Numerical Simulations of Fine Structures within Reconnecting Current Sheets in Solar Flares

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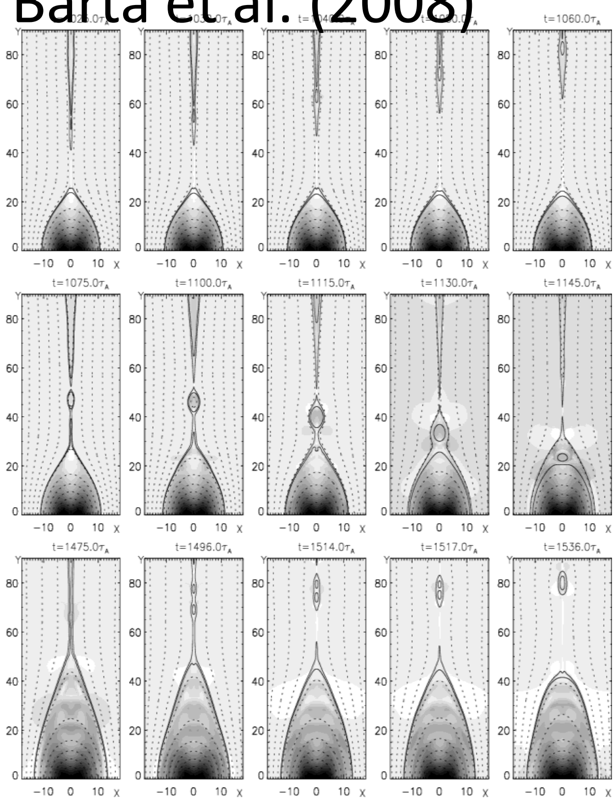
1.Background

- Numerical research of CS in flare
- Forbes & Malherbe (1991), Riley et al. (2007) Bárta et al. (2008)

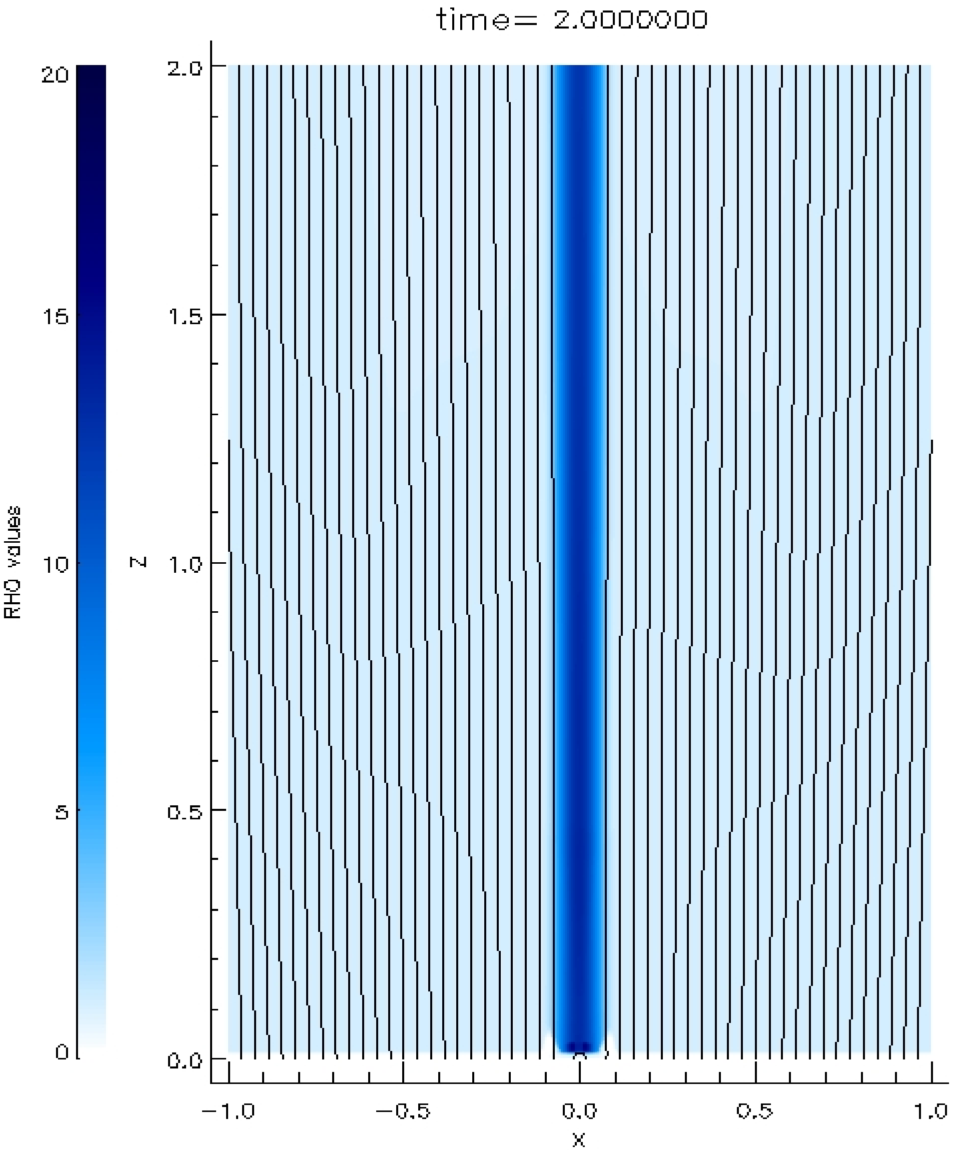


(Barta et al 2008)

- Plasmoid instability
- Loureiro et al. (2007) and Ni et al. (2010) study the reconnection process in Sweet-Parker current sheet. In larger Lundquist number situation, there are long wave instability when the rate of length to width is lager.
- Other recently research:
- Samtaney et al. 2009; Bhattacharjee et al. 2009 ; Skender & Lapenta 2010, Bettarini & Lapenta 2010; Huang & Bhattacharjee 2010 discuss the relationship of blob scale and Lundquist number.

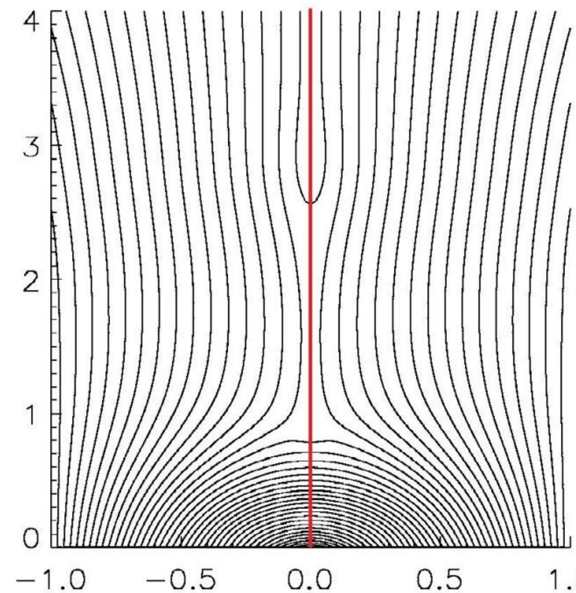
2. Evolution of Current sheet

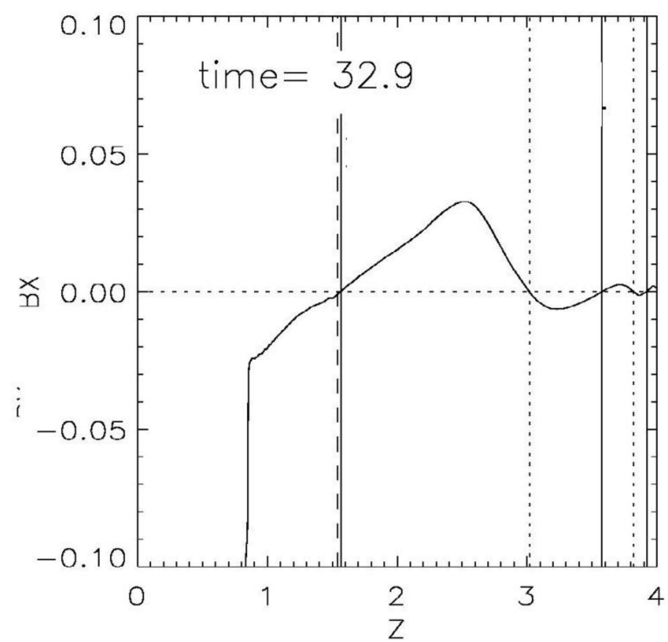
- Initial and Boundary conditions:
- The configuration is initially in both mechanical and thermal equilibrium;
- The left, right and top sides of the simulation domain are the open boundary. The magnetic field is line-tied at bottom.
- The initial width w=0.1L, and β=0.1, R_m = 5.0X10^4.
- The initial velocity perturbation is $v_{maxturb}$=0.05 v_A
- The system begins to evolve as the magnetic fields on either side of the sheet begin merging with each other.

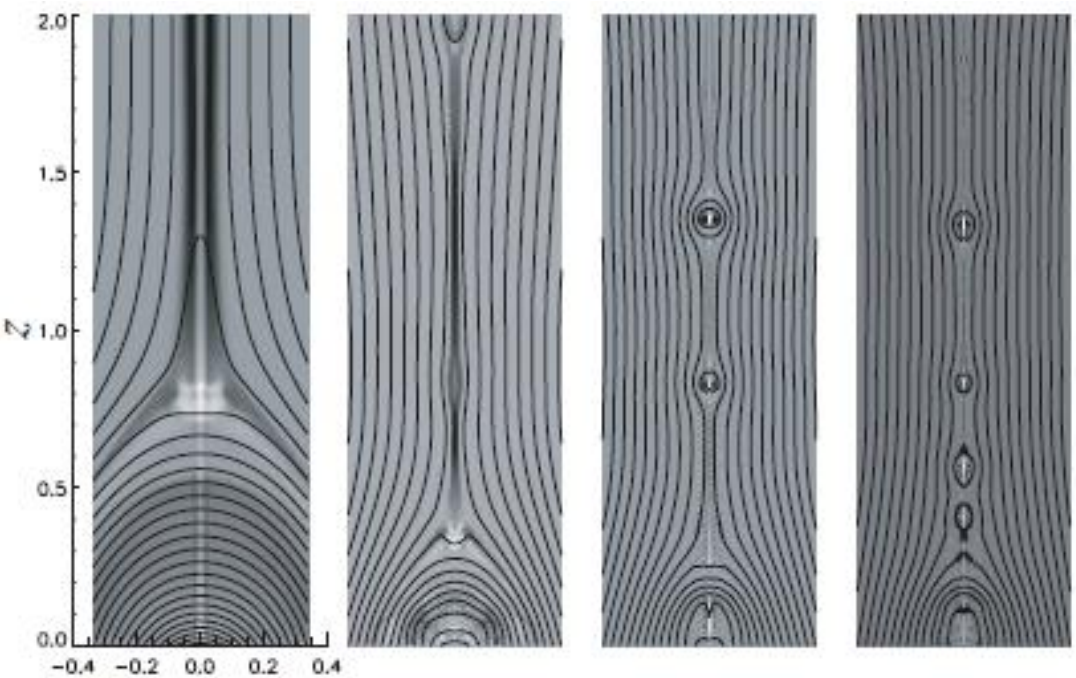


- Critical R_m is about 900 when multiple plasmoids appear during the current sheet evolution.
- Right: Initial $w = 0.1L$, β=0.1, R_m = 900.
- Below: R_m = 500, 10^4, 5×10^4, 5×10^5.

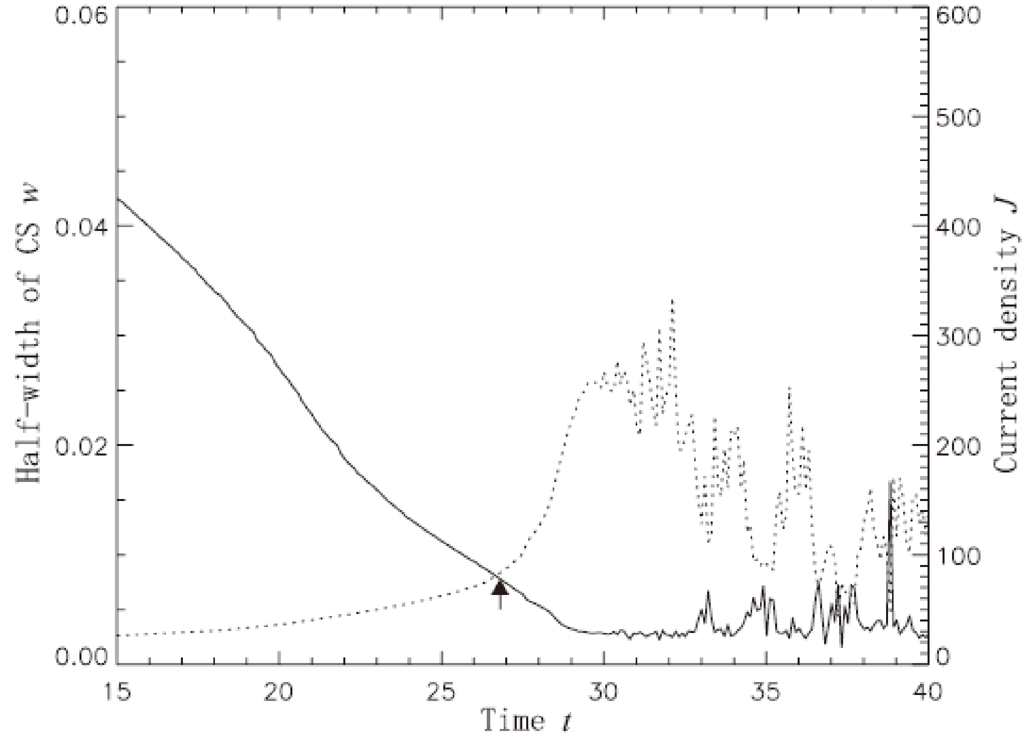
Magnetic field lines and B_x

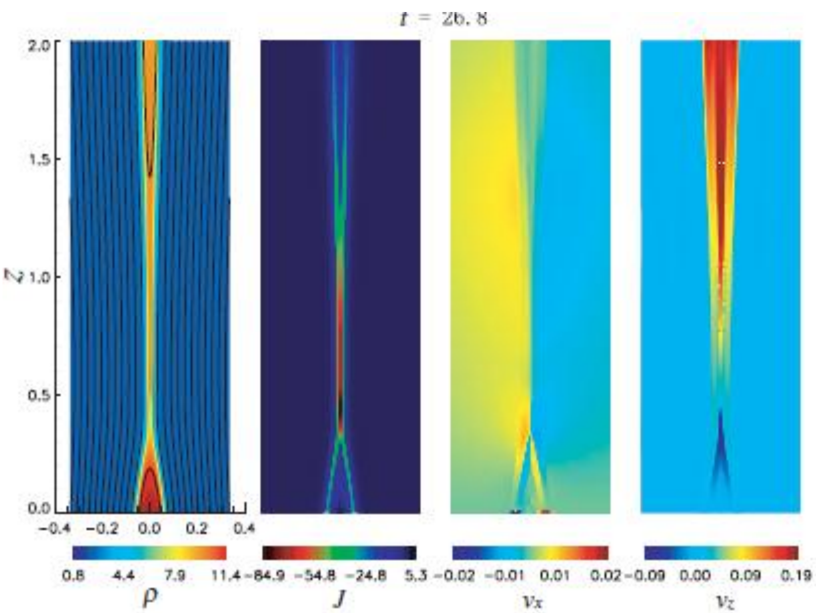


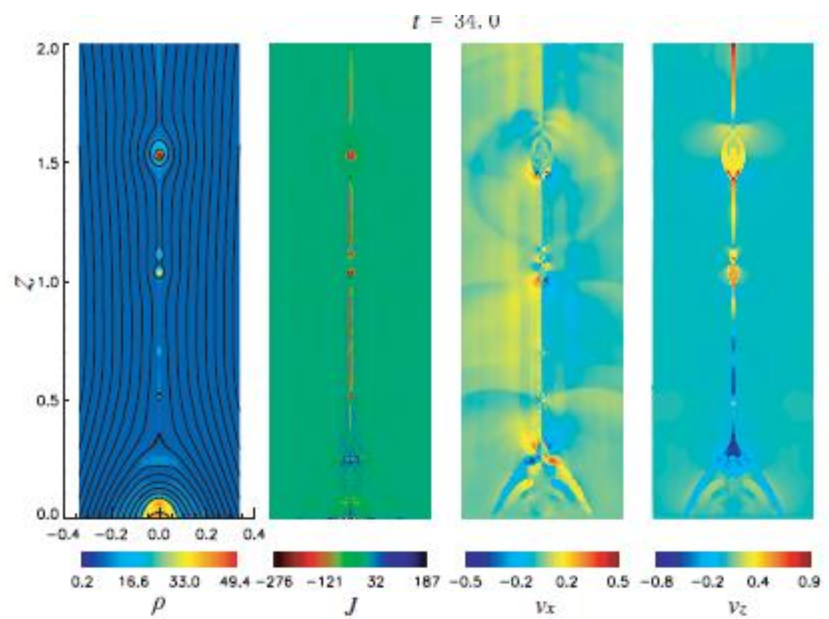




- Plasma and magnetic fields on the two sides of the sheet commence to move to one another gradually, causing the sheet to become thinner.
- The half-width *w* near the X-point, decrease to about 7.5×10^{-3} at time $t=26.8\tau_A$ when the first island appearing.
- Then *w* gradually decreases to the minimum value 2.5×10^{-3} and it subsequently fluctuates around this minimum value.

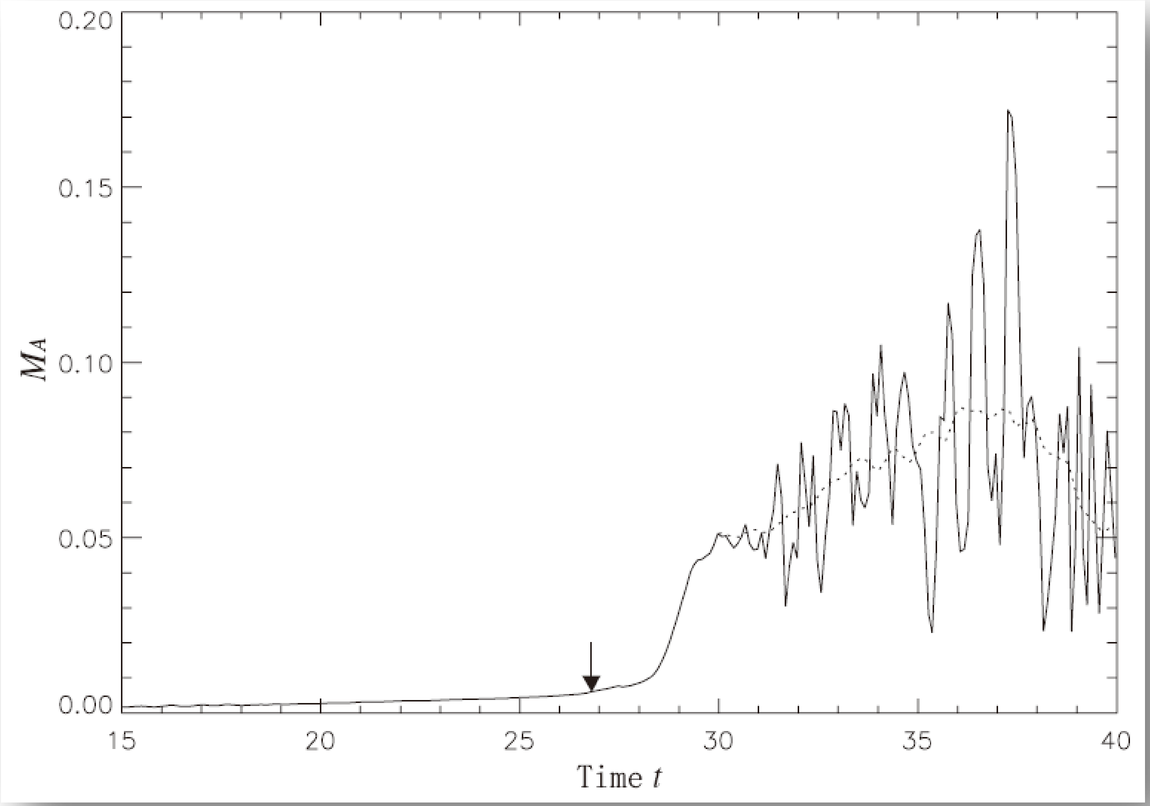




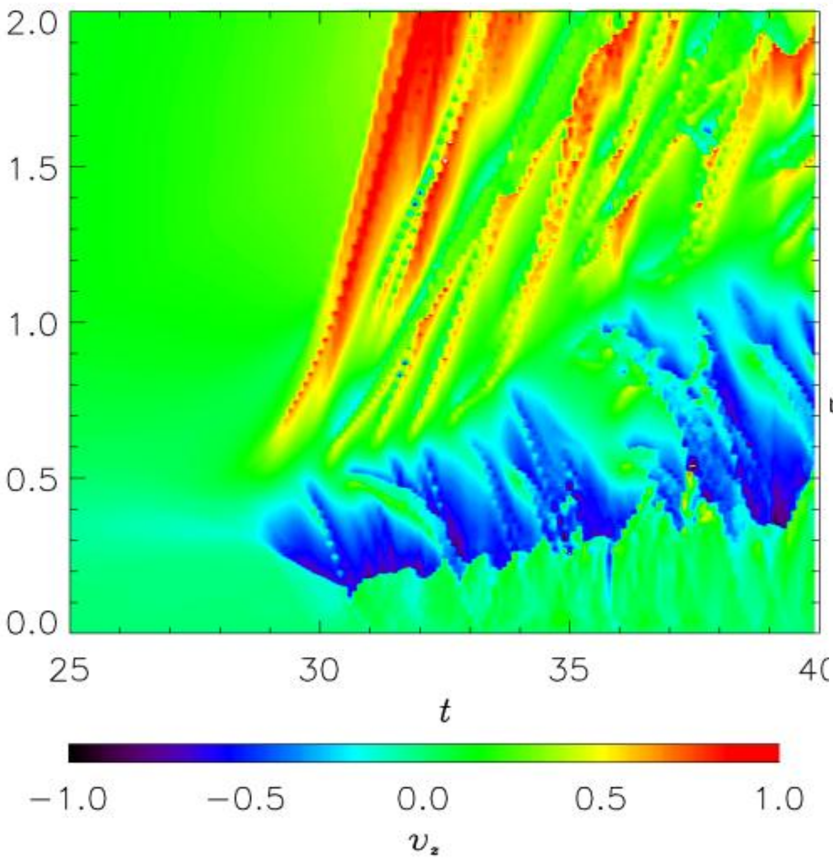


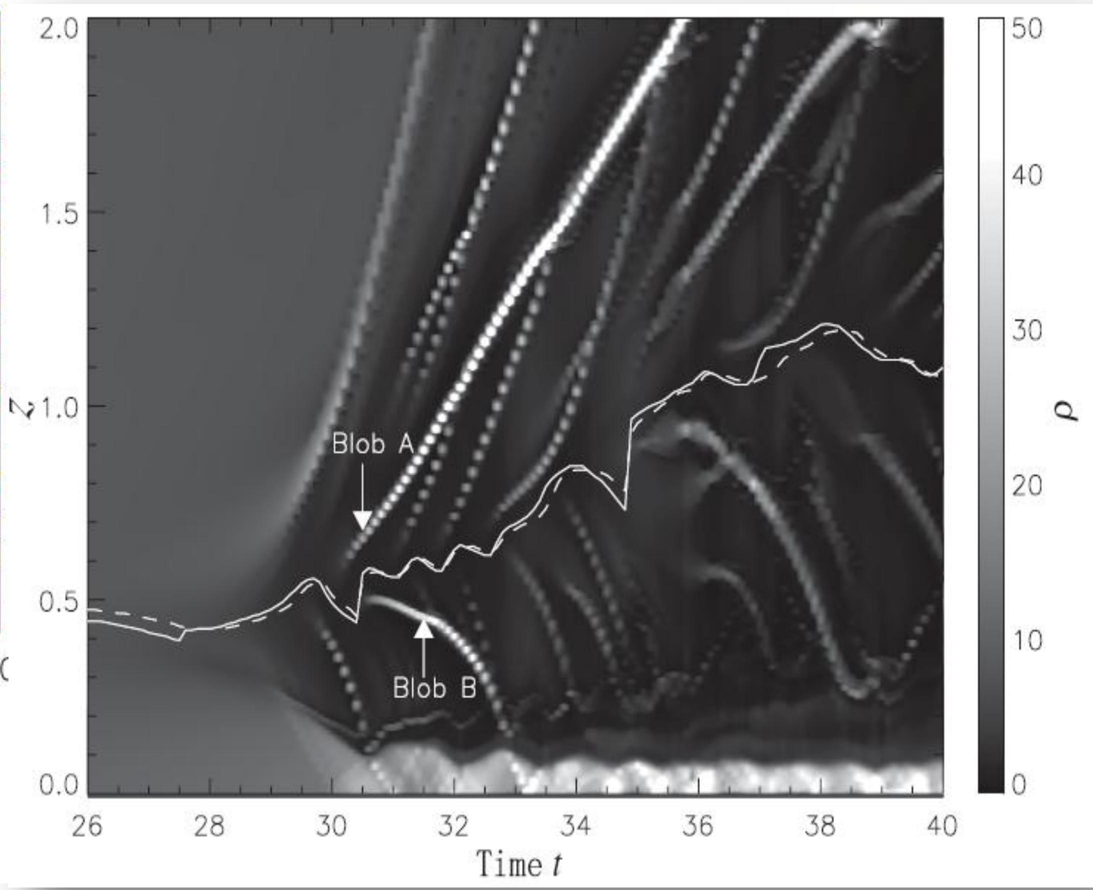
3.

- Rate of magnetic reconnection M_A near the PX-point as a function of time. The solid line shows the instant value and the dotted line is for the corresponding average value.
- The arrow indicates time t = 26.8 τ_A when the first magnetic island forms

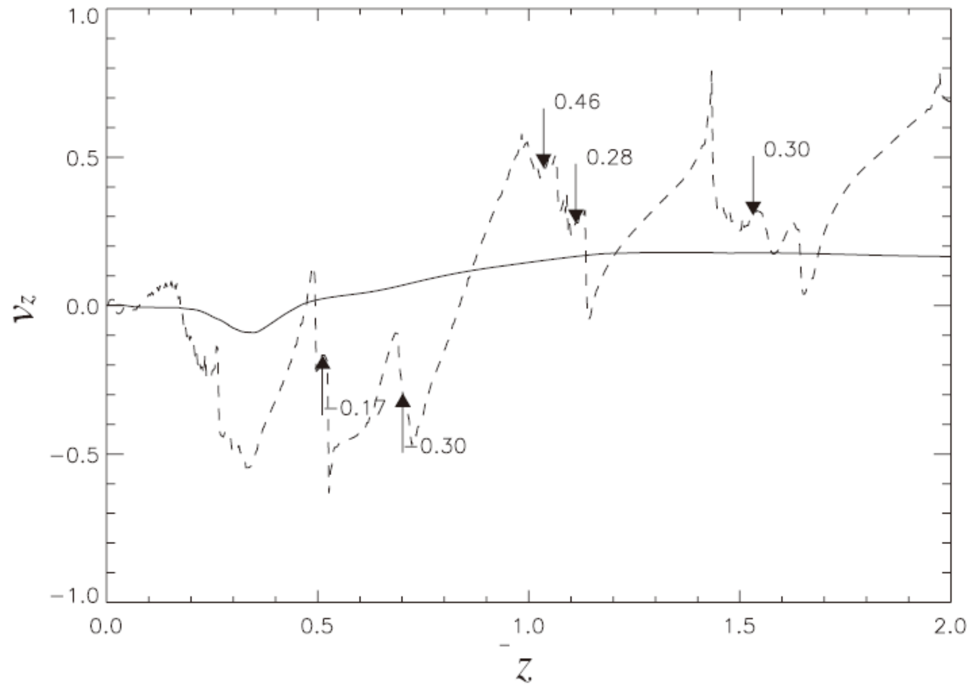


- Plasma density (gray scale) and locations of several well-recognized plasma blobs (white solid circles) along the z-axis as functions of time. Locations of the stagnation and principal X-point are plotted with dashed and solid curves, respectively.
- The direction in which a plasma blob moves is related to the relative positions of the S- and PX-points.
- When the S-point is above the PX-point, newly appearing blobs move upward. When the S-point is below… newly blobs downward.



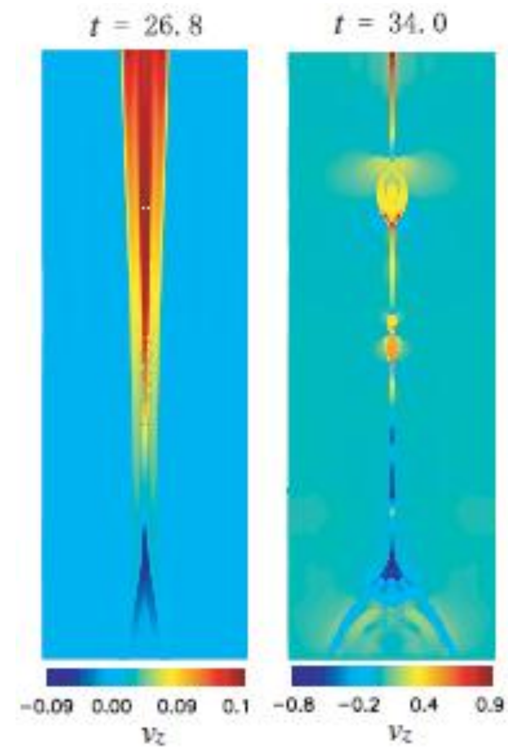


- Plasma velocity v_z distribution along the *z*-axis.
- The solid curve is for v_z at t = 26.8 τ_A, and the dashed one is for t = 34.0 τ_A.
- The arrows indicate positions plasma blobs along the *z*-axis, and their instant speeds are specified by those numbers (unit is v_A).



Reference	Sunward Blobs	Anti-Sunward Blobs
This work	89–159	147–242
McKenzie & Hudson (1999)	100–200	
Sheeley & Wang (2002)	50–100	
Ko et al. (2003)		140–650
Raymond et al. (2003)		1000
Asai et al. (2004)	100–250	
Sheeley et al. (2004)	100–600	
Lin et al. (2005)		460–1075
Vršnak et al. (2009)		100–1000
Milligan et al. (2010)	12	
Nishizuka et al. (2010)		250–1000
Savage et al. (2010)	21–165	280–460

(speed unit: *km/s*)



Scaling Law for Current Sheet Thickness

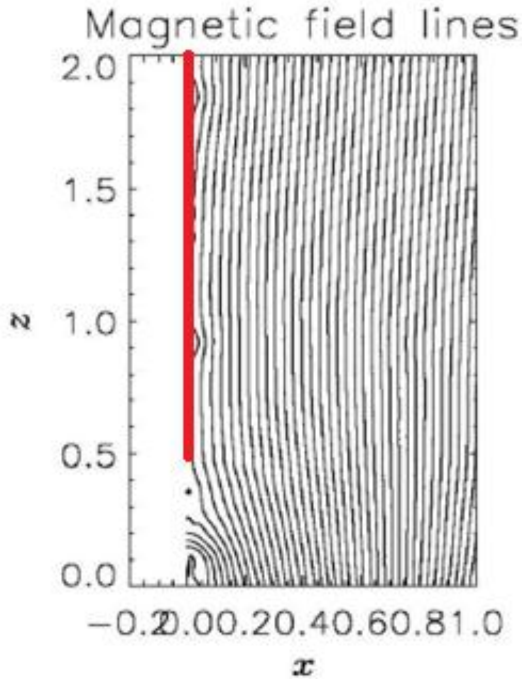
- Lin et al. (2007, 2009) related width of current sheet *w* to M_A and the wavelength of the tearing mode λ as below:

$$w_{min} = {M_A}^{\alpha} \frac{\lambda}{2\pi}$$

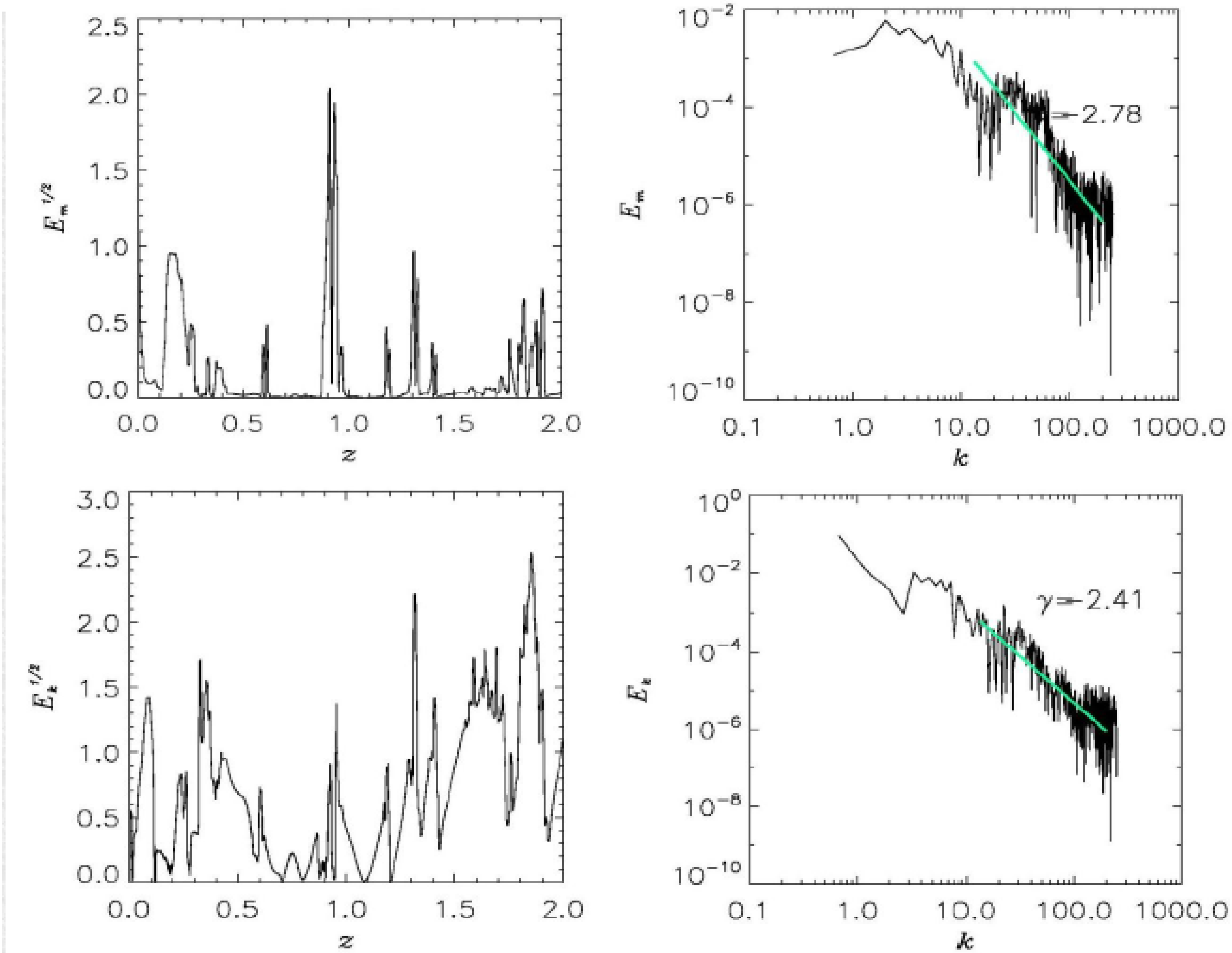
  α is a dimensionless parameter between 0 and 1.
- Lin et al. (2009) give α: $^1/_7 \backsim 1$.
- We have found 0.50 < α < 1.12 from three examples.

4. Spectral Analyses

- Spectral Analyses of the Reconnection Process in the Current Sheet .
- We perform 1D Fourier analysis of magnetic energy and kinetic energy along the direction of plasmoid movement to study the statistical properties of detailed structure in the reconnecting CS.



- Distributions of E_m (and E_k) and energy power along the red line.
- The average power law index varies gradually with time.



- Numerical experiments indicate that the magnetic energy cascades from large to small scales, magnetic islands move away form the CS, and they merge to one another occasionally where it is dissipated efficiently.
- The index of the power law spectrum is found steeper than 2 after the appearance of plasmoids inside the CS, compared to 5/3 for the Kolmogorov spectrum.

Conclusion

- Whether or not the tearing mode takes place in a long current sheet depends in an important way on the value of R_m. The critical value is 900~1000 in our simulations for β=0.1.
- Thinning of the sheet is not uniformly, a PX-point exist among multiple X- and O-points appear.
- Secondary X- and O-points move along the sheet either upward or downward depending on the relative location of the PX-point to the S-point.

Conclusion

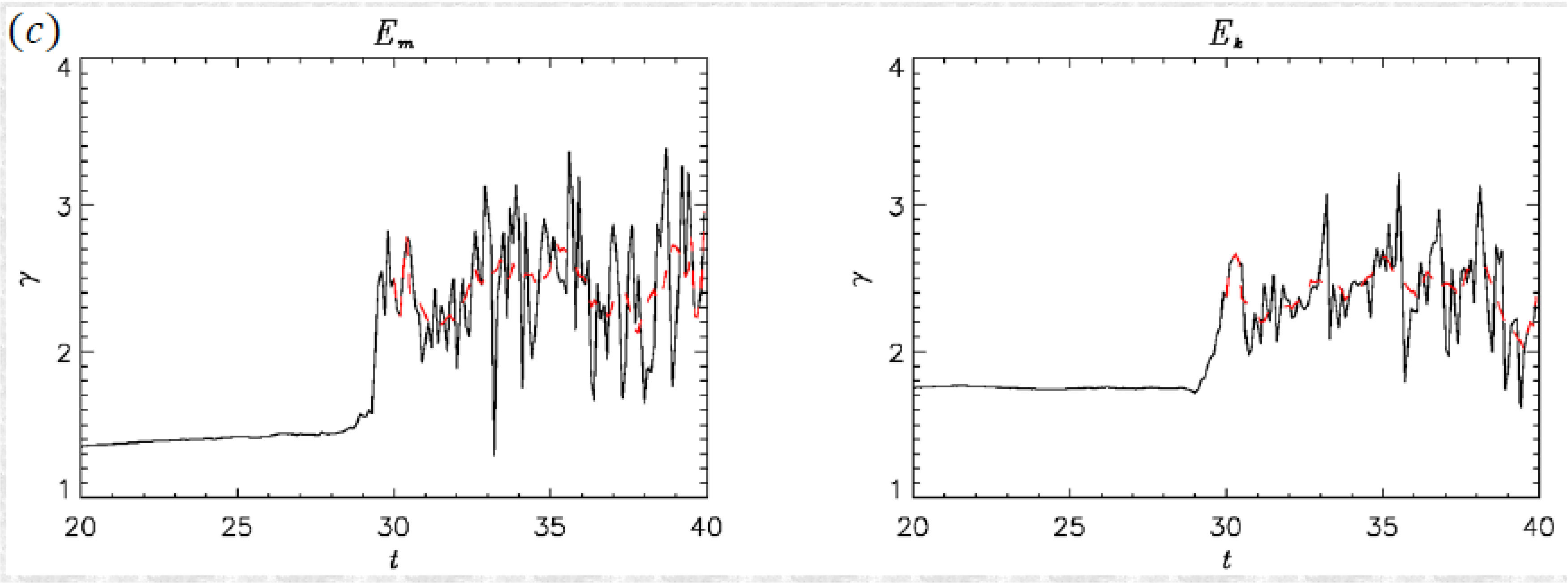
- In the same direction, the plasma behind a blob may flow faster than the blob.
- The appearance of the chain of magnetic islands is followed by a quick enhancement in both M_A and J.
- The relative locations of PX-point and S-point change with time and alternate back and forth.
- Values of α deduced in this work for the power law index is consistent with that obtained by Lin et al. (2009).

Thank you for

your attention!

Other pictures

- Power index and time



- Relative location of S-point to PX-point