On the origin of the consequent brightening of coronal loops in solar flare arcades

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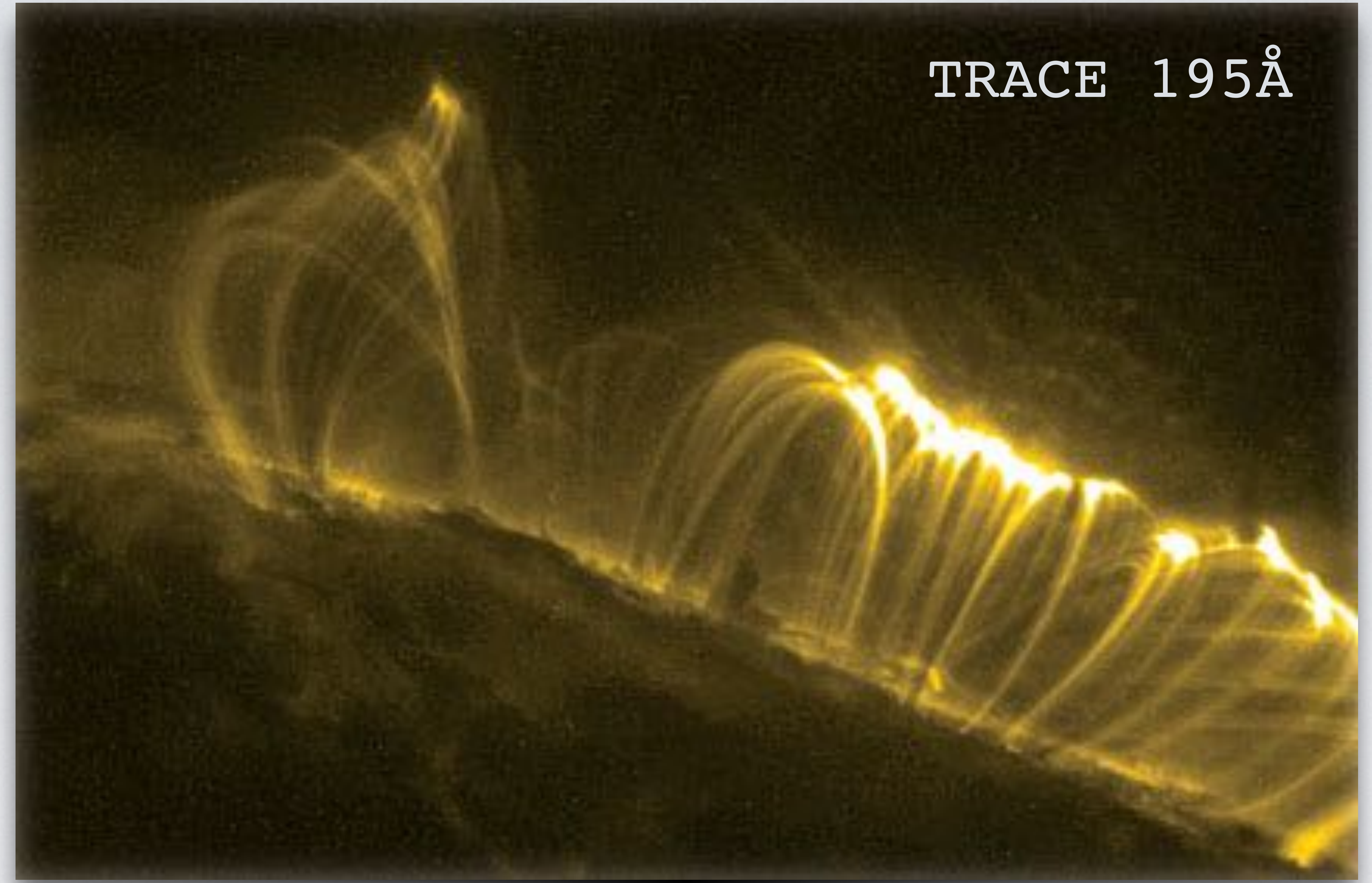
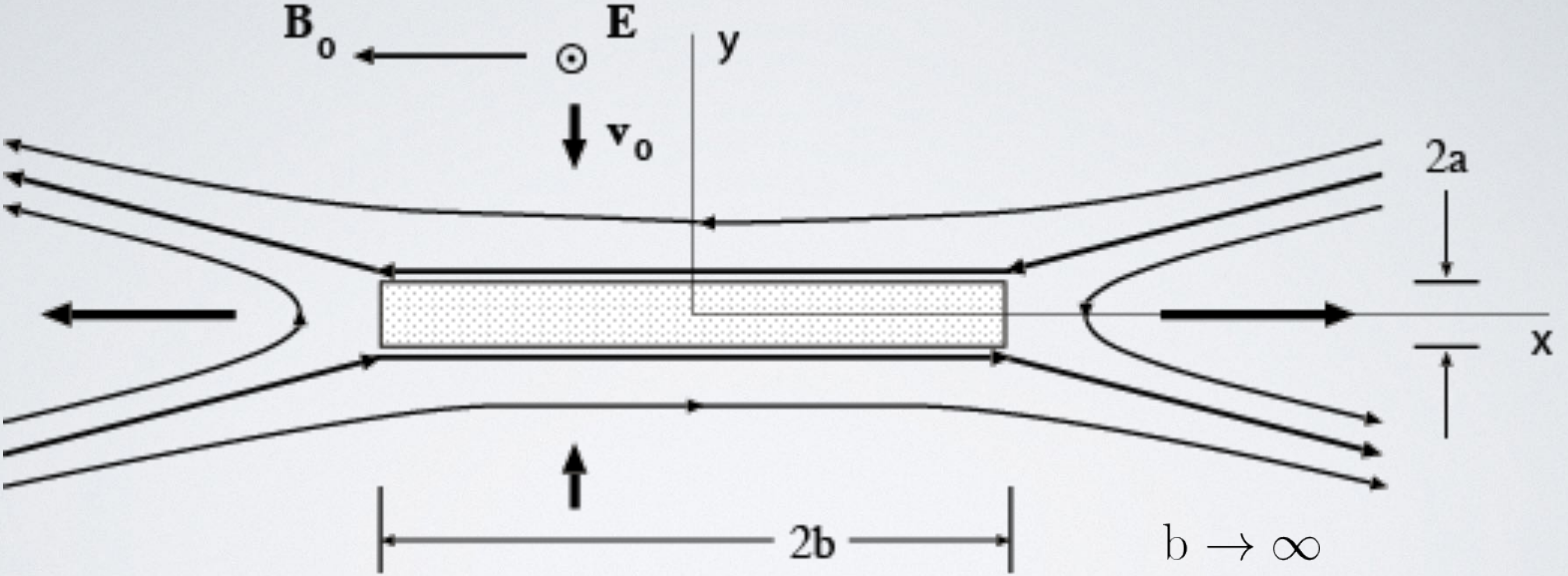
The main energy release of solar flares occurs in a thin current sheet located above an arcade of coronal magnetic loops.



Modern observations show that the energy release takes place near the individual spatially separated loops. We want to understand what process can form that quasi-periodic structure of the bright coronal loops.

We consider a piecewise homogeneous model of the current sheet (CS)



We denote the characteristics of the plasma outside the sheet by the index «0», and inside the sheet by the index «s»

Single-fluid MHD equations

$$\mu n \frac{\mathrm{d}\mathbf{v}}{\mathrm{d}t} = -\nabla(2nkT) - \frac{1}{4\pi}(\mathbf{B}\times\mathrm{rot}\mathbf{B})$$

$$\frac{\partial n}{\partial t} + \mathrm{div} n\mathbf{v} = \mathbf{0}$$

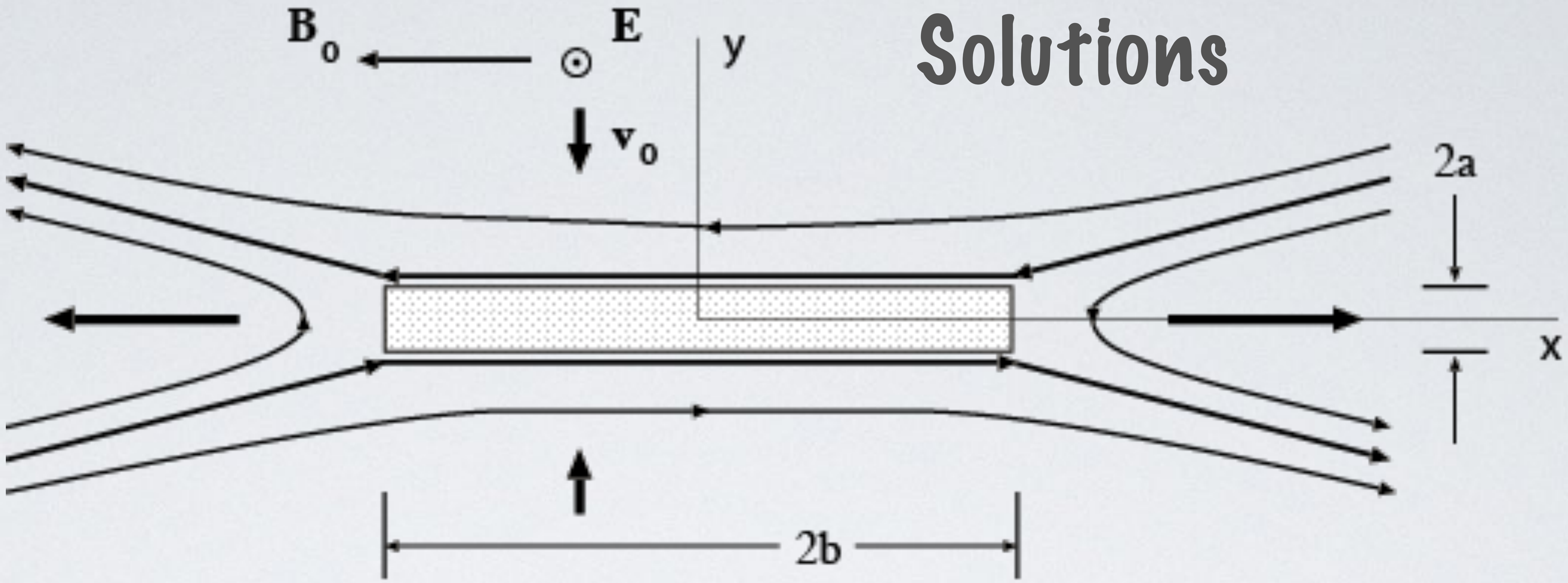
$$\frac{\partial \mathbf{B}}{\partial t} = \mathrm{rot}(\mathbf{v}\times\mathbf{B}) - \frac{c^2}{4\pi}\mathrm{rot}\left(\frac{1}{\sigma}\mathrm{rot}\mathbf{B}\right)$$

$$\frac{2nk}{\gamma-1}\frac{\mathrm{d}T}{\mathrm{d}t} - 2kT\frac{\mathrm{d}n}{\mathrm{d}t} = \frac{c^2}{(4\pi)^2\sigma}(\mathrm{rot}\mathbf{B})^2 + \mathrm{div}(\kappa\nabla T) - n^2 L(T)$$

$$\mathrm{div}\mathbf{B} = 0$$

with Joule heating, thermal conduction and radiative cooling

Solutions



Outside the CS

$$y \geq a$$
$$\kappa \to 0$$
$$L \to 0$$
$$\sigma \to \infty$$

$$f(y,z,t) = f_0 + f_1(y)\exp(-i\omega t + ik_z z)$$

$$f_1(y) = f_1 \exp[-k_{y1}(y-a)]$$

$$\mu n \frac{\mathrm{d}\mathbf{v}}{\mathrm{d}t} = -\nabla(2nkT) - \frac{1}{4\pi}(\mathbf{B}\times \mathrm{rot}\mathbf{B})$$

$$\frac{\partial n}{\partial t} + \mathrm{div} n\mathbf{v} = \mathbf{0}$$

$$\frac{\partial \mathbf{B}}{\partial t} = \mathrm{rot}(\mathbf{v}\times\mathbf{B}) - \frac{c^2}{4\pi}\mathrm{rot}\left(\frac{1}{\sigma}\mathrm{rot}\mathbf{B}\right)$$

$$\frac{2nk}{\gamma-1}\frac{\mathrm{d}T}{\mathrm{d}t} - 2kT\frac{\mathrm{d}n}{\mathrm{d}t} = \frac{c^2}{(4\pi)^2\sigma}(\mathrm{rot}\mathbf{B})^2 + \mathrm{div}(\kappa\nabla T) - n^2 L(T)$$

$$\mathrm{div}\mathbf{B} = 0$$

Inside the CS

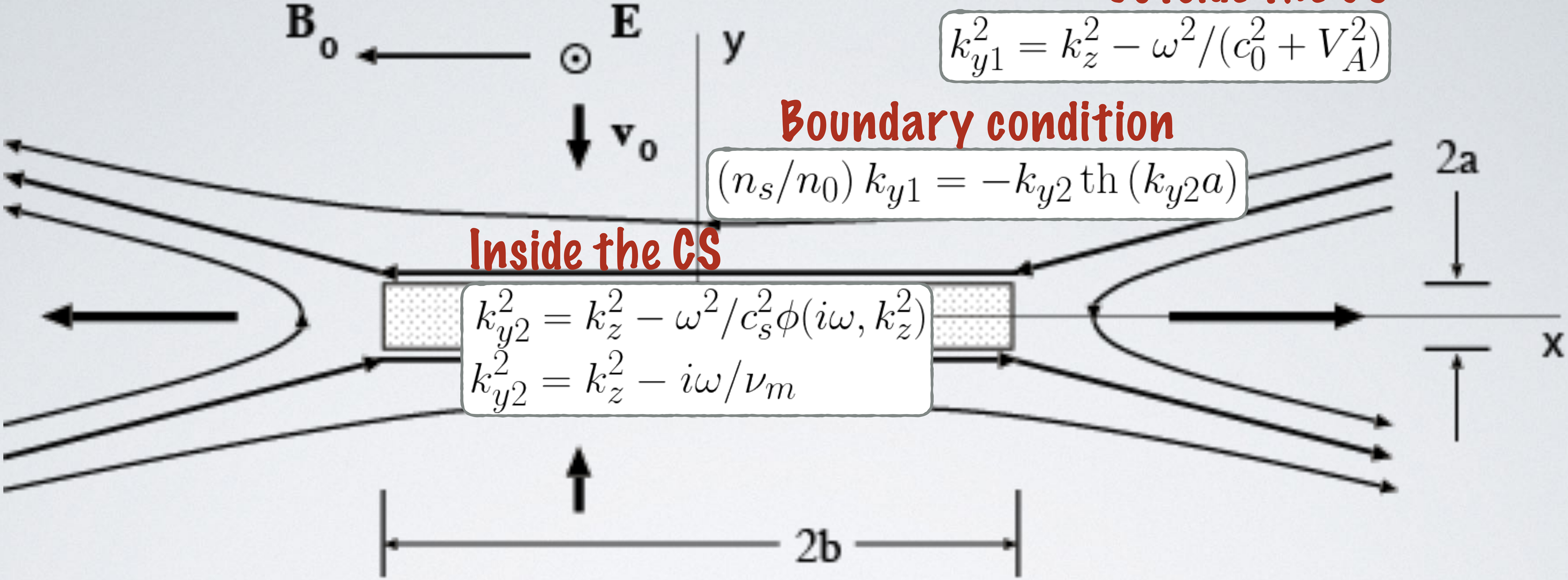
$$y < a$$
$$B_s = 0$$
$$v_s = 0$$

$$f(y,z,t) = f_s + f_2(y)\exp(-i\omega t + ik_z z)$$

$$\left\{\begin{matrix} v_y(y) \\ B(y) \end{matrix}\right\} = \left\{\begin{matrix} v_{y2} \\ B_2 \end{matrix}\right\} \mathrm{sh}(k_{y2}y)$$

$$\left\{\begin{matrix} v_z(y) \\ n(y) \\ T(y) \end{matrix}\right\} = \left\{\begin{matrix} v_{z2} \\ n_2 \\ T_2 \end{matrix}\right\} \mathrm{ch}(k_{y2}y)$$

Dispersion relations



Outside the CS

$$k_{y1}^2 = k_z^2 - \omega^2/(c_0^2 + V_A^2)$$

Boundary condition

$$(n_s/n_0)\, k_{y1} = -k_{y2}\, \mathrm{th}\,(k_{y2} a)$$

Inside the CS

$$k_{y2}^2 = k_z^2 - \omega^2/c_s^2 \phi(i\omega, k_z^2)$$

$$k_{y2}^2 = k_z^2 - i\omega/\nu_m$$

c, V_A - sound and Alfven speed

$\phi(i\omega, k^2_z)$ - function dependent on the thermal balance of the plasma

ν_m - magnetic viscosity

Boundary condition (tangential discontinuity)

$$\{p_1\}_{total} = \{p_2\}_{total}$$

$$v_{y1} = v_{y2}$$

Instability rate $\Gamma = -i\omega$

$$\Gamma^2 + \left[\left(\frac{r}{r-1} \right) \frac{\gamma\alpha}{\tau_r} - \left(\frac{r-\gamma^{-1}}{r-1} \right) \frac{c_s^2}{\nu_m} \right] \Gamma - \left(\frac{r}{r-1} \right) \frac{\alpha - 2}{\tau_r} \frac{c_s^2}{\nu_m} = 0$$

In the solar corona

$$\Gamma \simeq \frac{r}{r-1} \frac{1}{\tau_r}$$

Stable

$$r \ll 1$$

$$\Gamma_- \simeq -\frac{r}{\tau_r}$$

Unstable

$$r \gtrsim 2$$

$$\Gamma_+ \simeq \frac{1}{\tau_r}$$

α - logarithmic derivative of the cooling function with respect to temperature

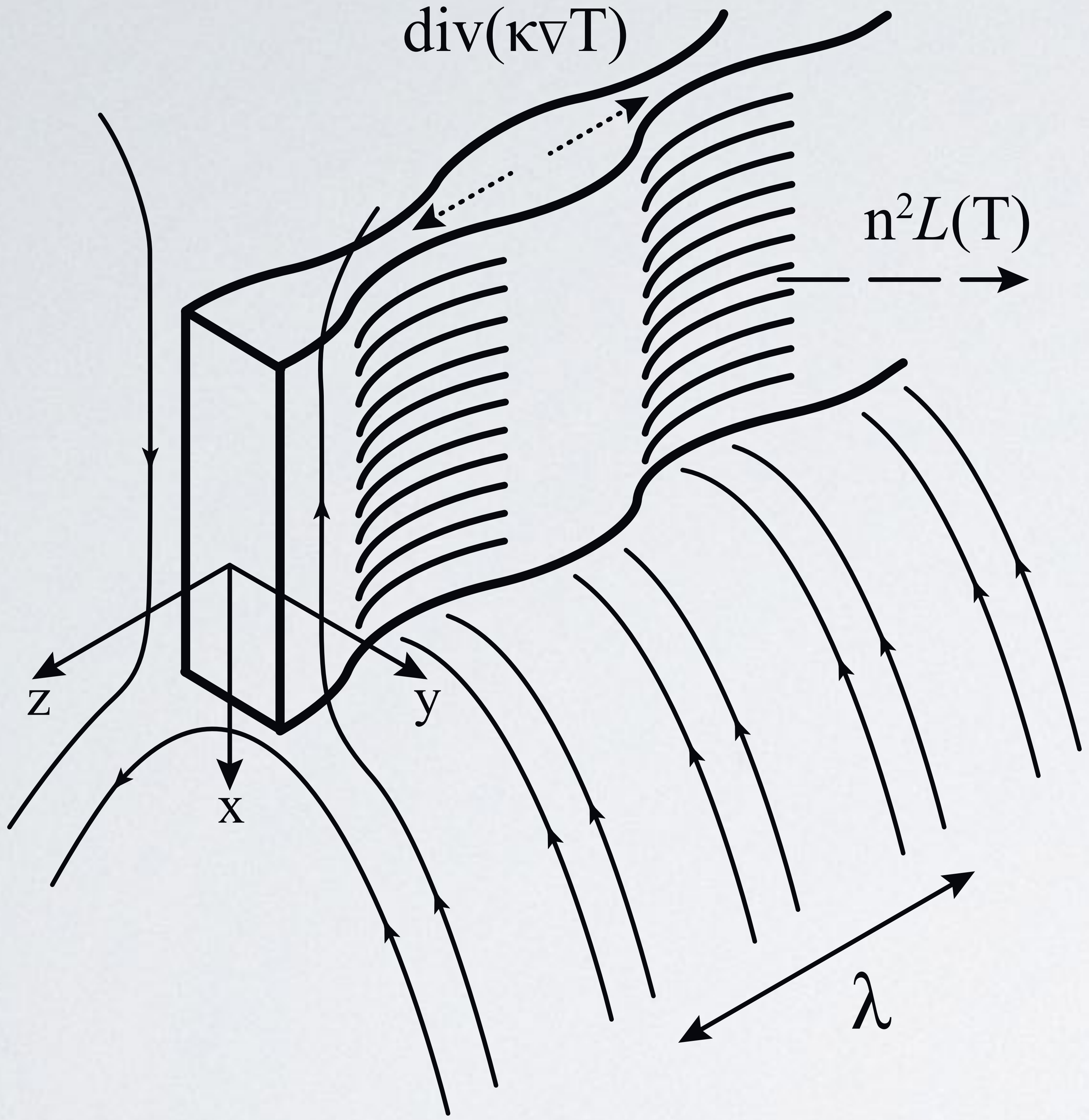
c - sound speed

ν_m - magnetic viscosity

τ_r - characteristic time of the radiative cooling

r - ratio of the thermal conduction characteristic time to the Joule heating characteristic time

Conclusions



The current sheet model can be **unstable** due to the heat losses caused by radiative cooling.

The instability grows in a characteristic time of the **radiative cooling** at the linear phase.

The instability **spatial scale** ($\lambda \sim 1$Mm) corresponds to the distance between the individual loops of a solar flare.

The instability can be completely suppressed by the **thermal conductivity**.

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Thermal Instability of the Reconnecting Current Layer in Solar Flares
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