PHD THESIS PROPOSAL

Advanced models for plasma-wall and plasma-neutrals interaction in a turbulent environment

Context

Carbon-free power production using magnetic confinement fusion is an ambitious scientific and technological endeavor requiring a sustained research effort. Among the challenges on the path to fusion reactors, the management of heat exhaust is one of the most critical ones. The strategy to manage the extreme heat fluxes to the reactor wall relies on the dissipation of the plasma's energy through interaction with the neutral gas present in the edge of the plasma due to plasma-surface interaction. The physics at play consists in a balance between plasma transport, dominated by turbulence, and atomic and molecular reactions related to plasma-neutrals collisions. The modelling of this extremely non-linear phenomenology is mandatory for the design and operational space definition of future devices like ITER. However, owing to the difficulty of the task, the modelling effort has until now essentially been separated along 2 separate axes. On the one hand, edge plasma turbulence codes have addressed the modelling of turbulent transport without considering the presence of neutral particles; on the other hand, edge plasma mean-field codes have focused on the modelling of plasma-neutrals interactions but with a heuristic and oversimplified description of turbulence transport based on a diffusive approach. Progress in understanding and predictive capabilities of the phenomenology at play in the heat exhaust of magnetic fusion devices is now largely dependent on the consistent integration of both aspects in the same numerical tool.

The proposed PhD thesis is part of a project funded by the French National Research Agency aiming to achieve this critical step and to develop and exploit for the first time a code able to describe self-consistently edge plasma turbulence and neutrals dynamics and their interaction with the plasma. In order to achieve this, the project brings together complementary expertise from different laboratories belonging to two related scientific communities: the fusion plasma community (IRFM/CEA Cadarache) and the low-temperature plasma community working on applications such as Hall thrusters which are also governed by plasma-neutrals interactions and turbulence (LAPLACE Toulouse).

Objectives and work description

The objective of the PhD thesis is to improve several key aspects of the current models by combining the modeling methods and knowledge existing in these two communities. The thesis will thus be co-supervised by researchers from the LAPLACE and IRFM laboratories. Two distinct topics will be addressed:

(1) Improvement of plasma turbulence models in the presence of strong plasma-neutral coupling. Turbulence fluctuations add small length- and time-scales which will make the system more sensitive to some of the assumptions used in current algorithms. The physics of turbulence is also strongly dependent on drift-velocities whose derivation relies on orderings which become questionable in high coupling regimes when plasma-neutrals interactions become dominant. LAPLACE has developed in the last decade an expertise in the modelling of partially magnetized/ionized low temperature plasmas, which could be transposed to edge plasma models in high recycling or detached divertor regimes. The PhD candidate will confront the approaches used in both communities to in order to assess their validity/limitations and eventually propose a model with a wider range of validity in terms of plasma-neutral coupling strength.

(2) Plasma-wall interaction and the correct description of the properties of the sheath that forms in front of surfaces is of crucial importance. It is the link between plasma conditions at the magnetic pre-sheath entrance (used as boundary conditions for fluid models) and the distribution function of ions in angle and energy at the wall. Experimental evidence from tile topography in Tore Supra (the Tokamak in CEA Cadarache) showed that a guiding center approximation misses important features of this distribution.

It turns out that finite ion Larmor radius effects must be taken into consideration for the calculation of the ion incidence angle while impacting the divertor surface (the magnetic field lines are at grazing incidence). This affects consequently the reemission angle of neutrals off the wall and has implications on the plasma-neutral interaction and hence on the overall properties of detached plasmas. Particle drifts will be assessed in detail and in particular the changes induced by a reversal of the magnetic field direction. This task will be both of theoretical and numerical nature. The candidate will use and modify a 1D/2D-3V parallelized explicit Particle-In-Cell algorithm developed in house (written in Fortan 90).

General information

Candidate profile: MSc degree or equivalent in Physics, Fluid Dynamics or a related field, knowledge of Plasma Physics being a strong plus, strong affinity with theory and simulation.
Duration and starting date: 36 months, starting preferably on 1 October 2022 but possibly (somewhat) later.
Location: The candidate will be mainly based at the LAPLACE laboratory at the University of Toulouse but will spend about 1/3 of the time at the IRFM/CEA in Cadarache, ideally the second year of the PhD; details to be arranged.
How to apply: Please send (by e-mail) a motivation letter, Curriculum Vitae (CV), list of grades, and references or recommendation letters from supervisor(s), to the contacts below.
Contacts: G. Fubiani (fubiani@laplace.univ-tlse.fr), G. Hagelaar (hagelaar@laplace.univ-tlse.fr), P. Tamain (patrick.tamain@cea.fr)