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ITER Implications of the Beta Scaling of Energy Confinement ITR

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There is emerging evidence that the variation in the measured beta dependence of energy confinement in H-mode plasmas is due in part to different turbulent modes being dominant, with ion temperature gradient (ITG) modes being important in weak beta scaling cases (Fig. 1) and micro-tearing modes being potential candidates explaining strong beta degradation (Fig. 2). Another factor is that the normalized H-mode pedestal height may not be constant over a beta scan, which affects core transport and global confinement. To resolve the differences in the measured beta scalings, the ITPA topical group on Transport and Confinement has conducted coordinated experimental and modeling activities.

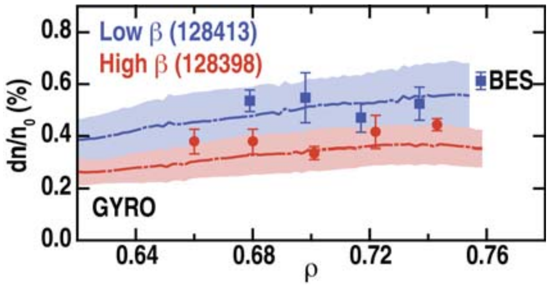

Fig. 1. Comparison of BES density fluctuations and "flux matching" GYRO simulations with electrostatic ITG-mode turbulence for a H-mode beta scan on DIII-D.

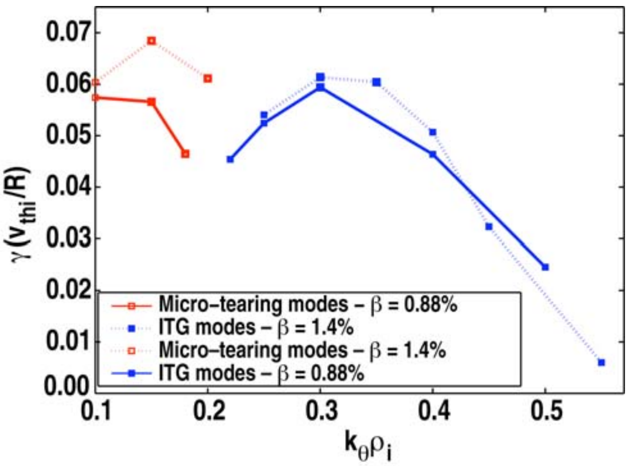

Fig. 2. Growth rate spectra from GS2 for R/L_n=1.5 for an H-mode beta scan on ASDEX Upgrade.

Determining the scaling of transport with beta helps to differentiate between various proposed theories of turbulent transport that are primarily electrostatic or primarily electromagnetic. Most models of drift wave turbulence in which $E\times B$ transport is the dominant mechanism show little enhancement or even a reduction in transport with increasing beta. On the other hand, transport from magnetic flutter, such as from micro-tearing modes or kinetic ballooning modes, increases rapidly with higher beta. This is important for ITER because the fusion gain will actually start to decrease at high density and temperature if transport has a strong unfavorable beta scaling.

Several devices around the world have measured the beta scaling of global confinement and local transport in H-mode plasmas with disparate results. Figure 3 shows a summary from a review article [1] for the beta scaling exponents of thermal energy confinement, i.e., $\Omega\tau_{th} \propto \beta^{-\alpha}$, determined on different tokamaks while keeping the other important dimensionless parameters fixed. These initial experiments on JET, DIII-D and NSTX found that the (normalized) global confinement times and local thermal diffusivities have a weak dependence on beta. However, this picture of primarily electrostatic turbulent transport was brought into question by experiments on JT-60U and ASDEX Upgrade that observed a strong unfavorable beta scaling of confinement. The effect of upper triangularity has been identified as a possible origin of the various beta dependences [2]; however, a comparison of different plasma shapes on ASDEX Upgrade, DIII-D and JET did not observe any correlation with beta scaling. An important factor that can impact the scaling results is experimental imperfections in the beta scans. For some experiments the normalized H-mode pedestal height decreases with higher beta, which can result in an unfavorable beta scaling even if core transport is primarily electrostatic.

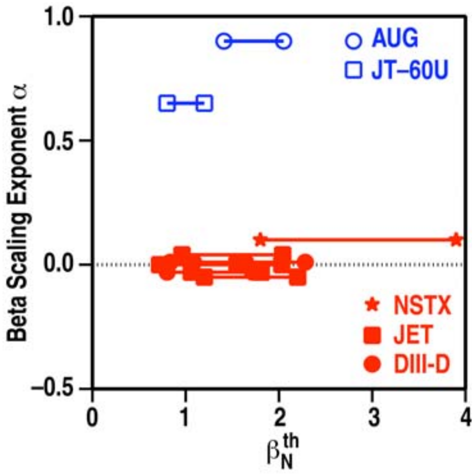

Fig. 3. Beta scaling exponents ($\Omega\tau_{th}\propto\beta^{-\alpha}$) of thermal energy confinement for H-mode plasmas on various tokamaks.

A DIII-D experiment with joint participation by the ASDEX Upgrade team found a stronger beta degradation of confinement ($0.1\leq\alpha\leq0.4$) than in Fig. 3, but there was no beta dependence in the local thermal diffusivities outside of the ≈15% error bars. This small beta dependence of local transport was reproduced in TGLF simulations; furthermore, the magnitude and trend with beta of density fluctuations were found to be in reasonable agreement with "flux matching" GYRO simulations for electrostatic ITG-mode turbulence (Fig. 1). In contrast, turbulence modeling of ASDEX Upgrade experiments using the GS2 gyrokinetic code found that micro-tearing modes are unstable in the high beta cases but their contribution to the beta degradation remains to be assessed quantitatively [3]. As shown in Fig. 2, for plasma parameter ranges close to the conditions on ASDEX Upgrade, micro-tearing modes are the dominant instability and coexist in the spectrum with ITG modes with a comparable growth rate. Micro-tearing modes should be important for high collisionality and flat density profiles, which are the conditions for the ASDEX Upgrade and JT-60U experiments. Linear calculations for DIII-D that artificially scale collisionality and R/L_n to better mimic ASDEX Upgrade find micro-tearing to become more important. Micro-tearing modes are also calculated to be significant for NSTX, but in this case a favorable pedestal scaling with beta may have an offsetting effect. Therefore, the disparate beta scalings may be explained by either different dominant turbulence modes, or experimental imperfections such as changes in the H-mode pedestal height during the beta scan. The former points out the need to determine whether micro-tearing modes are expected to appear in ITER.

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[1] C.C. Petty, Phys. Plasmas **15**, 080501 (2008).
[2] T. Takizuka, *et al.*, Plasma Phys. Control. Fusion **48**, 799 (2006).
[3] L. Vermare, *et al.*, J. Phys.: Conf. Ser. **123**, 012040 (2008).