Small ELMs in quasi-double null plasmas at JET

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1. Introduction

This paper describes the results of recent identity experiments with ASDEX Upgrade in quasi double null (QDN) plasmas to access the type II ELM regime. These ELMs are defined as "irregular, high frequency, low amplitude", appearing when the plasma is in QDN configuration. With the new JET divertor (MKII-HD), it has been possible to develop a QDN plasma configuration matching simultaneously upper and lower triangularity as well as the elongation of a quasi double null plasma of ASDEX Upgrade and a steady state regime has been achieved. The proximity to double null configuration was varied from lower single null to upper single null defining an optimum interval of Δ_{sep} to obtain type II ELMs. These results show that double null configuration is important to access this regime, but not sufficient. To achieve collisionalities relevant for ITER a plasma current (I_p) scan, from 0.86MA to 1.6MA, was performed. A regime with small ELMs is reproducible at both these plasma currents.

2. JET/ASDEX Upgrade identity experiments on type II ELMs

Regimes with reduced ELM size but still with good H-mode energy confinement that meet the predicted parameters of ITER, such as collisionality, q_{95} and reduced ELM size, are necessary. Several regimes are being studied, such as the type II ELMs on ASDEX Upgrade [1,2], the grassy ELMs on JT-60U [3,4], the "Enhanced D-Alpha" (EDA) H-mode in Alcator C-Mod [5,6] or the Quiescent H-mode on DII-D, ASDEX Upgrade and JET [7,8]. This paper is dedicated to the study of type II ELMs at JET.

Previous dedicated experiments to reproduce the type II ELM behaviour observed in ASDEX Upgrade were carried out at JET [9,10]. These dimensionless identity experiments showed that it was possible to obtain long type II like ELM phases with steady pedestal parameters. However, this regime could not be found at higher plasma currents.

Due to constraints of the previous JET divertor geometry, the upper and lower triangularity were not matched (figure (a) and (b)). Also the proximity to double null, Δ_{sep}, defined as the distance between the two separatrices mapped to the midplane ($\triangle_{sep} = (\psi_2 - \psi_1)/2\pi R_{sep}B_{p,sep}$), was somewhat larger ($\psi_1$ and ψ_2 are the flux for the first and second separatrix respectively). With the new JET divertor (MKII-HD), it was possible to develop a QDN plasma configuration matching simultaneously upper and lower triangularity as well as the elongation and Δ_{sep} of a QDN plasma of ASDEX Upgrade as shown in figure (a) and (c). A steady state regime with type II like ELMs similar to ASDEX Upgrade was

obtained showing small irregular ELMs with good confinement and similar Greenwald fraction. The geometric and pedestal parameters for both ASDEX Upgrade and JET identity discharges are shown in table 1. With this new configuration, core peaking and collapse was avoided, providing steady state type II like ELMs for the first time at JET.
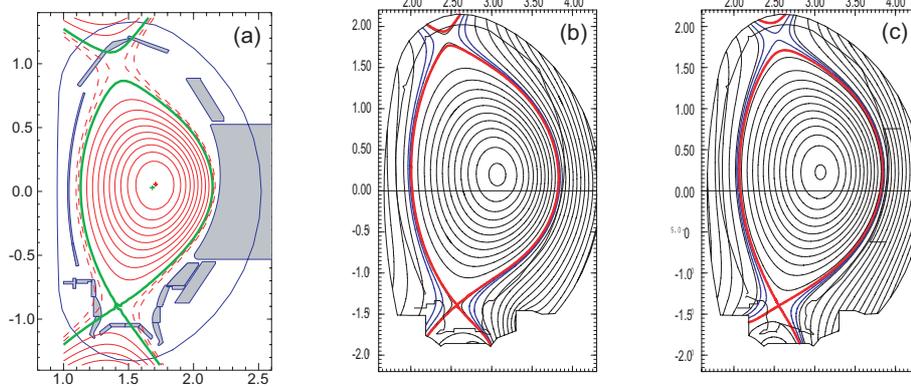

Figure 1: Configurations used for the type II ELM experiments in (a) ASDEX Upgrade, (b) JET 2003 and (c) JET 2006.

	I_p	B_T	q_{95}	ν^*	ρ^*	δ_u	δ_l	κ	Δ_{sep}(mm)
AUG (a)	1	2	4.3	0.9	4.9e-3	0.338	0.449	1.64	< 10
JET (b)	0.87	1.17	4.1	2		0.5	0.37	1.72	< 10
JET (c)	0.86	1.23	4.35	0.8	4.1e-3	0.34	0.448	1.79	6

Table 1: Identity parameters for ASDEX Upgrade and JET quasi-double null plasmas.

3. Proximity to Double-Null

The dimensionless identity results show that the plasma magnetic geometry plays an important role in accessing the steady state type II like ELM regime. The impact of magnetic geometry was further explored by varying, $\triangle_{sep}$. The plasma shape was changed from a dominant lower single-null (LSN) to a dominant upper single null configuration (USN) (see figure 2). Type I ELMs were obtained for large values of $\triangle_{sep}$ (in LSN), whilst for values of
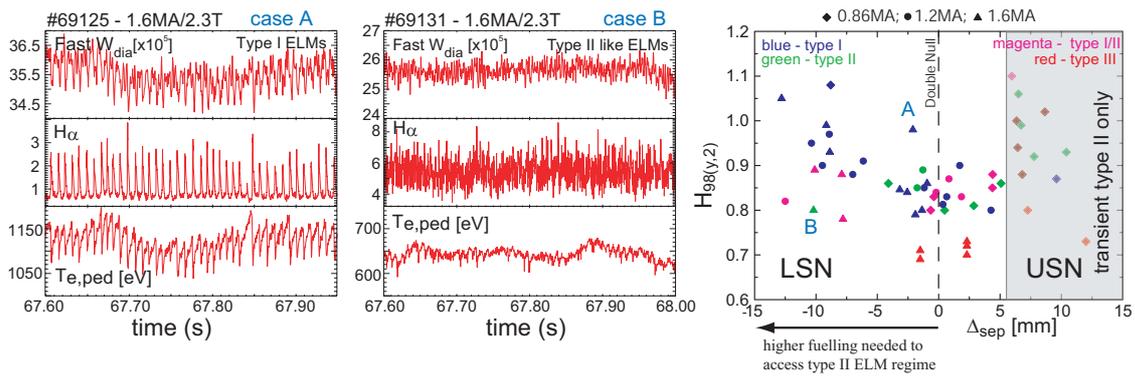

Figure 2: Confinement variation with Δ_{sep} for type I ELMs (blue), type II-like ELMs (green), type III ELMs (red) and type I/II ELMs (magenta).

$\Delta_{sep} \geq +6$cm (USN), the plasma becomes vertically unstable, so the ELMs couple with the plasma vertical oscillation. Note that by varying $\triangle_{sep}$, δ_u and δ_l also vary which makes it difficult to clearly separate the effect of proximity to double null and triangularity to access this regime. Figure 2 shows the variation of H-mode confinement for a range of Δ_{sep} values. As QDN is approached, a degradation of $\approx$10-20% in confinement occurs. Two discharges are shown in detail in this figure. Case A corresponds to a plasma with Δ_{sep} of -2.5mm

and no fuelling where type I ELMs were obtained while type II like ELMs were obtained in case B in a strongly fueled discharge and Δ_{sep} of $\approx$-10 mm. These results suggest a possible optimum interval of $\triangle_{sep} \approx$ 4mm "USN dominant" to $\approx$ -10mm "LSN for which this regime is accessible. However, although double null configuration is a necessary condition to obtain the type II like ELM regime, also the pedestal parameters plays an important role.

4. Type II ELMs operational space
Having successfully reproduced the type II like ELM regime of ASDEX Upgrade, I_p and density scans were performed in order to explore the operational space for access to this
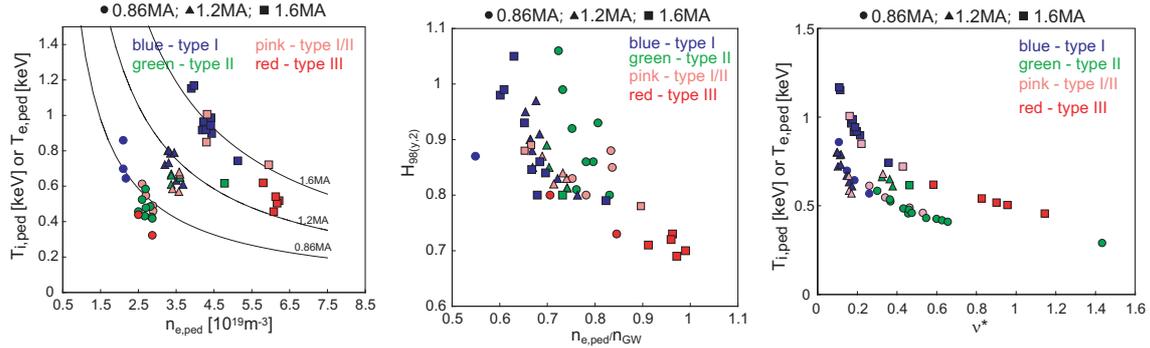

Figure 3: Power and density scan for I_p=0.86MA (circles), 1.2MA (triangles) and 1.6MA (squares). (a) edge operational diagram $n_e - T_e; T_i$, (b) global plasma confinement versus Greenwald fraction and (c) dependence of collisionality on pedestal temperature.

regime. Contrary to previous experiments [8,9], this regime showed to be reproducible at higher plasma currents. The behaviour of pedestal parameters for all the I_p and density scans performed are shown in figure 3. These results show that the operational space for this regime is narrow with $n_{e,ped}/n_{GW} \approx$ 0.7 - 0.8 with an ELM size, $\Delta W_{ELM}/W_{ped} \leq 5\%$ ($\Delta T_e \approx$ 20-30 eV), where ΔW_{ELM} defines the upper limit, determined for the largest excursions seen on the diamagnetic loop signal. The reduction of the ELM size was confirmed by the infra red camera data showing a reduction of the heat load (lower divertor) in the type II like ELM discharges (relative to type I ELM) of $\approx$ 25% on the inner divertor and $\approx$ 20% on the outer divertor. The lowest value of ν^* is $\approx$ 0.23, almost ten times smaller than previously achieved in type II ELM experiments at JET. Therefore it can be concluded that the parameter space for the access to this regime with good confinement and reasonably low collisionality is quite narrow. Edge MHD stability analysis using the new high resolution Thomson scattering diagnostic shows that the Type II like ELMy plasma is in the stable region (figure 4). The reason for
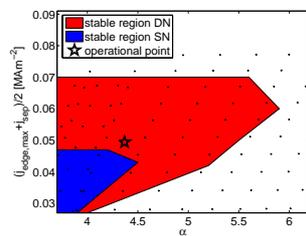

Figure 4: Effect of double null configuration in stability analysis.

this is not low pressure gradient as in the case of a Type III ELMy plasmas, but instead the plasma shape. If the double null shape is replaced by a single null configuration (the boundary is taken from the Type I ELMy plasma) and the profiles are kept as they were in the Type II-like ELMy discharge, the edge plasma is at the stability limit for the peeling-ballooning modes. The marked improvement in ideal stability may explain why Type I ELMs are supressed.

Although the experimental results suggest an upper limit for the pedestal temperature ($\approx 600 - 800eV$; see figure 3), above which type I ELMs appear, stability analysis shows that, because of the improved stability to peeling-ballooning modes, there is still operational space to reduce ν^* for the type II-like ELMs. To clarify this point, more experiments at higher current, hence lower ν^*, are needed.

5. Density fluctuations

The behaviour of the density fluctuations in the pedestal region was also investigated. Fast (1MHz) interferometry measurements in the region of the pedestal top, show an increase of the broadband fluctuations around 10-20 kHz which is not seen in discharges with type I ELMs (see figure 5). Magnetic fluctuations are also observed around the same frequency but with very small amplitude. Thus it is possible that this enhanced inter-ELM transport may explain the access to stationary profiles associated with type II like ELM regime.
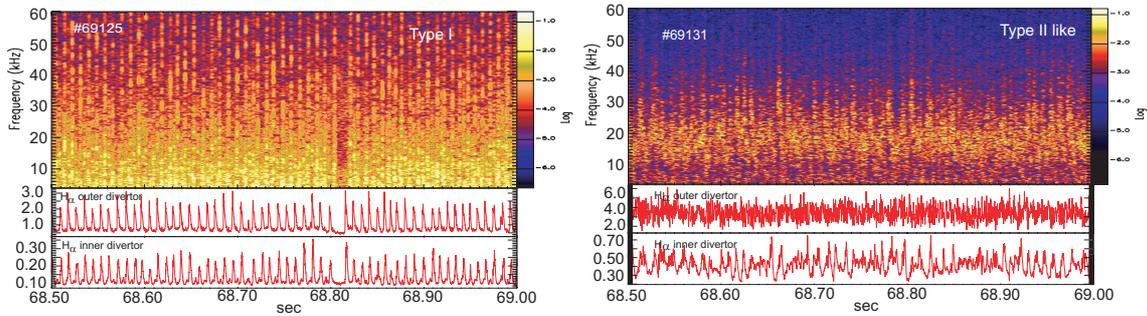

Figure 5: Density spectrograms from interferometry for (a) type I ELMs and (b) type II like ELMs.

6. Summary and Conclusions

New ASDEX Upgrade/JET identity experiments on QDN plasmas were performed at JET. The plasmas dimensionless identical to ASDEX Upgrade were very similar and type II-like ELM steady state discharges were obtained for the first time at JET. Contrary to previous experiments at JET, this regime showed to be reproducible for higher values of I_p with $\nu^* \approx 0.23$, much closer to ITER values than previously achieved. Plasma current and density scans to explore further the operational space were performed. It is found that the type II-like ELM regime has reasonable confinement $H_{98(y,2)} \approx 0.8 - 1.0$ and Greenwald fraction around 0.7-0.9. The ELM size is small, $\Delta W/W_{ped} \leq 5\%$ and the temperature drop due to these ELMs is around 20-30eV. The density drop is within the diagnostic noise level. The heat load to the divertor decreases of $\approx 20\%$ in the outer divertor and $\approx 25\%$ in the inner divertor. A scan of Δ_{sep} shows that double null configuration is essential but not sufficient to access this regime; certain pedestal characteristics have to be met. A fine scan of the pedestal density shows that a limit on the maximum pedestal temperature exists, above which a transition from type II-like to type I ELMs is observed ($\approx 600 - 800eV$). This limit in temperature will impose a minimum value for collisionality for this regime. However, stability analysis shows that this regime can be extended to lower collisionality.

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