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ABSTRACT

Considerable effort has been devoted in recent years to diagnose turbulence in forward toroidal field (ion $B \times \vec{\nabla} B$ drift direction downwards towards the divertor) experiments in the JET plasma Scrape-Off-Layer (SOL). New observations from reversed field campaign have now allowed this earlier analysis to be extended. This paper presents a comparative study of the structure of turbulent transport and fluctuation levels in discharges which are ostensibly similar in terms of plasma parameters, but which the directions of plasma current and toroidal magnetic field are reversed. Experiments were carried out in the plasma boundary region using a fast reciprocating Langmuir probe system.

1. EXPERIMENT

Plasma profiles and turbulence have been investigated in the JET plasma boundary region using a fast reciprocating Langmuir probe system located at the top, low field side of the poloidal cross-section. The local time resolved radial ExB turbulent induced fluxes, $\tilde{\Gamma}(t) \propto \langle \tilde{n}(t)\, \tilde{E}_\theta(t) \rangle / B$, (where $\tilde{n}$ and $\tilde{E}_\theta$ are, respectively, the fluctuating density and poloidal electric field) are computed neglecting the influence of electron temperature fluctuations. The poloidal electric field has been estimated from floating potential signals measured by poloidally separated probes, $E_\theta / \Delta\tilde{\Phi}_f / d$ being d the distance between probe tips in the poloidal direction. The Mach number is estimated as M=0.4 $\ln(I^{ct}/I^{co})$ where I^{co} and I^{ct} represent the ion saturation currents (I_s) measured on each side of the Mach probe (i.e. co and counter direction magnetic field) [1]. Date reported in this paper were obtained in X-point configurations in ohmic and neutral beam heated L-mode regimes with toroidal magnetic fields B = 1.6-2.4T and plasma current Ip = 2MA, in “matched” forward (FWDB) and reversed (REV-B) toroidal field discharges. In the reversed field experiments there was an uncertainty of about 2cm in the EFIT magnetic equilibrium reconstruction which prevents correct identification of the position of the separatrix. A previous paper [2] studied this problem in some detail and concluded that for the experimental period over which the measurements reported here were made, an approximate correction of 22mm is required to probe-separatrix distances. The presence of a strong gradient of the floating potential, V_f (linked with a reversal in the poloidal phase velocity) provides a good indicator for the location of the separatrix in many devices [3] and is consistent with the correction applied here.

2. EXPERIMENTAL RESULTS AND DISCUSSION

In both magnetic configurations a reversal in the poloidal phase velocity of fluctuations (shear layer), computed from the wave number and frequency spectra S(k,ω) using the two points correlation technique [4], is observed in the separatrix vicinity (Fig.1). The shear layer location provides a convenient reference point for comparing the structure of turbulence in forward and reversed field configurations. The chosen matched pairs of discharges have very similar I_s and V_f profiles (Fig.2(a)). The level of fluctuations in the I_s near the shear layer is ~10–20%, RMS and the level in V_f in the range of 50% (Fig.2(b)). Mean frequencies are ~50kHz and poloidal wave numbers in the range of 1 cm^{-1}. In both configurations, the local ExB turbulent transport has been measured. The maximum in the fluctuation flux appears to be linked to the location of the velocity shear layer; on the SOL side of the velocity shear Γ_{ExB} decreases when moving radially outwards (Fig.3). For matched pairs of discharges no significant difference in shape and magnitude was found in the profiles between forward and reversed field measurements. A comparison between the parallel flow profiles between forward and reversed field discharges is presented in Fig.4. The parallel SOL flow on JET at the probe location has been measured to change from $M_{||}$~0.5 in forward field to $M_{||} \sim -0.1$ in reversed field [5]. This change is significantly larger than predicted by the fluid transport code EDGE2D with classical drifts [5] or by the SOLPS5 code [6]. Experiments in forward field have pointed out the possible influence of turbulence in explaining a component of the anomalous flows observed in the SOL [7].

In the forward field direction, a strong parallel flow is measured at the top of the machine in the direction from the outer to the inner divertor. For reversed field, the measured flow is smaller but approximately symmetric with respect to a symmetry axis given by a positive offset. These profiles are comparable to the previously reported data from JET at the same poloidal location [2].

The normalized Probability Distribution Function (PDF) shows that the distributions of fluctuations in the I_s and V_f are very similar in both magnetic field directions (Fig.5(a) and 5(b)). The PDFs were calculated over a range of 1cm around the point at which the probe movement changes direction during its fast reciprocation in order to avoid effects related to the probe movement itself. It should also be noted that the PDF's were obtained at different radial positions. Some differences in PDF shape are observed for the measurements from the far SOL (star points). The variation of the I_s PDF across the SOL was intensively described in [8] for the TVC case, being demonstrated there that it is well described by a gamma distributed random variable.

The normalized PDFs of the turbulent flux are also remarkably similar (Fig.6). A reduction of the intermittence is observed in REV-B discharges (closed symbols) being this reduction more pronounced in inward intermittent flux events ($\Gamma_{ExB} < -5 <\Gamma_{ExB}>$, negative tail of the curve). This small difference is not reflected in the turbulent flux profiles because the contribution from intermittent events to the total flux is small.

Quadratic terms in velocity fluctuations have been also investigated in REV and FWD field configurations. Figure 7 shows radial profiles of $<\tilde{v}_r \tilde{M}_{||}>$ obtained in forward and reversed field in the proximity of the separatrix in the JET tokamak. The errors in the velocity component cross-correlation were estimated following [9] and are given by $\varepsilon(<\tilde{v}_r \tilde{M}_{||}>) = \sigma(v_r)\sigma(M_{||})/\sqrt{N}$ where N is the number of samples used to calculate the cross correlation and $\sigma(v_r)$, $\sigma(M_{||})$ are the standard deviations of radial velocity and Mach number fluctuations. In the plasma region where the V_f becomes more negative (close to the region where the perpendicular velocity shear is developed) there is evidence of significant radial gradients (on the order of $10^3 - 10^4$ s^{-1}) in the cross-correlation between parallel and radial fluctuating velocities. It should be noted that the quadratic term of fluctuating velocities changes sign when the magnetic field is reversed.

In summary, basic turbulence properties (e.g.level of fluctuations, ExB turbulent transport) are comparable in normal and reversed field configurations. It was observed that the SOL turbulence is less intermittent in REV-B discharges. A smaller parallel flow, but approximately symmetric with respect to a symmetry axis given by a positive offset, was observed in reversed field experiments. Parallel turbulent forces (related to gradients in the cross correlation between parallel and radial fluctuating velocities) are modified in reversed and standard B-field configurations.

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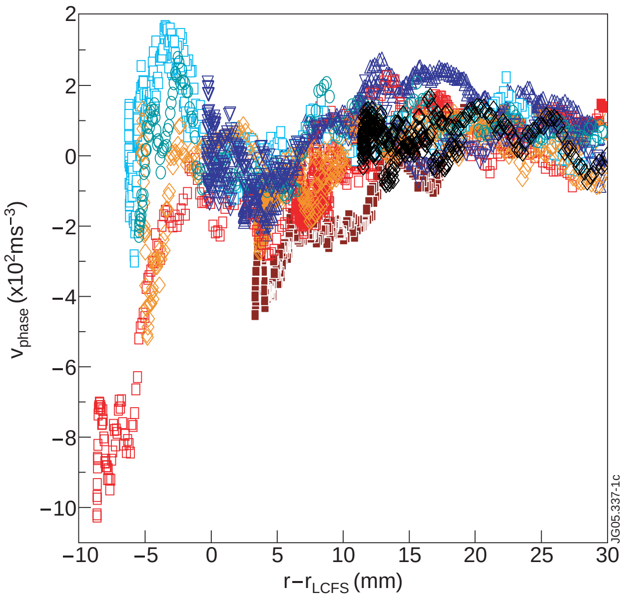


Figure 1: Phase velocity profile in REV-B (closed symbols) and FWD-B (open symbols).

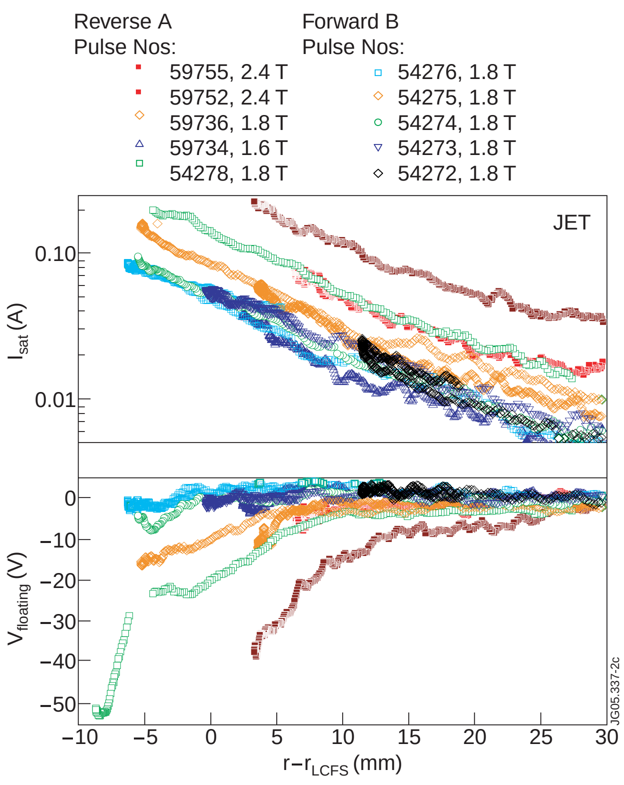


Figure 2(a): I_s and V_f profiles near the separatrix in FWD-B and REV-B configuration at the JET top region.

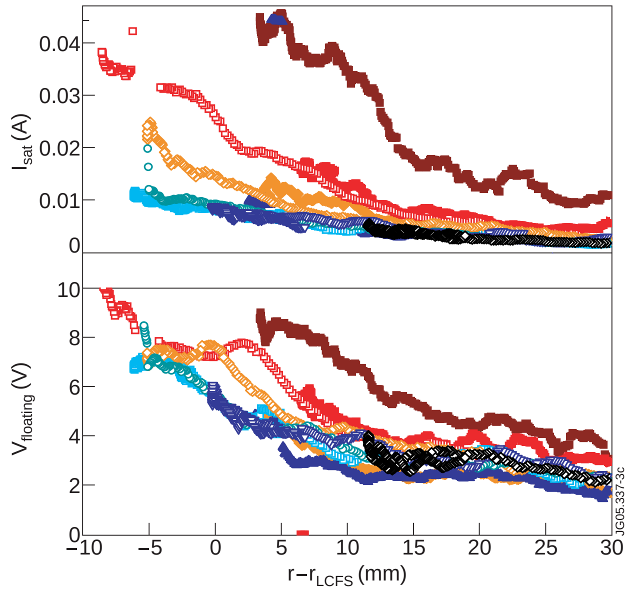


Figure 2(b): Profile of the level of fluctuations in FWDB and REV-B discharges.

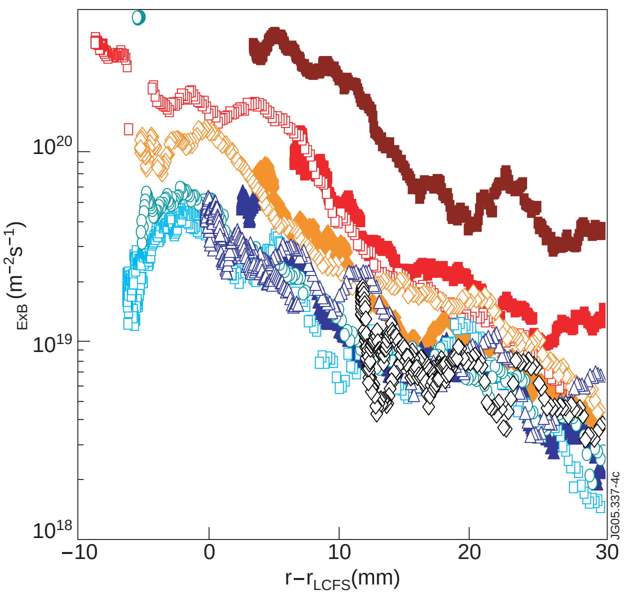


Figure 3: Profile of the turbulent ExB flux. Similar behaviour is observed for FWD-B and REV-B discharges.

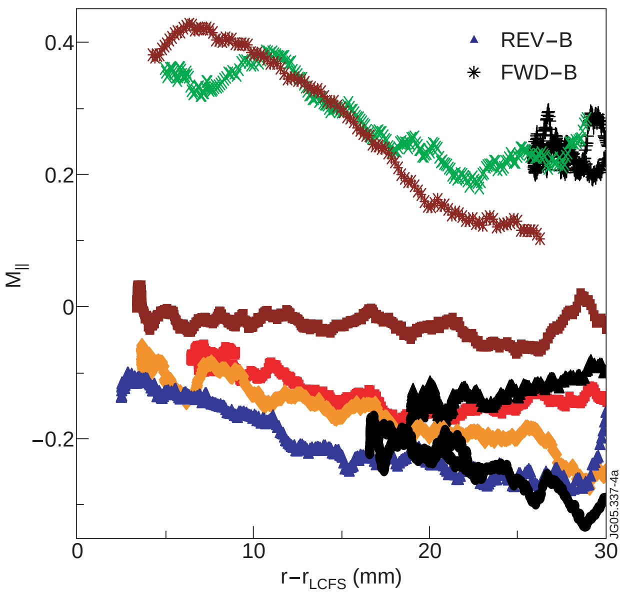
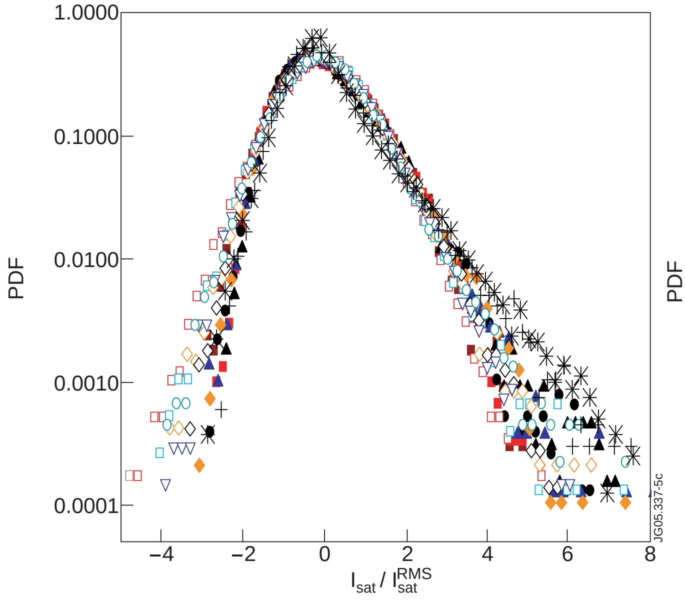


Figure 4: Comparison of Mach number profiles between a FWD-B and REV-B discharges in JET.



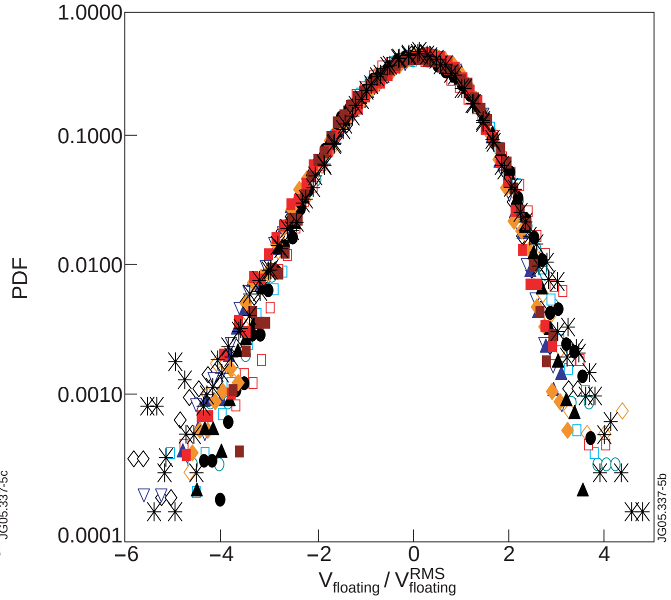
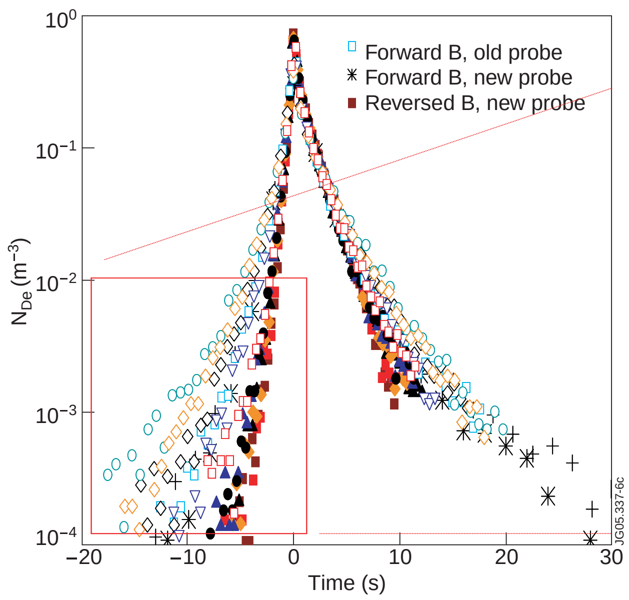


Figure 5a: Probability Distribution function of the I_s normalized to the level of fluctuations

Figure 5b: Probability Distribution function of the V_f normalized to the level of fluctuations



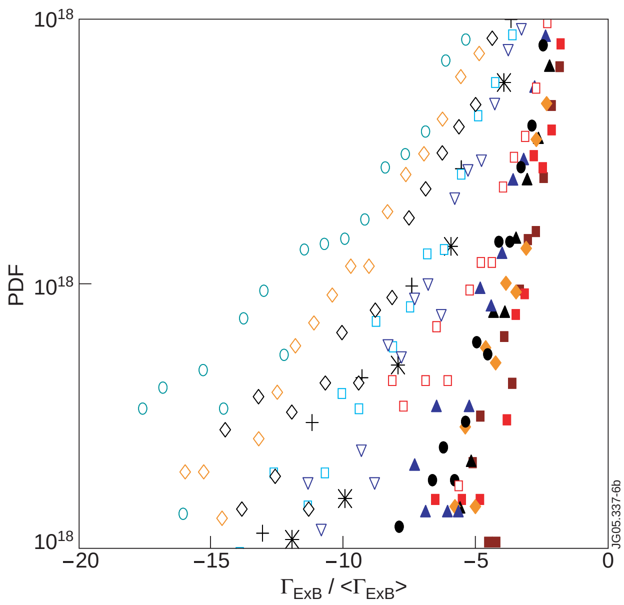


Figure 6: a) PDF of the turbulent ExB flux. b) A detail of the tail of the distribution shows a reduction in the inward intermittent events for the reversed field discharges.

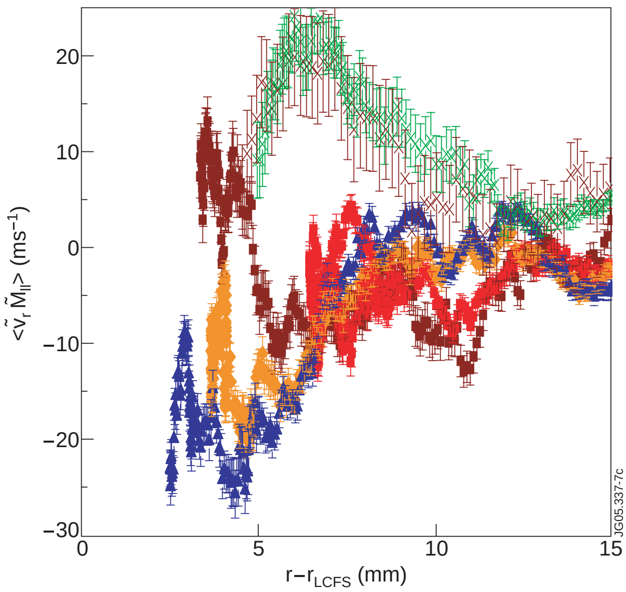


Figure 7: Radial profiles of the cross-correlation between parallel and radial fluctuating velocities in JET L-mode plasmas near the separatrix in forward and reverse field discharges.