Discussion of SOL turbulence properties in TEXTOR by means of ESEL simulations.

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Abstract

A lot of experimental observations in magnetic confinement devices show that the particle and thus heat transport in the scrape-off layer (SOL) of the plasma is characterized or even dominated by turbulent intermittency. In this contribution, we discuss the underlying parameters used in the ESEL code [1] (Edge SOL Electrostatic, a 2D interchange turbulence code). To this end, runs of the code, applied on the geometry of TEXTOR with relevant SOL-parameters, are analysed and compared to results of ohmic scenario experiments at first. In particular, we address again the q_a-dependence (safety-factor at separatrix) of the generated intermittency.

Introduction and motivation

Since 2003, the DED (dynamic ergodic divertor) has been operated in TEXTOR in various configurations. This utility creates an ergodized magnetic boundary and is important in optimizing the plasma-wall interactions. Measurements of the SOL-turbulence with and without the DC-operation of the DED on TEXTOR have been reported extensively [2]. However, a clear theoretical understanding of how this DED influences physically the SOL intermittency, is – in our opinion – still lacking at this moment. As the DED perturbation field acts mainly on the magnetic field in the edge-SOL region, producing magnetic connection lengths to the divertor tiles (in so-called ergodic and laminar zones) which are substantially different from ohmic shot conditions, these stochastic magnetic connection lengths appear to us the key ingredient for this understanding.

On the other hand, in turbulence studies the understanding benefits mostly from the simplest possible models used in simulations. We believe the SOL intermittent turbulence physics is mainly a 2D-phenomenon, condensed in the name of 'blobs'. These blobs appear as field aligned 'high-density' structures, produced mainly in the balloonning angle (of which the limits are $\Delta\theta_{\pm} \approx \pi/6$ up and down from the equatorial plane at the outboard) by the Rayleigh - Taylor instability. For sure, the theatre of boundaries and forces acting on our blobs, is fully 3-dimensional, but the $\vec{B}-$parallel direction – although very important in view of the physical understanding – can be approximated by an 'effective' parallel connection length. In ESEL, this effective parallel connection length is up to now modelled as such that it represents the blob structure in the ballooning angle, without taking into account any physical boundary imposed by eg. target sheaths of the divertor. The main argument for this is the rather long real parallel connection length from the outboard midplane to these plates in divertor machines, on which ESEL has been applied. The blobs are thus supposed to be ‘electrically disconnected’ from the targets, so that sheath boundary conditions are not used up to now. However, the difference between ‘electrically disconnected’ (effective parallel connection length) and ‘electrically connected’ (parallel direction represented by sheath boundary conditions) situations in terms of resulting turbulence, is huge.

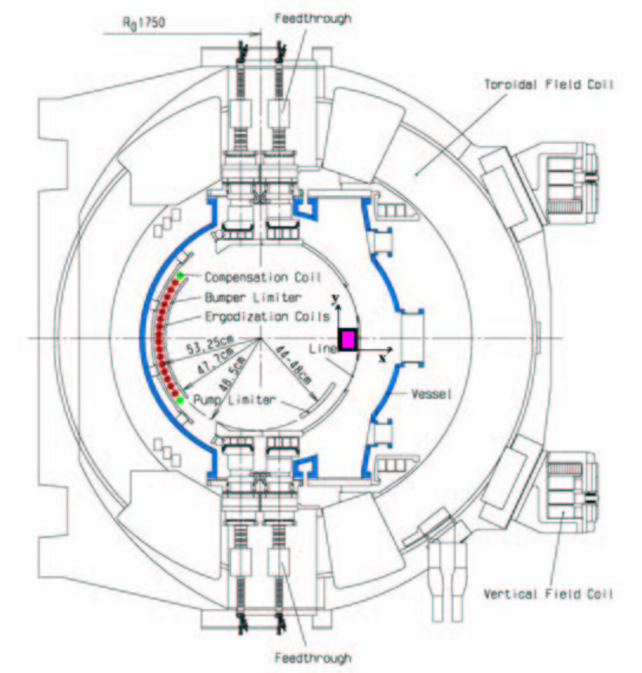

Figure 1: TEXTOR with (x,y)-ESEL domain in pink

This discrepancy is the reason why we would like to fully understand the influence of this parallel connection length (in simulations and in the TEXTOR-experiment), at first in ohmic conditions [3] in order to adapt and use ESEL with a 2-D parallel ‘connection length-image’(or footprint seen in eg. Poincaré-plots from [4]) caused by the DED. The choice between both versions of the parallel damping coefficient becomes even more crucial in limiter machines like TEXTOR. In ohmic shot modus, the real parallel connection length from the outboard midplane (where the probe is sitting as well) towards the toroidal ALT-limiter is somewhat like $\frac{\pi/6}{\pi}\pi q R_0$. This means that for TEXTOR ohmic shots, we are probably at the limit of being ‘electrically disconnected’ from the limiter. However, in this contribution we follow this ‘disconnected’ assumption and hence an effective parallel connection length, proportional to q.

The parameters of the simulation code - results from the simulations

The reduced fluid equations, where ESEL is based upon, represent the drift ordered low-frequency dynamics of the electron density n, the electron temperature T and the electrostatic potential ϕ. They are in depth discussed in [1] and can be written down as

$$\frac{d\nabla_\perp^2\phi}{dt} = \mathscr{C}(nT) + \Lambda_{\nabla_\perp^2\phi}, \tag{1}$$

$$\frac{dn}{dt} = \mathscr{C}(nT) - n\mathscr{C}(\phi) + \Lambda_n, \tag{2}$$

$$\frac{dT}{dt} = \frac{7}{3}\mathscr{C}(T) - \frac{2}{3}T\mathscr{C}(\phi) - \frac{2}{3}\frac{T^2}{n}\mathscr{C}(n) + \Lambda_T, \tag{3}$$

ESEL implements these equations in an inhomogeneous magnetic field ($\frac{1}{B} = (1 + \frac{a+\rho_{s,0}x}{R_0})$) inside a (x,y)-slab geometry on the low-field side (LFS) of the tokamak. As the real probe measurements in TEXTOR are done in the equatorial plane at the LFS, it makes sense to compare both results. The advective derivative and the curvature operator are abbreviated as $\frac{d}{dt} = \frac{\partial}{\partial t} + \frac{1}{B}\mathbf{b} \times \nabla\phi \cdot \nabla$ and $\mathscr{C} = -\frac{\rho_{s,0}}{R_0}\frac{\partial}{\partial y}$. All quantities are dimensionless and expressed in the Bohm normalization (typical temporal and spatial scales are chosen to be the ion gyro-frequency ($\omega_{ci,0} = eB/m_i$) and the drift-scale-radius ($\rho_{s,0} = c_{s,0}/\omega_{ci,0}$)). Here $c_{s,0} = (T_{e,0}/m_i)^{1/2}$ stands for the cold ion sound speed. The Λ_α terms on the right-hand side of Eqs. (1-3), represent the loss terms (dissipation as a result of perpendicular diffusion and the effective parallel damping to the divertor/limiter), as well as the source terms S_α: $\Lambda_\alpha = D_\alpha \nabla_\perp^2 \alpha - \frac{\alpha}{\tau_{\|,\alpha}} + S_\alpha$. The damping coefficient $1/\tau_{\|,\alpha=T}$ for temperature is larger than its counterparts for the vorticity and the density, due to the predominant parallel loss of hot electrons in the region of open magnetic-field lines [5]. The corresponding n and T-profiles, coming out of the simulations, confirm this statement.

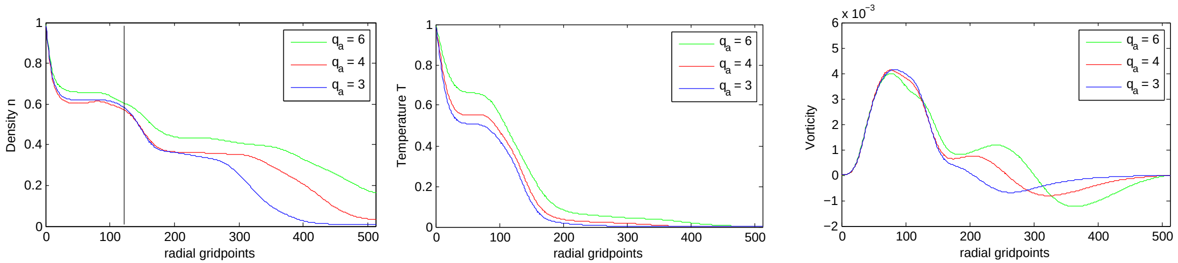

Figure 2: Profiles $\langle n \rangle_{y,t}$, $\langle T \rangle_{y,t}$ and $\langle \nabla_\perp^2 \phi \rangle_{y,t}$.

All simulations presented here, are computed on a grid consisting of 512 × 256 grid-nodes, covering an (x,y)-slab of $100\rho_s$ by $50\rho_s$ respectively. The boundary conditions and TEXTOR-parameters used in the code are the same as in [3]. In order to study the q-dependence of the resulting intermittency with respect to the experimental results from TEXTOR, the neoclassical q^2-dependency in the perpendicular diffusion coefficients (standard in ESEL and used in [3]) has been removed. Comparing these results in Fig. 3 to Fig. 4 in Ref. [3] one can see that these q^2-factors do not make the difference. The only remaining q-dependency (besides the one in $L_\|$) is hiding in the D_T-coefficient due to the coupling with the ions (second term, $D_{Ti}/(1+\frac{3.2m_i}{3m_e\nu_*^2})$), because ν^* scales with $L_\|$ which is for us proportional to q_a. In a special run (‘spec’), all the diffusion coefficients for $q_a = 6$ have been put identically equal to those in the $q_a = 3$-run. For these code-parameters, we see that the q_a-dependence in this ‘electrically disconnected’ version of $L_\|$ is sufficient to make the difference in kurtosis K (and thus intermittency). These simulation results are in line with eg. the TCV-results [6], but not at all with the tendencies detected in TEXTOR (see table). To find a better agreement for TEXTOR, where the ALT-limiter is making most probably the blobs on the outboard midplane electrically connected to it, we will have to implement the sheath boundary conditions in the code.

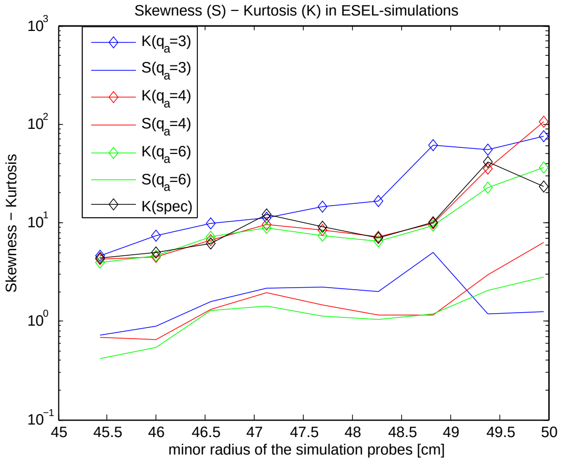

Figure 3: S and K of the radial particle flux signal for different values of $q(a)$.

Shotnumber - q_a	S	K	number of blobs	S	K	number of blobs
101801 - 3.2	0.85	6.91	25	0.93	5.07	43
101792 - 4.3	1.07	5.32	33	1.11	5.09	27
101800 - 5.8	1.58	9.37	26	1.74	7.94	21

Table 1: S- and K- values at $r \approx 49$ cm (left) and $r \approx 48$ cm (right) in TEXTOR.

Besides all this, the exercise of comparing the simulated SOL-turbulence by ESEL with the real TEXTOR-experiment is worthwhile. One can see a rather nice agreement in the conditionally averaged time-traces of the generated blobs.

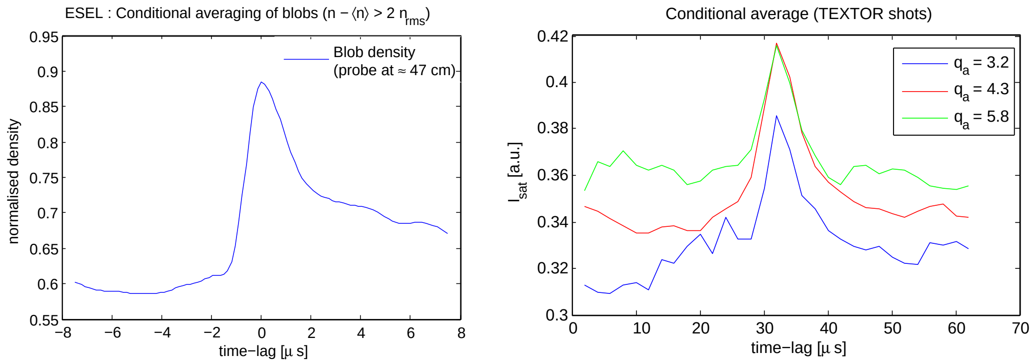

Figure 4: Left : Conditionally averaged blob time trace from the ESEL simulation (seen by the probe sitting at ≈ 47 cm). Right : same conditional average for the TEXTOR I_{sat} -signal of the shots mentioned in the table (measured by a reciprocating probe, at ≈ 49 cm).

Conclusion and outlook

In this paper, we discussed different runs of the ESEL code with the TEXTOR experimental parameters as input. It appeared that the experimental tendency with respect to the dependency for the SOL-intermittency from the safety-factor $q(a)$, is opposite from the results of the simulations, based on the ‘electrically disconnected’ effective parallel damping. In our opinion, the ALT-limiter position with respect to the outboard midplane, is responsible for this. Therefore, one needs to be careful by comparing SOL-turbulence results from ohmic shots (where the plasma is limited by the ALT-limiter) and DED-results.

References

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