Theoretical studies and simulations of mode structure symmetry breaking in tokamak plasmas

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The symmetry breaking of the mode structure, as described by finite flux surface averaged parallel wavenumber \( \langle k || \rangle \) and poloidal angle \( \langle \theta \rangle \), is important for estimating the off-diagonal component of momentum flux [1]. Energetic particles (EPs) bring in new features of symmetry breaking and in turn, the EP behaviors can be affected by symmetry breaking [2]. In this work, theoretical methods are developed and simulations are performed to study the symmetry breaking of the ion temperature gradient (ITG) mode and beta induced Alfvén eigenmode (BAE). The results are compared with ORB5 and GKW for ITG and XHMGC for BAE.

The Mode Structure Decomposition approach is developed for the symmetry breaking study of the ITG mode for which poloidal harmonics are strongly coupled [3,4]. A complex ballooning parameter is introduced to include the symmetry breaking due to the “profile shearing” [5] and the turbulence intensity gradient [6] on the same footing in tokamak geometry. The agreement with GKW and ORB5 simulation is shown. “Global-oriented local simulations” are suggested where global symmetry breaking properties are taken into account in the local model.

For the BAE problem, the weak coupling formula is adopted with EPs’ non-perturbative effect taken into account. The theoretical global analysis and HMGC simulation demonstrate the essence of “boomerang” structures with/without asymmetric tails in the poloidal plane as well as the radial and parallel symmetry breaking [7]. Global effects and the non-perturbative EP response are important ingredients for the symmetry breaking and their effects on EP transport as well as the implications to experimental observations using ECEI are discussed.

Further studies based on theoretical analyses and ORB5/XHMGC simulations explore the symmetry breaking in broader parametric regimes, with the consideration of higher frequency AEs such as reversed shear Alfvén eigenmode (RSAE). The EPs effects on radial mode width, momentum transport, residual zonal flow and other nonlinear behaviors are discussed.

ZL appreciates input from A. Koenies, A. Mischenko, A. Biancalani, O. Maj and E. Poli, and T. Hayward-Schneider. This work has been carried out within the framework of the EUROfusion Consortium and has received funding from the Euratom research and training programme 2014-2018 under grant agreement No 633053. The views and opinions expressed herein do not necessarily reflect those of the European Commission.

[7]. Z. X. Lu, X. Wang, Ph. Lauber, F. Zonca. Nucl. Fusion, 2018, accepted