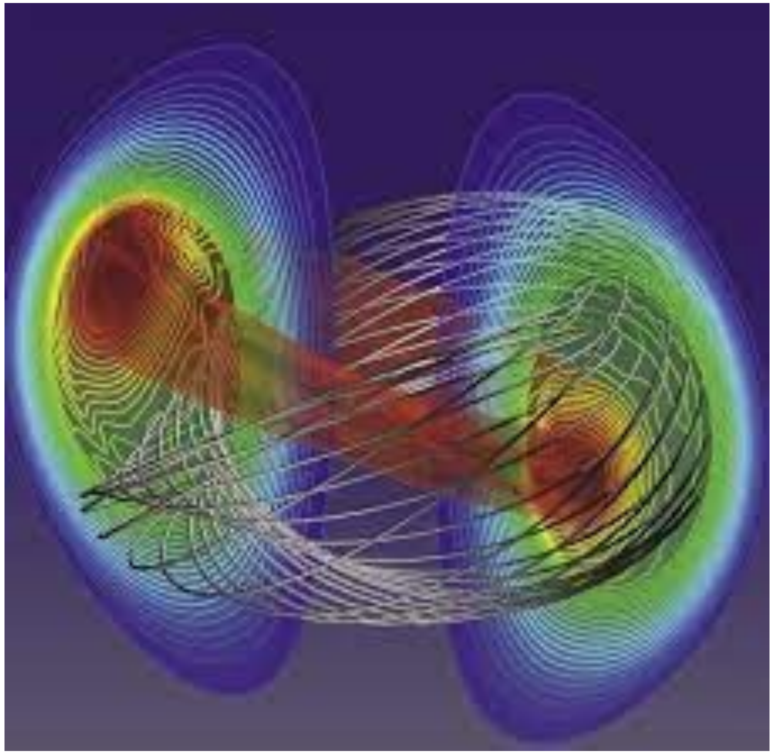
Margherita Salerno

CONFINEMENT REGIMES



Visualization of the sawtooth instability in a tokamak. (Courtesy of the U.S. Department of Energy)

Plasma confinement

- the act of **maintaining plasma** in a discrete volume.

Why?

- Requirement to **achieve fusion power**

How?

- Two different approaches
  - magnetic confinement → **TOKAMAK**
  - inertial confinement

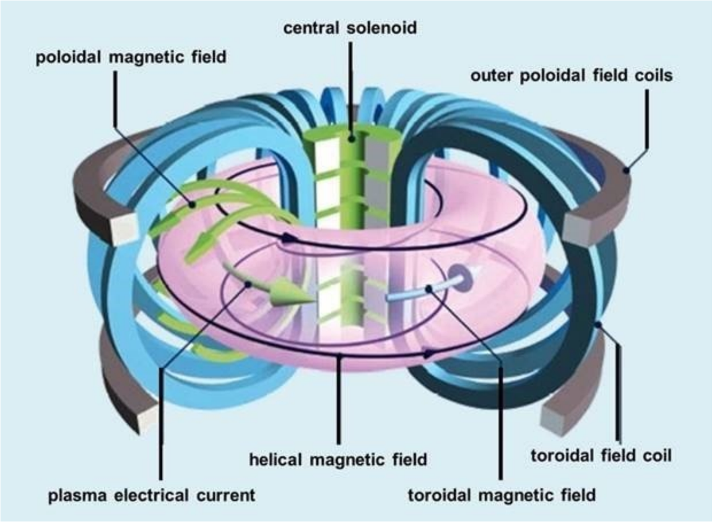
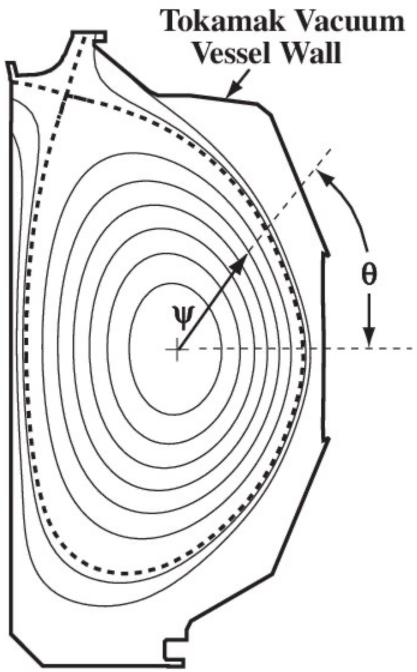
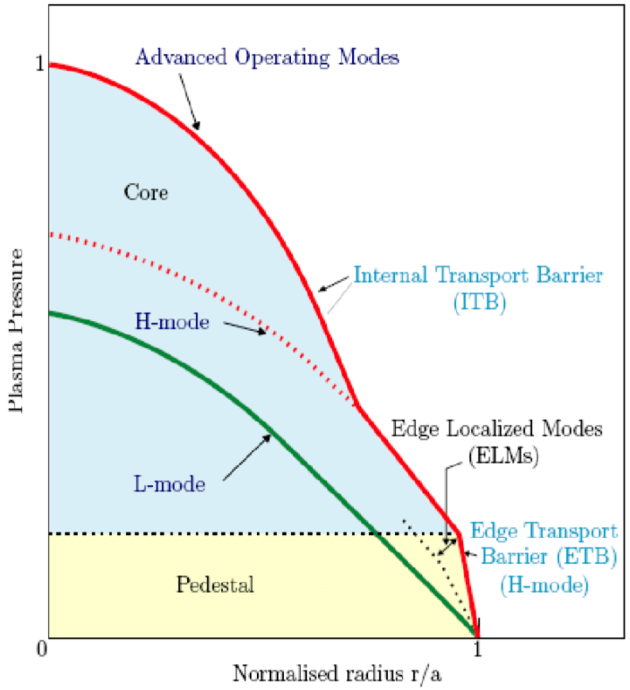


Image courtesy of EUROfusion

Confinement regimes

- **State** by which the plasma is **confined** within the magnetic field.





T. E. Evans, Journal of Physics Conference Series (2012) A. Murari, IEEE Transactions on Plasma Science (2012)

Pressure profiles typical of the various confinement regimes in a Tokamak plasma. The parameter a is the minor radius of the device

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Low confinement mode >> L - mode

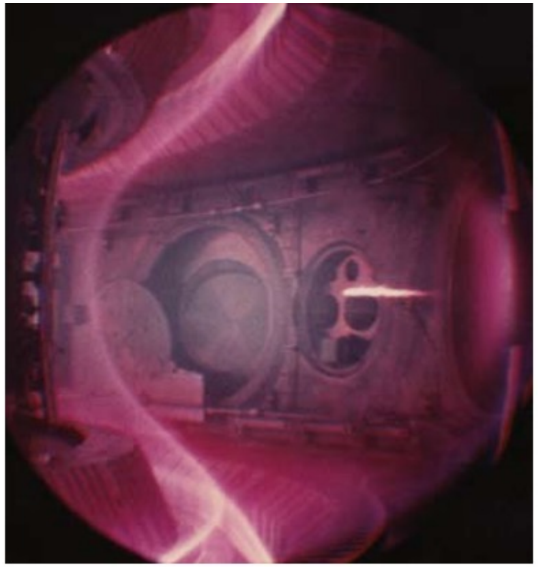
- Standard regime for tokamak
- Low impurity concentration
- High tourbolence
- Low energy confinement time
- More diffuse and less centrally concentrated energy profile
- Easier to achieve and maintain
- It often has lower plasma performance in terms of temperature and density compared to other modes

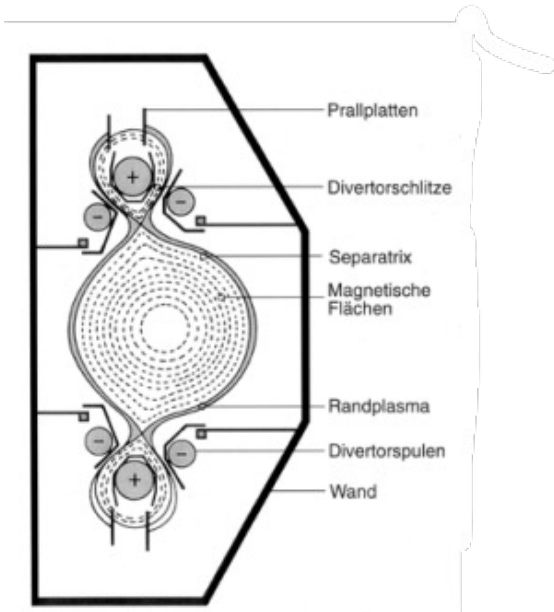
High confinement mode >> H - mode

- **When?**
  discovered in 1982
- **Where?**
  IPP of Garching – ASDEX
- **Who?**
  Friedrich Wagner et al.
- **How?**
  studying plasma with NBI
- **What?**
  let see what we are talking about…..

It was clear that the plasma made a **transition** from one state to another state

ASDEX





[Asdex tokamak pictures : F. Wagner et al. , Tokamaks]

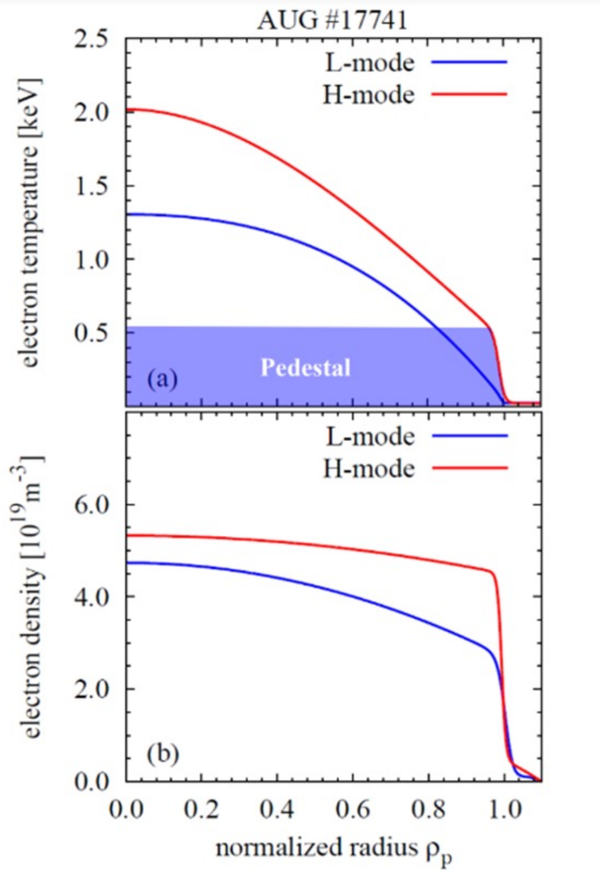
Properties of H - mode

- Primary operating mode for ITER

- High confinement mode → Particles, Energy

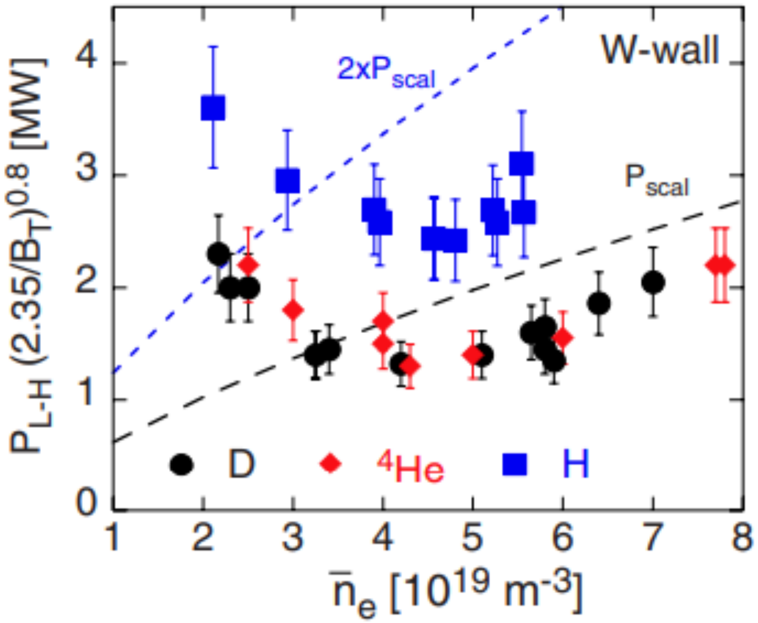
- Pedestal → Edge Transport Barrier (ETB)
    - sudden drop of light emission

- Energy confinement time $\tau_E = \frac{W}{P}$ → 2 times the one of L- mode



P. Schneider, PhD Thesis (2012)

How do we get H – mode ?



A. Hubbard et al., Nuclear Fusion 57 (2017)

$$P_{\text{scal}} = 0.049\,\bar{n}_e^{\;0.72} B_T^{\;0.80} S^{0.94}$$

n_e density
B magnetic field
S tokamak surface

↓

Heating power threshold to overcome

- Minimum heating power to satisfy the H – mode
- Direct impact on the size of tokamak reactors

Experimental observations of the L – H transition

- Spontaneous transition
- **Local Edge Parameters** → L – H transition is a edge phenomenum
- **Spatial and temporal characteristics** → creation of an edge transport barrier

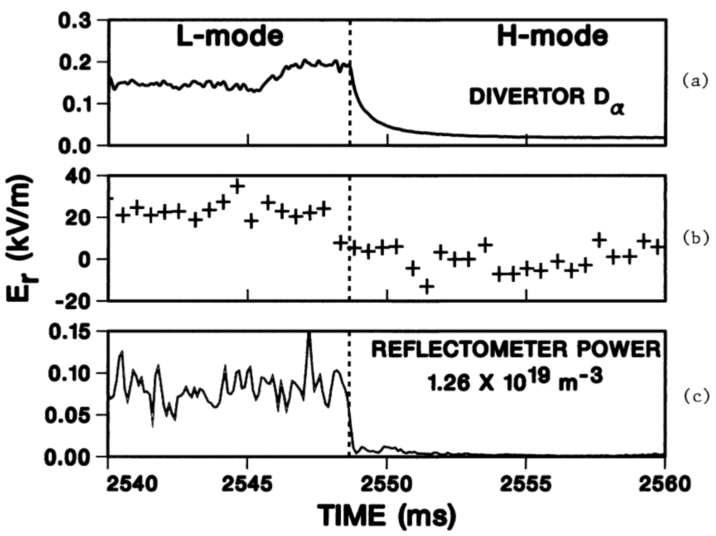
→ time scale of 1 -10 ms

→ temporal sequence of events :

- the creation of steep electric field gradients

- suppression of turbulence

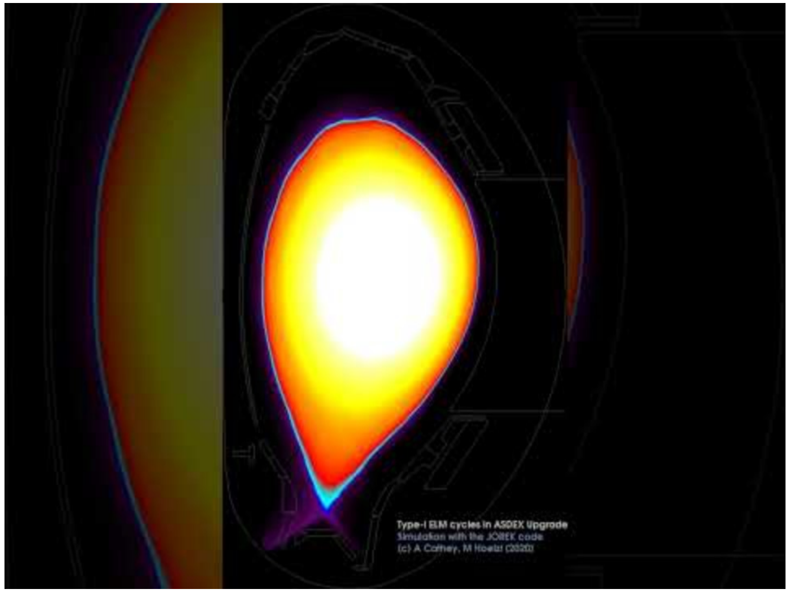
- steep of density and temperature
  → heat and particle transport is lower



Doyle E J et al 1993 Plasma Physics and Controlled Nuclear Fusion Research

Edge Localized Modes

- Periodic disturbance of the plasma confinement
- Different types with different sizes and frequency dependencies on heating power
- Filament structures
- MHD instabilities at the edge
- Edge plasma loses its confinement for a short time
  - Cause thermomechanical stress
  - Damage wall components

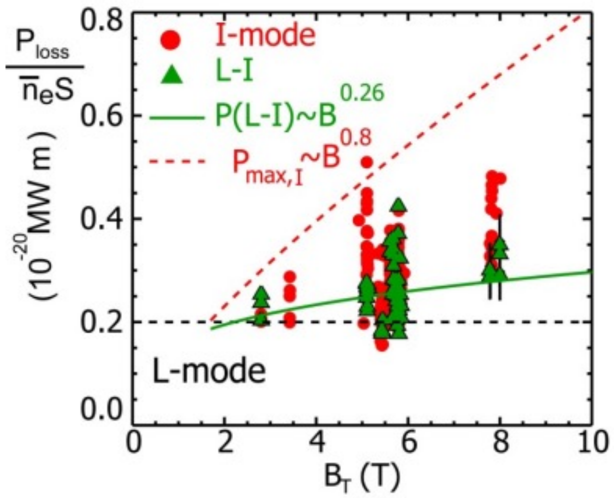


[Computersimulation von Type-I-ELMs Short]

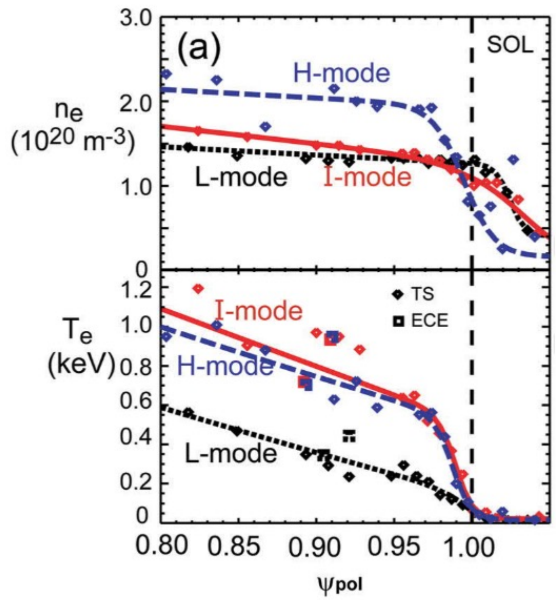
Confinement regimes without ELMs

- **I – mode**
  - Unfavourable magnetic configuration
  - Limited power heating

$$\vec{v}_D = -\frac{1}{2} m v_\perp^2 \frac{\nabla B \times \vec{B}}{q B^3}$$



A. E. Hubbard et al, Revision 1 8-Jun-17



A. E. Hubbard et al., Physics of Plasmas 18 (2011)

→ Temperature pedestal - H – mode
→ No density pedestal - L – mode

Other confinement regimes

- **EDA H – mode**:
  - Different shape of the plasma
    - High triangularity and elongation of the plasma
  - heating the plasma only marginally above the H-mode power threshold with wave heating
  - high levels of D_α light emission at the edge
    - measure of particle transport

- **QH – mode** :
  - Unfavourable configurations
  - Achieved thanks to injection beams
  - High torque (lot of spinning of the plasma along the poloidal direction)

Summary

Confinement regimes in a tokamak

→ Fundamental to reach the ignition conditions

→ L – mode : basic mode

→ H – mode : best one to reach fusion conditions

- → BUT : there are ELMS
  - → Big dispersion of energy
  - → SO we need to find new alternative regimes
    - → Some examples:
      - → EDA – H mode
      - → I - mode
      - → QH- mode