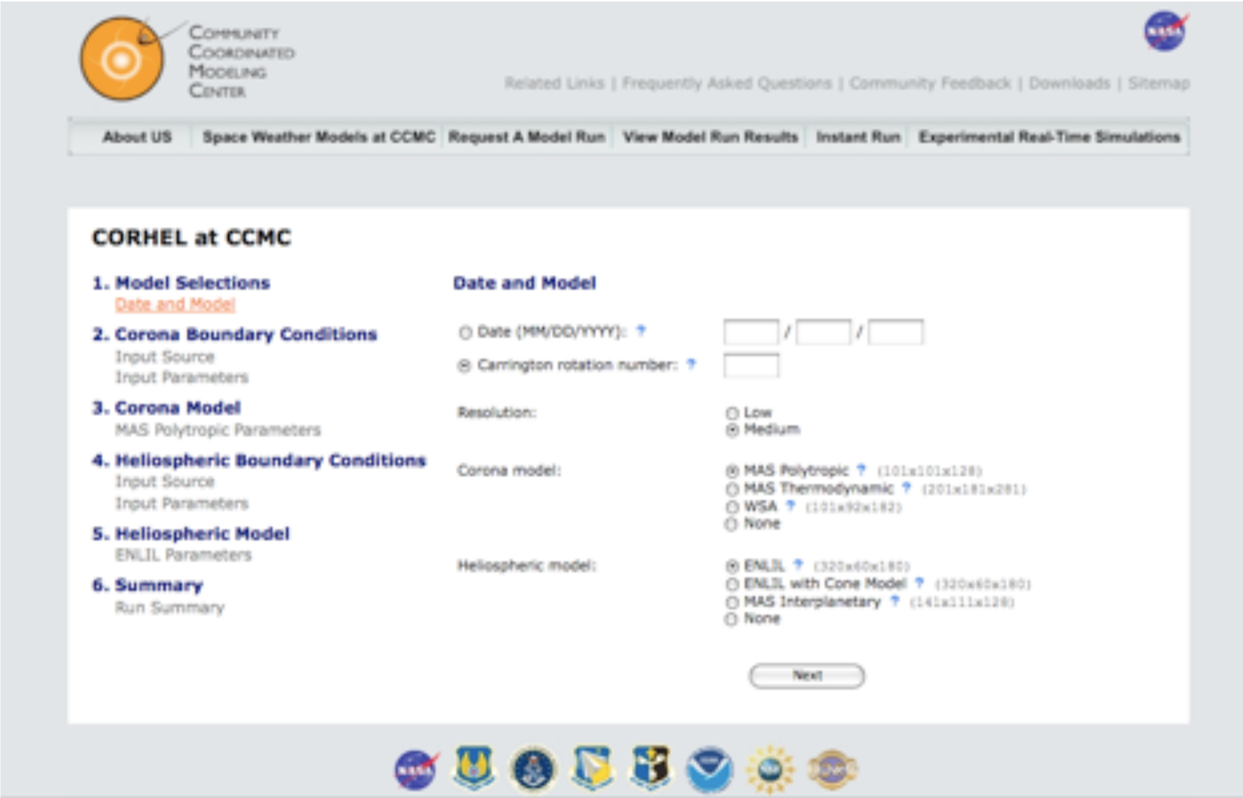
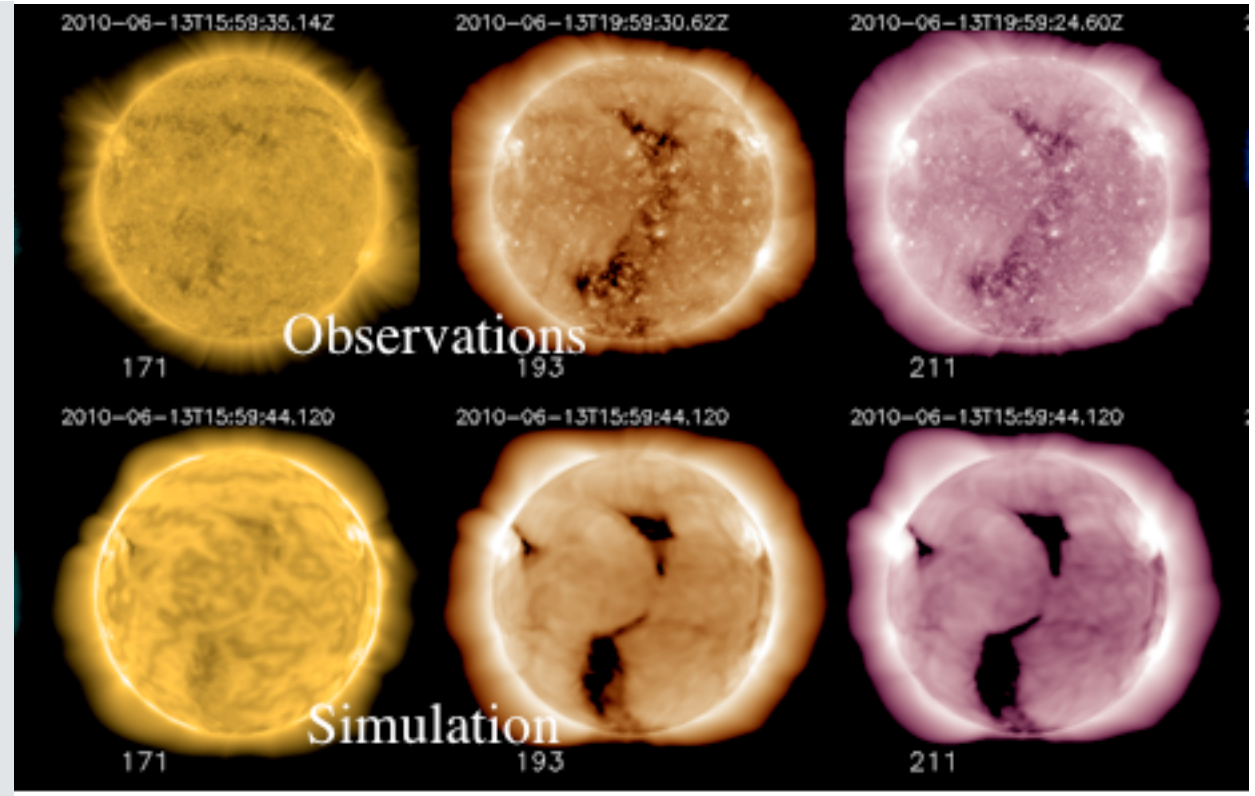
CORHEL at the CCMC





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Introduction

- The ambient solar corona and solar wind play a key role in how the Sun influences the Earth's space environment
- The region is vast in both real and parameter space
- Present/future missions sample the corona & inner heliosphere
- Coronal/solar wind models are required to synthesize these measurements into a coherent picture
- Important aspects of the physics of the corona and solar wind are still unknown or highly controversial.
- Models in different approximations are required for studying different aspects of solar and heliosperic physics.

What is CORHEL?

- CORHEL - "Corona-Heliosphere"
- A coupled set of models and tools for quantitatively modeling the ambient solar corona and solar wind
- The principal observational input to CORHEL are maps of the radial magnetic field at the photosphere, derived from solar magnetograms
- CORHEL provides coronal solutions using 3 approximations:
  - WSA model (numerical potential solver)
  - Polytropic MHD (MAS Code)
  - Thermodynamic MHD (MAS code)
- CORHEL provides two different heliospheric codes: Enlil & MAS
- CORHEL outputs plasma and magnetic field quantities in 3D space
- It also outputs observable quantities for validation
- CORHEL has been delivered to AFRL, CCMC, and CISM

CORHEL Features

- Allows input from 7 different Solar magnetographs
- Processes synoptic maps into boundary data for calculations
- The map processor is web based and interactive:
  - Interactive display of the raw magnetogram and processed map
  - Interactive display of pole fitting and smoothing
- Can provide cone model CMEs
- CORHEL has PSI's implementation of the WSA model (with help from N. Arge)
  - Numerical Potential Solver
  - Allows consistent processing between WSA and MAS input
  - Allows for meaningful comparisons between WSA and MHD models, and comparison of different magnetograms
- Codes run on parallel architectures using MPI

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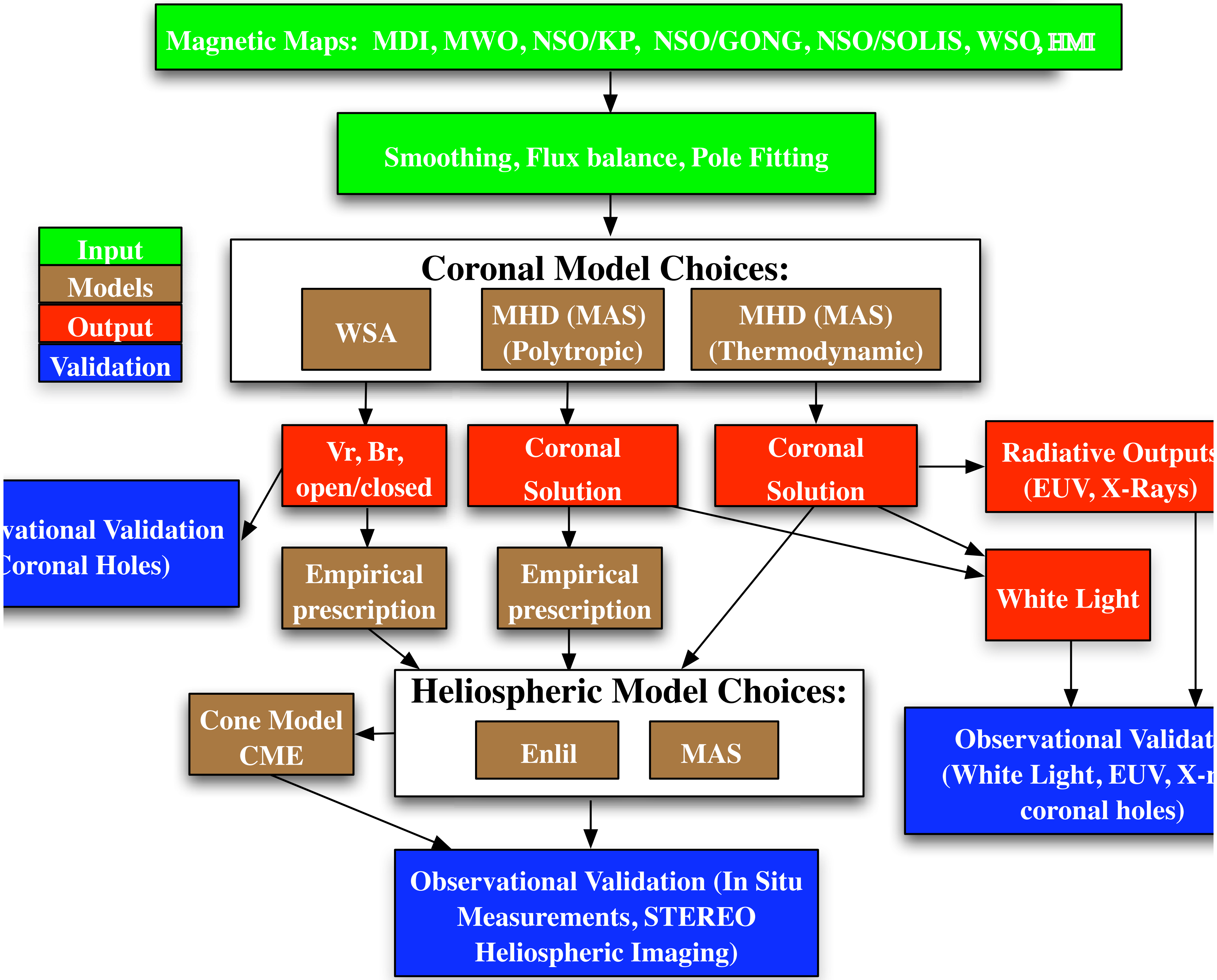
CORHEL: Present Status

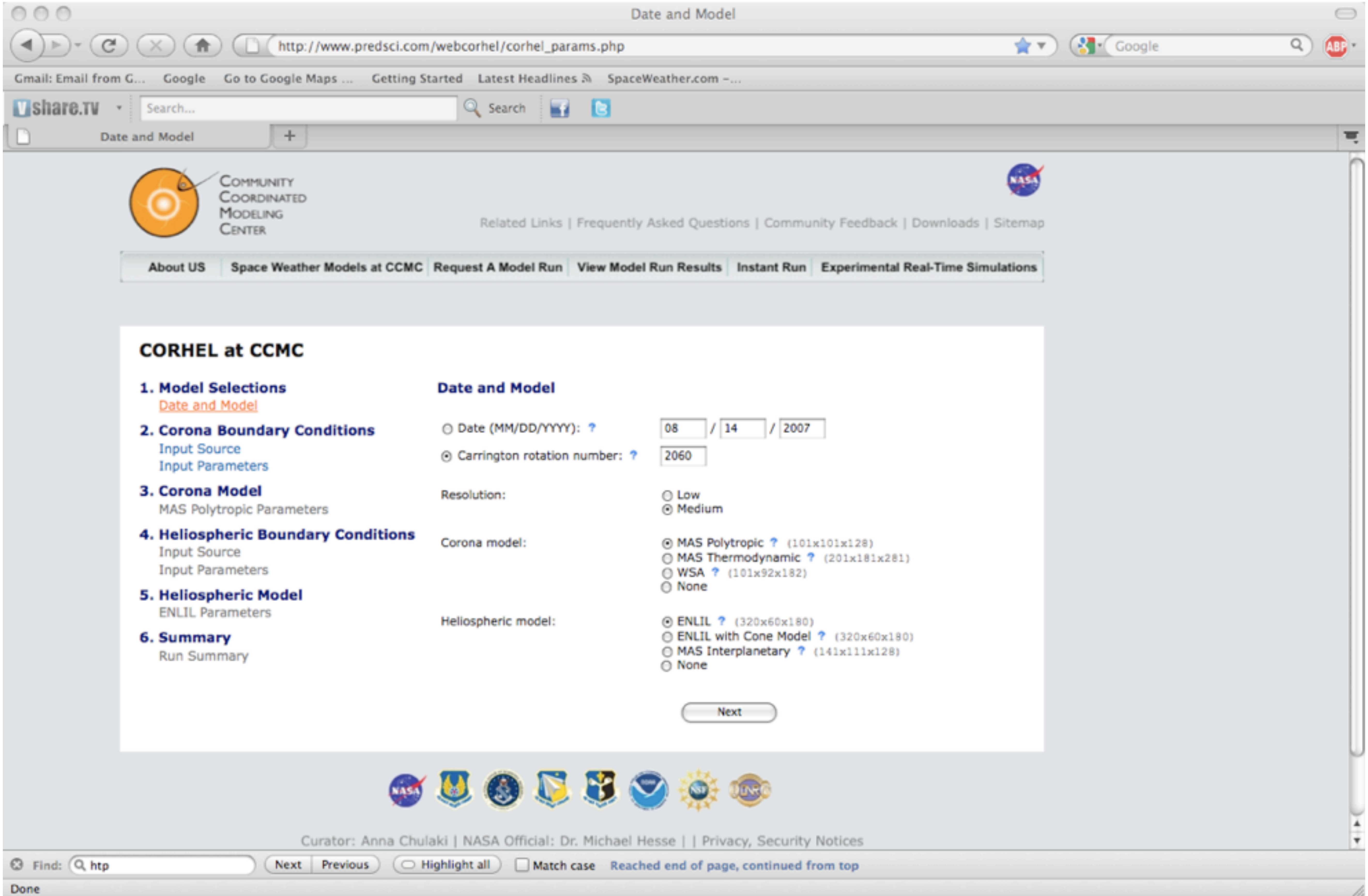


MAS and CORHEL at the CCMC

- The MAS (Magnetohydrodynamic Algorithm outside a Sphere) code has been available at the CCMC for 11 years.
- The original MAS at CCMC was a serial code that provided MHD solutions for the solar corona, using Kitt Peak photospheric magnetic maps as boundary conditions.
- CCMC developed the original interface to MAS. CCMC supplied all of the manpower, with guidance from us.
- CORHEL is a far more complex product than the original MAS.
- As CORHEL has expanded in capability and sophistication, there are many more choices and uses not envisioned by the original interface.

A New Interface for CORHEL

- Users want more flexibility to tailor their runs.
- To access all of the features of CORHEL, users need an intuitive interface that guides them through different choices
- We have also found that users like certain products derived from the solutions (e.g. coronal hole boundaries, pB, emission) that we provide on our web site
- Interface development requires deep knowledge of CORHEL:
  - Requires many more man-hours for someone outside our team.
  - It is unrealistic to expect the CCMC to provide all of this manpower.
- We developed a new interface for CORHEL, and in close collaboration with CCMC staff, have ported it to the CCMC.
- Presented at interface at the 2012 workshop; the interface is now fully operational



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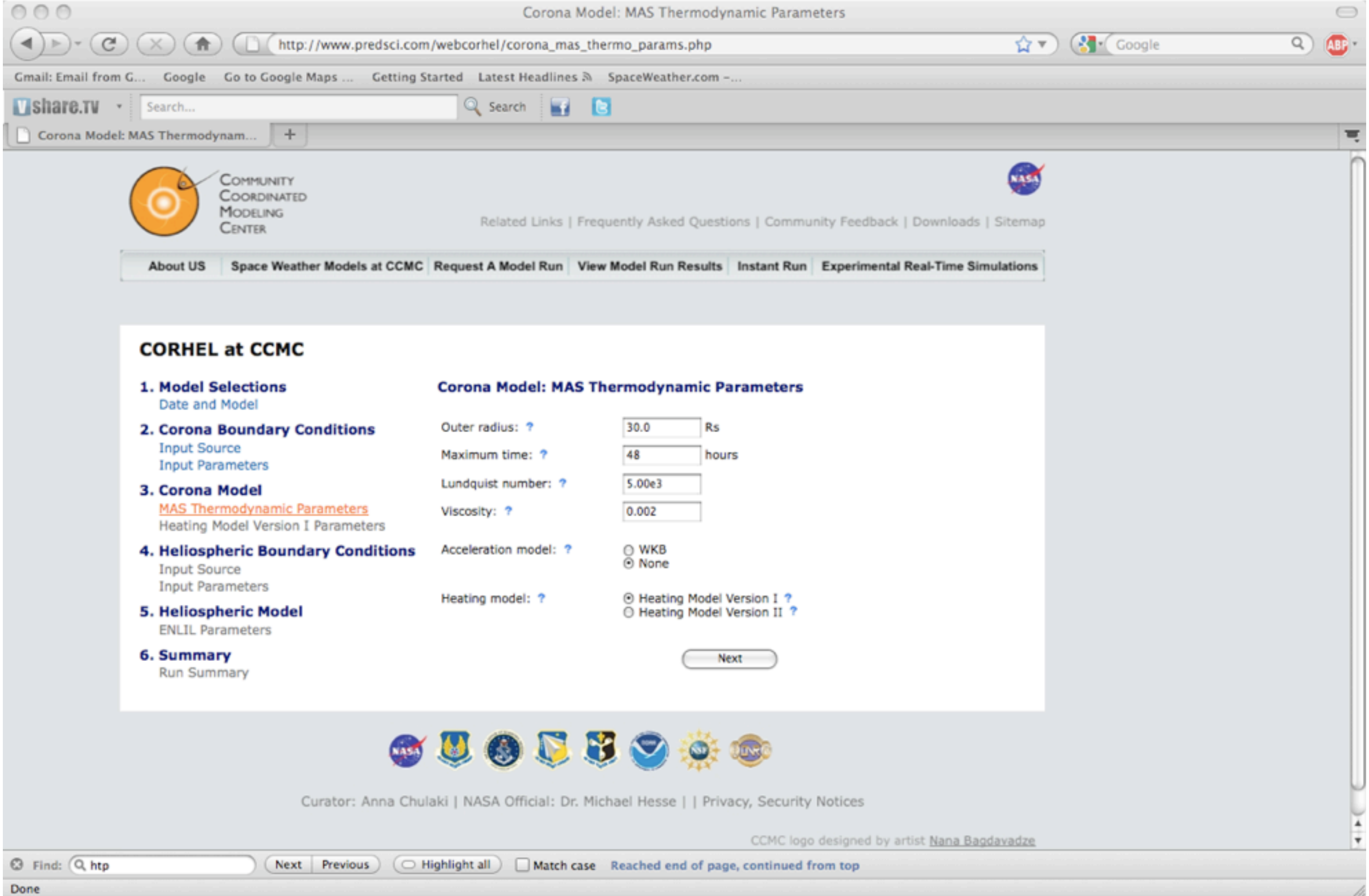
Thermodynamic MHD Model Now Available at CCMC



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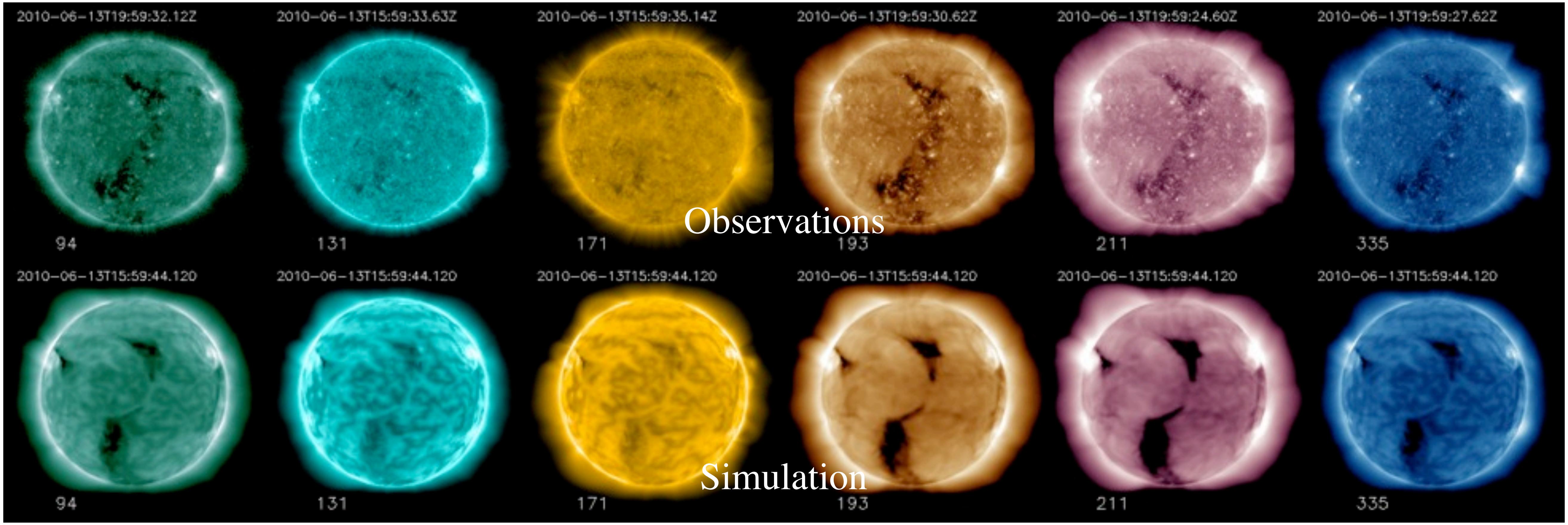
Thermodynamic MHD Models

June 6 - July 3, 2010: Simulated and Observed Emission Lines



94Å 131Å 171Å 193Å 211Å 335Å

- To accurately simulate plasma density, a more sophisticated energy treatment is required (coronal heating, radiative cooling, thermal conduction)
  - γ = 5/3 retained for ratio of specific heats
- Can be validated by simulating emission in EUV and X-rays

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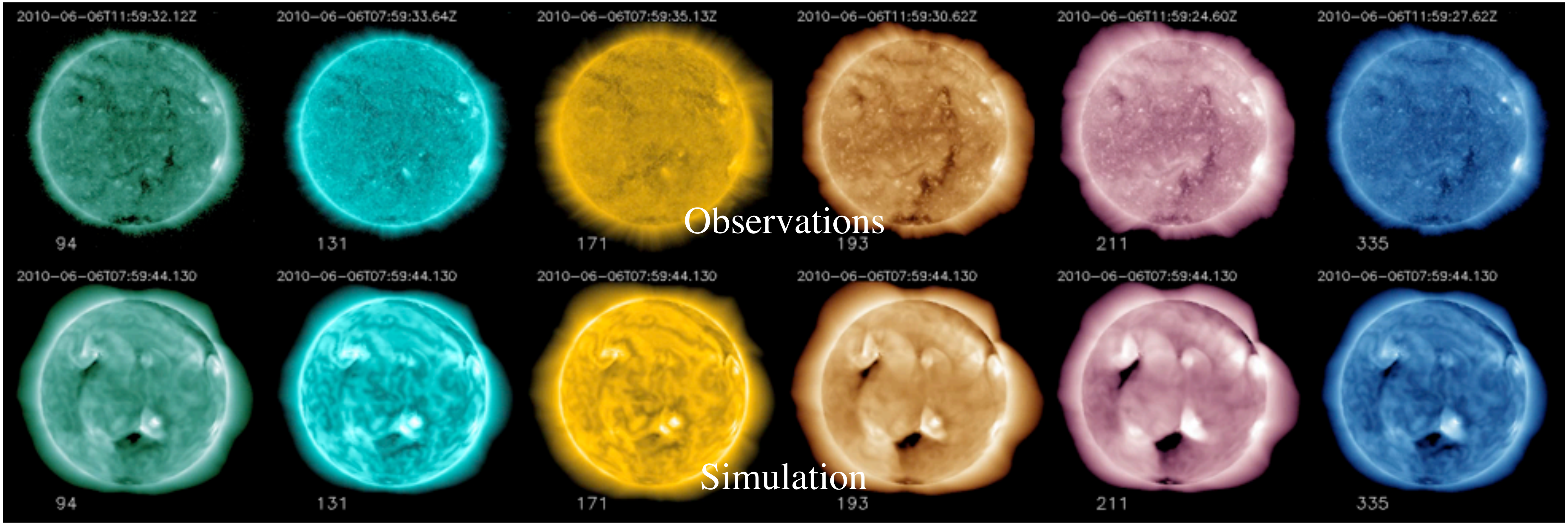

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Optimization of the MAS code

- In the solar corona, local regions can have very high Alfven speed (e.g. active regions), making explicit calculations intractable
- The semi-implicit solve in MAS allows the time step to greatly exceed the CFL condition (e.g. 100s of times CFL)
- We have spent a lot of effort in optimizing the MAS code:
  - Improved CG solvers for the implicit parts of our code
  - Improved efficiency of matrix storage and matrix-vector multiplies
  - Improved MPI communication
- We have improved the preconditioning in the CG solve to use incomplete LU preconditioning, with variable fill-in, using an additive Schwarz decomposition
- This reduces the number of iterations in our solvers, speeding up the code
- As a result our newest version of the code can be up to 7 times faster!
- The optimized version will be implemented at CCMC soon.

Optimization (continued)

- On parallel computers, communication is costly - one attempts to maximize computational work on a processor while minimizing communication between processors
- Thus, a solver that does a better preconditioning (i.e., more work) on the part of the matrix on each CPU, will reduce the number of iterations in the solve (i.e., less communication)
- Example:

Zero-beta simulation of the energization of an active region, 151x237x312 mesh, on 720 processors, run on NASA Pleiades

- Semi-implicit solve (wall clock time):

Old code, preconditioner with diagonal scaling: 38 sec/step, 495 iterations/step

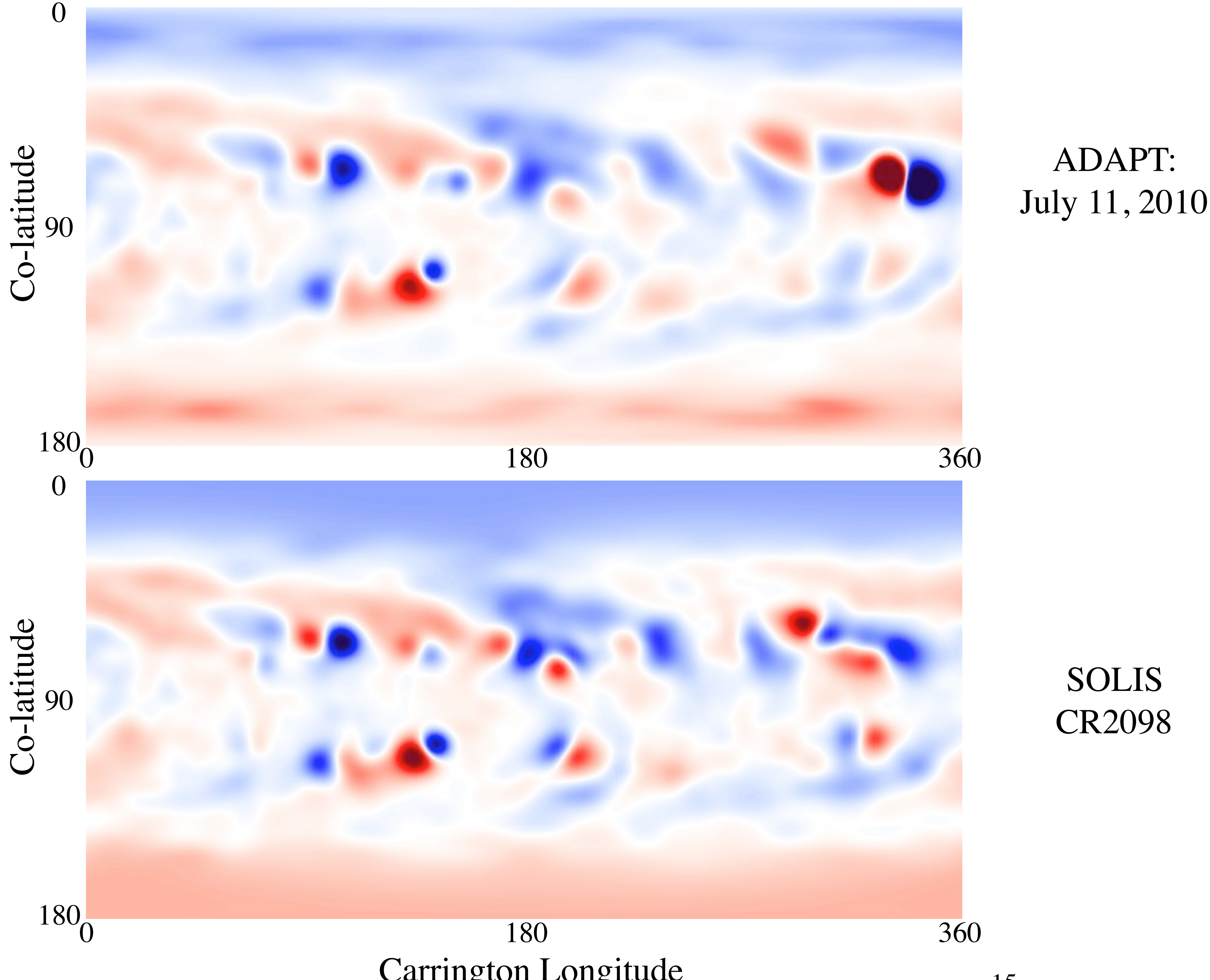
New code, ILU preconditioner w/additive Schwarz: 5 sec/step, 161 iterations/step

- The speedup is case-dependent, but there is a significant improvement in all cases

Incorporation of ADAPT Map Into CORHEL

- The Air Force Data Assimilative Photospheric Flux Transport (ADAPT) 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

Diachronic vs. Synchronic Maps (NSO SOLIS Magnetograms)



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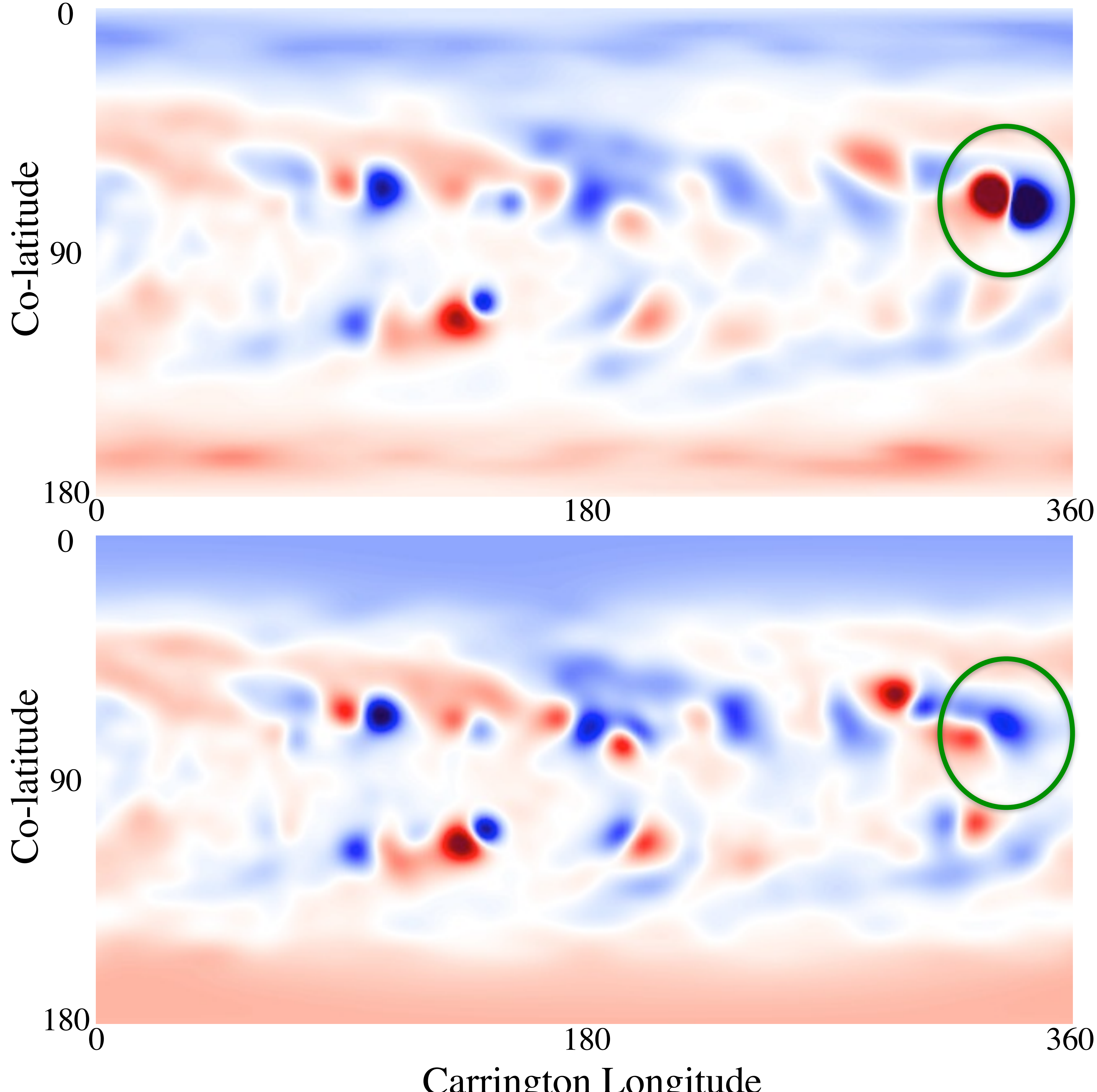
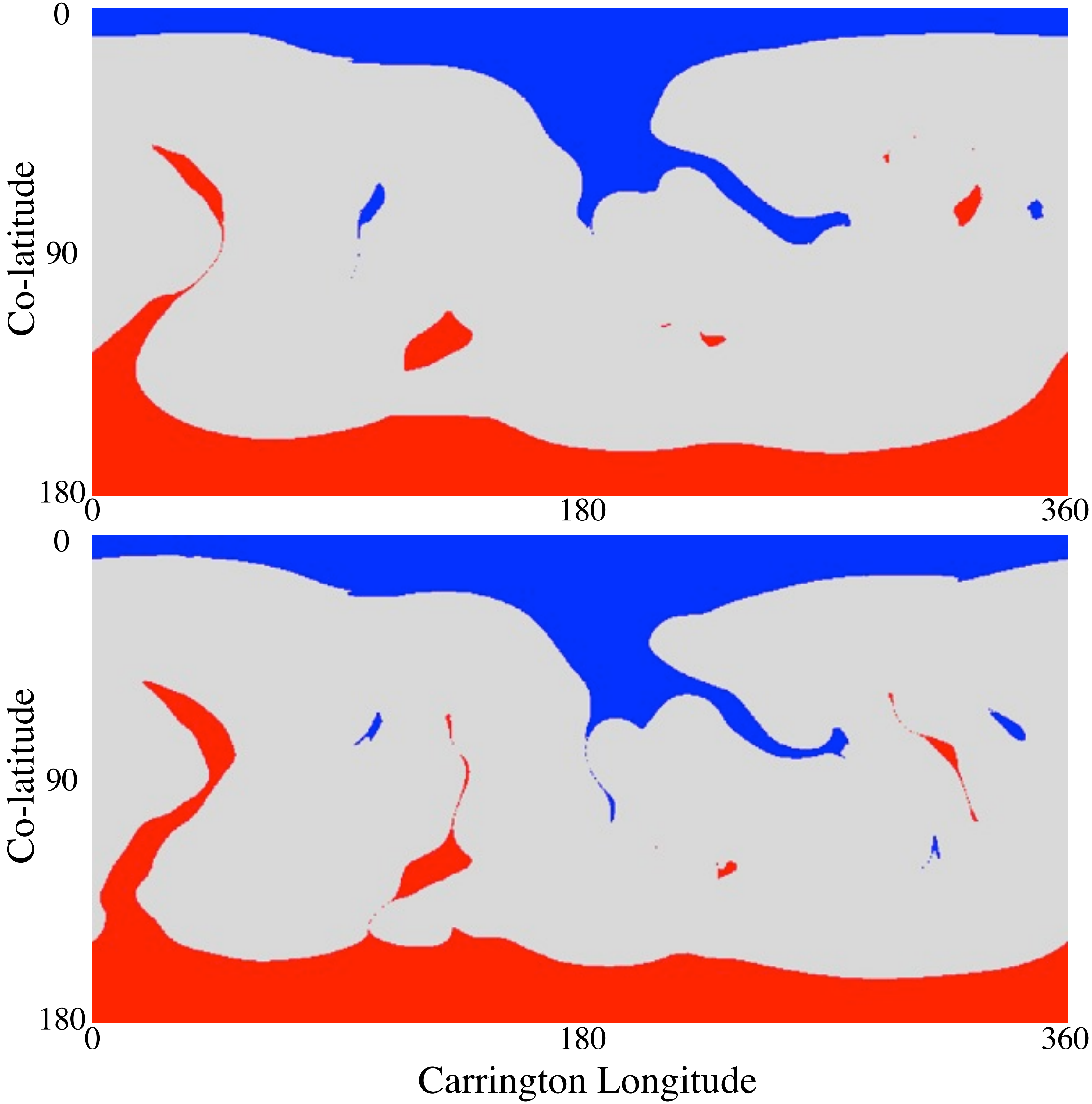


ADAPT:
July 11, 2010

SOLIS
CR2098

Diachronic vs. Synchronic Maps: Coronal Hole Boundaries



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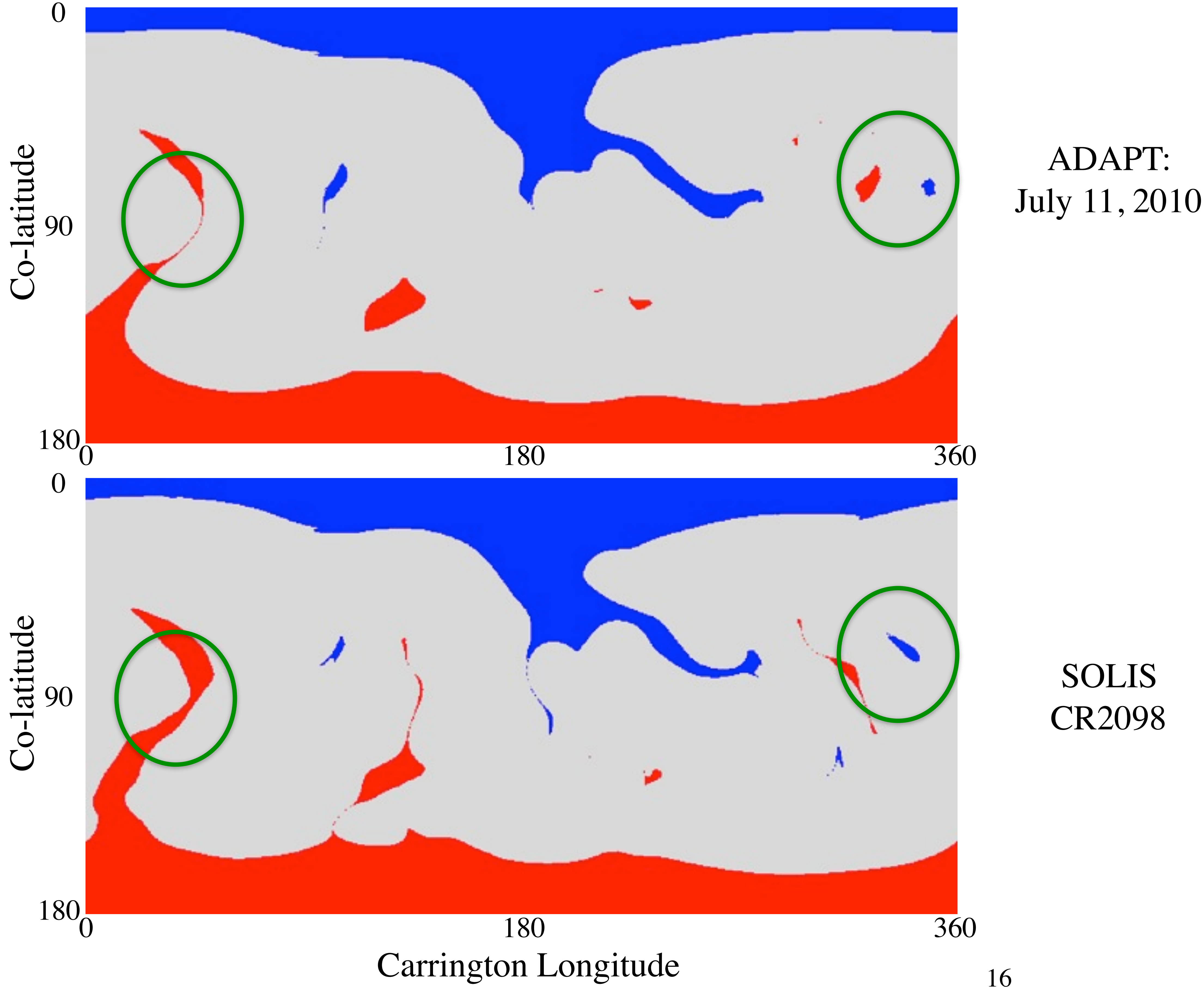
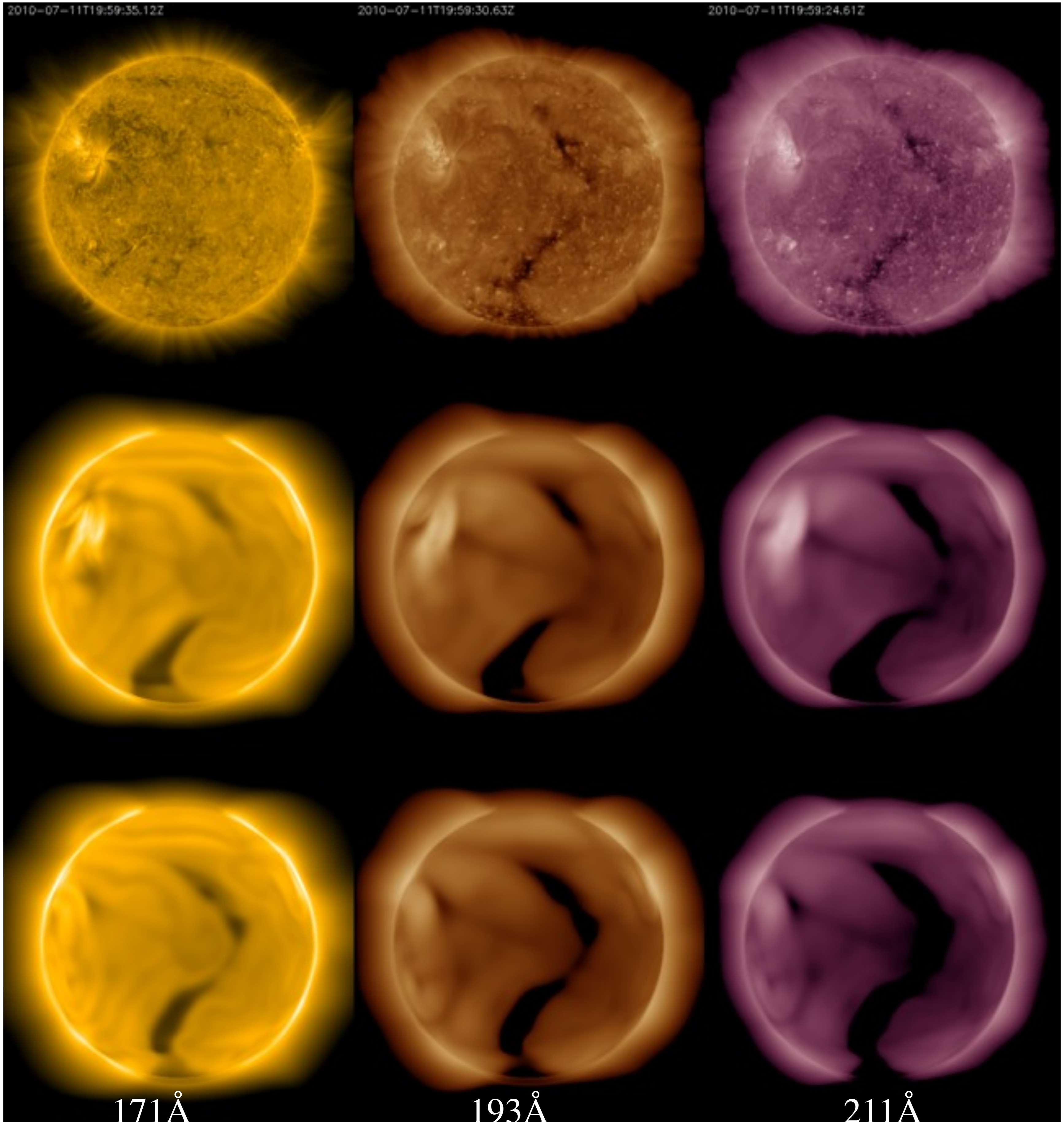


Emission Comparison

AIA Observations (2010/07/11 20:00:00)

ADAPT: July 11, 2010

SOLIS CR2098



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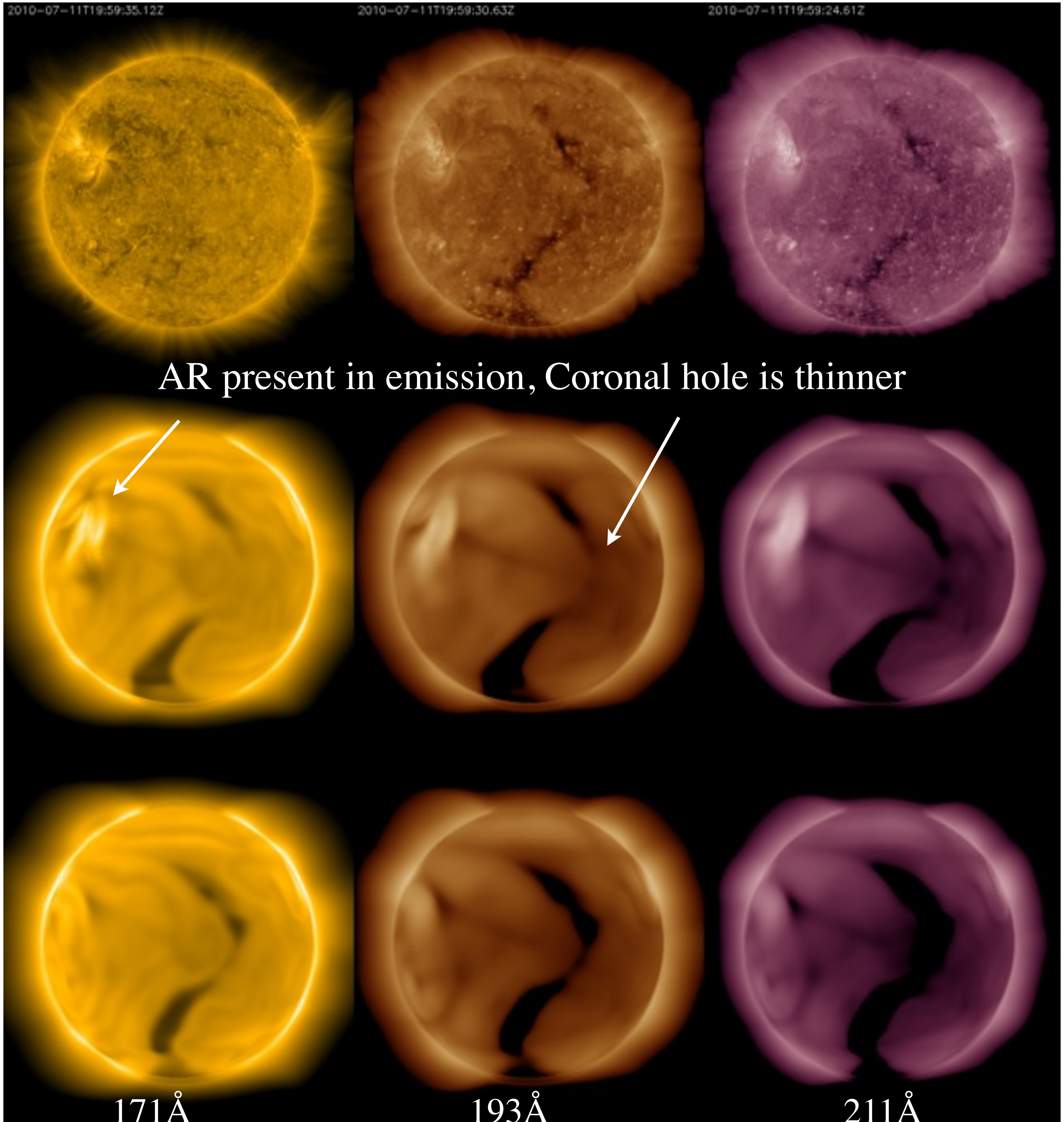

Coupled MAS Coronal and Interplanetary Simulations: A CME Test

- Test simulation to 50 R_S (Polytropic MHD for simplicity)
- Left: Coupled simulations (coronal boundary at 20 R_S)
  Right: Entire domain is 50 R_S
- CME propagates seamlessly through the boundary

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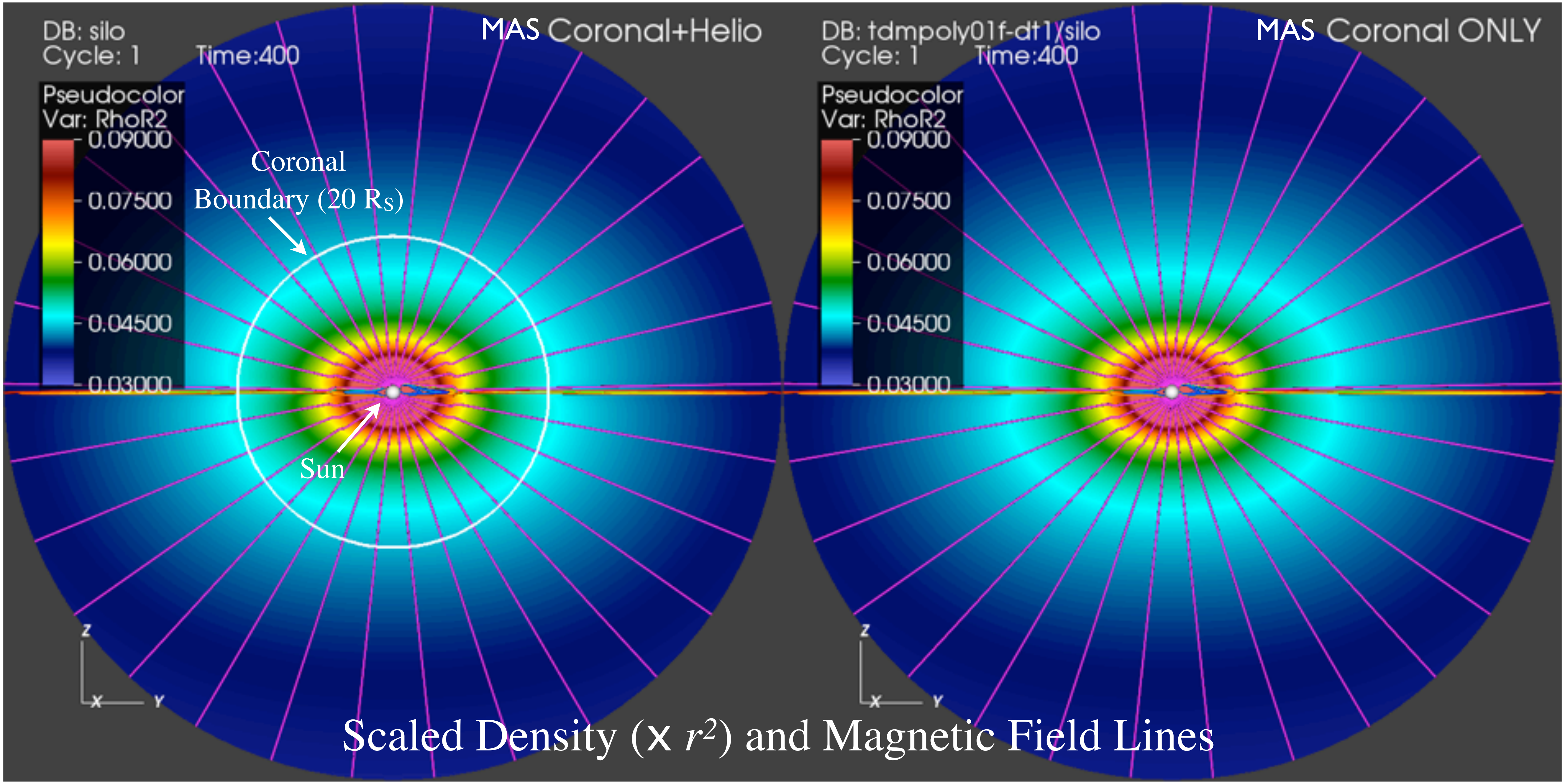

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Ongoing Work

- Time-dependent solar wind based on evolving photospheric B_r
  - Uses ADAPT model to evolve the flux
- Physics-based heating/acceleration models (wave-turbulence formalism)
- CME initiation and propagation in the corona
- Coupling with EPREM/EMMREM for SEP modeling
- Collaboration with Slava Merkin/John Lyon on LFM coupling