# On the momentum re-distribution via fluctuations in fusion plasmas

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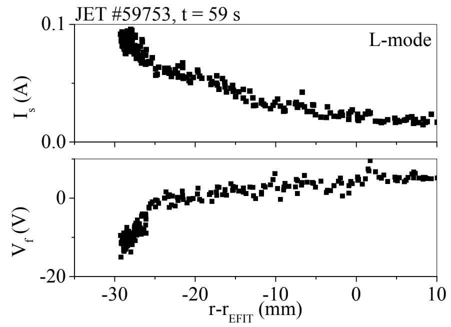
## I. Introduction

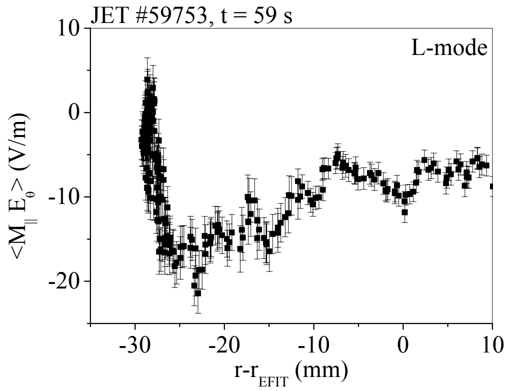
The mechanisms underlying the generation of plasma flows play a crucial role in understanding transport in magnetically confined plasmas. The amplitude of parallel flows in the scrape-off layer is significantly larger than those resulting from simulations[1]. Recent experiments have pointed out the possible influence of turbulence to explain flows in the plasma boundary region[2,3,4]. In this context, it has been suggested that poloidal gradients induced by ballooning like turbulent fluxes in the outer SOL region are drivers for parallel flows and coupling between turbulent transport and parallel flows have been reported[2]. In order to quantify the link between flows and turbulence, the energy transfer between them is under investigation[5]. However, in view of recent results[6], some caution should be taken in the interpretation of probe results since it may locally perturb the plasma. In the plasma core region evidence of anomalous toroidal momentum transport has been reported in different devices[7] and different mechanisms have been proposed to explain those results including neoclassical effects[8], turbulence driven models[9,10] and, in the case of ICRF heating, fast particle effects. Spontaneous toroidal flow not driven by neutral beams has also been observed in stellarator devices[11].

This paper reports recent experimental results dealing with the link between parallel flows and fluctuations in the plasma boundary region of tokamaks (JET) and stellarators (TJ-II).

## II. On the cross-correlation between parallel and radial fluctuating velocities

The contribution of the Reynolds stress term, $d < \tilde{v}_r \tilde{M}_{||} > / dr$, $\tilde{v}_r$ and $\tilde{M}_{||}$ being the fluctuating (ExB) radial velocity and the fluctuating parallel Mach number respectively, provides the mechanism to convert the turbulent scales (high frequency fluctuations) into a mean parallel flow. Figure 1 shows radial profiles of $< \tilde{v}_r \tilde{M}_{||} >$ as well as floating potential, ion saturation current and parallel Mach number in the proximity of the LCFS in the JET tokamak. In the plasma region where the floating potential becomes more negative (which turns out to be very closed to the region where the perpendicular velocity shear is developed) there is evidence of significant radial gradients (in the order of $10^3 - 10^4$ $s^{-1}$) in the cross-correlation between parallel and radial fluctuating velocities. Experiments in progress in the TJ-II stellarator have also shown radial variations in the cross correlation between parallel and radial velocity fluctuations (comparable to JET) near the LCFS. These gradients are due to the radial variations in the level of poloidal electric filed fluctuations and in the cross-phase coherence.



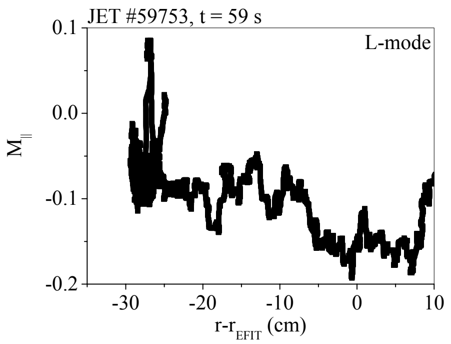




Fig. 1: Radial profiles of ion saturation current, floating potential, Mach number and cross-correlation between parallel and radial fluctuating velocities in JET L-mode plasmas near the LCFS. Since the EFIT determination of the LCFS has proved to have an uncertainty of about 2 cm, the LCFS is considered to be near the region where the shear in the floating potential is observed. Measurements were taken in reversed magnetic field configuration at the probe position (JET top region).

An estimate of the importance of turbulence in the evolution equation of the parallel flow requires a comparison of $d < \tilde{v}_r \tilde{M}_{||} > / dr$ with the magnitude of the parallel flows damped / driven by different mechanisms. The damping of the plasma rotation due to charge-exchange can be expressed as, $\nu_{cx} M_{||}$, ($\nu_{cx}$ being the collision frequency for the charge-exchange reaction). Assuming for JET neutral density near the LCFS, $n_n \approx 10^{16}$ $m^{-3}$ (the upper limit value obtained from EDGE2D) it follows that $\nu_{CX} = n_n < \sigma v >_{CX} \approx 10^3\ s^{-1}$. Experimental results show therefore that the contribution of $d < \tilde{v}_r \tilde{M}_{||} > / dr$ is larger than charge-exchange loss mechanisms in the parallel momentum balance equation at the plasma boundary region. However, a quantitative estimate of the role of turbulence would need to consider all mechanisms (driving / damping) contributing to the parallel momentum.

## III. On the dynamical relation between parallel flows and instabilities in JET and TJ-II

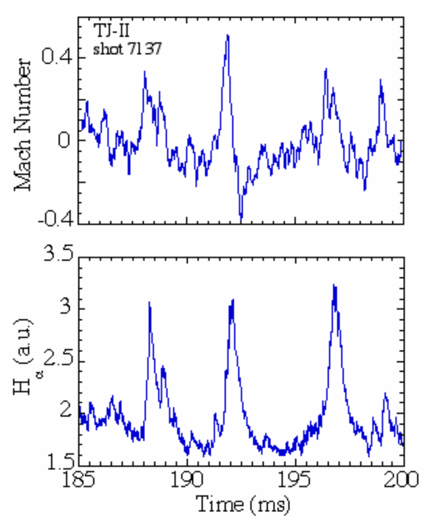



Fig. 2 Time evolution of parallel flows and edge instabilities in the boundary region of the TJ-II stellarator.

The influence of low frequency instabilities (ELM-like) on the transient behaviour of parallel flows has been recently investigated in the JET tokamak[12] and TJ-II stellarator[13]. Due to the flexibility of the TJ-II configuration, both the magnetic well depth and its radial variation may be modified over a broad range of values. It has been shown that the level of edge fluctuations and the degree of intermittency show a significant increase when magnetic well is reduced in the TJ-II stellarator. The time evolution of parallel flows and edge instabilities (indicated by the $H_\alpha$ variation) is shown in figure 2 for configurations with reduced well in the edge. With the appearance of edge instabilities parallel flows are significantly modified, showing a coupling between edge transport and parallel flows[13].

This result is consistent with recent experiments carried in the plasma boundary of JET tokamak, which has shown that during the appearance of ELMs, perturbations in the ion saturation current are larger (about a factor of 3) in the Mach probe facing the outer divertor (e.g. region of bad curvature) than in the Mach probe facing the inner divertor (e.g. region of good curvature). Considering that the parallel Mach number can be computed as $M_{||}=0.4 \ln(I^{ct}/I^{co})$ where $I^{co}$ and $I^{ct}$ represent the ion saturation current measured at each side of the Mach probe (i.e. co and counter magnetic field direction)[14], it follows that parallel flows are modified during the appearance of ELMs. This result might reflect the strong ballooning character of ELMs but it also shows the parallel momentum redistribution during the generation of ELM events[12].

## IV. Influence of plasma density on parallel flows and fluctuations in TJ-II

Plasma density plays a key role on plasma confinement and in the structure of flows in the TJ-II stellarator. Figure 3 shows the evolution of parallel Mach number and the level of edge fluctuations (quantified as the rms value of poloidal electric filed fluctuations) during a density scan in the range (0.3 – 1 x $10^{19}$ $m^{-3}$) for measurements taken at $\rho \approx 0.85$. As the density increases the level of plasma turbulence increases until a critical edge gradient is reached (where sheared perpendicular flows are developed). Above this value the level of turbulence decreases with a concomitant development of ExB sheared flows. Those results point out that the evolution of parallel flows is coupled both with the level of poloidal electric fields fluctuations and the generation of ExB sheared flows.

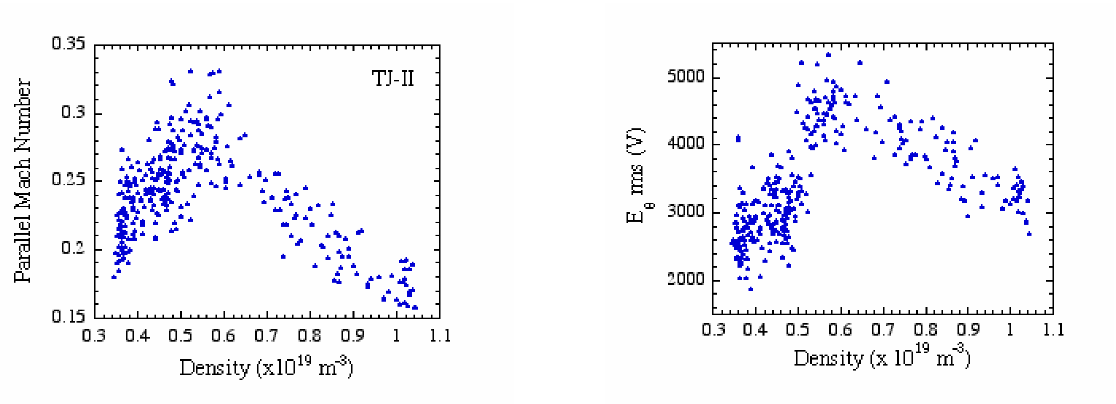



Fig. 3: Parallel flows and level of edge fluctuations versus plasma density in the plasma boundary of the TJ-II stellarator. Measurements were taken near $\rho \approx 0.85$.

## V. Conclusions

The investigation of the interaction between flows and fluctuations becomes one of the important open issues in the plasma edge dynamics and an active research programme in progress in tokamaks and stellarators. Experiments carried out in the plasma boundary of JET tokamak and TJ-II stellarator have shown the existence of significant gradients in the cross-correlation between parallel and perpendicular flows as well as a dynamical coupling between edge (ELM-like) instabilities and parallel flows. In the TJ-II stellarator, the level of edge fluctuations is linked with the evolution of parallel flows.

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