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Simultaneous measurements of the main ion and impurity toroidal rotation have revealed a significant discrepancy between measured differences in the toroidal rotation of these ion species and neoclassical predictions [1]. While neoclassical predictions of the main-ion rotation generally predict a toroidal rotation speed that is faster than impurity ions in the co-current direction [2], these new measurements indicate deuterium rotation slower than carbon, similar to previous measurements in helium plasmas [3]. Detailed analysis of this comparison indicates that this discrepancy is due to the neoclassical prediction for the main-ion and impurity poloidal velocities. This discrepancy has potentially important implications for ITER as the performance will depend on the E_r shear stabilization of turbulence and since the toroidal rotation is expected to be low in ITER, E_r will be dominated by the pressure and poloidal rotation contributions. Hence, an improved understanding of the mechanisms controlling poloidal flow is required for making performance projections for ITER.

New spectroscopic measurements and integrated modeling capabilities on the DIII-D tokamak have enabled direct measurement of the bulk deuterium ion temperature, toroidal rotation and density. Displayed in Fig. 1 is the radial profile of the measured carbon and deuterium toroidal rotation under ECH induced H-mode “intrinsic’’ rotation conditions. At major radius R=1.90 m the steepest pressure gradient exists in this plasma, and neoclassically this pressure gradient should drive a differential rotation between carbon and deuterium. However, the neoclassical predicted differential rotation is not observed, and the observed differential rotation has the opposite sign of the neoclassical prediction. In the intrinsic rotation discharges examined there appears to be no measureable discrepancy between the ion temperature of the impurity carbon and thermal deuterium.

The discrepancy between the measured and neoclassically predicted toroidal rotation can be related to the neoclassically prediction for poloidal rotation. By invoking the radial force balance relation we compute the deuterium ion poloidal flow from our measurements. We find that the deuterium ion poloidal flow speed exceeds that predicted by neoclassical theory, here calculated by the widely used NCLASS code, and can even have the opposite sign. Figure 2 displays the

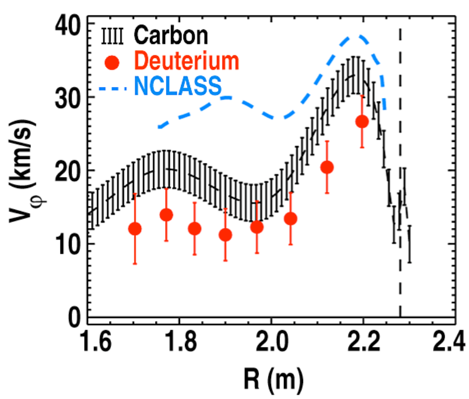

Fig. 1. Radial profile of measured ion toroidal rotation velocity of carbon and deuterium, and NCLASS neoclassical prediction of deuterium toroidal rotation. Measured deuterium toroidal rotation displays significant disagreement with neoclassical estimates.

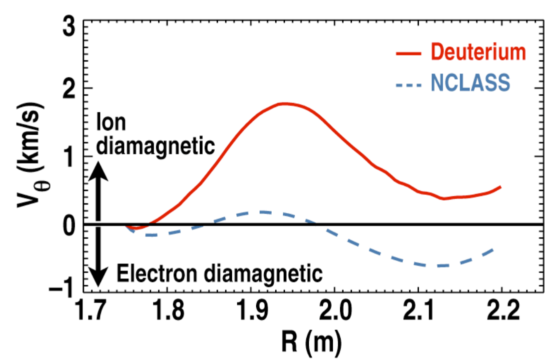

Fig. 2. Radial profile of inferred deuterium ion poloidal rotation velocity and NCLASS prediction of deuterium ion poloidal rotation velocity. The inferred ion poloidal rotation is in the ion diamagnetic drift direction with a velocity greater than the neoclassical prediction.

deuterium ion poloidal rotation obtained from radial force balance, as well as the neoclassically predicted deuterium ion poloidal flow, indicating that the bulk ion poloidal flow is significantly larger than neoclassical estimates, and has the opposite sign over much of the plasma radius. The experimentally determined deuterium ion flow is obtained from measurement of carbon pressure, toroidal and poloidal flow, as well as the newly measured deuterium toroidal flow. It is found that the deuterium ion poloidal flow is more similar to the banana regime limit of the analytic neoclassical theory ($V_\theta \approx 2.0$ km/s at R=1.9 m) than the NCLASS code predicts.

Modeling of ITER performance [4,5] displays a strong dependence on toroidal rotation levels obtained by fixing the ratio of χ_φ/χ_i, however this ratio is poorly understood and databases of this scaling are based on measurements of impurity ions [6,7]. The assessment of rotational stabilization of deleterious MHD modes in future, larger machines, where the effectiveness of neutral beams to provide a torque to spin the plasma toroidal is greatly diminished, relies heavily on the accuracy of toroidal rotation predictions based on assumed χ_φ/χ_i. Current and previous measurements of bulk ion toroidal rotation indicate that this ratio may be larger than that measured from impurity rotation databases.

In low rotation conditions expected in ITER, the contribution of toroidal rotation to the radial electric field is weakened, and the pressure and poloidal rotation terms may become dominant. In conventional tokamaks with strong uni-directional neutral beam heating, the radial electric field is dominated by the toroidal rotation contribution. However, predictions of toroidal rotation and its contribution to E_r in ITER vary widely across various rotation models. Transport modeling of ITER is dependent on the interplay between the toroidal rotation, poloidal rotation and pressure gradient contributing to the total E_r and E×B shear stabilization of turbulence. Therefore precise predictions of each contribution to E_r are required for accurate transport modeling.

An important conclusion from this work is that the use of the NCLASS model for poloidal rotation is suspect due to discrepancy with measurements on DIII-D [1,8] and JET [9]. In ITER the contributions to E_r from pressure and poloidal rotation are predicted to be of opposite sign and same magnitude, reducing the advantageous effectiveness of E×B shear stabilization enhancing confinement. Current and previous measurements indicate that the poloidal flow is generally larger than neoclassical estimates, imposing a larger influence on the total radial electric field.

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