# ROLE OF THE SEPARATRIX DENSITY IN THE PEDESTAL PERFORMANCE IN JET-ILW AND JET-C

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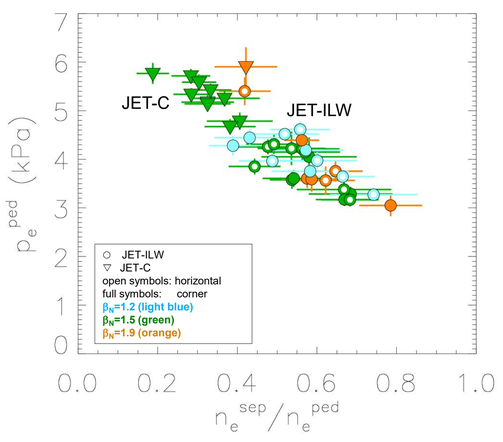
* see J. Mailloux et al., Nuclear Fusion Special Issue IAEA 2021

## INTRODUCTION

- JET has changed wall from carbon (JET-C) to metal (JET-ILW) in 2011. The initial results have shown a lower $p_e^{ped}$ in baseline JET-ILW plasma
- In recent years, confinement comparable to JET-C has been obtained. However:
  - the origin of the low pedestal is still unclear
  - the understanding the pedestal behavior is essential to improve pedestal predictions.
- Recent results in AUG and Alcator C-mod show that $n_e^{sep}/n_e^{ped}$ could be relevant parameter

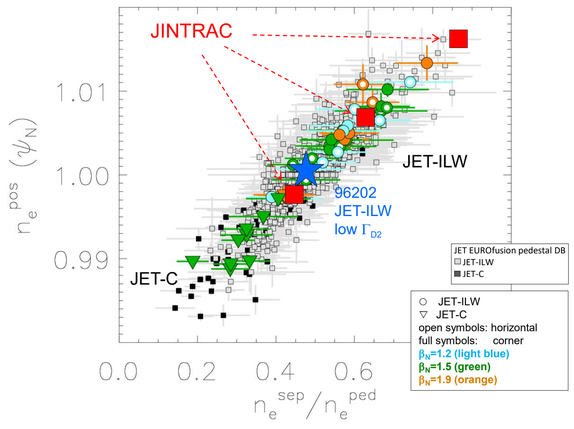
## PEDESTAL PRESSURE vs $n_e^{sep}/n_e^{ped}$.




**JET-ILW dataset:** (circles)
- Type I ELMs ($f_{ELM}$ increases with $P_{sep}$ at constant $\Gamma_{D2}$)
- 2MA / 2.3T / low-$\delta$ / deuterium
- Gas scans at constant $\beta_N$.
  - Three subsets:
    - ➢ $\beta_N$=1.2 (blue), $\beta_N$=1.5 (green), $\beta_N$=1.9 (orange)
  - $\Gamma_{D2}$=0.4·10$^{22}$ - 6.0·10$^{22}$ e/s
  - $P_{NBI}$=8-22MW
  - $T_i$=$T_e$ (within 10%)
  - two divertor configurations: horizontal and corner.

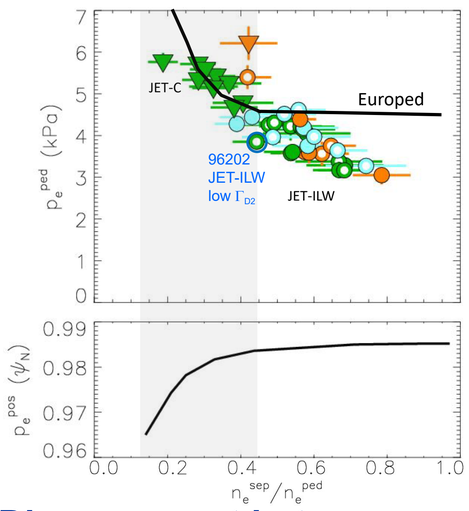
**JET-C dataset:** (triangles)
- 11 pulses at 2MA/2.3T, low-$\delta$
- $\Gamma_{D2}$ < 0.4·10$^{22}$ e/s

## $n_e^{sep}/n_e^{ped}$ AND DENSITY PROFILE



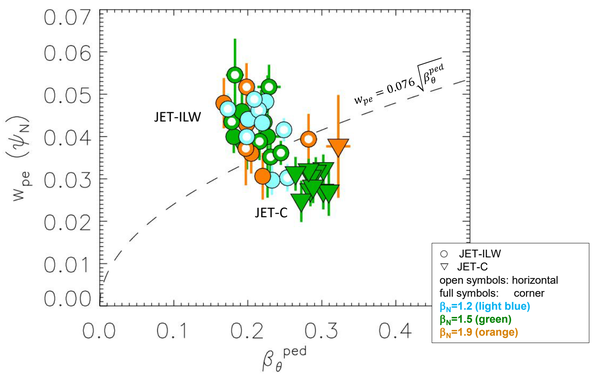

- The decrease of $n_e^{sep}/n_e^{ped}$ is correlated with a radial inward shift in the pedestal $n_e$ position
- The $n_e^{sep}/n_e^{ped}$ vs $n_e^{pos}$ corelation is very robust.
- JINTRAC has been used to test if the increase in $\Gamma_{D2}$ can reproduce the qualitivate trends
  - JINTRAC: EDGE2D-EIRENE in the SOL + JETTO in the core + simple model for the ELMs
  - Transport coeffiecient have been kept constant
  - increase of $\Gamma_{D2}$ lead to increase in modelled $n_e^{sep}/n_e^{ped}$ and $n_e^{pos}$
  - reasonable qualitative agreement

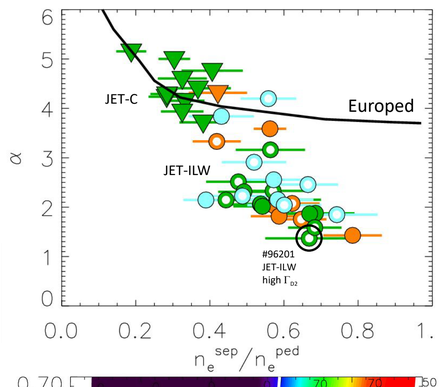
## Europed modelling: effect of $p_e^{pos}$ on the pedestal stability

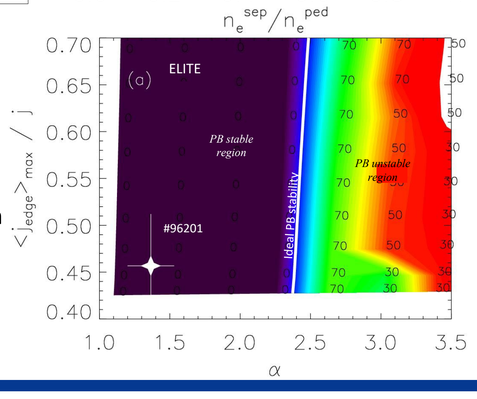



- Variation of $n_e^{pos}$ affects $p_e^{pos}$. Radial inward shift of $p_e^{pos}$ stabilizes ballooning modes and increase pedestal
- Europed (based on EPED1)
  - PB stability
  - KBM constraint.
- Reference case reasonably predicted (within 20%)
- $n_e^{sep}/n_e^{ped}$ variation modeled via the change in $n_e^{pos}$
  - Reduction of $n_e^{sep}/n_e^{ped}$:
    - ➢ increase of $p_e^{ped}$ due to outward shift of $p_e^{pos}$
    - ➢ quantitative agreement with JET-C
  - Increase of $n_e^{sep}/n_e^{ped}$:
    - ➢ $p_e^{pos}$ is not related anymore with $n_e^{sep}/n_e^{ped}$
    - ➢ no pressure reduction is predicted
    - ➢ disagrement with JET-ILW

## Disagreement between experimental data and Europed modelling

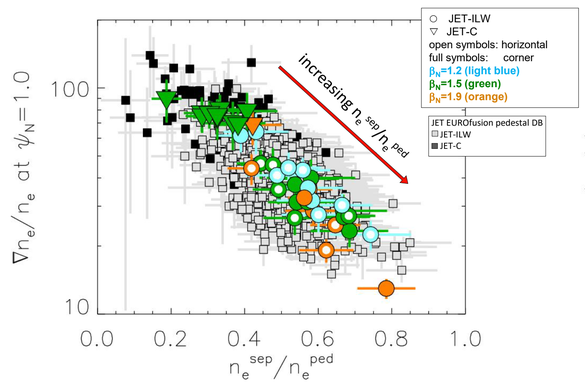


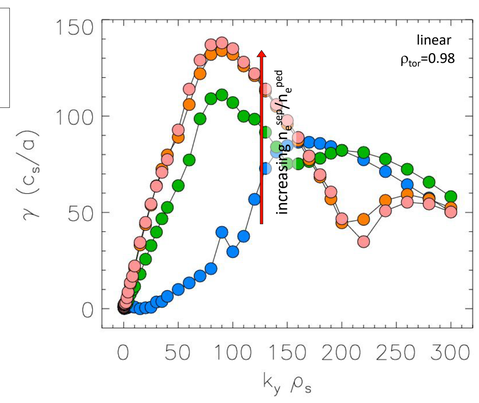




- **Pedestal width**
  - No reasonable agreement with the model
- **Experimental normalized pressure gradient**
  - $n_e^{sep}/n_e^{ped}$ < 0.4: agreement
  - $n_e^{sep}/n_e^{ped}$ > 0.4: disagreement
    - ➢ Europed overestimates the pressure gradien
    - ➢ ELMs are triggered before the ideal PB boundary is reached.

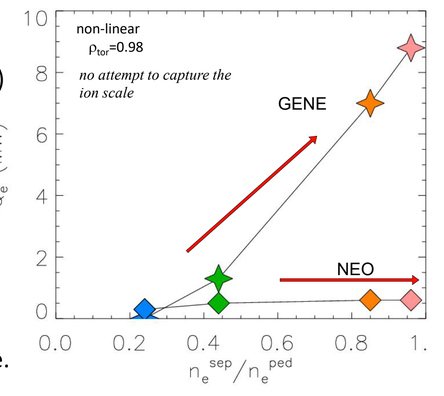
## TURBULENT TRANSPORT INCREASE WITH INCREASING $n_e^{sep}/n_e^{ped}$




*Simulation details:*
- *fully electro-magnetic,*
- *include collisions and parallel magnetic fluctuations*
- *tested a range of ballooning angles.*
- *$T_i$=$T_e$ has been assumed*
- *no ExB flow shear has been included.*
- *No attempt to capture the ion scale*

- Linear and non-linear local GENE modelling for
  - JET-ILW reference case (low $\Gamma_{D2}$)
  - $n_e$ profile shifted inwards (to $n_e^{sep}/n_e^{ped}$ JET-C range)
  - $n_e$ profile shifted outwards (to $n_e^{sep}/n_e^{ped}$ high $\Gamma_{D2}$ JET-ILW range)
  - reduction of $\nabla n_e/n_e$ with increasing $n_e^{sep}/n_e^{ped}$.
- **Slab-ETG** observed *[Chapman EPS2021, Hatch 2016, Parisi 2020]*
- Growth rates increase with increasing $n_e^{sep}/n_e^{ped}$
- Heat flux increases with increasing $n_e^{sep}/n_e^{ped}$
- At high $n_e^{sep}/n_e^{ped}$, turbulent $Q_e$ >> total neoclassical heat flux
- $\nabla T_e/T_e$ can also play a role, but it is not investigate here.



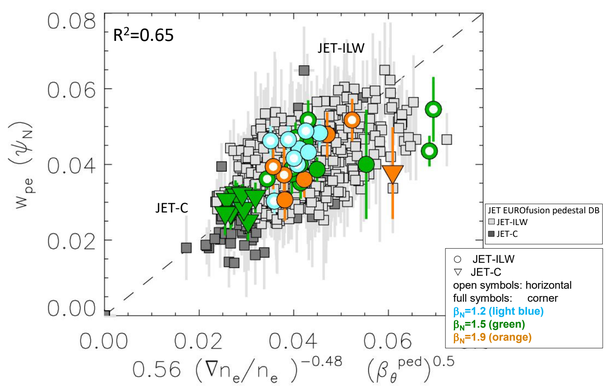

## PEDESTAL WIDTH AND TRANSPORT

- $w_{pe}$ EPED1 predictions in JET reliable only at low $\Gamma_{D2}$. *[Maggi NF2015]*
- Transport is supposed to affect the width.
  - →Improved expression proposed:

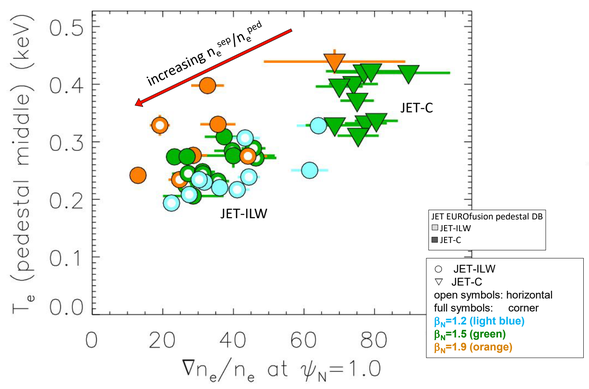
$$w_{pe} = k \underbrace{\left(\frac{\nabla n_e}{n_e}\right)^{\alpha}}_{\text{slab-ETG}} \underbrace{\left(\beta_\theta^{ped}\right)^{0.5}}_{\text{EPED1}}$$

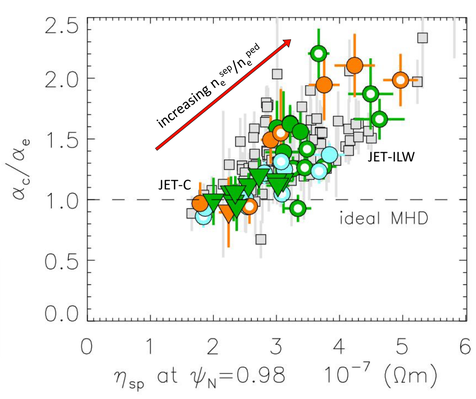
  - →data consistent with $w_{pe}$ correlated to the transport driven by slab-ETG
- at low gas or for JET-C: $\frac{\nabla n_e}{n_e} \approx 50 - 100\ (\psi_N^{-1})$

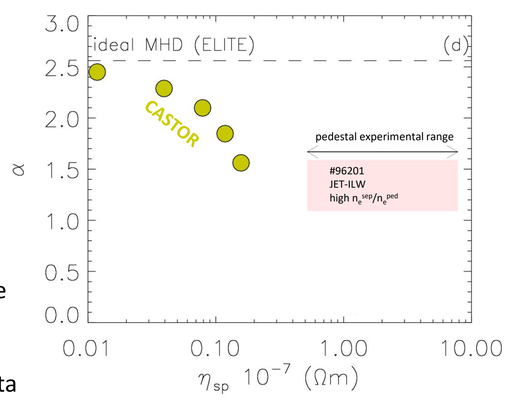
$$\Rightarrow 0.56\left(\frac{\nabla n_e}{n_e}\right)^{-0.48} \approx 0.061 - 0.085$$ (consistent with 0.076, from EPED1)




## ELM TRIGGERING MECHANISM: POSSIBLE ROLE OF RESISTIVE MHD



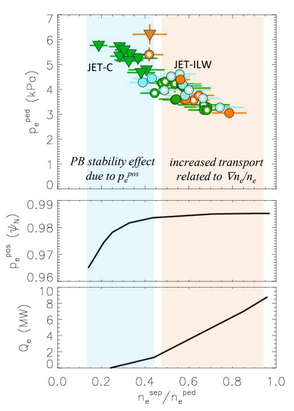




- The increased transport reduces the temeperature
  - →The resistivity in the pedestal increases with increasing $n_e^{sep}/n_e^{ped}$
- Empirical correlation between:
  - $\alpha_{crit}/\alpha_{exp}$ (ratio between ideal MHD predicted $\alpha$ and experimental $\alpha$)
  - resistivity
- → Resistivity MHD might necessary to explain the ELMs trigger at high $n_e^{sep}/n_e^{ped}$.
- Hypothesis tested with CASTOR. Flat resistivity profile assumed, non-self consistent resisitivty yet.
- Increasing resistivity → reduction in predicted $\alpha$
- No quantitative agreement yet with experimental data

## CONCLUSIONS

- The correlation between $p_e^{ped}$ and $n_e^{sep}/n_e^{ped}$ is due to two distinct mechansims:
  1. $n_e^{sep}/n_e^{ped}$<0.4
     - the increase of $n_e^{sep}/n_e^{ped}$ shifts the pressure outwards
     - PB modes are destibilized and the $p_e^{ped}$ decreases.
     - The effect saturates at $n_e^{sep}/n_e^{ped}$≈0.4
  2. $n_e^{sep}/n_e^{ped}$>0.4
     - the increase of $n_e^{sep}/n_e^{ped}$ reduces $\nabla n_e/n_e$
     - increase of turbulent transport
     - The pedestal gradients are reduced
     - Resistive MHD might be neccesary to explain the ELMs
- Extrapolation to ITER are not trivial: ITER will operate on the peeling boundary

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