§17. Impact of Radial Mean Electric Field and Toroidal Rotation in Flux-driven Micro-scale Turbulence

Imadera, K., Kishimoto, Y., Li, J.Q. (Kyoto Univ.),
Satake, S.

Profile stiffness is a long standing problem, which may limit the overall performance of H-mode plasmas. In the JET experiment, while strong temperature profile stiffness is observed around the nonlinear threshold of ion temperature gradient driven instability, it can be greatly reduced by co-current toroidal rotation in weak magnetic shear plasma[1]. To understand such a mitigation mechanism, we have newly developed a 5D global gyrokinetic code *GKNET* with heat and momentum sources[2,3]. By means of this code, we found that a stiff temperature profile is established in the absence of momentum source[2]. The mean E_r is found to play an important role in triggering global transport by recovering the up-down symmetry of the ballooning structure. This indicates that the mean E_r can enhance the stiffness.

In this study, we introduce a momentum source to control the mean E_r. The radial force balance relation in circular concentric Tokamak configuration,

$$E_r + \frac{k}{e}\frac{dT_i}{dr} - \frac{rB}{qR}U_{\parallel} - \frac{1}{n_i e}\frac{dp_i}{dr} = 0 \qquad (1)$$

indicates that the toroidal rotation in outer core region with small safety factor, which corresponds to weak or reversed magnetic shear case, can effectively change the mean E_r. Based on this idea, we perform flux-driven ITG simulation with momentum source in weak magnetic shear plasma. Employed parameters are $a/R = 0.36$, $a/\rho_{ti} = 150$ and $\nu^* = 0.28$. Figure 1 (A) shows the radial ion temperature profile in the case without momentum input, with co- and counter-current input around $r = 0.6a$. It is found that only co-current momentum injection has a strong impact on local temperature build up in momentum source region, where the ion thermal diffusivity decreases to the neoclassical transport level, as shown in Fig. 1 (B). This implies that co-input and weak magnetic shear can benefit ITB formation, which is consistent with the observations in the JET experiment qualitatively[1]. Figure 2 shows the radial profile of each term in radial force balance relation in the case with (A) co-input and (B) counter-input. From Fig. 2 (A), we can clearly see that E_r is strongly triggered by toroidal rotation in outer region, while the other two terms do not change so largely in this unit. So it is natural to conclude that the mean E_r shear triggered by toroidal rotation, which is much stronger than the zonal flow shear, suppresses the turbulence, leading to ITB formation. Note that the established ITB is enough stable in the quasi-steady state.

The underlying mechanism why only co-input is effective for ITB formation is identified to originate from the resultant momentum diffusion. According to the momentum transport theory[4], the residual stress coefficient of momentum flux is given by

$$\frac{C^* R}{\chi_\varphi v_{ti}} \sim -s\left(\frac{R}{L_n} + 4\right)\frac{\theta_0}{2qk_\theta \rho_{ti}} \qquad (2)$$

Here, θ_0 is ballooning angle, which is positive/negative in enough strong negative/positive E_r shear region based on the non-local ballooning theory. As a result, E_r shear triggered by co-input can work to reduce momentum diffusion in positive magnetic shear case, as shown in Fig. 2 (A). On the other hand, the role of counter input is opposite so that the momentum diffusion is enhanced as shown in Fig. 2 (B). Thus, there exists a positive feedback loop between the enhanced E_r shear and resultant momentum pinch only in the co-input case, signifying a favorite trend to ITB formation.

In summary, we found that co-current toroidal momentum injection benefits ITB formation because modified mean E_r can produce momentum pinch. These new findings contribute to controlling ITB formation in ITER and DEMO plasmas.

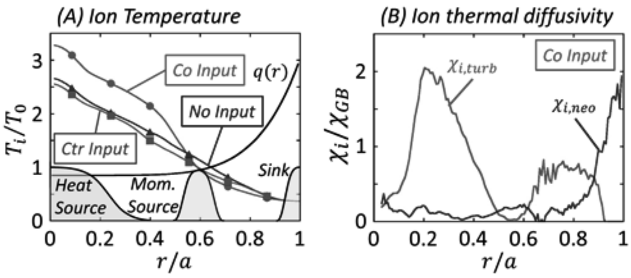

Fig. 1. (A) Radial ion temperature profile in the case without momentum input, with co- and counter-input around $r = 0.6a$. (B) Radial profile of turbulent/neoclassical ion thermal diffusivity with co-input.

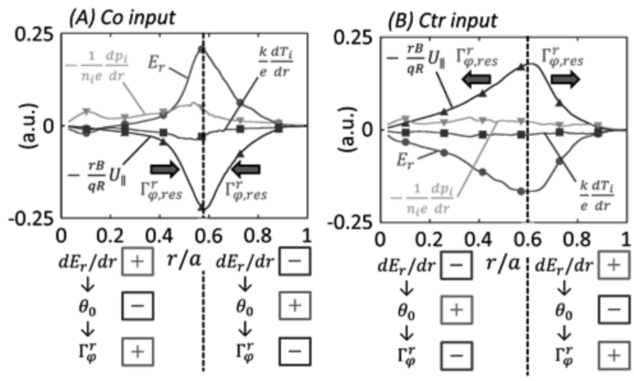

Fig. 2. Radial profile of each term in radial force balance relation in the case with (A) co-input and (B) counter-input around $r = 0.6a$.

1) P. Mantica, *et al.*, Phys. Rev. Lett. **107** (2011) 135004.
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4) Y. Camenen, *et al.*, Nucl. Fusion **51** (2011) 073039.