Global vs local gyrokinetic studies of core microinstabilities in JET hybrid discharges with ITER like wall

S. Moradi[1], I. Pusztai[2], J. Citrin[3,4], Hyun-Tae Kim[5], I. Lupelli[5], WJ. Kettlewell[1], and the JET contributors *

EUROfusion Consortium, JET, Culham Science Centre, Abingdon, OX14 3DB, UK
[1] *Fluid and Plasma Dynamics, Université Libre de Bruxelles, Brussels, Belgium*
[2] *Applied Physics, Chalmers University of Technology, Göteborg 41296, Sweden*
[3] *FOM Institute DIFFER, P.O. box 6336, 5600 HH Eindhoven, The Netherlands*
[4] *CEA, IRFM, F-13108 Saint Paul Lez Durance, France*
[5] *CCFE, Culham Science Centre, OX14 3DB Abingdon (UK)*

Introduction

In recent years there has been an increasing worldwide effort to further the development of the so-called hybrid or improved H-mode scenarios. In these plasmas, representing a hybrid between “baseline" and “advanced tokamak" scenarios, enhanced normalized confinement is achieved (compared to the ITER baseline ELMy H-mode) through current profile optimization, avoiding deleterious MHD, and access to high β_N. We present a study on the characteristics of core microinstabilities in two hybrid plasmas from recent JET experiments with ITER like wall (selected from Ref. [1]) based on local and global gyrokinetic simulations with the *GYRO* code [2]. In particular, we study the role of various plasma parameters such as normalized plasma pressure and Shafranov shift on the onset and stability of the microinstabilities. The time evolution of the selected plasma discharges from the ILW power scan experiments: #84545 (high-δ) and #84792 (low-δ) are shown in Fig. 1. In these discharges, a “current overshoot” before the Neutral Beam Injection (NBI) pulse allows the formation of a wide region of low magnetic shear in the plasma core which allows access to the hybrid conditions with high β_N and $H_{98} > 1$ [3].

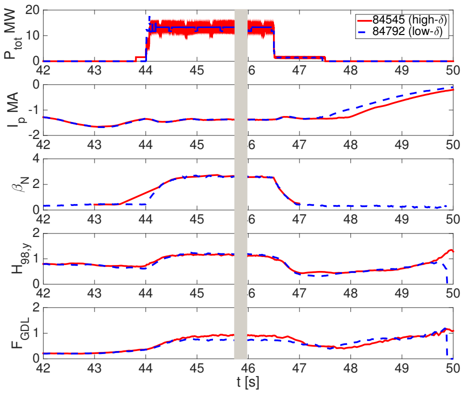

Figure 1: *Time traces of main plasma parameters for the selected plasmas.*

Results of gyrokinetic simulations

For our microinstability analysis three radial positions are selected: $\rho = 0.3,\ \ 0.45$ and 0.6, where ρ is the normalised toroidal flux (as defined in [2]). Magnetic geometry parameters are taken from EFIT constrained by MSE measurements, and the profiles calculated by TRANSP are averaged over a time window of 0.5 s over the period of the highest $H_{98}(y,2)$ factor with nearly stationary temperatures and density (shown by the grey field in Fig. 1).

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* See the Appendix of F. Romanelli et al., *Proceedings of the 25th IAEA Fusion Energy Conference 2014, Saint Petersburg, Russia*

Figures 2(a-f) show the result of a β_e scans for the three selected radial positions of #84545 (high-δ) discharge computed by Local (solid red lines) and Global (dashed-dotted blue lines) linear simulations. A significant difference between the two types of simulation, as seen in this figure, is the lower KBM threshold in the local runs in all three radii, while the global scans show no onset of KBMs throughout the β_e scan range. In #84792 (low-δ) discharge we did not find any significant difference in the overall results and similar trends were observed. At the experimental levels of β_e ($\rho = 0.3 \rightarrow \beta_e \sim 0.015$, $\rho = 0.45 \rightarrow \beta_e \sim 0.01$ and $\rho = 0.6 \rightarrow \beta_e \sim 0.006$), ITGs are found to be the dominant instability in Global simulations at all the considered radii. Here, as β_e is increased the ITGs are completely stabilised without any transition to a KBM branch of instabilities. Note, that the modes with almost zero real frequency are potentially numerical rather than physical modes as we find ITGs to be completely stabilised here.

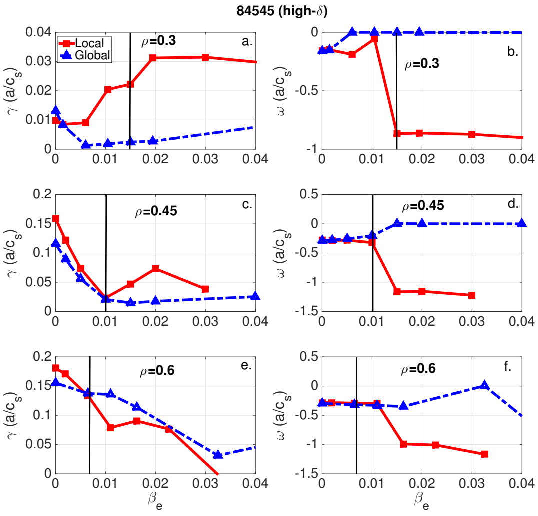

Figure 2: *Imaginary and real frequency of the most unstable modes as functions of β_e with self-consistent variation of the α_{MHD} at $\rho = 0.3$ (a and b), $\rho = 0.45$ (c and d) and $\rho = 0.6$ (e and f). Note that negative frequencies are in the ion diamagnetic direction. Black vertical lines represent the experimental values of β_e.*

Comparing Local and Global results, the largest difference is observed for the inner core radius at $\rho = 0.3$ as can be seen in Fig. 2 (a and b), while for the outer core radii i.e. $\rho = 0.45$ and 0.6, the Local and Global simulation results are closer and specially for the experimental values of β_e they overlap (see Fig. 2 (c-f)). Such a trend is expected because for the inner core due to very low magnetic shear the Local assumptions are less valid while as the magnetic shear is increased by moving away from the core we expect the Local assumptions to hold and therefore the Global and Local results to be close. However here, the impact of profile variation still plays an important role and therefore there are further differences found as β_e is increased further beyond the experimental values.

We have examined the stabilisation role of Shafranov shift on the unstable modes with Local and Global simulations and the results are presented in Figs. 3. Here the variation of Shafranov shift is applied by varying the parameter c_p defined as $\alpha_{MHD} = -q^2 R_0 8\pi/(B^2_{unit})\frac{dp}{dr}c_p$, where R_0 is the major radius of the centroid of the flux surface, and $p = \sum_a n_a T_a$ is the total plasma pressure. c_p is the geometric pressure gradient scaling parameter which allows an artificial adjustment of α_{MHD} without modifying the background gradients as presented in Ref. [5]. As

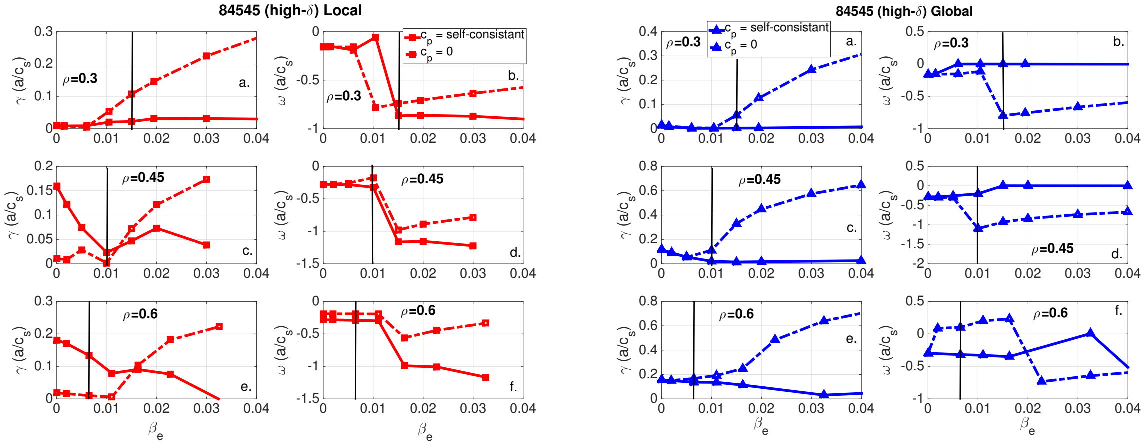

Figure 3: *Imaginary and real frequency of the most unstable modes as functions of β_e with self-consistent variation of the α_{MHD} and without i.e. $c_p = 0$ at $\rho = 0.3$ (a and b), $\rho = 0.45$ (c and d) and $\rho = 0.6$ (e and f). Left figures are Local and right figures are Global results, with black vertical lines representing the experimental values of β_e.*

seen in this figure in both Local and Global simulations we observe a strong stabilisation effect of Shafranov shift on the growth rates at large β_e, while the effect is minimal or destabilising e. g. in the case of Local runs at $\rho = 0.45$ and $\rho = 0.6$ (see Figs. 3 left (c-f)). A significant impact of the Shafranov shift is on the ITG/KBM transition which is found to be strongly shifted towards lower β_e values in Global simulations and without it we find KBMs to be dominant unstable mode at the experimental values of β_e for $\rho = 0.3$ and $\rho = 0.45$. Furthermore we investigate the role of magnetic shear on the stability characteristics in the two simulation types. Figures 4 illustrate the results of β_e scans with the experimental values of magnetic shear (solid lines) and with a 30% increase in the magnetic shear (dashed-dotted lines). As can be seen in this figure in the case of Local simulations (left figures) an increase in the magnetic shear results in a strong stabilisation of the unstable modes for the whole range of considered β_e and at all radii. Here we find that such an increase will result in the complete stabilisation of KBMs at high β_e and the appearance of the subdominant TEM due to complete stabilisation of the dominant ITG by increasing β_e. In the Global simulations however, a 30% increase in magnetic shear does not impact the overall growth rate values for all radii, but here also we observe the appearance of the TEM as the ITG is stabilised at high β_e.

Summary and conclusions

In a series of β_e scans for the two selected hybrid discharge we have shown that indeed there is a significant difference in the characteristics of the dominant instabilities between the Local and Global assumptions. The most significant difference is the strong reduction of the ITG growth rate and the absence of the ITG/KBM transition in the Global simulations. The reason for this strong ITG stabilisation is found to be a combination of Shafranov shift and electromagnetic effects. A 30% increase in the magnetic shear is found to impact the Local results more strongly than the Global results however such an increase is expected to further

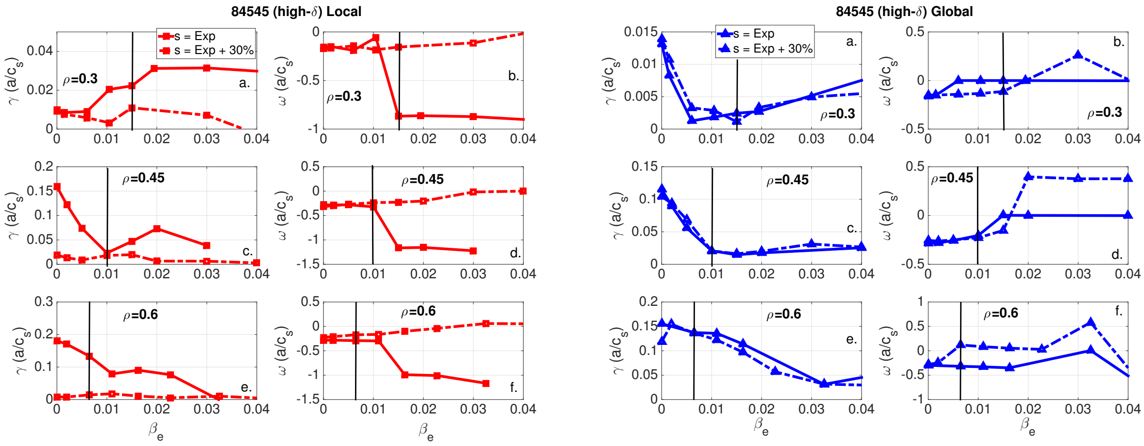

Figure 4: *Imaginary and real frequency of the most unstable modes as functions of β_e with self-consistent variation of the α_{MHD} with experimental (solid lines) and $+30\%$ (dashed-dotted lines) values of magnetic shear, at $\rho = 0.3$ (a and b), $\rho = 0.45$ (c and d) and $\rho = 0.6$ (e and f). Left figures are Local and right figures are Global results, with black vertical lines representing the experimental values of β_e.*

stabilise the ITG instability in the core. Our analysis suggest that electron directed modes such as TEM/MTM are subdominantly present in these plasmas and as the combination of high β and Shafranov shift effects result in complete stabilisation of the ITG modes, these modes become more visible since they are less affected by these effects. Strong reduction in KBMs growth rate, to an almost marginally unstable state, in global in global (in contrast to local) simulations was previously observed in Ref. [4] for the inner core of the C-wall hybrid plasmas. The importance of non-linear β stabilisation of the ITG modes in the core of the JET hybrids in both C-wall and ILW were shown in Refs. [6, 7] through local non-linear gyrokinetic simulations. Here it was presented that the β/β_{crit} ratio where β_{crit} is the critical β value for the onset of electromagnetic modes such as KBMs, is an important factor for the effectiveness of the β stabilisation of the ITGs. Our results shows the importance of global simulations on obtaining an accurate β_{crit} for the onset of KBMs in high-β regimes which are found to be significantly higher than what was found in local simulations. Hence, our findings suggest a possible rise of the upper power limit for regimes showing a lack of plasma confinement degradation [1], which may be restricted by destabilisation of KBMs as β is increased.

Acknowledgments

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