

Energetics of Reconnection:

A Comparison of Steady and
Transient Models in
1, 2 and 3 Dimensions

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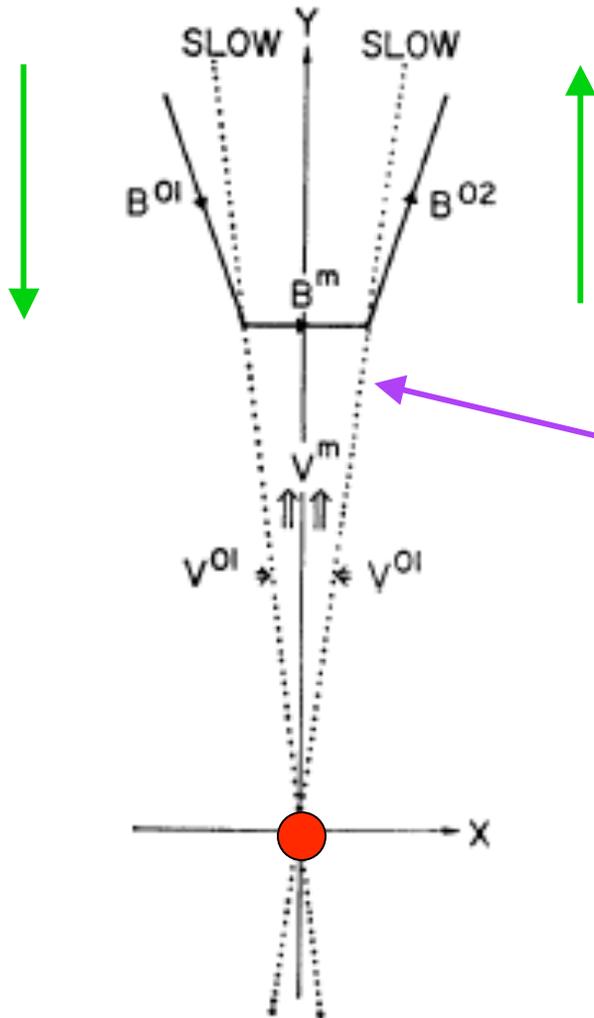
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Thanks: Terry Forbes

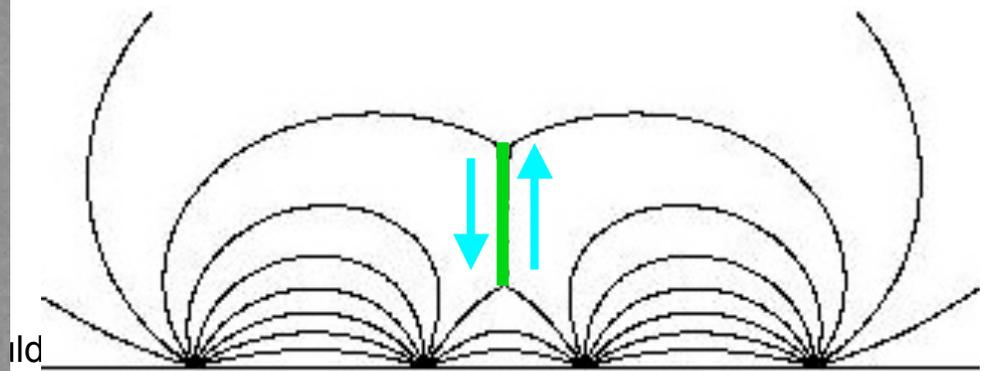
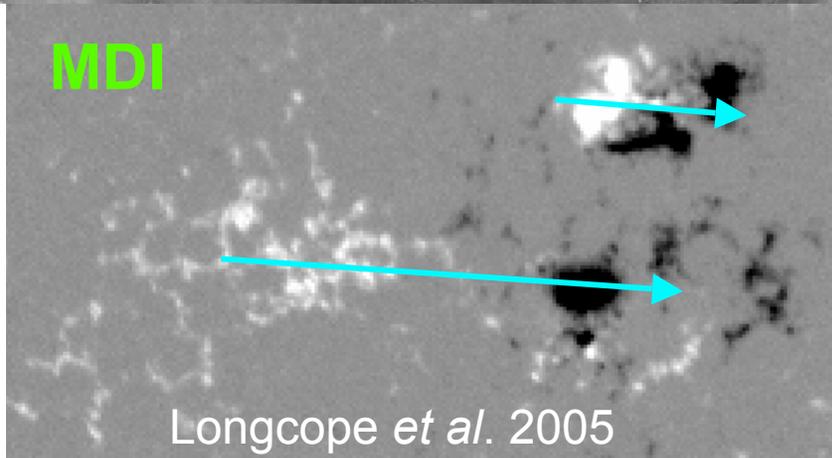
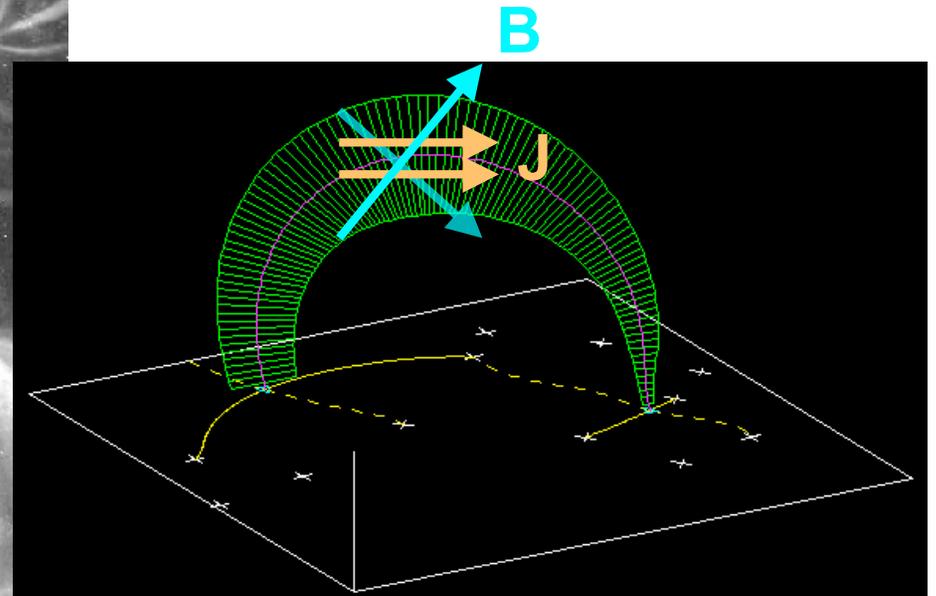
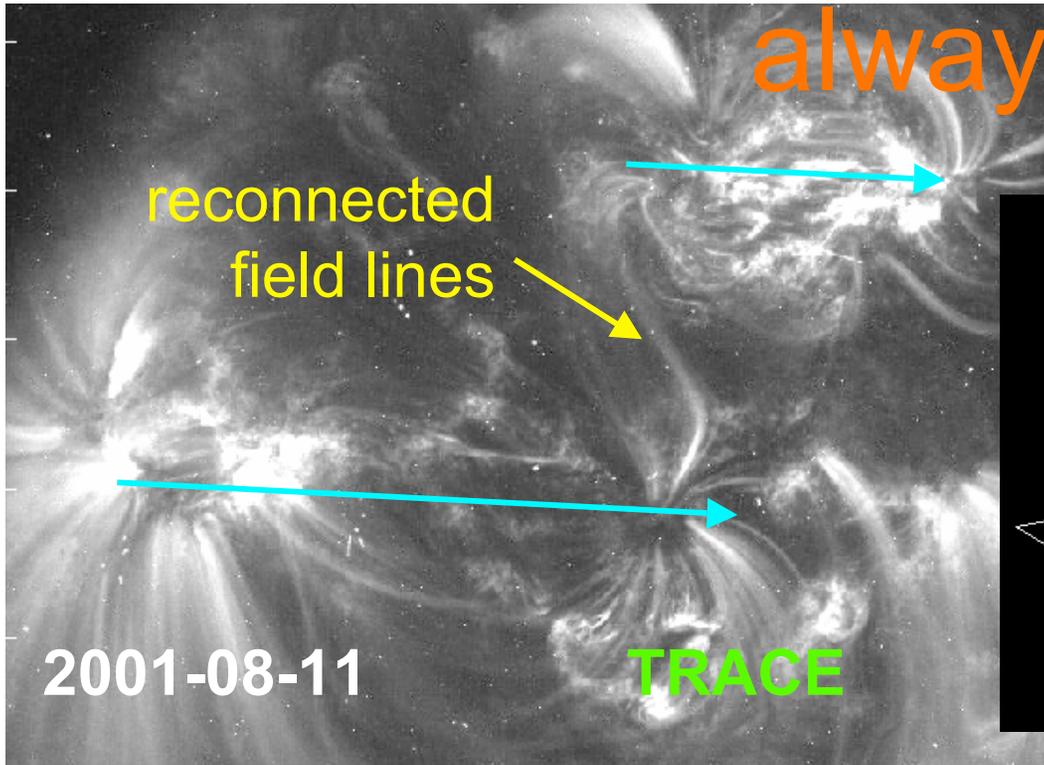
Classical Petschek

Petschek 1964
Vasyliunas 1975
Soward & Priest 1982

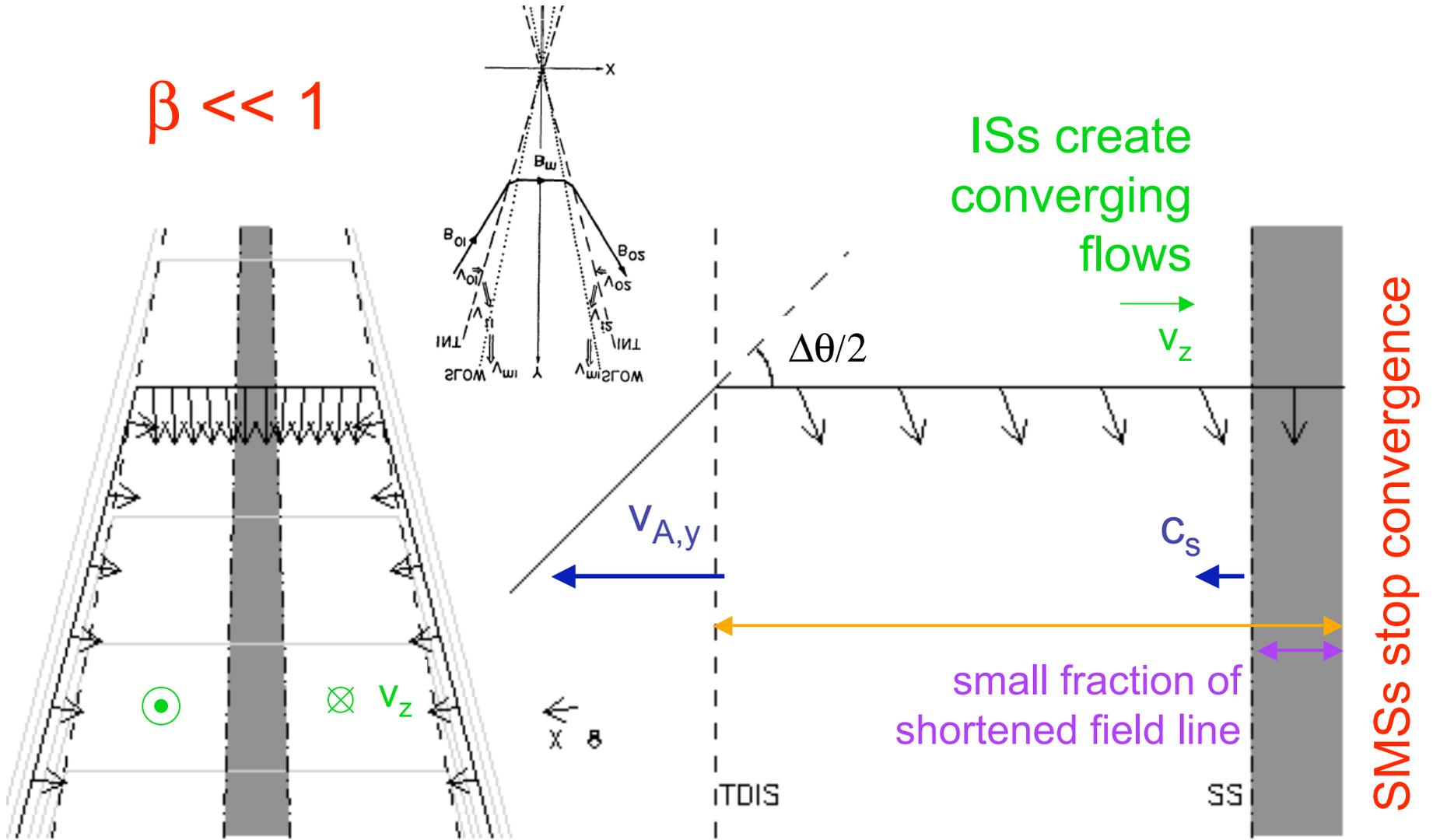


- 2d steady model
- CS separating perfectly **anti-parallel** field
- Recon'n @ **X-point*** on CS (localization, E_z imposed)
- ➔ **Slow mode shocks (SMS):**
 - connect to X-point
 - $|\mathbf{B}|$ significantly reduced at SMS
 - Magnetic energy ➔
 - **40%** thermal energy
 - **60%** bulk flow KE

Are reconnecting fields always anti-parallel?



$$\beta \ll 1$$



ISs create converging flows

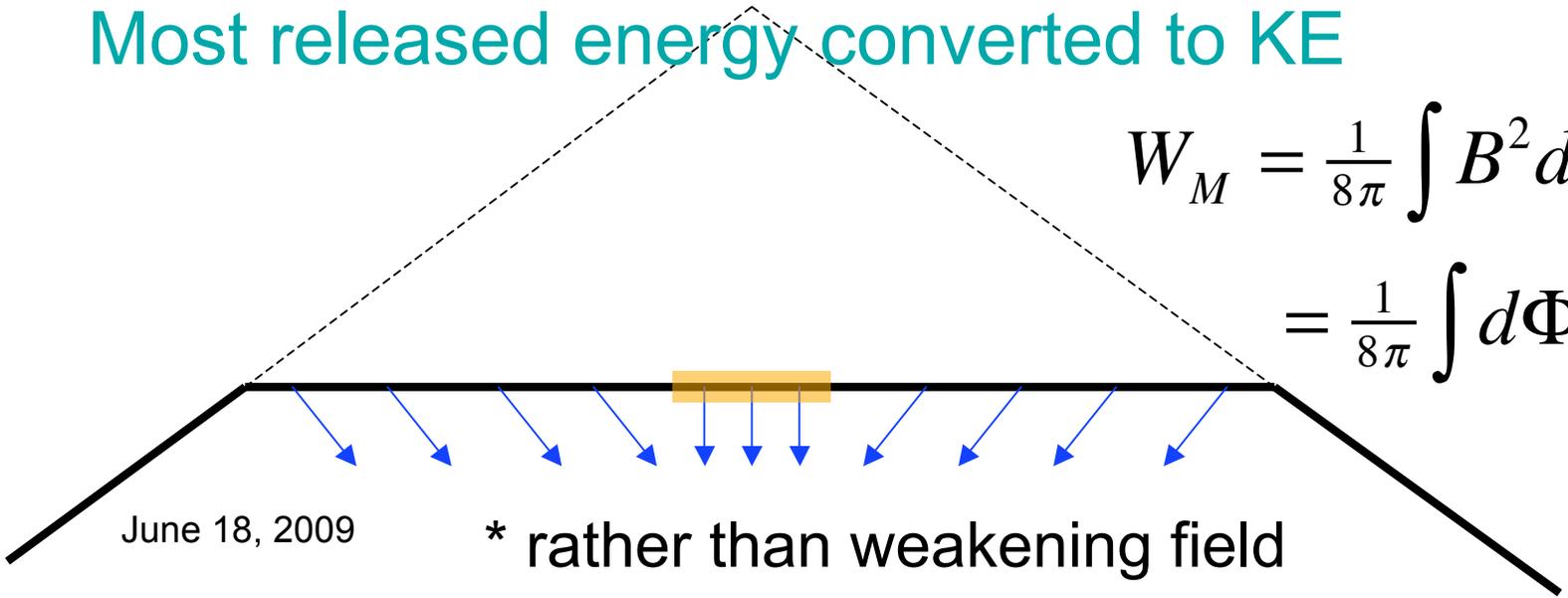
SMSS stop convergence

slow shock angle
 $\sim \beta^{1/2} \times \text{IS angle}$

In skewed ($\Delta\theta < 120^\circ$) low β reconnection:

- Magnetic field strength decreases only slightly
Q: what is the source of energy?
A: field lines are shortened (rather than weakened)
- SMSs mostly stop converging flows
(rather than weakening field, à la switch-off shock)
~ gas dynamic shocks ($M \sim \beta^{-1/2} \gg 1$)
- Heating occurs only in small central region
Most released energy converted to KE

$$W_M = \frac{1}{8\pi} \int B^2 da dl$$
$$= \frac{1}{8\pi} \int d\Phi \int B dl$$

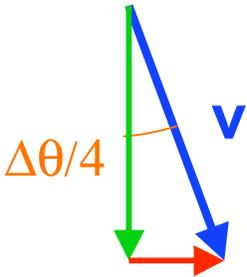
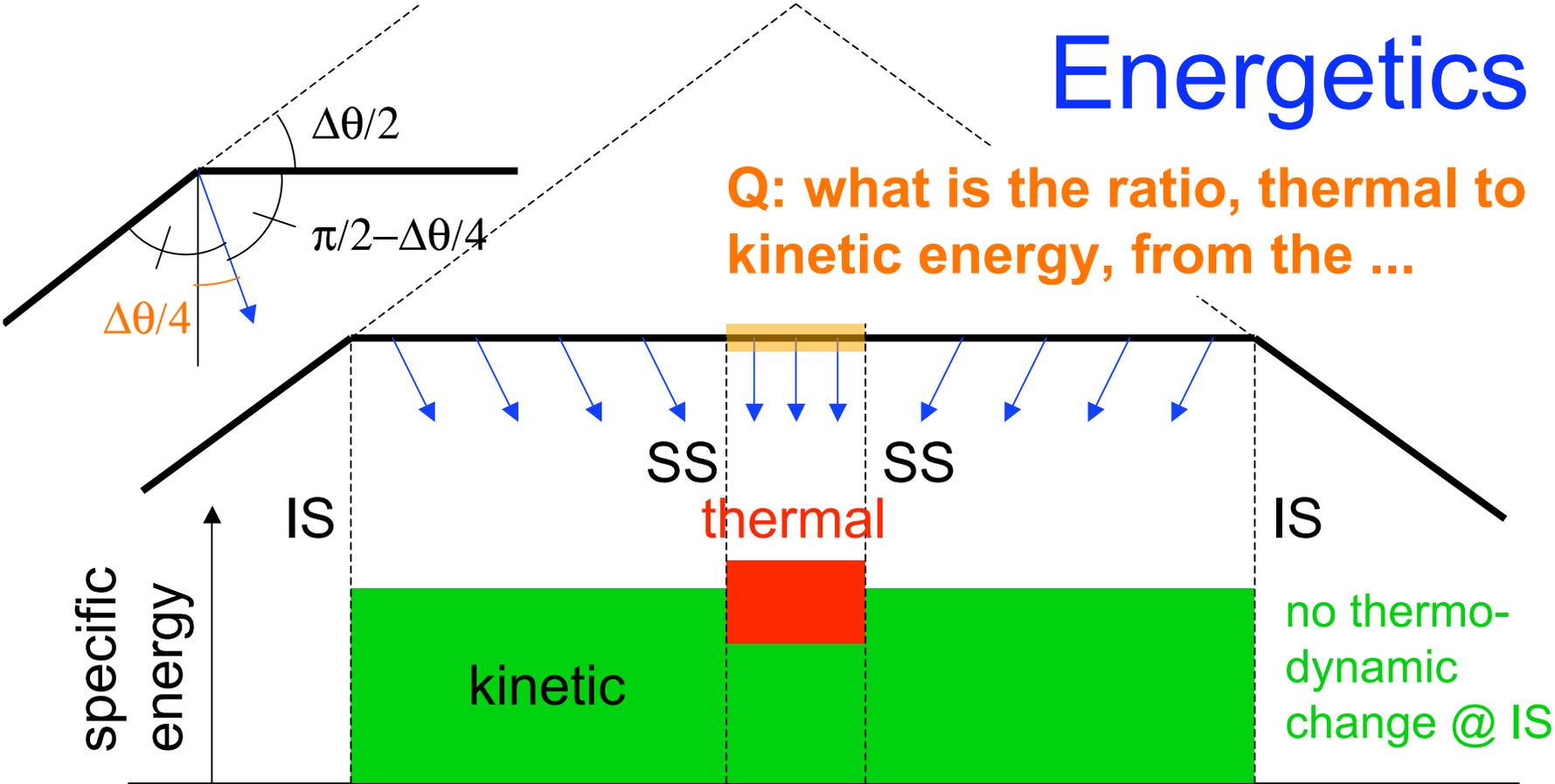


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* rather than weakening field

Energetics

Q: what is the ratio, thermal to kinetic energy, from the ...



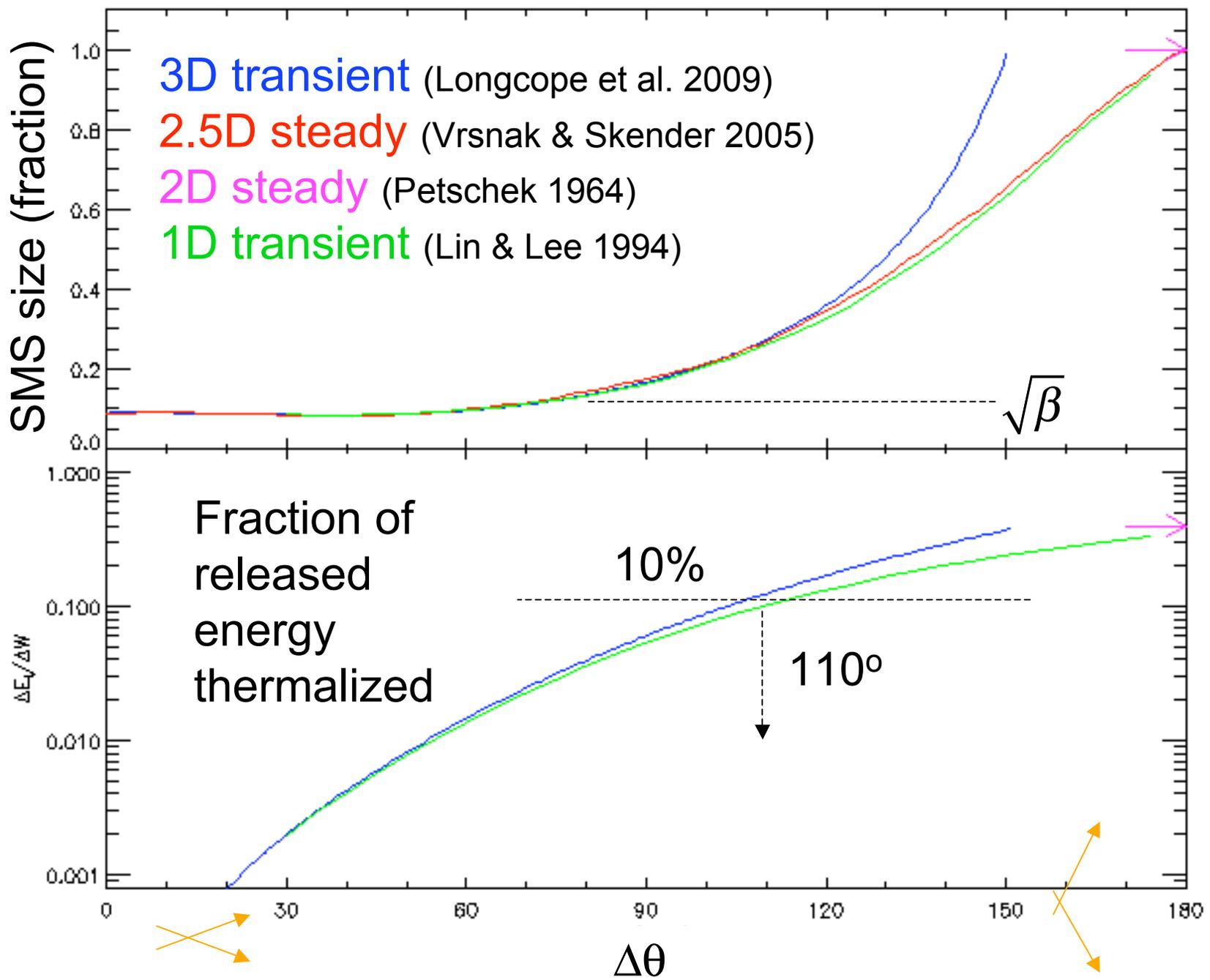
... post-SS region:
ratio of heights

$$\sim \tan^2 \left(\frac{\Delta\theta}{4} \right)$$

Boulder SPD

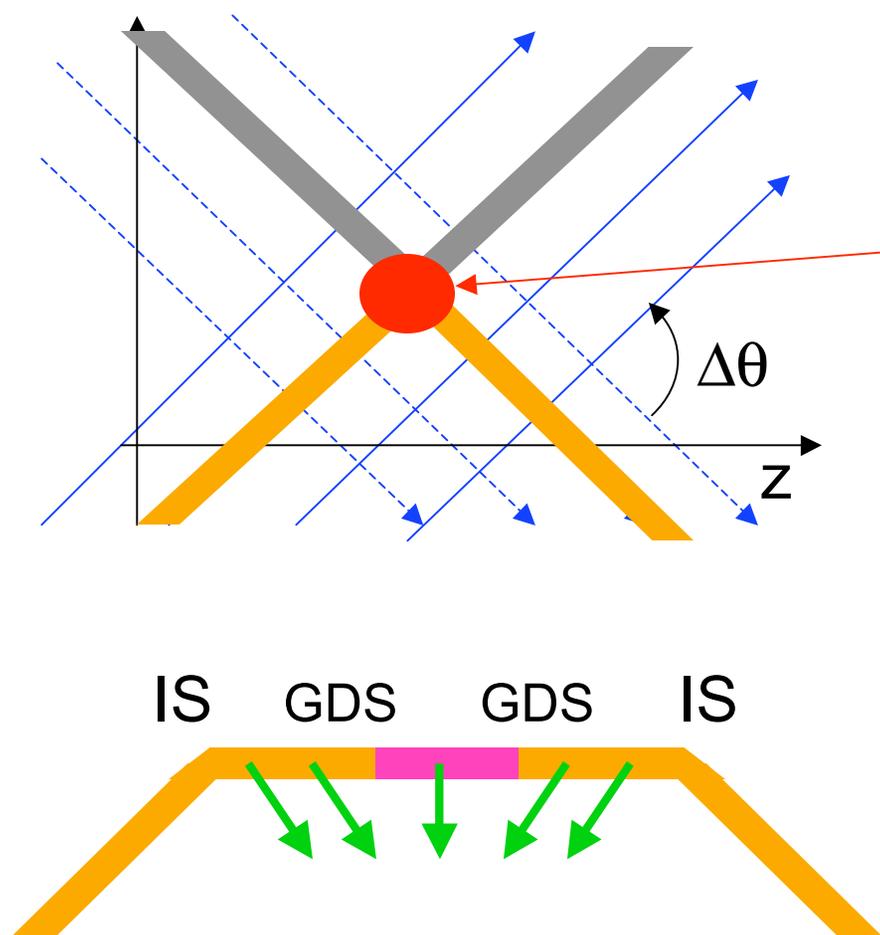
... all released energy:
ratio of areas

$$\sim \beta^{1/2} \tan^2 \left(\frac{\Delta\theta}{4} \right)$$



3D transient

Linton & Longcope 2006
Longcope, Guidoni &
Linton 2009

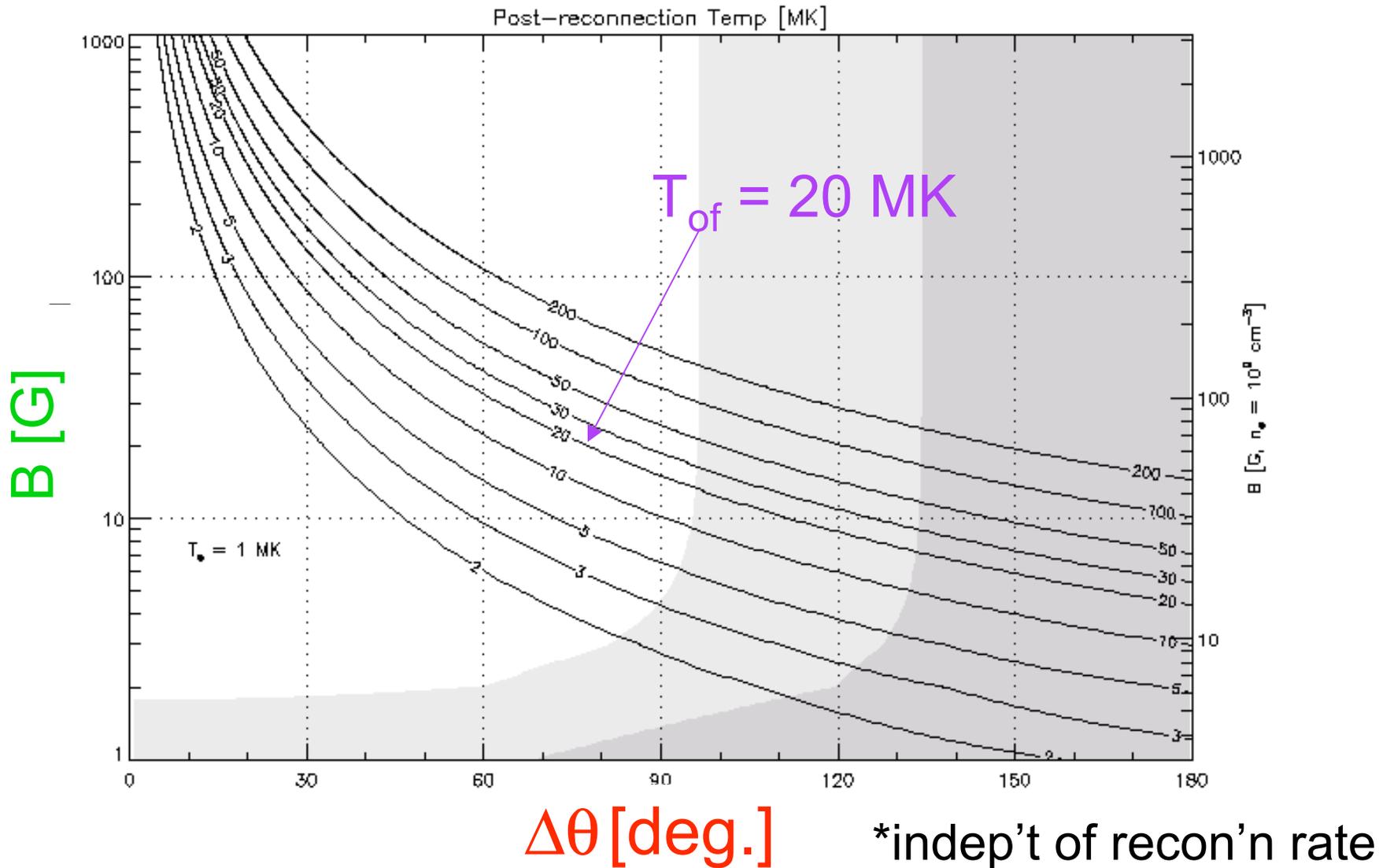


- CS between field @ $\Delta\theta$
(include “guide field” B_z)
- Recon'n @ **patch** on CS
- creates detached **flux tubes**
- bend \rightarrow non-equilibrium
- evolve as thin flux tubes
- “pull through” CS
- $|\mathbf{B}|$ fixed by external layers -
unchanged by reconnection
- Riemann problem \rightarrow 2 shocks
 - Bends (IS) move @ v_A
 - gas dynamic shocks (GDS) in
straight section -
disconnected from recon'n

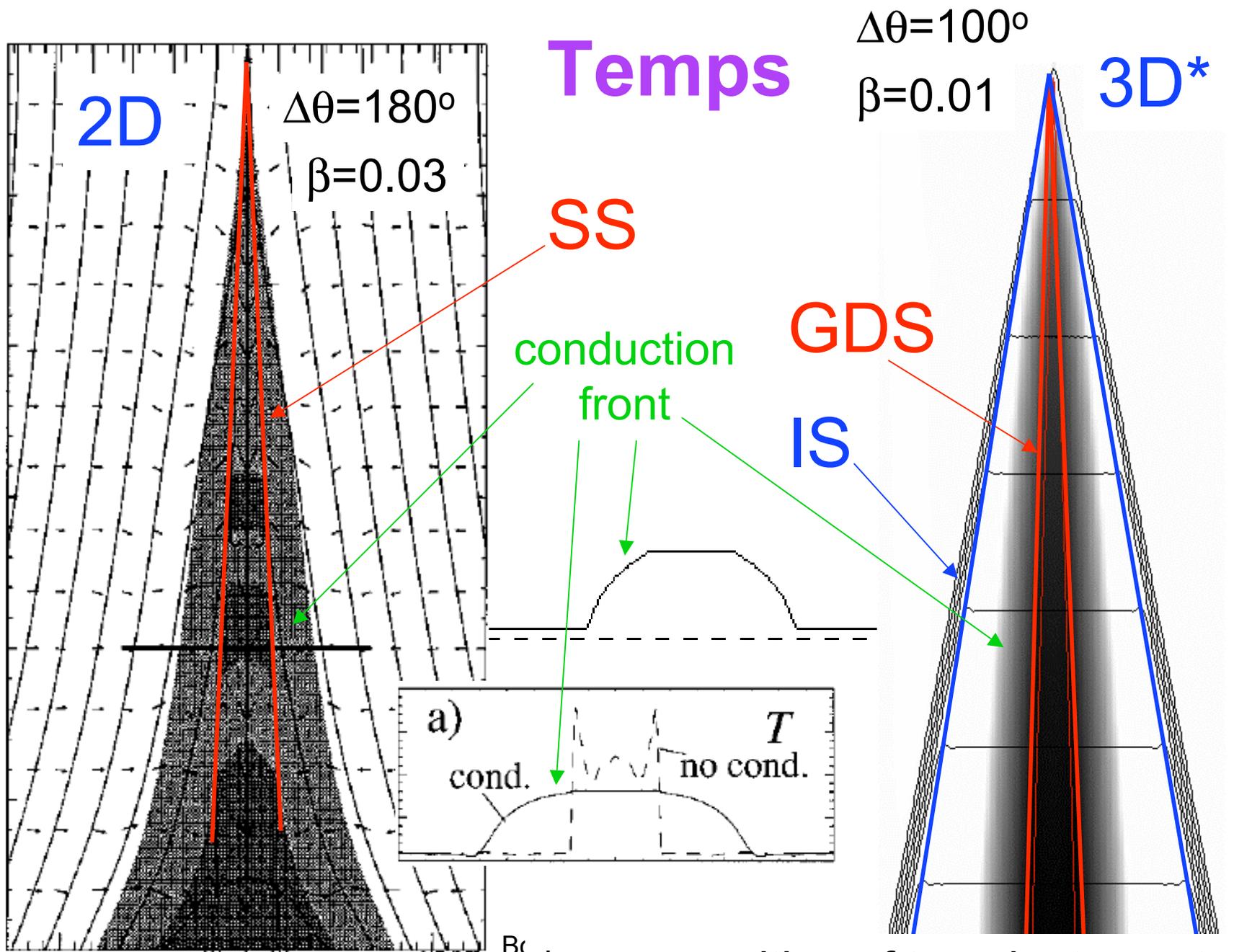
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B.

Temperature of “outflow” function of B & $\Delta\theta$ (little else*)



Yokoyama & Shibata 1997



* superposition of transient events

Summary

Reconnecting field lines w/ $\Delta\theta < 180^\circ$

common to steady/transient 1D,2D,3D models:

- Releases energy by shortening field lines (more than annihilating field)
- Most properties: indep. of reconnection rate
- Most energy \rightarrow kinetic energy of retracting flux
- shortening \rightarrow flows converging at $\sim v_A$
- Stopped in shocks (SMSs/GDS) which thermalize some kinetic energy (little $|\mathbf{B}|$)
- creates small ($\sim\beta^{1/2}$) hot central region