S.L / 2018

Coordination de la Formation par la Recherche

Sujet de Thèse CEA
"SUJET-LABO 2018"

Référence du dossier :

Pôle : DRF ***N° :*** SL-DRF-18-0570

1 - Laboratoire d'accueil au CEA

Centre :**Cadarache**

Département/Service :**IRFM / Service Chauffage et Confinement du Plasma**

Nom du laboratoire :**TTM/Transport Turbulence et MagnétohydroDynamique**

2 - Titre du sujet de thèse

Interaction bord-cœur: contrôle de la turbulence par le champ électrique dans les plasmas de tokamaks

3 - Thématique de Recherche

Physique corpusculaire et cosmos / Physique des plasmas et interactions laser-

4 - Pièce jointe

Y a t-il une pièce jointe associée ? **Non**

Intitulé de la pièce jointe :

5 - Résumé

Comprendre la turbulence et sa dynamique reste un des grands problèmes ouverts en physique. Dans les plasmas de fusion par confinement magnétique, la turbulence contrôle le confinement du plasma, et in fine ses performances. De manière quasi unique, l'auto-organisation multi-échelles dont elle est le siège peut conduire à des bifurcations spontanées vers des régimes à confinement amélioré, caractérisés par le développement de barrières de transport. Un des grands succès de la théorie est d'avoir identifié le champ électrique radial comme un des acteurs majeurs de ce processus.

Les observations expérimentales et notre compréhension théorique montrent que la périphérie du plasma confiné participe de façon décisive à la génération d'un tel champ, et de fait au contrôle de la turbulence. L'objectif de la thèse consiste à élucider son rôle dans cette dynamique, au travers notamment de simulations non-linéaires avec le code gyrocinétique GYSELA. La force du projet réside dans l'originalité de GYSELA, un des rares codes de par le monde capables d'étudier cette interaction cruciale bord-cœur du point de vue cinétique, et l'expertise de l'équipe encadrante, reconnue internationalement et active dans plusieurs projets Européens sur le sujet.

6 - Exposé du sujet

In magnetized controlled fusion plasmas encountered in tokamaks, energy and particle confinement is mainly governed by small-scale turbulence, which develops at scales of the order of a few ion Larmor radii. There, turbulence taps energy from the inhomogeneity of the magnetic field, and from the departure from thermodynamical equilibrium, in particular density and temperature gradients. One of the major theoretical breakthroughs regarding our understanding of this nonlinear regime has been to realize that turbulence was sensitive to the low-frequency radial – i.e. the direction of the confinement – electric field Er. Indeed, Er governs the mean rotation of turbulent convective cells on each magnetic flux surface. Any sheared radial electric field then translates into differential rotation of turbulent eddies. It appears that large enough shearing rates can efficiently tear apart convective cells and subsequently reduce turbulence correlation length. This regime of reduced turbulent transport is highly beneficial since characterized by an improved energy and/or particle confinement. However, controlling the radial electric field is far from obvious in tokamaks. Actually, many different mechanisms contribute to its build up and to its dynamics. The radial balance between Lorentz and pressure forces is the first of those. Also, turbulence itself can generate such a large scale electric field, called Zonal Flows, in a process similar to the one at work in Jupiter's atmosphere and leading to the famous latitudinal bands.

The main focus of this PhD thesis is to explore the kinetic properties of turbulence and transport in the vicinity of the edge region of tokamak plasmas, which is known to be particularly prone to such large magnitude and strongly sheared radial electric field. As a matter of fact, and not surprisingly, this region is the locus of the spontaneous bifurcation reported experimentally in most tokamaks, where a transport barrier develops steep temperature and/or density profiles as a result of turbulence suppression.

Because of their low density and high temperature, fusion plasmas are weakly collisional, so that gyrokinetic is the adequate framework to address core turbulence. It consists in the phase space reduction of the Vlasov-Poisson set of equations from 6-dimensions to 4+1-dimensions by removing the fast time scale dynamics. Pushing this description towards the edge of the plasma is extremely challenging, both from the physical and numerical points of view. Indeed, equilibrium quantities such as density, temperature, collisionality and safety factor (which measures the mean helicity of magnetic field lines) exhibit strong gradients when approaching the plasma edge. These large variations call for increased numerical resources, both in terms of memory and therefore of CPU time. Besides, the gyrokinetic theoretical framework itself may become questionable – the gyrokinetic ordering may break down – in extreme conditions such as those encountered at the very edge, especially when fluctuations over mean become of order one and when equilibrium gradient lengths shrink to the size of turbulent cells.

Yet, the edge region is key, standing at the confluence of core and edge turbulences. The central challenge is now to provide a unified view of turbulence properties when multiple scales and disparate regions of the plasma are self-consistently modelled. A single gyrokinetic code has already addressed this issue in the world (cf e.g. [Chang et al., PRL (2017)]). Open questions are still debated, calling for complementary investigations. The present PhD proposal addresses groundbreaking issues when edge and core plasma interplay, especially regarding turbulence self-organization and regulation via large scale flows. It builds upon the long standing effort of our team to develop the unique gyrokinetic code GYSELA, which is now mature enough and contains the necessary ingredients to address this problem as a whole.

The uttermost importance of the subject regarding fusion performance calls for several approaches. In this framework, refined experimental measurements of turbulence properties and 3-dimensional fluid approaches accounting for the complex topology of the edge magnetic equilibrium constitute active research fields. This PhD proposal focuses, yet not exclusively, on two main aspects which are potentially critical in the generation of the edge radial electric field, and which require a dedicated kinetic treatment:
1) The trajectories of plasma ions are not tied to magnetic flux surfaces, even in the absence of turbulence or collisions. They are characterized by finite Larmor and orbit widths, which can exceed the Larmor radius by more than one order of magnitude at the edge. Such ions may then quit the confined plasma region and get lost, hence polarizing the edge plasma [Heikkinen et al., PRL (2000)]. The resulting radial electric field will then back react on both ion trajectories and turbulence. The aim here is to account for this polarization effect in gyrokinetic simulations, and to study its impact on edge and core confinement.
2) Large scale plasma flows are efficiently regulated by the collisional friction exerted by trapped – in the local wells of the magnetic field – particles on passing ones. Consequently, neoclassical theory predicts a weak plasma rotation. The important property here is that this rotation is expected to scale like the ion temperature gradient. It readily appears that the edge region can act as an amplifier of the flow shear. Actually, recent nonlinear simulations in the fluid framework using a fluid approximation of neoclassical theory have reported that this large gradient could play a critical role in triggering a transport barrier [Chôné et al., PoP (2014)], possibly mimicking the experimental spontaneous transition from Low to High confinement regimes. Quantifying the role of neoclassical friction on the strength of the edge radial electric field by means of state-of-the-art gyrokinetic simulations is the second target of this work. Exploring possible routes towards spontaneous turbulence bifurcations is the main goal.

This work will require nonlinear numerical simulations with the 5D gyrokinetic code GYSELA, developed at IRFM in collaboration with national and European labs. This code is among the few in the world capable of describing both turbulent and collisional transport on an equal footing. It is flux-driven, in the sense that gradients adjust self-consistently to prescribed sources. Since recently, it also includes a simplified modelling of the outer edge region. Its global character, without any scale separation assumption between equilibrium and fluctuations, allows it to capture possible nonlocal effects due to large scale flows interacting with turbulence and edge-core interplay. More than one hundred million CPU hours are allocated to the GYSELA team on national and European supercomputers.

The student will join the GYSELA team, made of 8 permanent researchers at CEA-IRFM and Aix-Marseille University (AMU), and several PhD students and post-docs. Weekly meetings are organized by the team, which also contributes to other research groups in the lab. Importantly, all team members are actively involved in several European projects. The PhD thesis is actually part of a recently submitted "SOLeCORE" 3-year PRACE project, of the "PEACE" (Physics Effort at Analyzing Core-Edge transport) EUROfusion project submitted for 2019-2020, and of the "EoCoE-2" (Energy oriented Center of Excellence) H2020 proposal for 2019-2021. Last, the PhD student will participate to the "Festival de Théorie", a 4 weeks meeting organized by the team every even year in the summer in Aix-en-Provence, gathering experts from Fusion and Earth and Solar physics.

7 - Collaborations (éventuelles) prévues

Laboratoire :

Organisme : **AMU / LPIIM**

Responsable : **BEYER Peter**

Raison de la collaboration :

Peter Beyer est un expert en simulations non-linéaires et en turbulence des plasmas de fusion. Notre collaboration est ancienne. Nous avons récemment mis en évidence, à l'aide d'un modèle réduit, le rôle critique de la collisionalité et de son fort gradient à la périphérie du plasma dans l'apparition d'une barrière de transport. Ces résultats seront confrontés à ceux du modèle gyrocinétique utilisé pendant la thèse.

Duree : **36**

Laboratoire :

Organisme : **AMU / LPIIM**

Responsable : **ZARZOSO David**

Raison de la collaboration :

David Zarzoso est un expert en simulations gyrocinétiques, notamment avec le code GYSELA au développement duquel il participe activement. Ancien thésard de l'équipe, il s'attache entre autres actuellement à caractériser les trajectoires des ions avec GYSELA. Les outils qu'il a développés seront d'une grande utilité pour estimer les pertes ioniques à la périphérie du plasma.

Duree : **36**

8 - Partenariat(s) industriels prévu(s) (éventuellement)

9 - Correspondant chargé du suivi de la thèse au CEA

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Habilitation à diriger des recherches : **Oui**

Organisme de rattachement : **CEA**

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10 - Directeur de thèse

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Habilitation à diriger des recherches : **Oui**

Organisme de rattachement : **Aix-Marseille Université**

Combien de thèses avez-vous déjà encadrées **7**

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