§21. Physics of Internal Transport Barrier of Toroidal Helical Plasmas

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The turbulence-driven transport and the structural formation in confined plasmas has been advanced much [1]. We study the role of zonal flows (ZFs) [2] in the formation of an e-ITB. [3,4] The turbulent transport coefficient, in which the screening influence of ZFs is included, is shown to be suppressed when the plasma state changes from the branch of weak negative E_r to that of strong positive E_r. This new transition of turbulent transport is induced by the change of the damping rate of the ZFs, which is strongly influenced by the neoclassical ripple transport. The analytic theory is explained first. Then the transport analysis is shown. Finally, the experimental verification based on the CHS plasmas is demonstrated. This is the first report to clarify that the collisional damping rate of the ZFs governs the transition of global confinement of toroidal plasmas including the experimental test. This gives an answer to the basic question, in the laboratory plasma turbulence and in the planetary zonal flows, of how turbulent transport and frictional damping couple to each other in generating zonal flows [5].

The transport code analysis of LHD plasma with e-ITB is performed. By taking into account of the effects of the zonal flow, the reduction of thermal conductivity in the core plasma is explained.

The reduction of the turbulent transport in the core of e-ITB plasma, via the enhanced ZFs, has been experimentally confirmed on CHS plasma. The ZFs have been identified in the CHS plasma, and the temporal evolution of the intensities of the micro fluctuations and the ZFs have been measured simultaneously [6]. Figure 1 illustrates the simultaneously observed ZFs and microturbulence intensities during the e-ITB phase. Vertical and horizontal axes indicate normalized fluctuation amplitude $|e\tilde{E}_r / \nabla T_0|^2$ and ZFs amplitude $|E_{\mathrm{ZF}}|^2$, respectively. The observed difference of $|e\tilde{E}_r / \nabla T_0|^2$ between the e-ITB and L-mode plasmas does not contradict the theoretical prediction. It should be noted that the pressure gradient at the observation radius is weaker in the L-mode plasma compared to the e-ITB plasma. (Other parameters such as geometrical factors and magnetic field, etc. are unchanged between the two states.) Thus, the enhanced normalized fluctuation level in the L-mode is opposite to the reduction of mean pressure gradient and cannot be simply explained by linear instability. When E_r jumps to a strongly positive value, damping rate of ZFs is reduced, and microfluctuations (which are responsible for turbulent transport) become smaller. Thus, the increased ZFs causes the further reduction of the turbulent transport in the entire region of the e-ITB, in addition to the strong $\mathrm{d}E_r/\mathrm{d}r$ at the interface.

The bifurcation of E_r (from the negative value to the strong and positive value) was found to induce the transition of the turbulent transport coefficient. The electron ITB is established by the mechanisms of (i) the bifurcation of the radial electric field via the neoclassical process and the reduction of neoclassical energy transport, (ii) the establishment of the electric field interface that quenches the turbulence, and (iii) the reduced damping of ZFs which causes the suppression of turbulent transport.

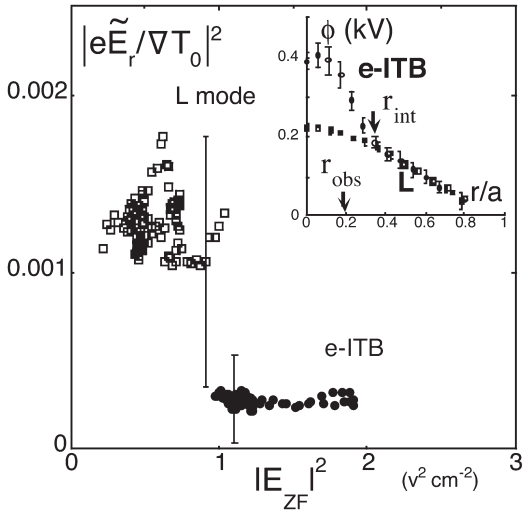

Fig.1: ZFs and microturbulence intensities during the e-ITB phase (solid circle, red) and the L-phase (open circle, blue). The insert shows the profile of mean potential. Locations of interface and observation, r_{int} and r_{obs}, are also indicated.

References

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