

## Peripheral plasma perturbations and transient improved confinement in JET optimized shear discharges

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Peripheral plasma cooling is known to induce a transient state of improved core energy confinement detected in the form of a transient core electron temperature ( $T_e$ ) rise. The effect has been observed in many tokamaks [1-5] in both Ohmic and auxiliarily heated plasmas at sufficiently low density. In JET, earlier peripheral plasma cooling experiments had been performed at a density too high for the effect to be observed. This paper presents the first attempts to perform such experiments in JET in Optimised Shear conditions, where the low density and high heating power are favourable to the occurrence of the effect. Ultimately the aim for these experiments would be to look for a synergy between peripheral cooling and formation of a persistent internal transport barrier (ITB), in order to exploit the peripheral cooling as a triggering tool for the ITB formation.

The experiments have been performed in JET plasmas with Optimised Shear (OS) scenario [3] ( $2.6 \text{ T} < B_T < 3.4 \text{ T}$ ,  $2.3 \text{ MA} < I_p < 3.1 \text{ MA}$ ,  $210^{19} \text{ m}^{-3} < n_{e0} < 410^{19} \text{ m}^{-3}$ ,  $P_{\text{NBI}} \leq 12 \text{ MW}$ ,  $P_{\text{ICRH}} \leq 8 \text{ MW}$ ). Transient peripheral cooling is induced either by Laser Ablation (LA) of metal impurities (mainly Ni) or Deuterium Shallow Pellet Injection (SPI) injected from the low field side; see [6] for details. The time evolution of  $T_e$  and  $T_i$  have been measured by ECE and active CX diagnostics. The  $n_e$  and radiated power profile evolution have also been monitored.

Only a few experiments were attempted in the pre-ITB phase of plasma discharges that developed an ITB. The post-ITB phase was investigated more extensively; there the aim was to seek for a "retriggering" effect. Perturbations were also applied during the ITB phase for other purposes [6].

An example of  $T_e$  time evolution following a LA pulse in the pre-ITB phase is shown in Fig.1a. This result is representative of the effect sought: an ITB forms shortly after a LA pulse. There are other discharges, however, where no temporal correlation between LA and ITB triggering is observed. Similarly in Fig.1b, where an ELM occurs at the time the ITB is triggered (ELMs were "used" in the past as another edge cooling mechanism [7]), it is not possible to decide whether the ELM is the cause or the effect of ITB formation. Unfortunately, the present data set of cold pulses in pre-ITB phase is too scarce to attach

statistical significance to the few cases of observed correlation between cold pulse and ITB formation. More extensive and careful experiments are required.

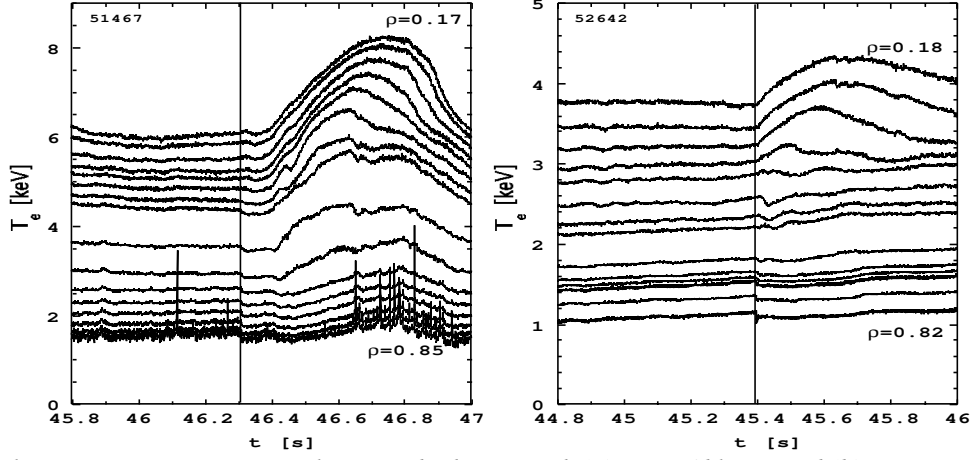


Fig.1: Electron temperature time evolution in discharges with (a) Laser Ablation and (b) ELM instability. The time of the perturbations is marked by a vertical line. In both discharges, an ITB forms shortly after the perturbation.

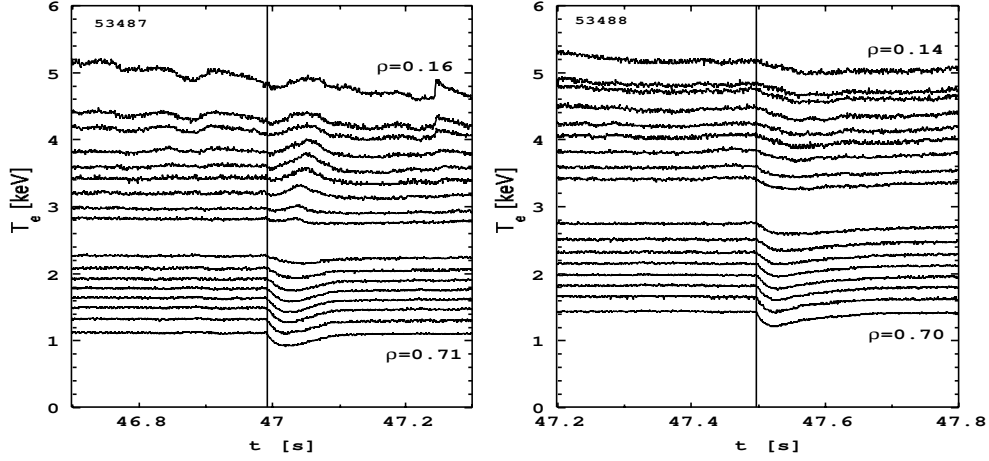


Fig.2: Electron temperature time evolution in discharges with Shallow Pellet Injection and either (a) ICRH heating or (b) ICRH+NBI heating. The injection time is marked by a vertical line. A core  $T_e$  rise is observed in (a) but not in (b).

In the post-ITB phase, there are a few cases where a rise in the core  $T_e$  was observed following peripheral cooling by either LA or SPI. These are the first observations in JET plasmas of a well known phenomenon [1-5], whose explanation is still under discussion [8]. However such  $T_e$  rise did not turn into a fully developed ITB. An example is shown in Fig.2a. Only ICRH was used at the time of the SPI. The effect is very sensitive to plasma conditions, indicating it is marginal. In Fig.2b, the core  $T_e$  rise is not observed. This was a discharge similar to the previous one except for the addition of some NBI power. The conditions for the core  $T_e$  rise seem to be more restrictive on JET than predicted by the TFTR scaling [2].

In two cases where a core  $T_e$  rise was observed,  $T_i$  was measured and observed to rise in the core similarly to  $T_e$  (Fig.3). This allows for the first time a comparison with transport

simulations using the IFS/PPL transport model [9] which depend critically on the assumed  $T_i$  perturbation. The model has two key ingredients that allow it to yield an amplitude reversal and a fast response: (i) the  $T_i/T_e$  dependence of the critical  $T_i$  gradient is essential in reproducing amplitude reversal through the associated change in diffusivities (Fig.4); (ii) the "stiffness" of the model leads to fast propagation of pulse fronts. Indeed the model reproduces the qualitative features seen in experiment except for the core region where the temperature increase is overestimated (Fig.5).

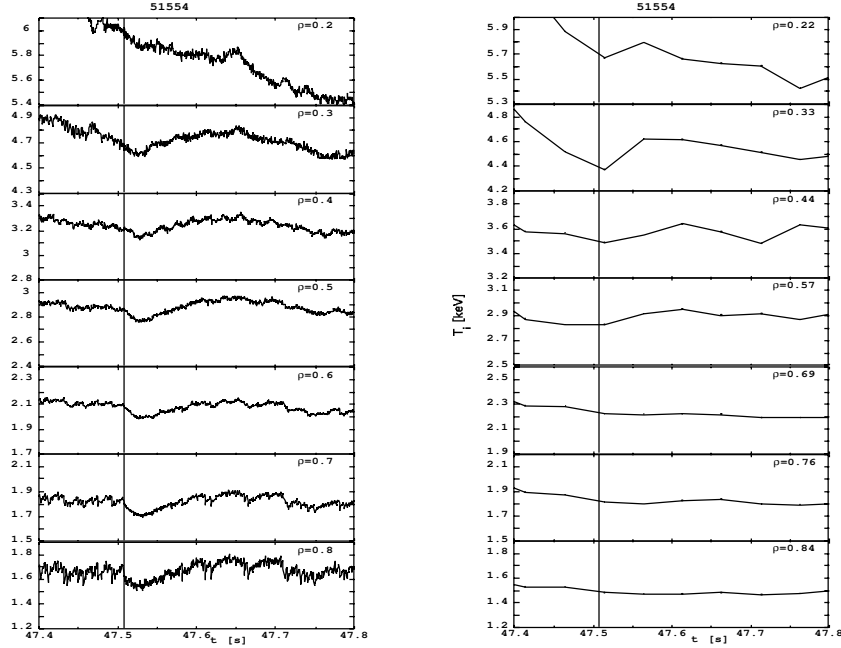


Fig.3: Electron and ion temperature time evolution in a discharge with Laser Ablation yielding a core temperature rise. The injection time is marked by a vertical line.

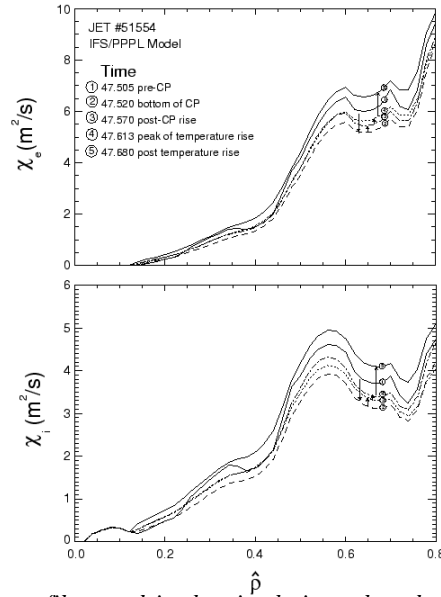


Fig.4: Electron and ion diffusivity profiles used in the simulation, plotted as a function of normalized minor radius.

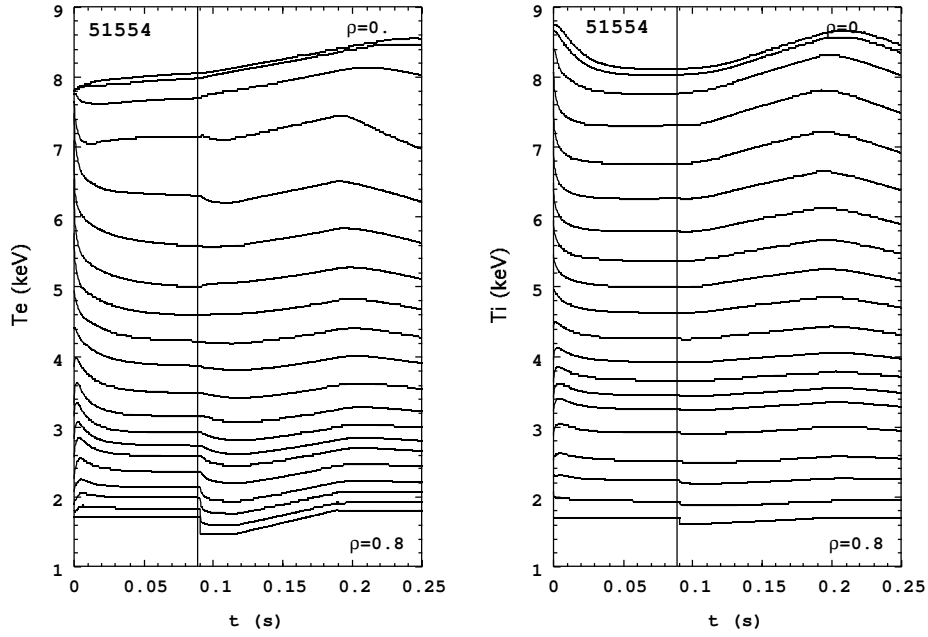


Fig.5: Electron and ion temperature time evolution simulated using the IFS-PPL model for the discharge of Fig.3. The injection time is marked by a vertical line.

The absence of ITB retriggering, the marginal character of the core  $T_e$  (and  $T_i$ ) rise, and the IFS/PPL simulation suggest that (i) other conditions (e.g.,  $q$  profile) have to be met before the triggering mechanism can play a role, if any; (ii) the post-ITB phase is not suitable for investigations of the proposed triggering mechanism; (iii) the transient improvement in confinement associated with peripheral cooling is not necessarily to be interpreted as an attempt to form a barrier.

In conclusion, peripheral cooling has led to transient improved transport in a few post-ITB cases where both electron and ion temperature rises were observed. This phenomenology can be qualitatively simulated using the IFS/PPL transport model. More careful investigation of the ITB triggering effect of peripheral cooling in the pre-ITB phase is required before we can assess whether peripheral cooling can be of any use for controlling the time of ITB formation.

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## References

- [1] K.W.Gentle et al, Phys Rev Letters 74 (1995) 3620.
- [2] M.W.Kissick et al, Nucl Fusion 38 (1998) 821.
- [3] P.Mantica et al, Phys Rev Letters 82 (1999) 5048.
- [4] X L Zou et al, Plasma Phys Control Fusion 42 (2000) 1067.
- [5] F.Ryter et al, Nucl Fusion 40 (2000) 1917.
- [6] P. Mantica et al, this conference.
- [7] P.Galli et al, Nucl Fusion 38 (1998) 1355.
- [8] J.Kinsey et al., Physics of Plasmas 5 (1998) 3974.
- [9] M.Kotchenreuter et al., Phys. Plasmas 2 (1995) 2381