Linear stability of the inner core of JET plasmas using gyrokinetic simulations

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Tokamak operation with metallic plasma facing components raises issues regarding the control of high Z impurities in the confined plasma. This makes the prediction and control of tungsten (W) transport in the core an important milestone to achieve the desired fusion performance.

Transport of W in the central part of ITER is expected to be determined by neoclassical and turbulent processes, which strongly depend on the main ion density, temperature, and rotation profiles. Thus, to predict the W core transport behavior accurately in the central part, one needs to know the transport processes determining the density and temperature gradients of the main ions. Study of transport in the central part, $r/a < 0.3$, is crucial to this respect but has not been explored extensively so far. Previous studies mostly focused on the edge and core regions, $r/a > 0.3$.

In the central zone key questions for ITER are 1) whether turbulent diffusion is sufficiently large to offset the neoclassical (inward) pinch of W, 2) if yes, up to which radius and how sensitive this is to the background gradients. An auxiliary question is to which degree standard quasi-linear models such as QuaLiKiz [1] or TGLF [2] are valid in the central zone. To start providing an answer to these questions, linear gyrokinetic simulations are first performed in the central zone of JET hybrid H-mode # 75225 using the gyro-kinetic code GKW [3] in the local approximation limit. This JET hybrid H-mode of the Carbon wall era was analysed in details in $[4-6]$ and chosen for the following reasons: High quality core profile measurements for electron and main ions (Thomson scattering and charge exchange spectroscopy), no sawteeth $(q > 1)$ and no other significant core MHD activity. The experimental profiles were fitted with GPR (Gaussian process regression) tools [7] to compute the gyrokinetic simulation inputs. Simulations are performed for three species (deuterium, electron, and carbon), and include electromagnetic perturbations $(A_{||}, B_{||})$, rotation, collisions, with a Miller parametrization of the magnetic equilibrium. After linear grid convergence tests the following grid set-up was chosen: 64 points in the parallel velocity direction, 16 points in the perpendicular direction, and 32 points per poloidal turn. The number of poloidal turns was varied from 5 to 80 depending on the type of instability. Two radial locations, $\rho = 0.15$ and $\rho = 0.33$, were investigated, where ρ is the normalized toroidal flux coordinate. The corresponding input parameters normalized in GKW units are listed in table 1.

ρ	R/L_{Ti}	R/L_{Te}	R/L_{ne}	R/L_{nC}	T_i/T_e	$\hat{s}$	$\beta_e[\%]$	q	ν^*	Z_{eff}
0.15	4.2	1.99	1.51	-0.70	1.44	0.01	4.6	1.10	0.30	1.74
0.33	7.7	4.09	2.74	-1.51	1.19	0.21	2.6	1.14	0.06	1.74

ρ	n_C/n_e	u	u'	β'	κ	δ	ζ	dR_{mil}
0.15	0.01	0.31	0.59	-0.37	1.35	0.02	0.001	-0.08
0.33	0.01	0.32	1.31	-0.66	1.34	0.04	0.001	-0.16

Table 1: Normalized input parameters in GKW simulations for the discharge 75225. ν^* is normalized collisionality, q is safety factor, and $\hat{s}$ is magnetic shear. u is toroidal rotation, u' is toroidal rotation gradient, κ is elongation, δ is triangularity, and ζ is squareness.

The linear growth rates and frequency spectrum as function of wave numbers $k_\theta \rho_i$ are plotted in figure 1. Interestingly, ETG scales are found to be stable at $\rho = 0.15$ and at $\rho = 0.33$ (not shown).

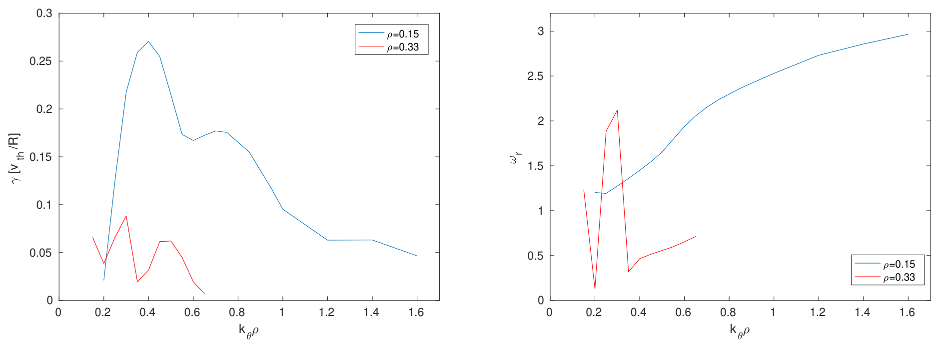

Figure 1: *Linear growth rate (a) and frequency spectra (b) as a function of $k_\theta \rho_i$, for JET 75225 at $\rho = 0.15$ and $\rho = 0.33$.*

Surprisingly, in spite of the lower gradients lengths, a much higher growth rate is obtained at $\rho = 0.15$ than at $\rho = 0.33$. The mode is rotating in the ion magnetic drift direction. It was also noted that the mode structure at $\rho = 0.15$ are extremely elongated along field lines (up to 60 poloidal turns) especially for low wave numbers unlike the modes are more localised at $\rho = 0.33$

as expected for interchange ITG. We try to investigate the possible reasons for this behavior at $\rho = 0.15$ by scanning first the magnetic shear and plasma beta which differ significantly at the two different locations.

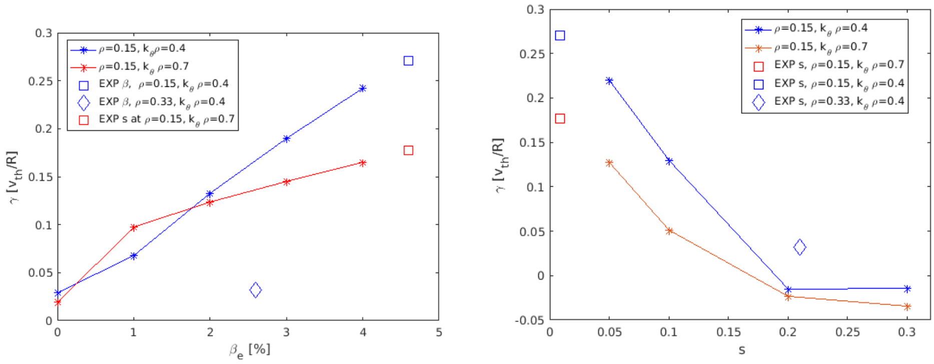

Figure 2: *Linear* β *(a) and magnetic shear (b) scans, for two wave vector* $k_\theta \rho_i = 0.4$ *and* $k_\theta \rho_i = 0.7$. *Blue curve for* $k_\theta \rho_i = 0.4$, *red curve for* $k_\theta \rho_i = 0.7$. *Square indicates experimental values at* $\rho = 0.15$ *and pentagon experimental values at* $\rho = 0.33$ *for* $k_\theta \rho_i = 0.4$.

As can be seen from figure 2, the mode growth rate at $\rho = 0.15$ increases with plasma beta and decreases with increasing magnetic shear. Both parameters play an important role, but the impact of the magnetic shear is much stronger and the low magnetic shear is the dominant parameter responsible for the instability at $\rho = 0.15$. A similar kind of behavior has also been observed at $\rho = 0.20$ and $\rho = 0.25$.

Following this, main ion temperature gradient, electron temperature gradient and electron density gradient are scanned around the experimental value. As can be seen from figure 3, main ion temperature gradients and electron density gradients are playing important roles in driving the mode at $\rho = 0.15$. The extended eigenfunction, the destabilization always R/L_{Ti} and low $\hat{s}$, suggest a slab ITG character.

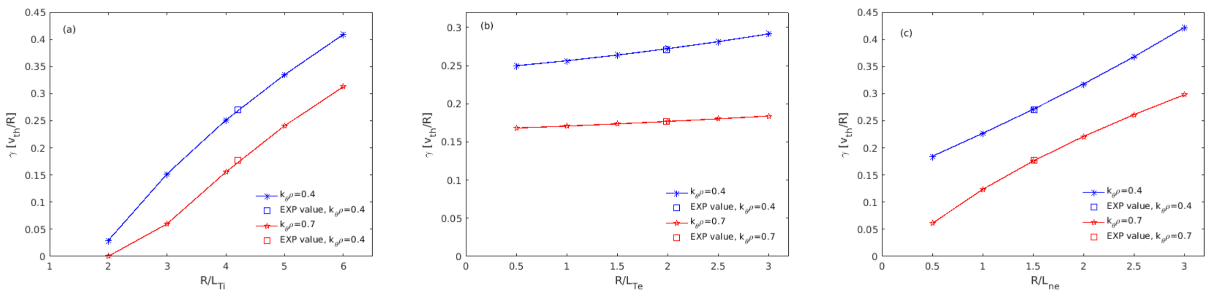

Figure 3: *Main ion temperature gradient (a) electron temperature gradient (b) and electron density gradient (c), scans for* $k_\theta \rho_i = 0.4$ *(blue) and* $k_\theta \rho_i = 0.7$ *(red).*

Finally, the ratio of heat fluxes to the mode amplitude together with a quasilinear heat fluxes estimate at the two radial locations are presented in figure 4.

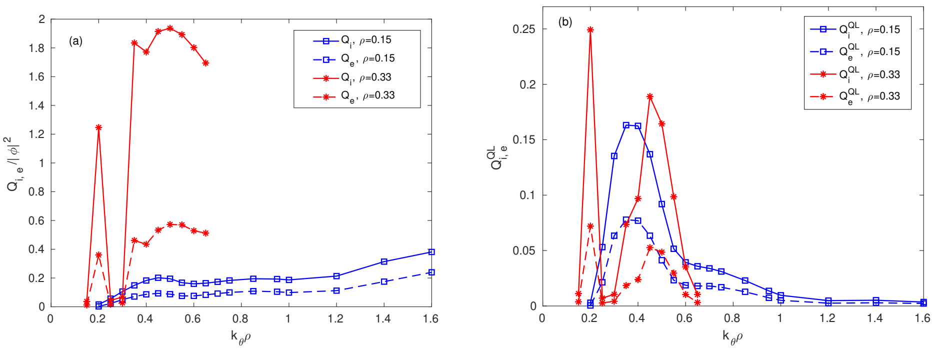

Figure 4: *Ratio of heat fluxes and mode amplitude (a) quasilinear (ion, electron) heat flux estimate (b) as a function of* $k_\theta \rho_i$*, at* $\rho = 0.15$ *and* $\rho = 0.33$*. Quasilinear heat flux calculated as:* $Q^{QL}_{i,e} = Q_{i,e}/|\phi|^2 * \gamma/\bar{k}^2_\perp$*. With* $\bar{k}^2_\perp$ *the perpendicular wave vector averaged over the parallel mode structure.*

As can be seen from figure 4 (a) ratio of heat fluxes to the mode amplitude for electron and ion is higher at $\rho = 0.33$ than at $\rho = 0.15$. However, the higher growth rate and lower $\bar{k}^2_\perp$ which enters the quasilinear weight make the resulting quasilinear fluxes of the same order of magnitude at the two radial locations figure 4 (b).

The linear gyrokinetic study presented here for the JET plasma discharge # 75225 suggests that in spite of lower gradients, the turbulent transport level may not be negligible for $r/a < 0.3$ provided the magnetic shear is sufficiently low. The future scope of this work is to compare the quasilinear heat fluxes with nonlinear gyrokinetic simulations and test quasilinear approximations in the inner core for JET plasma, and then predict ITER core.

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References

[1] C. Bourdelle, et al., Physics of Plasmas **14**, 112501 (2007)

[2] G. M. Staebler, et al., Physics of Plasmas **12**,102508 (2005).

[3] A.G. Peeters, et al., Comput. Phys. Comm. **180**, 2650 (2009)

[4] J Citrin, et al., Plasma Phys. Contr. Fusion **57**, 014032 (2015)

[5] J Hobirk, et al., Plasma Phys. Contr. Fusion **54**, 095001 (2012)

[6] J Garcia, et al., Nucl. Fusion **53**, 043023 (2013)

[7] A. Ho, et al., Nucl. Fusion **59**, 056007 (2019)