

## §7. Density Profile and Microturbulence in LHD

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Understanding physical mechanisms for the determination of electron density profiles is one of the essential issues for the control of a future fusion reactor. The neoclassical mechanism, driven by collisions of confined particles, is too weak to be responsible for observed density profiles in tokmaks and helical devices in many experimental observations. In LHD, neoclassical transport was found to play a role for core particle convection at  $R_{ax} > 3.6m$ , where  $R_{ax}$  is the magnetic axis position, while anomalous effects seem to play a significant role for core diffusion at  $R_{ax} \leq 3.6m$  [1]. Thus, turbulence effects for particle transport are important in LHD. However, the role of turbulence in formation of the density profiles is not clear experimentally because turbulence measurements in the plasma core have been very limited. In order to investigate the effects of turbulence driven particle transport, plasma density fluctuations in spectral range  $f=20-500kHz$ ,  $k=0.1-1mm^{-1}$  (poloidally dominated) were measured by 2D-Phase Contrast Imaging[2]. Linear and quasi-linear characteristics of turbulence and turbulence driven particle transport were studied by using gyrokinetic code GS2 [3].

Figure 1 shows  $T_e$ ,  $T_i$ ,  $n_e$ , fluctuation phase velocity and fluctuation amplitude profiles of  $R_{ax}=3.5m$  and  $R_{ax}=3.6m$ . Heating is 10MW NBI for both cases. Figures b-1 and b-2 show [1] peaked and hollowed density profiles at  $R_{ax}=3.5m$  and  $R_{ax}=3.6m$  respectively. Neoclassical transport is similar at  $\rho=0.4-0.7$  because of almost identical effective helical ripples, thus, the  $n_e$  profile difference is due to the effect of anomalous transport [1]. As shown in Fig.1 (d-1) and (d-2), peaks of fluctuation amplitude are visible at  $\rho \sim 0.7$  and  $\rho \sim 1.0$  at both configurations. The clear difference between turbulence characteristics for these configurations is propagation direction of the component having peaks around  $\rho \sim 0.7$  as shown in Fig.1 (c-1),(c-2). It propagates to the electron and ion diamagnetic directions in the laboratory frame at  $R_{ax}=3.5m$  and  $R_{ax}=3.6m$  respectively. The measured poloidal  $E_r \times B_t$  velocity by CXS at closest to  $\rho=0.7$  location is near to zero, thus, the measured propagation direction can be related to the plasma frame as well. This suggests that turbulence at  $R_{ax}=3.5m$  and  $3.6m$  are Trapped Electron Mode (TEM) and Ion Temperature gradient mode (ITG) respectively. Figure 2 (a) shows growth rate ( $\gamma$ ) and real frequency ( $\omega_r$ ) calculated by GS2. As shown in Fig.2 (a), the growth rate is clearly higher at  $R_{ax}=3.5m$ . This may correspond to higher contribution of anomalous particle transport at  $R_{ax}=3.5m$  [1]. The real frequency is the ion diamagnetic one in both cases. However,  $\omega_r$  at  $R_{ax}=3.5m$  is closer to zero indicating the increase of TEM contribution. This qualitatively agrees with measurements, which suggests that turbulence is dominated by TEM at  $R_{ax}=3.5m$ .

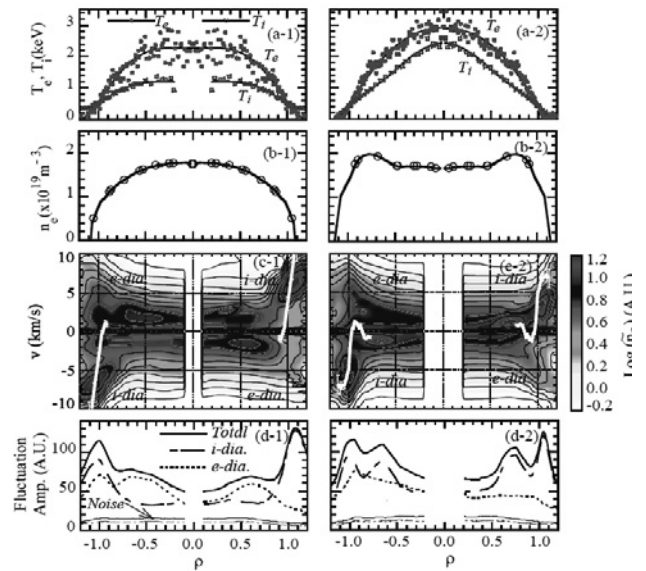


Fig.1 Profiles of (1)  $T_e$ ,  $T_i$ , (2)  $n_e$ , (3) phase velocity, and (4) fluctuation amplitude. Contours of (4) are  $\text{Log}(\text{amplitude})$ .  $E_r \times B_t$  rotation velocities are plotted by the white line in (4) (a-1,b-1,c-1)  $R_{ax}=3.5m$ ,  $B_t=2.8T$ , (a-2,b-2,c-2)  $R_{ax}=3.6m$ ,  $B_t=2.75T$

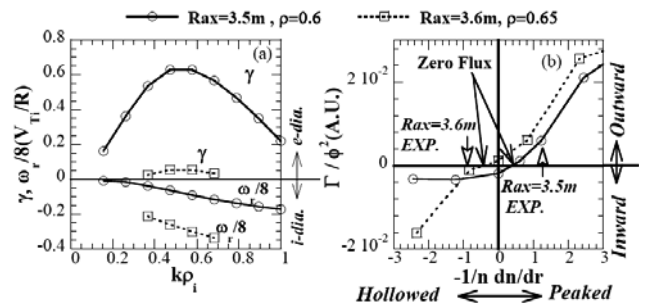


Fig.2 (a) Growth rate and real frequency, (b) Density gradient dependence of quasi linear particle flux.

Figure 2 (b) shows density gradient dependence of quasi-linear particle flux. Calculations were done at  $\rho=0.6$  and  $\rho=0.65$  for  $R_{ax}=3.5$  and  $R_{ax}=3.6m$  respectively, where particle source is negligible and density gradient is opposite at both configuration. In the steady state of core region, where particle source is close to zero ( $\rho < \sim 0.9$ ), particle flux should be zero. Plasma parameters such as  $T_e$ ,  $T_i$  gradients,  $T_e/T_i$ , and collisionality were kept constant in calculations while experimental values and normalized density gradients were scanned to search zero flux condition. As shown in Fig.2(b), the normalized density gradient, which determines zero flux condition of both experiment and gyrokinetic predictions, is positive at  $R_{ax}=3.5m$  and negative at  $R_{ax}=3.6m$ . This shows that gyrokinetic prediction qualitatively agrees with the experimental observation. The remaining discrepancy may be due to contribution of the neoclassical particle flux and NBI particle deposition.

- 1) Tanaka, K., et al., Fusion Sci., Tech, 70 (2010)
- 2) Tanaka, K., et al., Rev. Sci. Instrum. 79, 10E702 (2008)
- 3) Dorland, W., et al., Phys. Rev. Lett. 85, 5579 (2000)