19th International Workshop on H-mode Physics and Transport Barriers

Pedestal structure and stability of high-performance scenarios with I-mode-like pedestals in JET with the Be/W wall

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Content of the talk

Two very different high-performance scenarios at low density (f_{GW}<0.5) with no/small ELMs in stationary conditions for density and radiation have been recently achieved in JET

A baseline scenario at low q_{95} (=3.2, 3 MA), with moderate NBI power (20-25 MW) and where the gas fuelling is completely removed (known as **'no-gas' Baseline Small ELMs** (BSE) regime)[1,2]

A high-performance scenario at lower I_p=1.9-2.5 MA (q_{95}=4.5) with dominant electron heating (ICRH) and low torque, explored in D and D-T plasmas [3]

- Heat and particle transport decoupled in the pedestal region:
  - H-mode-like temperature pedestal
  - weak pedestal ∇n_e

Similar to I-mode plasmas
BUT no edge WCM observed

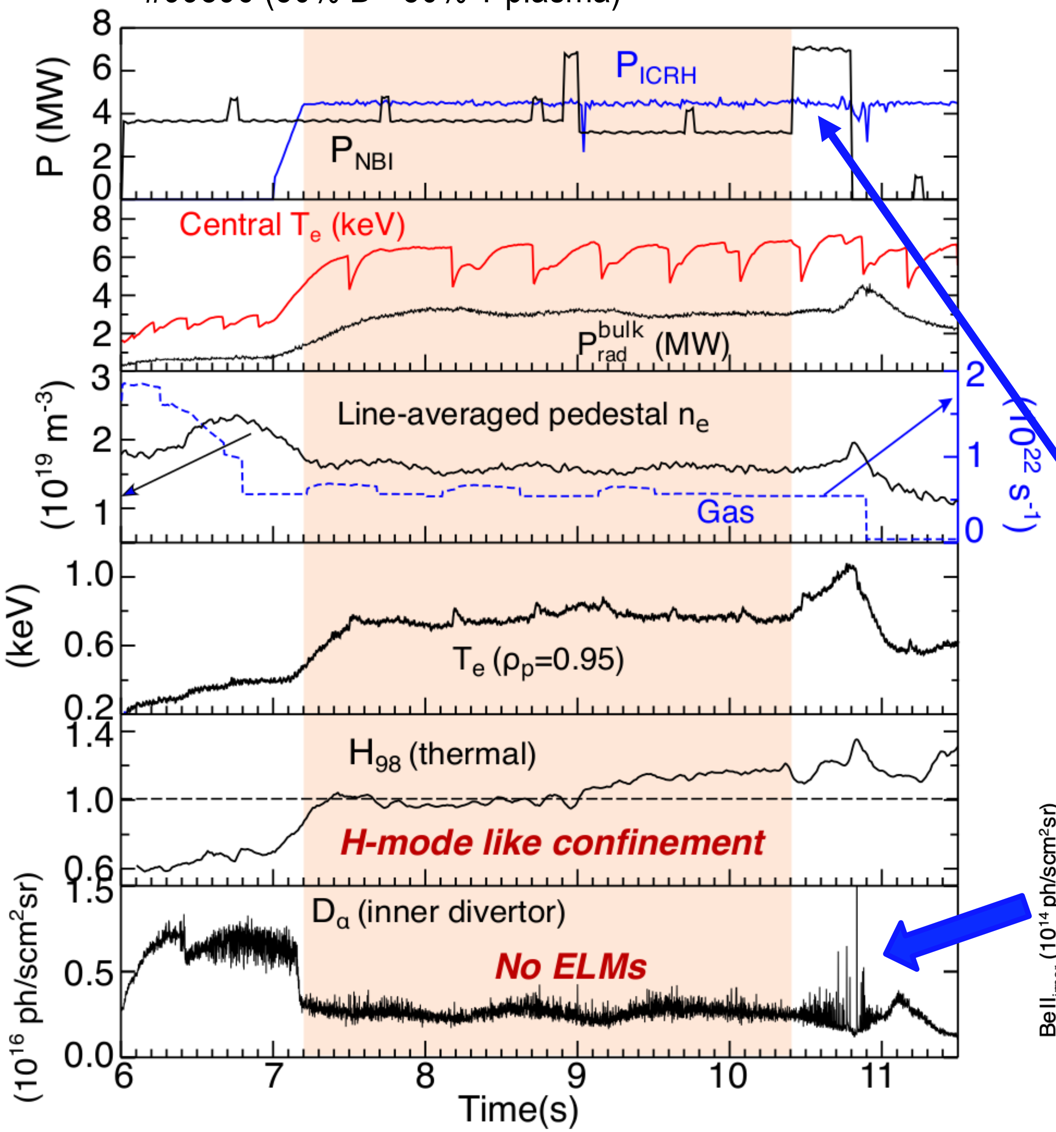
↓

'I-mode-like pedestal'

(also seen in low density H-mode access experiments [4])

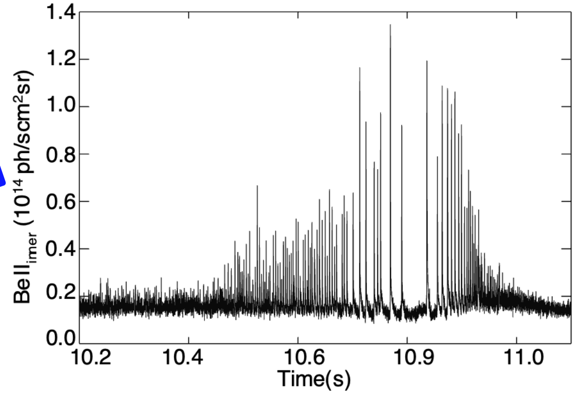
*[1] J. García et al., Physics of Plasmas **29** (2022) 032505*
*[2] E. de la Luna et al., Nuclear Fusion **64** (2024) 096014*
*[3] J. García et al., Nature Communications **15** (2024) 7846*
[4] E. Delabie et al, APS conference, 2016

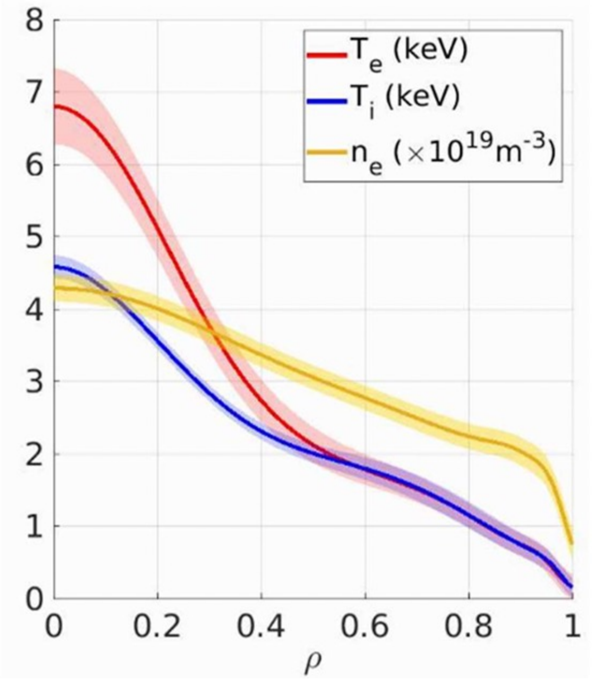
High confinement regime with no large ELMs observed in DT plasmas with dominant electron heating and low torque



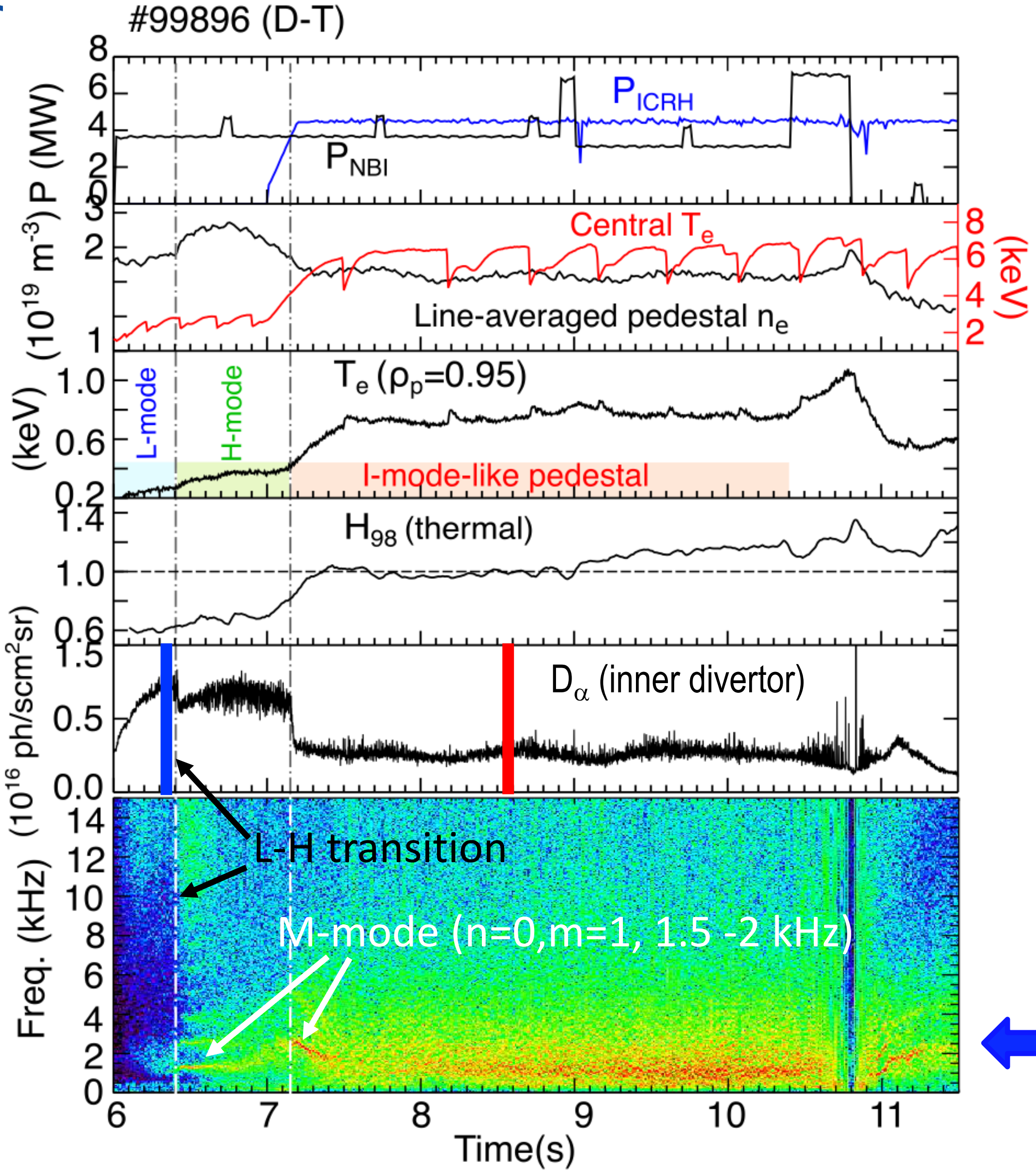
- **D-T plasmas** (1.9 MA, 2.8 T, q_{95}=4.5), f_{GW}=0.45
- High electron heating and low torque (low NBI + ICRH): $T_{e,0}/T_{i,0}$~1.4
- Good impurity transport properties (no impurity accumulation)
- **Good energy confinement ($H_{98,thermal}$ =1-1.2) with no ELMs**
- Pronounced increase in $T_{e,ped}$ without an increase in density
- Observed also in D plasmas, but it requires more heating power

ELMs return with increasing power

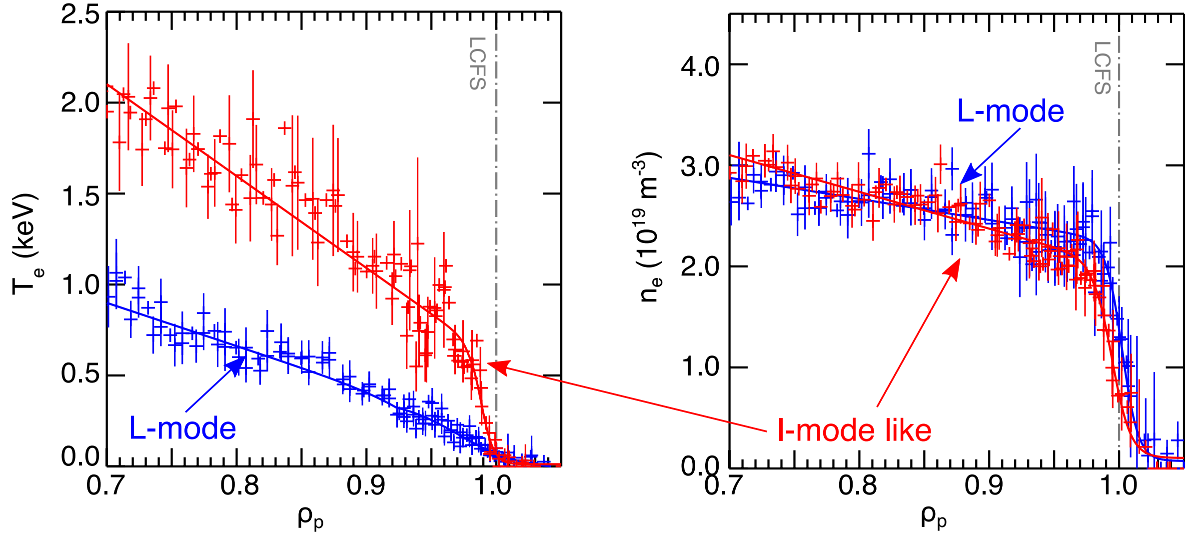




I-mode-like pedestals in DT plasmas

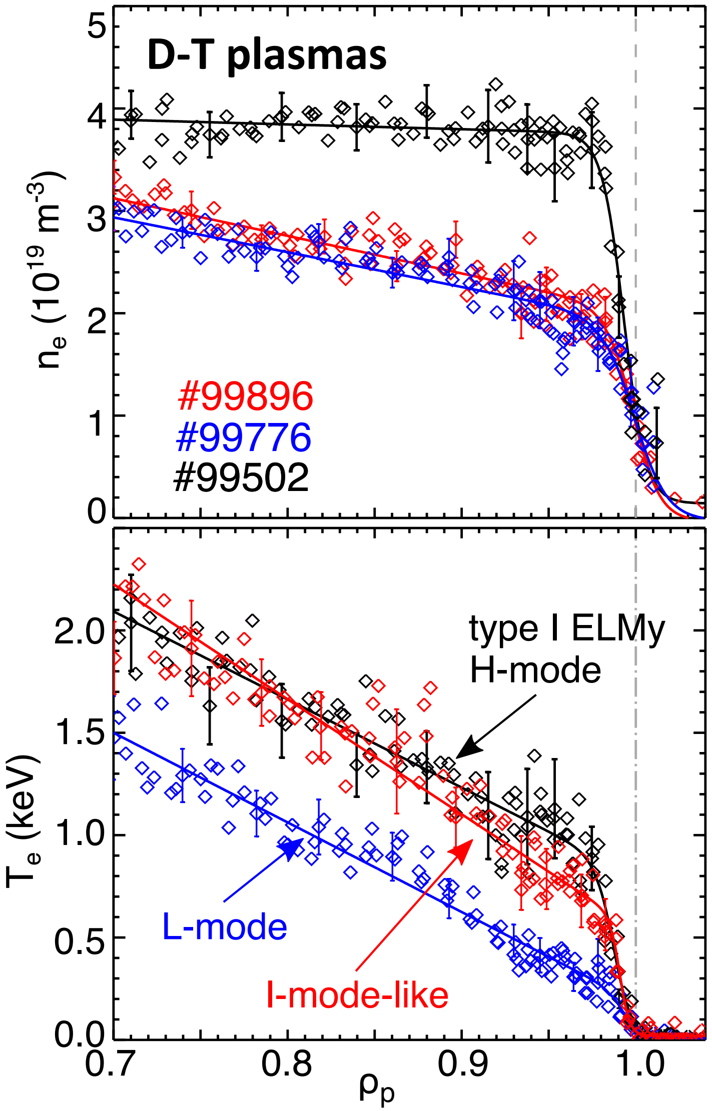


- **H-mode-like confinement ($H_{98,thermal}$ =1-1.2) with an I-mode-like pedestal:**
  - H-mode-like temperature pedestal (with $T_{i,ped} = T_{e,ped}$)
  - weak density gradient (similar to that observed in L-mode)
- No ELMs (weak ∇n_e → low ∇P)

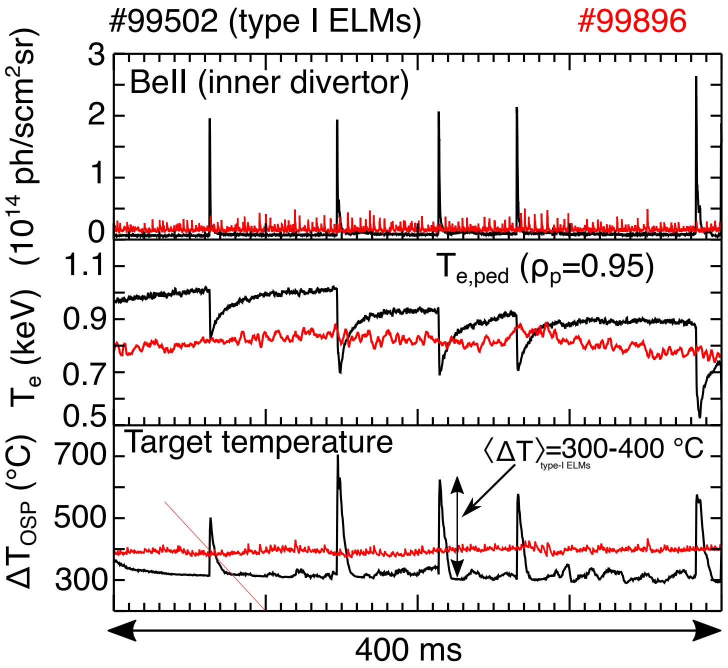


M-mode used to identify the L-H transition in JET

Similar to I-mode but with differences



- This high confinement regime has good impurity transport properties (no W accumulation) and pedestal profiles similar to those observed in I-mode plasmas, BUT:
  - favourable ion ∇B drift for H-mode access
  - no sign of edge coherence MHD activity (WCM)
- Plasma regime obtained close to the L-H transition, and therefore requiring low heating power



In the regime with an I-mode like pedestal:

- No ELMs
- Filaments observed in BeII/WI/D_α divertor signals but with no significant impact on pedestal or divertor IR signals

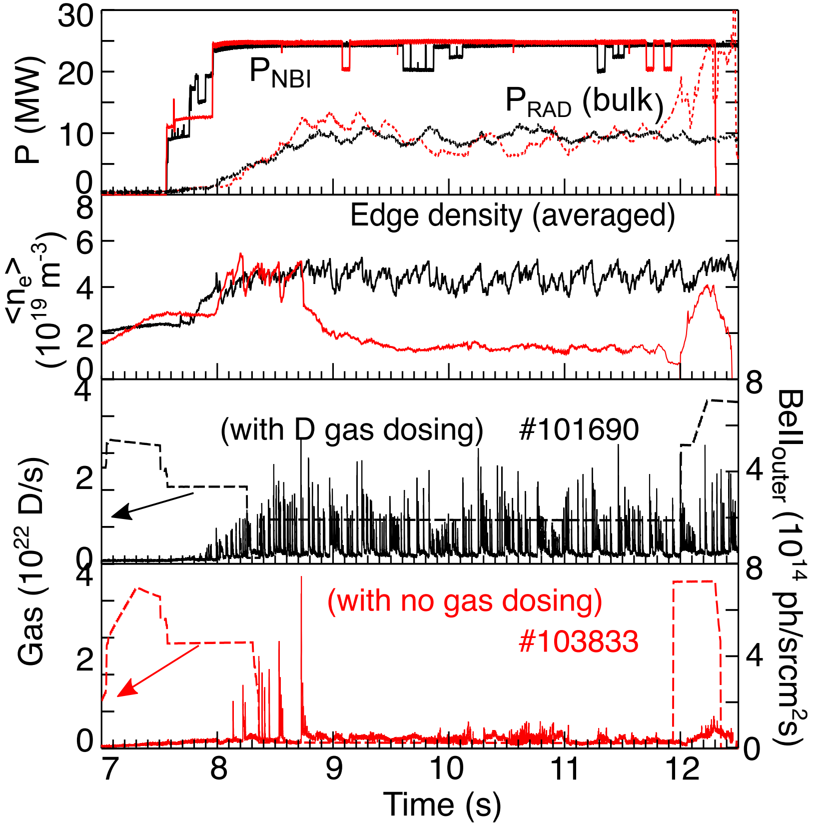
High performance H-mode regime, with small ELMs at low $\nu^*_{e,ped}$

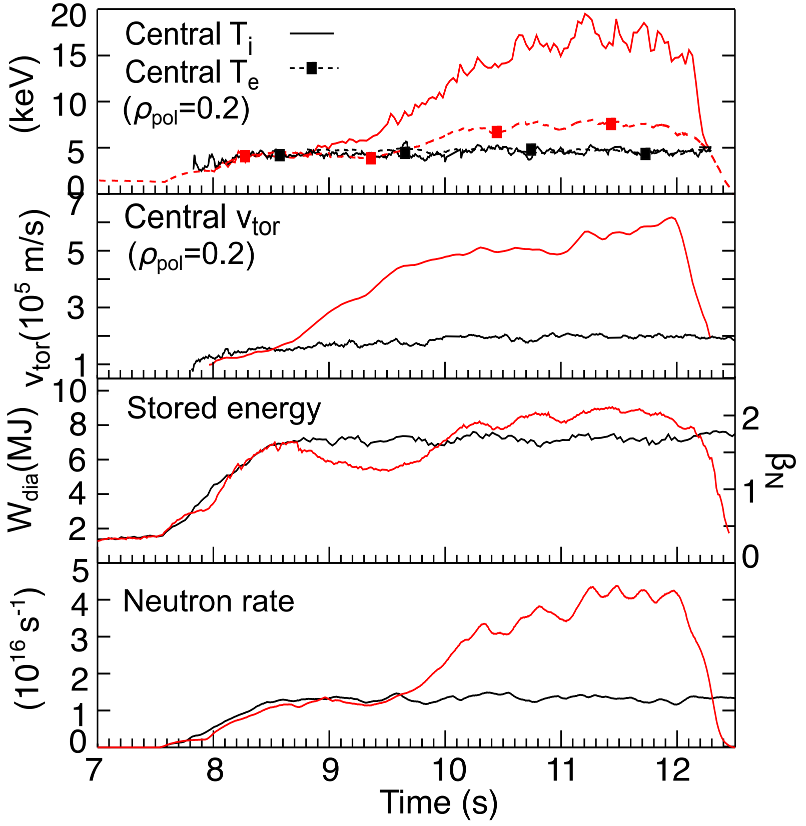
- Baseline regime: low q_{95} =3.2 (3 MA), β_p<1, β_N=1.8-2
- **Low edge collisionality ($\nu^*_{e,ped}$~0.1)**
- Small ELMs
- No impurity accumulation
- T_i (neutron rates) and stored energy reach quasi-stationary conditions for 1-1.3 s (~ 5-6 τ_E)

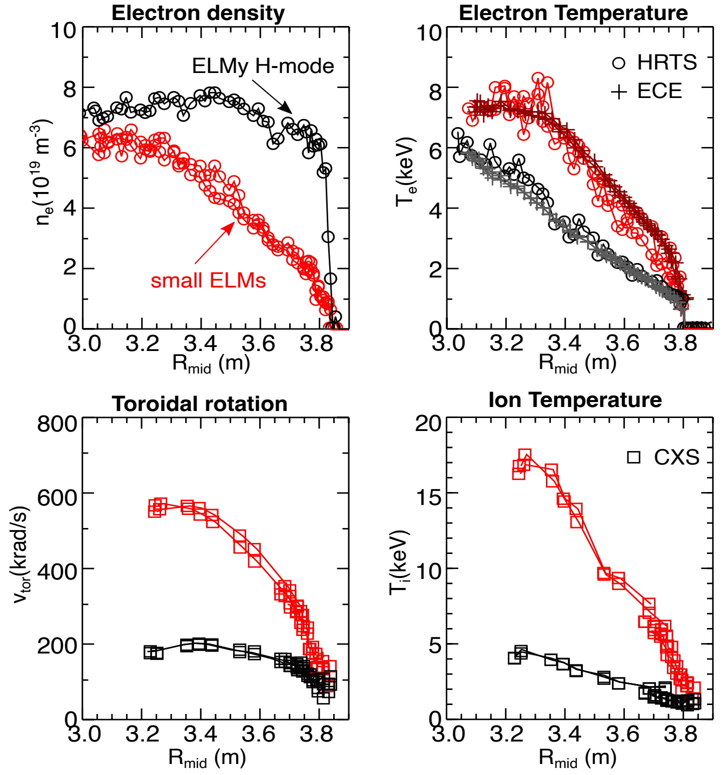
Compared to conventional ELMy H-mode:

- low plasma density (f_{GW}=0.35)
- higher T_i (at the pedestal and in the core, with T_i>>T_e)
- better confinement and stronger rotation
- higher DD neutron rates

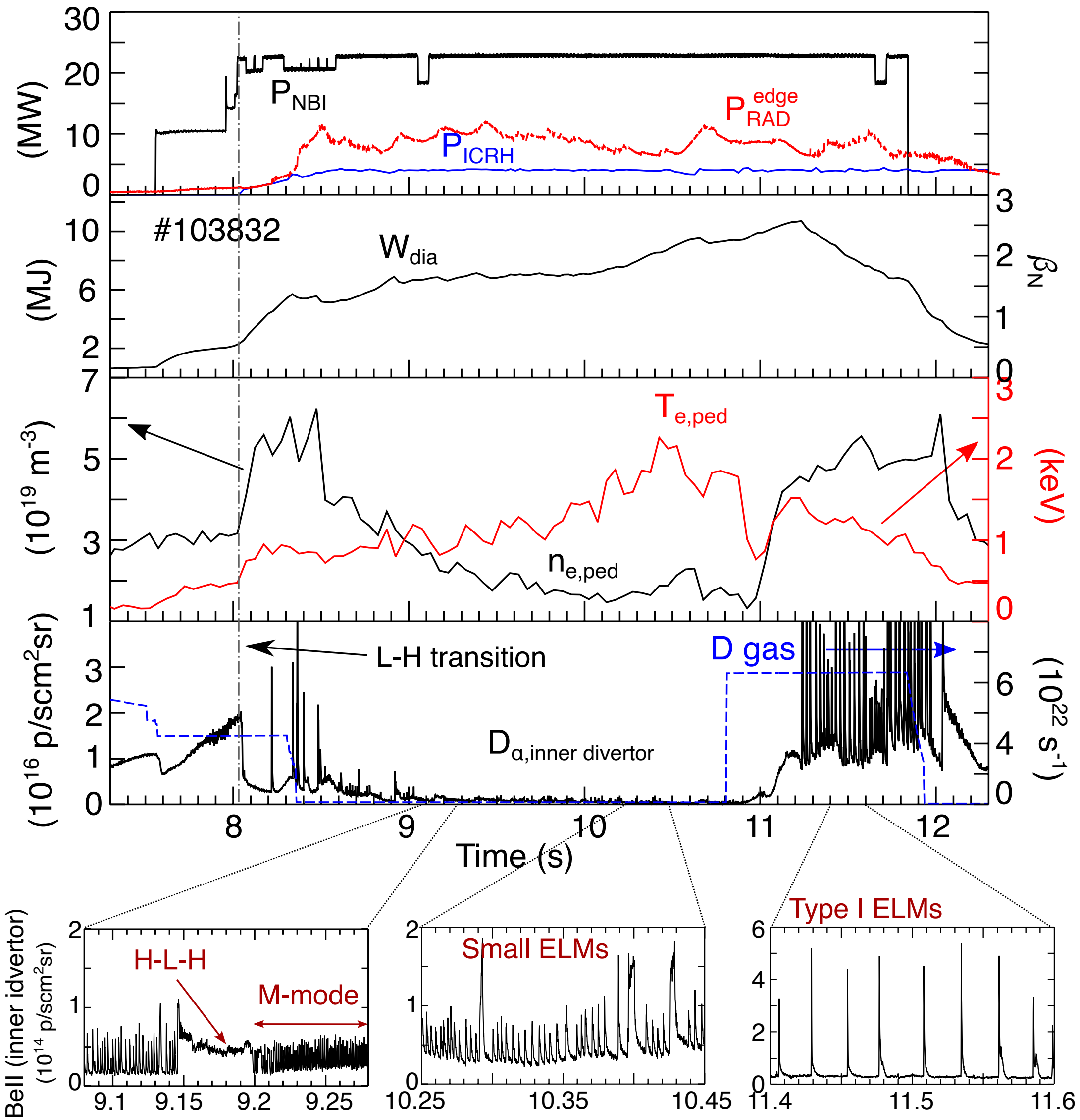
→ Similarities with 'hot-ion' in JET-C but also clear differences



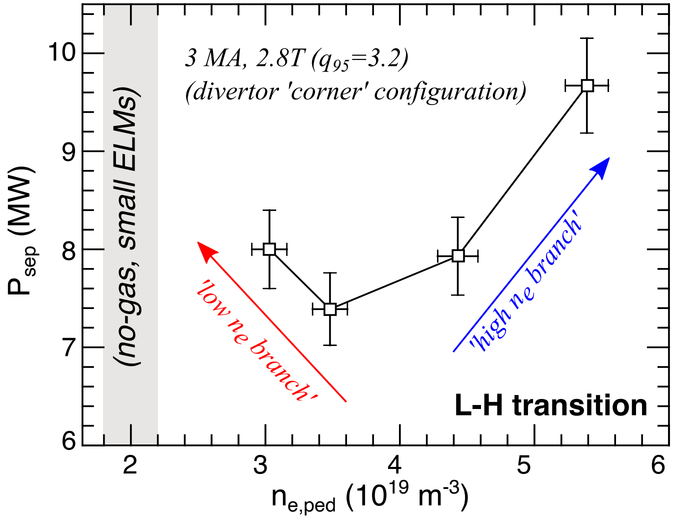




Small ELMs access linked to operation high P_{LH} ('low density branch')

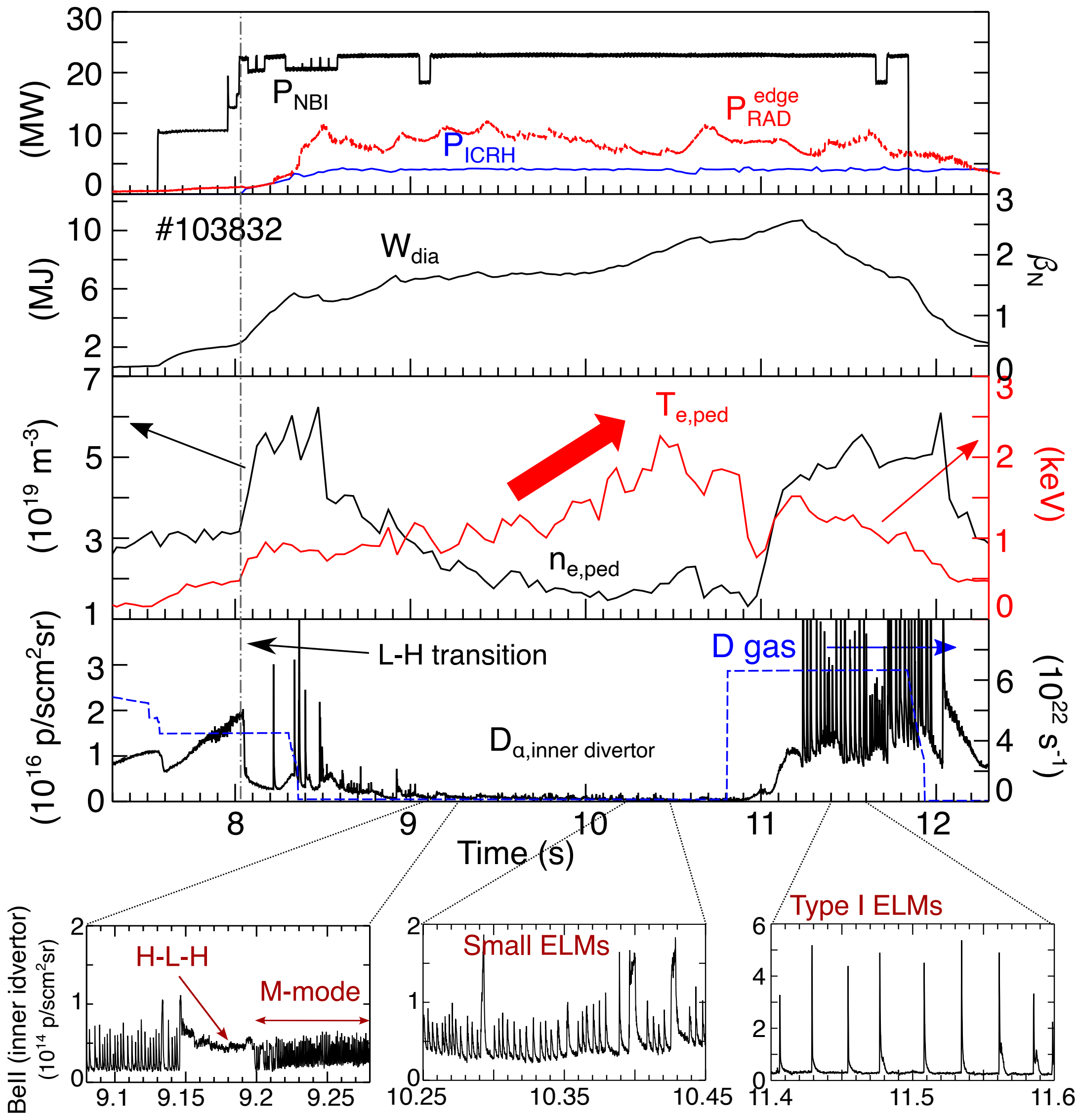


- D_α divertor signals indicate operation close to the L-H transition, despite $P_{sep}/P_{LH}^{ITPA-08}$ ~1.45
- Type I ELMs return with increasing $n_{e,ped}$ (& ∇n_e)(gas fuelling)
- Dedicated experiments confirmed that plasmas with no-gas and small ELMs operate in the 'low density branch' of the L-H threshold power (favourable ion ∇B drift for H-mode access)



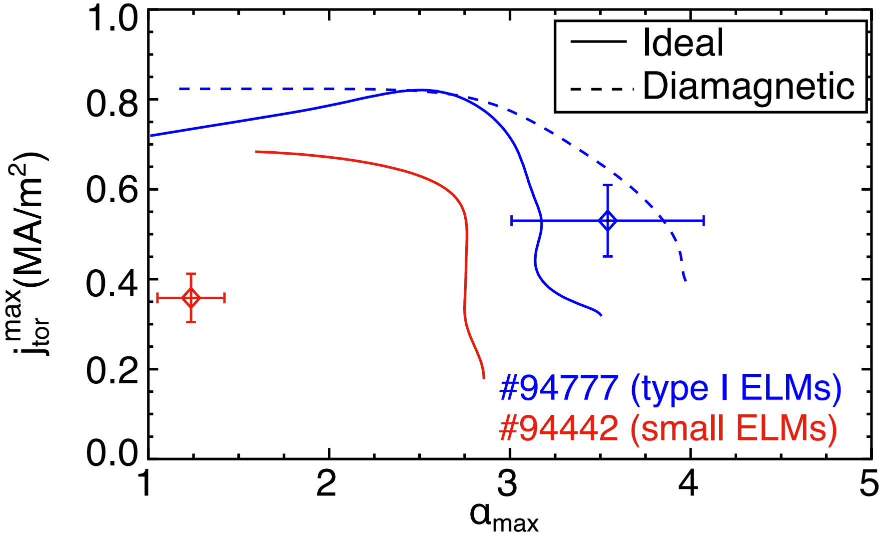
Courtesy of E.R. Solano

Heat and particle transport decoupled in the pedestal region



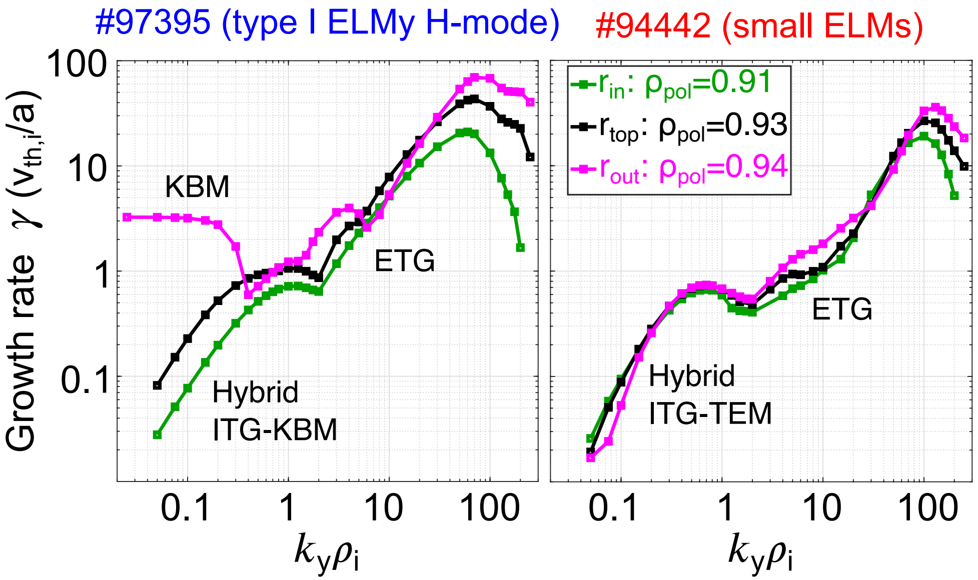
- Operation at low P_{sep}/P_{LH} ('low density branch')
  - → D_α divertor signals indicate operation close to the L-H transition, despite $P_{sep}/P_{LH}^{ITPA-08}$ ~1.45
- Plasmas with no-gas and small ELMs operate in the 'low density branch' of the L-H threshold power (favourable ion ∇B drift for H-mode access)
- Large $T_{e,ped}$ (T_{iped}>$T_{e,ped}$) with H-mode like pedestal T_e profile, but weak ∇n_e (low $n_{e,ped}$, wide pedestal density profile):
  - → **heat and particle transport decoupled in the pedestal region,** similar to I-mode plasmas, but no edge WCM

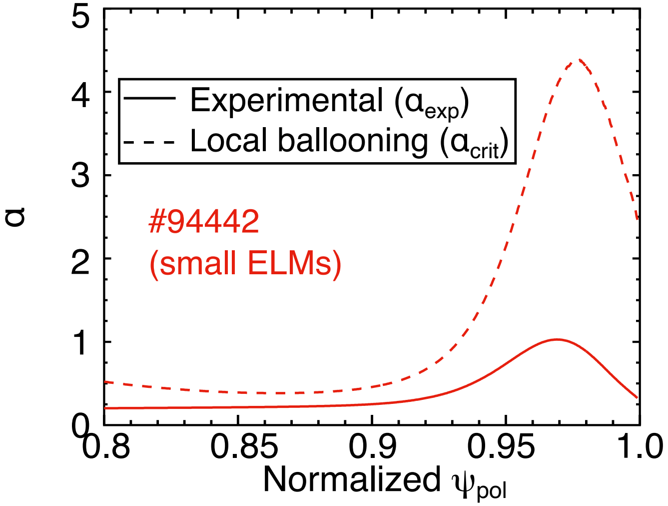
Pedestal are well below pedestal linear MHD limits, explaining lack of type I ELMs



- Pedestal in unfuelled BSE discharges (small ELMs) are well below linear MHD limits for P-B modes:
  - low ∇n_e → lower ∇P and lower $j_{boots.}$
- Different instabilities regulating the pedestal [5]:
  - type-I ELMs: KBM unstable
  - small-ELMs: hybrid ITG-TEM (w/o KBM)

[5] M. Dicoratto, submitted 2024





- α_{exp} is far from the local ballooning predictions across the entire pedestal profile → different from the QCE regime[6] where $\alpha_{exp} = \alpha_{crit}$ at the separatrix (higher $\upsilon^*_{e,ped}$, higher $n_{e,SOL}$)

[6] M. Dunne, EPS invited 2024

Conclusions & open questions

- Recent experiments in JET have shown that operation at low density opens a path for developing plasma regimes that allow simultaneous access to **good energy confinement in stationary conditions with no/small ELMs and no impurity accumulation.**
- **H-mode-like confinement with an I-mode-like pedestal**. BUT, in contrast to observations of the I-mode regime in other devices, no edge coherent MHD activity (WCM)
- The access conditions with very no/small ELMs at low density in JET do not depend on the heating mix or the isotope plasma composition. In both regimes, plasma operates close to the L-H transition

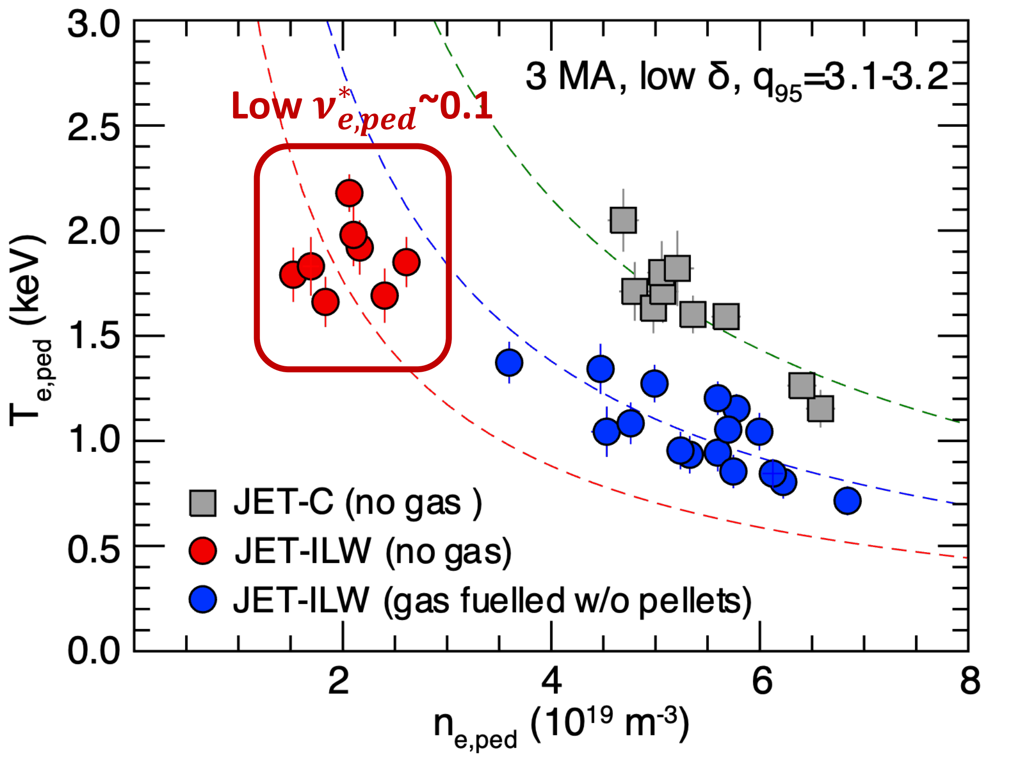
These regimes provide a valuable platform for further validation work using experimental data to refine and gain confidence in the predictions for ITER

- **Similarities with Q=10 ITER pedestal:**
  - low $n_{e,ped}/n_{e,sep}$ (high $n_{e,sep}$ in ITER, low $n_{e,ped}$ in JET) with high $T_{e,ped}$, $T_{i,ped}$
  - edge ∇P is primarily driven by temperature gradients rather than density gradients (as in ELMy H-mode plasmas)
- Open questions:
  - *why is there a thermal but not a particle barrier in the JET no/small ELM regimes?*
  - *what keeps the plasma stationary in those conditions? what causes the small ELMs?*
  - *what is the role of the Weakly Coherent Mode (WCM) in the I-mode regime? Is it an essential feature?*

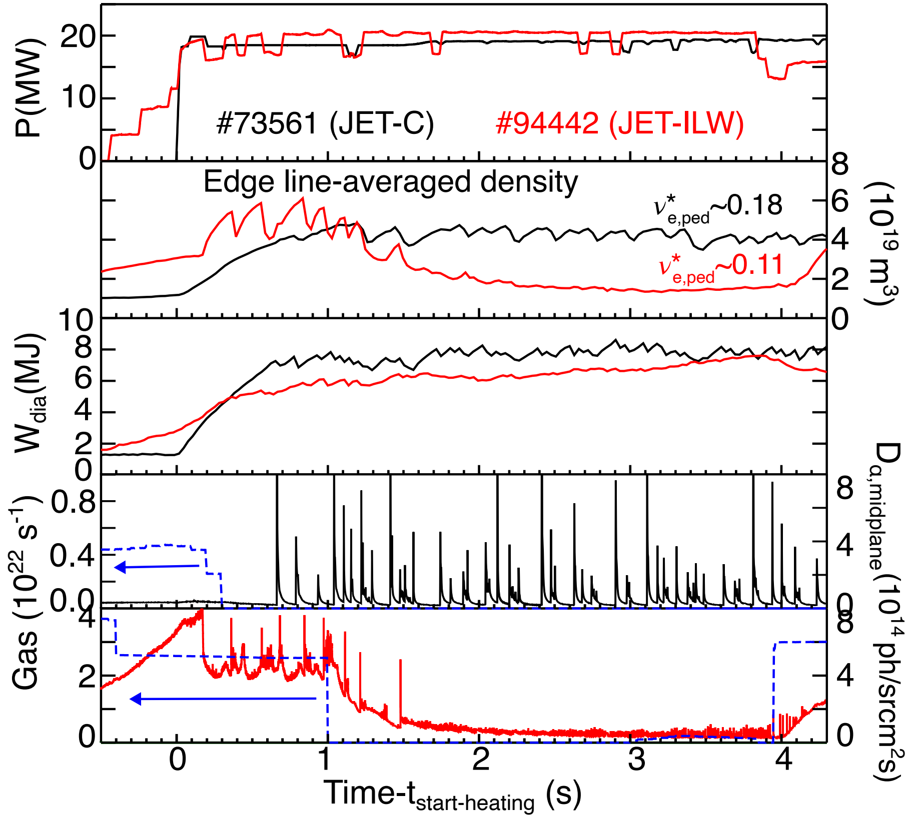
Additional material

Impact of wall materials on the access to small ELMs in JET

'natural' density (no gas injection, fuelling provided only by NBI) in JET-C is about twice that seen in JET with the Be/W-wall



Low frequency type I ELMs typically observed in low δ, unfuelled plasmas in JET-C



The lower recycling and wall retention of the Be-wall allowed access to a low-density regime (in the absence of external gas injection) that was not accessible with the C-wall