Transport Modeling and Gyrokinetic Analysis of Advanced High Performance Discharges

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Predictive transport modeling and gyrokinetic stability analysis of demonstration hybrid[1,2] and Advanced Tokamak (AT)[3] discharges from the International Tokamak Physics Activity (ITPA)[4] profile database will be presented. Both regimes have exhibited enhanced core confinement (above conventional H-mode) but differ in their current density profiles. Recent contributions to the ITPA database has facilitated an effort to study the underlying physics governing the confinement in these advanced scenario discharges in multiple tokamaks. In this paper, the level of commonality of the turbulent transport physics and the relative roles of the transport suppression mechanisms (i.e. ExB shear, magnetic shear, Shafranov shift (□) stabilization, temperature ratio effects) are assessed. Transport simulations are used in conjunction with gyrokinetic stability analysis in order to elucidate the underlying turbulent transport properties and the suppression mechanisms responsible for the observed enhanced confinement. Various transport models are employed including the GLF23, Weiland, mixed Bohm/gyro-Bohm, and Current Diffusive Ballooning Mode (CDBM) models. Comparisons are made between the hybrid and AT regimes in various devices using data from DIII-D, JET, AUG, and JT-60U H-mode discharges. The origin of the enhanced core confinement in both regimes is not yet fully understood, such that obtaining a predictive understanding of the transport and relative roles of the transport suppression mechanisms in both these regimes is sorely needed.

While the Advanced Tokamak concept has received considerable attention, another alternative to the ITER reference H-mode scenario[5] has emerged in recent years. A regime has been developed demonstrating high beta operation with the central safety factor maintained close to unity, a broad region of low magnetic shear, and the absence of sawtooth activity. This regime has been dubbed the ‘hybrid’ regime by working groups of the International Tokamak Physics Activity and offers the potential of achieving many of the performance goals of ITER including high fusion gain[3,4]. The hybrid regime is intermediate between conventional sawtoothing H-modes with a monotonic q-profile and reversed magnetic shear H-modes with internal transport barriers (ITBs). Hybrid discharges have achieved higher beta than sawtoothing H-mode discharges at a reduced inductive current. The hybrid regime is distinct from the AT regime in that the current and pressure profiles have relaxed to a stationary state with lower values of the central safety factor. In any case, both regimes are worthy of study from a transport physics standpoint and it is likely that they share common elements in achieving good core confinement.

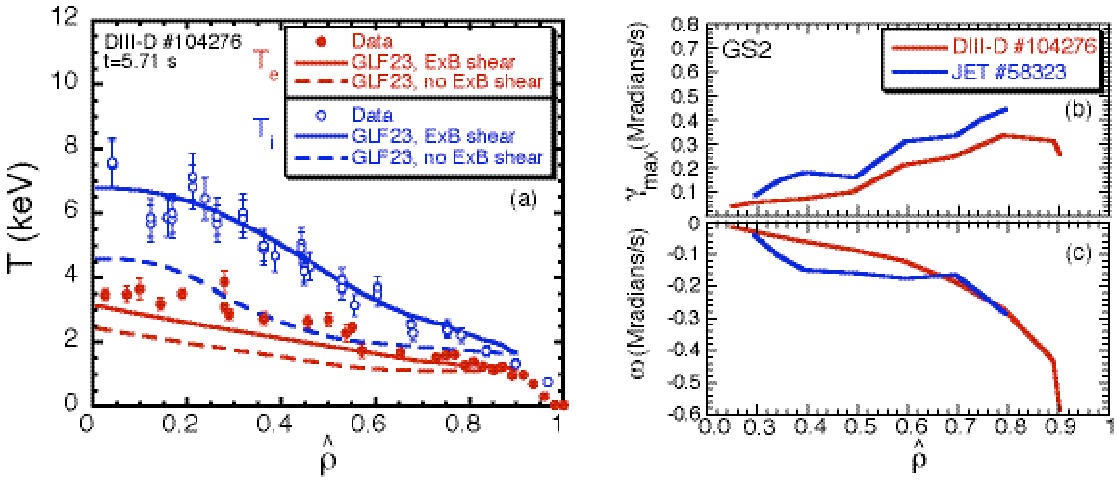

Fig. 1. (a) Predicted ion (blue) and electron (red) temperature profiles with (solid lines) and without (dashed lines) the effects of ExB shear in the GLF23 transport model for DIII-D hybrid discharge #104276 and experimental temperature profiles (dots) and (b) maximum linear growth rates and (c) mode frequencies for DIII-D #104276 and JET #58323 hybrid discharges using the GS2 gyrokinetic stability code.

GLF23 transport modeling of typical DIII-D and JET hybrid discharges indicates that ExB shear stabilization is an important ingredient in reproducing the experimental temperature profiles. With ExB shear stabilization included in the GLF23 simulations, the measured ion and electron temperature profiles are well reproduced. Without ExB shear included, the predicted ion temperature profiles are approximately 40% lower for both the DIII-D and JET discharges (see Fig. 1a). The predicted transport is noticably reduced by ExB shear, yet the effective thermal diffusivities remain above the neoclassical level. Analysis of the simulations also indicate that the DIII-D and JET electron temperature (T_e) profiles are predicted to be unstable to ETG modes and limit the T_e profile across a substantial region of the core plasma. Gyrokinetic stability analysis for both the hybrid and AT discharges already exisiting in the ITPA profile database is underway using the GS2, GKS, and KINEZERO codes. GS2 analysis (electrostatic, real geometry) indicates that long wavelength ITG modes dominate over most of the core plasma with similar maximum linear growth rates in the DIII-D and JET hybrid cases as shown in Fig. 1b. Further studies will examine the impact of the q-profile, magnetic shear (including □-stabilization), parallel velocity shear, and ion to electron temperature ratio effects on the ITG/TEM mode growth rates.

Another objective of this paper will be to utilize the ITPA data from AT and hybrid discharges and test how well various transport models can reproduce the measured profiles. The accuracy of the predicted profiles from the GLF23, Weiland, mixed Bohm/gyro-Bohm, and CDBM models will be assessed. The operable transport suppression mechanisms within the context of the models will also be compared.

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