Investigation of the middle corona with SWAP and a data-driven non-potential coronal field model

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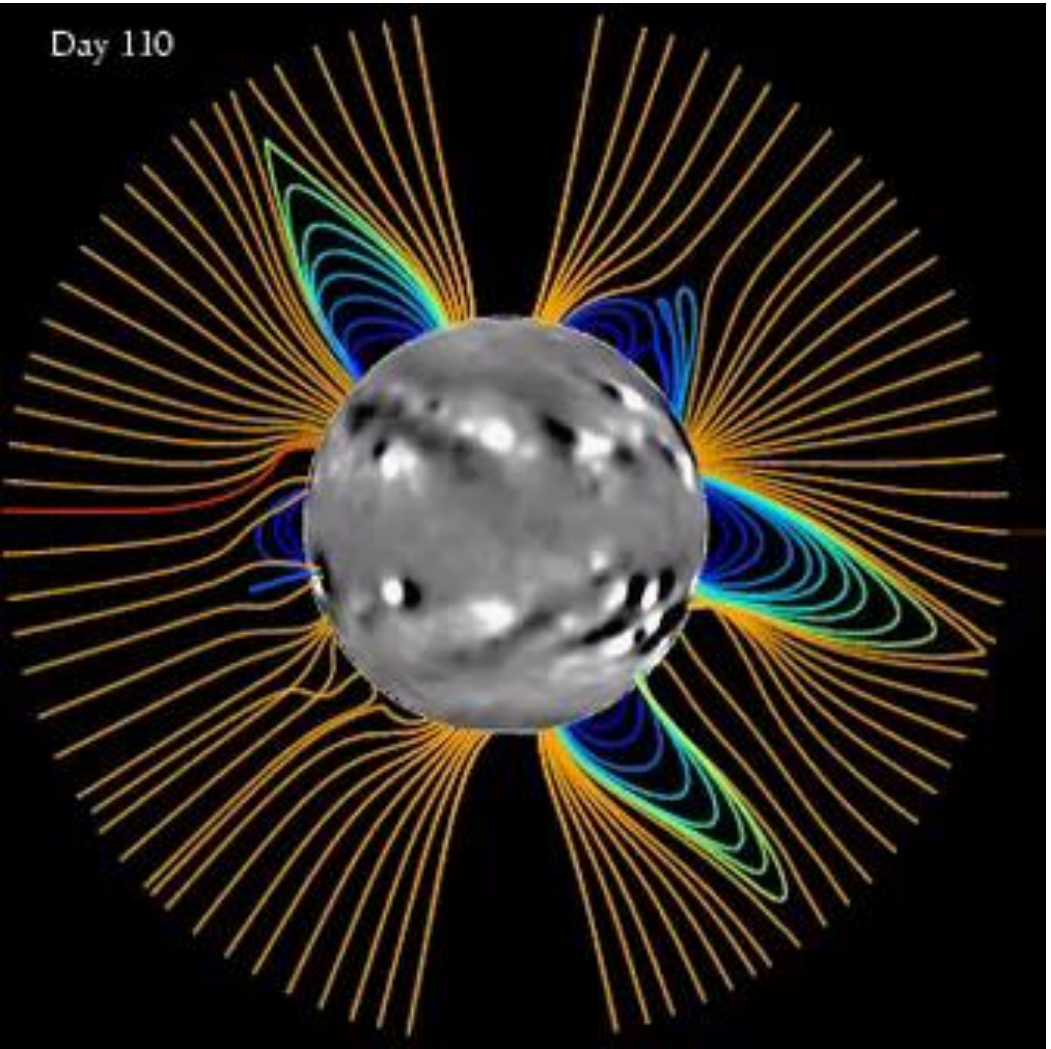
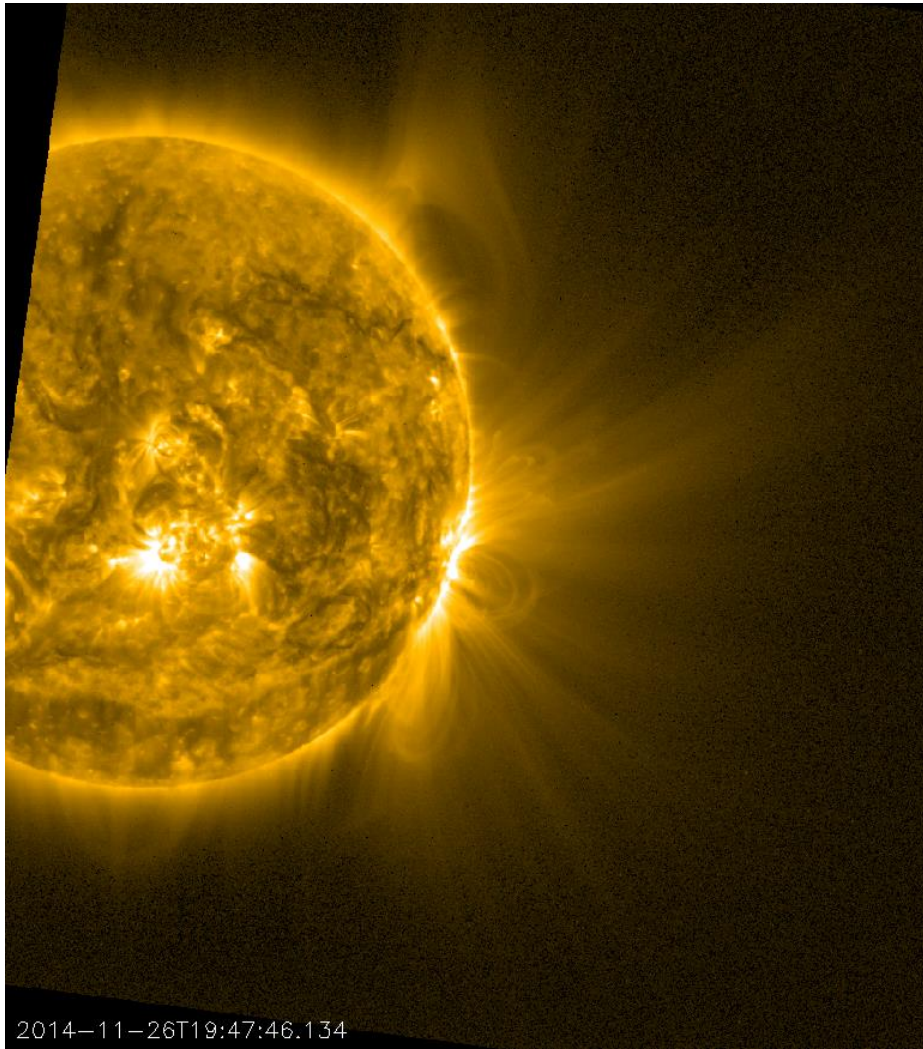


Non-linear force-free field model for corona

Model corona out to 2.5 solar radii

Flux transport model for evolving photosphere

Bipole parameters determined from observations



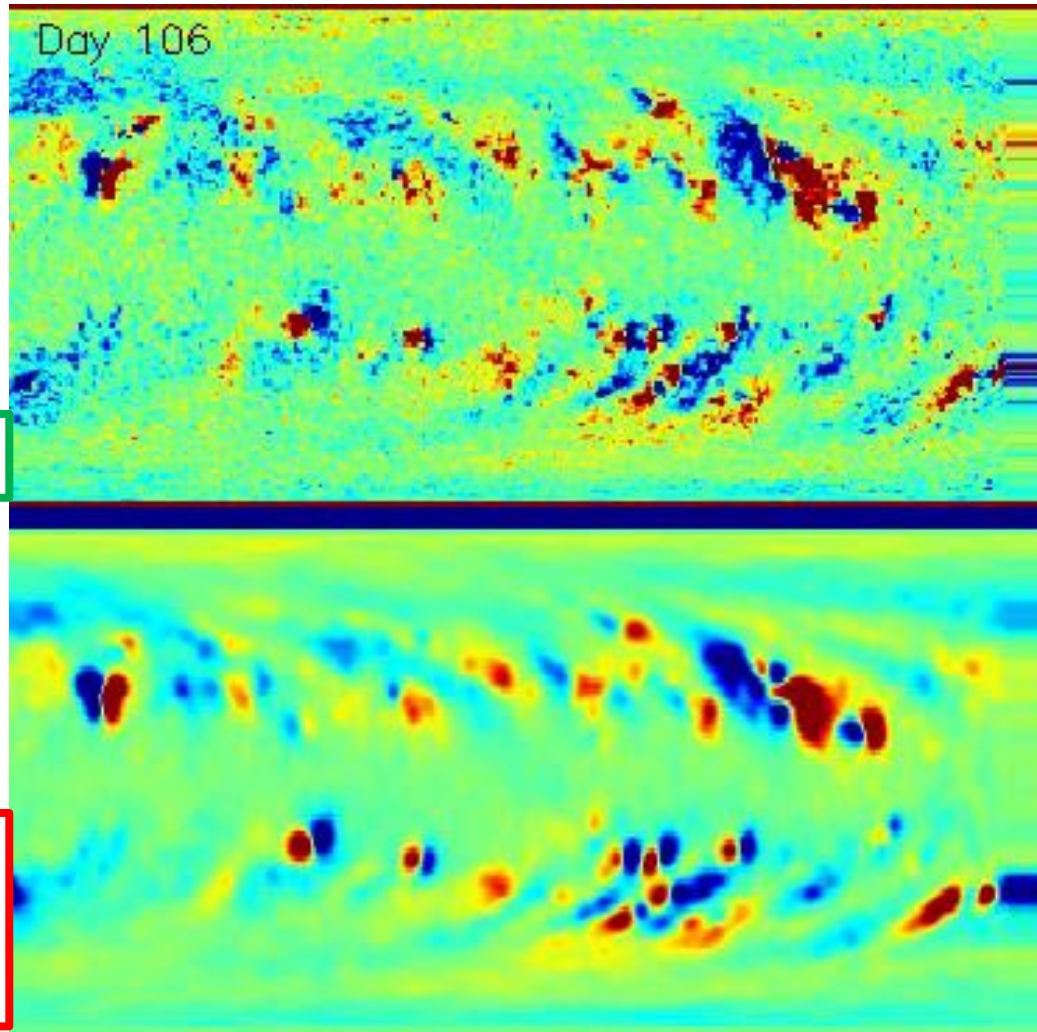
Flux Transport Model

- Initial condition: PFSS source surface based on synoptic magnetogram (e.g. Kitt Peak, SOLIS)

- Evolution: - Differential Rotation
  - Meridional Flow
  - Surface Diffusion

- New bipoles: Properties (e.g. flux, tilt, location) determined from subsequent synoptic magnetograms

- Lower boundary condition for coronal model



Simulation

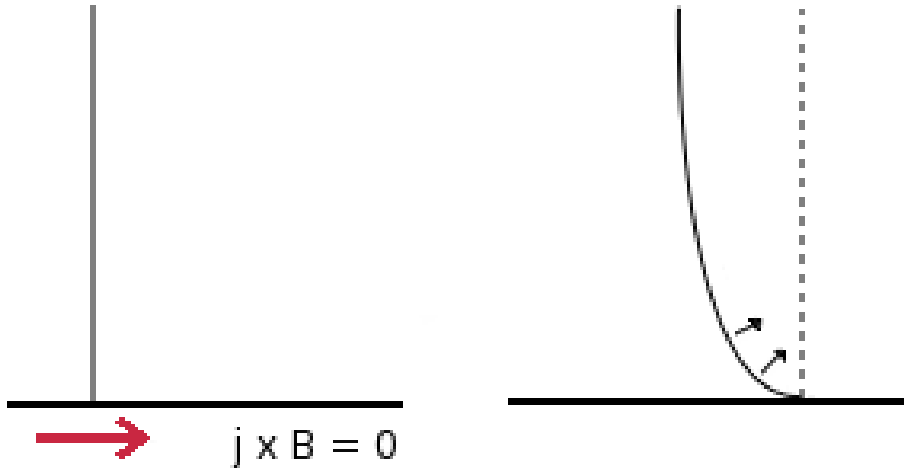
Smoothed observed synoptic magnetograms

Magnetofrictional Coronal Model

- Coronal field induction equation: $$\frac{\partial \mathbf{A}_0}{\partial t} = \mathbf{v}_0 \times \mathbf{B}_0 - \mathbf{E}_0,$$

$$\mathbf{E}_0 = -\frac{\mathbf{B}_0}{B_0^2}\nabla \cdot (\eta_4 B_0^2 \nabla \alpha_0), \qquad \alpha_0 = \frac{\mathbf{B}_0 \cdot \mathbf{j}_0}{B_0^2} \qquad \mathbf{v}_0 = \frac{1}{\nu}\frac{\mathbf{j}_0 \times \mathbf{B}_0}{B_0^2} + v_{\text{out}}(r)\mathbf{e}_r.$$

- Coronal field evolves through continuous series of quasi-static force-free states (jxB=0).

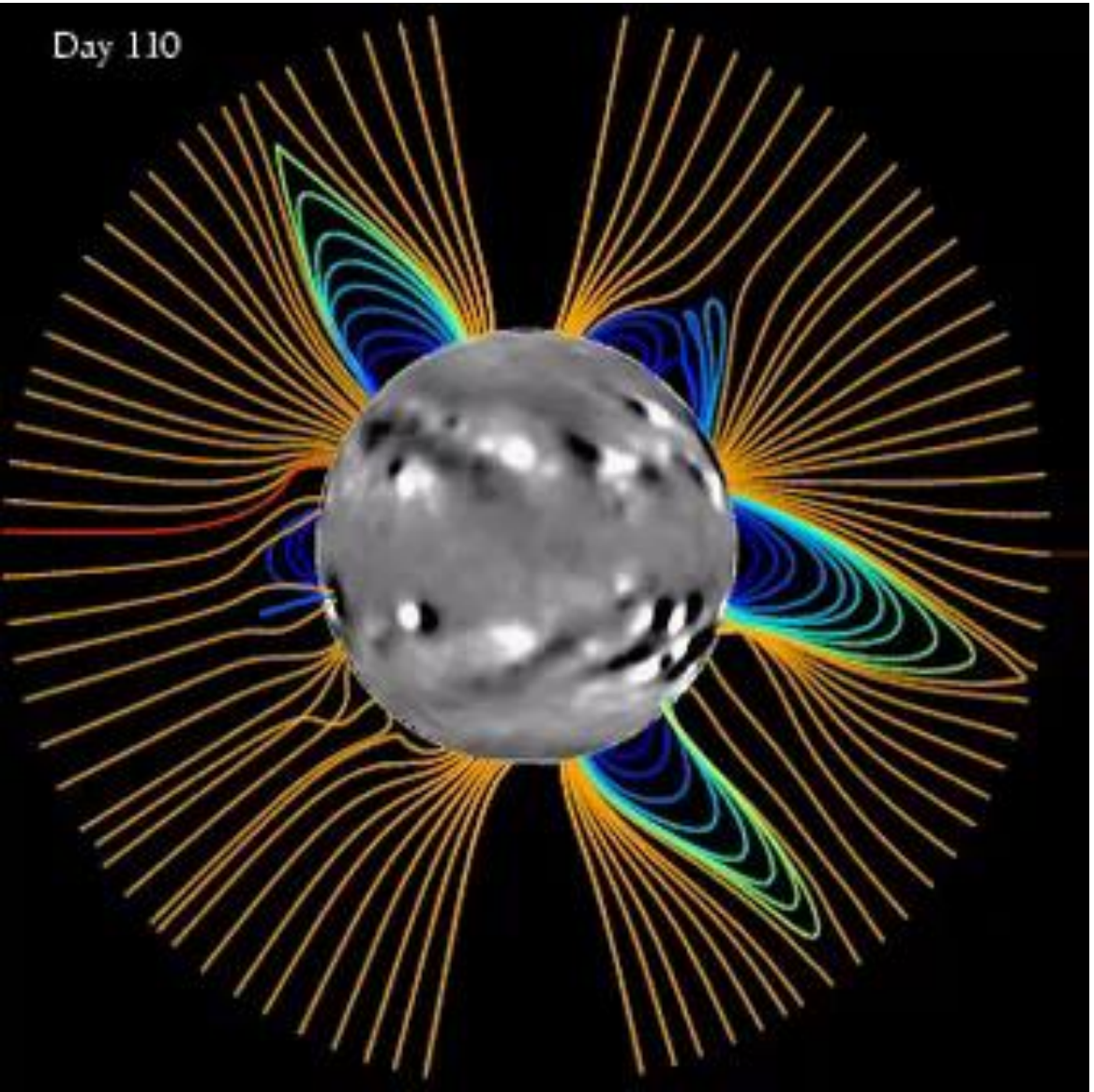


Alternative non-ideal term:

$$\eta(|\mathbf{j}|) = \eta_o\left(1 + c\frac{|\mathbf{j}|}{B_{max}}\right)$$

$$\eta_o = 0.1D, \quad D = 600 km^2 s^{-1}, \quad c = 0.2$$

Example simulation: May – Aug 1999



- Sample fieldlines plotted in plane of sky.
- For model development and applications, see e.g.

  van Ballegooijen et al 2000;
  Mackay and van Ballegooijen 2006a,b;
  Yeates et al. 2007, 2008a,b, 2009a,b, 2010, 2012

- Also Yeates et al. 2018

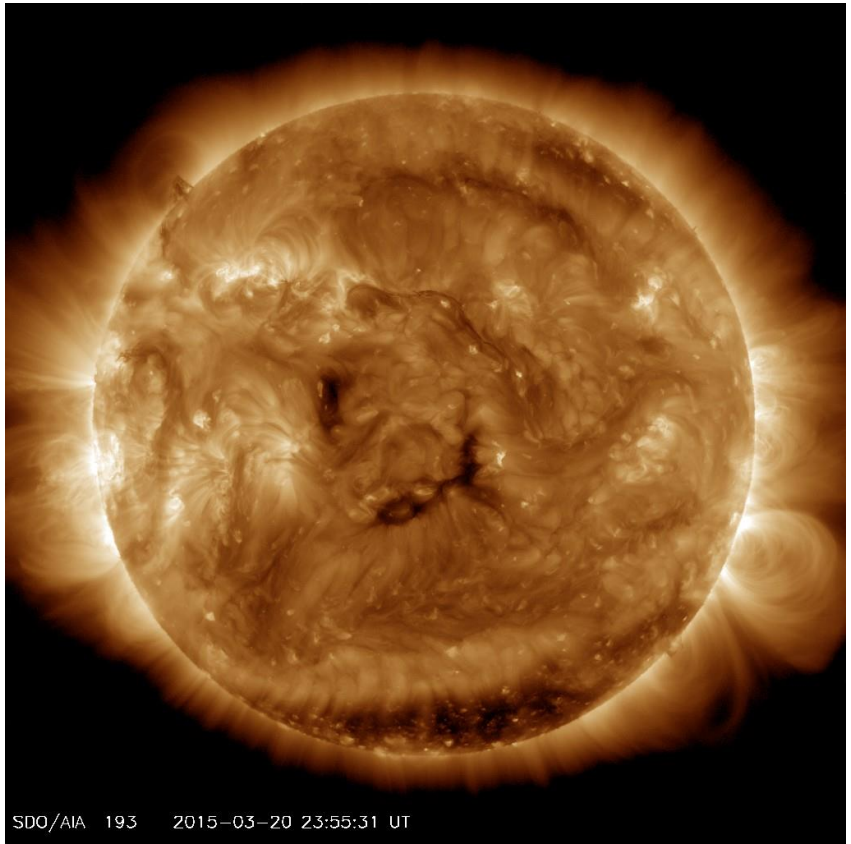
"Global Non-Potential Magnetic Models of the Solar Corona During the March 2015 Eclipse"

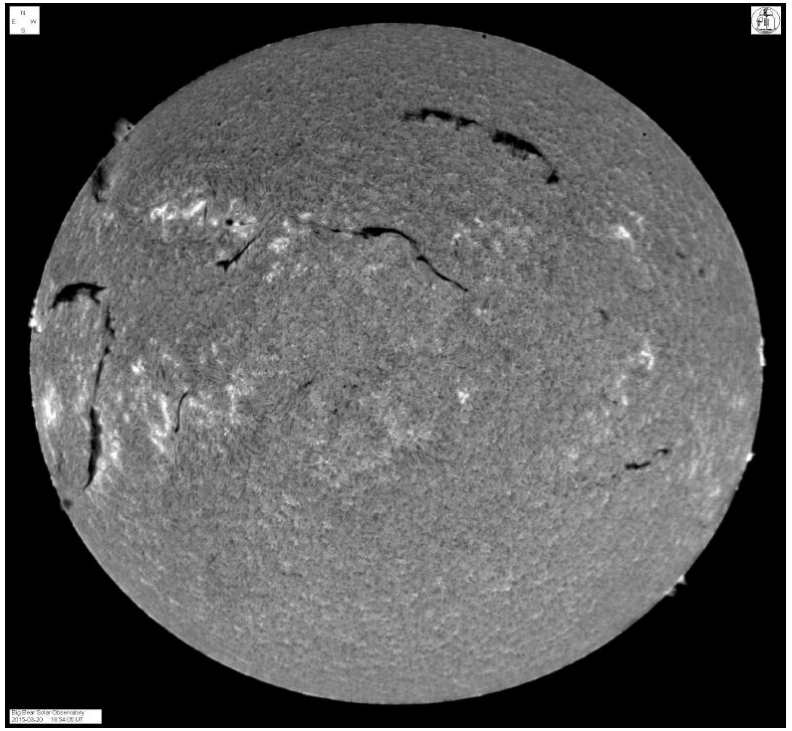
Initial study: March 2015 Eclipse Simulation – Comparison of Global Structure

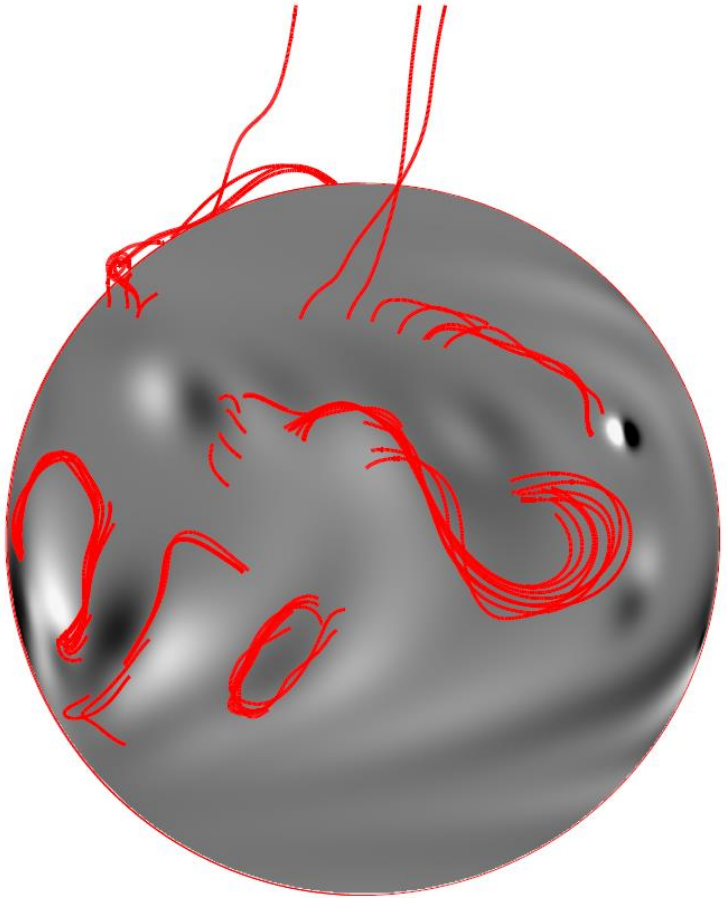
Simulation: 1st September 2014 – 21st March 2015 (Eclipse 20th March 2015)

Filaments well reproduced (see also filament studies by Yeates et al.)

Compare global structure with SWAP mosaics and CR movies

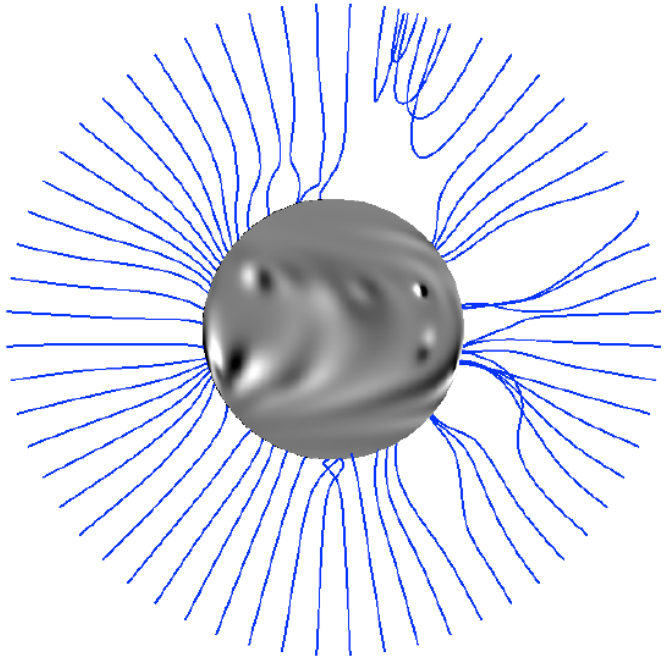




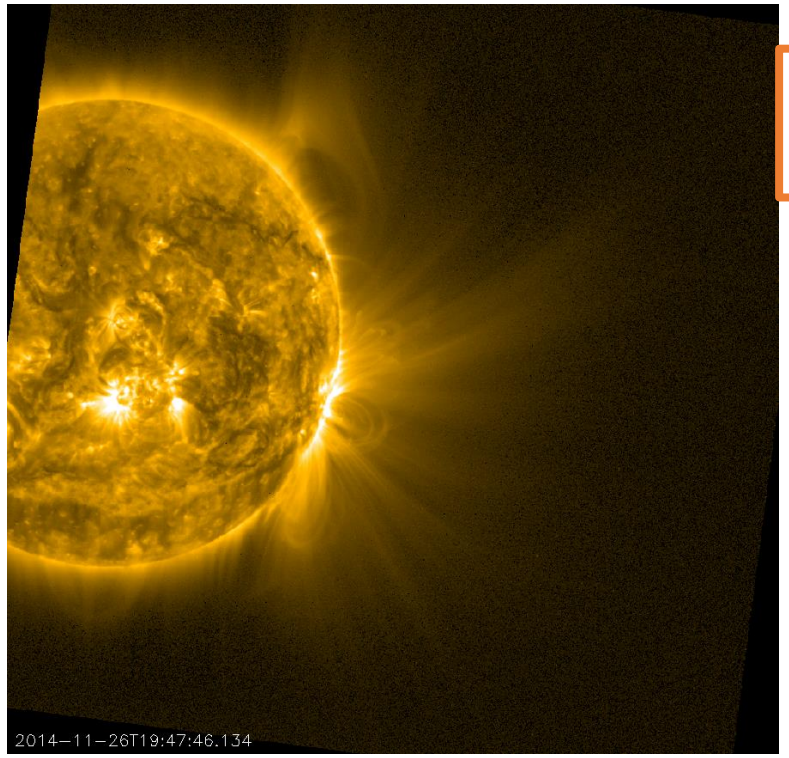


Comparison: 2015 eclipse simulation and SWAP

Global magnetic field structure: sample fieldlines on eclipse day

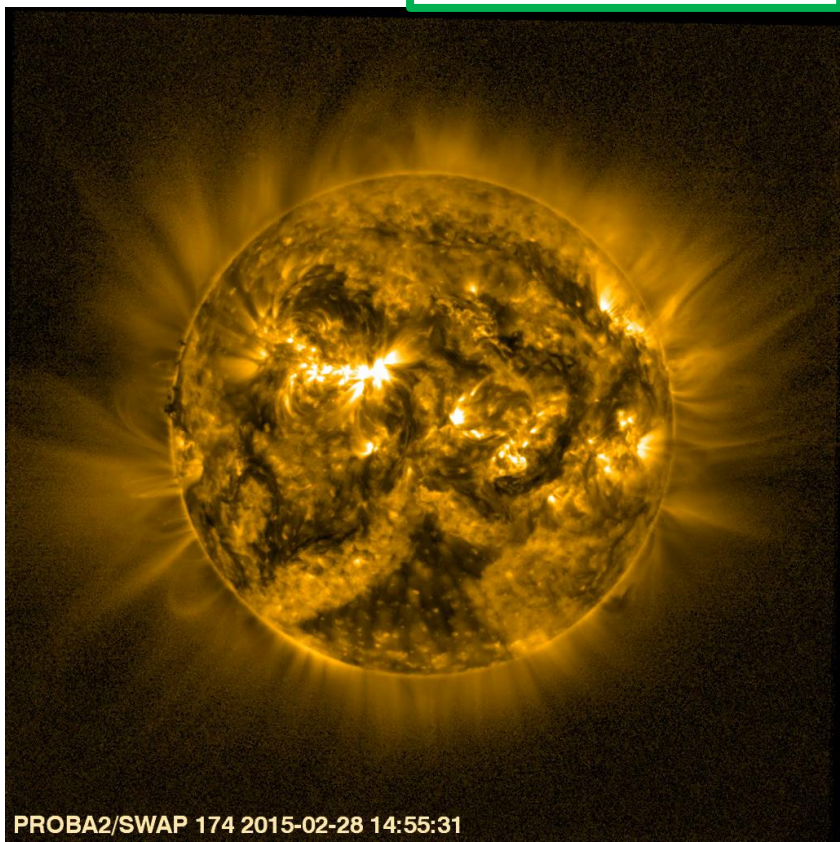


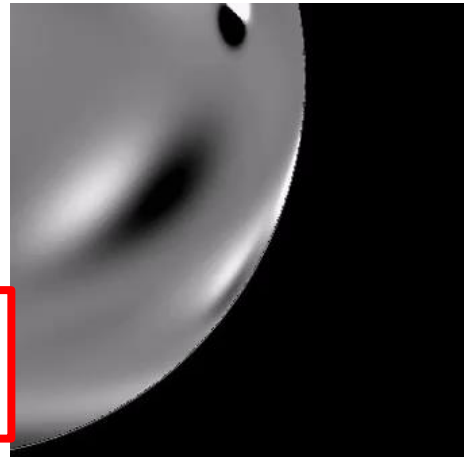
run4_60



Extended features: SWAP off-point image from 26th Nov 2014

Evolving features: SWAP CR movies



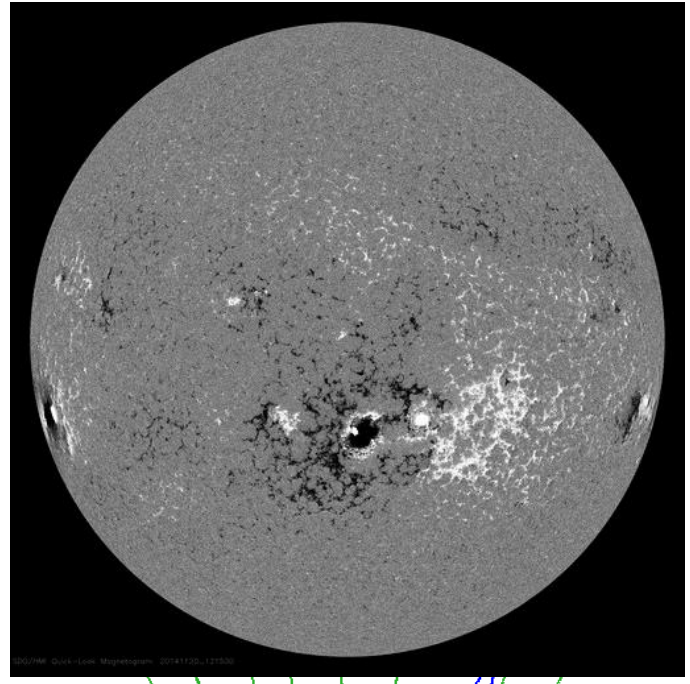


Evolving features: flux rope formation and lift-off

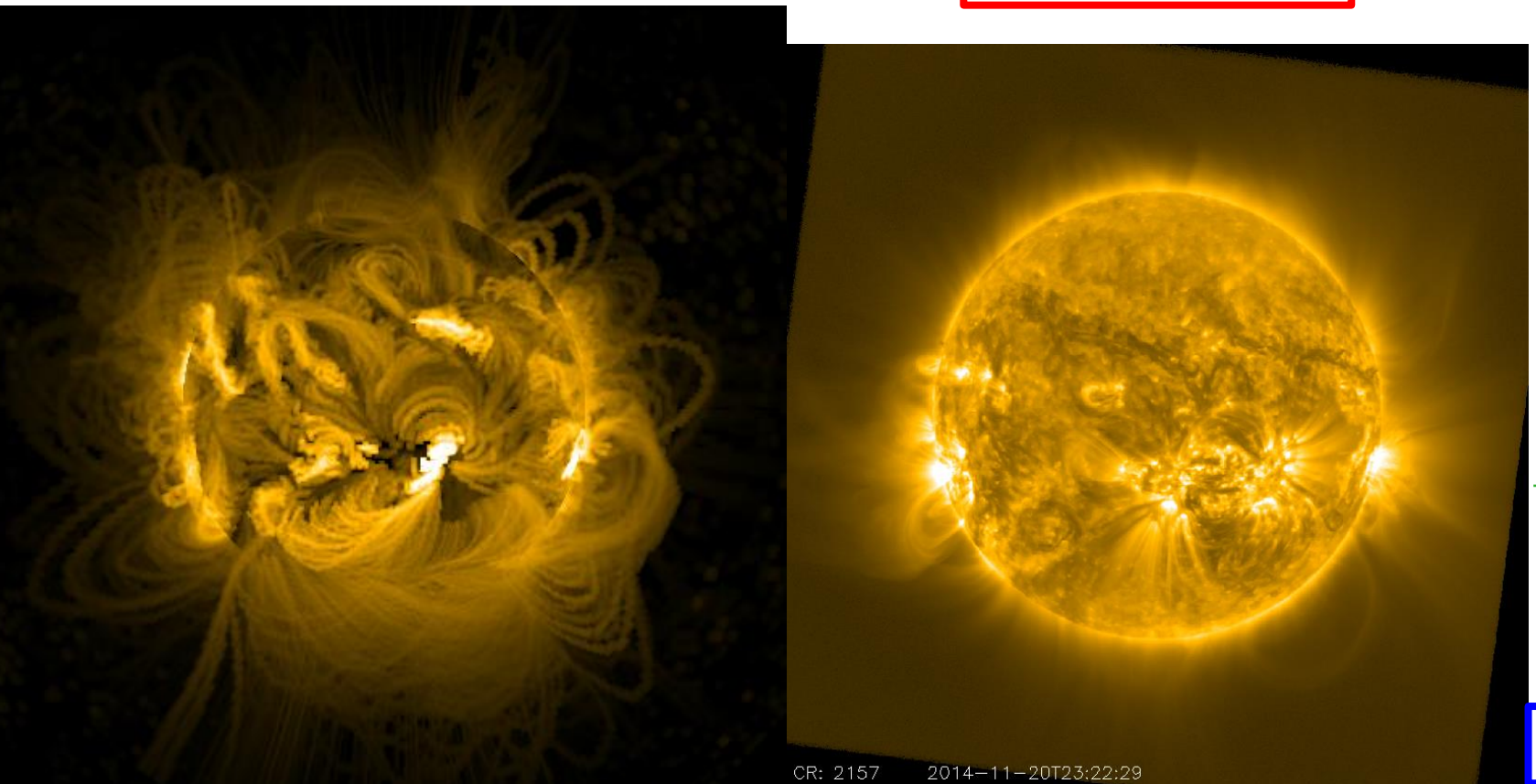
Simulation data: 21st Nov 2014

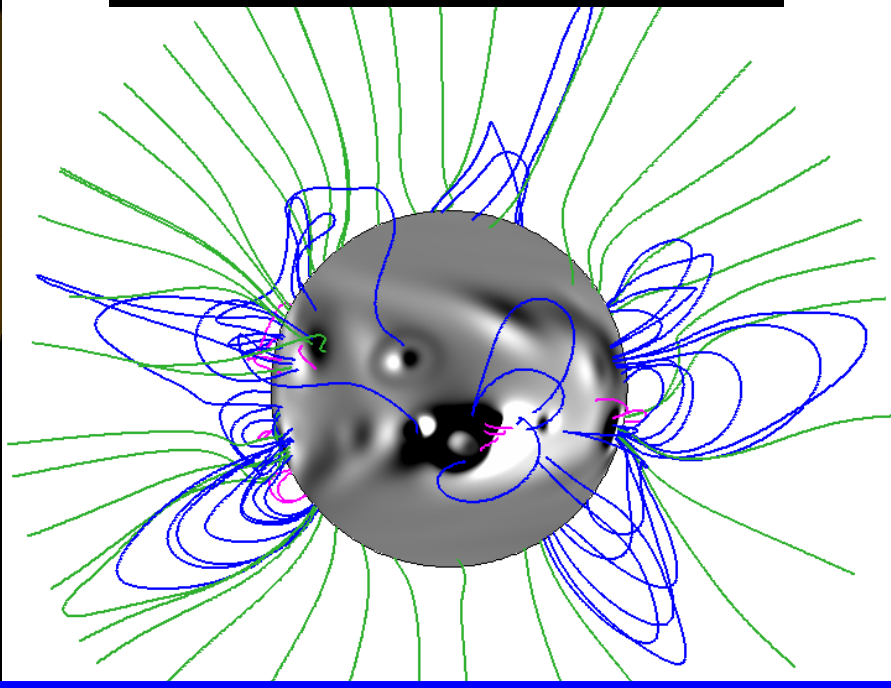
Simulated Emission: j^2 averaged along fieldlines, summed along line of sight

HMI magnetogram



SWAP stacked image



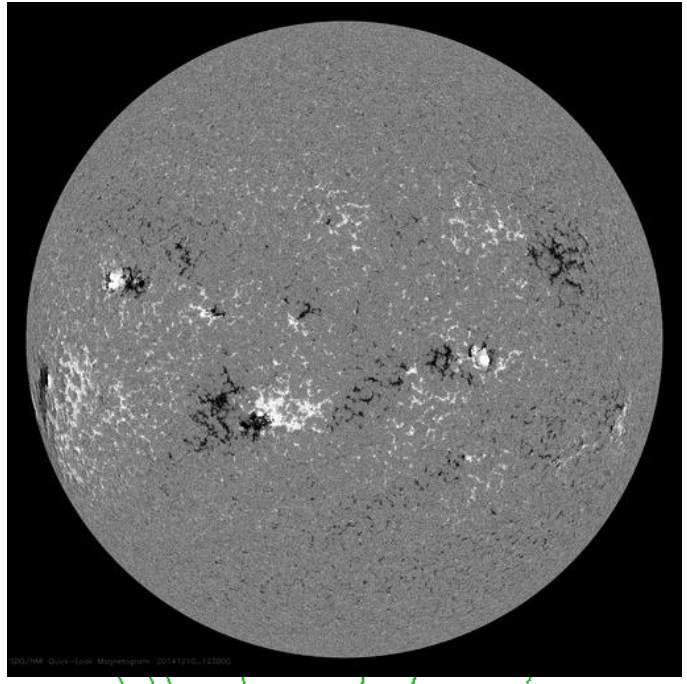


Flux Transport Simulation + Field lines

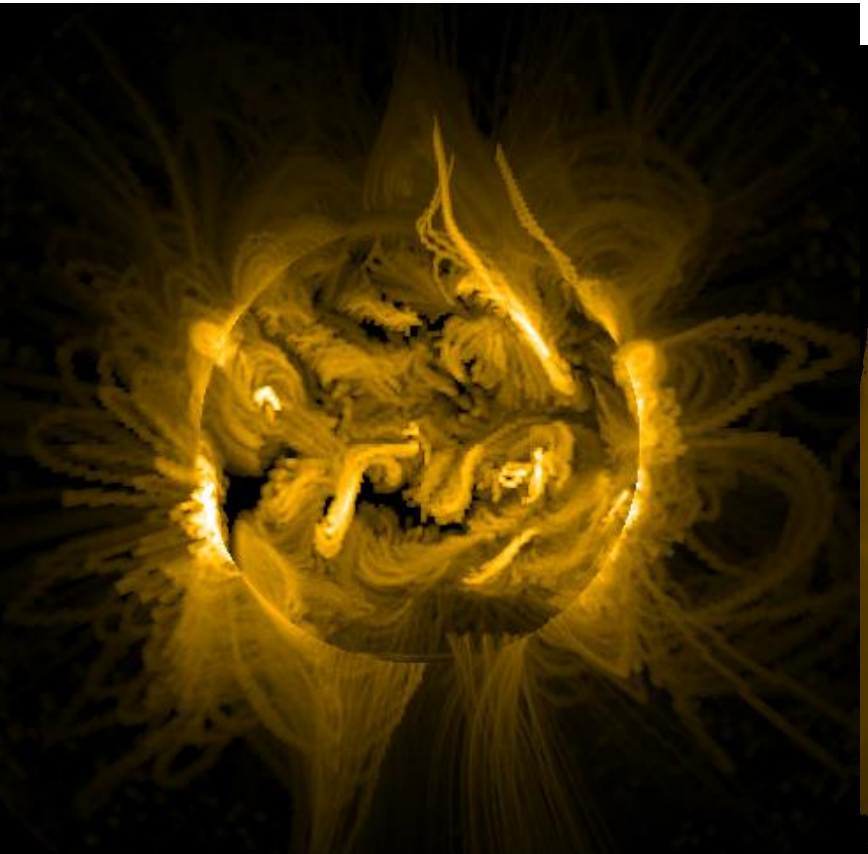
Simulation data: 11th Dec 2014

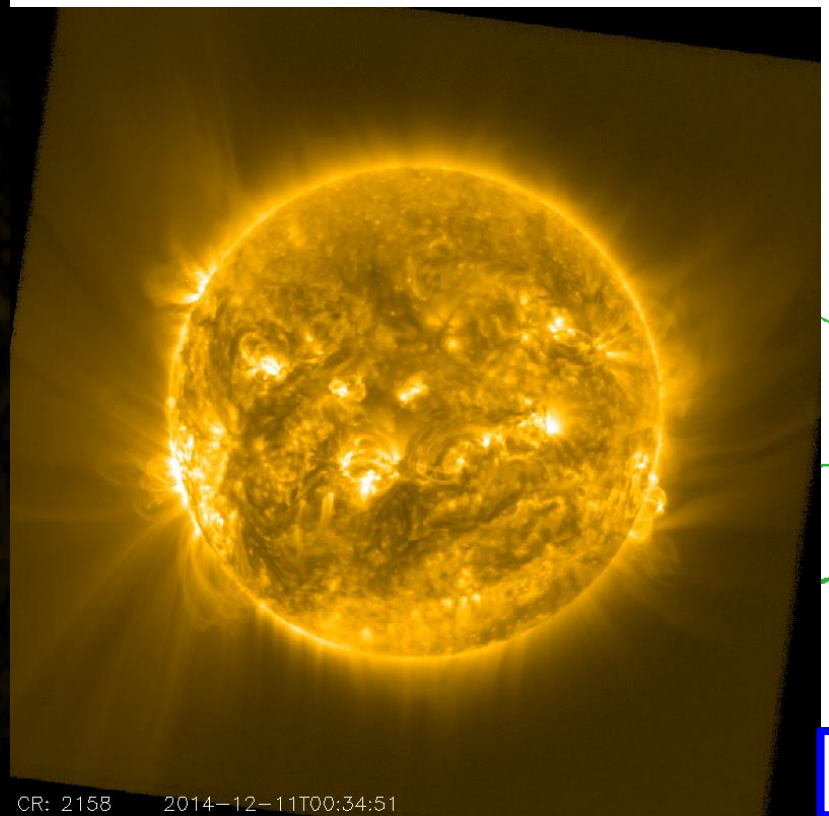
Simulated Emission: j^2 averaged along fieldlines, summed along line of sight

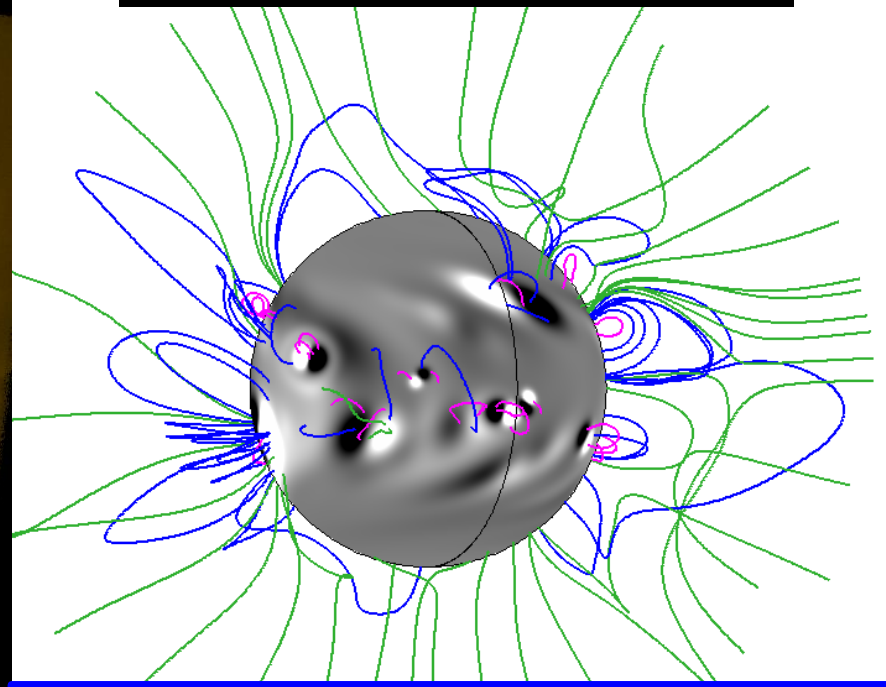
HMI magnetogram



SWAP stacked image





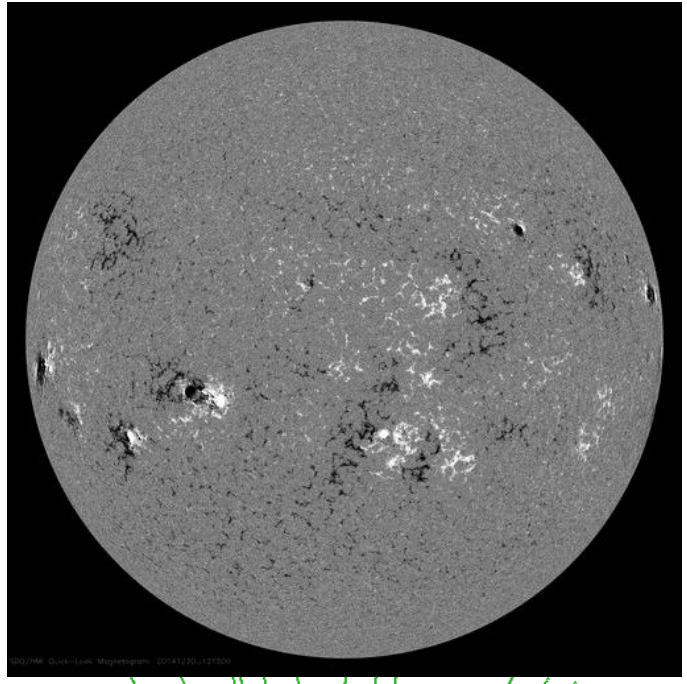


Flux Transport Simulation + Field lines

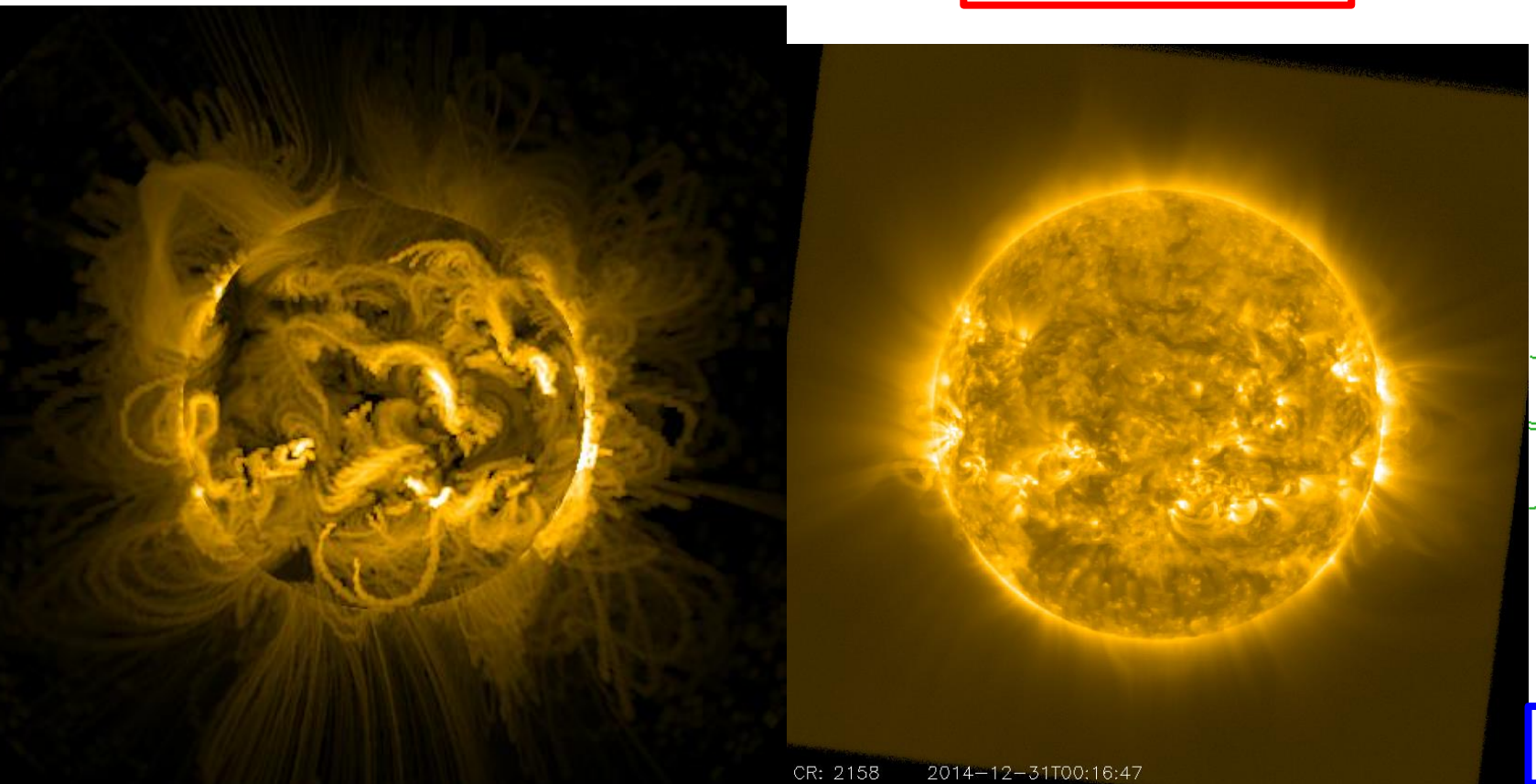
Simulation data: 31st Dec 2014

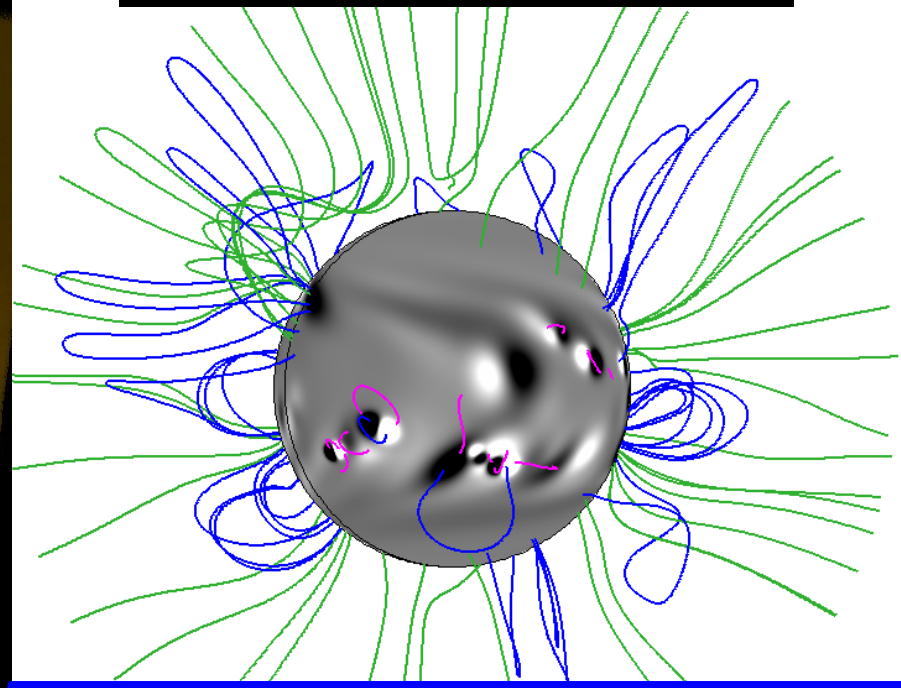
Simulated Emission: j^2 averaged along fieldlines, summed along line of sight

HMI magnetogram



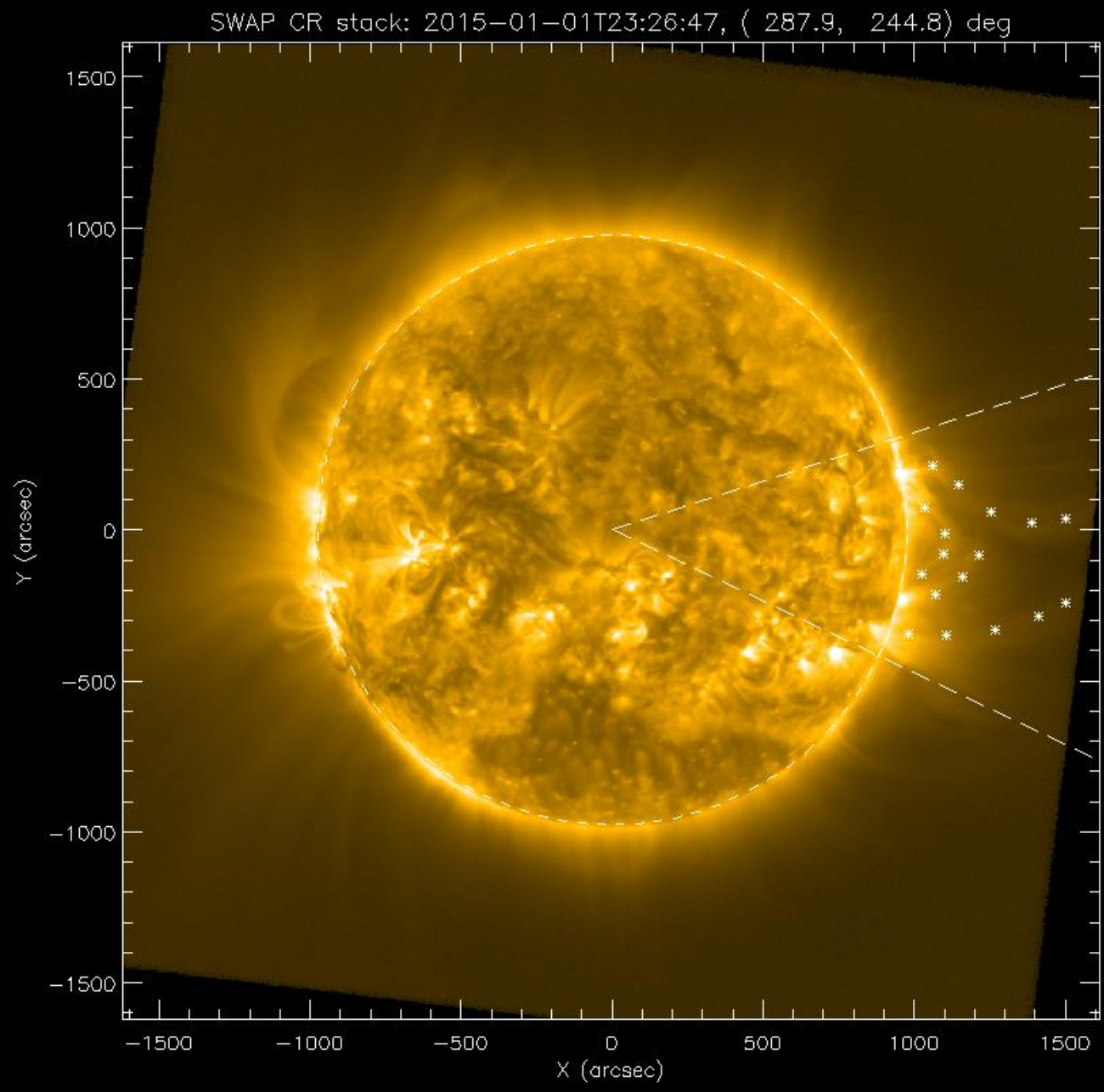
SWAP stacked image

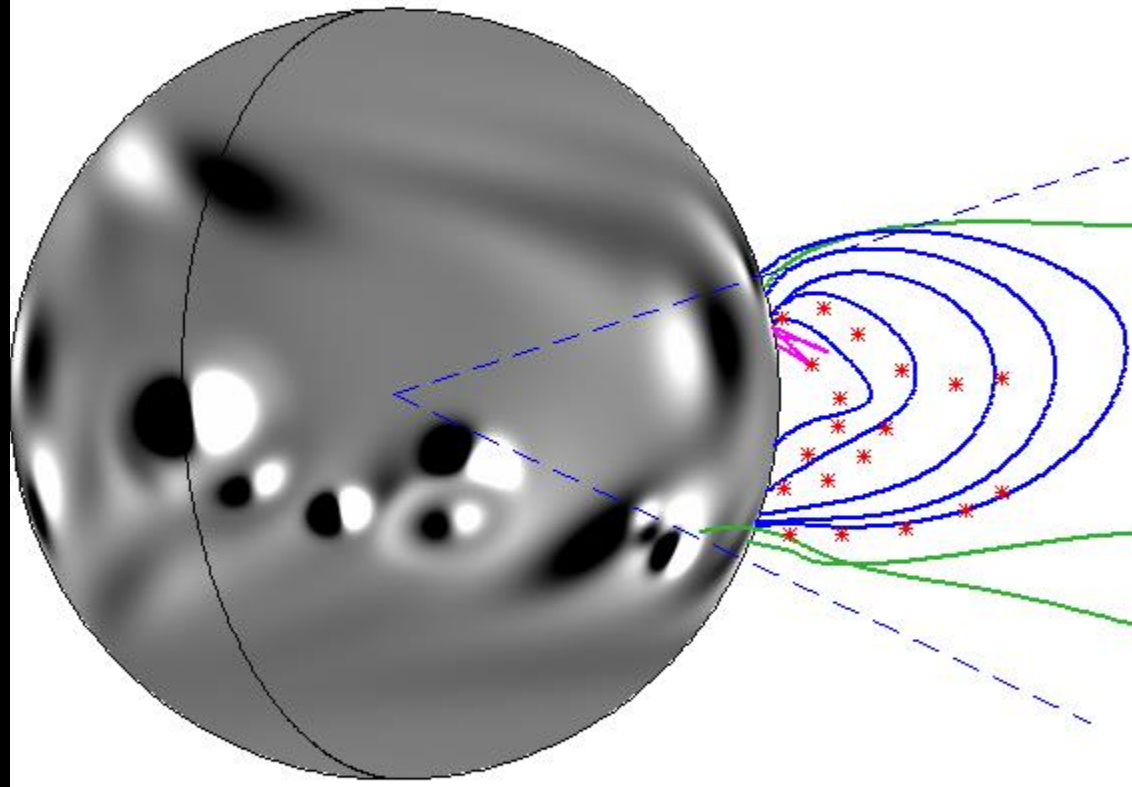




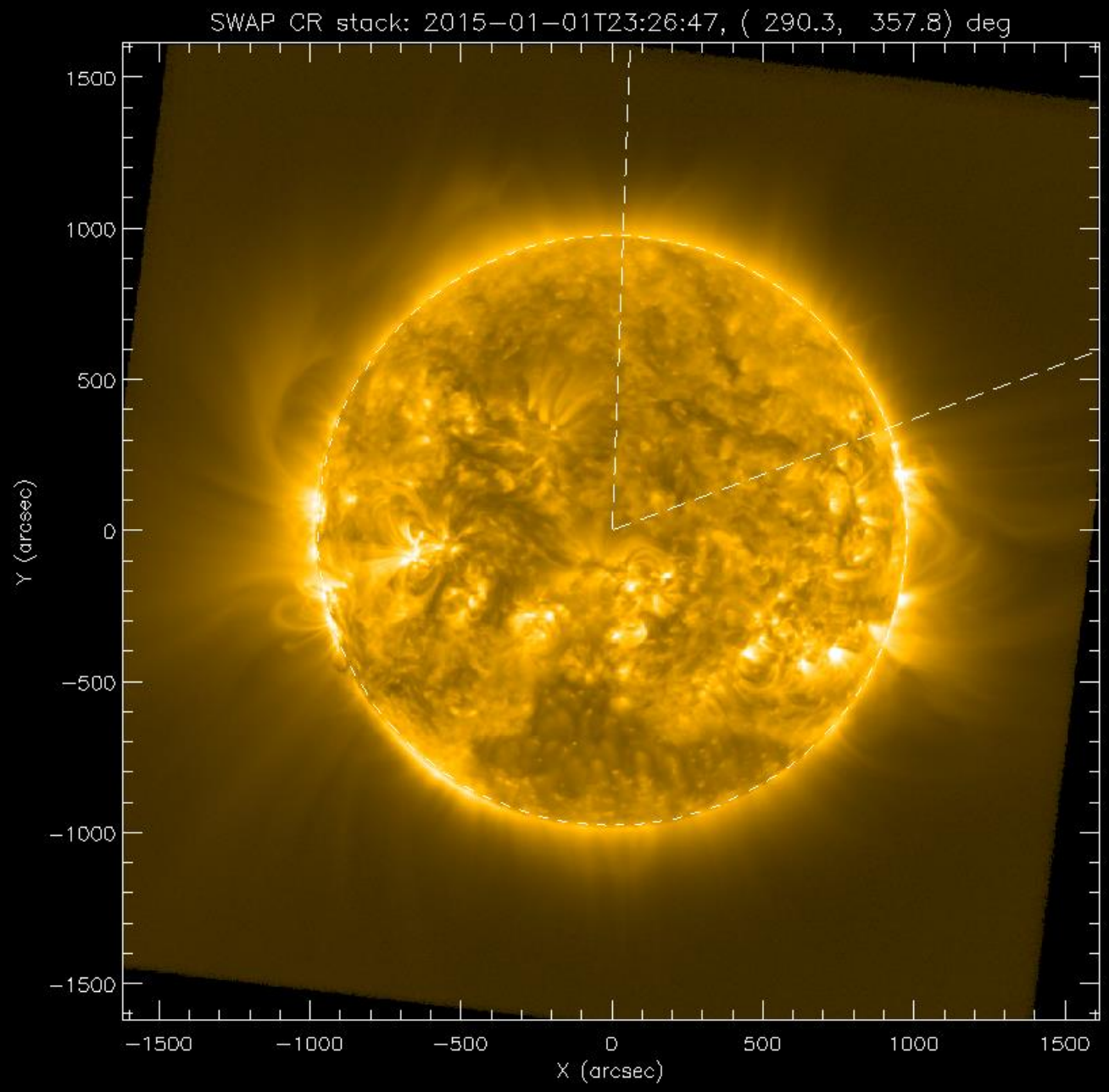
Flux Transport Simulation + Field lines

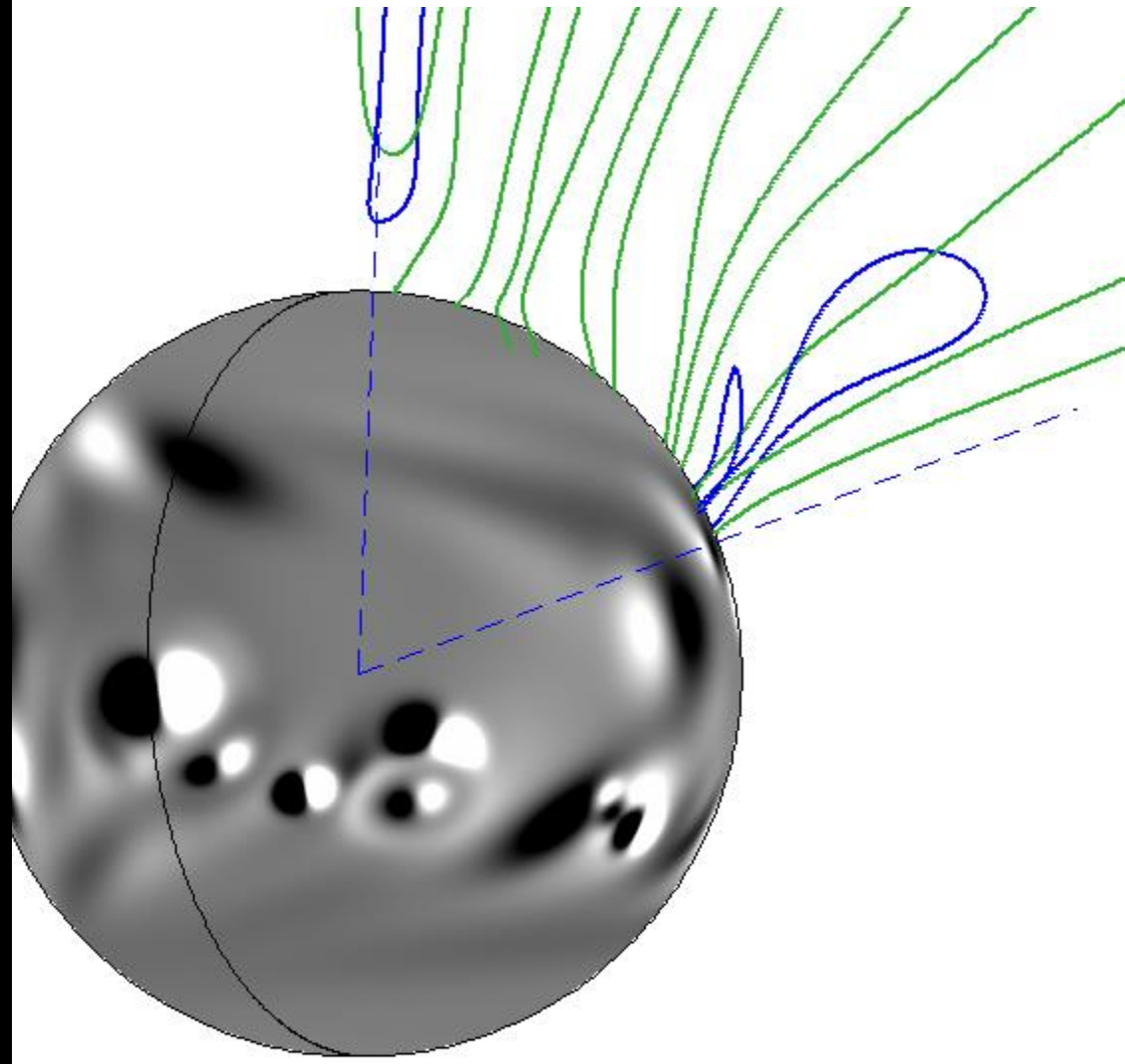
Comparison of Coronal Structure





Comparison of Coronal Structure





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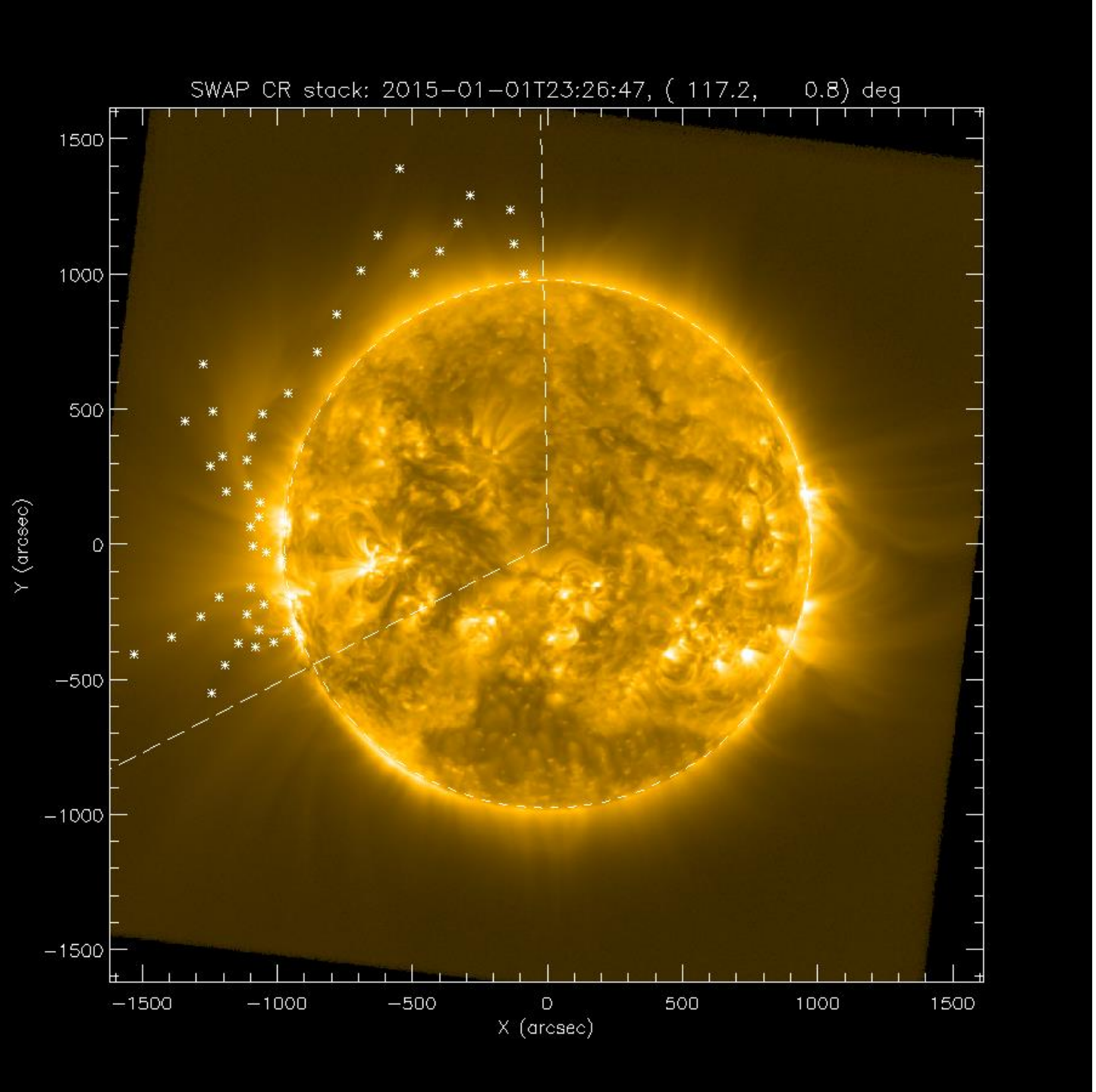

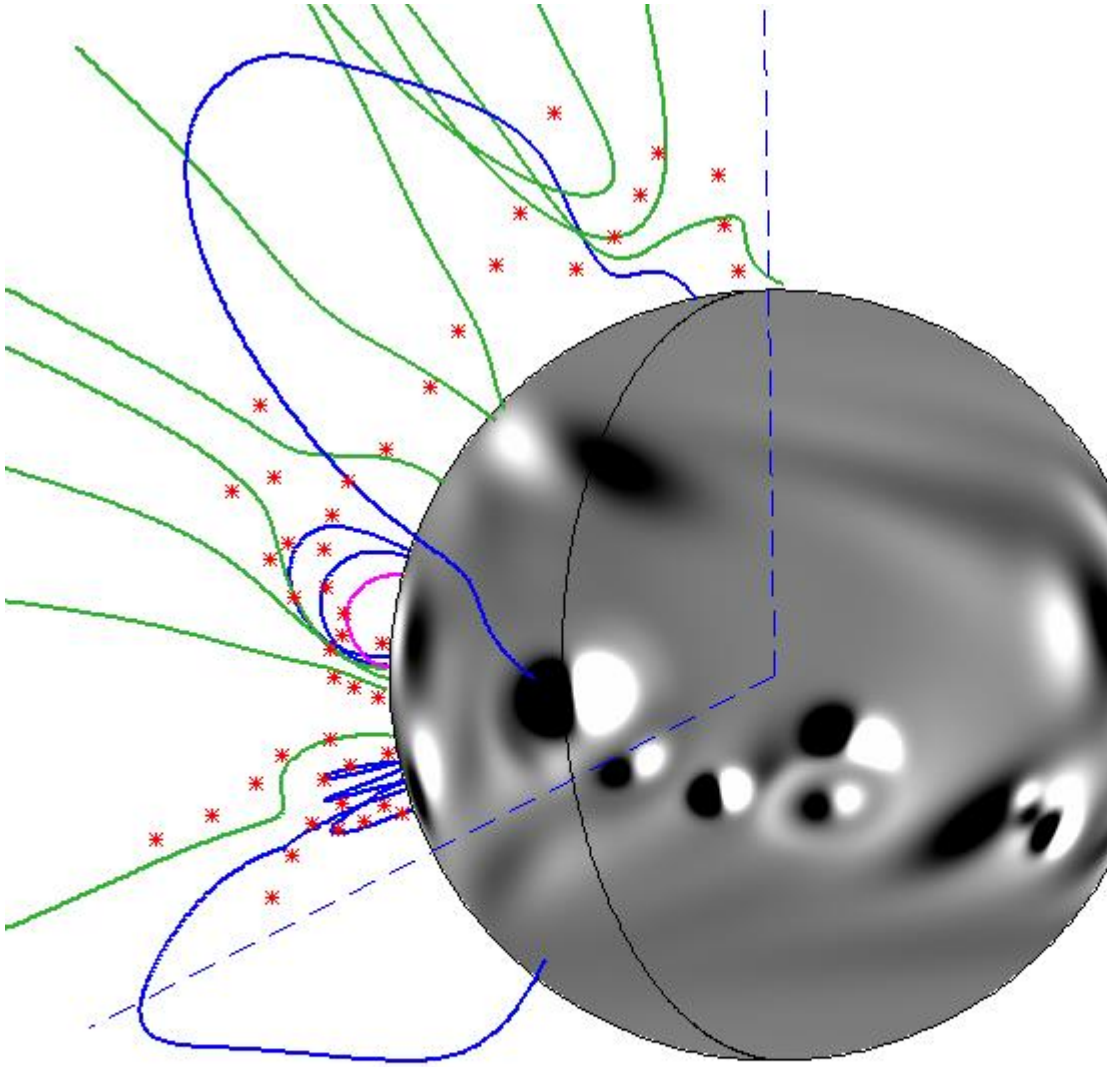

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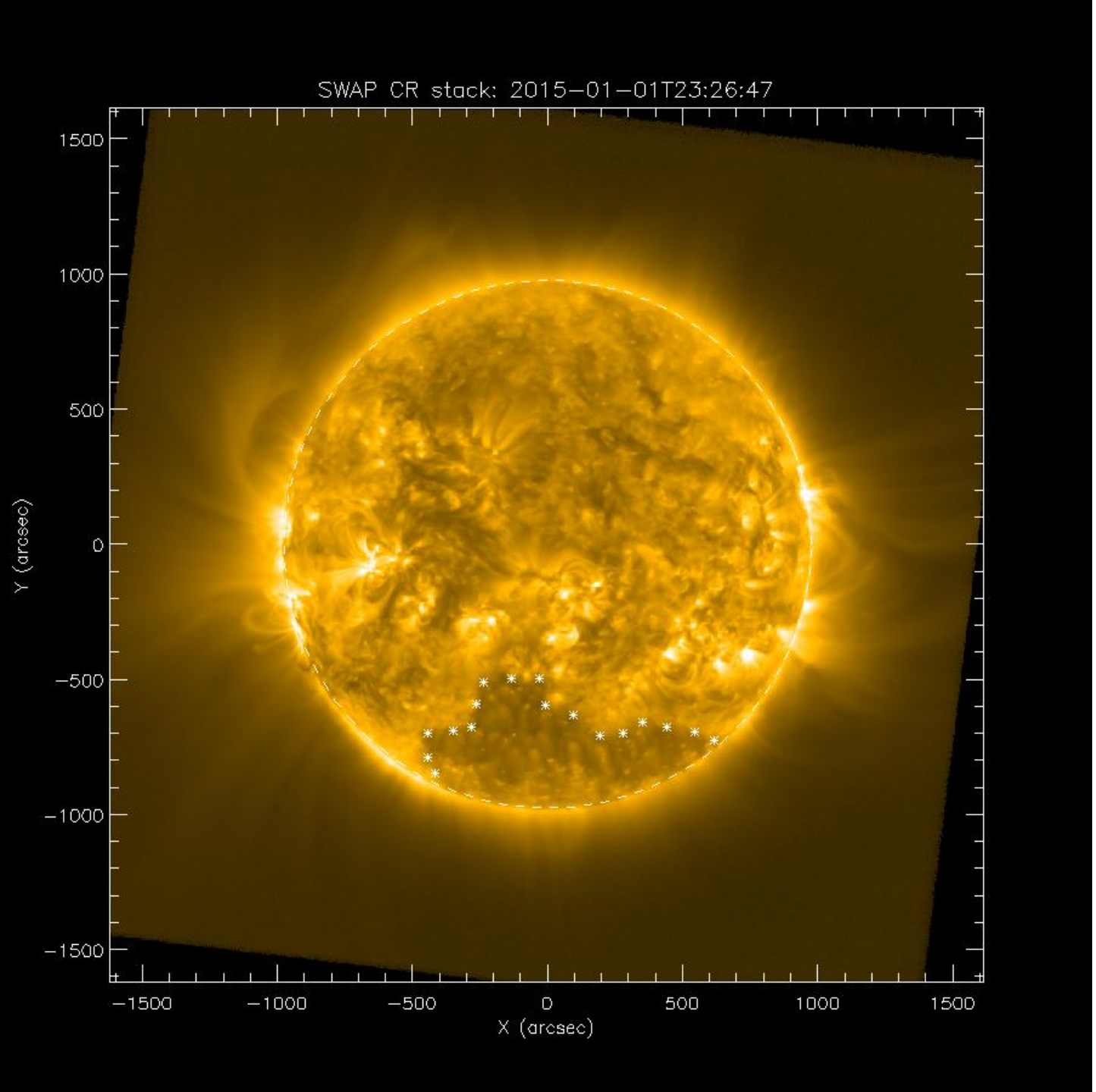

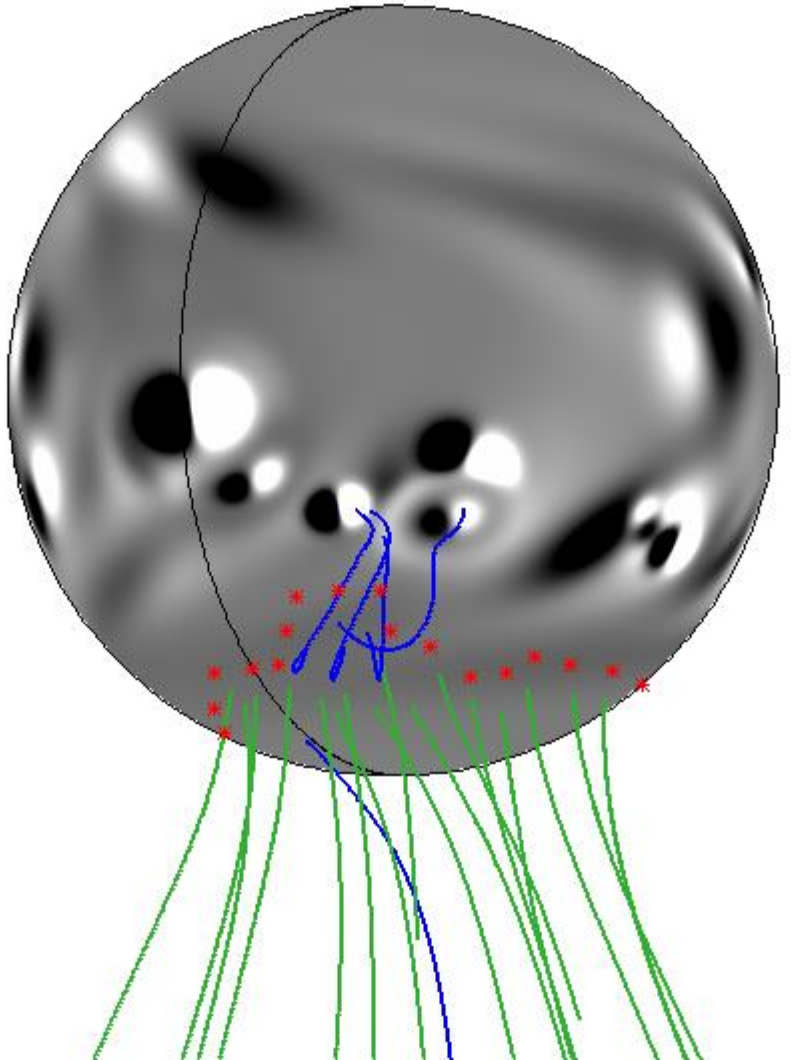

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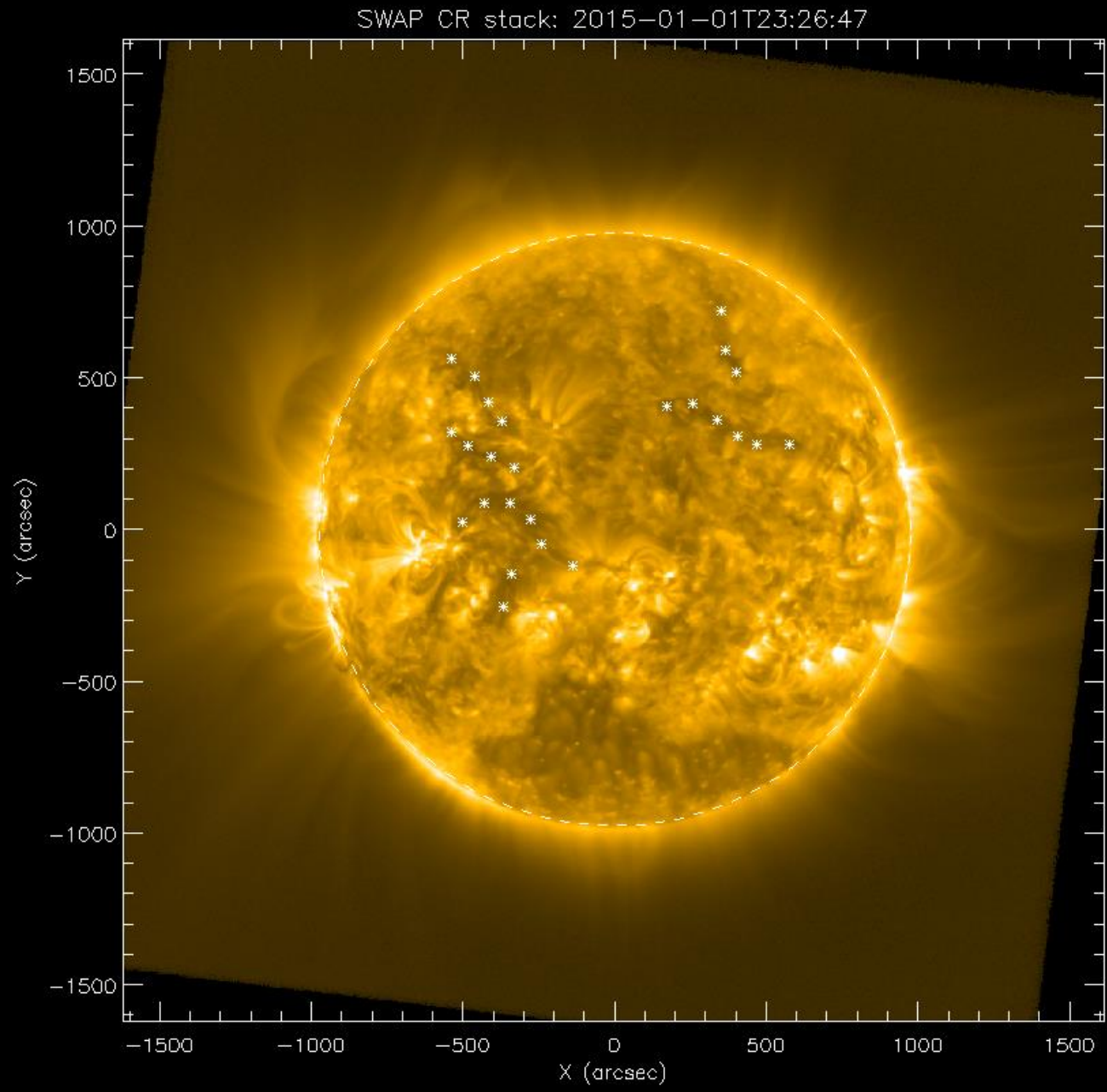
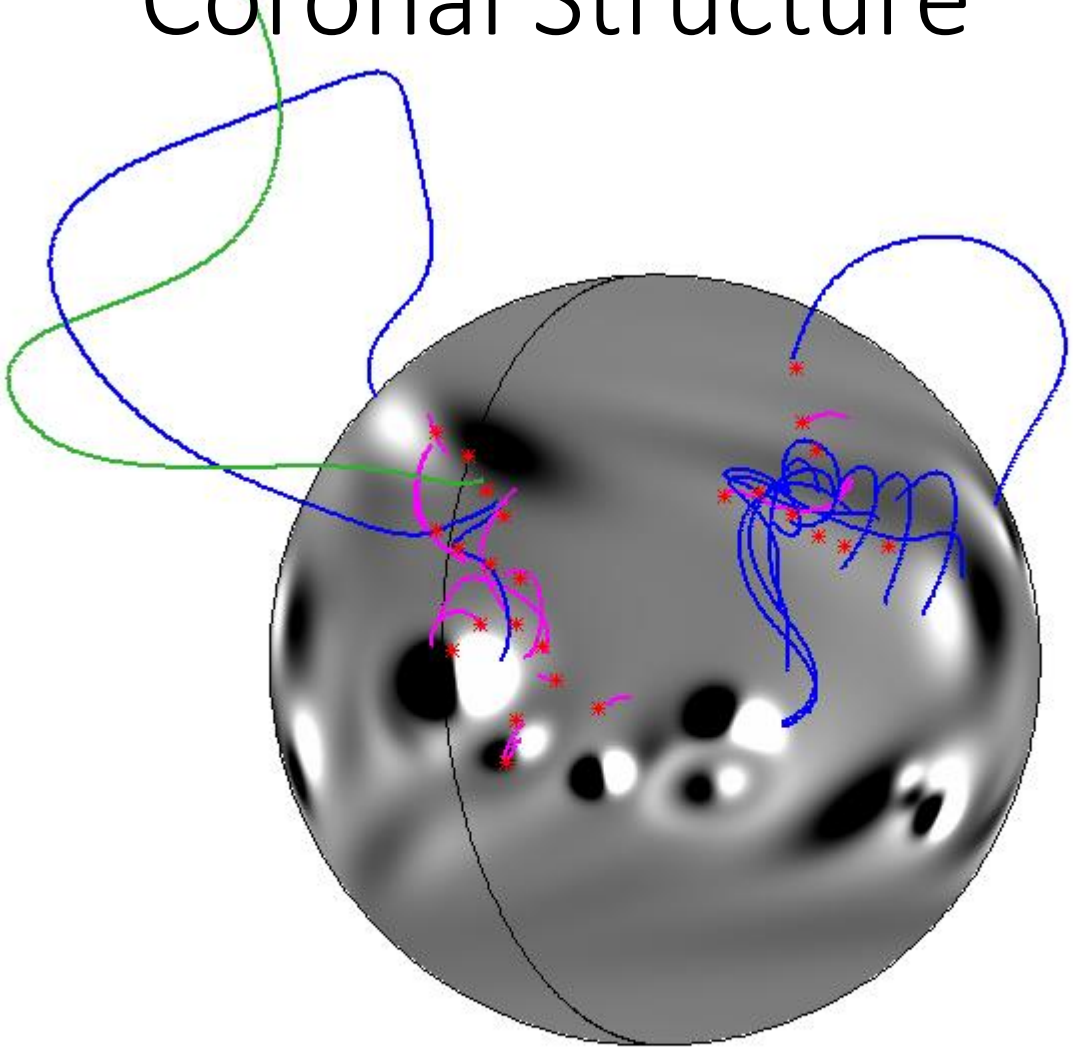
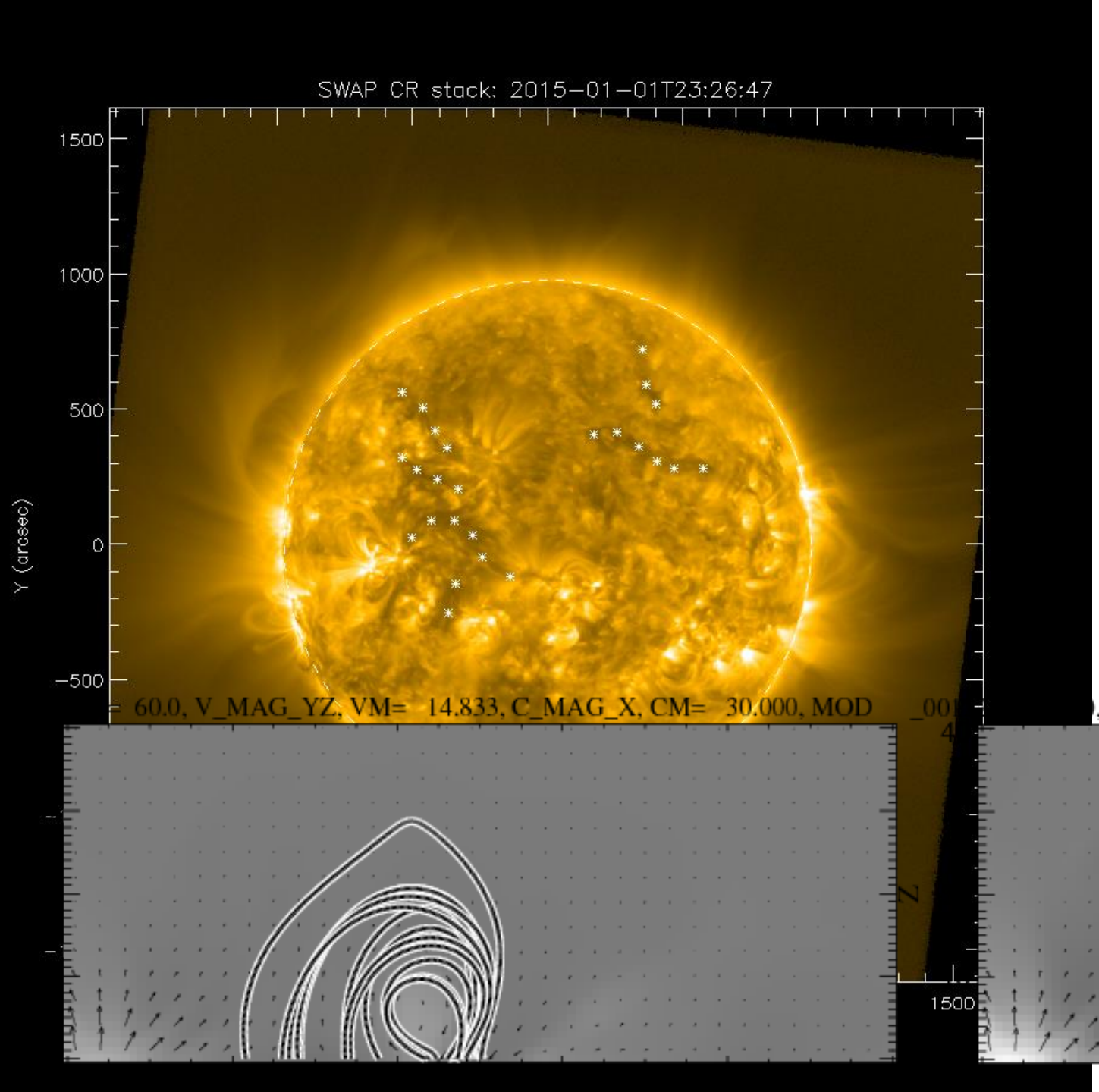
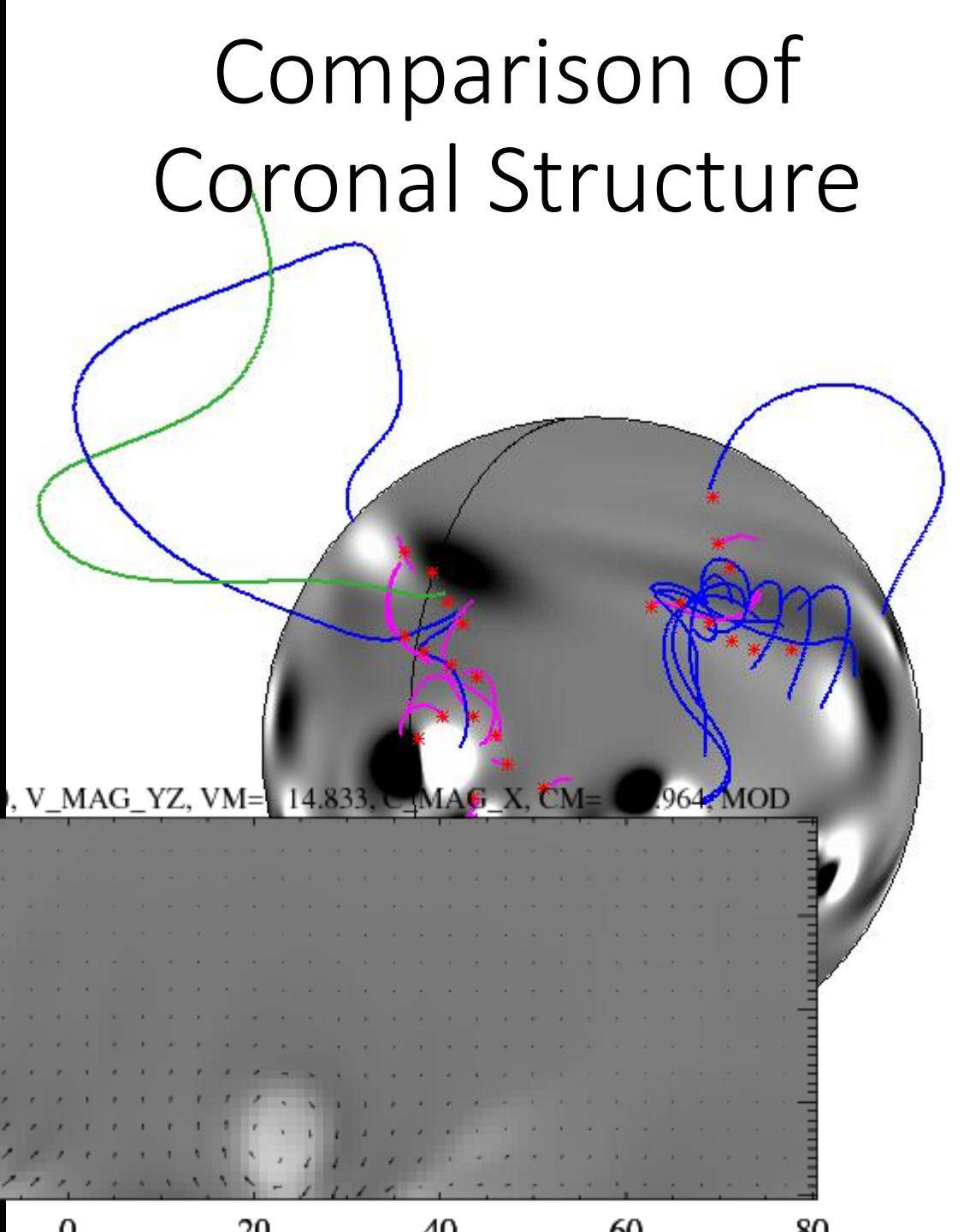


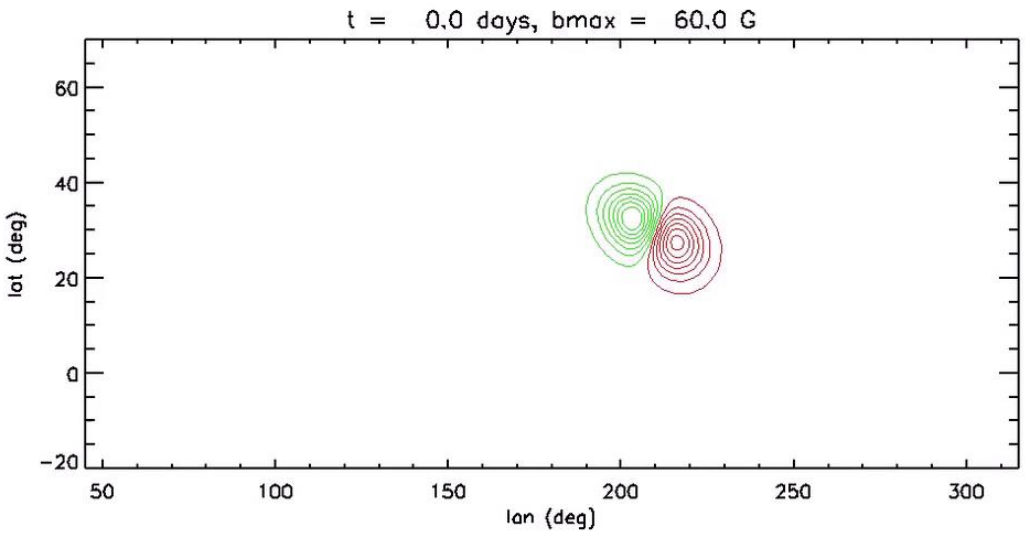


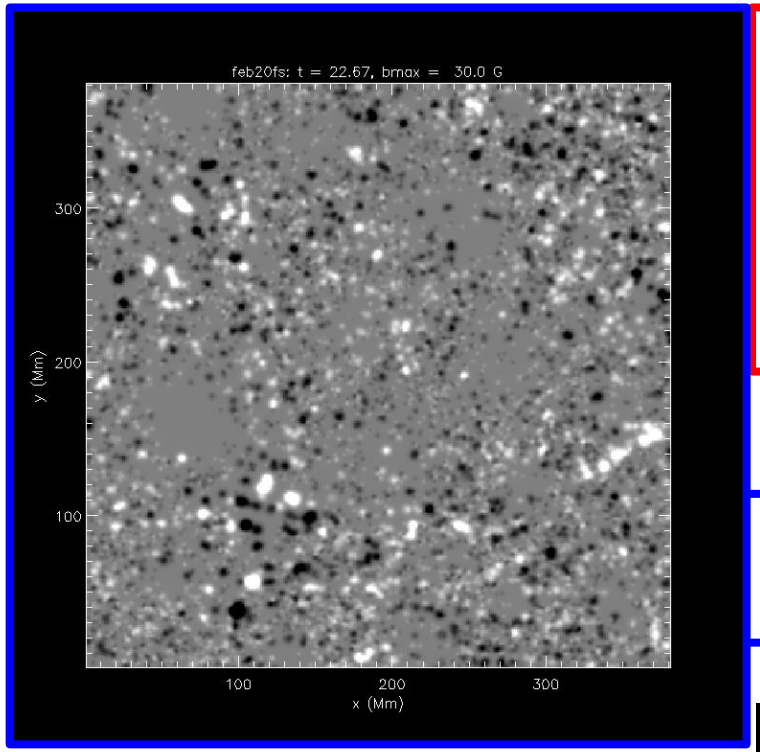
Comparison of Coronal Structure

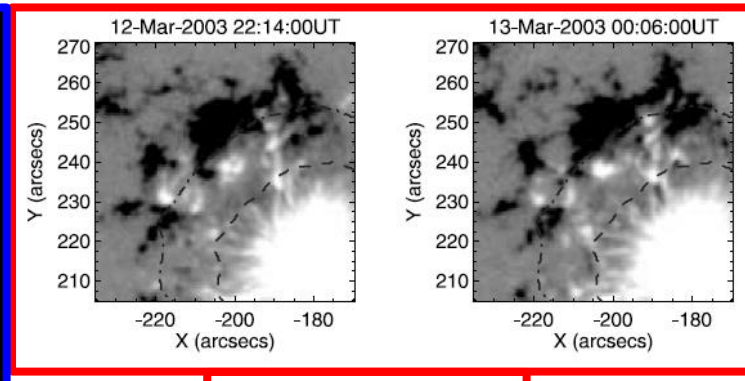




Next: more realistic photospheric evolution – active region decay







Moat Flow

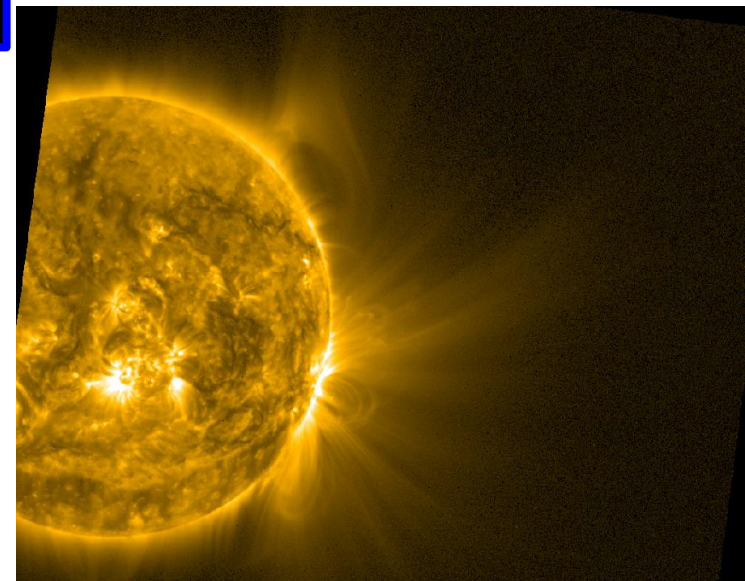
Small-Scale "Magnetic Carpet" Model

Includes:

- Differential rotation (+ meridional circulation)
- Spot decay – fragments break off
- Moat flow
- Supergranulation
- Cancellation, coalescence, fragmentation
- Interaction with surrounding smaller-scale features

Effect on coronal evolution

Simulate active region evolution e.g. as it rotates out of field of view



Summary

- Comparison: 2015 eclipse simulation and SWAP data
  - Simulated emission images – bright active regions
  - Flux ropes – filaments
  - Global magnetic field structure
  - Evolving large-scale features – CR movies

- Improving the photospheric evolution model
  - More realistic active region decay
  - Effect on coronal evolution
  - Consider off-limb structures