



Simulating Shocks in Solar Flares:

Flux Tube Retraction Following Multiple Simultaneous Reconnection Events

Daniel Gordon

Supervisor: Dana Longcope

Presentation Outline



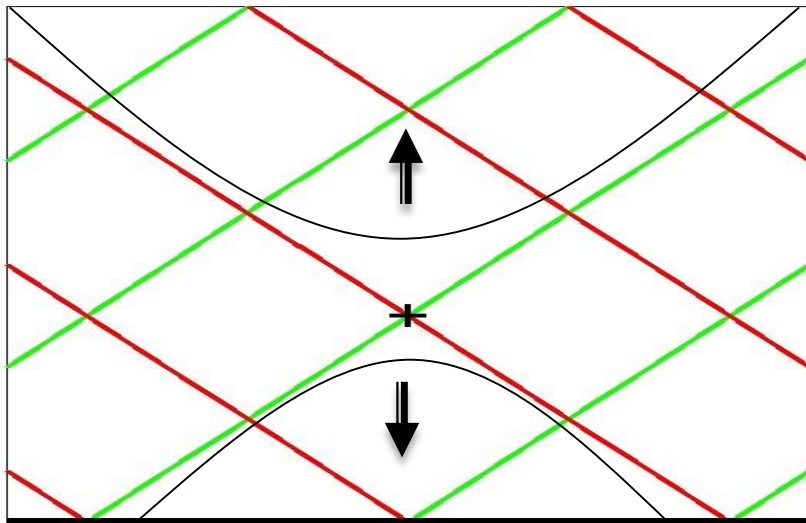
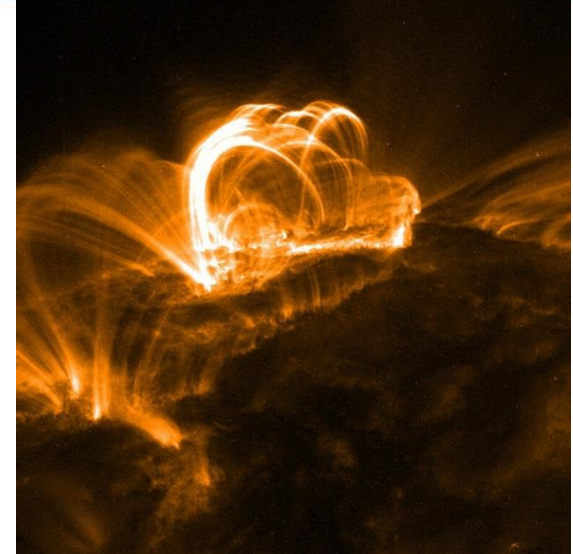
- Introduction
 - Background
 - The model
 - Previous results (single reconnection event)
 - The multiple reconnection case
- Results
 - Overview
 - Similarities and differences between cases
 - The differences in more detail
- Summary & References

Introduction

Background



- Reconnection a significant mechanism for phenomenon involving high energy release; solar flares, CME's.



- Post-reconnection field lines act like a string under tension. What happens to the plasma in the tube in terms of density, temperature, velocity, etc?

Introduction

The Model



- Tube dynamics well approximated by Thin Flux Tube equations (for plasma beta $\ll 1$).
- Solved on 1D Lagrangian grid of 1000 points.
- Includes heat conduction, diffusion, viscosity (no gravity). B constant in this case.

Code: PREFT
(Guidoni, Linton,
Longcope)

Motion

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

Density Evolution

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

Energy Equation

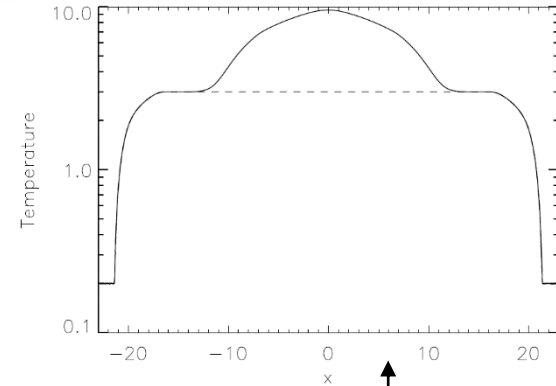
$$\frac{dp}{dt} = \frac{5}{3} p \frac{d \ln \rho}{dt} + \frac{2}{3} \mu \left(\hat{\mathbf{b}} \cdot \frac{\partial \mathbf{v}}{\partial \ell} \right)^2 + \frac{2}{3} B \frac{\partial}{\partial \ell} \left(\frac{\kappa}{B} \frac{\partial T}{\partial \ell} \right)$$

& more.

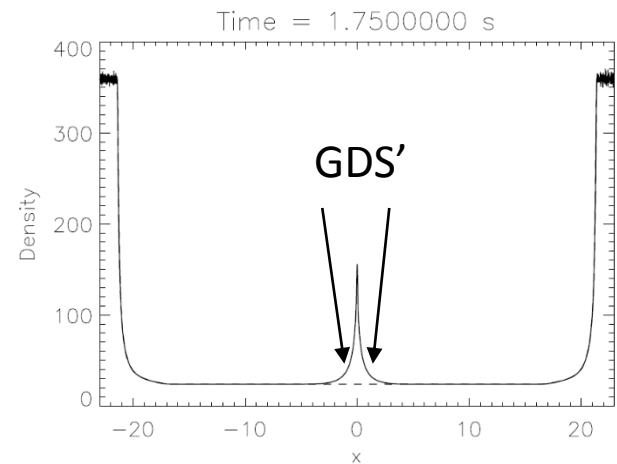
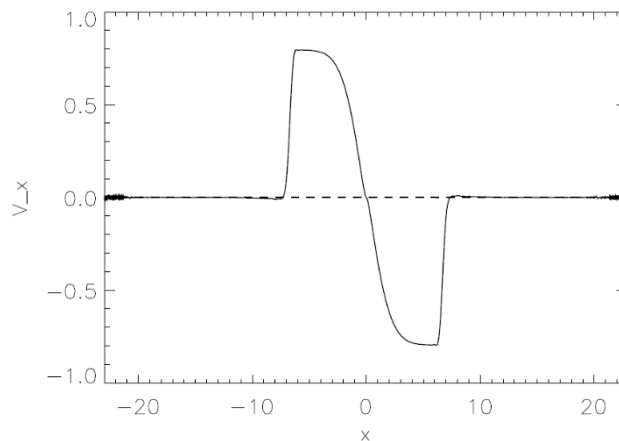
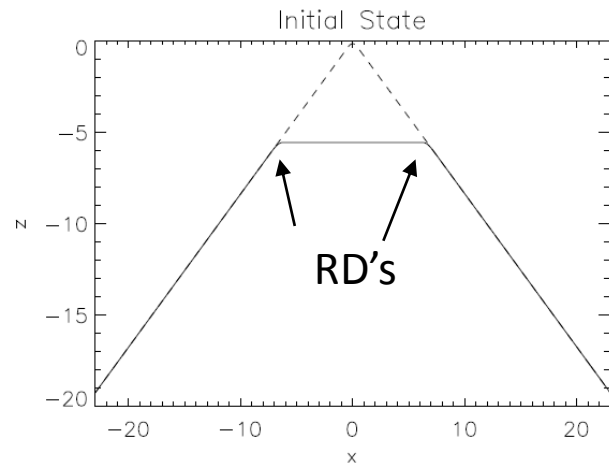
Introduction

Some Important Previous Results

- Field line shortens from initial state. Rotational discontinuities (RD's) – Alfvén speed.
- Plasma compression rate \gg diffusion rate \rightarrow gas dynamic shocks (density build up). Field line shortens as it retracts.

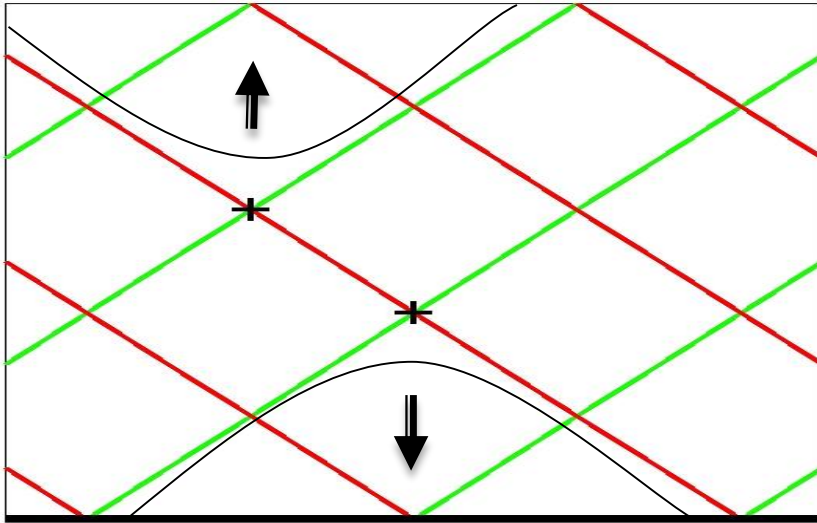


High thermal conductivity



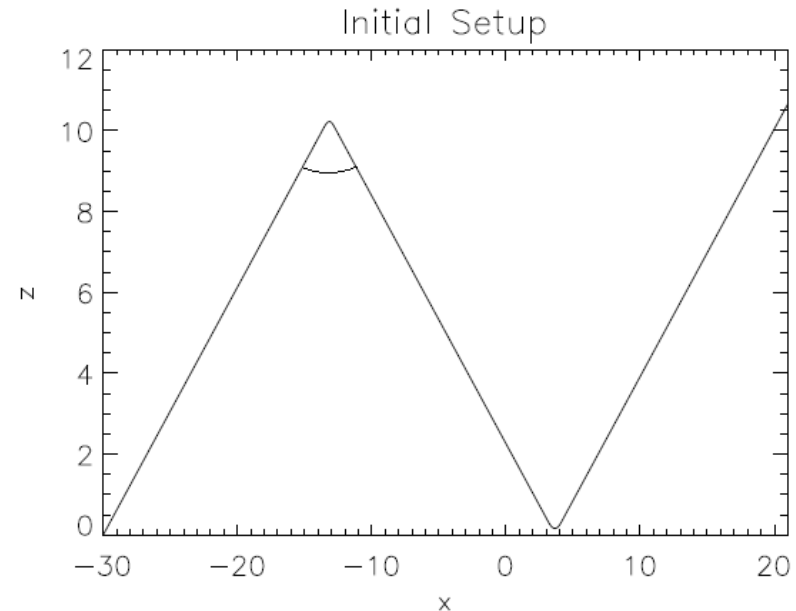
Introduction

The Multiple Reconnection Case



- We consider the ‘new’ section.
- How does it evolve in time?
- Similarities and differences to single point case?

- Multiple points of reconnection – separates in to three ‘sections’.

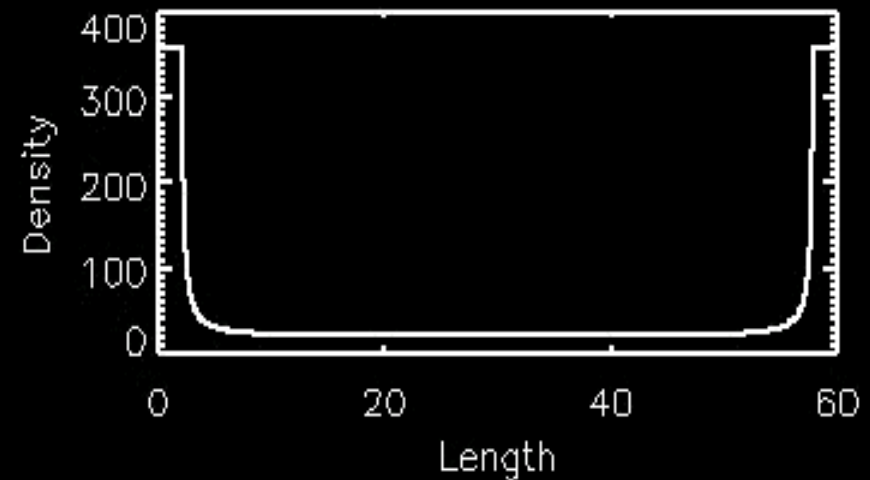
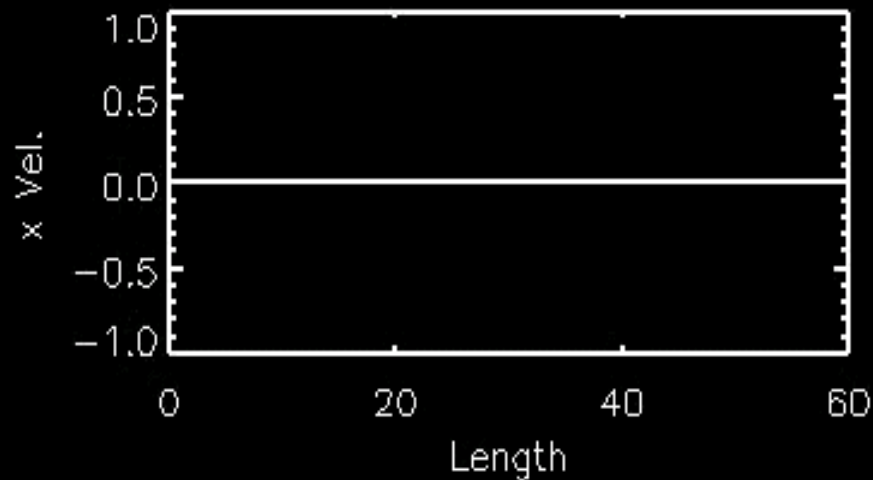
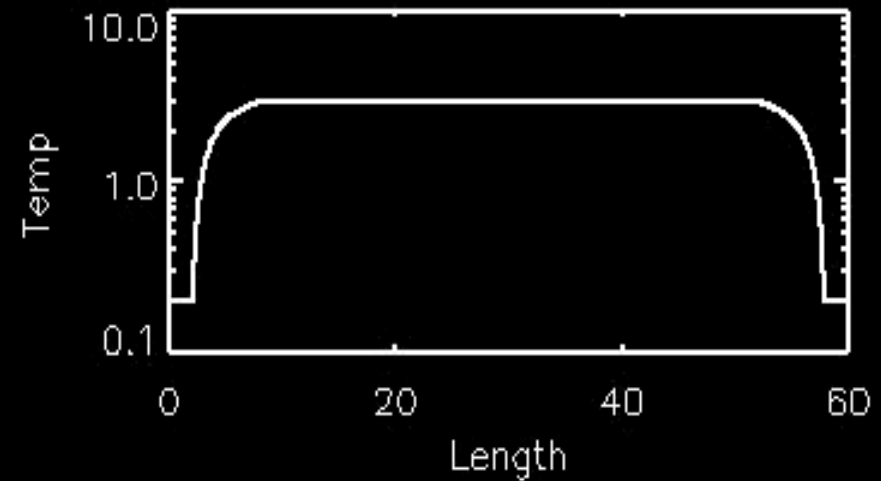
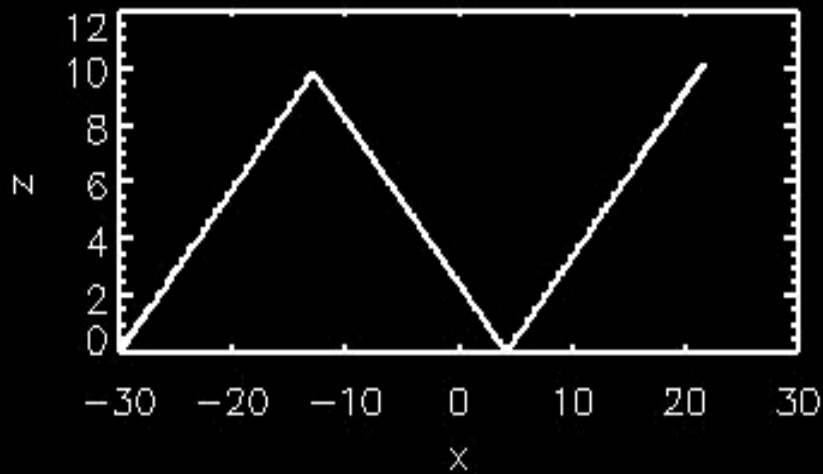


Results

Overview



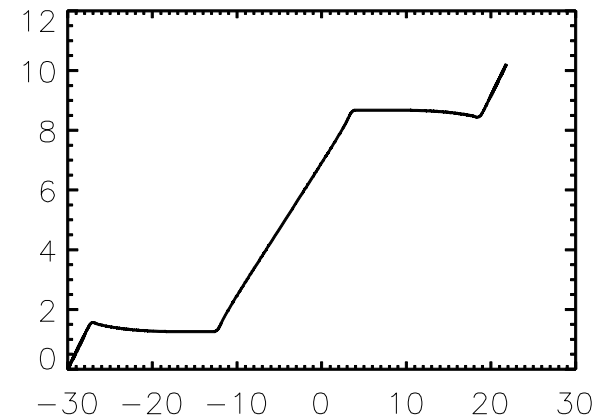
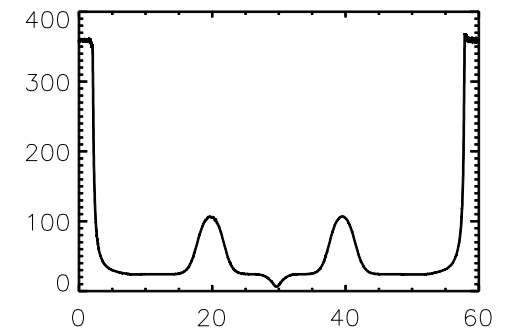
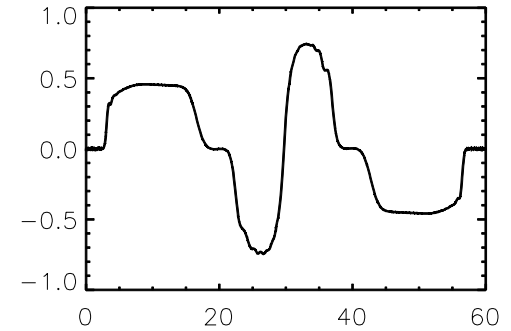
Time = 0.0000000 s



Results

Differences to single reconnection case

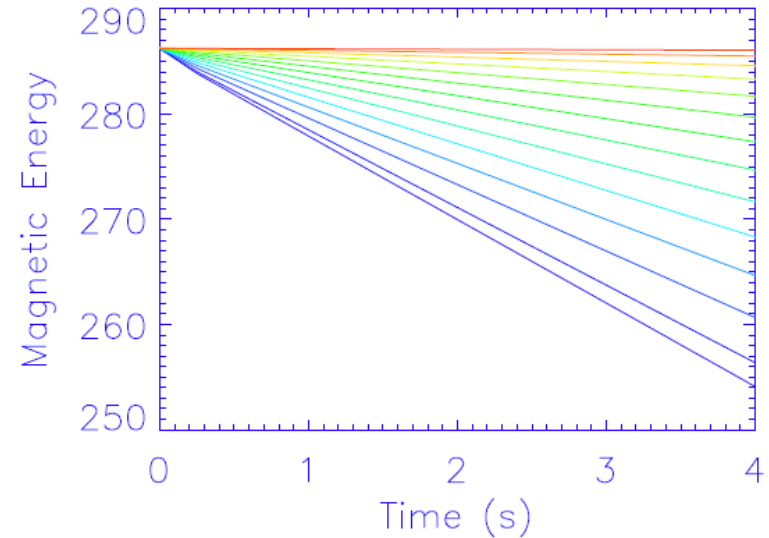
- Shocks collide at approx. 2.75s
- V_x rarefaction wave => density drop-off
- Field line curves at later times
- Field lines cease shortening



Results

Field line shortening: single reconnection case

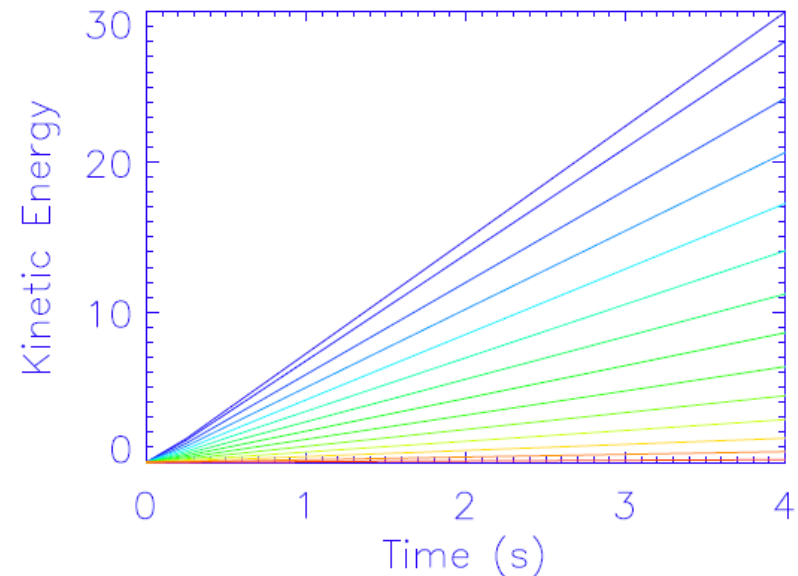
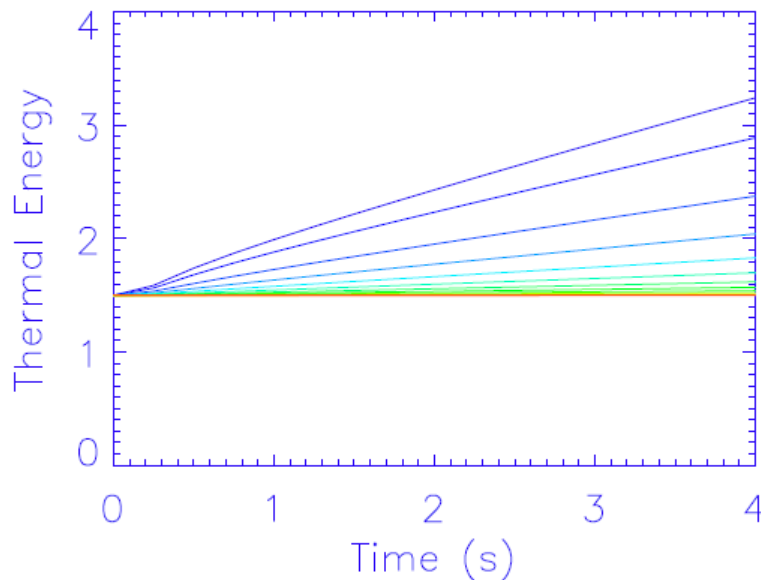
- Transfers magnetic \rightarrow kinetic energy, comparatively minimal energy lost to heat



99



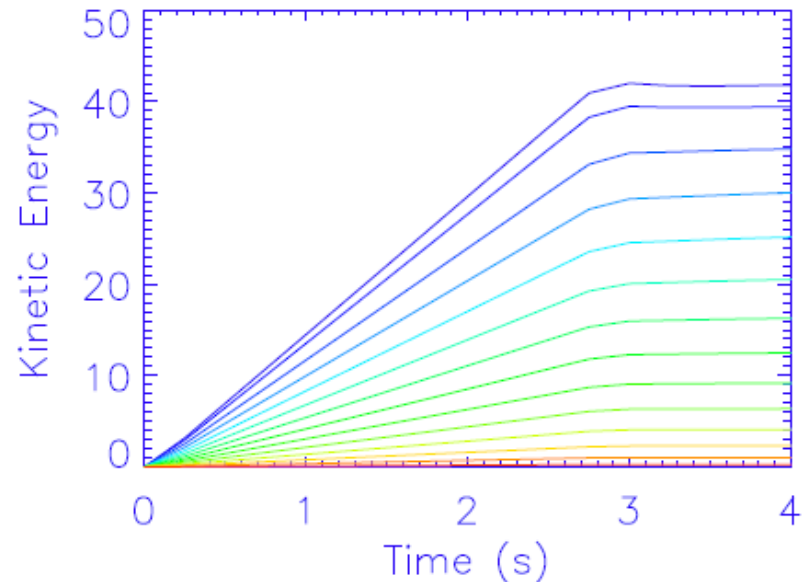
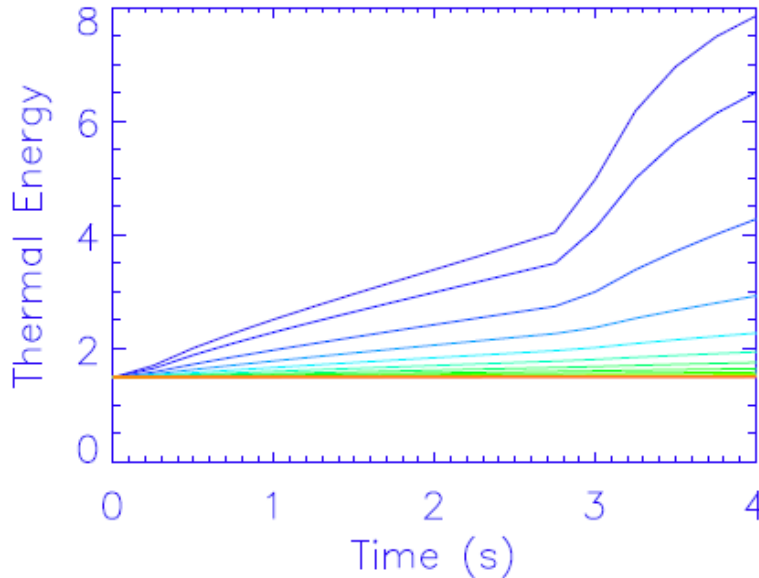
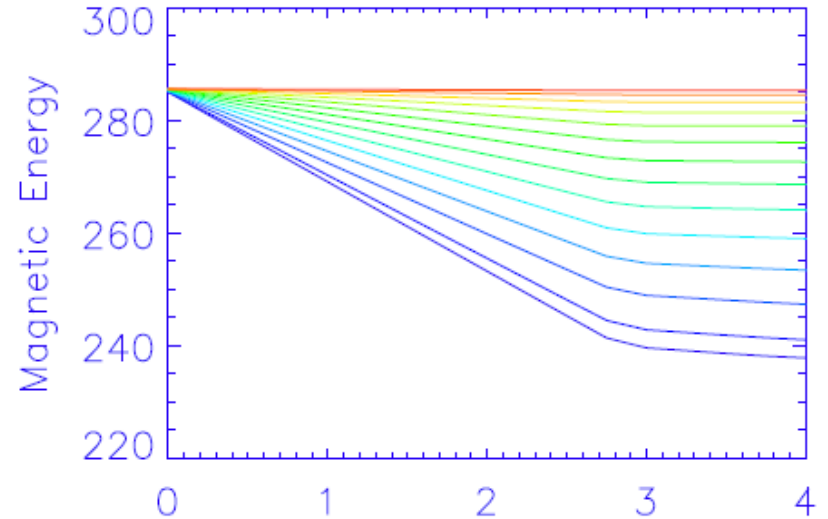
177



Results

Field line shortening: double reconnection case

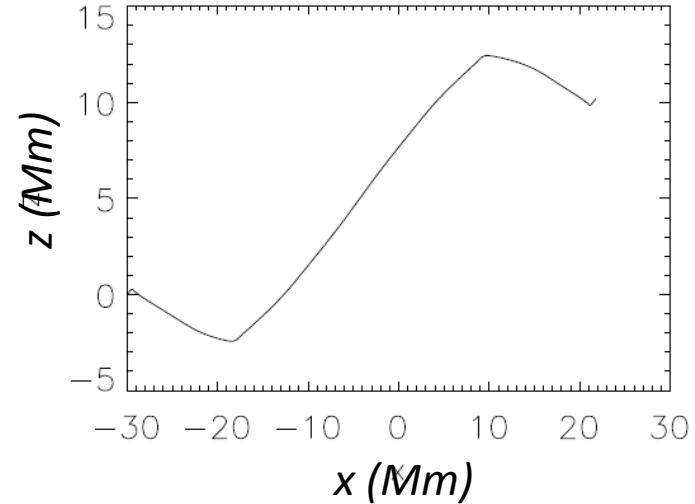
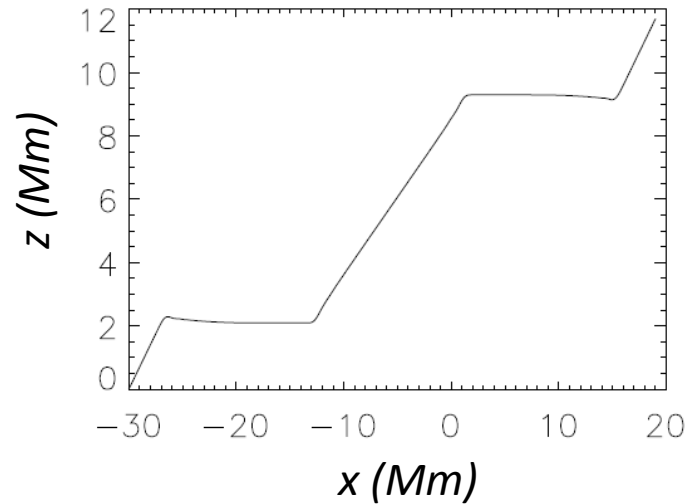
- After shocks interact: plateau reached, thermal conversion pronounced
- Energy transfer rate doubled



Results

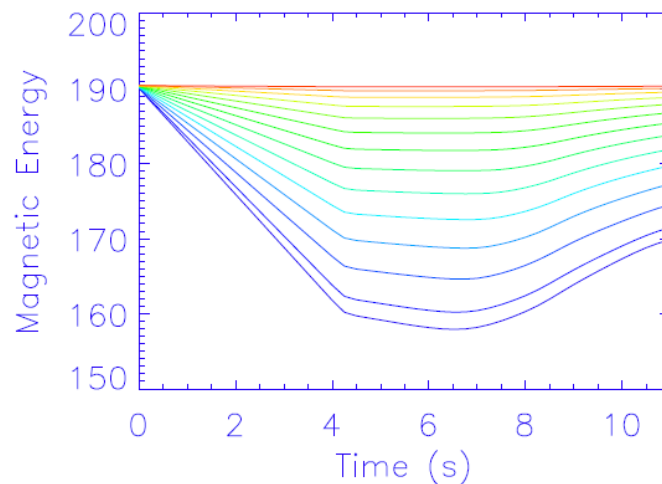
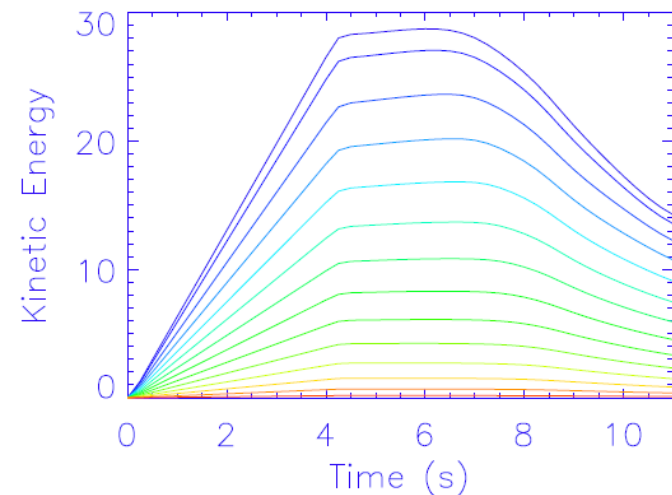
Field line bending

- From ~ 7 s (left) tube begins to bend.



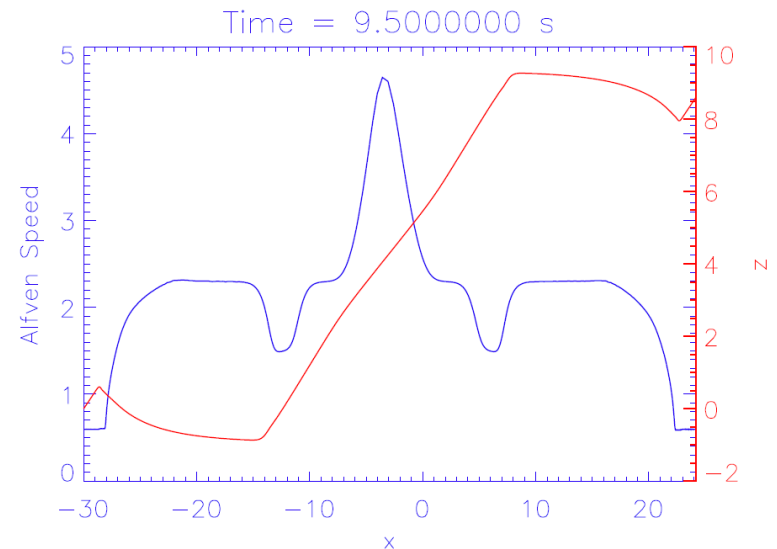
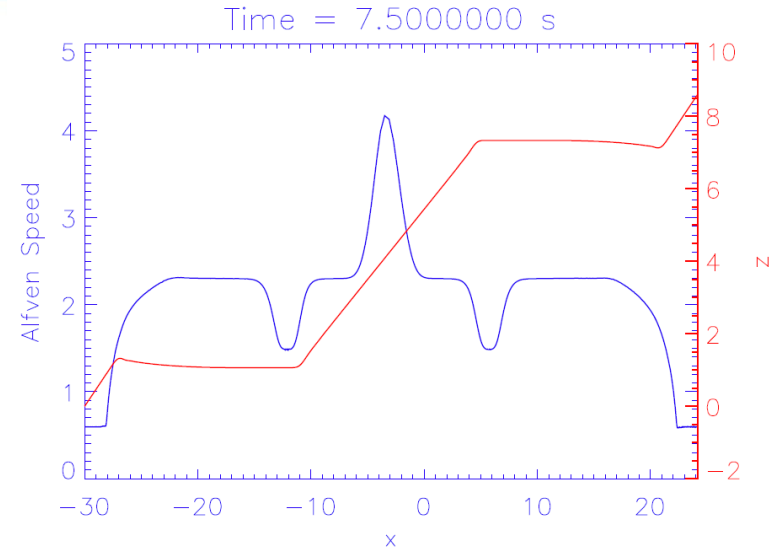
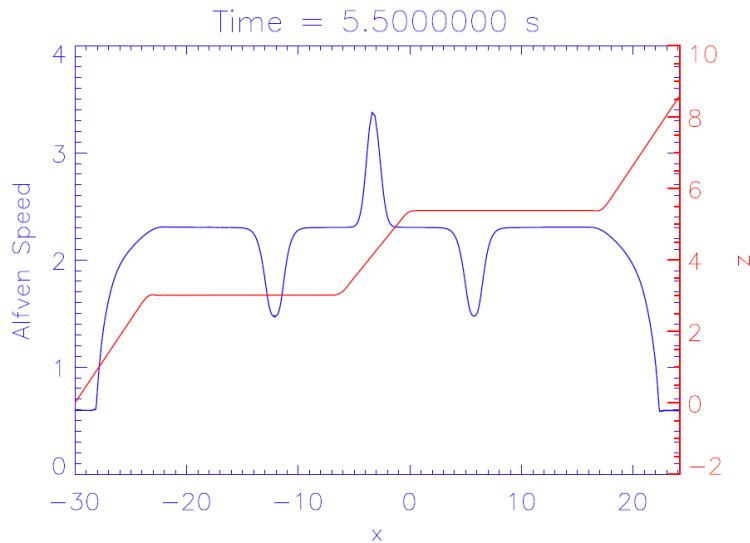
- Right: 11.0s

- As tube bends kinetic energy reconverted to magnetic



Results

Field line bending: explanation



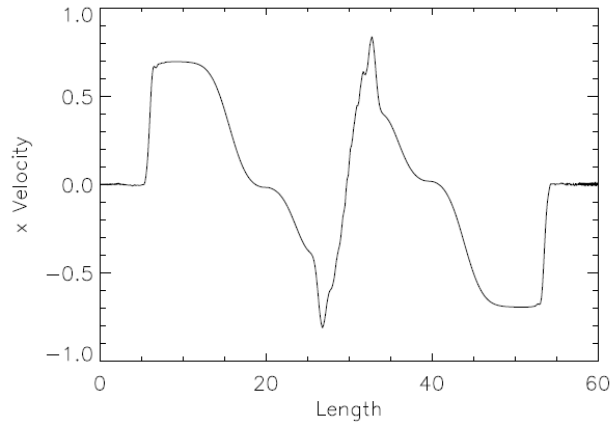
- Alfven speed influenced by the chromosphere.
- Outer RD's generally slow down, inner speed up, resulting in the observed bending.

Results

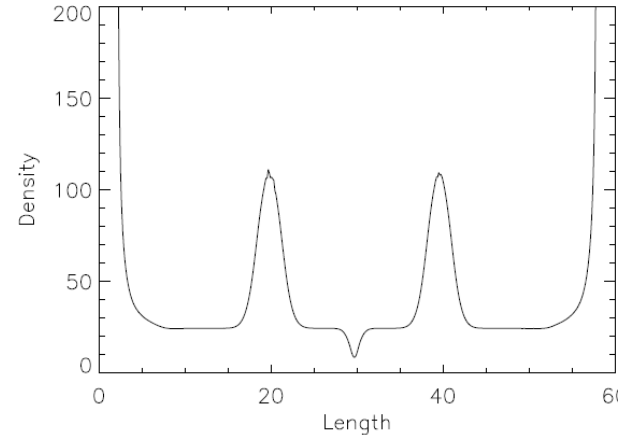
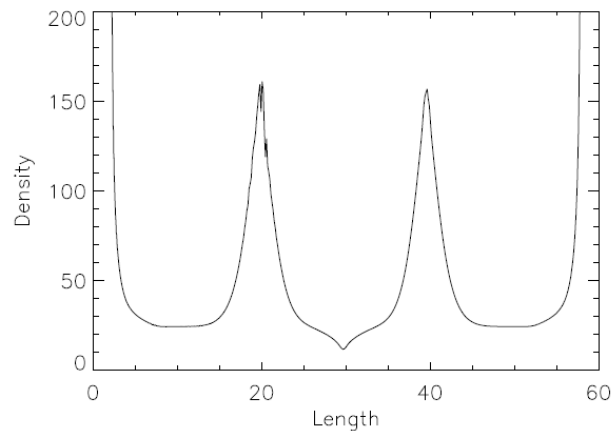
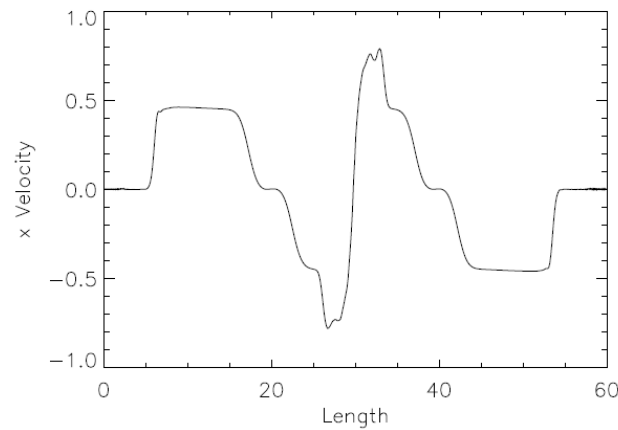
Density drop-off



Angle: 105 deg



Angle: 120 deg



t=4.0s

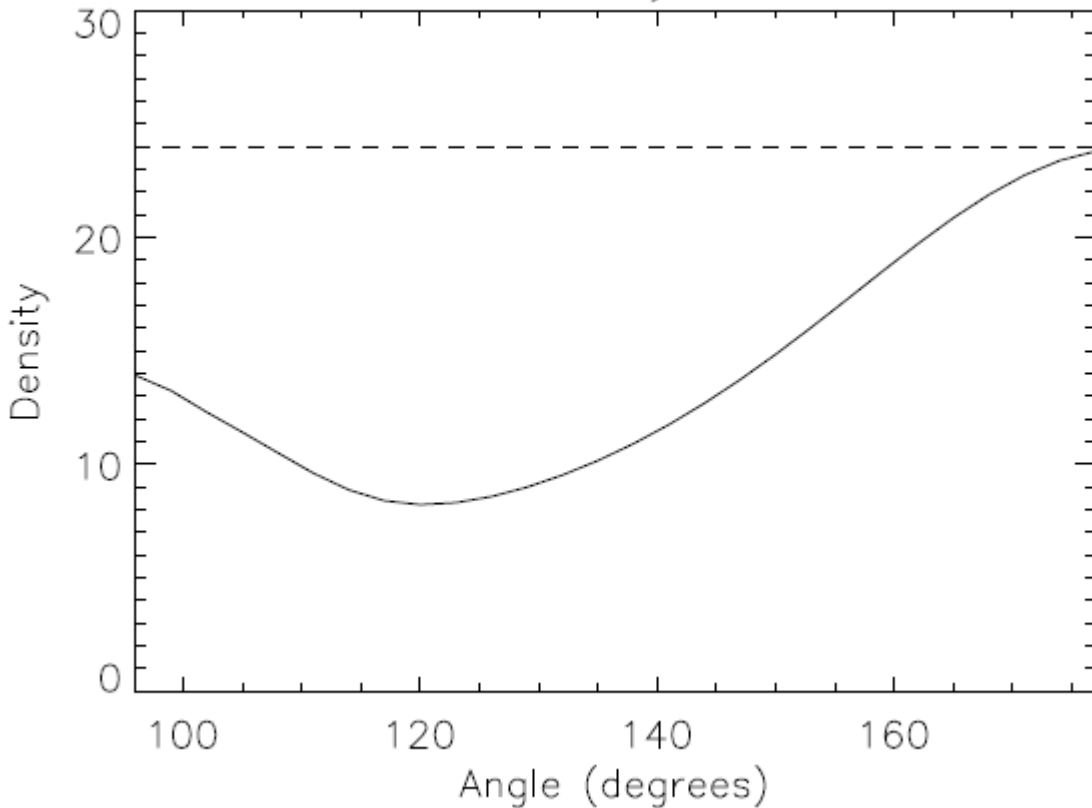
- Rarefaction evacuates mass from tube centre.
- Degree of density deficit is angle dependent; steeper rarefaction at 120 degrees.

Results

Density drop-off

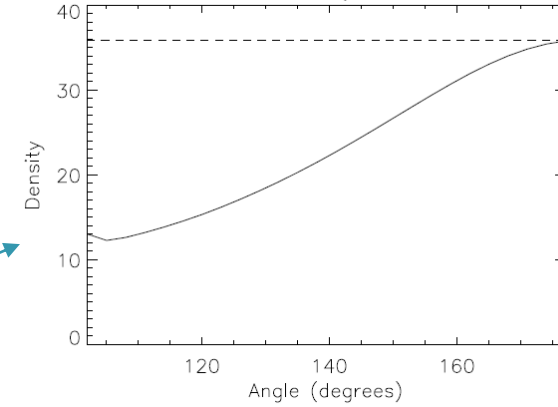


Minimal Density over 4.0s



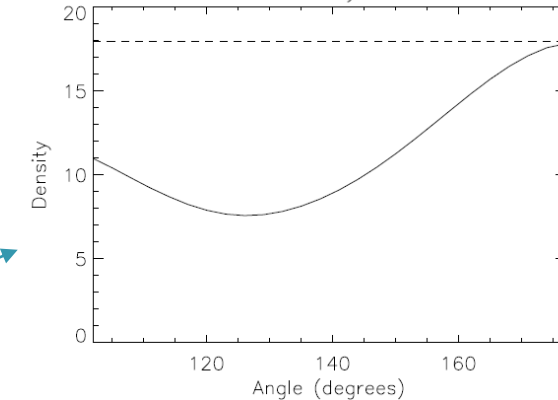
T=3MK

Minimal Density over 4.0s



T=2MK

Minimal Density over 4.0s



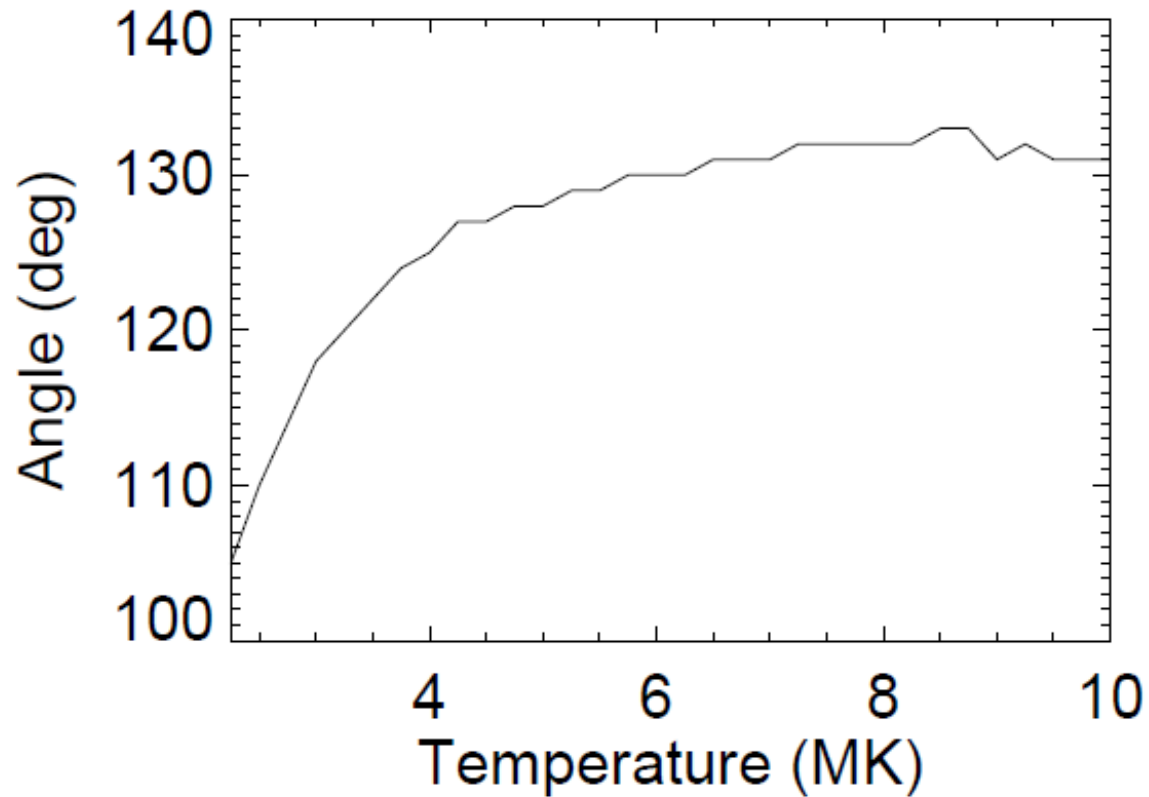
T=4MK

- About 60% reduction near 120 deg. Why this angle?
- Not 'special', angle varies with temperature. How?

Results

Density drop-off

- 'Minimum' angle a function of temperature.
- Initial steady rise with temp.
- Seems to even off slightly above 130 degrees.



Summary



RD's collide to produce interesting effects:

- Tube shortening ceases at point of collision, as does conversion of energy (at least temporarily).
- RD's interact with (mainly) chromosphere but also GDS' to cause tube bending; energy conversion continues but in reverse!
- Rarefaction wave produced which evacuates mass from central portion of tube, decreasing density by more than 50% in some cases - easier to explain high energy particles?
- Density removal not inversely proportional to angle

References

1. Linton, M. G., & Longcope, D. W. 2006, ApJ, 642, 1177
2. Longcope, D. W., Guidoni, S. E., & Linton, M. G. 2009, ApJ, 690, L18
3. Guidoni, S. W., & Longcope, D. W. 2010, ApJ, 718, 1476
4. Longcope, D. W., & Guidoni, S. E. 2011, ApJ, 740, 73
5. Priest, E.R, 1981, Solar Flare Magnetohydrodynamics (New York: Gordon and Breach Science Publishers)

Results

Field line shortening (find way of graphing length)