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

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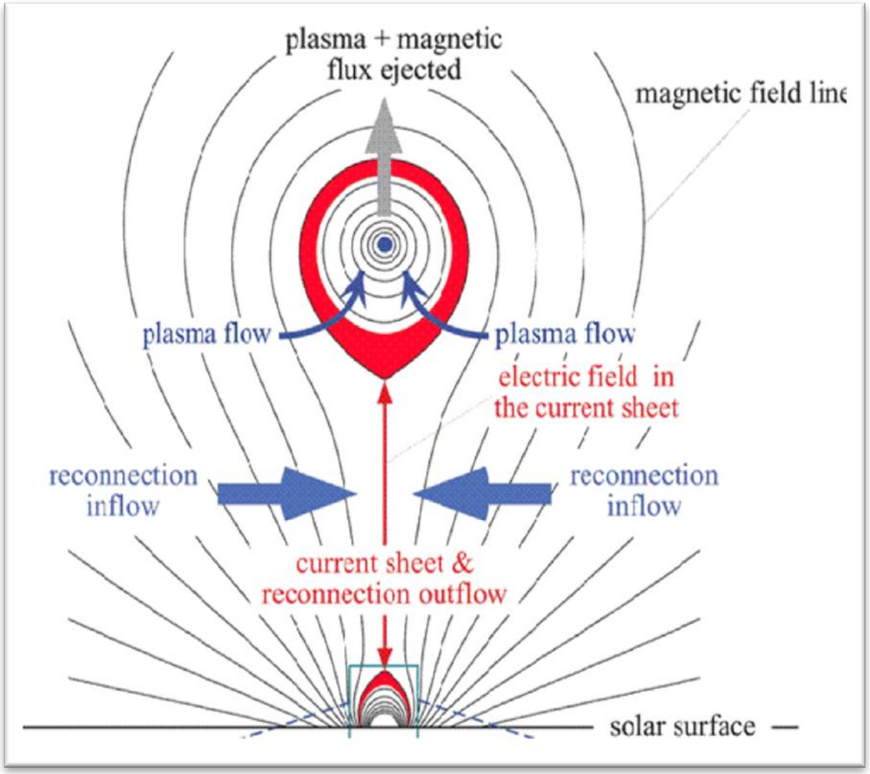
Content

- Background
- Dynamic characteristics of plasmoids in CME/flare current sheet
- Spectral properties of current sheet
- Conclusion

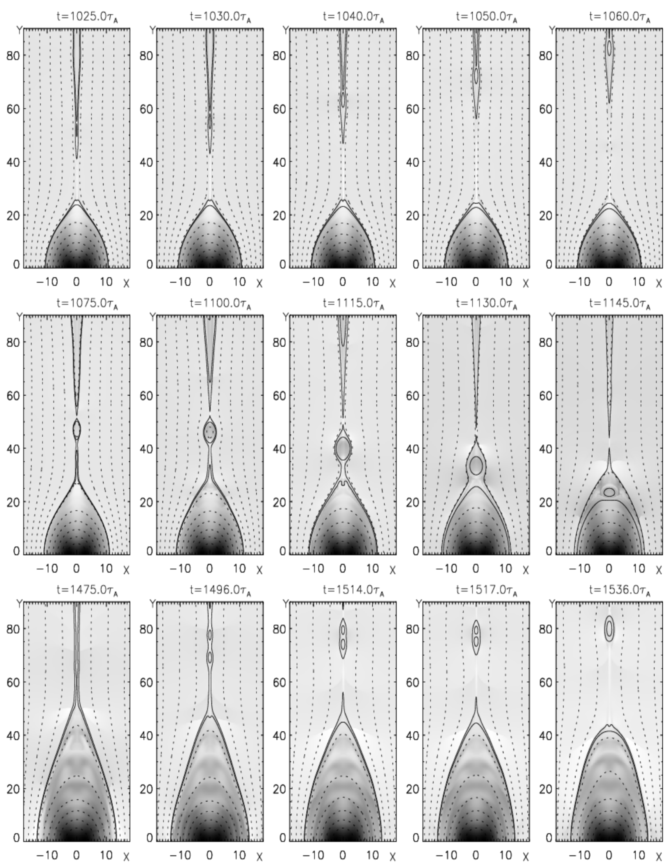
1. CME/Flare Current Sheet and Instability

- The CME/flare current sheet dynamically forms and develops in the eruptive process.
- Various plasma instabilities, such as the tearing mode and the plasmoid instabilities, may easily develop.
- Turbulent structures naturally form inside the sheet.
- Plasma blobs or plasmoids in the CS are observed during the eruptive events (e.g., see Ko *et al.* 2003; Lin *et al.* 2005; Savage *et al.* 2010)



(Lin & Forbes, 2000)

1. CME/Flare Current Sheet and Instability



(Bárta et al 2008)

- Numerical researches of CS in flare

Forbes & Malherbe (1991), Riley et al. (2007) Bárta 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 length instability when the ratio of length to width is large.

- Other recently researches:

Samtaney et al. 2009; Bhattacharjee et al. 2009 ; Skender & Lapenta 2010, Bettarini & Lapenta 2010, Murphy 2010, Shen et al 2011, Huang & Bhattacharjee 2010 discuss the relationship of blob scale and Lundquist number.

2. Dynamic characteristics of plasmoids

- 2D-MHD simulations
- The initial configuration is in both mechanical and thermal equilibrium;

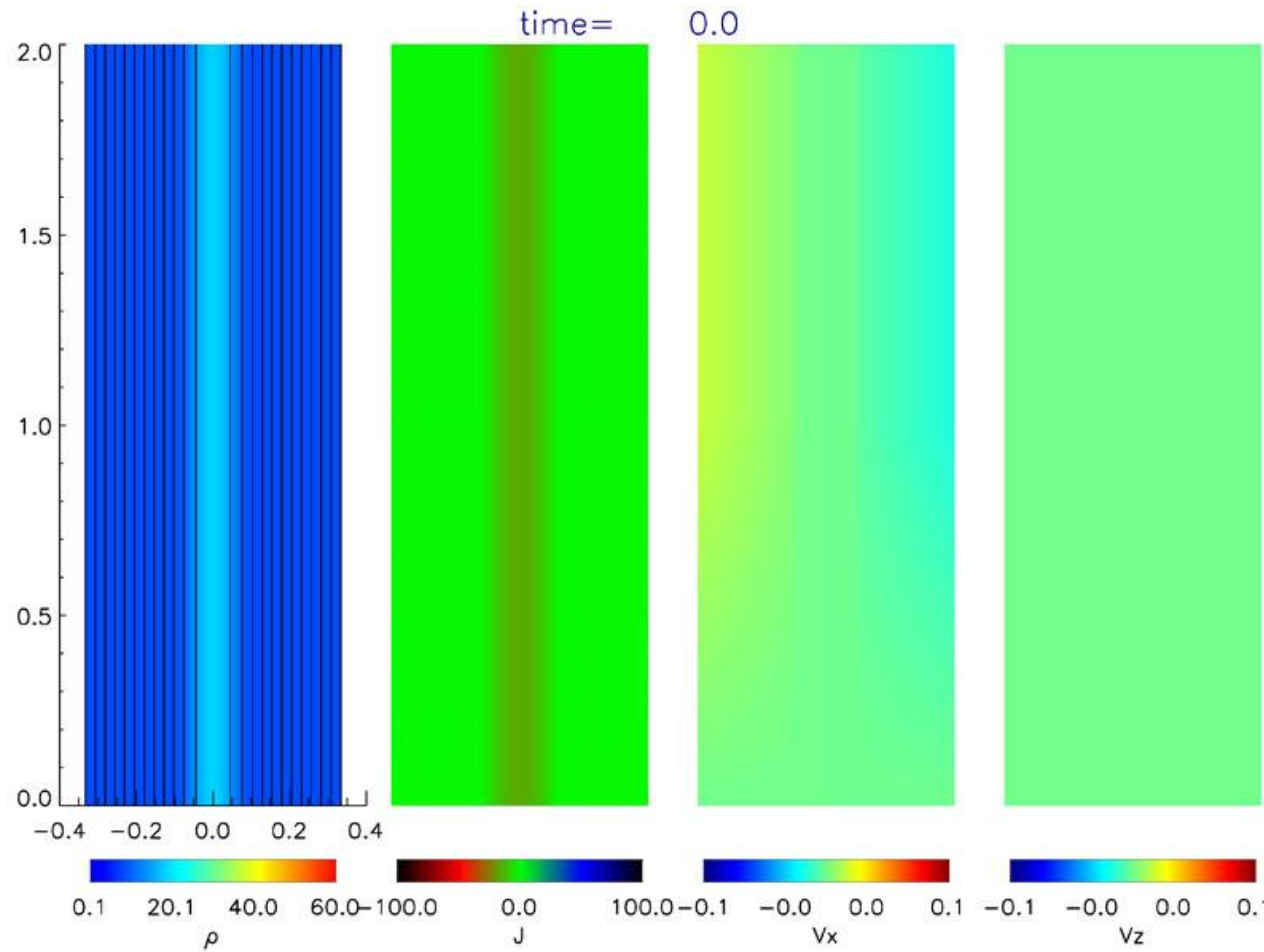
- Conditions:

(1) The left, right and top boundary are open boundary. The magnetic field is line-tied at bottom.

(2) The initial width of current sheet w=0.1L, and plasma β=0.1, R_m = 5.0X10^4.

(3) 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.

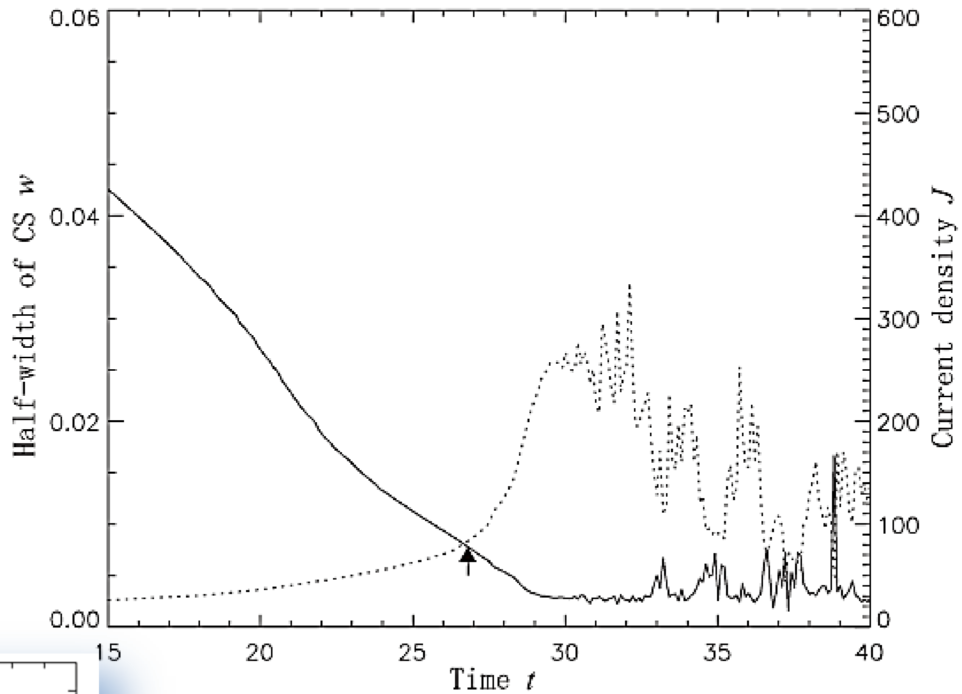


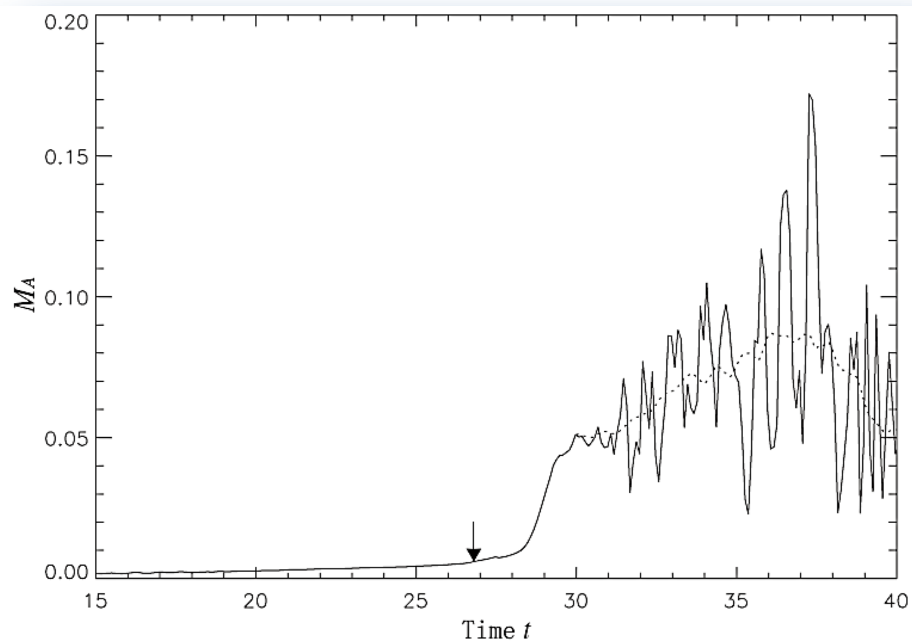
The distribution of density, current density and velocity during the evolution of CSs. (Shen, Lin & Murphy,2011)

- **Current density and Half-width of Current sheet**

The half-width w (solid line) 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.





- **The Rate of magnetic reconnection M_A.**

$$M_A = \frac{v_i}{v_A}$$

The solid line shows the instant value and the dotted line is for the corresponding average value. The arrow indicates time $t = 26.8\ \tau_A$ when the first magnetic island forms

2. Dynamic characteristics of plasmoids

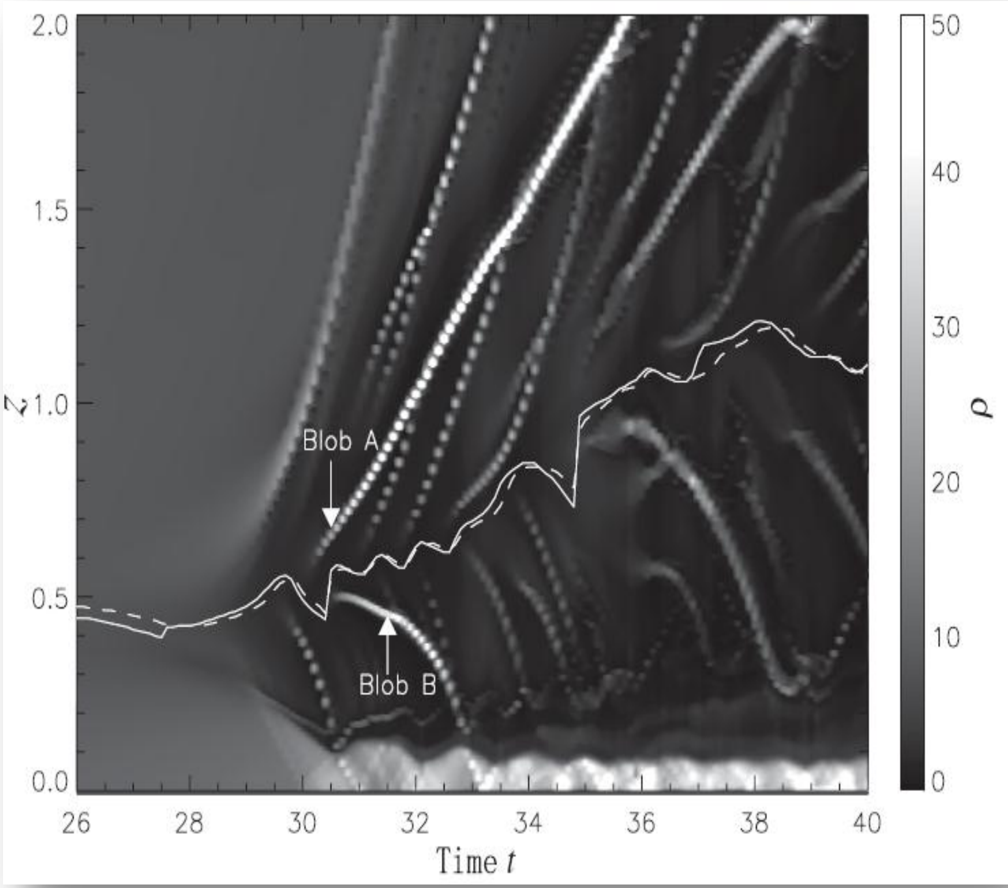
- **Movement of plasmoid**

Right figure shows locations of plasma blobs (white solid circles) along the z-axis as functions of time.

The relative locations of the stagnation (S-dashed) and principal X-point (PX-solid) change with time

- The direction in which a plasma blob moves is related to the S-point and PX-point

When the S-point is above the PX-point, newly appearing blobs move upward. When the S-point is below, newly formed blobs move downward.



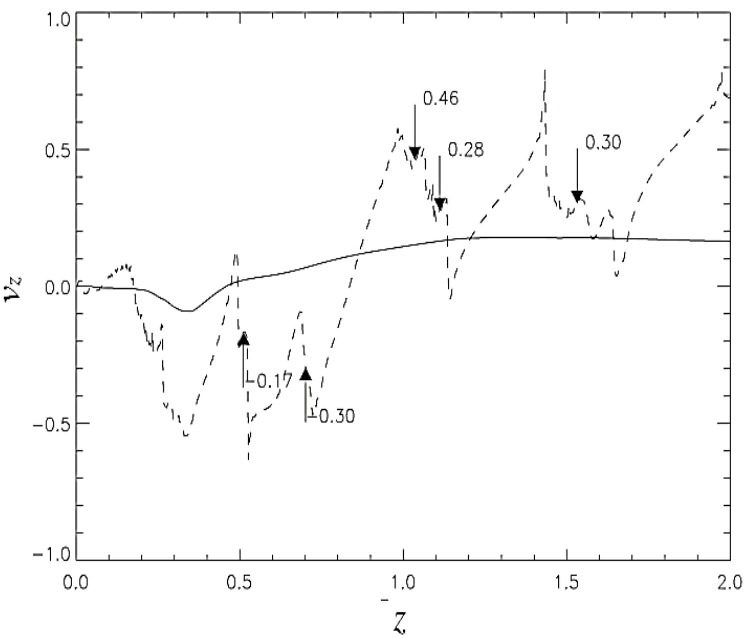
- **Plasmoid velocity**: Observational & numerical results

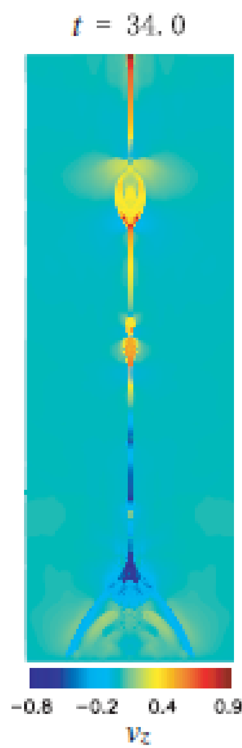
Reference	Sunward Blobs	Anti-Sunward Blobs
This work	89–159	147–242
McKenzie & Hudson (1999)	100–200	
Sheeley & Wang (2002)	50–100	
Ko et al. (2003)		140–650
Raymond et al. (2003)		1000
Asai et al. (2004)	100–250	
Sheeley et al. (2004)	100–600	
Lin et al. (2005)		460–1075
Vršnak et al. (2009)		100–1000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

(speed unit: *km/s*)

- Outflow velocity & plasmoid velocity:

The arrows indicate positions plasma blobs along the *z*-axis, and their instant speeds are specified by those numbers (unit is v_A).

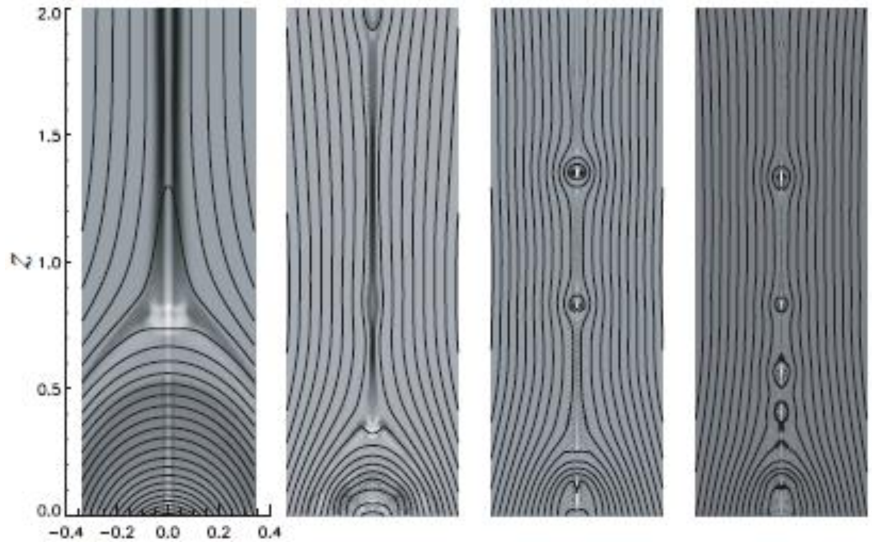


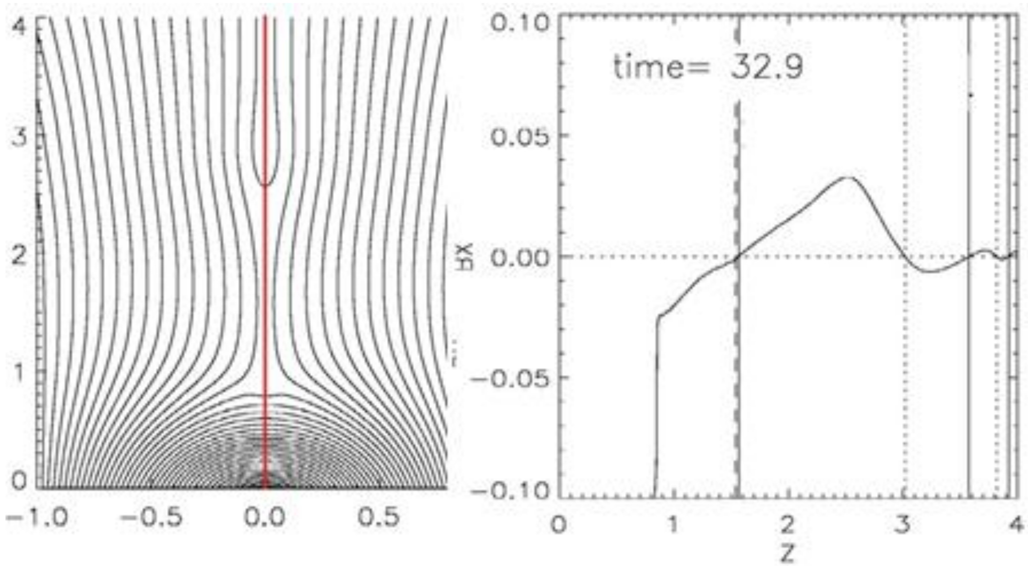


- **Critical R_m when plasmoids appear during the current sheet evolution**.

Right: the magnetic lines and current density for different case (R_m = 500, 10^4, $5\mathrm{x}10^4$ and $5\mathrm{x}10^5$).

Below: Critical R_m is about 900 for β=0.1 cases.



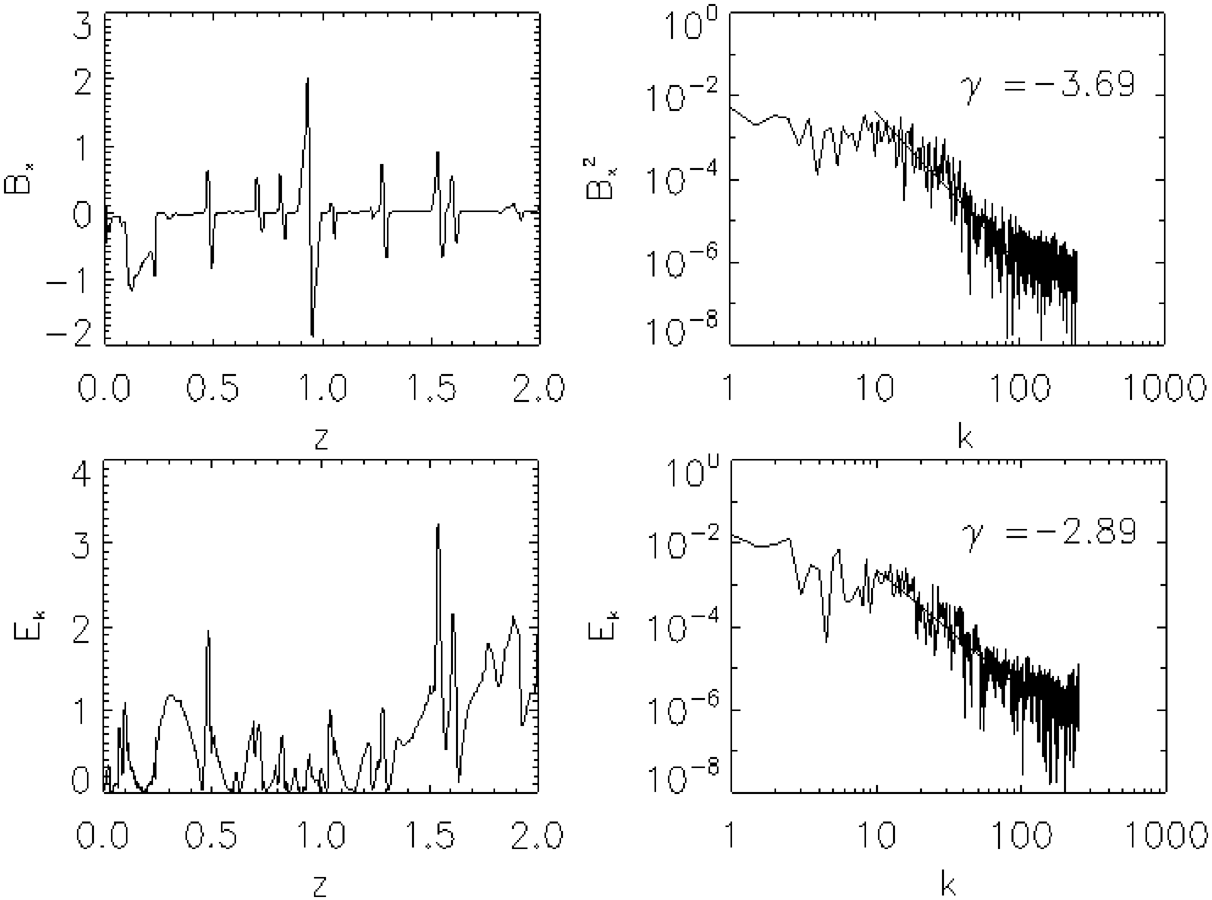


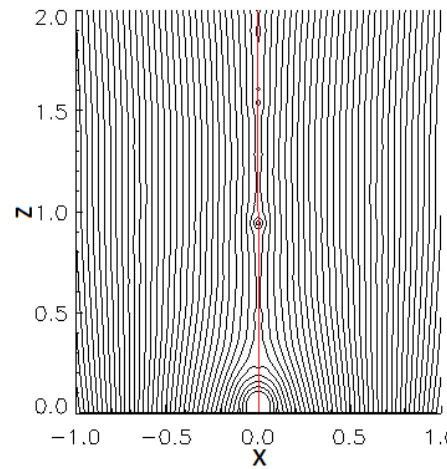
Left figures: Magnetic field lines and distrbution of B_x Initial w = 0.1L, β=0.1, R_m = 900.

The vertical dotted line indicate the location of magnetic island along the symmetrical axis(red line)

3. Spectral Properties of CSs

Below: Distributions of *Bx* (and E_k) and energy power along z-direction (red line) at time = 40.0 for case Rm = 10^5.
The power index γ is fixed in a range k=10 to k=100.

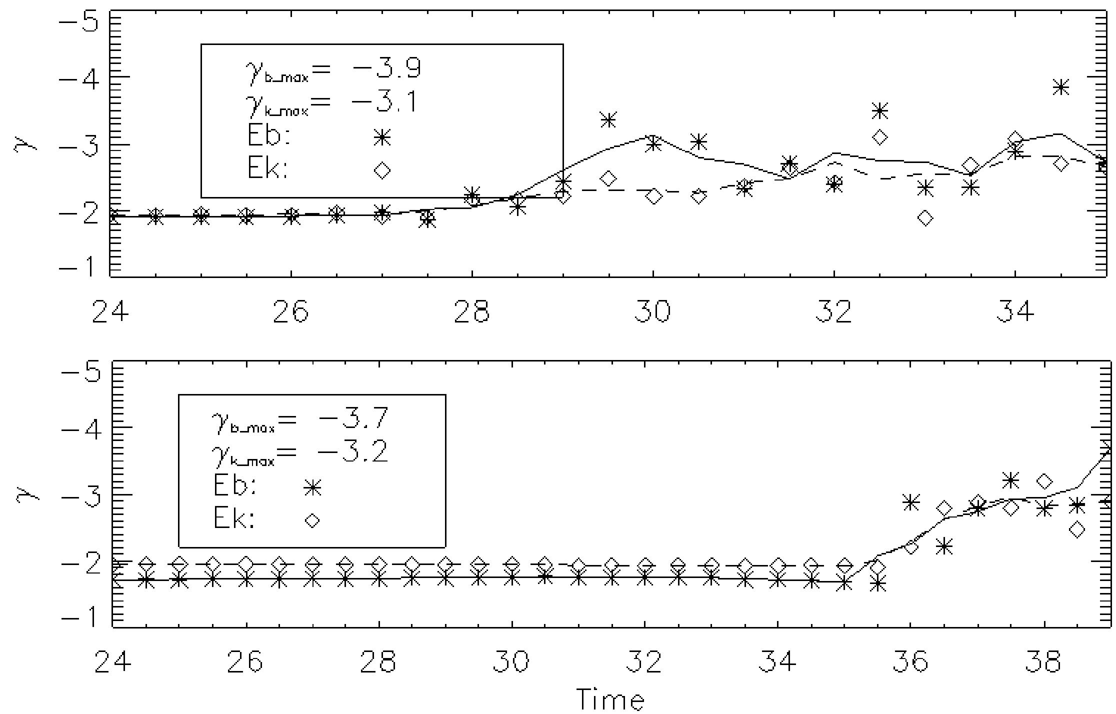




- The power law index is steeper than the Kolmogorov spectrum 5/3.
- Spectral properties of turbulent reconnection (Matthaeus & Lamkin 1986, Servidio et al. 2010) and cascade reconnection(Barta et al. 2011) are studied.

3. Spectral Properties of CSs

- Variations spectrum index γ with time.
- The average power law index varies gradually with time.
- power law index spectrum steeper than 2 after the appearance of plasmoids.



Above: $R_m = 1.0 \times 10^4$; Below: $Rm = 1.0 \times 10^5$

4. Conclusion

- The appearance of the chain of magnetic islands is followed by a quick enhancement in both M_A and J.
- The formation of plasmoids depends on R_m.
- Thinning of the sheet is not uniformly, a PX-point exist among multiple X- and O-points appear.
- Moving direction of newly plasmoids depends on the relative location of the PX- to the S-point.
- The relative locations of PX- and S-point change with time and alternate back and forth.

4. Conclusion

- The plasma flow behind a blob is faster than the moving blob.
- Power low index γ is steeper than Kolmogorov spectrum 5/3 after formation of plasmoids.
- γ varies gradually with time.

Thank you!