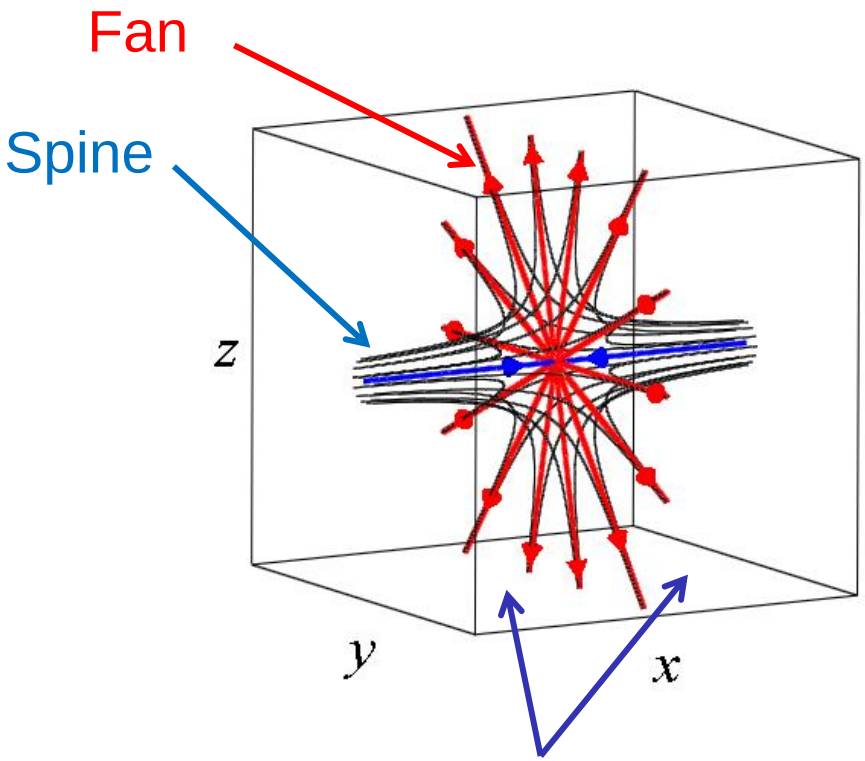
Spine-Fan Reconnection

P. F. Wyper[1], Rekha Jain[1] & D. Pontin[2]

[1] Department of Applied Mathematics, The University of Sheffield, S3 7RH, UK

[2] Division of Mathematics, University of Dundee, DD1 4HN, UK

3D Null Points



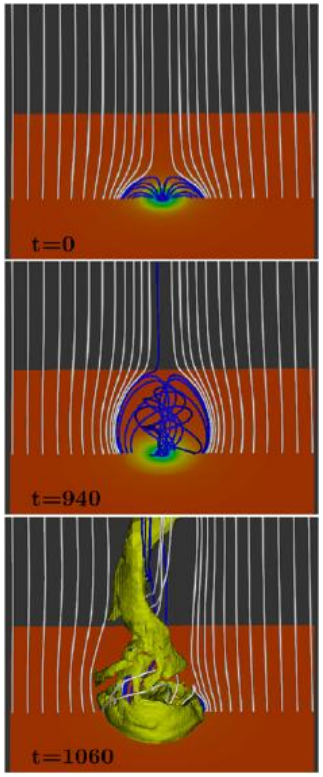
- Fields with strongly diverging field lines naturally develop current sheets[1].
- The Spine & Fan of 3D nulls are one such region.

- Two distinct topological regions
- Fan plane = Separatrix surface

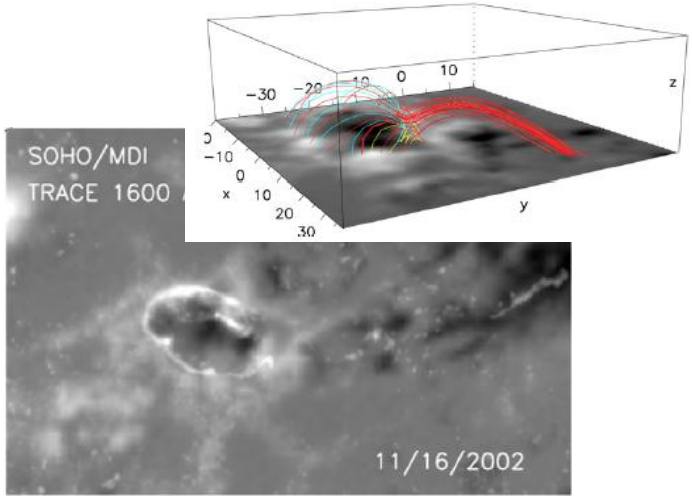
1: Priest & Démoulin (1995)

Null Point Reconnection...

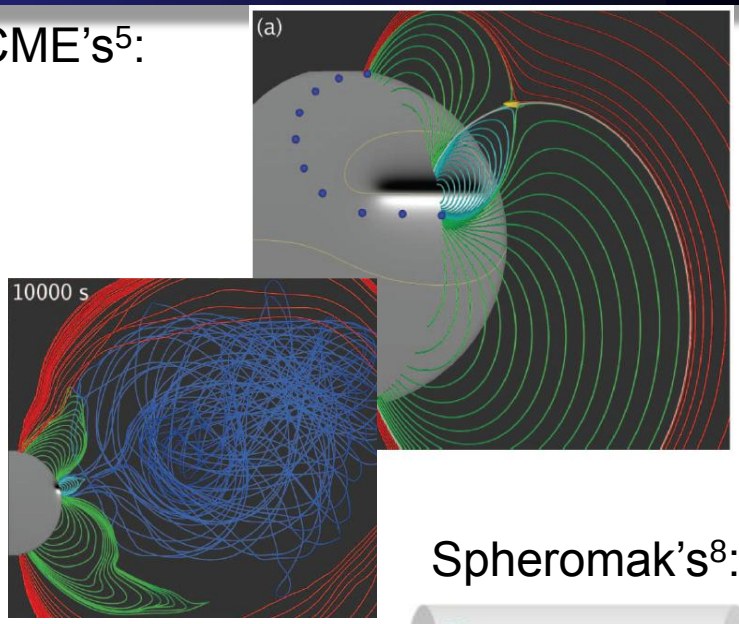
Solar Jets[3]



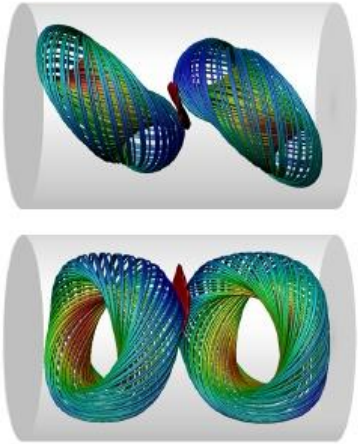
Flare brightening[4]



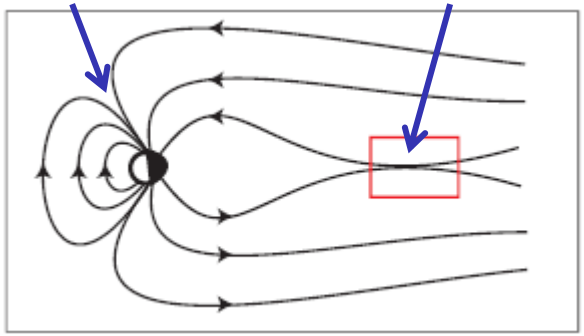
CME's[5]:



Spheromak's[8]:



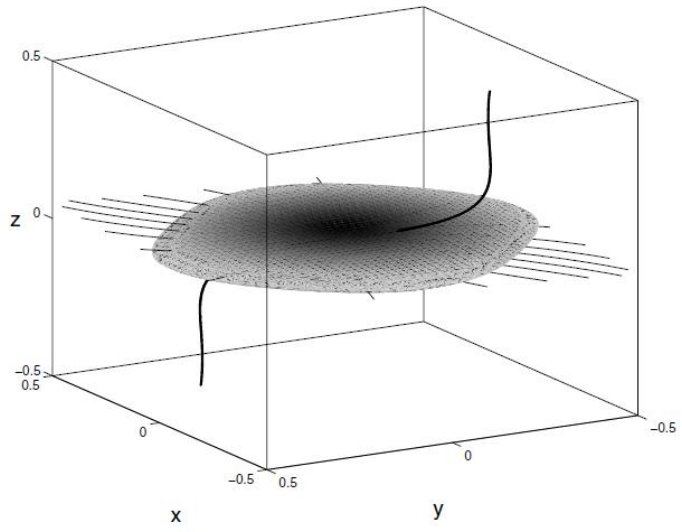
Cusp regions[2] ***J*** sheet in tail[6,7]



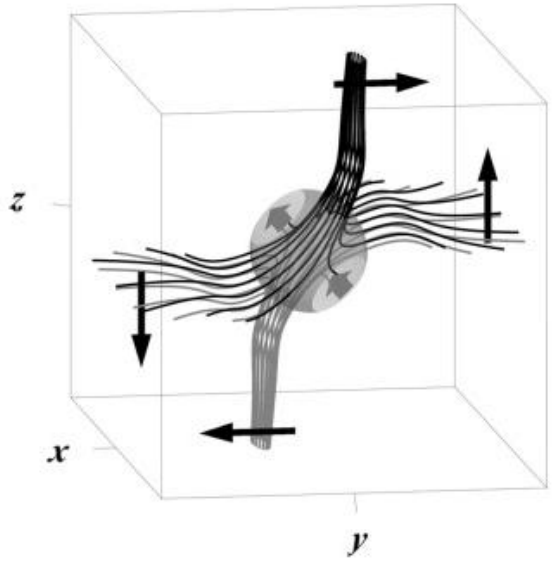
2: Dorelli et al. 07, 3: Pariat et al. 09, 4: Masson et al.,
5: Lynch et al. 2008, 6 & 7: Xiao et al. 06,07, Gray et al. 10

Spine-Fan

Fan



Spine-Fan



- Incompressible case:

  Exact analytical solutions[8]

  of reduced dimensionality

- Compressible case:

  Transiently[9] *and continuously*[10] *driven cases studied numerically*

8: Heerikhuisen & Craig (2004), 9: Priest & Pontin (2009), 10: Galsgaard & Pontin (2011)

Questions

All previous investigations of Spine-Fan reconnection use:

- *Symmetric driving*
- *Driving of fixed spatial extent*

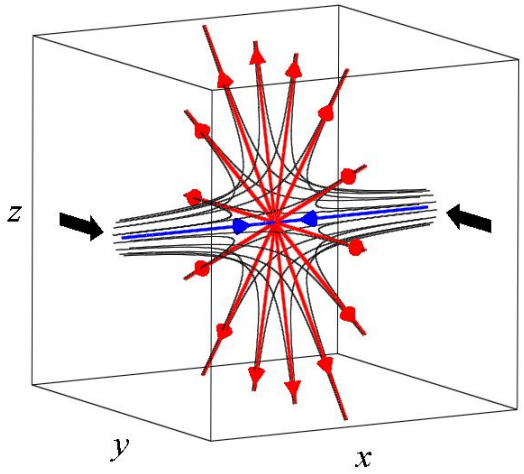
→ **Driving in the solar atmosphere is not often symmetric**

Questions

- *How do the Spine and Fan collapse with asymmetric driving?*
- *Are the relationships seen with symmetry robust without?*
- *What is the effect on reconnection rate and current?*

Set Up

$$\boldsymbol{B} = B_0(-2x, y, z)$$



- Ideal Gas: $\gamma = 5/3$
- Plasma $\beta = \dfrac{10\mu_0\beta^*}{3B^2}$
- $\beta^* = 0.05, B_0 = 1$

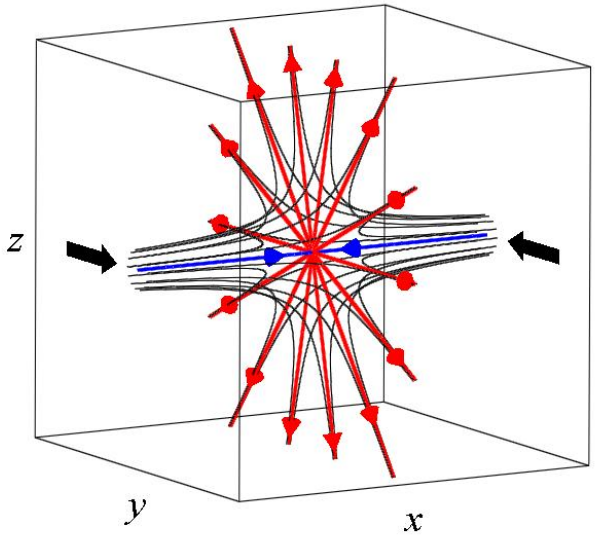
- Using the Copenhagen Staggered Mesh code[11,12]
- Box: $[\pm 0.5, \pm 3, \pm 3]$
- Resolution: 128^3
- Stretched grid:

  $\delta x \sim 0.005, \delta y = \delta z \sim 0.025$
- *Line tied* driving boundaries
- *Closed* side boundaries with thin damping region.

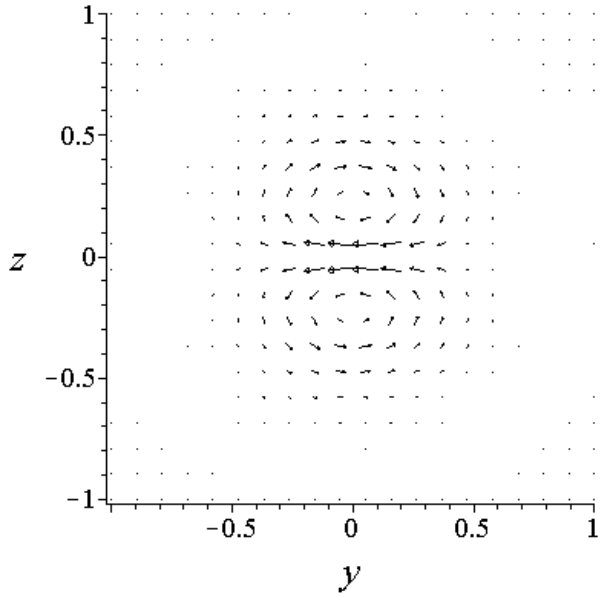
11: Galsgaard & Nordlund (1997), 12: http://www.astro.ku.dk/~kg

Driver

$$\boldsymbol{B} = B_0(-2x, y, z)$$

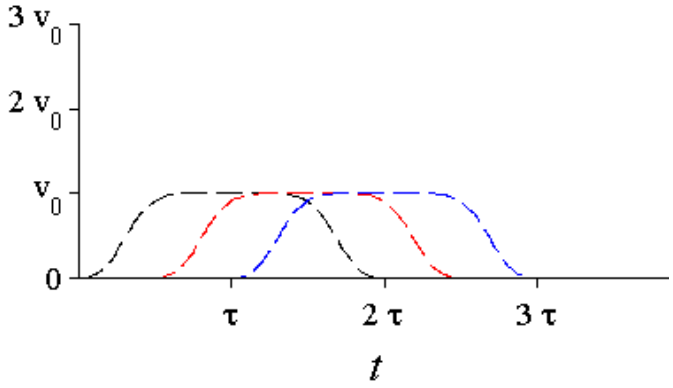


Driving patch



Time dependence:

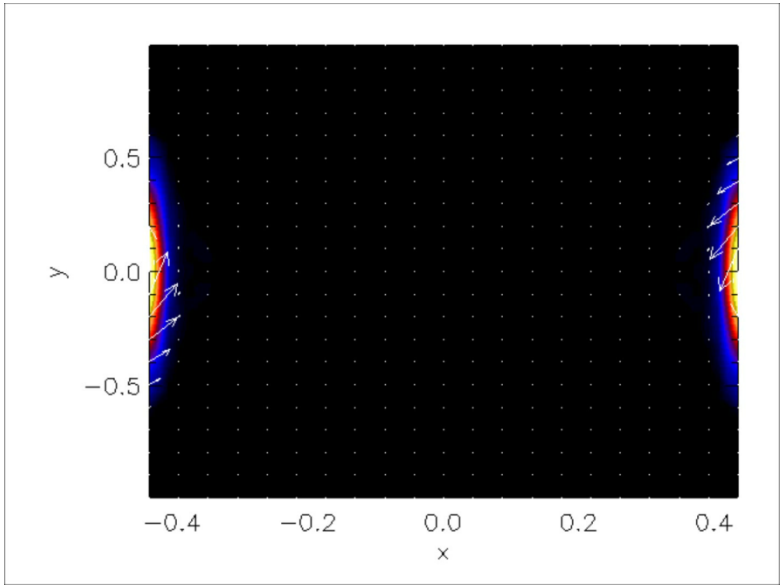
$$V_0(t) = v_0 \tanh(t/0.1)^2 \begin{cases} e^{-0.2(t-\tau)^2}, & x = -0.5 \\ e^{-0.2(t-\tau-t_{lag})^2}, & x = 0.5 \end{cases}$$

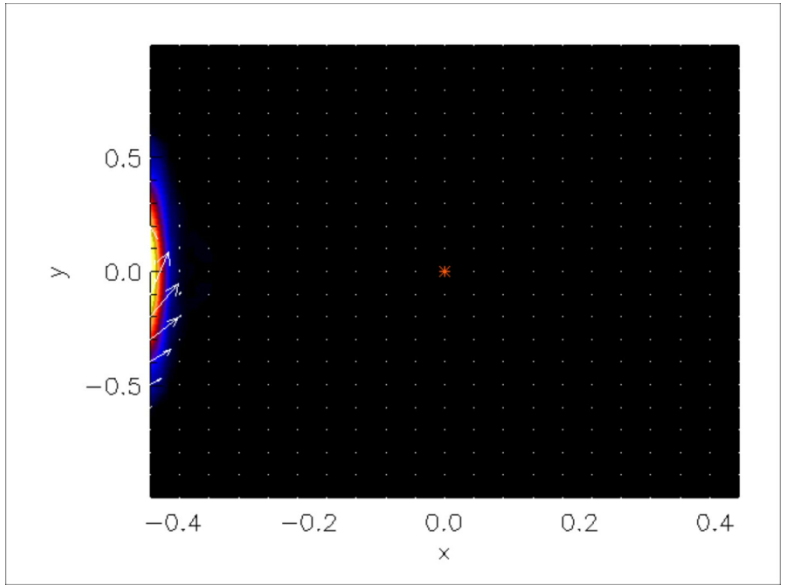


13: Pontin *et al.* (2007)

One vs Two Pulses

- $z = 0$ plane with $\eta = 5 \times 10^{-4}, \tau = 1.8, v_0 = 0.04$



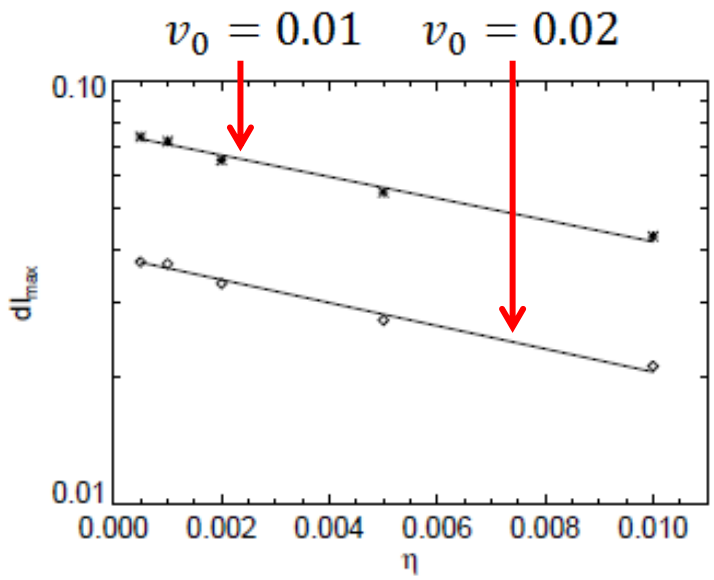


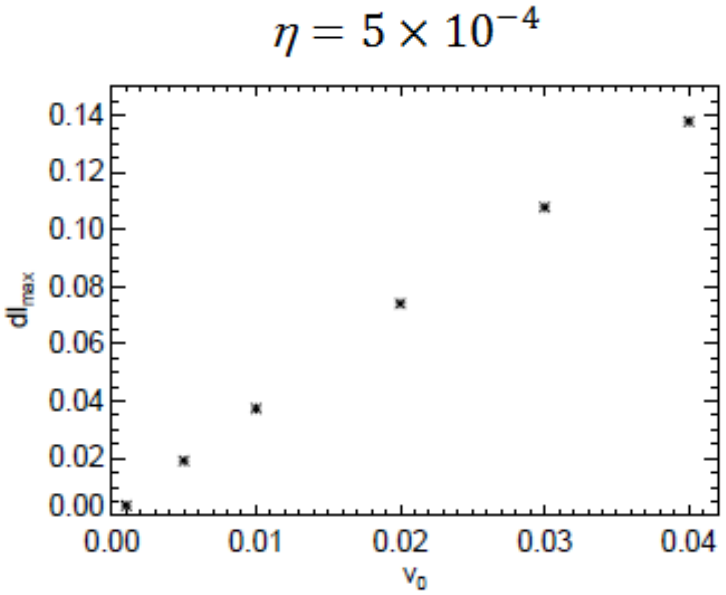
- Null position maintained
- Spine & Fan crossing flows

- Null position shifts
- Spine moves with null

Null Displacement

Null displacement relationships: $dl = \sqrt{x_{null}^2 + y_{null}^2}$

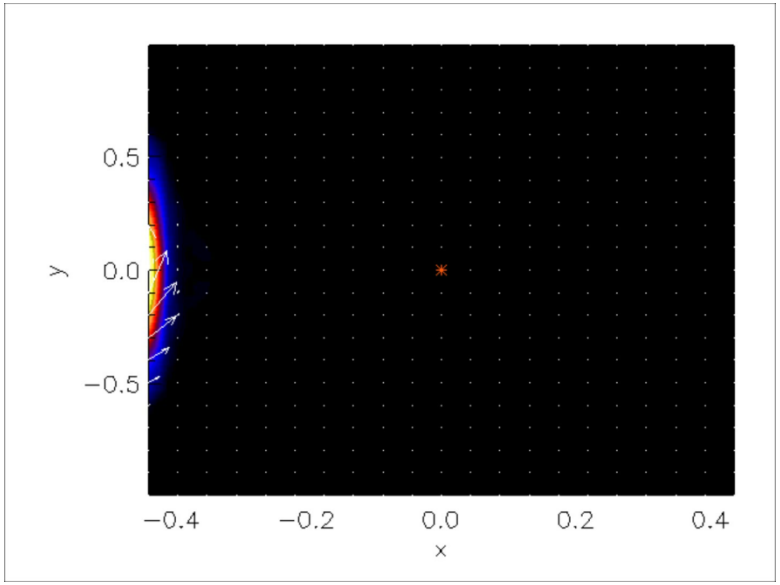




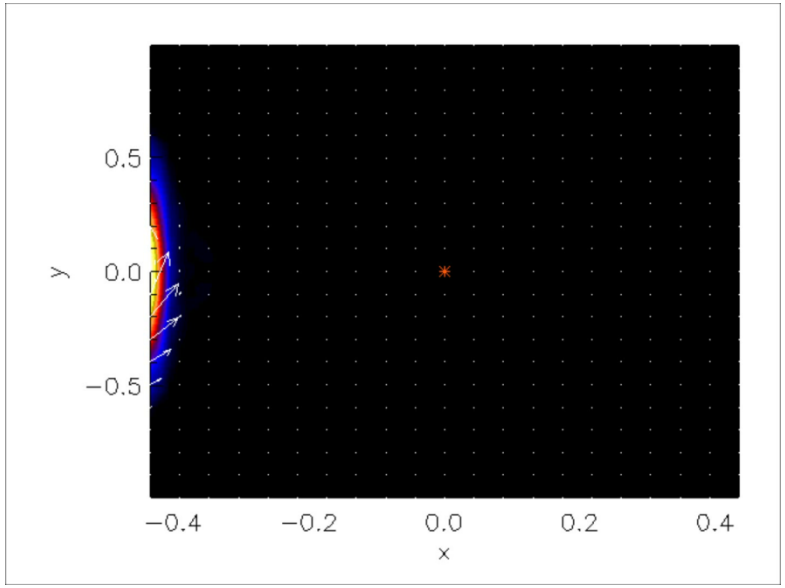
- dl_{max} increases linearly with v_0 and decreases exponentially with η.
- Smaller η = more collapse (stronger ***J***×***B***)

Pulses separated by a lag period

- $z = 0$ plane with $\eta = 5 \times 10^{-4}, \tau = 1.8, v_0 = 0.04$



$t_{lag} = 0.9$

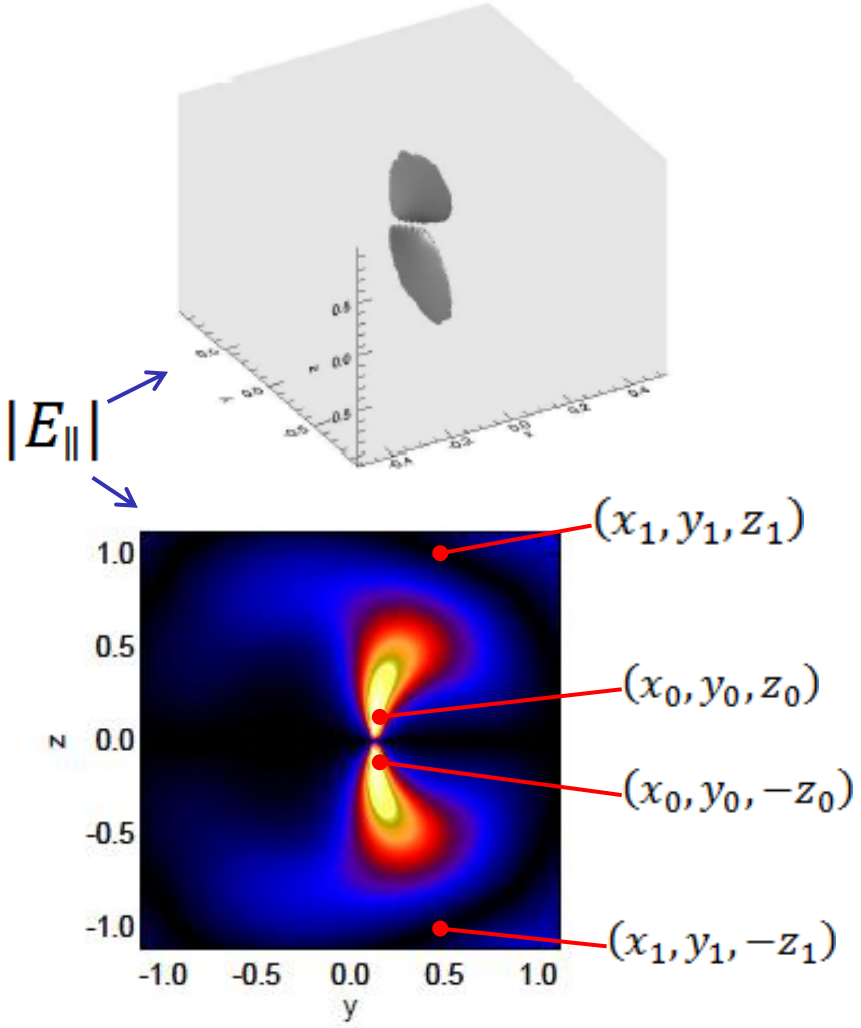


$t_{lag} = 1.8$

- Greatest Spine-Fan collapse when pulses best overlap.
  - Null shifts back and forth with the pulses

Reconnection Rate

- Field line of max $E_\parallel$ must be found iteratively:



$$F = max\left\{\int_{(x_0,y_0,z_0)}^{(x_1,y_1,z_1)} E_\parallel dl + \int_{(x_1,y_1,-z_1)}^{(x_0,y_0,-z_0)} E_\parallel dl\right\}$$

$$+null\ contribution$$

$$= max\left\{\int_{(x_1,y_1,-z_1)}^{(x_1,y_1,z_1)} E_\parallel dl\right\}$$

- The values of each point change at every step.
- $z_0 = 0.05$ throughout.

14: Pontin *et al.* (2005)

Variation in Time

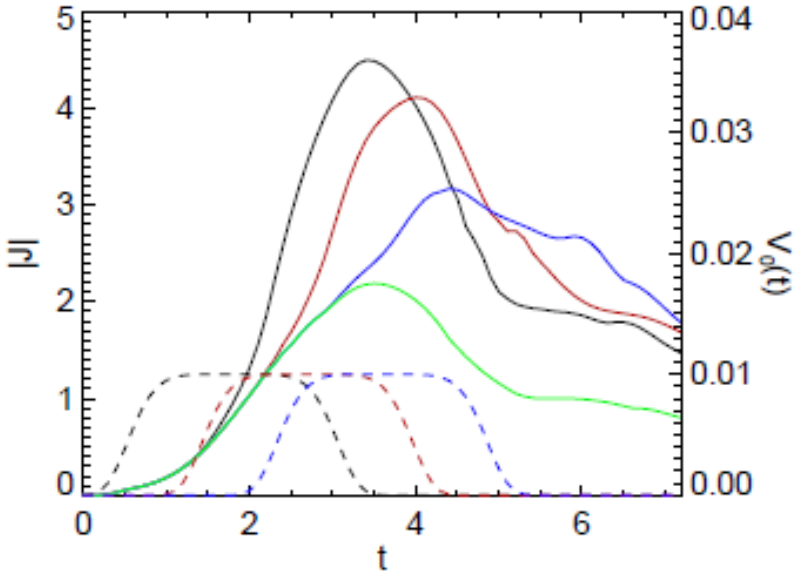
Green: *One pulse*

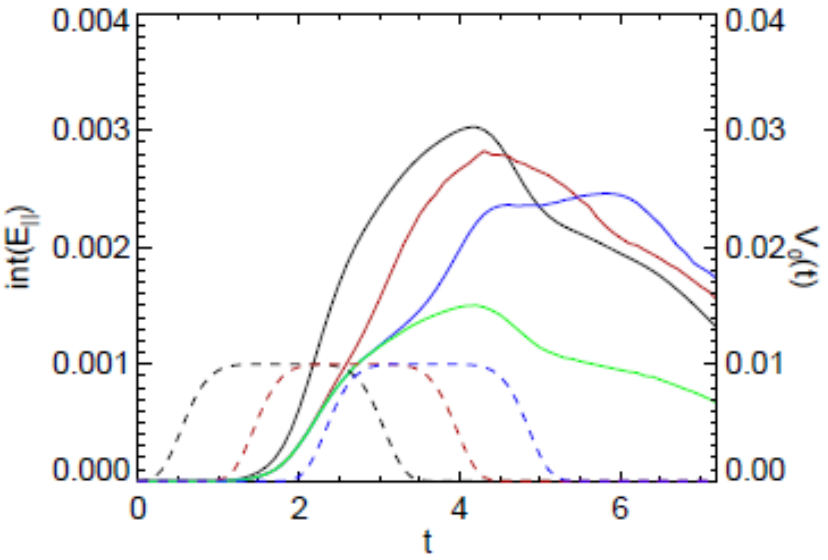
Black: $t_{lag} = 0$

$v_0 = 0.01$

Red: $t_{lag} = 0.9$

Blue: $t_{lag} = 1.8$





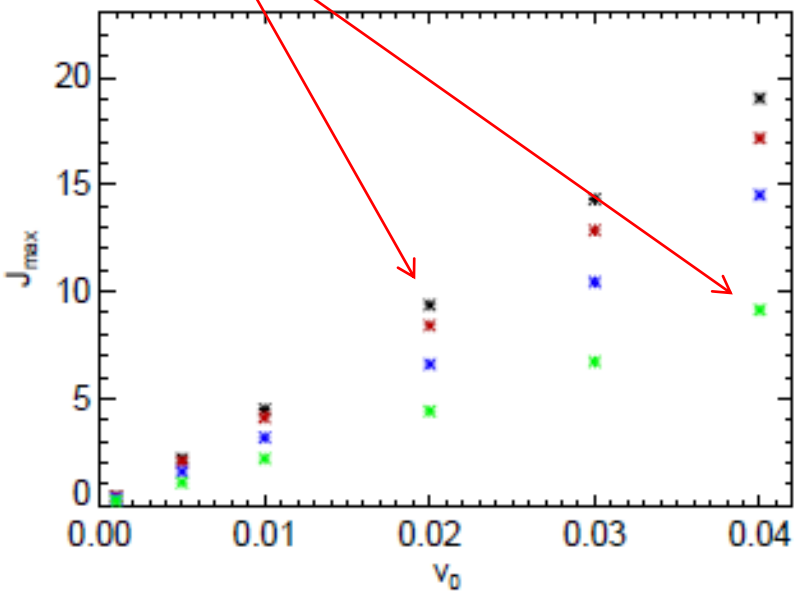
- Peaks occurs when the latent shear from the 1st pulse best overlaps the 2nd

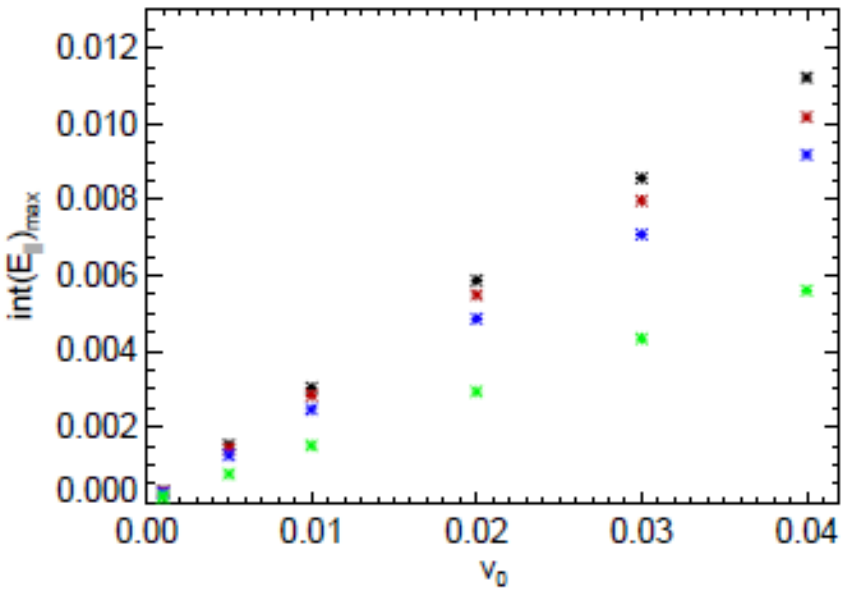
- Peaks later than current
- Difference in overlaps

Qualitative Trends

Gradient is half

Linear trends remain



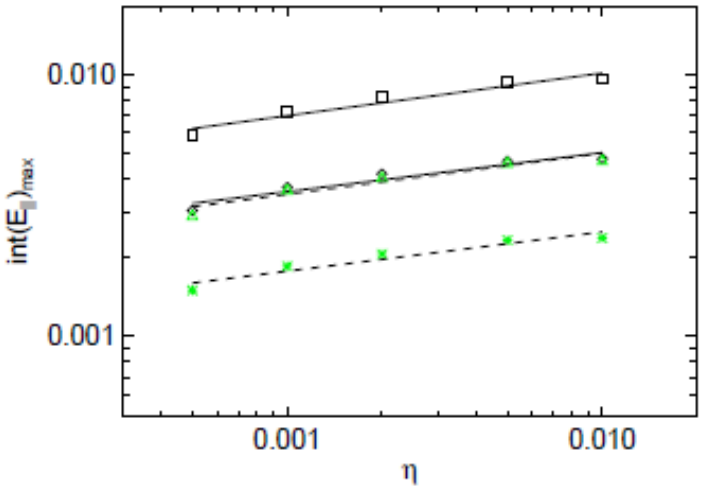


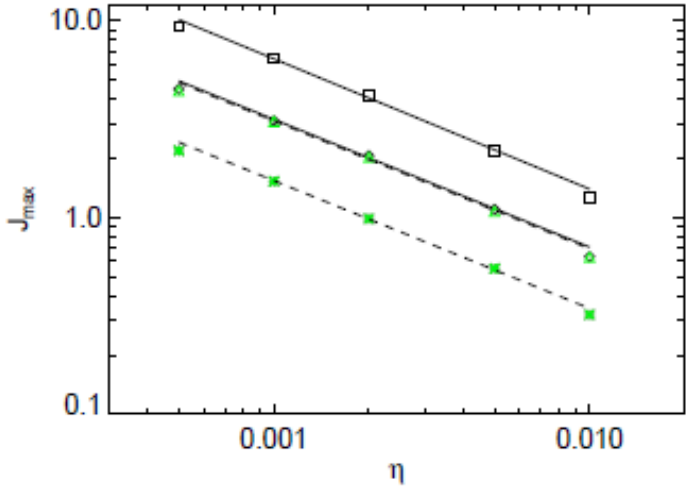
Resistive Scalings

Does the null shifting affect scaling relations?[15,16,17]

Green: *One pulse* Black: Two symmetric pulses

Dashed: $v_0 = 0.01$ Solid: $v_0 = 0.02$





- Scaling relations not changed by null movement

$$\left[\int E_{\parallel} dl\right]_{max} \propto \eta^{0.15}$$

$$|J|_{max} \propto \eta^{-0.65}$$

15: Lukin & Linton (2011), 16: Heerikhuisen & Craig (2004), 17: Galsgaard & Pontin (2011)

Conclusions

Questions/Answers

- ***How does Spine-Fan collapse with asymmetric driving?***

  Asymmetrically with null movement depending on η and v_0.

- ***Are the relationships seen with symmetry robust without?***

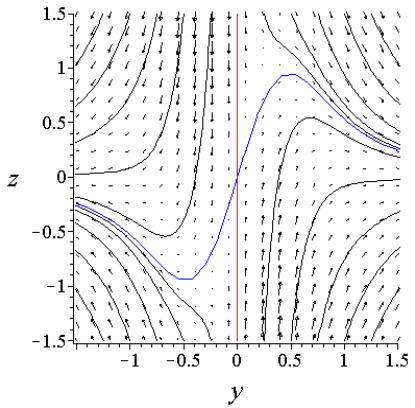
  Linear trends in J_{max} and $int(E_{\parallel})_{max}$ with v_0 robust. η scaling independent of null movement.

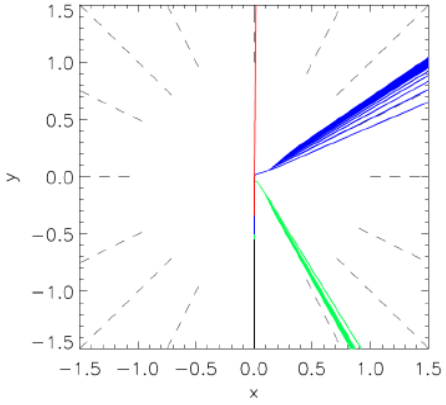
- ***What is the effect on reconnection rate and current?***

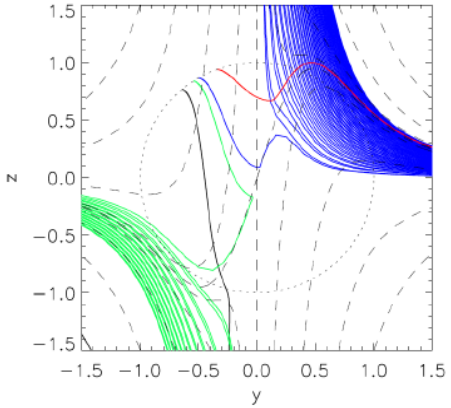
  Heavily dependent on the timing and size of the driving patches.

Future Work

- ***Particle acceleration?***
- ***Non-potential initial fields?***
- ***Sheet fragmentation?***
- ***Small scale physics?***





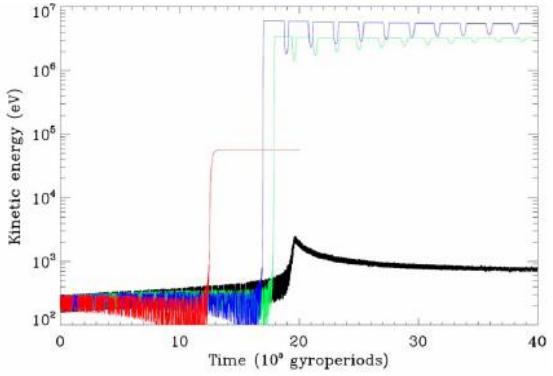


$$\vec{B} = \frac{B_0}{L}\left(x, y, -2z + j_0 y \exp\left(-4R^2\right)\right)$$

$$\Phi = -\int \eta \vec{J} \cdot \vec{B} ds$$

$$\frac{d\vec{x}}{dt} = \frac{\vec{p}}{\gamma m}$$

$$\frac{d\vec{p}}{dt} = q\left(\vec{E} + \frac{1}{\gamma m}\left[\vec{p} \times \vec{B}\right]\right)$$



18: Dalla & Browning (2005)