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Understanding the L-H Transition in Tokamak Fusion Plasmas

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Tokamak plasma can spontaneously transit from a low-confinement (L) mode to a high-confinement (H) mode due to the suppression of plasma turbulence and the formation of a transport barrier at the plasma edge, known as L-H transition. The mechanism for the L-H transition is a 34-years long mystery in the field of magnetic fusion since it was firstly discovered in 1982[1]. There are substantial evidences that the suppression of turbulence is due to the formation of a shear layer of $E\times B$ flows at the plasma edge. However, the issues about how shear flows lead to turbulence suppression are still ambiguous in the magnetic fusion community. .

The turbulence suppression in experiments usually occurs very fast, typically of 100 microseconds. Thus a significant increase of the mean flow shear in a very short time scale is required to suppress the turbulence at the transition. However, the mean flow change prior to the transition is usually small. It indicates that edge turbulence intensity may have a much stronger nonlinear dependence with the flow shear. In a recent theory, it is proposed that the turbulence suppression can be induced by a radial wave number spectral shift k_r and a tilt of 2D eddy structures due to breaking down of the ballooning symmetry by the flow shear[2]. The spectral shift scatters turbulence energy to high perpendicular wave number region. It leads to local turbulence suppression without the assistance of zonal flows.

In order to address the key questions for turbulence quench at the L-H transition, a series of experiments and model analysis have been extensively carried out on the EAST superconducting tokamak. For the first time, it was observed that the L-H transition occurred spontaneously mediated by a shift in the radial wave number spectrum of turbulence[3]. Radial wave number spectral shift and turbulence structure tilting took place tens of milliseconds prior to L-H transition at the plasma edge. Across the L-H transition, the spectral shift accelerated, and the local turbulence got suppressed. In addition, the spectral shift appeared to be correlated with the time evolution of radial electric field shear at the plasma edge. In the geometry space, the spectral shift manifests itself as ordered turbulence eddies tilting, which scatters the turbulent energy to higher wave number region where the turbulence energy is dissipated. It does not require a pretransition overshoot in the turbulent Reynolds stress, shunting turbulence energy to zonal flows for turbulence suppression as demonstrated in the experiment.

These new findings may help elucidate discrepancies between the recent experimental observations and the previous zonal flow theories on the L-H transition, concerning the causality between the electric field and turbulence and the presence of zonal flows at the transition.

References

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