Turbulent transitions in fusion plasmas

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08/12/2021

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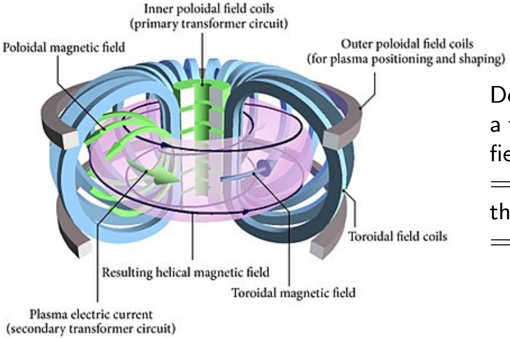
European Research Community On Flow, Turbulence And Combustion

PHD subject : Turbulent transitions in fusion plasmas

- Context : Preparation of the ITER experiment
- Purpose : Increase the performance of a Tokamak by improving plasma confinement
- Goal of the thesis : Understanding of the Low-High transition observed in Tokamaks which improves confinement

The tokamak (toroidal camera with magnetic coils)

Magnetic confinement : Fuel heated and maintained confined by magnetic fields in a chamber : tokamak, stellarator, RFP



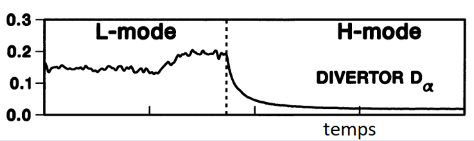
Deuterium-tritium plasma confined by a toroidal and inhomogeneous magnetic field
$\Longrightarrow$ Drift problem : Particles derived to the edge of the chamber
$\Longrightarrow$ A poloidal magnetic field is added

Produced power of 500MW for 50MW of power introduced
$\Longrightarrow$ efficiency ratio $Q = 10$
Plasma maintained at 150 million degrees for at least 400 seconds : neutral beam injection, radio frequency heating (ion and electron cyclotron resonance heating)

L-H transition

ASDEX experiment,1982

Transition between two confinement states, Low confinement and High confinement.



turbulent kinetic energy

Dramatic decrease of the turbulence in H confinement

$\Rightarrow$ Energy confinement time multiplied by two $\Rightarrow$ Better energy efficiency

Some phenomena have been observed :

- Decrease of the turbulent transport, particularly at the edge of the plasma.
- High temperature gradient at the edge of the plasma.

$\Longrightarrow$ Formation of an Internal Transport Barrier (ITB)

Main explanations

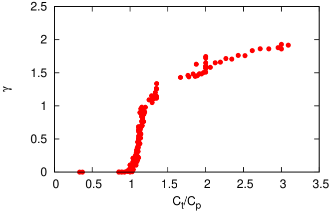
- Shear flow induced by the electromagnetic flow.
- Formation of zonal flows

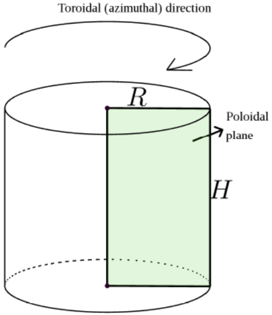
Our proposition

We propose to study a transition between two-dimensional turbulent states in axisymmetric flow : 2D2C and 2D3C with two and three velocity components respectively (PHD subject of Z.Qin)

Transition between two 2D turbulent states related to the anisotropy of an imposed forcing

Goal :recover this transition in a toric geometry and find a relation with the loss of confinement observed in tokamaks



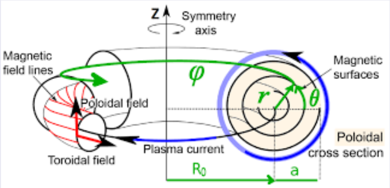


Numerical study

Geometry

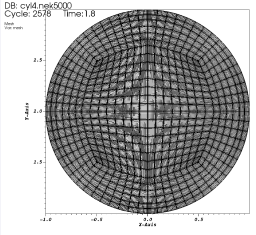
Study of a two-dimensional system (r, θ) with three velocity components (r, θ, ϕ) : The flow is studied in a poloidal cross-section of a tokamak modelled as a disk

$\mathbf{u} = \mathbf{u_{pol}} + \mathbf{u_{tor}}$ avec $\mathbf{u_{pol}} = \mathbf{u_r} + \mathbf{u}_\theta$ et $\mathbf{u_{tor}} = \mathbf{u}_\phi$



Numerical tools

Numerical simulations with Nek5000 (spectral element method)



Choice of the forcing

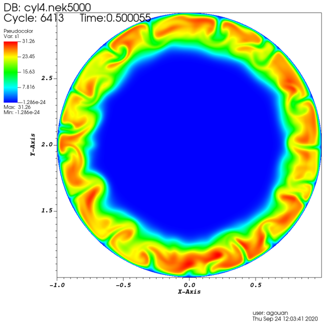
Navier Stokes equation + forcing $\mathbf{F} = \mathbf{F_{pol}} + \mathbf{F_{tor}}$:

$$\frac{\partial \mathbf{u}}{\partial t} + (\mathbf{u}.\nabla)(\mathbf{u}) = -\frac{1}{\rho}\nabla P + \nu\Delta\mathbf{u} + \mathbf{F}$$

- Scalar field $T(r)$ such that

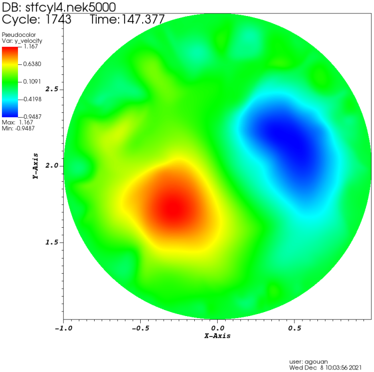
  $$\frac{\partial T}{\partial t} + (\mathbf{u}.\nabla)(T) = \kappa\Delta T + S(r)$$

  with $S(r)$ source term
- Poloïdal forcing induced by the scalar field
  $\mathbf{F_{pol}} = c_p T(r)\mathbf{e_r} - \beta r\mathbf{e_{tor}} \times \mathbf{u_{pol}}$
- Toroïdal forcing at the same place :
  $\mathbf{F_{tor}} = C_t \left(B(r_{min}, r_{max})u_\phi - \tau \frac{\overline{u_\phi y}}{y} \right)$

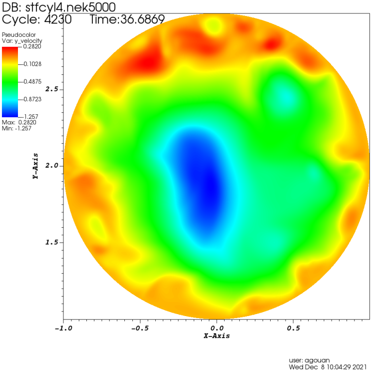


Scalar field $T(r)$

Friction $\beta r \mathbf{e}_{\mathbf{tor}} \times \mathbf{u}_{\mathbf{pol}}$ added :



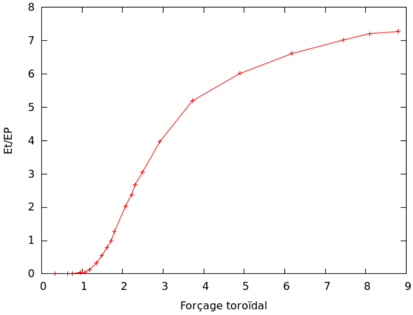
Stream function field without friction



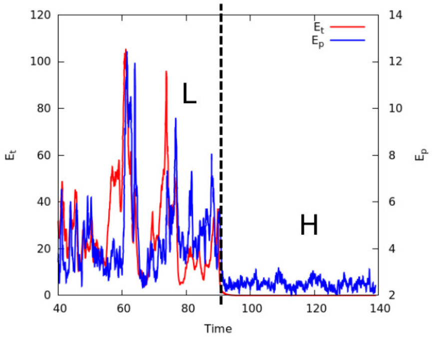
Stream function field with friction

Highlighting of the transition with the evolution of the parameter $\gamma = E_t/E_p$
Variation of the anisotropy of the forcing ($\xi \approx c_t/c_p$)

Transition from a 2D2C state ($Et/E_p = 0$)to a 2D3C state (2D3C)

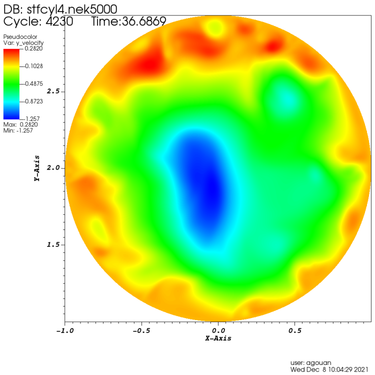


Relation between γ and ξ

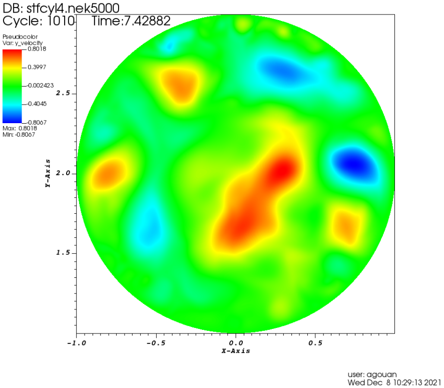


Visualisation of the transition with the energy

Structures of the flow are modified during the transition



Stream function field in H mode



Stream function field in L mode

Next step

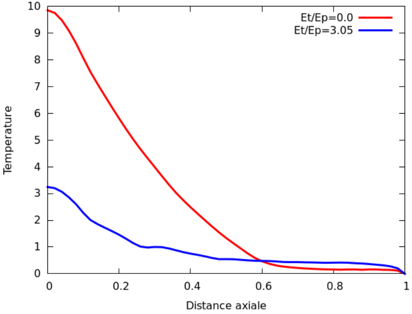
Toroidal perturbations generated by the scalar field

Idea : violation of the axisymmetry $\Rightarrow$ T slightly advected by the toroidal

$$(\mathbf{u}.\nabla)(T) = u_r \frac{\partial T}{\partial r} + \frac{u_\theta}{r}\frac{\partial T}{\partial \theta} + u_\phi \frac{\partial T}{\partial \phi}$$

Introduction of a scalar field Θ in the center of the disk.
Study of the relation between this scalar field's temperature and the anisotropy of the forcing.

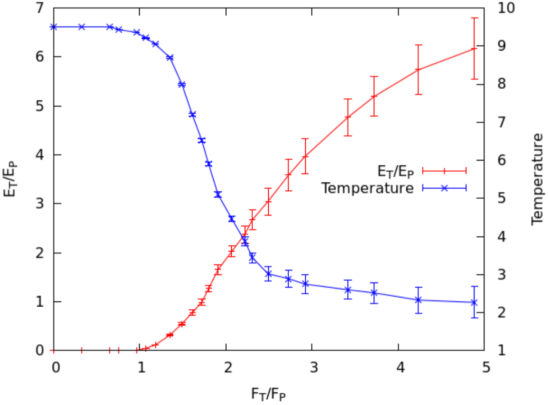
Consistent results : drop of the temperature in L mode
$\Longrightarrow$ **Weaker confinement for $E_t/E_p > 0$**



Radial profile of the temperature in L mode and H mode

Link with the LH transition

Drop of temperature can be linked to the transition to the 2D3C state caracterised by E_t/E_p



Relation of γ and the temperature of the tracer at the center of the disk with the control parameter ξ.

Conclusion

Résults

- A 2D2C-2D3C transition occurs in a toric geometry
- This transition can be related to a loss of confinement in a torus

Perspectives

- Improvement of the forcing
- Spectral study of energy transferts (GHOST)
- Spontaneous generation of zonal flows ?
- Hysteresis ?