Investigation of cross-scale interaction between high-k and low-k turbulence in Large Helical Device (LHD)

T. Nasu[1], T. Tokuzawa[1,2,3], M. Nakata[4], S. Maeyama[2], Y. Nagashima[3], K. Ida[2], S. Inagaki[5], M. Nishiura[2,6], Y. Yoshimura[7], R. Yanai[2], S. Satake[2], M. Yoshinuma[2], K. Tanaka[2,3], T. Kobayashi[1,2,3], A. Ejiri[6], K.Y. Watanabe[2,8], I. Yamada[2], D. Nishimura[2], and LHD Experiment Group

[1] *The Graduate University of Advanced Studies, Department of Fusion Science, Toki, Japan*
[2] *National Institutes of Natural Sciences, National Institute for Fusion Science, Toki, Japan*
[3] *Kyusyu University, Research Institute for Applied Mechanics, Kasuga, Japan*
[4] *Komazawa University, Faculty of Arts and Sciences, Tokyo, Japan*
[5] *Kyoto University, Institute of Advanced Energy, Uji, Japan*
[6] *The University of Tokyo, Graduate School of Frontier Sciences, Kashiwa, Japan*
[7] *National Institute for Quantum Science and Technology, Naka, Japan*
[8] *Nagoya University, Department of Energy Engineering and Science, Nagoya, Japan*

We investigated high-k and low-k turbulence intensity dependence on T_e/T_i by scanning ECH power and compared with the linear local gyrokinetic Vlasov simulation result. Both of their intensities increase with increasing T_e/T_i although their trends are different. The low-k turbulence can be explained by the simulation, but the high-k turbulence is similar with mid-k trend of the simulation rather than high-k.

Introduction

Micro-scale turbulences, around Larmour radius scale, in fusion plasma has significant influence on their confinement. Some simulation studies reveal cross-scale interaction within micro-scale turbulence also modify expected turbulence transport significantly. [1,2] Cross-scale interaction have hardly been investigated experimentally, even difference between turbulences of high wavenumber (high-k, ~ electron Larmour radius scale) and low wavenumber (low-k, ~ ion Larmour radius scale). The motivation of this research is to investigate cross-scale interaction between high-k and low-k turbulence.

Methodology/Experimental Setup

Main approaches and methods are following:

1. To investigate the difference of the dependence on temperature ratio T_e/T_i between electron-scale and ion-scale turbulence, we scanned electron temeperature T_e by ECH Power scan while keeping ion temperature T_i constant.
2. For co-located simultaneous measurement of low-k and high-k turbulences, we used Doppler backscattering system (DBS) [3] and millimeter wave backscattering system (BS) [4] dedicated measurement for the low-k and high-k turbulent fluctuation,

respectively. They enable such a high resolution of wave numbers based on Bragg reflection or scattering. Their scattered wave amplitudes $I_{\mathrm{amp,low-k}}$ and $I_{\mathrm{amp,high-k}}$ are proportional to electron density fluctuation amplitude of certain scales $|\delta n_{\mathrm{e,low-k}}|$ and $|\delta n_{\mathrm{e,high-k}}|$, respectively, which are signals indicative of turbulence intensities of their scales. Our DBS can observe multiple radial positions while our BS has the steerable receiving antenna controlling radial observation position. The antenna angle was scanned shot by shot to achieve co-located measurement.

As a result of these methods, the co-located measurement of DBS and BS were achieved at edge region $r_{\mathrm{eff}}/a_{99} \sim 0.9$ with the different wavenumbers: $k_{\perp}\rho_{\mathrm{ti}} \sim 0.2$ and $k_{\perp}\rho_{\mathrm{ti}} \sim 3$, where r_{eff}, a_{99}, $k_{\perp}$, and ρ_{ti} stand for effective minor radius, the minor radius at which 99 % of plasma kinetic energy stored, perpendicular wave number to toroidal direction, and ion thermal gyro radius, respectively. Note that since DBS observation position depends on electron density n_{e} profile, line averaged electron density $\overline{n_{\mathrm{e}}}$ was kept constant by gas puff feedback control throughout the discharge to fix the observation position. The realized discharge summaries are shown in Fig.1. The T_{e} increases while keeping n_{e} and T_{i} constant, even at the observation position. Since the electron temperature gradient $\partial T_{\mathrm{e}}/\partial r_{\mathrm{eff}}$ also increases at the similar rate as T_{e}, the scale length of electron temperature $L_{T_{\mathrm{e}}}^{-1} \equiv \partial T_{\mathrm{e}}/\partial r_{\mathrm{eff}}/T_{\mathrm{e}}$ is hardly changed. We attained $T_{\mathrm{e}}/T_{\mathrm{i}}$ scan from 1.3 – 2.3, consequently.

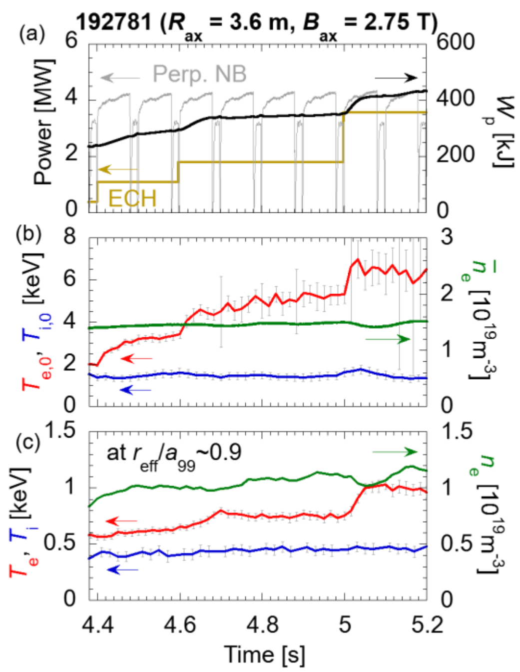

Fig.1 Time traces of (a) heating power of ECH (yellow) and NBI (grey) with plasma stored kinetic energy W_{p} (black), (b) core electron temperature (red), core ion temperature (blue), and line averaged electron density (green), and (c) edge electron temperature (red), edge ion temperature (blue), and edge electron density (green)

After the experiment, we calculated linear growth rates and real frequencies by linear local gyrokinetic Vlasov simulation using the GKV code.[5]

Results and Discussion

The observed turbulence intensities are shown in Fig.2. Here, we can sometimes see abrupt increase and subsequent decay in both intensities right after ECH power step-up. This phenomenon may be caused by velocity space distortion because the slowing down time of fast electron ~ 100 keV by ECH is ~ 70 ms. We cut 70 ms after the ECH power step-up to exclude this effect. Both of $I_{\mathrm{amp,low-k}}$ and $I_{\mathrm{amp,high-k}}$ increases with time. Additionary, the trends of their turbulences are different.

The turbulence Intensities were compared with T_e/T_i in Fig.3. Both of $I_{\mathrm{amp,low-k}}$ and $I_{\mathrm{amp,high-k}}$ increases with T_e/T_i increasing and have different trends with T_e/T_i. $I_{\mathrm{amp,high-k}}$ increases more faster than $I_{\mathrm{amp,low-k}}$ but has threshold at T_e/T_i ~ 0.8.

As shown in Fig.4, the dependence of low-k, $k_y \rho_{ti} \sim 0.2$, linear growth rate is comparable with the experimental result, where k_y stands for wave number parallel to

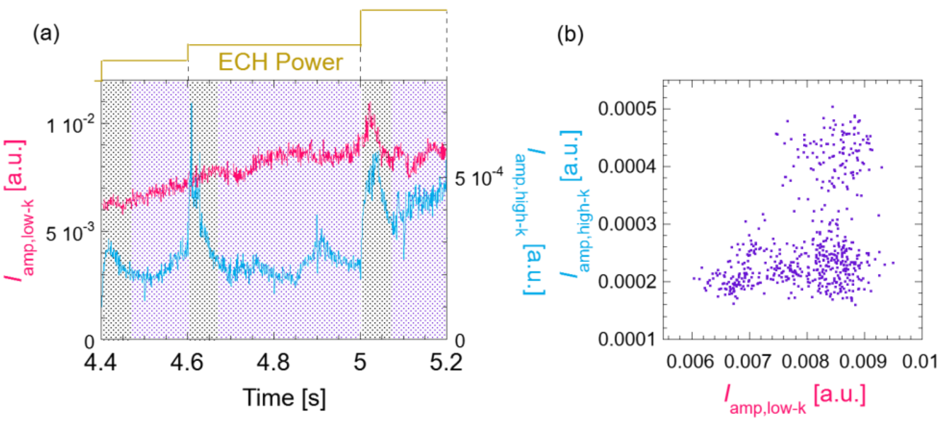

Fig.2 Turbulence intensities of low-k ($I_{\mathrm{amp,low\text{-}k}}$) and high-k ($I_{\mathrm{amp,high\text{-}k}}$) shown as (a) time traces and (b) scatter plots cut 70 ms after ECH step-up to exclude velocity space distortion effect

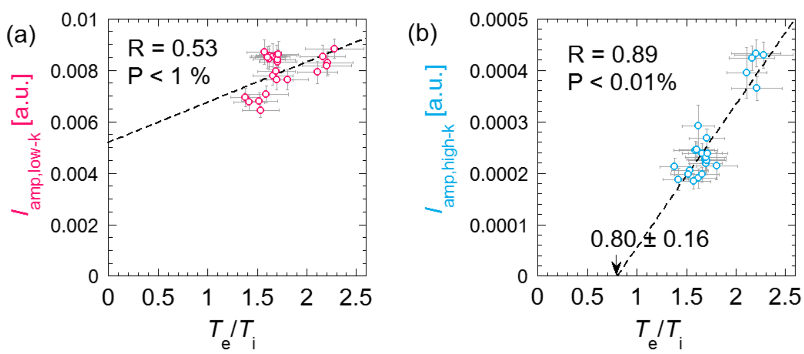

Fig.3 Dependences on T_e/T_i of (a) low-k turbulence intensity ($I_{\mathrm{amp,low\text{-}k}}$) and (b) high-k turbulence intensity ($I_{\mathrm{amp,high\text{-}k}}$). R and P stand for correlation coefficient and p-value of t-test for correlation, respectively. Black dotted lines are linear regression lines.

magnetic surface and perpendicular to field line. However, the dependence of high-k, $k_y\rho_{ti} \sim 3$ is totally different with the experimental result. Rather than high-k, the dependence of mid-k, $k_y\rho_{ti} \sim 0.5$, is similar to the experimental high-k result. The observed high-k turbulence is mainly affected by mid-k instability. We will discuss mode identification in the poster session.

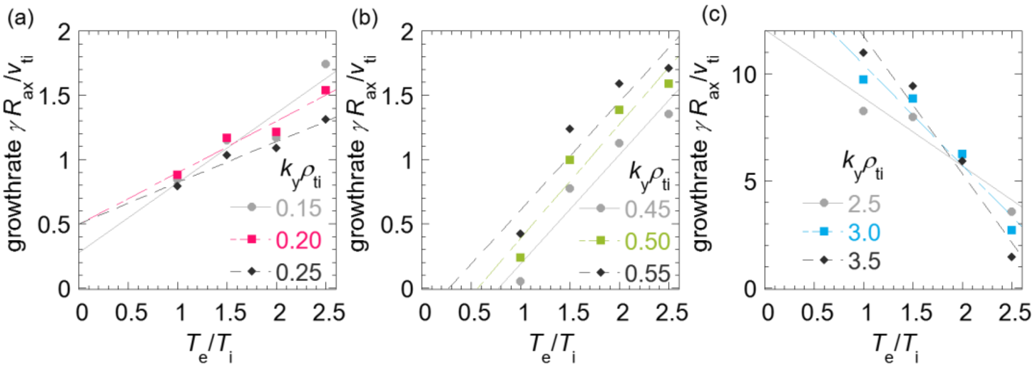

Fig.4 Linear growth rate dependences on T_e/T_i
around (a) $k_y\rho_{ti} \sim 0.2$, (b) $k_y\rho_{ti} \sim 0.5$, and (c) $k_y\rho_{ti} \sim 3$

Conclusion

Low-k, $k_\perp\rho_{ti} \sim 0.2$, and high-k, $k_\perp\rho_{ti} \sim 3$, turbulence dependence on T_e/T_i from 1.3 – 2.3 were observed at edge region, $r_{eff}/a_{99} \sim 0.9$, by scanning ECH power. Both of their intensities increase with increasing T_e/T_i but the trends are different each other. Low-k turbulence dependence is identical to the simulated low-k growth rate dependence, but high-k turbulence dependence is similar with the mid-k, $k_\perp\rho_{ti} \sim 0.5$, growth rate dependence rather than high-k growth rate dependence. These results suggest the necessity of taking nonlinear or non-local phenomena into account for micro-scale turbulence nature.

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