Characterization of the turbulence during LOC-SOC transition using Poloidal Correlation Reflectometry at ASDEX Upgrade

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1. Introduction

In several tokamaks a linear increase of the energy confinement time of Ohmic plasmas with the line averaged electron density has been reported. However, above a critical density the energy confinement time saturates. The corresponding regimes are named LOC and SOC, respectively. One hypothesis is that the transition is due to a change from trapped-electron-mode (TEM) to ion-temperature-gradient (ITG) driven turbulent transport associated with the change of collisionality $\nu_{eff} \propto n_e/T_e^2$ [1]. Reported here are new results on the LOC-SOC transition from the Poloidal Correlation Reflectometer (PCR) system installed on ASDEX Upgrade (AUG) [2, 3]. The diagnostic measures density fluctuations at 4 positions separated by small distance in poloidal-toroidal plane and provides information on the density fluctuation characteristics, such as perpendicular velocity $v_\perp$, correlation length $l_\perp$ and decorrelation time τ_d over a wide range of densities $(0.9-4.1\times10^{19}\ \mathrm{m}^{-3})$. These properties in different regimes are presented.

2. Reversal of v_{ExB} rotation in different regimes

Even in the absence of an external torque (e.g. due to NBI) the v_{ExB} rotation in the L-mode plasma core is defined not only by the $-\nabla p_i/(enB)$ term, but may have an additional component due to 'spontaneous' (or 'intrinsic') rotation parallel to the magnetic field $v_{||}$. Several symmetry breaking mechanisms have been proposed to explain generation of parallel velocity [4]. One of them is the residual stress arises due to tilting of the turbulent eddies in radial-poloidal plane [5].

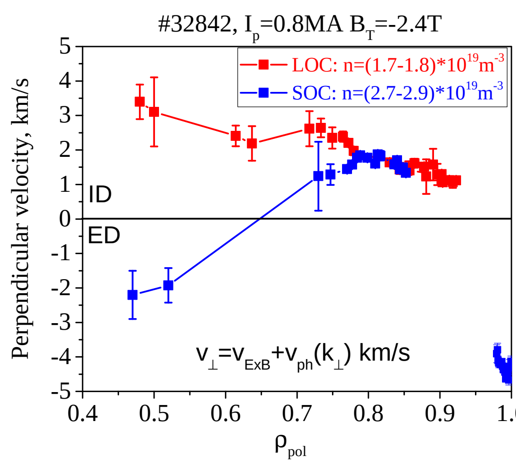

Figure 1: *The Perpendicular velocity profiles $v_\perp = v_{ExB} + v_{ph}(k_\perp)$ measured with PCR.*

The tilting appears due to the dependence of the turbulence phase velocity v_{ph} on the underlying instability and change sign for different turbulence regimes (TEM and ITG), resulting in a reversed direction of residual stress. This may reverse the direction of v_{ExB} as well, however, it is not clear if this effect plays the dominant role [6].

The PCR system allows us to measure the fluctuation propagation velocity $v_\perp = v_{ExB} + v_{ph}(k_\perp)$ with $k_\perp = 0-3$ cm^{-1} by means of time delay estimations [2, 3]. Profiles obtained using frequency sweeps in the LOC and SOC regime for AUG shot #32842 are shown in figure 1. In the LOC regime $v_\perp$ is in the ion diamagnetic (ID) direction almost at all radial positions. Rotation in the SOC regime inverts $v_\perp$ to the electron diamagnetic (ED) direction for $\rho_{pol} < 0.6$, however, it stays in the ID direction for $0.7 < \rho_{pol} < 0.9$. These profiles have been compared with measurements of v_{ExB} from the CXRS diagnostic, where agreement has been obtained suggesting that the turbulence phase velocity is small [7]. Gyro-kinetic simulations predict that a phase velocity $v_{ph} < 1.0$ km/s is expected [8]. Further analyses of density fluctuation have been performed in the region $0.6 < \rho_{pol} < 0.9$ where velocity remains in ID direction for both regimes.

3. Quasi-Coherent structures at low collisionality

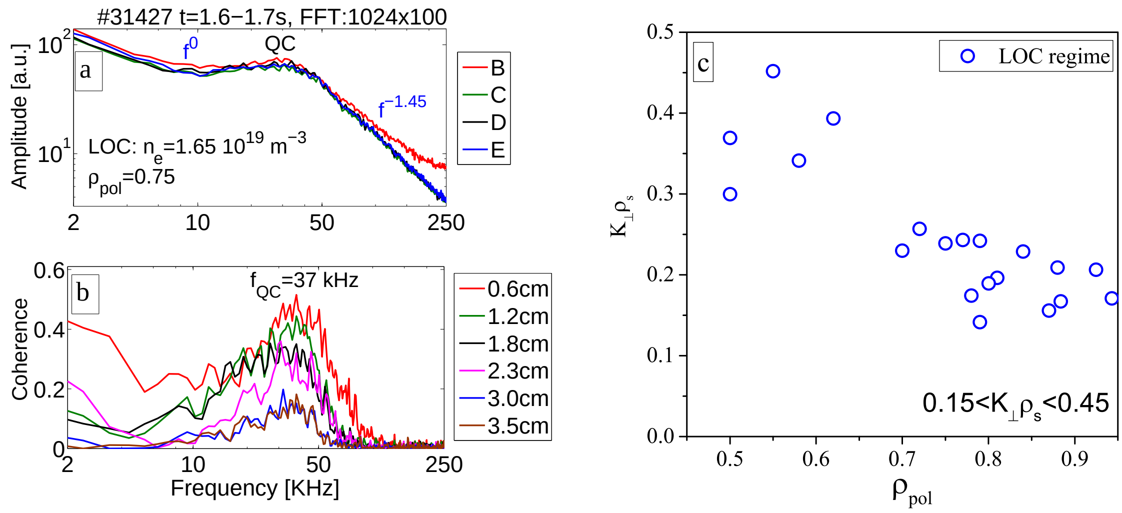

Figure 2: (a) Spectrum of density fluctuations (δn_e) measured at 4 position on the same magnetic surface. (b) Coherence spectra between density fluctuations at different perpendicular separation. (c) Dependence of normalized wavenumber $k_\perp \rho_s$ of QC mode on the radius of plasma.

Experimentally in Tore Supra has been observed that a Quasi-Coherent (QC) mode in density fluctuation spectra exists in the LOC, but disappears in the SOC regime [9]. Nonlinear gyro-kinetic GENE code simulation have been performed where QC mode (as a nonlinear feature of TEM turbulence) have been found in the density fluctuations spectra as well [9]. At AUG, analyses of experimental density fluctuation spectra have been performed at $\rho_{pol} = 0.7-0.8$ where the v_{ExB} rotation remains approximately constant in both regimes. Figure 2(a) shows density fluctuation spectra measured in the LOC regime on the same magnetic surface (ρ_{pol} ≈0.75) at 4 different positions. The separation between the measurements in the perpendicular to magnetic field line direction amounts to $\Delta s = (0.6, 1.2, 1.8, 2.3, 3.0, 4.5)$ cm. All spectra look similar and a weak QC mode is observed only. Calculating the coherence spectra $\gamma(f) = |\langle \delta n_1(f) \delta n_2(f) \rangle| / |\langle \delta n_1(f) \rangle| |\langle \delta n_2(f) \rangle|$ between density fluctuations (figure 2 (b)) with different separation shows a clear QC Peak. It is suggested that the QC mode is not clearly observed in the density fluctuation spectra because the mode is hidden behind broadband uncorrelated density fluctuations and only the coherence allows to highlight this mode. It is important to note that QC mode in the Tore Supra was stronger, probably because collisionallity was smaller [9]. The QC structure at AUG can be observed at several radii simultaneously. The frequency of the QC mode is not the same at different radii, connected to the local plasma rotation. The perpendicular wavenumber of QC structures have been calculated using the measured velocity using $k_\perp = 2\pi f_{QC}/v_\perp$. This parameter is found to be independent of the rotation velocity. The dependence of $k_\perp$ normalized to the drift wave scale $\rho_s = \sqrt{T_e m_i}/(eB_t)$ is shown in figure 2(c). It is interesting to note that the value of $k_\perp \rho_s \approx 0.2-0.4$ is close to the most unstable TEM/ITG mode predicted by gyrokinetic simulations. QC mode indeed disappears with increasing collisionality, but, not exactly at the point of the LOC-SOC transition. More detailed studies are needed to explain the nature of the QC mode. Nonlinear gyrokinetic simulations will be performed to identify similarities between measured and predicted fluctuations in different regimes.

4. Perpendicular correlation length and decorrelation time in different regimes

The analyses has been performed in the region $0.6 < \rho_{pol} < 0.9$. The perpendicular correlation length $l_\perp$ has been calculated from the approximation $l_\perp = v_\perp \tau_a$, where τ_a is the autocorrelation time of the density fluctuations calculated at the e^{-1} level. This approximation is only valid when $\tau_a/\tau_d \ll 1$, where τ_d is the decorrelation time of the turbulence. The $l_\perp$ shows a dependence on both temperature and magnetic field and varies from 0.5

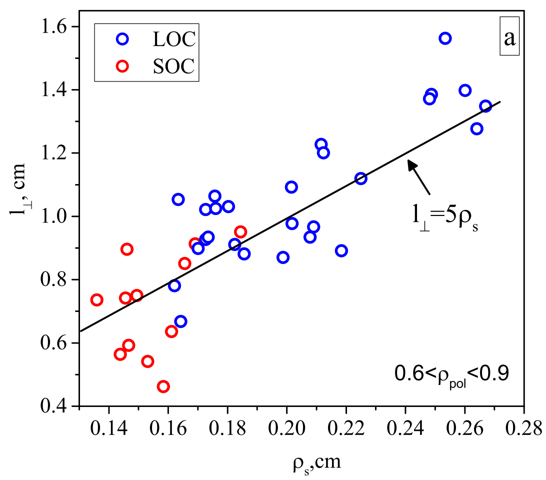

Figure 3: *The Perpendicular correlation length $l_\perp$ in the LOC (blue) and SOC (red)*

to 1.5 cm. $l_\perp$ approximately follows a $l_\perp \approx 5\rho_s$ scaling in the plasma core (figure 3(a)). The scaling of $l_\perp$ does not change between LOC and SOC regimes. This could be a consequence of the fact that both TEM and ITG are predicted to have similar injection scales.

The decorrelation time of the density fluctuation has been measured from the envelope of the cross-correlation at different separations [3]. The decorrelation time shows the life time of the turbulent eddies. The decorrelation time is found to scale as $\tau_d \propto n_e^{-0.5} T_e^{-0.8}$, however, dependence on velocity $\tau_d \propto v_\perp^{-1}$ is also observed. The scaling also does not change between different regimes. This result will be compared to nonlinear gyro-kinetic simulations.

5. Discussion

Analyses of density fluctuation characteristics at $0.6 < \rho_{pol} < 0.9$ in the LOC and SOC using Poloidal Correlation Reflectometry have been performed. The perpendicular correlation length and decorrelation time of the eddies do not change their dependence between the two regimes, however, they do depend on local plasma parameters. It was noticed that a QC mode in the density fluctuations during LOC regime is observed by calculating the coherence between spatially separated density fluctuations. The QC mode disappears with increasing collisionality, however, not exactly at the LOC-SOC transition. The explanation of the LOC-SOC transition through a sudden change of the turbulence regime can be an oversimplification. Detailed studies will be performed, including cross-comparison with gyro-kinetic simulation, to explain the QC mode paradigm and its impact on particle and energy transport.

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