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H-mode Inhibition in Negative Triangularity Tokamak Reactors

A. O. Nelson[1], C. Paz-Soldan[1], S. Saarelma[2]
[1] Department of Applied Physics and Mathematics, Columbia University, New York, NY, USA
[2] Culham Centre for Fusion Energy, UK Atomic Energy Authority, Culham, Abingdon, UK

e-mail (speaker): a.o.nelson@columbia.edu

Negative triangularity (NT) has recently emerged as a promising candidate for fusion reactors by allowing for strong core performance simultaneously with an L-mode edge [1]. As a result, the core-integration issue is significantly alleviated for NT reactor designs: NT plasmas are inherently free of edge localized modes (ELMs) and offer greater flexibility in power-handling for divertor designs. Important to this scenario is the robust inhibition of H-mode in the edge region, even at input powers that would otherwise trigger an L-H transition. In NT scenarios, this can be accomplished by preventing the growth of pedestal gradients by increasing edge instability to high toroidal mode number (n) ideal ballooning modes [2].

In this work [3], we explore the potential for robust L-mode reactor operation through this mechanism by modeling infinite-n ballooning stability as a function of internal profiles and equilibrium shape using a combination of the CHEASE and BALOO codes. Negative triangularity is found to be a primary lever on preventing access to the 2nd stability region for high-n modes, though the critical triangularity necessary for L-mode operation is observed to depend in a complicated way on the equilibrium aspect ratio, elongation and squareness. In order to stabilize high-n ballooning modes, the local shear over the entire bad curvature region must be sufficiently negative to overcome curvature destabilization on the low field side, which is not possible below a critical triangularity. Extreme low or high squareness can also be employed to close access to the 2nd stable region.

Utilizing an extensive database of equilibria and profiles, predictions of H-mode inhibition and scalings of the resulting ballooning-limited pedestal height are provided as a function of plasma and machine parameters to aid future scenario design. These results suggest that negative triangularity reactors should maintain L-mode-like operation, and offer a strategy for optimizing core performance with an L-mode edge under reactor conditions.

References
[1] M. Austin, *et al*, Physical Review Letters **122** 115001 (2019)
[2] S. Saarelma, *et al,* Plasma Physics and Controlled Fusion **63** 205006 (2021)
[3] A. O. Nelson, *et al*, in review at Nuclear Fusion (2022)

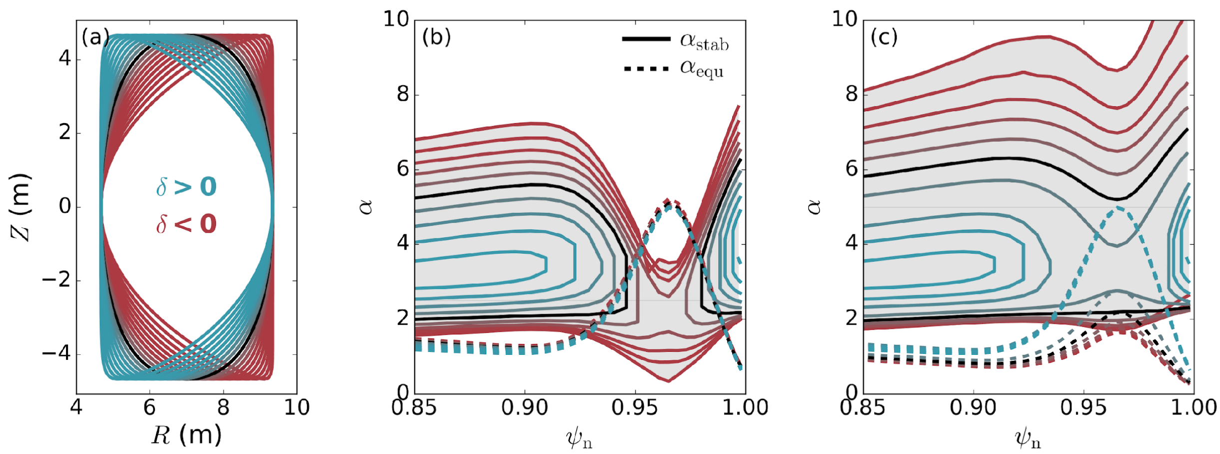

Figure 1: The effect of triangularity on infinite-n ballooning stability is demonstrated by scanning δ for fixed equilibrium parameters. (a) The separatrix of each equilibria is plotted, providing a color scale for the rest of the figure. (b) In a scan with constant edge pressure gradient, the critical gradient required for instability (α_{stab}) solid lines – is found to vary with δ. The unstable region is indicated by a grey shading. In (c), any unstable pressure profiles are reduced to remain in the stable region, leading to dramatically reduced α at strong NT. Figure adapted from reference [3].