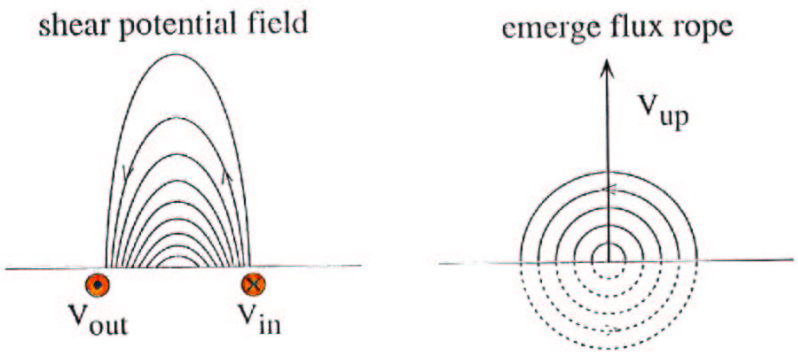
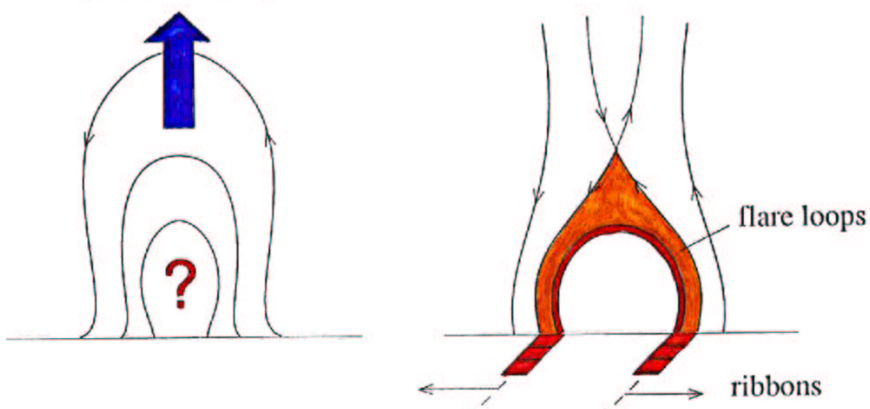
Reconnection in Solar Eruptions

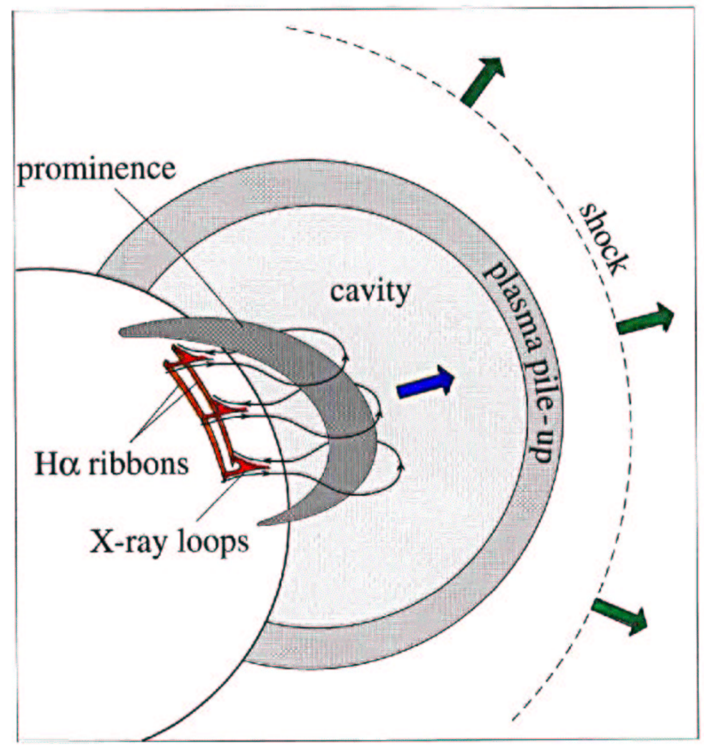
Creation of Coronal Current



Eruption **Reconnection**

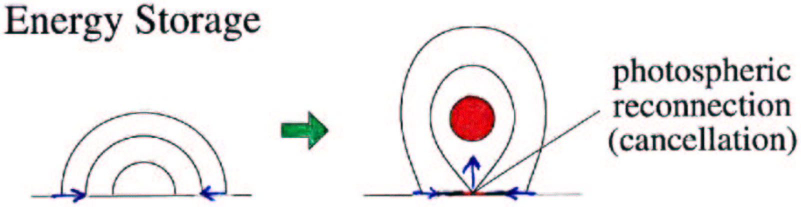


Magnetic Reconnection in Solar Eruptions

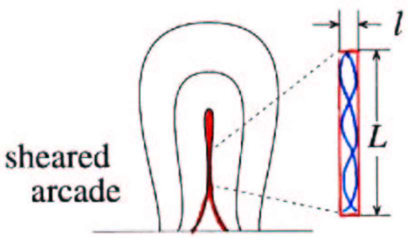


Possible Roles:

1. Energy Storage



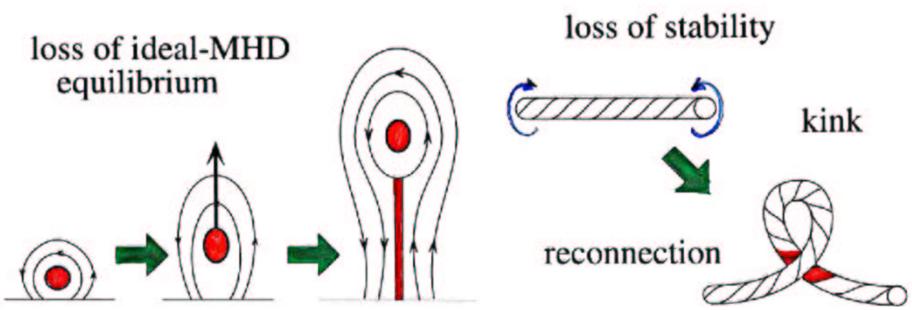
2. Trigger Mechanism



tearing threshold
$L > 2\pi l$

anomalous resistivity
$j > j_{critical}$

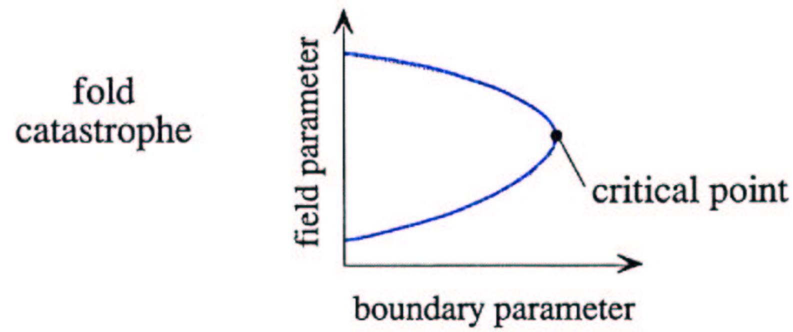
3. Energy Release



Trigger Mechanisms

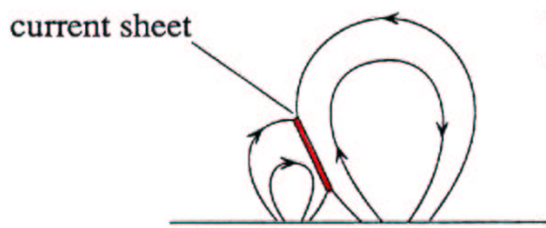
1. Loss of ideal-MHD equilibrium / instability
Catastrophe Theory

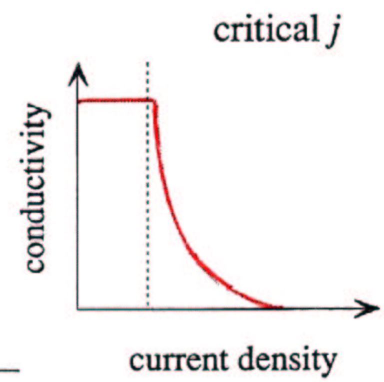
an old idea but many flawed solutions



2. Kinetic processes

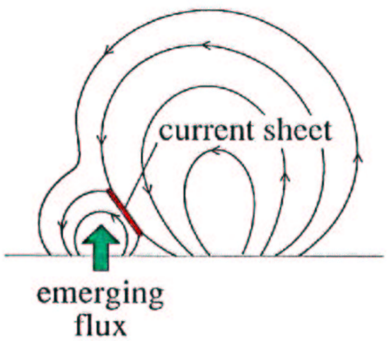
colliding loops:

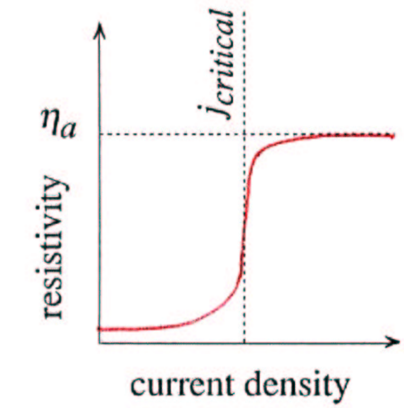




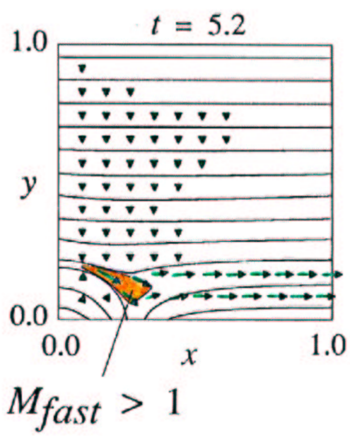
Does a Current Sheet Exist Prior to Onset?

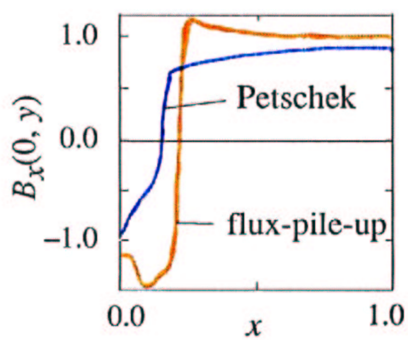
Emerging flux model:





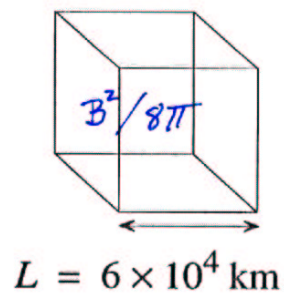
Simulation at $R_m = 10^3$

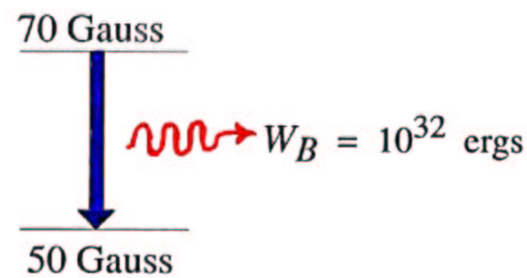




Answer: Not very likely

Reconnection Rate





$$\tau_d = L^2 / \eta$$

$\eta = 0.35\ \text{m}^2/\text{s}$ (collisional) → $\tau_d = 3 \times 10^8$ yrs !

Two routes to fast reconnection:

1. Reduce scale-length L
2. Anomalous resistivity for η

Two Routes to Fast Reconnection:

1. Reduce scale-length from L to l

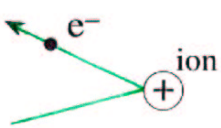
$$\tau_d = \tau_{flare} = 10^3 \text{ sec} \quad l = \sqrt{\eta\, \tau_{flare}} = 20 \text{ meters}$$

↑ collisional

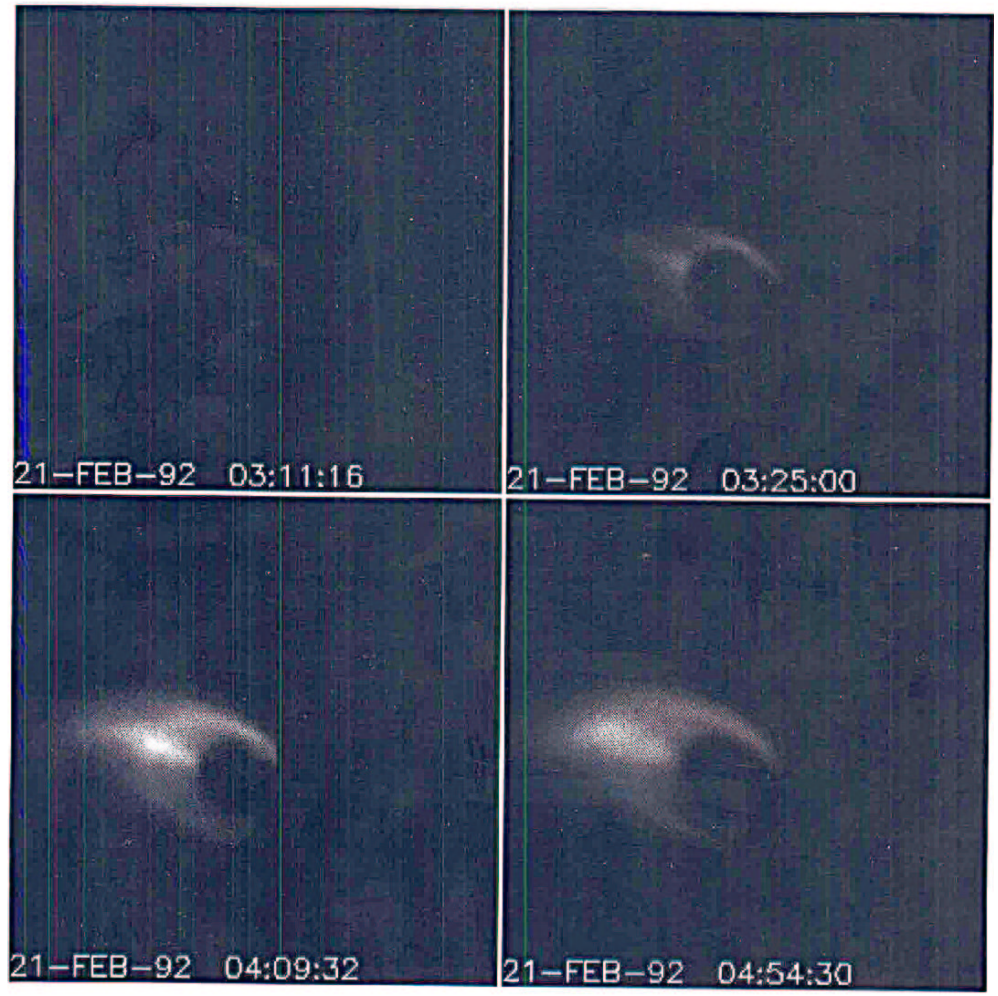
turbulence x collapse Petschek

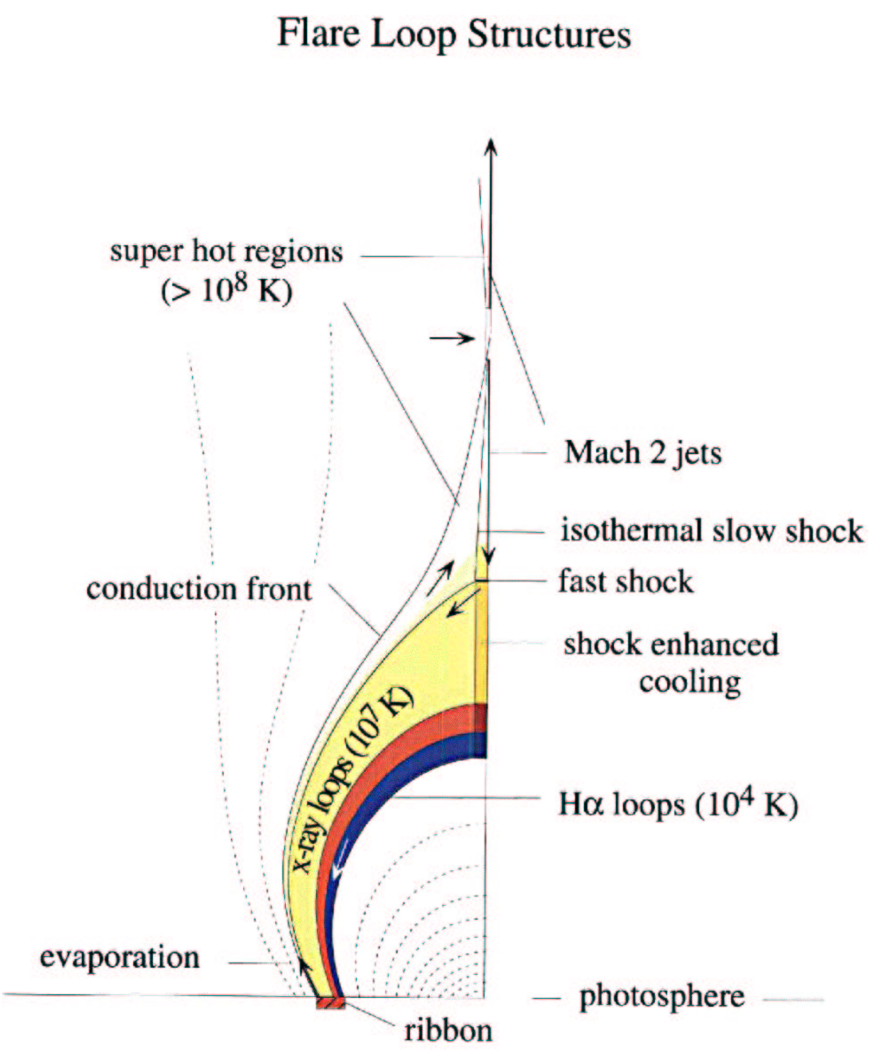
2. Anomalous resistivity η_a

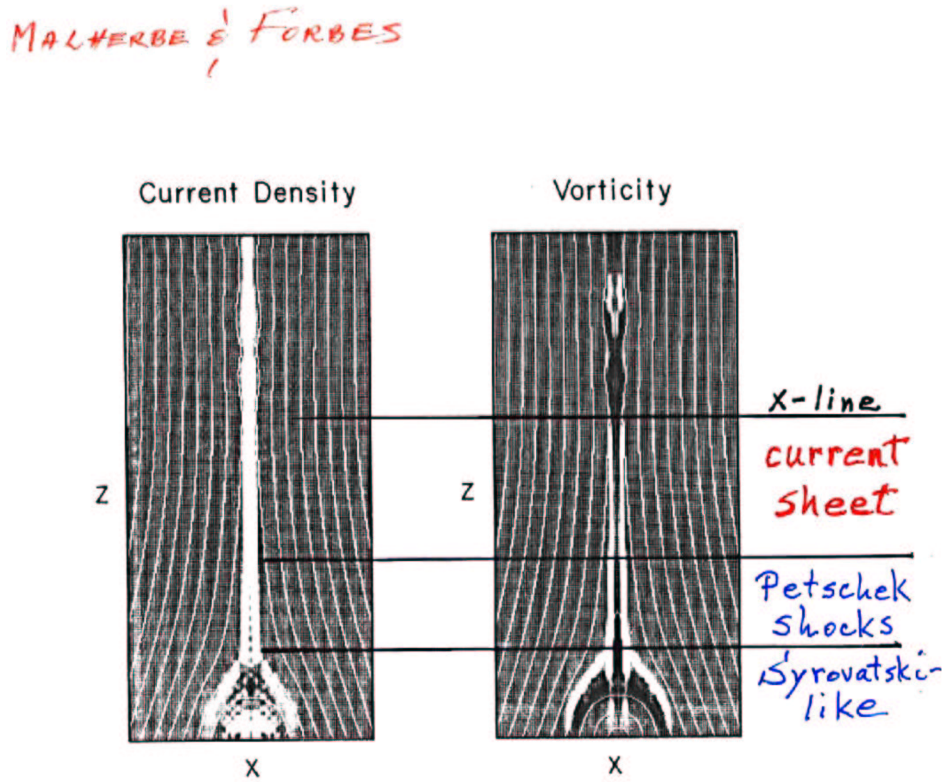
collisional mean free path $\lambda_{ei} \gtrsim 10$ km



$$\eta_a = \lambda_{ei}^2 / \tau_{flare} = 3 \times 10^5 \ \eta$$

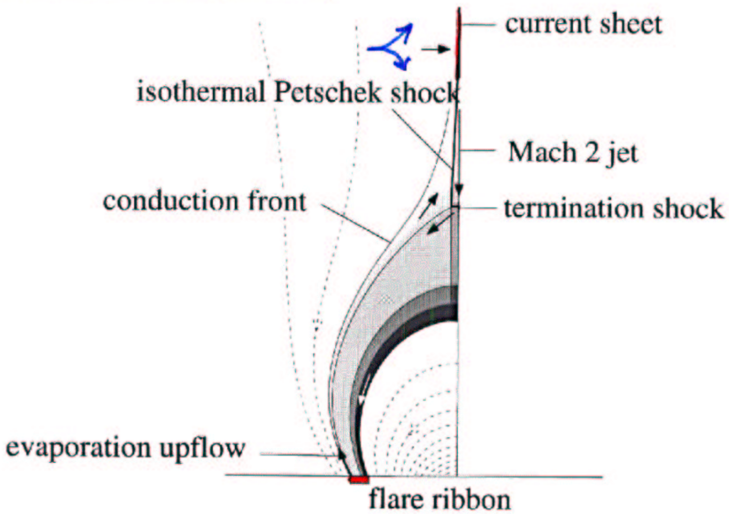



Flare Loop Structures
super hot regions
(> 10^8 K)
Mach 2 jets
isothermal slow shock
fast shock
conduction front
shock enhanced
cooling
x-ray loops (10^7 K)
Hα loops (10^4 K)
evaporation
photosphere
ribbon

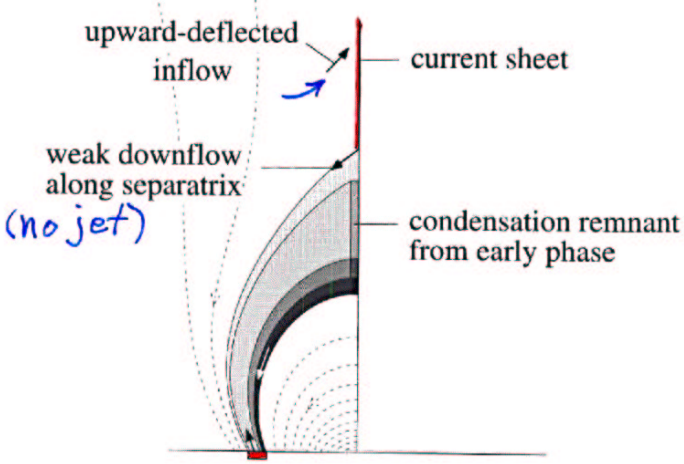

MALHERBE & FORBES
Current Density
Vorticity
z
z
x
x
x-line
current
sheet
Petschek
shocks
Syrovatski-
like

Flare Loop Models

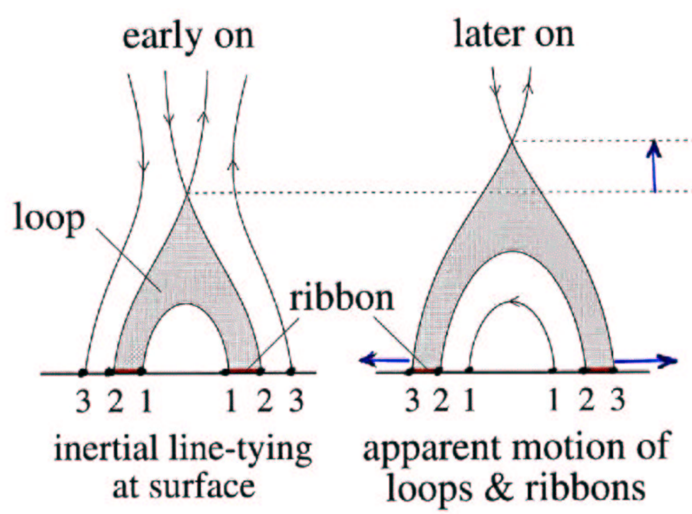
Supermagnetosonic ($\beta < 1$)

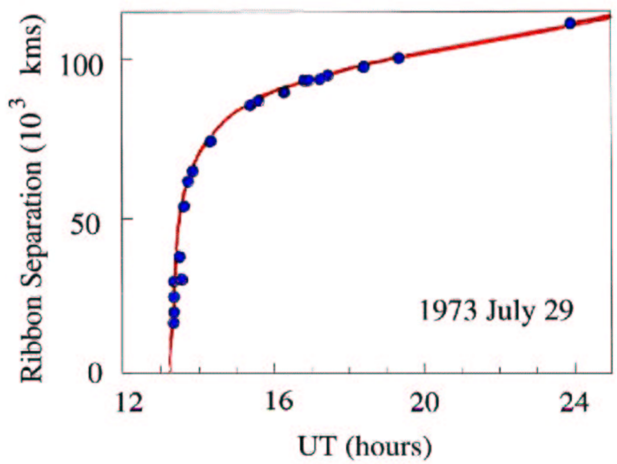


Submagnetosonic ($\beta > 1$)

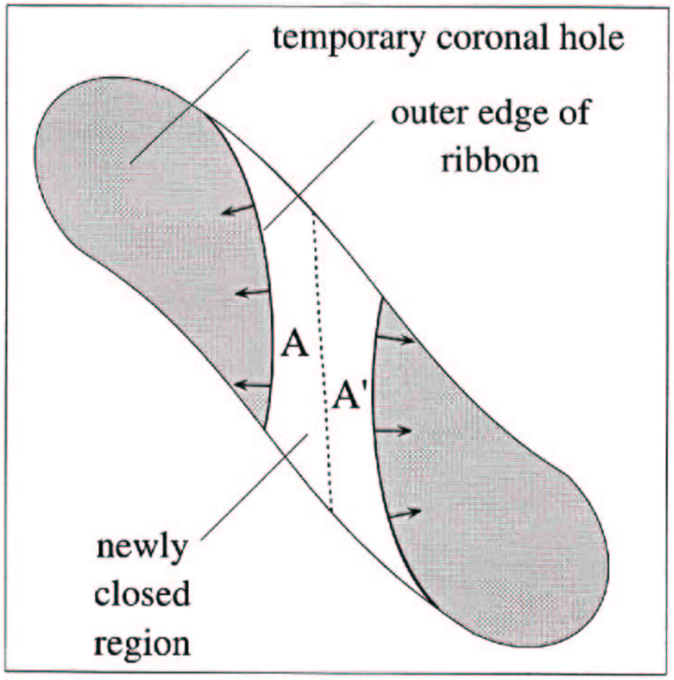


Apparent Motion of Loops & Ribbons





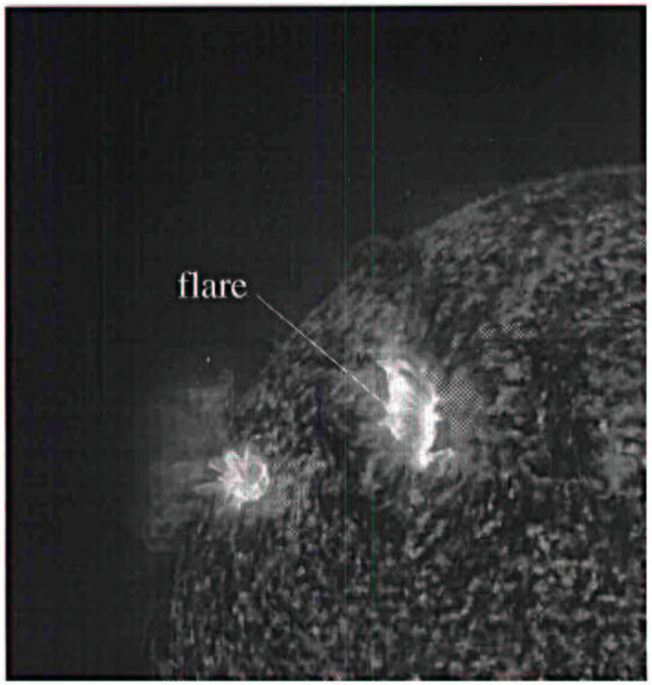
Global Rate of Reconnection



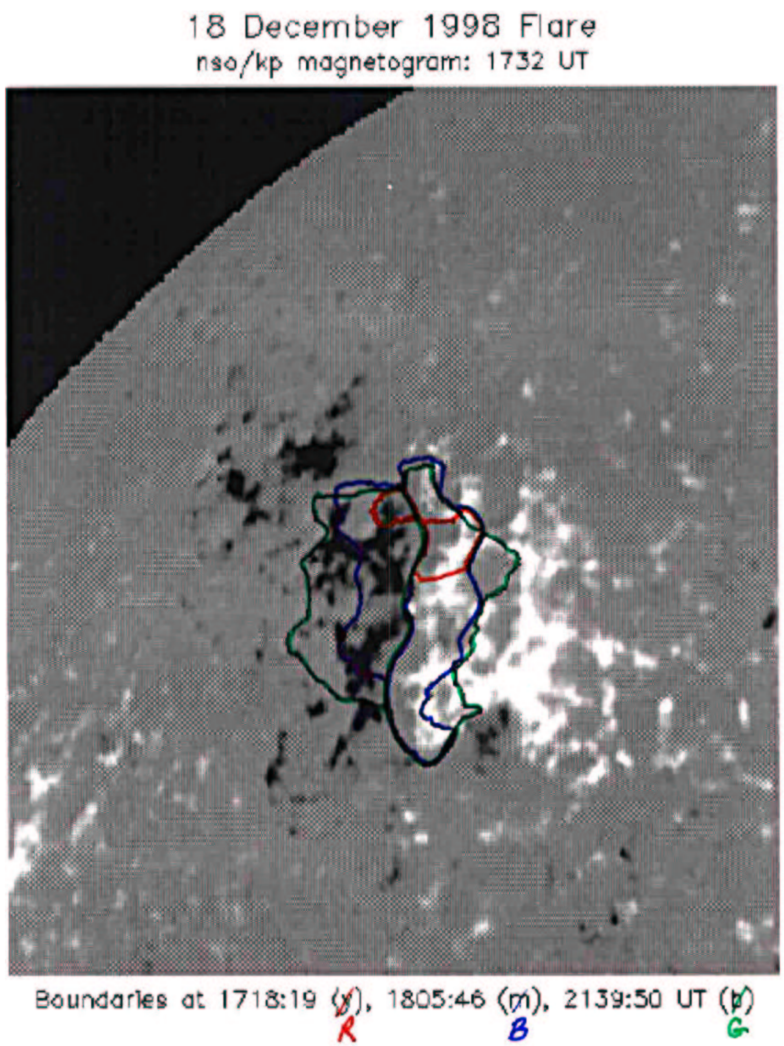
$$\dot{\Phi} = \int E_o ds = \oint_c B_n V_\perp dl$$

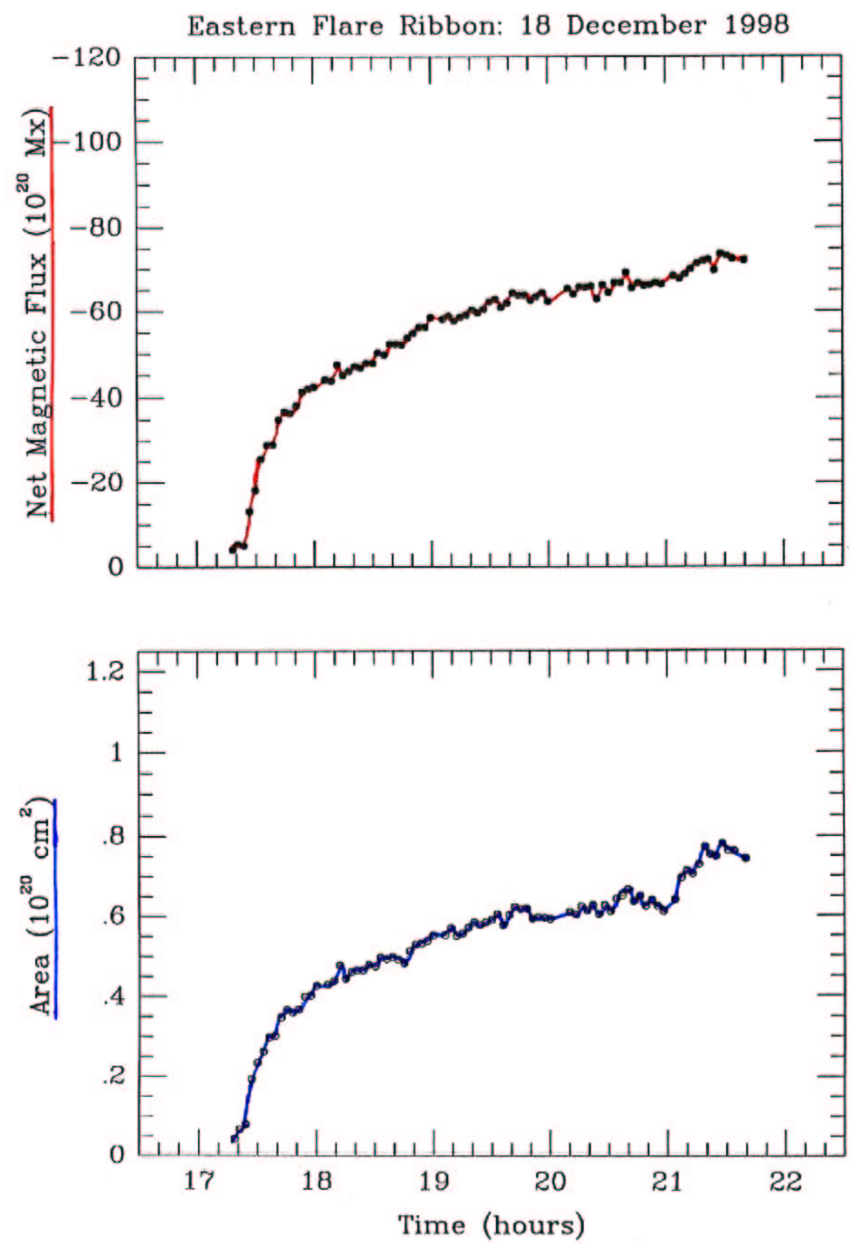
growth of flux in A — voltage drop along separator — normal magnetic field — boundary (ribbon) velocity

Calculation of Reconnection Rate from Ribbon Motion

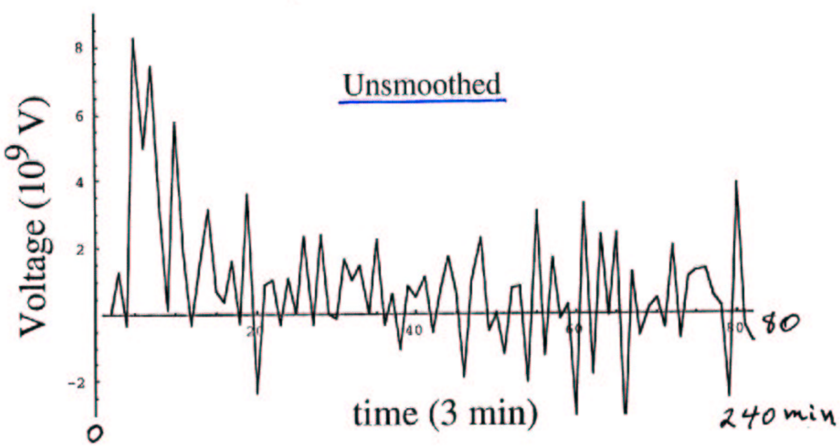


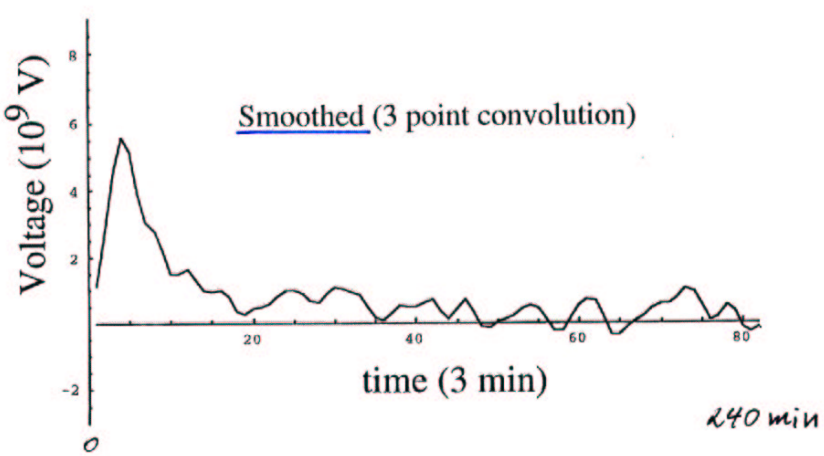
SOHO EIT, He II line, 304 Å
December 18, 1998 at 19:23


18 December 1998 Flare
nso/kp magnetogram: 1732 UT
Boundaries at 1718:19 (y), 1805:46 (m), 2139:50 UT (b)
R
B
G

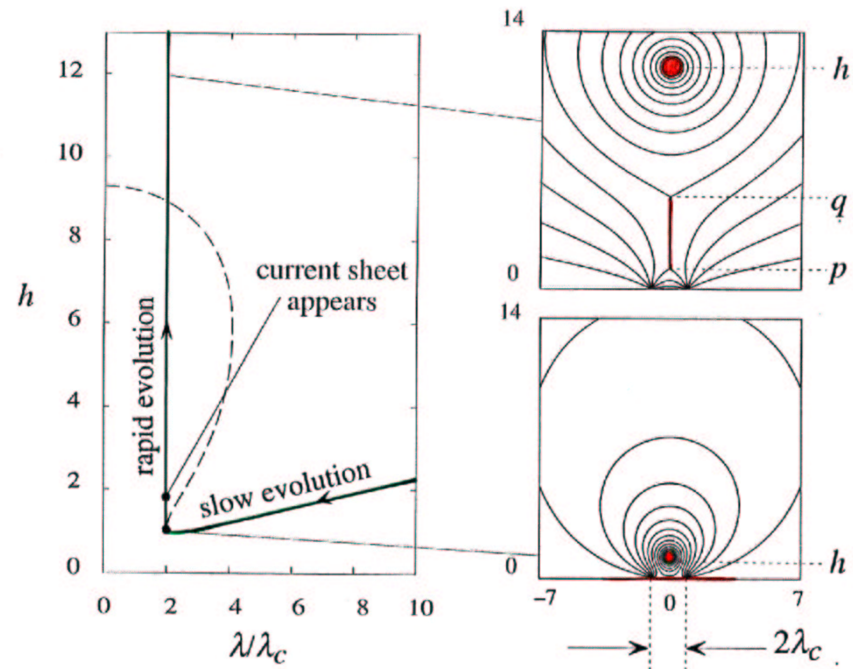

Eastern Flare Ribbon: 18 December 1998
Net Magnetic Flux (10^{20} Mx)
−120
−100
−80
−60
−40
−20
0
Area (10^{20} cm^2)
1.2
1
.8
.6
.4
.2
0
17
18
19
20
21
22
Time (hours)

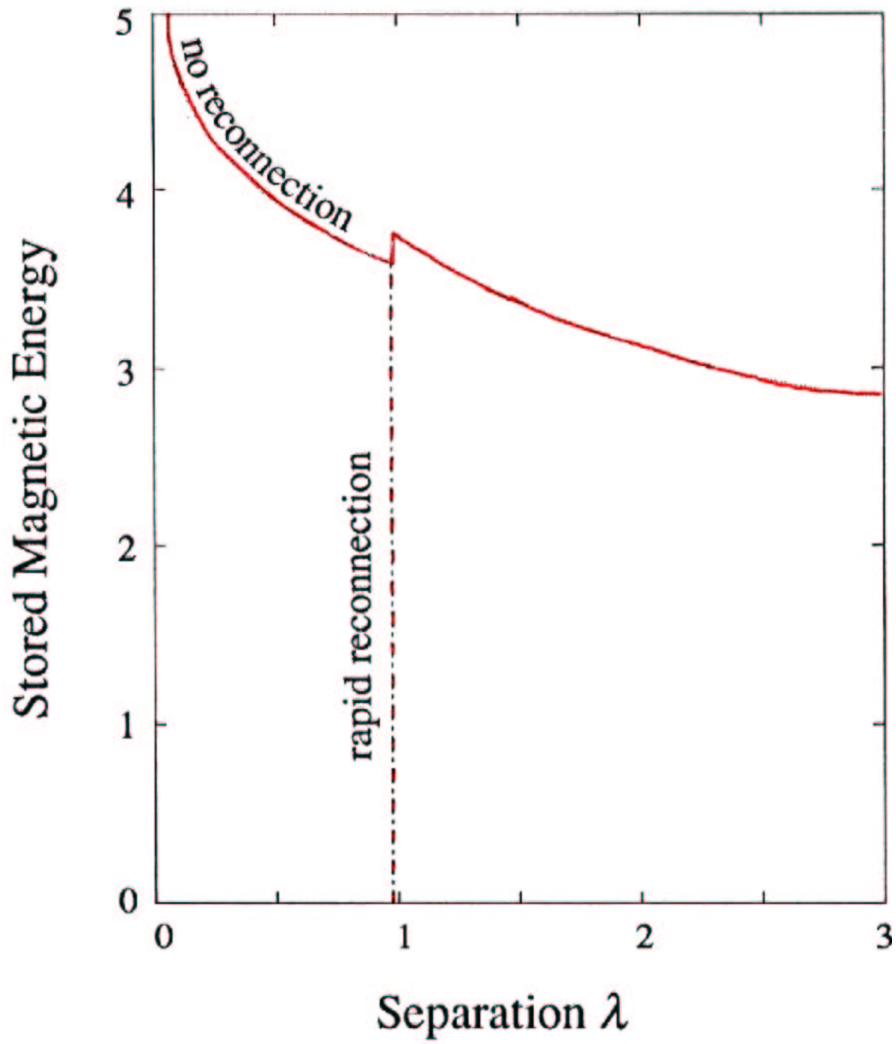
Voltage Drop Along Separator
(from east ribbon)

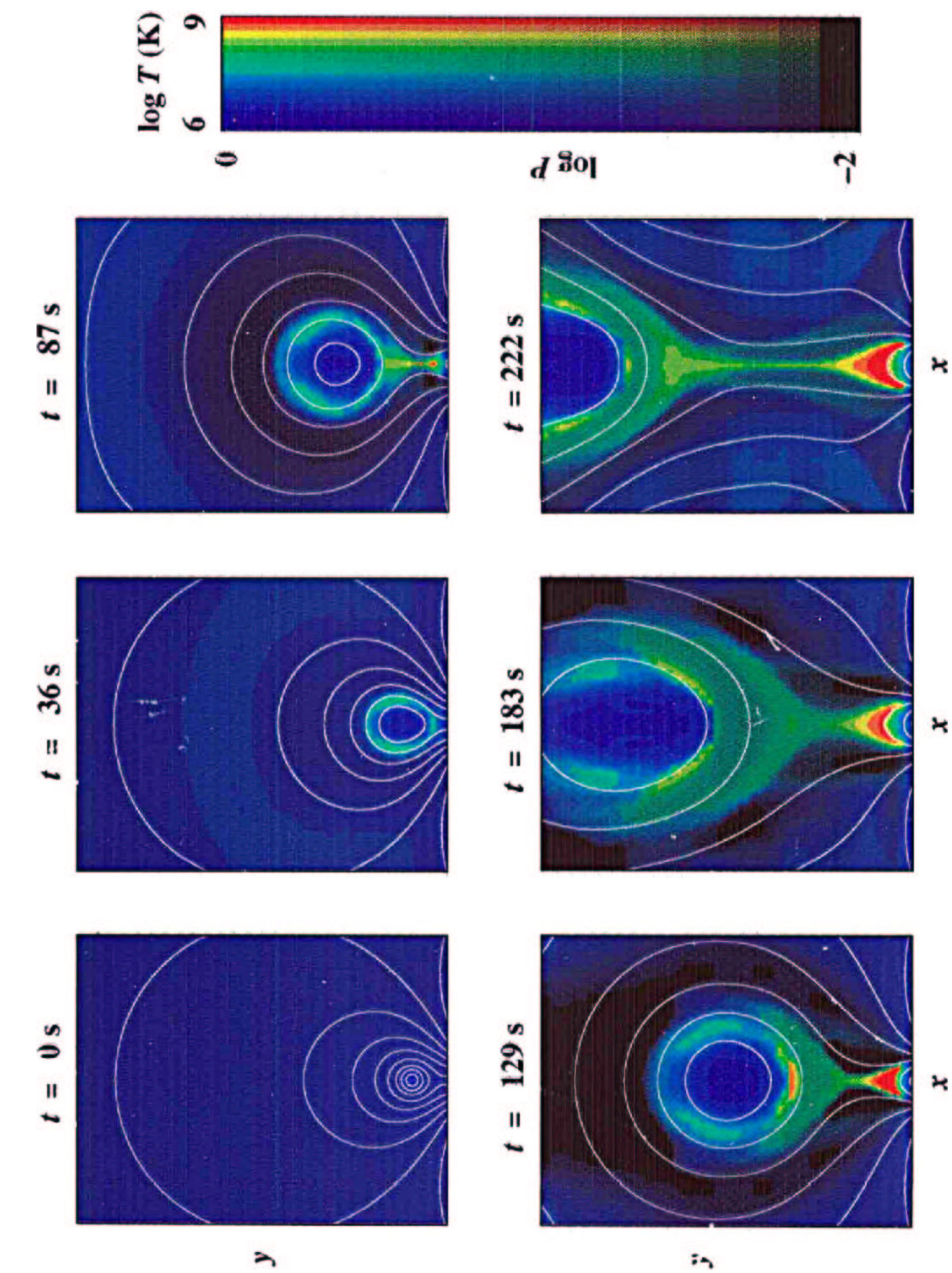


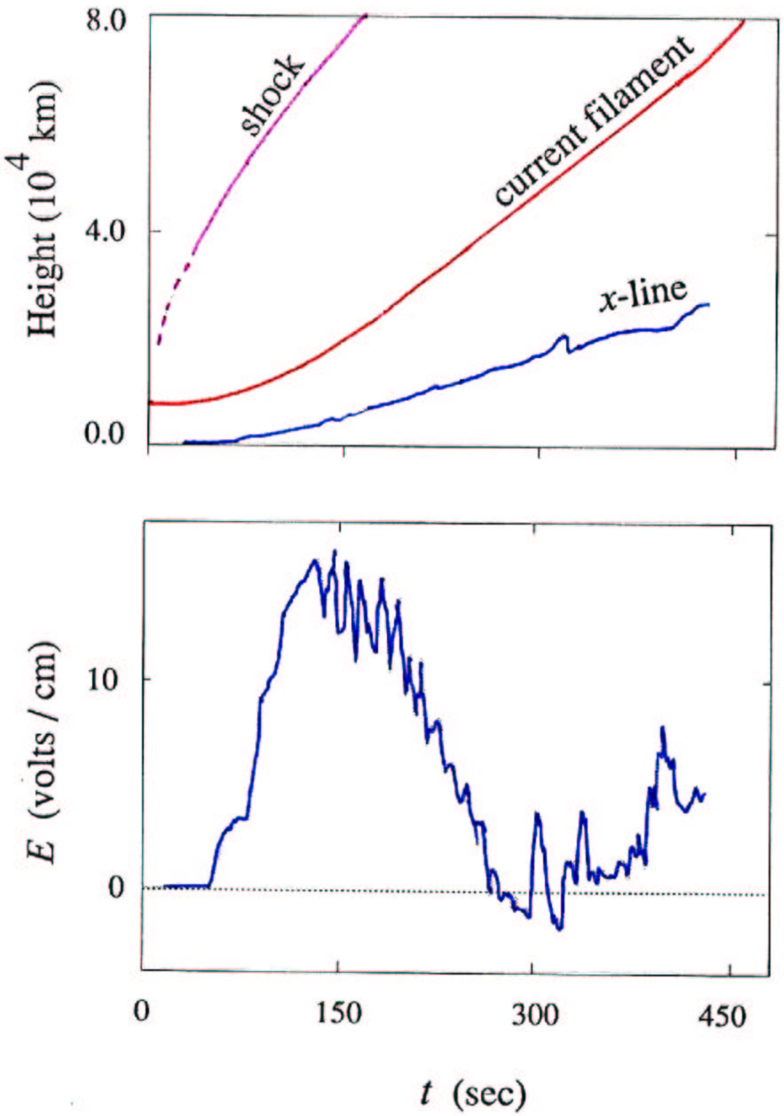


2D Flux-Rope Model




Stored Magnetic Energy
Separation λ
no reconnection
rapid reconnection
0
1
2
3
4
5

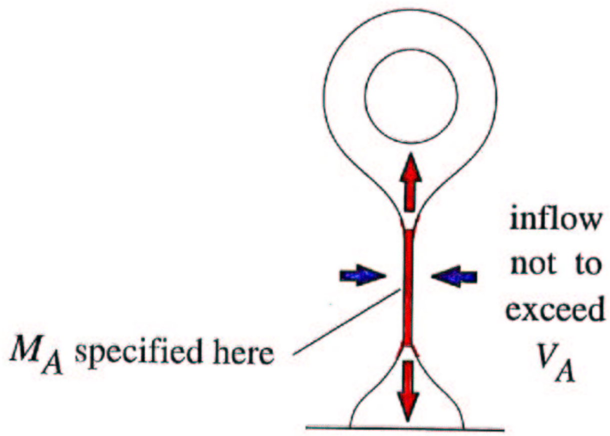

log T (K)
6
9
log ρ
0
−2
t = 87 s
t = 36 s
t = 0 s
t = 222 s
t = 183 s
t = 129 s
x
y

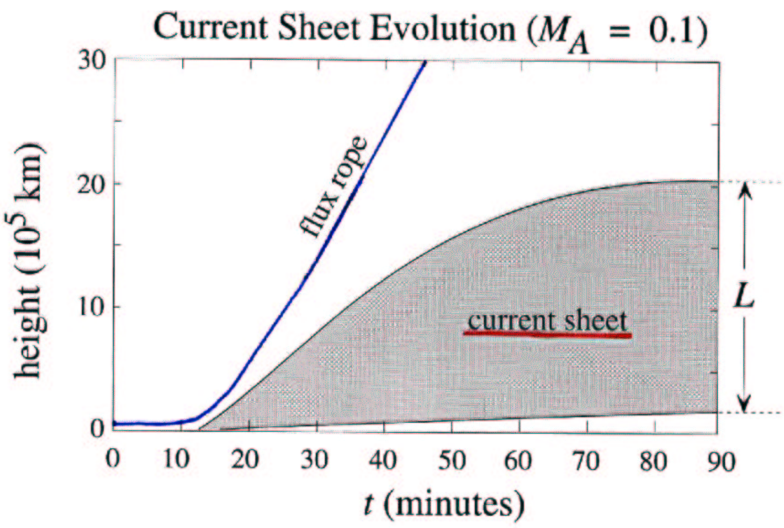


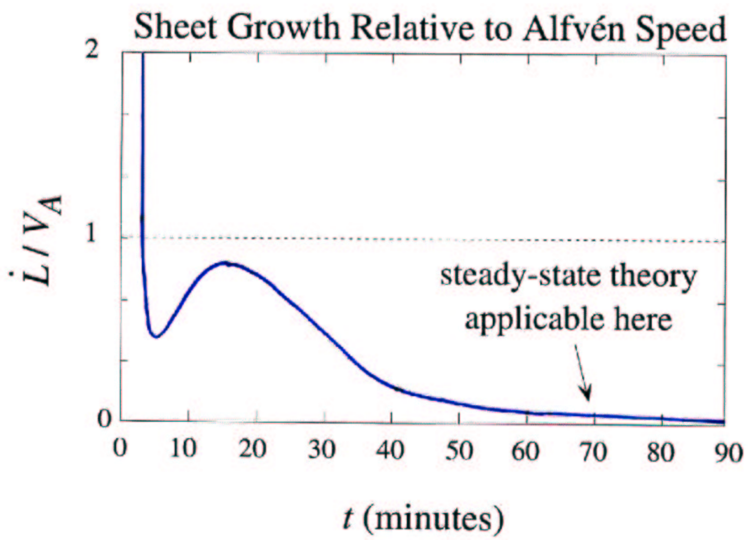
Dynamics

- Parameterize reconnection by Alfvén Mach number, M_A, at midpoint of current sheet
- Treat the flux rope as a projectile
- Consider three types of reconnection:

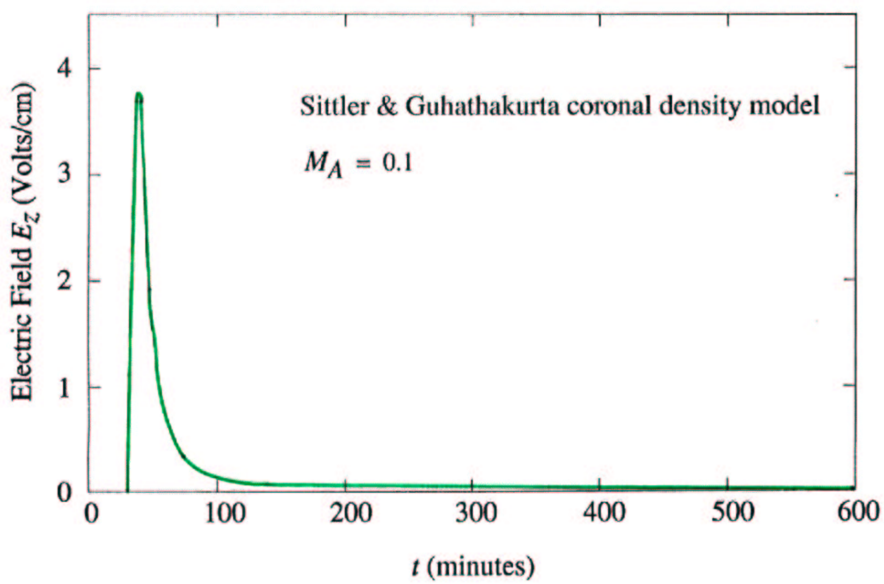
1. Turbulence: $M_A = \text{const.} < 1$
2. Petschek: $M_A = \pi / (8 \log R_m)$
3. Sweet-Parker: $M_A = R_m^{-1/2}$







Electric Field Predicted by 2D Flux-Rope Model



Reconnecting Current Sheet

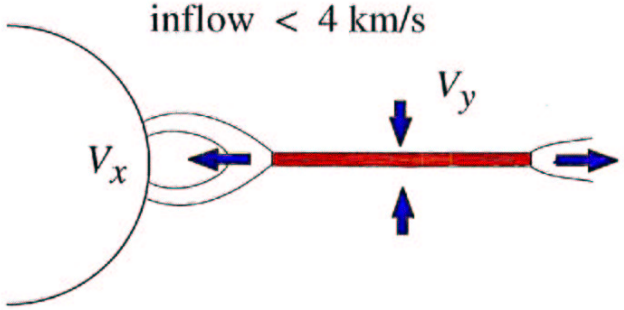
McKenzie & Hudson:

> 16 events

sheet outflow ≈ 50 to 400 km/s

Yokoyama et al.:

inflow < 4 km/s



Observables	Theory Parameters
emission measure: $n^2\, l \sin\theta$	magnetic field: **B**
temperature: T	density: n
flow along sheet: V_x	temperature: T
flow into sheet: Vy	flow: **V**
sheet length: L	~~electrical resistivity~~ magnetic diffusivity: η
	sheet thickness: l
	sheet length: L

$V_y = \eta / l$

Unanswered Questions

1. What roles does reconnection play?
   (a) storage
   (b) trigger mechanism
   (c) energy release & field relaxation?
2. What are the relative importance of kinetic and MHD processes in the current sheet and how do both work?
3. How does reconnection work during impulsive phase?
4. What observations are needed to calculate the effective anomalous resistivity in the corona?