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PEDESTAL STABILITY COMPARISON AND ITER PEDESTAL PREDICTIONS

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Pedestal Stability Comparison and ITER Pedestal Prediction IT

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The pressure at the top of the edge transport barrier (or "pedestal height") strongly impacts fusion performance, while large edge localized modes (ELMs), driven by the free energy in the pedestal region, can constrain material lifetimes. Accurately predicting the pedestal height and ELM behavior in ITER is an essential element of prediction and optimization of fusion performance. Investigation of intermediate wavelength MHD modes (or "peeling-ballooning" modes) has led to improved understanding of important constraints on the pedestal height and the mechanism for ELMs. The combination of high-resolution pedestal diagnostics, including substantial recent improvements, and a suite of highly efficient stability codes, has made edge stability analysis routine on several major tokamaks, contributing both to understanding and to experimental planning and performance optimization. Here we present extensive comparisons of observations to predicted edge stability boundaries on several tokamaks. We use the stability constraint on pedestal height to rigorously test models of the pedestal width, and self-consistently combine a width model with peeling-ballooning stability calculations to make predictions for future experiments on existing devices and for ITER.

The implementation of diagnostic improvements has allowed the measurement of high spatial and temporal resolution profiles in the edge barrier region necessary for rigorous testing of the peeling-ballooning model of ELMs. Such tests, involving high resolution equilibrium reconstruction and MHD stability calculation over a wide range of mode numbers (typically n~3-30), have now been successfully conducted on all of the world's major tokamaks in well over 100 different discharges [e.g., 1-6]. Numerous comparison experiments between machines, as well as dedicated experiments on particular devices, have elucidated the role of shape [e.g., 1,2,5], aspect ratio [e.g., 2-4], beta [2,5,7], collisionality [1,2], and rotation [2,3] on edge stability. We present extensive tests of peeling-ballooning calculations against observations, and also benchmark six MHD codes used in the analysis, and explore theoretical issues such as the impact of rotation, diamagnetic stabilization, and proximity to the X-point. The edge stability limit provides a constraint on the maximum pedestal height, which is reached in high performance Type I ELM discharges, e.g. JET discharge 70355 in Fig. 1(a). Calculated ELM structures [Fig. 1(b) inset] and mode numbers are also compared to extensive direct ELM observations using fast imaging and magnetics.

Because of the potential impact of large ELMs on plasma facing materials on ITER, a number of techniques have been developed to avoid or mitigate large Type I ELMs. These include both passive (e.g. Quiescent H-Mode, Type II, Type III, Grassy ELMs, EDA) and active (e.g. RMP, pellets) ELM control techniques. Stability studies on these discharges provide important insight into the mechanisms for ELM mitigation. For example, RMP, high density Type III, and EDA discharges are generally found to have large particle transport which holds the pedestal below peeling-ballooning stability boundaries. QH mode is found to exist in the kink/peeling-limited regime, allowing prediction of its density limits in present machines and in ITER [2]. While many issues remain under investigation, we comment on current understanding of the expected constraints for ITER operation with small or no ELMs.

Pedestal height projections for ITER require predictions of the edge barrier width, as well as stability calculations which provide a constraint on the height as a function of the width (typically height~width$^{3/4}$ [2]). Because of the strong correlation between pedestal width and height imposed by the stability constraint, and the difficulties of accurately measuring the narrow edge barrier, previous efforts to determine the physics of the width itself have led to ambiguous results. However, recent experimental studies [5,7,8], together with self-consistent evaluation of the stability constraint to remove this strong correlation from the analysis, have found commonalities in the scaling of the average pedestal width. In particular, while the Shafranov shift effect on edge stability can explain much of the observed pedestal beta dependence [Fig. 1(b)], an additional scaling of the width, roughly with $\beta_{\mathrm{pol,ped}}^{1/2}$, must be invoked to explain observations [5]. A similar width scaling also accurately accounts for shaping effects on pedestal height, allowing their prediction without using a measured width as an input. Coupling this width model to peeling-ballooning stability calculations, it is possible to predict pedestal heights using only information known before an experiment is carried out. Tests on a large DIII-D database [e.g., Fig. 1(c)], and initial cases from other tokamaks, find encouraging agreement, including prediction of a wide range of trends. Planned experiments will test pedestal height predictions made before the experiment is conducted. Refinements, further width physics analysis, and tests of alternate width models are in progress. Predictions for ITER find high pedestal temperatures due to strong shaping, and explore the impact of variations in magnetic field and current on pedestal height in ITER.

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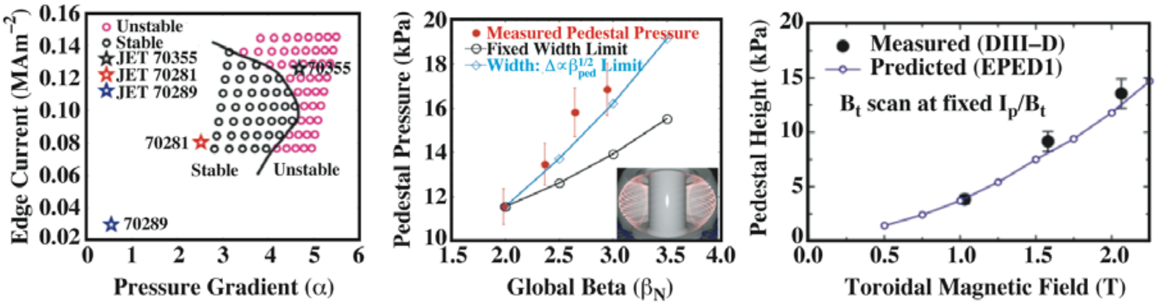

Fig. 1. (a) Edge stability analysis finds Type I ELM discharge (JET 70355) at the stability boundary, while highly radiative discharges without large ELMs are below the boundary. (b) Increase in pedestal height with global beta is due to a combination of the fixed width effect of the Shafranov shift, and an increase in pedestal width (n=18 mode structure inset). (c) Pedestal model accurately predicts DIII-D pedestal height in B_T scan.

[1] H.R. Wilson, *et al.*, Plasma Phys. Control. Fusion **48**, A71 (2006).
[2] P.B. Snyder, *et al.*, Nucl. Fusion **47**, 961 (2007); Plasma Phys. Control. Fusion **46**, A131 (2004).
[3] G. Saibene, *et al.*, Nucl. Fusion **47**, 969 (2007).
[4] S. Saarelma, *et al.*, Plasma Phys. Control. Fusion **49**, 31 (2007).
[5] A.W. Leonard, *et al.*, to appear in Phys. Plasmas (2008).
[6] M. Beurskens, *et al.*, ITPA Pedestal Meeting, Naka, Japan, October 2007.
[7] C.F. Maggi, *et al.*, Nucl. Fusion **47**, 535 (2007).
[8] H. Urano, *et al.*, ITPA Pedestal Meeting, Naka, Japan, October 2007.