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# Comparison study between micro turbulence measured by two dimensional phase contrast imaging and gyro kinetic simulation in LHD

# LHDにおける二次元位相コントラストイメージングにより計測した乱流揺動とジャイロ運動論シミュレーションの比較

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Micro turbulence of ion temperature gradient mode (ITG) and trapped electron mode (TEM) regime were measured by two dimensional phase contrast imaging (2D-PCI) in Large Helical Device (LHD). Its characteristics at ρ=0.4-0.7 were compared with experimentally measured density profile and linear and quasi linear gyro-kinetic calculation by GS2 code. The measured fluctuation is likely to be dominated by TEM in the peaked density profile, while it is dominated by ITG in the hollowed density profile. GS2 showed ITG dominant for both case, however, larger contribution of TEM was found in the peaked density profile. Zero flux condition agreed qualitatively between experiment and simulation.

## 1. Introduction

Control of density profiles is one of the important issues for future reactor operation in order to optimize fusion output power and stabilize magnetohydrodynamic instability and microinstabilities. Therefore, it is of utmost importance to understand the mechanisms governing particle transport. In this paper, the physical mechanisms of two clear different density profiles of LHD are investigated. One is peaked density profile, which was obtained at $R_{ax}$=3.5m, the other is hollowed density profile at $R_{ax}$=3.6m. Here, $R_{ax}$ is the magnetic axis position. Since, the neoclassical properties are almost comparable at both $R_{ax}$, the difference of the density profile can be caused by the difference of the anomalous behavior[1]. For this study, two approaches are tried. One is fluctuation measurements by using 2D-PCI [2].. The other is gyrokinetic linear and quasi-linear calculation by using GS2 code [3]. Linear stability and dependence of particle flux on density gradient were studied around experimentally achieved density gradient.

## 2. Experimental Results

Figure 1 shows radial profiles of $T_e$, $T_i$ , $n_e$, fluctuation phase velocity and their amplitudes at $R_{ax}$=3.5 and 3.6m. The heating power was kept almost the same, namely powers for $R_{ax}$=3.5 and 3.6 m were 8.1 and 7.4 MW, respectively. Even though heating powers were almost the same, the resulting profiles were quite different. As shown in Fig. 1 (a-1), (a-2), (b-1), and (b-2), the achieved $T_e$ and $T_i$ were higher at $R_{ax}$=3.6 m than at $R_{ax}$=3.5 m, and density profiles were peaked at $R_{ax}$=3.5 m and hollowed at $R_{ax}$=3.6 m.

In Fig. 1 (c-1) and (c-2), spatial profiles of phase velocity are shown. Since measured wavenumbers were dominated by poloidal components, propagations in ion and electron diamagnetic directions in the Lab. frame can be identified. In Fig. 1 (d-1) and (d-2), fluctuation amplitudes integrated over k are shown.

As shown in Fig.1 (c-1,2) and (d-1,2), two peaks are visible with one being at around |ρ| = 0.4-0.7, and the other at around |ρ| =1.0. The former propagates to e-dia. direction at $R_{ax}$=3.5m and to i-dia. direction at $R_{ax}$=3.6m. The plasma poloidal rotation measured by CXRS at closest point is near zero, thus, the progation direction measured by PCI is likely to be same as in the plasma frame. The e-dia. propagating components at $R_{ax}$=3.5m can be indication of TEM, while i-dia. propagating components at $R_{ax}$=3.6m can be attributed to ITG. The fluctuation around $|\rho|$ = 0.4-0.7 would take an important effect on the different density profile.

## 3. Comparison with gyrokinetic calculation

Figure 2 (a) shows growth rate ($\gamma$) and real frequency ($\omega_r$ ) of peaked density profile and for hollowed density profile. The calculation is done for the electrostatic fluctuation with nonadiabatic electrons and finite collisionality. Calculated location is $\rho$=0.6 for peaked density profile and $\rho$=0.65 for hollowed density profile. The normalized density gradient ($-1/n_e$ $dn_e/dr$) is positive for $R_{ax}$=3.5m and negative for $R_{ax}$=3.6m at these locations. The calculations were done for $k\rho_i$=0.1~1, where k is poloidal wavenumber and $\rho_i$ is ion Larmor radius. As shown in Fig.2 (a), $\gamma$ was clearly higher at $R_{ax}$=3.5m (peaked density profile) than at $R_{ax}$=3.6m (hollowed density profile). In latter case, only limited region with $k\rho_i$=0.37-0.68 was unstable. The real frequency is both i-dia.

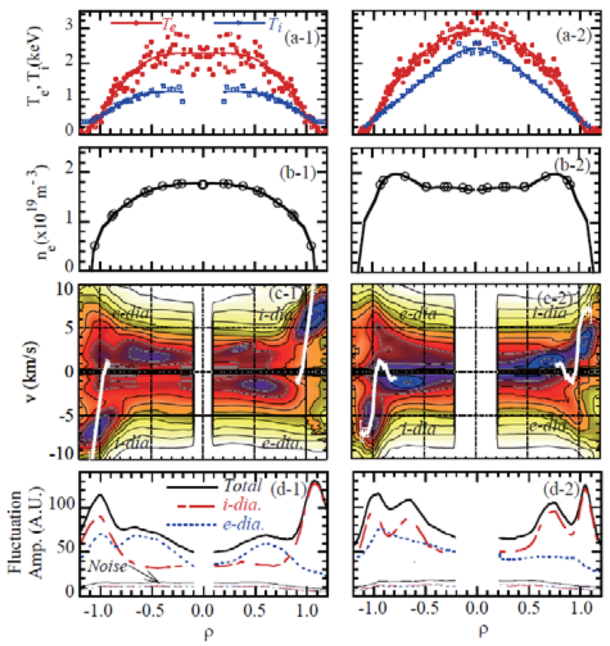


Fig.1 Comparison of $n_e$, $T_e$, $T_i$ , fluctuation profiles and spectra for $R_{ax}$=3.5 m (a-1)-(c-1) and 3.6 m (a-2)-(c-2). (a-1) and (a-2) are $T_e$ and $T_i$ profiles, (b-1) and (b-2) are $n_e$ profiles, (c-1) and (c-2) are phase velocity profile. In (c-1) and (c-2), poloidal rotation velocity measured by CXRS are shown by white line. and (d-1) and (d-2) are profiles of fluctuation amplitudes profiles In (d-1) and (d-2), noise levels are shown by thin lines .

directed for both cases, however, $\omega_r$ is smaller at peaked density profile indicating larger contribution of TEM. Figure.1 suggests that dominat turbulence mode is TEM at $R_{ax}$=3.5 and ITG at $R_{ax}$=3.6. This qualitatively agrees with gyro kinetic calculation.

The particle source is localized at the very edge region. The Monte Carlo simulation of neutral penetration showed the peak of the particle source rate was outside of the last closed flux surface [1]. Thus, the particle balance in the steady state condition results in the zero particle flux in the source free core region, which is likely to be inside of $\rho$=0.9. The calculation was linear, therefore, saturated fluctuation level cannot be estimated. However, linear calculation with nonadiabatic electrons can estimate phase difference between density and potential, then, direction of the particle flux can be known. If the target fluctuations, which are calculated by GS2, determine the particle transport in source free region, estimated flux by GS2 should be zero. In order to determine zero particle flux condition, the quasi linear particle fluxes are estimated scanning normalized density gradient around experimental value. As shown in Fig.2 (b), particle flux is directed outward at lower normalized density gradient and inward at higher normalized density gradient. Zero flux is obtained in the negative gradient at Rax=3.6m, and positive gradient at Rax=3.5m. The signs of the gradient agree between experiments and simulation, although there are quantitative differences.

## References


[1] K. Tanaka et al., : Fusion Sci. Tech. (2010)

[2] K.Tanaka, C. A. Michael, L. N. Vyacheslavov et al., : *Rev. Sci. Instrum.*, **79**, 10E702 (2008)

[3] http://sourceforge.net/apps/mediawiki/gyrokinetics/


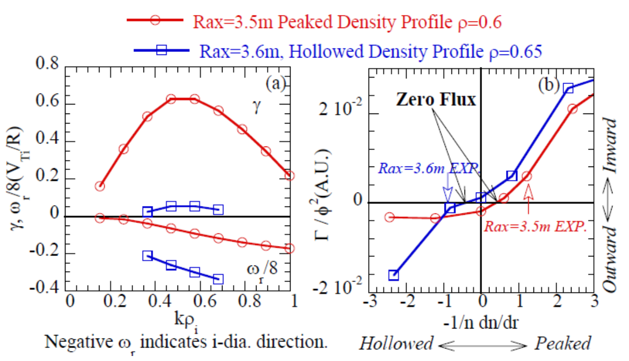


Fig.2 Comparison of gyrokinetic calculation (a) growth rate and real frequency and (b) density gradient dependence of quasi-linear particle flux. $k\rho_i$=0.5