2-3D numerical model of jet formation in solar atmosphere

Ben Snow, V. Fedun, J. J. Gonzlez-Avils, F. S. Guzmn, G. Verth, S. Shelyag and S. Regnier

Plasma Dynamics Group, Department of Automatic Control and Systems Engineering, University of Sheffield, Sheffield, UK
Instituto de Fsica y Matemticas, Universidad Michoacana de San Nicols de Hidalgo. Morelia, Michoacn, Mxico
Plasma Dynamics Group, School of Mathematics and Statistics, University of Sheffield, UK
Department of Mathematics, Physics and Electrical Engineering, Northumbria University, Newcastle upon Tyne, UK

Type ii Spicules

1. Shorter-lived (10-150 seconds), fast (50-150 km/s)
2. Typically only exhibit upwards motion (e.g., de Pontieu+ 2007)
3. Observed in Ca II band of Hinode.
4. Thought to form via magnetic reconnection.

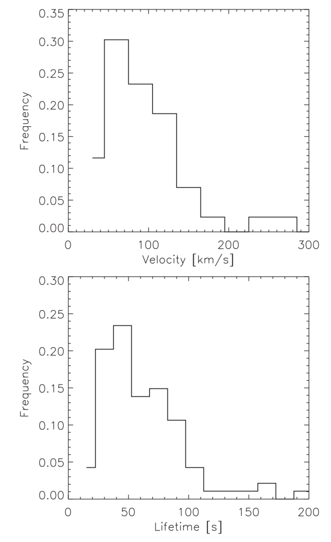


Figure 1: Type II spicules velocities and lifetimes.

Overview

1. Use resistive 2-3D numerical simulations (CAFE) to form jets with the features of type-II spicules.
2. Model low chromosphere-corona connection using C7 equilibrium solar atmosphere model featuring two neighboring loops with opposite polarity.
3. Analyse symmetric (equal and opposite polarities), and asymmetric configurations.
4. Resistivity is uniform and constant at $10^{-2}\Omega^{-1}m$. Magnetic field strength varies between 20-40 Gauss.

Model Atmosphere

Initial hydrostatic equilibrium is given by the C7 model (Avreet E. H & Loeser R. 2008)

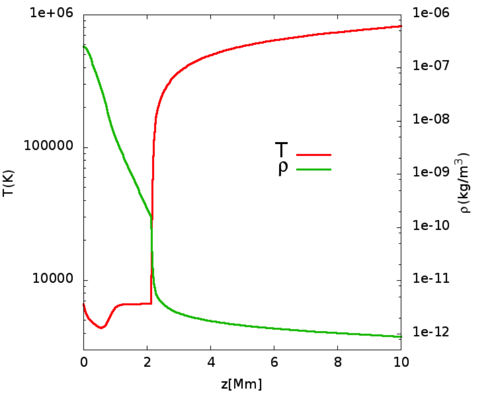
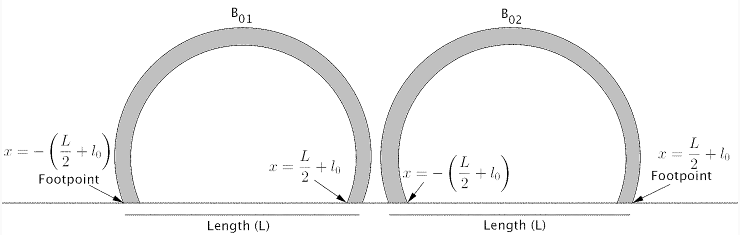


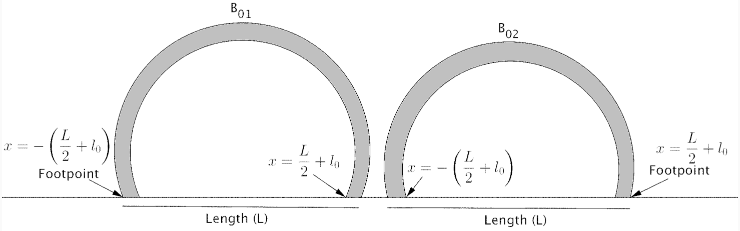
Figure 2: Initial temperature (red) and mass density (green) as a function of height.

Magnetic Field Configuration

$$A_y(x,y) = \frac{B_{01}}{k}\cos(k(x-l_0))\exp(-kz) + \frac{B_{02}}{k}\cos(k(x-l_0))\exp(-kz)$$



Symmetric Configuration



Non-symmetric configuration

Symmetric Results

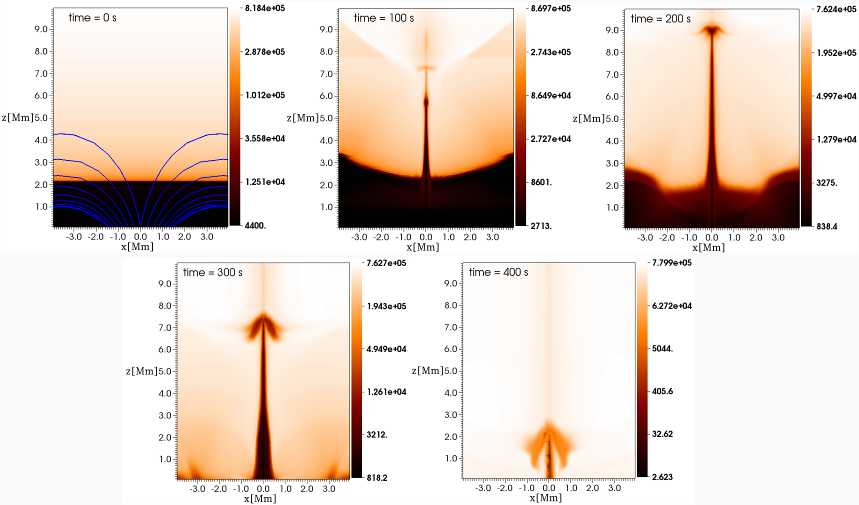


Figure 3: Snapshots of temperature for $B_{01} = B_{02} = 40$ G, $l_0 = 3.5$ Mm

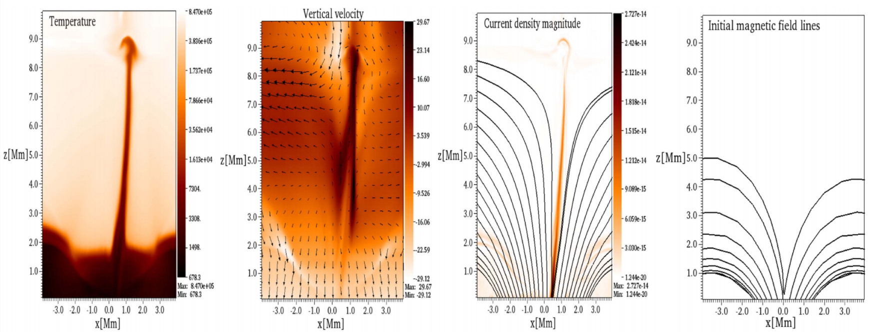


Figure 4: Non-symmetric case with $B_{01} = 40$ G, $B_{02} = 30$ G. Maximum height obtained by the jet.

Jet Properties

Maximum Height, Vertical Velocity, Temperature, Density, and Time When the Jets Reach the Maximum Height for Each Magnetic Field Configuration

Run #	B_{01} (G)	B_{02} (G)	l_0 (Mm)	h_{max}(Mm)	$v_{z,h_{max}}$ (km s^{-1})	$T_{inside,h_{max}}$ (K)	$\rho_{inside,h_{max}}$ (kg m^{-3})	$t_{h_{max}}$ (s)
1	40	40	3.5	7.3	15.4	14200	1.32×10^{-10}	210.2
2	30	30	2.5	2.3	33.9	48452	2.5×10^{-10}	70.4
3	30	30	3.5	3.9	13.4	22532	1.3×10^{-10}	196.8
4	20	20	2.5	1.5	12.1	25933	1.2×10^{-10}	94.4
5	20	20	3.0	1.8	3.7	47990	1.0×10^{-10}	142.4
6	20	20	3.5	1.2	8.7	27334	1.4×10^{-10}	160
7	40	30	3.5	7.2	16.8	34112	4.0×10^{-11}	213.3
8	40	20	3.0	1.2	76.5	76467	1.0×10^{-9}	11.2
9	40	20	3.5	6.7	31.0	110560	1.2×10^{-11}	211.2
10	30	20	2.5	2.8	61.4	30565	6.4×10^{-10}	52.8
11	30	20	3.0	2.7	11.0	31201	8.6×10^{-11}	139.2
12	30	20	3.5	3.1	5.8	31931	5.8×10^{-11}	204.8

	Simulation jet	Type II spicules
Lifetimes [s]	11-213	10-150
Velocity [km/s]	5.8-76.5	50-150
Temperature [K]	14200-110560	Ca II, Hα, Si IV, ...
Height [Mm]	1.2-7.3	< 11

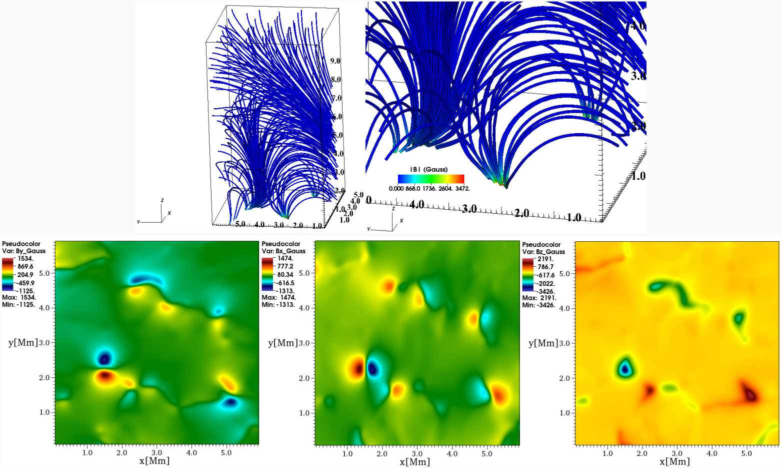


Figure 5: (top) 3D magnetic field lines and (bottom) magnetic field components B_x, B_y, B_z at $z = 0.1$ Mm.

3D results

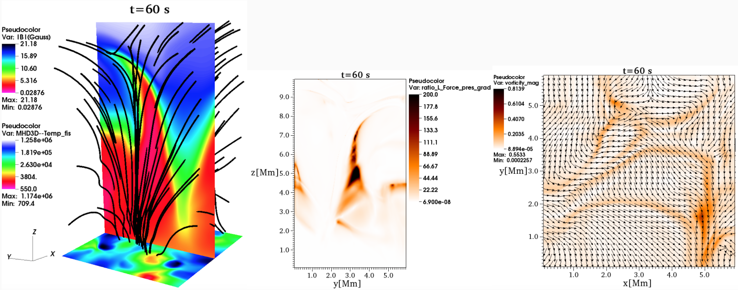


Figure 6: Snapshots at time t=60 s showing: (left) temperature and magnetic fieldlines, (centre) ratio of $|\mathbf{J} \times \mathbf{B}|/|\nabla p|$, (right) vorticity magnitude and velocity vector field.

Conclusions

1. In 2D simulations, magnetic reconnection forms jets with the features of type II spicules. Gonzlez-Avils, J.J., Guzmn, F. S., & Fedun, V. 2017, ApJ, 836, 24
2. In 3D simulations using a potential magnetic field extrapolation, features of type II spicules can again be created via magnetic reconnection. The formation depends on the Lorentz force. The jet has upflows of order 100 km/s and lifetimes of greater than 100 s. Gonzlez-Avils, J.J. et al. 2017, ApJ, submitted

Magnetic shocks and substructures from torsional wave collisions in coupled expanding flux tubes

Ben Snow, V. Fedun, F. A. Gent, G. Verth and R. Erdelyi

School of Mathematics and Statistics, University of Sheffield, UK
Plasma Dynamics Group, Department of Automatic Control and Systems Engineering, University of Sheffield, Sheffield, UK School of Mathematics and Statistics, University of Sheffield, UK
ReSoLVE Centre of Excellence, Department of Computer Science, Aalto University, Helsinki, Finland

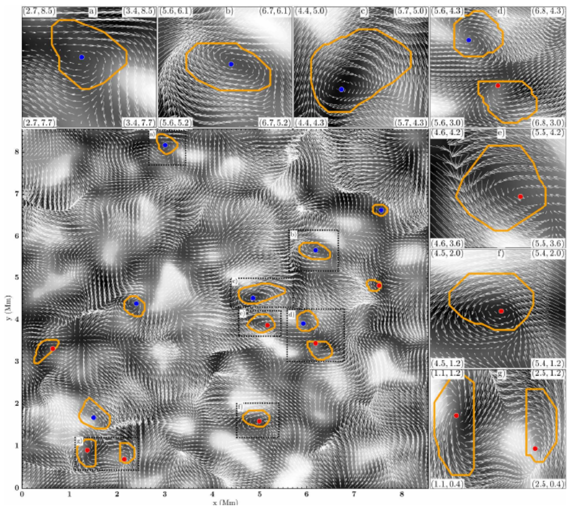


Figure 7: Vortex motions observed at photospheric levels (Giagkiozis+ 2017).

Overview

1. Use 3D ideal MHD simulations (SAC) to investigate the mixing of torsional motions in a pair of expanding and merging flux tubes.
2. VAL IIIC model temperature and mass density profile specified along tube axes.
3. Velocity driver specified at the base of each tube of the form:
   $v_x = A\sin(2\pi t/\omega)$,
   $v_y = A\cos(2\pi t/\omega)$
   where
   $A = A_0 \exp(\frac{-(r-r_0)^2}{\Delta r^2}) \exp(\frac{-(z-z_0)^2}{\Delta z^2})$

Initial Configuration

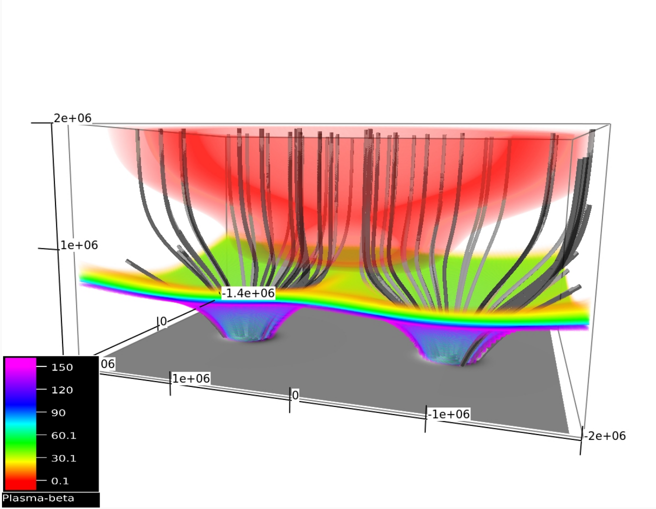


Figure 8: Initial configuration. Selected isosurfaces of plasma-β and arbitrary streamlines of magnetic field.

Results

Magnetic Substructures

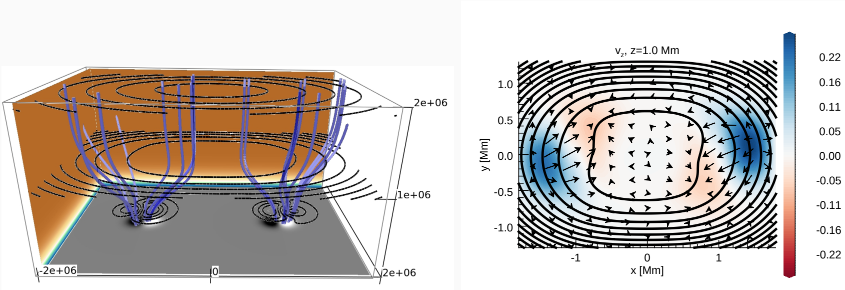


Figure 9: (left) Snapshot of the domain at time t=108 s. (right) Magnetic field line contours and v_z velocity colourmap.

Magnetic Substructures

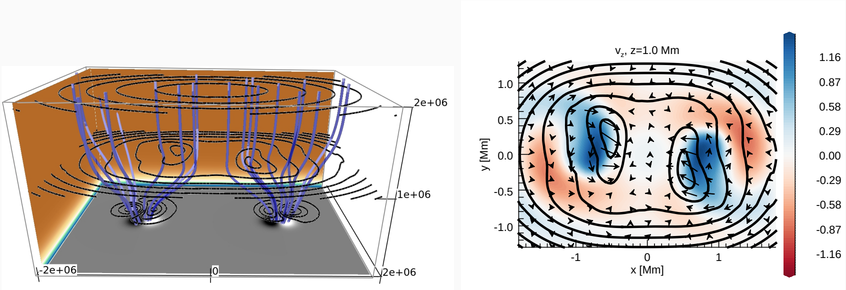
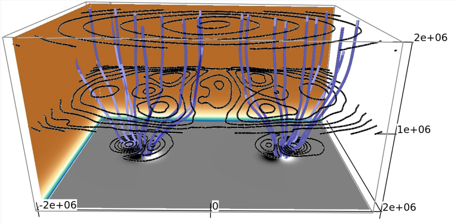


Figure 10: (left) Snapshot of the domain at time t=152 s. (right) Magnetic field line contours and v_z velocity colourmap.

Magnetic Substructures



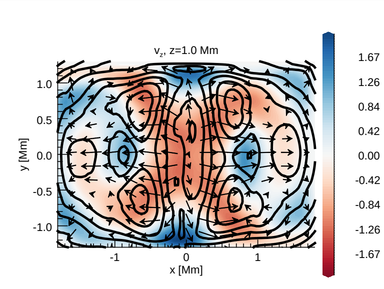
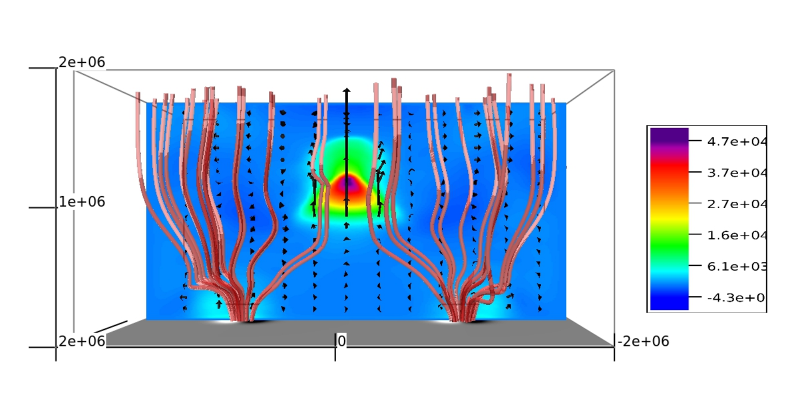
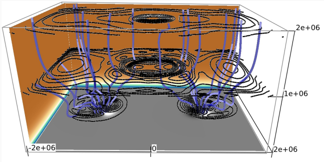


Figure 11: (left) Snapshot of the domain at time t=254 s. (right) Magnetic field line contours and v_z velocity colourmap.

Shock Formation



Vertical velocity (v_z) colour plot showing the high-velocity upflow region created in the centre of the domain at time $t = 360$ s. Arbitrary streamlines of magnetic field. Black arrows show the velocity field.



Conclusions

1. Mixing of torsional drivers is investigated in a pair of expanding and merging flux tubes.
2. Multiple transient magnetic substructures form.
3. Superposition of torsional motions develops into a shock with $v_z \simeq 50$ km/s and increases temperature to $T \simeq 60,000$ K.
4. Snow et al, 2018, in prep.