Plasma Dynamics and Connectivity Evolution in a Time-Evolving Model of the Global Solar Corona

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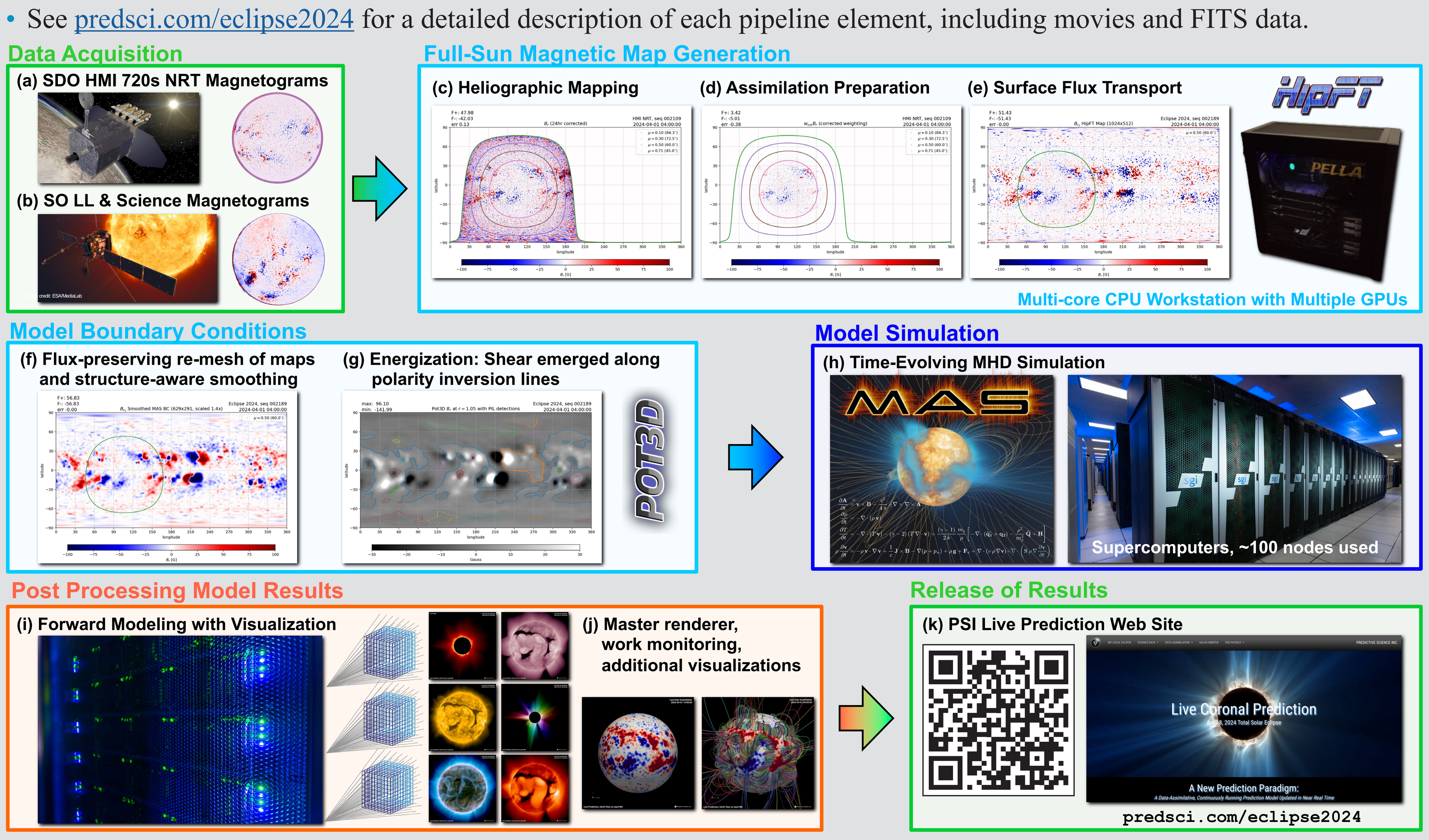
Abstract

In this poster we explore properties of a data-assimilative, data-driven, continuously evolving thermodynamic MHD simulation of the global solar corona. This simulation spans 32 days and 7 hours during the weeks leading up to and after the April 8th 2024 total solar eclipse. Because the simulation is driven by the continuous evolution of the surface flux distribution, which includes large-scale flux-emergence, helicity injection, supergranular flows, and random small-scale flux evolution, dynamical aspects emerge that cannot be captured in a traditional steady state MHD relaxation. Here we focus on how these dynamics pertain to our understanding of connectivity and plasma properties near structures that bound the open and closed corona. We map how open, closed, and disconnected fluxes evolve over time and relate to small-and large-scale topological features in the corona. ~~We also explore how the temperatures and densities of the bounding plasma structures evolve in time.~~ A comparison to several steady state calculations made over the same time period helps contrast the differences between these and the data-driven evolutionary calculation.

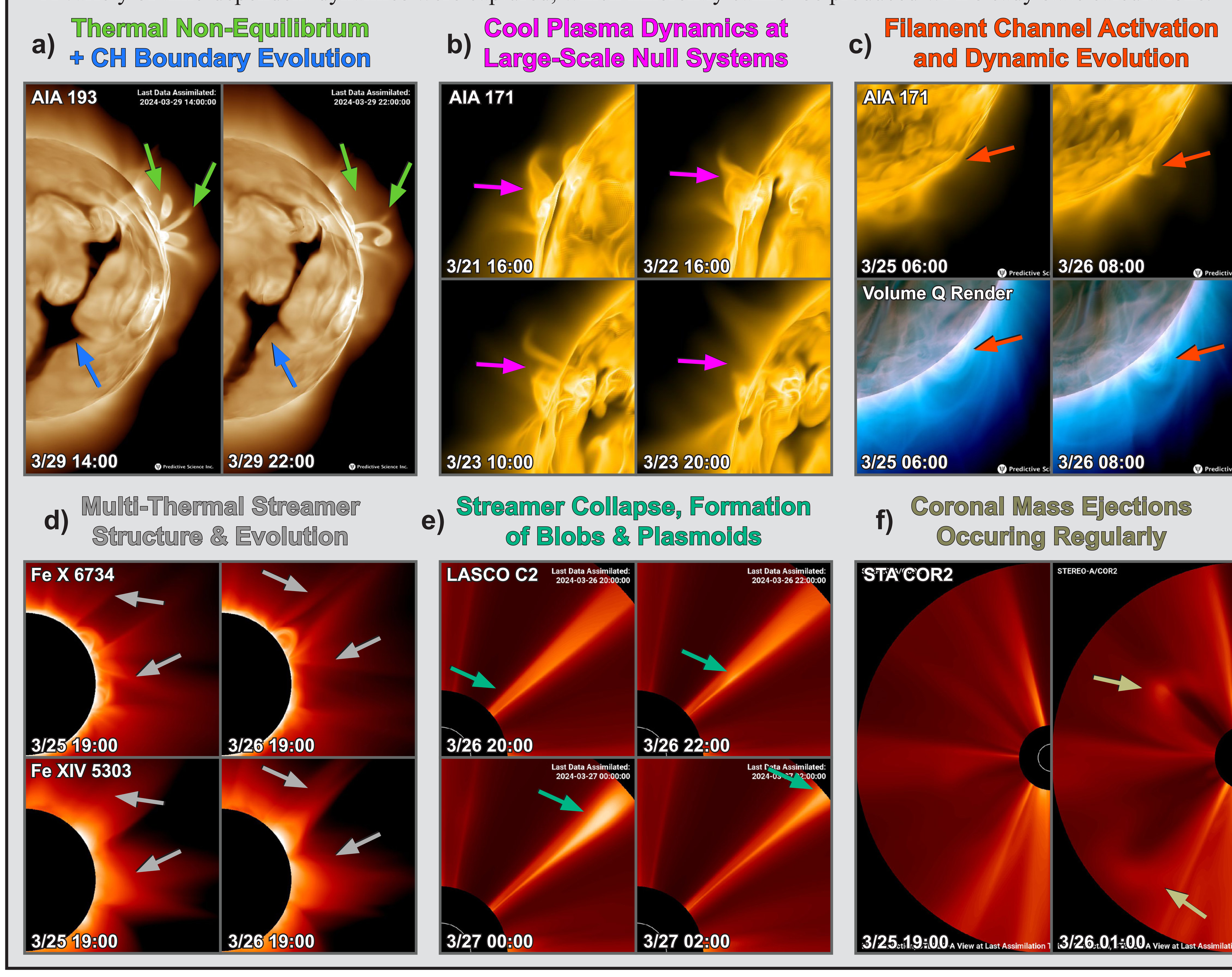
1. A Time-Evolving, Data Driven MHD Model

- During the weeks leading up to the April 8th 2024 total solar eclipse we ran a continuous "Live Prediction" MHD model.
- The modeling pipeline combined near-real-time SDO/HMI and SO/PHI data assimilation, a surface flux transport model, and a time-evolving, data driven MHD calculation, which included helicity/shear injection along filament channels.
- See predsci.com/eclipse2024 for a detailed description of each pipeline element, including movies and FITS data.



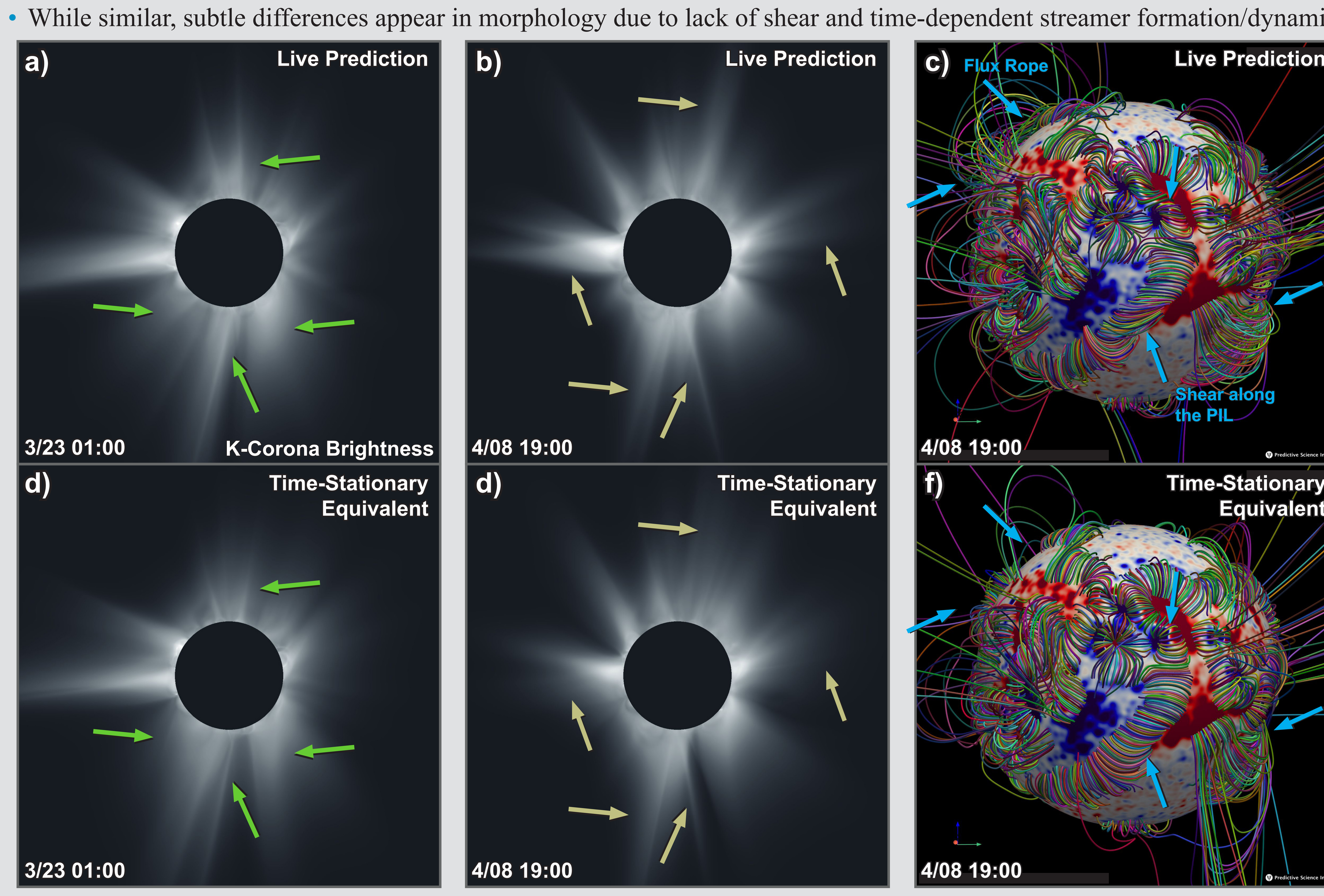
2. Time Dependent & Multi-Thermal Plasma Dynamics

- The MHD model was driven continuously at the inner boundary for 32.3 days of solar time, with data dumped every hour.
- A variety of time-dependent dynamics were captured, which inherently cannot be produced with steady state calculations.



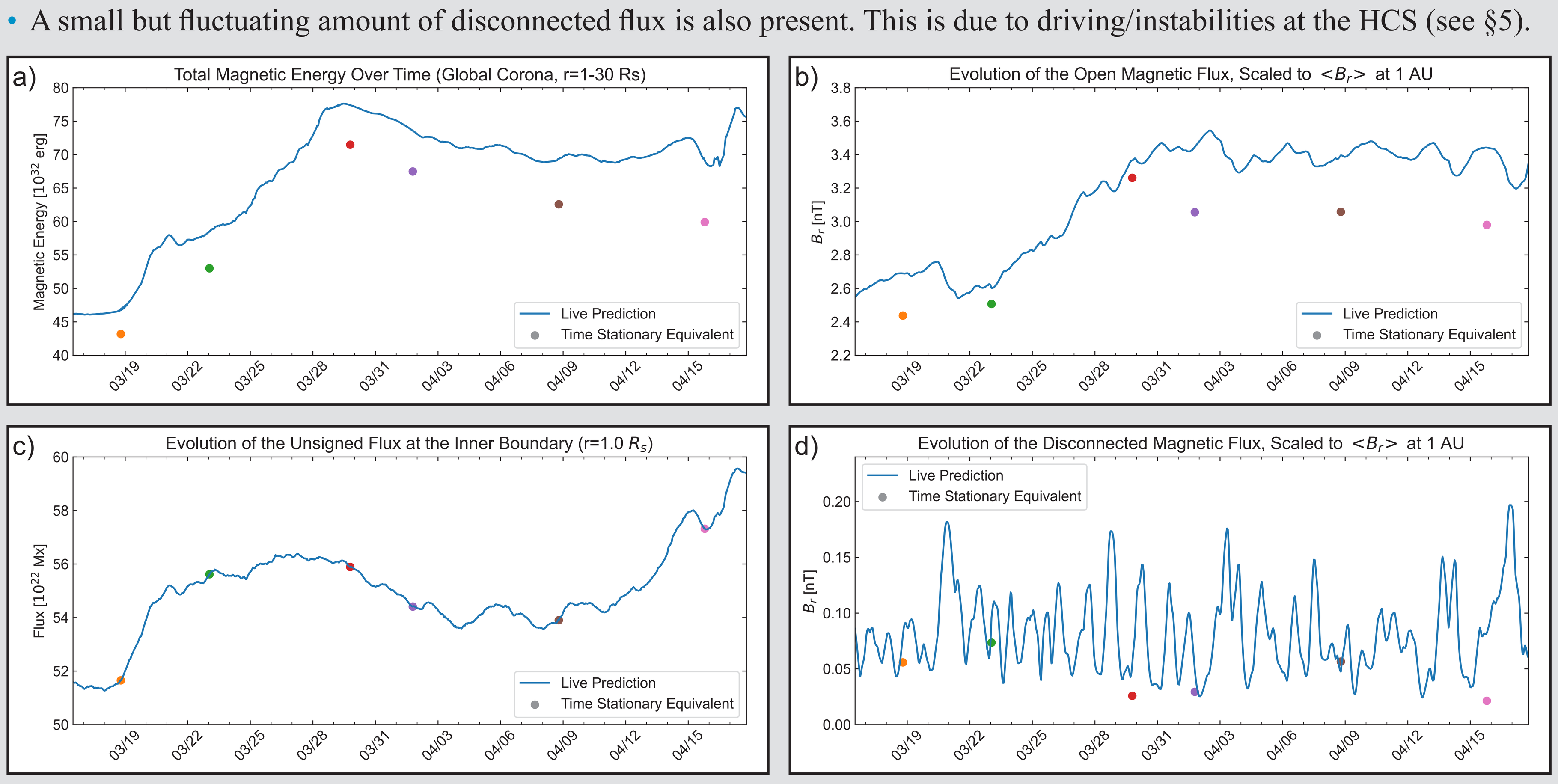
3. Comparison to Time Stationary MHD Calculations

- We also computed six time-stationary (steady state) MHD models covering the simulated time period.
- These use an otherwise identical setup but are not driven at the boundary (no flux evolution, no energization).
- While similar, subtle differences appear in morphology due to lack of shear and time-dependent streamer formation/dynamics.



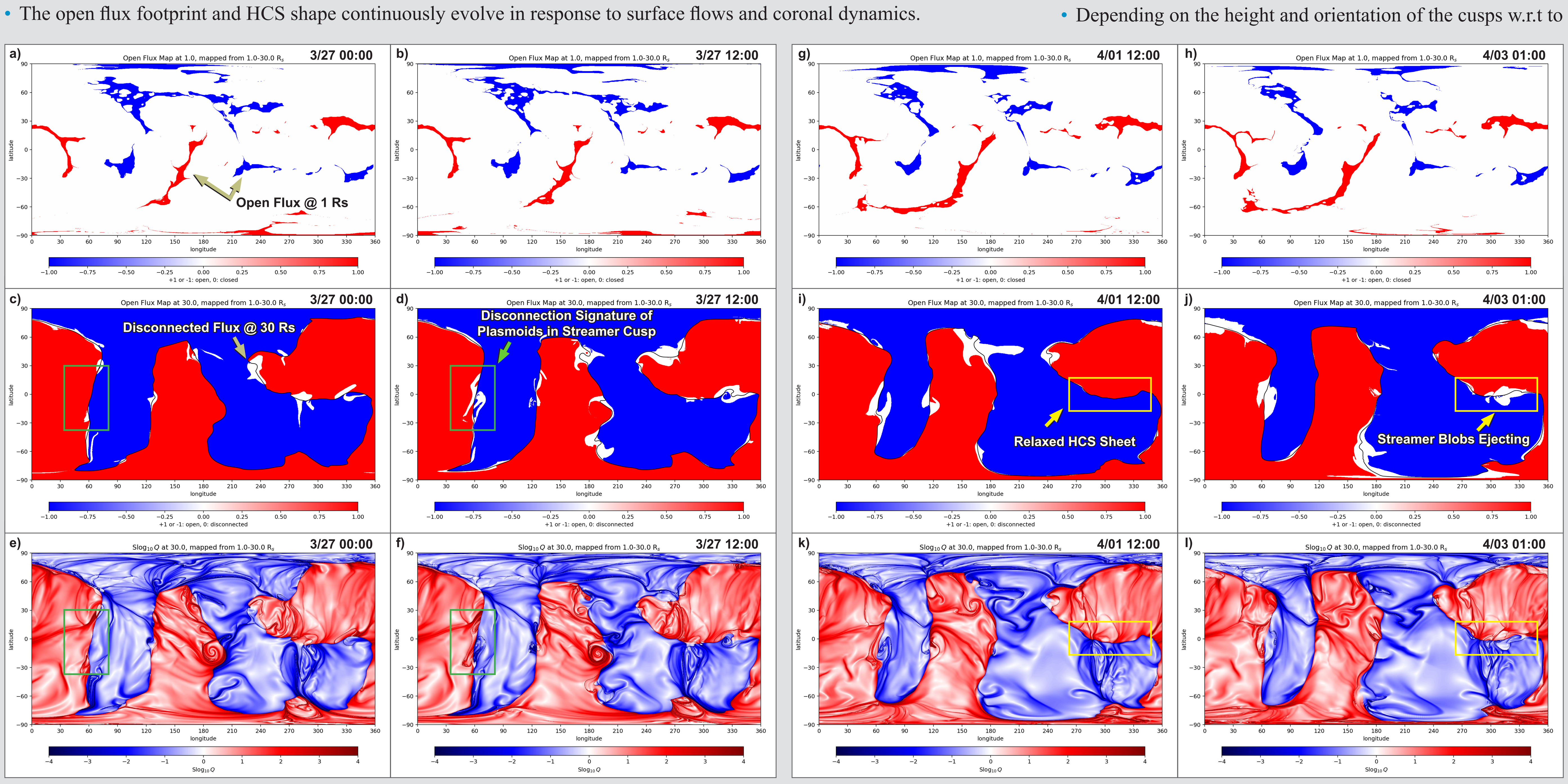
4. Magnetic Energy and Fluxes Over Time

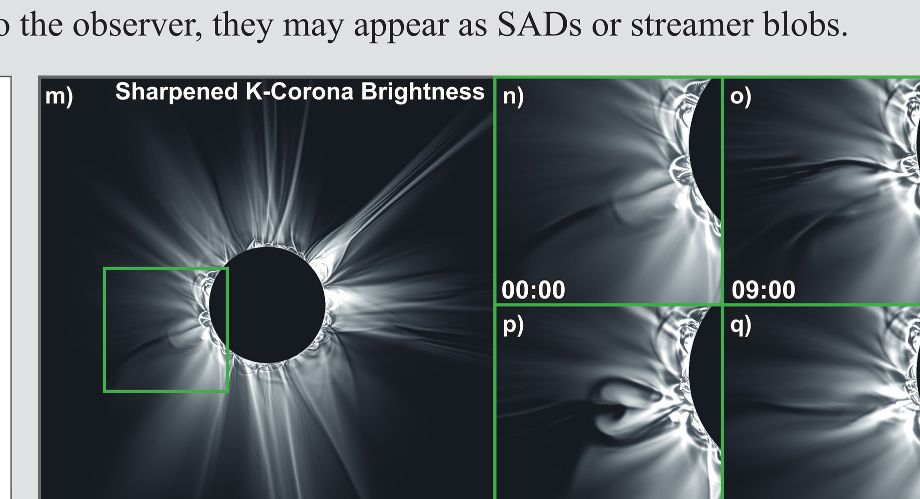
- Compared to steady-state, the time-evolving model stores a fair amount of free-magnetic energy, which grows over time.
- The time-evolving model is also ~10-15% more open, consistent with a more energized global magnetic state.
- A small but fluctuating amount of disconnected flux is also present. This is due to driving/instabilities at the HCS (see §5).



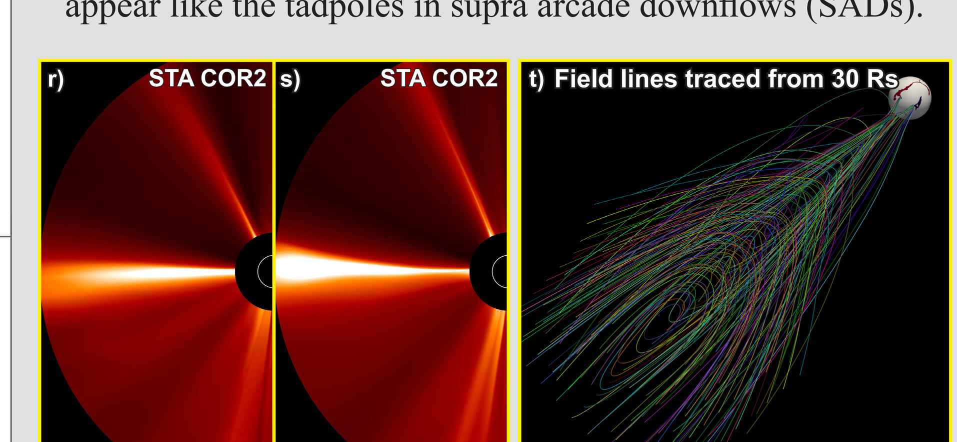
5. Connectivity Evolution

- We use field line mappings to track flux systems and the structure of the heliospheric current sheet (HCS).
- The open flux footprint and HCS shape continuously evolve in response to surface flows and coronal dynamics.
- Along the HCS, we consistently find intermittent pockets of disconnected flux that last for 12-24 hr.
- These are the imprints of plasmoids & reconnection at the streamer cusps at the base of the HCS in the middle corona.
- Depending on the height and orientation of the cusps w.r.t to the observer, they may appear as SADs or streamer blobs.





- For a N/S oriented streamer/HCS (panels c-f, green box), we are looking normal to the current sheet plane.
- Here the reconnection/disconnection signatures at the cusp appear like the tadpoles in supra arcade downflows (SADs).



- For an E/W oriented streamer/HCS (panels i-l, yellow box), we are looking along the current sheet plane.
- Here the reconnection/disconnection signatures look like the prototypical streamer blob (r,s) and flux-rope (t).