

# Modelling Shocks in Solar Flares

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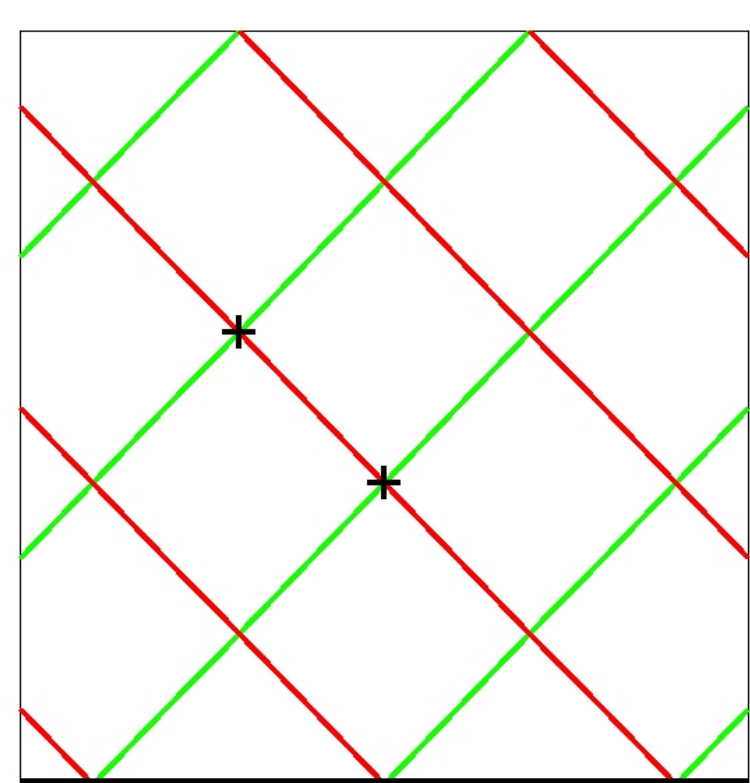
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## Abstract

We examine the process of flux tube retraction, following the occurrence of magnetic reconnection at two points along a single field line emerging from the solar surface. Using the PREFT model [1][2][3], we see the midpoint between the two points of reconnection experience a marked decrease in density following the collision of compressive plasma flows. An analysis over a range of bend angles reveals a specific angle, which is itself a function of temperature, corresponding to the maximum density decrease.

## Introduction & Model Description

Magnetic reconnection is a significant mechanism for phenomenon involving powerful energy release, such as solar flares [5]. Following reconnection at a single point along a flux tube, the retraction of the magnetic field lines instigates the formation of gas-dynamic shocks, which heat the flux tube and compress nearby plasma in to the reconnection point [4]. Assuming multiple points of reconnection leads to behaviour not observed in the single point case.



**Figure 1:** A view of the photosphere (bold black line) where a current sheet is lying parallel to the plane of the image. Field lines are both emerging from (green) and entering (red) the photosphere. Possible points for reconnection are given by the + symbols.

A 1D Lagrangian grid is used to solve the following:

$$\rho \frac{dv}{dt} = -\hat{\mathbf{b}} \frac{\partial p}{\partial \ell} + \frac{B^2}{4\pi} \frac{\partial \hat{\mathbf{b}}}{\partial \ell} - \frac{1}{4\pi} \nabla_{\perp} B^2 + B \frac{\partial}{\partial \ell} \left( \frac{\mu}{B} \hat{\mathbf{b}} \cdot \frac{\partial \mathbf{v}}{\partial \ell} \right)$$

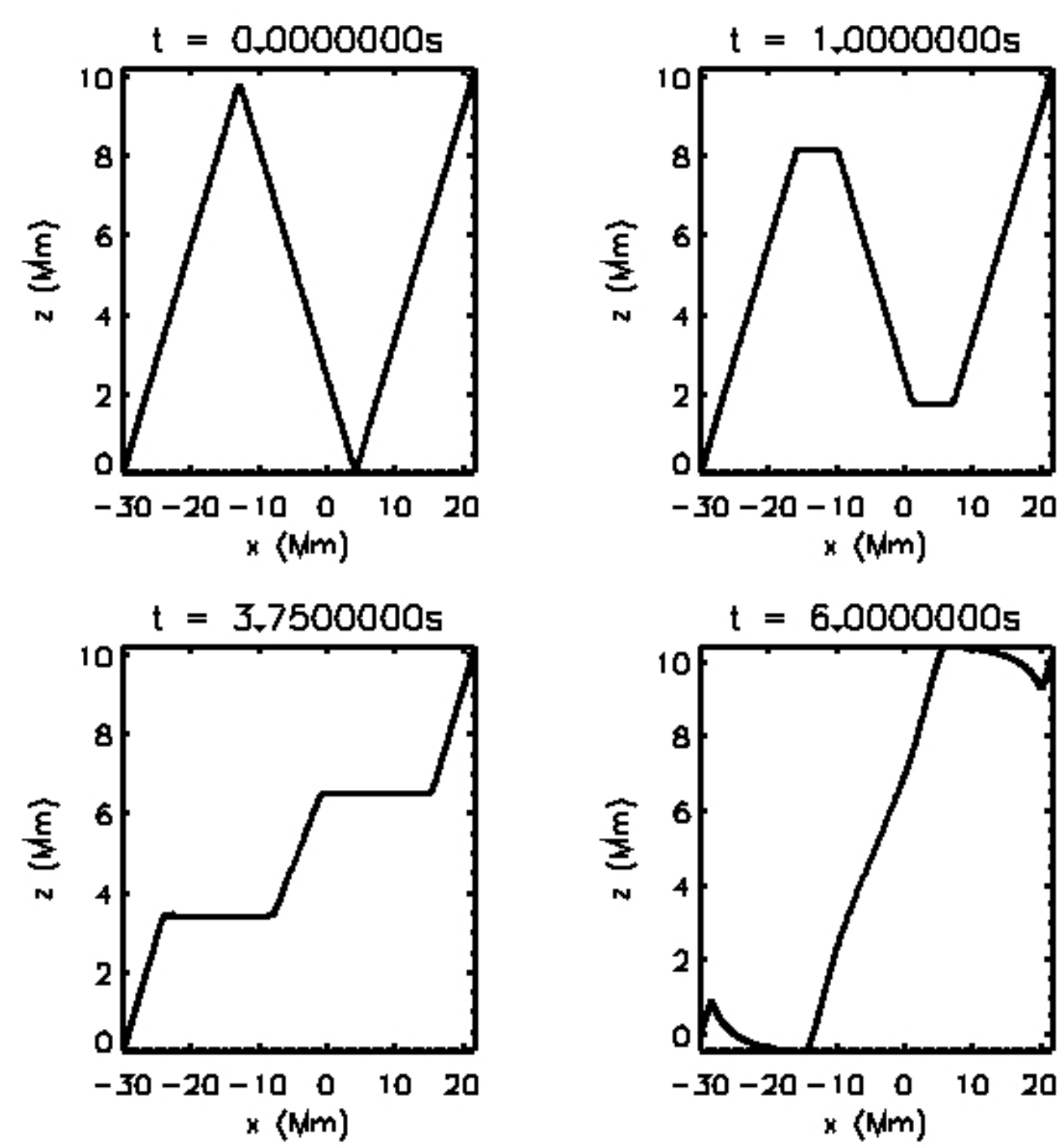
$$\frac{d \ln \rho}{dt} = \frac{d \ln B}{dt} - \frac{\partial(\hat{\mathbf{b}} \cdot \mathbf{v})}{\partial \ell} + \mathbf{v} \cdot \frac{\partial \hat{\mathbf{b}}}{\partial \ell}$$

$$\frac{dp}{dt} = \frac{5}{3} p \frac{d \ln \rho}{dt} + \frac{2}{3} \mu \left( \hat{\mathbf{b}} \cdot \frac{\partial \mathbf{v}}{\partial \ell} \right)^2 + \frac{2}{3} B \frac{\partial}{\partial \ell} \left( \frac{\kappa}{B} \frac{\partial T}{\partial \ell} \right)$$

where the unit vector  $\mathbf{b}$  is tangent to the internal magnetic field. The magnetic field strength,  $B$ , is constant in this case. The model accounts for thermal conductivity, diffusion and viscosity, but neglects gravity [4].

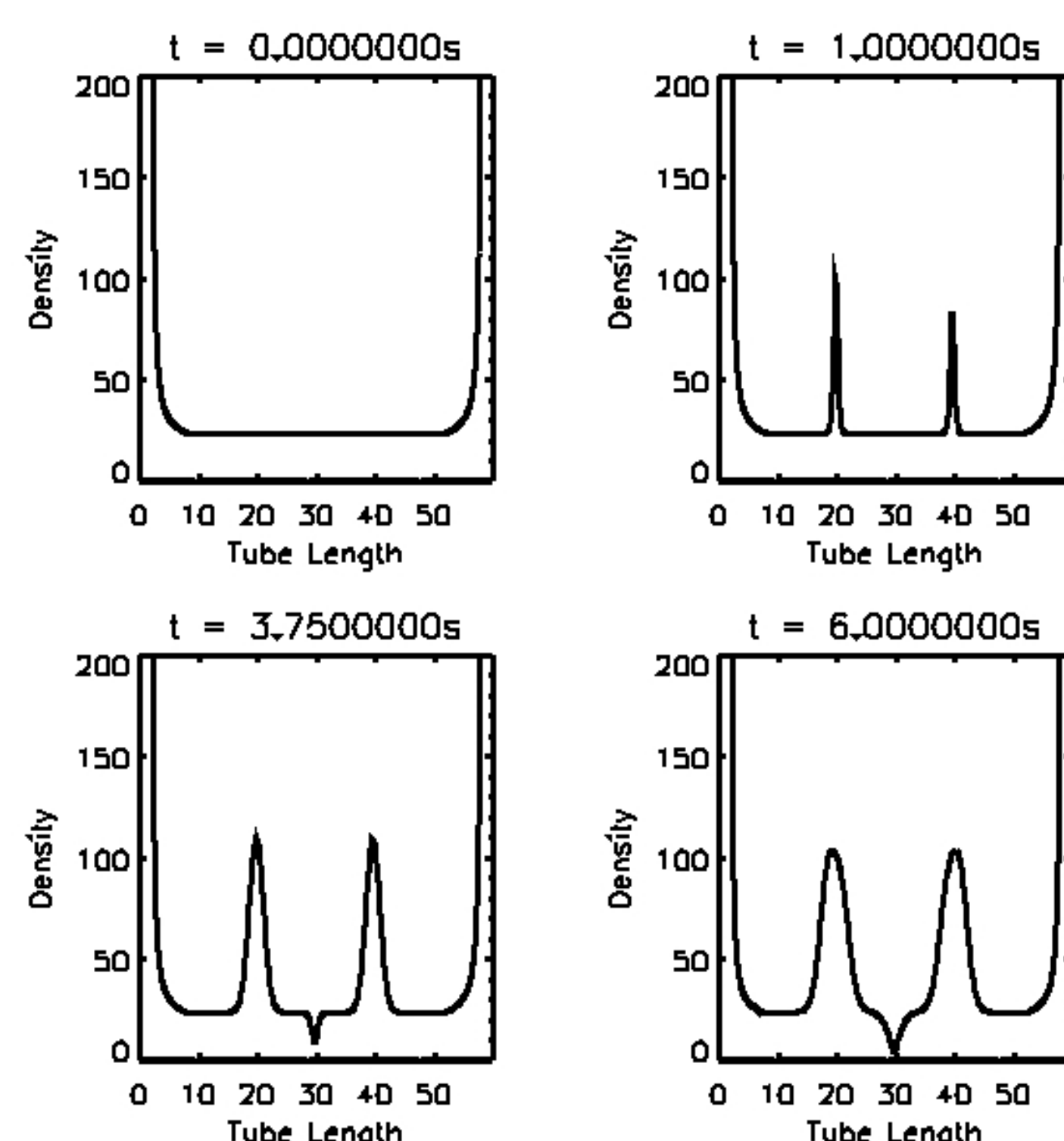
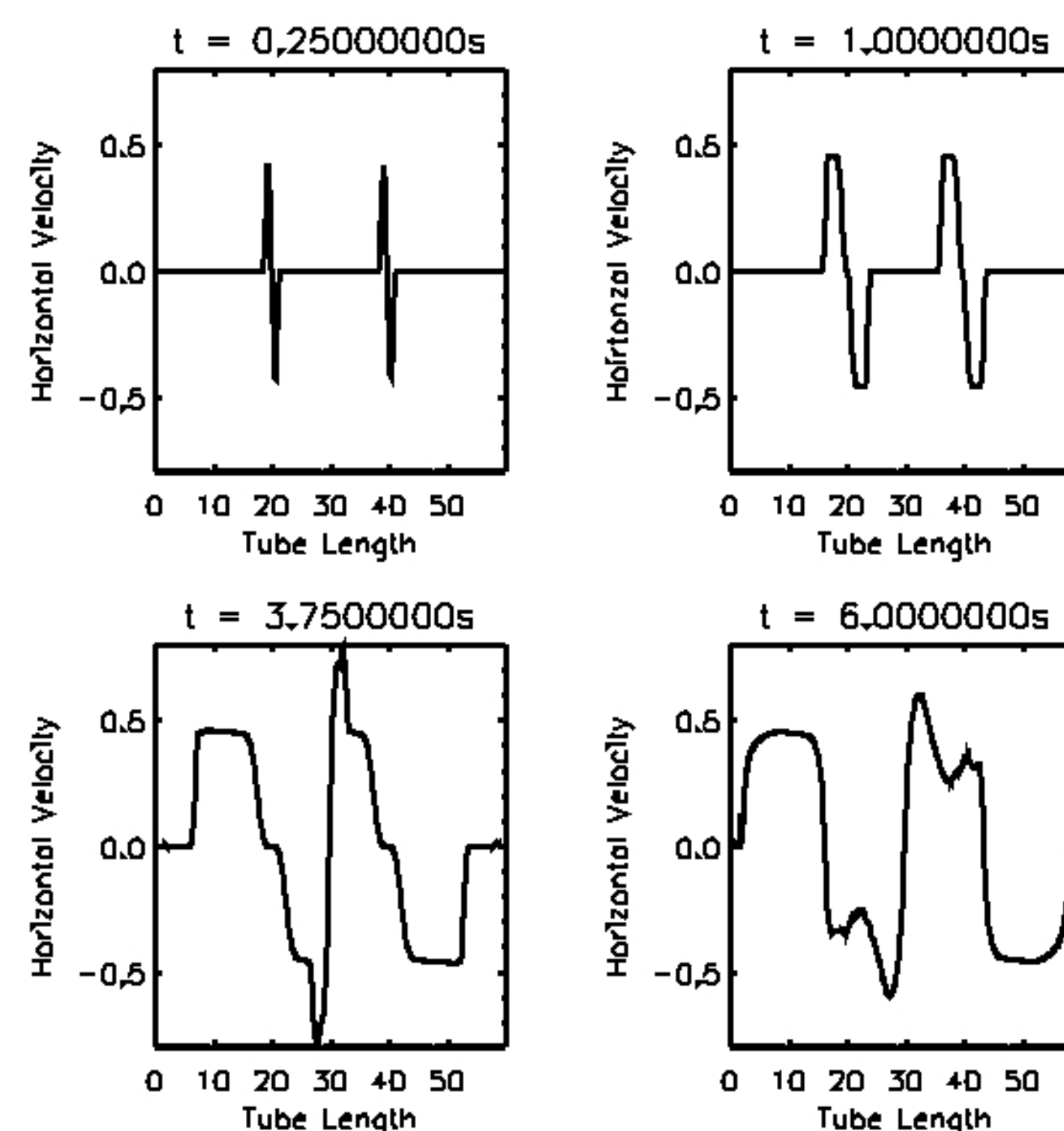
## Results

Below are results showing the evolution of a field line with two 120 degree bends spaced equally along the tube length. The quantities shown are: position,  $x$  component of velocity and density, respectively.



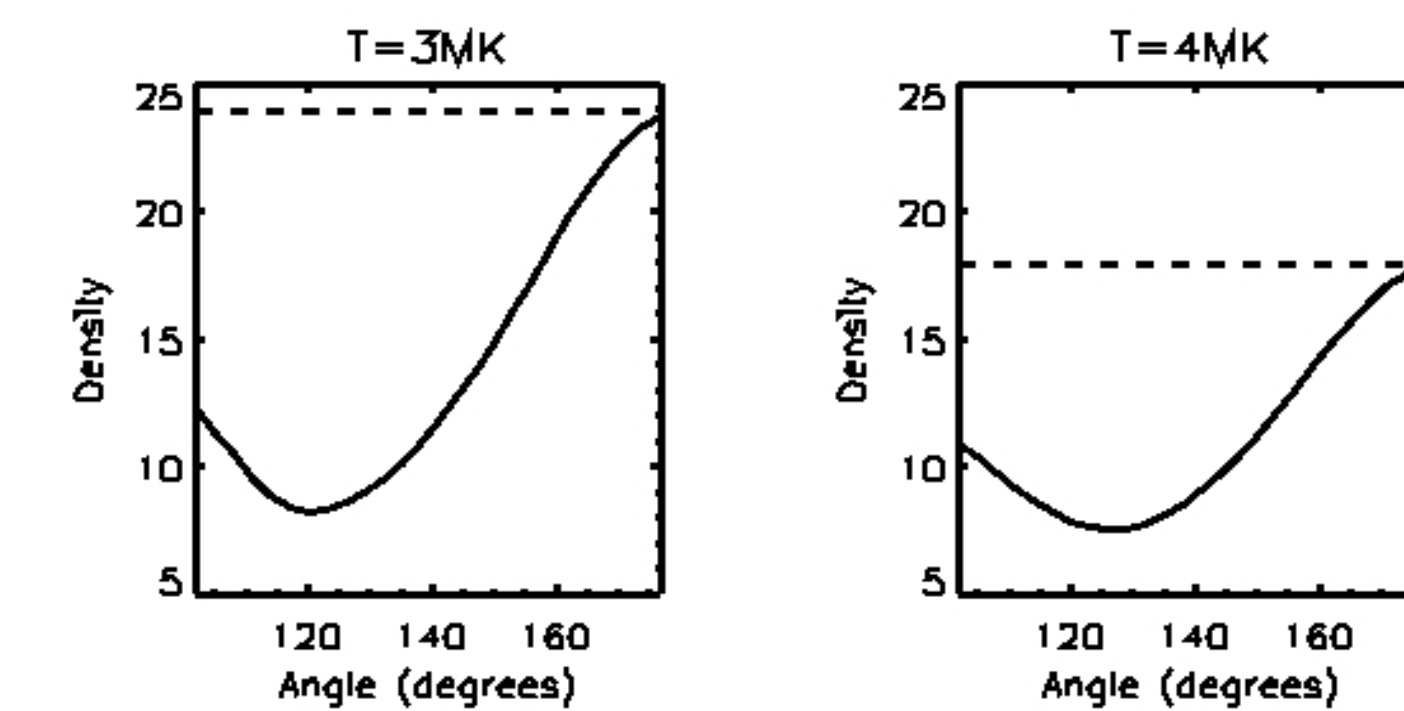
**Figure 2:** Spatial evolution. The field line initially retracts from the initial condition at the Alfvén speed, decreasing in total length as it does so. In the final frame we see that the interaction between the shocked regions of plasma influences the Alfvén speed near the mid-point between the bends, causing the field line to bend as shown.

**Figure 3:** Horizontal velocity evolution. Two supersonic, compressive flows are generated near each bend site, which then propagate outwards. Upon collision of these flows in the centre a stronger flow results, directed away from the centre of the tube. This region serves to evacuate plasma from the central portion of the tube as seen in figure 3.



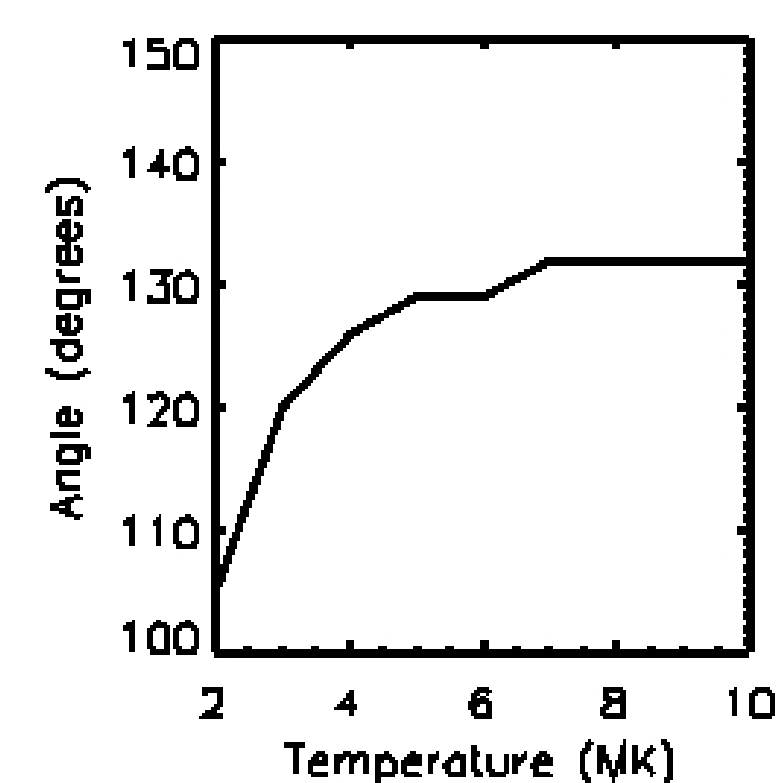
**Figure 3:** Density evolution. Two density spikes appear at the location of the bends due to the compressive flows near these regions. These maintain approximately constant magnitude, but grow in width as further plasma is added. Following the collision of the flows seen in figure 2, density is evacuated from the centre of the tube, decreasing to some minimum value greater than zero.

The following graphs depict the results of a more thorough investigation in to the density evacuation of the flux tube.



**Figure 5:** An angle-density phase plane analysis reveals the existence of an angle at which the density reduction is maximal. Furthermore, this angle is a function of temperature. Dashed line: minimum density at  $t=0s$ .

**Figure 6:** A temperature-angle phase plane analysis shows more explicitly the dependence of the angle resulting in the minimum density on temperature. Temperature changes initially significantly affect this angle, while above temperatures of 7MK no further alteration is observed. A smoother curve is desirable here.



## Conclusion & Next Steps

The results presented here share both similarities and differences with previous studies of single point reconnection. With respect to the density profile of the tube, interesting evacuative effects are observed only in the multiple angle case. It is seen that the collision of the parallel plasma flows causes a density drop off in the centre of the tube, with magnitude dependent on the reconnection angle. This critical angle is itself a function of temperature. Further work will strive towards a physical explanation for this phenomenon.

## References

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## Acknowledgments

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