AWSoM: Modeling the heliosphere from the chromosphere to planets

Bart van der Holst, I. Sokolov, T. Gombosi
Alfvén Wave Solar Model (AWSoM)

Extended MHD physics:
- Two ($T_i$, $T_e$) or three ($T_{i∥}$, $T_{i⊥}$, $T_e$) temperatures
- Equations for parallel and antiparallel propagating turbulence ($w_±$)
- Physics-based reflection of $w_±$ 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:
  \[
  (S_A/B)_\odot = 1.1 \times 10^6 \text{ W m}^{-2} \text{ T}^{-1}
  \]

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

\[
\frac{\partial w_{\pm}}{\partial t} + \nabla \cdot [(u \pm V_A)w_{\pm}] + \frac{w_{\pm}}{2}(\nabla \cdot u) = \mp R\sqrt{w_-w_+} - \Gamma_{\pm}w_{\pm}
\]

The wave reflection is due to field-aligned component of the Alfvén speed gradient and vorticity.

Phenomenological wave dissipation (Dmitruk et al., 2002): \(\Gamma_{\pm} = \frac{2}{L_\perp \sqrt{\frac{w_{\pm}}{\rho}}}\)

Similar to Hollweg (1986), we use a simple scaling law for the transverse correlation length \(L_\perp \sqrt{B} = 150 \text{ km} \sqrt{T}\)

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

**Synthetic XRT**

**Hinode XRT**

- Plasma jet
- Dome of mixed temperature plasma
- Foot point brightening

Judit Szente et al., submitted to ApJ
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.
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.
Recognize that between $1R_s$ and $1.15R_s$ $u \parallel B$ and $u \ll V_{\text{slow}}, V_A, V_{\text{fast}}$

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**

1. **Ur [km/s]**
   - OMNI (red line)
   - AWSOM (black line)

2. **Np [cm⁻³]**

3. **Temperature [K]**

4. **B [nT]**

Start Time (12–Apr–11 08:20:00)

**CR2123**

1. **Ur [km/s]**
   - OMNI (red line)
   - AWSOM (black line)

2. **Np [cm⁻³]**

3. **Temperature [K]**

4. **B [nT]**

Start Time (28–Apr–12 04:33:00)
Significant speed-up (about 200 times) of the 3D global solar corona and inner heliosphere model AWSoM:

- 1D solutions between $1 \ R_{\text{sun}}$ and $1.15 \ R_{\text{sun}}$ along PFSS model field lines provide inner boundary conditions at $1.15 \ R_{\text{sun}}$
- 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