Influence of Edge Current Profile on Type III-Type I ELMs Transition in Optimised Shear Discharges on JET.

Bécoulet M., Joffrin E., Sartori R.**, Lomas P.*, Saibene G.**, Parail V.*, SarazinY .,Challis C.*, Litaudon X., Bécoulet A., Matthews G*.,Ghendrih Ph. and the contributors to JET-EFDA Workprogramme.

Association Euratom-CEA, Cadarache, F-13108 St. Paul-lez-Durance, France.

* *Euratom/UKAEA Fusion Association, Culham Science Centre, Abingdon,OX143DB, U.K.*

** *EFDA Close Support Unit, D-85748, Garching, DE.*

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 (#51672) terminated by a type I ELM (at~46s) 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 for rather low elongation and triangularity standard H-modes has shown that the power threshold of the type III to I ELMs transition can be estimated as follows: $P_{th\ typeI} \sim \alpha P_{L/H}$, where P_{LH} is L/H transition threshold and $\alpha \sim 2$ [3]. Low elongation ($\kappa \sim 1.61$) and triangularity ($\delta \sim 0.21$) ITB pulses (see also [4] for comparison) considered in this paper deviate strongly from empirical power scaling for H-modes [3], since type III ELMs are still observed at up to $\sim 5 \times P_{L-H}$ in ITB scenarios (Fig.3). Moreover, the transition to type I ELMs happens with the increase of the pedestal pressure at constant input power. Possible hypotheses to explain this difference between the observed type III/I transition in ITB discharges and that seen in standard ELMy H-modes are 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 there are many experimental examples of stationary (dW/dt=0) and long (~10s) ITBs with small type III ELMs [5], some of these shots are 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 (#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]:

$$n_{[10^{19}m^{-3}]} = \sqrt{\frac{c_1^2 T_{[eV]}^{4}}{T_{[eV]}^{17/3} - c_1^2 c_2^2}};\ c_1 = 0.296 \frac{c_\tau^2 c_f q^3 B^{5/3}}{A^{4/3} s^2 R^{1/3} Z^{1/3}}; \qquad (1)$$

$$c_2 = 500 c_v q R Z; c_\tau^2 c_f = 5469.27/q^2; c_v = 9; A = 2; Z = 2$$

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 typical ITB scenario in JET is characterised by rather low target density $n/n_{Greenwald}$~0.15 rising up to the $n/n_{Greenwald}$~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 discharge #52498 was run in the same configuration as a shot #51672 using the same heating scheme but without producing an ITB. In order to avoid ITB formation in #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 #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. 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 $\tilde{B}\Big|_{R=3.75m} \sim \int_{-z0}^{z0} B_\theta n dz$, and hence to introduce the parameter $B_{tet} = \tilde{B} \Big/ I_p \int_{-z0}^{z0} n dz \sim \frac{I_p - I_{ped}}{I_p}$. Here Iped is the pedestal current. The dependence of pedestal density on li, sh95, B_{tet} in the series of ITB shots presented in Fig.6 suggests 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 experimental examples presented in this paper suggest that the larger edge current fraction in ITB discharges as 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 rely on 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.

[1] Söldner, F.X. et al. Plasma Phys. Controlled Fusion 39(1997) B353.
[2] Sarazin Y. et al, Proceedings of the 27th EPS,Budapest (2000), ECA Vol. 24B, 253.
[3] Sartori,R., et al, 'Study of type III ELMs in JET', to be published.
[4] Lomas P.J. et al, this conference.
[5]Litaudon X. et al , this conference.
[6] Igitkhanov, Yu., Pogutse, O., et al, Contrib. Plasma Phys., 40(2000)3-4, p.368
[7]R Sartori et al., Plasma Physics controlled Fusion 40, N 5, 1998, p.757
[8] J.W.Connor et al Physics of Plasmas,5(7)1998,2687.

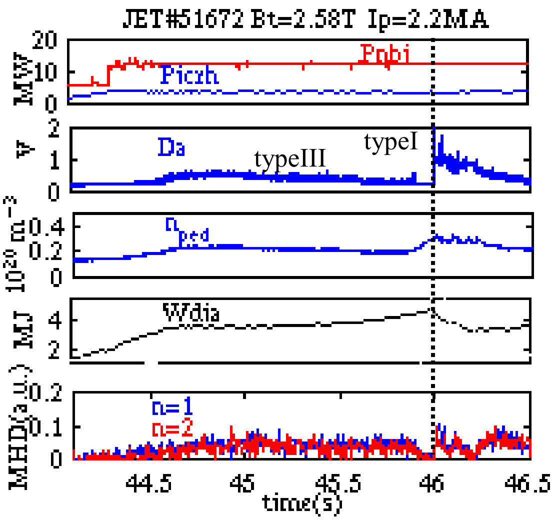

Fig.1 Example of ITB terminated by type I ELM.

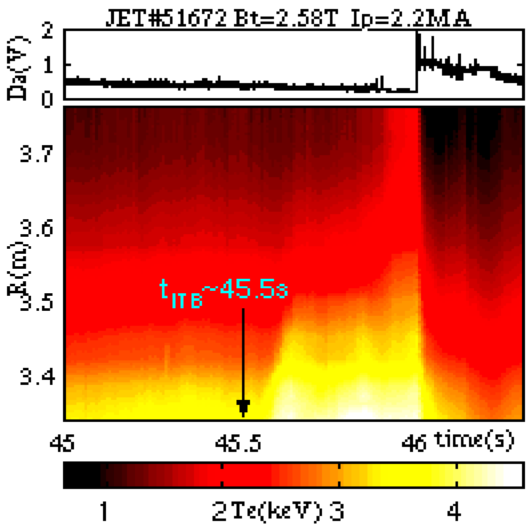

Fig.2 Electron temperature evolution in #51672.

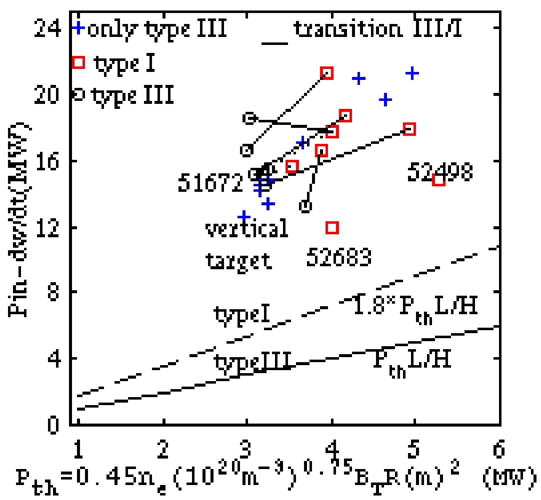

Fig.3 Type III/I ELMs transition in ITB discharges .

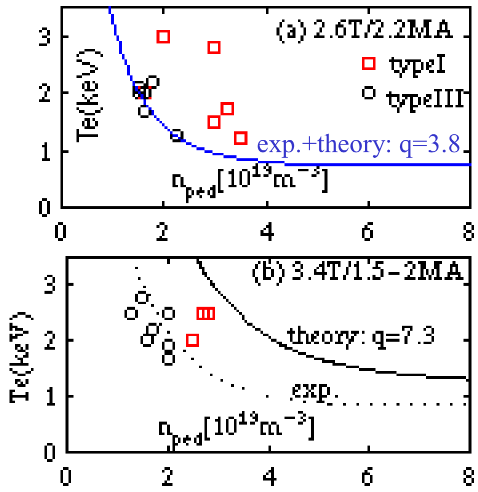

Fig.4 Pedestal temperature (ECE) and density (interferometer edge chord) in ITB shots. (a)-B=2.6T, q=3.8; s=2.8; (b)-B=3.4T, q=7.3; s=3.

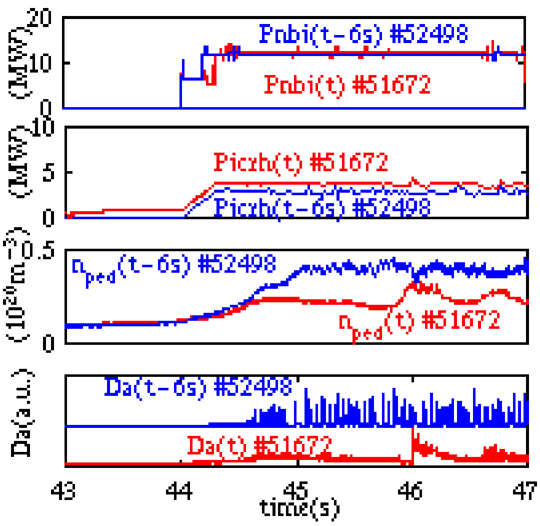

Fig.5. H-mode shot #52498 in the same geometry as ITB shot #51672, but 6s delayed main heating .Time traces of #52498 are shifted in time by -6s for comparison with #51672.

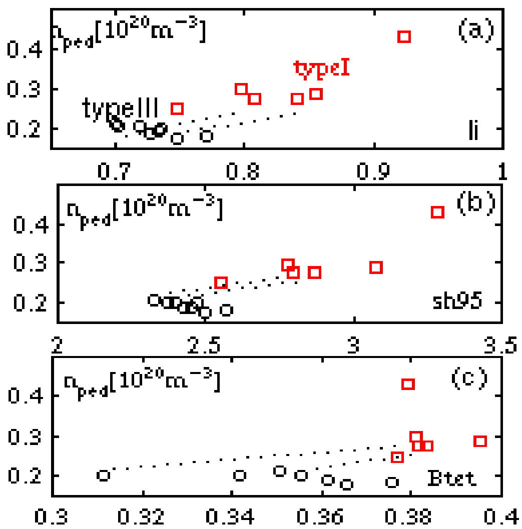

Fig.6. Pedestal density dependence on li(a),sh95(b),Btet(c) and type III/I ELMs in ITB shots ~2.6T/2.2MA. Dotted lines-type III/I ELM transition.