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Investigation of turbulence transition and its threshold in LHD

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Ion-scale turbulences play a key role in transport processes in magnetically confined plasmas. In tokamaks, trapped electron mode (TEM) and ion temperature gradient mode (ITG), have been reported to realize different confinement properties such as linear-ohmic confinement and saturated-ohmic confinement, respectively[1]. Therefore, it is important to understand turbulence mode to improve plasma confinement.

In order to investigate a comprehensive nature of ion-scale turbulence in the Large Helical Device (LHD), firstly, the systematic density scan experiments in hydrogen (H) and deuterium(D) plasmas were conducted. Figure 1 (a) and (b) show the line-averaged electron density dependence of ion-scale turbulence level $\tilde{n}_e/n_e$(i.e., the local turbulence amplitude normalized by the local electron density) and its phase velocity on a plasma frame V_{turb} (i.e., subtract $E \times B$ poloidal rotation velocity from phase velocity in the laboratory frame). In this study, the transition density n_{tr} is defined to be the density when the turbulence level become a minimum, as indicated by the dashed lines in Fig. 1. The transition densities in the H and D plasmas are $\sim 1.6 \times 10^{19} \mathrm{m}^{-3}$ and $\sim 2.6 \times 10^{19} \mathrm{m}^{-3}$, respectively. In terms of isotope effects, there are negligible and clear isotope effects in low-density $(\bar{n}_e < n_{tr})$ and high-density $(\bar{n}_e > n_{tr})$ regimes, respectively. Simultaneously, as shown in Fig. 1(b), the turbulence in the low- and high-density regime propagates to the ion-diamagnetic (i-dia) and the electron-diamagnetic (e-dia) direction. As mentioned above, the opposite density dependences, different isotope effects and propagation direction indicate different turbulence modes were excited in each density regime. To identify turbulence modes, the dependence of measured turbulence on plasma parameters and the density dependence of the linear growth rate evaluated in two-types of simulations were investigated. As a result, it was found that the turbulence propagating in the i-dia direction in the low-density regime is ITG, and in the e-dia direction in the high-density regime is resistive interchange (RI) turbulence.

Secondly, a transition threshold between ITG and RI turbulences has been evaluated. This is because the transition threshold is essential information not only for knowing the current turbulence mode, but also for conducting experiments with suppressed anomalous transport. As shown in Fig.1 (a), the higher transition density in the D plasma indicates the turbulence transition cannot be detected with only electron density. Figure 1(c) shows the density dependence of the normalized density gradient, which shows a similar trend to that of the turbulence level, indicating that it contributes to turbulence destabilization regardless of ITG or RI turbulence. On the other hand, Fig. 1(d) shows the density dependence of the ion-electron temperature ratio, which shows different dependence on the turbulence level in the low-density ITG and high-density RI regimes, respectively. That is, the turbulence transitions are described by a complex combination of plasma parameters, including ion masses.

In this presentation, turbulent transitions in LHD will be introduced including identification studies and their thresholds will be discussed.

[1] J. Rice et al., Nuclear Fusion 60, 105001 (2020).

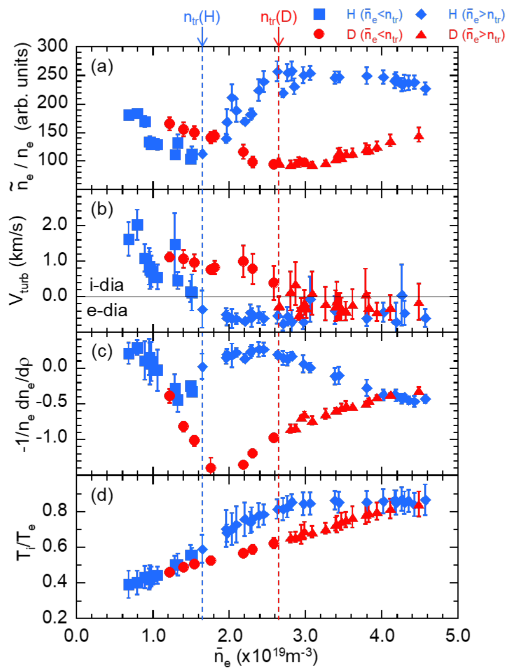

Figure 1 Line-averaged electron density dependence of (a) the ion-scale turbulence level, (b) phase velocity in the plasma frame, (c) normalized density gradient and (d) ion-electron temperature ratio. These values are averaged values at normalized radii $\rho = 0.5 - 0.7$.