Density driven rotation changes in DIII-D low collisionality H-mode plasmas

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Density driven rotation reversals have been observed in core plasmas on C-Mod as well as AUG in plasmas that rotate spontaneously [1, 4]; this driving mechanism is usually refered to as the so-called intrinsic torque [2]. The existence of the intrinsic torque is linked to the natural occuring turbulence in the plasma and the observed rotation reversals have been attributed to changes in the underlying turbulence regime, which affects the direction of the intrinsic torque [3].

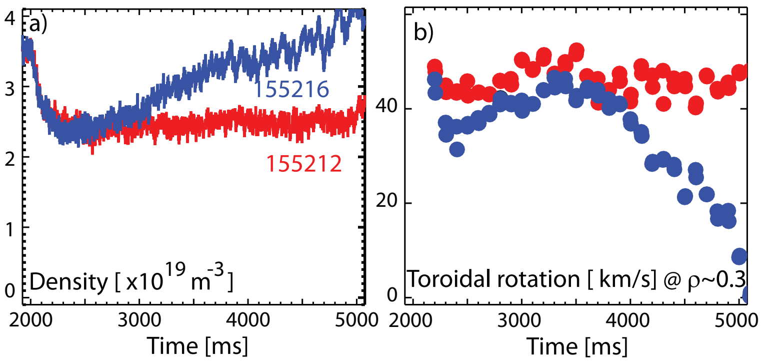

Figure 1: *Time evolution of the (a) Electron density and (b) Toroidal Carbon rotation of the 2 discharges. Where red is the discharge at a steady density and blue is the discharge, where an increase in gas puffing slowly increases the line averaged density.*

In this paper, we will show that H-mode plasmas in DIII-D that are in the Trapped Electron Mode (TEM) regime observe a strong reduction in the core Carbon toroidal rotation, such that the rotation gradient reverses when the density is increased at constant $0.2-0.4\ N-m$ injected torque. This reduction in the core carbon toroidal rotation is not the result of the conservation of angular momentum due to the increase in density. Similar observations are also made in the steep pedestal region. These results seem to indicate that there is a correlation between the electron density (n_e) or electron density gradient and the intrinsic rotation. On AUG, previous work has shown that there is a correlation between $u' = \frac{R}{v_{th_i}}\nabla v_{tor}$, where R is the major radius, v_{tor} is the toroidal rotation and $v_{i_{th}}$ is the thermal ion velocity and the inverse density gradient $R/L_n = -\frac{R}{n}\nabla n_e$ [5].

We compare 2 dedicated discharges where in one discharge the density is kept at a constant value (155212) and in the other discharge (155216) we slowly increase the electron density. Both experiments are dominantly Electron Cyclotron Heating (3.1 *MW* ECH and 1 *MW* NBI) heated. All other conditions are kept the same (see [6] for more plasma parameters), with exception of the gas fueling. Both ECH heated discharges have gas puffs. The ECH discharge at low constant density has a gas puff to keep the line averaged density at $2.5 \times 10^{19}\ m^{-3}$ and the other ECH heated discharge has a gas puff to slowly increase the line averaged density from $2.5 \times 10^{19}\ m^{-3}$ to $4.0 \times 10^{1}9\ m^{-3}$, see figure 1. We observe when the density is rising steadily throughout the discharge, that the core rotation starts to drop. There is no change in the injected momentum during these conditions and the drop in the toroidal rotation cannot be explained by conservation of angular momentum due to an increase in the density. As a result, there must or be a change in momentum transport, or an intrinsic torque or a change in MHD. No MHD modes are observed during the time of analysis. Earlier in the discharge, in which we increase the density there is a core MHD mode, which does not seem to affect the rotation and dissappears about 700 *ms* before we perform our analysis.

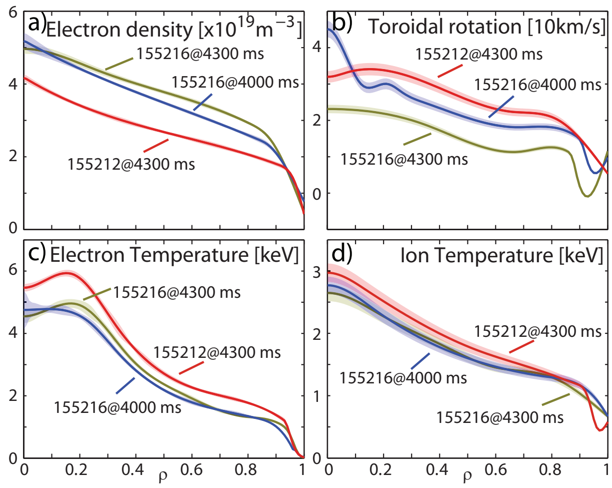

Figure 2: *Profiles of the low density ECH heated plasma (red), the higher density ECH heated plasma at two times (green and blue) (a) Electron density (b) Toroidal Carbon rotation (c) Electron temperature and (d) Ion temperature.*

We use TGLF to calculate the linear gyro-kinetic stability and we find that both ECH heated discharges are predominantly Trapped Electron Mode (TEM) unstable around mid-radius. Typically, in previous experimental observations the reduction in the toroidal rotation has been ascribed to a change in turbulence regime and a reversal of the intrinsic torque [1, 4, 3]. However, in these experiments, there is no change in turbulence regime during the increase in density [6]. These plasmas do not transition from the TEM regime to an Ion Temperature Gradient (ITG) regime and thus potentially changing the direction of the turbulence propagation.

When we compare the profiles from the two discharges that are TEM unstable, but at different densities, we can observe that the ion temperatures are nearly identical and that the lower density ECH heated discharge has a slightly higher electron temperature profile, see figure 2 (c) and (d). However, when we compare the profiles at two different time points, during the higher density ECH heated discharge, we can observe that in this case the electon temperature profiles are nearly identical (see figure 2 (c)). We can thus exclude the changes in electron temperature to be the driving force behind the changes in toroidal rotation. Meanwhile, we can observe that the reduction in toroidal rotation is not directly proportional to an increase in density. While there is a large change in the density between the low density ECH heated plasma (red) and the higher density ECH heated plasmas (green and blue), the reduction in toroidal rotation is larger for a small density increase.

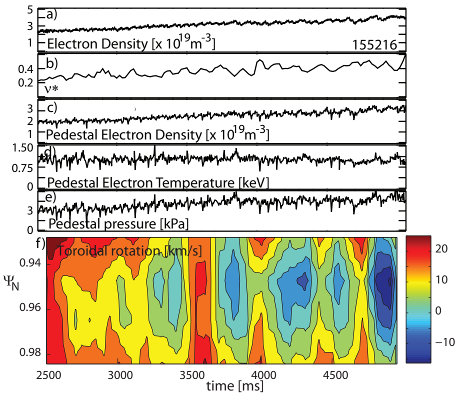

Figure 3: *Strong reduction in edge Carbon toroidal rotation versus time and comparison on how the line averaged density, collisionality, pedestal electron density, temperature and pressure evolve during the same time span.*

However, counter to observations on AUG, we observe no correlation for a wide range of discharges with similar conditions as the ones shown in this paper, but with various levels of ECH versus NBI heating between u' and R/L_n [7]. The lack of correlation over a wider set of discharges could have been affected by changes in MHD. The changes in heating in these low density and rotation H-mode discharges tends to affect core MHD modes. In the discharges presented in this paper we were careful to exclude the effects of core MHD modes.

The reduction in toroidal Carbon rotation with increasing density is not just limited to the plasma core, but similar changes are also observed in the plasma edge, see figure 3. During the density increase in this ECH heated plasma, the Carbon toroidal rotation at the edge reduces and a 'well' in the toroidal rotation is introduced (see figure 2 (b)). Sudden reductions in the edge rotation are observed as the density slowly increases. The electron pedestal temperature is not affected by the increase in density, whereas the electron density pedestal increases, as does the collisionality. From the transient changes it is not conclusive that an even higher pedestal density would have resulted in a permanent change in the edge rotation for the ECH heated discharge. Recent new CER measurements show that while the edge toroidal Carbon rotation can exhibit a 'well', this well is not observed in Deuterium rotation measurements. So, while there are strong changes in the toroidal Carbon rotation, it is unclear how these would translate to the toroidal Deuterium rotation.

For the plasma edge as well as the core we have Doppler Back Scattering measurements. In the core we find that intermediate scale density fluctuations increase [6], but without ion-scale measurements it is unclear whether this is the result of an increase in broadband turbulence or a change in turbulence type. Ion-scale turbulence measurements were not available, to give priority to rotation measurements capabilities at low torque. At the plasma edge, changes to the intermediate scale density fluctuations in the pedestal area at wave number $k_\theta \sim 5cm^{-1}$ are shown in figure 4. In this figure, we compare the density fluctuations for the ECH discharge in which the density is increasing at the same time slices for which the profiles are given in figure 2 and for which we highlight the changes in Carbon edge rotation in figure 3. There is however an uncertainty in the exact radial location of the measurements, which depend on EFIT reconstructions and a small radial shift (see radial errorbars) could minimize the difference between the density fluctuation measurements. As such, the density fluctuations are similar within the experimental uncertainties. The $v_{E\times B}$ velocities measured with the DBS are also within error bars of each other, with the exception of the innermost measurement point at $\rho \sim 0.93$. At this radius, at 4300 ms the $v_{E\times B}$ is much smaller than for 4000 ms. This difference is partially the result of a change in the diamagnetic component of the $E\times B$ flow, see figure 2.

In this paper we show that the Carbon toroidal rotation is affected by the electron density. Prior work has shown that the change in density and/or density gradient affects the toroidal rotation through a change in turbulence characteristics. In this paper, we find that the reduction in toroidal rotation can occur without a change in turbulence from the ITG to the TEM regim. These changes in toroidal rotation are observed in the core as well as the plasma edge. So far, no direct links have been found to existing changes in turbulence regime, nor turbulence characteristics. Futher analysis will examine the changes in momentum transport versus the changes in intrinsic torque in order to better understand how the density profile can affect the toroidal rotation. Finally, all these results are based upon Carbon measurements, which can deviate from Deuterium rotation measurements. New experiments are needed to investigate if these effects also apply to Deuterium.

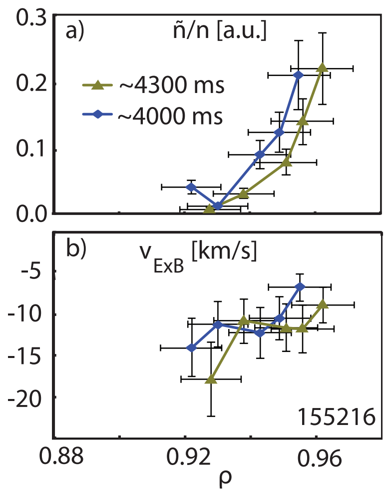

Figure 4: *(a) $\tilde{n}/n$ fluctuations as measured with the DBS system at $k_\theta \sim 5cm^{-1}$. The fluctuations levels might be slightly larger at 4000 ms (blue) than 4300 ms (green). (b) The changes in plasma flow are within error bars of each other with the exception of one point, close to $\rho \sim 0.93$, the same location at which the dip in toroidal rotation is observed.*

Acknowledgements

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