DE LA RECHERCHE À L'INDUSTRIE

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

P. Manas[1], C. Angioni[2], J.F. Artaud[1], C. Bourdelle[1], J. Citrin[3], E. Fable[2], F. Felici[4], P. Maget[1], C.D. Stephens[2], K.L. van de Plassche[3], X. Yang[5] , the ASDEX Upgrade Team* and the WEST team**

[1] CEA, IRFM, F-13108 Saint Paul-lez-Durance, France.
[2] Max-Planck-Institut für Plasmaphysik, D-85748 Garching, Germany
[3] DIFFER-Dutch Institute for Fundamental Energy Research, Eindhoven, the Netherlands.
** see http://west.cea.fr/WESTteam
[4] Ecole Polytechnique Federale de Lausanne (EPFL), Swiss Plasma Center (SPC), CH-1015 Lausanne, Switzerland.
[5] Institute of Plasma Physics, Chinese Academy of Science, Hefei, 230031, China/P.R. China
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Summary

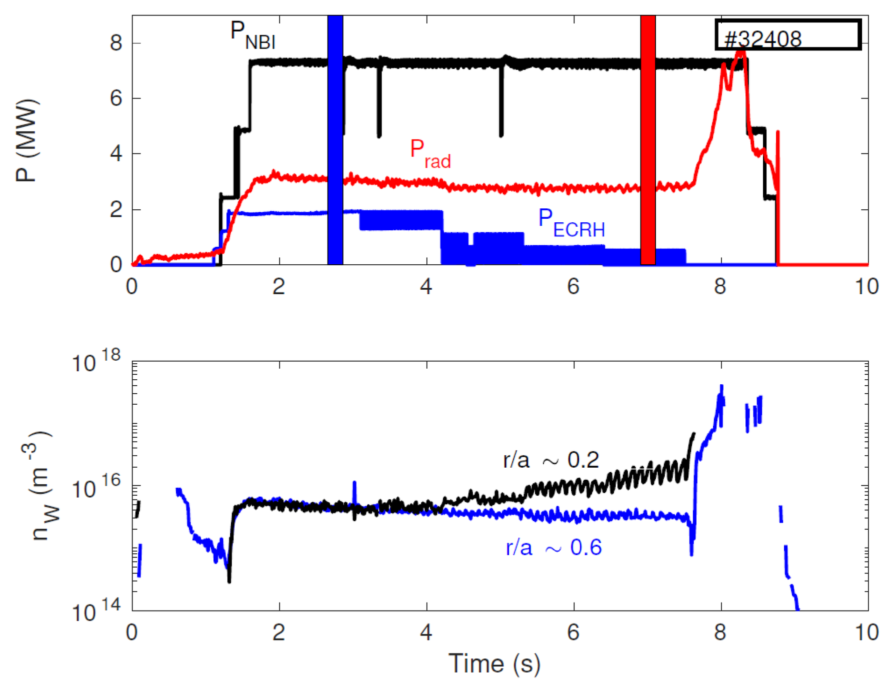
Predict and analyse W transport with the same modelling tools in two tokamaks: AUG and WEST -> validation of reduced transport models

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



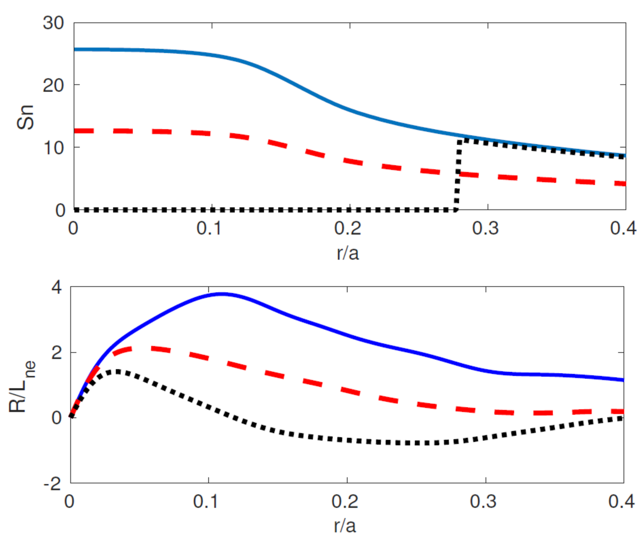
- **Central increase of tungsten density in between sawtooth crashes** (from grazing incidence UV spectroscopy)

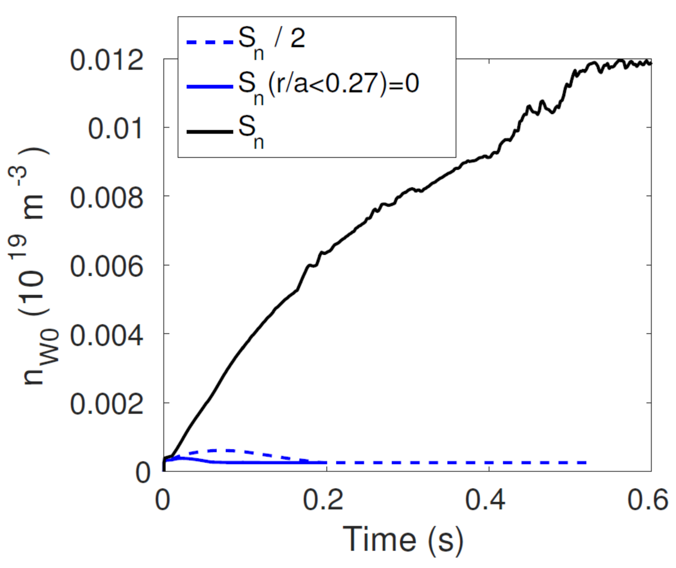
Analysis of 2 phases with 2 MW and 0.2 MW of ECRH

- 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**

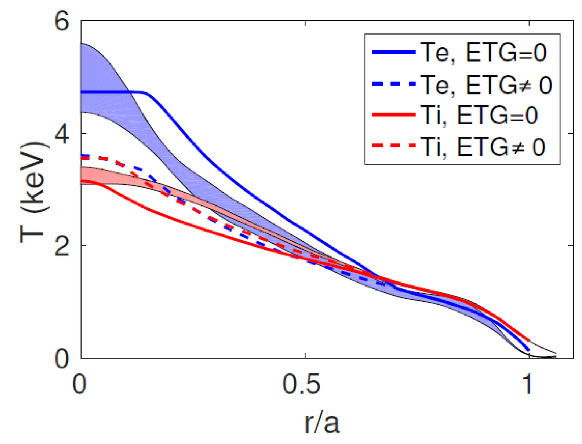




- **Central R/Ln decreased with reduced source (and corresponding neoclassical inward convection of tungsten)**
- Residual R/Ln from Ware Pinch
- **Accumulation only obtained with sufficient central particle source**

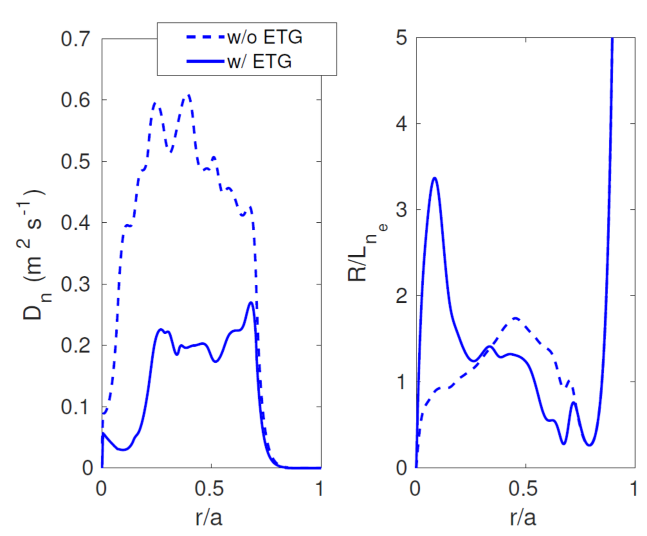
Central particle source vs turbulent diffusion: Te/Ti

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)

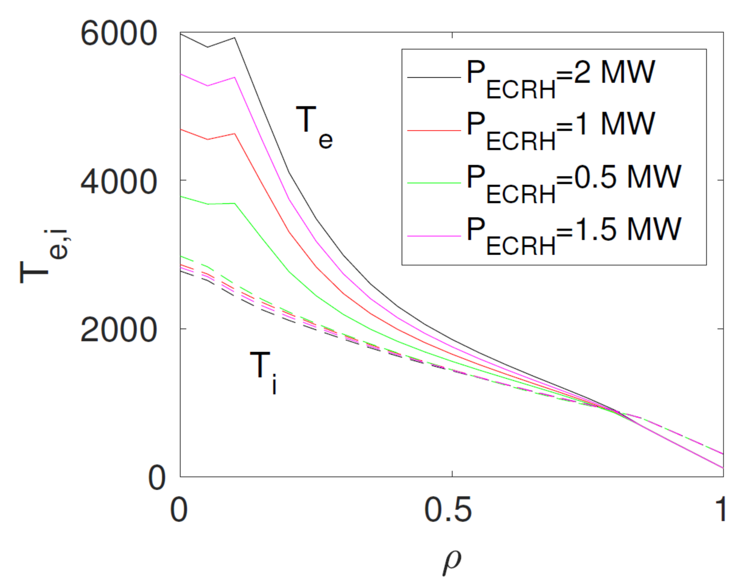


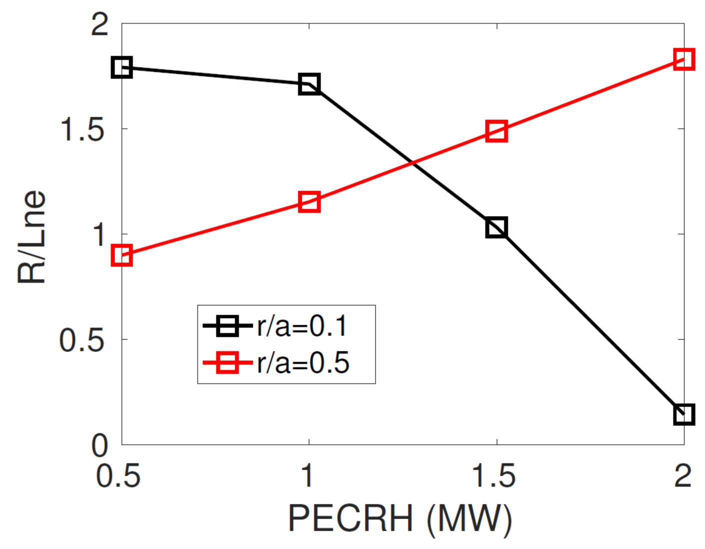
Important ingredients for tungsten accumulation modelling:
- **Central particle source**
- **Te/Ti (turbulent particle diffusion)**

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?





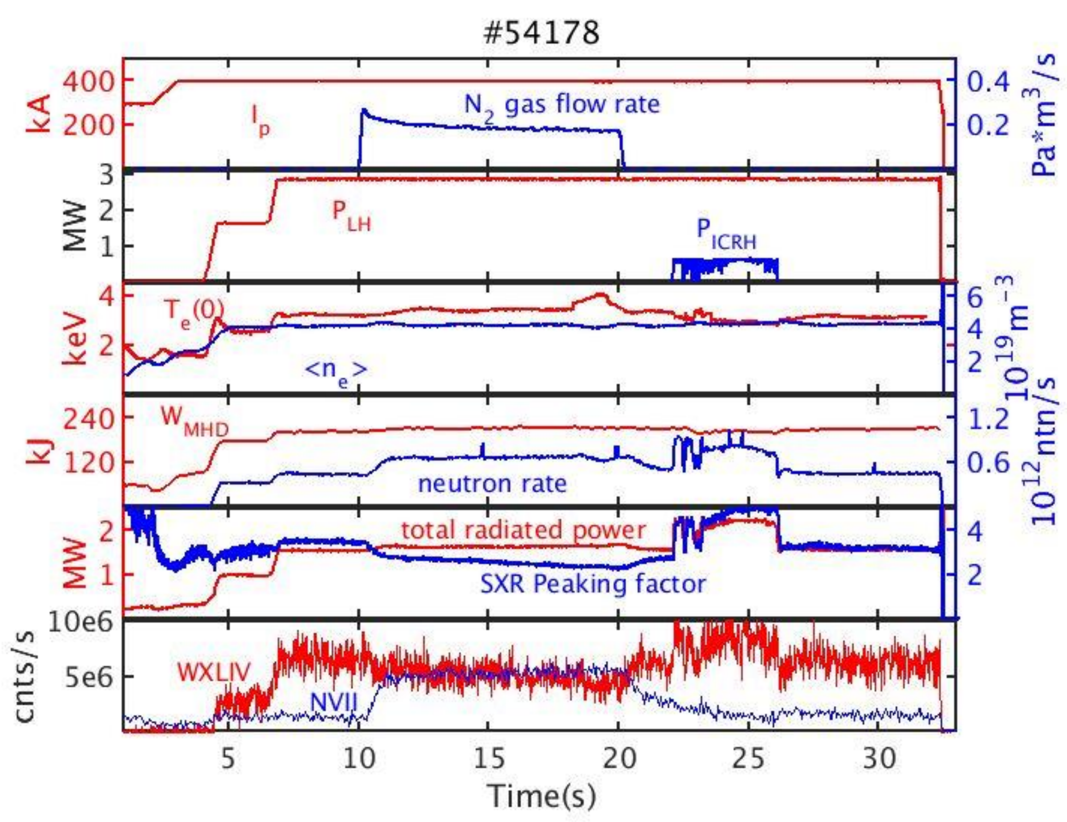
With increasing ECRH power, central density peaking decreases

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

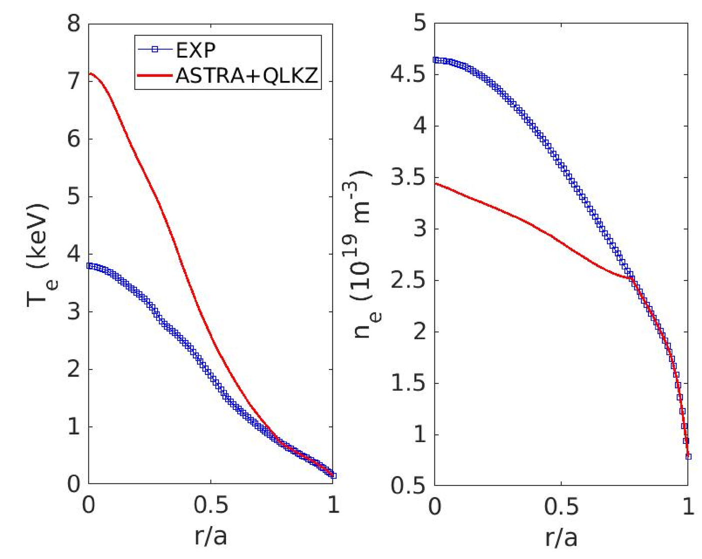
Central electron peaking driving the W accumulation qualitatively reproduced with fast transport models

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

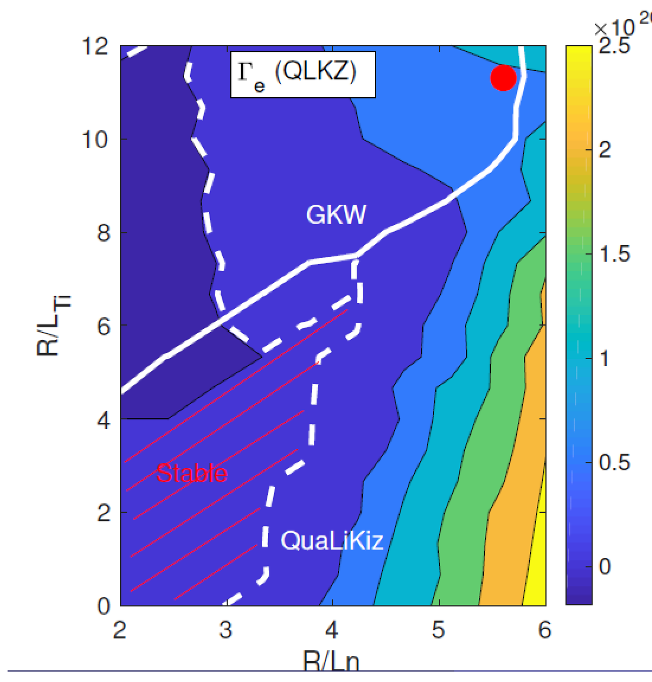


Dominant electron heating: **trapped electron mode turbulence**
- **Further investigation in gradient driven simulations**

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}	ν_*	$Q_e(\mathrm{kW/m^2})$	$Q_i(\mathrm{kW/m^2})$
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 (∇Te 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**

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

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