CLASSICAL MODELS OF MAGNETIC RECONNECTION

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- Sweet-Parker Model: a classical perspective
- Petschek's Model: a faster reconnection
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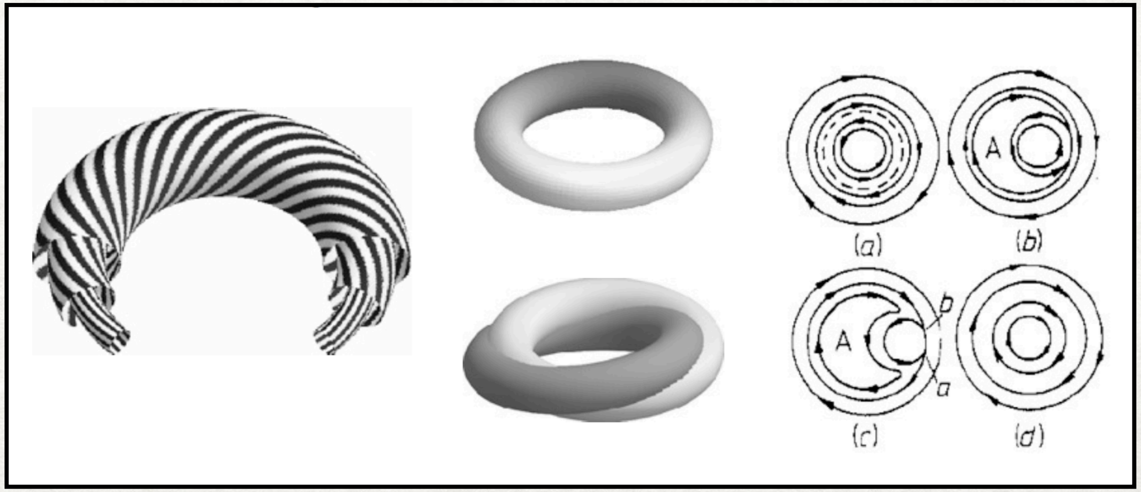
INTRODUCTION: WHAT IS MAGNETIC RECONNECTION?

- **Magnetic reconnection** is a physical process occurring in highly conducting plasmas in which the magnetic topology is rearranged and magnetic energy is converted to kinetic energy, thermal energy, and particle acceleration.

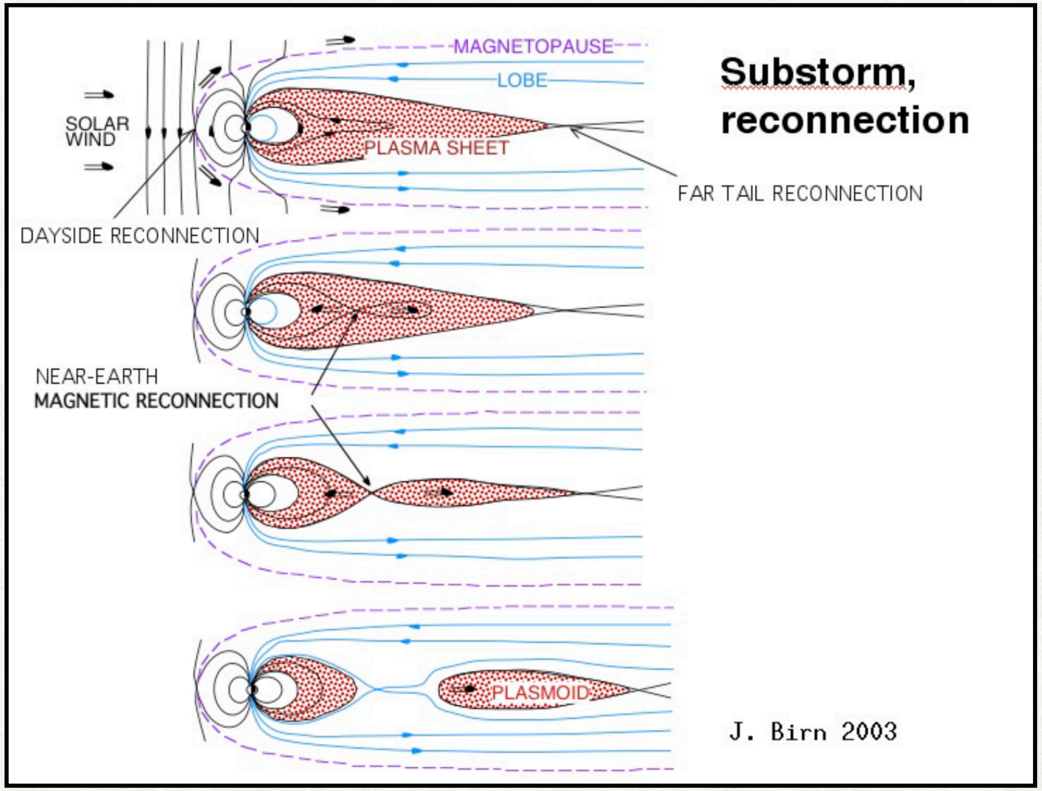
- A magnetic reconnection process in solar flares: https://en.wikipedia.org/wiki/File:SDO_Observes_a_Reconnection_Event.ogv

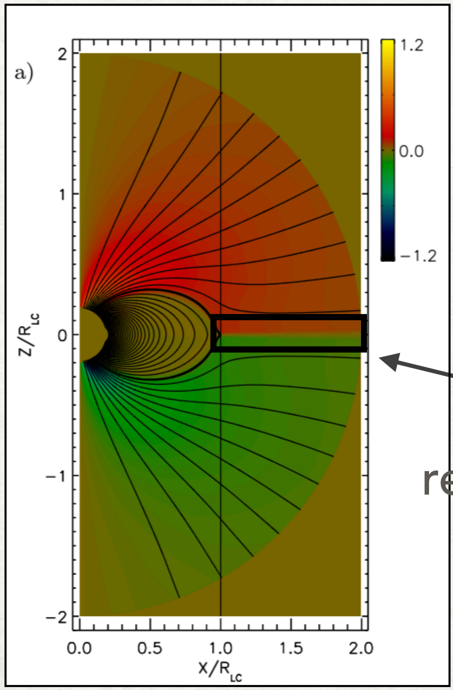
- Tokamak experiments



INTRODUCTION: WHAT IS MAGNETIC RECONNECTION?

- Earth Magnetospheres
- accretion disks
- Plusars & Magnetars





reconnection region&current sheet

(ANATOLY SPITKOVSKY, 2006)

INTRODUCTION: WHAT IS MAGNETIC RECONNECTION?

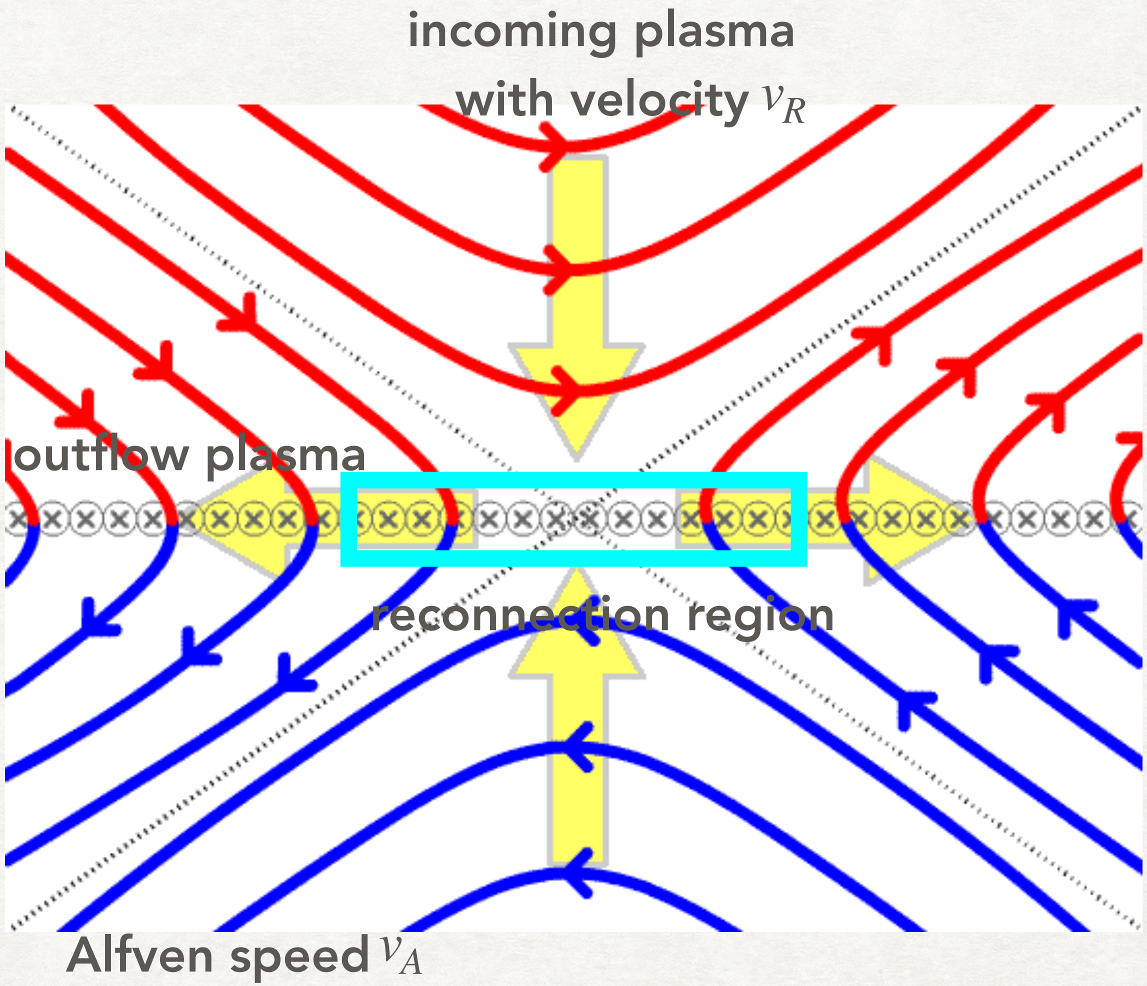
- Characteristics
  - change the magnetic topology (further relaxation can release more energy)
  - generate an electric field which accelerates particles parallel to magnetic field
  - dissipate magnetic energy (direct heating)
  - accelerate plasma, i.e. convert magnetic energy into kinetic energy

INTRODUCTION: A SHORT HISTORY

- In 1946, Giovanelli suggested reconnection as a mechanism for particle acceleration in solar flares.
- 1957-58, Sweet and Parker developed the first quantitive model, currently known as Sweet-Parker model.
- 1961 Dungey investigated the interaction between a dipole (magnetosphere) and the surrounding (interplanetary) magnetic field which included reconnection.
- 1964 Petschek proposed another model in order to overcome the slow reconnection rate of the Sweet-Parker model.
- …

SWEET-PARKERS MODEL: A CLASSICAL PERSPECTIVE

- Magnetic reconnection happens when two plasma coming closer to each other, and the magnetic field lines are able to rearrange their structure, bringing the plasma inside the reconnection region outside by the electric field.



SWEET-PARKER MODEL: A CLASSICAL PERSPECTIVE

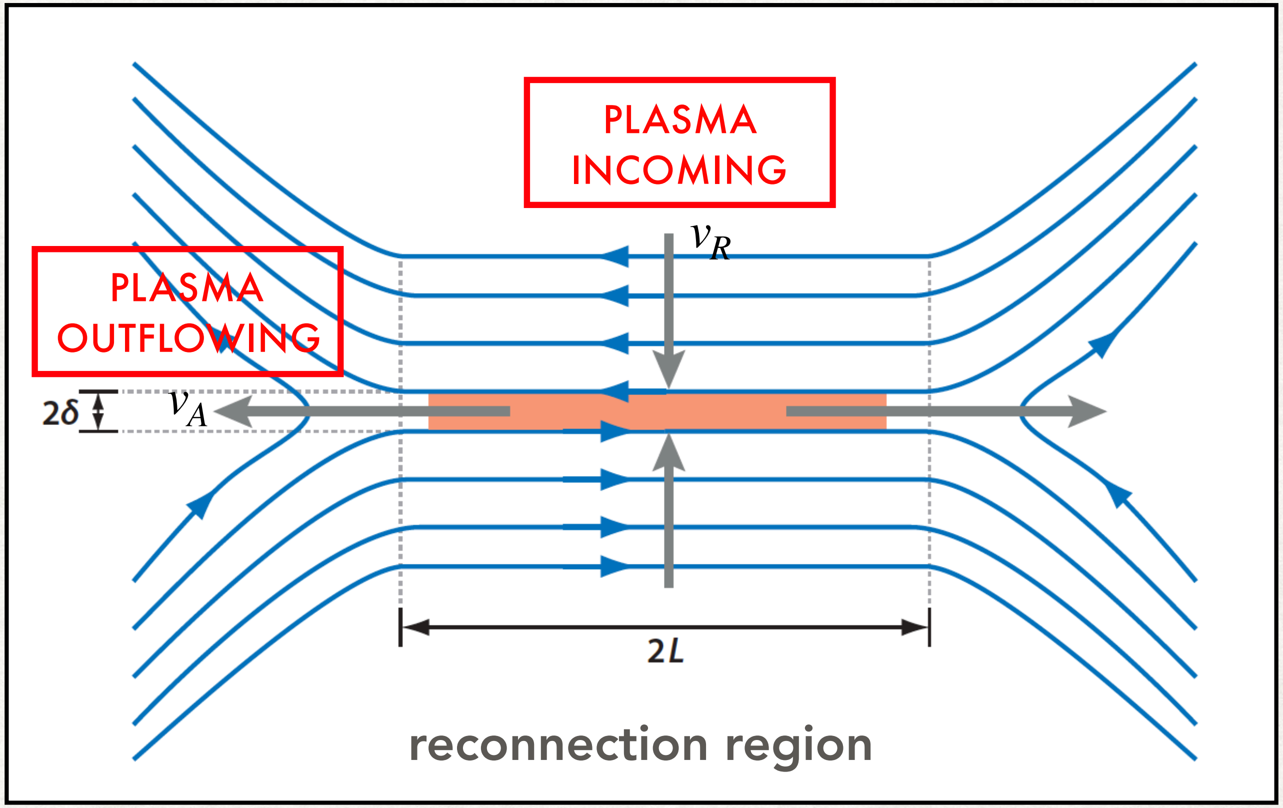
- Some typical values of the magnetohydrodynamic(MHD) regime
  - Magnetic diffusivity: $\eta = \frac{c^2}{4\pi\sigma}$
  - Alfven speed: $v_A = \frac{B}{\sqrt{\mu_0 \rho}} \sim 10^6 cm/s$
  - Lunquidst number: $S = \frac{L v_A}{\eta c / 4\pi}$ the ratio of the global Ohmic diffusion time $\tau_{diff} \equiv L^2/\eta$ to the global Alfven time $\tau_A \equiv L/v_A$, typically $S \sim 10^{12}$

SWEET-PARKER MODEL: A CLASSICAL PERSPECTIVE

- How does reconnection happen?
  - Ideal flux freezing: slow moving plasmas

Ideal condition for flux freezing:

$$l = \sqrt{\frac{\eta c t}{4\pi}} < \delta$$



  - Reconnection happens if:

$$l \sim \delta$$

SWEET-PARKER MODEL: A CLASSICAL PERSPECTIVE

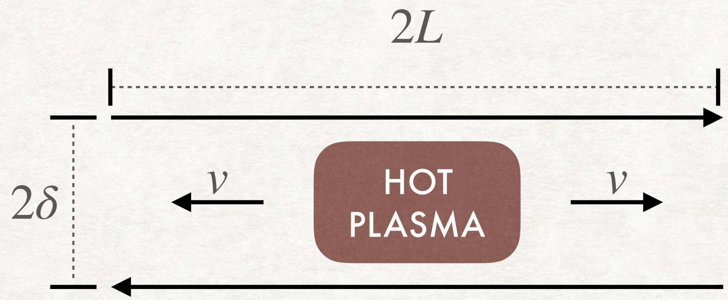
- How does reconnection happen?
  - restrictions on current layer:

current density: $j \approx B/4\pi\delta$

Ohmic heating rate (CGS):

$$\eta c j^2 = \frac{\eta c B^2}{(4\pi)^2 \delta^2} \rightarrow$$ INCREASING PRESSURE

Heating timescale: $\tau_A = L/v_A$



current layer geometry

  - pressure relation:

$$p = \eta c j^2 \tau_A < B_0^2/8\pi \rightarrow \delta > L/\sqrt{S}$$

DEFINE: $\delta_{SP} = L/\sqrt{S}$

  - Lundquist number: $$S = \frac{L v_A}{\eta c/4\pi}$$

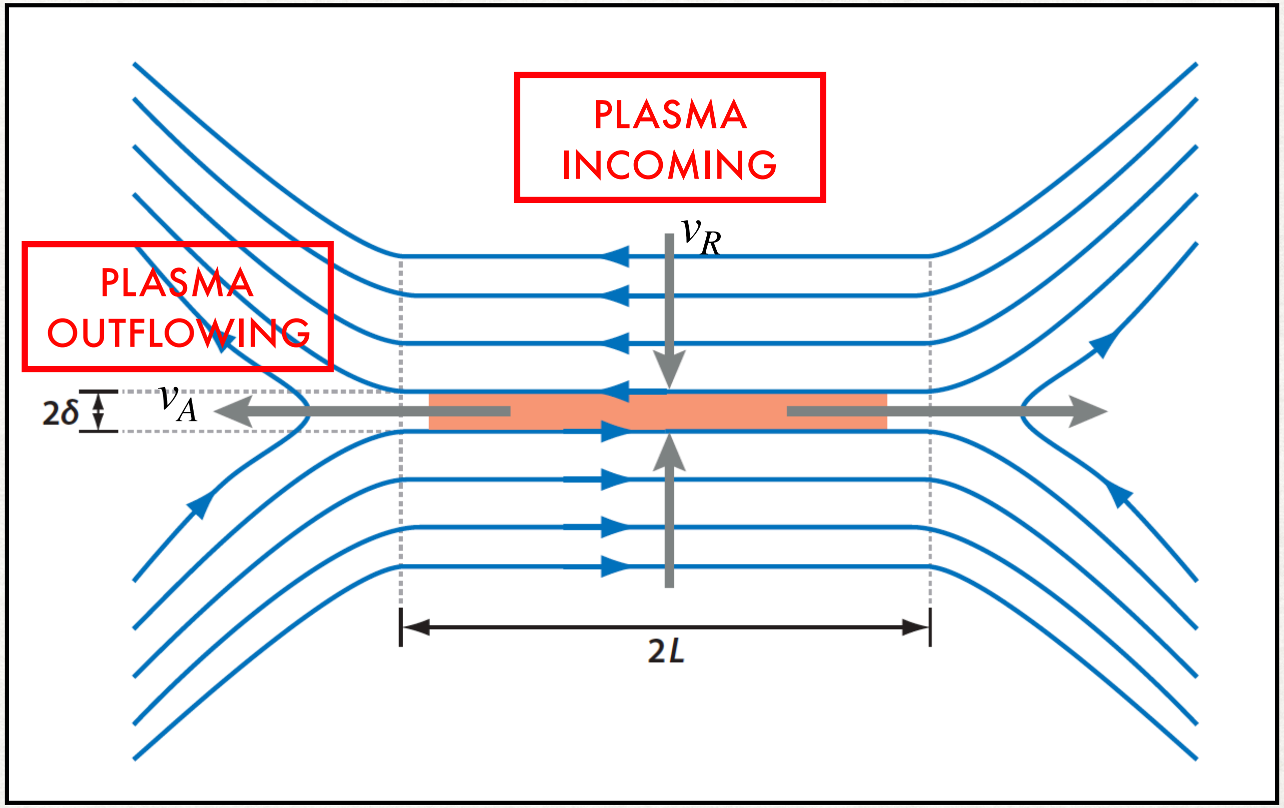
SWEET-PARKER MODEL: A CLASSICAL PERSPECTIVE

- How does reconnection happen?
  - reconnection speed: plasma flux conservation

$$v_R = \frac{\delta_{SP}}{L} v_A = \frac{v_A}{\sqrt{S}}$$

  - with given Alfven speed

$$v_R = \frac{\eta c}{4\pi\delta_{SP}}$$



SWEET-PARKER MODEL: A CLASSICAL PERSPECTIVE

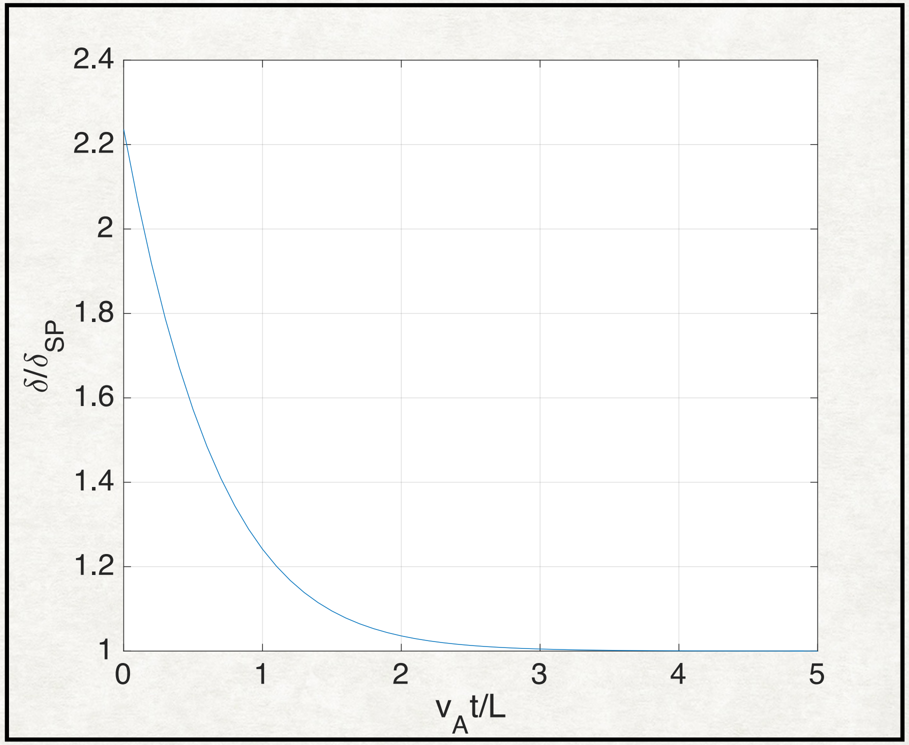
- How does reconnection happen?
  - adiabatic heating and Ohmic heating

    Recall that: $\delta > \delta_{SP}$, Ohmic heating is not sufficient for producing the excess pressure because $p \sim 1/\delta^2$, adiabatic heating is required.

    In Sweet-Parkers Model, δ must decrease to provide such mechanic.

  - time evolution for δ

$$\delta^2 - \delta_{SP}^2 = (\delta_0^2 - \delta_{SP}^2)\exp(-\frac{2v_A t}{L})$$



SWEET-PARKER MODEL: A CLASSICAL PERSPECTIVE

- Time scale for reconnection

$$\tau_{SP} \sim L/v_R = L\sqrt{S}/v_A$$

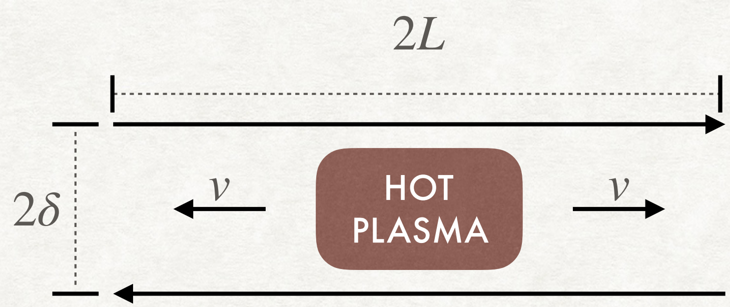
- consider an actual solar flare,

$$L \sim 10^4 km$$

$$v_A \sim 2.7 \times 10^7 cm/s$$

$$S = \frac{Lv_A}{\eta c/4\pi} \sim 2.7 \times 10^{12}$$

$$\tau_{SP} \sim 2 \times 10^6 s \sim month$$



current layer geometry

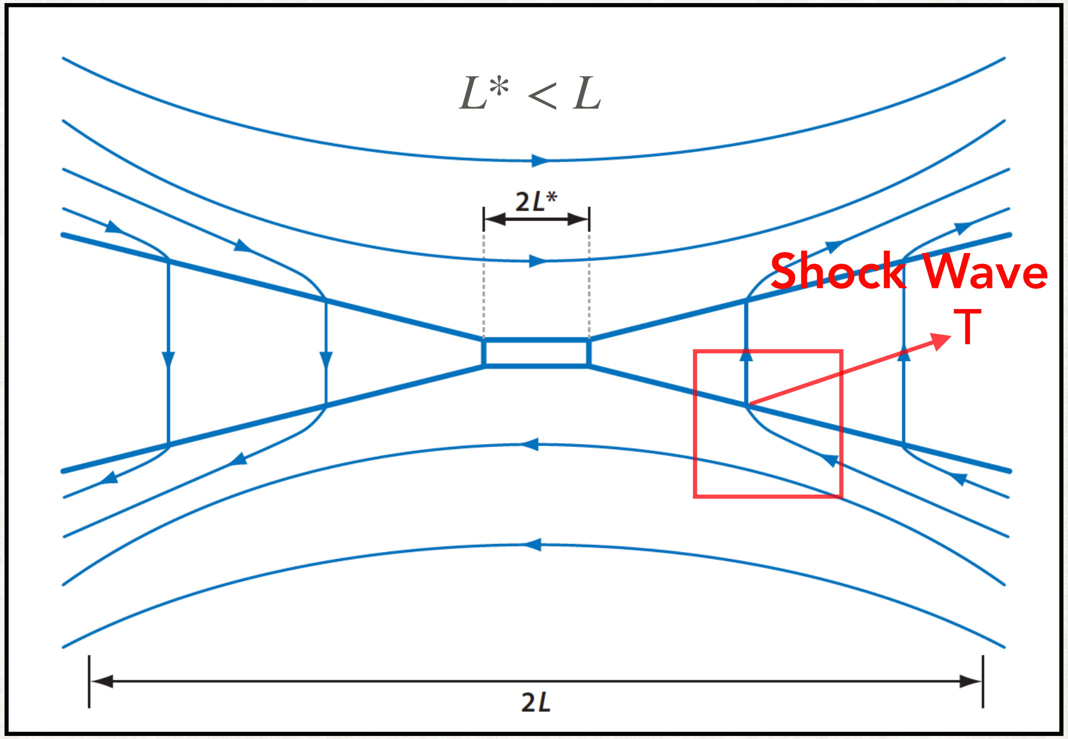
- typical time: minutes to hours for a solar flare, making Sweet-Parker model a terribly long reconnection model.

PETSCHEK'S MODEL: A FASTER RECONNECTION

- Reconnection occurs in a smaller scale, such as near a point.

$$v_R = \sqrt{\frac{L}{L^*}} v_{SP}$$

- Plasma fluid doesn't have to reach the current sheet to flow out. It is considered to be dragged out the reconnection region by the tension generated by the curved magnetic field line.



PETSCHEK'S MODEL: A FASTER RECONNECTION

- Petschek derived that the reconnection speed satisfies:

$$v_R = \frac{\delta}{L^*} v_A$$

where L* is a free parameter, can this be true?

- Restrictions on L^* : current densities in the shock are finite,

$$v_R = \frac{\pi}{8} \frac{v_A}{\ln[(v_R/v_A)^3 S]} \rightarrow v_R(max) \approx \frac{\pi}{8} \frac{v_A}{\ln S}$$

- check it for the Sun! $\tau_P = \frac{8\tau_A}{\pi} \ln S = 30s << \tau_{SP}$, works perfectly for fast reconnection process.

PETSCHEK'S MODEL: A FASTER RECONNECTION

- Ion dynamics do not allow a shock structure
- Numerical simulations shows this model is unstable
- η needs to increase around the reconnection point, which is not expected as the background resistivity varying rapidly around certain point.

SUMMARY

- Magnetic reconnection releases magnetic energy, accelerates plasma, and changes topology of the magnetic field.
- First quantitive model: Sweet-Parker Model, though its slow for reconnection.
- Fast reconnection model by Petschek, unstable in MHD simulations, require increasing magnetic diffusivity near reconnection point.

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