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Isotope Effects on Nonlinear Turbulence System in a Torus Plasma

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Confinement improvement in deuterium(D) plasmas has been widely accepted as "isotope effect", nevertheless, it has been a long-standing mystery for decades in the study of fusion plasmas. The isotope effect contradicts a fundamental model of transport because an increase of characteristic scale (ion Larmor radius or turbulence scale size here) simply gives the increase of transport. The D plasmas should have, in other words, a degraded performance compared with the hydrogen(H) plasmas, incompatible with the experimental observations. A couple of theoretical works explain the mechanism of isotope effect, which is attributed to isotope dependence of turbulence system including a zonal flow activity [1,2]. Some experimental works, including our work, also report the dependence of long-range correlation, —as an indication of zonal flow activity —, exists against the H/D isotope ratio [3-6]. However, turbulence responses behind the isotope dependence of zonal flow have not yet been studied so far. In this study, we exhibit experimental evidence of the isotope effect on a nonlinear turbulence system, and it includes not only the zonal flow activity but also turbulence responses and nonlinear interaction between the turbulence and the zonal flow.

In this study, dependences of turbulence and zonal flow activity against H/D isotope ratios were characterized. The experiment was conducted in a medium-sized helical device, Heliotron J with a/R = 0.17/1.2 m and B = 1.25 T on the axis. The plasma was produced with 70 GHz ECH and the plasma density was kept low at ~ 0.2 x 10^{18}m^{-3} with good reproducibility within the error < 5% in the series experiment. Two Langmuir probes, located at different toroidal sections, were used by fixing them at the same flux surface of r/a ~ 0.8 to measure the local turbulence and zonal flow. A spectrometer with a visible light range was utilized to monitor an H/D gas ratio. The isotope mass ratio HD ratio defined as = $n_H/(n_D+n_H)$ was carefully controlled from ~0.1 (D dominant) to ~ 0.8 (H dominant), and the isotope dependence of the turbulence was examined.

The enhancement of the zonal flow activity manifests as the D gas becoming dominant in the series of discharges. The toroidal long-range correlation and zonal-flow amplitude in the frequency range of < 4 kHz are plotted as a function of the HD ratio in Figure 1. The inset figures on the right have the same information as the three-dimensional figure but from different viewpoints. These figures show that the toroidal correlation and the zonal flow amplitude increase in proportion to the fraction of the D gas content. As the H gas becomes dominant, both toroidal correlation and ZF amplitude decrease. Note that no confinement degradation was observed, and the stored energy remains

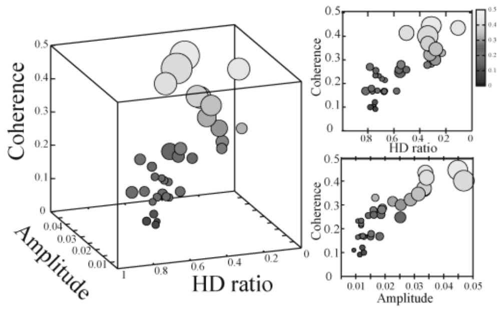

Fig.1 Isotope dependence of zonal flow activity. Amplitude and coherence (long range correlation) are plotted as a function of the H/D ratio. The plot size/color are proportional to the values of amplitude/coherence. The ratio was varied from ~ 0.1 (D dominant) to ~0.8 (H dominant). The inset figures on the right contain the same information as the three-dimensional figure but from different perspectives.

at almost the same level even in the D plasmas of Heliotron J, which is inconsistent with the Gyro-Bohm scaling.

The isotope dependence of turbulence properties was assessed. It is found that density and potential fluctuation level and the correlation between them decreases as H gas dominates. The suppression of turbulence and decoupling between density and potential fluctuations would contribute to the reduction of turbulence-induced transport and would have a favorable effect on confinement in D plasmas, although turbulence scale size with the increase of ion mass.

The turbulence response against isotope ratio discussed in the previous paragraph is attributed to the enhancement of zonal flow in D plasmas, Indeed, enhanced nonlinear interaction between the zonal flow and the turbulence is evident in D-dominant discharges in bicoherence. A clear increase in nonlinear coupling is observed in the frequency range below 4 kHz. The enhancement of nonlinear coupling plays a role in the confinement improvement of D plasmas owing to the contribution of the suppression and decoupling between the density and potential fluctuations turbulence in D plasmas.

References

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