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. Jena, Germany) and Markus Roth (Focused Energy)

Program (see schedule in pages 4-5)

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 Rankine-Hugoniot relations, blast waves, solution by Sedov-Taylor

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

- Radiation emission from plasmas (bound-bound, recombination, bremsstrahlung, 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*)

- 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:

Laboratory session (LAB) (2h30 per sub-group of 4 or 5 students, *J.J. Santos*)**:**

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

Numerical sessions (3x 3h, per group of 9 students):

- **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 (see schedule in pages 4-5):

Seminar 1: "Laser-based plasma diagnostics (optical diagnostics)" by Ioannis Fitilis (HMU); https://u-bordeaux-fr.zoom.us/j/81672935458

Seminar 2: "Hydrodynamics driven by short-pulse laser-plasma interactions" by John Pasley (Univ. York); https://u-bordeaux-fr.zoom.us/j/81672935458

Seminar 3: "Ion stopping power: theory, experiments and diagnostics" by Luca Volpe (UPM, Spain); https://u-bordeaux-fr.zoom.us/j/85212209084

Seminar 4: "Theory of laser plasma instabilities in direct drive ICF" by David Blackmann (ELI beamlines, Czech Rep.); https://u-bordeaux-fr.zoom.us/j/85212209084

Seminar 5: "Laser-plasma experiments and diagnostics on laser plasma interactions" by Gabriele Cristoforetti (CNR, Italy); https://u-bordeaux-fr.zoom.us/j/87128932868

Seminar 6: "Plasma diagnostics for inertial fusion energy" by Sébastien Le Pape (IPP, France); https://u-bordeaux-fr.zoom.us/j/87128932868

Seminar 7: "Achieving ignition and gain in inertial fusion energy" by Matt Zepf (Univ. Jena, Germany); https://u-bordeaux-fr.zoom.us/j/88392416067

Special session with an actor from industry:

Presentation and exchange debate with Markus Roth, *Focused Energy*
Monday 21 July, 16:15 to 17:15; https://u-bordeaux-fr.zoom.us/j/82771938608

Evaluation:

Initial test (1h) on the 16th July;

Final examination (1h30') on the 24th July;

IP evaluation (online) after completion of the IP.

Support documentation:

Textbooks, slideshows, etc., are available at this shared *Google drive* folder (evolving contents):
https://drive.google.com/drive/folders/1nQXuUFLYCD1EOma3p2MZAhuVkgctNDyt?usp=sharing

Schedule

Students are expected to join the school on the 15 July. Upon your arrival, please pass by the office of João Santos at CELIA laboratory (see location maps in page 6) in order to fill in administrative formalities, recover your scholarity certificate and student card from Univ. Bordeaux, and your room keys (for those being lodged at the student residence).

The room keys should be handled back to João Santos on the departure day, 25 July, from 9 am. There are no in-person activities scheduled that day, so you can organize your travel back to your home institutions without any time constraints (besides handling back your room keys).

The 18 enrolled students will be divided in two groups G1, G2, for the practical courses. Each group is split in sub-groups of 4 or 5 students for the experimental practical courses (LAB); You will be working by teams of 2 or 3 students*.

Week #1

	Tuesday 15 July	Wednesday 16	Thursday 17	Friday 18	Saturday 19	Sunday 20
AM	**Students' arrival to Bordeaux**	**8:00** **Evaluation test** *J.J. Santos* Amphi 2 / A9 **9:00** **COFFEE BREAK** Amphi 2 / A9 **9:15 – 12:15** **Chapter 1** *E. d'Humières* Amphi 2 / A9	**Practical courses** **8:00 – 11:00** **G1 HYDRO** *E. d'Humières* Harel room / CELIA **G2a LAB** *J.J. Santos* IOA, Plateau Laser **11:15** **COFFEE BREAK** Amphi 2 / A9 **11:30 – 13:00** **Chapter 2** *J.J. Santos* Amphi 2 / A9	**Practical courses** **8:00 – 11:00** **G1 PIC** *E. d'Humières* Harel room / CELIA **G2b LAB** *J.J. Santos* IOA, Plateau Laser **11:15** **COFFEE BREAK** Amphi 2 / A9 **11:30 – 13:00** **Chapter 3** *D. Batani* Amphi 2 / A9	**9:00 – 12:00** **Chapter 4** *E. d'Humières* Amphi 2 / A9	**9:00 – 15:00** **Touristic visit** Bordeaux city center & boat trip over Garonne
PM	**Students' arrival to Bordeaux** **18:00** **IP introduction** **+ Welcome party**	**13:30 – 16:30** **Chapter 2** *J.J. Santos* Amphi 2 / A9 **16:30** **COFFEE BREAK** Harel room / CELIA **16:45 – 17:45** **Seminar 1** *Ioannis Fitilis* Harel room / CELIA **18:00 – 19:00** **Seminar 2** *John Pasley* Harel room / CELIA	**14:30 – 16:00** **Chapter 2** *J.J. Santos* Amphi 2 / A9 **Practical courses** **16:15 – 19:15** **G2 HYDRO** *E. d'Humières* Harel room / CELIA **G1a LAB** *J.J. Santos* IOA, Plateau Laser	**14:30 – 16:00** **Chapter 3** *D. Batani* Amphi 2 / A9 **16:00** **COFFEE BREAK** Amphi 2 / A9 **16:30 – 19:30** **Chapter 4** *E. d'Humières* Amphi 2 / A9	**Free afternoon**	

Week #2

	Monday 21 July	Tuesday 22	Wednesday 23	Thursday 24	Friday 25
AM	**9:00 – 10:45** **Chapter 5** *D. Batani* Amphi 2 / A9 **10:45** **COFFEE BREAK** Amphi 2 / A9 **11:00 – 12:00** **Seminar 3** *Luca Volpe* Amphi 2 / A9	**Practical courses** **9:00 – 12:00** **G2 RAD** *D. Batani* Room 108 / A1 **G1b LAB** *J.J. Santos* IOA, Plateau Laser	**Visit to LMJ** Gathering at 7:20 am in front of CELIA	**Practical courses** **9:00 – 12:00** **G2 PIC** *E. d'Humières* Harel room / CELIA **G1 RAD** *D. Batani* Room 108 / A1	**Learning conclusions** **IP evaluation (online)** **Students' departure**
PM	**13:30 – 14:30** **Chapter 5** *D. Batani* Harel room / CELIA **14:45 – 15:45** **Seminar 4** *David Blackmann* Harel room / CELIA **15:45** **COFFEE BREAK** Harel room / CELIA **16:15 – 17:15** **Focused Energy** *Markus Roth* *(remote)* Harel room / CELIA	**14:00 – 15:00** **Seminar 5** *Gabriele Christoforetti* Harel room / CELIA **15:00** **COFFEE BREAK** Harel room / CELIA **15:15 – 16:15** **Seminar 6** *Sébastien Le Pape* Harel room / CELIA	**15:00** **COFFEE BREAK** Harel room / CELIA **15:30 – 18:00** **Visit to CELIA**	**14:00 – 15:00** **Seminar 7** *Matt Zepf (remote)* Harel room / CELIA **15:30 – 17:00** **Exam** *J.J. Santos* Amphi 2 / A9 **18:00** **Farwell party**	

* List of enrolled students with group, sub-group and team splitting

G1a Lucille AVIGNON – Angelo Maria RASO
Antonios KAVROULAKIS – Guillermo PEÑA MARTÍNEZ
Stavros BAKANDREAS

Stavros BAKANDREAS – Paul IDHE
for the simulation practicals: HYDRO, PIC, RAD

G1b Paul IDHE
Alessandro MILANI – Argyris ALEXAKIS
Ryan SAPUTIL – Antonio GOMEZ MARTINEZ

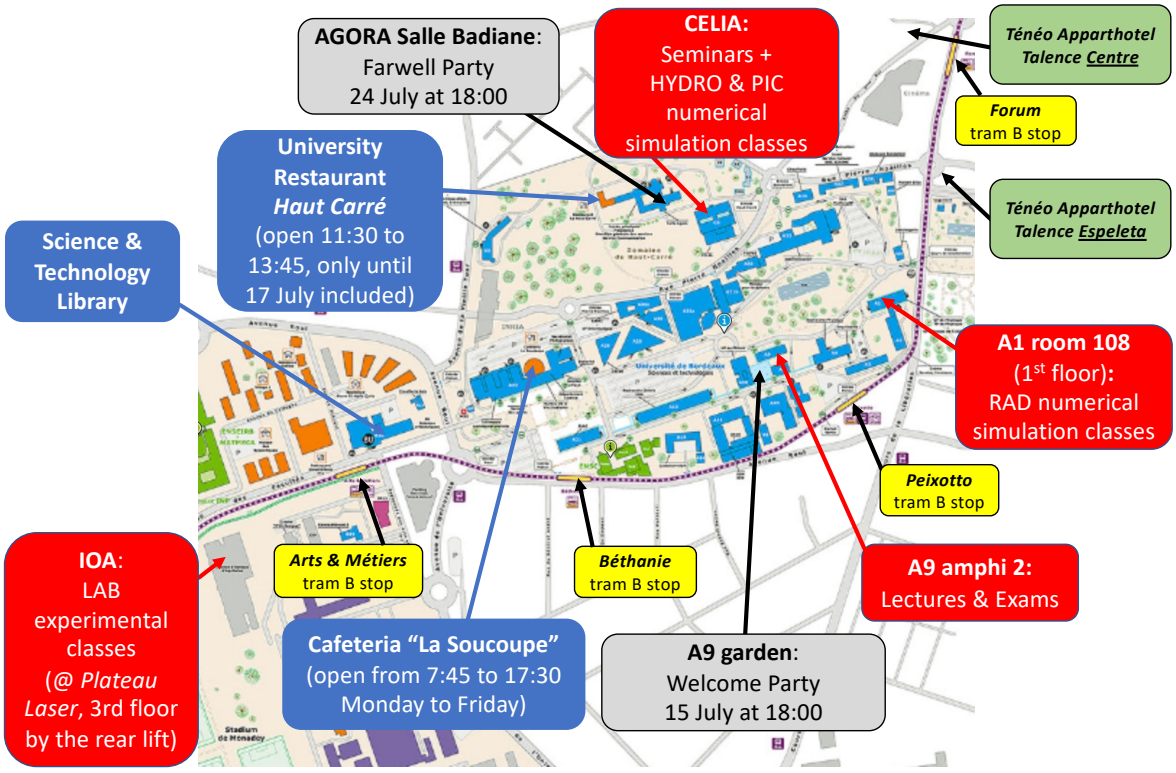
G2a Cyril MAQUIN – Conor CHRISTON
Christos KARVOUNIS – Federico Diego TUYA PRADO

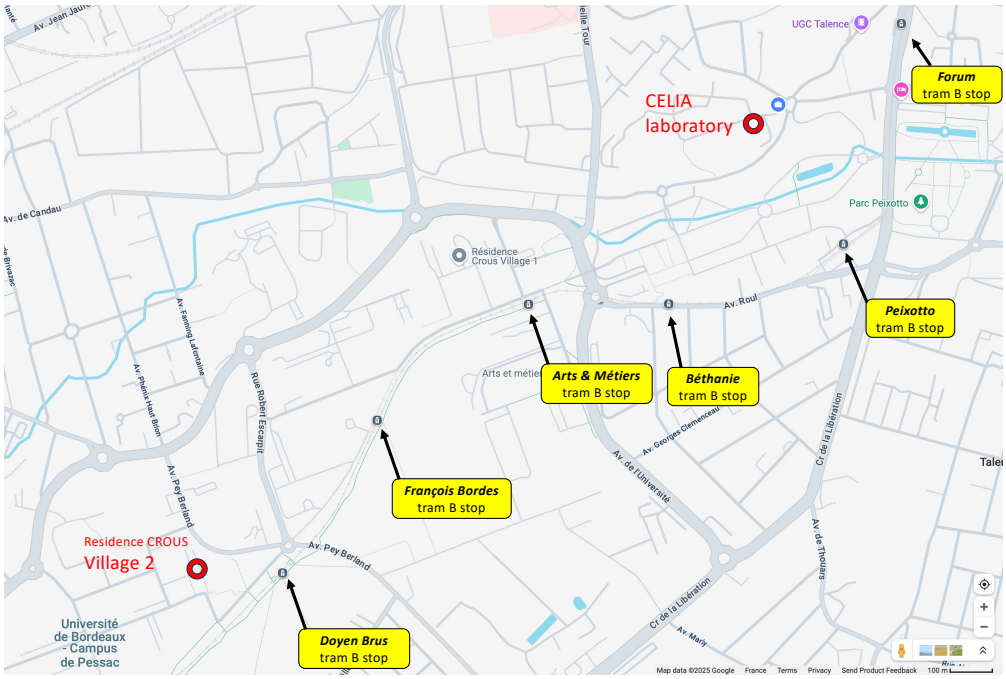
G2b Simon Gerasimus VLACHOS – Roland KIRMER
Lucy ARMITAGE – David PROKOP

Orientation maps

All activities will take place within the Talence part of the "Talence-Pessac Campus" of University of Bordeaux.

The residence for the lodged students is on the Pessac part of the Campus (see as well page 8), at walking distance of maximum 20' to the different locations of the planned activities, or alternatively at 2 to 4 tram stops (line B).





Activating your IDNUM account at the *digital work environment* of Univ. Bordeaux

It is advised that students bring their own laptop PC with granted access to the eduroam network.

On the day of your arrival, you will receive a certificate of your scholar inscription at University of Bordeaux (UB). This document includes a personal code that allows to activate your UB digital ID, called "IDNUM". This will namely provide access to the Univ. Bordeaux *digital environment network* (ENT, for the French acronym) and to your personal e-mail account NAME.SURNAME@etu.bordeaux.fr (see contact list in page 10), on the *Zimbra* platform.

https://www.u-bordeaux.fr/en/education/support-and-success-in-your-studies/digital-services

Your IDNUM and UB e-mail account will be useful during the IP. Namely, the IT team administrating the computers and servers used on the simulation classes will be communicating instructions to you via your UB e-mail accounts.

Visit to CELIA laboratory, on Wednesday 23 July

A visit to CELIA laboratory is organized on Wednesday 23 July from 15:30 to 18:00. The visit will be scheduled as follows:

- 15:30 – General presentation of the laboratory by the CELIA Director, Prof. Eric Mével

- 16:00 to 18:00 – Meetings with the research teams, with a visit to the experiment rooms and discussions in front of posters. You will be divided in 3 groups of 6 people each, and the groups will rotate.

Visit to Laser MegaJoule (LMJ), on Thursday 24 July

Meeting in front of CELIA laboratory at 7:00 am. The bus will leave from CELIA at 7:15 a.m. to the CEA-CESTA centre, and will leave the CEA-CESTA after the visit. We should be back at CELIA before 2 pm.

All visitors must present a valid identification document – passport or national identity card.

No electronic device (telephone, camera, laptop, etc.) is allowed on the site. During the visit, you can store your phones at CESTA reception in a specifically dedicated locker.

It is recommended to wear flat (no heels) and comfortable shoes, to tie up long hair and to favour the wearing of long pants (do not wear skirts or dresses).

Touristic visit of Bordeaux city center and Garonne banks

A touristic visit of Bordeaux is organized on Sunday 20 July, from 9 am to 3 pm. It comprises a guided tour of Bordeaux old city centre, followed by a commented cruise on the Garonne river along Bordeaux banks (way and back between *Pont de Pierre* and *Bec d'Ambès*).

Meeting point is at the Bordeaux Office of Tourism, 12 Cours du 30 Juillet, Bordeaux, on 20 July at 8:55.

A lunch will be served during the cruise (lunch is included, but you must take in charge the payment of any drink taken at the bar). Please communicate promptly with milena.kerkour@u-bordeaux.fr in case of any food allergy or special dietary requirement.

Students lodging

Students will be lodged in individual rooms (13 m²) at the CROUS residence « Village 2 », located at 7 avenue Pey Berland, in Pessac.

https://www.crous-bordeaux.fr

Résidence Crous Village 2
3,6 ★★★½☆ (103) · Student dormitory
7 Av. Pey Berland · 05 57 35 56 40
Open · Closes 6 pm

Website Directions

https://www.google.com/maps/search/«+Village+2+»+au+7+avenue+Pey+Berland+à+Pessac/@44.7999819,-0.6153546,17z/data=!3m1!4b1?entry=ttu&g_ep=EgoyMDI1MDYyMy4yIKXMDSoASAFQAw%3D%3D

The residence provides a “Welcome Kit” that includes bed linens, toilet paper, trash bags, cleaning products and a “Toiletries Kit” that includes toilet linens, bath mat, soap and shampoo pouch.

Life in Campus

A ***Student Guide*** and a ***Bordeaux City Guide*** will be handled to you the day of your arrival.

Meanwhile, information for newcomers and about life in campus can be found here:

https://www.u-bordeaux.fr/en/international/come-to-bordeaux/international-students/welcome-to-bordeaux

https://www.u-bordeaux.fr/en/campus/daily-life

Information about University Restaurants (RU)

Lunches

From 15 to 17 July (included) you can have lunch at RU *Haut Carré*, open from 11:30 to 13:45. It is located close to CELIA laboratory (see map on page 6), therefore more practical to stay in the activity area of the IP.

From 15 to 25 July you can have lunch at RU2, open from 11:30 to 13:45 Monday to Friday. It is located close to the Student Residence *Village 2* and Tram B Stop *Doyen Brus* (see map on page 8):

https://www.crous-bordeaux.fr/restaurant/resto-u-n2-3/

Dinners

From 15 to 25 July you can have dinner at RU *Capucins* in Bordeaux downtown, 26-2 Rue Jules Guesde, open from 18:30 to 19:45 Monday to Friday:

https://www.crous-bordeaux.fr/restaurant/resto-u-le-capu-3/

In all the above places you can pay either directly by bank card (9.50 EUR) or using your UB student *Aquipass* card (between 5 EUR and 7.50 EUR) once you have created and topped up your *Izly* account (see the Student Guide, page 15):

https://www.izly.fr

Cafeteria

A cafeteria “La Soucoupe” is open from 7:45 to 17:30 Monday to Friday at the ground floor of building A22 (see map in page 6). It proposes small snacks, sandwiches, cafeteria, etc. This place can be a solution for breakfast. You can pay using an *Izly* account on your UB student *Aquipass* card, or your bank card:

https://www.crous-bordeaux.fr/restaurant/crous-market-la-soucoupe-3/