

Introduction à la physique des plasmas – Cours 12

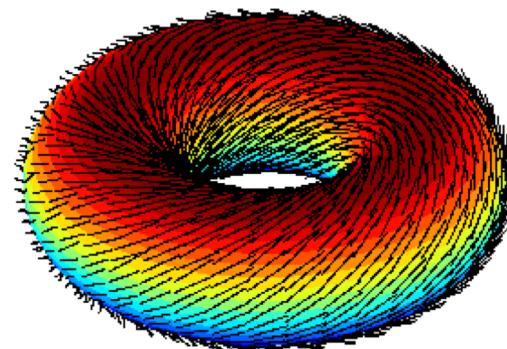
<http://ttpoll.eu>

session ID: introplasma

Équation d'équilibre MHD

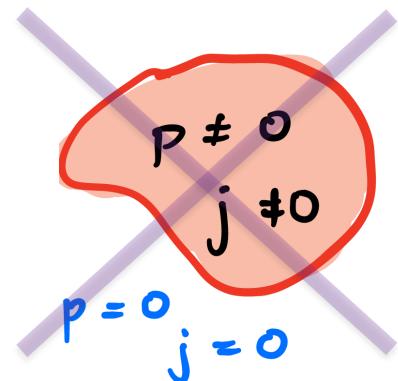
$$\frac{1}{\mu_0} (\vec{\nabla} \times \vec{B}) \times \vec{B} = \vec{\nabla} p$$

↓ (6.1)
force de Lorentz $j \times B$ force de pression



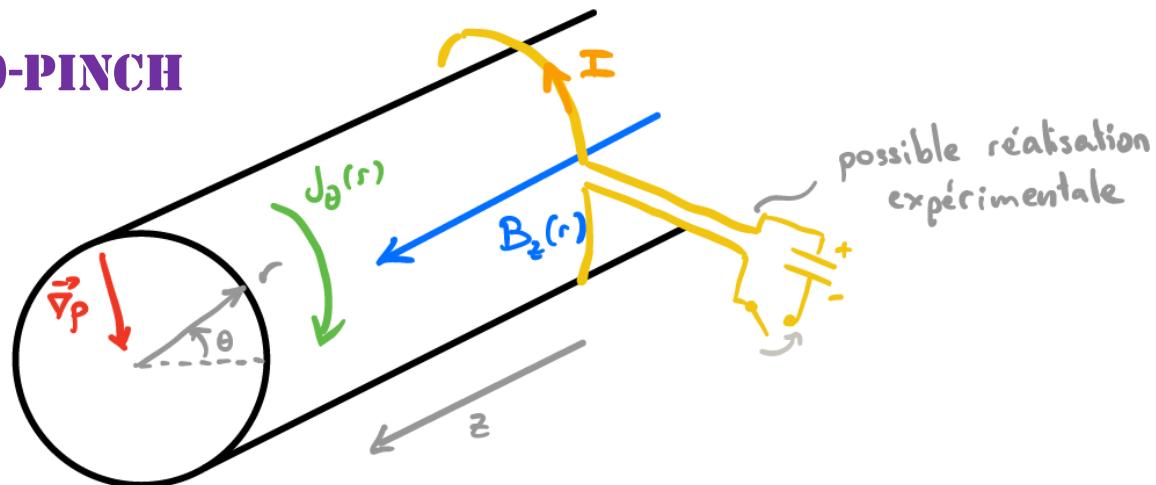
Le théorème du viriel montre que le confinement magnétique d'un plasma...

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



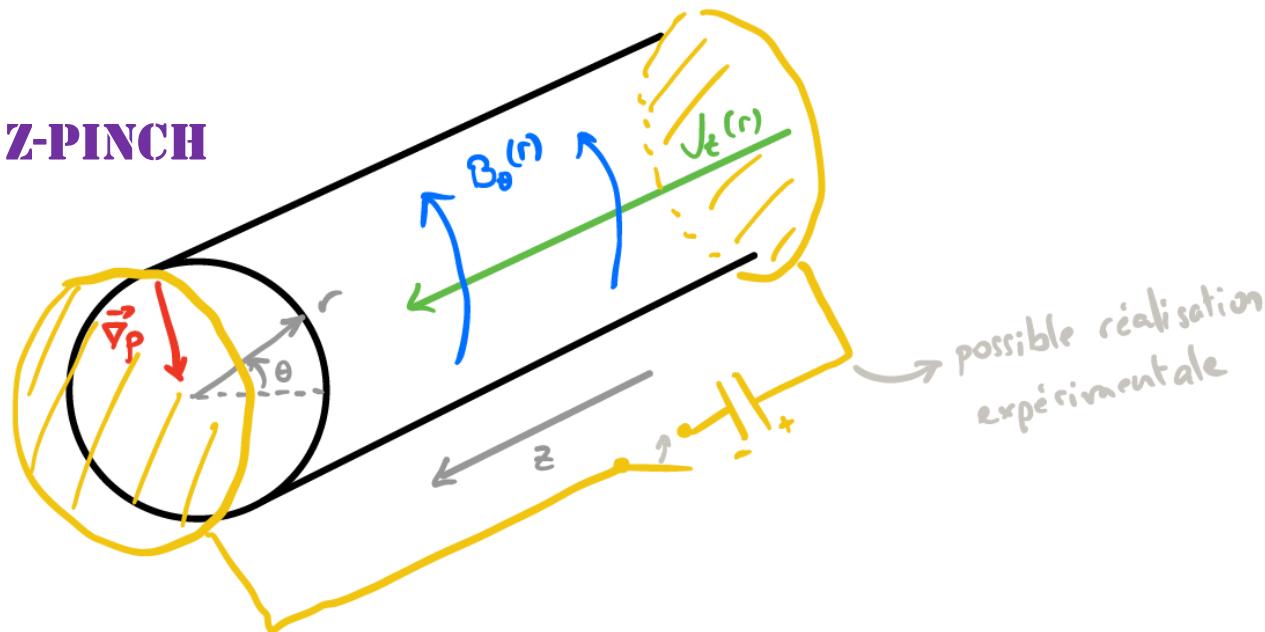
Équilibre canoniques MHD: θ -pinch et z -pinch

θ -PINCH



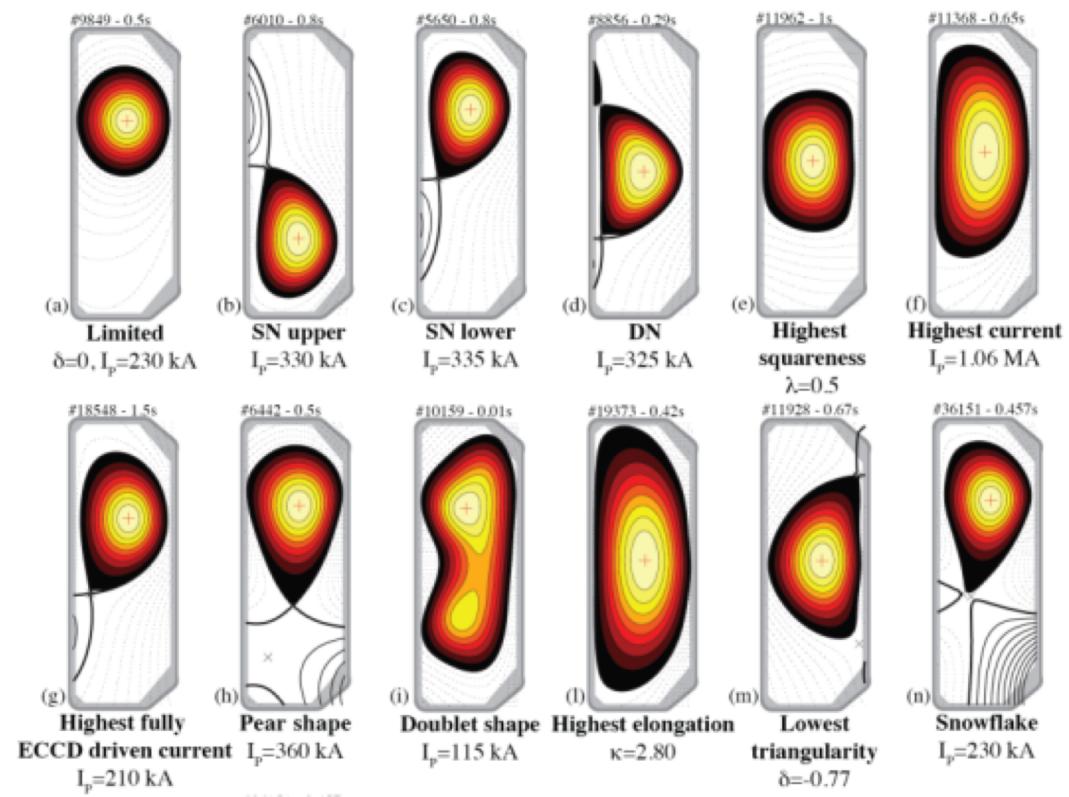
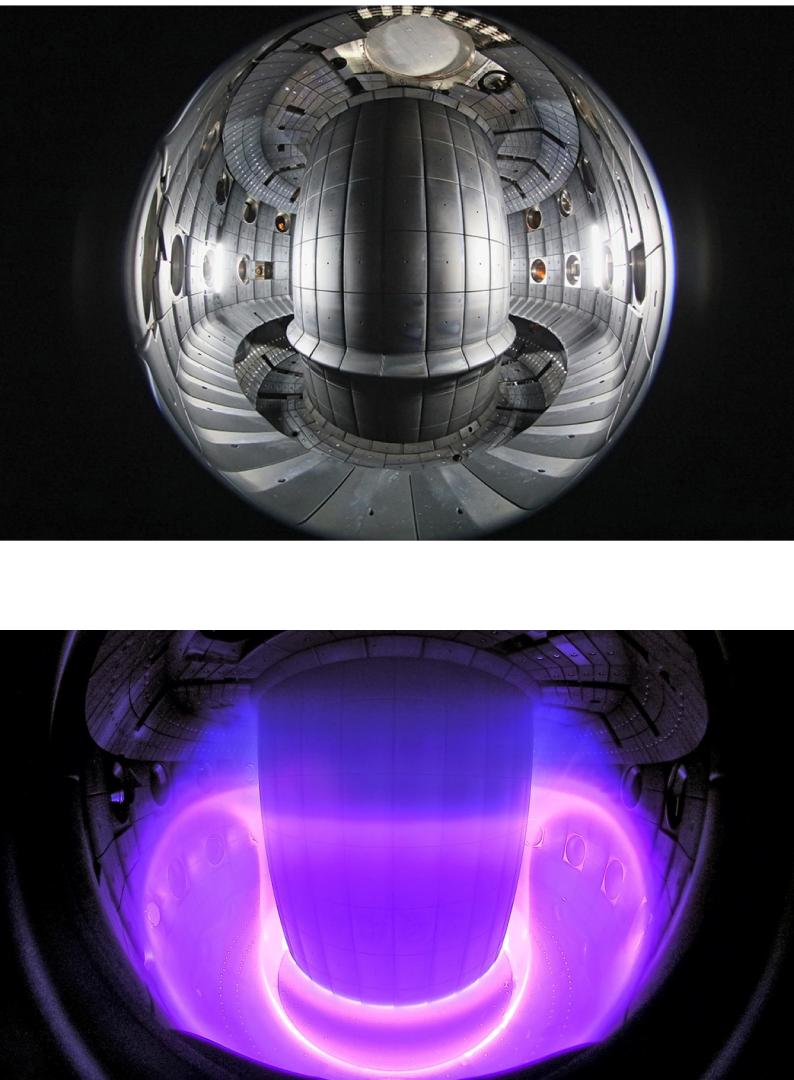
- équilibre stable
- confinement limité

z -PINCH



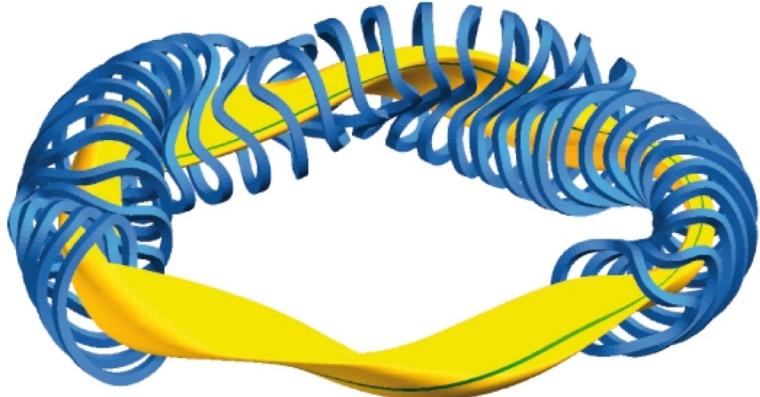
- équilibre instable
- bon confinement

Les équilibres tokamak sont 2D

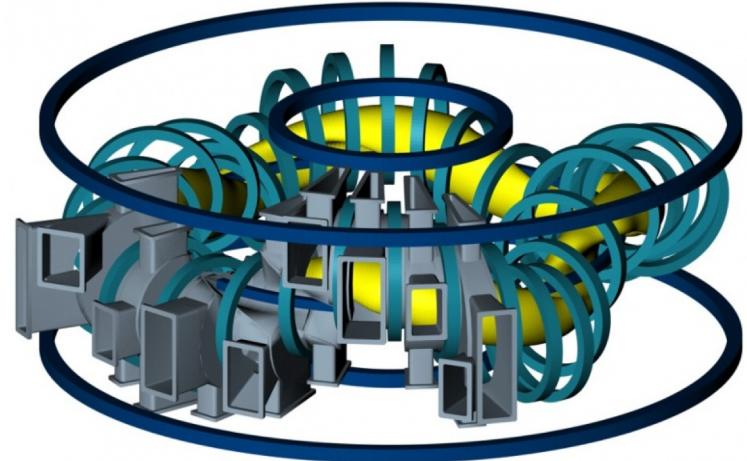


TCV (Switzerland)

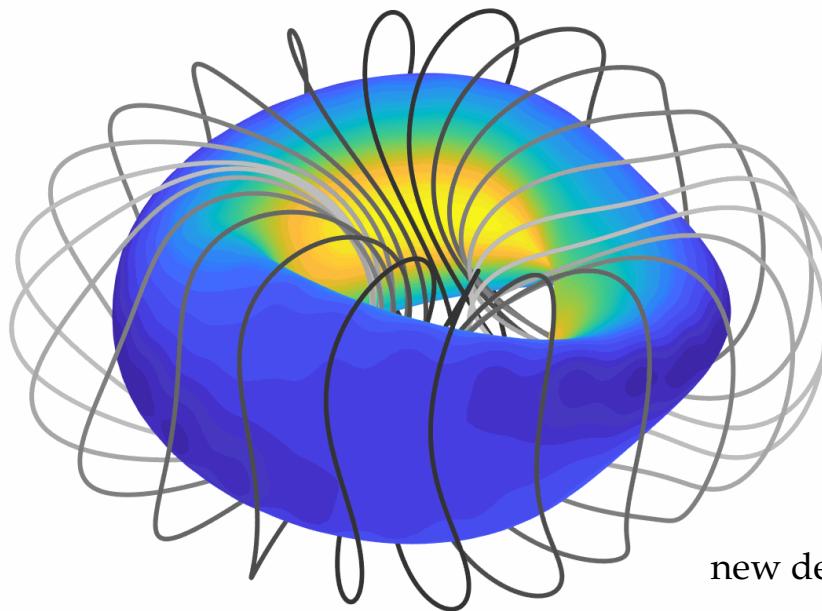
Les équilibres stellarator sont 3D



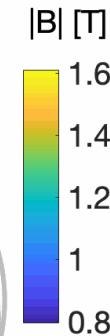
W7-X (Germany)



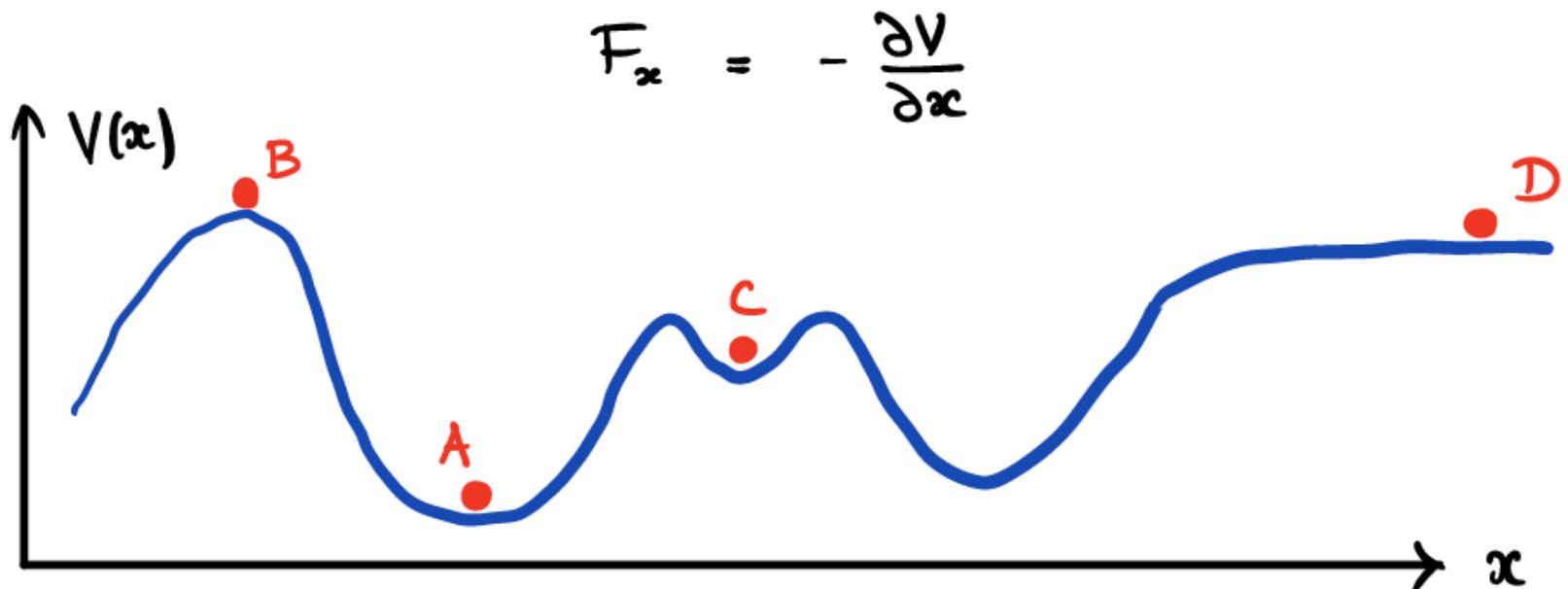
TJ-II (Spain)



new designs (M. Landreman)



Stabilité MHD: analogie mécanique



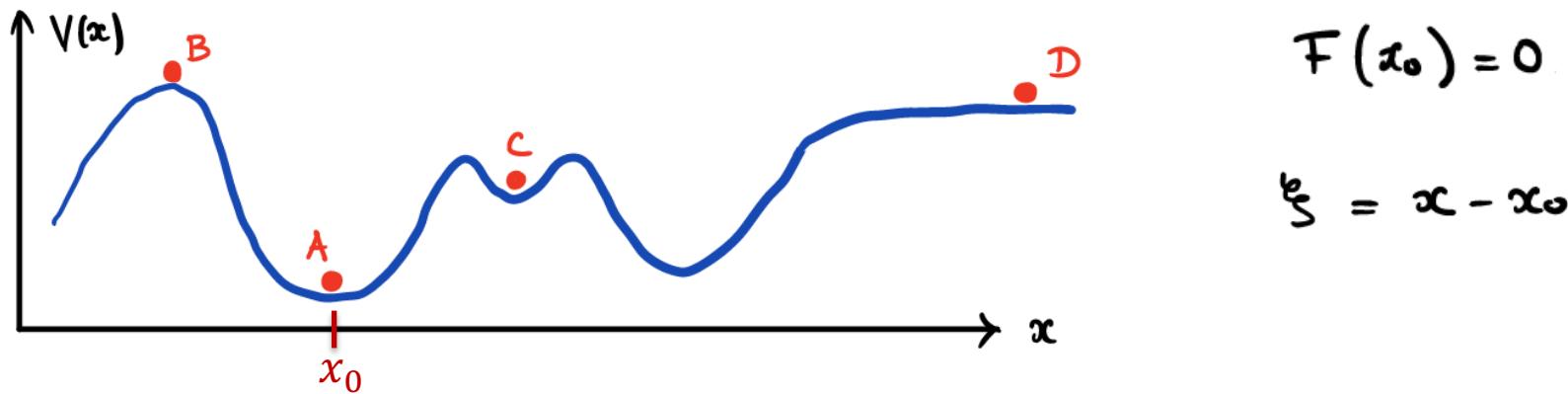
A: linéairement stable

B: linéairement instable

C: linéairement stable, nonlinéairement instable

D: marginalement stable

Stabilité MHD: analogie mécanique



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

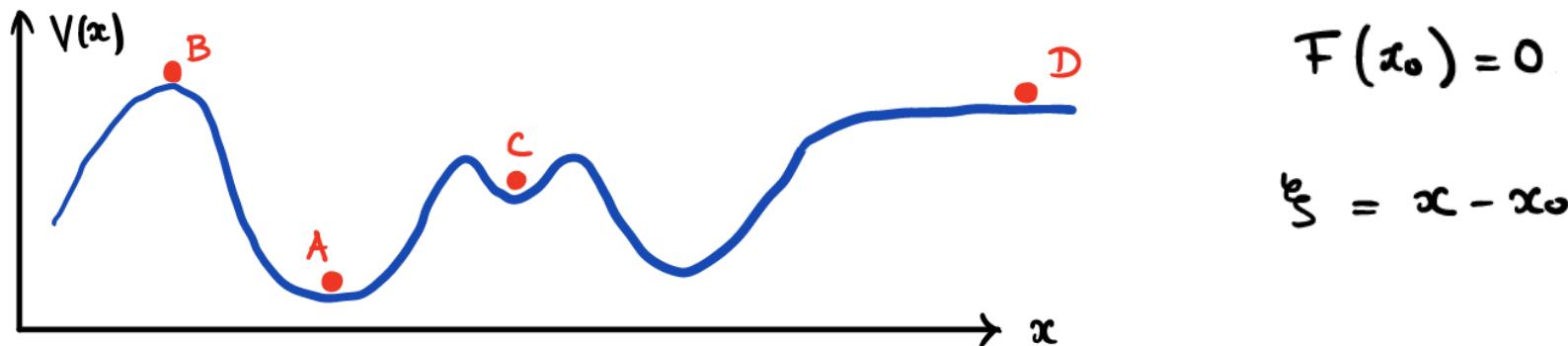
↓ $= 0$ ↓ petit

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

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

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

Stabilité MHD: analogie mécanique



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

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

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

Conservation de l'énergie dans la MHD

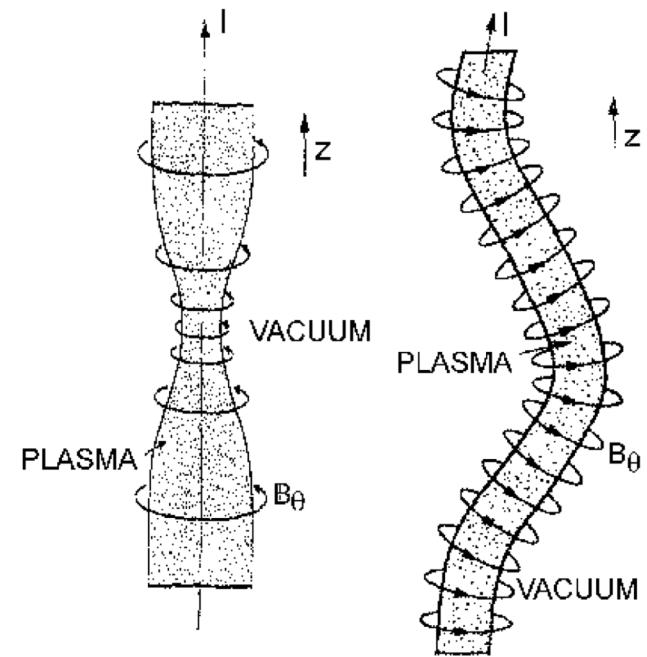
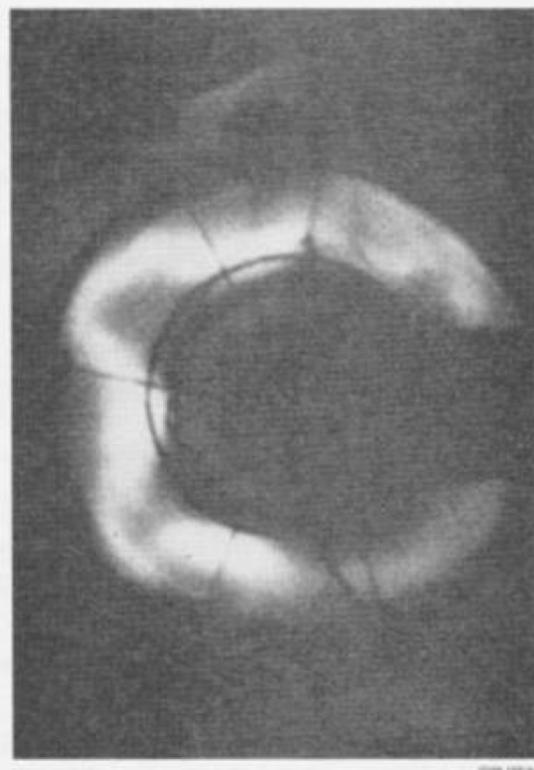
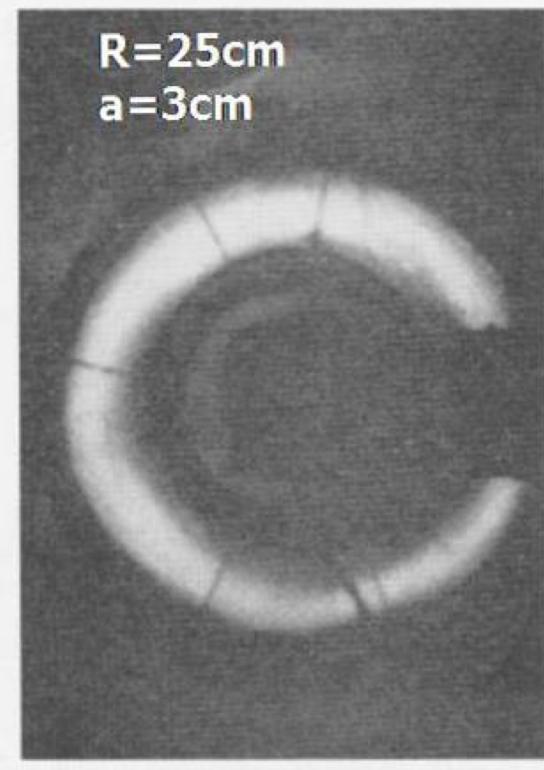
$$E_{\text{MHD}} = \int_V \left(\frac{1}{2} \rho u^2 + \frac{P}{\gamma - 1} + \frac{B^2}{2\mu_0} \right) dV$$

The diagram shows the expression for the total MHD energy integrated over a volume V. Three terms are identified with arrows pointing to their respective parts in the formula:

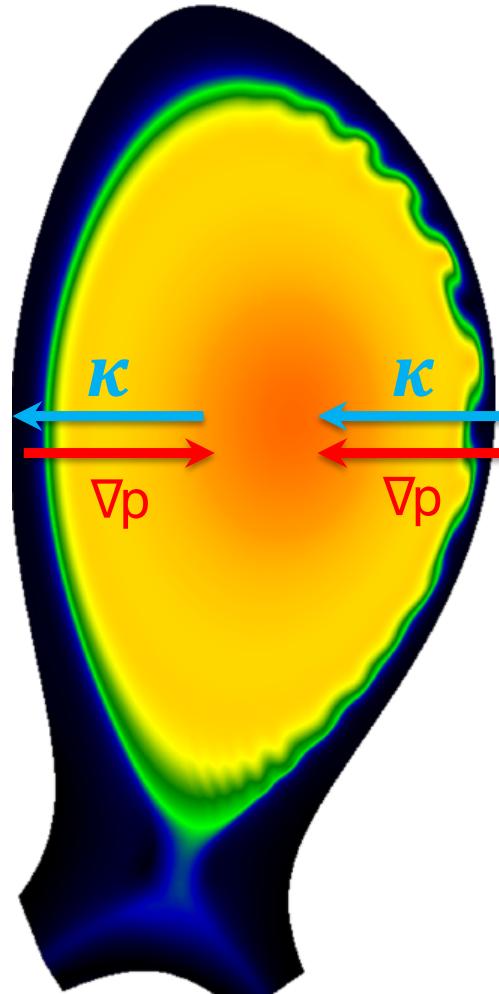
- An arrow points to the first term $\frac{1}{2} \rho u^2$ with the label "énergie cinétique".
- An arrow points to the second term $\frac{P}{\gamma - 1}$ with the label "énergie thermique".
- An arrow points to the third term $\frac{B^2}{2\mu_0}$ with the label "énergie magnétique".

A blue bracket below the last two terms is labeled "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)