L to H mode transition: on the role of Z_{eff}

C. Bourdelle[1], C.F. Maggi[2], L. Chôné[3], P. Beyer[3], G. Fuhr[3], X. Garbet[1], A. Loarte[4], F. Millitello[5], A. Monnier[3], M. Romanelli[5], S. Saarelma[5], Y. Sarazin[1] and JET EFDA Contributors*

JET-EFDA, Culham Science Centre, Abingdon, OX14 3DB, UK

[1] *CEA, IRFM, F-13108 Saint-Paul-lez-Durance, France.*

[2] *Max Planck Institut fur Plasmaphysik, EURATOM Association, Garching, Germany*

[3] *PIIM - UMR 7345 - Université d'Aix-Marseille - CNRS, 13397 Marseille Cedex 20, France*

[4] *ITER Organization, Route de Vinon sur Verdon, 13115 St Paul Lez Durance, France*

[5] *Culham Centre for Fusion Energy, Abingdon, UK*

In this paper, the nature of the primary instability present in the pedestal forming region prior to the transition into H mode will be analyzed by a gyrokinetic code GENE on JET ITER Like Wall (ILW) profiles. It will be shown that the primary instability is of resistive nature, and can therefore be stabilized by increased temperature, hence power. Its growth rate reaches a minimum for a temperature of the order of the experimentally measured temperature at the transition. Its resistive nature leads to a reduced growth rate as the effective charge Z_{eff} is increased. This dependence will be shown to be in qualitative agreement with recent experimental observations. The impact of the ILW shows a L to H mode power threshold reduced by $\simeq 40\%$ in ILW with respect to similar experiments in C wall [1]. The experiments were carried out with slow power ramps and matched plasma shapes, divertor configurations and I_p/B_T pairs. In ASDEX Upgrade as well, a reduction of the power threshold, linked to the metalization of the machine, has been observed [2] when compared to the ITPA-2008 scaling law [3]. A common feature of JET ILW and ASDEX Upgrade is an observed significant reduction of the Z_{eff} when switching from C walls to metallic ones.

On JET ILW, at $2.4T/2.0MA$, there was a variation of plasma shape at fixed divertor configuration and a variation of divertor configuration at fixed plasma shape. These variations modify the power threshold from 3 MW down to 1.5 MW [4]. To test the potential role of Z_{eff}, the power thresholds are plotted versus Z_{eff} on figure 1. The reduction of the power threshold is observed to be clearly correlated with a reduction of Z_{eff} rather than with shape/divertor specificities.

In the following, the nature of the turbulence is investigated for JET ILW data just prior to the transition in H mode. The code used is a gyrokinetic turbulence code, GENE [5]. The linear analysis are performed using experimental data at $\rho = 0.97$, in the pedestal forming region, for pulses at $1.8T/1.7MA$ detailed in [1, 4]. The electron temperature and density profiles are time averaged over 50ms. A residual uncertainty of order 0.5 cm remains in the separatrix position.

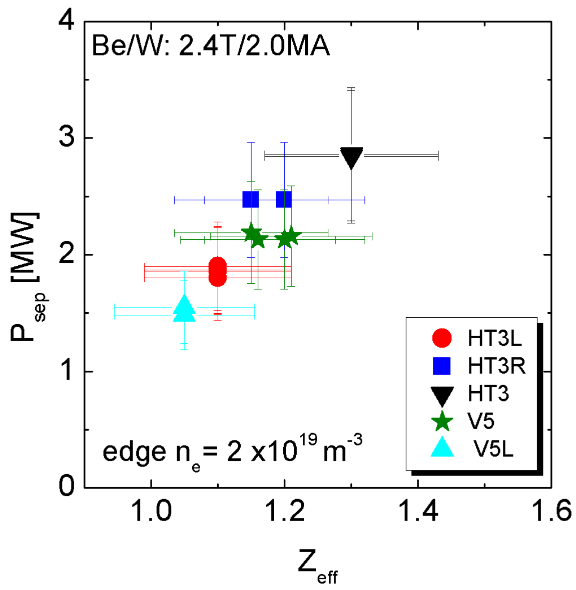

Figure 1: *Variation of P_{sep} with Z_{eff}. $P_{sep} = P_{thr} - P_{rad,bulk}$, with P_{thr} the loss power at the H mode transition and $P_{rad,bulk}$ the radiated power from the bulk plasma.*

The ion temperature is taken to be equal to the electron temperature, as found experimentally at the pedestal top [4]. The q profiles have been reconstructed thanks to the HELENA equilibrium code [6]. Z_{eff} is measured by the horizontal line of sight of the Bremsstrahlung diagnostic. A flat Z_{eff} profile is assumed. The main parameters useful for the linear gyrokinetic analyses are summarized in table 1.

The key ingredients to a microstability analysis are the local Z_{eff}, the q profile and its shearing,

pulse	ρ	R/L_T	R/L_n	T	n	ν^*	s	q	Z_{eff}	B
JET 82228	0.97	55	9	122	2.6	9.2	3.8	4.3	1.3	1.8

Table 1: *Edge parameters for a JET discharge 82228 prior to the L to H transition. The temperature is given in eV, the density n in $10^{19}m^{-3}$ and the magnetic field B in T.*

as well as various gradient lengths. These data being subject uncertainties, a gyrokinetic analysis can mostly provide a qualitative information. A quantitative information can be extracted only once the impact of various uncertainties have been discussed.

GENE is using an adaptive time step scheme. It is run linearly in its initial value version. The circular geometry is used. The analysis focuses on mode at $k_\theta \rho_s < 0.4$ where most of the transport is driven and where RBM are potentially active [7].

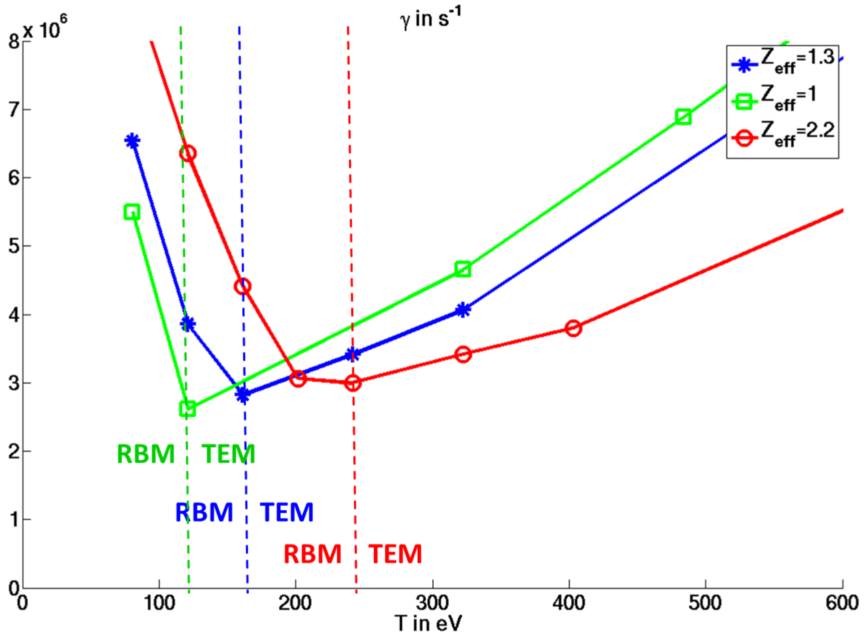

Figure 2: *Blue asterisks: growth rates at* $k_\theta \rho_s = 0.1$ *versus temperature for the parameters as given in table 1. Green squares: same as asterisks but with* $Z_{eff} = 1$*. Red circles: same as asterisks but with* $Z_{eff} = 2.2$*.*

Experimentally, the power is ramped while keeping the density fixed. To mimic such a ramp in the simulations, the temperature is scanned at a given density. The blue asterisks on figure 2 illustrate a temperature scan with the other parameters fixed to the values given in table 1. As the temperature is increased, the modes are firstly stabilized. These modes are drifting in the electron direction and are stabilized by higher T, hence lower resistivity. They are identified as Resistive Ballooning Modes. For more details on the RBM mechanisms, see [7]. As the temperature is further increased, the growth rates reach a minimum above which Trapped Electron Modes take over. TEM being further destabilized as the collisionality is reduced. Assuming that the L to H mode transition is a predator-prey mechanism, the RBM could be identified to the prey, i.e. the primary instability. In such a framework, the transition into H mode is likely to be facilitated as the primary instability is weakened. In parallel, it is interesting to note that the T at which the growth rate is minimum, T_{min}, is of the order of the experimental temperature prior to the transition. Indeed, for $Z_{eff} = 1.3$, T_{min} varies from 120 up to 160 eV while varying the input parameters within reasonable uncertainties as summarized in table 2. The experimental T value at $\rho = 0.97$ is 122 eV as reported in table 1.

To qualitatively mimic the wall change in JET, from C to Be/W, where Z_{eff} was reduced as found for the dataset of the L-H experiments, Z_{eff} is taken around a typical observed ILW value:

Input parameters	ref case, table 1	$R/L_T = 30$ (55)	$R/L_n = 4$ (9)	$s = 2$ (4.3)	$q = 3$ (3.8)
T of min(γ) (eV)	$\simeq 160$	$\simeq 120$	$\simeq 160$	$\simeq 160$	$\simeq 120$

Table 2: *The temperature of the minimum growth rate tested versus various input parameter uncertainties.*

1.3 with a mix of D and Be and for the C wall 2.2 is chosen as a typical value with a mix of D and C [1, 4]. To mimic the divertor configuration impact reported on figure 1, Z_{eff} is increased from 1 up to 1.3 with a mix of D and Be. By increasing Z_{eff}, the resistivity is increased and leads to more unstable RBM. On the contrary, high Z_{eff} provokes dilution and stabilizes both ITG and TEM. Therefore, increasing Z_{eff} reduces the growth rates at low T and shifts T_{min} to higher values as illustrated on figure 2. This behavior is in qualitative agreement with the shift of the L to H threshold towards higher power at higher Z_{eff}.

The power threshold increases almost linearly with density in the so-called 'high density branch' [3]. If the density is decreased from 2.6 to by $1.0 \times 10^{19} m^{-3}$, the collisionality decreases, and the RBM are more stable while the TEM more unstable, resulting in a robust decrease of the growth rates for $T < T_{min}$. This behavior is in qualitative agreement with a higher power threshold at higher density.

To go further than the present first principle linear analysis, both players: the prey and the predator mechanisms need to be modeled, i.e. the RBM drive and the ExB stabilization. An effort in this direction using a non-linear, fluid, fixed flux code (EMEDGE3D) is presently on-going [8].

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* See the Appendix of F. Romanelli et al., Proceedings of the 24th IAEA Fusion Energy Conference 2012, San Diego, US.

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