$$\frac{\partial u_T}{\partial t} = \frac{e^2 q_T^2 \ln\Lambda\, n_e}{4\pi\varepsilon_0^2 m_T^2}\Bigg[\underbrace{Z\left(1+\frac{m_T}{m_i}\right)\frac{d}{du}\left(\frac{\mathrm{erf}\left(\sqrt{\frac{m_i}{2T_i}}\,u\right)}{u}\right)}_{\text{Friction with ions}}$$

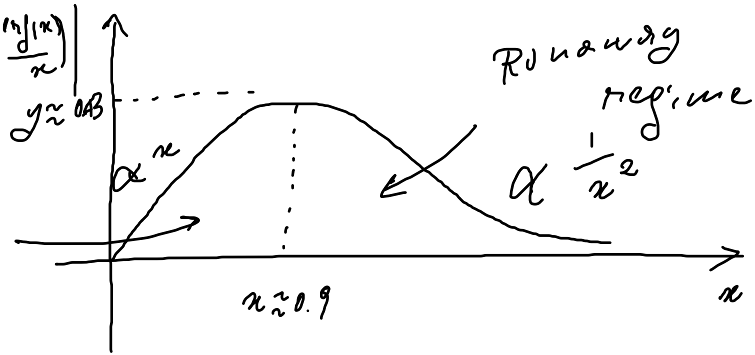
deceleration

$$+\underbrace{\left(1+\frac{m_T}{m_e}\right)\frac{d}{du}\left(\frac{\mathrm{erf}\left(\sqrt{\frac{m_e}{2T_e}}\,u\right)}{u}\right)}_{\text{Friction with electrons}}\Bigg]$$

$x \ll 1$

$x \gg 1$

$$\frac{d}{dx}\left(\frac{\mathrm{erf}(x)}{x}\right) < 0 \qquad y = \left|\frac{d}{dx}\left(\frac{\mathrm{erf}(x)}{x}\right)\right|$$



Runaway regime

Resistive regime

$a = qE/m$

$$g = \frac{d}{dx}\left(\frac{\operatorname{erf}(x)}{x}\right)$$

$x \ll 1$

$$\operatorname{erf}(x) = \frac{2}{\sqrt{\pi}} \int_0^x dy\, e^{-y^2} = \frac{2}{\sqrt{\pi}} \int_0^x dy\,(1 - y^2) = \frac{2}{\sqrt{\pi}}\left(x - \frac{x^3}{3}\right)$$

$$0 < y < x \ll 1 \Rightarrow e^{-y^2} \approx 1 - y^2$$

$$\frac{\operatorname{erf}(x)}{x} = \frac{2}{\sqrt{\pi}}\left(1 - \frac{x^2}{3}\right) \qquad \frac{d}{dx}\left(\frac{\operatorname{erf}(x)}{x}\right) \approx -\frac{4}{3\sqrt{\pi}} \cdot x$$

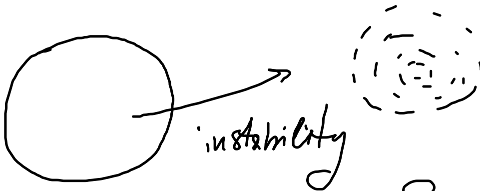
$x \gg 1$

$$\operatorname{erf}(x) \approx \frac{2}{\sqrt{\pi}} \int_0^\infty dy\, e^{-y^2} = 1 \qquad x = \frac{u}{v_{th}}$$

$$\frac{\operatorname{erf}(x)}{x} \approx \frac{1}{x} \qquad \frac{d}{dx}\left(\frac{\operatorname{erf}(x)}{x}\right) \approx -\frac{1}{x^2} \qquad x_e = \frac{u}{v_{the}} \quad x_i = \frac{u}{v_{thi}}$$

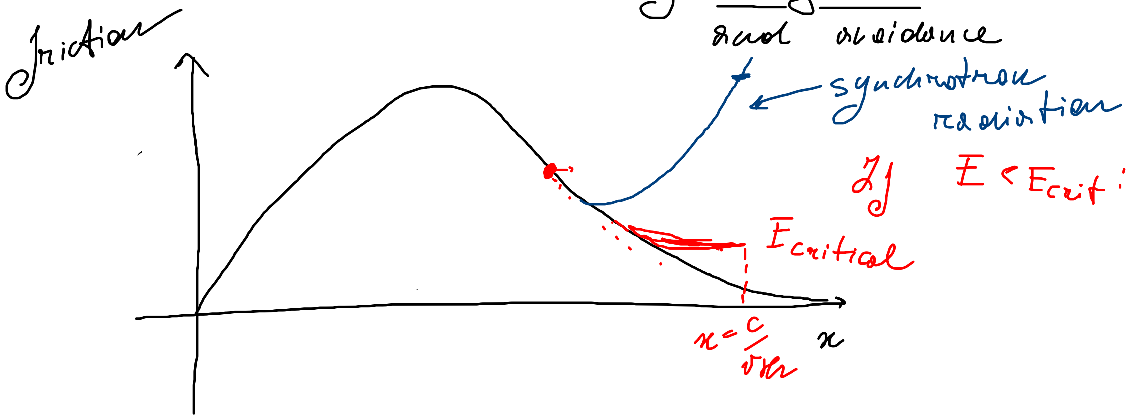
$$T_e \sim T_i \Rightarrow v_{the} \gg v_{thi}$$

Disruption : sudden loss of plasma confinement



$$-\frac{d\phi}{dt} = \mathcal{E}_{m}$$

Runaway <u>mitigation</u> and avoidance



If $E < E_{crit}$: no runaway elec.