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H-mode-like confinement with L-mode edge in negative triangularity plasmas on DIII-D

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Plasmas with negative triangularity (δ) shape have been created on the DIII-D tokamak that are characterized by H-mode-like confinement (H_{98y2} = 1.2), high normalized beta (β_N = 2.6) and feature pressure profiles typical of an L-mode plasma without Edge Localized Modes (ELMs). This work was motivated by previous results on the TCV tokamak, where the energy confinement time of collisionless, inner-wall limited, L-mode plasmas subject to pure electron heating was shown to double when reversing triangularity [1] with other parameters held fixed. The amelioration of confinement was attributed to a modification of the toroidal precession drift of trapped electrons in the negative triangularity shape, thus weakening Trapped Electron Modes which were the dominant ion-scale instability [2]. The DIII-D experiment presented in this work investigated negative triangularity plasmas in both pure electron and mixed ion-electron heating regimes, thus exploring for the first time a more reactor relevant regime where Te~Ti. Plasmas are inner-wall limited, up-down symmetric, and characterized by line averaged density of 4-5 10^{19} m^{-3}, elongation k=1.4, triangularity δ=-0.4, toroidal field B_T=2 T and current I_P~1 MA, resulting in q_{95}~3.6, or q_{lim}~4.5.
Compared to plasmas with matched elongation, current, density, toroidal field and auxiliary power, but positive triangularity (δ=+0.4), plasmas at negative triangularity show better confinement, which results in higher ion and electron temperatures with either electron cyclotron heating (ECH) or neutral beam injection (NBI) heating. The intensity of density and temperature fluctuations, monitored by the full suite of turbulence diagnostics in DIII-D, is seen to decrease in plasmas at negative triangularity both in ECH and in NBI dominated phases, consistent with the increased confinement.
The H-mode power threshold in such plasmas is found to be higher at negative δ, which allowed a comparison between a δ=-0.4 plasma with an L-mode edge and a δ=+0.4 plasma with an ELMy H-mode edge at the same heating power. The negative triangularity plasma featured similar confinement and fluctuation properties as the positive triangularity that had transitioned to H-mode, thus confirming that these negative triangularity plasmas are characterized by H-mode-like confinement. Additionally, the plasma at negative triangularity produced 30% more neutrons than the positive triangularity counterpart, primarily thanks to a reduced main ion dilution due to lower impurity content.
These results show that negative triangularity is a viable candidate for reactor scenarios owing to high core confinement, low impurity content and ELM-free characteristics. In case of a diverted solution, the negative triangularity shape would offer a more economical and effective option for divertor placement.

[1] Y. Camenen et al., *Nucl. Fusion* **47** (2007) 510
[2] A. Marinoni et al., *Plasma Phys. Control. Fusion* **51** (2009) 055016

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