ERASMUS+ KA220-HED-13A477C3

"Innovative Education & Training in Laser Inertial Fusion Energy"

IP1 – WP2 July 15-25, 2025

"Physics and technology of Inertial Fusion Energy"

Intensive program on plasma physics

University of Bordeaux

Pedagogical team (Univ. Bordeaux) :
Dimitri Batani, Emmanuel d'Humières, João Jorge Santos (coord.)

Seminars by :
David Blackman (ELI-beamlines, Check Rep.), Gabriele Cristoforetti (CNR, Italy),
Ioannis Fitilis (HMU, Greece), Sébastien Le Pape (IPP, France), John Pasley (U. York, UK),
Luca Volpe (EPM, Madrid), Matt Zepf (Univ. Zepf, Germany) and Markus Roth (Focused Energy)

Theoretical courses:

Chapter 1: Introduction and classification of plasmas + individual charge drifts in plasmas (3h, *E. d'Humières*)

- Main plasma parameters (Debye length, Landau length, ion/electron plasma frequency, ion/electron Larmor radius, ion/electron cyclotron frequency, ion/electron mean free path, collision frequency, …)
- Classification of plasmas (classical / coupled / degenerate / relativistic plasmas in temperature/density diagram)
- Examples of plasmas (natural plasmas, hot plasmas, cold and industrial plasmas)
- Drifts in a uniform magnetic field, crossed electric and magnetic fields
- Magnetic field gradient drift and magnetic mirroring (conservation of the magnetic moment)
- High frequency electric field, ponderomotive force

Chapter 2: Hydrodynamic description of a plasma (6h, *J.J. Santos*)

- Equations for the bi-fluid plasma model (continuity + Euler + EOS + Maxwell)
- Dispersion of electromagnetic waves and the critical density
- Dispersion of electron-plasma waves and of ion-acoustic waves
- Mono-fluid description of a plasma, extended-Magnetohydrodynamics
- Shock waves and relations Rankine-Hugoniot, blast waves, solution by Sedov-Taylor

Chapter 3: Radiative properties of plasmas (3h, *D. Batani*)

- Radiation emission from plasmas (bound-bound, recombination, bremsstrahulng, with some remarks on H-like and He-like spectra)
- Line broadening mechanisms
- Equilibrium in a plasma (Maxwell, Boltzmann, Saha)
- Photon absorption and opacity (in particular collisional absorption)
- Equation of radiative transfer and blackbody limit

Chapter 4: Kinetic description of waves and instabilities in plasmas (6h, *E. d'Humières*)

- Velocity distribution function and mean quantities
- Landau damping of electron plasma waves
- Beam-plasma instabilities
- Laser light propagation in non-uniform plasmas
- Parametric instabilities in laser-plasma interaction

Chapter 5: Principles of inertial confinement fusion (3h, *D. Batani*)

- Principles of inertial confinement fusion
- Nuclear fusion reactions, cross section and reactions rate
- Lawson criterion
- Fraction of burned fuel
- Energy spent in compression and in heating, energy balance
- Hot spot physics
- Radiative losses and thermal conduction losses
- Laser lighting, mass ablation and shock creation
- Setting in motion of the target, rocket model
- Implosion, stagnation, hot spot creation
- Temporal shaping of the laser pulse
- Hydrodynamic instabilities

Practical courses: *4 groups of 5 students: 2h30 experiments + 3x3h numerical training*

Laboratory session (LAB) (2h30, *J.J. Santos*)**:**

- Laser discharge at the surface of a solid target and propagation of a deflagration wave in air

Numerical sessions (3x 3h):

- **PIC simulations (PIC):** 2-stream instability and plasma expansion in vacuum exercises with code SMILEI (*E. d'Humières)*
- **Hydro-rad simulations (HYDRO):** Laser-driven target implosion, shock formation, target gain (*E. d'Humières)*
- **Plasma radiation simulations (RAD):** Spectral calculations with FLYCHCK (*D. Batani*)

Seminars

Seminar 1: "Laser-based plasma diagnostics (optical diagnostics)" by Ioannis Fitilis (HMU)

Seminar 2: "TBA" by John Pasley (Univ. York)

Seminar 3: "Ion stopping power: theory, experiments and diagnostics" by Luca Volpe (UPM, Spain)

Seminar 4: "Theory of laser plasma instabilities in direct drive ICF" by David Blackmann (ELI beamlines, Cech Rep.)

Seminar 5: "Laser-plasma experiments and diagnostics on laser plasma interactions" by Gabriele Cristoforetti (CNR, Italy)

Seminar 6: "Plasma diagnostics for inertial fusion energy" by Sébastien Le Pape (IPP, France)

Seminar 7: "Achieving ignition and gain in inertial fusion energy" by Matt Zepf (Univ. Jena, Germany)

Evaluation

Initial test (1h)

Final examination (1h30')

IC evaluation (online)

Program planning: up to 24 students divided in three groups G1, G2, G3

July 15 - 25, 2025

Week #1

	Tuesday 15	Wednesday 16	Thursday 17	Friday 18	Saturday 19	Sunday 20
AM	**Students' arrival to Bordeaux**	**8:00 Evaluation test** **9:00 – 12:00 Chapter 1** *E. d'Humières*	Practical courses 8:00 – 11:00 **G1 HYDRO** *E. d'Humières* **G2a LAB** *J.J. Santos* **11:30 – 13:00 Chapter 2** *J.J. Santos*	Practical courses 8:00 – 11:00 **G1 PIC** *E. d'Humières* **G2b LAB** *J.J. Santos* **11:30 – 13:00 Chapter 3** *D. Batani*	**9:00 – 12:00 Chapter 4** *E. d'Humières*	**Touristic visit**
PM	**Students' arrival to Bordeaux** **18:00 IP introduction + Welcome party**	**13:30 – 16:30 Chapter 2** *J.J. Santos* **16:45 – 17:45 Seminar 1** *Ioannis Fitilis* **18:00 – 19:00 Seminar 2** *John Pasley*	**14:30 – 16:00 Chapter 2** *J.J. Santos* Practical courses 16:15 – 19:15 **G2 HYDRO** *E. d'Humières* **G1a LAB** *J.J. Santos*	**14:30 – 16:00 Chapter 3** *D. Batani* **16:30 – 19:30 Chapter 4** *E. d'Humières*	**Free afternoon**	

Week #2

	Monday 21 July	Tuesday 22	Wednesday 23	Thursday 24	Friday 25
AM	**9:00 – 12:00 Chapter 5** *D. Batani*	Practical courses 9:00 – 12:00 **G2 RAD** *D. Batani* **G1b LAB** *J.J. Santos*	Practical courses 9:00 – 12:00 **G2 PIC** *E. d'Humières* **G1 RAD** *D. Batani*	**Visit to LMJ**	**Learning conclusions** **IP evaluation (online)** **Students' departure**
PM	**13:30 – 14:30 Seminar 3** *Luca Volpe* **14:45 – 15:45 Seminar 4** *David Blackmann* **16:15 – 17:15 Focused Energy** *Markus Roth (remote)*	**14:00 – 15:00 Seminar 5** *Gabriele Christoforetti* **15:15 – 16:15 Seminar 6** *Sébastien Le Pape*	**14:00 – 15:00 Seminar 7** *Matt Zepf (remote)* **15:30 – 18:00 Visit to CELIA**	**15:30 – 17:00 Exam** **18:00 Farwell party**	