Energy transport investigation in spherical tokamak by means of integrated modelling and gyrokinetic theory

The achievement of the production and exploitation of fusion energy via magnetic confinement is strongly related to our capacity to predict the evolution of macroscopic plasma profiles on long time scales comparable with the energy confinement time.
Integrated modelling represents a very powerful instrument to predict the plasma evolution in tokamak physics. An important example of integrated modelling tool is represented by JINTRAC that, with its different modules such as JETTO, TGLF, EDGE2D and so on, is particular suitable to analyse the physics at the basis of the investigated scenarios including principal instabilities due to ion temperature gradient (ITG), electron temperature gradient (ETG), trapped electron mode (TEM) and zonal flow mixing saturation processable to reproduce the nonlinear spectrum of the multiscale saturated potential.

However, the models at the basis of this tool can be improved in order to include more sophisticated physical ingredients. This is particularly important and suitable for the new spherical tokamak machines such as MAST-U that operate at high beta values, aspect ratio R/r close to 1, and so on. The improvement of the models for device such as MAST-U is extremely important in the perspective of ITER and of new projects such as STEP. It can be done by observing that the macroscopic evolution of the profiles is the result of the nonlinear evolution of multi-scale process. A multi scale plasma treatment that keeps essential kinetic effects until the cyclotron scales is obtained by means of the gyrokinetic theory.

This PhD project would like to combine the efficacy of both gyrokinetic theory and integrated modelling to investigate the properties and the dynamics of multiscale process in order to improve the prediction of the plasma scenario in the MAST/-U machines.
To this purpose, an important element in burning plasmas that will be investigated is represented by energetic particles (EPs). In fact, their physics involves an interplay between micro-scale instabilities and macro-scales plasma profiles which take place on intermediate spatio-temporal scales.

In particular, the EPs heating efficiency can be reduced by the interaction with the Alfvén eigenmodes (AEs) that can conduct to a flattening of the alpha spatial profile leading to a loss of particles.
Although, to the present, a qualitative understanding of EP physics has been established concerning the transport, there is not a full quantitative agreement between theory and experiments.
Good results have been obtained from machines such as JET and machines that work at low beta values.
For this reason, in this project we would like to start the investigation of interaction EP/Alfven eigenmodes from few selected shots performed on the JET machine on which there is already a good consolidate study of the problem. The idea is to move successively towards, less explored higher beta values, to study the problem in the MAST/-U configuration.

We would like to use for the gyrokinetic part, the ORB5 code originally developed for electrostatic ITG turbulence studies, and recently extended to its multi-species electromagnetic version in the framework of the NEMORB project. Concerning the work with integrated modelling we plan to use JINTRAC tool with its implemented modules.
The ORB5 nonlinear model with its lagrangian formulation allows us to investigate in a rigorous manner, turbulence in the presence of global modes and energetic particles, where all nonlinearities are treated on the same level.

A first theoretical and numerical study of Alfvén eigenmode branches (BAE, TAE, RSAE, EAE) will be done in linear regime, by taking into account different effects related to the triangularity, elongation and so on. Afterward, by starting from few selected experimental shots of MAST/-U, we will perform nonlinear simulations in order to explore energetic transfer processes between coherent modes and turbulence, addressing in particular the modification of energetic particle transport by Alfven eigenmodes. In this framework the self-consistent interaction with Zonal flow structures will be investigated.
In this way we aim to improve our understanding of turbulent transport in order to translate this in an improvement of coefficient values of ion and electron heat conductivity χ_i, χ_e.

The improvement of the transport model can be done by following different ways.
For example, by using the configuration of specific shots, the heating flux Q_i, Q_e for ions and electrons can be deduced from the turbulent transport observed in nonlinear gyrokinetic simulations. Then, the flux can be compared with that one obtained, for the same cases, by means of the JINTRAC simulations.
Any differences between the two approaches can further be studied by comparing the respective profiles of temperature, density and so on.

Moreover, where necessary, we will develop, specific diagnostics for the investigation of the mode coupling and on the energy transfer between wave-wave and wave-particles interactions in order to study the physical process at the basis of the transport. Further simulations with integrated models modified with new ingredients that will emerge from the work will be also done and compared with TGLF and shots. In this way we point to increase our capability to predict plasma scenario in MAST/-U experiments.

The PhD student will be based at the CCFE in Culham. The researcher will have the opportunity to work in an exciting international environment. In particular, a strong collaboration with the plasma group of the Warwick University will take place. Thus, the student will have the possibility to spend a period in this University within to the development of the project. An international partnership is also foreseen with the group of integrated modelling of the Max Planck Institute in Garching. The student will acquire experience in fundamental plasma physics focusing in particular on problems related to the turbulence in tokamak and integrated modelling description, by developing at the same time skills in the high-performance computational field.