2nd Asia-Pacific Conference on Plasma Physics, 12-17,11.2018, Kanazawa, Japan

Study of non-local turbulent transport and *E*×*B* staircase dynamics based on full-f flux-driven gyro-kinetic simulation

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Turbulent transport and $\boldsymbol{E}\times\boldsymbol{B}$ flow dynamics are long standing problems in magnetically confined fusion plasmas such as Tokamaks. On one hand, drift-wave instabilities e.g. ion temperature gradient mode (ITG) instability are believed to cause large heat transport along the radial direction, and have been widely investigated through theoretical, experimental and numerical approaches. In recent decades, a series of transport models such as SOC (Self-Organized Critical) type transport, profile stiffness, self-similar relaxation, transient process, etc. have been discussed to describe the turbulent state of the Tokamak system, in which global effects is crucial. On the other hand, $\boldsymbol{E}\times\boldsymbol{B}$ shear flows are found to play a role in suppressing the turbulent transport through the effect of decorrelation, and have been widely studied in fusion community. Among $\boldsymbol{E}\times\boldsymbol{B}$ shear flow patterns, the $\boldsymbol{E}\times\boldsymbol{B}$ staircase, which shows meso-scale and long-lived shear layers, has been discovered in both experiment and numerical simulations. Such staircase structure is found to provide an influence on the transport and then the confinement performance [1, 2]. However, turbulence behaviors and $\boldsymbol{E}\times\boldsymbol{B}$ shear flows are not isolated, but correlated with each other through a complex manner. The underlying physics is of specific importance in understanding transport processes in Tokamaks, which also leads to the formation of global temperature profile.

In recent decades, the development of large scale gyro-kinetic simulation has provided a powerful tool to investigate the micro-turbulence in Tokamaks. In the present work, through the simulations utilizing the advanced 5-D gyro-kinetic toroidal numerical code GKNET (Gyro-Kinetic Numerical Experiment of Tokamaks) [3, 4], we studied the characteristics of ITG mode driven turbulent transport and the $\boldsymbol{E}\times\boldsymbol{B}$ staircase dynamics in the framework of adiabatic electron response.

Through statistical approaches, we firstly investigate the characteristics of non-local turbulent transport as seen in figure (a). In particularly, we introduced a size PDF analysis for heat flux eddies in real space and studied the role of global turbulence in leading to the transport burst in a flux-driven system. On the other hand, such global structures are also found to play a critical role in leading to the $\boldsymbol{E}\times\boldsymbol{B}$ staircase in the steady state as seen in figure (b). Based on these facts, we investigated the formation mechanism of $\boldsymbol{E}\times\boldsymbol{B}$ staircase through GKNET simulations. We found that the radial electric field of the $\boldsymbol{E}\times\boldsymbol{B}$ staircase is primarily generated from the excitation of zonal flow via the action of Reynolds stress from the turbulence and enhanced by the radial mean field variation caused by the temperature fluctuation. It is also found that the background mean field can significantly change the behavior of transport and $\boldsymbol{E}\times\boldsymbol{B}$ shear flow pattern. Moreover, the sustainment mechanisms of the $\boldsymbol{E}\times\boldsymbol{B}$ staircase are discussed based on two effects: formation of global burst through phase matching, and temperature fluctuations through the avalanches transport.

Figures:

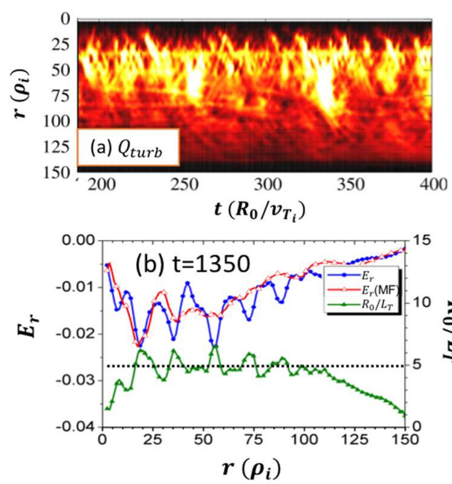

Figure (a) Time evolution of radial turbulent transport Q_r in flux-driven GKNET simulation.

Figure (b) Typical structure of the $\boldsymbol{E}\times\boldsymbol{B}$ staircase, shown with radial profiles of radial electric field E_r (blue line) and temperature gradient measured by R/L_{T_i}(green line). The red line indicates the mean field pattern which is calculated through the radial force balance equation.

References:

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