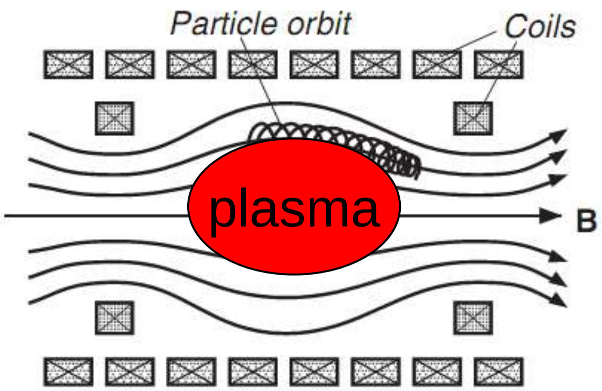
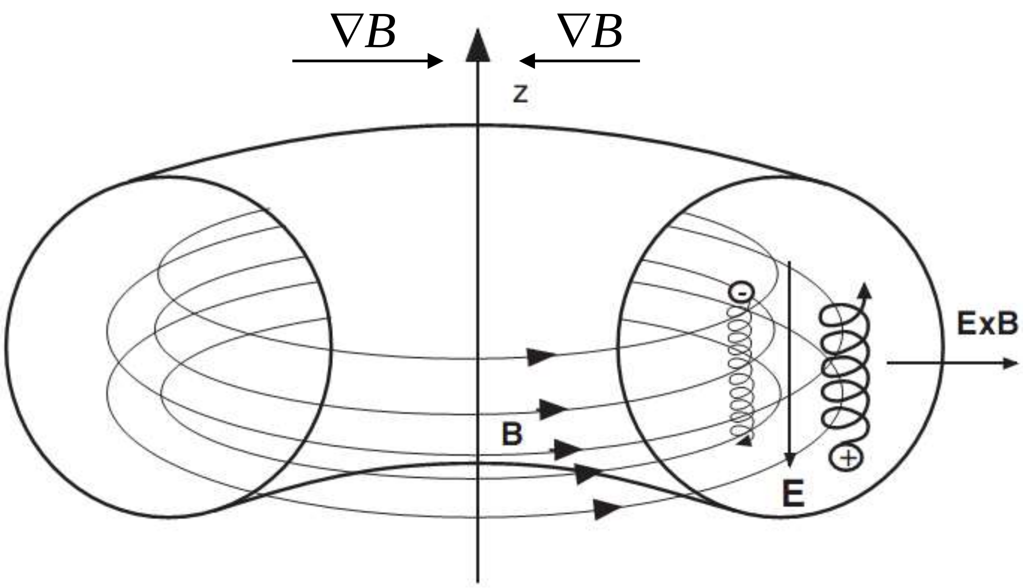
Introduction to physics of tokamaks

Valentin Igochine



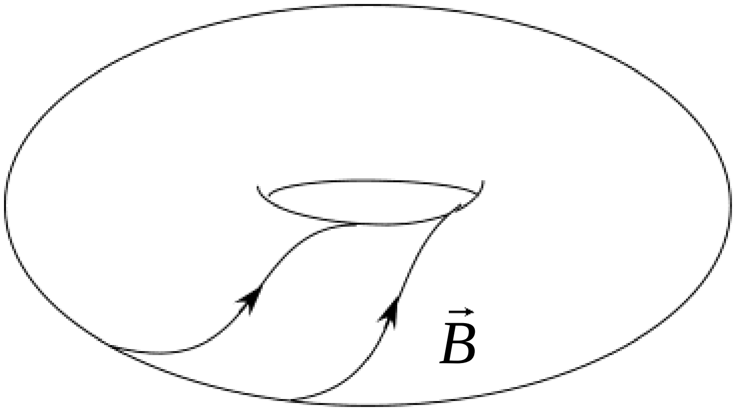
Particles are lost along the magnetic field lines.

Toroidal field lines solve this problem but …

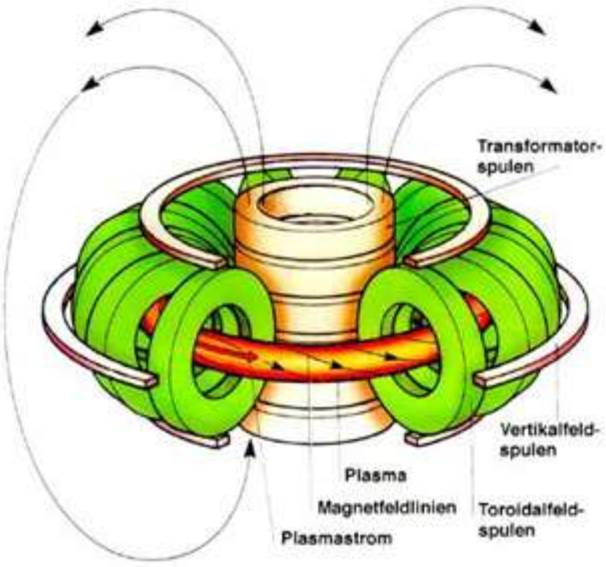


$$\mathbf{v}_{\nabla B} = \frac{m}{q}\left(v_{\parallel}^2 + \frac{v_{\perp}^2}{2}\right)\frac{\mathbf{B}\times\nabla_{\perp}B}{B^2}$$

gives separation of charged particles and this leads to ExB drift which shifts the plasma radially outward.

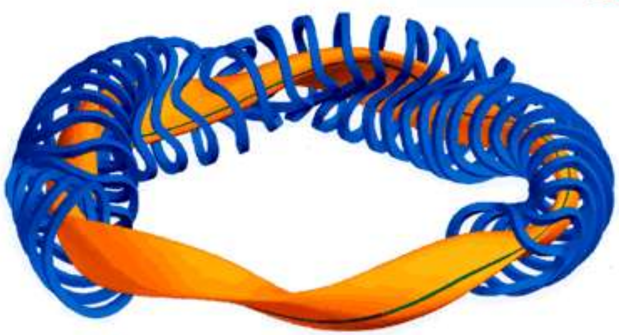


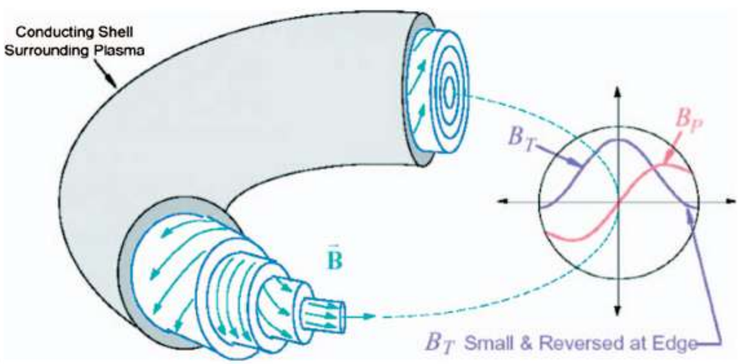
Equilibrium magnetic field has to have both: toroidal and poloidal component. This is true for most advanced concepts in fusion.



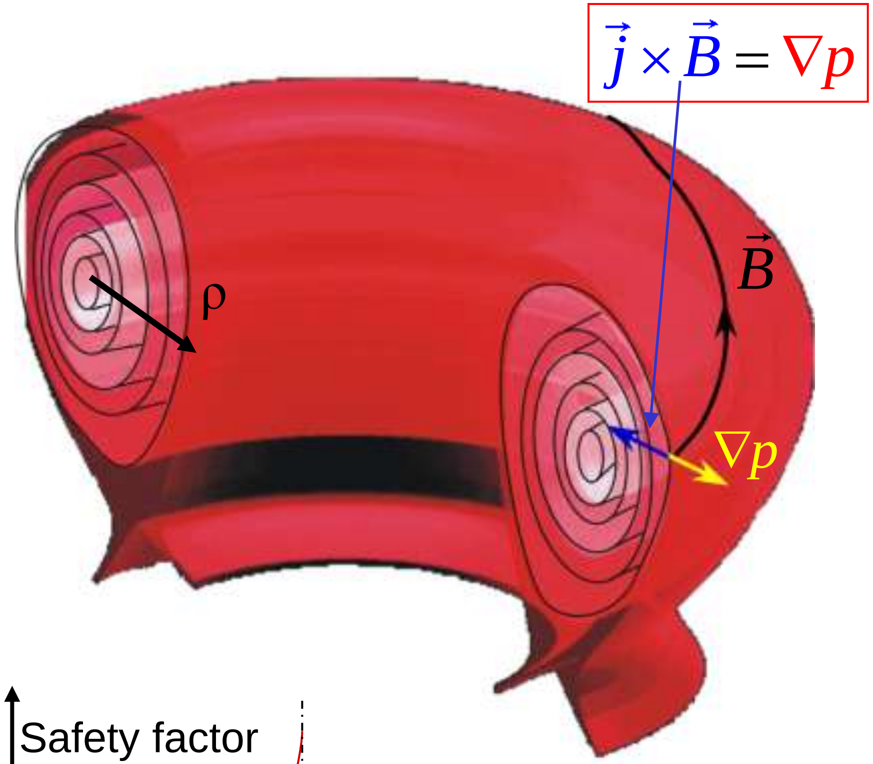
Tokamak

Stellarator





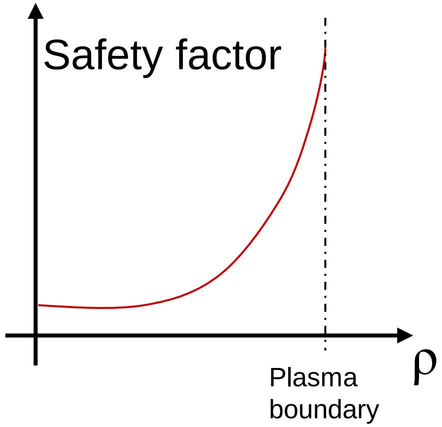
Reversed Field Pinch



Two important parameters:

Safety factor (represents windings of the magnetic field)

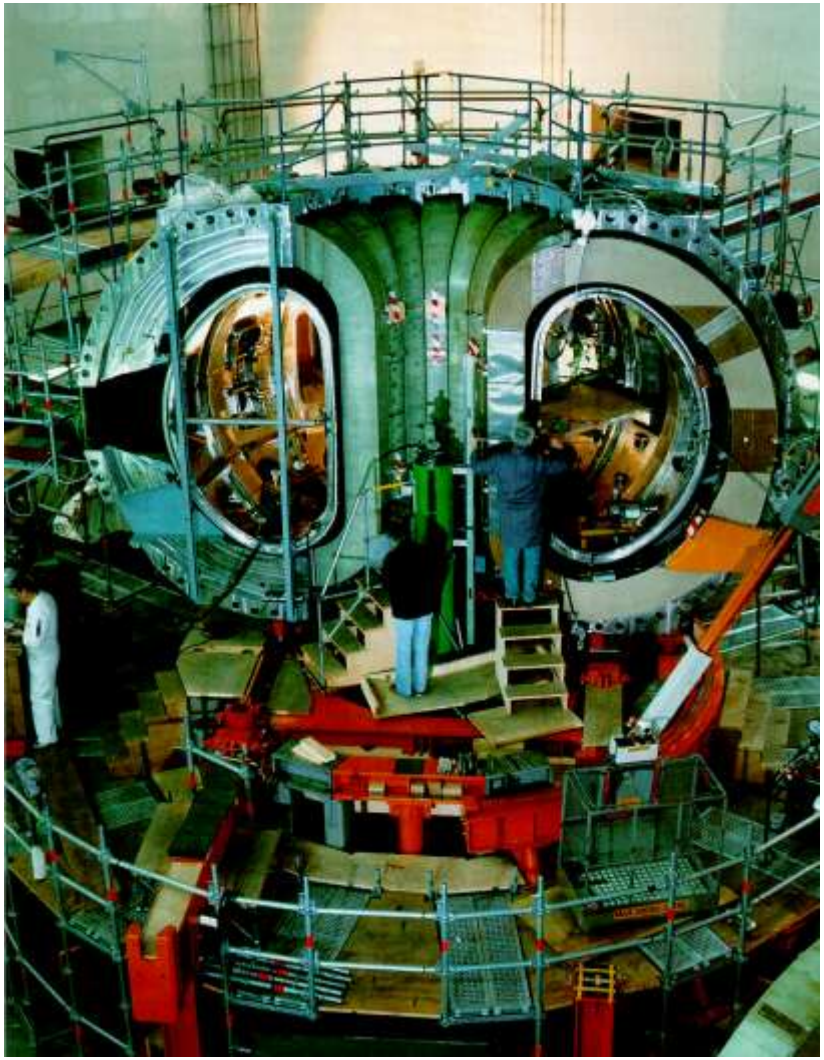
$$q = \frac{poloidal\_rotation\_angle}{toroidal\_rotation\_angle}$$

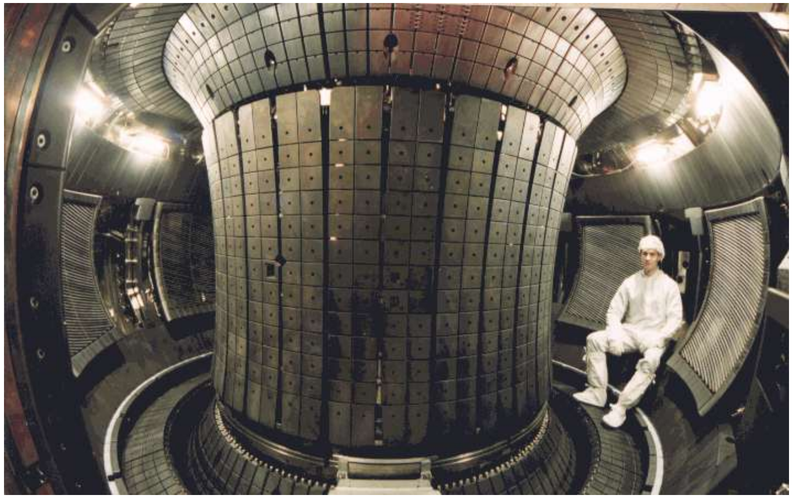


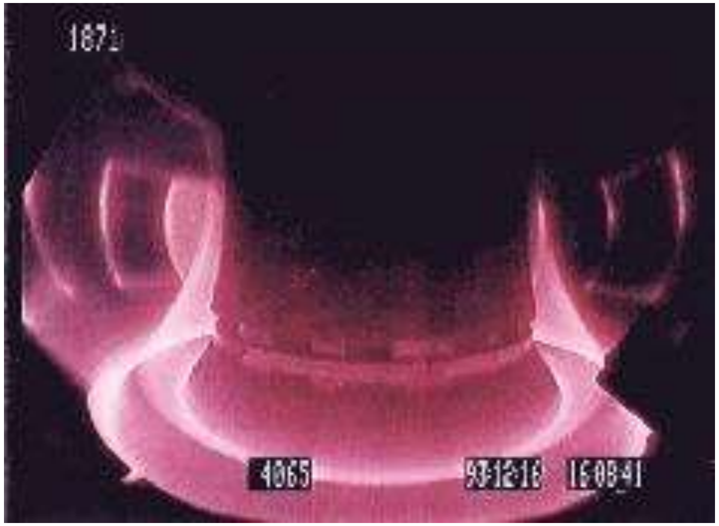
and normalized pressure

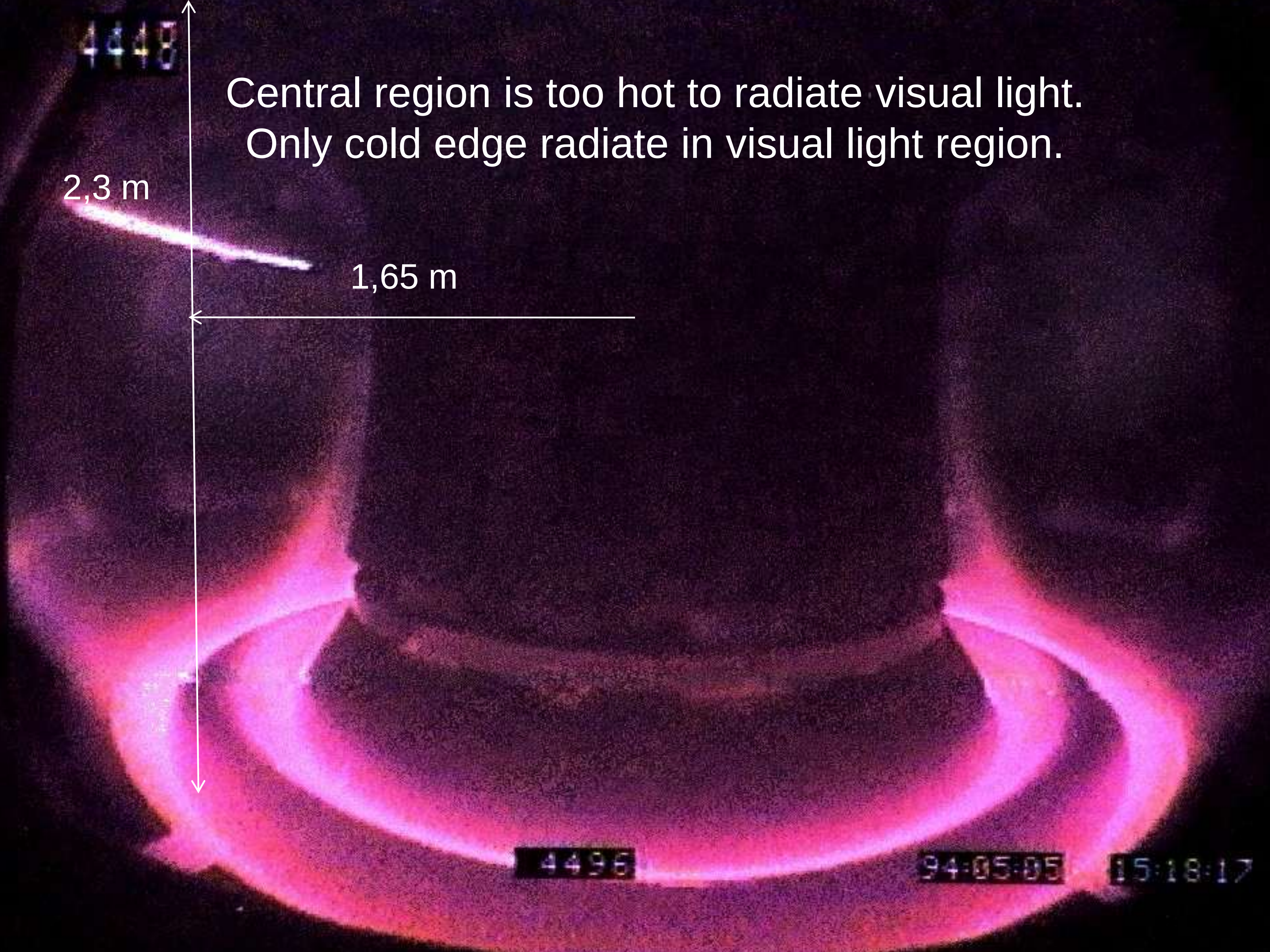
$$\beta \equiv \frac{\langle p \rangle_{volume}}{B^2 / 2\mu_0} = \frac{kinetic\_plasma\_pressure}{magnetic\_field\_pressure}$$

ASDEX Upgrade, Garching



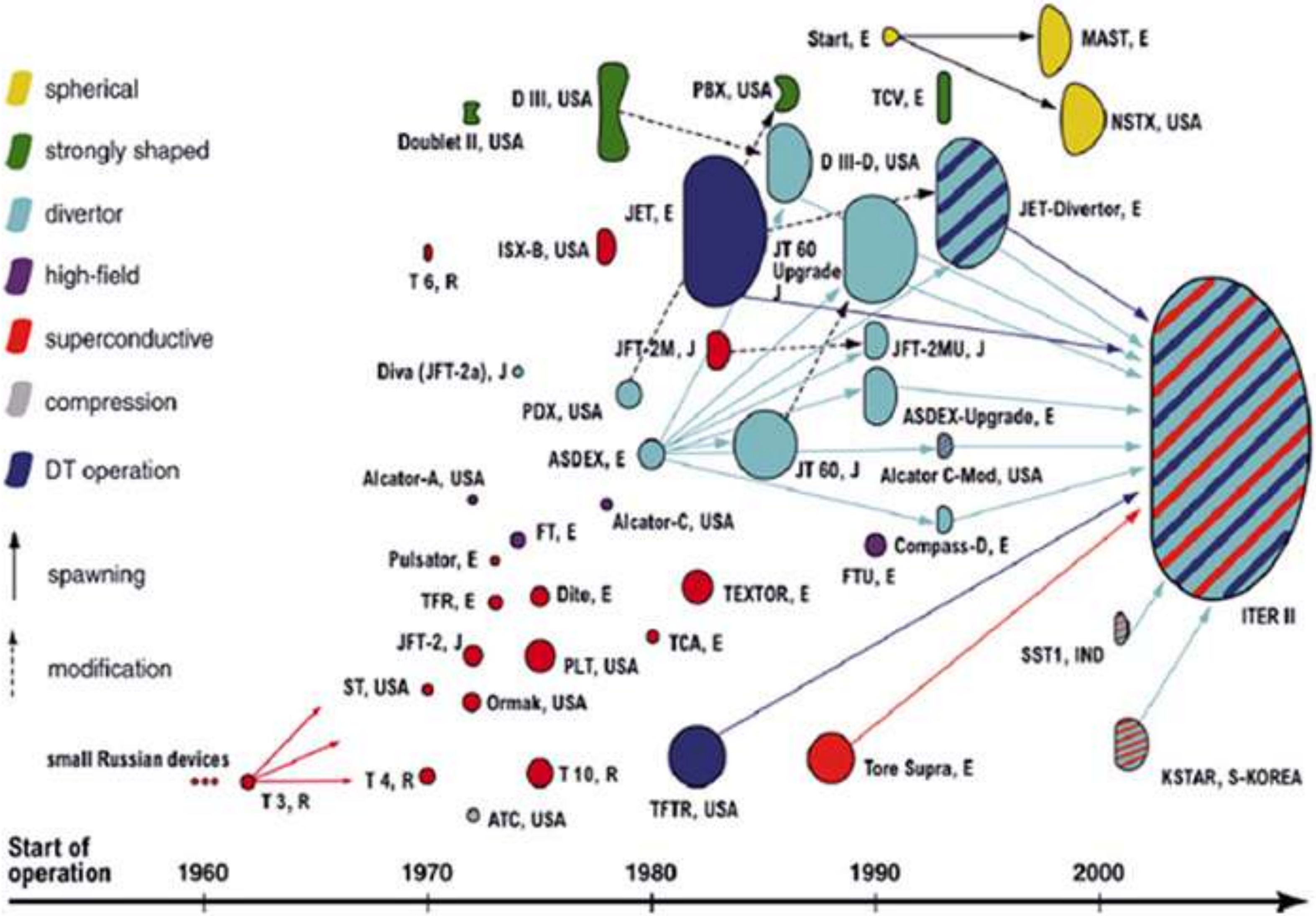




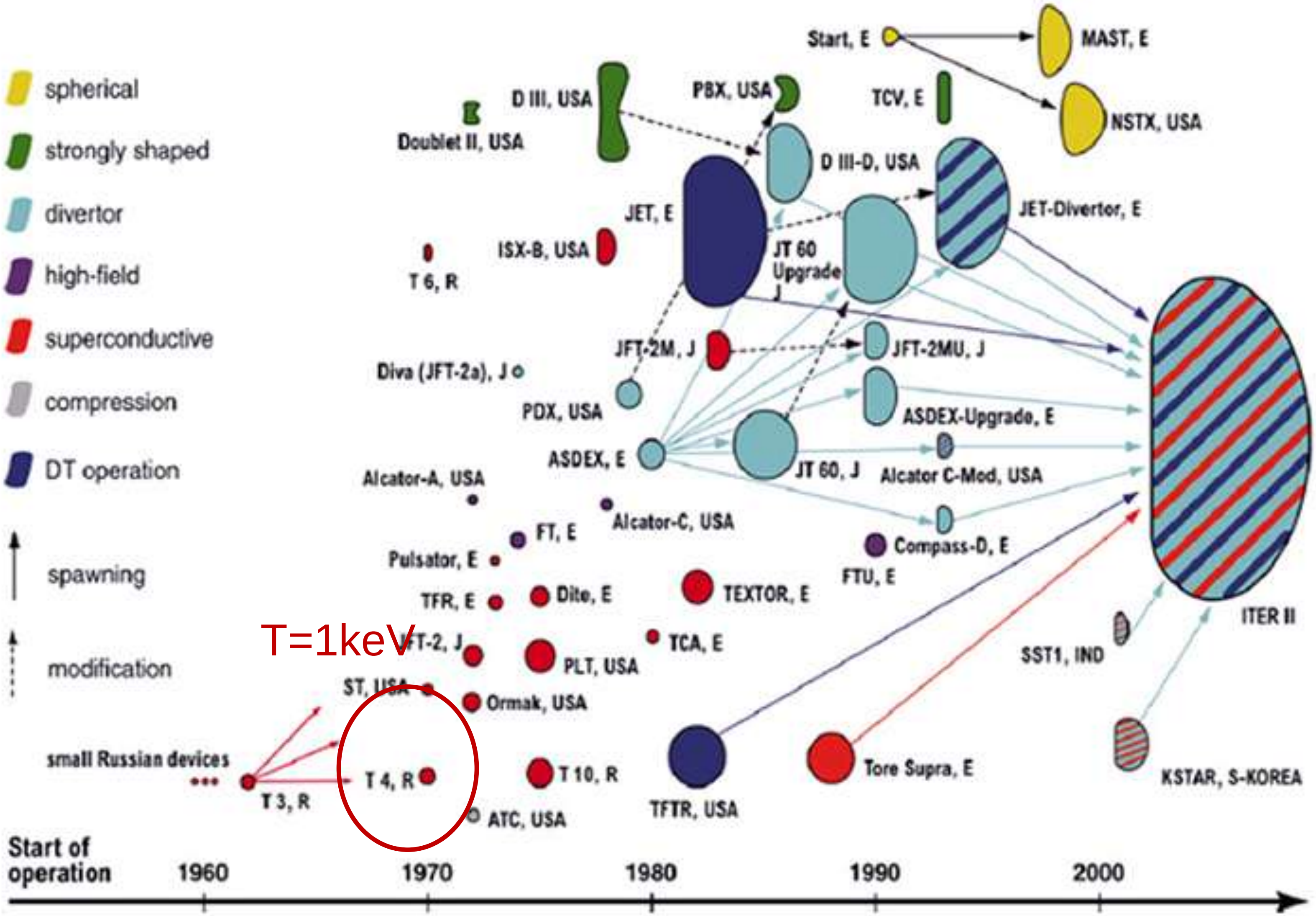


Central region is too hot to radiate visual light.
Only cold edge radiate in visual light region.
2,3 m
1,65 m
4448
4496
94:05:05
15:18:17

Evolution of tokamaks



Evolution of tokamaks



Evolution of tokamaks

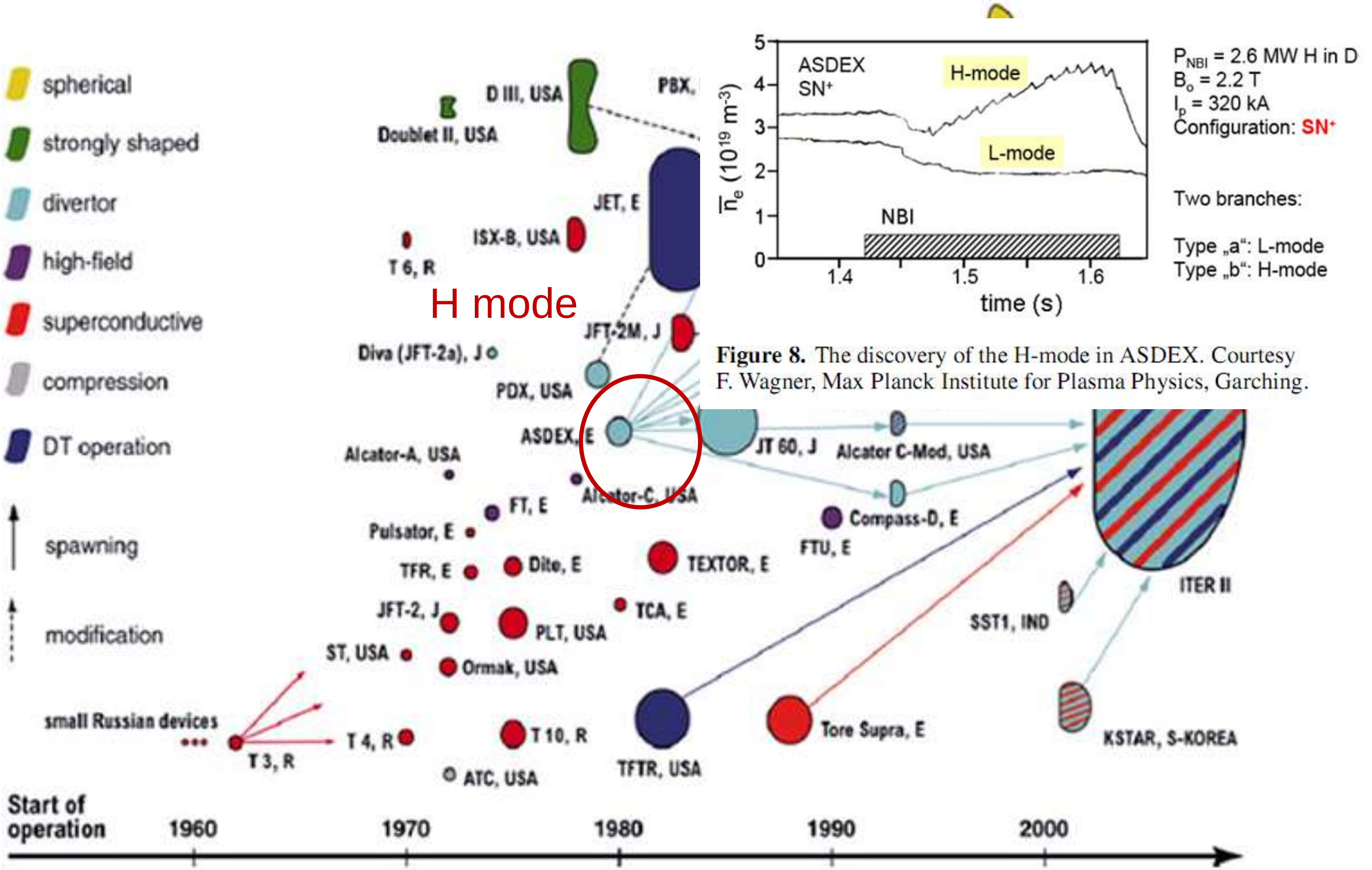
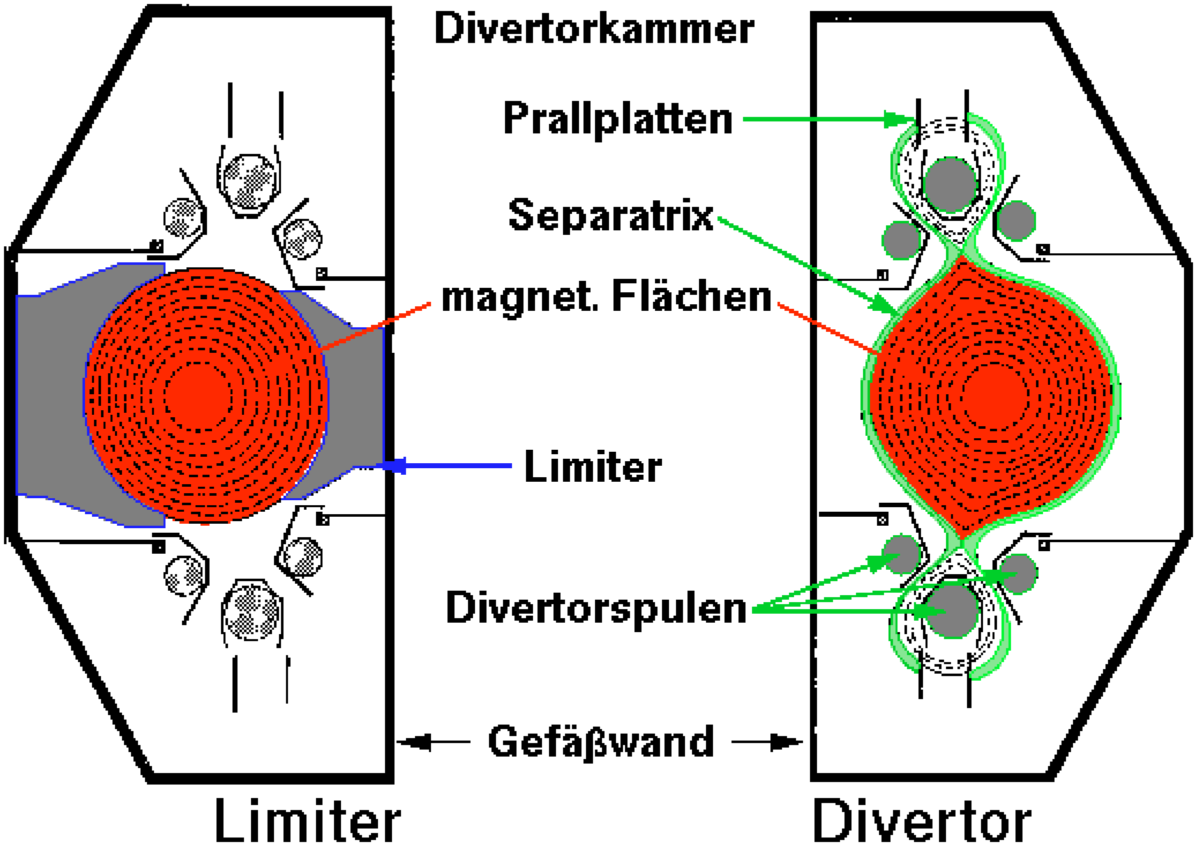


Figure 8. The discovery of the H-mode in ASDEX. Courtesy F. Wagner, Max Planck Institute for Plasma Physics, Garching.

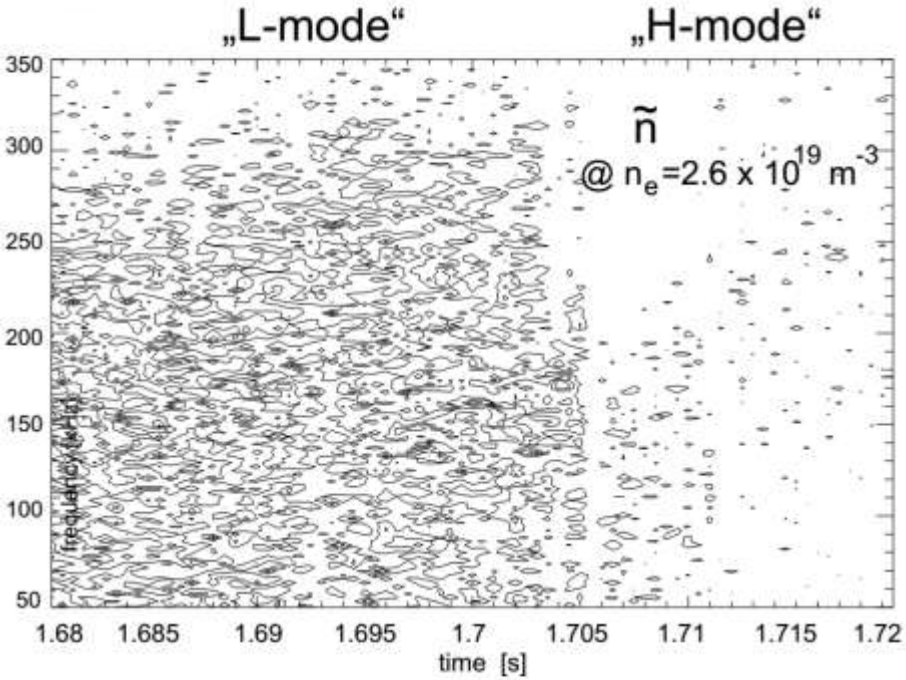
Limiter- und Divertor-Konfiguration

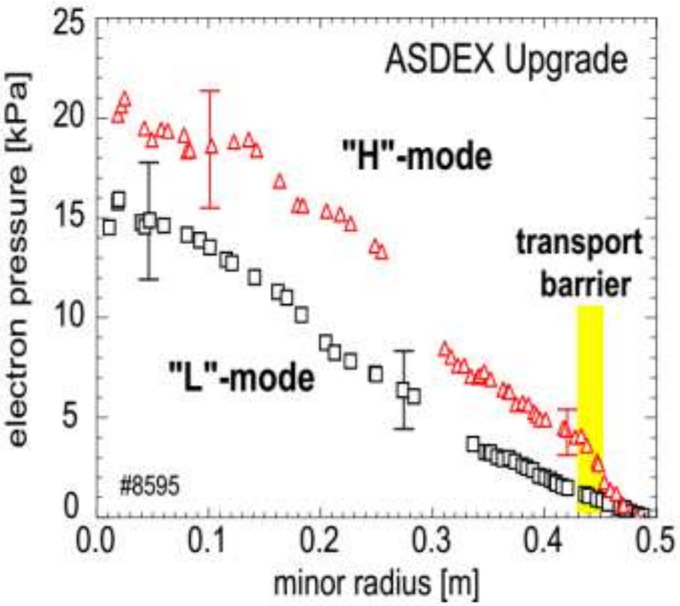


Phase transition to high confinement regime (ASDEX 1984)

Reduced density fluctuation level

Reduced radial diffusivity
⇒ stronger pressure gradient

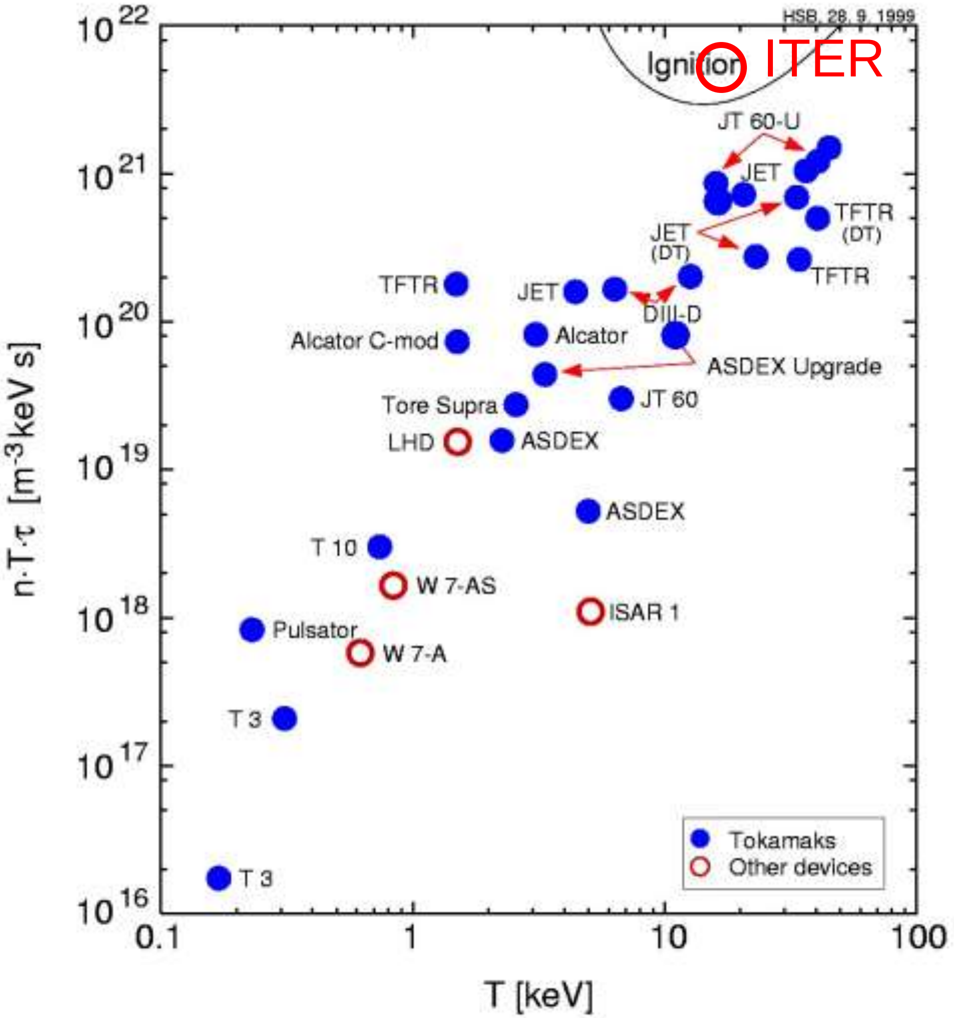




Wolfgang Suttrop PhD FSE network – Advanced Courses – H-mode pedestal 6/73

H-mode is also obtained in stellarators!

How close we are from ignition ?



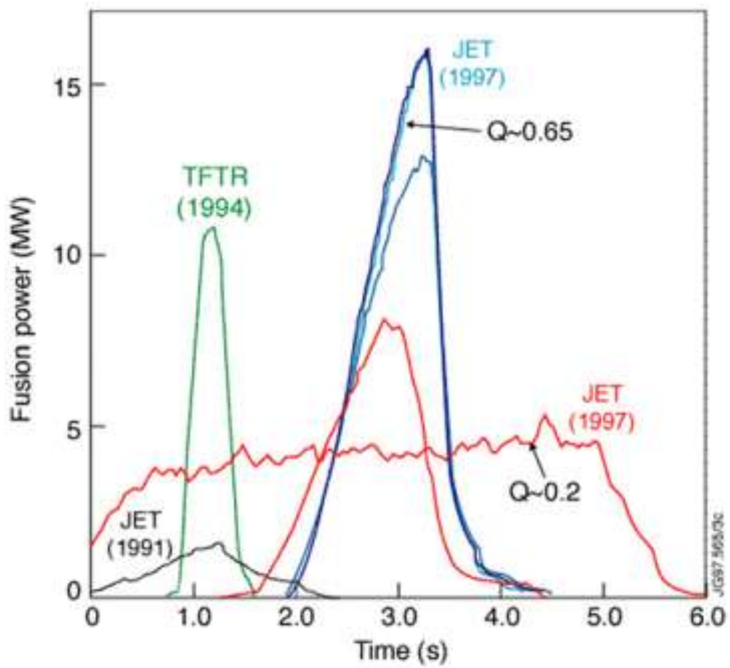


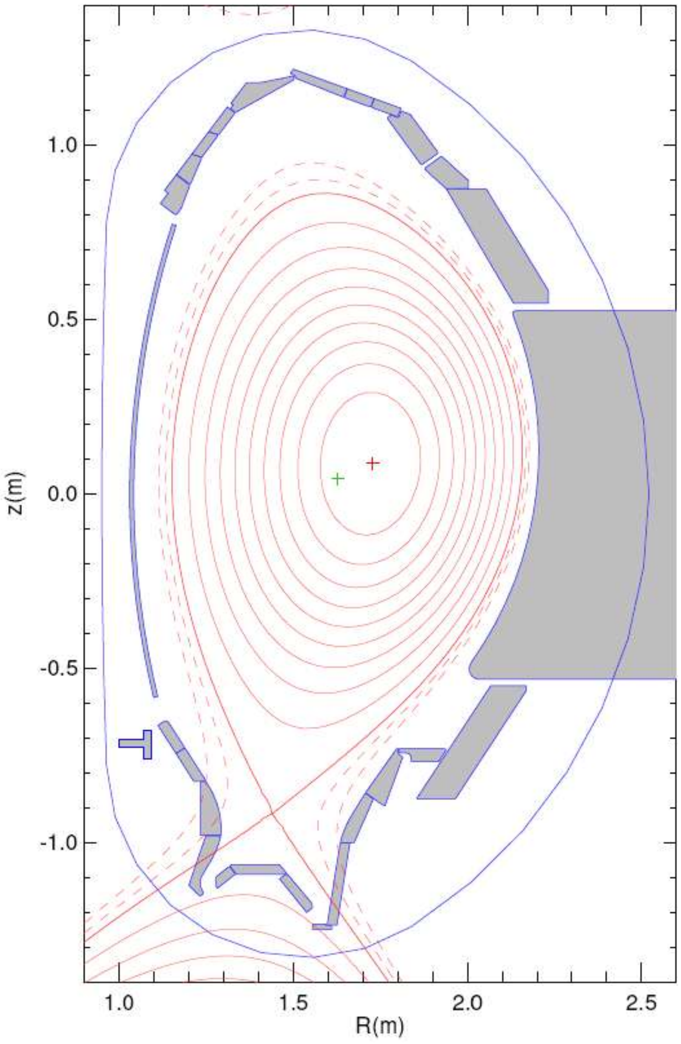
Figure 8. Evolution of fusion power produced in JET and TFTR using D/T fuel.

$Q = P_{fus}/P_{ext}$

Q = 1 break-even

Q = ∞ Ignition

Q = 10 (ITER minimum value)

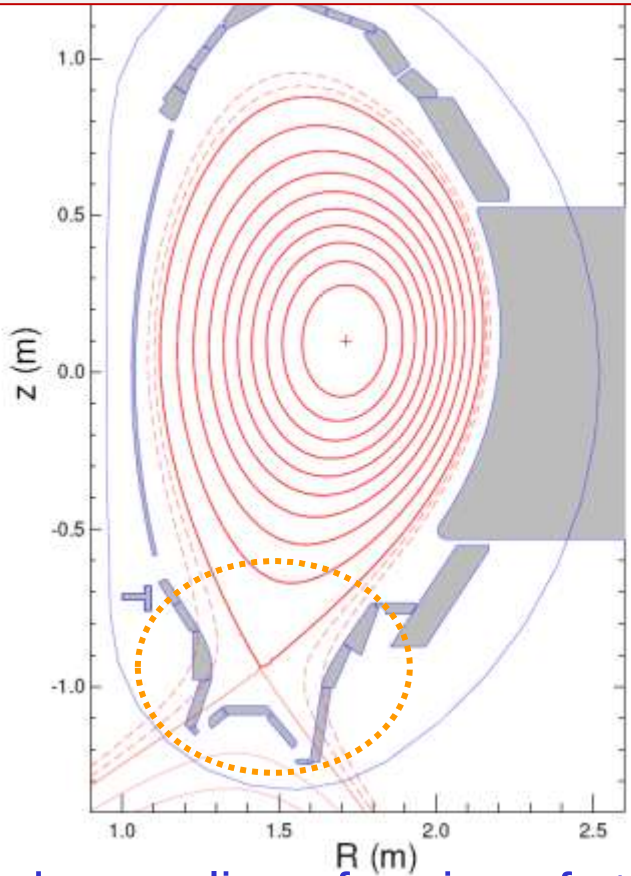


Three main branches of the tokamak physics:

- Scrape-off layer and divertor physics
- Transport and turbulence
- MHD instabilities

Divertor is main region of power exhaust

Scrape-off layer and divertor physics

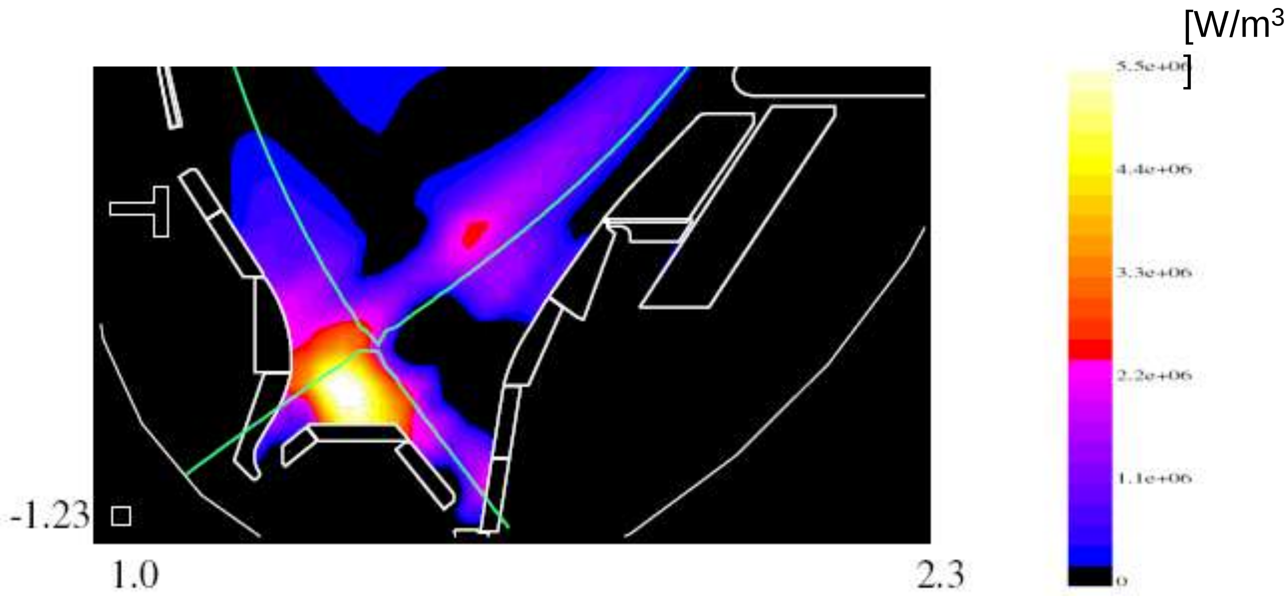


- de-coupling of region of strong plasma-wall interaction and core plasma
- power flux primarily along field lines towards divertor targets
- flux expansion and target tilt allow dilution of power flux density (fact. 10)

Experimental methods to improve power exhaust: impurity seeding

Scrape-off layer and divertor physics

Feedback controlled injection of (recycling) impurities, like N_2, Ne, Ar



Optimises for reduced/acceptable target power load

But: too much radiation causes degradation of core confinement

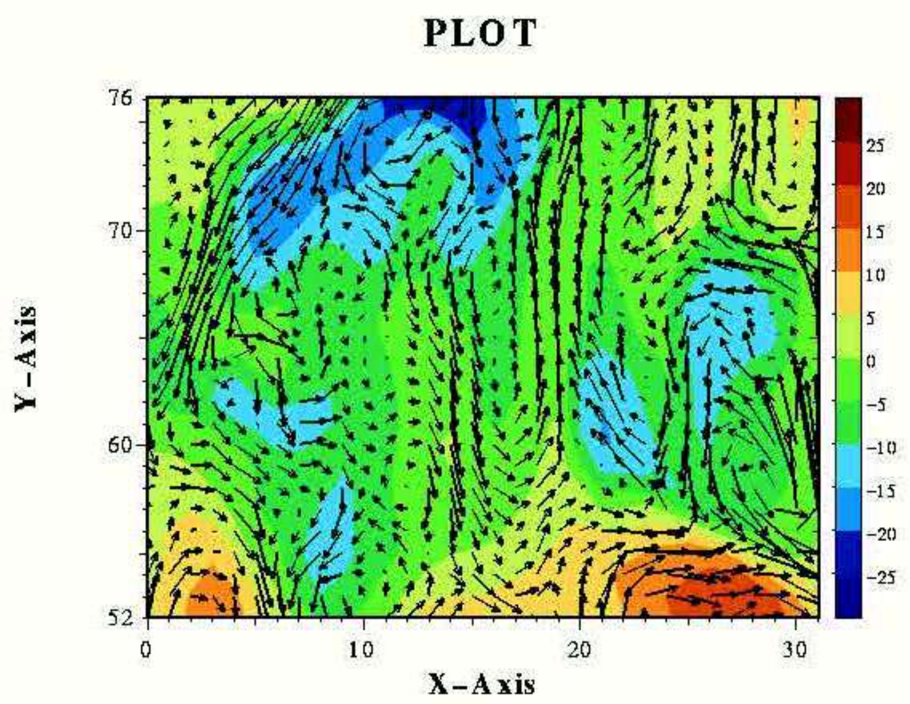
Anomalous transport

Transport and turbulence

The observed transport is much larger than can be explained on the basis of particle orbits and Coulomb collisions

General accepted opinion is that it is due to small scale instabilities that generate a turbulent state.

Our understanding of these transport processes is still incomplete, but progress has been made.



From B. Scott

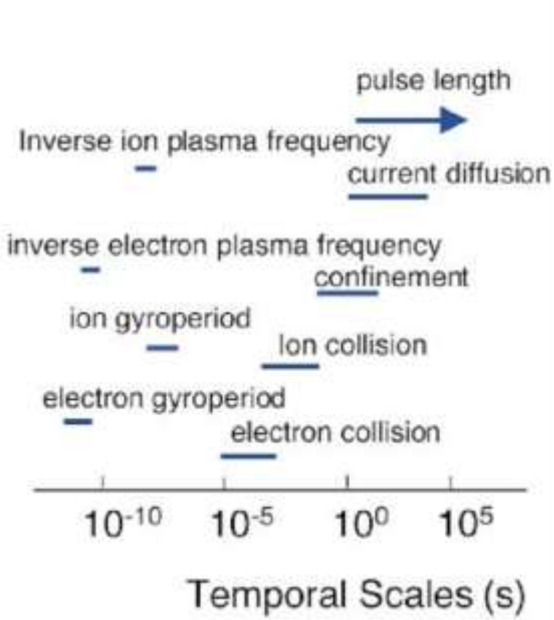
Gyrokinetic Simulations of Plasma Microinstabilities

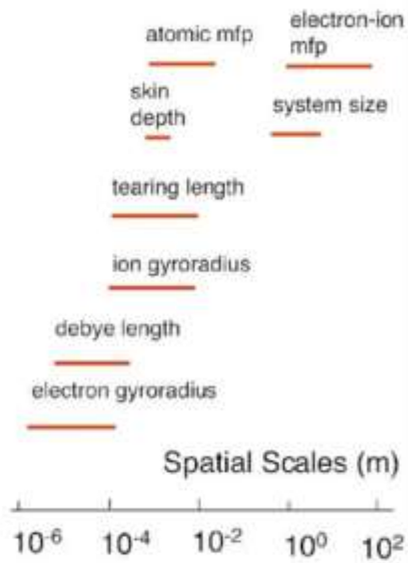
simulation by

Zhihong Lin et al.

Science 281, 1835 (1998)

Why plasma physics is so complicated?





Temporal and spatial scales have a huge separation but the processes are linked.

↓

No way to make a simple model!

<u>For tokamak:</u>

Scrape-off layer, transport and MHD instabilities are strongly linked.

In the following talks we will mainly discuss only the last part:

<u>MHD instabilities</u>!