High confinement regimes on SPARC: Access and Avoidance

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This work extends the examination of H-mode and I-mode access on the SPARC tokamak [1,2], combining new simulations of core L-mode power balance with the best empirical scalings available for L-H and L-I thresholds. Doing this informs the prospects of the device to access these regimes for a given set of operational parameters, or potentially to avoid them altogether. SPARC will seek to access high fusion energy gain Q in a compact (R=1.85m, a=0.57m) high field (reference B_T=12.2T) device fueled by DT [3,4], with a performance level that is highly sensitive to the plasma edge temperature obtained [5,6], and thus to the confinement regime in which it operates. While an H-mode pedestal provides the highest conceivable edge pressure and is the basis of a SPARC reference discharge with Q~10 [1—5], the early operation of SPARC will seek to avoid H-mode formation, and instead opt for obtaining a more modest Q value with reduced edge pressure. L-mode-like discharges have been simulated in the reference SPARC shape at full field parameters and with a range of assumed input auxiliary power, plasma density and temperature at ρ_{tor}=0.9. Simulations were accelerated using the PORTALS framework, first using non-linear CGRYO to compute flux-matched profiles for 12 example cases [6], and then using the quasi-linear TGLF solver to perform numerous additional simulations sampling the nominal L-mode space. PORTALS-TGLF has generated over 100 L-mode simulations, with additional variation in Z_{eff} and ion-electron temperature ratio included. The outputs of these simulations include realistic net power transported through the edge, along with its distribution within the ion and the electron channels. A substantial window for L-mode operation is seen, based on the net power through the edge being generally below typical H-mode or I-mode power threshold projections. However, margin to L-H and L-I thresholds is much tighter if one assumes that scalings of critical ion heat flux threshold are the appropriate thresholds to consider [2]. These and follow-on results will inform plans for SPARC operation, first by optimizing the approach to Q>1 demonstration, and second by providing a path to efficient access to higher performance plasmas.

Research supported by Commonwealth Fusion Systems

[1] J.W. Hughes *et al. Journal of Plasma Physics,* **86** (5) 865860504 (2020).
[2] J.W. Hughes *et al.* 29th IAEA Fusion Energy Conference, London UK, CN-316-2107 (2023).
[3] A.J. Creely *et al. Journal of Plasma Physics,* **86** (5) 865860502 (2020).
[4] P. Rodriguez-Fernandez *et al. Nuclear Fusion*, **62** 042003 (2022).
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[6] P. Rodriguez-Fernandez *et al. Physics of Plasmas*, **31** 062501 (2024).

Suggested Topic: 1 "No-ELM and small-ELM regimes and extrapolation to burning plasmas"