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Shape dependence of L-H transition physics and power threshold in negative and positive triangularity plasmas

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Negative triangularity L-mode plasmas in DIII-D exhibit H-mode-like thermal confinement and normalized pressure β_N (Fig.1). Their increased L-mode scrape-off layer width potentially opens a path for mitigating divertor power loading in future burning plasmas [1]. Understanding the shape dependence of the L-H transition power threshold P_{LH} is therefore important for avoiding H-mode at negative triangularity.

At moderate negative upper triangularity δ_U~ -0.2, sustained ELMing H-mode is still accessed in DIII-D, with a power threshold P_{LH}~3.8 MW that is moderately increased compared to a positive δ_U plasma with similar NBI torque input. However, DIII-D plasmas with high negative upper triangularity (δ_U= -0.325) access H-mode only transiently (Fig.2) followed by extended limit cycle oscillations (LCO [2]), where the edge electric field, normalized edge pressure gradient, and recycling (D_α emission) remain near L-mode values up to the highest coupled auxiliary power (~11 MW).

Fig. 2(b) shows that the density gradient is modulated during LCO (together with the diamagnetic velocity, radial electric field, and **E**×**B** shear), resulting in a periodically increased edge pressure gradient. However the time-averaged density gradient remains considerably below the values reached during transient ELMing H-mode. Time-averaged density fluctuation levels in the low and intermediate wavenumber range ($0.4 \leq k_\theta\rho_S \leq 1$), measured via Doppler Backscattering (DBS), are reduced compared to positive δ_U plasmas. The Trapped-Gyro-Landau-Fluid code (TGLF) indicates prevailing TEM instability, whereas comparable positive triangularity plasmas are characterized by mixed ITG/TEM instability. Preliminary quasilinear analysis indicates electron-heat dominated transport and ion/electron thermal diffusivities that are reduced by a factor of ~2 compared to the positive δ_U case, which shows significant thermal flux contributions from ITG, in agreement with transport analysis. This difference accounts partially for the substantially improved L-mode confinement with negative δ_U [Fig. 1].

On the other hand, in positive triangularity ITER-similar-shape (ISS) deuterium and hydrogen plasmas, slightly (~12%) reduced lower triangularity has been shown to reduce P_{LH} by 15-20%, indicating that a minor shape adjustment could potentially ease H-mode access in ITER hydrogen plasmas during the PFPO-1 campaign with marginal auxiliary heating power.

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[1] M.E. Austin et al. 2019 Phys. Rev. Lett. 122, 115001.
[2] L. Schmitz et al. 2012 Phys. Rev. Lett. 108, 155002.

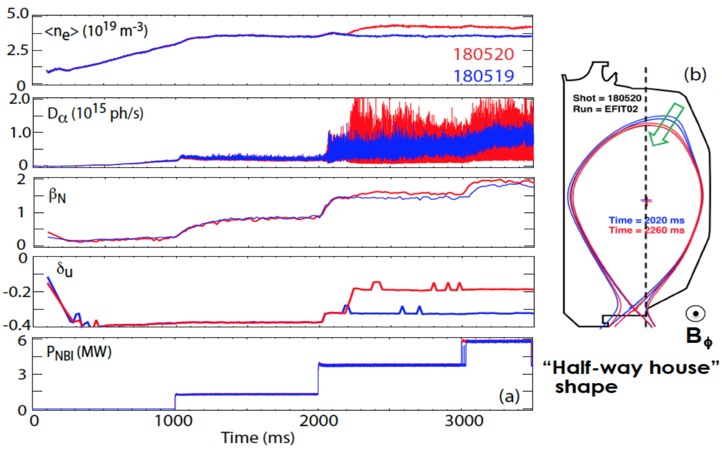

Fig.1: (a) Line-averaged density, D_α recycling light, normalized pressure β_N, upper triangularity δ_U, and injected neutral beam power for shot #180520 where the upper triangularity was reduced from δ_U= -0.375 to -0.2 (achieved H-mode) and #180519, where the plasma remained in L-mode at δ_U = -0.325; (b) plasma shape with δ_u=-0.325 (blue) and δ_u=-0.2 (red).

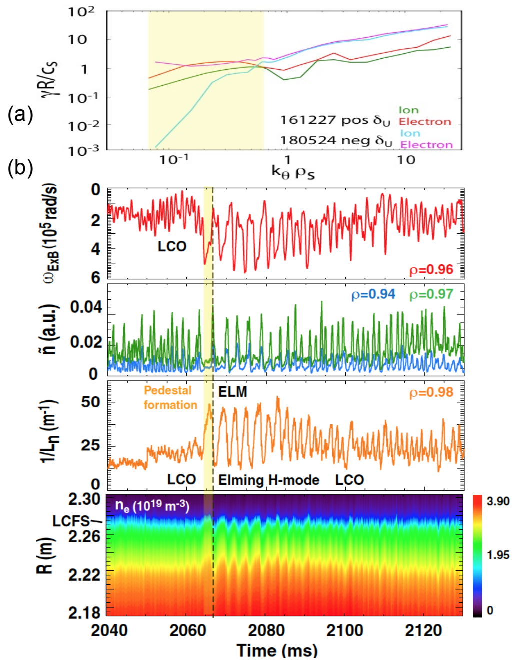

Fig.2: (a) TEM and ITG growth rates vs. $k_\theta\rho_S$ (ρ=0.95) for pos. and neg. δ_U; b) **E**×**B** shear and density fluctuation level in the outer/ inner shear layer; normalized density gradient, and equidensity contours across the transition from L-mode/LCO to transient ELMing H-mode and back to LCO.