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JT-60U におけるトロイダル回転方向に関連した熱輸送変化の物理機構

Mechanisms of changes in heat transport due to toroidal rotation direction in JT-60U

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Toroidal rotation is the key to improve the energy confinement in tokamak plasmas. In JT-60U, it has been reported that the higher confinement performance is observed with the steeper electron temperature gradient of the internal transport barrier when rotation is in a co-direction with respect to the plasma current than when rotation is in a counter- (ctr-) direction. The discharge in question was operated with the plasma current $I_\mathrm{p} = 0.9$ MA and the toroidal magnetic field $B_\mathrm{T} = 1.6$ T, and during the discharge, the impurity density increases as rotation varies from co- to ctr-direction. The previous study using the gyrokinetic flux-tube code GS2 has shown that the impurity density causes a change in the real frequency ω of the fastest growing mode; the mode tends to be more TEM-like with the increase in the impurity density [1]. The study has also shown that the effects of the rotation shear on the linear growth rate γ are not significant, but the study has not taken into account the rotation direction. This paper focuses on the influence of the rotation direction on heat transport with the gyrokinetic flux-tube code GKW, which includes the effect of a rigid body toroidal rotation, unlike GS2.

This study uses the parameters of the experiment mentioned above: at the normalized minor radius $\rho = 0.45$, the normalized gradients of the electron density, the electron temperature, and the ion temperature are $1/L_{n_\mathrm{e}} = 1.6$, $1/L_{T_\mathrm{e}} = 3.4$, and $1/L_{T_\mathrm{i}} = 2.4$, respectively, the safety factor is $q = 1.3$, the magnetic shear is $s = 0.71$, and the effective ion charge is $Z_\mathrm{eff} = 3.0$. The linear calculations using GKW and GS2 including the effects of collisionality and finite β show that the fastest growing mode is the ITG/TEM hybrid mode, and that the linear growth rate γ has the maximum around the wavenumber $k_\theta \rho_\mathrm{s} \sim 0.6$ (see Fig. 1(a)). In addition, the dependence of γ on the toroidal angular frequency $\Omega = \langle v_\phi / R \rangle$ and on its gradient $\Omega' = -\mathrm{d}\Omega/\mathrm{d}\rho$ is investigated in the manner of [2]. As shown in Fig. 1(b), at $\Omega' = 0$, an increase in the absolute value of Ω suppresses γ due to the Coriolis drift and the equilibrium electrostatic potential affected by toroidal rotation. On the other hand, when a finite Ω' is given, the change in the rotation direction can affect γ, since the value of Ω at which γ has the maximum shifts from zero. The qualitative change in γ agrees with [2], although the experimental values of Ω and Ω', $\Omega_\mathrm{exp} = 1.01 \times 10^4$ s^{-1} and $\Omega'_\mathrm{exp} = -1.12 \times 10^4$ s^{-1}, have little effects on γ. In this paper, the influence of Ω and Ω' on the nonlinear heat flux will also be presented.

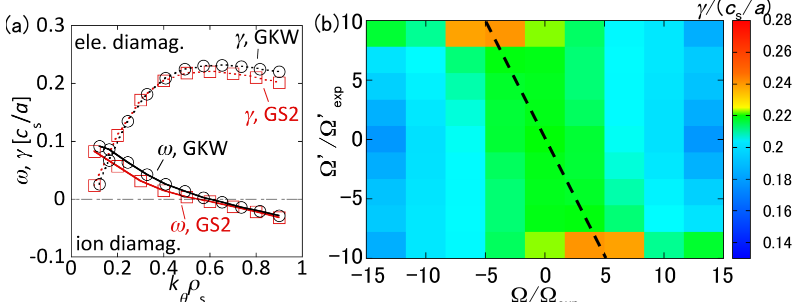

Fig. 1 (a) Real frequencies ω (solid) and linear growth rates γ (dotted) predicted by GKW (circle) and GS2 (square) at $\rho = 0.45$. (b) γ as a function of the toroidal angular frequency Ω and its gradient Ω' at $k_\theta \rho_\mathrm{s} = 0.57$. The dashed line denotes the value of Ω at which γ becomes the maximum when Ω' is constant.

[1] E. Narita *et al.*, Plasma Fusion Res. **10**, 1403019 (2015).
[2] Y. Camenen *et al.*, 42nd EPS conference on plasma physics (Proceedings), P5.106 (2015).