Phase mixing with multiple harmonics

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Introduction

- Our aim is to investigate laminar phase mixing of Alfvén waves as a standalone heating mechanism in coronal loops.
- We calculate an upper bound for the damping rate and compare with the heating requirement of the corona.
- We define the damping rate, γ, as

$$\gamma = \frac{\langle \text{Steady-state heating rate} \rangle}{\langle 2 \times \text{ Steady-state kinetic wave energy} \rangle}.$$

Model

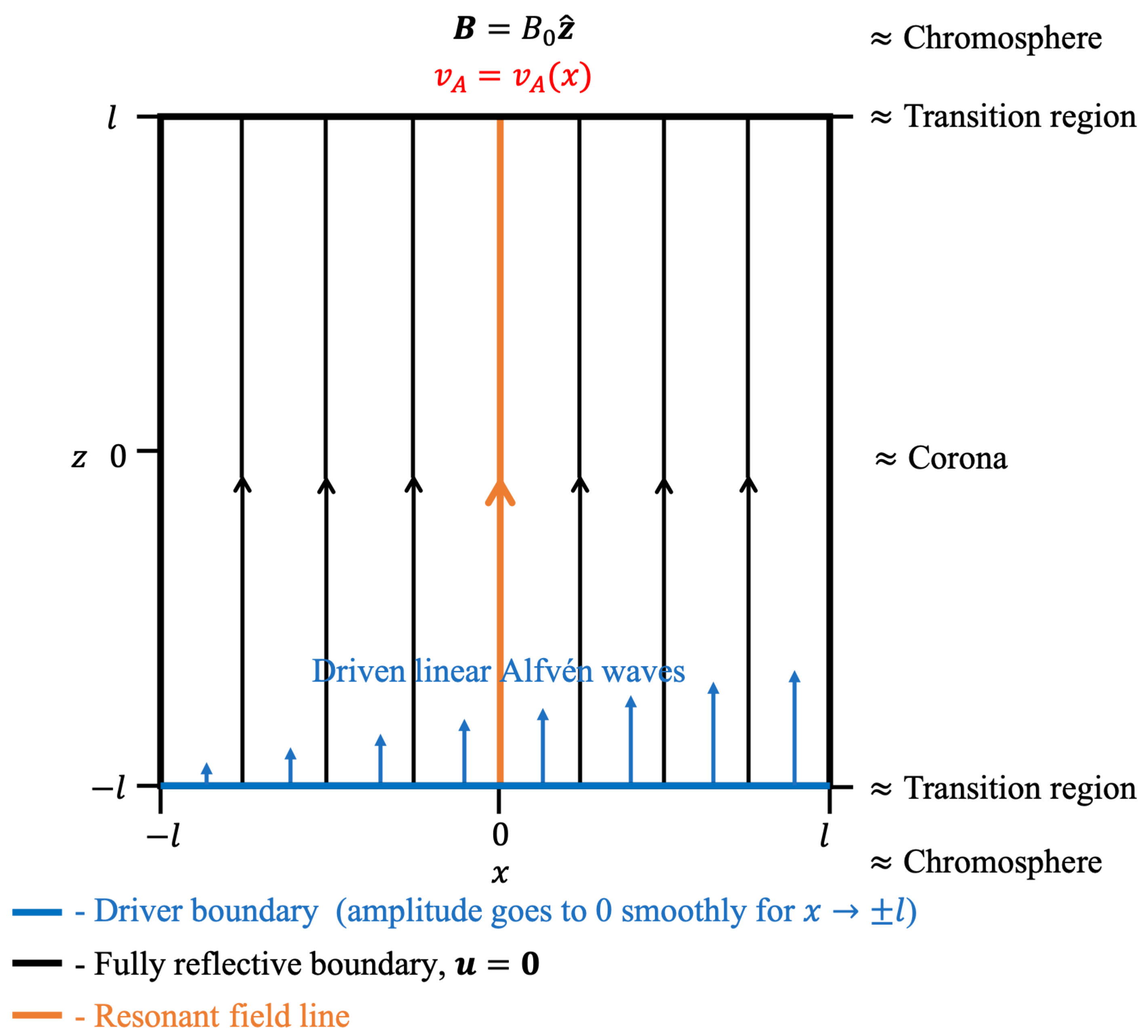

Fig. 1. Diagram of our model.

- **Driver** of the form:

$$\boldsymbol{u} = u_0 \sum_{n=1}^{N} A_n (n\omega_1)^{-\alpha/2} \sin(n\omega_1 t + \phi_n)\,\hat{\boldsymbol{y}},$$

ω_1 is the fundamental angular frequency of the resonant field line, ϕ_n is a random phase.

- Steady-state wave energy power spectrum with slope -α (Fig. 2).

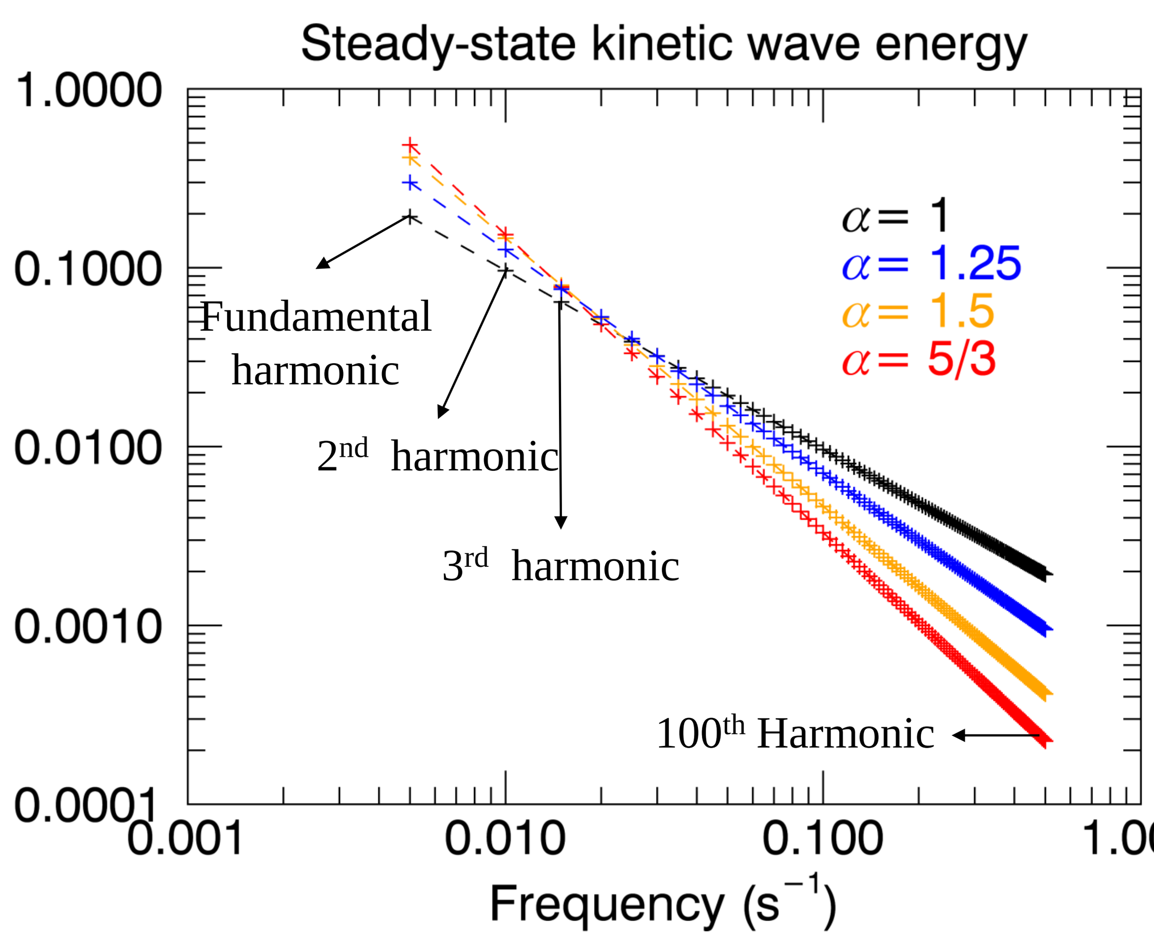

Fig. 2. Normalised power spectrum of the steady-state kinetic wave energy of the resonant field line.

References:
Cargill, P.J., De Moortel, I. and Kiddie, G., 2016. *The Astrophysical Journal*, *823*(1), p.31.
Heyvaerts, J. and Priest, E., 1983. *Astronomy and Astrophysics*, *117*, pp.220-234.
McIntosh, S.W., De Pontieu, B., Carlsson, M., Hansteen, V., Boerner, P. and Goossens, M., 2011. *Nature*, *475*(7357), p.477.
Prokopyszyn, A.P.K., Hood, A.W. and De Moortel, I., 2019. *Astronomy & Astrophysics*.

Damping rate

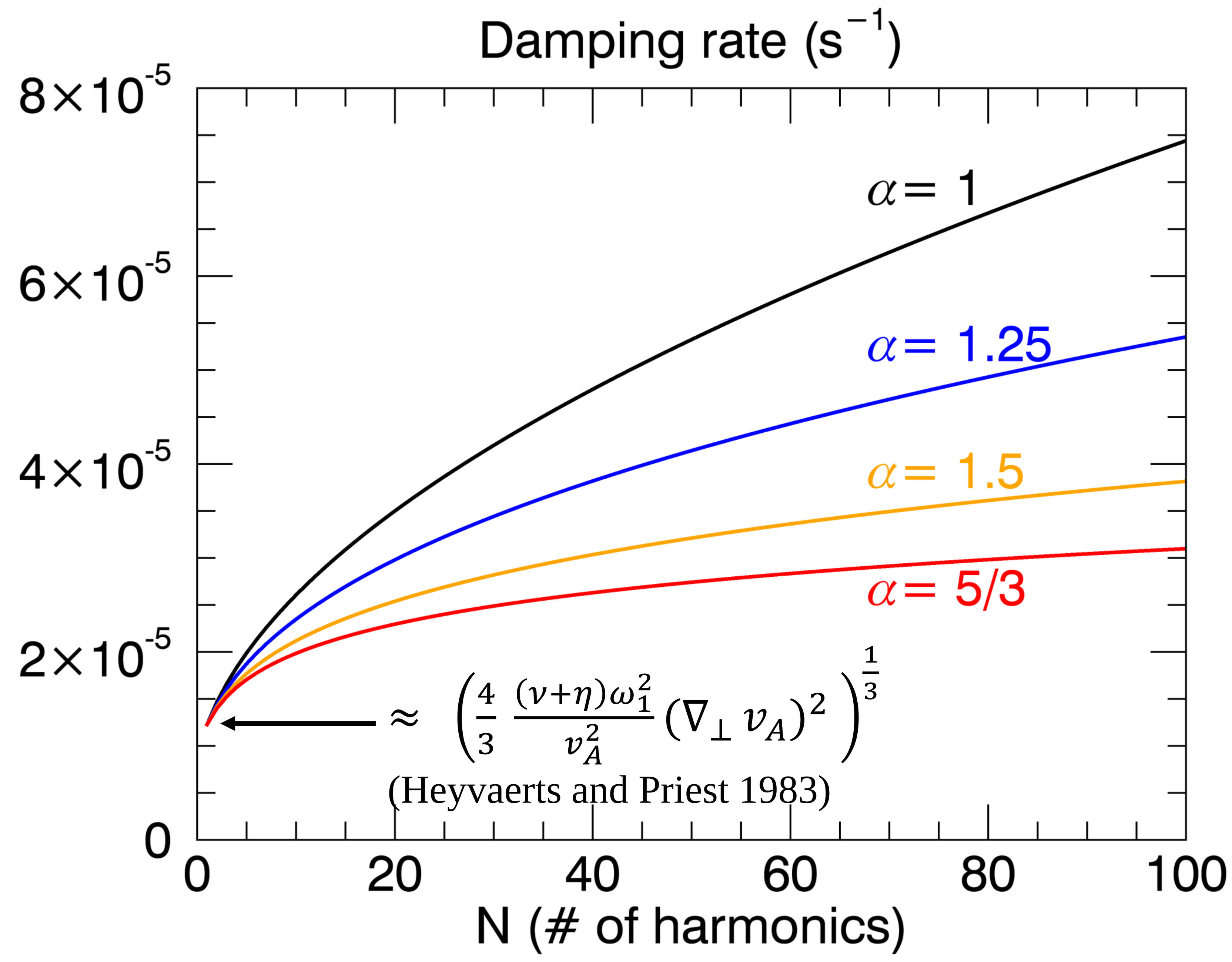

Fig. 3. Damping rate, γ, of the resonant field line as a function of the number of excited harmonics.

- Use $\nu + \eta = 1\ \mathrm{m^2\ s^{-1}}$, $v_A = 1\ \mathrm{Mm\ s^{-1}}$, $\nabla_\perp v_A = 1\ \mathrm{s^{-1}}$ and $L = 100\ \mathrm{Mm} \Longrightarrow$ fundamental frequency of $f_1 = 5 \times 10^{-3}$ Hz.
- Exciting higher harmonics gives a larger damping rate
- Figures 2 and 3 are independent of the phases ϕ_n.

Upper bound?

- We find that:
  - Leakage of waves though the transition region reduces the damping rate.
  - The damping rate increases with time but converges to a maximum as the system approaches steady-state.
  - The damping rate is largest at resonance.
- Cargill et al. (2016) showed that the thermodynamic response due to the heating reduces the density gradients, which reduces γ.
- Prokopyszyn et al. (2019) showed that nonlinearities have a negligible impact on γ for $u/v_A < 0.1$.
- Relaxing the 2.5D assumption and linear approximation could lead to turbulence which will increase γ, however, we focus here on laminar phase mixing.

$\Longrightarrow$ Fig. 3 is an upper bound for γ.

Conclusion

- Using a coronal heating rate, $H_c \approx 10^{-5}\ \mathrm{W\ m^{-3}}$ and observed amplitudes in the quiet sun $\approx 20\ \mathrm{km\ s^{-1}}$ (McIntosh et al. 2011)

$\Longrightarrow$ we require $\gamma \approx 10^{-1}\ \mathrm{s^{-1}}$.

- Figure 3 shows γ is too small by 3 orders of magnitude.
- **If our estimate is an upper bound $\Longrightarrow$ laminar phase mixing is not a viable standalone heating mechanism in coronal loops.**
- Laminar phase mixing may be significant in other setups, for example near null points where the Alfvén speed is small, and the cross-field viscosity is stronger.

This project has received funding from the Science and Technology Facilities Council (UK) through the consolidated grant ST/N000609/1, the European Research Council (ERC) under the European Union's Horizon 2020 research and innovation programme (grant agreement No 647214) and the Research Council of Norway through its Centres of Excellence scheme, project number 262622.