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Influence of large magnetic island structures on turbulence and quasi-coherent modes in tokamak plasmas

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In recent years the multi-scale interaction between large-scale tearing modes and micro-scale turbulence has been found to be of paramount importance for thoroughly understanding the tearing mode physics and the island-induced transport, which will ultimately lead to developing a more effective method of the tearing mode control and optimizing the plasma performance in fusion devices, such as ITER [1-2]. In this work, the impact on micro-turbulence, meso-scale quasi-coherent modes (QCMs) and large-scale zonal flows as well as plasma rotations by naturally rotating m/n=1/1 and 2/1 islands and by externally magnetic perturbation-induced static m/n=2/1 island has been investigated using 2D ECE imaging and reflectometers in HL-2A and J-TEXT tokamaks [3-5]. The results indicate that for sufficient large islands there exist strong interactions between the tearing mode (TM) island and turbulence, including QCMs and zonal flows. The critical island width is in general consistent with the theoretical prediction [6].

In the case of rotating m/n=1/1 island generated in NBI heated plasmas at HL-2A, it is observed that for large islands ($W_c \geq 10\rho_i \approx$ 4 cm) the electron temperature ($\tilde{T}_e$) and density fluctuations ($\tilde{n}_e$) are modulated periodically by the island rotation, with minimum amplitude at the O- and maximum at the X-point, respectively. The turbulence modulation is localized merely in the inner area of the island due to significant alteration of local profiles and gradient-driven turbulence. Evidence also reveals that for large islands turbulence spreading can occur across the island O-point from the region outside the island. The experimental observations of the turbulence modulation and spreading effects with large island are in general agreement with simulations for the trapped electron mode instability [3].

In the case of rotating m/n=2/1 island in HL-2A ohmic plasmas, it is found that for sufficient wide islands ($W_c \geq$ 4.5 cm) a quasi-coherent mode (QCM, peaked at ~100-180 kHz) in density fluctuations is excited at the island boundary as the island O-point passes by, where the local T_e profile is steepened, as shown in figure 1. Statistical analysis indicates that for the QCM excitation, a threshold value of T_e gradient is needed and the QCM is solely observed in low density discharges, consistent with the linear ohmic confinement regime. These experimental evidences and also the linear stability calculations both suggest that the observed QCMs are driven by the trapped electron mode instability. Bi-spectral analysis further shows that there exists non-linear coupling between the tearing mode and QCMs, whereas no nonlinear interaction is observed between the QCMs and ambient turbulence. The results verify that the observed QCMs are linearly driven by locally enhanced T_e gradient with large islands, but not driven by ambient turbulence via nonlinear energy coupling [4].

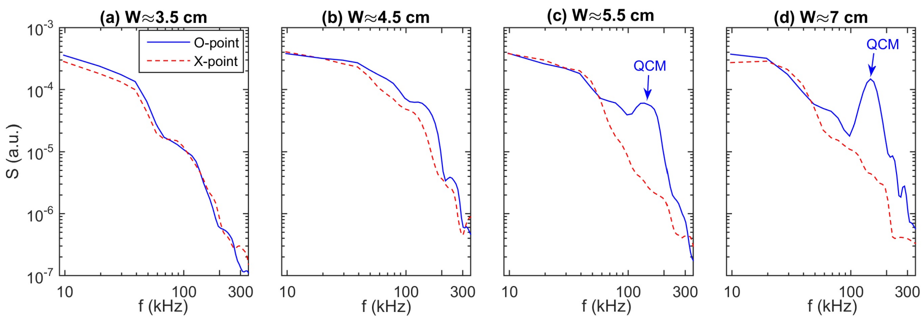

Figure 1: Phase-lock averaged power spectra of $\tilde{n}_e$ located outside but close to island during the O-point and X-point passing-by phases in different island-width cases (HL-2A, #31306)

In J-TEXT ohmic plasmas, the plasma rotations, geodesic acoustic mode (GAM) zonal flows and turbulence are found to be significantly modified by a static m/n=2/1 island induced by externally applied resonant magnetic perturbations (RMP). Whereas after the island formation the edge toroidal rotations shift from the counter-I_p

to co-I_p direction and the perpendicular rotations from the electron to ion diamagnetic drift direction, both of rotation changes do not show much difference between the island O- and X-point. However, the turbulence level at the O-point is substantially lower than that at the X-point. The amplitude of the GAM zonal flows measured outside the island is damped and the peak frequency slightly increase after the RMP. In addition, at certain island size (e.g., $W \approx 3.8$ and 4.5 cm in figure 2) the nonlinear coupling among ambient turbulence inside the island is considerably enhanced through the inverse energy cascading. However, this situation does not occur for a narrower or wider island, as depicted in figure 2. These results suggest a profound influence of the island size on the nonlinear interplay of turbulence and turbulent transport [5].

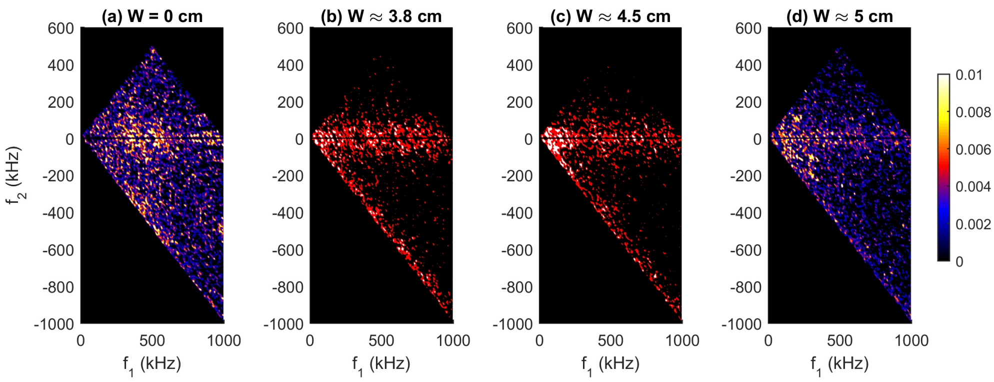

Figure 2: Contour-plots of squared auto-bicoherence of $\tilde{n}_e$ signals measured at $\rho \approx 0.78$ (inside the island) under different island widths (J-TEXT, #1050205).

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