CD-I6 AAPPS-DPP2019

3^{rd} Asia-Pacific Conference on Plasma Physics, 4-8,11.2019, Hefei, China

Studies of Reynolds Stress and the Turbulent Generation of Edge Poloidal Flows on the HL-2A Tokamak

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Plasma poloidal mass flow and E×B flow are of great interest for their contributions to shear decorrelation of turbulence, and to the trigger mechanism for edge and core transport barriers. A large excursion in the poloidal rotation of carbon impurity ions relative to the neoclassical prediction was associated with internal transport barrier formation in TFTR reversed shear plasmas. The theory of turbulence effects on mean poloidal flow via turbulent flux of momentum--Reynolds stress--has been widely studied in the fusion community. The divergence of the Reynolds stress $\langle\tilde{v}_r\tilde{v}_\theta\rangle$ shifts the poloidal flow from the neoclassical value [1]. Considering the case of a stationary flow, $\langle v_\theta\rangle$ is given by: $\mu_{ii}^{(neo)}(\langle v_\theta\rangle-\langle v_\theta\rangle_{neo})=-\partial_r\langle\tilde{v}_r\tilde{v}_\theta\rangle$. The Reynolds stress can be expressed in the form [2,3]: $\langle\tilde{v}_r\tilde{v}_\theta\rangle=-\chi_\theta\partial_r\langle v_\theta\rangle+v_r^{eff}\langle v_\theta\rangle+\Pi_{r\theta}^{Res}$. The first term on the right-hand-side represents the diffusive stress due to turbulent momentum diffusion, i.e. turbulent viscous flux. χ_θ is the turbulent viscosity for poloidal flow. The second term represents the radial convection of poloidal momentum, and the third term is the residual stress, which has no leading dependence on $\langle v_\theta\rangle$ or $\partial_r\langle v_\theta\rangle$. As a consequence of wave-flow momentum exchange, the residual stress drives an off-diagonal turbulent momentum flux, which is a function of the profiles of density and temperature (which drive the turbulence).

Several new results on the physics linking edge poloidal flows to turbulent momentum transport are reported. These are based on experiments on the HL-2A tokamak. Significant deviation from the neoclassical prediction for mean poloidal flow in Ohmic and ECRH heated L mode discharges is derived from direct measurement of the turbulent Reynolds stress. The deviation increases prominently with ECRH heating power. The turbulent poloidal viscosity is synthesized from fluctuation data, and is found to be comparable to the turbulent particle diffusivity, as shown by figure 1. The intrinsic poloidal torque characterized by the divergence of the non-diffusive residual stress is deduced from synthesis for the first time in a tokamak plasma, as shown by figure 2. Experimental evidence which demonstrates the dynamics of spectral symmetry breaking in drift wave turbulence is in good agreement with the development of the poloidal torque. Taken together, these results elucidate the connections between power injection, turbulence development, pressure gradient and residual stress from symmetry breaking. When line-averaged density is raised, not only the Reynolds power collapses, but the intrinsic torque – the turbulent momentum drive of edge poloidal flows also collapses, as shown by figure 3. Edge shear layer collapses and the particle flux enhances, leading to the further edge cooling of plasma and the density limit via MHD instabilities.

References

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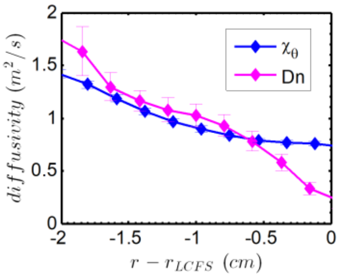

Figure 1. Comparison of turbulent momentum viscosity χ_θ to turbulent particle diffusivity D_n.

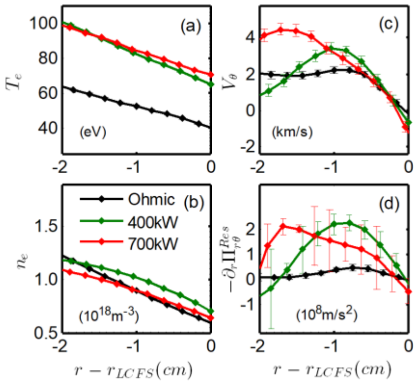

Figure 2. (a) Electron temperature; (b) electron density; (c) E×B poloidal rotation; (d) poloidal torque.

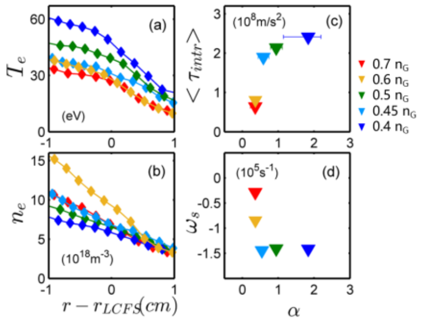

Figure 3. The dependence of rotation torque and poloidal shearing rate on adiabaticity parameter.