AWSoM: Modeling the heliosphere from the chromosphere to planets

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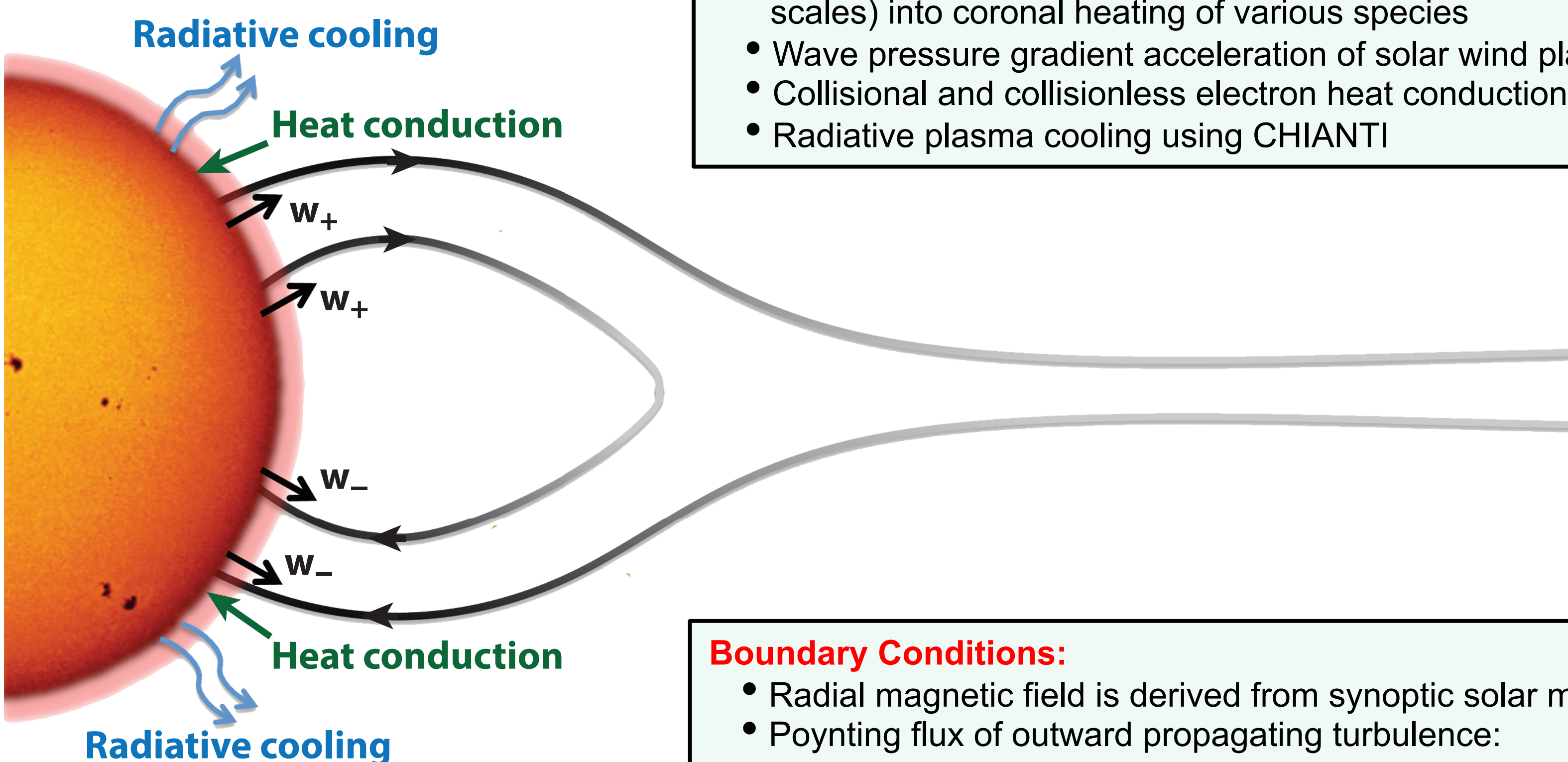
Alfvén Wave Solar Model (AWSoM)

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

Extended MHD physics:

- Two (T_i, T_e) or three ($T_{i\|}$, $T_{i\perp}$, T_e) temperatures
- Equations for parallel and antiparallel propagating turbulence ($w_\pm$)
- Physics-based reflection of $w_\pm$ results in turbulent cascade
- 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 using CHIANTI



Boundary Conditions:

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

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

Alfvén Wave Turbulence

- **Wave energy densities of counter-propagating transverse Alfvén waves parallel (+) and anti-parallel (-) to magnetic field:**

energy reduction in expanding flow

wave dissipation

$$\frac{\partial w_\pm}{\partial t} + \nabla \cdot [(\mathbf{u} \pm \mathbf{V}_A) w_\pm] + \frac{w_\pm}{2}(\nabla \cdot \mathbf{u}) = \mp \mathcal{R}\sqrt{w_- w_+} - \Gamma_\pm w_\pm$$

Alfvén wave advection

wave reflection

- **The wave reflection is due to field-aligned component of the Alfvén speed gradient and vorticity.**
- **Phenomenological wave dissipation (Dmitruk et al., 2002):** $\Gamma_\pm = \frac{2}{L_\perp}\sqrt{\frac{w_\mp}{\rho}}$
- **Similar to Hollweg (1986), we use a simple scaling law for the transverse correlation length** $L_\perp \sqrt{B} = 150 \text{ km} \sqrt{\text{T}}$
- **Poynting flux of outward propagating turbulence:**

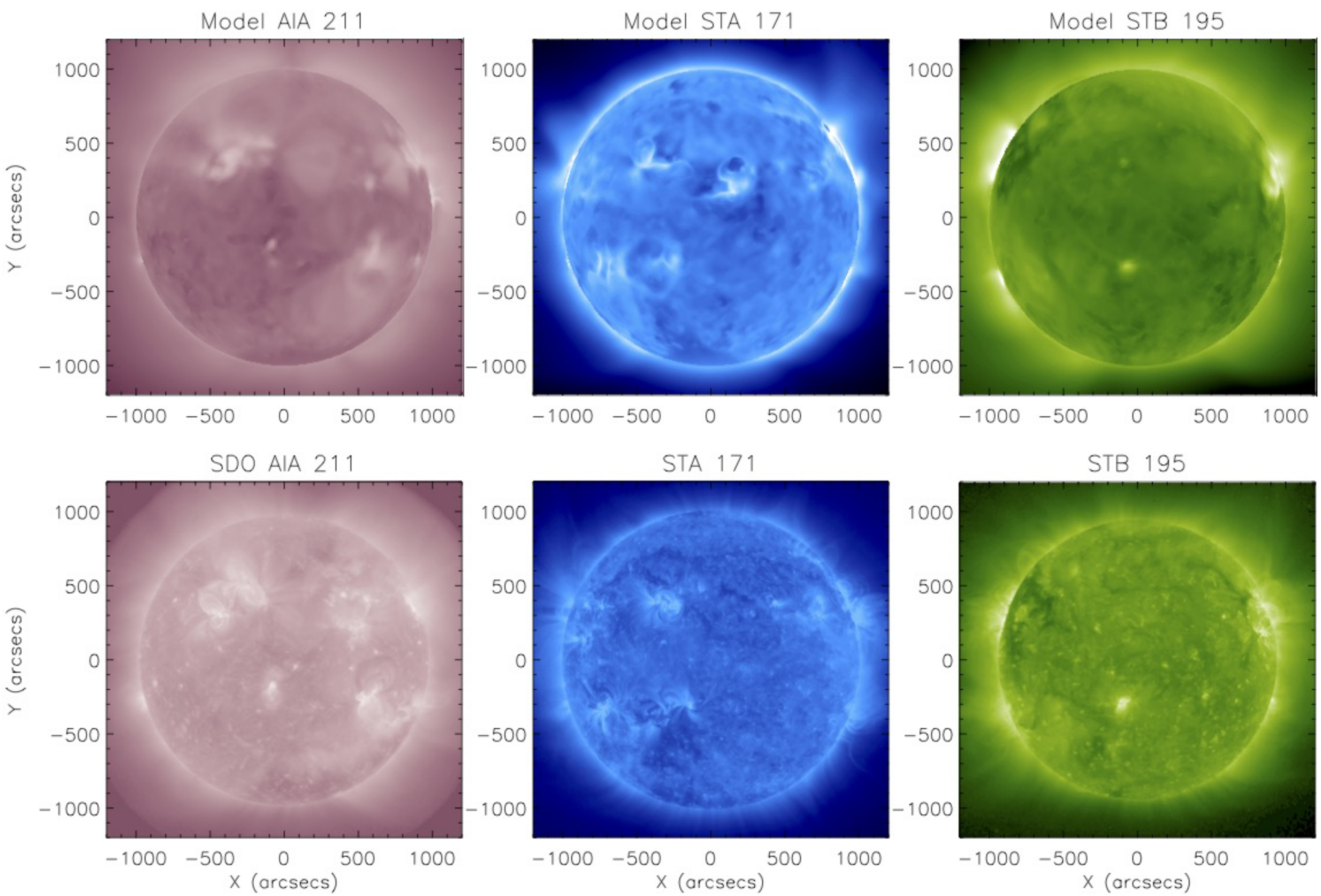
$$(S_A/B)_\odot = 1.1 \times 10^6 \text{ W m}^{-2}\,\text{T}^{-1}$$

Heat Partitioning

- **Counter-propagating Alfvén waves due to partial reflection of the waves**
- **Non-linear interaction of these waves results in transverse energy cascade**
- **Wave dissipation at the gyro-kinetic scales**

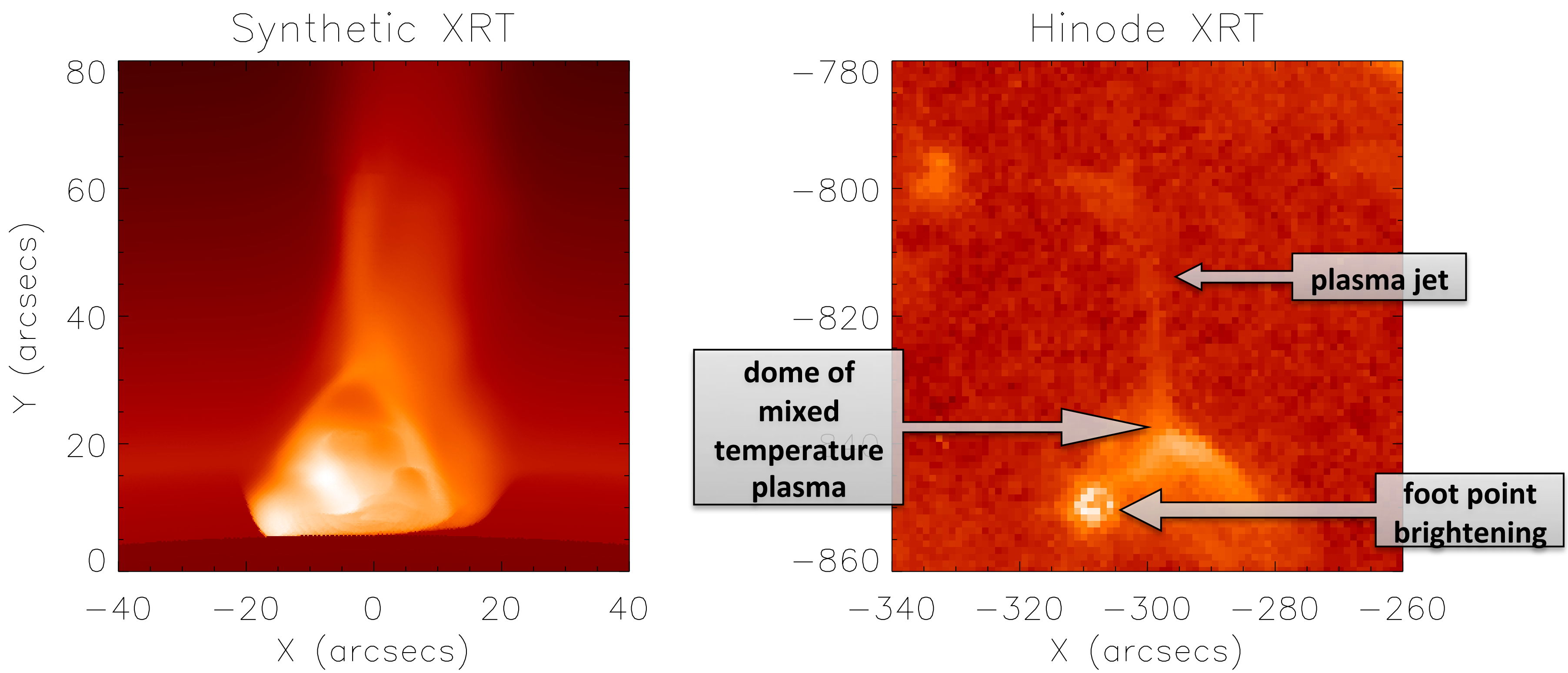
- **The coronal heating formulation used in AWSoM:**
  - Linear damping of kinetic Alfvén waves (KAW), resulting in electron and parallel proton heating
  - Electric field fluctuations due to transverse turbulent cascade can disturb the proton gyro motion enough to give rise to perpendicular stochastic heating
  - Electron heating at scales much smaller than proton gyro-radius

Validation: EUV Images for CR2107



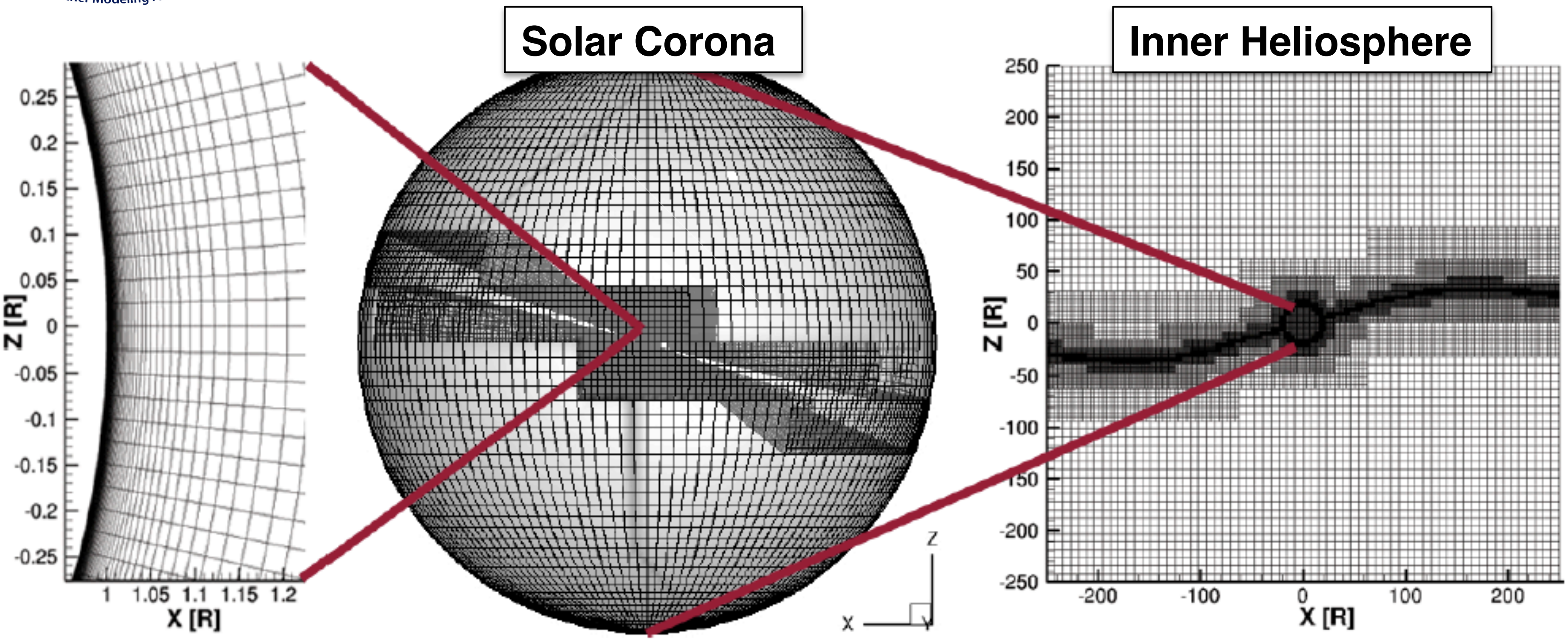
Simulations of Polar Jets

- Jet produced by adding small bipole below solar surface and rotating boundary plasma around bipole magnetic axis



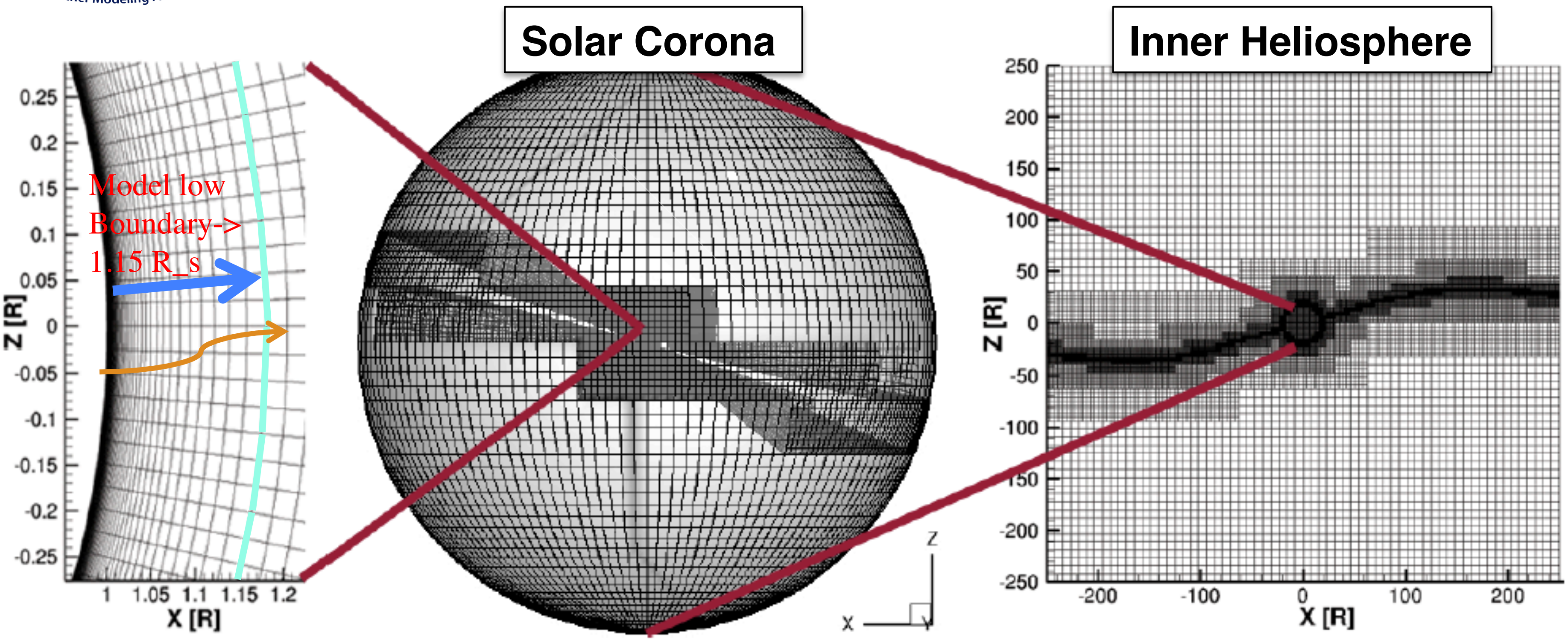
Judit Szente et al., submitted to ApJ

Computational Grid: AWSoM



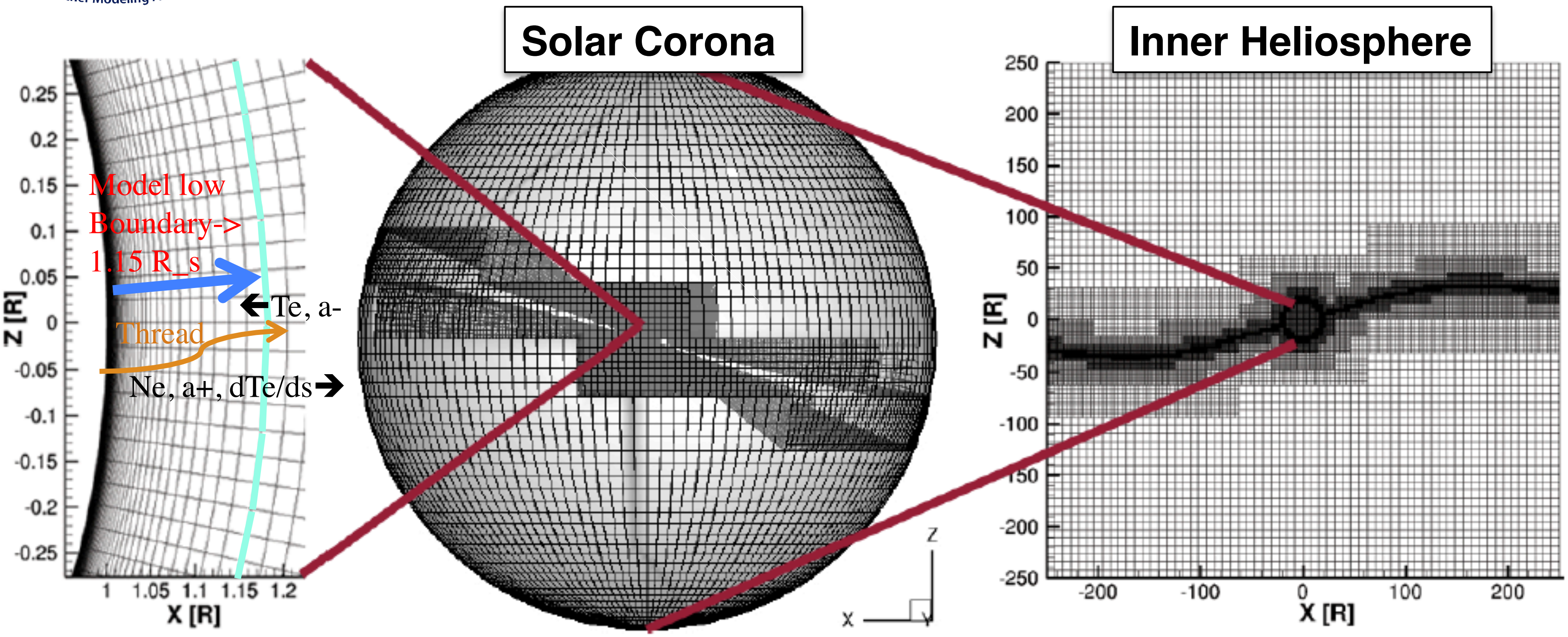
- AWSoM is split in two coupled framework components: stretched spherical grid for solar corona, cartesian grid for inner heliosphere
- Significant grid stretching to grid resolve the upper chromosphere and transition region in addition to artificial transition region broadening
- Due to the very high resolution below $1.15R_{sun}$ AWSoM is too slow to achieve faster than real-time.

AWSoM-R: Upshift the Inner Boundary



- We use the lower boundary of the AWSoM-R model at $R = 1.15R_s$
- We apply 1D thread solutions along PFSS model field lines to bridge the AWSoM-R model to the chromosphere through the transition region.

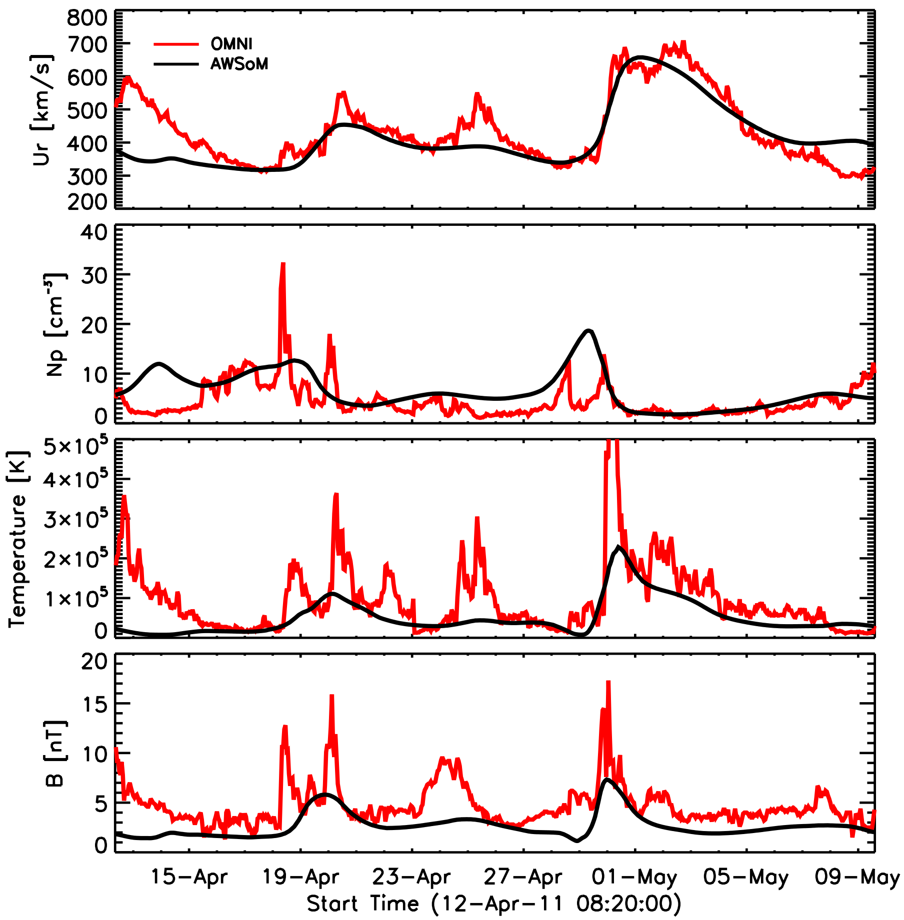
Apply 1D Thread Solution



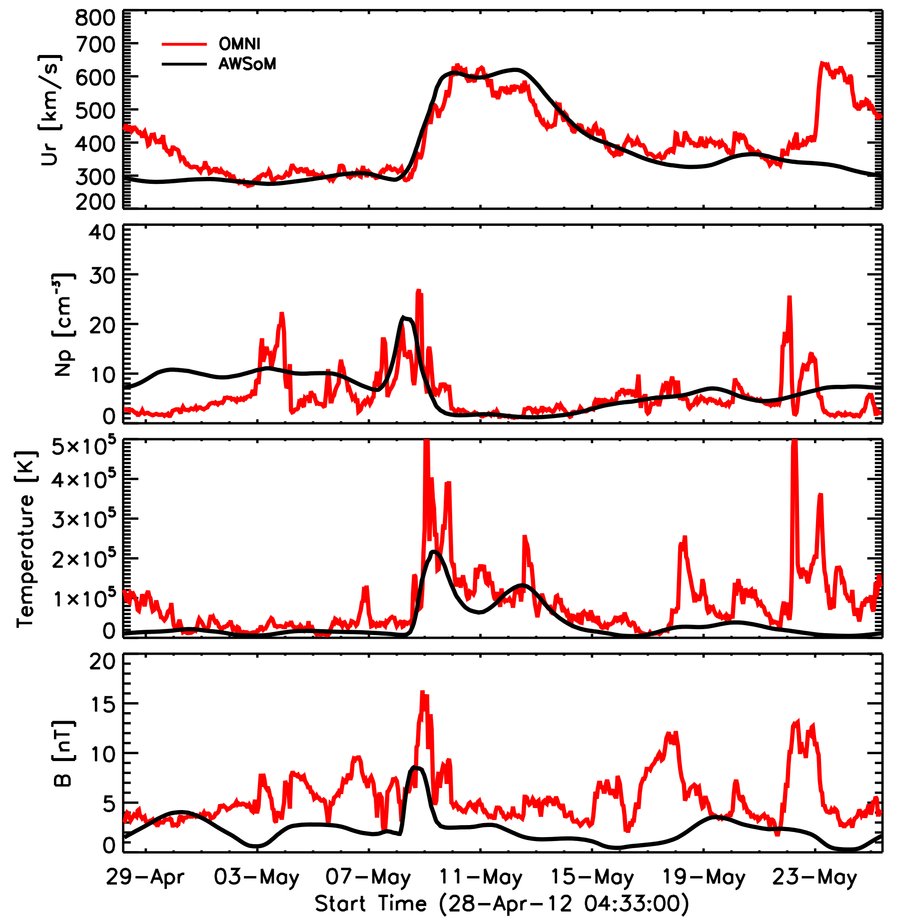
- Recognize that between $1R_s$ and $1.15R_s$ $u \parallel B$ and $u \ll V_{slow}, V_A, V_{fast}$
- Quasi-steady-state mass, momentum, energy transport and wave turbulence transport is solved along the connecting field line implicitly (1D equations!)
- The speed-up of AWSoM-R is about a factor 200 compared to AWSoM

Validation: MHD Quantities at 1AU

CR2109



CR2123



Outlook

- **Significant speed-up (about 200 times) of the 3D global solar corona and inner heliosphere model AWSoM:**
  - 1D solutions between 1 R_{sun} and 1.15 R_{sun} along PFSS model field lines provide inner boundary conditions at 1.15 R_{sun}
  - AWSoM real-time runs now require ~120 processor cores to be faster than real-time.

- **Run-on-request version (steady state synoptic solar wind) is presently AWSoM and will be updated to AWSoM-R for improved speed**