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Turbulent transport in the plasma edge in the presence of static stochastic magnetic fields

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Introduction

The technical option to ergodize magnetic fields in fusion relevant tokamak experiments by externally induced magnetic perturbation fields offers the opportunity to influence drift instabilities and therefore the turbulent behaviour of plasmas. Employing an electromagnetic four field model we study the non-linear evolution of turbulence for the plasma edge of TEXTOR-DED [1, 2, 3] in the presence of a static stochastic magnetic field, represented by a small number of perturbation modes resonant in the computational domain. The equations are solved numerically by the DALF3 code [4, 5, 6, 7, 8, 9] for a fixed background plasma. Perturbation fields of varying strengths (Chirikov-parameter close to and above 1) are studied for cases of low and high collisionality typical for drift wave driven or ballooning driven regimes. The perturbation field is approximated by three modes, namely m/n=11/4, 12/4 and 13/4 to reflect the situation close to the $q = 3$-surface in 12/4-mode operation of TEXTOR-DED.

Turbulence model and computational details

The turbulent dynamics is represented by a four-field model describing the non-linear evolution of the electric potential ϕ, the density n, the parallel magnetic potential $A_{\|}$ and the parallel ion velocity $u_{\|}$ [9, 10].

$$\frac{\partial n}{\partial t} = -\mathrm{v}_E \cdot \nabla(n_0 + n) + K(\phi - n) + \nabla_{\|}(J_{\|} - u_{\|}) \tag{1}$$

$$\hat{\beta}\,\frac{\partial A_{\|}}{\partial t} + \hat{\mu}\,\frac{\partial J_{\|}}{\partial t} = -\mathrm{v}_E \cdot \nabla J_{\|} + \nabla_{\|}(n_0 + n - \phi) - \hat{C}\,J_{\|} \tag{2}$$

$$\hat{\varepsilon}\,\frac{\partial u_{\|}}{\partial t} = -\hat{\varepsilon}\,\mathrm{v}_E \cdot \nabla u_{\|} - \nabla_{\|}(n_0 + n) \tag{3}$$

$$\frac{\partial w}{\partial t} = -\hat{\varepsilon}\,\mathrm{v}_E \cdot \nabla w - K(n) + \nabla_{\|} J_{\|} \tag{4}$$

These are the scaled equation of continuity, Ohm's law, the total momentum balance the quasineutrality condition, respectively, with vorticity w and current $J_{\|}$ defined by w=$-\nabla_{\perp}^2\phi$ and $J_{\|}$=$-\nabla_{\perp}^2 A_{\|}$. The definitions of the operators $\mathrm{v}_E \cdot \nabla$, $\nabla_{\|}$, $\nabla_{\perp}^2$ and K for a field aligned slab-geometry (s, y, x) used here, and the parameters $\hat{\beta}$, $\hat{\mu}$, $\hat{\varepsilon}$ and $\hat{C}$, can be found in [10]. The perturbations in the vector potential $A_{\|}$, entering the parallel derivative $\nabla_{\|}$, consist of two parts. One

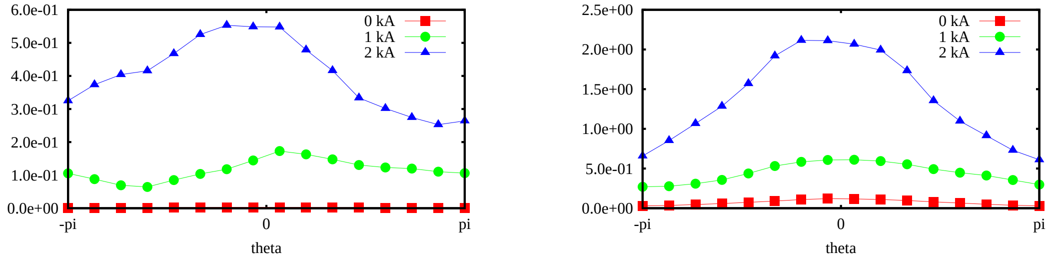

Figure 1: Plot of static $E\times B$ flux $\langle\Gamma\rangle_{xyt}$ vs poloidal angle θ for ν_B=0.04 (left) and ν_B=1.48 (right)

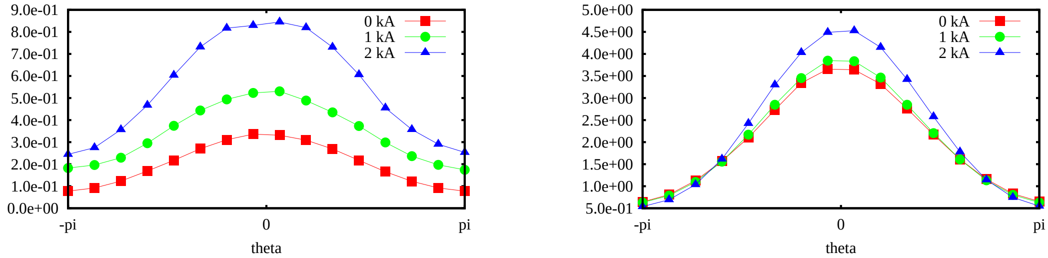

Figure 2: Plot of turbulent $E\times B$ flux $\langle\Gamma\rangle_{xyt}$ vs poloidal angle θ for ν_B=0.04 (left) and ν_B=1.48 (right)

is the self consistent intrinsic plasma response A_I arising from the parallel current as forced by gradients in the electrostatic potential and electron pressure. The other is a static contribution A_D externally imposed by coil currents, so that $\nabla_\perp^2 A_D$=0 within the computational domain, which is approximated in this work by (in physical units)

$$A_D = \sum_{m=-1}^{1} (-1)^{m+1} \frac{B_D r_c}{m+nq_0} \frac{\sin m\,\theta_c}{m\pi} e^{nk_y(x-x_c)} \cos(ms+nk_y y)$$

where x_c=$(r_c-a)/\rho_s$, r_c=0.5325 m, a=0.45 m, θ_c=$2\pi/10$, B_D=$4\mu_0 I_D/\theta_c r_c$, n=4, $q_0=3$ and k_y=$q_0\rho_s/a$ with ρ_s=$\sqrt{T_e/m_i}$. The coil current I_D determines the degree of stochasticity, and the estimated Chirikov-parameter is given by 1.25 $I_D^{1/2}$, where I_D is given in units of kA. This model field corresponds to perturbations of 11/4, 12/4 and 13/4 symmetry with respect to standard toroidal coordinates. In the turbulence simulations we consider dynamics in a thin radial range ($2.6\leq q\leq 3.4$) covering the basic resonances at q=11/4, 12/4 and 13/4, and due to the long-wavelength character of A_D we carry the entire flux surface. The physical parameters like density n_0, electron temperature T_e, density gradient length $L_\perp$ and geometrical dimensions are chosen close to realistic parameters of TEXTOR-DED discharges, namely n=$2\cdot 10^{19}\,\mathrm{m}^{-3}$, T=100 eV, B_0=2 T, q_0=3, $\hat{s}$=2, R_0=1.75 m, a=0.45 m, and $L_\perp$=3 cm for the low collisional case. The high collisional case is studied leaving all parameters unchanged but choosing a density and temperature of n_0=$6.5\cdot 10^{19}\,\mathrm{m}^{-3}$ and T_e=30.8 eV to keep the plasma β unchanged. The collisionality is characterized by the ballooning parameter ν_B=$\frac{m_e}{m_i}\frac{q^2 R_0 \nu_e}{c_s}$, which is 0.04 for our low collisional case and 1.48 for the high collisional scenario. To solve the model equations numerically we employ the DALF3 code [4, 5, 6, 7, 8, 9] on a 16×1024×64-grid in the s-y-x-domain, ensuring a perpendicular resolution down to the drift scale ρ_s. By means of time averaging an approximation for the stationary solution of the model equations is found.

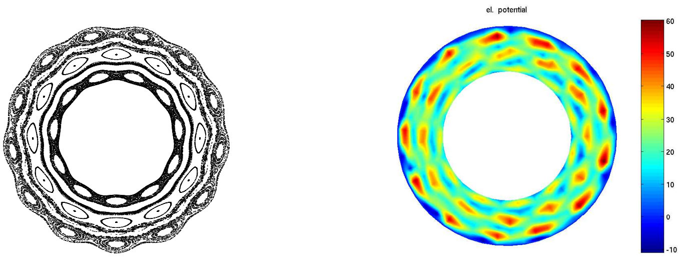

Figure 3: Poincaré-plot of the island structure for an coil current of I_D=0.3 kA (left) and poloidal pattern of the static piece of the electric potential for a coil current of I_D=1 kA (right)

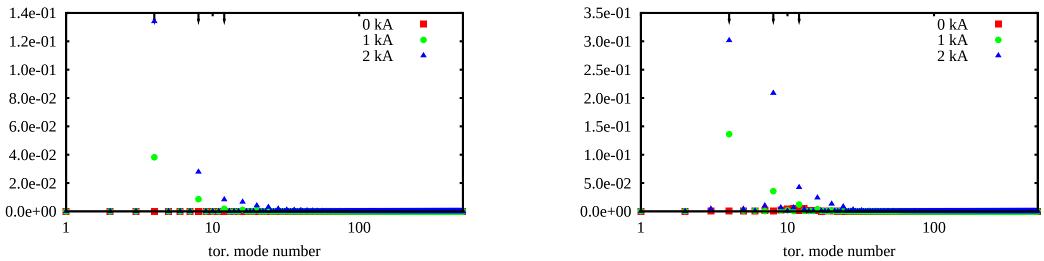

Figure 4: Fourier amplitude plot of the static $E \times B$ flux $\langle \Gamma_n \rangle_{xt}$ vs toroidal mode number n for v_B=0.04 (left) and v_B=1.48 (right)

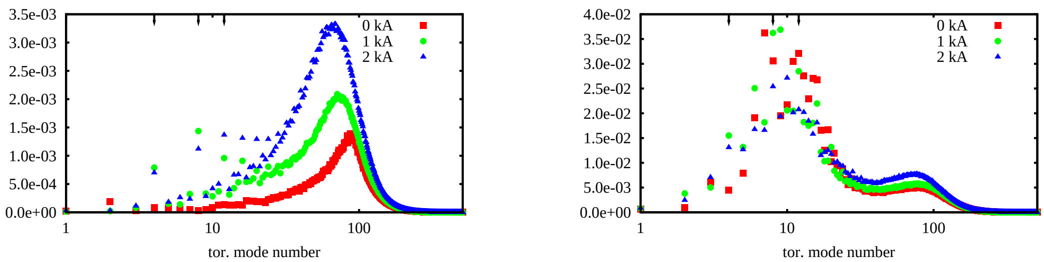

Figure 5: Fourier amplitude plot of the turbulent $E \times B$ flux $\langle \Gamma_n \rangle_{xt}$ vs toroidal mode number n for v_B=0.04 (left) and v_B=1.48 (right)

Numerical results

The Figs.1 and 2 show the x-y-t-averaged profiles of the static and turbulent radial $E \times B$-flux for different perturbation currents and different collisionalities. In both cases considered a significant increase of $E \times B$-transport is found, but the different regimes of low and high collisionality exhibit a different signature in that the turbulent transport of ballooning dominated case (v_B=1.48) is less affected. Whereas in the unperturbed case the static contributions to the radial transport are negligible compared to the turbulent transport, these contributions can be of the same order as the turbulent $E \times B$-flux for strong ergodization fields. The turbulent $E \times B$-transport is almost unchanged for v_B=1.48, but is increased by a factor of about 3 for the low collsional case with v_B=0.04. The Figs.4 and 5 show the spectral components of the radial $E\times B$-flux vs the toroidal mode number n. It can be seen, that the static part of the flux in the presence of a magnetic perturbation field is mainly determined by the resonant components with n=4 and its harmonics. The poloidal patterns of the density and the electric potential as well show a strong signature of the perturbation field (island structure) in the static pieces, as illustrated by Fig. 3, showing a Poincaré-plot for a small perturbation field (I_D=0.3 kA) and the signature of the island structure in the static electric potential even for a stochastic case (I_D=1 kA) . The fluctuating pieces do not exhibit this feature (the reminiscents of this resonant effect are likely to be a numerical artefact due to time averaging). The strong difference between the high and low collisional case occurs also in the spectral analysis. The low collisional case shows a strong increase of the $E\times B$-flux for high toroidal mode numbers ($n>$ 40), whereas the $E\times B$-flux in high collisional case is dominated by the components with $n<$40, which are less affected by the magnetic perturbation.

Conclusion

Turbulence simulations for different collisionalities and various magnetic perturbation fields show that the $E\times B$-transport is strongly affected by externally induced magnetic perturbations like e.g. realized in TEXTOR-DED. A strong static contribution reflecting the symmetry of the perturbation field builds up in both, low and high collisional plasmas. The turbulent transport is increased strongly for the low collisional, (electromagnetic) drift Alfvén turbulence dominated plasma, whereas in the high collisional, (electrostatic) balooning turbulence dominated plasma the turbulent transport is almost unchanged. A low collisionality seems to make the plasma more susceptible for an enhancement of turbulent transport due to magnetic perturbation fields.

References

[1] K. H. Finken, S. S. Abdullaev, A. Kaleck, G. H. Wolf, Nucl. Fusion **39**, 637 (1999).

[2] S. S. Abdullaev *et al.*, Nucl. Fusion **43**, 299 (2003).

[3] Th. Eich, D. Reiser, K. H. Finken, J. Nucl. Mater. **290-293**, 849 (2001).

[4] B. D. Scott, New J. Phys. **4**, 52 (2002).

[5] B. Scott, IPP Report, IPP 5/92, March 2001.

[6] B. Scott, Phys. Plasmas **8**, 447 (2001).

[7] B. Scott, Phys. Plasmas **5**, 2334 (1998).

[8] B. D. Scott, Phys. Fluids B **4**, 2468 (1992).

[9] B. D. Scott, Plasma Phys. Contr. Fusion **39**, 1635 (1997).

[10] V. Naulin, Phys. Plasmas **10**, 4016 (2003)