Magnetic Shocks and Substructures from Torsional Wave Collisions in Coupled Expanding Flux Tubes

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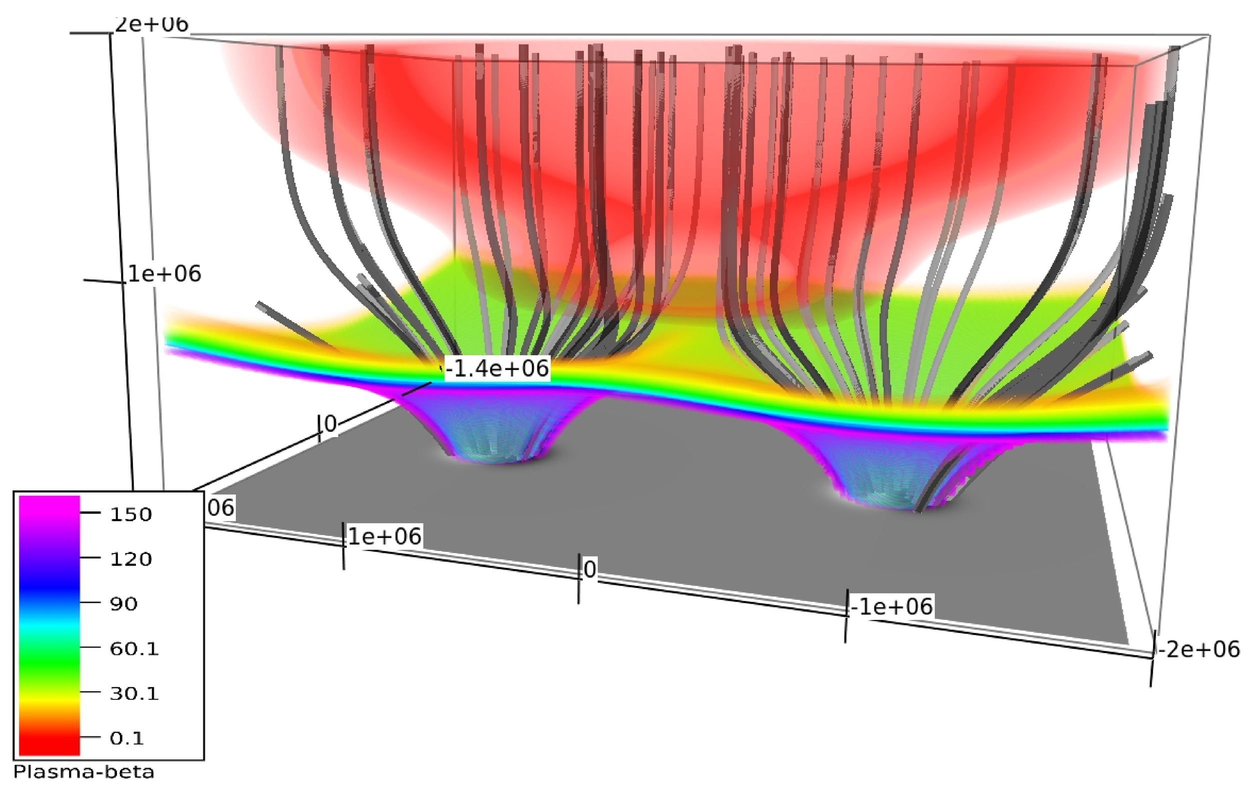
Introduction

Vortex motions are ubiquitous on the solar surface, transporting energy and momentum into the upper atmosphere. These vortex motions can propagate along the complex networks of magnetic flux tubes that exist in the lower atmosphere and expand and merge with height. Previous work has focused on isolated perturbations however more complex behaviour can arise when multiple perturbations interact. We perform 3D numerical MHD simulations to investigate the case of torsional motions propagating along a stable pair of expanding and merging flux tubes.

Background Configuration

3D numerical simulations are performed using the Sheffield Advanced Code (SAC) to analyse MHD perturbations in a gravitationally stratified atmosphere (Shelyag et al., 2008). The initial configuration is a pair of identical expanding flux tubes supported by a VALIIIC (Vernazza et al., 1981) temperature and density profile. The tubes are constructed using the formulations described in Gent et al. (2014) for stabilising networks of multiple flux tubes in stratified atmospheres. Our initial domain is shown below with selected isosurfaces of plasma-β and arbitrary streamlines of magnetic field.



At the photosphere ($z = 0$) the flux tubes are distinct. These tubes expand with height and at $z \simeq 0.8$ Mm, the previously independent tubes merge together.

Velocity Driver

Both flux tubes are perturbed at the photosphere using a torsional velocity driver of the form:

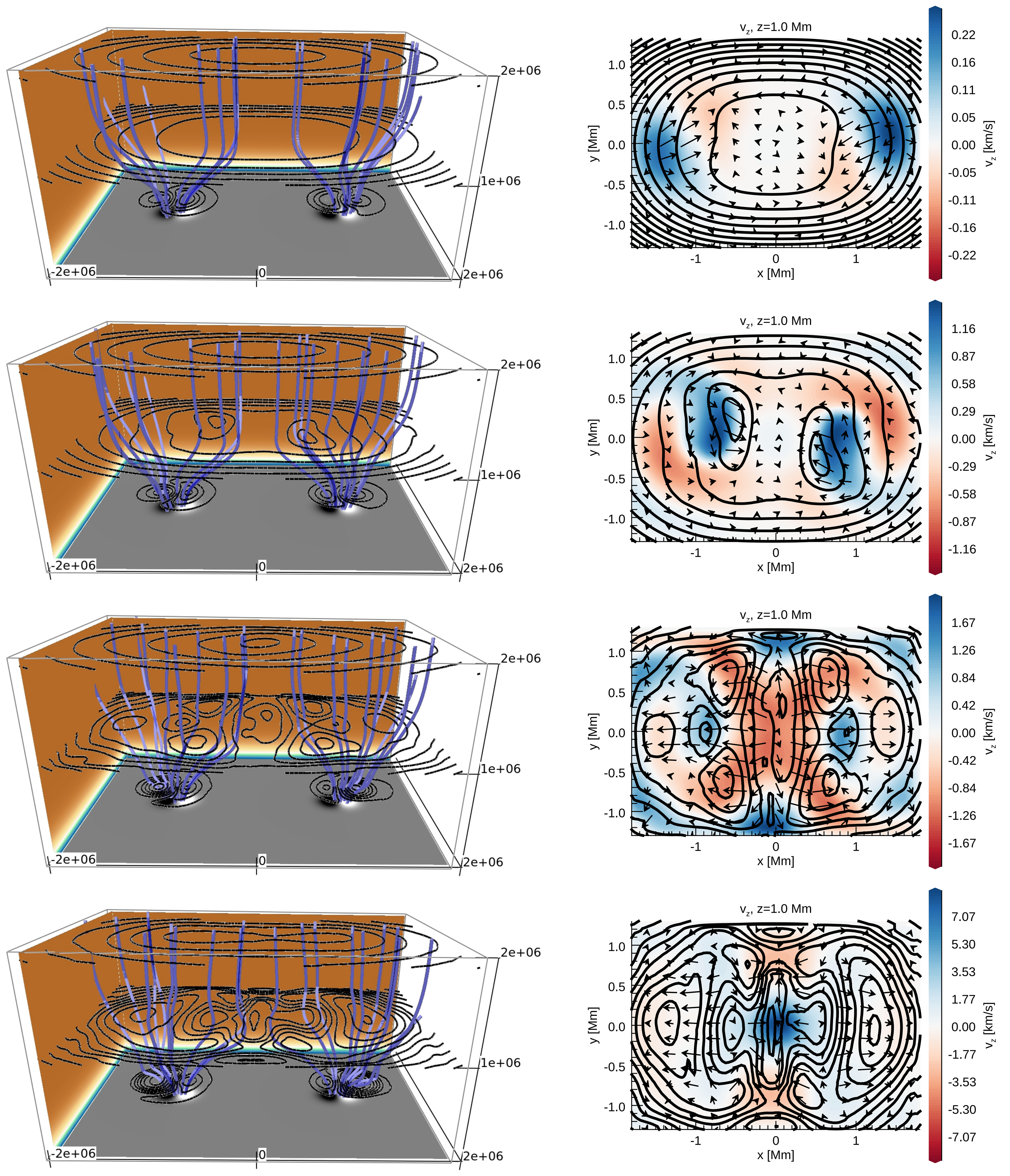
$$v_x = A_0 \exp\left(\frac{-(r-r_0)^2}{\Delta r^2}\right) \times \exp\left(\frac{-(z-z_0)^2}{\Delta z^2}\right) \sin\left(\frac{2\pi t}{\omega}\right), \quad (1)$$

$$v_y = A_0 \exp\left(\frac{-(r-r_0)^2}{\Delta r^2}\right) \times \exp\left(\frac{-(z-z_0)^2}{\Delta z^2}\right) \cos\left(\frac{2\pi t}{\omega}\right), \quad (2)$$

where the amplitude $A = \pm 1000$ m/s so the tubes are counter-rotating, preventing a shear layer developing on the $z = 0$ boundary.

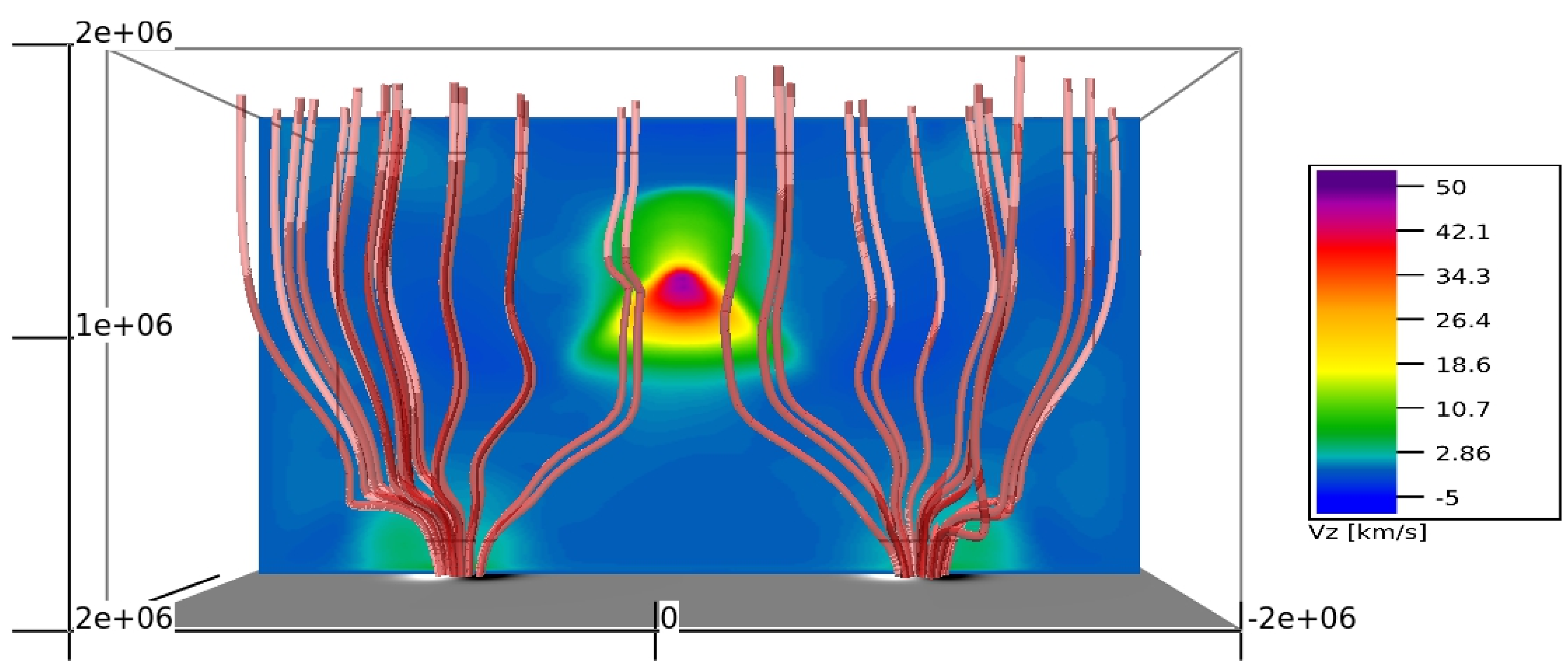
Formation of Magnetic Substructures

Below $z = 0.8$ Mm the torsional motions propagate along the independent flux tubes in a fairly well studied manner (e.g. Fedun et al., 2011; Mumford et al., 2015; Soler et al., 2017). At $z = 0.8$ Mm, the flux tubes merge and the vortex motions interact, reorganising the magnetic field creating a series of transient magnetic substructures, i.e. the initially monolithic tube has become multistranded. These magnetic substructures are co-located with peaks in vertical velocity on the order of 1 km s^{-1} and are effectively waveguides transporting energy upwards. As the motions propagate upwards, the magnetic substructures begin to form further up the tube.



Waveguide and Shock Formation

The vortex interactions generate a superposition where the flux tubes merge. The v_z velocity amplitude at this point increases until it exceeds the sound and Alfvén speeds (at the merge point, plasma-$\beta \approx 1$), driving shocks. The shock propagates upwards at approximately 50 km/s and heats the plasma to 60,000 K in the mid chromosphere.



Conclusions

We have shown that the interactions of torsional motions in merging flux tubes reorganise the magnetic field creating localised magnetic sub-structures, and can produce high-velocity shocks. Thus photospheric torsional motions are a potential mechanism for transporting energy and mass to the upper solar atmosphere, and reorganising the chromospheric magnetic field.

References

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