PETSCHEK-LIKE RECONNECTION WITH ANOMALOUS RESISTIVITY AND SOLAR FLARES

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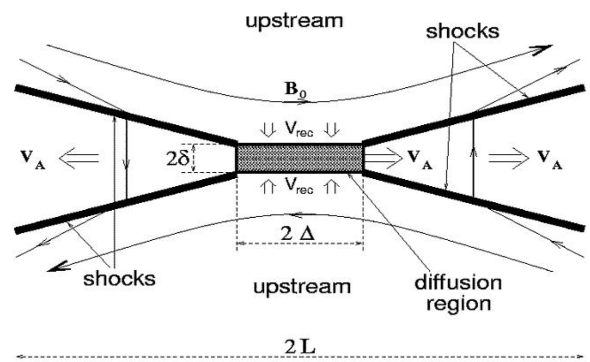
Petschek's Model of Reconnection



Petschek (1964)

- Reconnection layer structure: small central diffusion region and four slow shocks.
- Diffusion region: a Sweet–Parker-like layer with aspect ratio

$$\frac{\delta}{\Delta} \sim S_\Delta^{-1/2}, \qquad S_\Delta \equiv \frac{\Delta V_A}{\eta}$$

- Non-uniqueness: Petschek model does not predict a unique configuration (and hence a unique reconnection rate). Instead, there is a family of solutions parametrized by Δ. If Δ can be made sufficiently small, reconnection will be fast, which is needed to explain the short time scale of solar flares.

Results of Numerical Simulations

- 2D Numerical simulations (*e.g. Biskamp 1986; Scholer 1989; Ugai 1992; Uzdensky & Kulsrud 2000; Erkaev et al. 2000*) have shown that Petschek configurations with $\Delta < L$ are not sustainable when $\eta(x,y) = \mathrm{const}$. The system evolves towards a stable Sweet–Parker layer with no shocks ($\Delta = L$) and with a very slow reconnection rate

$$\frac{V_{\rm rec}}{V_A} \sim \frac{\delta}{\Delta} \sim S_L^{-1/2} \ll 1$$

$\tau_{\rm rec} \sim$ months — too slow for solar flares ($\tau_{\rm flare} \sim 10$ min).

- However, when $\eta(x,y) \neq \mathrm{const}$ (**strongly localized resistivity**), then a stable Petschek structure can form (*e.g. Ugai & Tsuda 1977; Sato & Hayashi 1979; Scholer 1989; Erkaev et al. 2000; Biskamp & Schwarz 2001*), with

$$\Delta \sim l_\eta \ll L$$

$l_\eta =$ resistivity localization scale.

- Question:

What determines l_η in practice ?

ANOMALOUS RESISTIVITY

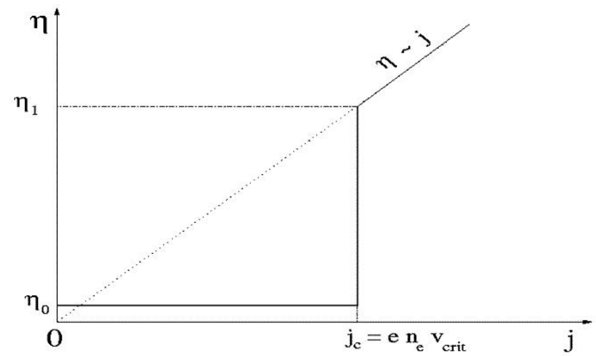
- Motivation for non-uniform η: *anomalous resistivity* due to current-driven microinstabilities: $\eta = \eta(j)$

- Physical Mechanism:
when

$$v_d = \frac{j}{en_e} > v_{\rm crit} \sim v_{\rm thermal}\,,$$

then kinetic instabilities (*e.g., lower-hybrid, ion-acoustic, Buneman*) get excited, leading to developed microturbulence. Scattering of current-carrying electrons off waves results in an enhanced effective resistivity.

- Anomalous Resistivity Model $\eta(j)$: 3 parameters: j_c, η_0, η_1.



- Ion-Acoustic Turbulence:

$$j_c \sim en_e v_s$$

$$\eta_1 \sim \frac{c^2}{\omega_{pe}}\frac{ZT_e}{T_i}\sqrt{\frac{Zm_e}{m_i}}$$

Unique Solution

- Combine:
  - $\Delta \sim l_\eta$ (num. simulations)
  - $\frac{\delta}{\Delta} \sim S_\Delta^{-1/2}$ (Petschek model)
  - model for $\eta(j)$

  $\Rightarrow$ *a unique Petschek configuration !!!*

- Parameters of Diffusion Region: $S_* \equiv \frac{\delta_c V_A}{\eta_1}$
  - thickness: $\delta \sim \delta_c \equiv cB_0/4\pi j_c$
  - aspect ratio: $\frac{\Delta}{\delta} \sim S_*$
  - reconnection rate: $\frac{V_{\rm rec}}{V_A} \sim S_*^{-1}$

  — independent of the global scale L.

- For $\eta(j)$ due to Ion-Acoustic Turbulence:

$$\delta_c \sim \frac{c}{\omega_{pi}\sqrt{\beta_e}}$$

$$S_* \sim \frac{V_A}{c\sqrt{\beta_e}} \frac{T_i}{ZT_e} \frac{m_i}{Zm_e}$$

where $\beta_e \equiv \frac{8\pi p_e(0,0)}{B_0^2}$

Application to Solar Flares

- Electron Heating:

  ion-acoustic turbulence heats up the plasma in the diffusion region with T_e increasing up to $\beta_e = O(1)$.
  Ion heating is not as strong.

- Fiducial Solar Flare Conditions:

$n_e = 10^{10}$ cm^{-3}	$T_e = 3 \cdot 10^7$ K
$B_0 = 100$ G	$T_i = 3 \cdot 10^6$ K

- Resulting Reconnection Layer Parameters:
  - $\delta_c \simeq 500$ cm
  - $S_* \simeq 50$
  - $\Delta \simeq 2.6 \cdot 10^3$ cm
  - $\tau_{\rm rec} \simeq 50$ sec — close to typical solar flare timescale !