A New Approach for Modelling Chromospheric Evaporation in Response to Enhanced Coronal Heating

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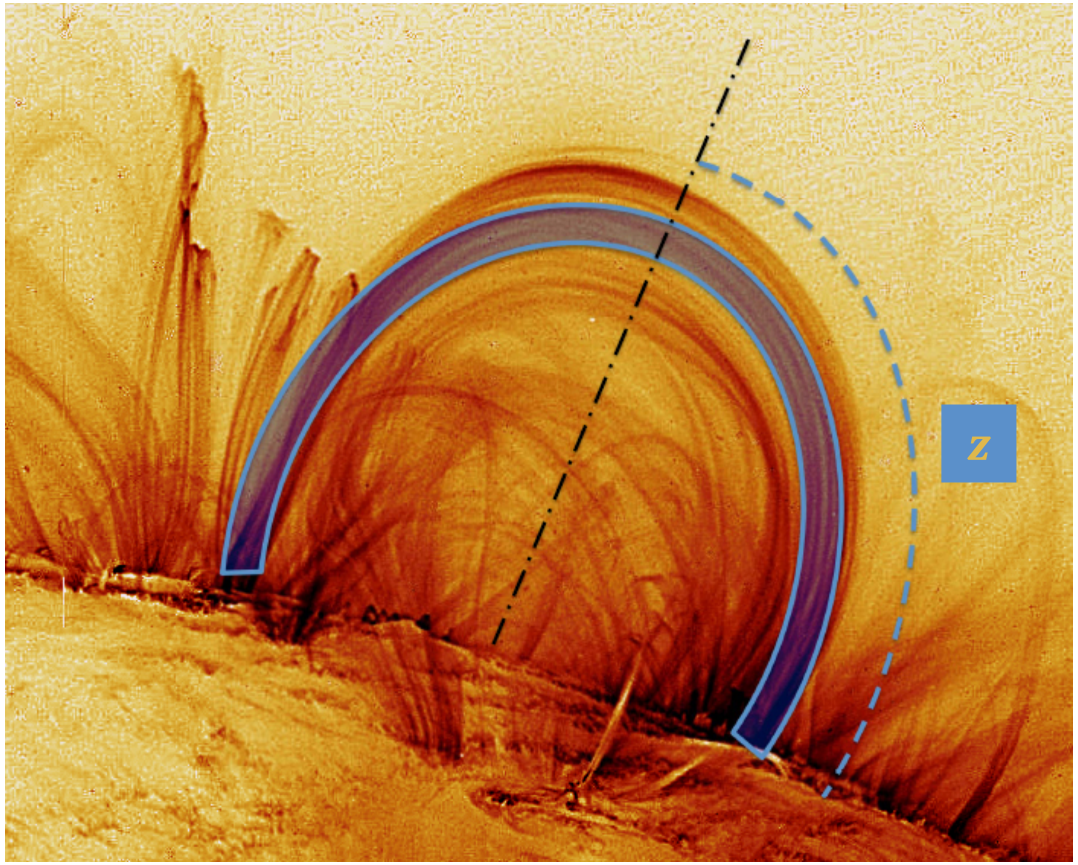
Modelling Chromospheric Evaporation



The plasma confined in a loop can be described with a 1D hydrodynamic model, with a single coordinate (z) along the loop (e.g. Reale 2014).

1D field-aligned model.

Global 3D MHD models.

$$\frac{\partial \rho}{\partial t} + v\frac{\partial \rho}{\partial z} = -\rho\frac{\partial v}{\partial z},$$

$$\rho\frac{\partial v}{\partial t} + \rho v\frac{\partial v}{\partial z} = -\frac{\partial P}{\partial z} - \rho g_{\|},$$

$$\rho\frac{\partial \epsilon}{\partial t} + \rho v\frac{\partial \epsilon}{\partial z} = -P\frac{\partial v}{\partial z} - \frac{\partial F_c}{\partial z} + Q(t) - n^2\Lambda(T),$$

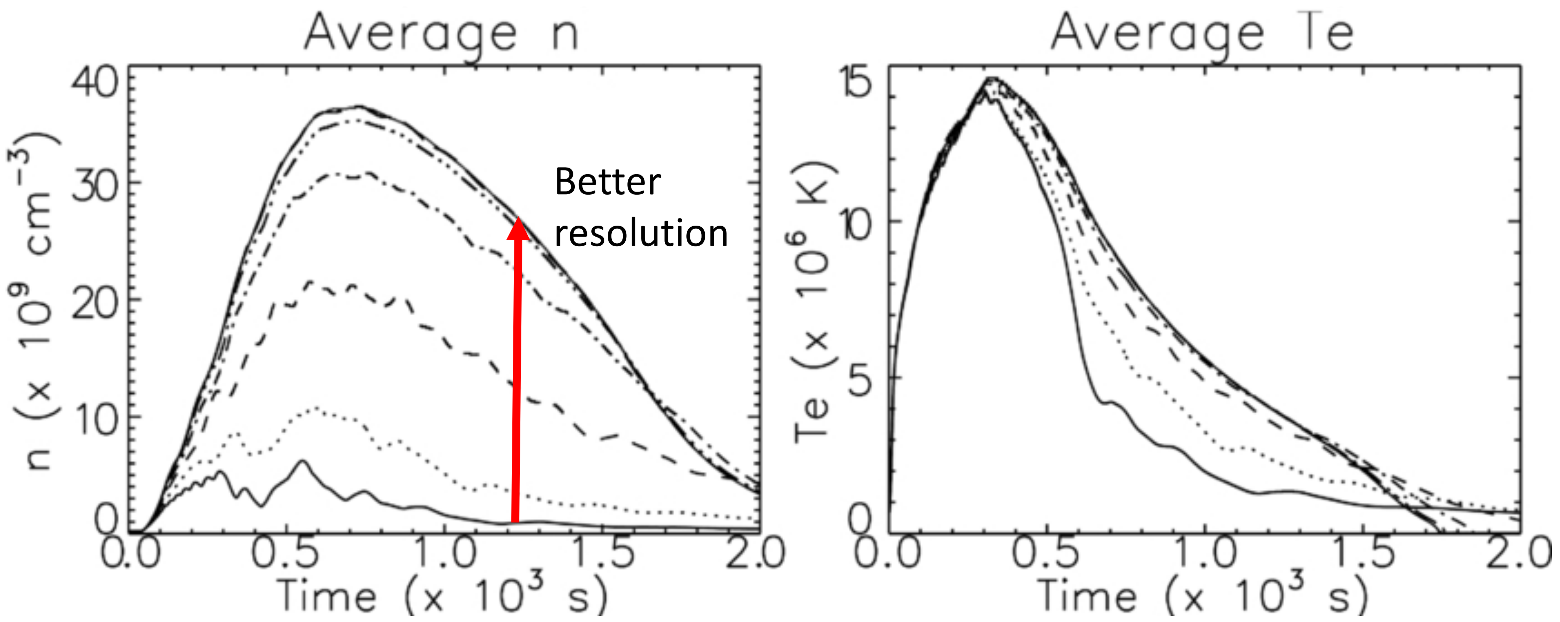
$$P = 2k_B nT,\ \epsilon = \frac{P}{(\gamma-1)\rho}.$$

$F_c = -\kappa_0 T^{5/2}\frac{\partial T}{\partial z}$ is the Spitzer heat flux.

Solved using a Lagrangian remap approach (Arber et al, 2001), adapted for 1D field-aligned hydrodynamics.

The Importance of TR Resolution (Bradshaw & Cargill, 2013)

Emission measure is proportional to n^2.



Heat flux jumps across the TR.

HYDRAD – fully resolved 1D model with an adaptive grid.

Difficulty of resolving downward heat flux is well known,

$$L_T \sim \sqrt{\frac{\kappa_o T^{7/2}}{n^2 \Lambda(T)}} \, .$$

Quantitative description by B&C (2013).

Showed that lack of spatial resolution leads to coronal densities that are far too low.

TR Resolution can be brute-forced in 1D.

But not in 3D. So develop approximate methods for use in 3D.

Jump Condition Approach (Johnston et al, 2017a,b)

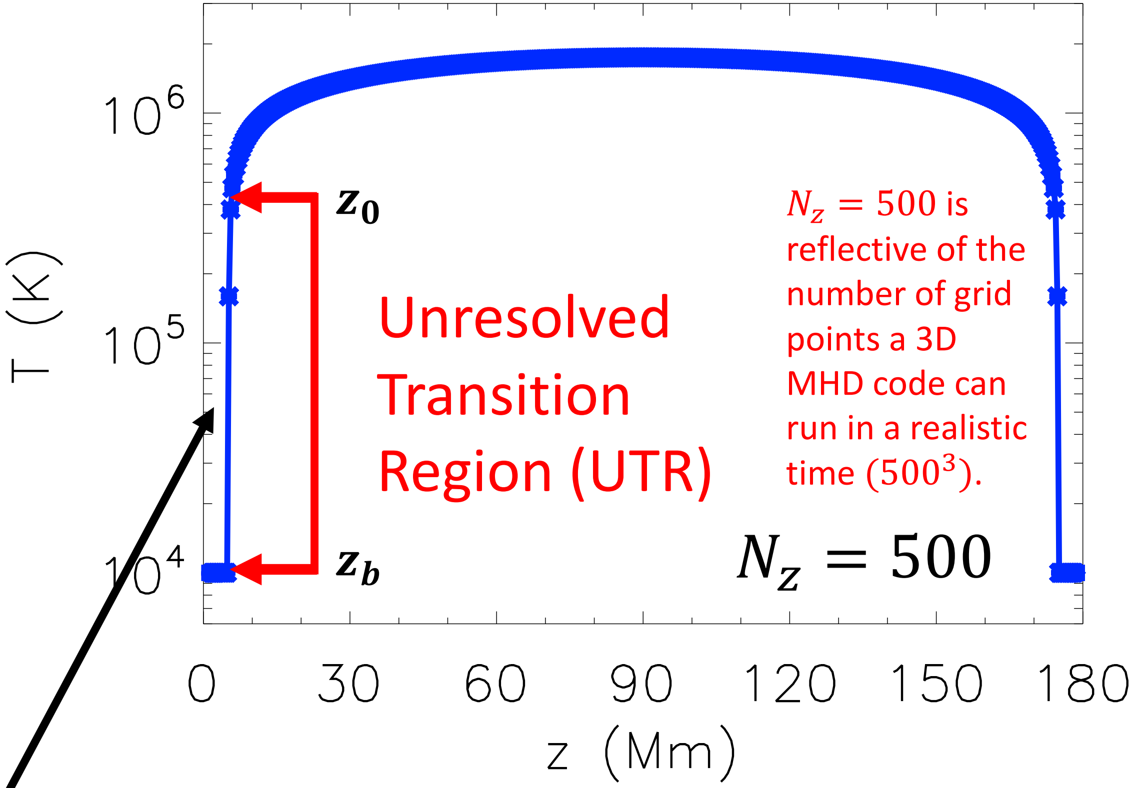
Model the unresolved transition region as a discontinuity using a jump condition.

The 1D field-aligned MHD equations can be written in conserved form for the total energy,

$$\frac{\partial E}{\partial t} = -\frac{\partial}{\partial z}\left(\frac{\gamma}{\gamma-1}Pv + \frac{1}{2}\rho v^3 + \rho\Phi v + F_c\right) + Q - n^2\Lambda(T),$$

where,

$$E = \frac{P}{\gamma-1} + \frac{1}{2}\rho v^2 + \rho\Phi.$$



Integrate over the UTR, neglecting LHS and z_b flux terms.

z_b is the base of the TR.

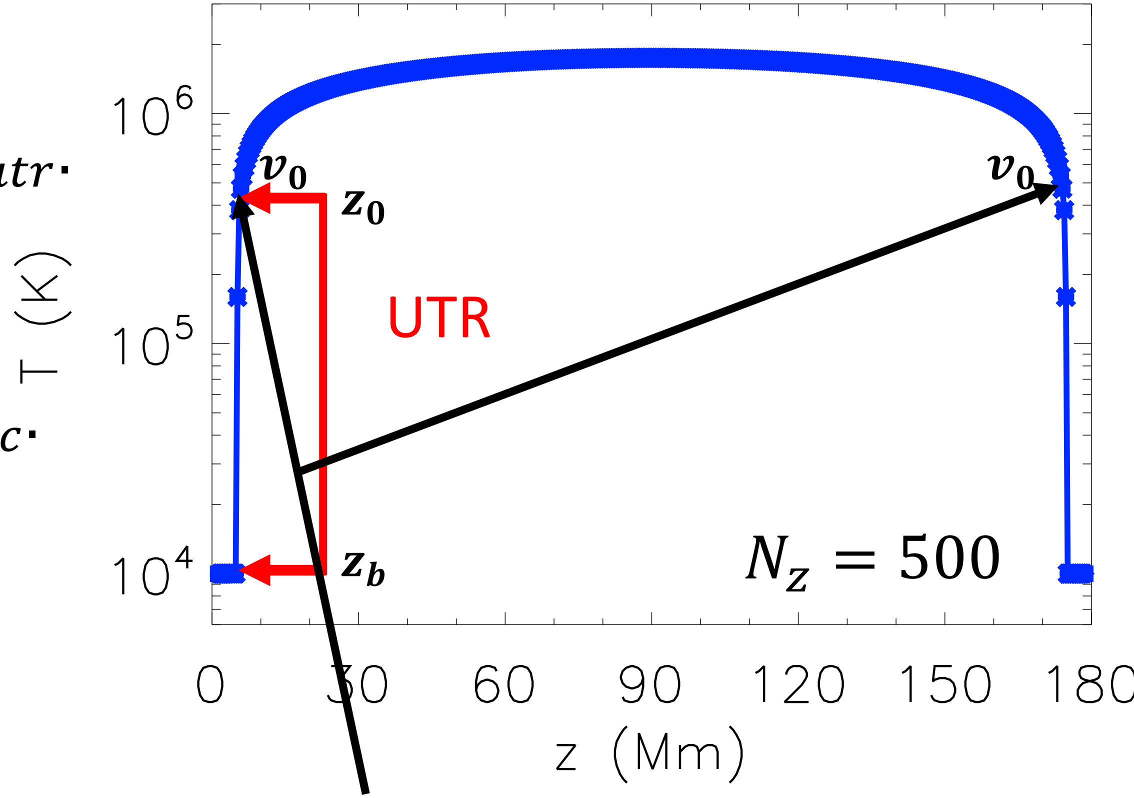
z_0 is the top of the UTR.

UTR Jump Condition

$N_z = 500$ is reflective of the number of grid points a 3D MHD code can run in a realistic time (500^3).

$$\frac{\gamma}{\gamma - 1} P_0 v_0 + \frac{1}{2}\rho_0 v_0^3 + \rho_0 \Phi_0 v_0 = -F_{c,0} + \ell \overline{Q} - \mathcal{R}_{utr}.$$

Need to approximate $\mathcal{R}_{utr} = \int_{z_b}^{z_0} n^2 \Lambda(T)\, dz \approx \mathcal{R}_{trc}.$



Then solve for the velocity v_0.

Impose corrected velocity at the top of the UTR to compensate for the jumping of the heat flux (Johnston et al, 2017a,b).

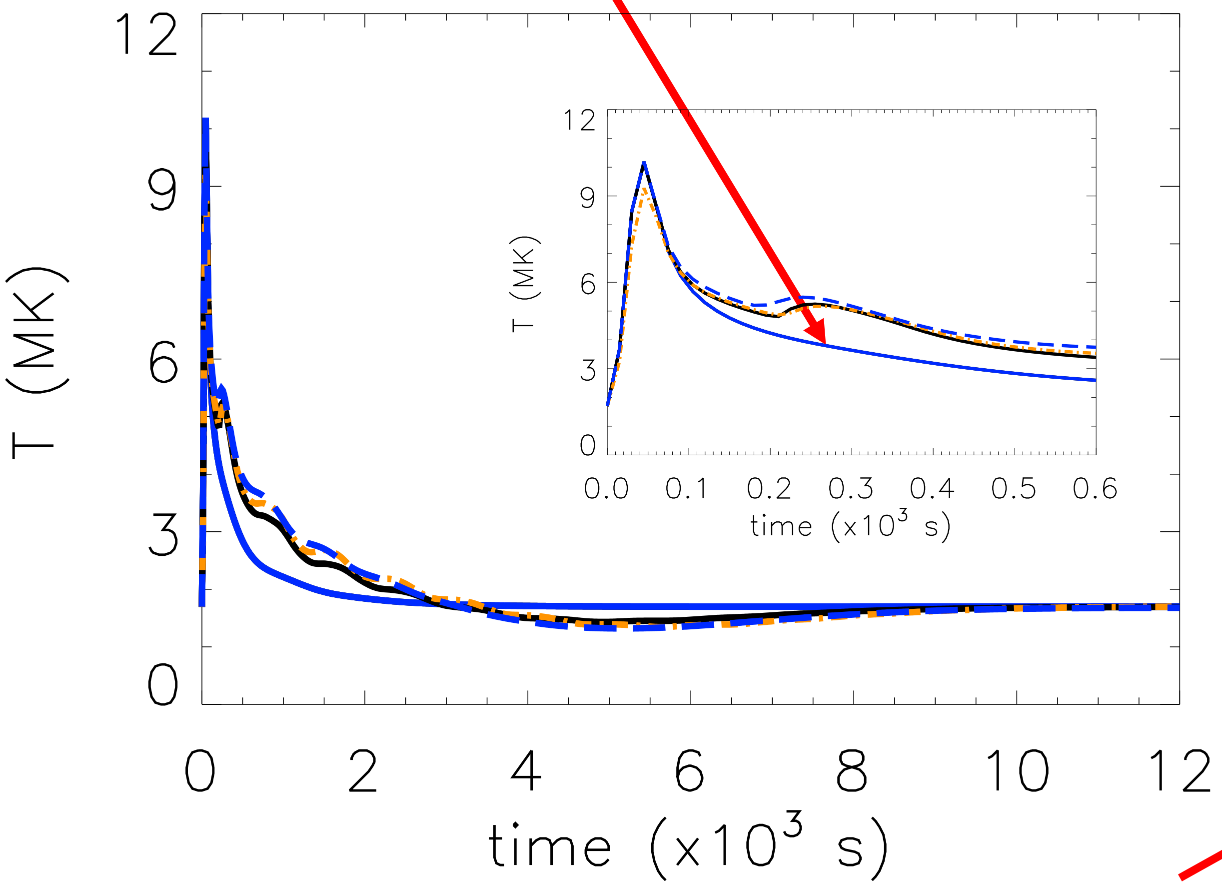
Three scenarios:

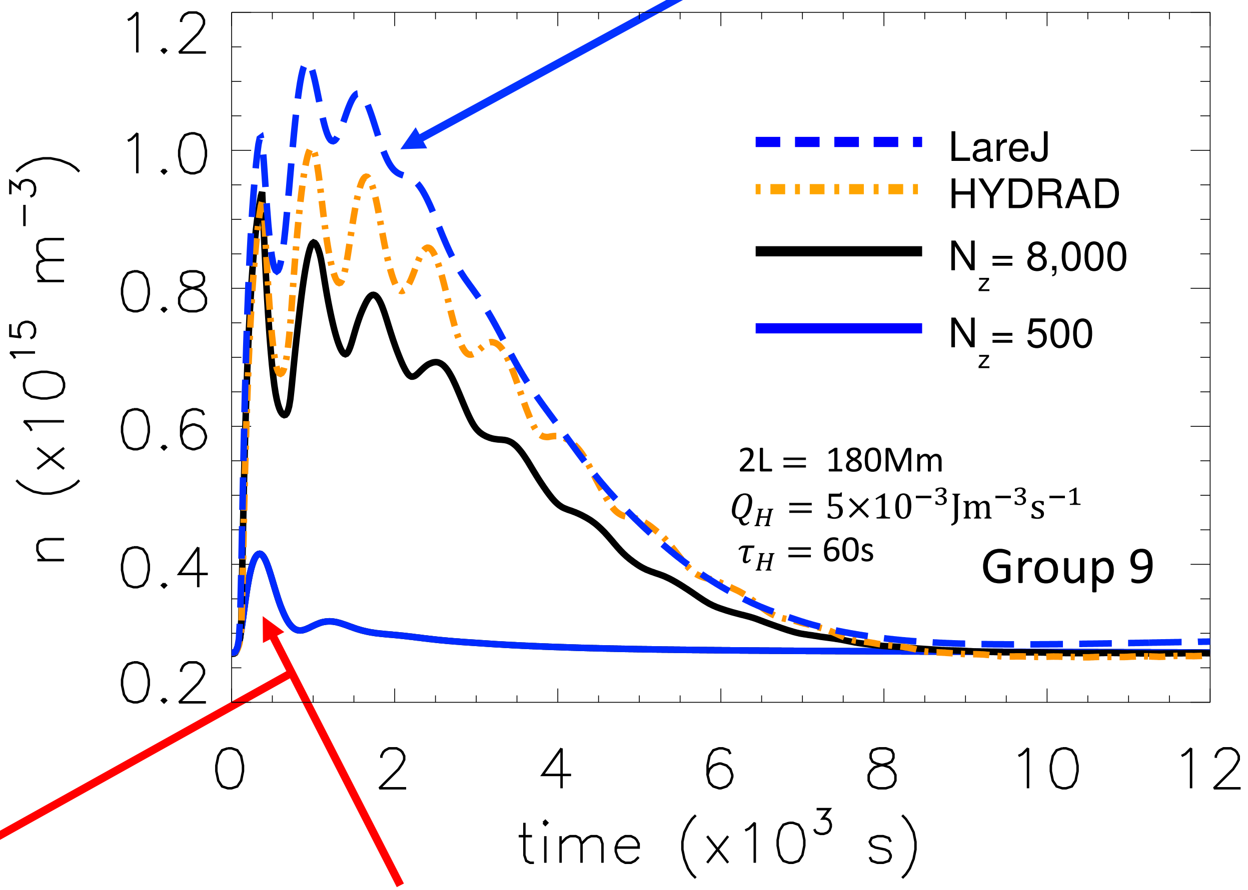
Equilibrium ($v_0 = 0$).
Evaporation ($v_0 > 0$).
Draining ($v_0 < 0$).

Uniform Heating - Long Loop, Short Pulse, Strong Heating.

Rapid cooling since conductive cooling timescale scales as $n/T^{5/2}$.

Jump condition solution provides a much improved approximation.





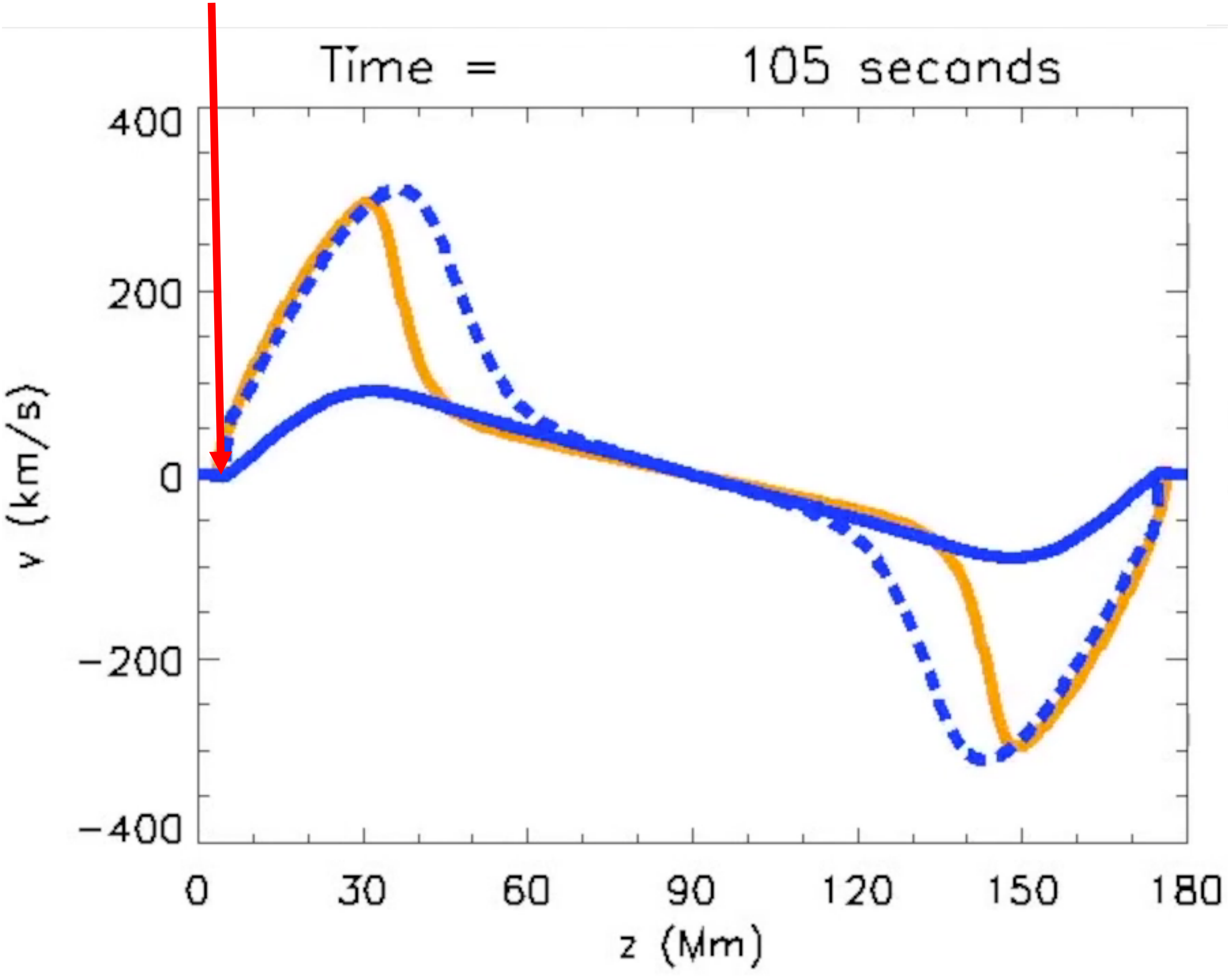
1D or 3D simulations would give very low density with $N_z = 500$.

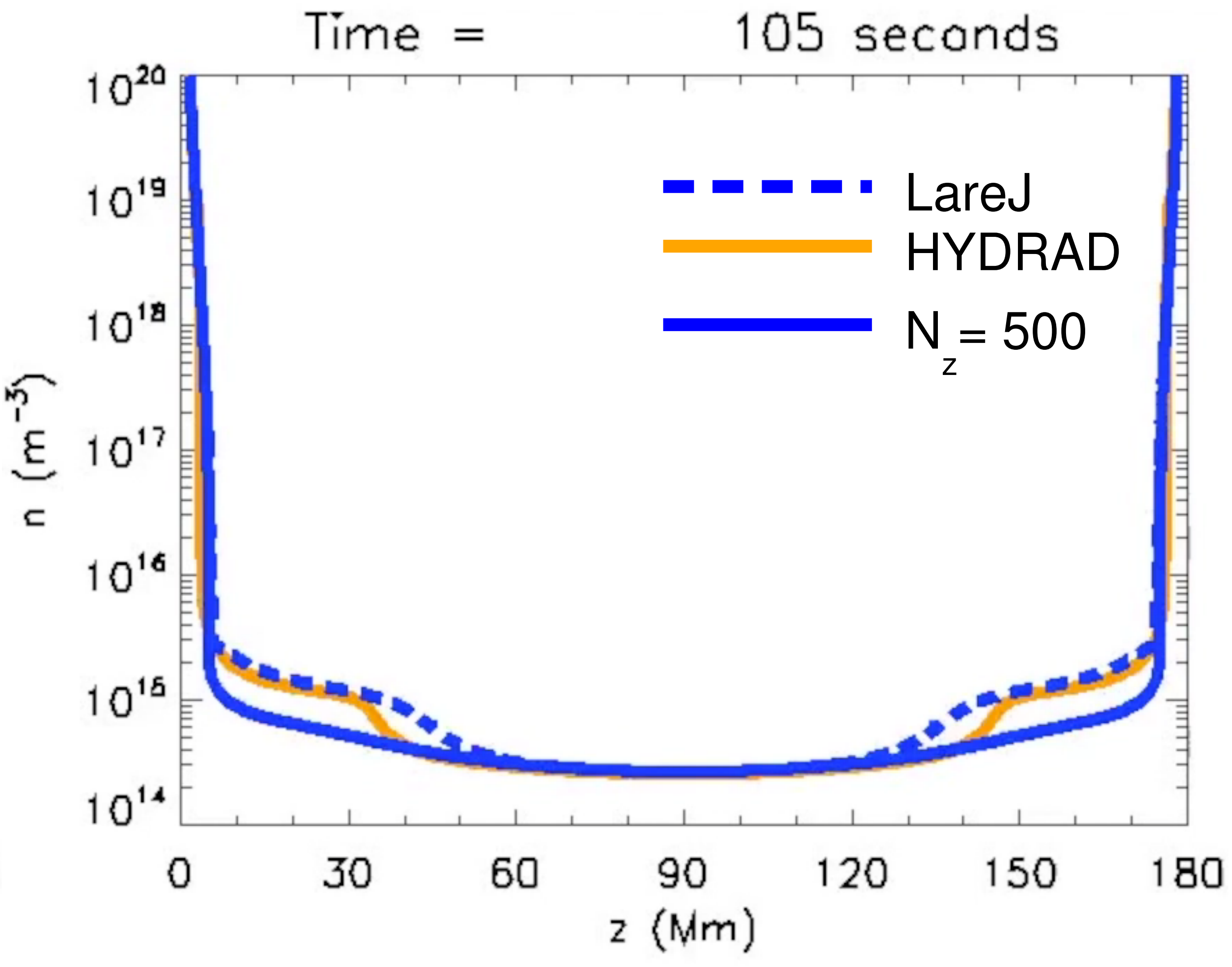
The peak is premature and there is no significant draining phase.

(Johnston et al, 2017a)

The corrected velocity ensures that the energy from the heat flux goes into driving the upflow.

Time Evolution of the Velocity & Density (Evaporation)





(Johnston et al, 2017a)

Long Loop, Short Pulse, Strong Heating.

Time Evolution of the Velocity & Density (Evaporation)

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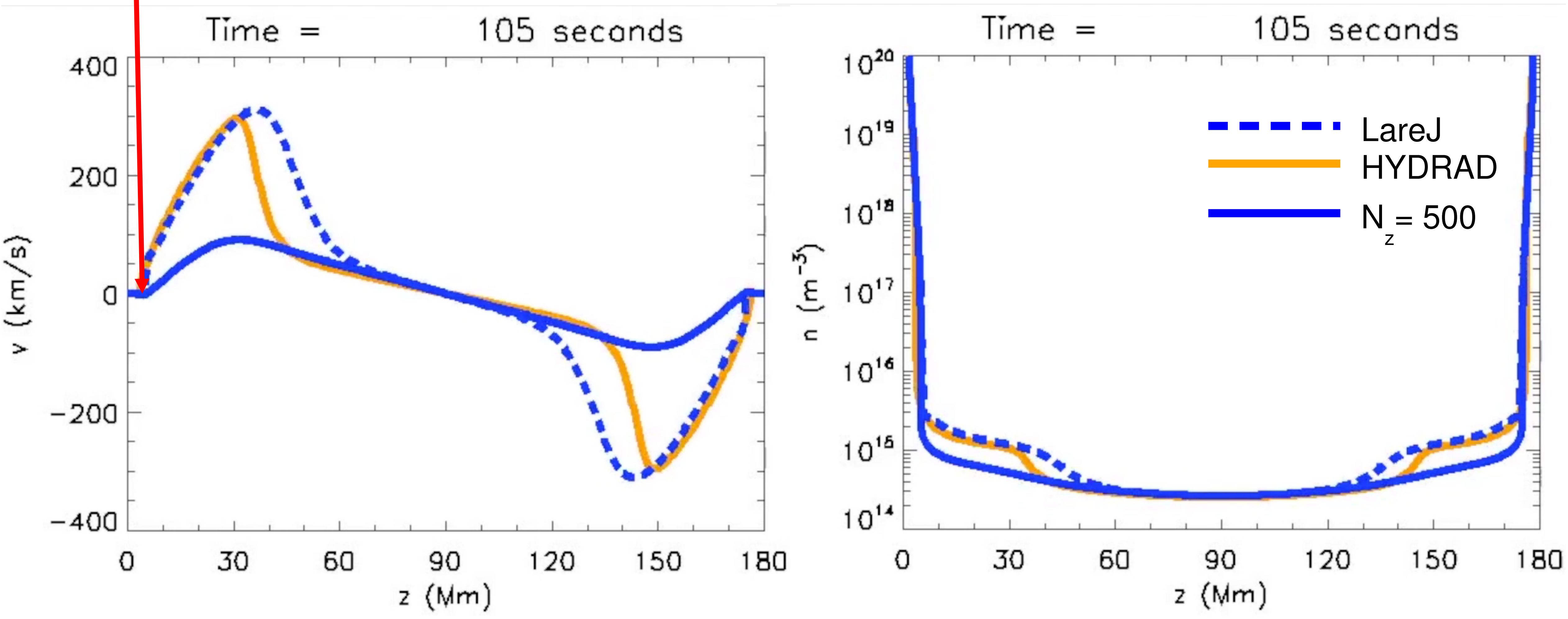
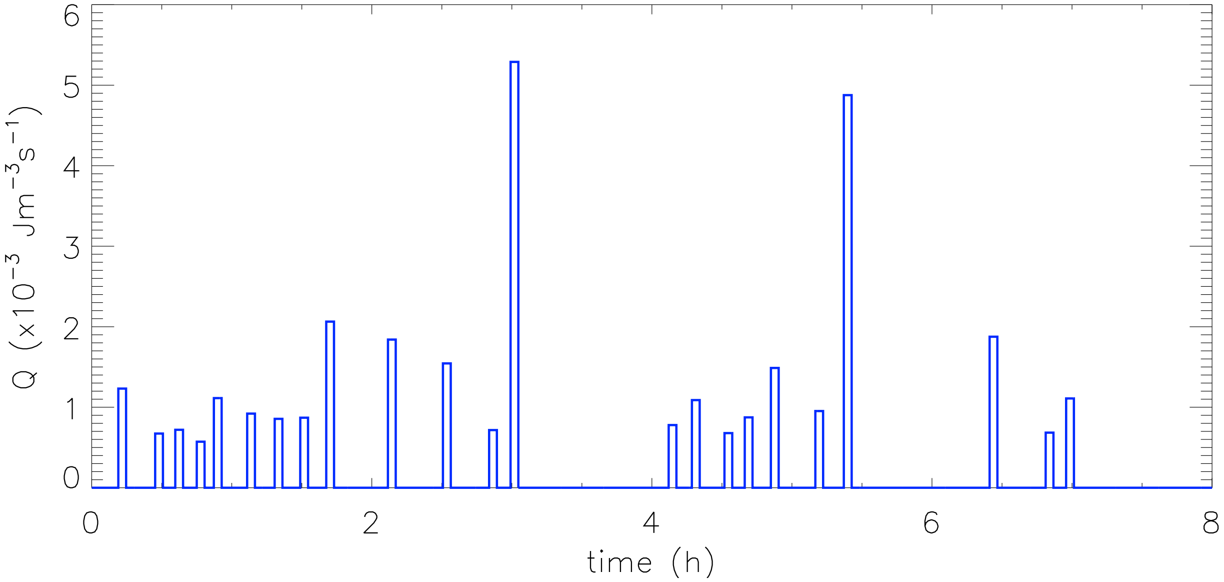
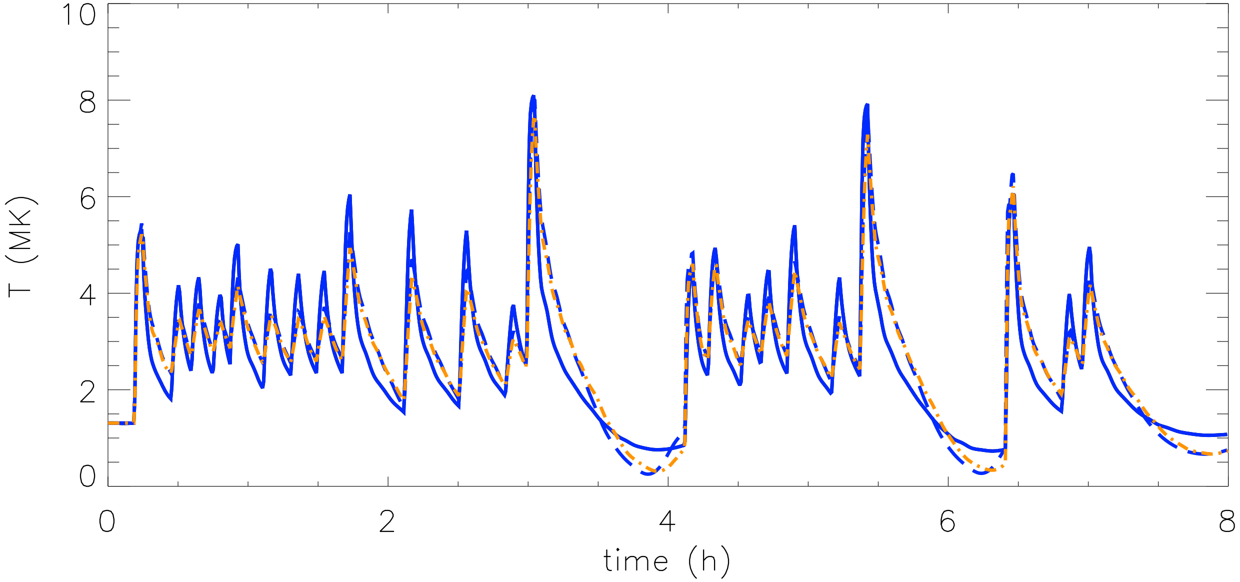


(Johnston et al, 2017a)

Long Loop, Short Pulse, Strong Heating.

Non-Uniform Heating – Nanoflare Train.

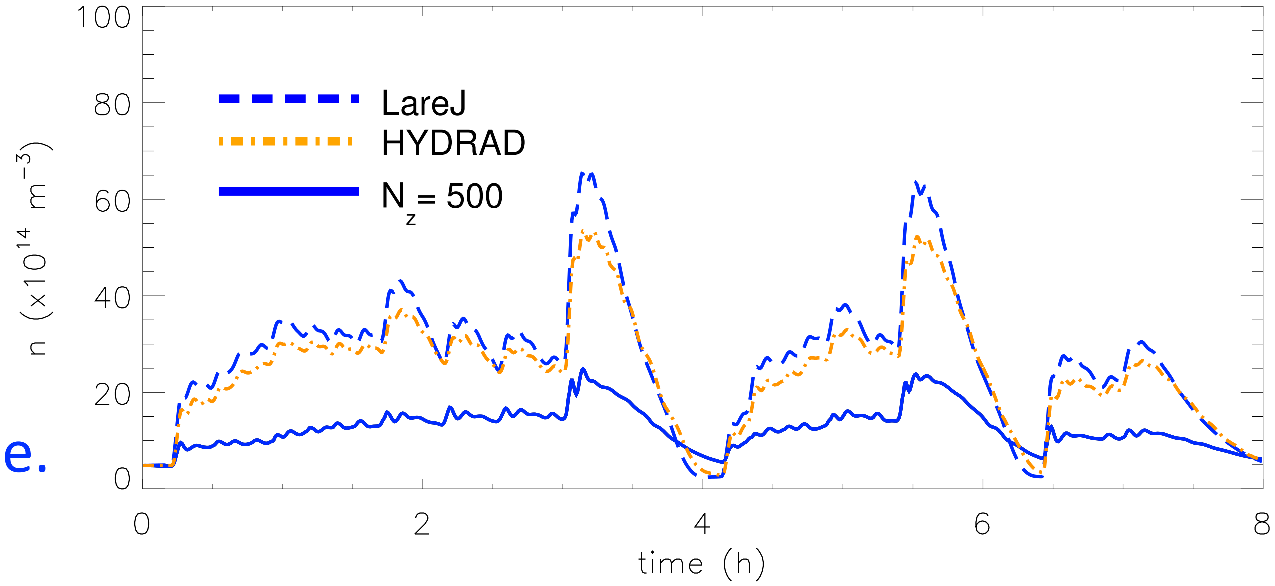




90Mm loop.

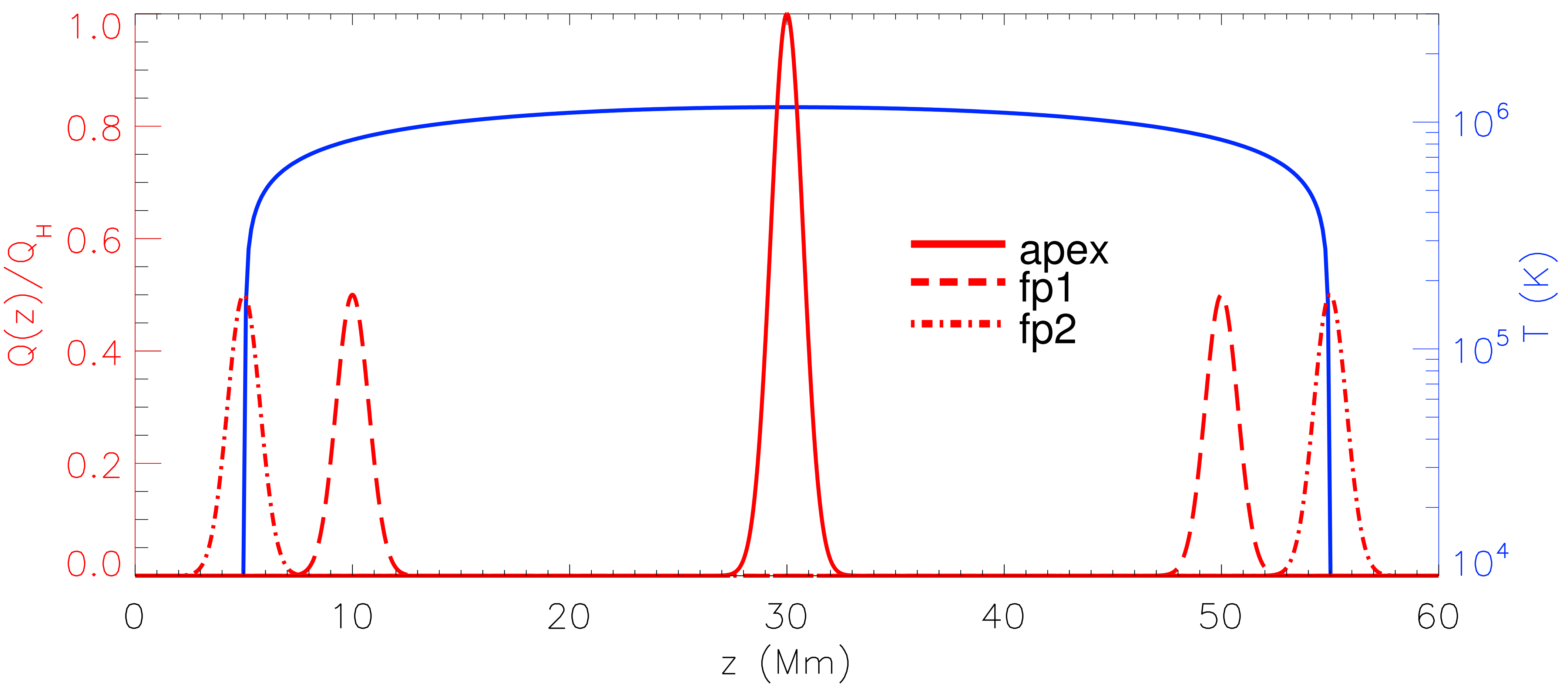
Spatial profile of the heating is uniform.

Application of the jump condition is not limited to a single heating and cooling cycle.



(Johnston et al, 2017b)

Non-Uniform Heating – Apex and Footpoint Heating.



fp1 heating - footpoint heating at the base of the corona.

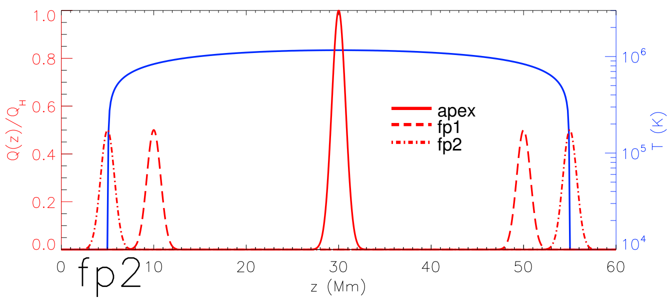
fp2 heating - footpoint heating at the base of the TR.

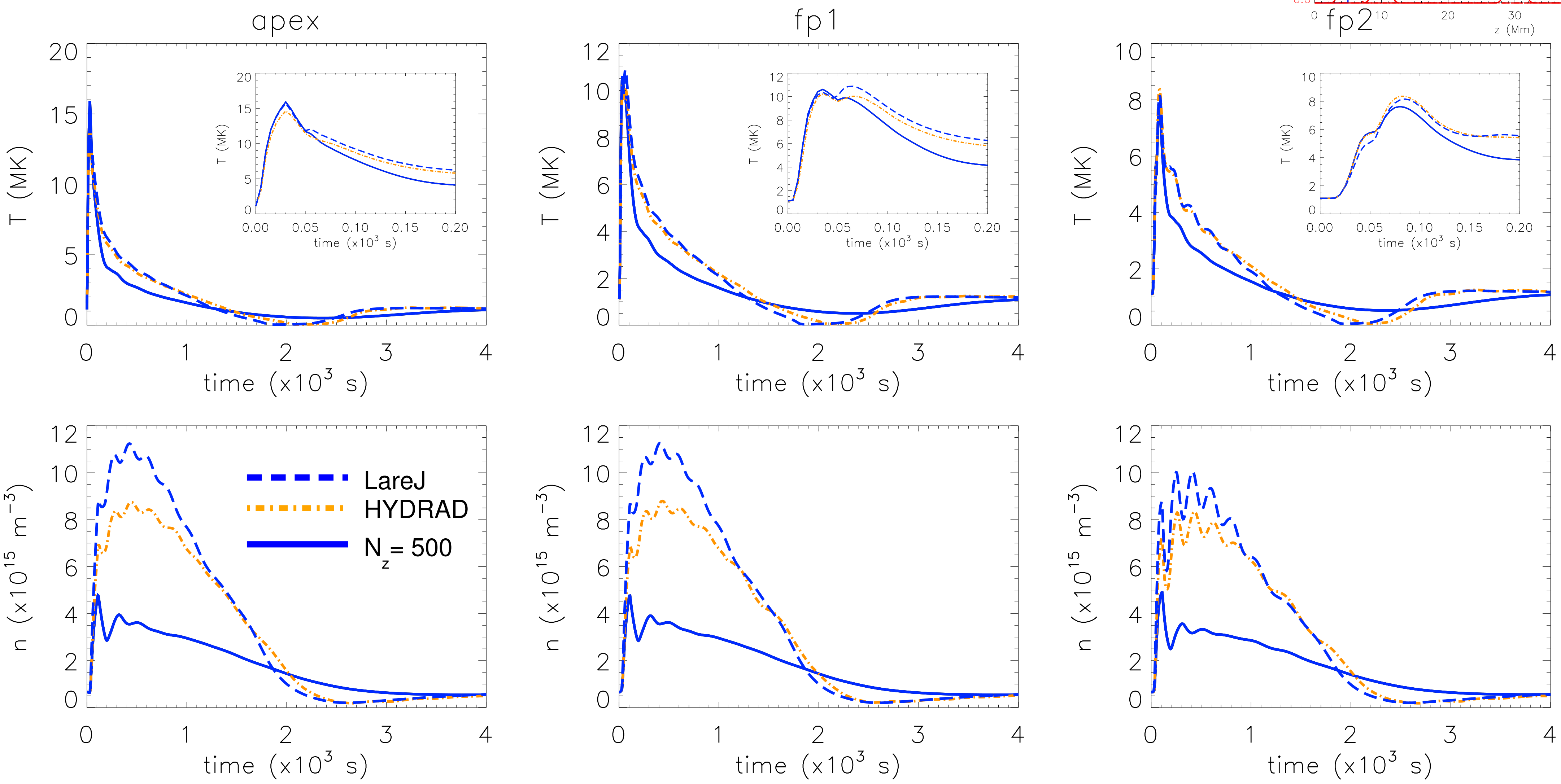
$$Q(z) = Q_H \exp\left(\frac{-(z - z_0)^2}{2z_H^2}\right).$$

(Johnston et al, 2017b)

Non-Uniform Heating – Apex and Footpoint Heating.

Short Loop, Short Pulse, Strong Heating.





Despite the complexity of the type of heating considered the jump condition still performs well (Johnston et. al 2017b).

Conclusions

Detailed Analysis of the Jump Condition Approach (Johnston et al. 2017a,b).

1. The method is physically motivated. Based on energy conservation.

2. Computationally efficient and easy to implement. The jump condition approach is between 1-2 orders of magnitude faster than fully resolved 1D models. Eliminates the need for very short time steps since we do not need to resolve the TR. Good accuracy is obtained with resolutions compatible with 3D MHD simulations.

3. Get the correct coronal T & n response. Ensures accurate comparisons between simulations and observations.

4. Can be used for active region modelling. Applicable for the required T range and simulation box size (loop length).

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