On the Energy Flux of Alfvén Waves in the Solar Atmosphere

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1. Introduction

Recent studies have revealed Alfvén waves in the solar corona have sufficient power to heat the solar corona and accelerate the solar wind. Alfvén waves have previously been shown to be highly reflective in the lower solar atmosphere, due to inhomogeneities, especially at lower frequencies. This indicates a gap in understanding. Previous studies have used simplified field geometries, such as the thin flux tube approximation, however this does not reflect reality of the solar atmosphere. By modelling the propagation of Alfvén waves and vortices along various magnetic field line geometries in a stratified atmosphere, we challenge the view that these motions are always strongly reflected. In certain geometries, the energy transport by Alfvén waves and vortices can reach 100% efficiency!

2. Methods

We show that Alfvénic motions in general field line geometries can be described by Klein-Gordon (KG) equations. Cases I and II correspond to degenerate forms of our KG equations. Case III is derived to be a case that has no reflection.

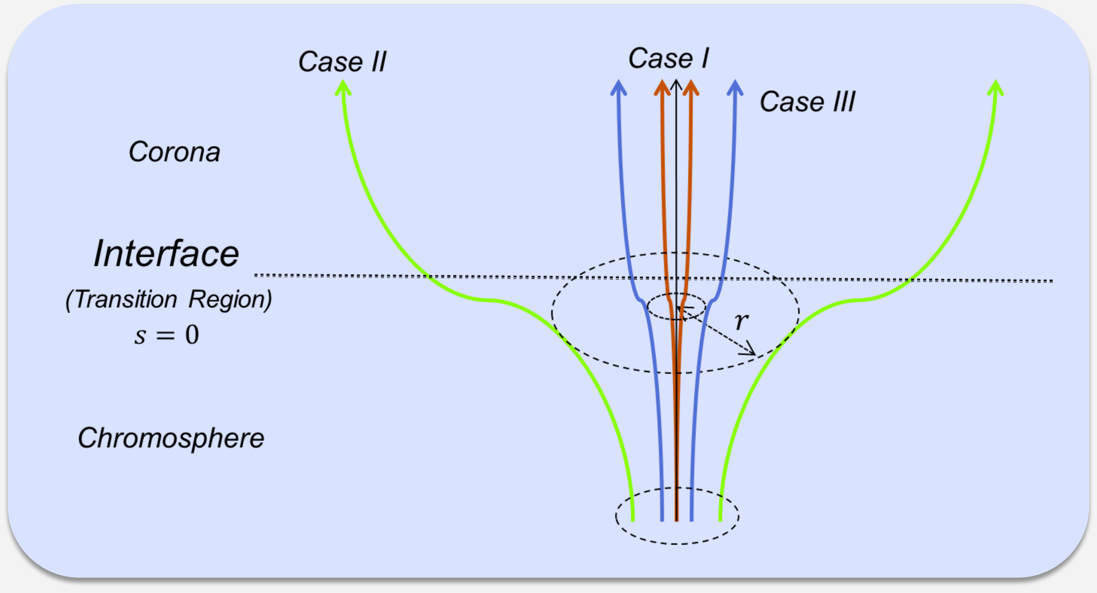

Fig. 1: Sketch of 2-layer model and three field line cases.

Case I	Case II	Case III
Thin flux tube approximation	Highly divergent field lines	Moderately divergent field lines
Up to 100% reflection as $\omega \to 0$		No reflection

Our 2-layer model involves setting the background quantities to be exponentials in the chromosphere, and then constant in the corona (Fig. 2a-c). The field line profile varies between cases (Fig. 1, 2d). Fig. 2e and 2f describe the cut-off frequencies.

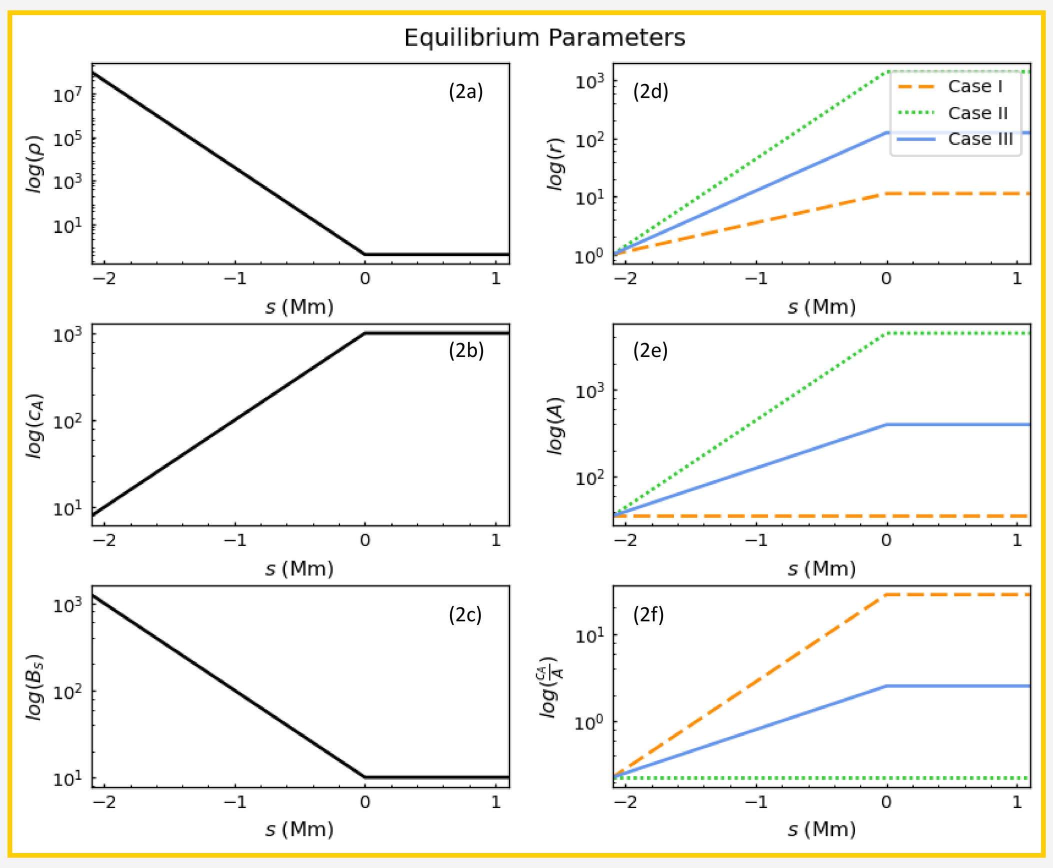

Fig. 2: Equilibrium parameters of our plasma scheme: (2a) density (2b) Alfvén speed (2c) magnetic field (2d) radial distance (2e, 2f) cut-off frequencies.

3. Alfvénic Perturbations

The KG equations give us the torsional velocity (V_ϕ) and magnetic field (B_ϕ) perturbations. These are calculated for 3 different frequencies (Fig. 3), with Fig. 3a corresponding to a vortical motion (0 Hz).

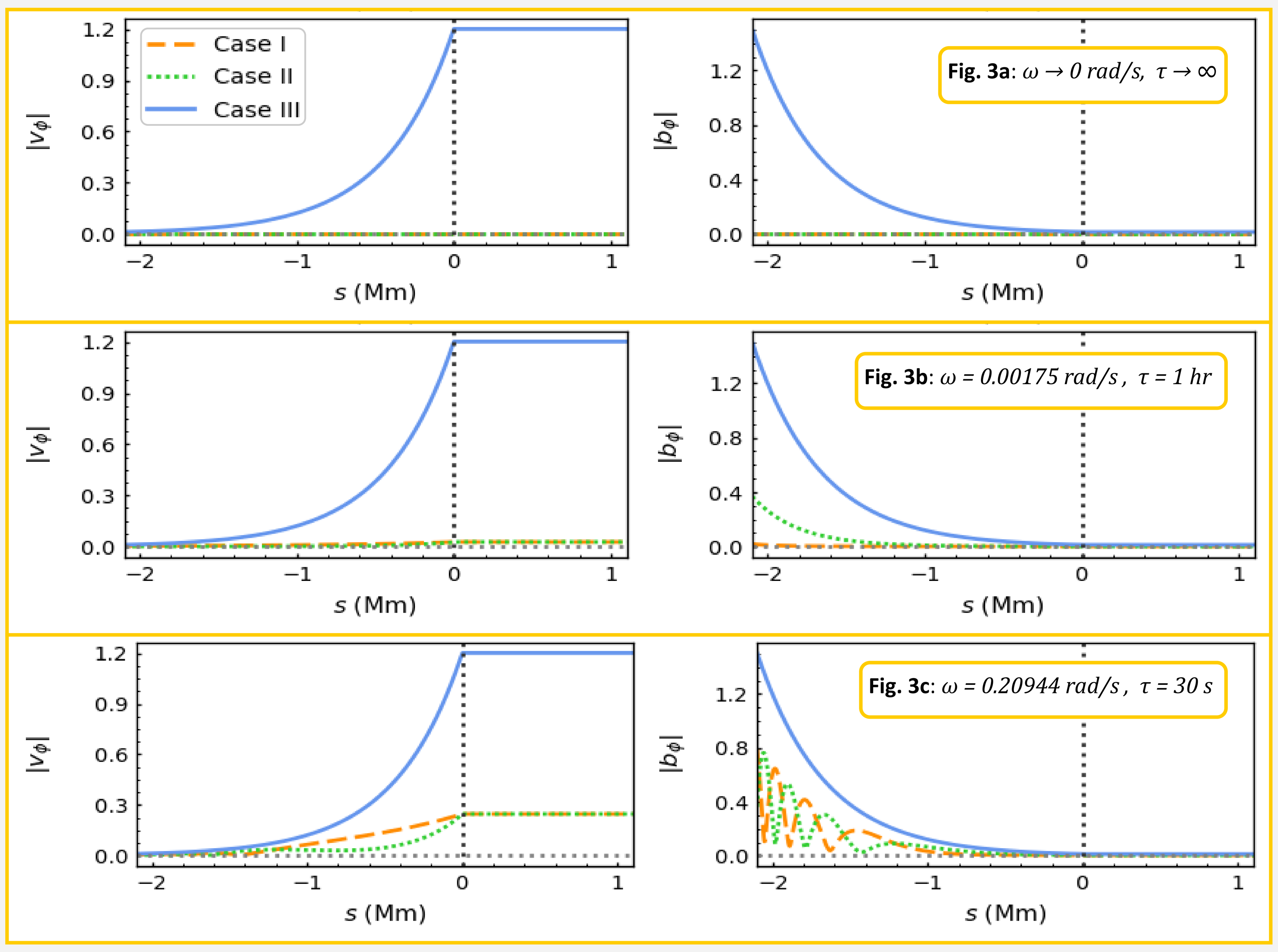

Fig. 3: Comparison of amplitudes of the velocity and magnetic field perturbations for various frequencies and the three cases.

For all 3 frequencies, case III shows larger amplitudes than cases I and II, with this difference becoming larger as $\omega \to 0$ (due to the decrease in I and II).

4. Energy Flux

The perturbations found are used to calculate the time-averaged flux of each of the cases for various frequencies. For Cases I and II, the flux tends to zero at low frequencies, whereas for case III the flux is completely independent of frequency.

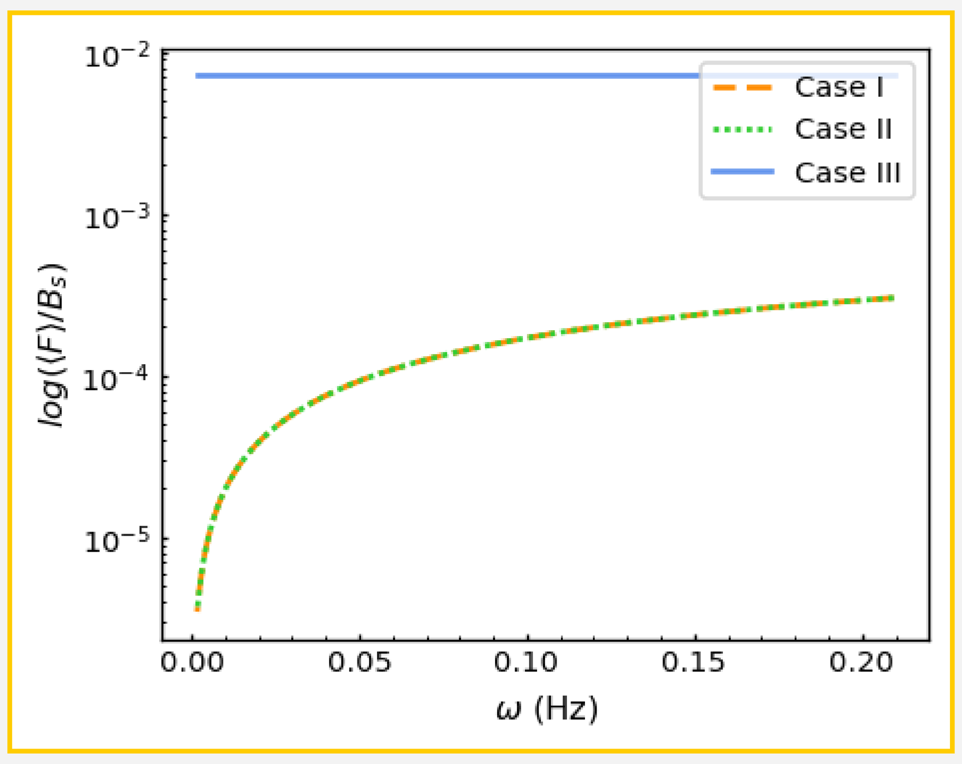

Fig. 4: Comparison of time-averaged flux for the three cases across various frequencies.

5. Conclusion

For standard geometries, Alfvén waves and vortices are strongly reflected. However, no reflection is seen in certain geometries. For these geometries the flux entering the upper atmosphere is independent of the wave frequency. Therefore vortices and low frequency waves - which are less likely to turn into shocks - can enter the corona and contribute to coronal heating and the acceleration of the solar wind. An on-going time-dependent study is required to solidify these results.

6. Key References

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