University of Craiova – Project in FP7- EURATOM-FUSION

Title of the project: **ANOMALOUS TRANSPORT IN PLASMA**
Support documents: EFDA Task Agreement,
Code: WP08-09-TGS-01b-06 [BS-3]

Research group: Prof. Dr. Steinbrecher Gyorgy, Conf. Dr. Constantinescu Dana, Lect. Dr. Pometescu Nicolae, Lect. Dr. Negrea Marian, Lect dr. Petrisor Iulian

Responsable of the project: Lect. Dr. Pometescu Nicolae

1. SCOPE OF THE PROJECT

To gain inside the anomalous transport of energy and particles in fusion turbulent plasma is a great chalenge and an important step for the impruvement of the plasma confining in fusion devices. The scope of the project is to explaine some features of the anomalous transport and develop analitycal and numerical skils to evaluate correctly the transport in fusion device like ITER. Also the project aim to deep insight the physics of plasma turbulence.

Some of the interesting features analysed are long-range correlations, intermittency in plasma edge turbulence, edge transport barriers, core impurity transport with different dominant core turbulence and different radio-frequency heating scheme. For that are used both analytical and numerical methods. Previously developed Stochastic models will be adapted to the study long-range correlations, self-similarity and intermittency. Gyrokinetic semi-Lagrangean codes with collision term will be adapted to the study of the particle transport in tokamak.

Some characteristics of the anomalous transport of magnetic field lines and charged particles, features that cannot be described in the context of the standard diffusion paradigm, will be explained using the memory effects. The long memory effects will be studied using fractional models and limited (short) memory effects will be studied using delay systems or hysteresis systems.

The results obtained in this project will be aplied to existing large plasma devices but are oriented specially to be aplied to plasma in ITER device.

2. STAGE OF PROJECT

A good experience acquired in solving stochastic differential equation will be used to model long-range correlations and multi-scale physics processes in edge plasma turbulence. The mathematical aspects of including collision terms in gyrokinetic semi-Lagrangean codes were outlined in last two years. These will be used to the adaptation of the existing codes to the study of the impurity transport.

Partial results was previously obtained by the study of the particle transport in stochastic fields which will be used to obtain new numerical results on impurity transport with improved codes.

The random multiplicative processes in fusion plasma was analysed and this will continue with the study of particle's transport driven by instabilities triggered by noise. The previous results on these random processes will be used to obtain new results on the characterization of the intermittent events and particle transport on the plasma boundary.

One of our objective was the transport of magnetic stochastic field lines in the anisotropic or isotropic, with or without magnetic shear. In this sense it were calculated the diffusion coefficients for the magnetic field lines using the decorrelation trajectory method (DCT) and the results were compared with those obtained by the stochastic Liouville equation. This comparison shown the agreement of the results and in consequence the validity of the DCT method even for non-homogeneous systems of Langevin equations. The research was continued applying the DCT method to others models such as the study of the electron diffusion in a stochastic electrostatic field combined with an unperturbed sheared magnetic field. In the same study we have compared the results obtained by DCT with those obtained by the numerical simulation and the comparison shown again the agreement of the DCT methos with the numerical simulations. We have used also the DCT method to the calculus of the diffusion coefficients in the case of the generation of zonal flow in the drift wave turbulence and to the calculus of some important characteristic quantities specific to zonal flow. We have also started the study of the influence of the magnetic stochastic drift on the diffusion of ions in guiding centre approximation. For the above mentioned studies we have developed specific codes, which can be adapted for the study of new models, such as the creation and the charactersitics of the filamentary structures. The study of test particles and heat transport in different models in fusion plasma will be a continutation of the project. We have analyzed until now some deterministic and stochastic aspects related to kinetic master equations of fractional order governing the generalized diffusion processes.

For the transport of energy and particles of ions in turbulent plasmas with radio frequency heating was evaluated the radial fluxes in axisymmetric toroidal magnetic field in the frame of kinetic theory.

The Hamiltonian description and the mapping techniques were used to describe the magnetic field and the dynamics of particle's guiding centre. Some features of the anomalous transport of particles were explained by the trapping effect in chaotic (stochastic) configurations and the magnetic reconnection was related with the stochastization of the magnetic field. In the mathematical models that were used for these studies the memory effects were not considered. Many studies indicate that these effects can be important; hence we will take them into account in the next step of our research.

Some phenomena for which the memory effects were already pointed out (formation and maintenance of the internal transport barriers, the L/H transition, the sawtooth crash in the ASDEX-Upgrade tokamak) were identified and a collection of mathematical models that can be used for explaining the anomalous transport was gathered.

A particular model, based on the hysteresis mechanism, for the study of the sawtooth crash of the central temperature in ASDEX-Upgrade tokamak was proposed and analysed.

3. OBJECTIVES in 2009

1. Characterization of the intermittent events, long range correlations and particle transport on the plasma boundary. (Prof.dr. Steinbrecher Gyorgy)

2. Influence of the collisions in the gyrokinetic simulations on the impurity transport. (Prof.dr. Steinbrecher Gyorgy)

3. Impurity transport driven by instabilities in plasma with radio-frequency heating. (Lect. Dr. Pometescu Nicolae)

4. Numerical simulation of test particle transport and comparison with theoretical models. (Lect. Dr. Petrisor Iulian)

5. The construction of a fractional diffusion equation in velocity and position space. (Lect dr. Negrea Marian)

6. Studies of transport and of saw-tooth crash phenomena based on mapping models. (Conf. dr. Constantinescu Dana)

4. WORK PROGRAM in 2009

1. Characterization of the intermittent events, long range correlations and particle transport on the plasma boundary.

We will develop class of low dimensional reduced models of the on-off intermittency in bifurcating systems, perturbed by stochastic perturbations. Our class of models include a stochastic version of the deterministic reduced models of ELM accepted in literature. Our series of models will be connected with the previous results on the modelling of the stochastic instability in the dynamical system below instability threshold and subjected to the influence of random noises. We will study the steady state probability density function of the intermittent events, as well as to the study of the dynamics of the approaching the steady state distribution. Will be investigated the effects of the long-range correlations in the driving noise on the intermittency on the particle transport by new mathemathical methods, adapted from the theory of the Anderson localization.

2. Studies of core impurity transport in tokamak plasmas with different dominant core turbulence.

- Influence of the collisions in the gyrokinetic simulations on the impurity transport.

This subject is connected with previous collaboration with DRFC-Cadarache, related to the inclusion in the gyrokinetic code GYSELA the Landau collision term. The subject is imposed by the difficulties to perform large scale, first principle numerical simulations with the existent gyrokinetic codes, as well as to discriminate the effects of statistical noise in the particle simulations of the gyrokinetic equations. Will be extended the semi-Lagrangean method, used in the GYSELA code at DRFC-CEA-Cadarache (V. Grandgirard et all, Communications in Nonlinear Science and Numerical Simulations, 13, (2008) 81-87; Journal of Computational Physics, 217, (2006), 395-423. The simulations will be performed on the low dimensional versions of the gyrokinetic code GYSELA with full Landau term as well as its linear approximation. Will be tested the effect of the linear approximation of the collision term on the particle transport. The research will be performed in collaboration with CEA-Cadarache, DRFC/GTTM. The numerical calculations will use the facilities from CEA-Cadarache.

3. Impurity transport driven by instabilities in plasma with radio-frequency heating.

The experiments have lights that auxiliary heating can influence impurity accumulation and transport and by consequences, the plasma confining regime.

3a Analitical expression for power density deposition profile of ICRH.

From numerical simulation and experimental data we construct analytical approximation for power density deposition profile in the case of second harmonic of ICRH absorption by Tritium in tokamak fusion device like ITER. This will be used to analyze the influence of ICRH on the transport of Tritium driven by ITG/ITM instabilities in plasma.

3b Study of variation of the density profile of impurities for different species

Influence of the ICRH on the density profile of Tritium and alpha-particles will be study in the case of transport driven by ITG/ITM instabilities. We aim to improve the prediction of the convection direction of impurities and their accumulation.

4. Numerical simulation of test particle transport and comparison with theoretical models

We will determine the mean square displacement and diffusivities as functions of different plasma parameters in electromagnetic stochastic field. The results obtained using this method will be compared with the results yielded by the decorrelation trajectory method (DCT method) for the same environments and we will determine its range of applicability. In particular, the study of the behaviour of impurities (general transport behaviour, effects of trapping and impurity accumulation).

5. The construction of a fractional diffusion equation in velocity and position space

We will start our study from the already developed Continuous Time Random Walk equations. In a continuous time random walk model, combined in position and velocity space, we will determine the fluid limit of the equations, derive a fractional diffusion equation for the model and analyse this equation. We will use this equation for the calculation of the particle and heat diffusivities or pinch velocities specific to the characterization of the transport processes.

6. Studies of transport and of saw-tooth crash phenomena based on mapping models

6a The study of the saw-tooth crash phenomena using mapping models

An approach based on a mapping technique will be proposed in order to reconstruct the evolution of the stochastic magnetic field during the crash stage of the sawtooth instability. This method, combined with the constraints on the magnetic fluxes provided by the theories of the sawtooth instability, will be able to generate poloidal cross sections of the magnetic field topology during the crash phase of the instability that have behavior similar to the experimental ones.

The configuration of the magnetic field during the sawtooth crash will be also studied using a model that involves the energy source, the magnetic field disturbance and the pressure gradient. The study of the sawtooth crash of the central temperature in ASDEX-Upgrade tokamak using some models that involves memory effects of hysteresis type will be continued.

6b The study of the test particles' dynamics using mapping models

In the frame of mapping techniques we will start the study from the equations of the guiding centre motion in Hamiltonian form and then we will derive a mapping model for the particles. We will transform somehow to the magnetic field as independent variable and construct a mapping model for the magnetic field (as a vector, in contrast to the mapping models for the magnetic field lines, as they exist).

The classical mapping models describing the magnetic field line transport does not provide information about the direction of the field lines and about the magnitude of the magnetic field in the Poincare section. As a consequence, the physical information given by the mapping model was limited. Our aim is to determine the direction of the field lines at the intersection points and the relative magnitude of the magnetic field (i.e. the magnetic field vector), as well as the currents in the Poincare section. In this way the mathematical results could be easier interpreted from a physical point of view.

5. SIGNIFICANCE OF RESULTS FOR JET and ITER

1. Characterization of the intermittent events, long range correlations and particle transport on the plasma boundary.

The problem to be studied is imposed by the huge technological problems generated by the intermittent heat load produced by ELM on the plasma facing components in ITER and JET. Because there are large technical difficulties to perform first principle numerical simulation, the study of the reduced models by analytic methods can by used to guide in setting the parameters. Reduced analytic models can also be used to extract the essential information from existing data or to classify various intermittency regimes in the large tokamaks like ITER and JET.

2. Studies of core impurity transport in tokamak plasmas with different dominant core turbulence. Influence of the collisions in the gyrokinetic simulations on the impurity transport.

The gyrokinetic first principle simulation allows reliable prediction of the impurity transport in large tokamaks. The correct prediction of the impurity transporrt is essential for the control of the efficient impurity and helium ash exhaust in large tokamaks. The expected outcome of this study will be a more physical version of the existing gyrokinetic codes.

3. Impurity transport driven by instabilities in plasma with radio-frequency heating.

Can improuve the prediction of the convective velocity and respective the acumulation of impurities in tokamak plasma corresponding to JET and ITER conditions.

4. Numerical simulation of test particle transport and comparison with theoretical models.

Will enhance the precision in calculating transport coefficients in the plasma. The behaviour of transport coefficients is an important task for ITER and JET.

5. The construction of a fractional diffusion equation in velocity and position space.

The results will clarify some experimental observations and they will point out some memory effects mechanism that could be responsible for the anomalous transport. From this point of view they provide important information for ITER.

6. Studies of transport and of saw-tooth crash phenomena based on mapping models.

We will focus on the memory effects that appear in L/H transition, in the frequency of ELM, saw-tooth crash in the ASDEX Upgrade tokamak. The results will clarify some experimental observations. They will point out some memory effects mechanism that could be responsible for the anomalous transport. A collection of mathematical models will be realized that could be applied to ITER.