Plasma Group from University of Craiova

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Particle and Impurity turbulent transport in plasma with RF heating

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Objectives correspond to EU Fusion Programme and EFDA Work Programme

2004-2007 : Physics R&D Needs for the EU Fusion Programme
Macro-task 3.6 and 5.1

Contract of Association:

3. Development of concept improvements and advances in fundamental understanding of fusion plasmas

3.4. Theory and modelling

2008-2009 *EFDA Work Programme*

1. Development of plasma scenarios for ITER

3. Theory and modelling

EFDA Work Programme 2008 and 2009 - V-1/1

WP08-TGS-02-01 (V-1-1) Transport Topical Group under EFDA

Objectives:

- Parallel fluxes in turbulent plasmas with ICRH
- Radial and poloidal particle and energy fluxes in turbulent plasmas with ICRH
- Ion density perturbation driven by electromagnetic turbulence and ICRH
- Impurity density perturbation profile due to ITG in plasma with ICRH
- Dispersion equation for ITG instability in plasma with ICRH

Colaborations:

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Tünde Fülop – Chalmers University of Technology, Sweden

Parallel fluxes in turbulent plasmas with ICRH

The ion parallel particle flux and ion parallel heat flux in electrostatic turbulent magnetically confined plasma in presence of ICRH are obtained analytically in terms of the thermodynamic forces.

- axisymmetric magnetic field (standard model)
- collisions are included
- interaction of ions with RF waves is described by the quasilinear RF operator (only its PAS part gives contribution)
- RF power density measured in terms of Stix parameter ξ
- define parallel fluxes using Laguerre – Sonine polynomials as in neoclassical transport theory
- The variation of the parallel particle and energy fluxes with Stix parameter ξ is studied for $\xi<0.4$

The equilibrium ion distribution function is deviated from Maxwellian for $\xi>0$

$$F_0^i = g_0(\lambda;\xi) f_0^i(x,\xi)$$

$$f_0^i(x,\xi) = n_i \left(\frac{m_i}{2\pi T_e (1+\xi)} \right)^{3/2} \exp\left(-\frac{x}{1+\xi} \right)$$

$$g_0(\lambda;\xi) = 1-(1-3\lambda B^0)\xi/2$$

$$0<\xi<0.4$$

$$x = \frac{m_\alpha v^2}{2T_\alpha}, \quad \lambda = \frac{1}{B}\frac{v_\perp^2}{v^2}$$

x = kinetic energy scaled by thermal energy

λ = ratio of the magnetic moment to the kinetic energy

$$\text{the Stix parameter}: \ \xi = \frac{\langle P \rangle \tau_s}{3 n_i T_e}$$

$\langle P \rangle$ = *the flux-averaged absorbed rf power density*

τ_s = *the electron relaxation time*

Conclusions

The intensity of parallel fluxes decrease when parameter ξ is increasing

Comparison of the different contributions to the parallel turbulent fluxes is obtained by performing the evaluation of the reduced transport coefficients using some plasma profiles (for the density, temperature and the absorbed power density

N. Pometescu, B. Weyssow, *Parallel and poloidal fluxes in turbulent non-ohmic plasmas: An ion-cyclotron resonance heating case*, Physics of Plasmas, vol 10, 1048-1059 (2003)

Radial and poloidal particle and energy fluxes in turbulent plasmas with ICRH

Motivation:

- Despite the large number of experiments, a clear description of majority species particle transport in tokamak has not emerged. Many experiments indicate an inward pinch in the outer region of the core r/a>0.7

Ref: ITER Physics Basis Editors, *Nuclear Fusion*, Vol.**39**, No.12 (1999): "Plasma confinement and transport"

- The simplest useful characterization of local transport in tokamak plasmas identifies the local particle flux as a combination of a diffusive term and a 'pinch' term:

$$\Gamma = -D \nabla n + nV$$

Features of the model:

- The ICRF heating induces a direct increase of the ion temperature. The local equilibrium distribution function deviate from a maxwellian distribution
- First order approximation with $k_{\|} \neq 0$

The radial ion particle flux

$$\left\langle \Gamma^{i,rad} \right\rangle_s = -\frac{n_i}{B_0^2(r)} \int d\vec{k} \left[C_{k,es}^{rad} \left| \overline{\delta\Phi}_k \right|^2 + C_{k,\zeta}^{rad} \left| \overline{\delta A}_{k,\zeta} \right|^2 + C_{k,\theta}^{rad} \left| \overline{\delta A}_{k,\theta} \right|^2 \right]$$

Transport coefficient for the electrostatic turbulence

$$C_{k,es}^{rad} = \frac{R_0}{\rho_{0s} c_s} c^2 q k_{\|} \left(k_\theta - \frac{\eta}{q} k_\zeta \right) C_{es}$$

Toroidal transport coefficient for the inductive turbulence

$$C_{k,\zeta}^{rad} = \eta k_\theta \omega_k C_j^{rad} - \eta \frac{R_0}{\rho_{0s} c_s} \omega_k^2 C_{es} + k_r \omega_k C_1$$

Poloidal transport coefficient for the inductive turbulence

$$C_{k,\theta}^{rad} = q k_\zeta \omega_k C_j^{rad} + \eta \frac{R_0}{\rho_{0s} c_s} \omega_k^2 C_{es} - k_r \omega_k C_2$$

Dispersion scale

$$\rho_{0s} = \frac{c}{eB_0} \sqrt{m_i T_e} \approx 0.268 \text{ cm}$$

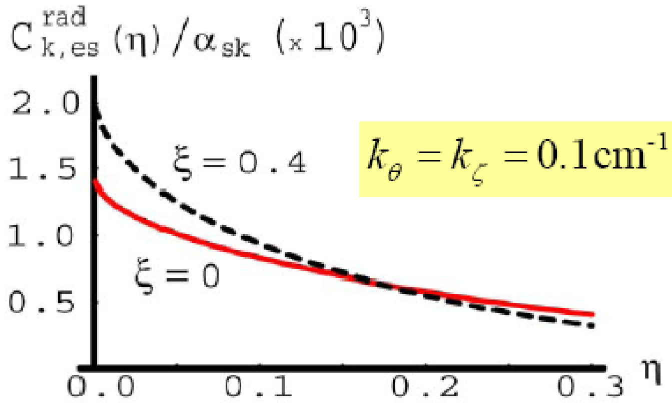
Sound speed

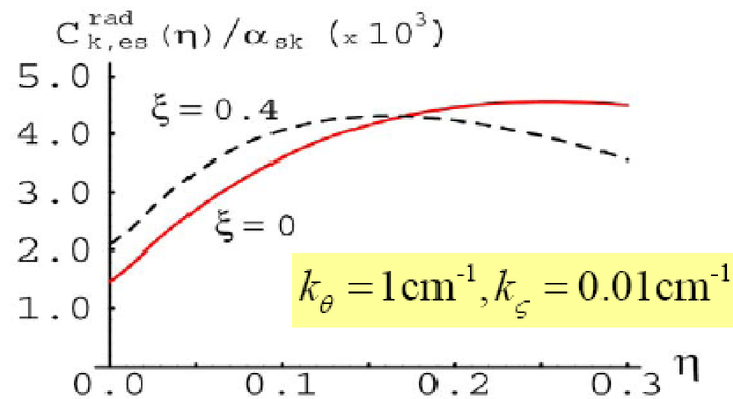
$$c_s = \sqrt{T_e / m_i}$$

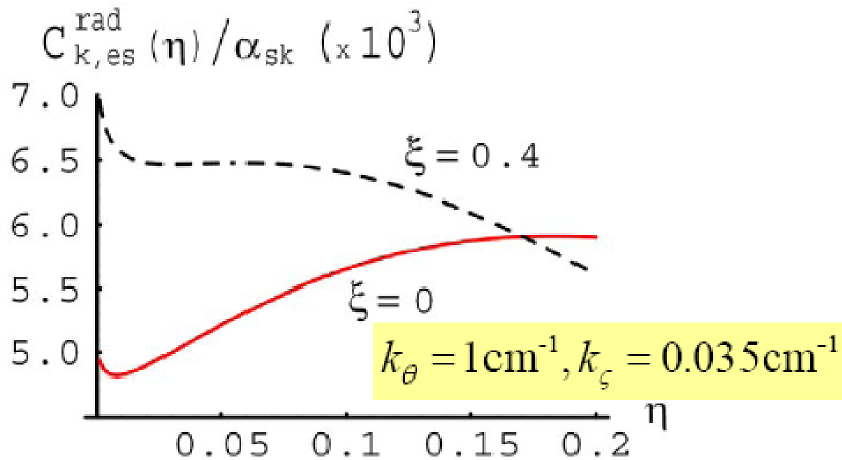
$$B(r,\theta) = \frac{B_0(r)}{1 + \eta \cos\theta} \quad , \quad \eta = \frac{r}{R_0}$$

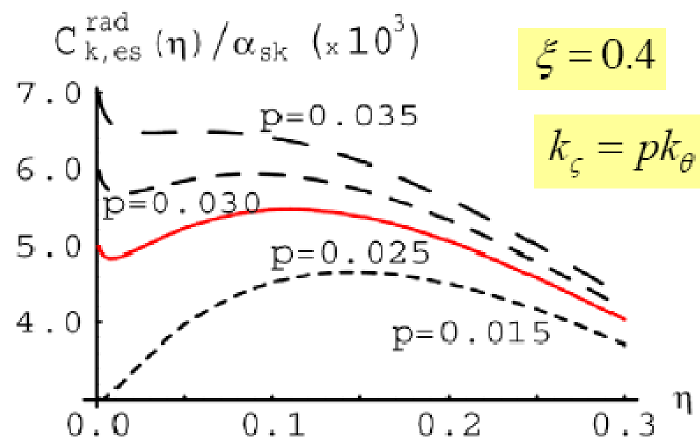
Electrostatic spectral coefficient

$$\alpha_{sk} = \left(\frac{qR_0}{\rho_{sk}}\right)^3 \omega_0 k_0 = 3.32\times10^{11}\,\mathrm{Hz/cm}$$









Conclusions

Consider values of parameters as for ITER

Plasma major radius R_0=620 cm, plasma minor radius *a* =200 cm, toroidal field B_0=5.3 T, volume averaged electron temperature T_e =8.9 keV.

Also we consider density scale length L_n =100 cm, safety factor value q=3, electrostatic scale length $L_\phi = L_n /3$

In the outer region of the core, with η>0.2 the inward flux pinch has comparable values with the outward pinch flux – which is in agreement with experimental observations in ASDEX Upgrade.

N. Pometescu, B. Weyssow, *Radial and poloidal particle and energy fluxes in turbulent non-ohmic plasmas: An ion-cyclotron resonance heating case*, Physics of Plasmas, vol 14, 022305 (2007)

N. Pometescu - Particle and impurity turbulent transport in plasma with RF heating

- Ion density perturbation driven by electromagnetic turbulence and ICRH

N. Pometescu, Journal of Optoelectronics and advanced materials vol.10, 1933-1937 (2008)

- Impurity density perturbation profile due to ITG in plasma with ICRH

N. Pometescu, B. Weyssow, 13-th European Fusion Theory Conference, 2009, Riga

- Dispersion equation for ITG instability in plasma with ICRH

N. Pometescu, International Workshop TFP – Craiova, 9-10 November, 2009

Work Programme 2010

- **Specific objectives: Particle and impurity transport in standard and advanced tokamak scenarios**
- ***Milestone: Impact of central electron heating on both electron and ion temperatures, and on particle and impurity densities*.**
- Co-operations: Task agreement WP10-TRA-03-03

  EFDA Work Programme 2010-III.2.3

  EURATOM-VR Association, Sweden, Chalmers

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A new numerical method was developed for the study of the transport due to the imperfections of the magnetic field configurations in tokamak. The numerical method was used for the study of the formation of the transport barriers by magnetic field line dynamics and can be used for a more general problem: solving systems of nonlinear equations [1] and [2].

The extreme heavy tail and the power-law decay of the turbulent flux correlation observed in hot magnetically confined plasmas are modelled by a system of coupled Langevin equations describing a continuous time linear randomly amplified stochastic process where the amplification factor is driven by a superposition of colored noises which, in a suitable limit, generate a fractional Brownian motion. An exact analytical formula for the power-law tail exponent β is derived. The extremely small value of the heavy tail exponent and the power-law distribution of laminar times also found experimentally are obtained, in a robust manner, for a wide range of input values, as a consequence of the (asymptotic) self-similarity property of the noise spectrum. As a by-product, a new representation of the persistent fractional Brownian motion (fBm) is obtained. In the study of the edge plasma turbulence, intermittency and ELM phenomenology were studied. The main achievement is that our stochastic model correlates two apparently distinct experimental facts: the extreme non-Gaussian character of the particle flux distribution function on the edge plasma and self similarity of the density fluctuations, measured on the DIII-D tokamak.

We studied the stochastic processes studied belongs to the class of Random Affine Processes. Continuous time version is described by the stochastic differential equation

$$\frac{d\mathbf{X}_{\omega}(t)}{dt} = \hat{\mathbf{A}}_{\omega}(t)\mathbf{X}_{\omega}(t) + \mathbf{B}_{\omega}(t) \qquad (1)$$

where $\hat{\mathbf{A}}_{\omega}(t)$ is a random time dependent linear operator, acting in vector space and $\mathbf{B}_{\omega}(t)$ is a random vector. The driving stochastic processes $\hat{\mathbf{A}}_{\omega}(t)$ and $\mathbf{B}_{\omega}(t)$ are stationary. The subscript ω denotes a particular realization of the stochastic process associated to $\hat{\mathbf{A}}_{\omega}(t)$ and $\mathbf{B}_{\omega}(t)$. In the DIII-D tokamak, the hidden driving Gaussian noise correspond roughly at the Hurst index H=0.75.

The fBm with H=0.75, contained in $\hat{\mathbf{A}}_{\omega}(t) - \left\langle \hat{\mathbf{A}}_{\omega}(t) \right\rangle$ (and measured in DIII-D) is responsible for the EXTREME HEAVY TAIL, i.e. $\beta \cong 0$ observed in DIII-D.

In figures 1-6 are shown different displacements for fBm with different Hurst index.

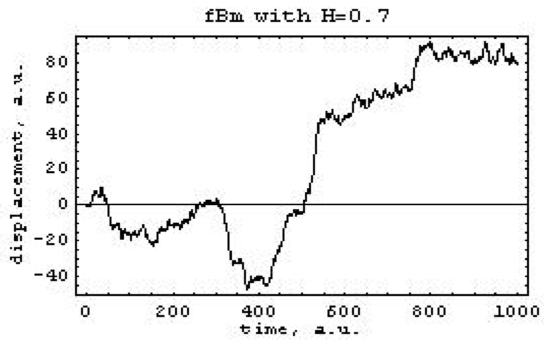


Figure 1

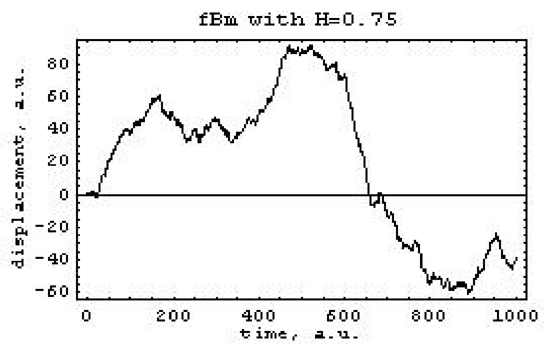


Figure 2

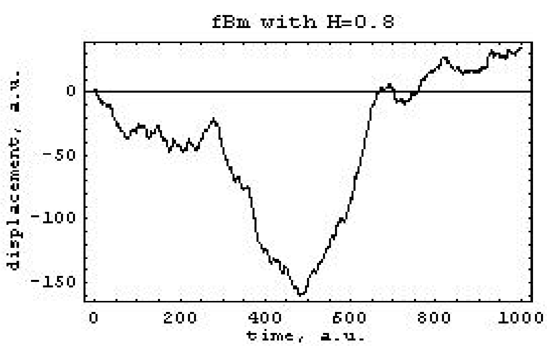
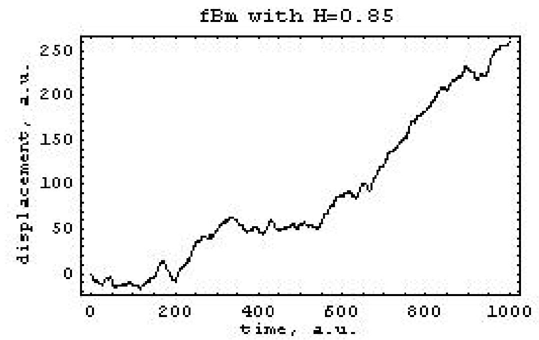


Figure 3



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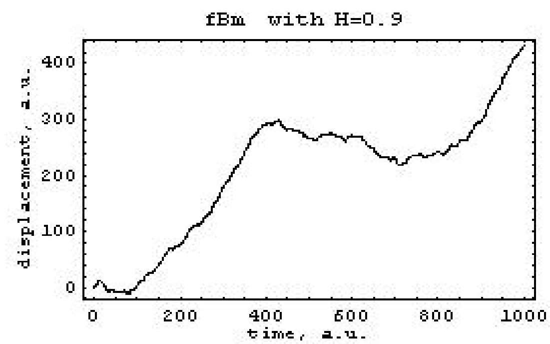

Figure 5

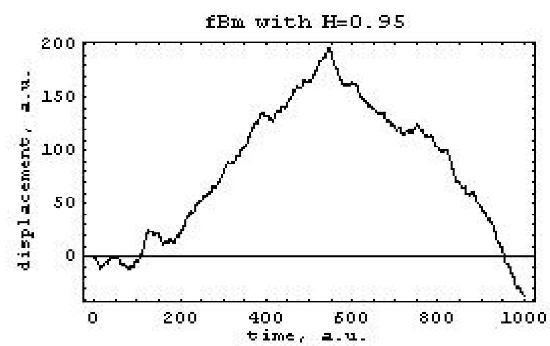

Figure 6

The methods described in our papers [3], [4], [5] concerning the study of the heavy tail effects by relating to Generalized Central Limit Theorem, were extended to the study of the intermittent character of ELM's. The model describes correctly the evolution of the ELMs versus fuelling rate (see figures 7-10).

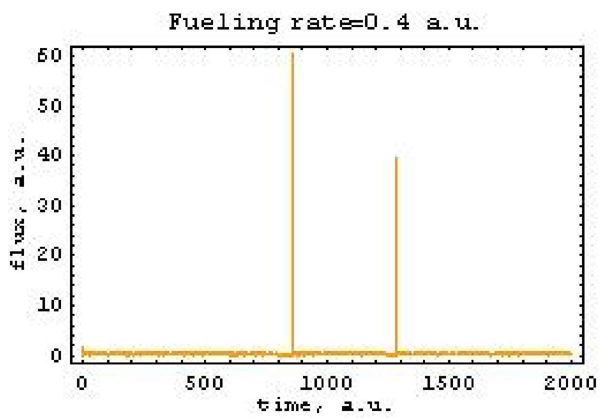

Figure 7

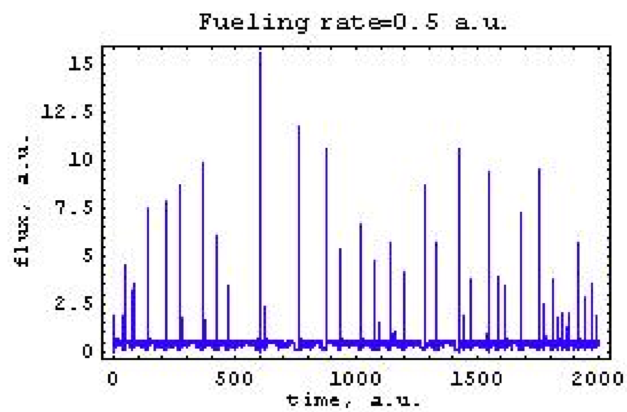

Figure 9

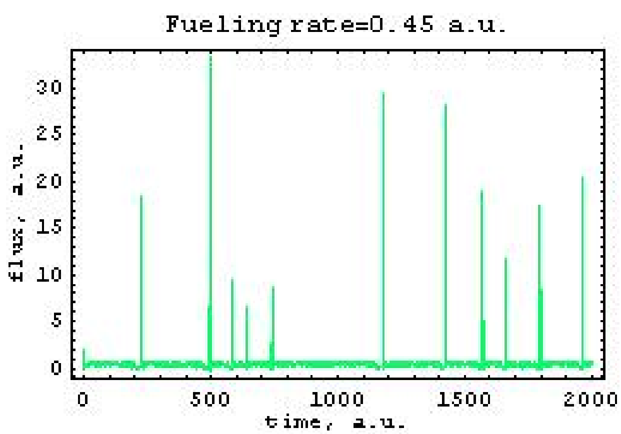

Figure 8

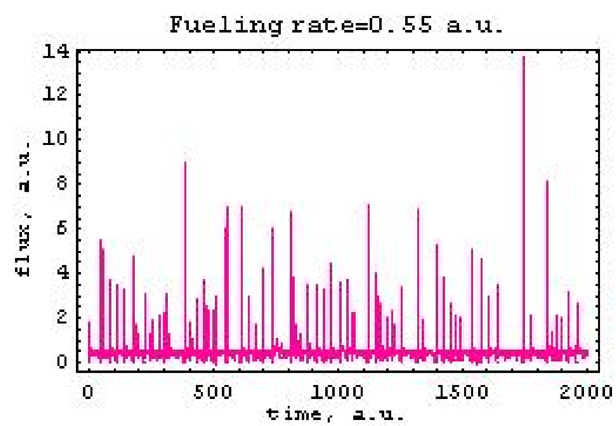

Figure 10

The intermittency studied in these models is characterized by the singularity exponent of the stationary probability density function of outgoing flux in tokamak. A typical dependence on the fuelling rate of the tokamak is represented in figure 11. The intermittency effects in the H mode produces large heat loads on the plasma facing components.

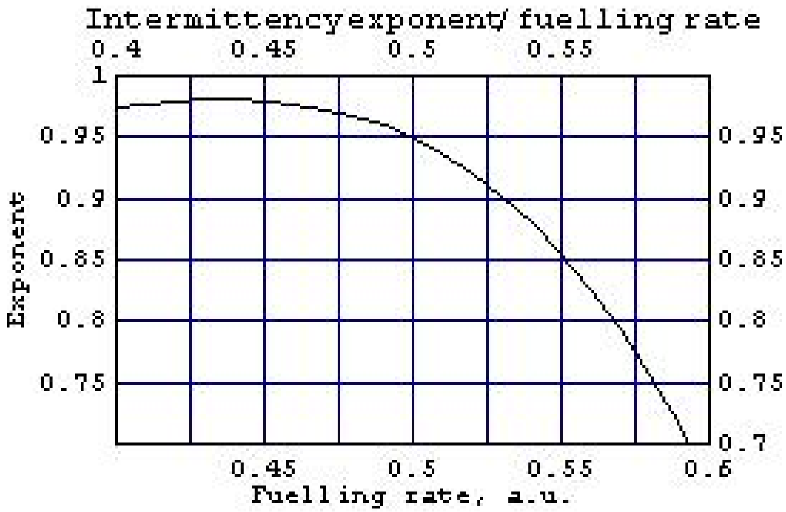

Figure 11

Perspectives

The study of the low dimensional reduced stochastic models could give useful information on the optimal planning of the time consuming first principle simulations of the edge plasma turbulence. Higher dimensional stochastic models are interesting candidates for the stochastic stability analysis of the equilibrium of the plasma in tokamak, as well as the stability of the multi-scale numerical methods. The modelling of the inverse cascade, streamers, by higher dimensional linear stochastic partial differential equations will be continued. The further study of the ergodic problems of the particle transport is important both from the point of view of fundamental scientific aspects, related to the very foundation of the whole edifice of the statistical physics, as well as from the point of view of elaborating mathematically sound alternative numerical methods for the study of the particle and energy transport in tokamak.

References

1. J. H. Misguich, J. D. Reuss, D. Constantinescu, **G. Steinbrecher**, M. Vlad, F. Spineanu, B. Weyssow, R. Balescu, Annales de Physique (FR), 2003, Vol. 8 (N° 6) November-December 2003, pag. 1- 101.
2. J. H. Misguich, J. D. Reuss, D. Constantinescu, **G. Steinbrecher**, M. Vlad, F. Spineanu, B. Weyssow, R. Balescu, "Noble Cantor sets acting as partial internal transport barriers in fusion plasmas", Plasma Physics and Controlled Fusion, 44 (2002), L29-L35.
3. **György Steinbrecher** and B. Weyssow Generalized Randomly Amplified Linear System Driven by Gaussian Noises: Extreme Heavy Tail and Algebraic Correlation Decay in Plasma Turbulence, Phys. Rev. Lett. 92, 125003-1, 2004
4. B. Weyssow, **G. Steinbrecher**, "Stochastic modelling of the edge plasma turbulence", 11^{th} European Fusion Theory Conference, 26-28 September 2005, Aix-en-Provence.
5. X. Garbet, **G. Steinbrecher**, "On-off intermittency. Exact results". Invited paper presented at the "Solvay Workshop <A Tribute to Radu Balescu>", Brussels, 6-8 March 2008.
6. **G. Steinbrecher**, X. Garbet, "Stochastic Linear Instability Analysis", International Workshop on "Hamiltonian Approaches to ITER Physics", CIRM, Marseille, 2-6 November 2009. http://www.cirm.univ-mrs.fr/web.ang/liste_rencontre/programmes/AbstractsProgRenc395.pdf
7. **G. Steinbrecher**, B. Weyssow, "Stability under Perturbations of the large Time Average Motion of the Dynamical Systems with Conserved Phase-Space Volume", posted on http://lanl.arxiv.org/abs/math-ph/0511091.

I The study of Magnetic Field in Tokamaks using Hamiltonian Description and Mapping Techniques (2000-2007)

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The magnetic field is described by a Hamiltonian system with 1 and ½ degrees of freedom (the Hamiltonian of the system is the poloidal magnetic flux). The mapping technique is applied to trace the magnetic field lines in a poloidal section of the tokamak.

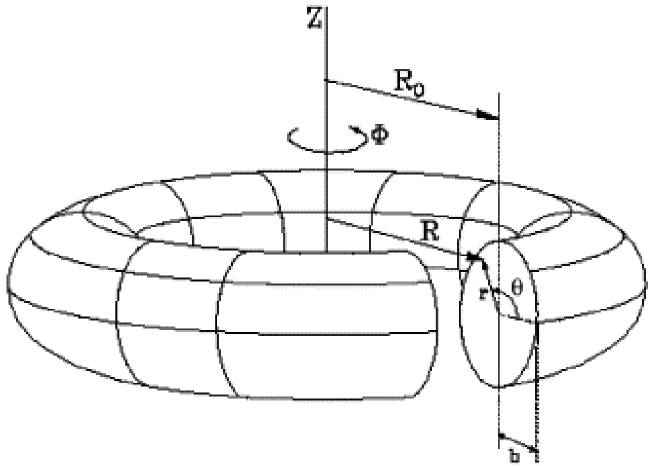

Figure 1 The basic geometry of the tokamak

a) the study of the internal transport barriers in models describing the magnetic configuration in Tore-Supra

Main results:

- **a double sided internal transport barrier**, characterized by a reduced magnetic transport, **was located and described**. It is composed of two Cantori located on two successive "most noble" winding number values of the perturbed safety factor. An external transport barrier (a KAM barrier) was also identified using the Greene's criterion
- **the statistical analysis of a large number of trajectories** representing a bunch of magnetic lines shows the slower dispersion in the chaotic regime, which is different from the usual quasi-linear diffusion in completely chaotic situation. For physical times of the order of the escape time the motion appears to be superdiffusive, but less dangerous than the general admitted quasi-linear diffusion
- **the threshold for breaking-up the external transport barrier** was numerically determined: $K^*=4.878$. For $K<K^*$ a closed magnetic surface exists in the peripheral zone of the tokamak limiting the radial motion of the magnetic line. For $K>K^*$ all the chaotic magnetic lines intersect the tokamak's wall and the magnetic confinement is compromised.
- **a localized control for stabilizing the chaotic orbits which are outside the transport barrier** was proposed and a systematic study of its effects on the transport barriers was realized.

References

[1] Misguich J. H., Reuss J.D., Weyssow B., **Constantinescu D.**, Steibrecher G., Balescu R., M. Vlad, Spineanu F, ***Noble Cantor sets acting as partial internal transport barriers in fusion plasmas,*** Plasma Physics and Controlled Fusion 44/2002, pp. L29-L35

[2] E. Petrisor, J. Misguich, **D. Constantinescu,** *Reconnection in a global model of Poincare map describing the magnetic field lines in a reversed shear tokamak* , Chaos, Solitons and Fractals **18** 2003, pp. 1085-1099

[3] Misguich J. H. , Reuss J. D., Weysow B., **D.Constantinescu**, Steinbrecher G., Balescu R., M. Vlad, Spineanu F., *Noble internal transport barriers and radial subdiffusion of toroidal magnetic lines,* Annales de Physique 28 (2003) N°6, pp. 1-101

[4] **D.Constantinescu**, R. Constantinescu , *Transport barriers and diffusion phenomena for the magnetic field lines in Tokamak",* Physica Scripta , T118 (2005), pp. 244-250

[5] **Constantinescu D**., Misguich J. H., Petrisor E., Pavlenko I., *Internal Transport Barriers in some Hamiltonian systems modeling the magnetic lines dynamics in tokamak",* Journal of Physics, Conference series 7 (2005), pp. 233-238

[6] **D. Constantinescu,** M. Negrea, I. Petrisor, N. Pometescu: On the chaotic magnetic field lines' behavior: the computation of the flux through a Cantorus, ***Physics AUC, vol 10/2000, pp. 95-100***

[7] **D.Constantinescu**, J. H. Misguich , J. D. Reuss, *The study of the breaking-up process of a KAM barrier in the Tokamap model,* Physics AUC vol 12/2002, pp. 78-87

[8] **D. Constantinescu**, B. Weyssow, *Hidden geometrical aspects in the dynamics of nonywist maps,* Physics AUC, vol 14/2004, 151-161

[9] **Constantinescu D**., *Non-linear dynamics and the structure of the magnetic field in tokamak* , Rom. J. Phys. 50, no. 3-4 (2005), pp 325-336

[10] **D. Constantinescu**, J. H. Misguich, J-D Reuss, B. Weyssow, The influence of the safety factor on the formation of the internal transport barriers, Physics AUC vol 17 (2007) pp 190-200

[11] D. Constantinescu, M.-C. Firpo and L. Nasi, *Influence of the q value in the low shear region on the robustness of internal transport barriers,* Presented at EFTC 13, Riga, 12-15 October 2009

b) the study of the FIR-NTM regime in ASDEX-Upgrade tokamak

In the FIR-NTM regime the amplitude of the NTM periodically decreases to a much smaller value and never reaches its saturated value.

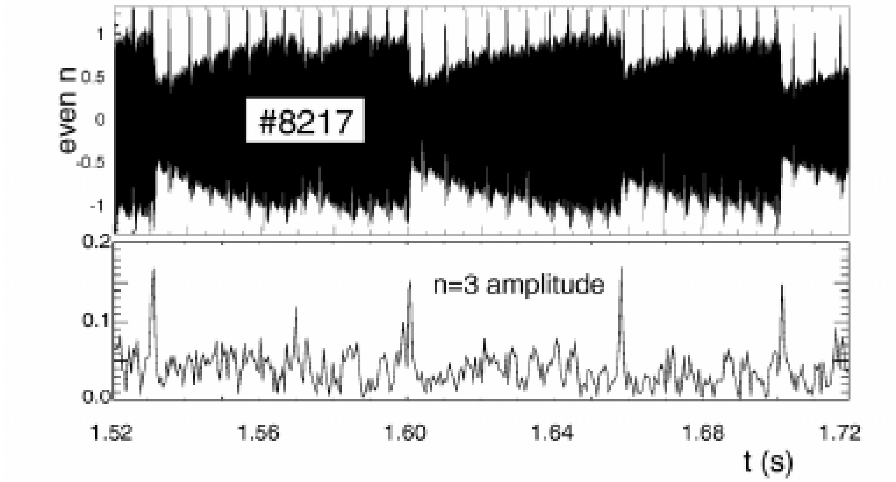

Figure 2. The evolution of the amplitude of the (3,2)mode during #8217

The main results

- **the FIR-NTM regime was explained by the breaking up of the magnetic internal transport barrier** separating the two modes and the stochastization of the magnetic field
- **It was proved that the experimental (4,3) perturbation does not play a special role** in the dynamics of the system and that the FIR-NTM regime is not restricted to these modes, similar phenomena being observed between the resistive mode (4,3) and the ideal (5,4) modes.

References

[1] O. Dumbrajs,V. Igochine**, D. Constantinescu**, H. Zohm, and ASDEX Upgrade team, *Stochastization as a possible cause of fast reconnection in the frequently interrupted regime of neoclassical tearing modes,* Physics of Plasmas **12** (2005), pp 110704-110708

[2] Igochine V., Dumbrajs O., **Constantinescu D**., Zohm Z., Zvejnieks G. and ASDEX-Upgrade team, *Stochastization as a possible cause for fast reconnection during MHD mode activity in the ASDEX Upgrade tokamak*, Nuclear Fusion, **46** (2006), pp 741-751

[3] **D Constantinescu**, O Dumbrajs, V Igochine, B Weyssow, *On the accuracy of some mapping techniques used to study the magnetic field dynamics in tokamaks*, Nuclear Fusion 48 (2008) 024017 (9pp)

[4] Y. Kominis, K. Hizanidis, **D. Constantinescu**, O. Dumbrajs, *Explicit near-symplectic mappings of Hamiltonian systems with Lie-generating functions,* J. Phys. A: Math. Theor. 41 (2008) 115202.

II The study of the sawtooth phenomena observed in ASDEX-Upgrade tokamak (2005-2009)

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Sawtooth oscillations are periodic relaxations of the plasma temperature, density and other plasma parameters in the central region of a tokamak.

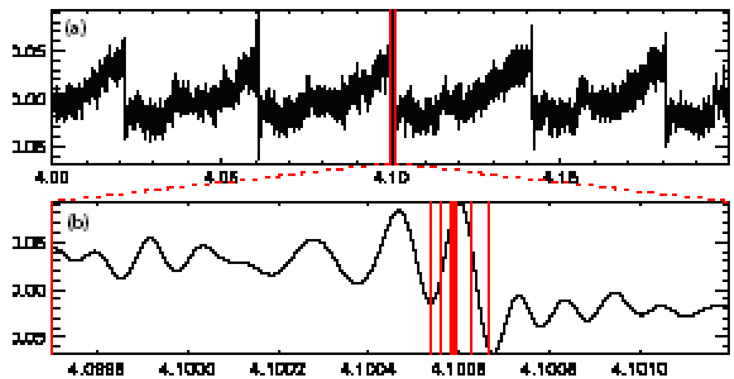

Figure 3 Sawtooth waveform of the repeating growth/crash cycle and a zoom of single crash event

c1)**A hysteresis model** describes the evolution of the central temperature of the plasma using memory effects

The main results

- the model reproduces correctly the two time scales of the sawtooth crash in ASDEX Upgrade tokamak: the slow rise time (~7 miliseconds) and the rapid crash time (~50 microseconds) for appropriate values of the parameters
- the influence of the parameters on the sawtooth period was systematically studied

c2) **A low dimensional model** describes the evolution of the gradient of the current profile during the sawtooth instability

The main results

- The model correctly simulates the sawtooth oscillations.

c3) **A mapping model** describes the changes of the magnetic configuration during the sawtooth instability

The main results

- The previously proposed scenario for the sawtooth magnetic reconnection is motivated by the general properties of Hamiltonian systems that involve a monotonous safety factor, so it is reproducible in many situations. It is crucial that the (1, 1), (2, 2), (3, 3) modes have the same rotation number, so they are situated in the same spatial region.
- This scenario cannot be applied in the case of reversed shear safety factors, due to the specific properties of the safety factor.

References:

[1] Mathematics in Engineering, Numerical Physics and Complexity, 9-11 October 2008, Bucharest, Romania
D. Constantinescu,
Dynamical systems with hysteresis. Applications in fusion plasma physics

[2] The 5th International Conference 2009 - Dynamical Systems and Applications,
June 15-18 Constantza, Romania
D. Constantinescu,
*Dynamical Systems with memory effects. Applications in fusion plasma physics***,**

[3] 10th International Balkan Workshop on Applied Physics", July 6-8 2009, Constanta, Romania
D. Constantinescu, M. Negrea, I.Petrisor,
The study of the sawtooth oscillations in tokamaks using mapping models,

[5] EFTC 13, Riga, 12-15 October 2009
D. Constantinescu, M-C Firpo , M Negrea and I. Petrisor
The study of the sawtooth oscillations in tokamaks using mapping models

[6] EFTC 13, Riga, 12-15 October 2009
D. Constantinescu, O. Dumbrajs, V. Igochine, K. Lackner, R. Meyer-Spasche, H. Zohm
A low-dimensional model system for quasi-periodic plasma perturbations

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1. Intrinsic trapping of stochastic sheared magnetic field lines, Phys. Rev. E **70**, 046409 (2004)

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In the present paper we analyzed the influence of a sheared reference magnetic field on the diffusion of fluctuating magnetic lines. We applied to this problem the decorrelation trajectory method [1]. The method of the decorrelation trajectories was specifically designed in order to take the trapping effect into account. It was applied in previous works to various plasma turbulence situations or, in particular, to the diffusion of guiding centers in presence of a fluctuating electrostatic potential and a constant magnetic field. The latter problem is equivalent to the present one for the shearless case. The behavior of the asymptotic diffusion coefficients is shown in Figs. 1 and 2. The somewhat unexpected feature appearing here is that the magnetic shear increases the final slope. Thus the global trapping effect is weaker for larger shear parameter is, whereas the transient trapping effect is enhanced by the shear. In all cases (except for the shear parameter = 6 for which the final slope was not reached) the final slope is below the Bohm =1.

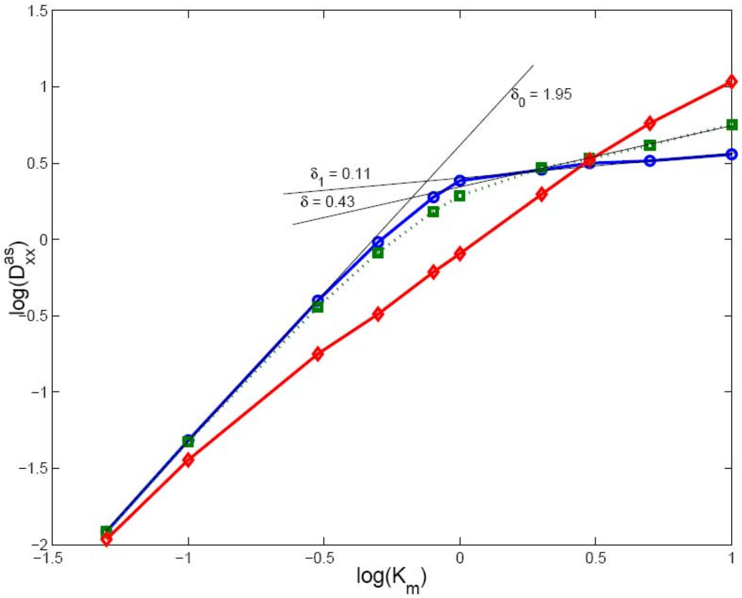

FIG. 1 . The diagonal asymptotic diffusion coefficient D^{as}_{xx} as a function of the magnetic Kubo number K_m for different values of the shear parameter in a $\log_{10}$-$\log_{10}$ plot. Diamonds: θ_s=6. Squares: θ_s=1. Circles: θ_s=0.

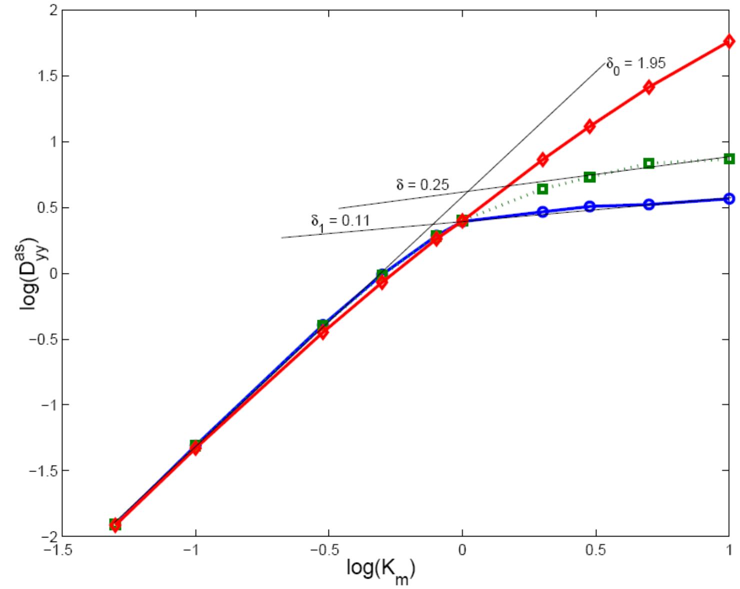

FIG. 2. Same as in Fig. 1 but for D^{as}_{yy}

[1] M. Vlad, F. Spineanu, J. H. Misguich, and R. Balescu, Phys. Rev. E **58**, 7359 (1998)

2. Role of stochastic anisotropy and shear on magnetic field lines diffusion, Plasma Phys. Control. Fusion **49** (2007) 1767–1781

M Negrea and **I Petrisor**, Department of Physics, University of Craiova, Association Euratom-MEdC, Romania
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The diffusion of field lines in a stochastic anisotropic sheared slab representation of the magnetic field in a tokamak is analyzed using the DCT method. In addition to the magnetic shear, the influence of the stochastic anisotropy of turbulence on the field line transport is also considered. This effect is introduced in the dynamics by considering different correlation lengths in the plane perpendicular to the main magnetic field. The third characteristic length is introduced to include a longitudinal decorrelation length. The study shows a rich variety of transport behaviors that are uncovered by varying the anisotropy parameter in the plane perpendicular to the main magnetic field. The strong stochastic anisotropy helps the growth of the averaged poloidal velocity. The averaged Lagrangian poloidal velocity is represented in Fig. 3 for different values of the stochastic anisotropy and for a single value of the magnetic Kubo number and two values of the shear parameter. An increase in the level of the stochastic anisotropy leads to a decrease in the trapping time interval. Once the trapping time is over, the average poloidal velocity increases again. The final stage is reached with the saturation of the average velocity. The ratio represented in Fig. 4 is in agreement with the result reported in [2]. A small deviation from the linearity is caused by the magnetic shear.

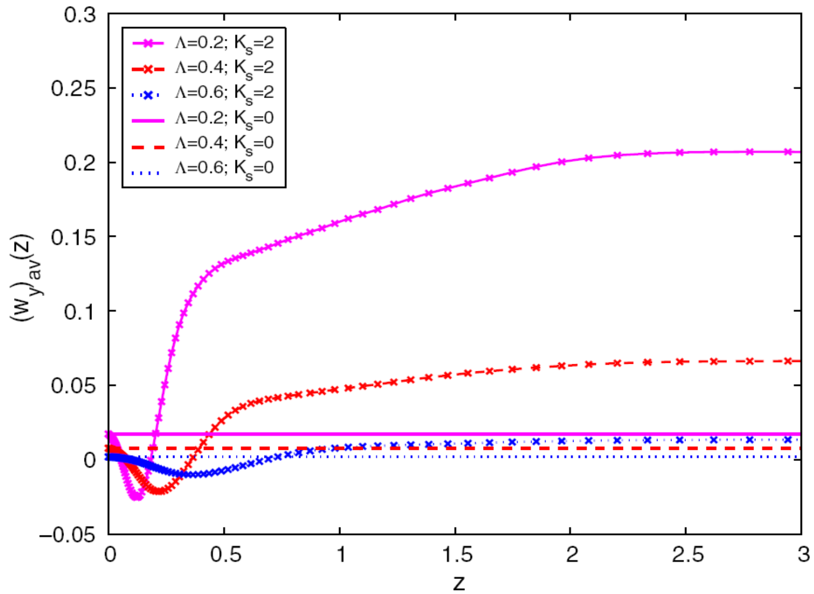

Figure 3. Average poloidal velocity for different values of the y-anisotropy. The other parameters are set to $K_m = 0.5$ and $K_s = 0$ or $K_s = 2$.

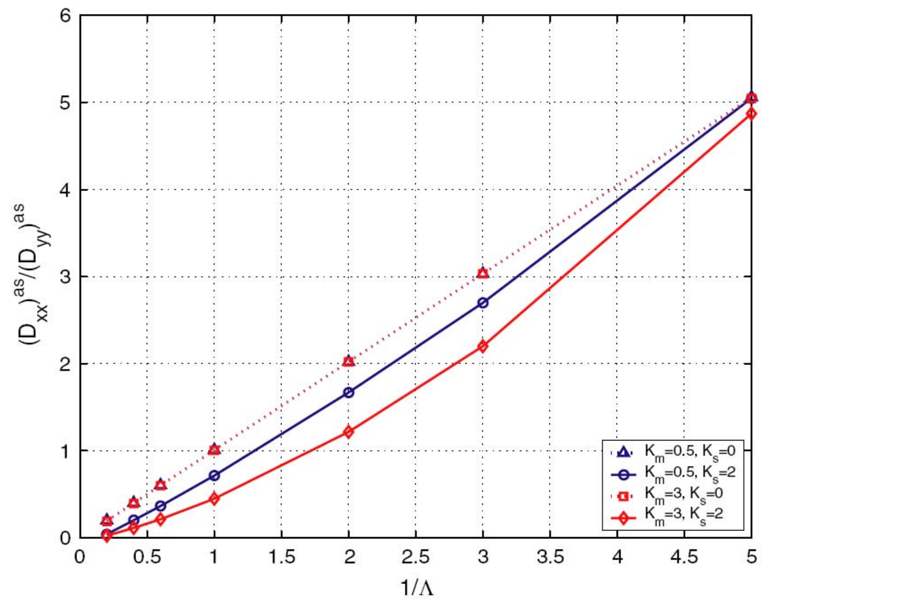

Figure 4. Ratio of the radial to the poloidal asymptotic diagonal diffusion coefficients as a function of $1/\Lambda$ for different values of K_m and K_s. (a) triangle: $K_m = 0.5$ no shear $K_s = 0$; (b) square: $K_m = 3$ and no shear $K_s = 0$; (c) circle: $K_m = 0.5$ and shear $K_s = 2$; (d) diamond: $K_m = 3$ and shear $K_s = 2$.

[2] P. Pommois, P.Veltri and G. Zimbardo, Phys. Rev. E 63 066405 (2001).

3. Electron diffusion in a sheared unperturbed magnetic field and an electrostatic stochastic field, Phys. Scr. **75** (2007) 1–12

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and **B Weyssow**, Physique Statistique–Plasmas, Association Euratom-Etat Belge, Universite Libre de Bruxelles, Belgium

The electron diffusion induced by a two-dimensional electrostatic turbulence, in a sheared slab approximation of the toroidal magnetic geometry, is studied firstly using the DCT method, secondly by direct numerical simulation. The DCT results are compared to the transport properties of the electrons obtained by numerical simulations assuming an isotropic spectrum of electrostatic drift type turbulence that is Gaussian for small wave-vectors and power law for large wave-vectors. The 'radial' and the 'poloidal' running and asymptotic diffusion coefficients of thermal electrons are obtained for physically relevant parameter values. The existence of enhanced diffusion in the poloidal direction is observed in the presence of magnetic shear. The agreement between the semi-analytical method and the purely numerical method is pointed out. In Fig. 5 the DCT results are presented while in Fig. 6 the numerical results are plotted.
It was shown in the case of isotropic 2D electrostatic turbulence that under certain circumstances, the drift-wave turbulence is able to generate spontaneously a shear flow in the poloidal direction. The average wave vector of this flow (or equivalently, its mean square) is much smaller in the poloidal direction in the tokamak than in the radial direction. This type of structure, elongated in the poloidal direction, is called a zonal flow.

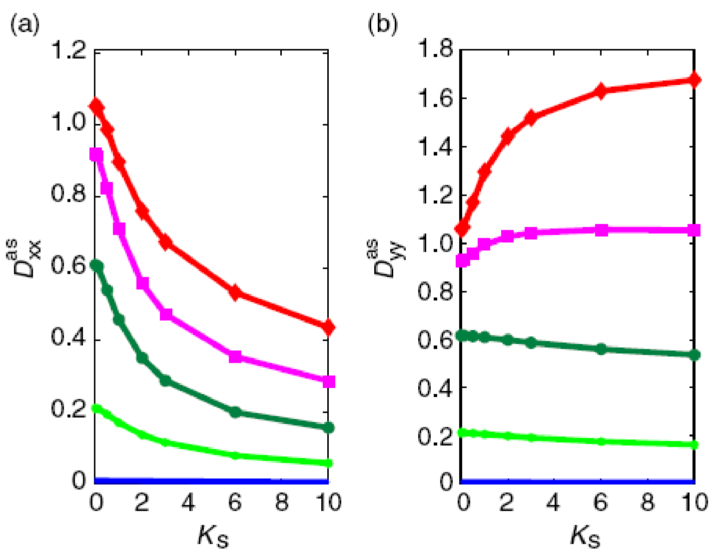

Figure 5. Asymptotic diffusion coefficients: (a) D^{as}_{xx} and (b) D^{as}_{yy} as functions of the shear Kubo number for different values of the level of turbulence: $K = 2$ (♦), $K = 1.5$ (■), $K = 1$ (•), $K = 0.5$ (∗), $K = 0.1$ (·).

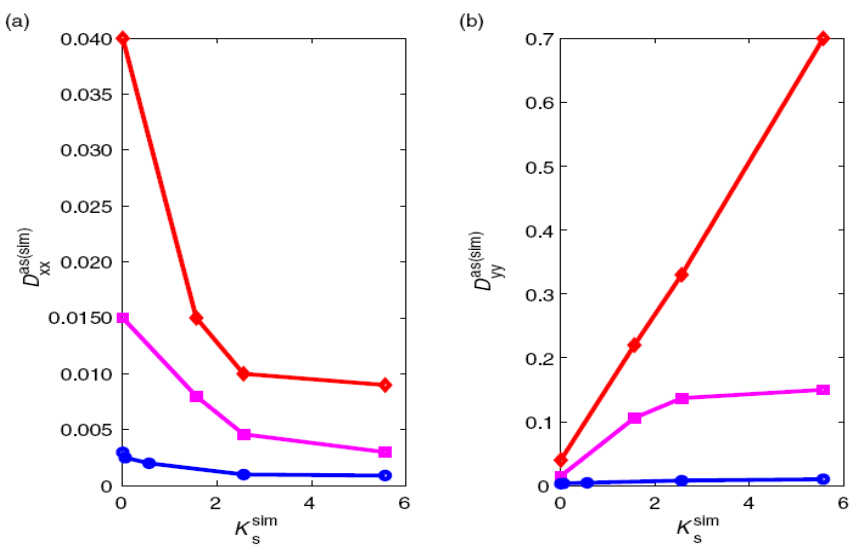

Figure 6. The asymptotic radial (a) and poloidal (b) diffusion coefficients as functions of K_s^{sim} for $K^{sim} = 2.56$ (♦), 0.56 (■), 0.056 (•).

4. Anisotropic electrostatic turbulence and zonal flow generation, Plasma Phys. Control. Fusion 47 (2005) 2145–2159

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In this paper we analyzed the running and asymptotic diffusion coefficients of plasma in the case of zonal flow generation by an anisotropic stochastic electrostatic potential. Both the weak and relatively strong turbulence regimes were analyzed. The analysis of the diffusion coefficients in wave vector space provides an illustration of the fragmentation of drift wave structures in the radial direction and the generation of long-wavelength structures in the poloidal direction that are identified as zonal flows. We have shown that the fragmentation of drift wave structures is strongly influenced by the anisotropy parameter, the electrostatic Kubo number and by the initial values of the wave vector. The main contribution of the present work consists in the analysis of the diffusion tensor components. The numerical analysis allows us to state that the generation of the zonal flow structures is strongly influenced by the anisotropy parameter, the pair of the initial wave-vectors and the level of turbulence given by the electrostatic Kubo number K. The value of the ratio from Figs.7 and 8, which must be greater than one in order to explain the radial fragmentation of the structures, i.e. the formation of the zonal flow, was confirmed by our results.

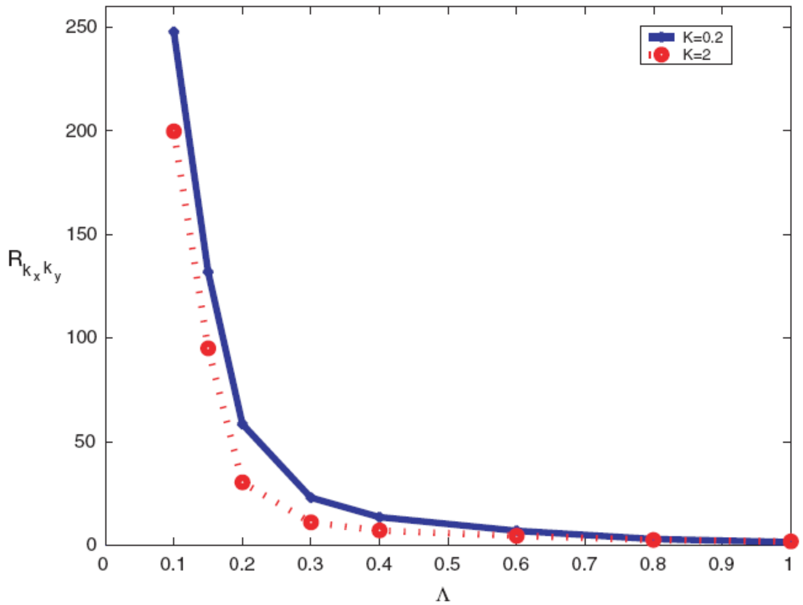

Figure 7. The ratio R_{k_x/k_y} as a function of Λ, for two values of the electrostatic Kubo number: $K = 0.2$, $K = 2$ and ($k_x^0 = \sqrt{0.2}, k_y^0 = \sqrt{0.8}$).

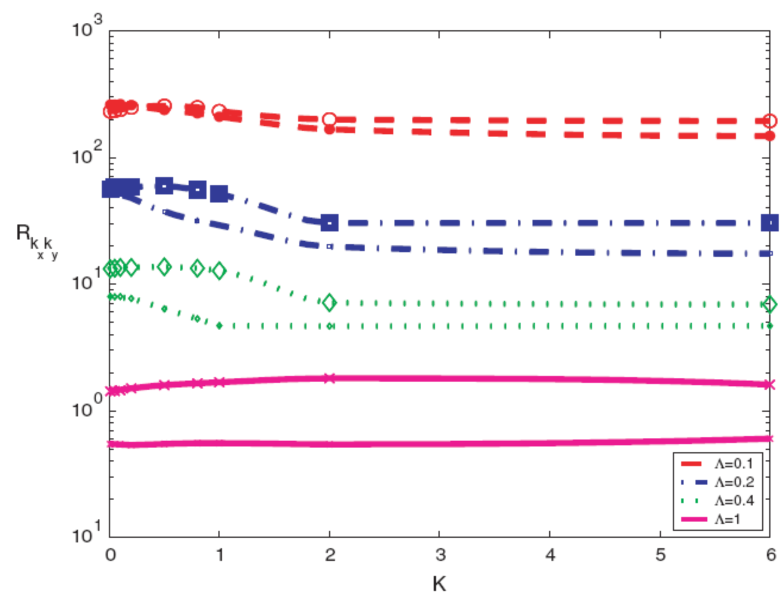

Figure 8. The ratio R_{k_x/k_y} as a function of K for four values of Λ ($\Lambda = 1, 0.4, 0.2, 0.1$); the small markers correspond to the pair ($k_x^0 = \sqrt{0.8}$, $k_y^0 = \sqrt{0.2}$) and the big ones correspond to ($k_x^0 = \sqrt{0.2}, k_y^0 = \sqrt{0.8}$).

5. Characterization of zonal flow generation in weak electrostatic turbulence, Phys. Scr. 77 (2008) 055502

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The influence of the diamagnetic Kubo number, which is proportional to the diamagnetic drift velocity, on the zonal flow generation by an anisotropic stochastic electrostatic potential is considered. The analysis is performed in the weak turbulence limit and as an analytical tool the decorrelation trajectory method is used. It is shown that the fragmentation of the drift wave structures (a signature of the zonal flow generation) is influenced not only by the anisotropy parameter and the electrostatic Kubo number as expected, but also by the diamagnetic Kubo number. The main result given here concerns the influence of the diamagnetic effect and of the stochastic anisotropy on the generation of zonal flow. We have also calculated global Lagrangian averages of the wave-vector, the group velocity and drift wave-frequency; their time evolutions have confirmed the tendency of suppression of zonal flow when the initial wave-vector is $k_{0x} = (0.8)^{1/2}$, $k_{0y} = (0.2)^{1/2}$. The diamagnetic effect and the stochastic anisotropy produce a suppression of the zonal flow mode; this tendency 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, i.e. in the values of the diffusion coefficients in wave-vectors space. In Fig.9 it is clear that the ratio diminishes when the diamagnetic Kubo number K_d increases for a fixed level of electrostatic turbulence but different values of the anisotropy; the zonal flow generation that is given by the ratio is suppressed by the increase in K_d (note the different orders of magnitude of the ratio which is influenced by the level of the anisotropy).

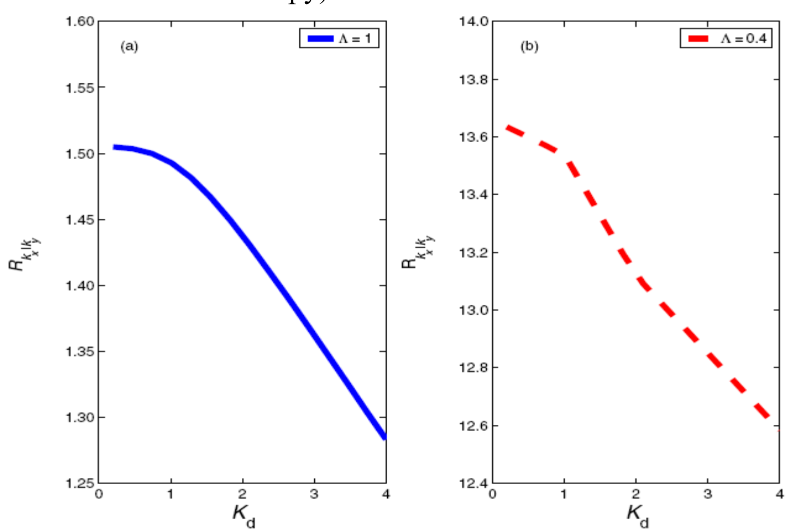

Figure 9. The ratio $R_{k_x/k_y} \equiv \mathcal{D}^{as}_{k_x|dk_x} / \mathcal{D}^{as}_{k_y|k_y}$ as functions of the diamagnetic Kubo number for $\Lambda = 1$ (subplot (a)) and $\Lambda = 0.4$ (subplot (b)).

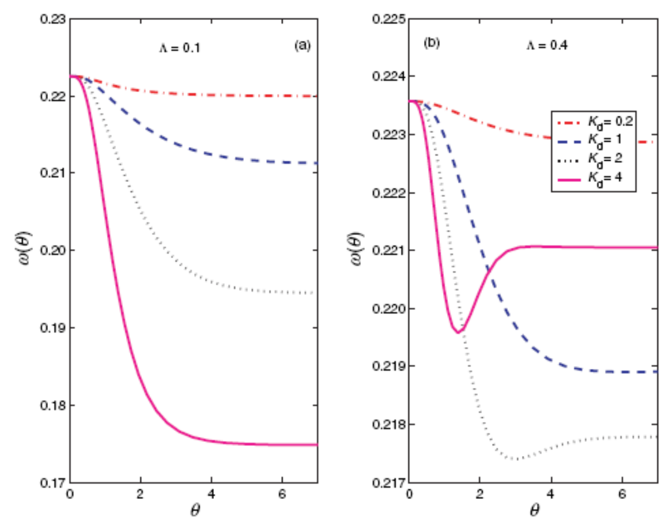

Figure 10. The Lagrangian global average of the normalized drift wavefrequency for $k_{0x} = (0.8)^{1/2}$, $k_{0y} = (0.2)^{1/2}$, $K = 0.2$, $\Lambda = 0.1$ (subplot (a)) and $\Lambda = 0.4$ (subplot (b)) and four values for the diamagnetic Kubo number.

6. ***Aspects of the Diffusion of Ions in Tokamak Plasma***, EFTC 13, Riga, 12-15 October 2009

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7. ***Aspects related to the magnetic field lines diffusion in tokamak plasma***,
Marian Negrea, Iulian Petrisor, Boris Weyssow and Heinz Isliker, invited lecture at Volos 2009 - School of Fusion Physics & Technology

8. ***Test-particle simulations of ion drift in stochastic magnetic fields***, at 36th EPS Conference on Plasma Physics, June 29 - July 3, 2009, Sofia, Bulgaria
H. Isliker, A. Vogiannou, L. Vlahos, **M. Negrea, I. Petrisor**, B. Weyssow

We considered ion diffusion in a magneto-static, perturbed magnetic field environment, and in the present study we have shown that the stochastic drifts provide a decorrelation mechanism of the particles from the magnetic lines. A subdiffusive behavior of the particle mean square displacement is not possible and the particles diffuse even in the absence of the perpendicular collisional diffusion. It was shown that the trapping effect is more pronounced, the larger drift Kubo number is. The diagonal coefficients start with a linear part, defining a ballistic regime followed by a trapping regime before reaching the saturation asymptotic value. Thus the global trapping effect is enhanced at larger drift Kubo number; the stochastic magnetic drift has practically the same influence on ion's diffusion as the magnetic shear on the intrinsic diffusion of magnetic field lines. An increased value of K_{dr} produces oscillations around the starting point in a given subensemble. The trapping effect is more pronounced the larger Λ and K_m are. We have constructed also a numerical code and we have calculated the diffusion coefficients. The system of equations is numerically integrated with a fourth order Runge Kutta, adaptive step-size method. By construction, the magnetic field was considered periodic in all three directions, and particles leaving the simulation box were re-injected at the plane opposite to the one through which they leave. We find that the diffusion is of normal nature. The diffusive process slows down with both, increasing strength of the magnetic perturbation, and increasing mass of the ions considered, respectively. The agreement between the decorrelation trajectory method and the numerical simulation result was pointed out, though a different scaling of the diffusion coefficient with the thermal Kubo number is found.

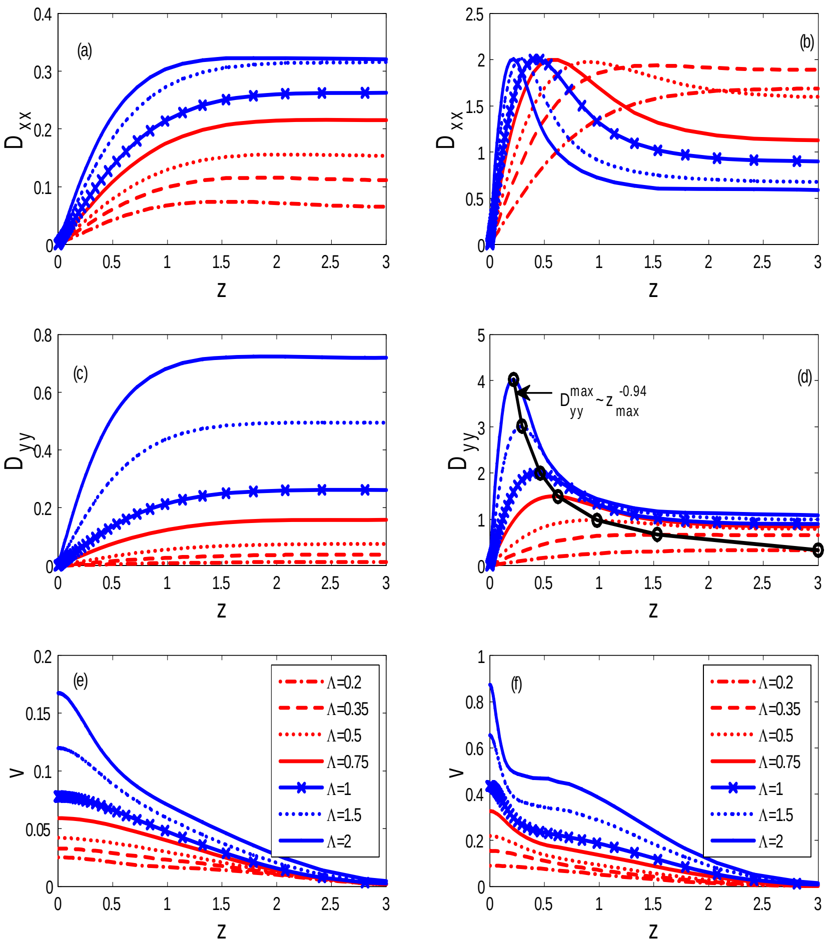

Figure 11. The radial and poloidal running diffusion coefficients and averaged velocities in different regimes in DCT approach.

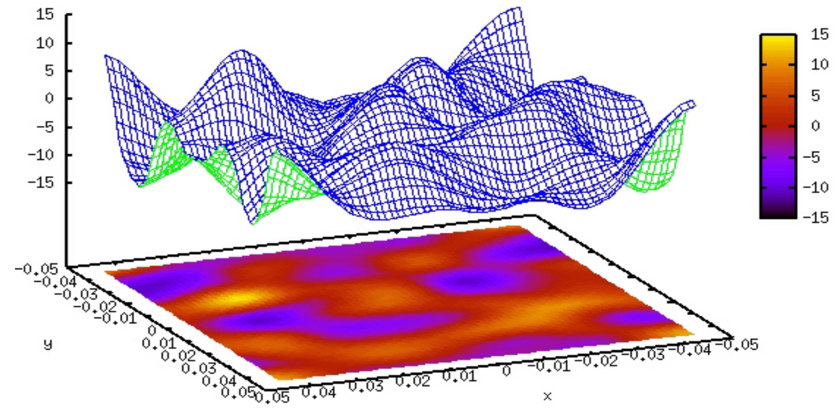

Figure 12. 3-D representation of the b_x component as function of x and y

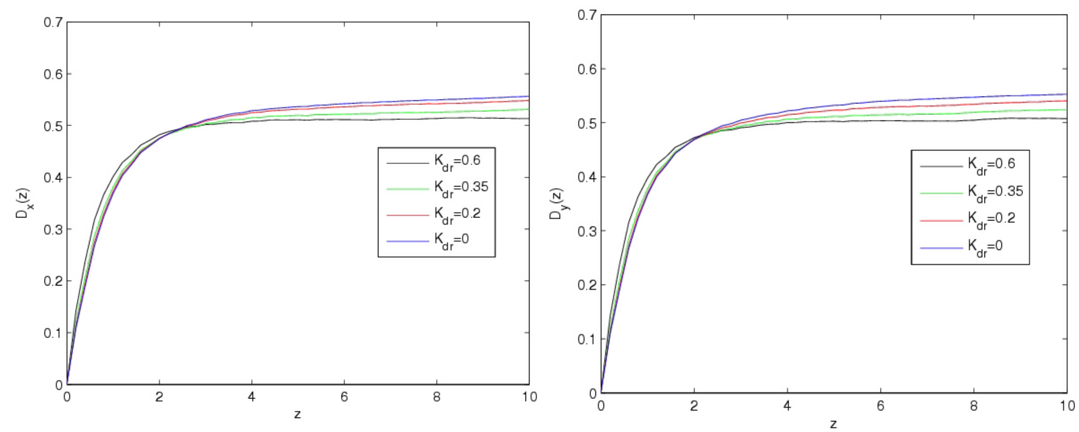

Figure 13. The radial and poloidal running diffusion coefficients obtained by numerical simulation

Future works

(Specific objectives)

Simulations of MHD turbulence

- Study of turbulent zonal flow including test particle and field line transport
- Stochastic magnetic field line diffusion and particle diffusion in MHD in presence of an imposed velocity profile

Study of anomalous transport

- Studies of non-diffusive particle transport using stochastic modelling with application to the edge turbulent transport
- Calculus of the diffusion coefficients for test particles in the edge region of tokamak plasma using the decorrelation trajectory method and numerical simulation.

Collaborations :

- Task agreement: WP10-TRA-05-03, EFDA Work Programme 2010
- Association EURATOM-Etat Belge sur la Fusion, Physique Statistique–Plasmas, Universite Libre de Bruxelles
- Association EURATOM- Hellenic Republic, Department of Physics, Aristotle University of Thessaloniki, Association Euratom-Hellenic Republic, Thessaloniki, Greece

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- Dr. Madalina Vlad and Dr. Florin Spineanu, National Institute of Lasers, Plasmas and Radiation Physics, Bucharest, Romania