

# TUNGSTEN TRANSPORT IN TOKAMAKS: TOWARDS REAL-TIME KINETIC-THEORY-BASED PLASMA PERFORMANCE OPTIMISATION

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## Summary

Predict and analyse W transport with the same modelling tools in two tokamaks: AUG and WEST -> **validation of reduced transport models**

Integrated modelling of **AUG**:

- NBI and RF heating
- Toroidal rotation
- ECRH heating as actuator

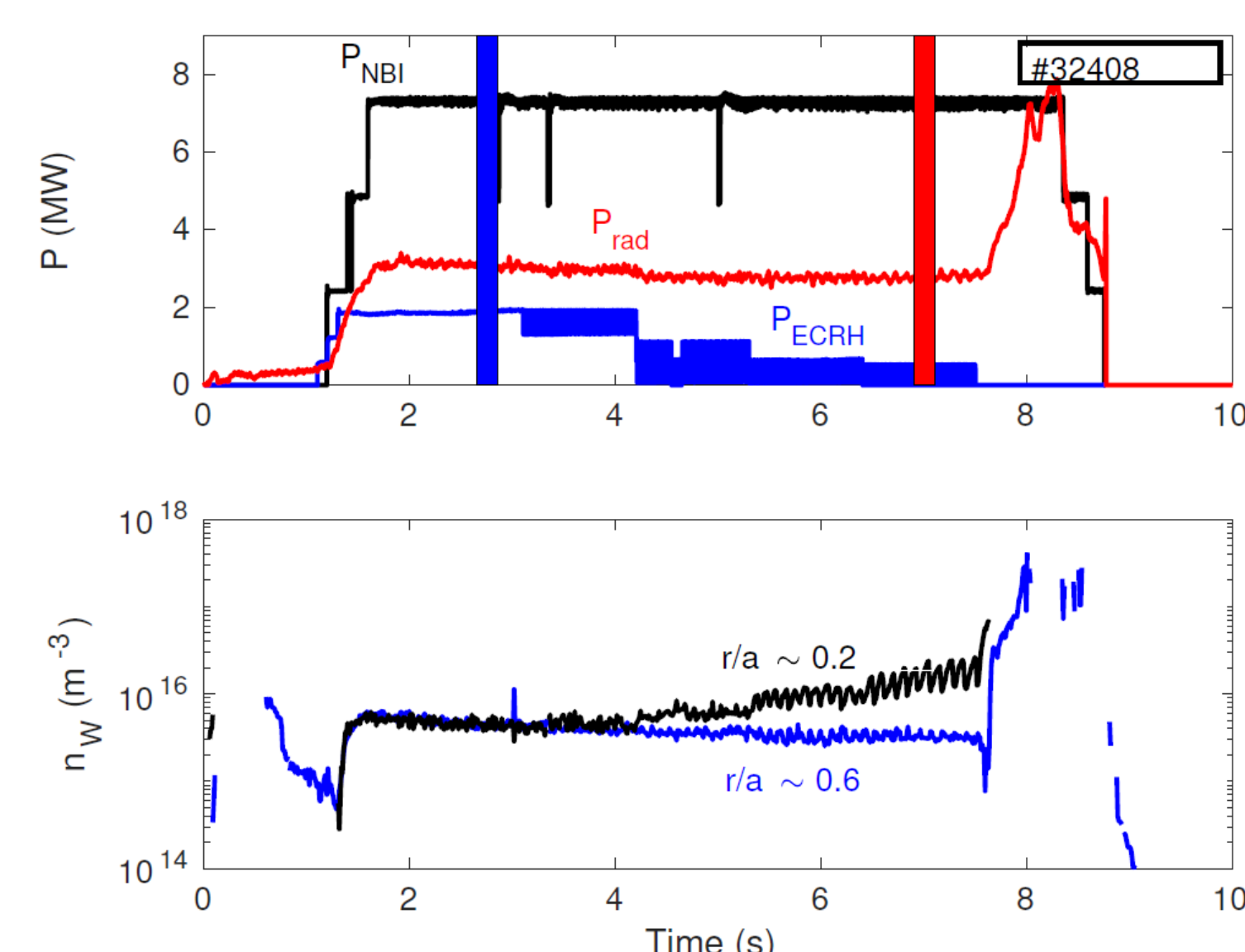
and **WEST**

- Dominant electron heating
- Large aspect ratio
- No injection of toroidal torque

## W accumulation in ASDEX Upgrade NBI heated plasma

ECRH scan in ASDEX Upgrade (H-mode)

- Set of H-mode discharges extensively studied in [1,2]
- Constant NBI power



- Central increase of tungsten density in between sawtooth crashes (from grazing incidence UV spectroscopy)

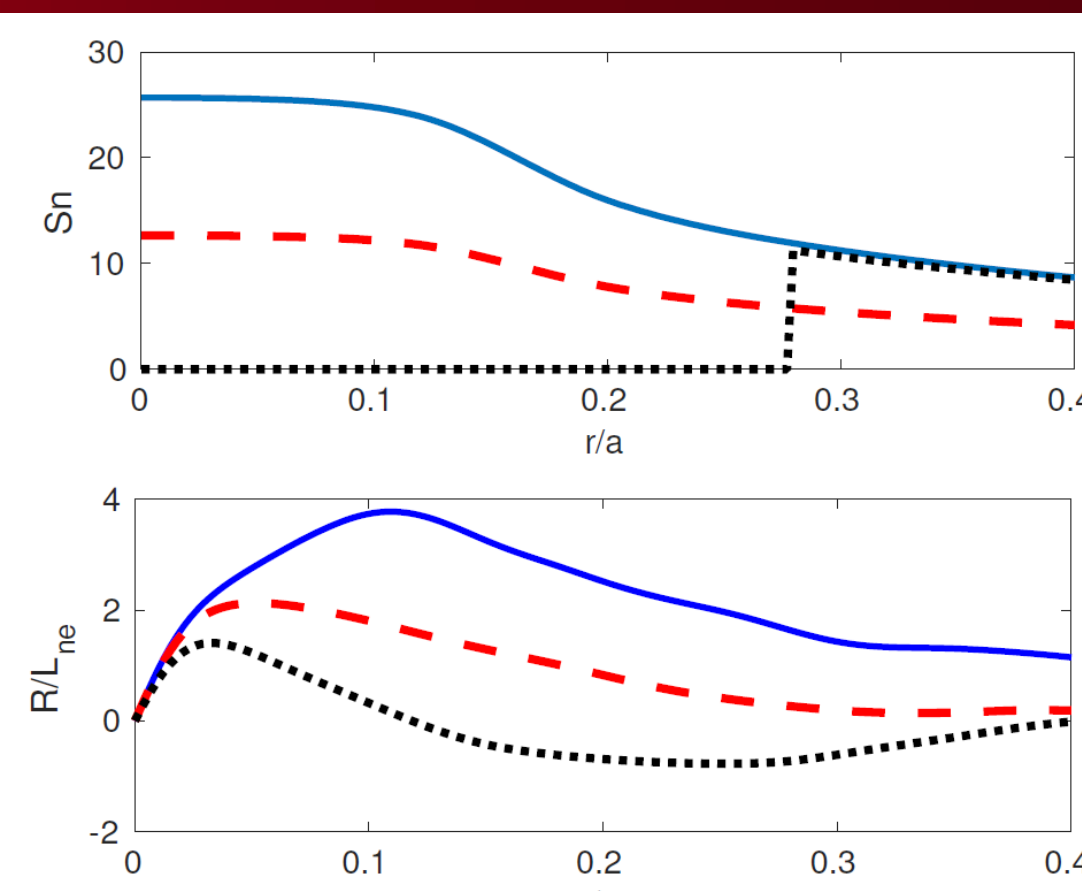
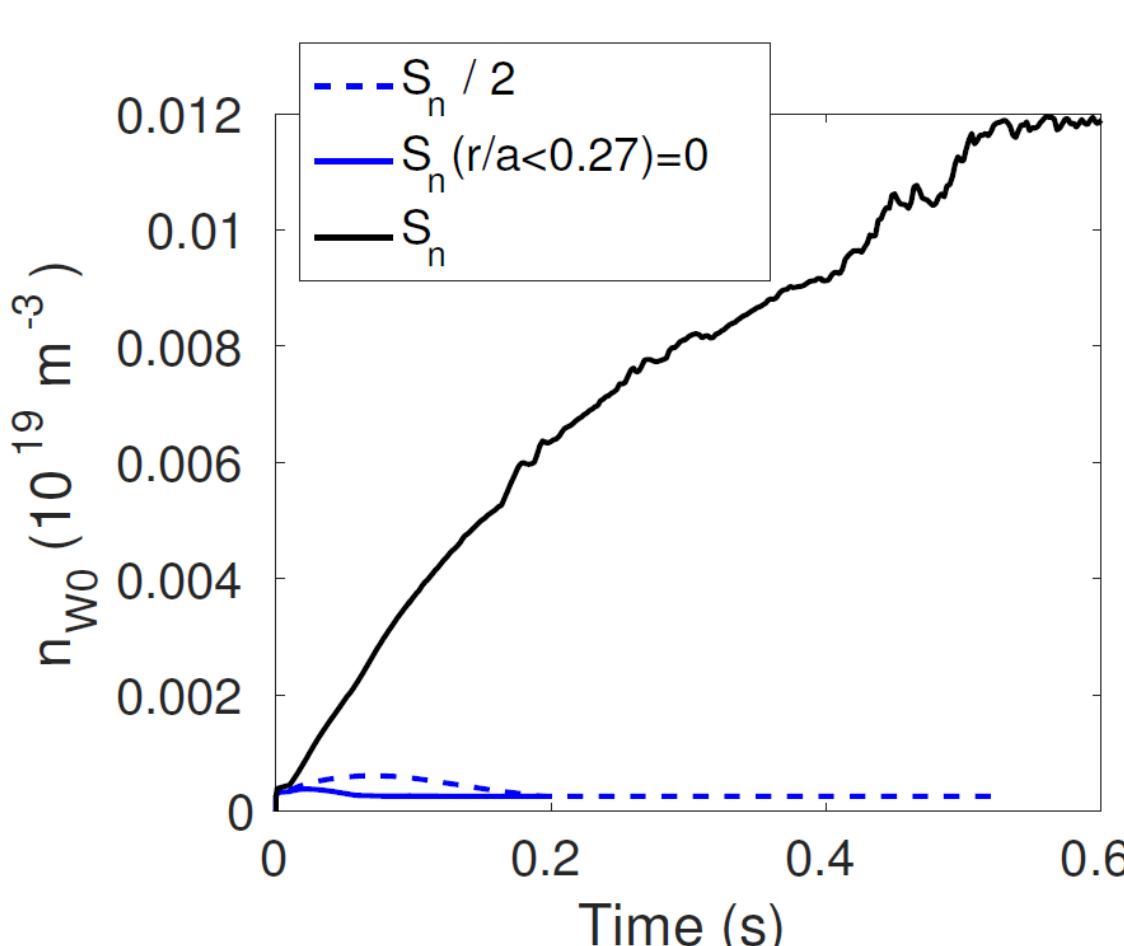
Analysis of 2 phases with 2 MW and 0.2 MW of ECRH

- Characterisation of the impact of ECRH on tungsten accumulation
- Integrated modelling tool: ASTRA
- Turbulent transport: QuaLiKiz [3]
- Neoclassical transport: NEO [4]
- Toroidal rotation included

## Integrated modelling: central particle source

Several particle sources used in ASTRA

- Nominal deposition computed from the NBI module in ASTRA
- Central source removed
- Half the nominal particle source



- Central R/Ln decreased with reduced source (and corresponding neoclassical inward convection of tungsten)
- Residual R/Ln from Ware Pinch
- Accumulation only obtained with sufficient central particle source

## Central particle source vs turbulent diffusion: Te/Ti

Predictions of Te and Ti sensitive to electron heat transport from Electron Temperature Gradient driven micro-instabilities

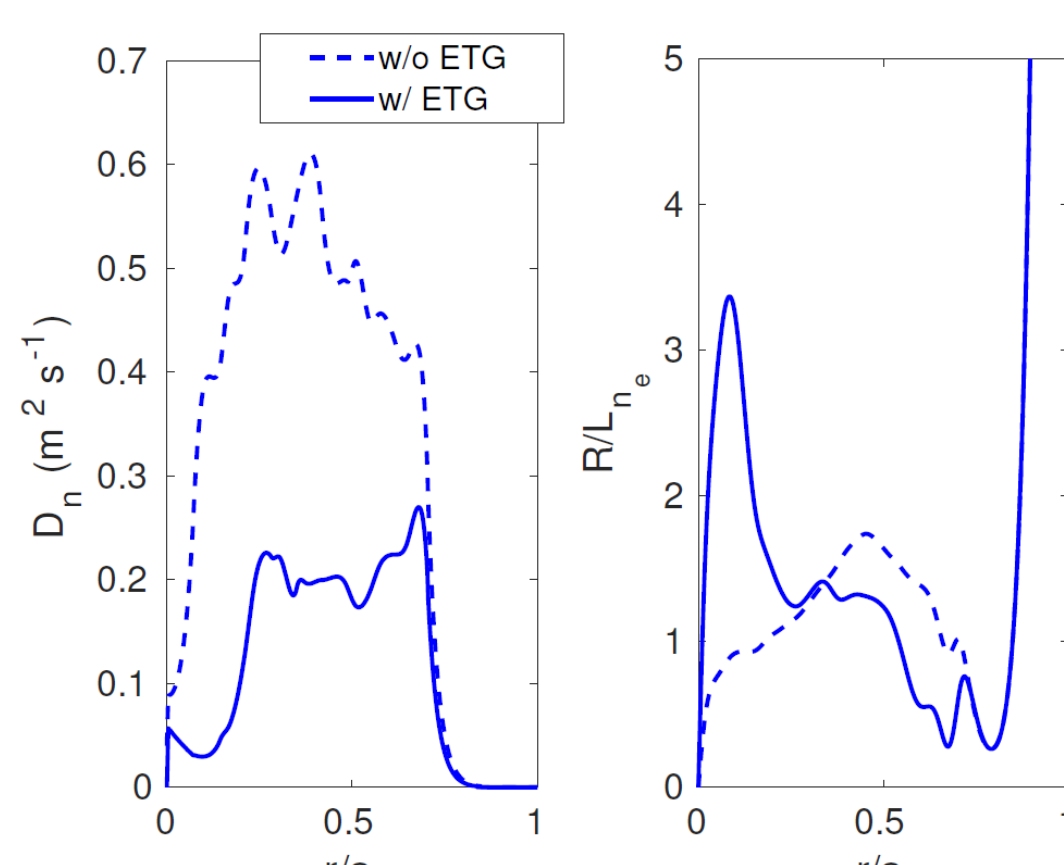
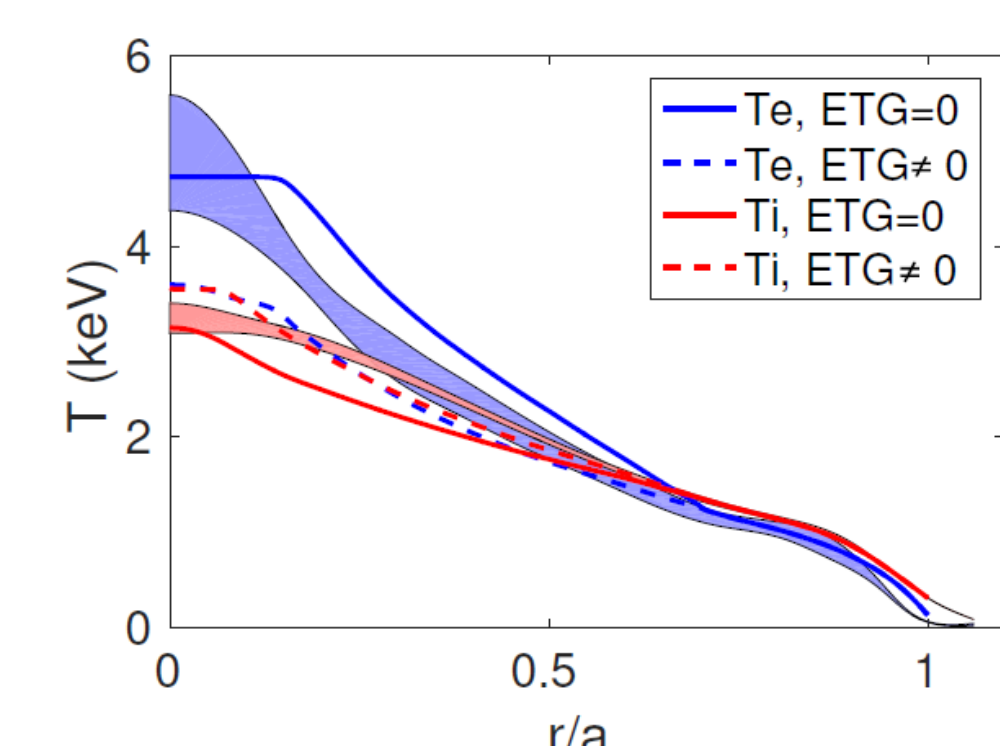
- Quasilinear approximation (ad-hoc inclusion of these scales)
- When electron heat transport from ETG removed, higher Te/Ti obtained

Increased Te/Ti generates more turbulent transport:

- Increased turbulent particle diffusivity
- Electron density peaking decreases (density pump-out)

Important ingredients for tungsten accumulation modelling:

- Central particle source
- Te/Ti (turbulent particle diffusion)



## References

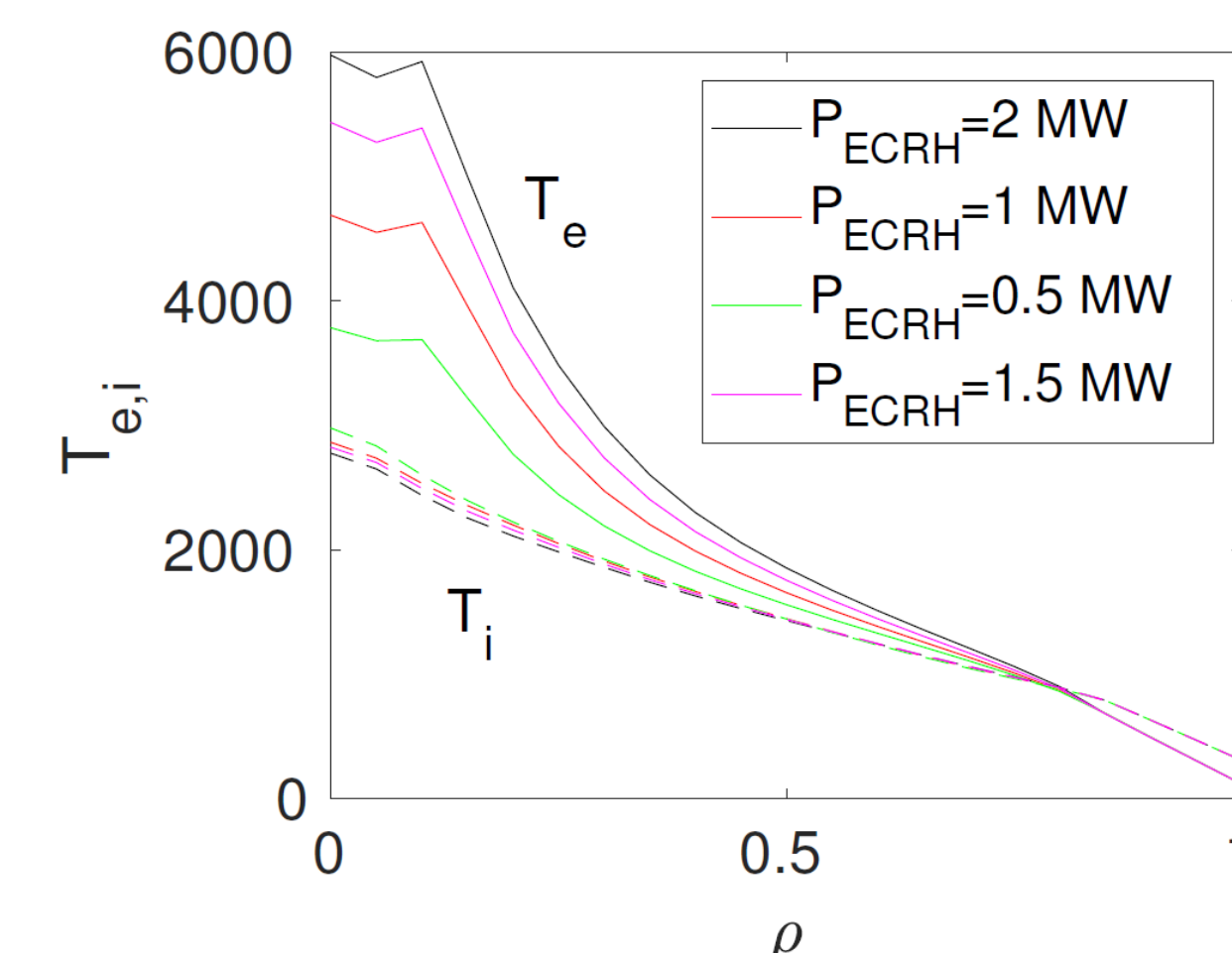
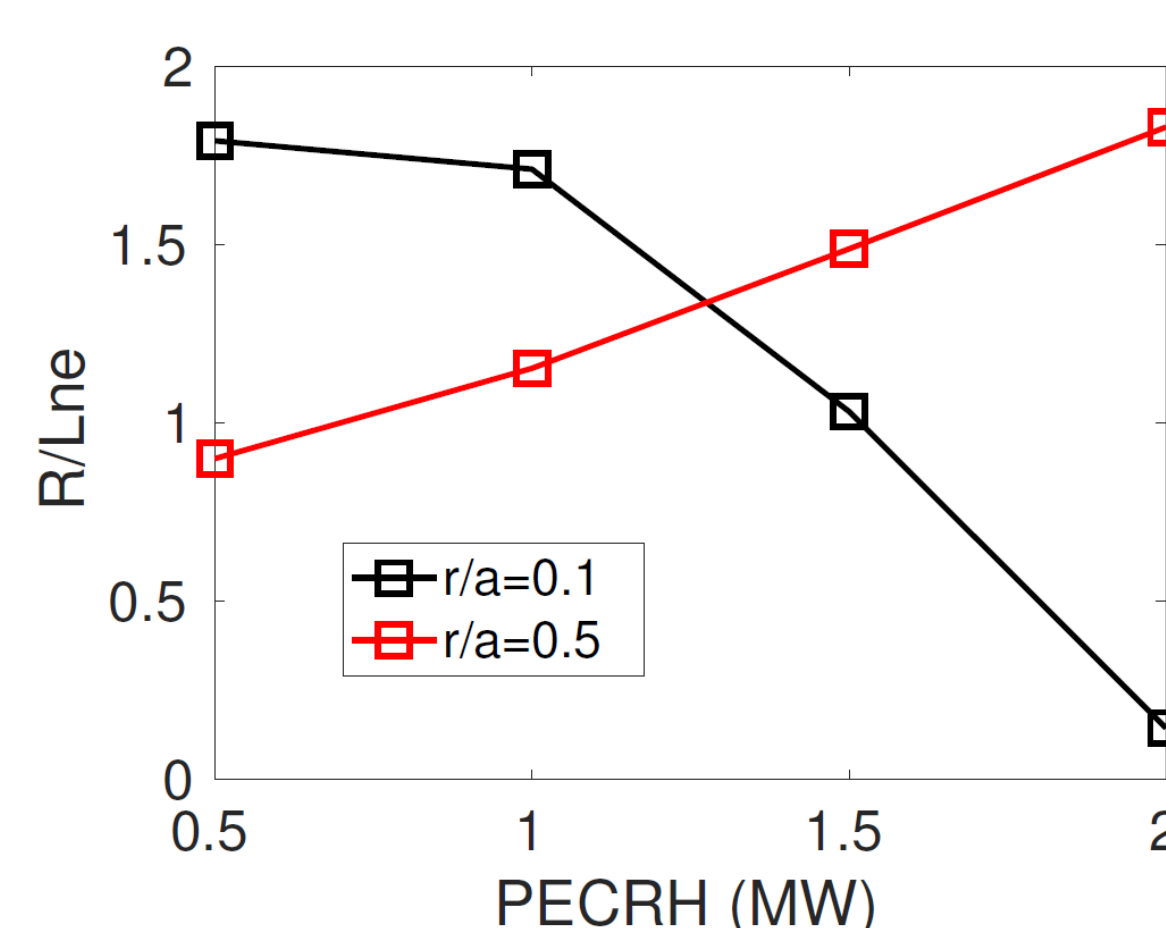
- [1] Angioni et al *NF* **57** 056015 (2017)
- [2] Sertoli et al, *PoP* **24** 112503 (2017)
- [3] Bourdelle *PPCF* **58** 014036 (2016)
- [4] Belli et al, *PPCF* **50** 095010 (2008)
- [5] Felici et al *NF* **51** 083052 (2011)

- [6] van de Plassche *PoP* **27** 022310 (2020)
- [7] Angioni, *PRL* **90** 205003 (2003)
- [8] Yang *NF* **60** 086012 (2020)
- [9] Peeters *CPC* **180** 2650 (2009)
- [10] Stephens to be submitted

## Fast transport models: towards real time control

Integrated modelling framework: ASTRA -> RAPTOR [5]

- Turbulent transport from 10D neural network of QuaLiKiz [6]
  - Transport equations solved for Te, Ti, ne and current diffusion
  - Sources taken from ASTRA and fixed in time
  - Impurity transport not implemented
- Can we reproduce the central particle accumulation with Te/Ti?



With increasing ECRH power, central density peaking decreases

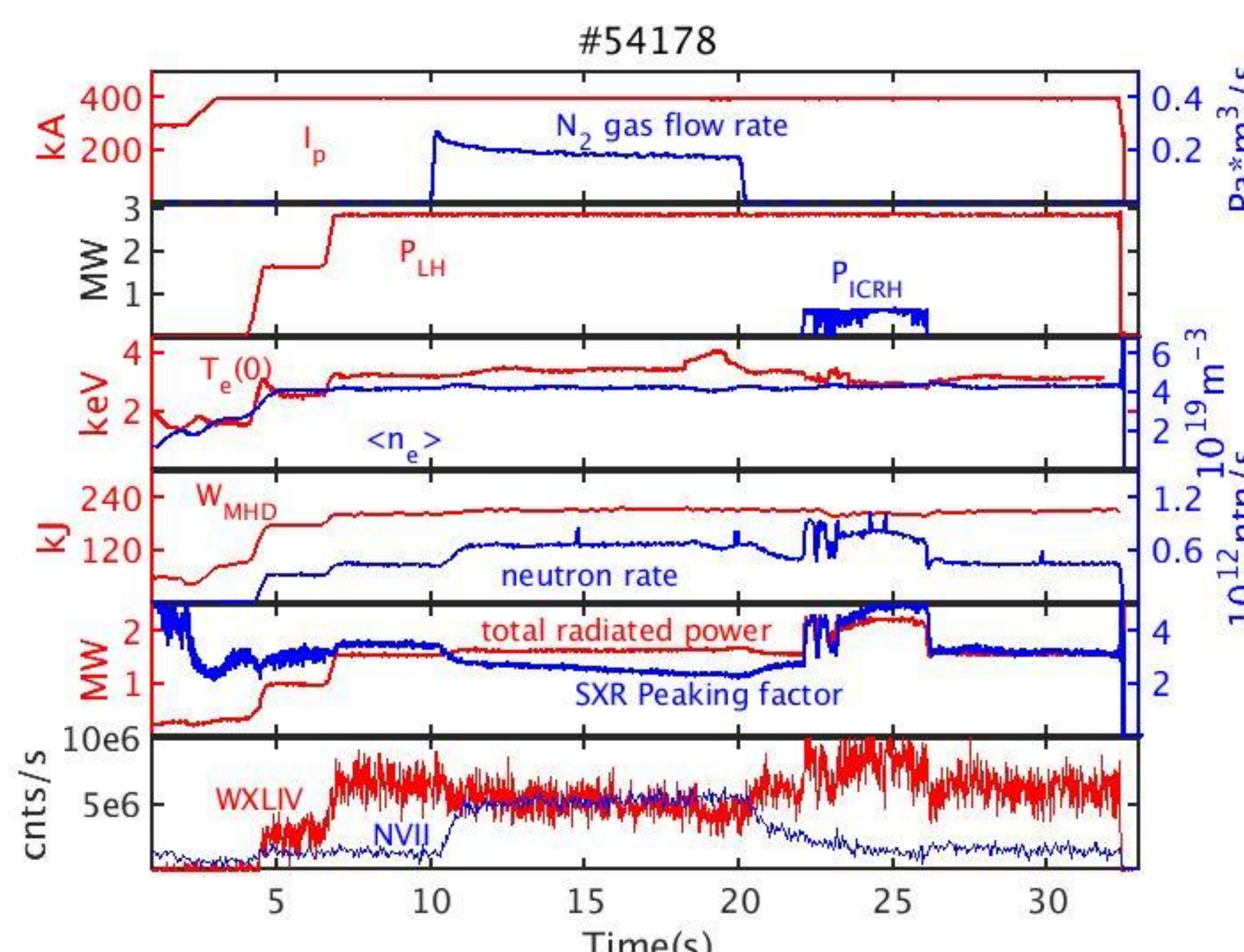
Mid-radius density peaking increases, consistent with increased Te and reduced collisionality [7]

Central electron peaking driving the W accumulation qualitatively reproduced with fast transport models

## WEST long pulse with dominant electron heating

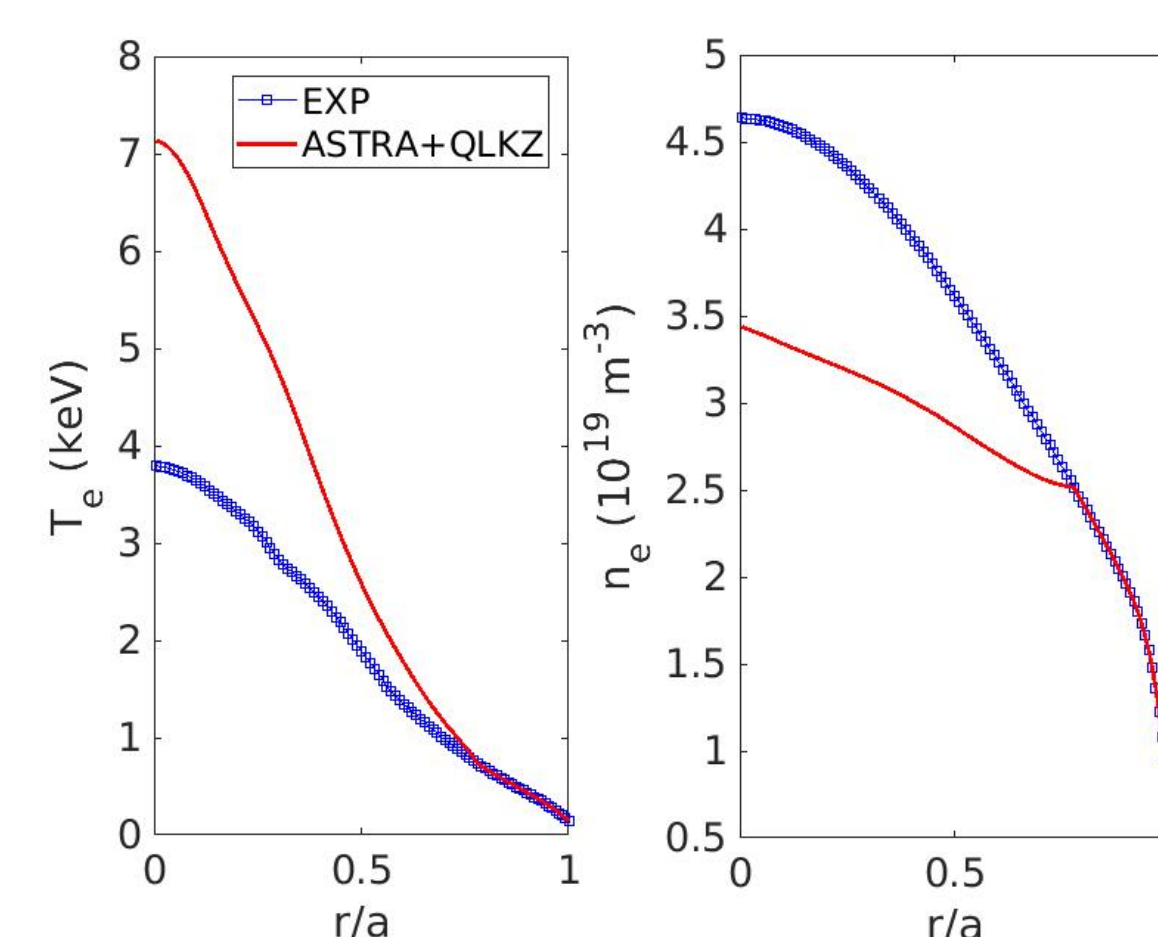
WEST upper single null long pulse L-mode plasma [8]

- Dominant electron heating: 2.8 MW of LHCD and a phase with 0.65 MW of ICRH
- Phase with nitrogen seeding -> increased neutron flux
- Tungsten content monitored with SXR and UV spectroscopy (no accumulation observed)



Integrated modelling with ASTRA+QuaLiKiz

- Overestimation of Te
- Underestimation of ne



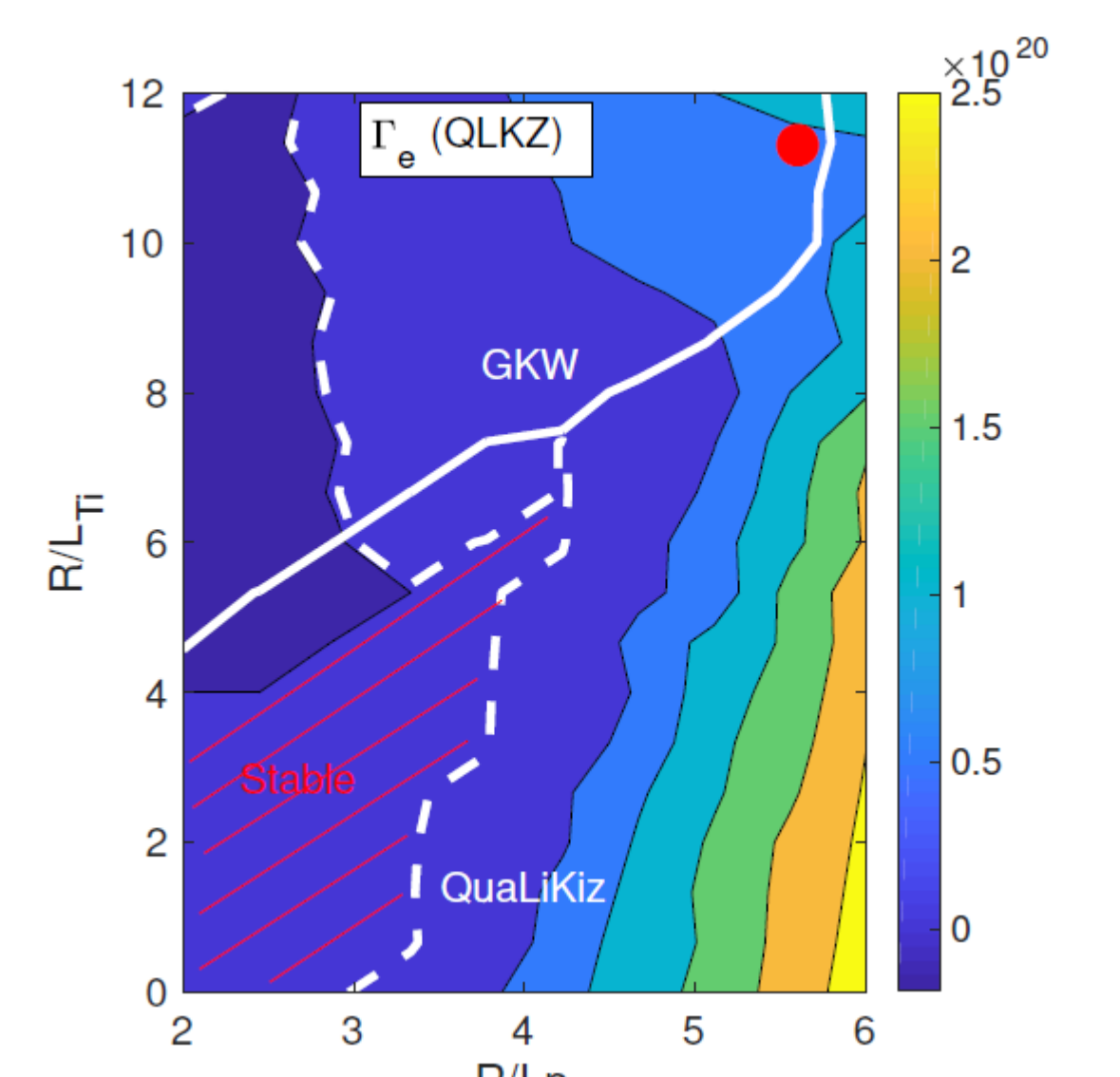
Dominant electron heating: trapped electron mode turbulence

- Further investigation in gradient driven simulations

## QuaLiKiz vs GKW: stabilisation of ∇Te TEM

Comparisons between GKW [9] and QuaLiKiz

$r/a$	$R/L_{T_e}$	$T_e/T_i$	$R/L_n$	$R/L_{T_i}$	$Z_{eff}$	$\nu_*$	$Q_e$ (kW/m <sup>2</sup> )	$Q_i$ (kW/m <sup>2</sup> )
0.5	15	1.8	5.6	11.3	2.8	0.5	46	15



Quasilinear particle flux

- Steady state given by  $\Gamma_e = 0$  (no particle source)
- Stable region found in QuaLiKiz but not in GKW ( $\nabla T_e$  TEM always unstable)
- Strong dependence of  $\Gamma_e = 0$  condition with collisions
- Overstabilisation of TEM found in QuaLiKiz from previous collision operator
- Testing of improved collision operator [10] ongoing and encouraging

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