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Momentum and Particle Transport Across the ITG-TEM Turbulence Regimes in DIII-D H-mode Plasmas

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Measurements in recent DIII-D experiments exploring transport dynamics across the ion temperature gradient-trapped electron mode (ITG-TEM) boundary reveal an increase in intermediate scale length density fluctuations, a strong decrease in density across the plasma radius, along with increases in measured perturbative particle transport coefficients (Fig. 1). These observations are indicative of an increase in outward particle transport in TEM as compared with ITG dominant plasmas. These results are in contrast to observations on other devices and theoretical predictions of an increase in density peaking or a rotation reversal when crossing the linear ITG-TEM boundary [1]. In order to isolate the effect of toroidal rotation on density peaking, we varied the neutral beam (NBI) torque input from co- to counter injected. Instead of observing an increase in density peaking in the counter rotating plasmas, we found a correlation between the radial location of the ITG-TEM boundary and the location of maximum (R/L_{ne}) (Fig. 2). These results indicate that changes in density peaking are not simply the result of a change in toroidal rotation, but depend on changes in turbulent transport characteristics. In this paper we present detailed analysis of changes in turbulence characteristics, linear stability, edge plasma parameters and perturbed transport analysis, to better understand the causes of density profile peaking and rotation profile reversal.

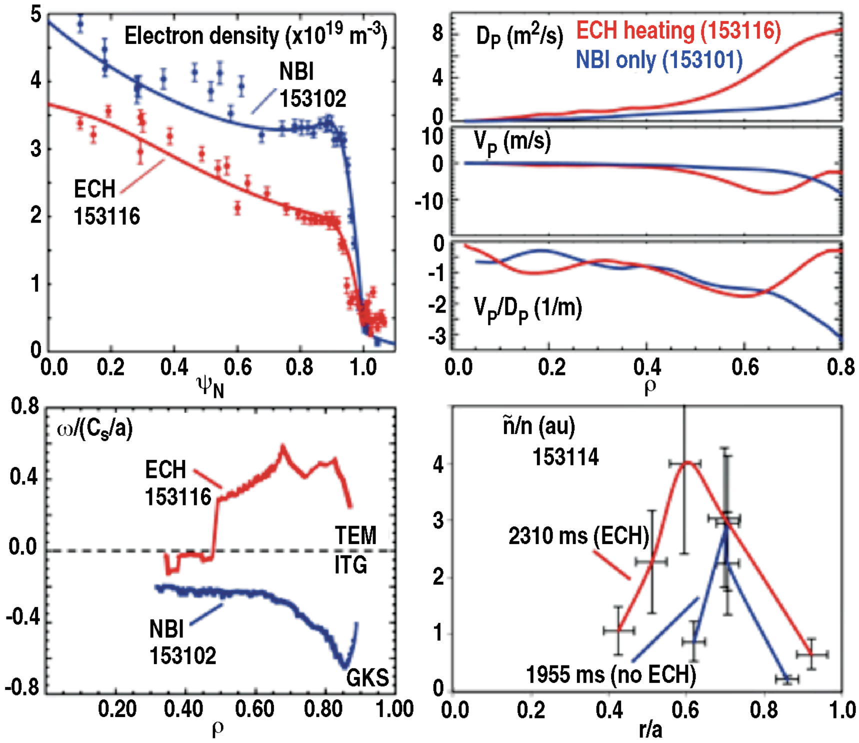

Fig. 1. (a) Strong reduction in the electron density profile as a result of ECH heating (b) A strong increase in outward diffusion is observed outside the mid-radius, which is partially counter by an increase in inward pinch. Perturbative particle transport increases strongly outside ρ~0.6 (c) The plasmas transition from ITG to TEM linear dominant instability from mid-radius outward (d) A strong increase in mid-range fluctuation levels is observed with the DBS in the ECH heated plasmas.

We compare a set of NBI-heated H-mode discharges in which the T_e/T_i ratio was increased through the use of electron cyclotron heating (ECH). In order to study the effect on particle and momentum transport, the NBI torque input was close to balanced. We find that these plasmas cross from an ITG to a TEM dominated turbulence regime around mid-radius using linear gyrokinetic simulations [Fig. 1(c)]. However, this change in turbulence regime does not result in an increase in the density profile instead we actually observe a strong density pump-out [Fig. 1(a)]. Also, density fluctuations at the intermediate scale increase for the plasmas that transition to the TEM regime around mid-radius and outward [Fig. 1(d)]. Finally, the measured perturbed transport coefficients show a strong increase in outward transport in the radial region in which the plasma is TEM unstable [Fig. 1(b)].

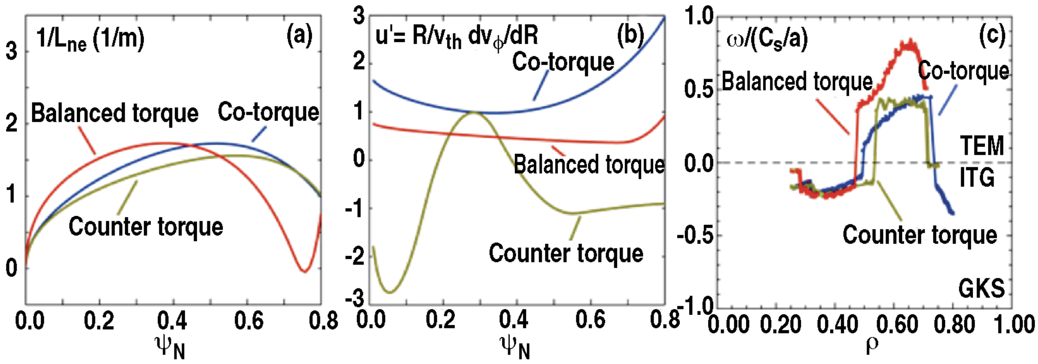

Fig. 2. (a) Density peaking ($1/L_{ne}$) does not increase by increasing the amount of counter injected NBI (b) Changes in u′ go from positive to negative as a result of changes in NBI injection. (c) The cross-over from ITG to TEM unstable regimes happens at different radii, which correlates with the value of max($1/L_{ne}$).

In DIII-D, we do not observe a reversal or strong reduction of the toroidal rotation at mid-radius and inward when transitioning from the ITG to the TEM linear regime. A reduction in the toroidal shear is observed, but the overall toroidal rotation is of similar or even higher magnitude than in the ITG dominant plasmas. The main change in toroidal rotation is at the plasma edge, where the ITG plasmas exhibit a “well” in the toroidal rotation. Conversely, the TEM plasmas don’t have such a “well” and thus have a higher toroidal rotation at the plasma edge. This higher edge rotation acts as a boundary condition for the core toroidal rotation, such that the TEM plasmas are rotating more strongly in the ion direction, even with a reduced toroidal shear. We find that this “well” in the edge toroidal rotation is density dependent and can be recovered by adding a gas puff to the TEM plasmas.

In order to study the role of reversed toroidal rotation with respect to density peaking, the NBI torque input was varied from co- to counter in these TEM dominant plasmas. This changes the u′ profile from positive to negative. We do not observe an increase in density peaking for the negative u′ plasma (Fig. 2). However, the change in radial location of max(R/L_n) does correlate with the location of the transition from linear ITG to TEM regime on DIII-D. This is another indication that the changes in turbulence dominate the changes in particle transport, not roto-diffusion. If we compare the density profiles as a function of rotation, we observe that the co- and balanced-injection cases have similar magnitudes, while the counter-injected case exhibits a much higher density (although with a similar shape as the co injected case). Moreover, we find that the intermediate scale density fluctuations in the counter injected plasma are lower in the plasma core than for the balanced and co-injected plasmas, but higher outside mid-radius. These changes in the turbulence for the counter injected plasma are likely due to the high ExB shear near midradius and low ExB shear near the edge. Contrary to what might be expected; these increases in micro turbulence amplitude do not result in an increase in outward particle transport. Perturbed transport experiments show that the increase in outward diffusion in countered by a large increase in the inward pinch.

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[1] C. Angioni et al., Nucl. Fusion **51** (2011) 023006