Effects of negative triangularity on SOL plasma turbulence

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Negative triangularity (NT) plasmas are considered a promising alternative to conventional H-mode operation in positive triangularity (PT) scenarios **[1]**. While experimental observations from various tokamaks have demonstrated that NT L-mode plasmas can achieve H-mode-like confinement, primarily due to reduced turbulence levels and inherently ELM-free behavior **[2]**, numerical and theoretical understanding, particularly of boundary plasma turbulence **[3]**, remains incomplete. Further investigations are needed to clarify the effects of triangularity on scrape-off layer (SOL) turbulence and its impact on key edge plasma phenomena, including power exhaust and impurity transport in NT configurations.

In this work, we investigate the effects of triangularity on SOL plasma turbulence in double-null (DN) L-mode plasmas using global, nonlinear, three-dimensional, flux-driven two-fluid simulations. NT plasmas exhibit suppressed interchange-driven instabilities, resulting in enhanced confinement and lower fluctuation levels compared to positive triangularity (PT) plasmas. This reduction in interchange instability is associated with the weakening of curvature effects in the unfavorable region, caused by the stretching of magnetic field lines at the outer midplane. Furthermore, the reduced turbulent level at the low-field side (LFS) results in most of the heat flux reaching the outer targets, while the quiescent high-field side (HFS) drives larger heat flux in the inner target in case of NT plasmas, reducing a in-out targets power asymmetry, compared to PT plasmas.

The reduction of interchange instabilities in NT plasmas also affects the blob dynamics. A three-dimensional blob analysis reveals that NT plasmas feature smaller blob sizes and slower propagation velocities. Finally, an analytical scaling law for blob size and velocity that includes plasma shaping effects is derived based on the two-region model and is found to qualitatively capture the trends observed in nonlinear simulations.

Finally, conventional neoclassical theory, which assumes circular flux surfaces, is revisited by including plasma shaping effects, i.e., elongation and triangularity, to describe heavy impurity transport near the edge region of NT plasmas. The revised theory indicates that shaping can significantly modify neoclassical impurity transport; in particular, the difference between PT and NT plasmas becomes pronounced in the presence of strong poloidal asymmetries. Numerical simulations further suggest that, although NT configurations are favorable for turbulence suppression, they may facilitate core accumulation of heavy impurities, potentially increasing the risk of radiative losses.

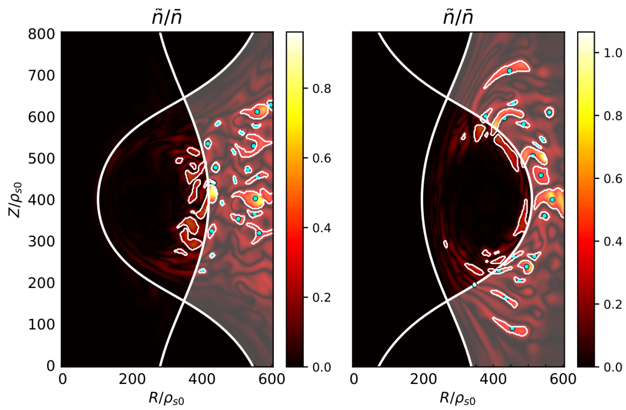

Figure 1: Two-dimensional snapshot of blob detection in NT and PT plasmas. Blobs that meet the threshold condition in the LFS region outside the separatrix (grey region) are detected, with their contours outlined as solid white lines. The center of mass of each detected blob is marked with a cyan dot.

References
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