8th Asia-Pacific Conference on Plasma Physics, 3-8 Nov, 2024 at Malacca

Evidence for a universal collisionality-driven mechanism of confinement saturation in L-mode, I-mode, and H-mode plasmas at ASDEX Upgrade

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Higher plasma densities are correlated with saturated energy confinement in ohmically-heated L-mode plasmas [1] and I-mode plasmas [2] and degraded confinement in H-mode plasmas [3]. This change in confinement directly impacts the achievable fusion gain of tokamak plasmas due to the dependence of the fusion Triple Product ($nT\tau_E$) on the plasma stored energy and energy confinement time. Though much previous work has examined the confinement properties of each operating regime, open questions remain about the exact mechanisms responsible for the observed changes in confinement with increases in density.

Previous work in ohmically-heated L-mode plasmas found that changes in turbulence are correlated with changes in confinement across the Linear Ohmic Confinement to Saturated Ohmic Confinement (LOC-SOC) transition [1]. On the other hand, the degradation of H-mode confinement has been associated predominantly with the degradation of the temperature pedestal and changes in pedestal stability [3, 4]. However, the quality of energy confinement in H-mode plasmas is also driven by density peaking at low collisionality, as already identified in early confinement studies in AUG [5] and also observed on JET [6]. Prior modelling work on particle transport has shown that changes in the balance of TEM to ITG instabilities have a major impact on the degree of density peaking at low collisionality in H-mode plasmas [7].

In this work, we propose and test the hypothesis that the quality of confinement of tokamak plasmas saturates at high density due to a universal collisionality-driven mechanism regardless of edge characteristics. Specifically, we investigate whether changes in core collisionality caused by increases in density lead to changes in turbulence and density peaking and eventually to a saturation of the core thermal stored energy in L-mode, I-mode, and H-mode plasmas.

We first examine connections between global changes in plasma confinement and local changes in collisionality and turbulence in the core of auxiliary (NBI and ECRH) heated ELMy H-mode plasmas at ASDEX Upgrade (AUG) using measurements from the Correlation Electron Cyclotron Emission (CECE) diagnostic. Quasi-linear modelling performed with TGLF [8] sheds light on the drift-wave instabilities driving the observed turbulence. We then compare correlations between density peaking and global changes in confinement in the H-mode dataset to correlations between these same parameters across the LOC-SOC transition in ohmically-heated L-mode plasmas as well as auxilliary-heated I-mode plasmas. We find that the onset of confinement saturation occurs when the peaking of the density profiles is maximized in all three operating regimes. Additionally, there appears to be a transition from dominant Trapped Electron Mode (TEM) to Ion Temperature Gradient (ITG) mode turbulence across the transition in confinement. Furthermore, the dependence of the saturation on the ratio of the density to the plasma current indicates that the collisionality may be the responsible mechanism. The results suggest that changes in the core collisionality and changes in the turbulent instabilities are relevant to energy confinement saturation regardless of edge characteristics and points to a universal Linear Confinement to Saturated Confinement (LC-SC) transition.

This work is supported by US DOE (grants DE-SC0014264, DE-SC0006419, and DE-SC0017381), EUROfusion Consortium (No. 101052200), and NSF GRFP (No. 1745302 and 2141064).

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