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One of the important problems facing internal transport barrier (ITB) scenarios in JET is their stationarity and in particular edge physics issues. A plasma edge with small type III ELMs and low pedestal pressure does not disturb the ITB. However, type I ELMs usually lead to a collapse of the ITB in JET [1,2].

Time traces for a typical ITB shot (Pulse No: 51672) terminated by a type I ELM (at~6s) are presented in Fig.1. One can notice that the giant ELM is preceded by a decrease in MHD signal and increase of edge density (Fig.1) and temperature (Fig.2) at constant input power. Experimental study of the type III to I ELMs transition for H-modes have shown that the power threshold for this transition can be estimated as follows: $P_{th\ typeI} \sim \alpha P_{L/H}$, where P_{LH} is L/H transition threshold and $\alpha \sim 1.8$ [3]. Here we consider rather low elongation ($\kappa \sim 1.61$) and triangularity ($\delta \sim 0.21$) shots compare to [4]. The data presented in Fig.3 demonstrate that the type III to I ELM transition in ITB discharges deviate strongly from this empirical power scaling for H-modes [3], since type III ELMs are still observed at up to $\sim 5P_{L\text{-}H}$ in ITB scenarios. Moreover, the transition to type I ELMs happens with the increase of the pedestal pressure at constant input power. Possible explanations for this difference between the observed type III/I transition in ITB discharges and that seen in standard ELMy H-modes have been considered in this paper.

A first hypothesis could be that the ITB formation consumes input power and hence decrease power flux to the edge and prevent pedestal formation. This argument can be easily eliminated by replacing in power scaling the input power Pin by Pin-dW/dt, where dW/dt is time derivative of plasma diamagnetic energy (Fig3). For most ITB shots presented in Fig.3 the value of dW/dt is relatively small (~2-3MW) during ITB formation. Also one should know that there are many experimental examples of stationary (dW/dt=0) and long (~4-6s) ITBs with small type III ELMs [5], some of these shots are also presented in Fig 3.

A second hypothesis for the observed differences in ELMs behaviour could be that in ITB experiments the strike points are placed in the entrance to the divertor pump ducts ("corner configuration") which provides low edge density compare to the standard H-mode with strike points on the vertical divertor target plates. In fact, in the devoted experiment where the H mode (Pulse No: 52683 in Fig.3) was realised in the same "corner configuration" as typical ITB pulses, the type III/I power threshold was found by 50% higher compare to normal vertical target cases but this is still not sufficient as an explanation. Moreover recent studies of the effects of divertor configuration on ITB showed that ITBs with type III ELMs could be obtained even with the strike points on the vertical targets [4], where the type III/I threshold follows the scaling [3]. These shots are also presented in Fig.3.

However, in terms of local pedestal density n_{ped} and electron temperature T_{ped}, the type III/I ELMs transition in OS and H-mode discharges demonstrate similar behaviour. In Fig. 4 the typical pedestal parameters in ITB discharges before and after transition to type I ELMs are presented with respect to theoretically predicted [6] and experimentally determined boundaries [3]. In this paper, for the boundary of type III to I ELMs transition we used formulas from [6] with coefficients which fit JET experimental data [3]:

$$n(10^{19}m^{-3}) = \sqrt{\frac{c_1^{\,2}T(eV)^4}{T(eV)^{17/3} - c_1^{\,2}c_2^{\,2}}}; \quad c_1 = 0.296\,\frac{c_\tau^{\,2}c_\mathrm{f}\,q^3B^{5/3}}{A^{8/6}s^2R^{1/3}Z^{1/3}}; \tag{1}$$

$$c_2 = 500c_vqRZ;\ c_\tau^{\,2}c_\mathrm{f} = 5469.27/q^2;\ c_v = 9;\ A = 2;\ Z = 2$$

The critical temperature for transition increases with magnetic field [3], but strong q dependence in (1) was not demonstrated experimentally both for H-modes [3] and for ITB discharges (Fig.4b). The most delicate argument is the difference in plasma density in ITB discharges and standard ELMy-H-mode. The usual ITB scenario in JET is characterised by rather low target density n/n $_{\mathrm{Greenwald}}$~0.15 rising up to the n/n $_{\mathrm{Greenwald}}$~0.3-0.4 during main heating phase. To compare the physics of the type III to type I ELM transition in ITB plasmas with standard ELMy H-modes the Pulse No: 52498 was run in the same configuration as Pulse No: 51672 using the same heating scheme but without producing an ITB. In order to avoid ITB formation in Pulse No: 52498 LHCD pre-heat was missing and the main heating was applied ~6s latter on the current plateau (Fig.5). As a result, even with the same low target density a standard H-mode with type I ELMs was obtained in Pulse No: 52498. Notice that just before the transition to type I ELMs in both discharges the pedestal density is higher than in type III ELMs phase, because of the external barrier formation.

However, the question is why in optimised shear discharges type III ELMs are observed for a longer time than in standard H-modes and why sometimes one can produce quasi-stationary high power (~20MW) ITBs without a transition to type I ELMs?

The hypothesis proposed in this paper is that type III/I transition is strongly influenced by the edge current profile. In fact, the main feature in optimised shear scenario compared to H-mode is the different current profile and in particular a larger current fraction at the edge. In this paper the internal inductance li and magnetic shear sh95 are used as characteristics of edge current fraction since they have lower values for larger pedestal current. Polarimetry measurements at R=3.75m corresponding approximately to the top of the pedestal can also give an indication of the relative current fraction in the pedestal compare to the central plasma. From the polarimetry diagnostic one can estimate $\widetilde{B}|_{R\,=\,3.75m} \sim \int_{-z0}^{z0} B_\theta n dz$, and hence to introduce the parameter $B_{\mathrm{tet}} = \widetilde{B}/I_p \int_{-z0}^{z0} ndz \sim \frac{I_p - I_{ped}}{I_p}$.

Here Iped is a pedestal current. The dependence of pedestal density on li, sh95, B_{tet} in the series of ITB shots presented in Fig.6 demonstrates that the transition to high pedestal density and type I ELMs corresponds to the lowest edge current and happens with the progressive current diffusion to the centre. Notice that the quasi-stationary long ITB shots with large non-inductive current fraction [5] keep optimised shear current profile and hence high edge current fraction without transition to type I ELMs.

CONCLUSIONS AND DISCUSSION.

The hypothesis confirmed by experimental examples presented in this paper is that the larger edge current fraction in ITB discharges compared to standard H-mode can prevent the type III to I ELMs transition. The experiments where a type I/III transition was observed during current ramps-up in H-mode [7] could have the same physics. A possible explanation for type I ELMs avoidance in ITB discharges could be the presence of the peeling mode instability [8] generated by plasma current in the pedestal region. This hypothesis still requires detailed stability analysis for ITB shots, which is difficult because of uncertainty in the edge current profile. Unfortunately this effect seems to be weak at high density and in particular for high shaped plasmas [4] may be also because of the more rapid edge current diffusion at high density.

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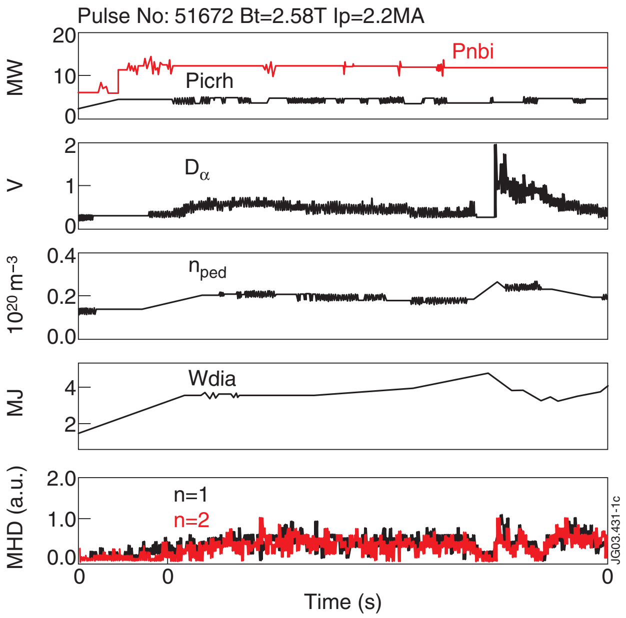

Figure 1: Example of ITB terminated by type I ELM.

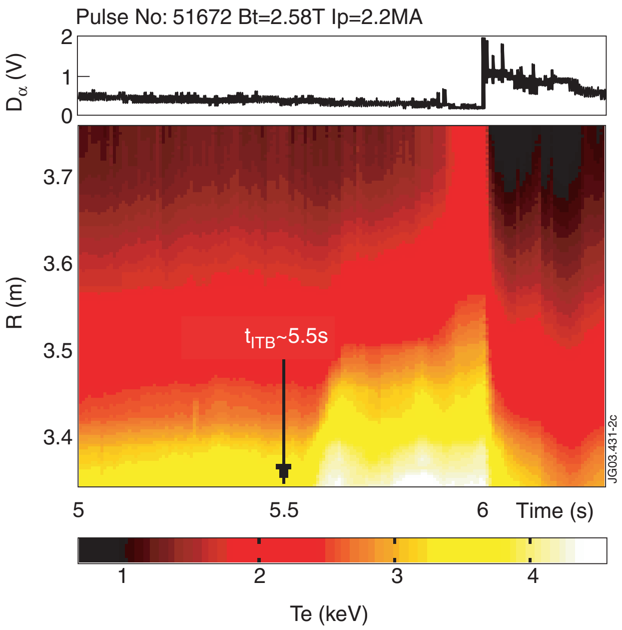

Figure 2: Electron temperature evolution in Pulse No: 51672.

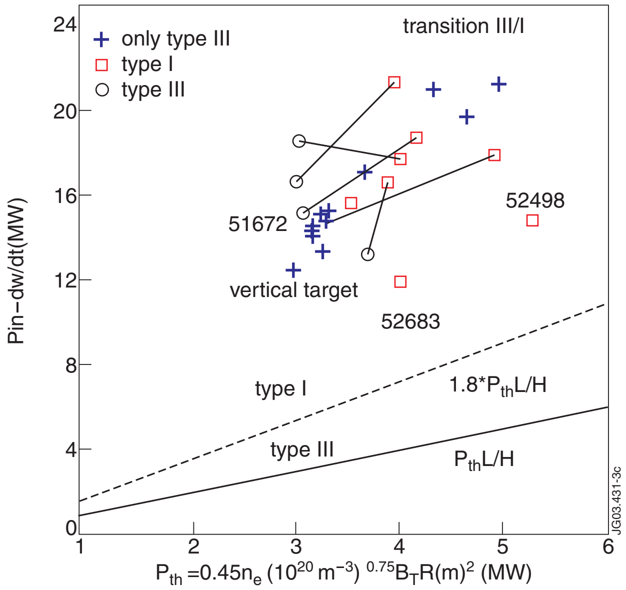

Figure 3: Type III/I ELMs transition in ITB discharges

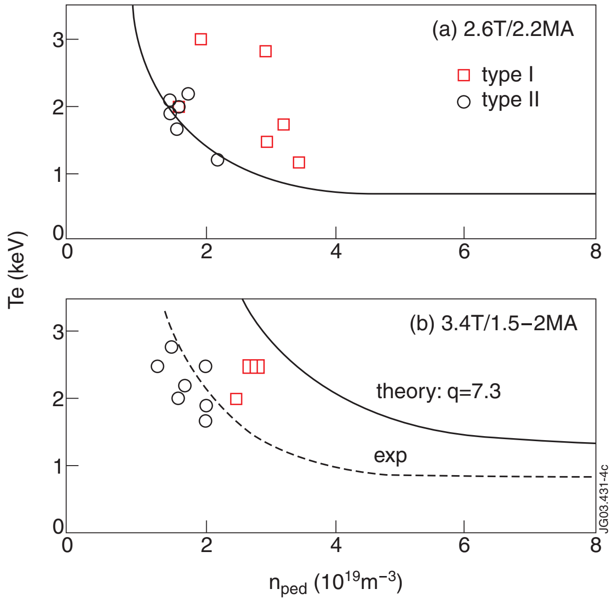

Figure 4: Pedestal temperature (ECE) and density (interferometer edge chord) in ITB pulses. (a)–B=2.6T, q=3.8; s=2.8; (b)–B=3.4T, q=7.3; s=3.

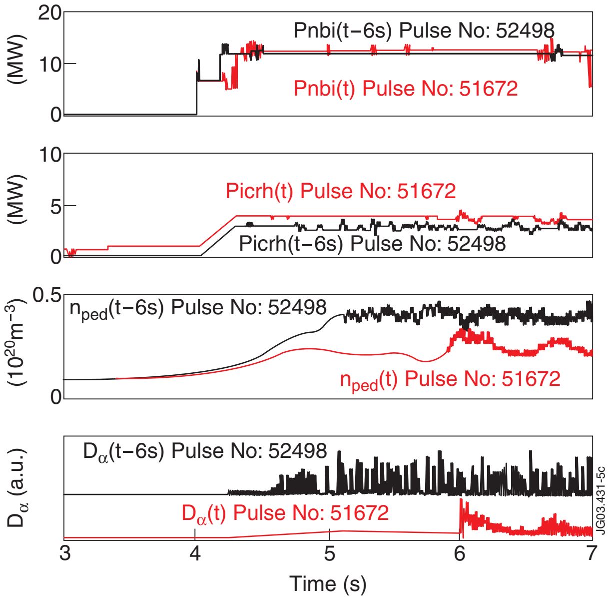

Figure 5: H-mode Pulse No: 52498 in the same geometry as ITB Pulse No: 51672, but 6s delayed main heating. Time traces of Pulse No: 52498 are shifted by −6s for comparison with Pulse No: 51672.

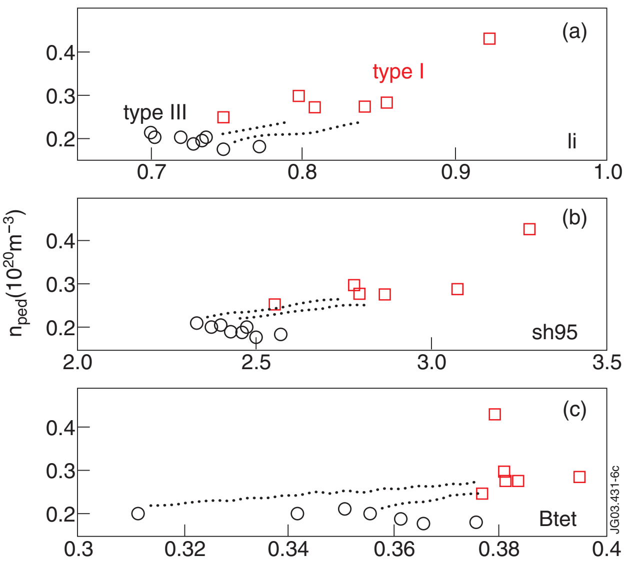

Figure 6: Pedestal density dependence on li(a), sh95(b), Btet(c) and type III/I ELMs in ITB shots ~2.6T/2.2MA. Dotted lines-type III/I ELM transition.