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A gyrokinetic discovery of fast L-H bifurcation physics in a realistic, diverted, tokamak edge geometry

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Despite over 30 years of routine H-mode operation in all the major tokamaks, there has not been a fundamental understanding at the kinetic level on how the H-mode turbulence bifurcation occurs. This is a concern over ITER's achievability of the H-mode operation with available heating power when the ∇⊠-driven neoclassical ExB shearing rate is expected to be weak due to smallness of ρ*=ρi/a. The answer to this concern relies on a more fundamental physics question: Will a neoclassically- driven mean ExB shearing (∇⊠-driven or X-point orbit-loss driven) be essential for the L-H turbulence bifurcation, besides the Reynolds-force driven ExB shearing? Experimental observations appear to diverge on the cause and dynamics of L-H bifurcation.
From the edge gyrokinetic code XGC1, we find that a neoclassical-driven ExB-shearing is essential to quench the turbulence irreversibly, and works together with the Reynolds-stress driven ExB-shearing. New XGC1 study also shows that, in ITER, the weak ∇⊠-driven ExB shearing can be compensated by the X-point orbit-loss driven ExB-shearing and toroidal flow if the edge Ti is high enough. The physics found in the XGC1 simulations reconciles a few different L-H bifurcation dynamics observed in experiments: They are not mutually exclusive but can work together, depending upon plasma conditions. These different mechanisms include not only the source of the sheared ExB flow (turbulent or neoclassical), but also the role of different shearing physics: 1) shearing of the turbulence eddies to smaller structure and higher frequency, leading to dissipation at high wave numbers, or 2) quenching of the turbulence via an eddy tilting-stretching-absorption process via Reynolds work through a conservative absorption process from the turbulence kinetic energy to the plasma ExB flow energy.
It is also observed that both ion and electron directional modes are involved in the bifurcation process, with a highly different dynamics from each other. Both modes exist before the bifurcation. The electron modes disappear immediately during the bifurcation process, but the ion modes remain until the end of the bifurcation process undergoing the dissipative ExB shearing action. Experimental observations of two directional modes exist just before the bifurcation process starts.

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