§22. Correlation between Core Heat Flux and Edge Temperature Gradient

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In the paradigm for anomalous transport in toroidal plasmas, it is presumed that the local turbulence led by a local microinstability drives local transport. Recent simulation studies indicate that the turbulence is extended radially by the non-linear effects. Such a mode has a long radial correlation length of $L_r = \sqrt{a_p \lambda}$ ($\sqrt{a_p \lambda}$ is the so-called meso-scale), here a_p and λ are the plasma radius and the individual mode wavelength, respectively. The coupling between the drift turbulence and the zonal flow is recognized as one of the most important players in the turbulence structure formation. The theories predict that the radial correlation length of zonal flow is the order of the meso-scale and a HIBP experiment has identified it. These meso-scale structures will provide the non-local transport mechanism.

In strongly magnetized plasma, the local heat flux correlates strongly with the local temperature gradient in the local transport nature, even if the flux is a non-linear function of the gradient. The non-local mechanism will exhibit a different flux-gradient correlation, and thus the correlation analysis is recognized as a very powerful tool to clarify the non-locality. In experiments, it is difficult to identify the flux-gradient correlation in the transport statics, however, the dynamic transport phenomena can show up time and space relationship of flux to gradient. The non-local transport phenomena have been observed in LHD [S. Inagaki et al., Plasma Phys. Control. Fusion 48 A251 (2006)]. Two-point temporal correlation is obtained by the plasma edge cooling. Two-point temporal correlation, $\mathrm{cor}(\rho_{\mathrm{ref}}, \rho, \tau)$, is defined as

$$\mathrm{cor}(\rho_{\mathrm{ref}}, \rho, \tau) = \frac{\frac{1}{T}\int_0^T f(\rho_{\mathrm{ref}}, t) g(\rho, t+\tau) dt}{\sqrt{\frac{1}{T}\int_0^T (f(\rho_{\mathrm{ref}}, t))^2 dt}\sqrt{\frac{1}{T}\int_0^T (g(\rho, t))^2 dt}}, \quad (1)$$

here δT_e is the electron temperature perturbation, $f(\rho, t) = \delta q_e(\rho, t)/n_e(\rho)$ and $g(\rho, t) = -\nabla \delta T_e(\rho, t)$. The perturbed heat flux, $\delta q_e(\rho, t)$, is estimated from

$$\delta q_e(\rho, t) = -\frac{1}{S(\rho)} \int_0^\rho \frac{3}{2} n_e(\rho) \frac{\partial \delta T_e(\rho, t)}{\partial t} dV, \quad (2)$$

where S is the surface area of the closed flux surface, and V is the volume. Strong correlation, $\mathrm{cor}(\rho_{\mathrm{ref}}, \rho_{\mathrm{ref}}, 0) = 1$, is expected when transport is dominated by Fick's law (i.e. $q_e = -n_e \nabla T_e$). Figure 1 shows a typical two-point temporal correlation between core (ρ_{ref}=0.19) heat flux and gradient. A very weak (≤ 0.4) local flux - local gradient correlation is observed in the core region for a short time lag ($\leq$ 4ms) . On the other hands, the core flux has strong negative correlation with edge ($\rho \sim$0.6) gradient. These features indicate a presence of a non-local transport directory. The strong positive correlation between local flux and local gradient appears in the core region 10-15ms after the TESPEL injection. A slow propagation of strong positive correlation from core to edge is also shown. The core T_e rise is terminated 25ms after the TESPEL injection, thus, the back transition may be related to this slow core-edge interaction.

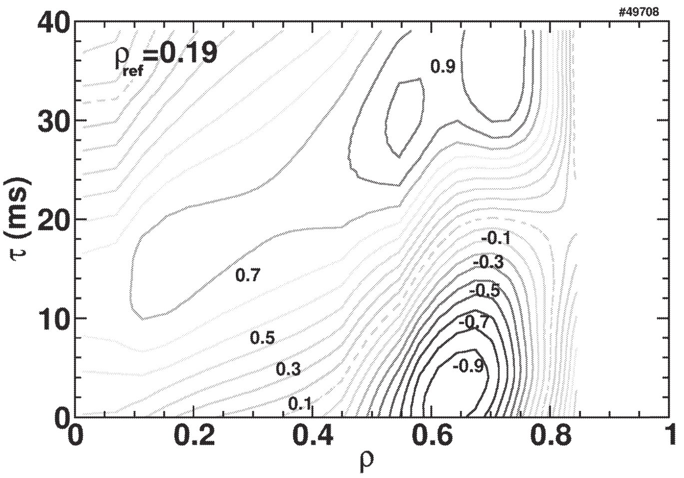

Fig. 1: Typical two point temporal correlation between the heat flux at ρ_{ref}=0.19 and the temperature gradient. Experimental parameters are as follows: a major radius at the magnetic axis of 3.5 m, an averaged minor radius of 0.56 m and a magnetic field at the axis of 2.829 T.