# §8. Entropy Transfer in Ion Temperature Gradient Turbulence in Helical Plasmas

Watanabe, T.-H., Sugama, H., Nunami, M.,
Nakata, M. (JAEA)

Gyrokinetic simulations have been carried out to study the anomalous transport mechanism in Large Helical Device plasmas by means of the GKV code [1]. In non-axisymmetric systems, the zonal flow response to a turbulence drive (Reynolds stress) is enhanced by optimizing collisionless orbits of helical-ripple-trapped particles for the neoclassical transport. The ambipolar radial electric field ($E_{r0}$) spontaneously generated by the neoclassical transport also influences trapped particle orbits, leading to enhancement of the residual zonal flow response [see for example, Ref. 2)]. Thus, the neoclassical transport influences the turbulent transport through zonal flows in non-axisymmetric systems.

The ITG turbulence simulation by means of the GKV-X code, which is extended to incorporate the equilibrium field reconstructed from the LHD experimental data, shows reasonable agreement with the radial profile of the ion heat flux in the LHD experiment [3]. The first validation activity of turbulent transport simulations for the LHD plasma encourages us to promote more detailed analysis of the turbulence and zonal flow interactions.

For a deeper understanding of interactions between the zonal flow and turbulence in helical systems, we have applied the entropy transfer analysis [4] to the GKV simulations of the ITG turbulence in LHD plasmas [5]. The new diagnostic of the simulation results elucidates the turbulence spectrum broadening into a high radial wavenumber region.

The time-averaged entropy transfer function, $\overline{\mathcal{J}}\,[\boldsymbol{p}_\perp\,|\,\boldsymbol{q}_\perp,\boldsymbol{k}_\perp]$, obtained in a saturation phase of the ITG turbulence simulation is shown in Fig. 1 for the inward-shifted (upper) and standard (lower) cases for the LHD plasmas, where the triad interactions of $\boldsymbol{k}_\perp+\boldsymbol{p}_\perp+\boldsymbol{q}_\perp=0$ with the pump mode of $\boldsymbol{p}_\perp\rho_i=(0,0.278)$ is investigated. It is clearly found that the entropy is transferred from the primary ($\boldsymbol{p}_\perp$) to the secondary ($\boldsymbol{q}_\perp$) non-zonal modes through the nonlinear interactions with the zonal flow ($\boldsymbol{k}_\perp$), where each mode is shown by arrows in Fig. 1. The result is consistent with our previous study for the tokamak ITG turbulence case [4]. In the standard LHD model configuration shown in Fig.1 (lower), the magnitude of $\overline{\mathcal{J}}\,[\boldsymbol{p}_\perp\,|\,\boldsymbol{q}_\perp,\boldsymbol{k}_\perp]$ is relatively small due to the weaker zonal flow generation than that in the inward-shifted case (upper). The horizontal striation pattern of $\overline{\mathcal{J}}\,[\boldsymbol{p}_\perp\,|\,\boldsymbol{q}_\perp,\boldsymbol{k}_\perp]$ found in the inward-shifted case is, thus, not clearly recognized in the standard one.

The strong entropy transfer via zonal flows in the inward-shifted case also influences the fluctuation spectrum. Due to the successive interactions with the zonal flow, the entropy of non-zonal components is transferred to the higher radial wavenumber ($k_x$) space [4]. Then,

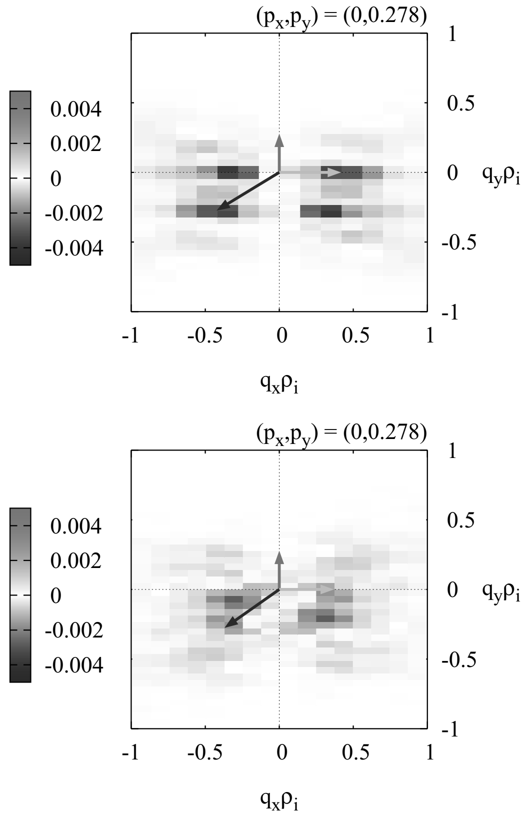


Fig. 1: Entropy transfer function obtained from the gyrokinetic simulations of ion temperature gradient turbulence in the inward-shifted (upper) and standard (lower) configurations of Large Helical Device plasma.

it is expected that an elongated turbulence spectrum is formed with spectral broadening in the radial wavenumber direction. Indeed, it is also clarified that a fluctuation spectrum elongated in the radial wavenumber direction is formed in the neoclassically optimized field configuration with the inward-shifted magnetic axis position, where the zonal flows are more effectively generated than in the standard case. The spectral transfer in the ITG turbulence is associated with the deformation of turbulent eddies by zonal flows, leading to the turbulence regulation and transport reduction.


1) Watanabe T H, Sugama H and Ferrando-Margalet S 2008 *Phys. Rev. Lett.* **100** 195002

2) Watanabe T H, Sugama H and Nunami M. 2011 *Nucl. Fusion* **51** 123003

3) Nunami M, Watanabe T H, Sugama H and Tanaka K 2012 *Phys. Plasmas* **19** 042504

4) Nakata M, Watanabe T H and Sugama H 2012 *Phys. Plasmas* **19** 022303

5) Watanabe T H, Sugama H, Nunami M, Tanaka K and Nakata M, 2012 *Plasma Phys. Control. Fusion* (submitted)