SWMF Solar/Helio

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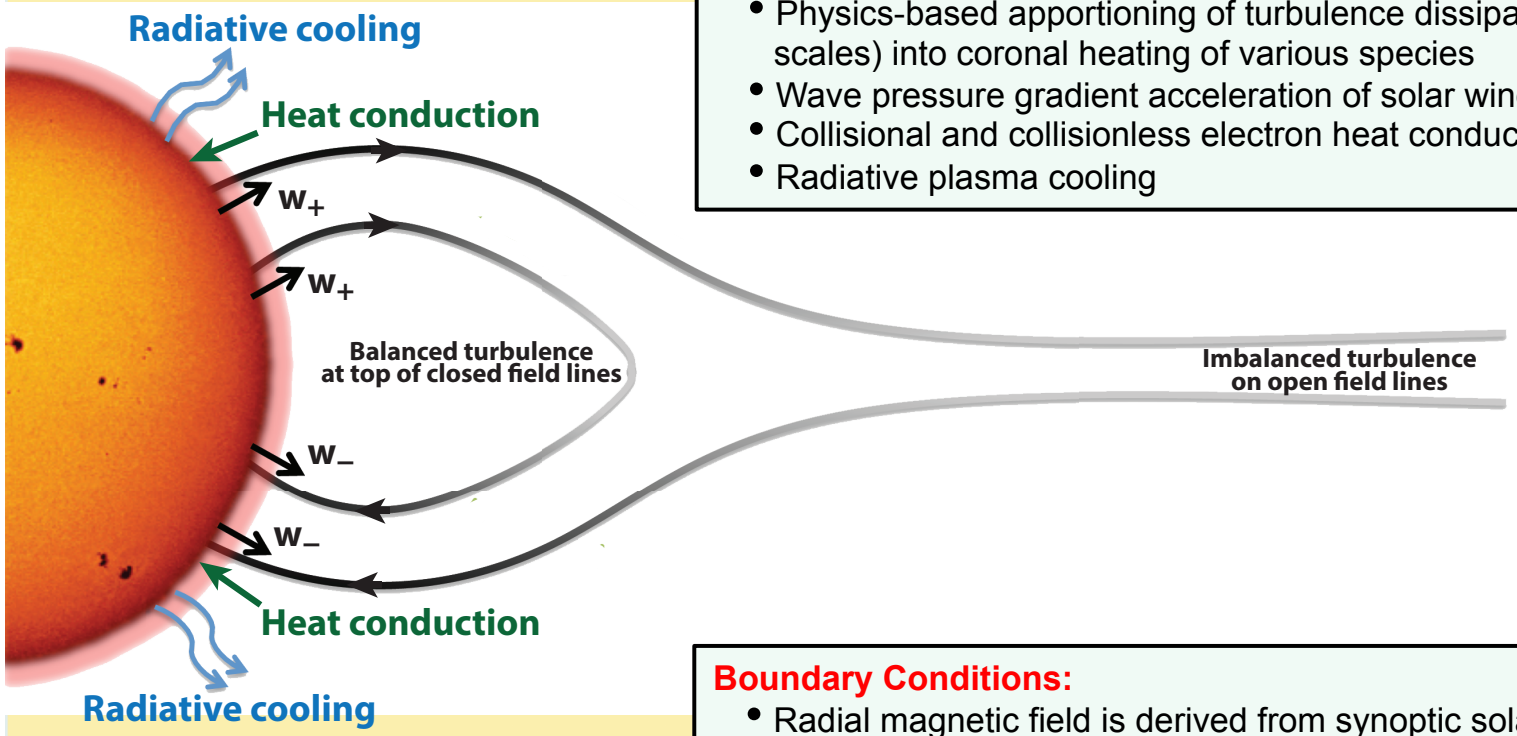
Outline

- **New solar corona and inner heliosphere model with low-frequency Alfvén wave turbulence**
  - Physics included in this model
  - Validation: EUV images
  - Temperature anisotropy and plasma instabilities
  - Validation: 1AU in-situ
  - Validation: Charge state
- **CMEs**
- **Magnetic flux emergence and regional models**

Alfvén Wave Solar Model (AWSoM)

B. van der Holst et al. ApJ **782**, 81 (2014).
R. Oran et al. ApJ **778**, 176 (2013).
I. Sokolov et al. **764**, 23 (2013).



XMHD physics:

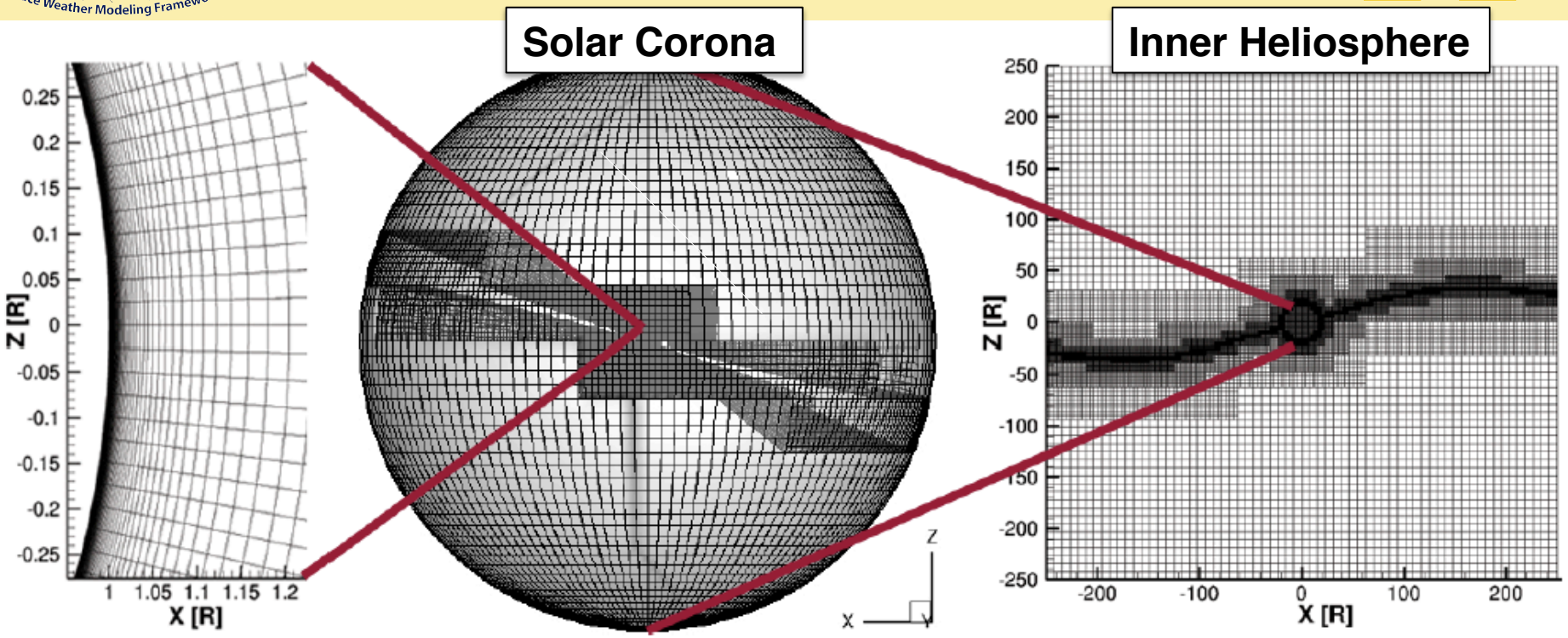
- Separate $T_{p||}$, $T_{p\perp}$ and T_e
- WKB equations for parallel and antiparallel propagating turbulence ($w_{\pm}$)
- Non-WKB physics-based reflection of $w_{\pm}$ results in turbulent cascade
- Correction for presumed uncorrelated waves $w_{\pm}$ in the balanced turbulence near apex of closed field lines
- Physics-based apportioning of turbulence dissipation (at the gyro-radius scales) into coronal heating of various species
- Wave pressure gradient acceleration of solar wind plasma
- Collisional and collisionless electron heat conduction
- Radiative plasma cooling

Boundary Conditions:

- Radial magnetic field is derived from synoptic solar magnetograms
- Poynting flux of outward propagating turbulence:

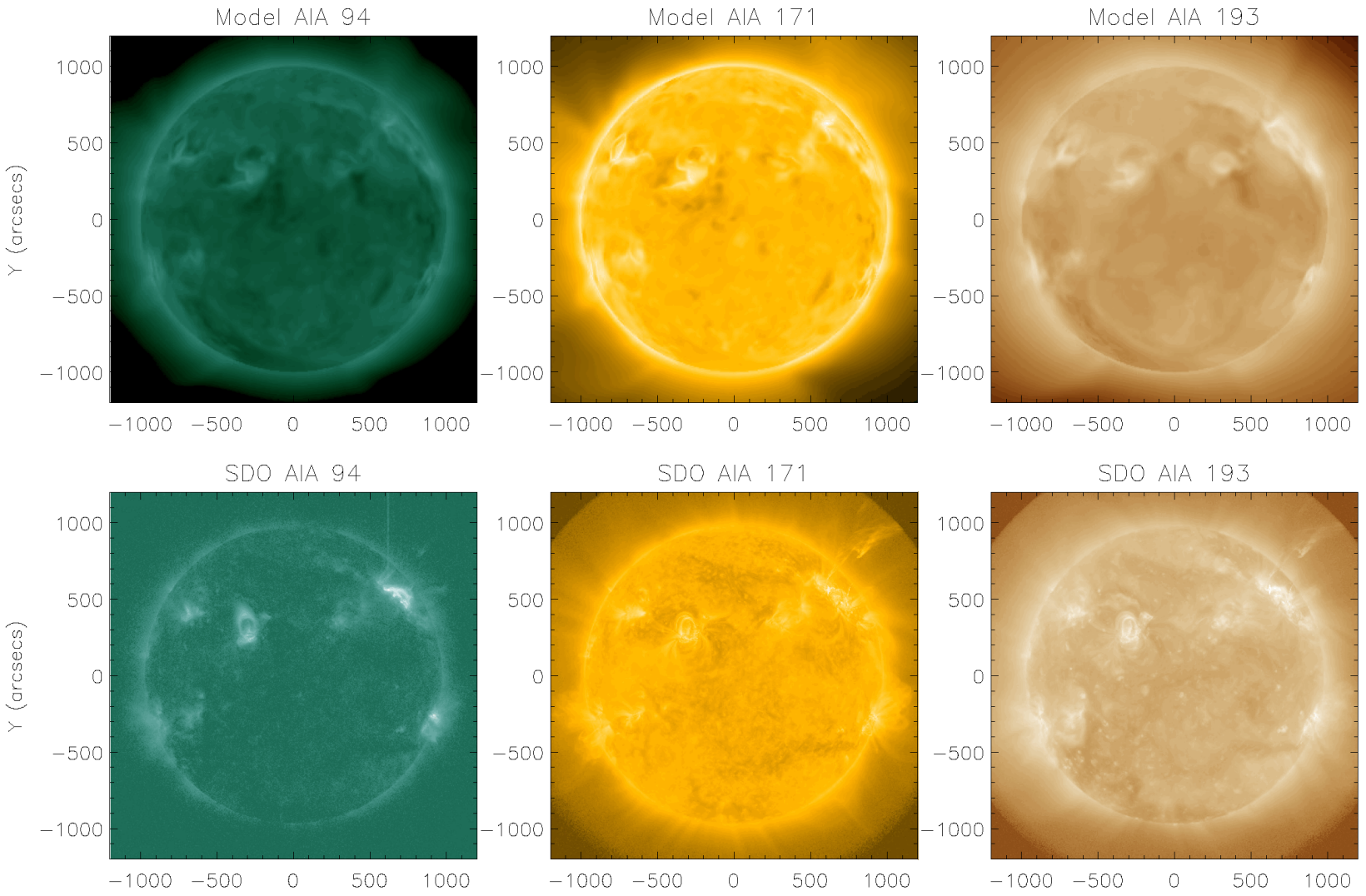
$$(S_A / B) = 1.1 \times 10^6 \,\mathrm{Wm^{-2}T^{-1}}$$

Computational Grids

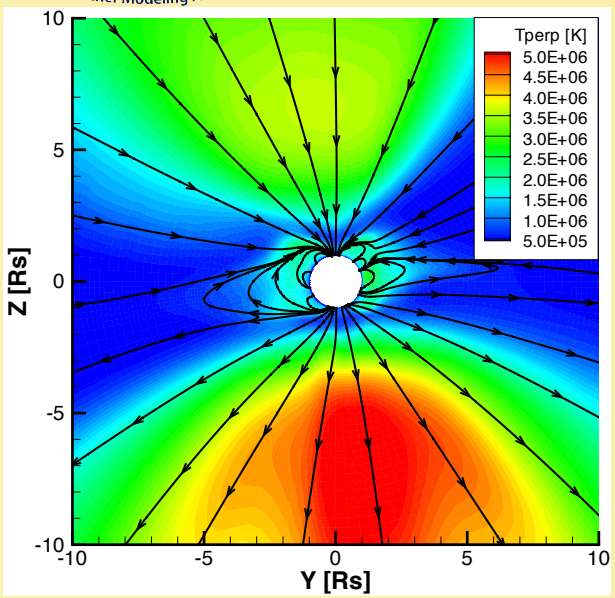


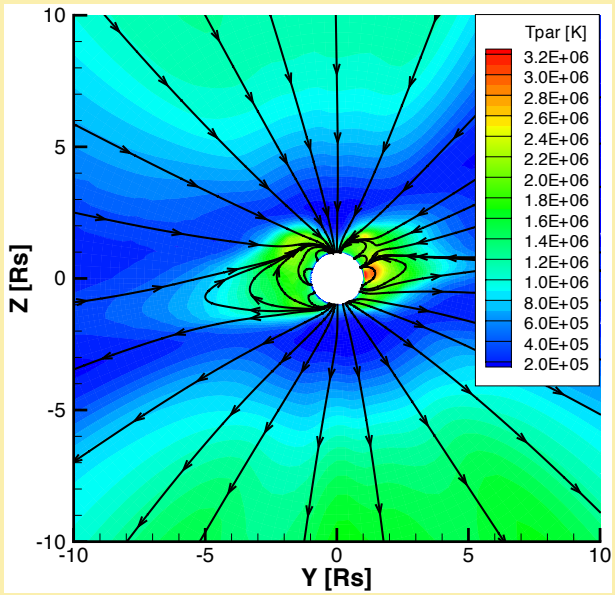
- AWSoM is split in two coupled framework components: stretched spherical grid for solar corona, cartesian grid for inner heliosphere
- Significant grid stretching to grid resolve the upper chromosphere and transition region in addition to artificial transition region broadening (Lionello et al. 2009, Sokolov et al. 2013)
- AMR to resolve the heliospheric currentsheet

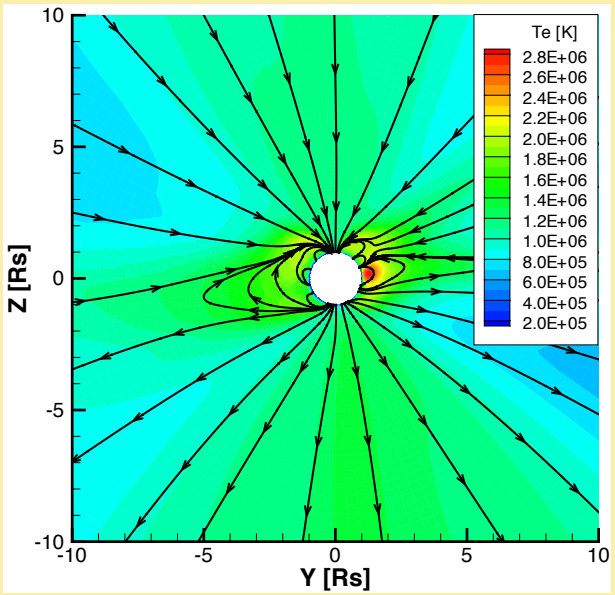
Validation: EUV Images for CR2107

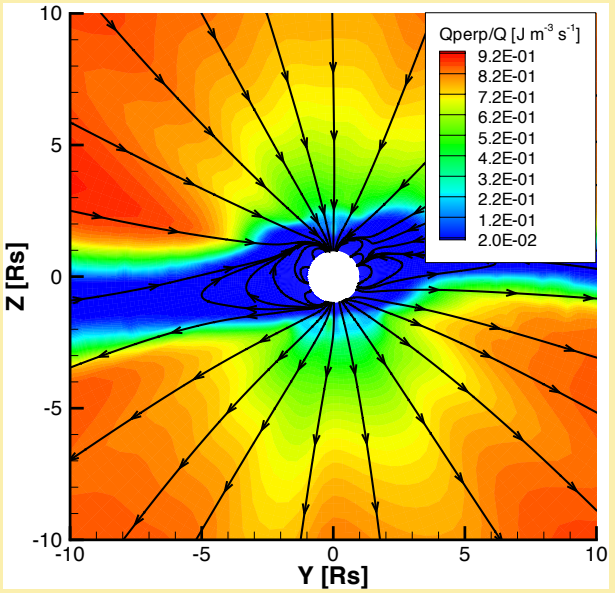


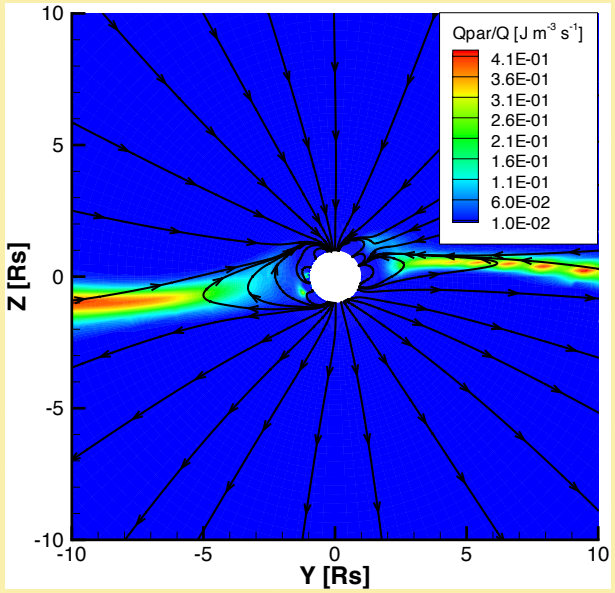
Heat Partitioning for the Electron and Anisotropic Proton Temperatures

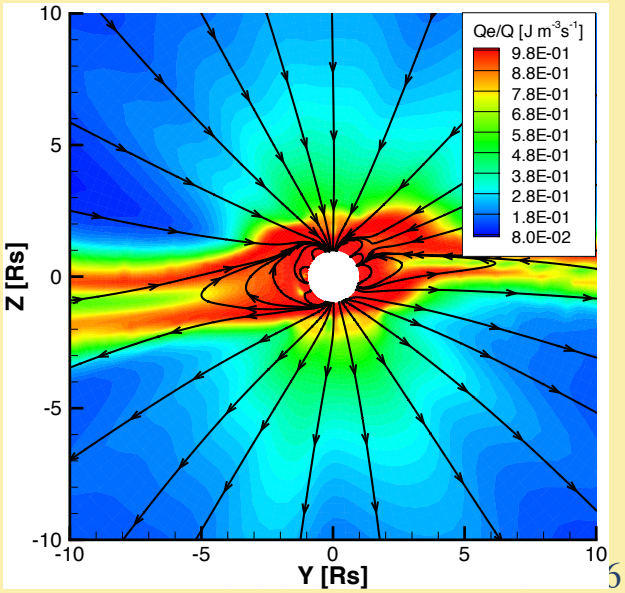












Limiting the Anisotropic Pressure

X. Meng et al. 2012 JCP, JGR

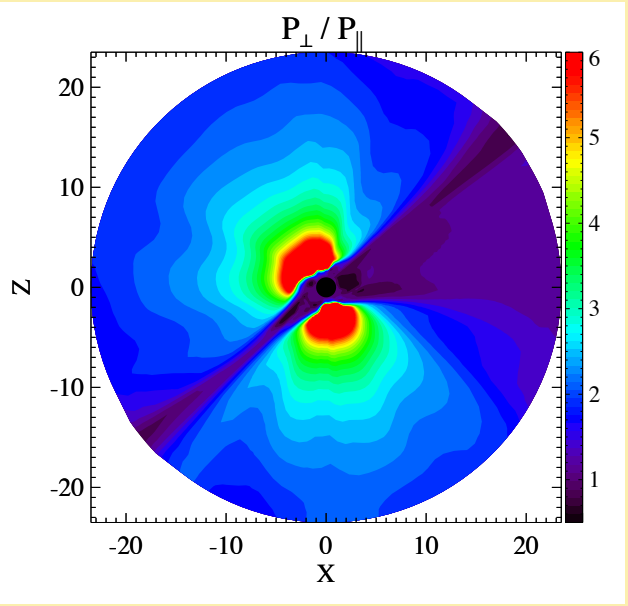
The instability-based anisotropic pressure relaxation towards the marginal stable pressure $\overline{p_{\|}}$ while keeping averaged pressure p unmodified: $\frac{\delta p_{\|}}{\delta t} = \frac{\overline{p_{\|}} - p_{\|}}{\tau}$

applied in firehose, mirror and proton cyclotron unstable regions. τ is taken to be the inverse of the growth rates of the instabilities (Hall 1979, 1980, 1981 and Southwood & Kivelson 1993):

	instability criteria	relaxation time τ
firehose	$\frac{p_{\|}}{p_{\perp}} > 1 + \frac{\mathbf{B}^2}{\mu_0 p_{\perp}}$	$\tau_f = \frac{1}{\gamma_{fFLR}(\lambda_f)} = \frac{2}{\Omega_i}\frac{\sqrt{p_{\|}(p_{\perp} - p_{\|}/4)}}{\Delta p_f}$
mirror	$\frac{p_{\perp}}{p_{\|}} > 1 + \frac{\mathbf{B}^2}{2\mu_0 p_{\perp}}$	$\tau_m = \frac{1}{\gamma_m(\lambda_m)} = \frac{3\sqrt{5}}{4\Omega_i}\sqrt{\frac{p_{\|}}{2\Delta p_m}}$
proton cyclotron	$\frac{p_{\perp}}{p_{\|}} > 1 + 0.3\sqrt{\frac{\mathbf{B}^2}{2p_{\|}}}$	$\tau_{ic} = \frac{10^2}{\Omega_i}$

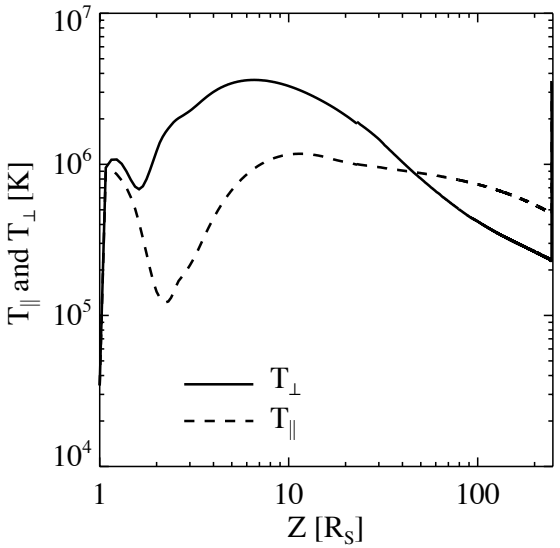
AWSoM with Temperature Anisotropy

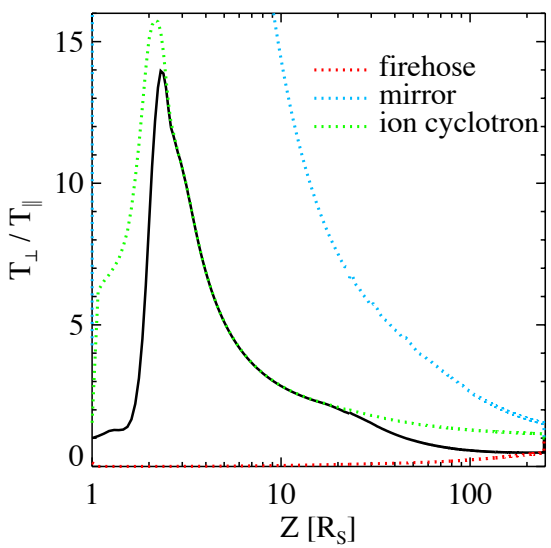
X. Meng et al., submitted to ApJ



- Temperature anisotropy in the simulated Y=0 meridional slice

- Temperature Anisotropy along the north axis

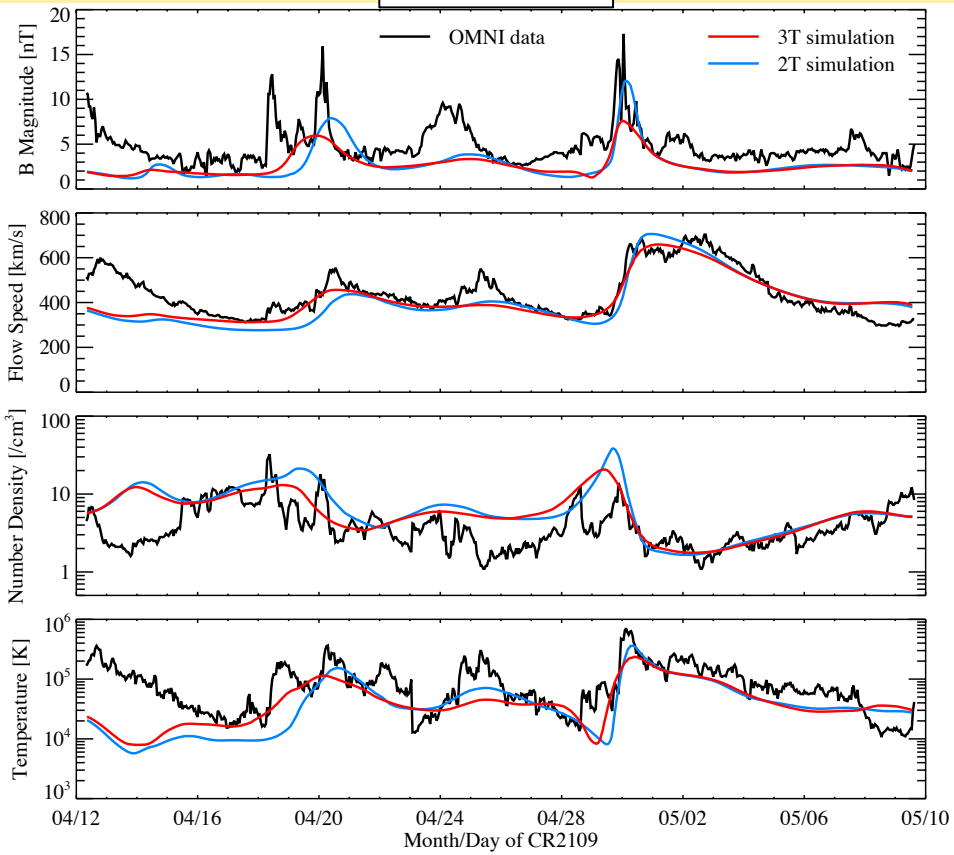




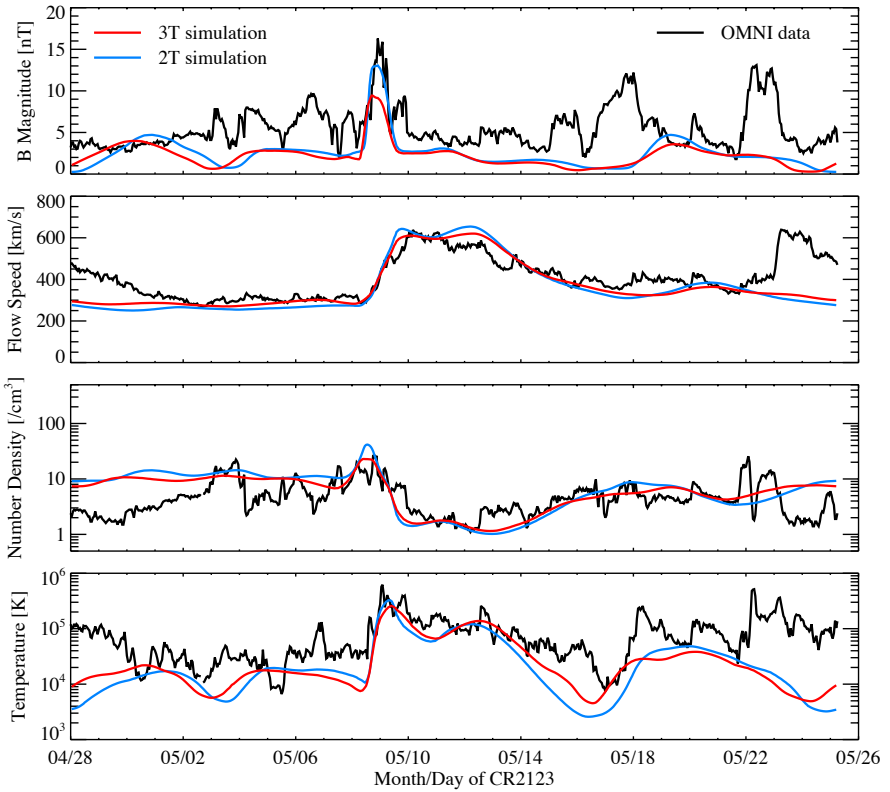
Validation at 1AU

ACE versus 2T and 3T models

CR2109



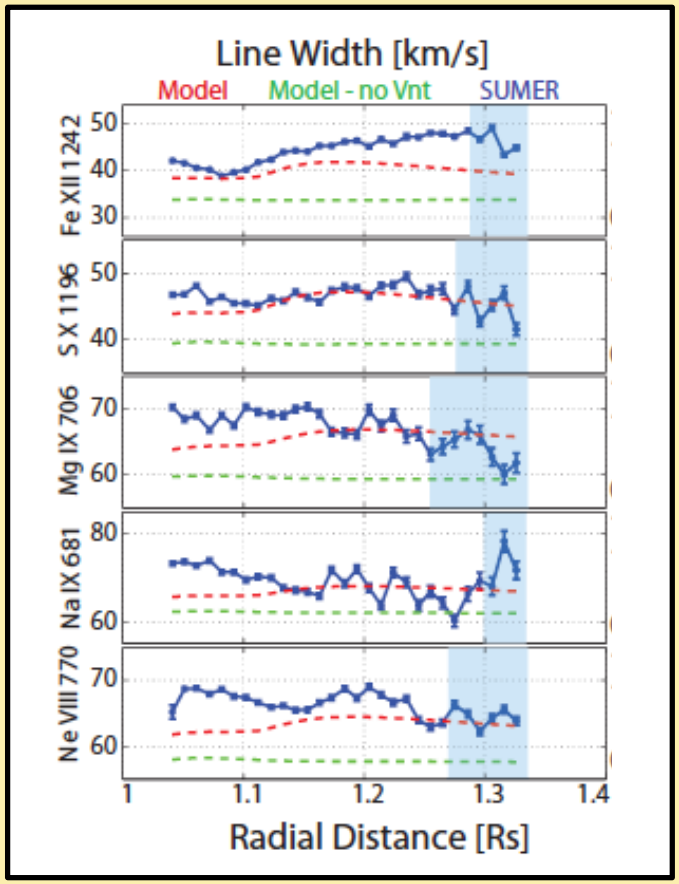
CR2123

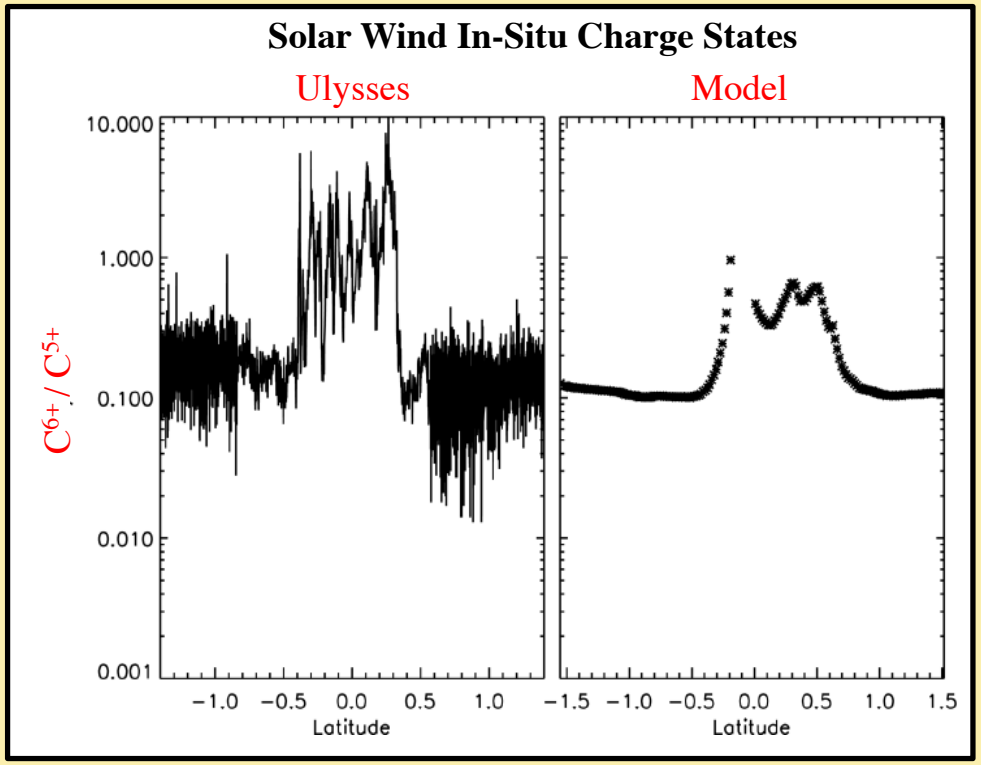


Validation: Charge State

R. Oran et al., submitted to ApJ

- The electron density, temperature and speed from the MHD model are used to drive charge state evolution along field lines, and compared to in-situ and remote observations



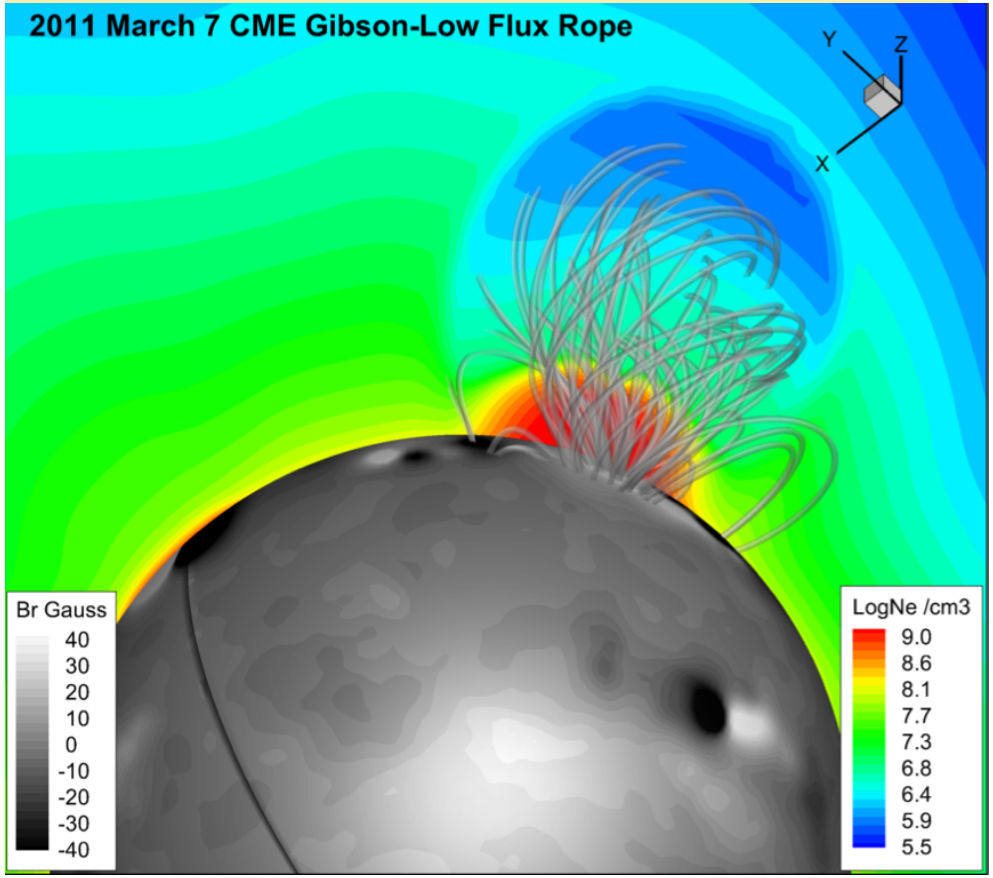


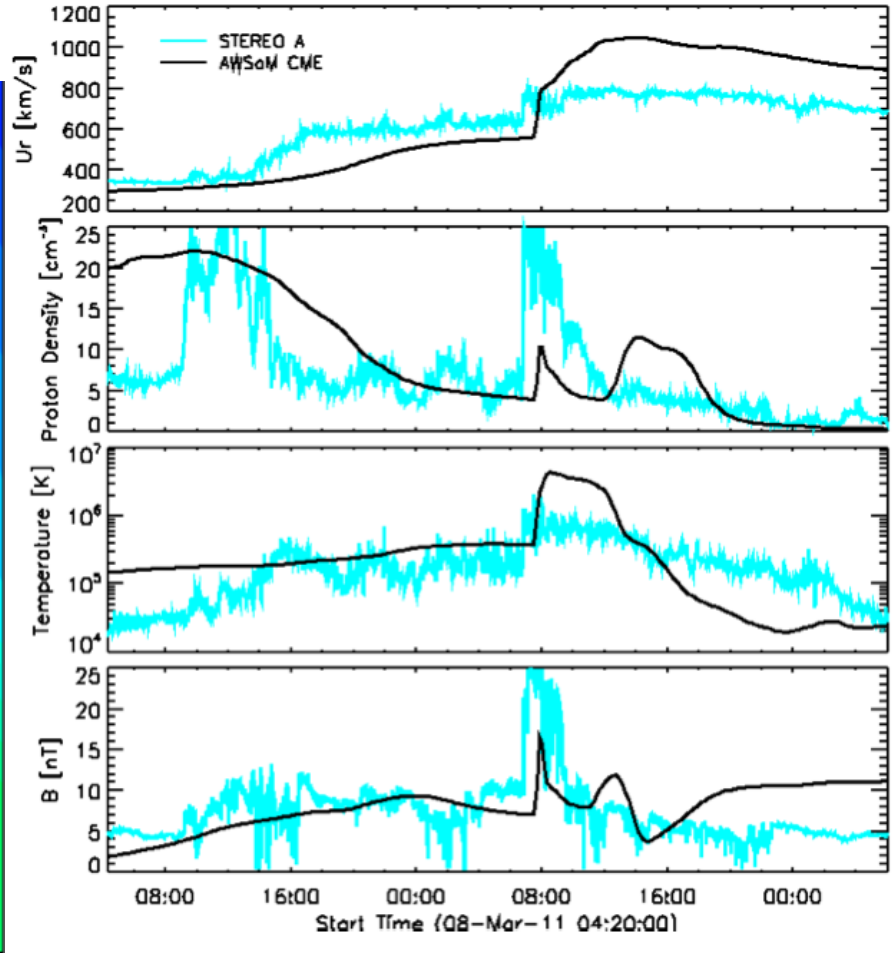
March 7th 2011 CME Simulation

CME simulation with the AWSoM model:

- Gibson-Low flux rope erupts from active region 11164
- Model produces 3 part density of CME progenitors: dense streamer with low density cavity containing a dense core
- SIR-CME interaction crucial to CME structure at 1AU

M. Jin et al. in preparation



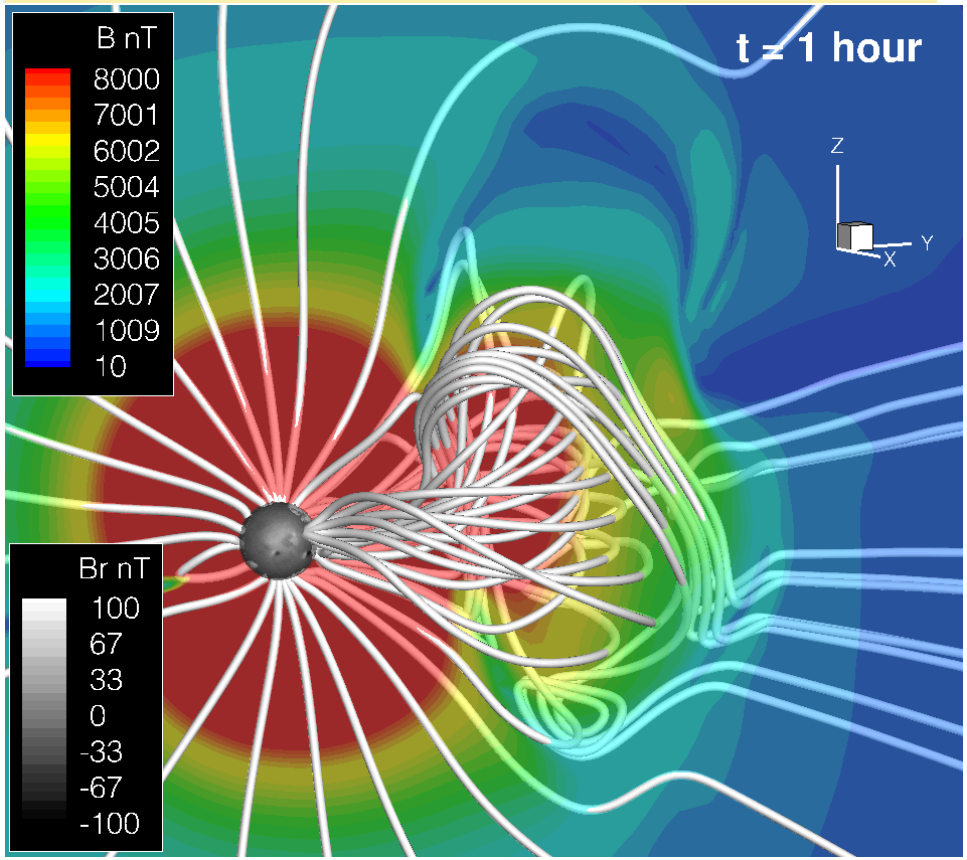


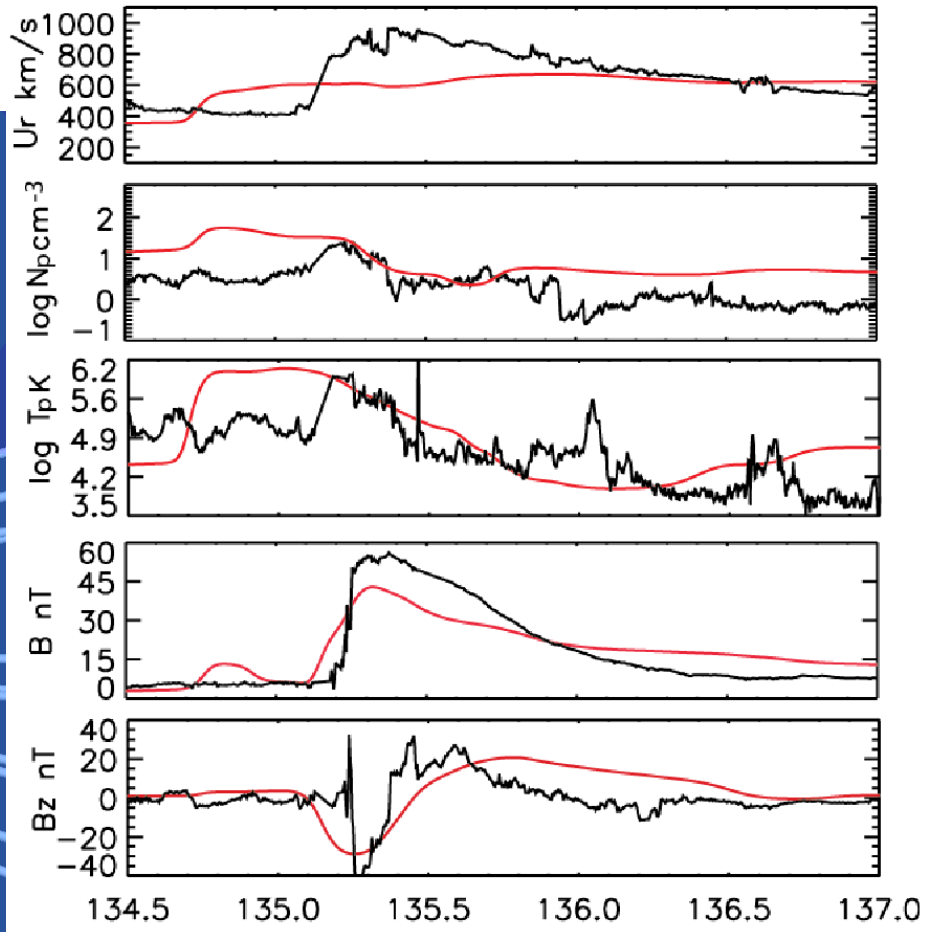
May 13th 2005 CME Simulation

CME Simulation with the AWSoM Model:

- Gibson-Low flux rope erupts from active region 10759
- The simulation reproduces the magnetic cloud signatures at 1 AU including the Bz rotation.

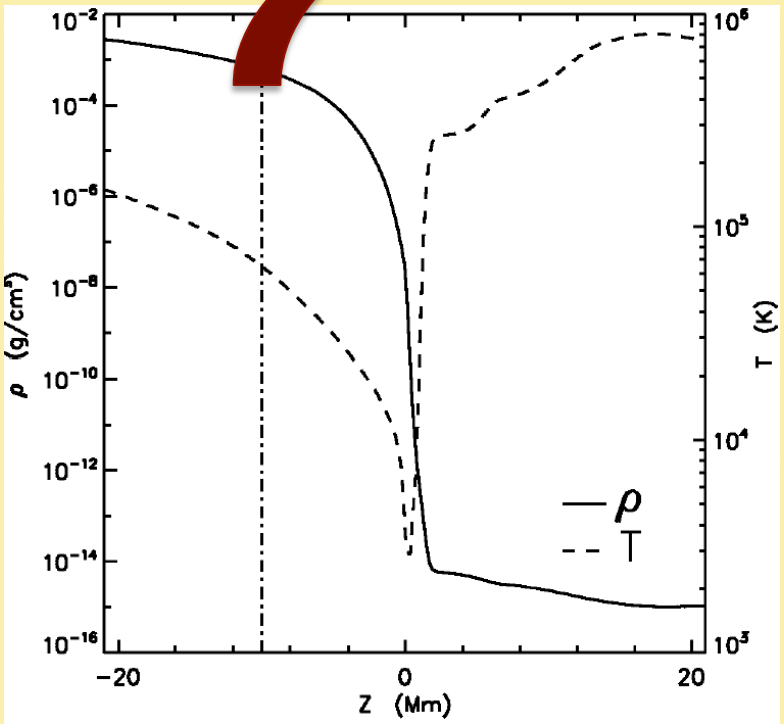
Manchester, van der Holst & Lavraud, Plasma Phys. Contol. Fusion, 56, 2014 .

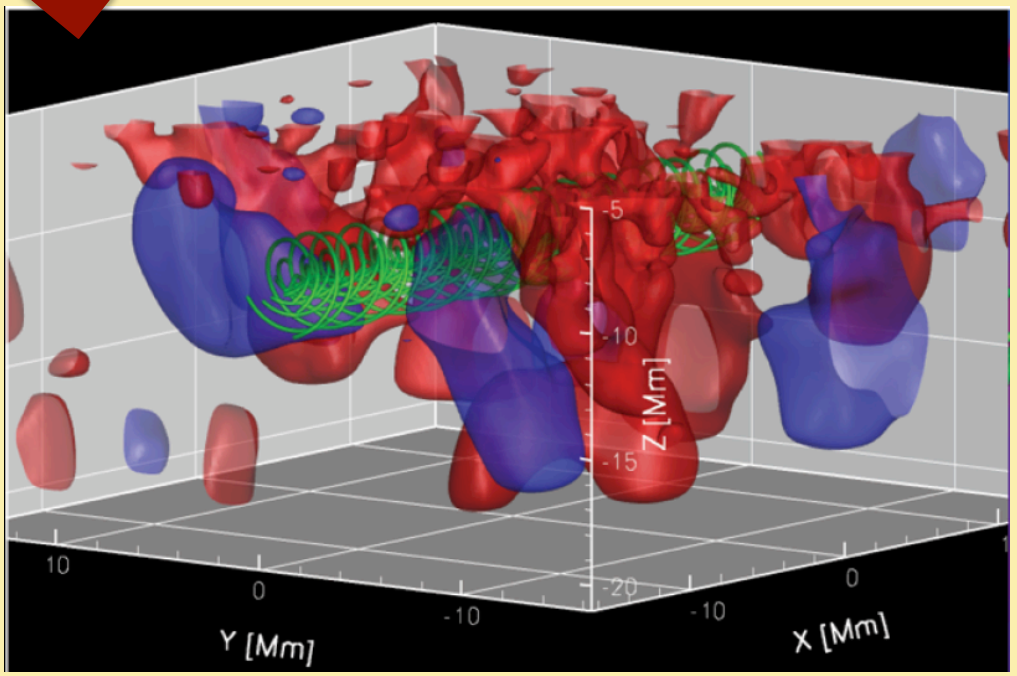




Magnetic Flux Emergence

F. Fang et al., ApJ 754, 15 (2012).





Vertical stratification of density and temperature

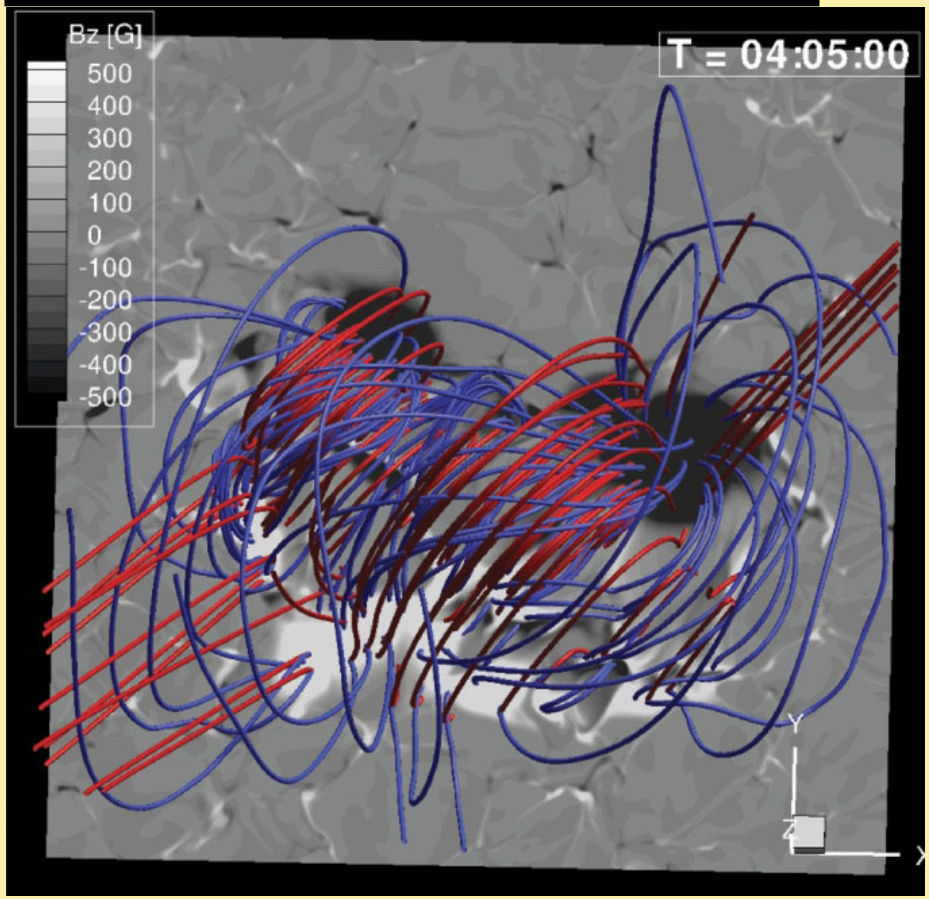
Initial flux rope (green rods) at Z = -10 Mm, surrounded by convective downflows (blue) and upflows (red)

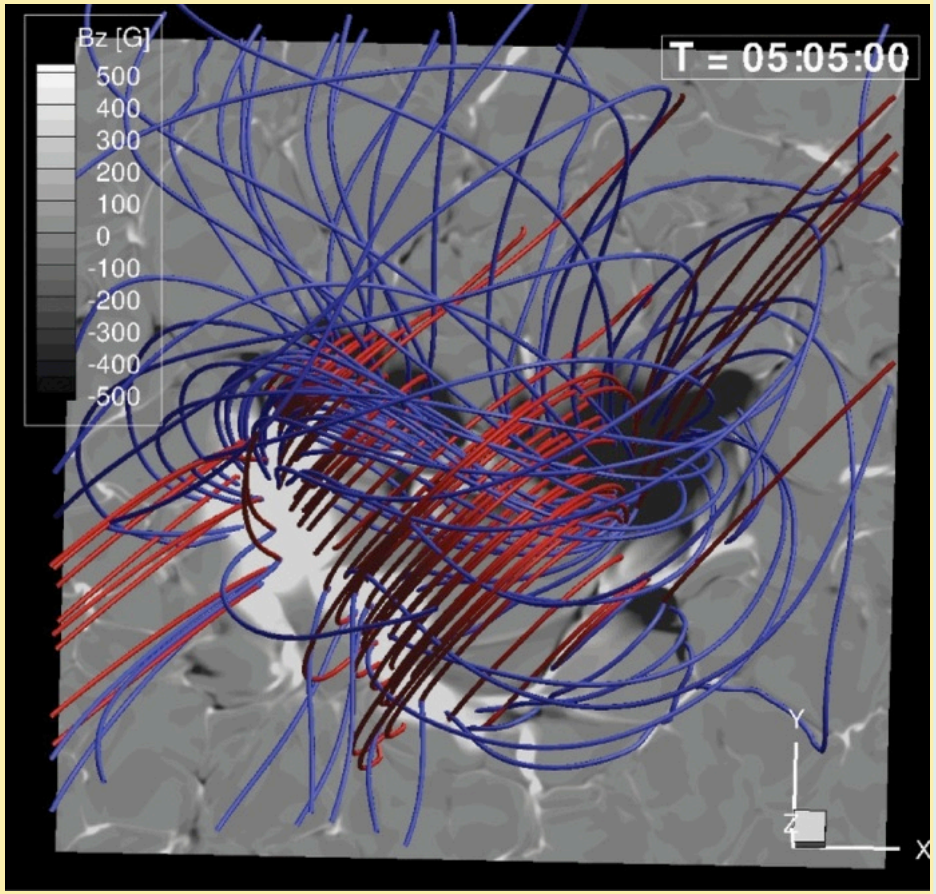
Build-up of Free Energy during Emergence

Plane: Photospheric Bz field

Blue rods: model field

Red rods: potential field





Summary and Outlook

- **AWSoM model for the solar corona and inner heliosphere:**
  - Alfvén-wave turbulence and three-temperature model
  - Validation studies with EUV images and 1AU data shows that this model can capture many features of the solar corona and inner heliosphere
- **AWSoM has just been transferred to CCMC for testing**
  - We are presently constraining the few model parameters to have good model-data comparison for all Carrington rotations.
- **Arrival time and Bz at 1AU of CMEs using Gibson & Low flux ropes**
  - Next: automated procedure for flux rope initiation to predict arrival time and Bz
- **Future directions:**
  - Regional model with MAGIC magnetogram processing suite of tools.
  - coupling of flux emergence and regional models with the AWSoM solar wind model. Gabor Toth will present a new coupler that will be used.