GDR
Lasers énergétiques et intenses et plasmas sous conditions extrêmes

Newsletter #1

April 2023

Edited by

Alessandra Benouzzi-Mounaix
alessandra.benuzzi-mounaix@polytechnique.edu

Andrea Ciardi
andrea.ciardi@sorbonne-universite.fr

Le prochain bulletin d'information paraîtra en juillet.
Merci de nous envoyer vos contributions avant la fin du mois de juin.

ABSTRACTS

Classical molecular dynamic simulations and modeling of inverse bremsstrahlung heating in low Z weakly coupled plasmas

R. Devriendt and O. Poujade

Classical molecular-dynamics simulations (CMDS) have been conducted to investigate one of the main mechanisms responsible for absorption of radiation by matter, namely, stimulated inverse bremsstrahlung. CMDS of two components plasmas (electrons and ions) for a large range of electron densities and electron temperatures, for ionization Z = 1, were carried out with 2×10^6 particles using the code LAMMPS. A parameterized model (with six adjustable constants), which encompasses most theoretical models proposed in the past to quantify heating rate by stimulated inverse bremsstrahlung, serves as a reference for comparison to our simulations. CMDS results are precise enough to rule out elements of these past models such as coulomb logarithms depending solely upon laser pulsation ω and not upon intensity. The six constants of the parameterized model have been adjusted, and the resulting model matches all our CMDS results and those of previous CMDS in the literature.

Physics of Plasmas, Volume 29, Issue 7, July 2022, Article number 073301
https://aip.scitation.org/doi/10.1063/5.0091662

Lawson Criterion for Ignition Exceeded in an Inertial Fusion Experiment

H. Abu-Shawareb et al. (Indirect Drive ICF Collaboration)

For more than half a century, researchers around the world have been engaged in attempts to achieve fusion ignition as a proof of principle of various fusion concepts. Following the Lawson criterion, an ignited plasma is one where the fusion heating power is high enough to overcome all the physical processes that cool the fusion plasma, creating a positive thermodynamic feedback loop with rapidly increasing temperature. In inertially confined fusion, ignition is a state where the fusion plasma can begin “burn propagation” into surrounding cold fuel, enabling the possibility of high energy gain. While “scientific breakeven” (i.e., unity target gain) has not yet been achieved (here target gain is 0.72, 1.37 MJ of fusion for 1.92 MJ of laser energy), this Letter reports the first controlled fusion experiment, using laser indirect drive, on the National Ignition Facility to produce capsule gain (here 5.8) and reach ignition by nine different formulations of the Lawson criterion.

Phys. Rev. Lett. 129, 075001 – Published 8 August 2022
https://journals.aps.org/prl/abstract/10.1103/PhysRevLett.129.075001

Benchmarking solid-to-plasma transition modeling for inertial confinement fusion laser-imprint with a pump-probe experiment

A. Pineau, K. R. P. Kafka, S. G. Demos, T. Z. Kosc, V. N. Goncharov, S. X. Hu, and G. Duchateau

For laser direct-drive (LDD) fusion implosions, intense laser beams are used to directly illuminate the inertial confinement fusion (ICF) capsule. The laser beams’ intensity nonuniformity (due to speckles) on the target can impose perturbation seeds which are subsequently amplified by Rayleigh-Taylor instability growth, thereby leading to degradation of ICF implosion performance. To devise methods to mitigate this issue, adequate understanding of the underlying so-called laser-imprinting process is required. Here, we report measurements and modeling of the initial plasma formation process which has been shown to affect the laser imprint. Specifically, we measured the transient transmission of a femtosecond probe pulse through a polystyrene target for different 100-picosecond pump pulse intensities pertaining to ICF conditions. The experimental data are used to benchmark a microphysics model of initial plasma formation that overall describes the observed dynamics, thus providing a validated solid-to-plasma modeling for laser-imprinting purposes in radiation-hydrodynamic codes to accurately simulate and design LDD targets.

Physical Review Research, Volume 4, Issue 3, September 2022, Article number 033178
https://link.aps.org/doi/10.1103/PhysRevResearch.4.033178

PhaseX: an X-ray phase-contrast imaging simulation code for matter under extreme conditions

Francesco Barbato, Stefano Atzeni, Dimitri Batani, and Luca Antonelli

We present PhaseX, a simulation code for X-ray phase-contrast imaging (XPCI), specially dedicated to the study of matter under extreme conditions (of pressure and density). Indeed, XPCI can greatly benefit the diagnosis of such states of matter. This is due to the noticeable contrast enhancement obtained thanks to the exploitation of both attenuation and phase-shift of the electromagnetic waves crossing the sample to be diagnosed. PhaseX generates synthetic images with and without phase contrast. Thanks to its modular design PhaseX can adapt to any imaging set-up and accept as inputs objects generated by hydrodynamic or particle-in-cell codes. We illustrate Phase-X capabilities by showing a few examples concerning laser-driven implosions and laser-driven shock waves.

Opt. Express, Volume 30, Issue 3, January 2022, Pages 3388-3403
https://opg.optica.org/oe/abstract.cfm?URI=oe-30-3-3388

Proton stopping measurements at low velocity in warm dense carbon

S. Malko, W. Cayzac, V. Ospina-Bohórquez, K. Bhutwala, M. Bailly-Grandvaux, C. McGuffey, R. Fedosejevs, X. Vaisseau, An Tauschwitz, J. I. Apiñaniz, D. De Luis Blanco, G. Gatti, M. Huault, J. A. Perez Hernandez, S. X. Hu, A. J. White, L. A. Collins, K. Nichols, P. Neumayer, G. Faussurier, J. Vorberger, G. Prestopino, C. Verona, J. J. Santos, D. Batani, F. N. Beg, L. Roso, L. Volpe

Ion stopping in warm dense matter is a process of fundamental importance for the understanding of the properties of dense plasmas, the realization and the interpretation of experiments involving ion-beam-heated warm dense matter samples, and for inertial confinement fusion research. The theoretical description of the ion stopping power in warm dense matter is difficult notably due to electron coupling and degeneracy, and measurements are still largely missing. In particular, the low-velocity stopping range, that features the largest modelling uncertainties, remains virtually unexplored. Here, we report proton energy-loss measurements in warm dense plasma at unprecedented low projectile velocities. Our energy-loss data, combined with a precise target characterization based on plasma-emission measurements using two independent spectroscopy diagnostics, demonstrate a significant deviation of the stopping power from classical models in this regime. In particular, we show that our results are in closest agreement with recent first-principles simulations based on time-dependent density functional theory.

Nature Communications, Volume 13, Issue 1, May 2022, Article number 2893
https://www.nature.com/articles/s41467-022-30472-8

In-Target Proton–Boron Nuclear Fusion Using a PW-Class Laser

Daniele Margarone, Julien Bonvalet, Lorenzo Giuffrida, Alessio Morace, Vasiliki Kantarelou, Marco Tosca, Didier Raffestin, Philippe Nicolai, Antonino Picciotto, Yuki Abe, Yasunobu Arikawa, Shinsuke Fujioka, Yuji Fukuda, Yasuhiro Kuramitsu, Hideaki Habara, and Dimitri Batani

Nuclear reactions between protons and boron-11 nuclei (p–B fusion) that were used to yield energetic α-particles were initiated in a plasma that was generated by the interaction between a PW-class laser operating at relativistic intensities (3 × 10^{19} W/cm^2) and a 0.2-mm thick boron nitride (BN) target. A high p–B fusion reaction rate and hence, a large α-particle flux was generated and measured, thanks to a proton stream accelerated at the target's front surface. This was the first proof of principle experiment to demonstrate the efficient generation of α-particles (10^{10}/sr) through p–B fusion reactions using a PW-class laser in the "in-target" geometry.

Applied Sciences, vol. 12, no. 3, article no. 1444, Mar. 2022. DOI: 10.3390/app12031444
https://www.mdpi.com/2076-3417/12/3/1444

Development of an experimental platform for the investigation of laser-plasma interaction in conditions relevant to shock ignition regime

Tamagawa, T., Hironaka, Y., Kawasaki, K., Tanaka, D., Idesaka, T., Ozaki, N., Kodama, R., Takizawa, R., Fujioka, S., Yogo, A., Batani, D., Nicolai, Ph, Cristoforetti, G., Koester, P., Gizzi, L. A., & Shigemori, K.

The shock ignition (SI) approach to inertial confinement fusion is a promising scheme for achieving energy production by nuclear fusion. SI relies on using a high intensity laser pulse ($\approx 10^{16}$ W/cm^2, with a duration of several hundred ps) at the end of the fuel compression stage. However, during laser-plasma interaction (LPI), several parametric instabilities, such as stimulated Raman scattering and two plasmon decay, nonlinearly generate hot electrons (HEs). The whole behavior of HE under SI conditions, including their generation, transport, and final absorption, is still unclear and needs further experimental investigation. This paper focuses on the development of an experimental platform for SI-related experiments, which simultaneously makes use of multiple diagnostics to characterize LPI and HE generation, transport, and energy deposition. Such diagnostics include optical spectrometers, streaked optical shadowgraph, an x-ray pinhole camera, a two-dimensional x-ray imager, a Cu Kα line spectrometer, two hot-electron spectrometers, a hard x-ray (bremsstrahlung) detector, and a streaked optical pyrometer. Diagnostics successfully operated simultaneously in single-shot mode, revealing the features of HEs under SI-relevant conditions.

The Review of Scientific Instruments, vol. 93, no. 6, article no. 063505, Jun. 2022. DOI: 10.1063/5.0089969
https://doi.org/10.1063/5.0089969

Path to Increasing p-^{11}B Reactivity via ps and ns Lasers

Mehlhorn, T. A., Labun, L., Hegelich, B. M., Margarone, D., Gu, M. F., Batani, D., Campbell, E. M., and Hu, S. X.

Proton-boron (p-^{11}B) fusion has a higher Lawson criterion compared to deuterium-tritium (DT) fusion due to its lower fusion cross section and peak at higher ion energies. Ultrashort pulse lasers (USPLs) have opened up new possibilities for initiating nonequilibrium thermonuclear burns, and significant numbers of p-^{11}B alpha particles have been reported from several experiments. However, the yields do not scale to net energy gain, and a postulated avalanche mechanism is not required to explain them. In this work, the authors present an analysis of the experimental parameters and cross sections that explain the alpha yields and discuss a path to increasing the p-^{11}B reactivity towards ignition.

Laser and Particle Beams, vol. 40, no. 4, article no. e2355629, Dec. 2022. DOI: 10.1155/2022/2355629
https://doi.org/10.1155/2022/2355629

3D Monte-Carlo model to study the transport of hot electrons in the context of inertial confinement fusion. Part I

A. Tentoria, A. Colaïtis, and D. Batani

We describe the development of a 3D Monte-Carlo model to study hot-electron transport in ionized or partially ionized targets, considering regimes typical of inertial confinement fusion. Electron collisions are modeled using a mixed simulation algorithm that considers both soft and hard scattering phenomena. Soft collisions are modeled according to multiple-scattering theories, i.e., considering the global effects of the scattering centers on the primary particle. Hard collisions are simulated by considering a two-body interaction between an electron and a plasma particle. Appropriate differential cross sections are adopted to correctly model scattering in ionized or partially ionized targets. In particular, an analytical form of the differential cross section that describes a collision between an electron and the nucleus of a partially ionized atom in a plasma is proposed. The loss of energy is treated according to the continuous slowing down approximation in a plasma stopping power theory. Validation against Geant4 is presented. The code will be implemented as a module in 3D hydrodynamic codes, providing a basis for the development of robust shock ignition schemes and allowing more precise interpretations of current experiments in planar or spherical geometries.

Matter and Radiation at Extremes 7, 065902 (2022)
https://doi.org/10.1063/5.0103631

3D Monte-Carlo model to study the transport of hot electrons in the context of inertial confinement fusion. Part II

A. Tentoria, A. Colaïtis, and D. Batani

We describe two numerical investigations performed using a 3D plasma Monte-Carlo code, developed to study hot-electron transport in the context of inertial confinement fusion. The code simulates the propagation of hot electrons in ionized targets, using appropriate scattering differential cross sections with free plasma electrons and ionized or partially ionized atoms. In this paper, we show that a target in the plasma state stops and diffuses electrons more effectively than a cold target (i.e., a target under standard conditions in which ionization is absent). This is related to the fact that in a plasma, the nuclear potential of plasma nuclei has a greater range than in the cold case, where the screening distance is determined by the electronic structure of atoms. However, in the ablation zone created by laser interaction, electrons undergo less severe scattering, counterbalancing the enhanced diffusion that occurs in the bulk. We also show that hard collisions, i.e., collisions with large polar scattering angle, play a primary role in electron beam diffusion and should not be neglected. An application of the plasma Monte-Carlo model to typical shock ignition implosions suggests that hot electrons will not give rise to any preheating concerns if their Maxwellian temperature is lower than 25–30 keV, although the presence of populations at higher temperatures must be suppressed. This result does not depend strongly on the initial angular divergence of the electron beam set in the simulations.

Matter and Radiation at Extremes 7, 065903 (2022)
https://doi.org/10.1063/5.0103632

Investigating particle acceleration dynamics in interpenetrating magnetized collisionless super-critical shocks

W. Yao, A. Fazzini, S.N. Chen, K. Burdonov, J. Béard, M. Borghesi, A. Ciardi, M. Miceli, S. Orlando, X. Ribeyre, E. d'Humières and J. Fuchs

Colliding collisionless shocks appear in a great variety of astrophysical phenomena and are thought to be possible sources of particle acceleration in the Universe. We have previously investigated particle acceleration induced by single super-critical shocks (whose magnetosonic Mach number is higher than the critical value of 2.7) (Yao et al., Nat. Phys., vol. 17, issue 10, 2021, pp. 1177–1182; Yao et al., Matter Radiat. Extrem., vol. 7, issue 1, 2022, 014402), as well as the collision of two sub-critical shocks (Fazzini et al., Astron. Astrophys., vol. 665, 2022, A87). Here, we propose to make measurements of accelerated particles from interpenetrating super-critical shocks to observe the 'phase-locking effect' (Fazzini et al., Astron. Astrophys., vol. 665, 2022, A87) from such an event. This effect is predicted to significantly boost the energy spectrum of the energized ions compared with a single super-critical collisionless shock. We thus anticipate that the results obtained in the proposed experiment could have a significant impact on our understanding of one type of primary source (acceleration of thermal ions as opposed to secondary acceleration mechanisms of already energetic ions) of ion energization of particles in the Universe.

Journal of Plasma Physics, 89(1), 915890101 (2023)
https://arxiv.org/abs/2208.06304

Multibeam Laser Plasma Interaction at Gekko XII laser facility in conditions relevant for Direct-Drive Inertial Confinement Fusion

Gabriele Cristoforetti, P. Koester, S. Atzeni, D. Batani, S. Fujioka, et al..

Laser Plasma Interaction and hot electrons have been characterized in detail in laser irradiation conditions relevant for direct-drive Inertial Confinement Fusion. The experiment has been carried out at Gekko XII laser facility in multibeam planar geometry at intensity $\sim 3 \times 10^{15}$ W/cm^2. Experimental data suggest that high-energy electrons, with temperature 20-50 keV and conversion efficiencies $\eta < 1$% , were mainly produced by the damping of electron plasma waves driven by Two Plasmon Decay. Stimulated Raman Scattering is observed in a near-threshold growth regime, producing a reflectivity of ~ 0.01%, and is well described by ananalytical model accounting for the convective growth in independent speckles. The experiment reveals that both TPD and SRS are collectively driven by multiple beams resulting in a more vigorous growth than that driven by single-beam laser intensity.

High Power Laser Science and Engineering, 1-11 (2023)
https://cnrs.hal.science/hal-03997437

POSTDOCS ANNOUNCEMENTS

Post-doctorat position

"Femtosecond dynamic of matter at atomic-scale
in the warm dense matter regime"

Subject:

A femtosecond intense laser pulse can transiently bring matter into extreme conditions with unprecedented properties. These properties strongly depend on both electron and ion structures, and their dynamic interplay. Such experimental situation makes it possible to study materials in a regime between condensed matter and plasma, called Warm Dense Matter (WDM), and consequently to test the predictive capacity of quantum molecular dynamics codes which are widely used to compute the properties of matter in a large domain of thermodynamic conditions. The challenge is to demonstrate that these codes describe, in a realistic way, the mechanisms involved during and after the laser irradiation in different types of materials with various complex electronic structures: noble metals, transition metals, insulators. More generally, such experiment can test the validity of the thermodynamic coefficients which are used, on the one hand, for hydrodynamic simulations and, on the other hand, for the description of astrophysical objects such as planetary interiors or the interpretation of experiments carried out in the context of inertial confinement fusion.

The candidate will be in charge of defining and performing time-resolved X-ray Absorption Near-Edge Spectroscopy (XANES) experiments on the already operational experimental stations of the CELIA (Talence) and LOA (Palaiseau) laboratories. This work is carried out within the framework of the ANR FemTraXS project, where the candidate will integrate a collaborative team spread over three laboratories (CEA, CELIA, LOA). He (she) will participate in studies already in progress on a transition metal, before defining new studies on a dielectric type material.

Travel in France and abroad is expected, in particular for carrying out the experiments (also planned at the European X-FEL in Hamburg). This postdoctoral position is funded over 2 years by the ANR FemTraXS project, and spread over two establishments, CELIA and CEA (1 year in each laboratory).

Candidate:

The candidate must have a PhD in plasma physics. Professional experience in the field of laser-plasma interaction will be considered: with experimental skills, even an ability to handle simulation codes or for programming (Python, Fortran). Experience in scientific computing of quantum molecular dynamics will be an added advantage.

A good level of English is required, oral and written, for writing reports and publications in scientific journals, as well as presentations at national or international meetings. The subject and its context require qualities of rigor, method, and autonomy, as well as an ability to organize teamwork with doctoral students / physicists, spread over several sites.

Contact :

Ludovic Lecherbourg – CEA, DAM, DIF, 91297 Arpajon – 01 69 26 40 00 – ludovic.lecherbourg@cea.fr
Fabien Dorchies – CELIA, UMR 5107, 33400 Talence – 05 40 00 25 87 – fabien.dorchies@u-bordeaux.fr

PhD ANNOUNCEMENTS

<u>Topic</u>: Study of low-frequency radiation produced by particle acceleration at ultra-high laser intensity in relativistic plasmas

Context: Laser-matter interaction – Laser-induced low-frequency radiation

Thesis objective: Today, petawatt laser sources deliver optical pulses lasting a few tens of femtoseconds with an intensity exceeding 10^{20} W/cm^2. When such light beams impinge onto a gas or a solid target, their electromagnetic field can drive electrons to MeV or GeV energies, depending on the interaction parameters. While the dynamics of those relativistic electrons is an efficient source of secondary high-energy photons, the laser-plasma interaction also gives rise, through the production mechanisms of plasma waves and particle acceleration, to low-frequency emissions in the gigahertz (GHz) and terahertz (THz) ranges.

Having high-power emitters operating in this frequency band is attracting more and more interest in Europe, overseas and in Asia. On the one hand, the generation of intense electromagnetic pulses with GHz-THz frequencies is harmful for any electronic device used on large-scale laser facilities like, e.g., the PETAL/LMJ laser in the Aquitaine region. It is therefore necessary to understand their nature to better circumvent them. On the other hand, the waves operating in this field not only make it possible to probe the molecular motions of complex chemical species, but they also offer new perspectives in medical imaging for cancer detection, in astrophysics, in security as well as for environmental monitoring. The processes responsible for this violent electromagnetic field emission also open new ways to modify some properties of condensed matter in strong field.

The objective of this thesis is to study the generation of such giant electromagnetic pulses by ultrashort laser pulses interacting with dense media, to build a model based on the different THz/GHz laser-pulse conversion mechanisms, and validate this model by available experimental data. The PhD student will be invited to deal with this problem theoretically and numerically, by means of a kinetic, particle-in-cell code whose Maxwell solver will be adapted to describe radiation coming from different electron/ion populations. Particular attention will be given to the different radiations associated with particle acceleration on femto- and picosecond time scales by dense relativistic plasmas and their respective roles in target charging models available in the literature. This field of physics requires a new theoretical and numerical modeling work, at the crossroads of extreme nonlinear optics and the physics of relativistic plasmas.

The candidate should have an advanced training in plasma physics and/or scientific computing, with an ability to handle simulation codes or for programming (Python, Fortran, C++).

Thesis Director & CoDirector: Luc Bergé & Emmanuel d'Humières – Centre Lasers Intenses et Applications (CELIA), Université de Bordeaux, CNRS, CEA, 33405 Talence, France.
PhD (Doctoral) School: Ecole Doctorale Sciences Physiques et de l'Ingénieur – Bâtiment A1 - 351, cours de la libération, 33405 Talence CEDEX. Tel : 05 40 00 65 26 ; courriel : edoc.spi@u-bordeaux.fr
Contact: Luc Bergé – luc.berge@cea.fr – CEA, DAM, DIF, 91297 Arpajon, France – 01 69 26 40 00
& Centre Lasers Intenses et Applications, Université de Bordeaux, CNRS, CEA, 33405 Talence, France
Emmanuel d'Humières - emmanuel.dhumières@u-bordeaux.fr – 05 40 00 37 77 - Centre Lasers Intenses et Applications, Université de Bordeaux, CNRS, CEA, 33405 Talence, France

Financement: Commissariat à l'Energie Atomique et aux Energies Alternatives (CEA)

<u>Topic</u>: Study of THz and XUV radiation produced by intense ultrashort lasers in gases and condensed matter

Context: Laser-matter interaction – Harmonic generation

Thesis objective: The generation of high order harmonics from the interaction between an intense, femtosecond few-cycle laser pulse and a gaseous or solid medium makes it possible to produce ultrashort light pulses close to a few tens of attoseconds in the X-XUV range and to create terahertz (THz) radiation. The process at the origin of high order harmonics lies in the ionization of atoms at high intensity levels allowing the electrons oscillating in phase with the laser pump to be accelerated over a fraction of the laser period and to recombine with the parent ion. This gives rise to a broad spectrum composed of multiple harmonics of the fundamental carrier wave. The resulting XUV pulses thus offer probe beams with unrivaled resolutions in space and time to study light-matter interactions at quantum levels that have yet to be explored.

One of the main difficulties to efficiently generate high order harmonics in long targets is to achieve phase matching conditions between the fundamental pulse and the produced secondary radiations.

The present thesis aims at optimizing the production of various secondary radiations, from terahertz to XUV, using time and space-controlled laser pulses irradiating gas jets or thin solid targets. Its objective will consist in describing the influence of the nonlinear propagation of laser beams operating in the near- or mid-infrared domains on the generation of low (terahertz) or high (XUV) frequencies, in order to optimize their conversion efficiencies in terms of their energy yield and spectral content. The study will be carried out over two stages: on the one hand, it will involve the handling of ab-initio codes integrating the time-dependent Schrödinger equation (TDSE) in order to precisely describe the electron density excited along the laser pulse. A new ionization model will be investigated and coupled to a numerical code of unidirectional propagation for the ionizing laser wave. On the other hand, this multi-scale model coupling ab-initio description and unidirectional propagation code will be used to predict the optimum conditions to produce secondary radiation by wisely selecting the laser-medium parameters.

The candidate should have an advanced training in nonlinear optics and/or plasma physics and/or quantum physics and/or scientific computing, with an ability to handle simulation codes or for programming (Python, Fortran, C++).

Thesis Director & CoDirector: Luc Bergé & Fabrice Catoire – Centre Lasers Intenses et Applications (CELIA), Université de Bordeaux, CNRS, CEA, 33405 Talence, France.
PhD (Doctoral) School: Ecole Doctorale Sciences Physiques et de l'Ingénieur – Bâtiment A1 - 351, cours de la libération, 33405 Talence CEDEX. Tel : 05 40 00 65 26 ; courriel : edoc.spi@u-bordeaux.fr
Contact: <u>Luc Bergé</u> – luc.berge@cea.fr – CEA, DAM, DIF, 91297 Arpajon, France – 01 69 26 40 00 & Centre Lasers Intenses et Applications, Université de Bordeaux, CNRS, CEA, 33405 Talence, France
<u>Fabrice Catoire</u> - fabrice.catoire@u-bordeaux.fr – 05 40 00 29 49 - Centre Lasers Intenses et Applications, Université de Bordeaux, CNRS, CEA, 33405 Talence, France

Funding: Commissariat à l'Energie Atomique et aux Energies Alternatives (CEA) - France

Exploring light C:H:N:O mixtures at conditions of ice giant interiors

The interiors of the ice giants Uranus and Neptune are largely composed of the light elements hydrogen, helium, carbon, nitrogen and oxygen (CHNO) at extreme pressures of several million atmospheres and temperatures of several thousand kelvins. These environments presumably allow the formation of unfamiliar structures, such as superionic states of water and ammonia, and exotic chemistry, e.g., the dissociation of hydrocarbons into diamond and metallic hydrogen. These processes are highly complex and, so far, cannot be modelled reliably with existing theory and simulation methods. At the same time, they are thought to significantly shape the internal structure and evolution of Uranus and Neptune and may be key to explain the unusual magnetic fields observed for both planets, and to elucidate their internal heat balance. Moreover, planets of similar size and probably composition, in particular so-called “sub-Neptunes”, are found to be highly abundant outside our Solar System. Thus, a better understanding of matter at conditions comparable to the interior of ice giants is required for both better models of our Solar System and a reliable classification of exoplanets from telescope data of mass and radius.

In the last years, the PHYHDEL group at the LULI laboratory at the Ecole Polytechnique in France started a scientific program focused on the characterisation of the properties of CHNO mixtures under high pressure and temperature conditions obtained with laser-generated shock compression. A DFG-ANR collaborative project, PROPICE, between PHYHDEL and the German team headed by Prof. D. Kraus, has lately been granted to pursue this research with focus on *in situ* microscopic probing. This PhD thesis fits into this context and it is funded by this project. It will build on the results previously obtained and enlarge their scope by leveraging on unique possibilities offered by high-power optical lasers and X-Ray Free Electron Lasers (XFEL) facilities based in Germany (EuropeanXFEL), USA (LCLS) and Japan (SACLA).
In this project the student will perform experiments to benchmark equations of state, melting curves and transport properties for new mixtures and over unexplored thermodynamic conditions. In particular, the candidate work will include water-ammonia mixtures with different concentrations, CH4 and various CHNO mixtures. At high pressures, calculations predict very peculiar properties that would highly impact interiors and dynamo models of ice giants and thus must be experimentally confirmed. These measurements will involve classical optical diagnostics.

In parallel, he/she will complement these results with microscopic data obtainable with X- ray diagnostics. This will allow a direct investigation of the physical and chemical processes into play. To this aim, the student will work in adapting the liquid samples of different ice mixtures to X-ray diagnostics implemented at current XFEL facilities. Direct characterization of super-ionic lattices, phase separation or polymerization will be obtained using x-ray diffraction, X-ray Thomson scattering and Small Angle Scattering diagnostics. The use of liquid samples gives enough freedom in changing H_2O/N/C stoichiometry so that N-H-O, C-H-O and more comprehensive C-H-N-O environments will be accessible. A comparison between various concentrations, including pure compounds, will underline the chemical processes associated with different specimens.

During this PhD project, the candidate will perform experiments on the most powerful lasers and XFEL facilities worldwide accessing unique data set that he/she will collect and analyze. The student will be based at the LULI laboratory, near Paros, but he/she will work in close collaboration with the German partner. He/She will profit from a fruitful environment benefiting from interactions and exchanges within both the French and German teams. Experiments will also be intermixed with discussion sessions on collected data with relevant experts from the ab-initio and planetary model communities.

Contacts:
Alessandra RAVASIO
Laboratoire LULI, Ecole Polytechnique
alessandra.ravasio@polytechnique.fr

Tommaso VINCI
Laboratoire LULI, Ecole Polytechnique
tommaso.vinci@polytechnique.fr

DIFFRACTION X DE MATÉRIAUX MULTIPHASIQUES DANS LE DOMAINE DE LA MATIÈRE DENSE ET TIÈDE

Un diagnostic de diffraction X a été mis au point sur l'installation LULI2000, et sera adapté prochainement sur le Laser MegaJoule. Un tel dispositif offre la possibilité d'étudier les transitions de phases de matériaux cristallins comprimés à l'aide d'un laser et soumis à de très hautes pressions relevant du domaine de la matière dense et tiède. Lors de la première étude, les changements de phase solide/solide et solide/liquide du fer, matériau d'intérêt géophysique, ont été explorés le long de son Hugoniot afin d'acquérir des données importantes quant à la compréhension des intérieurs planétaires. En outre, le diagramme de phase du bismuth a été exploré avec une cinétique inédite offerte par ce type d'installation, i.e. en comprimant le matériau avec l'aide de rampes laser. Ce diagramme apparait différent des diagrammes de phase statiques ou explorés sous choc et met ainsi en lumière toute l'importance d'étudier les effets cinétiques pour comprendre les processus de transition de phase.

A la manière des deux pré-études citées ci-dessus, l'objectif de cette thèse est d'exploiter ce nouveau dispositif sur l'installation LULI2000 afin d'identifier la fusion sous choc de matériaux pour lesquels il subsiste des désaccords majeurs entre les courbes de fusion statiques et dynamiques. Il s'agira aussi d'explorer le diagramme de phase de matériaux multiphasiques avec des dynamiques de compression inédites hors-Hugoniot. En plus de participer activement à la préparation et à la réalisation de ces expériences, le (la) doctorant(e) sera amené(e) à développer les outils nécessaires à la prévision et à l'analyse du diagnostic de diffraction X. En parallèle, il (elle) devra réaliser des simulations hydrodynamiques afin d'analyser les données parallèles permettant d'évaluer les conditions extrêmes de pression et de température sondées. Il (elle) participera en cela à l'amélioration et à la validation des modèles d'interaction laser-matière et des modèles hydrodynamiques (équations d'état multi- phases, conductivité thermique, cinétique des changements de phase) utilisés dans ces calculs.

Il sera tout d'abord demandé à l'étudiant(e) d'analyser la première expérience de diffraction X afin de se familiariser à la fois avec les méthodes expérimentales utilisées pour étudier la matière dense et tiède à l'aide d'un laser de puissance, avec les outils de dépouillement qu'il (elle) se devra de compléter, ainsi qu'avec les simulations hydrodynamiques. Ceci lui permettra ensuite de préparer, de réaliser et d'analyser les différentes campagnes expérimentales citées ci-avant. Pendant toute la durée du doctorat, l'étudiant(e) bénéficiera d'un co-encadrement multidisciplinaire CEA/LULI composé d'expérimentateurs laser et synchrotron, de théoriciens et de géophysiciens, ce qui l'amènera à participer également à des expériences sur des installations synchrotron (ESRF, Grenoble) et XFEL (Hambourg).

Financement CEA. Lieu : CEA - DAM Île-de-France, Bruyères-le-Châtel - 91297 Arpajon
Directeurs de thèse : A. Benuzzi Mounaix (LULI) et A. Denoeud (CEA)

Contacts: DENOEUD Adrien, adrien.denoeud2@cea.fr;
BRYGOO Stéphanie, stephanie.brygoo@cea.fr:
Alessandra Benuzzi Mounaix, alessandra.benuzzi-mounaix@polytechnique.edu

MEETINGS

EPS 2023 — 49th European Conference on Plasma Physics

03 Jul 2023 - 07 Jul 2023
Bordeaux, France
`https://epsplasma2023.eu/`

ICMRE 2023 — 6th International Conference on Matter and Radiation at Extremes

June 5-9, 2023
Zhuhai, Guangdong, China
website link

ECPD 2023 — 5th European Conference on Plasma Diagnostics

23 Apr 2023 - 27 Apr 2023
Rethymno, Greece
`https://ecpd2023.eventsadmin.com/Home/Welcome`

PLASMA 2023 — International Conference on Research and Applications of Plasmas

18 Sep 2023 - 22 Sep 2023
Warsaw, Poland
`https://plasma2023.ipplm.pl/`

Summer School : EXTREME MATTER

4 - 8 September 2023
Observatoire Oceanographique of Banyuls sur Mer, France
`https://luli.cnrs.fr/summer-school-extreme-matter/`