§5. How are Turbulence and Turbulence Transport Determined in Toroidal Plasmas?

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In magnetized toroidal plasmas, it is usually presumed that local turbulence led by a local micro-instability (e.g. drift instability) drives local transport. Thus one often employs the "local diffusive model" to explain steady state profiles and power degradation of global energy confinement. However, many experimental observations have demonstrated violations of local closure of flux and gradient. Then, how are turbulence and turbulence transport are determined in LHD? Recently, long-range T_e fluctuations (2-3 kHz) are discovered in the LHD [1]. Local micro-fluctuations are considered to communicate with those at distant radius via this long-range fluctuation.

In this study, we observed the dynamic response of turbulence because we can observe absolute value of nonlinear force appears in turbulent plasma. We performed a low frequency ECH modulation experiments and observed dynamic response of turbulence and turbulent transport to a ECH modulation [2]. The typical low-density (central density of 1.35×10^{19} m^{-3}) L-mode NBI plasmas are chosen as targets. Periodic change of mean variables are excited by central (normalized minor radius $\rho \sim 0.2$) ECH power modulation at 25 Hz while the modulation of line-averaged density is less than 1%. A power spectrum of density fluctuation at $\rho \sim 0.63$ measured with an O-mode reflectometer (31 GHz) has some peaks in a few kHz region as well as broadband high frequency (>20kHz) components. The amplitudes of these coherent (1-20 kHz) and incoherent (20-80 kHz) density fluctuations are modulated owing to the ECH modulation. The small changes in the amplitudes of density fluctuations (relative change of 5-10 %) are precisely extracted by conditional averaging technique. In this technique, timings of ECH-turn-off, $\tau_{\rm off}$, are detected in each period and signals of interest are averaged. Figure 1 shows conditional-averaged time evolution of the global heat wave (T_e and T_e-gradient measured with a 28-channel radiometer) and amplitudes of micro-fluctuations. The time scales of growth of fluctuations (> 1 kHz) are considered to be much shorter (< 1 ms) than characteristic time of the global heat wave (40 ms). However, amplitudes of the micro-fluctuations vary with the same frequency of the global heat wave but in a different way compared to T_e and T_e-gradient as shown in Figs. 1(d) and (e). This fact suggests that the turbulence is not proportional to the local T_e-gradient. Figure 2 demonstrates the non-linear response (hysteresis) of fluctuation amplitudes to local T_e-gradient. The change of heat flux has also hysteresis characteristics, and this indicates the violation of Fick's law. The existence of hidden parameters and long-distance correlation of turbulence may be possible candidates of observed hysteresis. Recently, the direct influence of heating on turbulent transport is possible theoretically through giving an immediate influence to phase space structure. This direct effect is more effective for long-range modes [3]. Thus, It is a conjecture here that the on-off of heating power at center immediately influences the long range modes which couples with microscopic fluctuations at far distance.

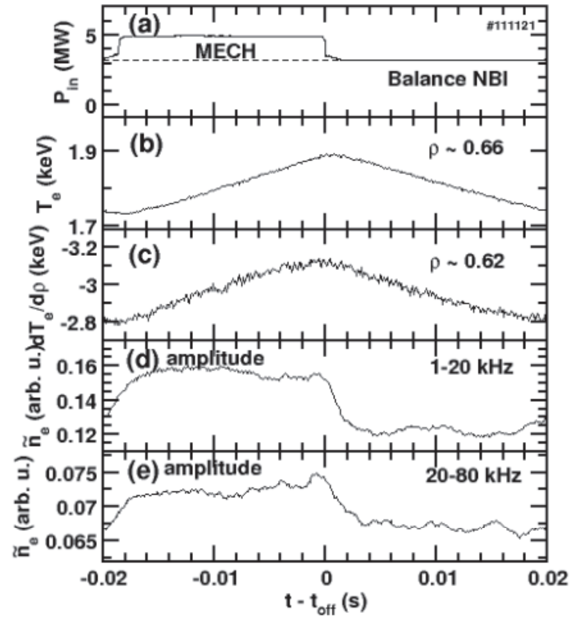

Fig. 1. Conditional-averaged time evolutions of (a) input power, (b) T_e, (c) T_e-gradient, density fluctuation amplitudes in the frequency range of 1-20 kHz (d) and 20-80 kHz (e). Time window to calculate the fluctuation amplitude is 2 ms. The 35 realizations are averaged.

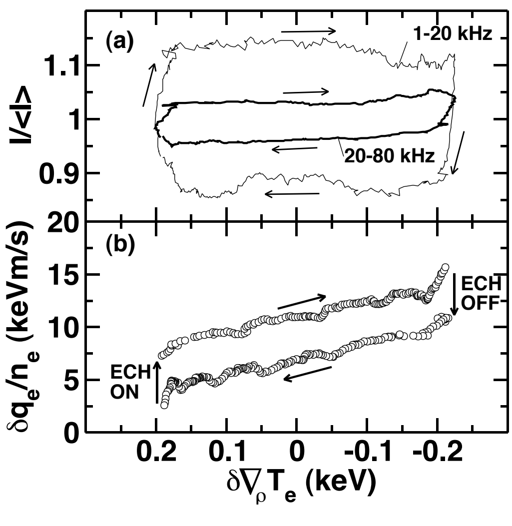

Fig. 2. Non-linear T_e gradient dependence of micro-fluctuation amplitudes and heat flux. (a) Lissajous diagram of the conditional-averaged T_e gradient and fluctuation amplitudes in the frequency range of 1-20kHz and 20-80 kHz and (b) gradient-flux relation. Arrows denote the direction of variation.

[1] S. Inagaki et. al., Phys. Rev. Lett. **107**, 115001 (2011)
[2] S. Inagaki, et. al., Submitted to Phys. Rev. Lett.
[3] S.-I. Itoh, K. Itoh, Sci. Rep. **2,** 860 (2012)