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Investigation of Turbulent Transport in the Inner core of JET H-mode Plasmas and Applications to ITER

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One of the key issues of present tokamak experiments and future fusion devices operating with high-Z materials as plasma-facing components, such as ITER, is to prevent and control high-Z impurities accumulation. Accumulation of heavy impurities such as tungsten (Z=74, M=183.84u) in the inner core can have very deleterious effects on fusion performance due to large radiative power losses associated with line radiation [1]. Transport of tungsten (W) in present devices is mainly determined by neoclassical transport in the central region of the plasma (r/a < 0.3) [2], and strongly depends on the gradients of main ion density, temperature, and rotation profiles. Thus, the proper understanding of the dominant transport mechanism in the central part is very crucial to predict W core accumulation accurately, however, it has not been explored extensively so far. Previous studies mostly focused on the edge and core regions, (r/a > 0.3). The physics picture describing transport processes in this region (r/a < 0.3) is still very limited.

In the present work, turbulent transport analysis of the inner core of high-β JET hybrid H-mode discharge #75225 is investigated extensively through linear and nonlinear gyrokinetic simulations using the gradient-driven gyrokinetic code GKW 3 in the local approximation limit. This JET hybrid H-mode of the Carbon wall era was analysed in details in [4, 5]. For the present study, the investigation domain has been extended towards the inner core region close to the magnetic axis, r/a < 0.3, where the density and temperature gradients get smaller and turbulence is expected to be closer to marginality. Surprisingly, in spite of lower gradients, a much higher growth rate is obtained at ρ=0.15 than at ρ=0.33 (fig. 1 (a)), in linear simulations. This linear stability analysis suggests that turbulent transport could be active in this region.

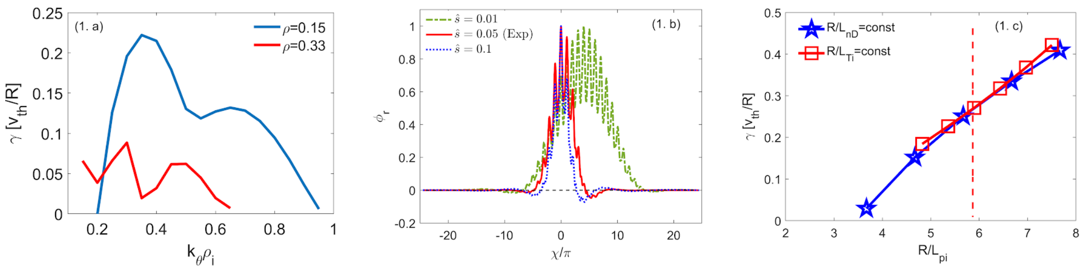

Figure 1: Linear Growth rate as function of $k_\theta \rho_i$ at two radial locations ρ=0.15 and ρ=0.33 , where k_θ is the binormal wave number and $\rho_i = \sqrt{(2T_i/m_i)}/\Omega_{ci}$ (a); Real part of electrostatic potential as function of parallel coordinate χ/π for different values of magnetic shear $\hat{s}$ (b); linear growth rate as function of normalized logarithmic ion pressure gradient (c); for JET discharge 75225.

The mode structure is extremely elongated along the field lines because of the very low magnetic shear. These unstable modes are driven by the pressure gradient as shown in fig. 1(c) and have been identified as kinetic ballooning modes (KBM), consistently with [6]. The key parameters responsible for the KBM destabilization in this region are the low magnetic shear and high-β values.

The non-linear analysis is carried out at ρ=0.15, the corresponding time-dependent nonlinear heat fluxes for the experimental input values of magnetic shear and plasma beta are shown in figure 2. The figure indicates that the nonlinear ion heat flux is dominated by the E×B contribution, consistently with linear fluxes ratio. In the case of electron heat fluxes, the most striking observation is that the magnetic flutter contribution to the non-linear heat flux is much larger and with an opposite sign to what is observed in linear simulations. The nonlinear turbulent particle fluxes generated by KBMs are positive and outward-directed, with higher E × B contribution agreeing with linear particle fluxes ratios.

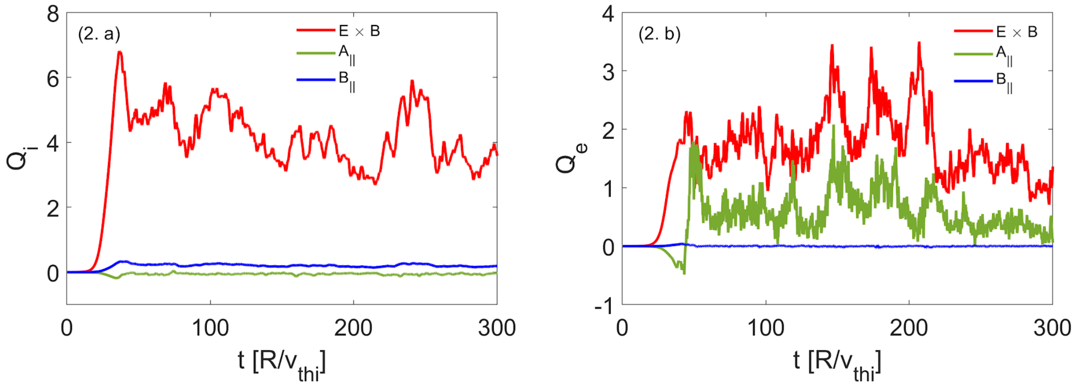

Figure 2: Time trace of GKW simulated nonlinear ion heat flux (a); electron heat flux (b) for JET 75225 at ρ=0.15. The red curve is for ES, green for magnetic flutter and blue is for magnetic compression contribution to the total nonlinear heat flux.

A sizeable level of turbulent diffusion transport in the inner core is favourable to avoid W accumulation. Turbulent diffusion transport can mitigate the neoclassical inward pinch of W in the inner core and help in preventing W accumulation. This mechanism could be particularly relevant for ITER where the level of neoclassical transport to overcome is low. To test this mechanism, the gyrokinetic analysis has been extended to ITER high Q scenarios starting with the conventional DT H-mode with 15MA plasma current and Q=10. In these plasmas, it is also found that KBM is unstable. Further investigations for other ITER scenarios, such as the steady-state Q =5, are ongoing and will be reported in the paper.

In conclusion, the presence of turbulent transport can have a positive impact from the W accumulation point of view. The discrepancy in electron nonlinear and linear heat fluxes indicates that nonlinear theory is necessary to predict the mechanisms for energy and particle turbulent transport in the inner core of high-performance plasmas. These results give an insight to understand the transport mechanism in the inner core and the implications for ITER are being investigated.

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