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Electrode biasing maintains the edge shear layer at high density in the J-TEXT tokamak

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High plasma density is desirable for fusion, and thus is part of the operating scenario for ITER and devices beyond. Intrinsic limits on density are thus of great interest. At present, the Greenwald (line-averaged) density scaling $n_G[10^{20}\text{m}^{-3}] = I_p[\text{MA}]/\pi a^2[\text{m}^2]$ is the empirical figure-of-merit for the density limit. Note while the Greenwald scaling nominally applies to a line-averaged value, edge density is of great importance to fusion plasma performance, and so limits on edge density are of comparable interest.

Density limit phenomenology is complex, and reflects the interaction of enhanced edge turbulence and transport, edge cooling, radiation, MHD activity and disruption. While the sequence of casual relations between all of these has yet to be established, enhanced edge turbulent transport is a good candidate for initiating edge cooling. The edge shear layer collapses and strong turbulence spreading can be observed as $n \rightarrow n_G$ in experiments. In terms of the shear flows-turbulence paradigm, this "density limit regime" emerges as one of the three basic states of the edge plasma, the other being the L-mode and the H-mode. In the L-mode, the edge turbulence has modest intensity and is regulated by zonal flows, and turbulence spreading is weak. In the H-mode, the edge turbulence and turbulence spreading both are very weak, and the edge turbulence is strongly regulated by mean shear flows. It has been suggested that the plasma enters the density limit regime when edge electron adiabaticity, $\alpha \equiv k_{||} v_{Th,e}^2/|\omega| v_{\text{ei}}$, drops below unity (i.e., $\alpha<1$), thus allowing the development of strong, fluid-like turbulence as opposed to, say, the expected drift wave turbulence with near-adiabatic electrons (i.e., $\alpha>1$). To this end, recent experiments have linked the approach to n_G to a sharp drop in adiabaticity and the appearance of strong turbulence phenomena, such as spreading.

A series of experiments together suggest that the collapse of the edge shear layer at high density is of central importance. We report on the use of a bias electrode to sustain the edge shear flow of J-TEXT as $n \rightarrow n_G$. Absent the bias, the edge shear layer is observed to collapse. However, with a positive bias of +240V, the edge Reynolds stress is enhanced and the zonal flows thus sustained. The level of edge density fluctuations $\langle(\tilde{n}/n)^2\rangle$ is significantly lower than in the no-bias state, and the particle flux, electron heat flux and turbulence internal energy flux are also comparatively reduced. A stable state which manifests a modest increase in line-averaged density and a doubling of the edge density is maintained. With +240V bias, the electron adiabaticity is larger in comparison to the no-bias case. The study of the causality relation between edge flow shear and adiabaticity indicates that the evolution of edge flow shear leads the evolution of adiabaticity. These results are consistent with the hypothesis that edge shear layer collapse underpins the increase in edge particle transport, turbulence levels and turbulence spreading characteristic of the density limit regime. They also suggest that external edge E×B shear drive may be of interest for sustaining edge plasma states at high edge density. Moreover, for the shear-flow-as-order picture, these results indicate that an externally driven edge shear may prevent the edge plasma back transition from the L-mode to the density limit regime. This bolsters support for the key role of edge flow shear in density limit physics.

References

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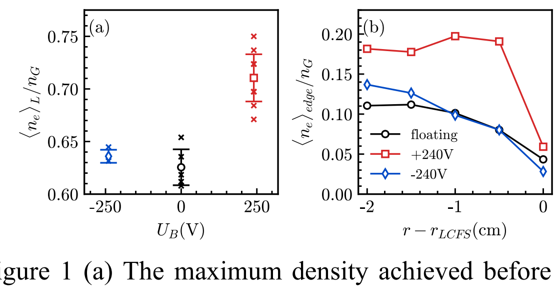

Figure 1 (a) The maximum density achieved before the plasma has a strong MHD or disruption with -240V (blue diamond) biasing, floating or 0V biasing (black circle), and +240V biasing (red rectangle). (b) The maximum edge density achieved before strong MHD or disruption with -240V (blue diamond) biasing, floating or 0V biasing (black circle), and +240V biasing (red rectangle).