Campagne 2020 Contrats Doctoraux Instituts/Initiatives

Proposition de Projet de Recherche Doctoral (PRD)

Appel à projet IPhyInf - Initiative Physique des infinis 2020

Intitulé du Projet de Recherche Doctoral : New generation of opacities for astrophysics

Directeur de Thèse porteur du projet (titulaire d'une HDR) :

NOM : **Ciardi** Prénom : **Andrea**
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Unité de Recherche :
Intitulé : LERMA
Code *(ex. UMR xxxx)* : UMR 8112

Ecole Doctorale de rattachement de l'équipe & d'inscription du doctorant : ED127-Astronomie&AstrophysiqueIdF

Doctorants actuellement encadrés par le directeur de thèse (préciser le nombre de doctorants, leur année de 1ere inscription et la quotité d'encadrement) : 3 - 2018 A.Marret encadrement 50%, 2019 V.Tranchant encadrement 20% , 2019 J.C.Porto encadrement 20%

Co-encadrant :

NOM : **Koenig** Prénom : **Michel**
Titre : Directeur de Recherche ou HDR ☒
e-mail : michel.koenig@luli.polytechnique.edu

Unité de Recherche :
Intitulé : LULI
Code *(ex. UMR xxxx)* : UMR 7605

Ecole Doctorale de rattachement : Choisissez un élément :
Ou si ED non Alliance SU : **ED 626**

Doctorants actuellement encadrés par le co-directeur de thèse (préciser le nombre de doctorants, leur année de 1ere inscription et la quotité d'encadrement) : MK:1-2017-75%

Co-encadrant :

NOM : **Delahaye** Prénom : **Franck**
Titre : Astronome Adjoint HDR
e-mail : franck.delahaye@obspm.fr

Unité de Recherche :
Intitulé : LERMA
Code *(ex. UMR xxxx)* : UMR 8112

Ecole Doctorale de rattachement : **ED 127**

Doctorants actuellement encadrés par le co-directeur de thèse (préciser le nombre de doctorants, leur année de 1ere inscription et la quotité d'encadrement) : 0

Cotutelle internationale : ☒ Non ☐ Oui, précisez Pays et Université :

Description du projet de recherche doctoral *(en français ou en anglais)*

3 pages maximum – interligne simple – Ce texte sera diffusé en ligne

Détailler le contexte, l'objectif scientifique, la justification de l'approche scientifique ainsi que l'adéquation à l'initiative/l'Institut.
Le cas échéant, préciser le rôle de chaque encadrant ainsi que les compétences scientifiques apportées. Indiquer les publications/productions des encadrants en lien avec le projet.
Préciser le profil d'étudiant(e) recherché.

Description du projet de recherche doctoral *(en français ou en anglais)*

3 pages maximum – interligne simple – Ce texte sera diffusé en ligne

Détailler le contexte, l'objectif scientifique, la justification de l'approche scientifique ainsi que l'adéquation à l'initiative/l'Institut. Le cas échéant, préciser le rôle de chaque encadrant ainsi que les compétences scientifiques apportées. Indiquer les publications/productions des encadrants en lien avec le projet. Préciser le profil d'étudiant(e) recherché.

Context. The large scale dynamics and thermodynamics of plasmas can be strongly affected by the interaction with photons. From inertial confinement fusion and laser-matter interaction, to the physics of stellar interiors, being able to model the coupling of plasma and radiation is fundamental. Indeed, one of the most widely used models of plasmas, radiation-magneto-hydrodynamic, treats both plasma and photons as "fluids" that are coupled by one key microscopic transport parameter: the opacity. More generally this quantity enters all radiation transport calculations and it is the results of complex and time-consuming quantum-mechanical (or semi-classical) calculations involving atomic processes in high-energy density plasmas, such as electron impact excitation, photoionization, recombination, photo-excitation and radiative decay. Accurate opacities calculations of plasmas under different physical conditions are fundamental to be able to model and interpret experiments and observations.

In that respect, the experimental validation of theoretical opacity calculations is paramount and recent advances in high-energy density plasma physics facilities now allow their direct verification under extreme conditions of temperature and density. Indeed, experiments conducted at Sandia National Laboratory have now yielded precious results on the opacity of Iron in conditions typical of the Solar plasma at the base of the convection zone (Bailey et al. Nature 2015, Nagayama et al. Phys Rev L. 2019). Importantly, these results are actually questioning the ability to calculate such fundamental microscopic parameters. The difference between the measured Fe opacities and all of the existing theoretical calculations disagree by a factor of two. Such discrepancy impacts all the different domains of research where radiative transfer is at play, and could be crucial, for example, to understand the long standing problem of the Solar composition.

Aims. It is therefore important to collect more experimental data and to develop a better theoretical framework for this outstanding problem.

1) Experiments: We are developing an experimental platform to measure opacities with new diagnostics to accurately determine the state of the probed plasma (temperature, density). To probe the plasma condition, we will use a combination of X-ray Thomson scattering diagnostic and light elements spectroscopy. We will benchmark and use this platform to measure opacities for some elements from Si to Ni in order to test our ability to calculate theoretically opacities of open L-shell ions, seriously questioned by SANDIA experiments. This work, in collaboration with the LULI and CEA for a three years program on the GEKKO laser in Japan, and LULI lasers will also pave the path to future opacity experiments on the Laser MegaJoule.

2)Theory: We will build a theoretical framework with an improved state-of-the-art suite of codes to calculate raw photoionization cross sections and other radiative data and different approximations for the line broadening.

3) Applications: We will model stellar structure and evolution, from Solar model to Red giants and pulsating stellar candles, will help to quantify the effects of the newly improved opacities and give feedback for future improvement, as well as providing clues as to which new elements should be included in more complete calculations.

Thesis work and student. The student will (i) help develop the new experimental platform with a new set of diagnostics to determine the state of the plasma and perform hydro-radiative simulation to design the experiment. (ii) he will analyze spectroscopic and X-ray Thomson scattering data. (iii) he will study the impact of different theoretical approximations on the computation of raw atomic data and the derived opacities.

The student should have a strong background in plasma physics.

Environment. The student will benefit from the supervision from the MUMEO team (Multi Measurement of Opacities project) regrouping experimental and theoretical experts from Sorbonne Universite, LULI, Observatoire de Paris and CEA.

The student will take advantage of the measurement campaign granted and programmed at GEKKO XII facility for 2021.

Expertise of the supervisors.

Andrea Ciardi: theory and simulations of laser produced plasmas, magneto-hydrodynamics, astrophysics, high energy density physics. In charge of supervising the radiation-hydrodynamics modelling. *Supervision at 25%*

Michel Koenig: experimental plasma physics, hydrodynamics and shock physics, astrophysics, planetary physics, high energy density physics. In charge of the experiments. Supervision of the student on the experiments. *Supervision at 25%*

Franck Delahaye: theory and simulations of atomic physics, opacities (Member of the International collaboration The Opacity Project - The Iron Project), stellar modeling. In charge of the supervision of the modelling of the experimental spectra. *Supervision at 50%*

This project is approved by B. Semelin, Director of the LERMA

Selected publications of the proposing team.

1) Albertazzi, B. et al., "Experimental characterization of the interaction zone between counter propagating Taylor Sedov blast waves", Physics of Plasmas 27, 022111 (2020)

2) Khiar, B. et al. "Laser-produced magnetic-Rayleigh-Taylor unstable plasma slabs in a 20 T magnetic field", Physical Review Letters 123, 205001 (2019)

3) Filippov, E. D., "X-ray spectroscopy evidence for plasma shell formation in experiments modeling accretion columns in young stars", Matter and Radiation at Extremes 4, 064402 (2019)

4) Hare, J. D., et al, "An Experimental Platform for Pulsed-Power Driven Magnetic Reconnection", Physics of Plasmas 25, 055703 (2018)

5) Van Box Som, L., et al, "Numerical simulations of high-energy flows in accreting magnetic white dwarfs", Monthly Notices of the Royal Astronomical Society, Volume 473, Issue 3, Pages 3158–3168 (2018)

6) Michel, Th.; Albertazzi, B.; Mabey, P.; Rigon, G.; Lefevre, F.; Van Box Som, L.; Barroso, P.; Egashira, S.; Kumar, R.; Michaut, C.; Ota, M.; Ozaki, N.; Sakawa, Y.; Sano, T.; Falize, E.; Koenig, M., "Laboratory Observation of Radiative Shock Deceleration and Application to SN 1987A"; ApJ, Volume 888, Issue 1, article id. 25, 5 pp. (2020)

7) P. Mabey, B. Albertazzi, G. Rigon, J. R. Marquès, C. A. J. Palmer, J. Topp-Mugglestone, P. Perez-Martin, F. Kroll, F.-E. Brack, T. E. Cowan, U. Schramm, K. Falk, G. Gregori, E. Falize, and M. Koenig,"Laboratory study of bilateral supernova remnants and continuous MHD shocks",Accepted. To ApJ

8) Delahaye F, Badnell, N.R., Ballance C.P. et al., “A quantitative comparison of opacities using the distorted wave and the R-matrix methods: Fe XVII case” submitted april 2020 to MNRAS

9) Badnell, N. R., Bautista M.A., Butler K. et al. ”Updated opacities from the Opacity Project” MNRAS. Vol 360 pp458-464, 2006

10) Delahaye, F. & Pinsonneault, M. H ”The Solar Heavy-Element Abundances. I. Constraints from Stellar Interiors”, ApJ vol 649 p 529, 2006