Fully predictive modelling of H-L transition in ITER and present day tokamaks

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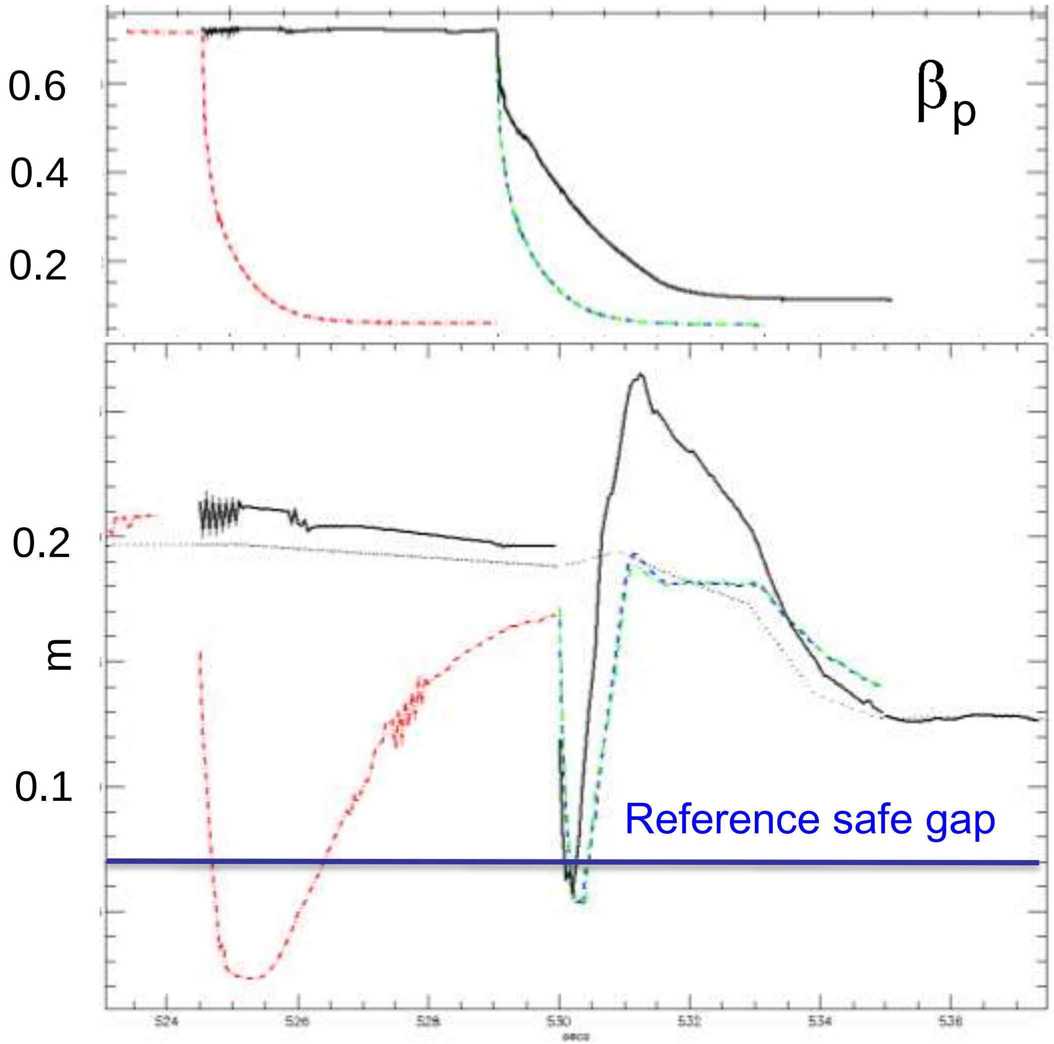
Outline:

- Modelling of H-L transition in ITER – why it is important?
- Models for L-H and H-L transition, type-III ELMs and pass to and from high performance;
- Role of impurities;
- Summary.

Coupled JINTRAC/CREATE-NL simulation of H-L transition in *ITER Scenario-2*– can ITER PF system cope with it?

β_p (top) and Inner gap (bottom) time evolution following "expected*" fast (blue/green), slow (black) and "unexpected" fast H-L transition (red)

**) "expected"=highest gain and ideal controller*



Transport models for L-H and H-L transition

Two models for L-H and H-L transitions were used in simulations- “global” and ”local” models;

- In *“global approach”* the code compares total heat flux through the selected magnetic surface (either top-of-barrier or deeper inside, for code stability) with most recent parametric fits for L-H transition power threshold from Martin et al. J. Phys 2008 (including an atomic mass dependency):

$$P_{L-H} = 0.0488 \cdot n_{e,20}^{0.717} \cdot B_t^{0.803} \cdot S^{0.941} \cdot \left(M/2\right)^{-1}$$

- In *“local approach”* the code compares electron temperature at the selected magnetic surface (normally on top-of-barrier or anticipated top-of-barrier) with the “local” parametric fits for the electron temperature at L-H transition (from *E. Righi et al, Plasma Phys. Control. Fusion* ***42*** *(2000) A199–A204*):

$$T_{crit,keV} = 0.39 n_{e,20}^{-0.64} B^{1.69} M^{-0.14} q_{95}^{-0.86}$$

Transport models for L-H and H-L transition

After either comparing the heat flux Q with the power threshold P_{LH} in "global" approach or $T_{e,top}$ with the critical temperature in "local" approach transport within edge barrier is modified in 3 possible ways:

✓ Plasma stays in L-mode if $Q < P_{LH}$ or $T_{e,top} < T_{e,crit}$;

✓ Plasma enters H-mode with type-III ELMs if $P_{LH} < Q < \gamma * P_{LH}$, $1.5 > \gamma > 1$ or $T_{e,crit} < T_{e,top} < \zeta T_{e,crit}$, $\zeta < 2\text{–}4$.

✓Transport within edge barrier is reduced to neo-classical level between ELMs.

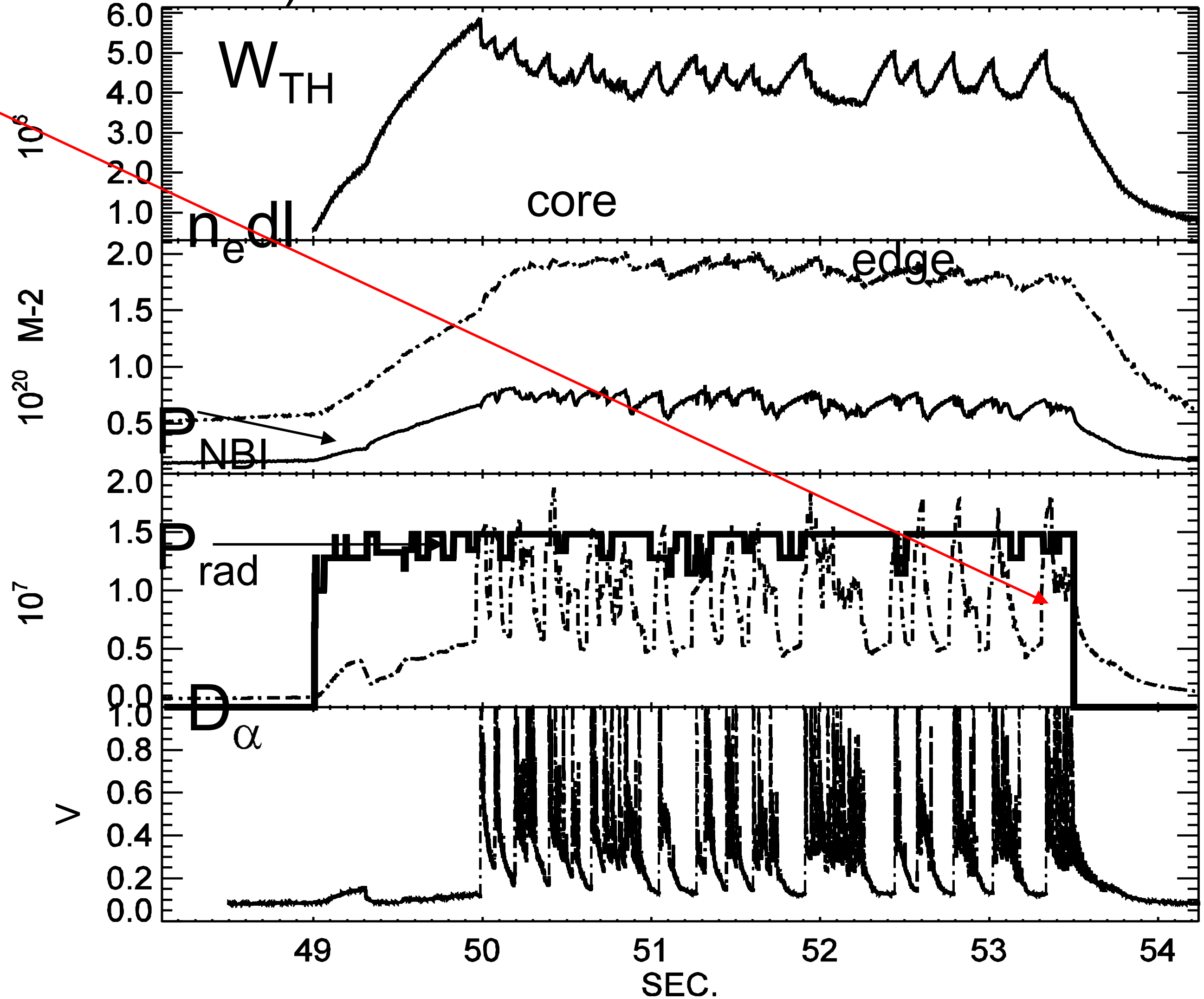
✓Type-III ELMs are similar to type-I ELMs (with Gaussian increase in edge transport coefficients) but with lower value of critical pressure gradient $\alpha_{cr\text{-}III} < 1$;

✓ Plasma enters H-mode with type-I ELMs if $Q > \gamma * P_{LH}$ or $T_{e,top} > \zeta T_{e,crit}$ with type-I ELMs having higher value of critical pressure gradient $\alpha_{cr\text{-}I} \sim 1.8$

Transport models for L-H and H-L transition

- We simulate all main plasma profiles including ion density and, in some simulations, impurity;
- Modelling of ion density (and impurity) is probably the most difficult task since it involves modelling of cold neutrals, which originate in the SOL;
- Modelling on density pump out following H-L transition is even more difficult as it involves not only SOL physics but also plasma-wall interaction and neutrals removal by the cryopumps;
- Since we do not include SOL modelling in simulations presented here, we assume that all neutrals and impurities originate at the separatrix;
- We also assume that outgoing ions are recylced from the separatrix with REC<1.

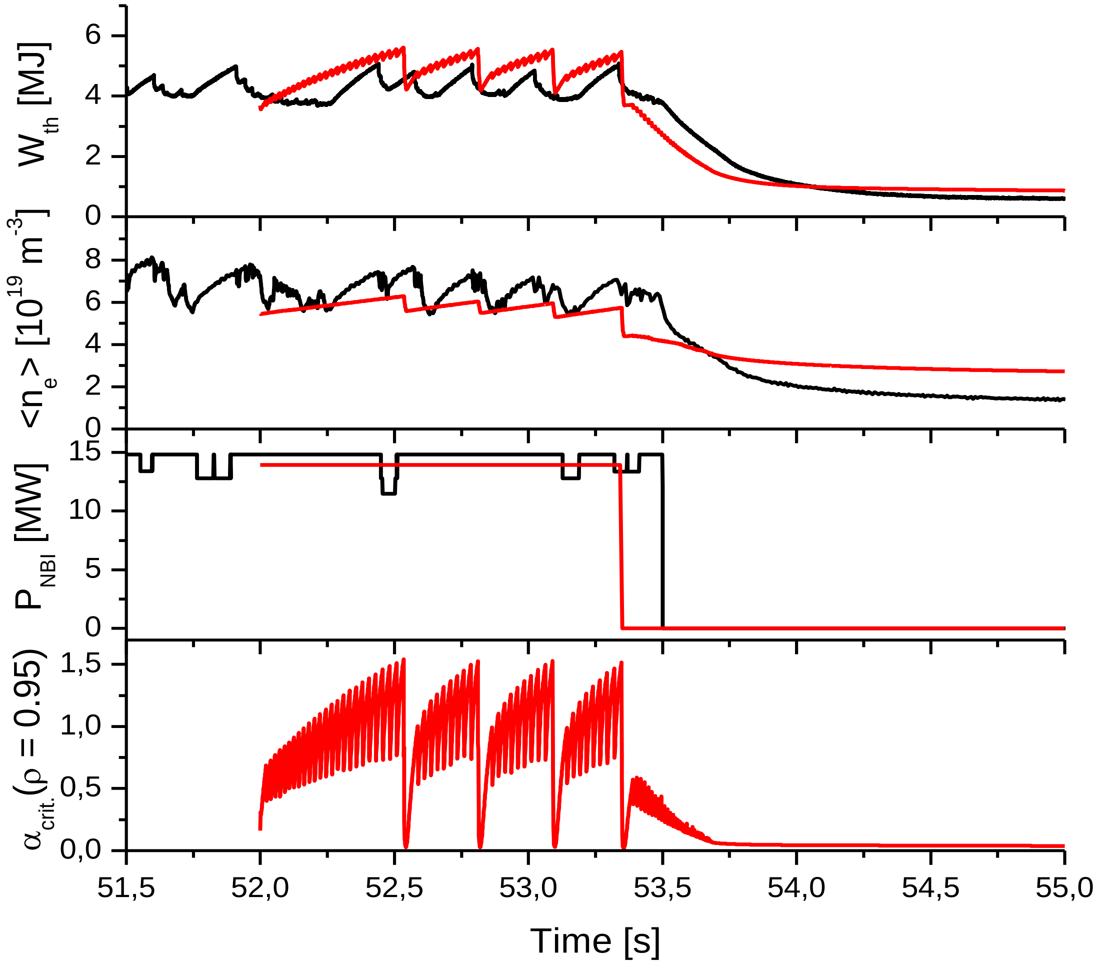
A typical JET H-mode plasma with composite ELMs and fast H-L transition, which is used as a template in our simulations (note a significant increase in *line radiation* after each ELM).



- Non-local model can be tuned to give the temporal evolution in W_{th} qualitatively in line with experiment;
- Density trend is not so well reproduced (adjustment of recycling could help);
- Discrete ELM model undergoes a series of repetitive L-H-L transitions caused by sudden energy flux drop after L-H transition, which are not usually observed in experiment

•JET #72207: preliminary data

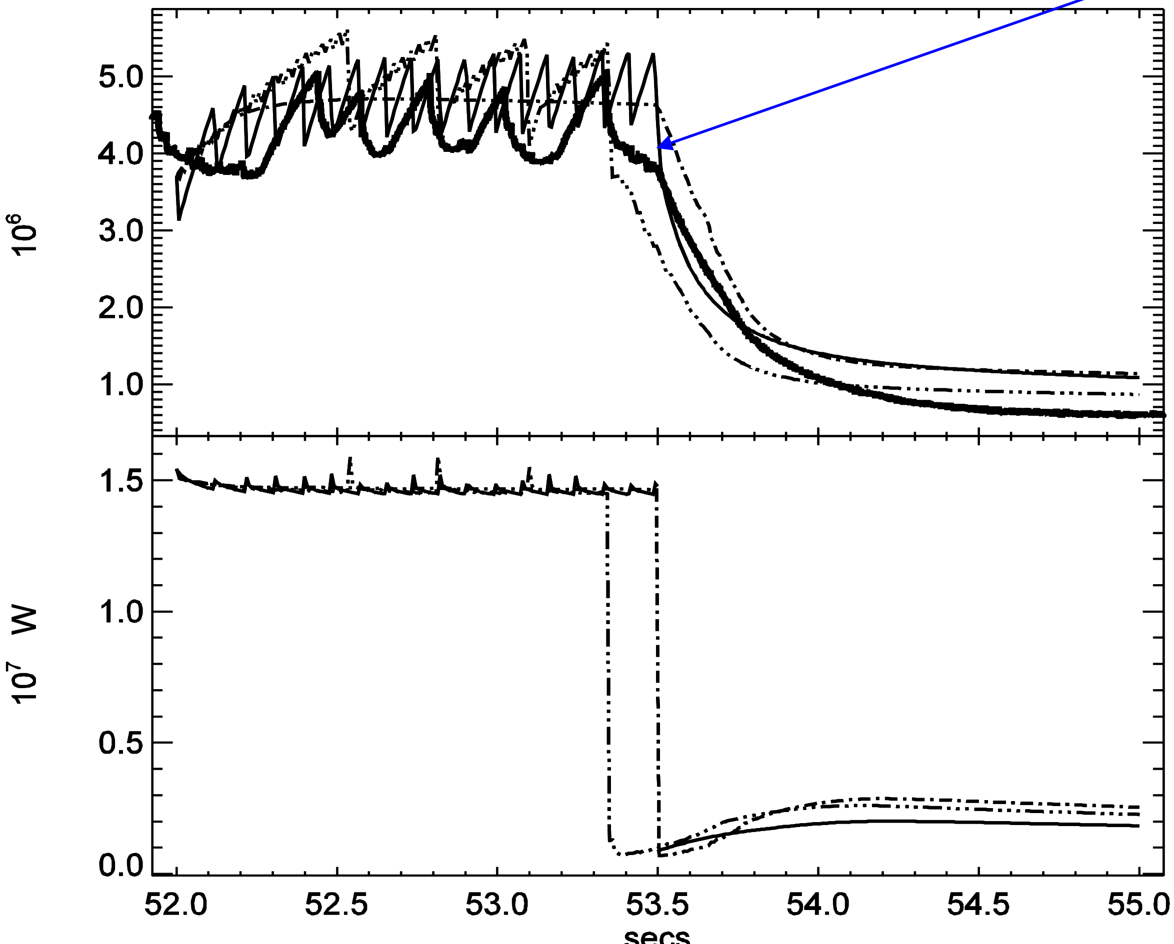
•Discrete ELM model



"Non-local" model (2)

It is important to stress that description of H-L transition, which includes transition to type-III ELMs (two broken lines, one with discrete and one with continuous ELMs), matches experimental observation much better than instant transition to L-mode.

Instant H-L transition



$$\frac{T_e^{0.9}}{T_{crit}} < 1 \Rightarrow$$ **L-mode**

$$1 < \frac{T_e^{0.9}}{T_{crit}} < B_{III-I} \Rightarrow$$ **type-III H-mode**

$$B_{III-I} < \frac{T_e^{0.9}}{T_{crit}} \Rightarrow$$ **type-I H-mode**

$2<B_{III-I}<4$

$$T_{crit,keV} = 0.39 n_{e,20}^{-0.64} B^{1.69} M^{-0.14} q_{95}^{-0.86}$$

Righi PPCF (2000)

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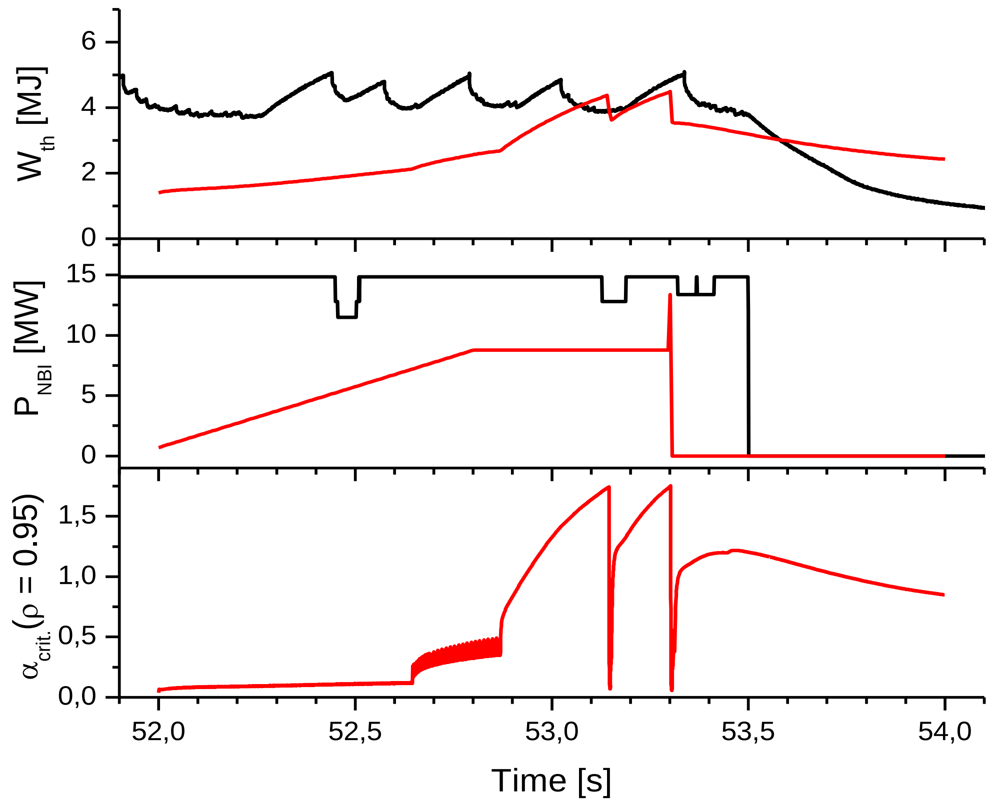
Local model



Comparison between "Global" and "Local" model

- Local model avoids non-physical dithering transitions of the non-local model
- Reasonably good description of the L-H transition
- Fails to describe the fast fall in energy and density during H-L transition
- Possible ways to improve model include:
  - *Fine tuning of heat and particle transport within barrier;*
  - *Include radiation;*
- No validated multi-machine local model exists!

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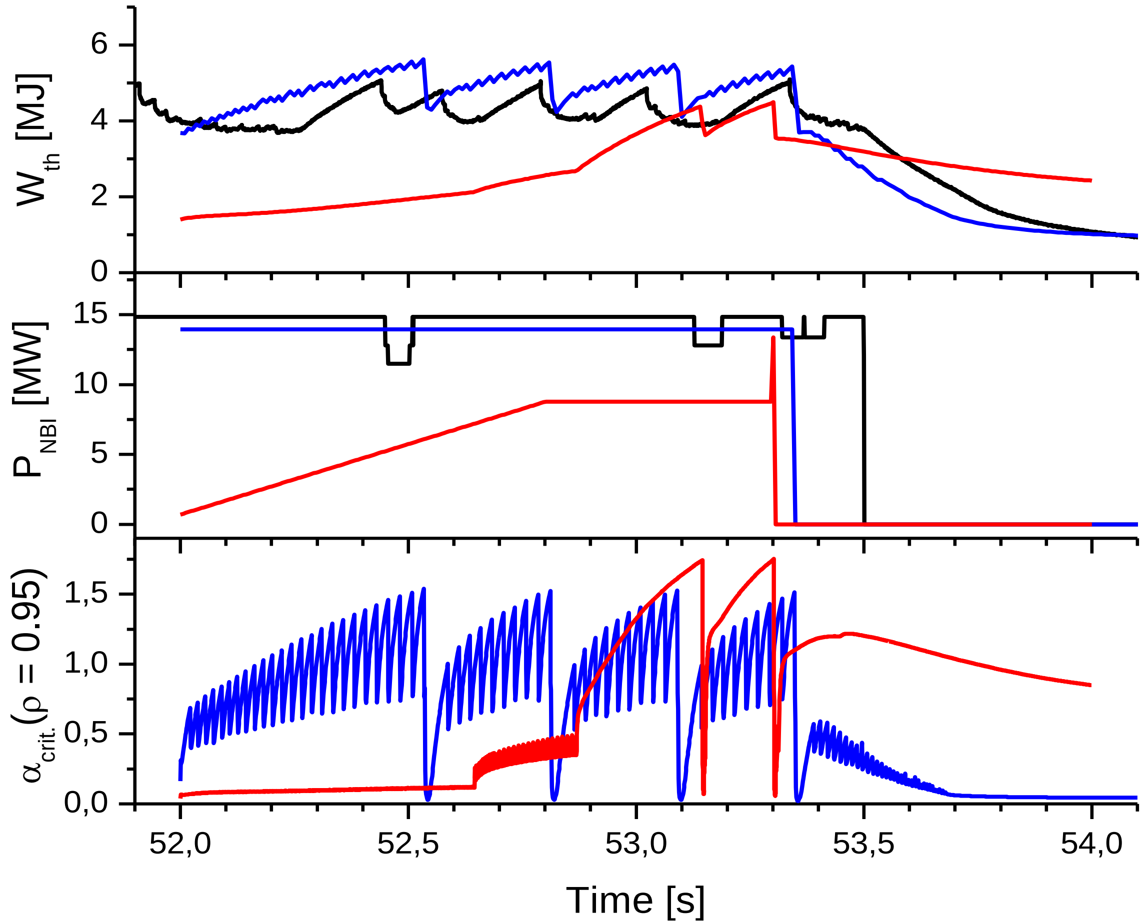
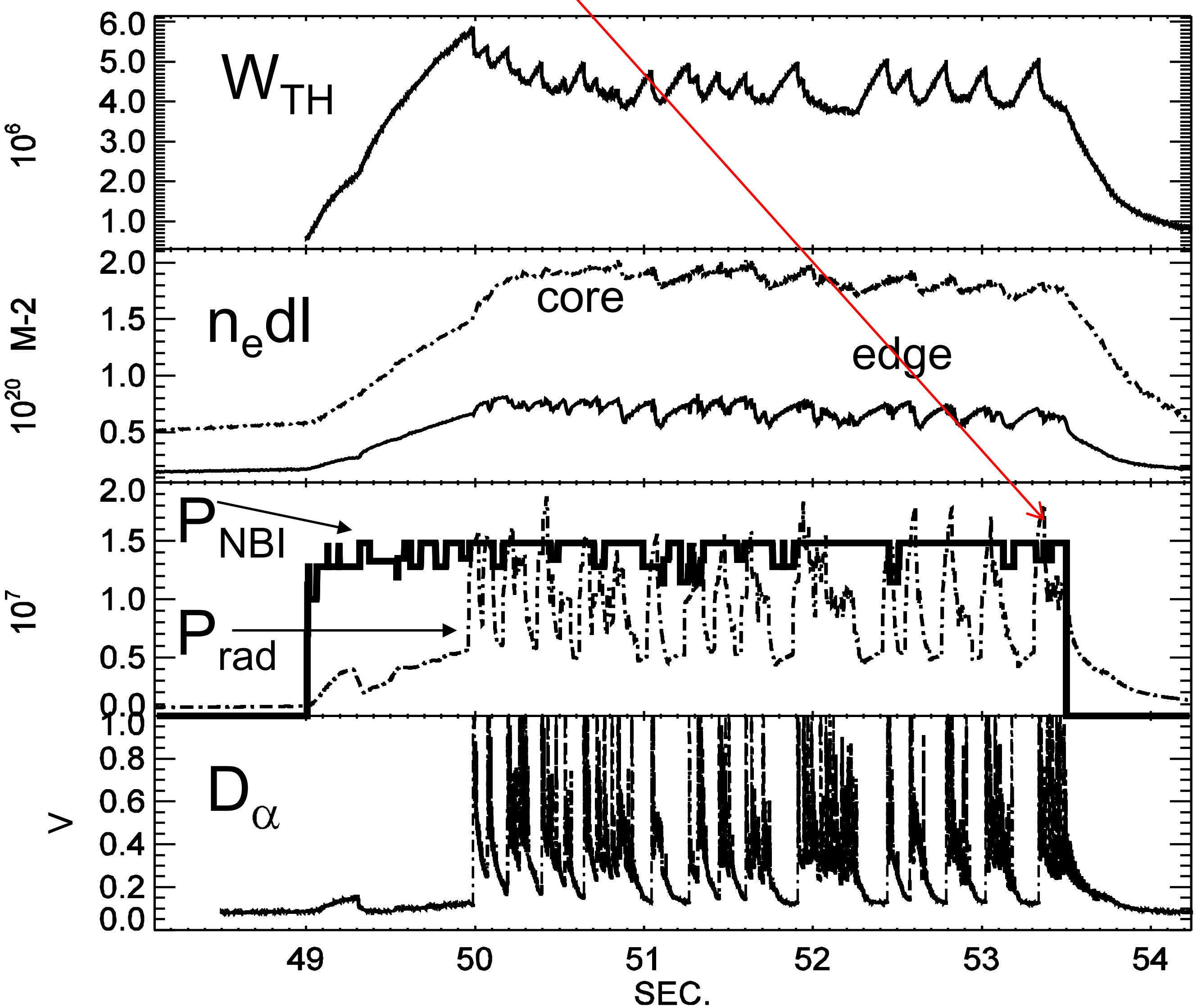
Local model

Non-local model



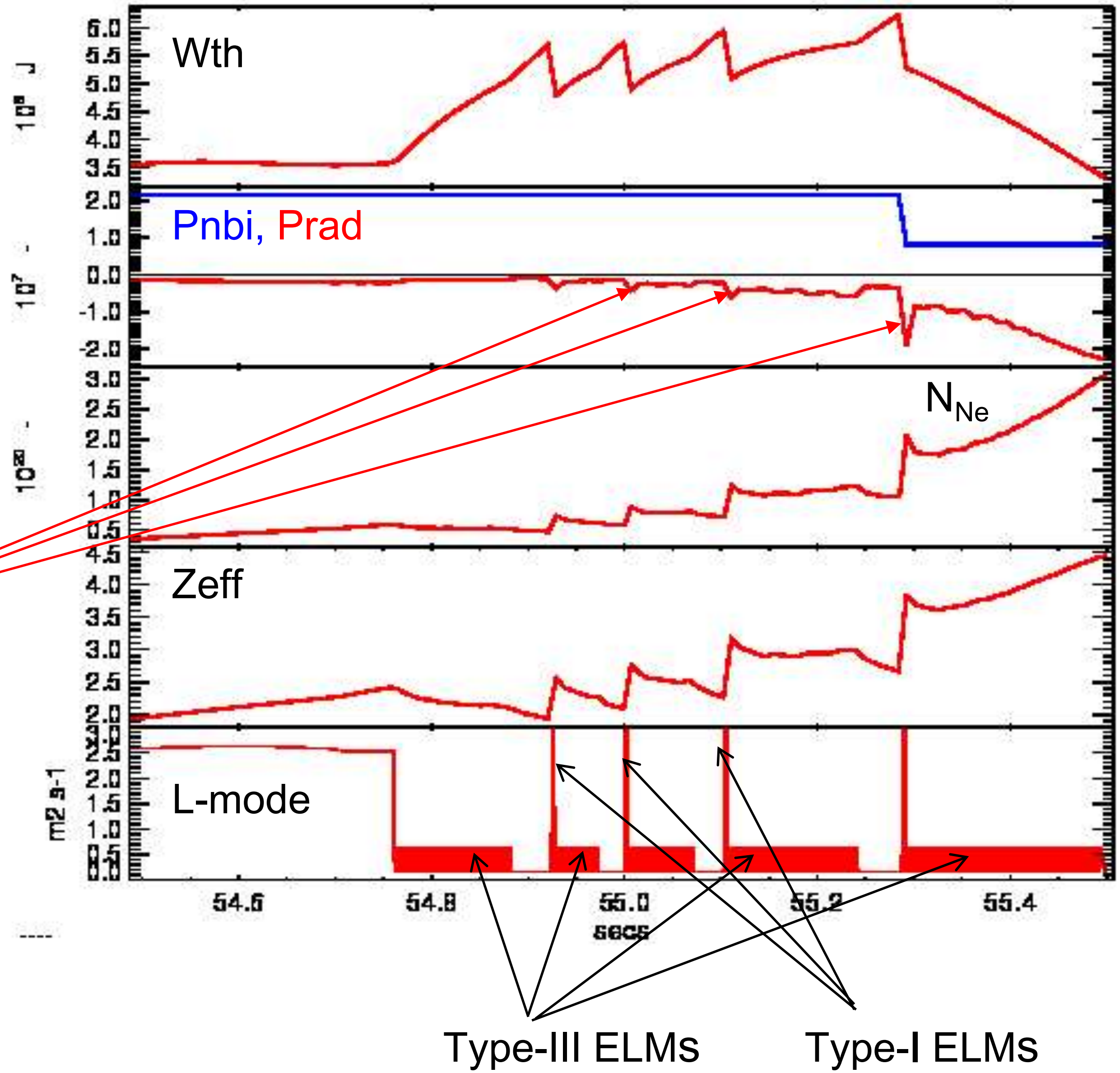
Role of radiation (1)

(note a significant increase in *line radiation* after each ELM).



Role of radiation (3)

- Recent example of self-consistent predictive modelling of impurity redistribution on top of main ion density and ion and electron temperature simulation;
- Note significant temporary rise in line radiation following each type-I ELM (as observed in experiments)



Summary and unresolved issues

✓ *Global model describes better H-L transition but fails to reproduce L-H transition due to persistence of strong dithering;*

✓ *On the other hand, local model reproduces the dynamics of L-H transition reasonably well but fails to reproduce fast H-L transition;*

✓ *Much more work is needed to bring density evolution in better agreement with experiment;*

✓ *Impurity radiation might play an important role in the dynamics of H-L transition;*

✓*Systematic comparison with experimental results are needed before applying either model to ITER.*

backup

"Non-local" model (1)

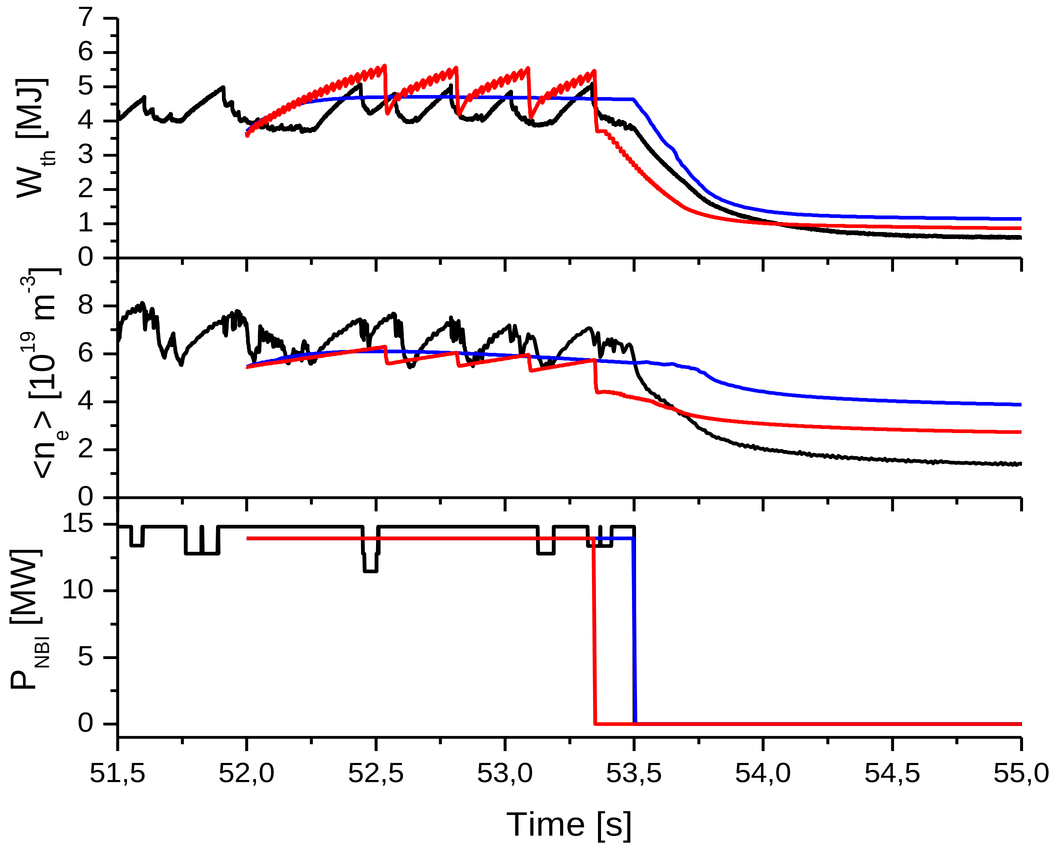
$$\frac{P_{loss}\ 0.8}{P_{Martin08}} < 1$$ ⇒ **L-mode**

$$1 < \frac{P_{loss}\ 0.8}{P_{Martin08}} < A_{III-I}$$ ⇒ **type-III H-mode**

$$A_{III-I} < \frac{P_{loss}\ 0.8}{P_{Martin08}}$$ ⇒ **type-I H-mode**

$1<A_{III-I}<1.5$

- **JET #72207: preliminary data**
- **Continuous ELM model**
- **Discrete ELM model**



$$P_{Martin08} = 0.0488 n_{e,20}^{0.717} B^{0.803} S^{0.941}$$

Martin PPCF (2008)

$P_{loss}\ 0.8$ loss power at ρ=0.8

Role of radiation (2)

- Adding some impurity radiation after big ELM crash helps to bring plasma to a long type-III period even with local H-L transition model;