Background credits: SolarOrbiter/ESA

Contact: quentin.noraz@astro.uio.no

Role of Poynting flux injection by magneto-convection on the chromospheric energy balance

Quentin Noraz[1], Mats Carlsson[1]

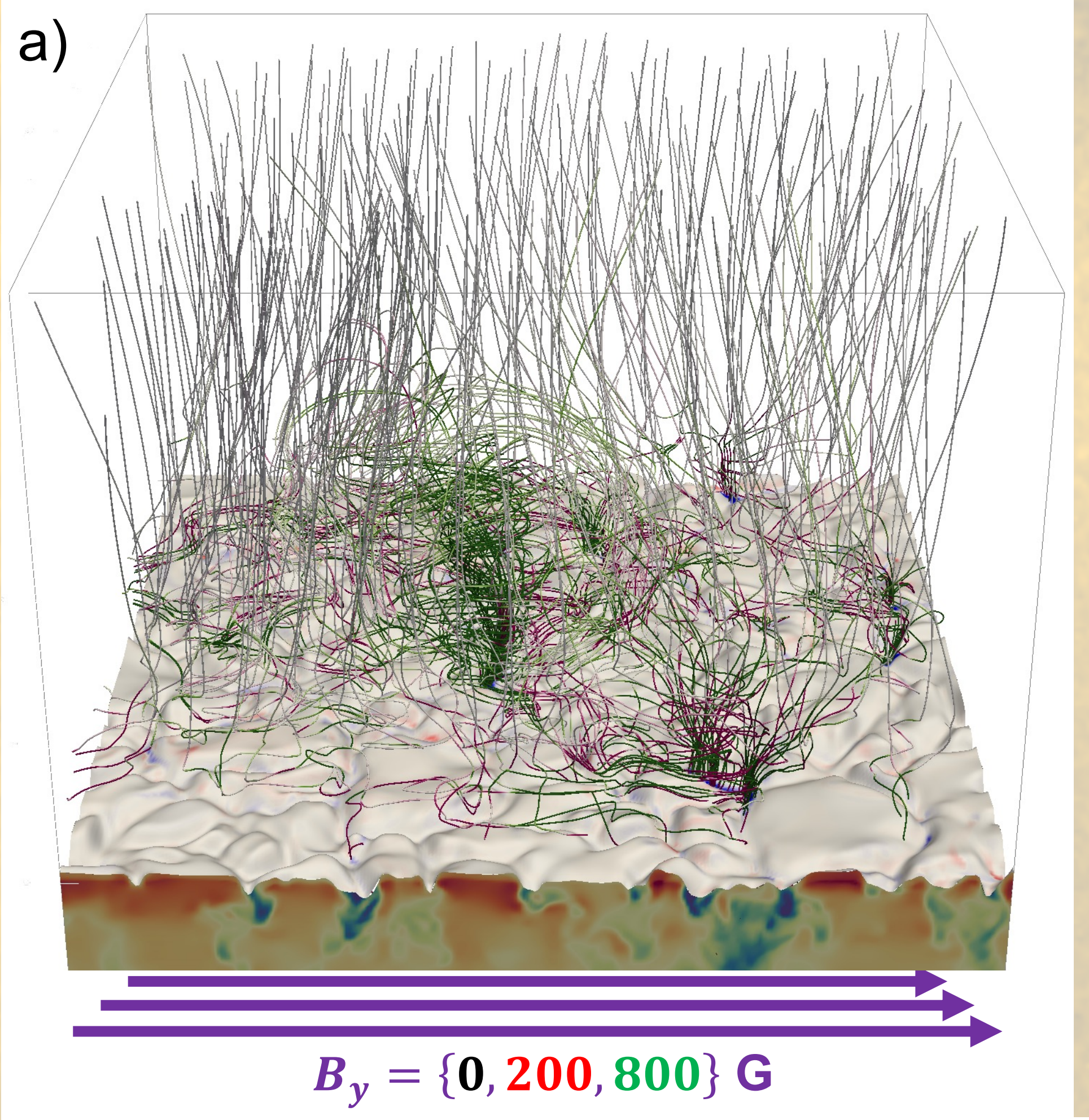
[1] Rosseland Centre for Solar Physics, University of Oslo, Norway

Context

The solar atmosphere exhibits a diverse range of dynamical processes that contribute to the **heating of the outer atmosphere**. Recent observations and simulations have highlighted the importance of **waves and magnetic reconnection** in the chromosphere, providing energy to balance the radiative cooling. However, the precise amount of energy and the **relative roles** of these processes in different solar regions (e.g., coronal hole, quiet sun) are still under debate.
Magnetic fields play a major role for the atmospheric heating. Numerical simulations have especially demonstrated that the **braiding of magnetic field** lines by photospheric convection can sustain a million-degree corona by **injecting energy through Poynting flux** (Gudiksen & Nordlund 05, Finley+22). However, the **initial magnetic field** in such models remains a free parameter, and limited resolution may dampen velocity dispersions, impacting the accuracy of the simulations.

In this context, we perform a **numerical parametric study**, where we investigate the chromosphere heating and dynamics under **different flux emergence configurations**, using high-resolution *Bifrost* simulations of coronal hole.

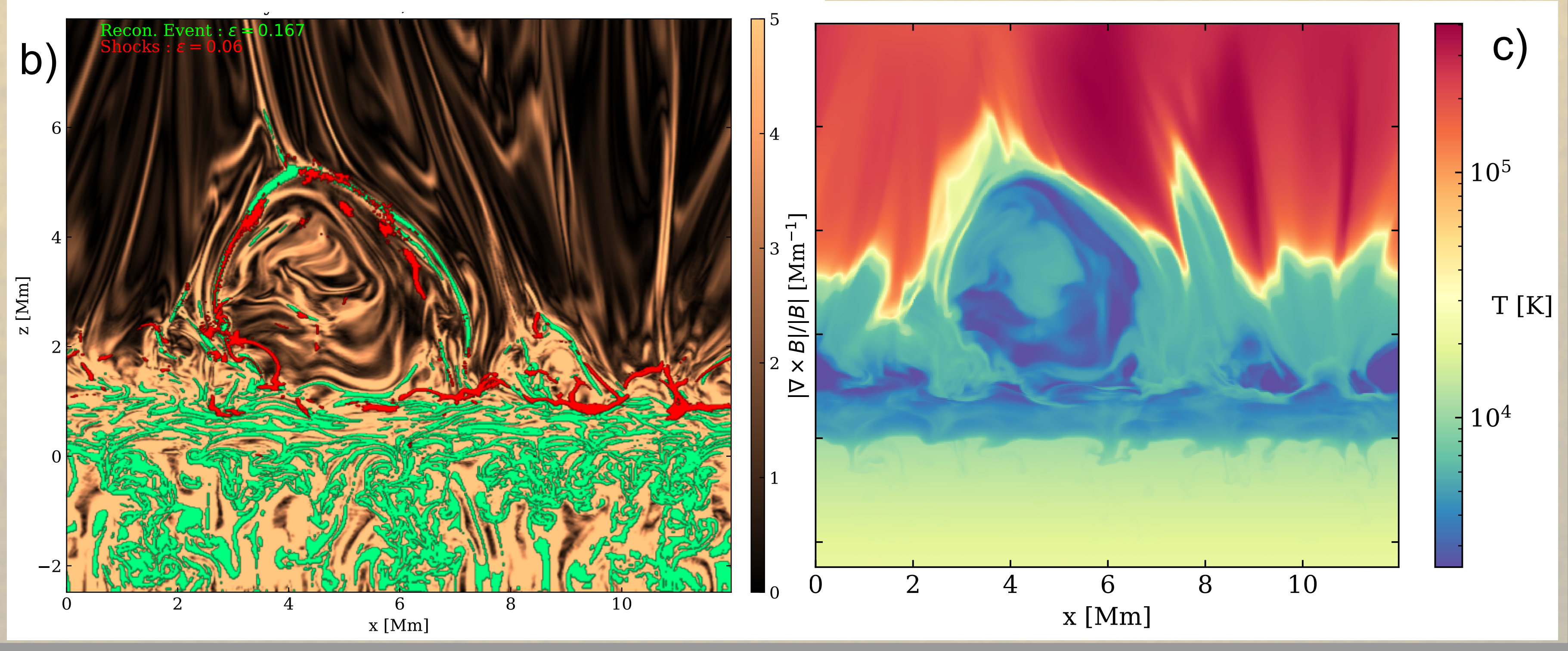
Numerical parametric study



Code: ***Bifrost*** (Gudiksen+11)
Size: 12 x 12 x 10.5 Mm
Resolution:
- Horizontal 23 km
- Vertical from 70 to 12 km

Coronal hole configuration
$\langle B_z \rangle = 2.5\ G$

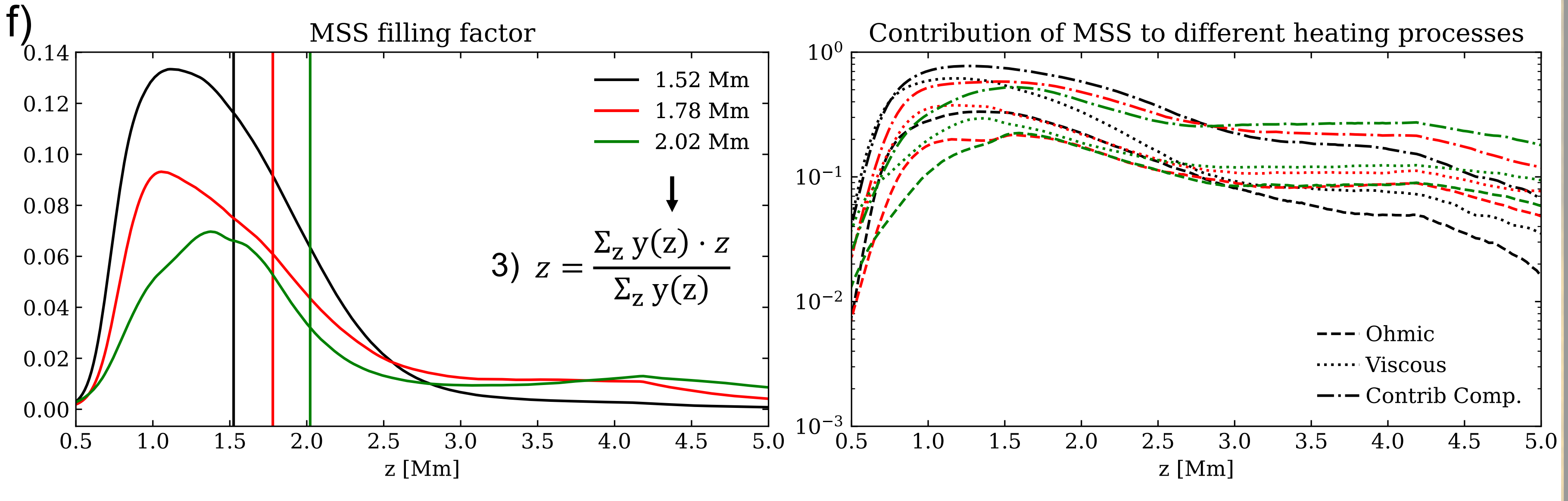
Using this reference setup, we vary the amount of **upwardly advected magnetic field** at the bottom boundary ($z = 2.5$ Mm), in 3 models with
$\boldsymbol{B_y} = \mathbf{0}$, **200 and 800 G**.



Shocks and Reconnection

2) $\boxed{-\nabla \cdot v > \epsilon \cdot c_S \,/\, ds}$

Magneto-sonic waves rising through the **chromosphere** can produce **shocks** (colored in red on Figure b). We **locate** these shocks in the simulation following the sound-speed c_S criteria 2) (see Finley+22), where ds is the local-minimum size of the grid and ϵ a parameter we calibrate to **distinguish shocks from** compression by **linear-wave** propagation (see Wang & Yokoyama 20).
The volume filled by magneto-sonic shocks **(MSS)** is globally **decreasing** as a function of the imposed $\boldsymbol{B_y}$, especially **in the chromosphere** where their contribution to viscous heating drops from 60 to 30% (f). However, shocks still represent 50% of the chromospheric **compressional heating** in the **800G** case despite a 7% filling factor, and their overall contribution on the contrary **increases in the transition region**.



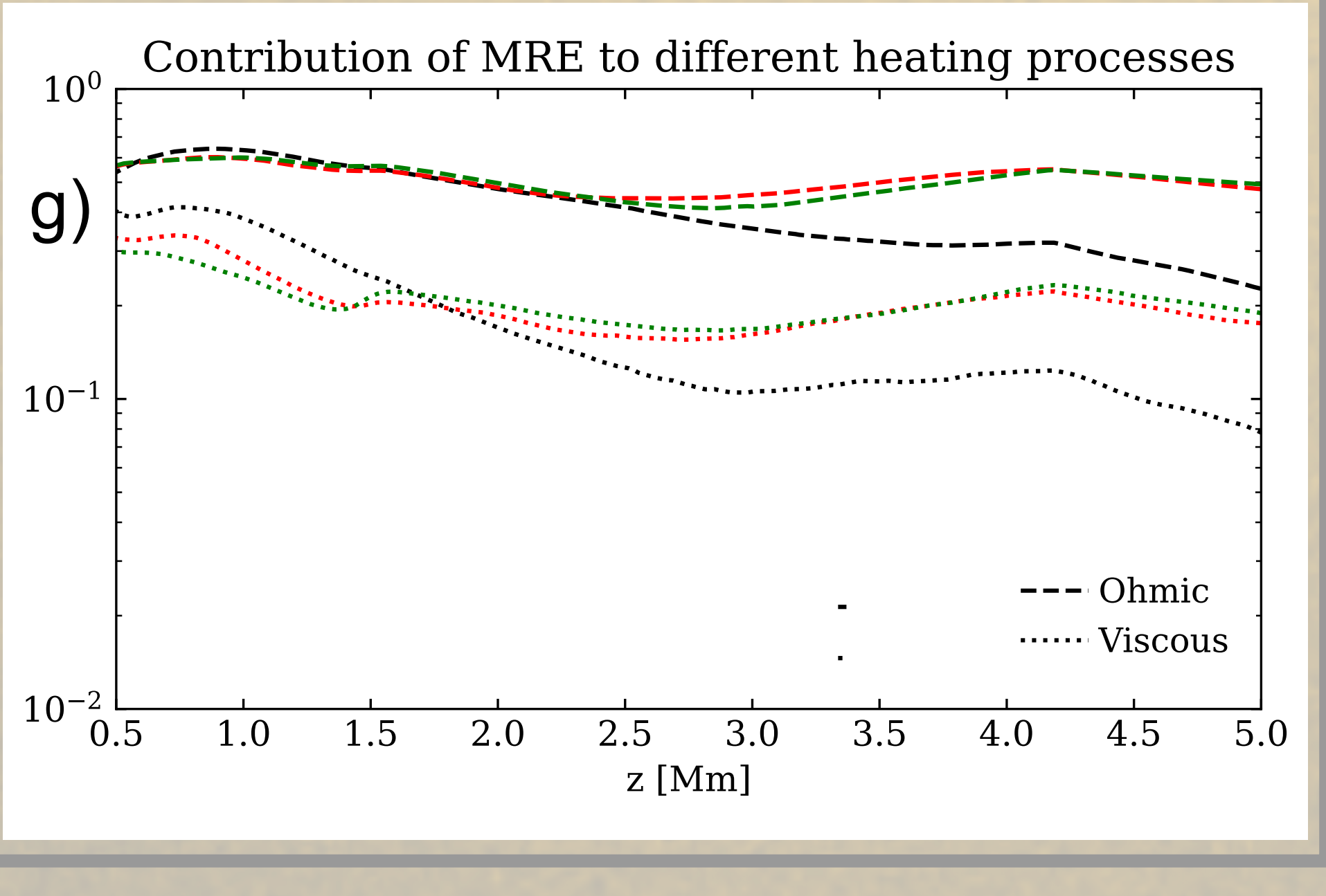
3) $z = \dfrac{\Sigma_z\, y(z) \cdot z}{\Sigma_z\, y(z)}$

Magnetic reconnection events (MRE) contribute to atmospheric heating on a large range of spatial and temporal scales. We here focus on the more energetic but rare episodes **happening in strong and large-scale current sheets** (colored in green on Fig. b).
We **locate** them the criterion (4), which tracks parallel currents $J_{//}$ related to magnetic topology changes becoming spatially smaller than the numerical resolution, where ϵ_2 is calibrated to focus on large scale magnetic currents.

4) $\boxed{J.B/B^2 > \epsilon \,/\, ds}$

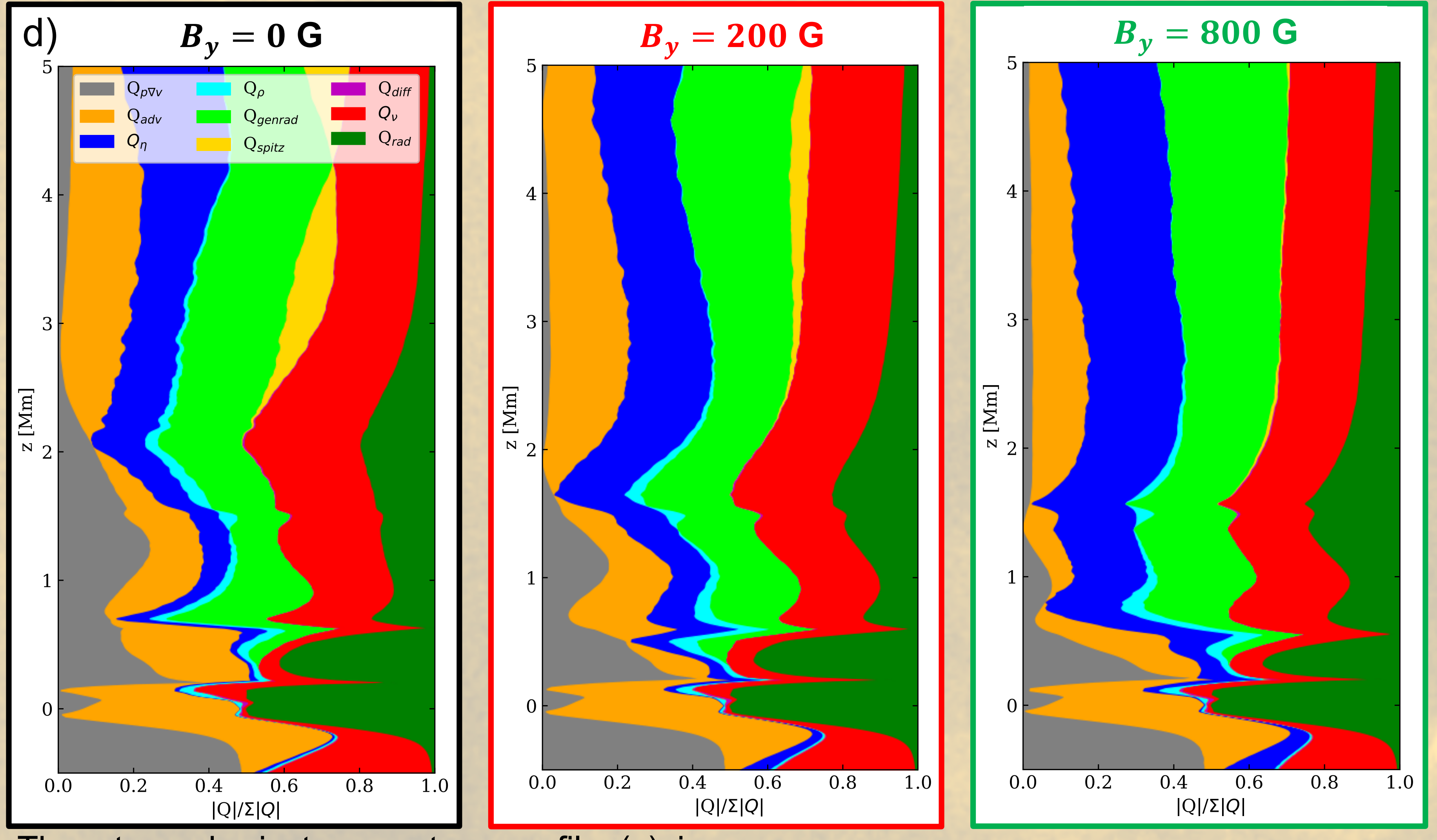
The nature and filling factor of these large current-sheets reconnection events do not change significantly in the chromosphere as we increase $\boldsymbol{B_y}$, where they still contribute to **60% of the overall chromospheric Ohmic heating.**

However, we note a **significant increase** of this contribution up to 50% **in the transition region**, with a **filling factor increasing from 4 to 20%** when increasing the bottom boundary to **800G.**



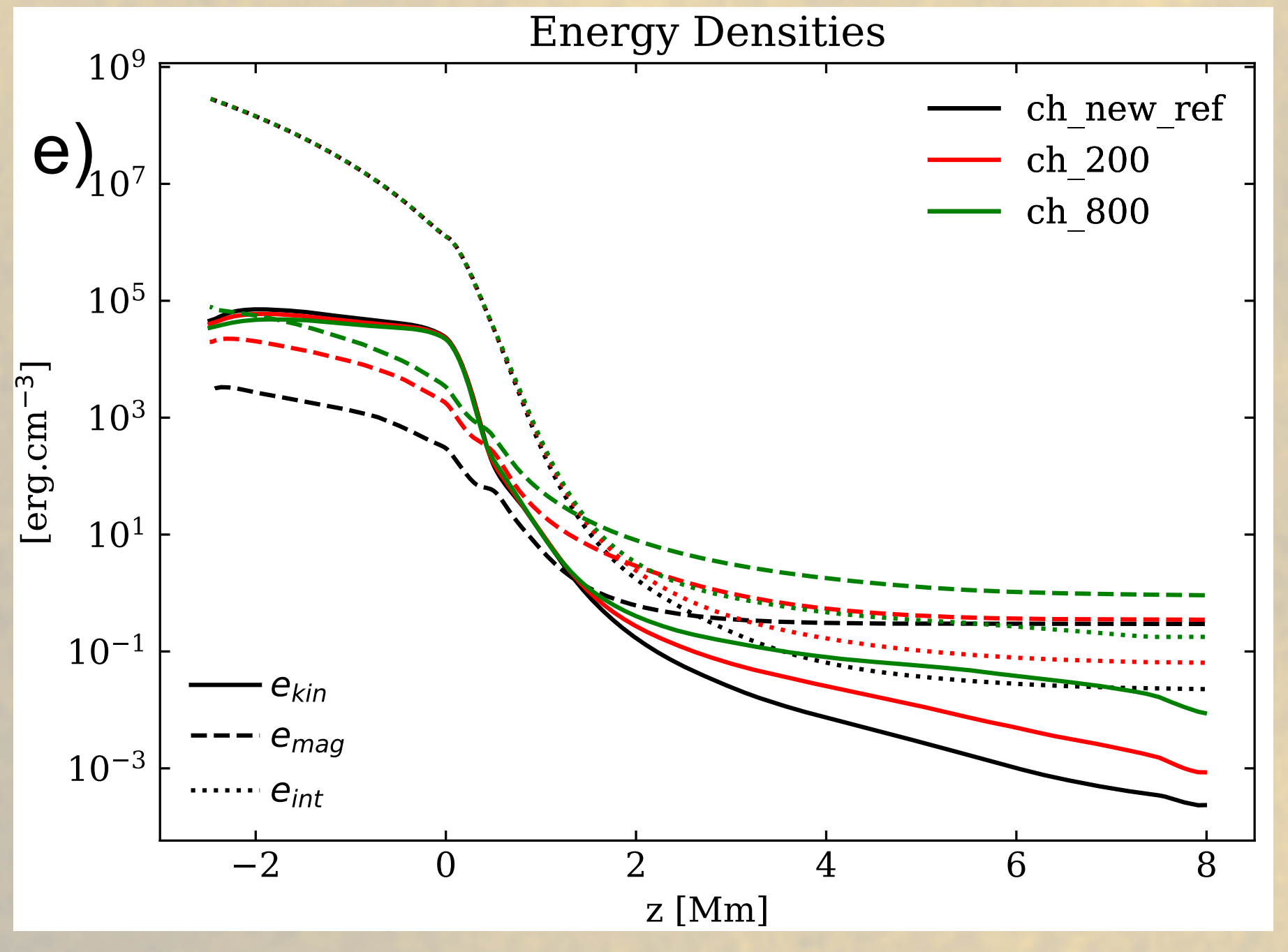
Internal energy balance

1) $\boxed{\dfrac{\partial e_{int}}{\partial t} = \Sigma Q}$



The atmospheric temperature profile (c) is sustained by the equilibrium of several **heating/cooling processes**. We show in Figures d) their unsigned relative contribution profiles to this balance (1). The ones from **Ohmic heating and radiative cooling increases** when the emerging-flux amplitude we impose rises.

Looking at the energy profiles (e), we see that **magnetic energy dominates** kinetic one **from mid-chromosphere**, and even from **its bottom** in the $\boldsymbol{B_y} = \mathbf{800}$ **G** case.

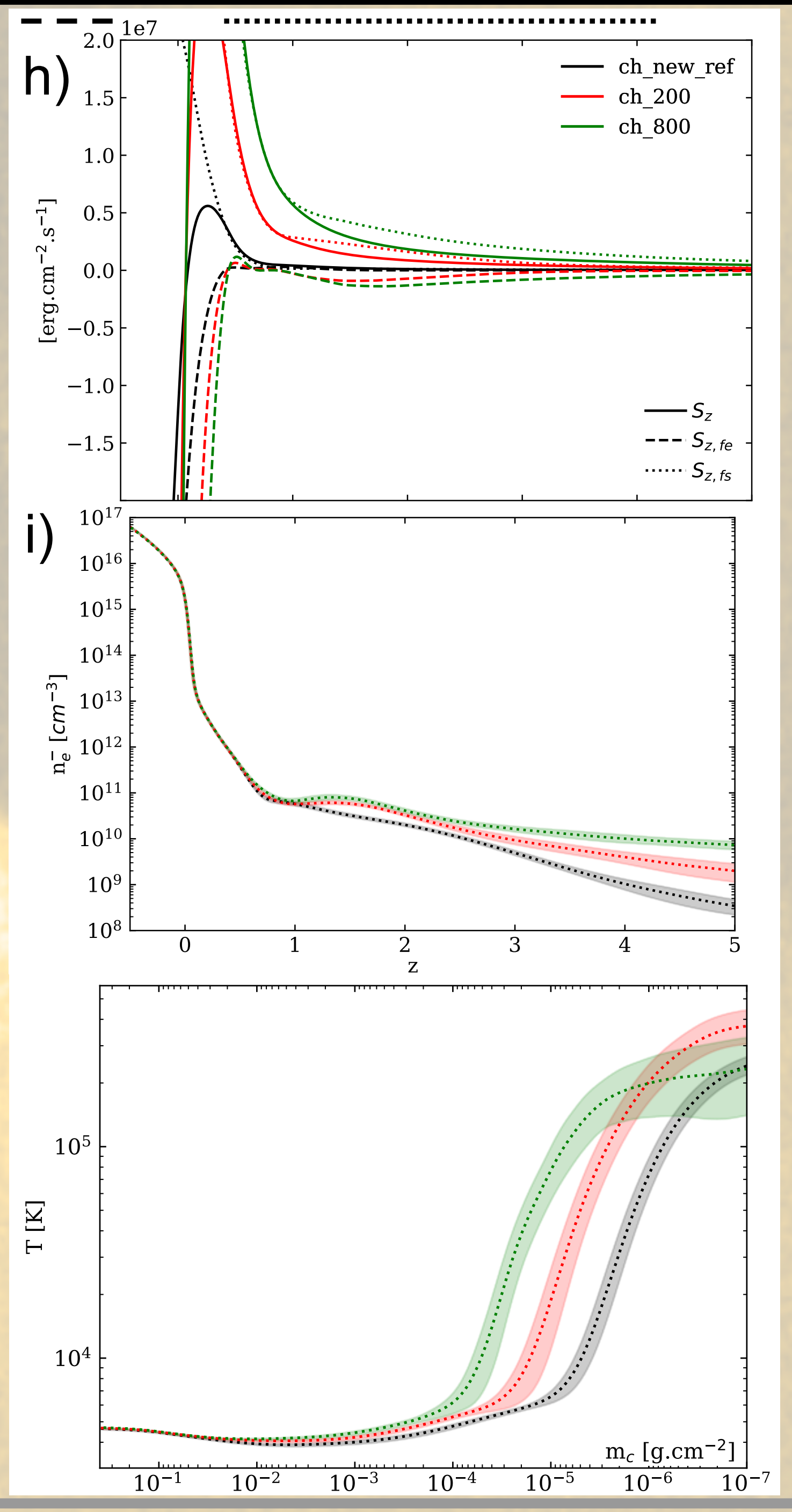


Atmospheric response

$\boxed{S_z = \left[B_h^2 v_z - B_z(v_x B_x + v_y B_y)\right]/4\pi}$

Part of the atmospheric heating balance is sustained by the transport of hot/cold material (Q_{adv} in eq. 1). The upward transport is enhanced **as we increase** the imposed $\boldsymbol{B_y}$ (Figs. h-i) changing then:
the **chromosphere**, partially ionized, where the temperature and thus electron density n_{e^-} are higher (i), likely due to the significant increase in Ohmic heating (d) ;
the **transition region**, which is formed at a higher column mass ;
the **low-corona**, fully ionized, where density, and thus n_{e^-}, have been increased, triggering radiative cooling. This latter is moderate in the **200G** case, where **coronal temperature $\boldsymbol{T_c}$ is** increased, but is stronger in the **800G** case and **decreases $\boldsymbol{T_c}$**.

This dynamics also quickly become magnetically dominated when going through the chromosphere (e), and the Poynting flux $\vec{S}$ quantifies the **transport of magnetic energy**, which increases with the imposed $\boldsymbol{B_y}$. Looking at its vertical-component S_z profile (h), it is then oriented upward and dominated by magnetic **field shaking** ("fs") **above the photosphere**, arising from the shear/twist of vertical field lines by horizontal flows (a).



Summary & Perspectives

We present a parametric study with a specific focus on coronal holes, where we increase the upwardly advected magnetic field $\boldsymbol{B_y}$ at the bottom boundary. We report a notable **enhancement** in both atmospheric Ohmic **heating** and radiative **cooling**, especially focused on the **chromosphere** for the former case, and the **low corona** for the latter. The augmented Ohmic heating is related to the increased amplitude of **upward Poynting flux**, whereas the radiative cooling is likely to be triggered by **mass loading**.
We currently investigate the specific magnetically-driven processes at play, with **MSS** contributing significantly to the chromospheric compressional heating and their occurrence diminishing in the chromosphere as the imposed ***B_y*** increases. Future comparisons of these models with **forthcoming observations**, from the IRIS mission and the exploration of polar caps by Solar Orbiter, hold the promise of providing more precise insights into the dynamics of coronal holes and the energy injection into the solar wind.