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Physics insights from the aspect ratio dependence of turbulence in negative triangularity plasmas

A.Balestri[1], J.Ball[1], S.Coda[1], D.J.Cruz-Zabala[2,3], M.Garcia-Munoz[2,3] , E.Viezzer[2,3]
[1] Ecole Polytechnique Fédérale de Lausanne (EPFL), Swiss Plasma Center (SPC), 1015 Lausanne, Switzerland
[2] Dept. of Atomic, Molecular and Nuclear Physics, University of Seville, Seville, Spain
[3] Centro Nacional de Aceleradores, (U. Seville, CSIC, J. de Andalusia), Seville, Spain
e-mail (speaker): alessandro.balestri@epfl.ch

Many years of plasma and fusion research have shown that plasma shaping can greatly influence the quality of confinement in a tokamak plasma. A large effort by means of experiments (TCV [1], DIII-D [2] and AUG [3]) and first-principle simulations showed that plasmas with a Negative Triangularity (NT) shaped poloidal cross-section can inhibit the access to H-mode and reduce turbulent transport with respect to Positive Triangularity (PT). These characteristics enable a scenario where harmful Edge Localized Modes (ELMs) are avoided while achieving core performance comparable to H-mode plasmas. However, the community still lacks a deep and thorough understanding of the beneficial effect of NT on turbulent transport, which is crucial to extrapolate performance to a possible NT fusion reactor.

In this talk, we will give an overview of the physics insights on turbulent transport that we achieved while studying the interplay between the aspect ratio A and NT using linear and nonlinear flux tube GENE [4] gyrokinetic simulations. The talk will be divided into two topics. One on the effect of NT on electrostatic turbulence (i.e. Ion Temperature Gradient (ITG) modes and Trapped Electron Modes (TEMs)). The other on electromagnetic turbulence (i.e. Micro-Tearing Modes (MTMs)), which is especially relevant for spherical tokamaks, where larger β (plasma pressure over magnetic field squared) can be reached in the edge region.

For the electrostatic study [5], we considered several different scenarios inspired by TCV and DIII-D experimental data. We report a surprising and non-trivial dependence. NT significantly improves confinement at any value of A for ITG turbulence, while for TEM turbulence confinement is enhanced only in the case of large and conventional aspect ratios. Additionally, through a detailed study of a large aspect ratio case with pure ITG drive, we developed an intuitive physical picture that explains the beneficial effect of NT at large and conventional aspect ratios just in terms of magnetic drifts and Finite Larmor Radius (FLR) effects. This picture does not hold in TEM-dominated regimes, where a complex synergistic effect of many factors is found.

In the second part, we will consider scenarios from six devices: the new SMART [6] spherical tokamak, MAST-U, TCV, DIII-D, DTT [7] and EU DEMO. Using linear flux tube simulations, we performed multi-parameter scans changing the local electron β, the electron temperature gradient and the magnetic shear $\hat{s}$, covering a range of physically relevant values. At sufficiently large β, $\hat{s}$ and electron to ion temperature gradient ratio, all NT scenarios entered an MTM-dominated regime regardless of aspect ratio. On the contrary, PT always stayed in a regime dominated by ITGs or TEMs, as already observed in the electrostatic cases. The comparison of the linear growth rates between NT and PT showed that when NT accesses the MTM-dominated regime, it becomes more unstable than PT. On the other hand, even when β is large, as long as magnetic shear is sufficiently low ($\hat{s} < 2.0$) and the electron to ion temperature gradient ratio is slightly lower than 1, NT stays in an ITG-dominated regime and is more stable than PT. Preliminary nonlinear simulations seem to confirm the linear predictions. We conclude that operating at large β in a NT device will still be beneficial at conventional aspect ratios, where β is sufficiently low at the edge, but might become detrimental in spherical tokamaks if these observations are not taken into account. All these predictions can and will be tested soon on SMART, which very recently started first operations.

References

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