Characterization of Turbulence in the JET Limiter Plasma Boundary

I. García-Cortés[1], S.J. Davies, M. Endler[2], R. Balbín[1], J. Bleuel[2], A. Chankin, S.K. Erents[3], C. Hidalgo[1], A. Loarte[4], G.F. Matthews, E. Sánchez[1] and H.Thomsen[2]

JET Joint Undertaking, Abingdon, Oxfordshire, OX14 3EA, UK.
1) Asociación EURATOM-CIEMAT, 28040 Madrid, SPAIN.
2) Max-Planck-Intitut, EURATOM Association, 85740 Garching, GERMANY.
3) UKAEA/Euratom Fusion Association. Abingdon, Oxfordshire OX14 3DB, UK.
4) NET 85740 Garching, GERMANY.

1. Experimental set-up

The turbulent particle transport has been studied in the plasma boundary by using a specially adapted Langmuir probe (figure 1).

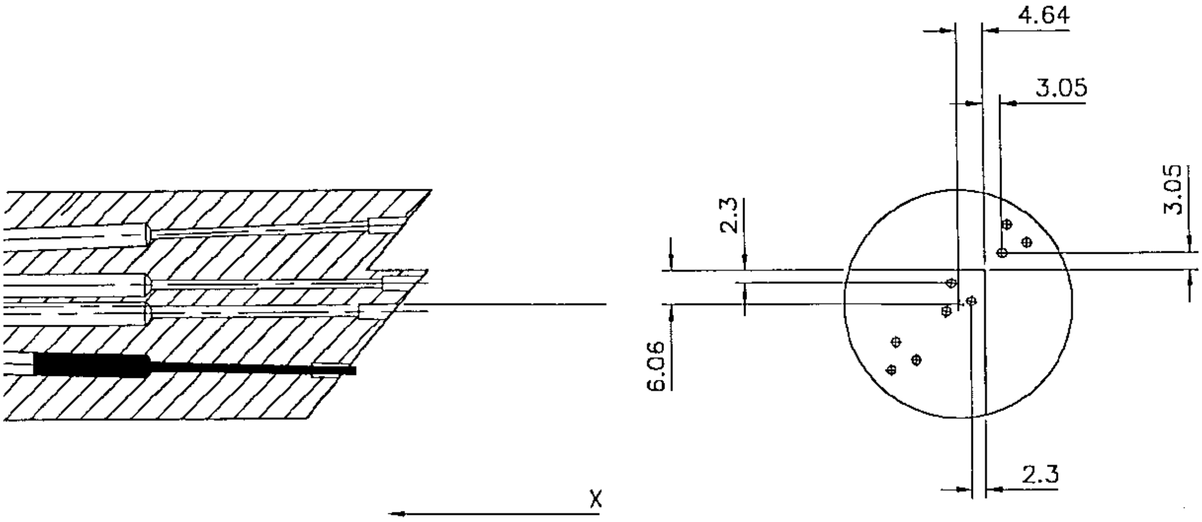

Figure 1. Nine element fluctuation probe. Direction of x coincides with direction of B_T in frontal view. Distances are given in mm.

Nine tips on the new probe head have been arranged in three groups of three. Two of them are at the same poloidal position, being separated radially 0.8 cm and the third is located radially at the same position as the innermost group of tips (out of the previous two) but separated by 1.5 cm from them poloidally. This experimental set-up provides measurements of both the radial and poloidal structure of fluctuations. From these measurements the electrostatic Reynolds stress term, proportional to the cross-correlation between radial and poloidal fluctuating electric fields, can be estimated. Fluctuating poloidal electric fields and ion saturation currents from individual groups of tips has been used to evaluate the radial profile of the turbulent radial particle transport ($\Gamma_{E\times B}$).

The experiments reported in this paper were carried out in the Joint European Torus (R=2.85m, a=0.95m, b/a=1.85, JET Gas-Box pumped divertor) boundary plasmas. The general characteristics of the turbulence were analysed in the limiter phase of the shots: 45783 and 45798 (B_T = 2.4 T, I_P = 2.6 MA and n_e = 1.6 10^{19} m^{-3}). The position of the Last Closed Flux Surface (LCFS) is determined by the equilibrium code EFIT and the figures are plotted versus distance from LCFS at the outer midplane of the plasma.

2. Turbulent transport

The profile of the ion saturation current (I_S) increases and the floating voltage goes to more negative values as the probe is moving into the plasma edge. The normalised density fluctuation levels approach unity near the wall and decrease across the SOL as the probe is moving to the plasma edge. The fluctuations level goes to (10-20)% in the innermost probe position as it has been observed in most of the plasma fusion devices. The fluctuations are dominated by frequencies bellow 100kHz. The poloidal wave number is in the range of k_θ = (0.5-1) cm^{-1}, in the SOL and changes sign as the probe approaches the edge of the plasma.

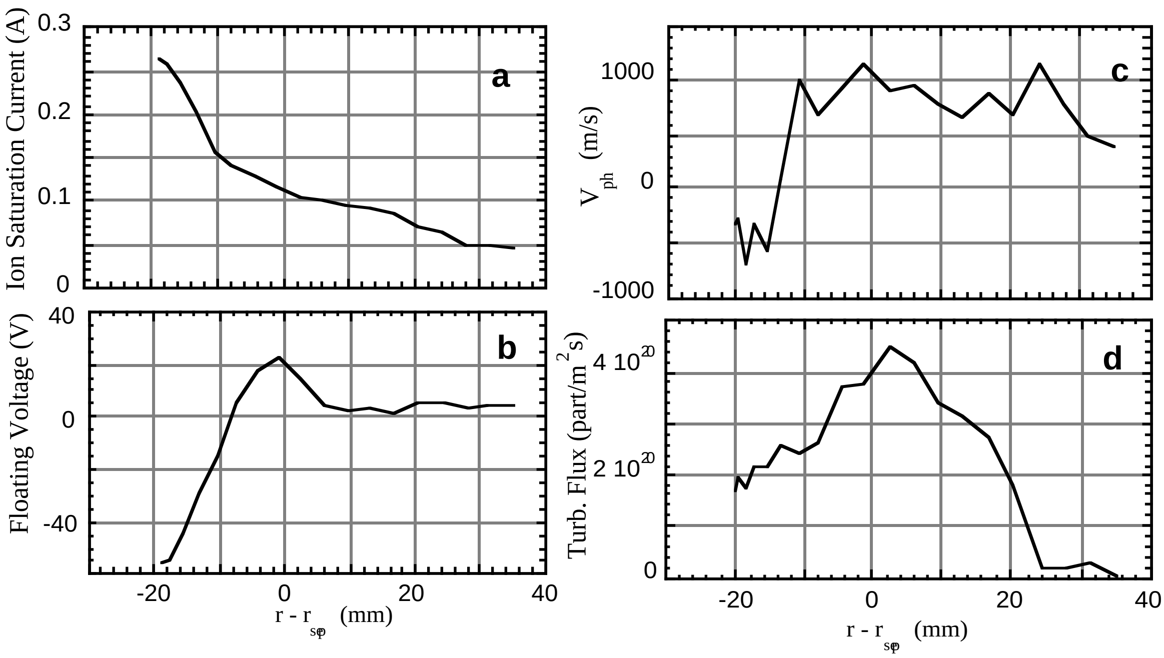

Figure 2. Radial profile of ion saturation current (a), floating voltage (b), poloidal phase velocity of the fluctuations and E×B turbulent particle flux in the limiter phase of the shot 45783.

The poloidal phase velocity reverses sign to the electron diamagnetic drift direction inside the LCFS, the radial position where this change occurs is called the velocity shear layer (VSL). The radial profile of the turbulent flux shows a maximum about the LCFS (figure 2d).

The perpendicular diffusion coefficient, D_{perp}, is estimated subject to the assumption that the transport is dominated by turbulence and using the expression: $D_{perp}=<\tilde{I}_S\tilde{E}_\theta>\lambda_n/B_T I_S$. The value obtained is D_{perp} = 1.5 m^2/s taking a density decay length (λ_n) of 1 cm at the outer mid-plane of the plasma.

The SOL input power, computed as the difference between the input and the radiated power, is about 1 MW. The convected energy flux associated with turbulent transport is: 3/2 $k_b T_e \Gamma_{turb}$ and the convective power: P_{conv} = 3/2 $k_b T_e$ Γ_{turb} A_{SOL} = (0.3-0.4) MW. Where: P_{conv} is the total convective power to the SOL, T_e is the separatrix temperature (about 40 eV), Γ_{turb} is the turbulent particle flux measured by Langmuir probes at the LCFS (4 10^{20} $m^{-2}s^{-1}$), and A_{SOL} is the SOL area (about 100 m^2). Therefore, the total power carried by the turbulent particles flux measured by Langmuir probes is not in contradiction with the SOL total input power.

Turbulent particle flux measurements have been carried out in X-point configuration plasmas. The obtained turbulent flux is about one order of magnitude larger than in limiter phase (for similar plasma conditions). This could be related to the convected cells found in the divertor SOL plasmas. Studies are underway to clarify this issue.

3. Shape of the fluctuation spectra

The experimental plasma edge fluctuation spectrum measured at JET limiter plasmas is consistent with the existence of three distinct frequency ranges in the fluctuations power spectra.

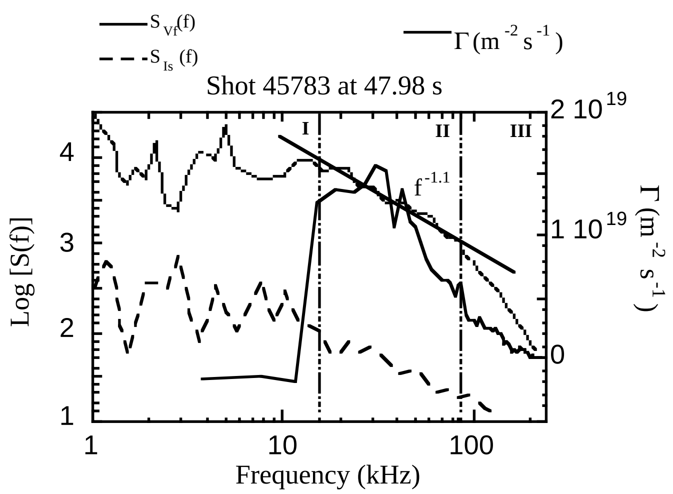

Figure 3: Spectra of the Is and potential fluctuation in limiter phase of the plasma. It is also shown the spectral turbulent flux function.

Each of these regions has a distinct characteristic power dependence. The lowest frequency part is found to be nearly independent of the frequency. The high frequency part presents an asymptotic falls off with decay indices close to -2 or even higher. More attention is given to the intermediate frequency region. As it is shown in figure 3 the turbulent flux spectral function at the plasma edge, peaks in the intermediate frequency range, where the decay index in the fluctuation power spectra is close to -1. This correlation between the 1/*f* fluctuation range and transport dynamics is clear in all the analysed cases. The range characterised by a decay index close to –1 also points to a possible connection to a self organized criticality behaviour [1] of the edge plasma turbulence.

4. Physics of poloidal flows and Reynolds stress measurements.

The electrostatic Reynolds stress term (R_e), $<\tilde{v}_\theta \tilde{v}_r>$, being the poloidal and radial E×B fluctuation velocities respectively, has been measured in the boundary of the JET limiter plasmas. The radial gradient in the Reynolds stress [2] shows a maximum at the velocity shear layer location (figure 4a) and it is in the range of $dR_e/dr \approx 10^8$ ms^{-2}, (figure 4b). The importance of fluctuation induced flows obtained ($dR/dr \approx 10^8$ ms^{-2}) in the evolution of the poloidal flow requires a comparison with the magnitude of the flows driven or damped by other mechanisms. The damping term due to magnetic pumping at the edge is $\gamma_m v_{i\theta}$, where $v_{i\theta}$ and γ_m are the ion poloidal velocity and the damping rate, respectively. Assuming $v_{i\theta}$ of the order of the E×B poloidal velocity, $v_\theta \approx 10^3$ ms^{-1}, the magnetic pumping contribution to the poloidal flow time evolution is expected to be of the order (10^6-10^7) ms^{-2} for JET edge plasma parameters. This result suggests the importance of fluctuation induced flows in the JET plasma boundary region.

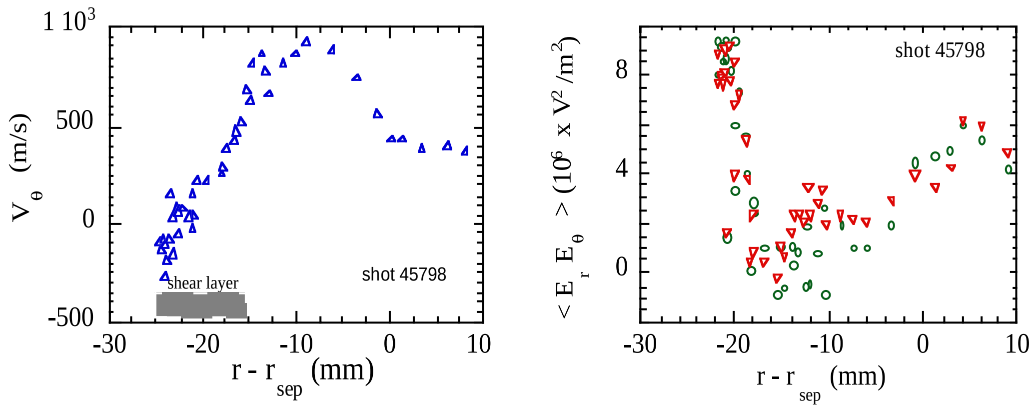

Figure 4. Poloidal phase velocity of the fluctuations (a) and correlation between radial and poloidal electric field (b) versus distances from the LCFS in the limiter phase of the shot 45798.

[1] B. Carreras, R. Balbín et al. submitted to Plasma Phys. and Contr. Fusion (1999)
[2] C. Hidalgo et al. IAEA (1998).