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3D Simulations of coronal condensations and their mass circulation

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Abstract

We present a 3D full MHD simulation (including anisotropic thermal conduction, optically thin radiative losses, and parametrized heating as main thermodynamical features) to construct a realistic arcade configuration from chromospheric to coronal heights. The plasma evaporation from chromospheric and transition region heights eventually causes localized runaway condensation events and we witness the formation of plasma blobs, that evolve dynamically in the heated arcade part and move gradually downwards due to interchange type reconfiguration. Unlike earlier 2.5D simulations, here there is no large scale prominence formation observed, but a continuous coronal rain develops and shows clear indications of Rayleigh-Taylor or interchange instability. After the plasma blobs descend through interchange, they are guided by the magnetic dips.

Initial setup

As initial conditions we take 1D stratified ***ideal MHD*** *equilibrium. Though, we extend the MHD equations by including* ***non-ideal terms*** *and study non-ideal effects including:*

1. *optically thin radiative losses,*
2. *anisotropic thermal conduction along magnetic field lines and*
3. *a parametrized heating function.*

The density and pressure are calculated by the gravitational stratification along y-axis. The velocity is set to zero throughout, and the magnetic field topology is taken as

$$
\begin{aligned}
B_x &= B_{p0} cos\left(\frac{\pi x}{2L_0}\right) e^{-\frac{\pi y}{2L_0}} - B_{p0} cos\left(\frac{3\pi x}{2L_0}\right) e^{-\frac{3\pi y}{2L_0}},\\
B_y &= -B_{p0} sin\left(\frac{\pi x}{2L_0}\right) e^{-\frac{\pi y}{2L_0}} + B_{p0} sin\left(\frac{3\pi x}{2L_0}\right) e^{-\frac{3\pi y}{2L_0}},\\
B_z &= B_{z0}.
\end{aligned}
$$

The parametrized heating term has the following prescription

$$
\begin{aligned}
H &= H_{bg} + H_{lh},\\
H_{bg}(y) &= H_0 e^{-y/L_{bg}},\\
H_{lh}(x,y,z,t) &= H_1 R(t) C(y) F(x,z),
\end{aligned}
$$

$$
\begin{aligned}
F(x,z) = \Bigg[& exp\left(-\frac{(x-x_l)^2}{\sigma_2}\right) exp\left(-\frac{sin\left(\frac{\pi(z-x_l)}{\Delta z}\right)^2}{\sigma_3}\right)\\
& + exp\left(-\frac{(x-x_r)^2}{\sigma_2}\right) exp\left(-\frac{sin\left(\frac{\pi(z-x_r)}{\Delta z}\right)^2}{\sigma_3}\right)\Bigg],
\end{aligned}
$$

$$
C(y) = \begin{cases} 1, & \text{if } y < y_h,\\ e^{-\frac{(y-y_h)^2}{\lambda_h}}, & \text{if } y \geq y_h. \end{cases}
$$

Numerical Method

Simulations are done with the block adaptive MPI-AMRVAC code [1] as described in Keppens et al., 2012 [2] and updated in Porth et al., 2014 [3].
The simulation uses a base grid of $120 \times 120 \times 120$ grid points, activating a 3-level mesh refinement based on mixed evaluation of weighted discrete second derivates involving density and both poloidal magnetic field components $\rho : B_x : B_y$ in a $0.6 : 0.2 : 0.2$ ratio. The effective mesh size is $480 \times 480 \times 480$ corresponding to physical distances of $208\text{km} \times 167\text{km} \times 208\text{km}$ in a single grid.

Coronal condensation and mass circulation

At the first phase of the simulation, after the localized heating is applied, the heated material starts evaporating from the chromosphere through the transition region. Then localized condensation events take place and plasma blobs are formed on the top heated part of the arcade. Like earlier 2.5D simulations [4], there is no large scale prominence formation observed, but a continuous coronal rain develops showing clear indications of ***Rayleigh-Taylor or interchange instability****, figure 2.*

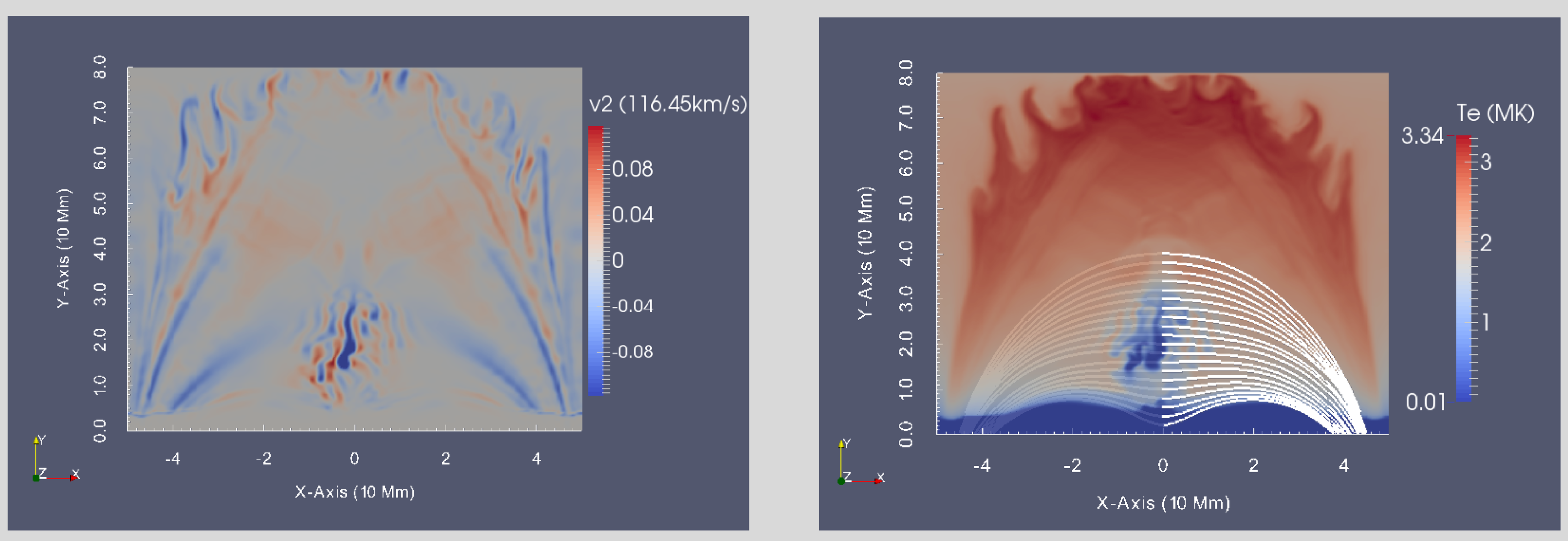


Figure 2: Left: The second component (v_y) of the plasma velocity on a slice at the middle of the simulation domain (z=0). Right: Temperature profile and magnetic field topology (at the time snapshot 235min of physical time).

The plasma blobs start to gradually move downwards through interchange, and as they enter the bottom half of the simulation box, they follow the magnetic field topology more closely in the lower coronal regions, where they are guided by the magnetic dips, as demonstrated using the integrated views through the z-direction in figure 3.

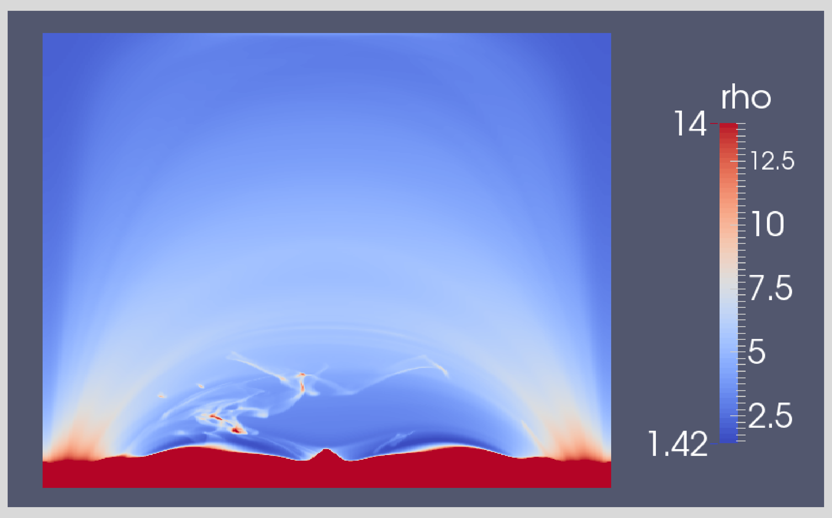


Figure 3: Density profile capturing the condensed matter circulation.

Blob dynamics and statistics

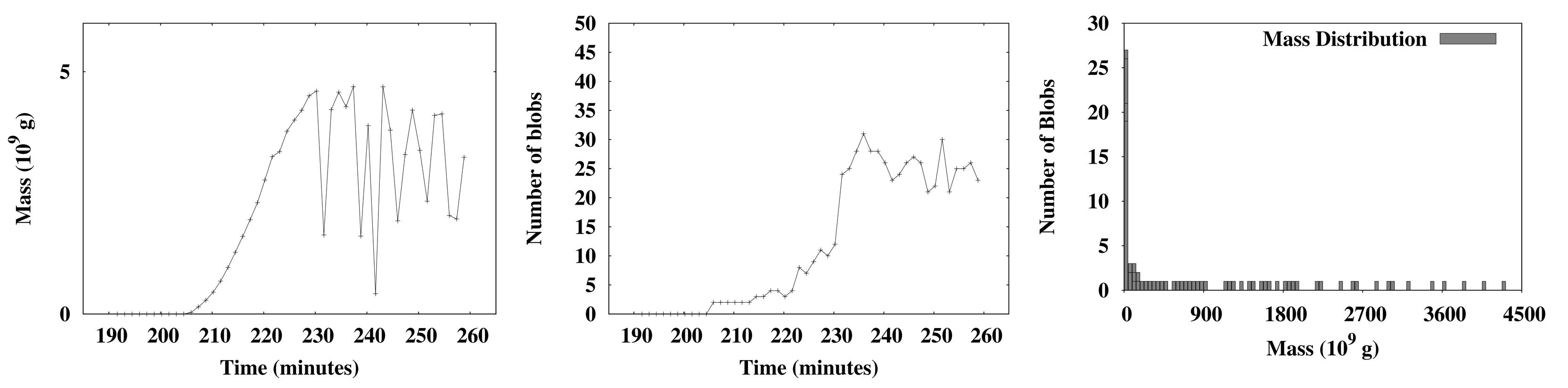
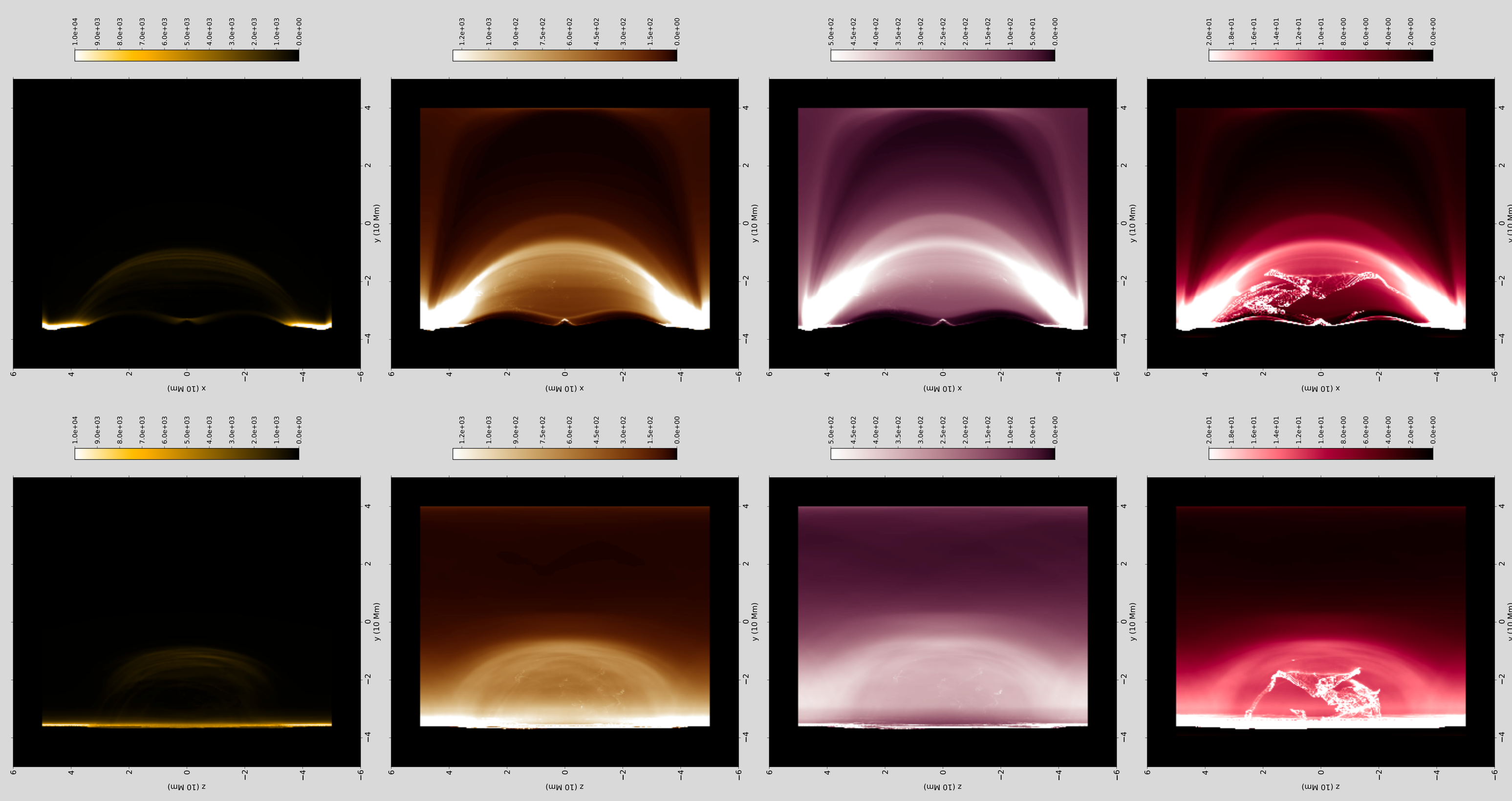


Figure 4: Left: Evolution of the blob mass with time. Middle: Evolution of the number of blobs. Right: Mass distribution of the blobs throughout the entire simulation.

SDO/AIA synoptic views



171 Å	193 Å	211 Å	304 Å
0.8MK	1.5 MK	1.8MK	0.08MK

Figure 5: Four different wavelengths showing the xy-plane on the top row and the zy-plane on the bottom row of the whole simulation box depicting the mass circulation for a specific snapshot (235min).

Conclusions

- *We present a 3D simulation on coronal rain phenomena taking MHD including thermodynamic gain-loss terms to study non-ideal effects.*
- *Due to evaporation from the chromosphere localized runaway condensation events occur and plasma blobs are formed.*
- *Indications of Rayleigh-Taylor instability are evident and a continuous coronal rain develops following the magnetic field topology on the bottom parts of the configuration.*

References

[1] MPI-AMRVAC website: https://gitorious.org/amrvac/

[2] Keppens, R. et al. JCP 231, 718, 3 (2012)

[3] Porth, O.; Xia, C.; Hendrix, T.; Moschou, S. P.; Keppens, R. ApJS 26, 214, 4 (2014)

[4] Fang, X., Xia, C., & Keppens, R., ApJL, 771, L29 (2013)

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