PhD Student (M/F)

Characterization and modeling of nonlinear instabilities in plasmas containing nanoparticles

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Application Deadline: Monday June 16, 2025 23:59:00 Paris time
CV + motivation letter by email to maxime.mikikian@univ-orleans.fr
Remuneration: 2200,00 € gross monthly
Section(s) CN : 10 - Fluid and reactive environments: transport, transfer, transformation processes
41 - Mathematics and mathematical interactions
Subject significance:

This thesis has been selected by the MITI (Mission pour les Initiatives Transverses et Interdisciplinaires) of the CNRS as part of the 80PRIME - 2025 call for projects.

This interdisciplinary topic is at the interface of physics, engineering and mathematics fields covered by CNRS Ingénierie and CNRS Mathématiques. It will explore aspects related to the control of plasma processes that are heavily involved in industry, the mathematical description of stochastic dynamical systems, and the understanding of non-equilibrium phenomena by improving their control and prediction. Extending the mathematical models used to describe oscillating systems in chemistry, biology and climatology to the field of plasmas would enable to better understand and control the origin of these instabilities. This new field of application will, in turn, improve the understanding and predictive capability of these systems of equations, which are involved in a wide range of fields, particularly on the role of noise on disturbances that are still poorly understood.

Description of thesis topic

This project follows GREMI's discovery of the existence of nonlinear instabilities of the MMOs (Mixed Mode Oscillations) type in low-temperature plasmas containing nanoparticles [1,2]. These oscillations have been observed in rare experiments with plasmas created by continuous discharge without nanoparticles, but have never been the subject of precise studies in so-called "dusty" plasmas. GREMI now has a unique plasma experiment for obtaining and studying these particular oscillations. Their modelling will be envisaged thanks to an interdisciplinary collaboration with IDP based on the same campus. The coupling between

[1] M. Mikikian, M. Cavarroc, L. Couëdel, Y. Tessier, L. Boufendi, *Mixed-Mode Oscillations in Complex Plasma Instabilities*, Phys. Rev. Lett. **100**, 225005 (2008), https://hal.archives-ouvertes.fr/hal-00286650
[2] M. Mikikian, L. Couëdel, M. Cavarroc, Y. Tessier, L. Boufendi, *Threshold phenomena in a throbbing complex plasma*, Phys. Rev. Lett. **105**, 075002 (2010), https://hal.archives-ouvertes.fr/hal-00502767

plasma experiments and a mathematical approach is particularly original and ambitious. Advances in this study would have a dual impact, both for dusty plasmas, which would see the emergence of a system of differential equations capable of simulating observations, and for the mathematical modelling of dynamical systems, which would see a new field of application for these equations.

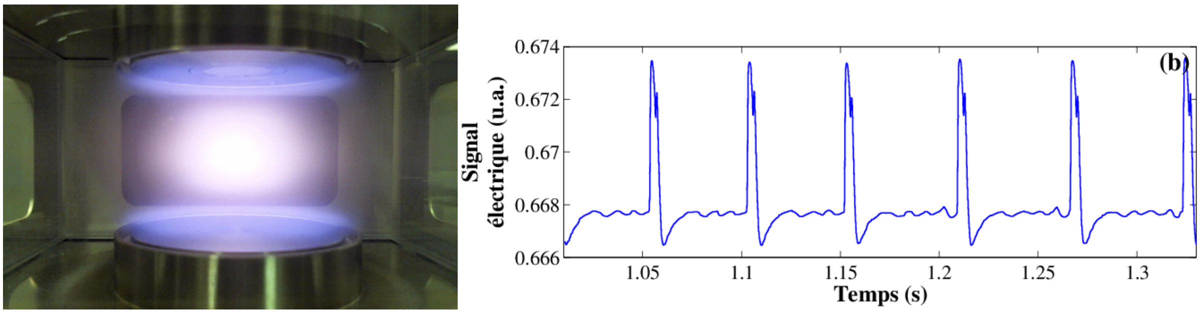

Fig. 1. (a) Low-pressure plasma used for nanoparticle synthesis triggering non-linear instabilities observed in (b) in the discharge current revealing the presence of Mixed-Mode Oscillations (MMOs)

In this context, the thesis work will address both experimental and theoretical aspects of MMOs. At GREMI, the PhD student will create a low-pressure plasma inside which he/she will synthesize nanoparticles, and will investigate the optimal experimental conditions for controlling instabilities. In particular, he/she will carry out experiments with a new radio-frequency power supply currently being installed. He/she will take charge of the diagnostic part, which involves measuring the discharge current and coupling its variations with high-speed plasma imaging. He/she will develop image processing programs to extract plasma and nanoparticle cloud evolutions during instabilities. He/she will familiarize himself/herself with methods for representing dynamical data, and research a method for classifying the different types of MMOs observed. He/she will carry out experiments for different plasma gases (Ar, Kr, Xe), in order to identify the precise role of the ions.

At the same time, at IDP, the PhD student will be familiarizing himself/herself with mathematical approaches of MMOs [3]. The IDP is currently working on this problem, and the preliminary aspects of the study have been addressed. The PhD student will be looking for the most appropriate system of differential equations to reproduce his/her own experiments. He/she will pay particular attention to the introduction of real plasma quantities into the equations. He/she will consider the development of new types of mathematical models, of the hyperbolic or hyperbolic-parabolic type, with a slow-fast structure, to describe periodic movements of density fronts.

This highly interdisciplinary project will give the PhD student a dual, or even triple, skill set, with expertise in experimental low-temperature plasma physics, dusty plasma theory and applied mathematics (differential and partial differential equations, numerical analysis).

Work context

The PhD student will work in Orléans in 2 laboratories only 1 km apart: the Groupe de Recherches sur l'Energétique des Milieux Ionisés (GREMI, UMR7344 CNRS-Université d'Orléans) and the Institut Denis Poisson (IDP, UMR7013 CNRS-Université d'Orléans-Université de Tours). He/she will be integrated into the doctoral student communities of both laboratories, and may if he/she wishes, take on additional teaching assignments in the physics or mathematics departments, depending on his/her profile.

[3] N. Berglund et al., *Mixed-Mode Oscillations and Interspike Interval Statistics in the Stochastic FitzHugh-Nagumo equations*, Nonlinearity **25**, 2303 (2012), https://arxiv.org/pdf/1105.1278.pdf

As the 2 laboratories are on the same campus, this will facilitate exchanges between the PhD student and the researchers involved in the project. It is important for the PhD student to be able to carry out the experimental and modeling parts of the project in parallel, so that the expertise acquired on the modeling side can improve the experimental part. In particular, this will enable to search for very specific signatures in experimental data, derived from the models. Reciprocally, experimental observations and dependencies will guide the definition of the most appropriate system of equations.

Constraints and risks

GREMI is a ZRR ("Zone à Régime Restrictif") laboratory, and in accordance with regulations, recruitment will only be effective after agreement from the "Haut Fonctionnaire de Défense et de Sécurité".

Profile required

This highly interdisciplinary subject requires a candidate with good adaptability skills, attracted both by experimental low-temperature plasma physics and by a more theoretical approach involving mathematical analysis of systems of differential equations.

The candidate could be a low-temperature plasma discharge experimenter who also wishes to get involved in the manipulation of complex equations, or an applied mathematician who wishes to get involved in experimental physics.

To successfully complete this project, the candidate will also need to be curious, independent and able to write in French and/or English. The interdisciplinary nature of the subject also requires strong motivation, organizational skills and a good ability to synthesize information.