Title : **Waves and Instabilities**

Acronym : TC4

EU Coordinator : Caterina RICONDA, Laboratoire de l'Utilisation des Lasers Intenses (LULI)

Teaching staff : Jérôme FAURE, Roch SMETS, Caterina RICONDA

Pre-requisites : First year of MSc in Physics or Engineering Schools.

Credits : 3 ECTS

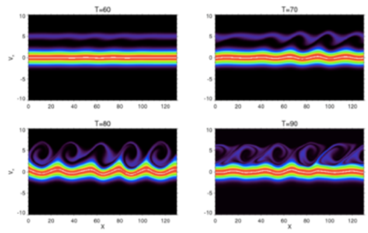
Language : French/English

Keywords : Linear theory, nonlinear phenomena, non uniform plasmas, fluid and kinetic theories.

This course is divided into three parts presented below.

I. Waves and instabilities in plasmas : the basics

This part aims at presenting in a very general way the theory of waves in plasmas in the framework of the fluid theory and the kinetic theory. The dispersion relations and the characteristics of the different wave solutions are calculated in the linear approximation. Several examples of nonlinear phenomena are then presented. The theory of linear instabilities is presented in non-magnetized media. The topics covered are the following:

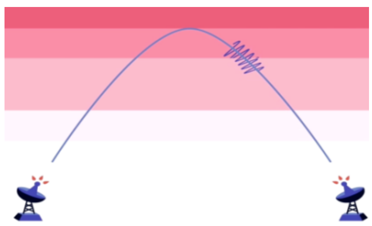


Simulation of a beam-plasma instability

- Fluid equations and dielectric function.
-Waves in non-magnetized plasmas.
- Electron plasma wave breaking in a cold plasma in fluid theory.
- Collisional absorption of electromagnetic waves.
- Propagation of an electromagnetic wave in an inhomogeneous medium (WKB theory).
- Resonant absorption.
- Low frequency nonlinear waves: ion acoustic solitons, non-collisional shock waves.
- Collisional shocks, Hugoniot curves, case of the perfect gas.
- Kinetic dielectric function.
- Landau damping of electrostatic waves in a Maxwellian plasma, electron plasma waves in a hot plasma, electron-acoustic waves.
- Kinetic beam-plasma instability (bump-in-tail).
- Fluid beam-plasma instability for electrostatic and electromagnetic waves (Weibel instability).
- Waves in magnetized plasmas: cyclotron resonance, right and left electromagnetic modes, whistler waves, ring instability.
- Ponderomotive force, three-wave resonant coupling.

II. Application to astrophysical plasmas : waves and instabilities

This course presents different examples of waves and instabilities in astrophysical plasmas, using the fluid and kinetic formalisms. The topics covered are the following:



Radio waves in the ionospheric plasma

-Alfvèn modes. The aim is to show how taking into account non-ideal terms in Ohm's law allows to sweep the spectrum of Alfvèn waves, firehose instability, mirror mode, kinetic Alfvèn waves and inertial Alfvèn waves.

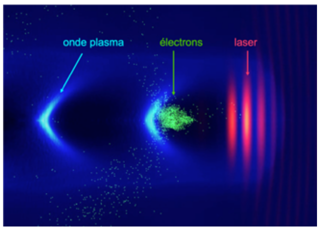
- Magnetic reconnection. We present the physical concept, the different historical (resistive) models, the Harris layer, the resistive tearing mode and the collisionless tearing mode.

- Beam-plasma instability. The dispersion equations of electrostatic and electromagnetic waves in a magnetized plasma are obtained, by the determination of the dielectric matrix. These calculations are applied to Type III radio bursts, which are intense electromagnetic emissions coming from solar flares, and to the drift instability of cosmic rays in the interstellar medium.

- Langmuir turbulence. After a reminder of the ponderomotive force, we derive the Zhakarov equations which describe the dynamics of the strong Langmuir turbulence. These are solved in the subsonic case (nonlinear Schrödinger equation). We explain the trapping of Langmuir waves in density depletions (cavitons), the wave-matter interaction, the modulational instability and the collapse process.

III. Application to the laser-plasma interaction at ultra-high intensity (UHI)

The topics covered are the following:



Simulation of a beam-plasma instability

- Introduction to ultra-intense lasers: ultra-short laser pulses, chirped pulse amplification. Ionization mechanisms in the short pulse regime.

- Reminders on relativity and Hamiltonian mechanics. Application of these concepts through the study of the motion of a charged particle in an ultra-intense laser field. Relativistic ponderomotive force.

- Fluid model of laser-plasma interaction in the relativistic regime: relativistic plasma wave excitation, relativistic nonlinear effects such as relativistic self-focusing, self-modulation...

- In the form of a seminar, topics currently studied in the laboratories are introduced: laser-plasma acceleration, generation of ultrafast X-rays, high harmonics generation.