PhD in gyrokinetic turbulence driven by multi-scale instabilities

COVENTRY UNIVERSITY (UK)

Applications are invited to apply for a PhD studentship in numerical plasma physics, relevant to the problem of controlled fusion, at the Applied Mathematics Research Centre, Coventry University. The detailed project description is given below. The candidate is expected to spend time at the Culham Centre for Fusion Energy (CCFE) as a way to familiarize oneself with the problem of magnetically confined plasma and will receive support from CCFE in this regard. The project will also involve collaborations with CCFE researchers (notably Dr. Colin M. Roach) and other gyrokinetic research groups form UCLA (USA) and IPP (Germany).

The proposed project will involve learning about gyrokinetics and how to use numerical tools needed to analyze the energetic coupling of scales in gyrokinetic turbulence driven by multi-scale instabilities. It will also consist in the development of appropriate models (Large Eddies Simulations or Shell Models), together with their validation with experiments and direct numerical simulations. The goal of the models is to capture multi-scale physics reliably and enable multi-scale simulations to be more routinely available to the fusion community.

Successful candidates are expected to hold an MSc or equivalent in plasma physics, fluid mechanics or a related discipline (Physics/ Engineering/ Mathematics) and have a pronounced taste for numerical methods. The student will receive a tax-free bursary in excess of £13.5k per annum (approx. £17k Euros). Please note that this position is available to EU citizens only.

To apply, please forward a CV and academic records to Dr. Bogdan Teaca (Coventry University, bogdan.teaca@coventry.ac.uk). Informal enquiries are welcome. The position will be open until a suitable candidate is found.

The energetic coupling of scales in gyrokinetic turbulence driven by multi-scale instabilities

Turbulence overview

In many physical systems, nonlinear interactions give rise to couplings between different dynamical scales and can lead to the development of turbulent states. In the case of hydrodynamic flows, the velocity field represents the dynamical quantity of interest and the couplings occur between different scales of motion. For this relatively simple system, analyzing the redistribution of energy due to the nonlinear interactions provides a way to characterize the turbulent state, which allows for simpler models to be build that in turn can be used in applications related to anomalous transport (turbulence related) of heat and mass.

This situation is present, as well, for magnetized fusion plasmas described kinetically using the gyrokinetic (GK) approximation. The GK formalism, valid for a plasma evolving under the influence of a strong magnetic guide field (the toroidal bottle that keeps the plasma confined) and which obeys the gyrokinetic ordering, represents a self-consistent method of removing the fast gyration phase from the motion of charged particles and decreasing the distribution function phase space from six to five dimensions. For multi-species plasmas, the probability distribution function for each species represent the dynamical quantities of interest and the redistribution of free energy will now help characterize the nonlinear interactions and thus, the turbulent state in gyrokinetics.

Three-dimensional hydrodynamic turbulence can be assimilated with the idea of kinetic energy moving from large scales to small scales of motion, in a process known as an energy cascade, where it will be converted into heat. For GK turbulence, the energy redistribution is not as straightforward and a few complications exist that need to be considered. One is related to the existence of the self-consistent electromagnetic fields generated by the motions of the charged particles. Another is related to the geometry induces by the magnetic guide field, which will shape the scale structures that will develop in the system. A third aspect is given by the intrinsic five dimensional natures of the gyrokinetic problems, which complicates the exchange of energy from large spatial scales to smaller one. Last but not least, different instabilities, i.e. sources of turbulence, introduce different particularities in the way turbulence behaves.

Multi-scale gyrokinetics

In the last years, gyrokinetic turbulence was analyzed via analytical, phenomenological and numerical approaches. While a lot has been learned, a few new questions appeared. Notably, it is known that in realistic conditions relevant in a tokamak, multiple instabilities coexist, acting at different scales and competing for dominance. Looking at the energy cascade, scale fluxes and the fundamental properties of gyrokinetic turbulence for multi-scale instabilities represents a main part of the proposed project.

The energy redistribution is typically analyzed numerically using one instability type at a time. This is due to the computational resources available. Multi-scale runs are expensive and as a consequence they end up being rare. Moreover, even on the largest supercomputers available, multi-scale runs cannot fully capture the entire physical range of scales of interest. Thus, making multi-scale gyrokinetic simulations to be more routinely available and capture multi-scale physics reliably represents the other part of the project. This can be achieved through modeling.

Modeling the energy cascade for gyrokinetics

For turbulent systems two classes of numerical models offer a way to deal with the energy redistribution between scales. The first class is given by the Large Eddy Simulation (LES) method, which simulates numerically only the large scales and model the impact made by the small scales. They are based on properly accounting for the scale energy flux that passes through the last numerically known scale surface. The second class is related to Shell Models, which account for the near-neighbor interaction between all scale structures, without taking into account the explicit modes that contribute to any given scale (drastically decreasing the degrees of freedom). Shell Models use the observed local nature of the energy transfers and are based on the ideas of locality of interactions in determining the correct couplings.

For gyrokinetics, LES models in the orthogonal directions of the magnetic field have been developed only recently. They are used primarily to resolve the small-scale energy accumulation and help determine the correct values for the transport. They are still to be fully utilized and further refinement of the models is desired, namely, accounting for the interaction along the magnetic field directions. While by design LES methods are not adequate for the study of multi-scale phenomena (they remove the small scales), using LES for the electrons would allow electron small scales to be well resolved, which will affect the resulting electron transport levels. As numeric simulations are expensive, electron small scales are poorly accounted for in multi-scale simulations, while the question of the correct electron transport represent one of the major points of interest. Form this aspect, an LES analysis of multi-scale GK turbulence will provide a cheaper alternative to huge simulations and provide interesting answers.

The use of Shell Models in plasma has been so far limited to fluid descriptions. Developing a GK Shell Model will allow a huge range of scales to be simulated at the same time for kinetic like ions and electrons, beyond the possibility of current direct numerical simulations. Shell Models offer a way to investigate the scaling of GK free energy for externally prescribe parameters and, due to their relative reduced computational cost, would be the perfect candidate for a parameter space scan. If using only one instability at a time would provide insight into 'pure' states of GK turbulence, performing a parameter scan for multi-scale turbulence would answer the question of which of the 'pure' turbulent states tend to dominate for different parameters regimes.

Regardless of the modeling techniques used, selected results would have to be investigated by direct numeric simulations of gyrokinetic turbulence, to build confidence in the predictions of the models. Using numerical diagnostics for quantities that can be recovered from experiments is also an important aspect that should not be neglected.