EFTSOMP2008 – Workshop on Electric Fields, Turbulence and Self-Organisation in Magnetized Plasmas

Satellite Meeting of the 35th EPS Conference on Plasma Physics and Controlled Fusion

June 16-17, Hersonissos, Crete

Organised by:
MTA KFKI – Research Institute for Particle and Nuclear Physics,
Plasma Physics Department, EURATOM-Association

General Information

EFTSOMP2008 – Workshop on Electric Fields, Turbulence and Self-Organisation in Magnetized Plasmas

Satellite meeting of the 35th EPS Plasma Physics Conference

The workshop is a forum to discuss specific topics in more detail and an interactive form after the EPS conference. The specific aim is to stimulate better interaction between the experimental and theoretical communities. The conference will take place on 16-17 June 2008 in Hersonissos, Crete at the Albatros Hotel. Detailed information can be found at the workshop homepage: www.rmki.kfki.hu/~eftsomp2008

Scope:

- Theory and simulation of turbulent transport
- Flow – turbulence interaction
- Edge – SOL transition
- Physics of transport barriers and ELMs
- Comparison of turbulence theory with experiments
- Diagnostic techniques for electric fields and fluctuations

International Advisory Board

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Presentations

Oral presentations are envisaged. Each section will consist of an invited talk of 35 minutes and several 20 minute oral contribution.

Social Programme

Informal dinner is planned at the end of the first day to strengthen current and encourage possible future collaborations. The dinner will be held in one of the traditional Greek restaurants of the island and will continue the tradition of the Czech-Hungarian heritage of the EFSREP satellite workshop series.

Proceedings

Refereed contributions will be published in Plasma Physics Reports (Journals homepage: http://www.springerlink.com/content/1562-6938/). The papers should be prepared in Word or TeX format. Templates can be found online on the workshop's or the journals' homepage.

Please send the paper and a signed copyright agreement form to eftsomp2008@rmki.kfki.hu. The copyrights agreement forms will be sent to each registered participant, but can also be found online on the workshop's homepage.

Registration and fees

Participants are invited to register by sending an E-mail to eftsomp2008@rmki.kfki.hu. Please include your full name, E-mail address and affiliation. The one page abstracts should be sent in Word or TeX format.

Fee: 150 €. The invoice and information on the payment will be sent out to each participant after acceptance of abstracts.

Deadlines

Abstract:	21 March
Notification of acceptance:	15 April
Submission of paper:	15 July

Organisation

The workshop is organised by the Hungarian Euratom Association – KFKI Research Institute for Particle and Nuclear Physics, Budapest, Hungary.

Organising Committee:

Sándor Zoletnik (KFKI RMKI - HAS)
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MONDAY, 16 June, 2008

Session 1 – Electric Fields in Plasmas Chair: M. Porkoláb

I1-1.1 Monday 8.30 - Invited talk

Mechanisms affecting radial electric field in the SOL

A.V.Chankin, et al.
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Radial electric field (E_r) is the key parameter influencing turbulent and steady state plasma flows in the SOL. Its direct experimental impact on the plasma behaviour was demonstrated in biasing experiments, where externally induced E_r was shown to be capable of varying parallel/toroidal plasma flow and triggering a sudden change in perpendicular turbulent transport (L-H transition). Understanding mechanisms responsible for the E_r formation in the SOL is therefore an important prerequisite for interpretation and prediction of various transport phenomena in current and future fusion devices.

In a simple SOL theory, E_r originates due to the radial gradient of the Debye sheath across the limiter/target leading to the relation $eE_r \approx -3\nabla_r T_e$, where electron temperature is assumed to be constant along the field lines right up to the contact with material surfaces. The largest departure from this simple relation is seen in regimes with high recycling divertors, where neutral ionisation and charge-exchange lead to the appearance of several additional indirect contributions to E_r, via poloidal asymmetries. Among them are: thermoelectric force ($-0.71\nabla_{||}T_e$, for singly charged ions), ion-electron friction force $ej_{||}/\sigma$ caused parallel currents, and parallel electron pressure gradient $-\nabla_{||}p_e/n_e$. All these contributions are included in the main present-day 2D edge fluid codes. The codes also account for direct generation of radial electric currents due to ion-neutral collisions as well as radial drift fluxes, but ignore prompt ion kinetic losses and turbulent-driven contributions via Reynolds stress.

The talk will cover qualitative analysis of main contributions to the E_r formation in the SOL, and will include results of simulations of JET and ASDEX Upgrade plasmas with EDGE2D and SOLPS (B2.5-Eirene) 2D edge fluid codes, respectively. These results were recently compared with experimental measurements of E_r by reciprocating Langmuir probes and Doppler reflectometer (the latter – only for ASDEX Upgrade plasmas). Discrepancies in E_r values between the code results and experiments will be discussed, focusing on the possible role of missing physics in the codes.

O1-1.2 Monday 9.10

Radial electric field profiles in JET advanced tokamak scenarios with toroidal field ripple

K. Crombé[1], Y. Andrew[2], T.M. Biewer[3], P. de Vries[2], C. Giroud[2], N.C. Hawkes[2], A. Meigs[2] , T. Tala[4] and JET-EFDA contributors*

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A dedicated campaign to study the effect toroidal field (TF) ripple on plasma performance has been carried out on JET. The toroidal rotation velocity (v_ϕ) profiles are modified by the ripple induced losses of both fast and thermal ions creating an edge region with counter rotation [1]. The changes in the toroidal rotation profile affect the radial electric field (E_r) and **ExB** shearing rate (ω_{ExB}) and influence the formation and sustainment of internal transport barriers (ITBs) [2]. Neoclassical estimates for poloidal rotation (v_θ) were calculated by NCLASS in the JETTO code.

However, a local spin-up of v_θ in the ITB region has recently been measured on JET [3] and was also observed in plasmas with both reversed and optimised magnetic shear in the presence of various levels of TF ripple. Experimental measurements of poloidal rotation velocity are considerably higher than the neoclassical values and seem to increase with the strength of the ITB (i.e. the pressure gradient). The dependence of v_θ on the local ion temperature gradient scale length and on the background toroidal rotation is examined. The edge and core rotation and pressure gradient profiles are combined for the first time to calculate the full experimental E_r and ω_{ExB} profiles over the entire plasma radius. The relationship between the ITB performance, ω_{ExB} and v_θ is explored for values of TF ripple similar to those expected on ITER. A comparison is made between plasmas with strongly reversed and optimised magnetic shear.

[1] P. de Vries et al., *Nucl. Fusion* **48** (2008) 035007
[2] P. de Vries et al., “Toroidal Field Ripple and the Formation of Internal Transport Barriers” accepted for publication in *PPCF* (2008)
[3] K. Crombé et al., *Phys. Rev. Letters* **95** (2005) 155003
*See appendix of M.L. Watkins et al., Proc. 21st Int. Conf. On Fusion Energy 2006 (Chengdu, China) Vienna: IAEA

O1-1.3 Monday 9.35

Charge Separation and Electric Fields at the Edge of a Cylindrical Plasma

M. Shoucri
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We use an Eulerian Vlasov code for the numerical study of the problem of the generation of radial electric fields and poloidal flows to achieve radial force balance at the steep gradient of a cylindrical plasma column, in the presence of an external magnetic field applied along the axis of the cylinder. This problem is of importance for the physics of an H-mode in a tokamak. The problem is solved for the case when the ion gyro-radius ρ_i is much larger than the Debye length λ_{De} (ρ_i/λ_{De}=14 in our calculation). An Eulerian code is used to solve the Vlasov-Poisson system for the ions [1], two-dimensional in space (r,θ) and in velocity space (radial and poloidal), and uniform in the z direction. The constant magnetic field directed in the z-direction is assumed of the form $B_z = B_0 (1+\varepsilon\cos\theta)$, where B_0 is the magnetic field in the center, and $\varepsilon=0.2$. Two cases will be considered. In the first case the plasma edge is assumed free (no floating limiter is placed in front of the plasma edge). In the second case the plasma is facing a floating limiter. The electrons, frozen by the magnetic field lines, have a constant density profile, which varies in space rapidly along the gradient over an ion orbit size. The frozen electrons cannot then move across the magnetic field to compensate the ion charge which results from the finite ions' gyro-radius along the gradient. Therefore a charge separation appears at the edge of the plasma. We compare the electric field calculated from the kinetic code along the gradient with the macroscopic values calculated for the gradient of the ion pressure term, and we find that these quantities balance each other along the gradient very well. For the two cases we mentioned, we find that the Lorentz force term is negligible along the gradient. For the two-dimensional problem we study, we find that the *ExB* drift is balanced fairly well by the diamagnetic drift along the gradient, so that the total poloidal current is essentially zero.

[1] M. Shoucri, H. Gerhauser, K.H. Finken, *Comp. Phys. Comm.* **164**, 138 (2004)

O1-1.4 Monday 10.00

Characterization of the electric potential profile in ECRH and NBI plasmas on TJ-II stellarator

A.V. Melnikov[1], L.I. Krupnik[2], C. Hidalgo[3], L. Eliseev1, A. Chmyga[2], A.D. Komarov[2], A.S. Kozachok[2], S. V. Perfilov[1], A. Zhezhera[2], M.A. Pedrosa[3], J. L. de Pablos[3]

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3 Laboratorio Nacional de Fusión, EURATOM-CIEMAT, Madrid, Spain

The direct measurements of an electric potential and its fluctuations in a core plasma are of a primary importance for the understanding of the mechanisms of the confinement improvement in toroidal plasmas and the role of the electric field in plasma confinement.

Heavy Ion Beam Probe diagnostics is used in TJ-II stellarator to study directly the plasma electric potential with a good spatial (up to 1cm) and temporal (up to 2 μs) resolution. The singly charged heavy ions Cs^+ with energies up to 125 keV are used to probe the plasma column from the edge to the core. On and off ECR heated plasmas (P_{ECRH}= 300 - 600kW) were studied.

The significant improvement in the beam control system and the acquisition electronics leads us to the increase of the possibilities of the diagnostics. The most crucial one is the extension of the signal dynamic range, which allows us to have the reliable profiles from the plasma center to the very edge [1].

Low density ($n = 0.3\text{-}0.5\times10^{19}$ m^{-3}) ECRH plasma in TJ-2 is characterized by positive plasma potential, $\varphi(0)$ = + 800 - + 400 V. At higher densities the minor area of the negative electric potential appears at the edge. This area increases with the density, finally makes potential fully negative. This tendency is affected by ECRH power and deposition area. The NBI plasmas (P_{NBI}= 300 - 600kW) are characterized by negative electric potential in the full plasma column from the center to the edge, $\varphi(0)$ = – 300 – 600 V.

These results show the clear link between plasma potential, temperature, density and particle confinement.

[1] A. Melnikov et al., *Fusion Science and Technology* (2007), **51** (No 1) 31

Session 2 – Statistics in Plasma Turbulence   Chair: U. Stroth

I1-2.1 Monday 10.50 - Invited talk

Test Particle Approaches in Plasmas

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The test particle approach provides a method to study transport from a very basic viewpoint and potentially provide improved understanding of the underlying processes. It is capable of providing information not retrieved using standard transport diagnostic methods (typically, via profile measurements): namely, the separation of convective and diffusive fluxes, the unambiguous detection of non-diffusive behaviour (non-Gaussian distributions, long-range and long-time correlations), etc.

In this talk, we will review some basic concepts of the Continuous Time Random Walk, providing a basic and general description of transport, very appropriate for the concept of test particles. We will then introduce a series of techniques allowing the extraction of important transport parameters, and illustrate this by showing some applications of these techniques on data from a turbulence code.

When looking towards applying such techniques in actual plasmas, a clear distinction should be made between 'mathematical' tracers and 'physical' particles.

Therefore, in our closing remarks, we will hint at some of the possibilities and limitations regarding the use of impurities as test particles in experiments.

O1-2.2 Monday 11.30

Nondiffusive transport in plasma turbulence

L. Garcia[1], J.A. Mier[1], R. Sanchez[2], B.A. Carreras[3], I. Calvo[4], D.E. Newman[5]

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Experimental evidence indicates that transport in magnetically confined fusion plasmas deviates from the standard diffusion paradigm. In particular, transport in fusion plasmas lacks of characteristic scales in space and time. Several theoretical approaches have been explored in the last years to explain these experimental findings. Among them, continuous-time random walk (CTRW) models with Lévy probability distribution functions (pdf) stand out since transport lacks any characteristic scale in these models [1]. In the fluid limit, these models lead to a description of transport in terms of fractional differential equations [2].

Here, we try to confirm the existence of this kind of distributions in numerical simulations of plasma turbulence. We have followed the evolution of fluctuations for three different fluid models: 1. pressure-gradient-driven turbulence in toroidal geometry (ballooning modes) [3]; 2. dissipative trapped electron mode in cylindrical geometry [4]; 3. tearing modes in cylindrical geometry. The first two correspond to electrostatic turbulence in tokamaks, and the third one to magnetic turbulence in a reversed field pinch.

To characterize the transport properties induced by the turbulence, we investigate the time evolution of pseudo-particle tracers. From the information on tracer orbits, we calculate the pdf of flights, and determine power-law tail exponents. From the information on the Lagrangian correlations along the particle tracer orbits, we determine the Hurst exponent. The results for the electrostatic modes show that the transport is superdiffusive and non-Markovian [3]. We are now characterizing the transport for the magnetic simulation.

[1] B.Ph. van Milligen, R. Sanchez and B.A. Carreras, *Phys. Plasmas* **11**, 2272 (2004)
[2] R. Sanchez, B.A. Carreras, and B.Ph. van Milligen, *Phys. Rev. E* **71**, 011111 (2005)
[3] L. Garcia and B.A. Carreras, *Phys. Plasmas* **13**, 022310 (2006)
[4] J.A. Mier, L. Garcia and R. Sanchez, *Phys. Plasmas* **13**, 102308 (2006)

O1-2.3 Monday 11.55

Long-range Correlation of Fluctuations during Edge Sheared Flows Development in the TJ-II Stellarator

M.A. Pedrosa, C. Silva[1], C. Hidalgo, D. Carralero,
B.A. Carreras[2], R.O. Orozco and the TJ-II team

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The importance of the *ExB* sheared flows as a stabilizing mechanism to control plasma fluctuations in magnetically confined plasmas has been widely established. First and secondorder phase transition models, with *ExB* sheared flow as a key ingredient, have been invoked to explain the transition to improved confinement regimes. The correlation length and relaxation time divergence at the critical point of a phase transition are universal characteristics.

TJ-II stellarator has shown up to be an ideal laboratory to unravel the physics of shear flow development and momentum transport in fusion plasmas. Edge sheared flows can be easily driven and damped at the plasma edge of TJ-II changing the plasma density or during biasing experiments. Measurements of the relaxation time of externally induced electric fields show an increase above the threshold gradient to trigger the development of sheared flows in TJ-II. Due to the recent development of two sets of Langmuir probes located at two different positions, approximately 160° toroidally apart, TJ-II has been positioned as an excellent laboratory for investigating also long-distance correlations.

Different edge plasma parameters were simultaneously characterized in two different toroidal positions using two similar multi-Langmuir probes, installed on fast reciprocating drives. The correlation between edge density and potential fluctuations measured toroidally apart has been investigated during edge sheared flows development. Results have shown the existence of long-range correlations in potential fluctuations, whereas there is no correlation between ion saturation current (i.e. density) signals, being the effect amplified during the transition to improved confinement regimes (in biasing experiments). These findings show the important role of long-distance correlation as a first step in the transition to improved confinement regimes and the key of electric fields to amplify them, providing a critical test for L-H transition mechanisms (role of ion orbit losses and second order phase transitions based on turbulence driven flows).

Present findings point out the important role of edge diagnostic development to characterize simultaneously at different plasma locations the structure of sheared flows and fluctuations to unravel of physics of sheared flows.

O1-2.4 Monday 12.20

Burst statistics of fluctuations in a simple magnetized torus configuration

K. Rypdal
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Tromsø, Norway

In a toroidal plasma confined by a purely toroidal magnetic field the plasma transport is governed by electrostatic turbulence driven by the flute interchange instability on the low-field side of the torus cross section.

In this presentation we revisit experimental data obtained from the Blaamann torus at the University of Tromsø previously presented in [1]. On time-scales shorter than the poloidal rotation time the time series of potential and electron density fluctuations measured on stationary Langmuir probes essentially reflect the spatial poloidal structure of the turbulent field (Taylor hypothesis). On longer time-scales one mainly observes global fluctuations of the plasma state.

On the short time scales the time-series to the lowest approximation have the character of a self-similar non-stationary process (a persistent fractional Brownian motion). However, both power spectra and variograms reveal marked deviations from this monofractal structure which is interpreted as clustering of bursts in the signals.

We quantify these deviations by computing the multifractal spectra of the time series, and study the multifractal statistics of waiting-time between bursts, and compare this to intermittency properties observed in other toridal devices [2].

We also perform similar analysis on the slow temporal time-scales, and contrast this to analysis aimed to detect low-dimensional chaos in the temporal bursts of global transport.

[1] K. Rypdal, and S. Ratynskaia, *Phys. Plasmas* **10**, 2686 (2003).
[2] V. P. Budaev, S. Takamura, N. Ohno, and S. Masuzaki, *Nucl. Fusion* **46**, S181 (2006).

Session 3 – Turbulence and H-mode Physics **Chair: G. Van Oost**

I1-3.1 Monday 14.00 - Invited talk

Turbulence Studies in Ohmic Plasmas in the Alcator C-Mod Tokamak with Phase Contrast Imaging and Gas Puff Imaging

M. Porkoláb, I. Cziegler, L. Lin, E. Edlund, M. Greenwald, G. Rost, J. Terry, and the C-Mod Team

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D. Mikkelsen, Princeton Plasma Physics Laboratory, Princeton, NJ 08544, USA

Results of ongoing turbulence studies in the Alcator C-Mod tokamak will be presented. The diagnostic technique to measure core turbulence is by means of phase contrast imaging (PCI), a form of internal reference beam interferometry that measures phase variations of an incident laser beam as it passes through the plasma. The reference beam also passes through the plasma and since the laser beam wavelength (CO_2) is much shorter than that of the turbulent fluctuations, the scattered beam is nearly forward scattered. The reference beam is reflected from a “phase plate” which imparts a 90 degree phase shift, and the scattered and reference beams are imaged optically onto a detector array which then transforms the pattern of fluctuations that propagate near perpendicular to the beam onto an image of interference pattern. Thus, the wavelengths and amplitudes of the fluctuations can be determined. With a special “masking plate” the direction of propagation (ie, ion or electron diamagnetic direction) of the shorter wavelength modes can also be determined. Interpretation of the signal is sometimes done by means of a “synthetic diagnostic” technique which account for the path integral of the beam in extended gyrokinetic codes, such as “global” gyro. Results of recent measurements of ITG modes will be presented for ohmically heated plasmas. We note that experiments on studying ITB plasmas in the presence of strong on and/or off-axis ICRF heating are also in progress, however, interpretation of the results is more complicated than in pure ohmic L mode plasmas and will not be discussed here.

In another series of experiments the edge and SOL turbulence has been investigated in the outboard midplane region of ohmic L-mode plasmas in C-Mod, using gas-puff imaging (GPI). GPI has excellent spectral resolution resulting from the vertical extent of the viewing array, an advantage over probe measurements. Poloidal wavenumber information was obtained by a vertical array of views (approximately aligned with a flux surface) which is coupled to a set of photo diodes with a 1 MHz sampling rate. The velocity field of the region was characterized by broad-band turbulence with a strong radial variation in the direction of propagation. The results show intricate behavior of the turbulence in the vicinity of the separatrix, which is not always in agreement with probe measurements. Fluctuations move in the ion diamagnetic direction outside the separatrix, and in the electron diamagnetic direction just inside the separatrix. The dispersions are largely linear with the velocities, in agreement with probe measurements, of order 1-2 km/sec in the ion direction and 3-4 km/sec in the electron direction. Because of the capability to measure fast time scale evolution of the turbulence, differences from probe measurements have been discovered. We believe that the mechanism of blob formation and ejection can be determined in future experiments.

Work supported by US DOE under DE-FG02-94-ER54235 and DE-FC02-99-ER54512.

O1-3.2 Monday 14.40

Quasi-Coherent Modes in the High Density H-mode regime of the W7-AS Stellarator

E. Belonohy[1], M. Hirsch[2], K. McCormick[3], G. Papp[4], G. Pokol[4], H. Thomsen[2], A. Werner[2], S. Zoletnik[1] and the W7-AS Team

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Impurity accumulation and ensuing radiation collapse of high density plasmas is a potentially serious problem in stellarators. In contrary, the High Density H-mode (HDH) of Wendelstein 7-AS is a promising ELM-free, high collisionality H-mode regime exhibiting surprisingly low impurity confinement coupled to improved energy confinement. Whereas the operational characteristics of the HDH mode have been extensively studied, the mechanism responsible for the low impurity concentration has not yet been found.

Quasi-coherent modes found in the Mirnov coils signals are a possible impurity pump out mechanism. These high frequency (50-350 kHz) modes reside in the pedestal region, can be characterized by high toroidal mode numbers (n~20), and more importantly show strong correlation to the impurity radiation. These properties strongly resemble the quasi-coherent modes in the Enhanced D-alpha (EDA) regime that are known to be responsible for the low impurity concentration in that high density ELM-free regime of the Alcator C-Mod tokamak.

This contribution characterizes the different instabilities present in the HDH mode and their possible role in the impurity transport, particularly focusing on Quasi-Coherent modes as a prime candidate for an impurity flushing mechanism. Occasionally present low frequency transients and ELMs including their effect on the QC mode will be discussed as well.

O1-3.3 Monday 15.05

External Modification of Intermittent Burst Temporal Characteristics at the Edge of CASTOR Tokamak

I. Nanobashvhili[1,2], P. Devynck[3], **J. Horáček[4],** S. Nanobashvili[1], J. Stöckel[4], G. Van Oost[5]

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Plasma turbulent transport at the edge of tokamaks is the object of one of the most intense studies in modern magnetic fusion research. Nowadays it is widely accepted that edge plasma transport has strong convective character. Large scale turbulent events – density bursts, which are formed intermittently on the diffusive background, play the important role in edge transport. These bursts cause rapid convective radial transport of plasma towards the wall with a speed which is a fraction of the ion sound speed. The most important result of this is that core plasma confinement degrades. At the same time in large scale tokamaks, especially in next generation devices like ITER, density bursts can cause the strong erosion of the first wall and unwanted retention of tritium. Therefore, it is very important to understand the physical nature of edge plasma turbulent transport – especially the origin and dynamics of density bursts – and develop the methods for their external modification and control.

Recently it has been shown that study of the intermittent burst temporal characteristics is an effective way for the understanding the plasma turbulent transport at the edge of tokamaks [1-3]. As for the methods for the external modification of intermittent density bursts in the CASTOR tokamak, we have used the plasma polarization (biasing). In particular, the graphite electrode has been inserted into plasma and biased with respect to the vacuum chamber wall. We used Langmuir probes for the detection of density bursts and measurements of their temporal characteristics such as average burst rate and average burst duration.

Plasma polarization – biasing at the edge of the CASTOR tokamak significantly modifies the burst temporal characteristics compared to the Ohmic discharge conditions. In particular, average burst rate increases and average burst duration decreases compared to the same characteristics in Ohmic regime. The reason of this is that biasing imposes strong shared poloidal rotation on plasma, splits large coherent structures which we had in Ohmic phase into smaller ones and rapidly moves them poloidally. As a result during biasing the Langmuir probe detects larger number of bursts than in Ohmic phase and average burst rate increases. As for the decrease of average burst duration during biasing the reason of this is that during biasing we have smaller structures which move faster than in Ohmic phase, therefore they need less time to cross the probe pins and ave-rage burst duration decreases. We also observe the increase of average plasma density during biasing. The reason of this is that biasing splits coherent structures and reduces the radial trans-port thereby improving confinement. Thus, biasing is an effective mechanism for the improvement of plasma confinement in tokamaks.

[1] I. Nanobashvili, J. P. Gunn, P. Devynck, *J. Nucl. Mater.*, **363-365**, 622, 2007.
[2] I. Nanobashvili, J. P. Gunn, P. Devynck, G. Ciraolo, Ph. Ghendrih, Y. Sarazin, *Czech. J. Phys.*, **56**, 1339, 2006.
[3] I. Nanobashvili, P. Devynck, S. Nanobashvili, P. Peleman, J. Stöckel, G. Van Oost, Plasma Phys. Reports, accepted for publication, 2008.

Session 4 – Edge Turbulence **Chair: Y. Xu**

I1-4.1 Monday 16.00 - Invited talk

Multi-Probe Measurements and Simulation of Global Edge-Turbulence Properties in the Torsatron TJ-K

M. Ramisch[1], A. Köhn[1], N. Mahdizadeh[2], P. Manz[1], B. Scott[3], U. Stroth[1]

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2 ABB Switzerland Ltd, Corporate Research, Switzerland
3 Max-Planck Institut für Plasmaphysik, Garching, Germany

In recent years, comprehensive turbulence investigations in the toroidally confined plasma of TJ-K have given insight into the structure of plasma edge turbulence. In agreement with turbulence simulations, drift-wave signatures in the density-potential cross-phase were found at all spatial scales [1]. Two-dimensional probe measurements resolved the dynamics perpendicular to the magnetic field [2]. The extension of the perpendicular measurements to 3D demonstrated the parallel structure [3]. The next objective is to measure turbulence properties on the entire flux surface to capture the global nature of the fluctuations in close comparison with state-ofthe-art simulation codes. This contribution is dedicated to detailed investigations of fluctuation properties on flux surfaces in the poloidal cross-section with the focus on poloidal asymmetries relying on curvature effects. The impact of good and bad magnetic curvature on drift-wave turbulence incorporating the spatial cross-phase and radial turbulent transport is studied. A novel diagnostics consisting of 128 probes allows for simultaneous measurements on four adjacent flux surfaces giving radial as well as poloidal information at the same time. Experimental results are compared with results from global gyrofluid computations.

[1] U. Stroth et al., *Plasma Phys.* **11**, 2558 (2004).
[2] M. Ramisch et al., *Plasma Phys.* **12**, 032504 (2005).
[3] N. Mahdizadeh et al., *Plasma Phys. Controll. Fusion* **49**, 1005 (2007).

O1-4.2 Monday 16.40

Turbulence investigation in TJ-K and ASDEX Upgrade

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and the ASDEX Upgrade Team

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2 Max-Planck-Institut für Plasmaphysik, Euratom Association, Garching, Germany

The typical properties of drift-wave turbulence have been observed in the low-temperature plasma of the torsatron TJ-K [1]. The dimensional similarity of TJ-K plasmas with the edge of fusion devices suggests that turbulence is dominated by drift waves in both cases. This behaviour is also predicted by numerical simulations using the GEM code [2].

In this contribution, plasma turbulence is investigated at the transition from the edge to the scrape-off layer (SOL) by means of Langmuir probes. Electrostatic fluctuations on both sides of the separatrix are measured, in the low-temperature plasma of TJ-K and the hot plasma of the divertor tokamak ASDEX Upgrade (AUG). A linear probe array for use with the movable midplane manipulator of AUG was designed and built. Similar investigations were carried out in limited TJ-K plasmas with an increased SOL.

The results from both devices support the concept of dimensional similarity. Of special interest are the abrupt changes of the poloidal phase velocities, shown in Fig. 1. They switch from the electron-diamagnetic drift direction in the confined plasma to the ion-diamagnetic drift direction in the SOL. The poloidal correlation length increases close to this shear layer and radial inward transport has been observed. These findings agree with earlier results from biasing experiments in TJ-K [3]. The probability density functions of the ion-saturation current fluctuations indicate that the intermittency in the SOL originates from the shear layer. The potential-density cross phase close to zero in AUG across the entire radial sweep is also consistent with drift-wave turbulence and, hence, with turbulence studies from TJ-K.

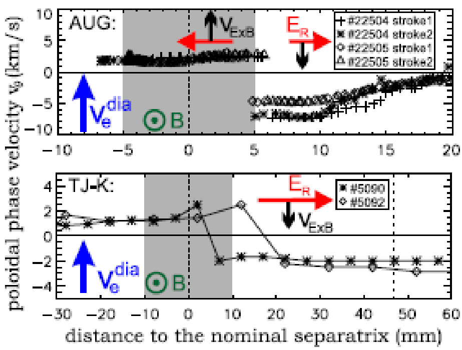

Figure 1: Poloidal phase velocities observed in ASDEX Upgrade and TJ-K. The direction of propagation changes close to the separatrix. The gray area indicates the uncertainty of the separatrix position.

O1-4.3 Monday 17.05

Magnetic and Electrostatic Structures Measured in the Edge Region of the RFX-Mod Experiment

N. Vianello, M. Spolaore, R. Cavazzana, E. Martines, G. Serianni, E. Spada, M. Zuin, V. Antoni

Consorzio RFX, Associazione Euratom-ENEA sulla Fusione, Corso Stati Uniti 4,35127 Padova, Italy

Coherent structures emerging from turbulence background have been detected in the edge region of the RFX-mod Reversed Field Pinch fusion device. These structures, often referred in literature as “blobs”, have been previously characterized in the perpendicular plane and in their electrostatic character. In order to gain insight into their electromagnetic nature and features in the parallel direction a new and original probe system has been used that allows measuring both magnetic and electrostatic fluctuations simultaneously and on the same location with a high time resolution

In particular the system consists of two sets of electric and magnetic probes toroidally spaced by 88 mm. Each set is equipped with a 2-D array of Langmuir probes and a radial array of 3-axial magnetic coils. So that fluctuations of velocity patterns and relative vorticity, of density and pressure gradients and of current density are available simultaneously.

Statistical methods have been applied in order to detect structure-related bursts in the turbulence. It has been found that bursts correspond to pressure structures with vortex-like behavior in the cross-field plane and are related to current density filaments mainly oriented along the magnetic field, confirming what postulated by [1,2] and observed in [3]. The associated diamagnetic current density, due to pressure gradient fluctuations will also be provided together with a complete electromagnetic characterization of these structures in terms of current density, pressure perturbation and vorticity.

[1] J. Bergmans, T.J. Schep *PRL* **87** (2001) 195002
[2] J. R. Myra *PPCF* **14** (2007) 102314
[3] Kirk et al. *PPCF* **48** (2006) B433

O1-4.4 Monday 17.30

Universal Properties of Edge Intermittent Turbulence in Different Fusion Devices

M. Agostini[1], R. Cavazzana[1], F. Sattin[1], P. Scarin[1], G. Serianni[1], M. Spolaore[1], N. Vianello[1], R.J. Maqueda[2], S.J. Zweben[3], Y. Yagi[4], H. Sakakita[4], H. Koguchi[4], S. Kiyama[4], Y. Hirano[4], J.L. Terry[5]

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2 Nova Photonics, Princeton, New Jersey, USA
3 Princeton Plasma Physics Laboratory, Princeton, New Jersey, USA
4 National Insitute of Advance Industrial Science and Technology, Tsukuba, Ibaraki, Japan
5 Plasma Science and Fusion Center, MIT, Cambridge, Massachusetts, USA

Statistical and spectral properties of the edge turbulence in different plasma fusion devices (Reversed Field Pinches and Tokamaks) are studied by means of the Gas Puff Imaging (GPI) optical diagnostic and electrostatic Langmuir probes. The edge fluctuations of the electron density show a common behaviour between the different machines: all the signals are characterised by large bursts, which are the signature of the presence of blobs propagating in the plasma edge; intermittent behaviour is found for all the devices, i.e. the statistical properties of the fluctuations depend on the time scale of the fluctuations themselves. Moreover, the Probability Distribution Function of fluctuations of both the GPI and Langmuir probes are well approximated by two Gamma functions: it can be assumed that one describes the background turbulence, and the other is related to the coherent part. Within this framework also the universally found parabolic link between Skewness and Flatness of the fluctuations can be explained.

This universality of findings between the different devices suggests a common physics that underlies the driving of edge turbulence. To study this common nature of the turbulence, the phase relation between electrostatic potential and electron density is characterised, together with the relation between the radial profile of the electron pressure and the number of blobs. The results indicate a possible common role of pressure-driven instabilities in turbulence generation and drive.

TUESDAY, 17 June, 2008

Session 1 – Turbulence Theory   Chair: E. Gusakov

I2-1.1 Tuesday 8.30 - Invited talk

Formation and Propagation of Turbulent Structures in Drift-Wave Turbulence

T. Windisch, O. Grulke, T. Klinger

Max-Planck-Institute for Plasma Physics, EURATOM Association, Greifswald, Germany

Regardless of the specific magnetic field topology, edge turbulence in toroidal fusion devices is characterized by intermittent fluctuations of the density and potential resulting in intermittent transport events. This fluctuation-induced transport of plasma particles and energy across the confining magnetic field affects several key reactor issues, e.g., heat and particle fluxes to the first wall, recycling, the divertor concept and strongly determines the radial evolution of the plasma profiles. Experimental results and numerical simulations clearly show that the intermittent bursts in the scrape-off layer (SOL) can be ascribed to large-amplitude self-organized coherent structures, called 'blobs', which propagate radially outwards through the SOL with a velocity of less than one tenth of the ion sound speed typically. A detailed comparison of the statistical properties of the spatiotemporal fluctuation dynamics revealed that the formation and propagation of such turbulent structures can also be investigated in linearly magnetized laboratory experiments. Studies in the linear helicon discharge VINETA demonstrated that in weakly developed drift wave turbulence the formation of coherent turbulent structures is observed. The turbulent structures peel off quasi-coherent drift wave modes and propagate radially outwards across the confining magnetic field with a velocity of less than one tenth of the ion sound speed [1]. The radial propagation of the structures is

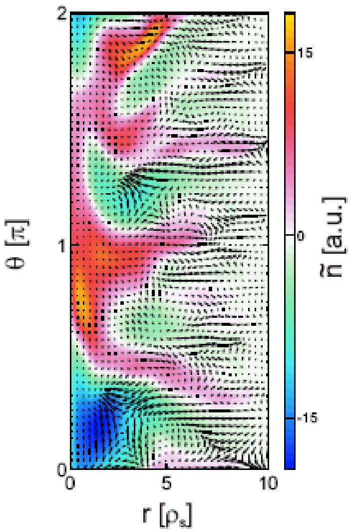

Figure 1: Simulated density fluctuations (colorcoded) in the azimuthal plane and superimposed $E \times B$-velocity.

explained as E_B-convection in the self-consistent potential perturbation, which is caused by the three dimensional dynamics of the drift wave. In this paper the experimental findings are quantitatively compared with numerical three-dimensional fluid simulations with appropriate geometry and boundary conditions usng the code CYTO [2]. Special attention is paid to the mechanism of radial structure propagation.

[1] T. Windisch, O. Grulke, and T. Klinger, *Phys. Plasmas* **13** (2006) 122303
[2] V. Naulin, T. Windisch, and O. Grulke, *Phys. Plasmas* **15** (2008) 012307

O2-1.2 Tuesday 9.10

Full–f Gyrokinetic Simulation of Edge Transport in Medium-Sized Tokamaks

T.P. Kiviniemi[1], J.A. Heikkinen[2], S.J. Janhunen[1], S. Leerink[1], M. Nora[1], F. Ogando[3]

1 Euratom-Tekes Association, Helsinki University of Technology, Finland
2 Euratom-Tekes Association, VTT, Espoo, Finland
3 Universidad Nacional de Educaci´on a Distancia, Madrid, Spain

In order to self-consistently simulate edge particle and heat transport both neoclassical and turbulence physics as well as proper boundary conditions and heating operator are required. In the present work, a global 5D full f gyrokinetic particle simulation code ELMFIRE [1] is used to simulate the tokamak plasma edge. The numerical techniques used are valid for steep gradients and distributions which can significantly deviate from Maxwellian.

This code has recently shown to reproduce the neoclassical electric field [2] and has been benchmarked to experimental results on plasma rotation and turbulence spectra obtained from the FT–2 tokamak Doppler reflectometry diagnostic [3]. Extending such self-consistent simulation from small to medium size tokamaks is a computational challenge. The importance of a proper heating and cooling model is pointed out in determining time behaviour of transport coefficients and profile evolution.

The facilities of CSC (Finnish IT Center for Science) and DEISA consortium have been used in this work.

[1] J.A. Heikkinen, S.J. Janhunen, T.P. Kiviniemi and F. Ogando, accepted for publication in Journal of Computational Physics
[2] S.J. Janhunen, F. Ogando, J.A. Heikkinen, T.P. Kiviniemi, and S. Leerink, *Nuclear Fusion* **47** 875 (2007)
[3] S. Leerink, J.A. Heikkinen, S.J. Janhunen, T.P. Kiviniemi, M. Nora, and F. Ogando, submitted to Plasma Physics Reports

O2-1.3 Tuesday 9.35

Gyrokinetic Turbulence Analysis in the FT-2 Tokamak Configuration

S. Leerink[1], O. Dumbrajs[1], J.A. Heikkinen[2], S.J. Janhunen [1],
T.P. Kiviniemi[1], M. Nora[1], F. Ogando[3]

1 Helsinki University of Technology, Euratom-Tekes Association, Espoo, Finland
2 VTT,Euratom-Tekes Association, Espoo, Finland
3 Universidad Nacional de EducaciÃ¸sn a Distancia, Madrid, Spain

The full f gyrokinetic code elmfire [1] has been developed to study turbulent transport in Tokamak plasmas. The code has been successfully benchmarked to neoclassical theory and other gyrokinetic codes. Experimental benchmarking of the ELMFIRE code is performed in co-operation with the FT-2 tokamak experiment at the Ioffe Institut in St Petersburg. Correlation lengths and times of density fluctuations as well as poloidal velocity and density fluctuation spectra are compared to experimental results from reflectometer diagnostics [2]. In figure 1, the simulated $E_r \times B$ velocity and total poloidal velocity of fluctuations are shown for typical Ohmic FT-2 parameters [3]. It can be concluded that $E_r \times B$ velocity arising from neoclassical and turbulent mechanisms is the main contributor to the poloidal velocity at the inner and outer region of the experiment. At the central region of the simulation, a contribution of mode phase velocity has been found from linear mode analysis, explaining the difference in Figure 1. The angular frequencies and growth rates obtained from the ELMFIRE linear mode analysis have been successfully benchmarked against the eigenvalue code GS2 [4]. Studies of turbulent coherent burst and their transport are performed with orthogonal wavelet techniques.

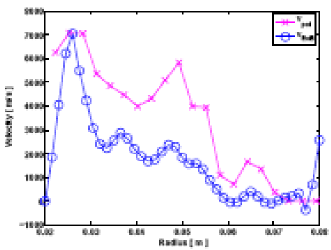

Figure 1: The simulated $E_r \times B$ velocity and total poloidal velocity of fluctuations in FT-2

[1] J.A. Heikkinen et al., to be published in Journ. Comp. Phys. (2008)
[2] A.D. Gurchenko et al. , *Nucl. Fusion* **47** (2007) 245-250
[3] S. Leerink et al. , to be published in Plasma Phys. Reports (2008)
[4] M. Kotschenreuther et al., *Comp. Phys. Comm.* **88**, 128 (1995)

Session 2 – Anomalous Transport and Reconnection

Chair: G. Bonhomme

O2-2.1 Tuesday 10.30

Evolution of Micro Turbulence Wave Number Spectra and Anomalous Electron Transport in Dynamic Experiments at FT-2 Tokamak

E.Z. Gusakov, A.D. Gurchenko, A.B. Altukhov, A.Yu. Stepanov, V.V. Dyachenko, S.I. Lashkul, D.V. Kouprienko, L.A. Esipov

IRAS Ioffe Institute, St.-Petersburg, Russian Federation

Fine scale drift wave turbulence excited due to the TEM and ETG mode instability is discussed nowadays as a possible candidate for explanation of the anomalous electron energy transport in tokamak plasmas, in particular in transport barriers. In spite of this the experimental information related to these modes till recently was not detailed, limited to frequency spectra measured by different modifications of the microwave reflectometry for TEM mode and missing for the ETG mode. At present new experimental techniques based on the microwave backscattering effect are being developed to fill in the gap at several tokamaks and first results confirming existence of the ETG mode scale turbulent fluctuations sensitive to electron temperature gradient have been obtained at FT-2 and DIII-D tokamaks. In particular, excitation of two (low and high frequency) modes possessing a factor of 2 different phase velocities was demonstrated in ohmic discharges at FT-2 under conditions when the ETG mode is unstable.

In the present paper we report results of systematic investigations of these small-scale turbulent low (LF) and high (HF) frequency modes performed in dynamic (fast (20 MA/s) current ramp up from 22 kA to 32 kA and lower hybrid (LH) heating) experiments at FT-2 tokamak (R = 55 cm; a = 7.9 cm; B_t= 2.2 T). Both frequency and wave number spectra (q-spectra) are measured with correlative enhanced scattering (CES) diagnostics utilizing X-mode probing from high field side performed out off equatorial plain simultaneously at different frequencies (f_i = 54-65 GHz) and measuring back scattering off density fluctuations with radial wave numbers $q_r > 4\pi f_i/c$ occurring in the very vicinity of the UHR. The turbulence q-spectra are reconstructed for $8 > q_r \rho_l > 0.8$ at a distance 1-3 cm from the limiter. It is found that all during the dynamic current ramp up discharge the LF component identified with the dissipative TEM mode possesses a wide q-spectrum which could be described by universal exponential dependence $|n|^2_{q_r} \sim |n|^2_0 \exp\{-q_r L\}$ in the range of 3-4 orders of amplitude, where $|n|^2_0$ is related to the turbulence level and L ~ (1-2) ρ_i is a typical turbulence length. In agreement with theoretical predictions both parameters are found to decrease substantially after the current ramp up when the shear of the poloidal plasma rotation estimated from the Doppler frequency shift of the

ES signal increases at plasma periphery. Simultaneously transition to the improved confinement resulting in suppression of anomalous electron transport is observed in the experiment.

The wave number spectrum of the HF turbulence component, identified as the ETG mode, looks very different from exponential. It is characterised by pronounced maximum at $q_r \rho_s \approx 9$ corresponding to the largest ETG instability growth rate. Behavior of HF ES component in the dynamic LH heating experiment, unlike the LF component, is correlated not with the electron thermal conductivity, but with the ratio of electron temperature and density scale lengths which is natural near the ETG mode threshold given, according to theoretical analysis, by condition $L_{n_e}/L_{T_e} > 0.8$

Financial support of RFBR Grants 07-02-00895, 08-02-00989, 08-02-00610, RFBR – NWO Grant 047.016.015, INTAS Grant 05-8046 and "Russian Science Support Foundation" is acknowledged.

O2-2.2 Tuesday 10.55

Anomalous Transport during Alfvén Wave Injection in TCABR Tokamak

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Anomalous energy transport severely reduces the economical attractiveness of any possible fusion energy reactor based on magnetically confined thermonuclear plasma.

Therefore, to understand and control the major mechanisms of this transport, mainly due to the anomalous particles losses, is vital to ameliorate a potential fusion reactor scenario.

In this context, plasma edge is a key area of research in which considerable efforts are put into theory and experiments in auxiliary heated plasma confinement devices such as tokamaks.

The results reported here are a substantial extension of the preliminary data recently shown from the tokamak TCABR under auxiliary heating via Alfvén Waves (AW), in which the edge properties and its connection with global plasma parameters during the AW were presented [1].

Anomalous particle losses due to plasma density, electric field, and electron temperature fluctuations, all simultaneously measured with a triple Langmuir probe located in the scrap-off layer of TCABR, and its statistical properties will be presented.

[1] C. Ribeiro et al., Europhysics Conference Abstracts 31F (2007) P-1.153

O2-2.3 Tuesday 11.20

Experimental Characterization of Current Sheets Associated to Spontaneous Magnetic Reconnection in a Reversed Field Pinch Plasma

M. Zuin, N. Vianello, M. Spolaore, V. Antoni, T. Bolzonella, R. Cavazzana, E. Martines, G. Serianni, D. Terranova

Consorzio RFX, Associazione Euratom-ENEA sulla Fusione, Corso Stati Uniti 4, Padova 35127, Italy

An experimental investigation of the fast dynamics of the discrete relaxation events in the RFX-mod reversed field pinch device is presented. The analysis is performed by means of a large system of probes internal to the vacuum vessel, measuring the fluctuation of the toroidal magnetic field, and of an insertable edge probe. The latter is equipped with matrices of electrostatic (Langmuir) and three-axial magnetic probes. It is shown that the relaxation events, which are due to a global rearrangement of the magnetic topology through reconnection of magnetic field lines, are associated to the formation of a toroidally localised poloidal current sheet. The current structure occurs in the toroidal position where the phase locking of the dynamo tearing modes has its maximum, with an extension of some tens of degree. Soon after its formation, the perturbation is observed to move toroidally, strongly perturbing the electric field along with the plasma density and temperature at the edge.

A characterization of the current density flowing in the poloidal sheet is performed by means of the insertable probe, and a local balance between the pressure gradient associated to the current structure and the Lorentz force, due to the interaction of the current structure with its own magnetic field, is found.

An estimate of about 400 μs is given of the resistive time decay of the perturbation in its motion along the torus, by which a radial width of the current sheet of few centimeters, comparable to the ion skin depth, can be deduced.

A flattening of the $E \times B$ shear flow at the edge plasma, during the transit of the current perturbation, is also measured, whose effect on the plasma confinement at the edge might be significant.

Session 3 – Structures in Plasma Turbulence **Chair: S. Zoletnik**

I2-3.1 Tuesday 13.30 - Invited talk

Coherent Vortex Extraction (CVE) in Fluid and Plasma Turbulence Using Wavelets

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M2P2-CNRS & CMI, Université de Provence, Marseille, France

We propose a wavelet-based method to extract coherent structures out of turbulent signals and flow fields. After projecting the signal/field onto an orthogonal wavelet basis, one filters out the wavelet coefficients whose modulus is smaller than a given threshold, which is recursively evaluated without requiring any adjustable parameters. The signal/field is split into two orthogonal components, a coherent and an incoherent one, whose properties are then independently studied. The extraction method is applied to ion density signals measured in the scrape-off layer of the tokamaks Tore Supra in Cadarache, France, and Castor in Prague, Czech Republic [1]. We find that coherent structures contain most of the density variance, are intermittent and long-time correlated with non-Gaussian statistics, while the incoherent background noise is much weaker, non-intermittent and almost decorrelated with quasi-Gaussian statistics. Statistical diagnostics based on the wavelet representation are introduced to compare the scaling behaviour and intermittency of the total signal and its coherent and incoherent components. The fluxes are shown to be dominated by their coherent contributions.

Applications of CVE to DNS data of isotropic [2] and sheared and rotating turbulence [3] shows that the vortical structures are well preserved by the coherent part using few percent of degrees of freedom. We also show that the coherency of the flow increases with the rotation rate which is reflected in an increased compression rate. The incoherent component is of dissipative nature. These results motivate further developments of the Coherent Vortex Simulation (CVS) method. It is based on a deterministic computation of the time evolution of the coherent flow using an adaptive wavelet basis, while the influence of the incoherent flow onto the coherent flow is neglected or statistically modeled.

This work is joint work with Marie Farge (LMD, ENS Paris).

[1] M. Farge, K. Schneider and P. Devynck, *Phys. Plasmas*, 13 (2), 042304, 2006
[2] N. Okamoto, K. Yoshimatsu, K. Schneider, M. Farge and Y. Kaneda, *Phys. Fluids*, 19, 115109 (13 pages), 2007.
[3] F. Jacobitz, L. Liechtenstein, K. Schneider and M. Farge, *Phys. Fluids*, 20(4), 045103 (13 pages), 2008.

Papers can be downloaded from the web site: http: //wavelets.ens.fr
This work is financially supported by the Association CEA-Euratom and the Agence Nationale de la Recherche.

O2-3.2 Tuesday 14.10

Investigation of the Statistical Properties of Electric Potential Oscillations in the T-10 Tokamak

A.V. Melnikov[1], L.G. Eliseev[1], S.V. Perfilov[1], S.E. Lysenko[1], V.A. Mavrin[1], S.A. Grashin[1], D.A. Shelukhin[1], I.A.Krasilnikov[1], A.P. Loginov[1], V.A. Vershkov[1], V.P. Budaev[1], I.B. Semenov[1], L.I. Krupnik[2], A.D. Komarov[2], A.S. Kozachek[2] and G. Van Oost[3]

1 Nuclear Fusion Institute, RRC "Kurchatov Institute", 123182, Moscow, Russia,
2 Institute of plasma physics, NSC "Kharkov Institute of Physics and Technology", Kharkov, Ukraine
3 Department of Applied Physics, Ghent University, Ghent, Belgium

Highlights in fusion plasma performance have been obtained under conditions where ExB shear stabilization mechanisms are likely play a key role; both edge and core transport barriers are related to a large increase in the ExB sheared flow. The oscillating shear flows, zonal flows and Geodesic acoustic modes (GAMs) are widely considered now as a turbulence stabilization mechanism. The study of the properties of plasma electric potential oscillations may explain the turbulence-zonal flow interplay [1, 2, 3].

Low frequency ($f<50$ kHz) electric potential oscillations were investigated on the T-10 tokamak using Heavy Ion Beam Probe (HIBP), Correlation Reflectometry (CR) and Langmuir probes (LP). Regimes with Ohmic heating and with on- and off-axis ECRH were studied (B = 2.2–2.5T, I_p = 180-330kA, n_e = 1.3 – 2.5 x 10^{19} m^{-3}).

It was shown that GAMs might have a complex structure, not similar to conventional periodical oscillations with a single frequency. GAMs have an intermittent character presenting the stochastic sequence of the wave packages with a "lifetime" in a range of 0.5-2 ms. GAMs are more pronounced in ECRH plasmas [1, 4]. At the outer one third of the plasma column GAMs may be characterized not only by single but also by a couple of closed but separated frequencies in a narrow interval 22-27 kHz. Each frequency peak is characterized by high potential/density correlation (coh>0.6) and constant cross-phase, $\theta = -\pi/2$ for the main GAM peak, similar to [5], and $\theta = +\pi/2$ for the satellite. The low frequency MHD mode m=3 is pronounced at 7 kHz.

The long-term correlation between potential (HIBP) and density (CR) oscillations was studied whereby the CR antenna was shifted toroidally by one quarter of the torus similar to the duo-HIBP experiments in CHS [3]. The result of the correlation measurements of the two diagnostics shows the high coherency (coh>0.4) for GAMs and low frequency MHD modes, suggesting the global character of the modes.

The MHD mode m=3 is also pronounced in core plasma potential and density (HIBP) and in floating potential at the plasma edge (LP) by quasi-coherent oscillations with f = 7 kHz with high coherency between plasma potential (HIBP) and floating potential (LP). It also exhibits the stochastic character with ~ 1-2 ms time-scale. Sawtooth oscillations presents the common mechanism modulating potential oscillations for both GAM and MHD mode m=3.

This work was supported by RFBR 08-02-01326, 07-02-01001, INTAS 100008-8046 and NWO-RFBR 047.016.015.

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[5] Y.Hamada et al., *Nuclear Fusion* **45** No 2, 81 (2005)

O2-3.3 Tuesday 14.35

Structure of the ISTTOK Edge Plasma Fluctuations

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Transport in magnetically confined plasmas is generally accepted to be driven by plasma turbulence. The dynamics underlying the turbulence processes have been therefore extensively investigated with the aim of understanding and enhancing the confinement in fusion plasmas.

The tokamak ISTTOK (R = 46 cm, a = 8.5 cm, B_T = 0.5 T, I_p ≈ 4-7 kA) is equipped with several diagnostics that allow the investigation of the edge fluctuations such as: (i) a poloidal and (ii) a radial array of Langmuir probes with 8 pins each; and (iii) a Heavy Ion Beam diagnostic with a multi-cell array detector that allows simultaneous measurements across the plasma column. Data were simultaneously sampled at 2 MHz and the analyses performed during the discharge flat top (~20 ms) using different analysis techniques.

It has been found that the fluctuations have distinct characteristics for r>a (scrape-off layer, SOL) and r $\lesssim$ a (core periphery). SOL fluctuations are characterized by short correlations both in space (poloidal) and time (λ_c~5-10 mm and τ_c~5-8 μs, respectively), poloidal wavenumbers in the range of k_θ<3 cm-1 and a broad frequency spectrum. In the core periphery the correlation is significantly larger (λ_c>>10 mm, τ_c~30 μs), the wavenumbers are shorter kθ<0.5 cm-1 and the spectrum is dominated by low frequency components (10-25 kHz).

A significant correlation (up to 0.7) has been found in the core periphery between probe systems toroidally apart measuring floating potential, which increases when probes are approximately at the same radial location. Furthermore, this correlation is only significant for frequencies around 10-25 kHz and its cross-phase is close to zero.

We can conclude therefore that the characteristics of the potential fluctuation in the SOL are consistent with the typical broad band turbulent fluctuations while in the core periphery they are consistent with a symmetric structure in the poloidal and toroidal directions.

O2-3.4 Tuesday 15.00

Statistical Description of Turbulent Particle Fluxes in the Edge Plasma of the L-2M Stellarator

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Plasma turbulence studies carried out in the last few decades have shown that the measured distributions of amplitudes of plasma density fluctuations in both the central and peripheral regions have non-Gaussian probability density functions. These distributions are leptocurtic and have slowly decreasing exponential tails. Besides, these distributions possess self-similarity. These characteristic features were observed in studies of fluctuations in both tokamaks and stellarators.

The paper presents results of studies of turbulent particle fluxes measured in the L-2M stellarator in essentially different regimes: with and without chamber wall boronization intended for improving discharge conditions.

Fluctuating particle fluxes were analyzed in terms of fractional stable (FS) densities. These densities appear as limit densities (at t→ ∞) in the compound process

$$S(t) = \sum_{j=1}^{N(t)} X_j, \quad \text{where} \quad \sum_{j=1}^{N(t)} T_j < t \leqslant \sum_{j=1}^{N(t)+1} T_j, \quad t > 0.$$

Here, $X_1, X_2, \ldots$, are independent, identically distributed random variables with a distribution function $P\{X_j < x\} \propto x^{-\alpha}$, $0 < \alpha \leq 2$, whereas $T_1, T_2, \ldots$ are independent, identically distributed random variables on the positive semiaxis with a distribution function $P\{T_j < t\} \propto t^{-\beta}$, $0 < \beta \leq 1$. The physical interpretation of *S(t)* is the particle coordinate in the CTRW model (Continuous Time Random Walk).

The parameters of fractional stable distributions were statistically estimated from measured signals. It is shown that fractional stable distributions give a good fit to the probability density functions of amplitudes of fluctuating particle fluxes. It appears that, with boronization, the scale parameter of FS density becomes reduced and, in its turn, reduces the diffusion coefficient in the corresponding generalized equation of diffusion. The Hurst parameter was calculated for all the discharges under study. Its values lie in the range 0.64 to 0.75, which agrees with results obtained in other devices. Algorithms for data processing and the algorithm for estimation of parameters of FS densities, along with results of calculations, will be presented in the report.

Session 4 – Diagnostics for Turbulence and Electric Fields

Chair: A. Melnikov

O2-4.1 Tuesday 16.00

Measurement Capabilities and Results of Beam Emission Spectroscopy Diagnostics on the System of Turbulence, Flows and Profiles

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During the past decade a general agreement has been reached within the fusion community that turbulence in fusion plasmas represents an important element of transport processes. Simulations show that turbulence at fixed profile parameters develops into a nonlinearly interacting system of flows and unstable drift waves. This loop determines anomalous transport processes which act on profiles. The resulting profile changes affect the stability of drift waves and therefore a second regulating loop appears. This complex double-feedback structure is suspected to be the background of self-regulating profiles and state transitions in fusion plasmas.

Beam Emission Spectroscopy (BES) is a diagnostic tool originally developed for the measurement of the electron density profile in fusion plasmas. Starting from the basic scheme different additional measurement capabilities have been developed in the past years which go well beyond density measurement and cover several aspects of the above wave-flow-profile system. Fluctuations are measured by optimizing light collection and detection of the beam light and flows can be measured via following the movement of eddies in the plasma. With these capabilities BES can measure both fluctuation amplitude, correlation time, flows and profiles therefore it is one of the few techniques capable of giving insight into the above complex system. This contribution describes the BES diagnostics developed and planned during the past years in Europe for the study of turbulence and show some results obtained so far.

On MAST a trial system is installed measuring density turbulence by BES on the heating beam. Although this system can discern only edge turbulence, it validated the light level calculations and provided a solid basis for a final 2D measurement to be installed in 2009.

On TEXTOR an optimized optical and detection system of the Li-beam diagnostic can resolve turbulence down to the 0.1% level, which has already been demonstrated by resolving core plasma fluctuations. In this diagnostic fast (~200 kHz) poloidal scanning of the beam gives the possibility of flow measurements.

On ASDEX Upgrade and JET 4-channel systems are being installed on the Li-beam diagnostic which will provide data on edge turbulence. JET has especially good observation properties as poloidally displaced measurement channels give the chance for poloidal flow velocity measurement without beam scanning.

On the reinstallation of COMPASS in Prague an additional feature is foreseen for the BES system. Given the relatively small size of the device the ions stemming form beam ionization can be collected for medium mass beam species. This gives the possibility to combine BES and the Heavy Ion Beam Probe (HIBP) concepts into an Atomic Bema Probe diagnostics which could resolve edge current modulations as well.

Additionally to the turbulence measurement capabilities these diagnostic can also give insight into MHD and fast transient transport phenomena, exemplified by ELM measurements.

O2-4.2 Tuesday 16.25

Studies of the Radial Electric Field in Different Operational Modes of the TUMAN-3M Tokamak

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This paper presents results of plasma potential profile and temporal evolution study performed in different operational modes of the TUMAN-3M tokamak: ohmic L and H-modes, NBI heated plasmas, discharges with strong MHD activity. Central plasma potential evolution was measured using the HIBP, whereas at the plasma edge the Langmuir probes were used for the measurement of radial electric field structure. A pronounced negative perturbation of the central plasma potential was observed during the H-mode transition caused by NBI heating pulse. In the presence of strong burst of low frequency, low m,n MHD activity both central plasma potential and peripheral plasma electric field was found to become positive. In the H-mode, this positive perturbation of the radial electric field destroyed "natural" negative H-mode radial electric field and caused backward transition clearly seen as a deterioration of confinement. Most probable candidate for the cause of the positive perturbation of the E_r seems to be a loss of fast electrons along partly destroyed magnetic field lines. The measurement of HXR radiation from the limiter supports this idea.

Another phenomenon observed with the help of HIBP is a strong quasi-coherent plasma potential oscillation with frequency ~ 30kHz and with

$\delta\varphi/\varphi >> \delta n/n$, revealing some characteristic features of GAMs. Spatial structure and temporal evolution of this GAM-like oscillation are discussed.

O2-4.3 Tuesday 16.50

Fast Camera Imaging and Langmuir Probe Measurements of Transport Events in a Linear Magnetized Plasma

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In magnetic confined plasmas, intermittent transport events (so-called "blobs") through the scrape-off-layer can cause damage to the wall materials as well as to the quality of plasma confinement. Low frequency gradient driven instabilities play a prominent role in non-diffusive transport. Thus, a better understanding and eventually control of the instabilities and their associated radial transport is an important issue.

The experimental investigations are performed on the low-b cylindrical magnetized plasma device "Mirabelle". With this device it is possible to observe the transition from regular to weakly turbulent states for several types of instabilities, i.e. drift waves and flute modes, by adjusting the radial electric field and consequently the rotation of the plasma column [1]. Two different methods to investigate the cross-field transport are presented.

On the one hand, density and potential fluctuations are measured by means of Langmuir triple probes. The data are analyzed by using wavelet-based methods, which make it possible to extract information not only about the average transport amplitude but also about its evolution in time [3]. On the other hand, fast camera imaging is performed, which provides a visualization of the density fluctuations dynamics in a whole section of the plasma column [2]. This permits to distinguish between different instabilities and to cross-check the interpretation of the probe measurements. Furthermore, the spatial propagation of coherent structures can be followed. The high resolution in both time and space allows the study of nonlinear coupling processes by using the wave number bicoherence [4].

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O2-4.4 Tuesday 17.15

Fast Temperature Fluctuation Measurements in SOL of Tokamak TCV

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A fast scanning assembly has been widely used on the TCV tokamak to insert a probe head equipped with an array of single Langmuir probe tips up to the separatrix at the plasma midplane. Using fast voltage sweeping, we obtain IV-characteristics every 8 μs, allowing an estimate of the electron temperature, Te on this timescale. Since this temporal resolution corresponds to typical Te autocorrelation times [1][2], it is just fast enough to resolve the temperature of individual turbulent structures (blobs).

Since at this voltage sweep frequency (~60 kHz) hysteresis is observed in the IV-characteristics, some effort is required to demonstrate the credibility of the Te derived from the characteristics. Following the methodology proposed in [3], we use both numerical (*5spice* code) and lab simulations of the equivalent probe circuit, together with a simplified plasma circuit to study the capacitative coupling both across the plasma sheath and in the probe circuit itself. Comparisons are also made between the results from higher frequency sweeping and the standard values derived from a slower sweep to show that the fast measurement is reliable.

Considerable effort has been expended in recent years to compare the statistical character of turbulence in the SOL particle flux on TCV with results from the 2D fluid electrostatic model ESEL [2][4]. Using results from the fast sweeping, similar comparisons can now be made with the fluctuating Te and will be described in this contribution. We also present basic statistics derived from the Te time series obtained at different radii in the SOL plasma and show, in particular, that the relationship between higher moments of the probability distribution function from both experimental and simulated Te's may be well described by the Beta probability distribution function, introduced for SOL turbulence in [5]. The fast Te capability also allows the SOL response to Edge Localised Modes

(ELMs) to be studied and new results will be presented for the far SOL Te response during Type III ELMs.

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Thank you for attending the EFTSOMP2008 Workshop!