A Near-Real-Time Data Assimilative Model of the Solar Corona

To Appear in Science (Downs, Linker, Caplan, Mason, Riley et al. 2025)

Time-Evolving
Coronal Magnetic Field
Structure

Jon A. Linker
Predictive Science Inc. (PSI), San Diego, CA, USA (linkerj@predsci.com, 858-337-6421)
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The Solar Corona

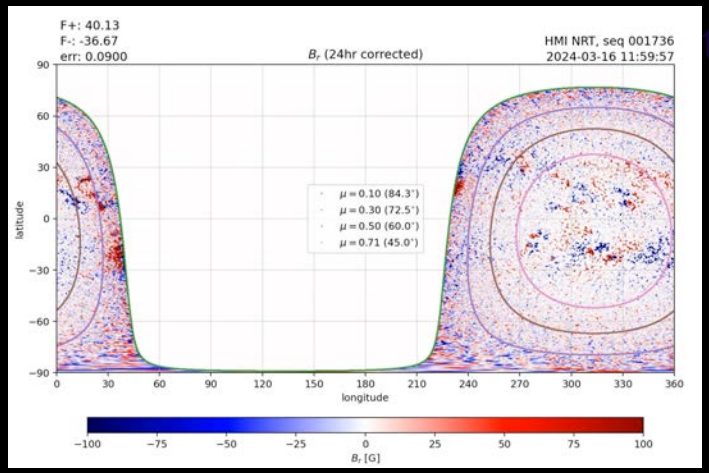
- The solar corona is a hot tenuous plasma that expands out as the solar wind to fill the heliosphere.
- The solar magnetic field permeates this plasma, and is key to understanding its structure and dynamics.
- We measure this field most easily in the photosphere (Sun's visible surface).
- To understand the corona, we extrapolate this field outward with a magnetohydrodynamic (MHD) model (the MAS model).
- The model can produce synthetic obsevables, such as the white light we observe with coronagraphs and during total solar eclipses.

Predicting Coronal Structure for the April 8, 2024 Total Solar Eclipse

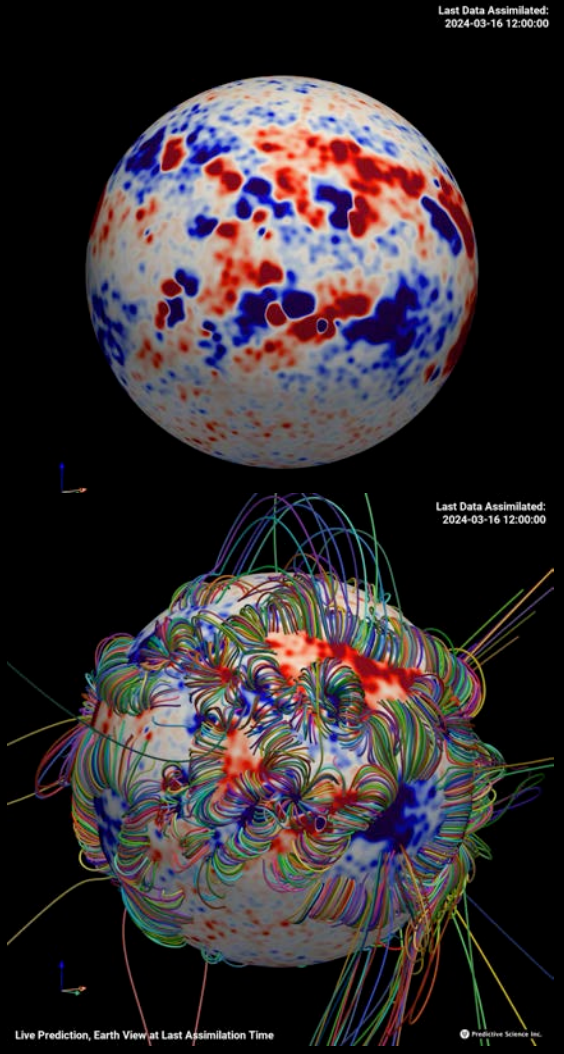
- Coronal structure is constantly evolving in response to the changing magnetic field.
- To predict the corona's appearance for the eclipse, we developed an assimilative model: *Continuously updated with new magnetic field data*.
- The model ran for 32 days, leading up to and past Eclipse Day.
- The resulting structure is highly dynamic, similar to the real corona.
- We believe this introduces a new paradigm for coronal modeling.

Results available at https://www.predsci.com/corona/apr2024eclipse/

Magnetic Data Assimilated Into a Surface Flux Transport Model

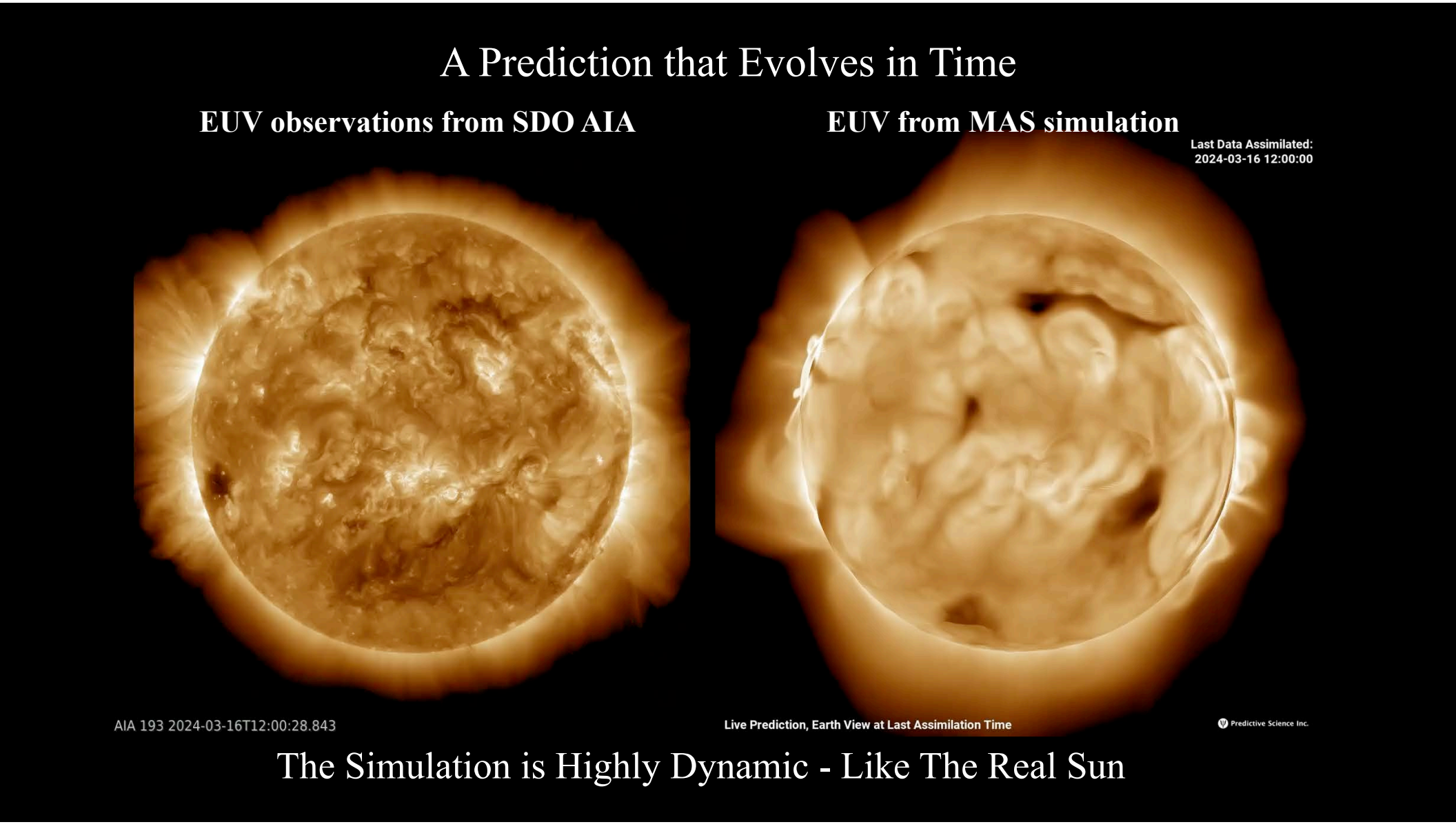


Magnetograms from Solar Dynamics Observatory (also Solar Orbiter)



- Surface flux transport model (HipFT) ingests data
- Builds full Sun map (incuding regions not observed)
- Creates boundary conditions for MHD Model

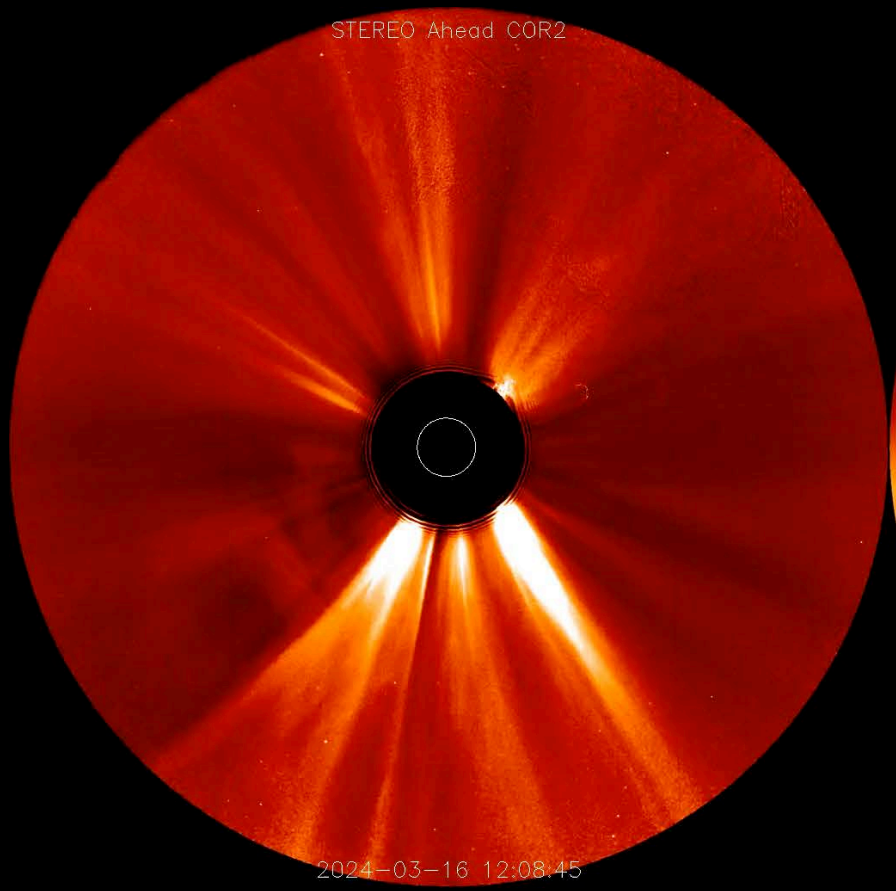
A Prediction that Evolves in Time



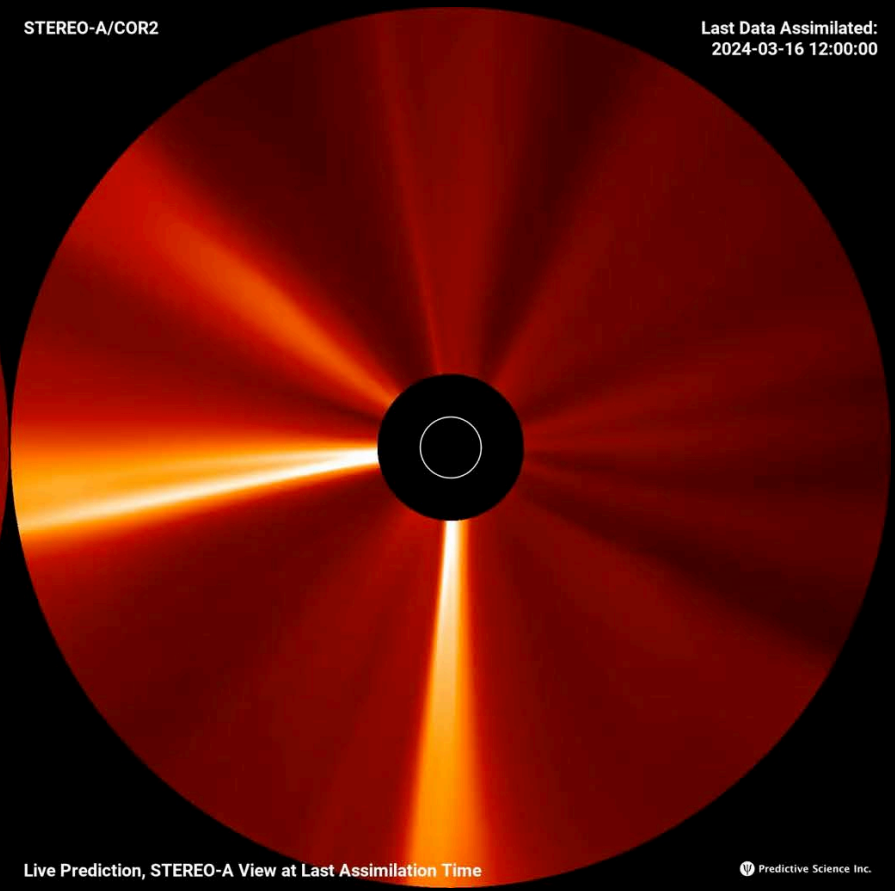
The Simulation is Highly Dynamic - Like The Real Sun

Many Small Scale Eruptions and CMEs in the Simulation

Coronagraph Observations from STEREO-A

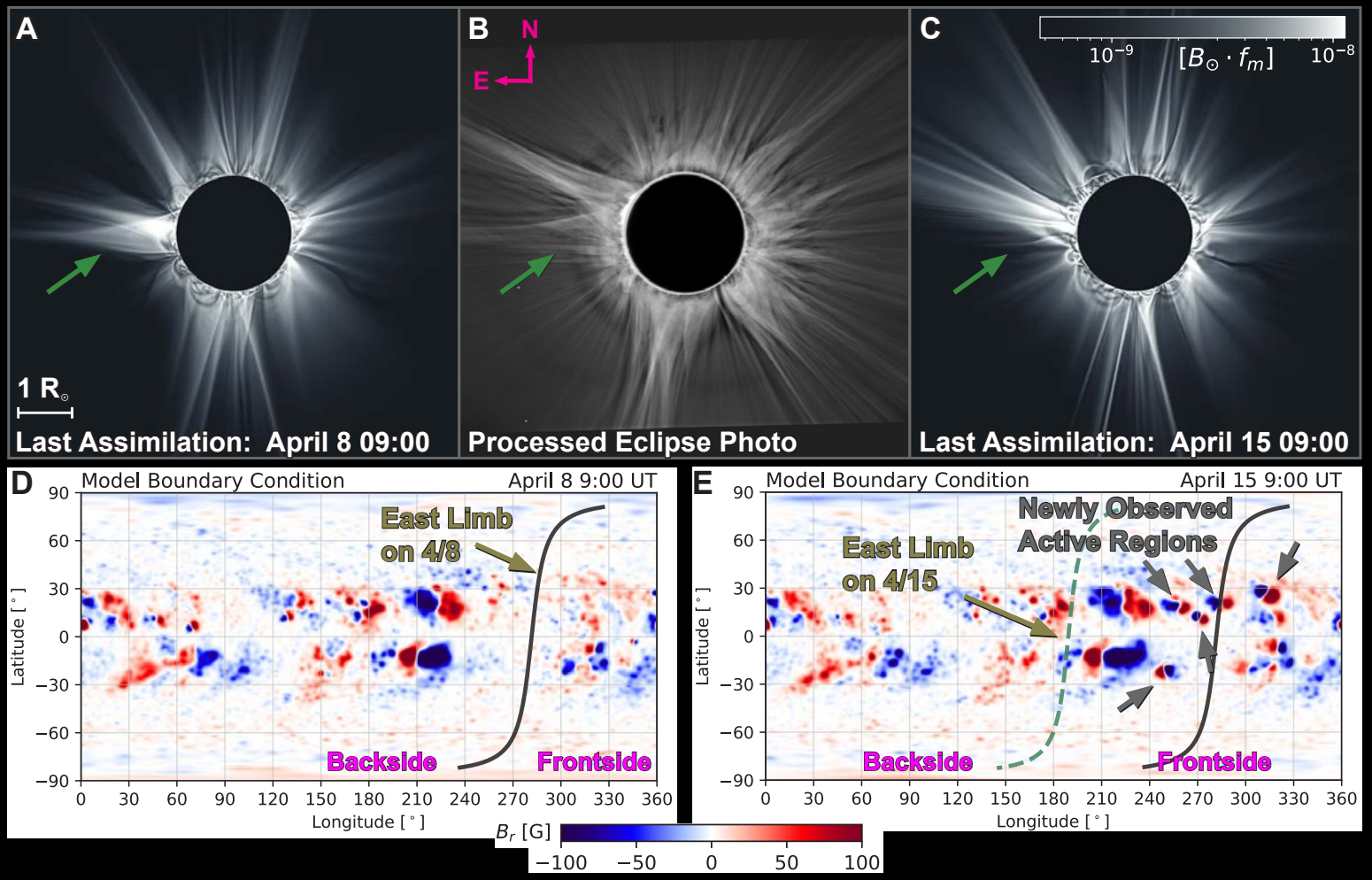


EUV from MAS Simulation



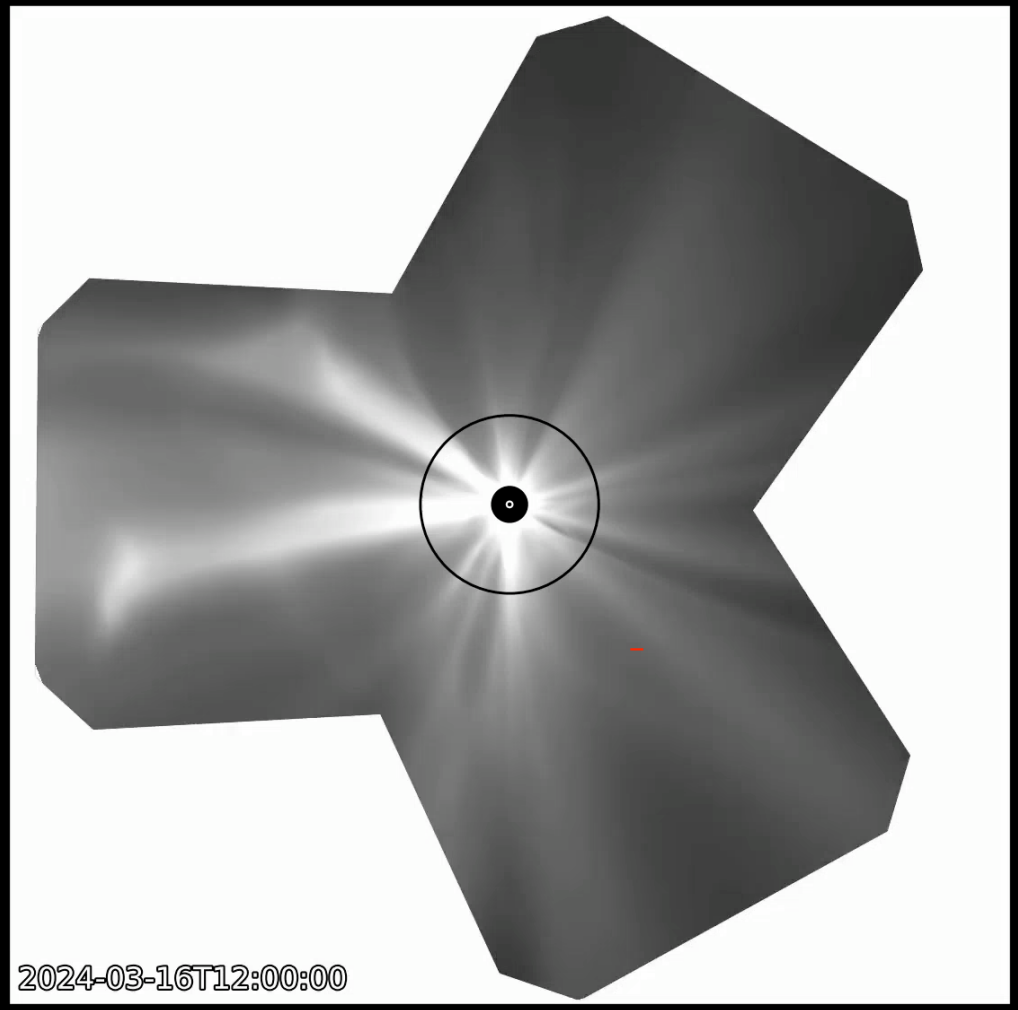
Comparison with an Eclipse Day Image

- Complex structure at solar maximum
- Unobserved active regions on east limb not accounted for in prediction
- Coronal structure modified when regions rotate into view



Assimilative Modeling Can Enhance the Science Return from New Missions

Simulated
PUNCH View



Summary

- We demonstrated a continuously running data assimilative model of the solar corona for the 32 days leading up to and past the April 8, 2024 total solar eclipse.
- Ubiquitous dynamics, small-scale eruptions and coronal mass ejections are present in the simulation - like the real Sun

- This approach is more akin to how terrestrial weather forecast models are run
- The model exhibits the highly complex coronal structure seen in this time period, but differs in some details from the observations
- It agrees best with observations where recently assimilated magnetic data is available

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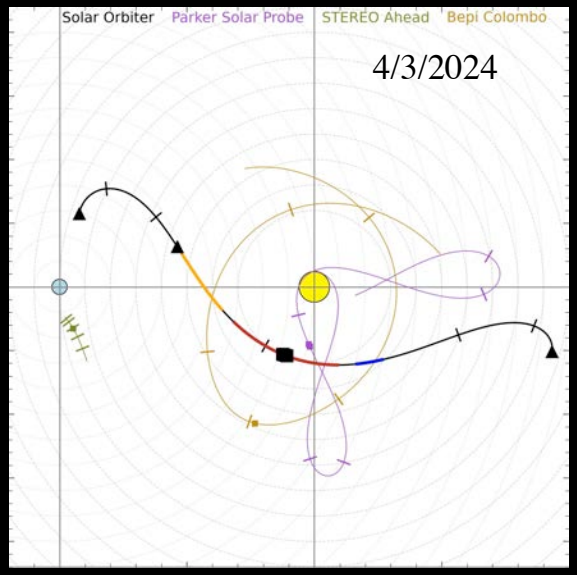
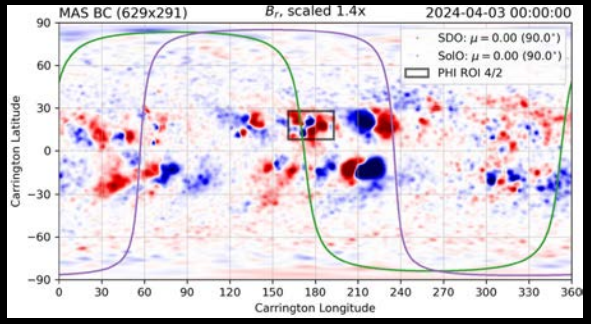
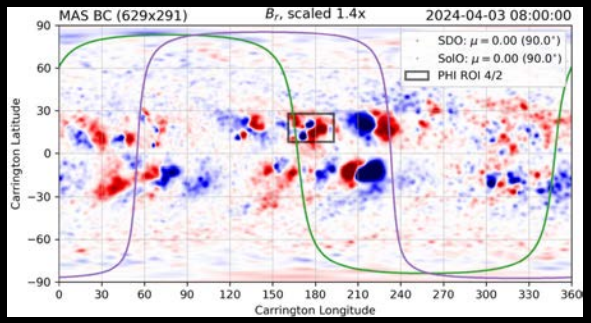
Extra Slides

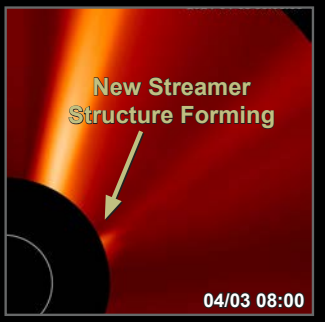
Assimilation of Solar Orbiter PHI Data Away from The Sun-Earth Line

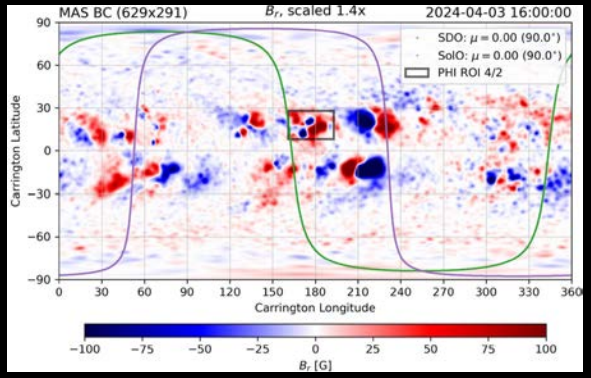
- We obtained PHI data when Solar Orbiter was west of the Sun-Earth Line
- This allowed us to incorporate a region not visible from HMI











Earth's View in Time