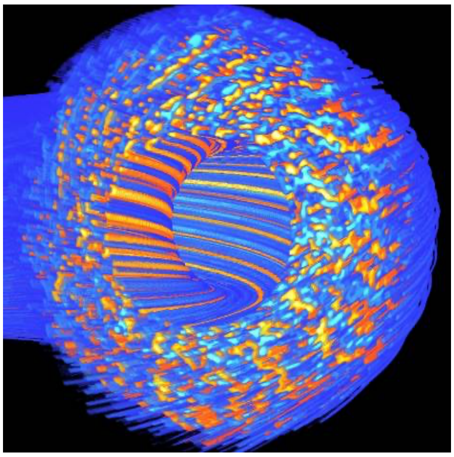
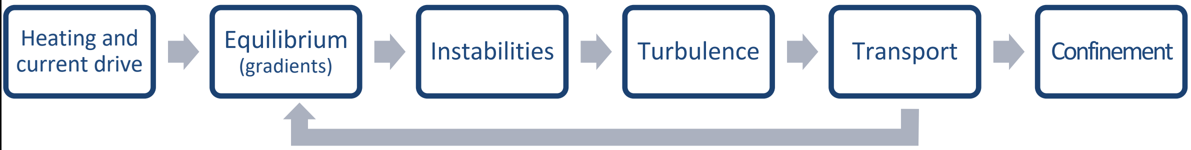
Title : **Magnetic fusion: turbulence, transport, heating, and confinement**
Acronym :O1
EU Coordinator : Maxime LESUR, Institut Jean Lamour, Nancy
Teaching staff : Maxime LESUR, Yves PEYSSON, Marie-Christine FIRPO
Pre-requisites : First year of MSc in Physics or Engineering Schools.
Credits : 3 ECTS
Language : French/English
Keywords : Particle trajectories in strong magnetic fields –Particle and fluid drifts – Quasilinear theories – Waves – Instabilities – Turbulence – Heating – Current drive.

This unit provides an in-depths study of processes underlying the dynamics of the core of a magnetic fusion plasma, with an emphasis on turbulence, anomalous transport, heating and current drive, and the current state of research. We aim at understanding the overall physics of confinementof thermal particles, of impurities, and of energetic particles (produced by NBI-type heating, and by fusion reactions).



Core tokamak turbulence: snapshot of electric potential fluctuations. Gyrokinetic simulation (GYSELA code)

Applications:
- predicting transport properties in modern tokamaks and stellerators, and future "burning plasma" experiments with deuterium-tritium fueling.
- control schemes, mitigating and channeling turbulence.
- design of operational scenarios to mitigate energetic particle losses (in ITER for example).
- design of future commercial reactors (the size and cost of a reactor strongly depends on a turbulent diffusion coefficient).



The teaching unit comprises three independent sub-units:
1. Turbulence, transport and confinement.
2. Heating and current drive.
3. Reduced prototype of confinement: magnetic viewpoint.

Content of sub-unit « Turbulence, transport and confinement »

1. Angle-action formalism, application toparticle trajectories in tokamaks
2. Main instabilities in magnetized plasmas
   + TD1: kinetic effects in the ITG (Ion Temperature Gradient) instability
3. Diffusion, random walk, quasilinear theory (fluid and kinetic approaches)
   + TD2: quasilinear calculation of ITG-driven transport
4. Turbulence: formation and properties – nonlinear coupling, energy cascades

5. Transport and confinement in tokamaks
   + TD3: impurity transport
   + TD4: confinement time
6. Energetic particles - instabilities, transport,and losses

Contentof sub-unit « Heating and current drive »

The course first deals with a general introduction showing that to reach the thermonuclear regime, additional heating systems are necessary because ohmic heating is insufficient. We also discuss why external methods are needed to continuously maintain magnetized plasma in a tokamak. The heating and current generation methods can be separated into two categories: those using particles (injection of fast neutrals) and those based on radiofrequency waves. We discuss the general principles for each of them, based on a kinetic description of the plasma. For radiofrequency waves, we focus on the three main methods, the ion cyclotron wave, the low hybrid frequency and finally the electronic cyclotron frequency. We describe the conditions for applying geometrical optics and the ray-tracing method to calculate the electric field that resonantly accelerate the electrons. We discuss the quasi-linear interaction within the framework of kinetic calculations to estimate the RF wave power absorbed by the plasma. Finally, we discuss the neoclassical effects and the bootstrap current on which great hopes for a self-sustained fusion reactor are based.

Contentof sub-unit « Reduced prototype of confinement: magnetic viewpoint »

An overview of the consequences of the divergence-free property of the magnetic field is presented. It is shown that, at any given time, the magnetic field lines can be seen as trajectories of a Hamiltonian system having one-and-a-half degrees of freedom. The notions of Poincaré application and mappings are introduced ; then we discuss the role and the importance of the chaos of magnetic field lines in tokamaks through the phenomena of transport barriers and sawteeth in tokamaks. The role played by the safety factor and the concept of resonance are highlighted.