Introduction à la physique des plasmas – Cours 12

http:\\ttpoll.eu

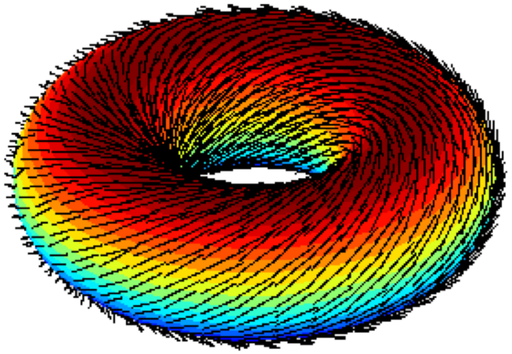
session ID: introplasma

Équation d'équilibre MHD

$$\frac{1}{\mu_0}\left(\vec{\nabla} \times \vec{B}\right) \times \vec{B} = \vec{\nabla} p \qquad (6.1)$$

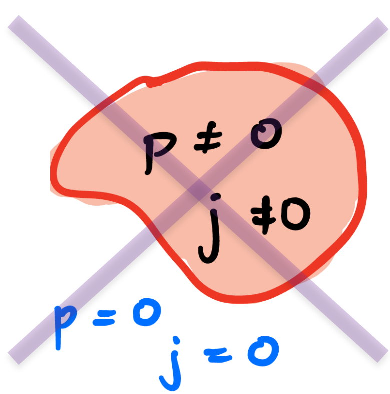
force de Lorentz $j \times B$

force de presion



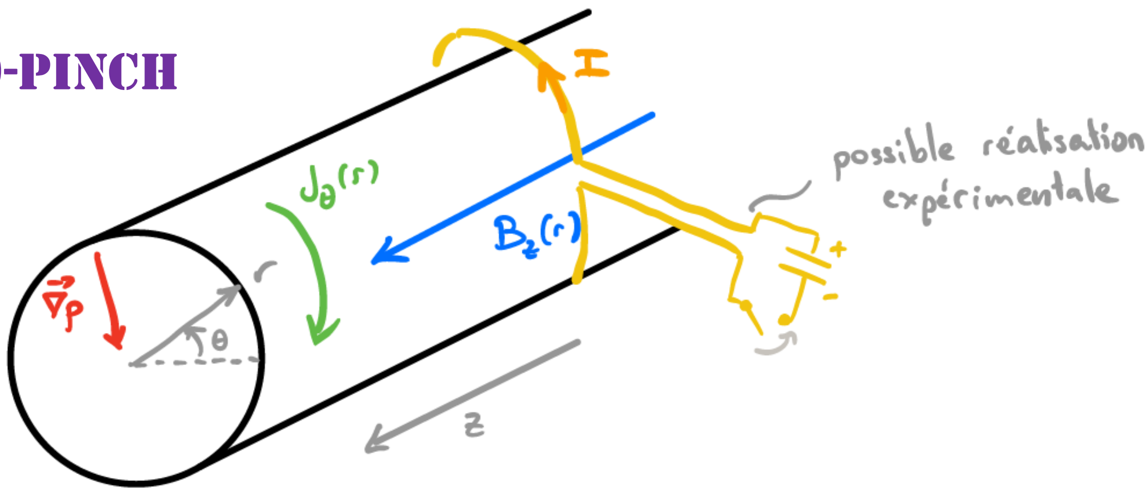
Le théorème du viriel montre que le confinement magnétique d'un plasma…

A. est impossible dans un volume fini
B. a besoin de courants internes au plasma
C. a besoin de courants externes au plasma



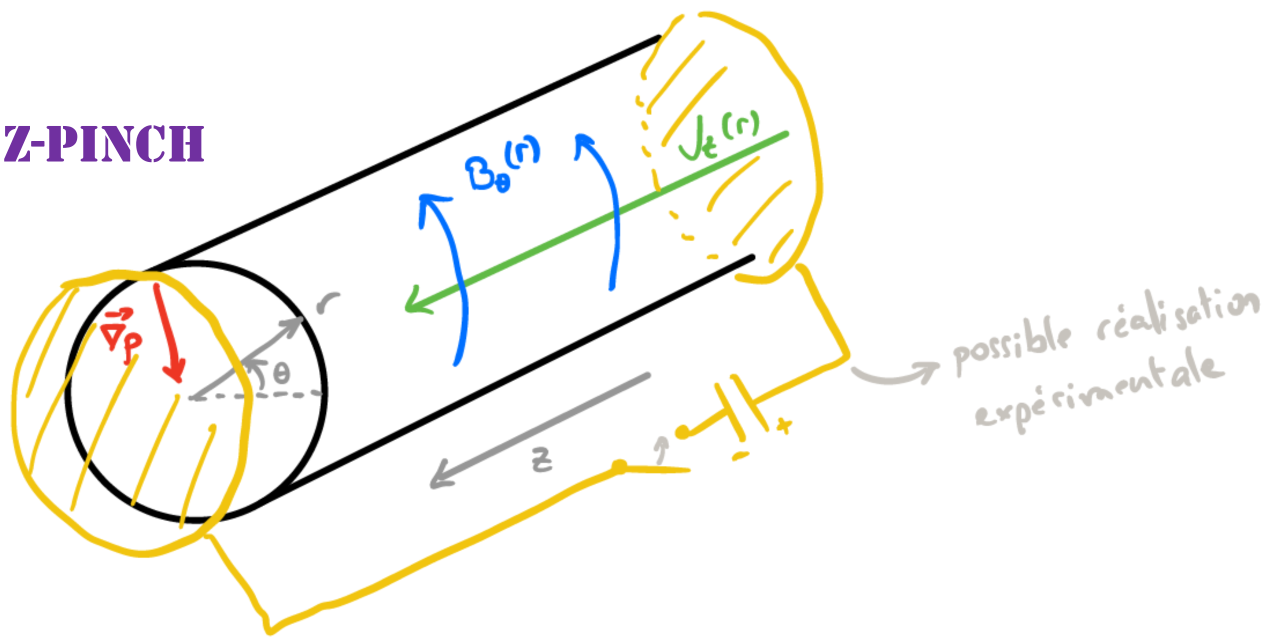
Équilibre canoniques MHD: **θ**-pinch et **Z**-pinch

θ-PINCH



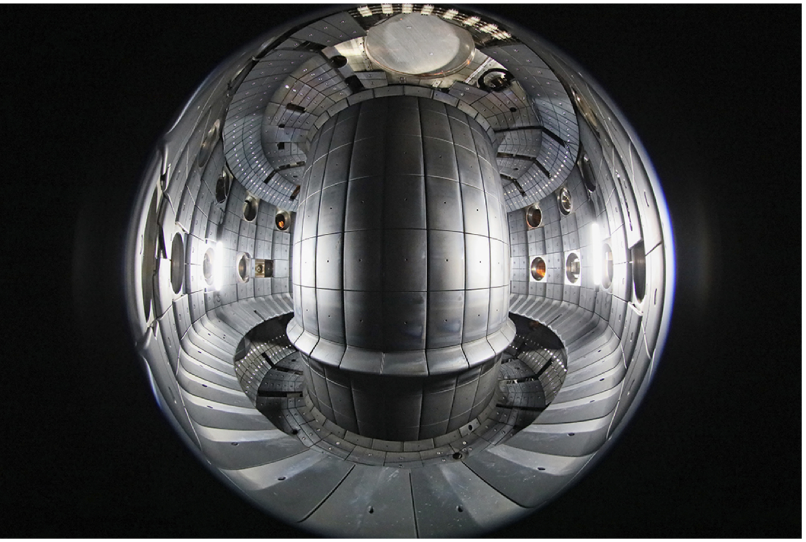
- équilibre stable
- confinement limité

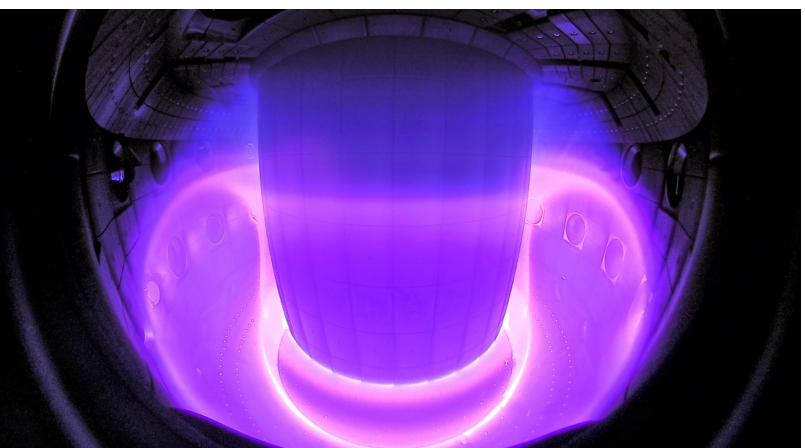
Z-PINCH



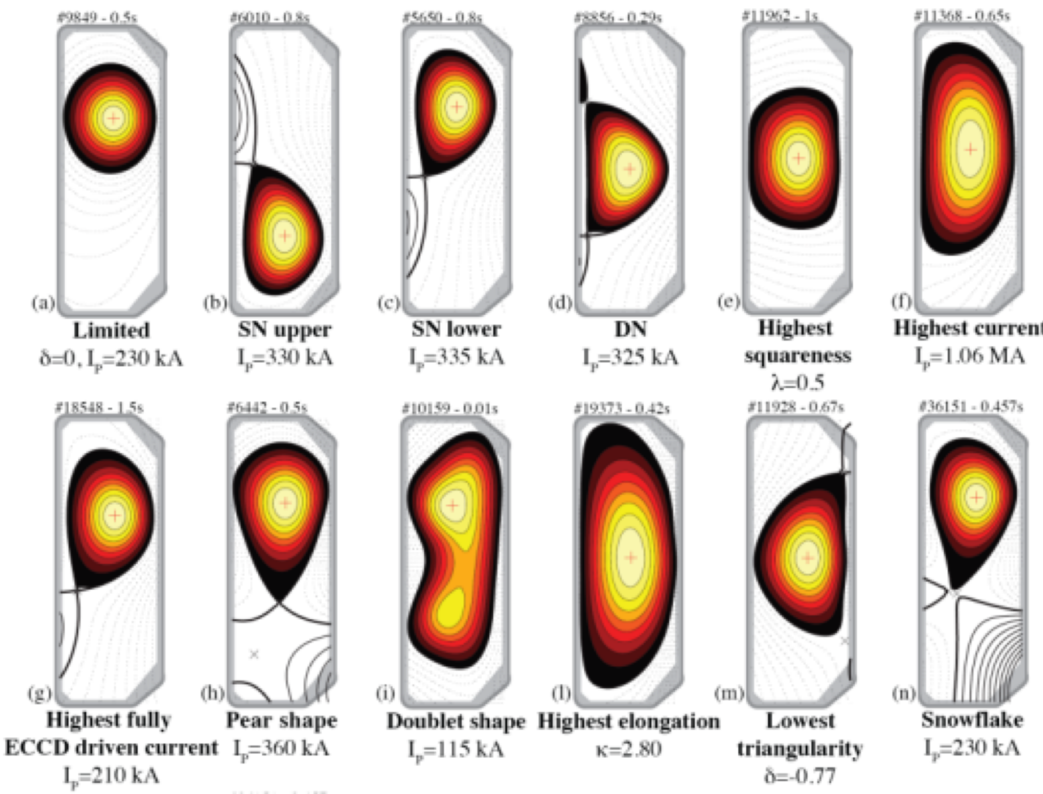
- équilibre instable
- bon confinement

Les équilibres tokamak sont 2D

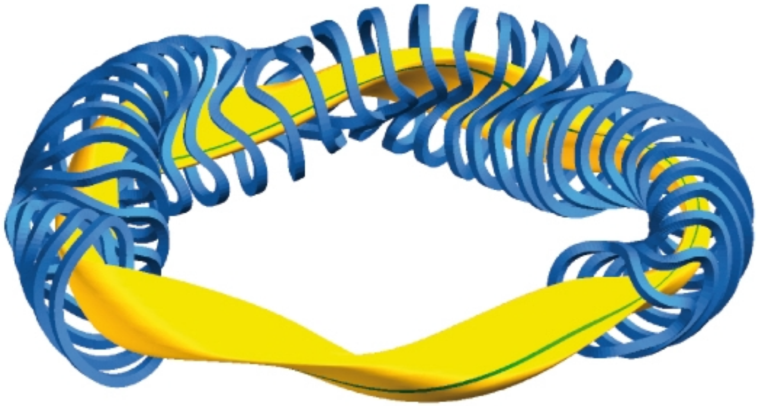




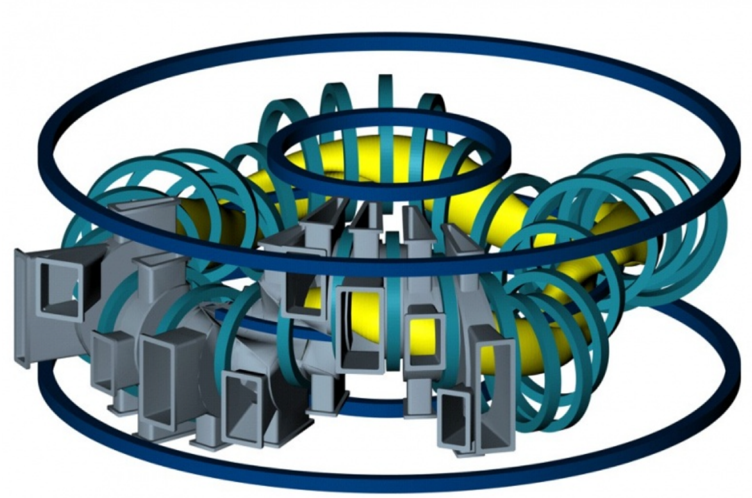
TCV (Switzerland)



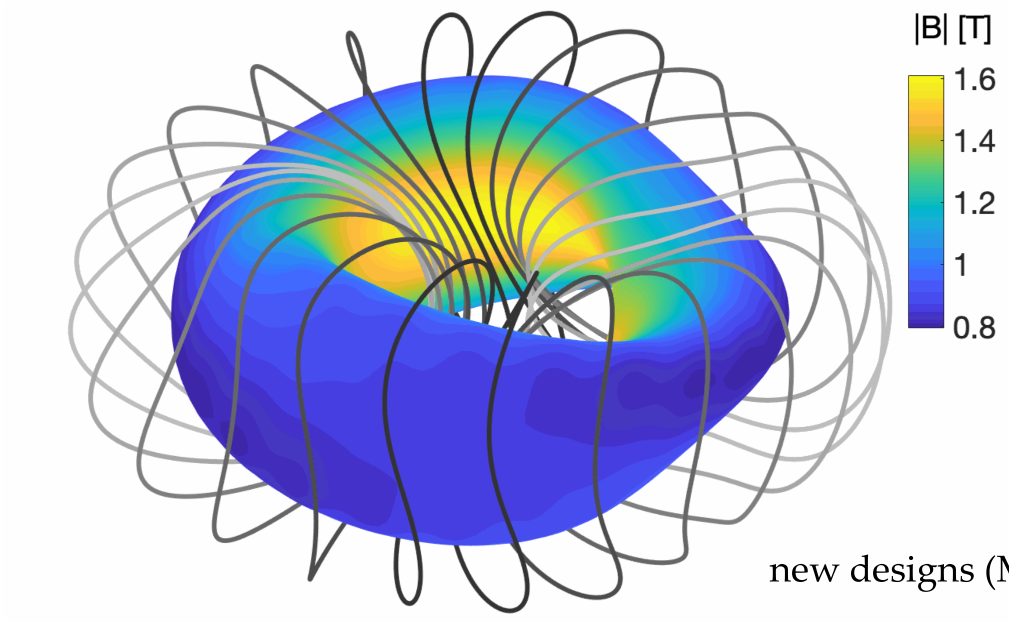
Les équilibres stellarator sont 3D



W7-X (Germany)

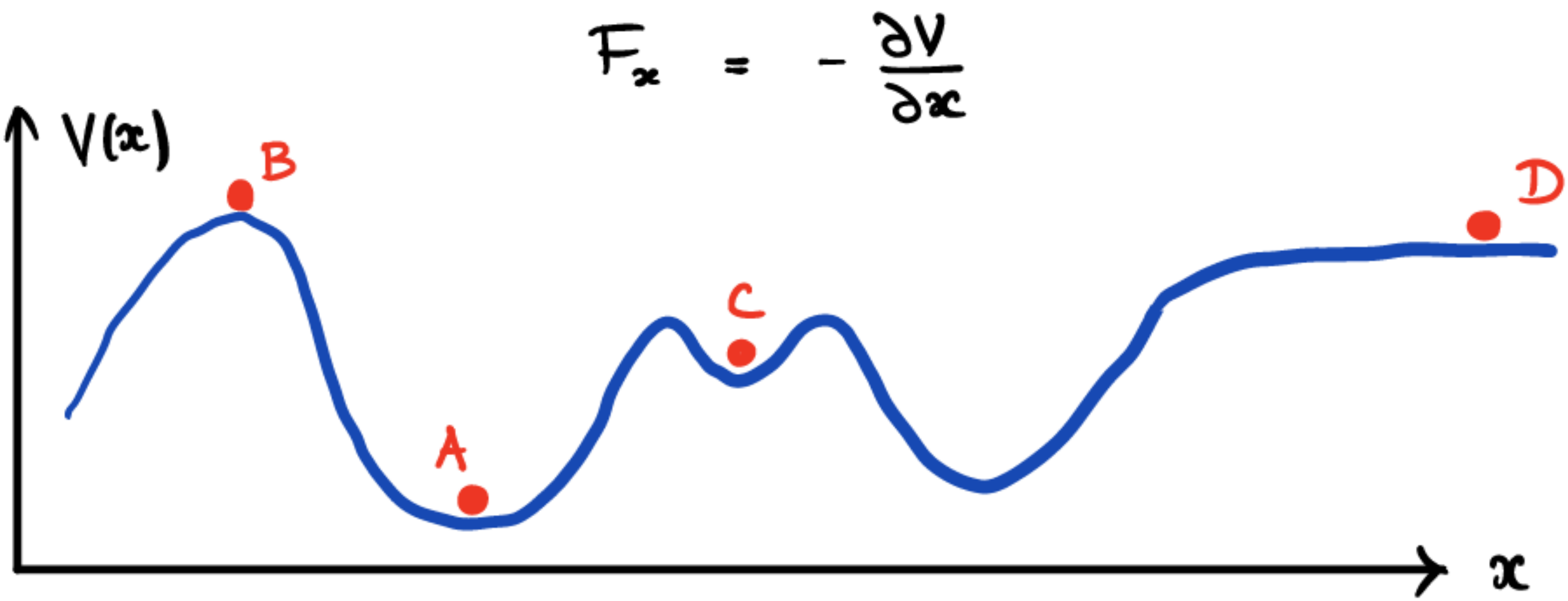


TJ-II (Spain)



new designs (M. Landreman)

Stabilité MHD: analogie mécanique



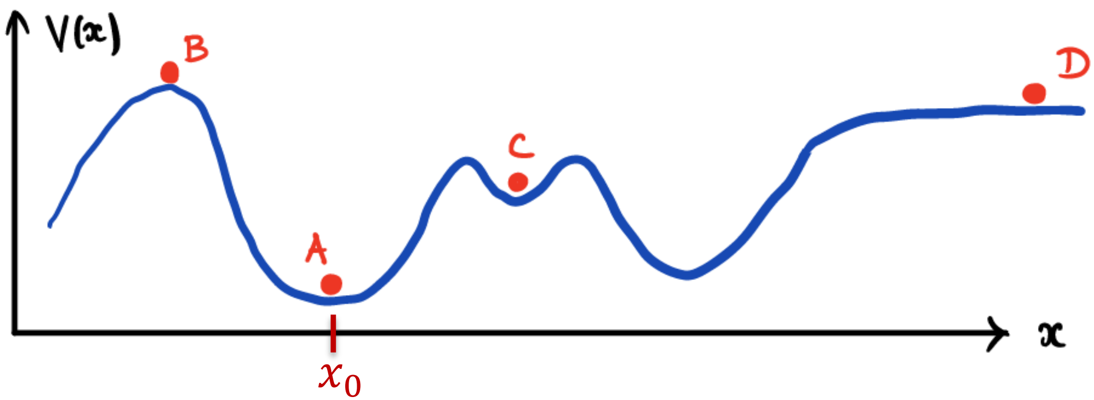
A: linéairement stable

B: linéairement instable

C: linéairement stable, nonlinéairement instable

D: marginalement stable

Stabilité MHD: analogie mécanique



$$F(x_0) = 0$$

$$\xi = x - x_0$$

$$m \frac{d^2 \xi}{dt^2} = F(x_0 + \xi) \simeq F(x_0) + F'(x_0)\,\xi + O(\xi^2)$$

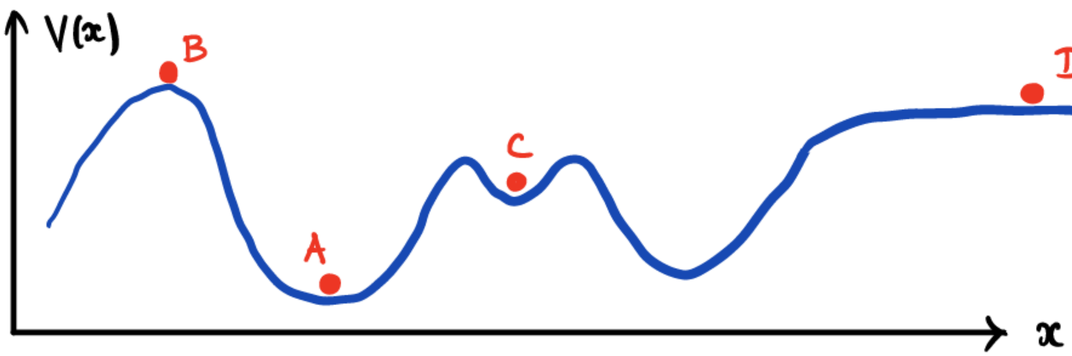
$F(x_0)$: $= 0$; $O(\xi^2)$: petit

$$\ddot{\xi} = -\omega^2 \xi \quad \text{avec} \quad \omega^2 = -\frac{F'(x_0)}{m}$$

$$\omega^2 > 0 \Rightarrow \xi(t) \sim e^{i\omega t} \quad \text{(STABLE)}$$

$$\omega^2 < 0 \Rightarrow \xi(t) \sim e^{|\omega| t} \quad \text{(INSTABLE)}$$

Stabilité MHD: analogie mécanique



$$F(x_0) = 0$$

$$\xi = x - x_0$$

$$\underbrace{V(x)}_{V_1} = V(x_0 + \xi) = \underbrace{V(x_0)}_{V_0} + \underbrace{V'(x_0)}_{=0}\xi + \frac{1}{2} V''(x_0)\xi^2 \ldots$$

$$\delta V = V_1 - V_0 > 0 \quad \Rightarrow \quad \text{STABLE}$$

$$\delta V = V_1 - V_0 < 0 \quad \Rightarrow \quad \text{INSTABLE}$$

Conservation de l’énergie dans la MHD

$$E_{MHD} = \int_V \left(\frac{1}{2}\rho u^2 + \frac{p}{\gamma - 1} + \frac{B^2}{2\mu_0} \right) dV$$

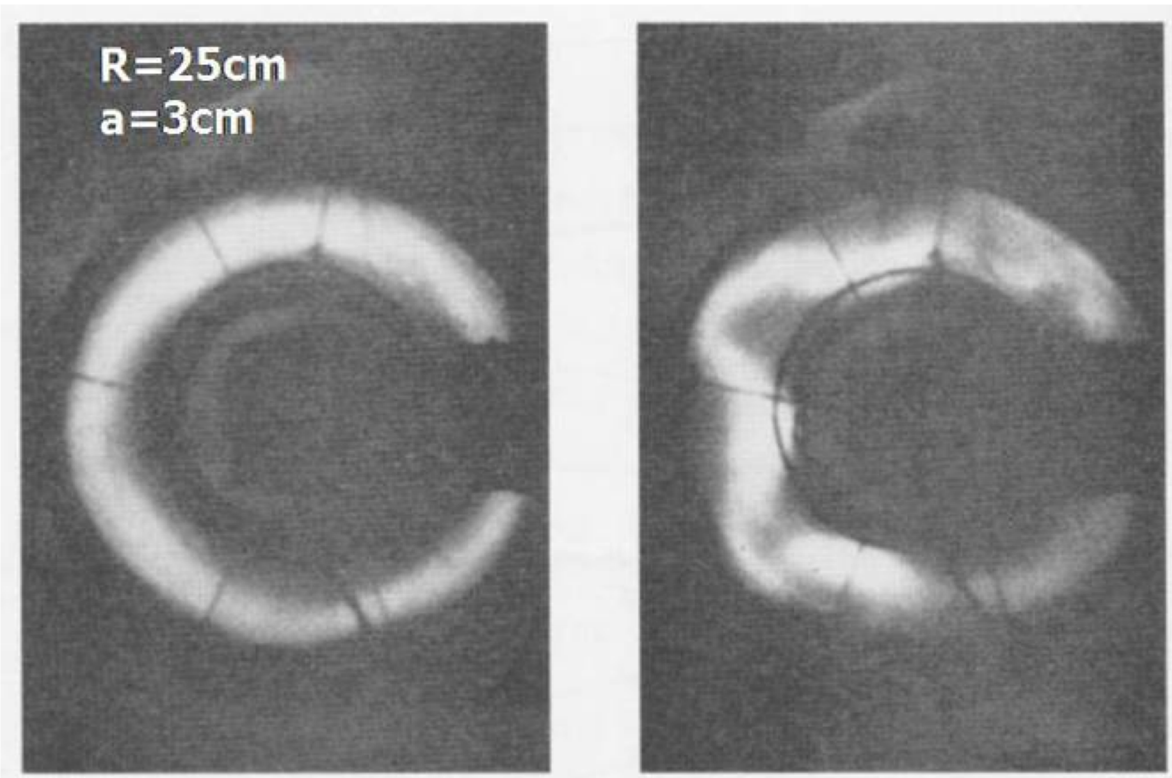
énergie cinétique

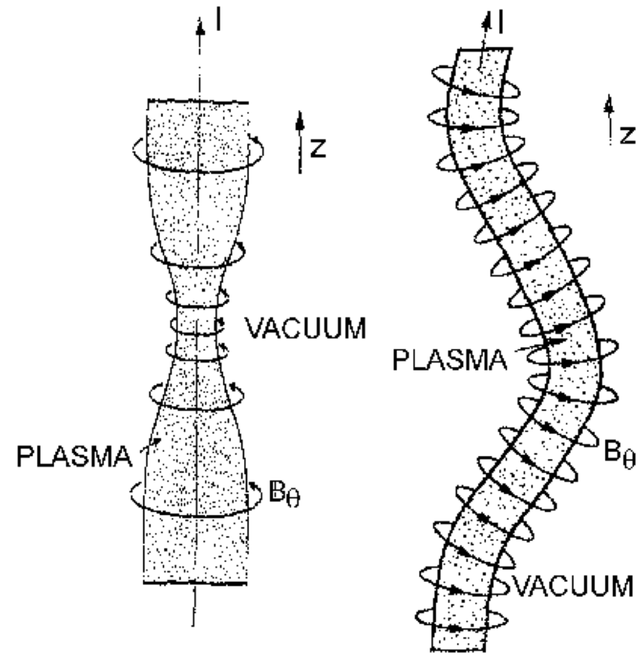
énergie thermique

énergie magnétique

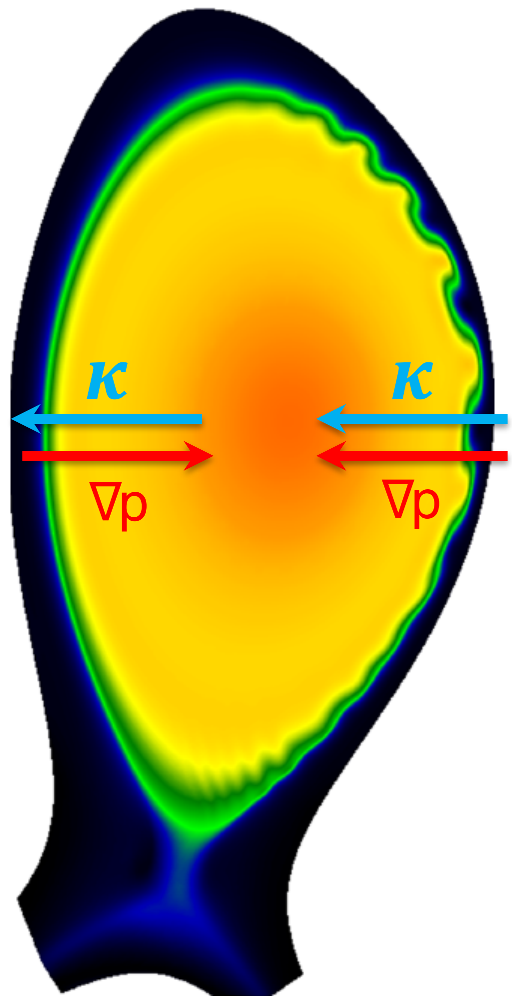
énergie potentielle MHD

instabilités MHD dans les Z-pinch





Instabilité due à pression/courbure dans un tokamak



MHD simulation (JOREK code)

Instabilités MHD dans un tokamak

MAST tokamak (UK)