Phd. projects 2023

Tungsten Collisional-Radiative Models in support of impurity-influx measurements : Drs Connor Ballance and Catherine Ramsbottom

Material choice for the plasma facing components in fusion experiments is determined by competing desirables: on the one hand the material should have a high thermal conductivity, high threshold for melting and sputtering, and low erosion rate under plasma contact, and on the other hand as a plasma impurity it should not cause excessive radiative energy loss. For the ITER tokamak, currently under construction at Cadarache, France, Tungsten (symbol W, atomic number 74) is the favoured material for the wall regions of highest particle and heat load in a fusion reactor vessel, with beryllium for regions of lower heat and particle load. ITER is to start operation with a W-Be or W wall for the main D-D and D-T experimental programme. In support of ITER and looking ahead to the prospect of a fusion reactor, other experimental plasma groups are also considering tungsten, including the ASDEX-Upgrade tokamak which now operates with an all-W wall and at JET (Joint European Torus) facility in Oxford. Smaller-scale experiments involving tungsten tiles are carried out on other tokamaks. Researchers from the ARC group have an ongoing relationship with magnetically-confined experimental groups at JET and both Auburn University and D-III-D, General Atomics in the US. *One of the major questions that these experimental groups are addressing is the determination the impurity influx from plasma facing components under ITER conditions.*

Atomic processes are central to energy transfer in magnetically confined plasmas. The energy balance in fusion devices such as tokamaks depends critically on how the plasma interacts with the walls of the vessel, demanding accurate cross sections and associated rates for a wide variety of collisional processes. At QUB, we develope both the theoretical methods and computer codes to provide accurate predictions of the atomic structure, electron-impact excitation/ionisation and recombination rates that underpin the intepretation of these observations.
These rates will enable us to understand and mitigate the causes of critical radiation losses that in minuscule concentrations prevent ignition. For modelling the behaviour of tungsten in a plasma a comprehensive understanding of most collisional processes is required for many ion stages. Beyond the first few charge states of Tungsten, open 4d and 4f shell configurations require complicated atomic structure calculations, and equally demanding electron-impact collisional calculations.

Plan of work

The project shall proceed as follows. There shall be a review of the underlying electron-impact driven collisional processes as well as collisional-radiative theory. The student will familiarize themselves with the numerical procedures required to provide rates, as well as solving the rate equations for a variety of distributions, starting initially with the Maxwellian. If any of the collisional processes are missing from the rate equations, we shall calculate them.
A large aspect of the project, shall be the interaction with experimental groups that carry out impurity measurements. Therefore, if they determine that a particular spectral line is important, we shall tailor our theoretical calculations to optimise the atomic structure and collisional calculations for that line.

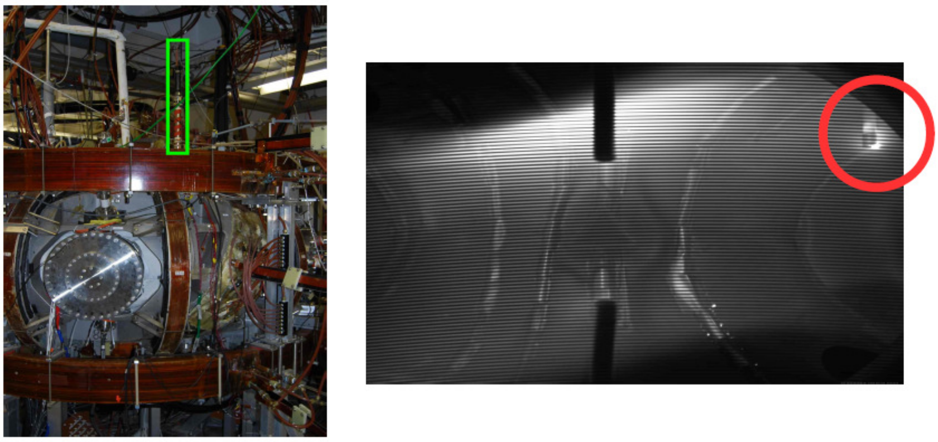

Figure 1. Compact Toroidal Hybrid Experiment at Auburn University. The device is approximately 10 feet high, with various diagnostic ports across the circumference. On the top left-side of the figure, the infra-red diagnostic port is highlighted by the green rectangle. The right picture illustrates a small block of Tungsten introduced into the plasma, radiating under normal operating conditions.

Background

It would be beneficial if the prospective student has had an entry-level quantum mechanical course. There is the intent that the student would develope , with guidance, their own collisional-radiative model. Therefore, some basic understanding of numerical methods with either Matlab, C++ , Fortran or their more modern equivalents would be desirable. However, more important is an interest in the topic as these skill-sets can be acquired during the project.

Aims and objectives of the project

- To provide the student with a complete survey of the collisional processess involved with plasma collisional-radiative modelling. To take first principle atomic calculations through to a valuable application.
- There is a strong computational aspect, therefore an interest in computational modelling, and in particular utilizing powerful parallel supercomputers is required.
- There will be a strong collaboration between experimental groups in the US and researchers at Queens. Identifying strong spectral lines obsevered from various experimental devices under particular temperature and density conditions shall be an integral part of the project. However, theoreticallly, collisional radiative modelling should allow us to be more proactive in suggesting diagnostic lines for the experimental groups to observe.
- The Phd student shall have to respond to experimental requests at quite short timeframes, due to the cyclical nature of experimental measurements on large scale devices.
- To acquire good programming and numerical skills valuable for graduate level work, which are also marketable skills within the workplace.

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