THE ANOMALOUS TRANSPORT IN TURBULENT PLASMAS

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1. Introduction

The particle and energy transport was analyzed for different regions and regimes of the plasma in tokamak with special attention for ITER. For the particle transport in the tokamak edge plasma was obtained results useful for the qualitative cross-check of the numerical models of the first principle simulations, including ITER, as well as in the elaboration of the simplified, reduced models of the edge plasma transport studies.

On the issue of the transport barrier relaxation in tokamak edge plasma was analyzed the problem of relaxation oscillations, manifested as ELM modes, essential for the control of helium exhaust and reduction of the intermittent heat load in ITER.

Anomalous transport in tokamak plasma with turbulent electrostatic field modeled by stochastic frozen Gaussian fields and quasiperiodic electric field was studied. The results are useful in the first principle modelling and optimization by particle methods of large tokamaks.

For tokamak plasmas with electromagnetic turbulence, the variation of the turbulent ion particle and energy flux with the intensity of RF heating in Ion Cyclotron range was evaluated with relevance for internal region of large tokamaks as ITER.

Diffusion coefficients were evaluated using the decorrelation trajectory method and the direct numerical simulations. Different models were analyzed: zonal flow generation, motion of a collisionless electron in a stochastic sheared electromagnetic field and stochastic anisotropic sheared magnetic field. These results are important for "Validation of physics-based transport models" and "Plasma edge characterisation and modeling", objectives for ITER.

A rigorous study of the magnetic field in ASDEX_Upgrade tokamak and dynamics of charged particles in some specific magnetic configurations was accomplished using the Hamiltonian description and the mapping method.

2. Results obtained in 2005

2.1. Particle dynamics response to stochastic perturbations in tokamak. Response to stochastic perturbations in tokamak. Higher dimensional linear stochastic dynamics of the anomalous transport.

In previous studies in 2004 the linearized approximation of the Hasegawa-Mima and Hasegawa- Wakatani equations was studied, by the methods of ref. [1]. The main result was the proof of the consistency of the physical assumptions of the model of the edge plasma turbulence from ref. [1]. In 2005 this subject was continued, by studying the particle dynamics in stochastic electrostatic field, having the properties predicted by the previously studied models.

In 2005 of the physical effects in the framework of the stochastic field models of tokamak turbulence, the particle transversal motion in the guiding center approximation, when self-similar random field models the stochastic electrostatic turbulence was investigated. This category of stochastic field is a soluble approximation for the fields generated by linear stochastic dynamics studied previously. We obtained exact results for the characteristic χ exponent of the anomalous diffusion in term of the Hurst exponent H of the random electrostatic field. The result is $\chi = 2/(2-H)$. This result is valid also in the case of non-Gaussian random fields. By the generalization of the methods from our previous work ref. [1], we studied the statistical properties of the instability growth in the linearized equations of the drift wave turbulence, under the effect of perturbations modeled by fractional Brownian landscape and fractional Brownian cloud. We studied this equation by numerical methods. From our numerical simulations it follows the existence of the heavy tail close to the extreme value. This result justifies the validity of our previous one dimensional random linear amplification model.

The proposed milestones were achieved and it is closed. The results are useful for the crosscheck and theoretical foundation of first principle modeling of large tokamaks, elaboration of reduced models. The results are exposed in refs. [2-4].

This work was performed in collaboration with Dr. B. Weyssow, U. L. B., Belgium. The numerical simulations were performed using the facilities from U.L.B.

2.2. Transport barrier relaxation in tokamak edge plasma.

The study is devoted to the elaboration of new category of models of the transport barrier relaxation, manifested as ELM modes, by using the results of previous work [1]. The starting point was the set of deterministic first principle equations from ref. [5-6]. Higher dimensional fractional Brownian, fractional Brownian cloud and landscape modeled the random pressure background. The mathematical foundations, speed of convergence of the numerical method were clarified. By projecting to the dominating eigenmodes the nonlinear one-dimensional partial differential equations of the ELM modes from the work ref. [5], the qualitative aspects of the models was possible to explore by analytic and very quick numerical methods. In the case of this reduced model, without noise, an analytic study of the “phase diagram”, i.e. the range of parameters corresponding to regimes with or without relaxation oscillations, L-H transitions, was performed. The qualitative behavior of the model was studied. Under the effect of stochastic noise the qualitative agreement with experiment was improved. Typical behavior can be seen in Figure1. The most important physical effect discovered in this model of the stochastic perturbations is the existence of the heavy tail and intermittency of the turbulence amplitude and of the outgoing particle flux.

The proposed results were achieved. This milestone will be continued in 2006.

Part of the results was exposed on ref. [7]. This work is in progress and was performed in collaboration with Dr. X. Garbet from CEA, DRFC, Cadarache, France, Dr. B. Weyssow, ULB, Bruxelles. By using the facilities from DRFC, Cadarache and U.L.B the numerical simulations was performed.

2.3. Variational and Hilbert space optimization methods in the study of the particle transport in the tokamak turbulent plasma.

In order to model the particle transport in the tokamak caused by the electric field fluctuation a simplified model of the $\mathbf{E}\times\mathbf{B}$ drift was studied, with constant magnetic field and fluctuating electrostatic potential with homogenous and isotropic statistics.

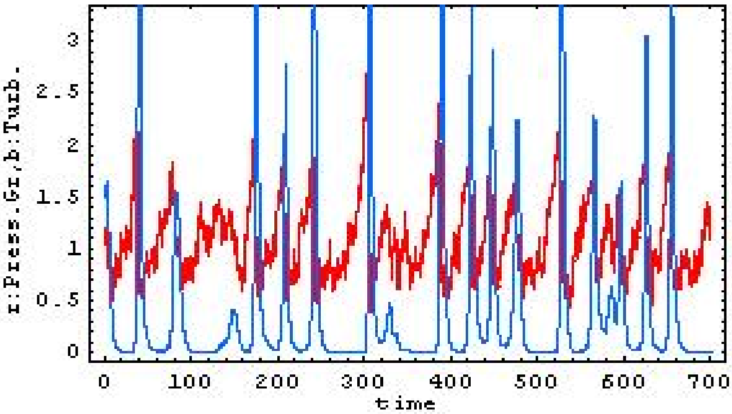

Figure 1. Evolution of the pressure gradient (red) and turbulence amplitude (blue) in ELM model

a) Exact soluble model.

An exact soluble time dependent Gaussian model was elaborated. When the mean square displacement is defined as $d_2(T) = \frac{1}{T}\int_0^T \left\langle [\mathbf{x}(t)]^2 \right\rangle_\omega dt$, the diffusion exponent χ is specified by $d_2(T) \propto const\, T^{\chi}$. The main result on this model is: If the stochastic self-similarity properties of the random electrostatic potential are characterized by the spatial and temporal Hurst exponents H_S , H_T then the diffusion exponent is given by $\chi = 2(1-H_T)/(2-H_S)$.

b) Trapping effects in the test particle motion in stochastic field.

The transverse stochastic particle dynamics, of the charged test particle in a constant magnetic field and stochastic static electric field (frozen turbulence) was studied by variational Hilbert space methods. The statistical ensemble of the stochastic electrostatic field was specified by the stochastic electrostatic potential $\Phi_\omega(\mathbf{x})$, $\mathbf{x} = (x_1, x_2)$, modeled by two-dimensional homogenous and isotropic Gaussian random scalar field. The two-point correlation function $C(d)$ is defined by $\left\langle \Phi_\omega(\mathbf{x})\,\Phi_\omega(\mathbf{y}) \right\rangle_\omega = C(|\mathbf{x}-\mathbf{y}|)$, with the large distance asymptotic form: $C(d) \propto O(d^{-\beta})$, with $0 < \beta < 1$. The results obtained on trapping effect are the following. The calculation of the trapping parameter can be related to Hilbert space optimization problem and can be treated within the framework of ergodic theory. According to the approximations, for parameter values of $0.1 \le \beta \le 0.25$, the fraction of the trapped particles has a numerically constant value of 0.07. In the soluble model studied the trapping is absent even in the frozen turbulence limit. For the numerical studies of the trapping process a specialized version of the conjugate gradient method was elaborated. These results extend the range of exact results and methods on anomalous particle transport in tokamak.

c) Bounds on the diffusion exponent.

In the framework of the model presented at *b)*, the following bounds on the diffusion exponent, defined previously, was obtained: in the range $0 < \beta < 0.5$ the upper bound $\chi \le (2+\beta)/(1+2\beta)$ **,** respectively for $0.5 < \beta < 1$ the lower bound $1+(1-\beta)^2 < \chi$.

d) Particle motion in periodic or quasiperiodic field.

Extension of the structural stability concept to statistical mechanics was performed, with the results. i) The particle motion in quasiperiodic field can be treated in the framework of general ergodic theory. ii) The smoothness of the transition from bounded to unbounded motion of the test particles moving in N-wave type periodic field, was explained and generalized. iii) Large class of structurally stable dynamical systems was found that contains the case of particle anomalous diffusion. This structural stability results has consequences on the Boltzmann Ergodic Hypothesis.

e) Numerical methods for Hilbert space optimization problems.

An adaptation of the conjugate gradient method for the minimization of the quadratic functions with high number of variables was performed. Suitable regularization was performed in order to avoid the slowing down generated by singularities of the functional.

The results are useful in the qualitative study of the deterministic chaotic dynamics, in order to verify first principle numerical calculations of the particle dynamics, theoretical foundations of the numerical simulations in large tokamaks. The proposed results were achieved. This milestone will be continued in 2006.

This work was performed in collaboration with Dr. B. Weyssow, U. L. B., Belgium. Parts of these results are published in the ref. [8]. By using the facilities from U.L.B the numerical simulations was performed.

2.4. Implications of the RF heating on the transport. Computation of transport coefficients in ICRH plasmas.

This milestone was continued in 2005 from 2004. In 2004 was evaluated the radial and poloidal ion particle flux for non-turbulent plasma in the presence of RF heating in the ion cyclotron range. Also the general formalism for the evaluation of radial fluxes in the electromagnetic turbulence case was established. In 2005 the solution for the fluctuating distribution function for plasma with electromagnetic turbulence in the presence of radio-frequency heating was evaluated up to the second order approximation.

The non-local effect on the tokamak fusion plasma of the RF heating is taken into account through the equilibrium distribution function that depends on the Stix parameter (as a measure of the radio-frequency power density). In the presence of the heating we consider non-Maxwell distribution function as reference equilibrium distribution function that, in our particular model, does not depend on the gradient of density or temperature.

The zero order approximation of the fluctuating distribution function (passing particles regime) averaged over gyro-phase angle $\overline{\delta f}_0$ is generated by the electrostatic turbulence and do not give direct contribution to the transport because of the wrong phase.

The first order approximation $\overline{\delta f}_1$ (passing particles regime) contains two kinds of terms: ones are even in the parallel velocity, the others are odd. The first one gives a direct contribution to the radial flux and contains also terms generated by purely magnetic fluctuations that can be present due to the Dynamic Ergodic Divertor (DED). The odd part in parallel velocity of $\overline{\delta f}_1$ contributes indirectly to the flux through the second order approximation. The distribution function $\overline{\delta f}_1$ contains classical forces generated by the gradient of number particle density, temperature, electric potential, magnetic field; it depends linearly on these. A pinch effect is not present in this approximation, with particular form of the reference distribution function. The second order approximation $\overline{\delta f}_2$ contains terms that are nonlinear in gradients and contain terms generated by the radio-frequency operator. A pinch effect appears in this case.

The radial and poloidal particle and energy flux of the ions in the passing regime using the first order approximation of the fluctuating distribution function was evaluated [8], [9]. We have described the variation of the radial and poloidal particle and energy flux of ions with the Stix parameter that is a measure of the radio-frequency power density. The coefficients depending on the small radius toroidal coordinate and the Stix parameter was evaluated numerical by using designed parameters for ITER. The results are relevant for the inner region of large tokamak as ITER. The results were analyzed for different range of electromagnetic instabilities. The results, partially obtained in collaboration with Dr. B. Weyssow, U. L. B., Belgium, were sent to publication to Physics of Plasmas in 2006.

This milestone will continue in 2006 with evaluation of the turbulent fluxes in ICRH plasma due to particles in trapped regime. Also the contribution from the second order approximation of the fluctuating distribution function will be analyzed.

2.5. The study of the influence of the diamagnetic Kubo number on zonal flow generation in turbulent plasma using the decorrelation trajectory method.

This study (which is a continuation of the analysis reported in the Annual Report 2004 where the main physical quantities were defined (see also [10])) is devoted to the evaluation of the diffusion tensor for plasma in a state of drift wave turbulence and a large numbers of the parameters involved in the problem. The main result consists in the exploring of the influence of the diamagnetic effect on the generation of zonal flow. The present analysis was done only for a relatively weak electrostatic turbulence regime (a relatively small electrostatic Kubo number) and a damping of the zonal flow mode was observed. This tendency of the suppression of the zonal flow is due to the spatial inhomogeneity of the density. Moreover, the spatial anisotropy of the stochastic electrostatic field plays an important role in the zonal flow evolution. This can be clearly seen from Figure 2 (a) and (b) where the radial and poloidal asymptotic diffusion coefficients as functions of the diamagnetic Kubo number are represented. This work is devoted to the analysis of the diffusion in the case of zonal flow generation in a relatively weak electrostatic turbulence. The results of the research were submitted to publication [11].

2.6. Diffusion of a collisionless thermal electron in a sheared unperturbed magnetic field and a fluctuating electric field: direct numerical simulation results

The diffusion of the collisionless thermal electrons in a combined fluctuating 2-dimensional electrostatic field and a sheared unperturbed confining magnetic field was analyzed by direct numerical simulations (see [12]) and performed using the computing facilities of ULB-VUB Belgium (on the parallel computer ASTER which accepts four matrices 4096 x 4096 for the discretized representation of the electrostatic stochastic field). The spectrum *S(k)* used in our numerical simulation is considered to be isotropic and is partly defined according to drift wave turbulence measurements and partly from the parameters (correlation length and the decorrelation time) used in the DCT method. The most adapted spectrum is Gaussian for small wave-vectors and a k^{-3} spectrum for large wave-vectors. The choice of the specific parameters for the direct numerical simulation results from two constraints: one is the discretization of the electrostatic potential that limits the upper value of the wave vector.

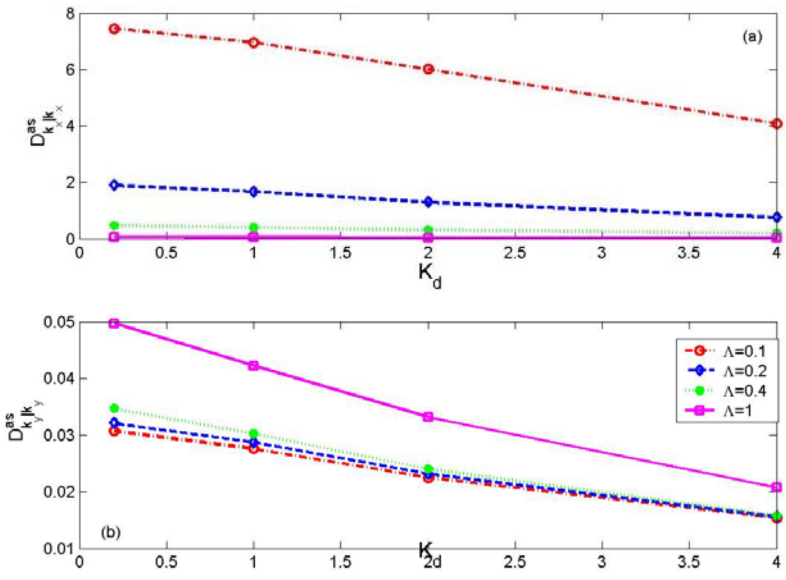

Figure 2: Asymptotic diffusion coefficients in the radial [the subplot (a)] and poloidal [the subplot (b)] directions as functions of K_d for different values of the anisotropy level and [$k_{0x} = (0.2)^{1/2}$, $k_{0y} = (0.8)^{1/2}$].

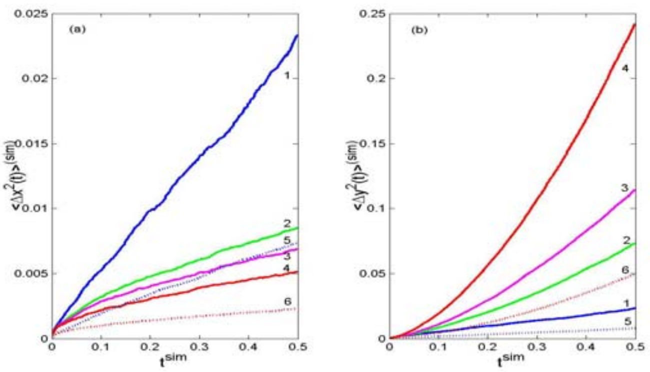

Figure 3: The mean squared displacements in the radial direction (a) and the poloidal one (b) for two values of the electrostatic Kubo number and different values of the shear Kubo number. The correspondences between the two pictures are: {1, 2, 3, 4} ≡ { K^{sim} =2.56; K_s^{sim} = 0, 1.56, 2.56, 5.56} and {5, 6} ≡ { K^{sim} = 0.56; K_s^{sim} = 0, 5.56}.

The other is the correlation of the potential, which in the DCT calculation (see the Annual Report 2004) is assumed to decrease without oscillations to zero. In Figure 3 (a) and (b) the mean square displacements in the radial (a) and poloidal (b) directions are displayed and it can be seen that, in general, a decrease of the radial diffusion coefficient at fixed value of the electrostatic Kubo number for different values of the shear Kubo number appears. We can also see from Figure 3 (a) that the mean square displacement in the radial direction is almost linear, thus an almost diffusive regime in that direction is present after a critical time. The main conclusion is that for both relatively weak and strong electrostatic turbulence regimes, the numerical simulations results are in agreement with the results obtained by the DCT method. A partial result was already published [13, 14]. This objective will be continued in 2006.

2.7. Diffusion coefficients of the stochastic anisotropic sheared magnetic field lines

In this work the theoretical framework necessary to study the diffusion of the magnetic field lines for a stochastic *anisotropic sheared* magnetic field using the decorrelation trajectory method already developed is used. This study is necessary for the calculation of the diffusion coefficient of a particle moving in a sheared stochastic magnetic field. Our work is an extension of the previous one presented in the Annual Report 2004 ([15], [16]) and the diffusion coefficients in the radial and poloidal direction (the two directions perpendicular to the main magnetic field) were calculated. It can be seen from the Figure 4 (a) that for a relatively high value of the magnetic Kubo number, a complicated "mixed" effect of all the three parameters is present for the running radial diffusion coefficient while for the poloidal one is observed an inversion of the evolution of the curves when the shear parameter increases (Figure 4 (b)). The radial and poloidal diffusion of the magnetic field lines were calculated for an anisotropic and stochastic sheared magnetic field. Partial results were already published [13]. This work will be continued in 2006.

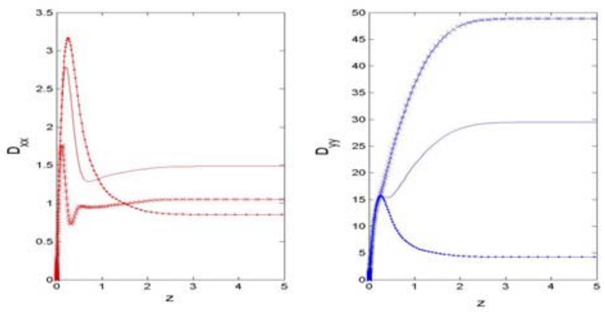

Figure 4: The running diffusion coefficients in the radial direction (a) and the poloidal one (b). The parameters are: the magnetic Kubo number K_m =1, the anisotropy parameter Λ = 5 and the values of the shear parameter θ_s= {0 (stars), 1 (straight line), 5 (dash-dot)}.

2.8. Transport phenomena in the scrape off layer (SOL) in tokamak plasma

Until now we have studied the behavior of the radial electric field in scrape-off layer taking into account various mechanisms of losses: ion loss cone loss, ion bulk viscosity flux of ions and the impurity flux (milestone closed in 2004).

This study will be continued in order to obtain the diffusion coefficients of a particle moving in SOL using the decorrelation trajectory method for a particular choice (in agreement with [17]) of the autocorrelation of the stochastic electrostatic potential. This work is in progress and will be continued in 2006.

2.9. Scenarios with internal transport barriers (ITB). The study of the magnetic internal transport barrier in the rev-tokamap model.

This milestone was begun in 2004 and finished in 2005. In the previous work a mathematical study of the reversed shear magnetic field in tokamak was realized using the rev-tokamap model. This model describes the magnetic field in DIIID tokamak (C.M.Greenfield et al, Plasmas 4 (1997), 1596; R. Balescu, Phys. Rev. E **3** (1998), 3782). Some important results concerning the location and the analytical description of the magnetic internal transport barrier in the rev-tokamap and related models were presented in [18], [19]. The effects of some control techniques on the dynamics of the magnetic field lines were presented in [18], [20].

The results give a theoretical explanation for the reduced magnetic transport observed in reversed shear magnetic configurations and show that the existence of an internal magnetic transport barrier deeply influences the magnetic and plasma confinement.

2.10. Scenarios with internal transport barriers (ITB). The construction and the study of realistic mathematical models which describe the magnetic field in tokamaks (ASDEX Upgrade tokamak) by taking into account the neoclassical tearing modes (NTM).

This milestone begins in 2005 and it will continue in 2006. The aim of this work is to model the regime of NTMs in which three wave coupling between an (m,n), an (m+1,n+1) ideal mode and a central (1,1) mode lead to a regime in which NTMs only modestly degrade confinement and allow to reach high beta values at good confinement in the presence of NTMs.

This so called FIR regime, first found on the ASDEX Upgrade tokamak, has a high value for future reactor class devices such as ITER.

In order to obtain the model we used the mapping technique: the magnetic field lines are traced over long distances around the torus and each intersection with a pre-selected poloidal section (the Poincaré section) is marked. The result is a pattern characterizing the magnetic field topology. This technique, more than one order faster than the (numerical) integration of the Hamiltonian system that characterizes the magnetic field's configuration, was also used for obtaining the tokamap and the rev-tokamap models, previously studied.

Our calculations confirm the anticipation that the nonlinear interaction between the (3,2) and (4,3) modes leads to stochastization and that the presence of the (4,3) mode really is able to prevent the (3,2) mode from growing to its saturated island size. It was also found that the (1,1) mode that is needed for a nonlinear coupling between the modes, has a negligible influence on stochastization itself. Similar conclusions refer to the interaction between the (4,3) and (5,4) modes. The results were published in [21]. The objectives of the first stage of the study were realized, the milestone will be continued in 2006.

2.11. Scenarios with internal transport barriers (ITB). The study of some mathematical models describing the dynamics of charged particles in a general magnetic configuration used in tokamaks and their particularization for special magnetic configurations.

This milestone started in 2005. A mathematical model for the study of the guiding center's motion was obtained by using the Hamiltonian formalism and the mapping technique.

The main importance of our model is that it takes into account all drifts specific to the toroidal configuration of the magnetic field, hence it is more realistic than other models. It is also important that the same system of coordinates is used for describing the motion of passing and trapped particles.

The general model was used in order to describe the motion of the guiding center in specific magnetic configurations (some particular choice of the safety factor and magnetic perturbations used in Tore Supra and ASDEX-Upgrade). In the ideal (unperturbed) case the numerical simulations case are in qualitative agreement with the theoretical expectations (the passing and the banana orbits were pointed out, the sizes of banana orbits practically coincide with the theoretical prediction and the equations of the magnetic field lines were obtained using the driftless cylindrical approximation). In the perturbed case some numerical difficulties were bypassed, but a systematic study was not yet realized. This work is in progress and the milestones will be continued in 2006.

3. <u>Conclusions</u>

In the study of the *higher dimensional linear stochastic dynamics of the anomalous transport,* soluble model for the particle dynamics in the edge plasma was elaborated. The diffusion exponent that quantifies the anomalous character of the particle transport was calculated.

In the study of *transport barrier relaxation in tokamak edge plasma,* the influence of the stochastic perturbations of the deterministic models of the transport barrier relaxation was studied. New effects were predicted: intermittency and heavy tail in the outgoing particle flux statistics, important for helium exhaust and heat load control of large tokamaks.

In the framework of models studied by *variational and Hilbert space optimization methods,* models of particle motion in the Gaussian frozen turbulence, exact results and rigorous bound on the diffusion exponent was obtained. New methodology and stability result on particle motion in turbulent plasma, modeled by quasiperiodic fields was elaborated. The stability results are related to the foundation of the statistical physics.

Variation with Stix parameter of the turbulent transport of ions in radial and poloidal direction in plasma with electromagnetic turbulence in the presence of ion cyclotron range heating was evaluated in the leading order approximation for inner region of tokamak plasma using plasma parameters designed for ITER.

Specific codes was developed [in collaboration with ULB, Belgium and CEA Cadarache, France] in order to evaluate the diffusion coefficients for different stochastic models related to the tokamak plasma**.**

The magnetic field configurations of DIIID and ASDEX-Upgrade tokamaks were studied using the Hamiltonian description and the mapping technique. Theoretical results concerning the internal transport barrier in the reversed-shear configuration (DIIID tokamak) were obtained. The influence of the stochastization on the fast reconnection in the frequently interrupted regime of neoclassical modes (ASDEX-Upgrade tokamak) was analyzed.

In this way the tasks assumed in prolongation of the Contract of Association for 2005 were achieved.

4. Previsional results for 2006

The study of the milestones "*Higher dimensional linear stochastic dynamics of the anomalous transport", and "Transport barrier relaxation in tokamak edge plasma"* will be extended in connection with the study of the intermittence effects in the ELM modeling by non-linear models. The results obtained in the study of the shell model will be used in ELM modeling.

The turbulent plasma transport of ions in trapped regime in plasma with electromagnetic turbulence in the presence of ion cyclotron range heating will be analyzed. The distribution function suitable to describe the turbulent transport of impurities in ICRH plasma will be chosen.

Diffusion coefficients will be calculated by decorrelation trajectory method and direct numerical simulation for the proposed models and different autocorrelations of the stochastic electrostatic (or magnetic) potential.

A study of the magnetic reconnection in ASDEX-Upgrade tokamak will be realized by using realistic perturbations of the ideal magnetic field, in deep connection with the experiments. The motion of the guiding centre in magnetic configurations specific to Tore-Supra, DIIID and ASDEX-Upgrade tokamaks will be analyzed using local and global perturbations of the magnetic field. These results provisioned for 2006 are in agreement with the tasks assumed in prolongation of the Contract of Association in 2006.

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5. Collaborative actions

5.1. Transport barrier relaxation in tokamak edge plasmas.

Collaboration with DRFC/GTTM, Cadarache, France.

The modelling of the ELM modes is very important for the reduction of intermittent heat load on PFC and for helium extraction from ITER.

Stochastic methods for the study of models of the transport barrier relaxation, manifested as ELM modes, by using previous results on stochastic instability analysis.

The mathematical foundations, speed of convergence of the numerical method were clarified. By projection to the dominating eigenmodes, the qualitative aspects of the models were explored by analytic and very quick numerical methods. In the case of this reduced model, the study of the "phase diagram", i.e. the range of parameters corresponding to regimes with or without relaxation oscillations, L-H transitions, was performed. Under the effect of stochastic noise the qualitative agreement with experiment was improved. Typical behavior can be seen in Figure1. The most important physical effect discovered in this model of the stochastic perturbations is the existence of the heavy tail and intermittency of the turbulence amplitude and of the outgoing particle flux. By using the facilities from DRFC Cadarache, the numerical computations were performed.

5.2. Variational and Hilbert space optimization methods in the study of the particle transport in the tokamak turbulent plasma.

Collaboration with Department of Statistical Physics and Plasmas, U. L. B., Brussels, Belgium.

The particle transport in the tokamak caused by the electric field fluctuation in the model of the $\mathbf{E}\times\mathbf{B}$ drift was studied, with constant magnetic field and fluctuating electrostatic potential, with homogenous and isotropic statistics.

The complete solution of this problem is essential for deriving correct macroscopic equation for anomalous transport simulation, in the optimization of the parameters of large tokamaks, including ITER. An exact soluble time dependent Gaussian model was elaborated: knowing the spatial and temporal Hurst exponents of the Gaussian random field of electrostatic fluctuations, it is possible to compute the exponent of the anomalous diffusion.

In the more general, homogenous isotropic Gaussian model, in the frozen turbulence limit the trapping effect was evaluated numerically and rigorous bound on the diffusion exponent was derived. The particle motion in quasiperiodic electric field was studied for the first time by the methods of ergodic theory. Stability results were derived, with implication on the numerical simulation of particle transport and foundations of statistical physics. The numerical studies were performed by new versions of the conjugate gradient optimization methods. By using the facilities from U.L.B the numerical simulations were performed.

5.3. Computation of transport coefficients in ICRH plasmas.

Collaboration with Boris Weyssow, Association EURATOM-Etat Belge, U.L.B., Belgium.

For ICRH plasma with electromagnetic turbulence was evaluated the radial turbulent fluxes of ions majority species with relevance for inner plasma region in large plasma tokamak as ITER. Evaluation was made in leading order approximation of fluctuating distribution function and with a particular expression of the reference distribution function. Results are sent to publication in 2006.

5.4. The influence of the generation of zonal flow on the anomalous transport in tokamak plasma.

Collaboration with Radu Balescu, Association EURATOM-Etat Belge, U.L.B., Belgium.

The fragmentation of the drift wave structures in radial direction and the generation of long-wave length structures in the poloidal direction were analyzed.

5.5. Theory and simulation of anomalous transport.

Collaboration with Radu Balescu, Association EURATOM-Etat Belge, U.L.B., Belgium.

In a combined fluctuating 2-dimensional electrostatic field and a sheared unperturbed confining magnetic field, the diffusion of thermal electrons was analyzed by direct numerical simulations [12]. The numerical simulations was performed using the computing facilities of ULB-VUB Belgium (on the parallel computer ASTER which accepts four matrices 4096 x 4096 for the discretized representation of the electrostatic stochastic field).

5.6. Transport phenomena in the scrape off layer (SOL) in tokamak plasma.

Collaboration with Boris Weyssow, Association EURATOM-Etat Belge, U.L.B., Belgium.

The diffusion coefficients of a particle moving in SOL using the decorrelation trajectory method for a particular choice (in agreement with [17]) of the autocorrelation of the stochastic electrostatic potential was analyzed. This work is in progress and will continue in 2006.

5.7. Scenarios with internal transport barriers.

Collaboration with Boris Weyssow, Association EURATOM-Etat Belge, U.L.B., Belgium, Jacques Misguich, CEA Cadarache, France, and Olgierd Dumbrajs Technical University of Riga, Latvia.

"The study of the magnetic internal transport barrier in the rev-tokamap model" was realized in collaboration with Dr. Jacques Misguich, CEA Cadarache, France.

"The construction and the study of realistic mathematical models which describe the magnetic field in tokamaks (ASDEX Upgrade tokamak) by taking into account the neoclassical tearing modes (NTM)" was realized in collaboration with Dr. Olgierd Dumbrajs, University Latvia, Riga, Latvia, and the ASDEX-Upgrade team.

"The study of some mathematical models describing the dynamics of charged particles in a general magnetic configuration used in tokamaks and their particularization for special magnetic configurations" was realized in collaboration with Dr. Boris Weyssow, ULB Belgium.

The entire obligations in collaborative actions anticipated for 2005 was respected and well finalized.