HOW NITROGEN SEEDING SECURIZES PLASMA RAMP-UP IN THE METALLIC ENVIRONMENT OF WEST

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DE LA RECHERCHE À L'INDUSTRIE

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Summary

- Plasma current ramp-up phase critical in Tungsten devices
  - Tungsten radiation peak at 1.5 keV to be crossed
  - Limited options for additional heating in this phase
  - MHD mode triggering when core cooling is too large
- Nitrogen injection proved to be an efficient tool on WEST
  - By increasing core temperature & current density peaking
- Integrated simulations with RAPTOR explain the main mechanism
  - N_2 seeding reduces mid-radius turbulence & peaks the current
  - Additional core ohmic heating if large Tungsten contamination

Experiments of early Nitrogen seeding on WEST

Example of Nitrogen seeding during the plasma ramp-up in L-mode

- Series of 3 consecutive pulses with increasing Nitrogen injection rates *(fig. 1)*
- The impact on electron temperature is localized in the plasma core

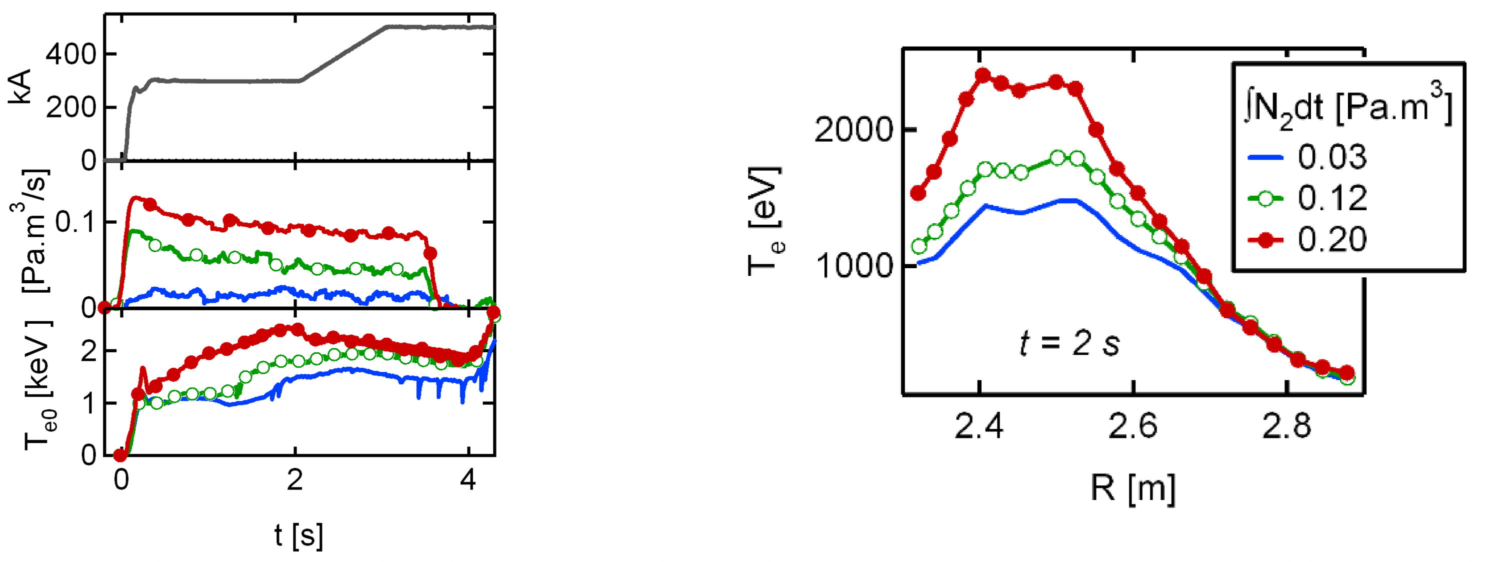

Fig.1 : Example of 3 consecutive pulses (54762, 54764, 54765) with increasing Nitrogen seeding rate. Left column: plasma current (top), Nitrogen injection rate (middle) and core temperature (bottom). Right figure: electron temperature profiles at t=2s.

Database

- The increase in core T_e and internal inductance is a robust feature *(fig. 2)*
- The resistive Z_{eff} is not affected & loop voltage decreases: net gain in flux consumption
- Moderate increase in radiative losses, ohmic power ~constant
- At too large N_2 injection, uncontrolled detachment

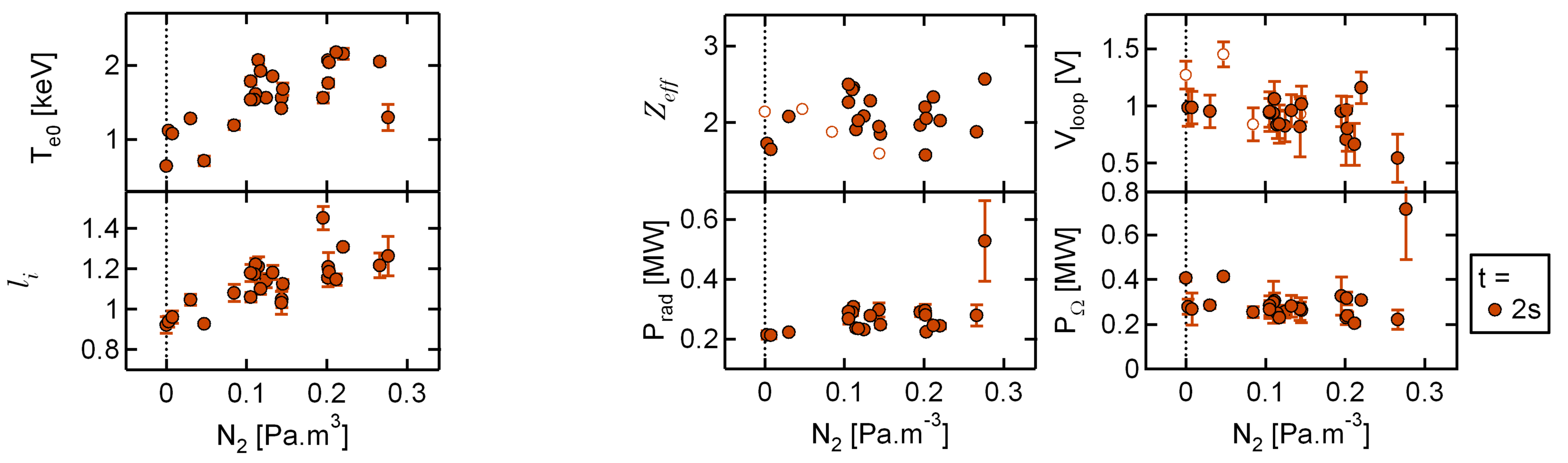

Fig.2 : Plasma parameter dependence on the quantity of Nitrogen injected up to t=2s

Divertor response to Nitrogen injection

- A transient detachment is induced (ends before t=3s at flat top) *(fig. 3, a)*
- Low WI signals (normalized to DI@4341A) at t=2s *(fig. 3, b)*
- Gets higher at t=3s at inner strike point: W sputtering is increased by Nitrogen
- However, bolometry inversion indicates no increase in W contamination *(fig. 3, c)*

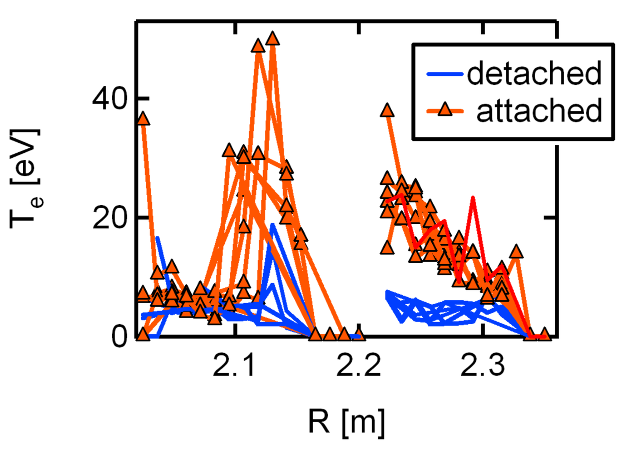

Fig.3a : Temperature profiles at lower divertor in the detached & attached phases for #pulses

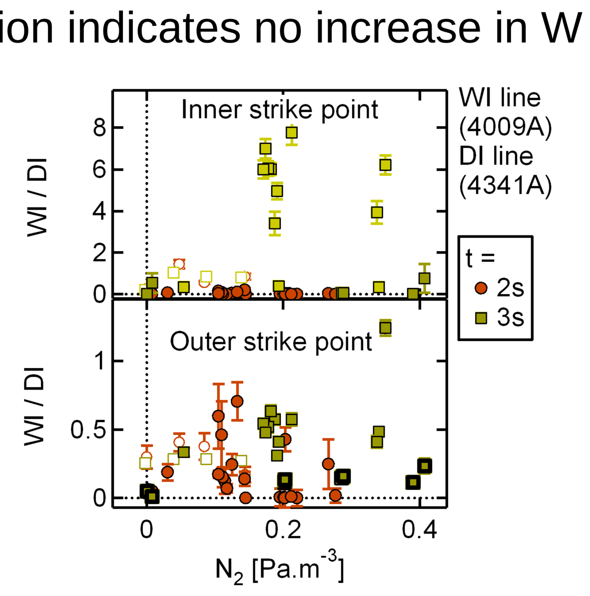

Fig.3b : Visible spectroscopy: normalized WI emission at inner and outer strike point.

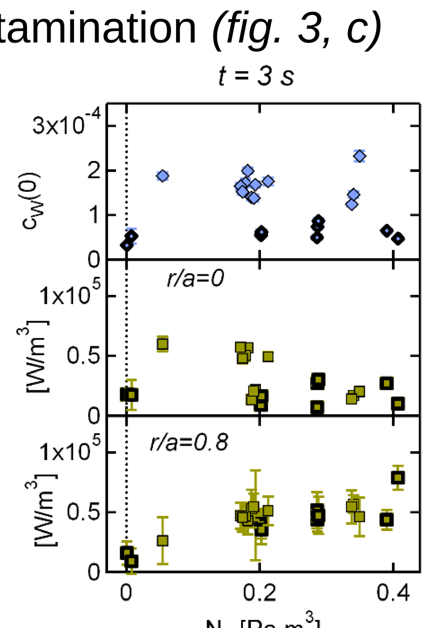

Fig.3c : Tungsten concentration, radiative losses, core and edge.

Integrated Simulations with RAPTOR : main settings

RAPTOR code [1,2] coupled to 10-D Neural Network [3] based on Qualikiz [4]

- Predicts ion & electron temperature evolution (density evolution from experiment)
- Nitrogen as impurity species, Tungsten only participating in the radiative losses
- Boundary at r/a=0.8: turbulent transport underestimated at the very edge *(cf. fig. 4)*
  - *Possibly due to resistive modes not taken into account by Qualikiz*
- Sawtooth model [5] to account for limited ohmic current accumulation in the core

Based on a pulse without Nitrogen injection (#55797)

- Nitrogen injection modelled via a prescribed effective ion charge (Z_{eff}) profile

References

[1] Felici et al., Nuclear Fusion **51** (2011) 083052
[2] Felici et al., Nuclear Fusion **58** (2018) 096006
[3] van de Plassche et al., PoP **27** (2020) 022310
[4] Bourdelle et al, PoP **14** (2007) 112501
[5] Porcelli et al, PPCF **38** (1996) 2163
[6] Yang et al., Nuclear Fusion **60** (2020) 086012.
[7] Fourment et al., PPCF **45** (2003) 233.

Simulations of Nitrogen seeding experiments

Settings for the Z_{eff} profile

- Set equal to 2 (as resistive Z_{eff}, flat profile) in non seeded reference: important dilution effect *(fig. 4)*
- must be hollow to reproduce lower ohmic source & radiation & resistive Z_{eff} increase *(fig.5)*

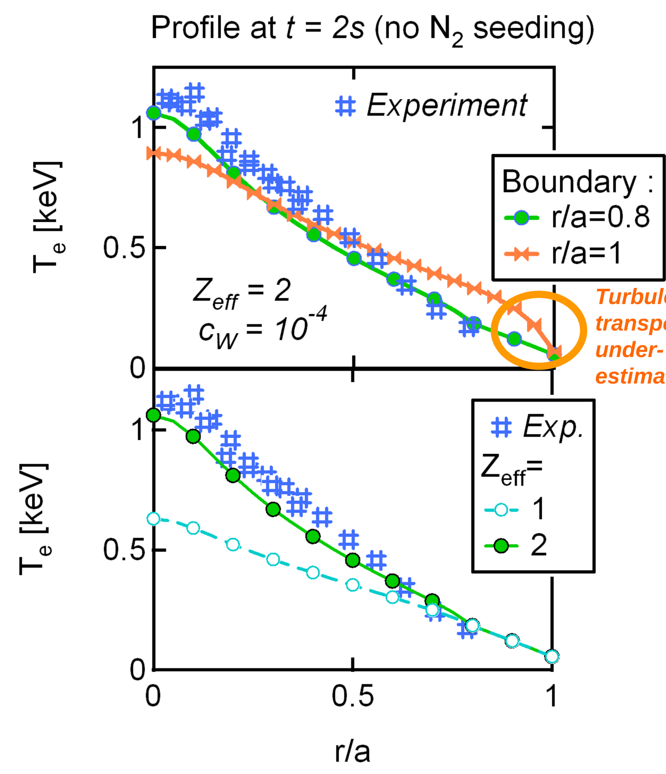

Fig.4 : Temperature profile without N_2 seeding: role of the boundary and Z_{eff} value

QLK-NN validated against TGLF & GKW in this phase (ITG dominant)

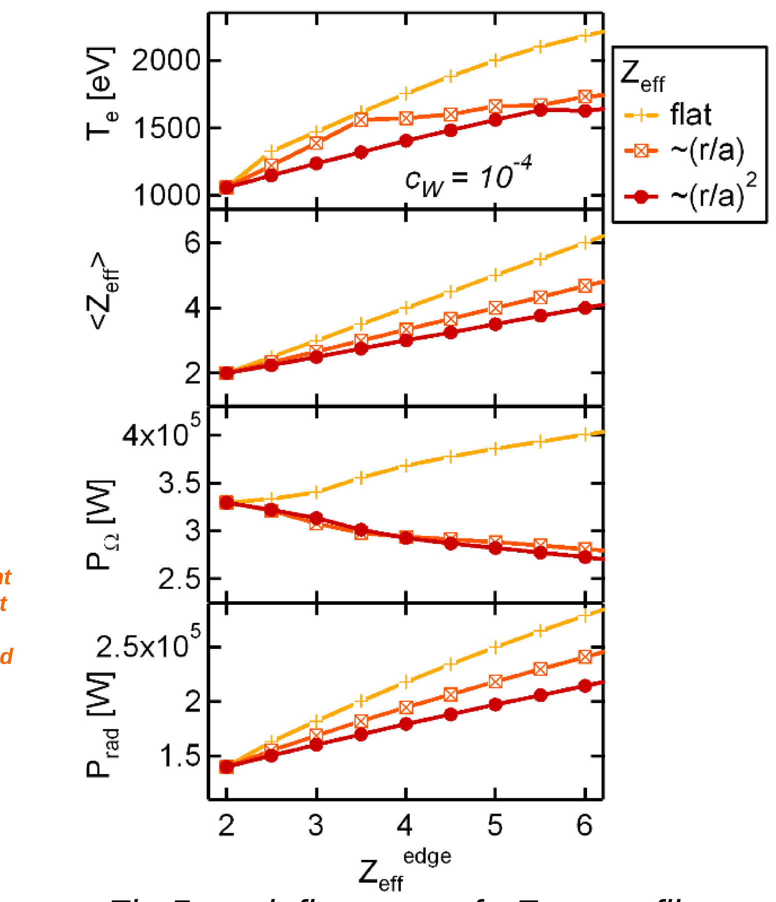

Fig.5 : influence of Z_{eff} profile during the N_2 seeding scan

($c_W \in [1, 2 \times 10^{-4}]$)

Temperature peaking well reproduced (fig.6)

- Change is limited inside r/a=0.6
  - not a global effect
- Amplitude slightly weaker:
  - But large sensitivity to Z_{eff} profile *(fig. 5)*
- Would require including particle transport (including impurity)

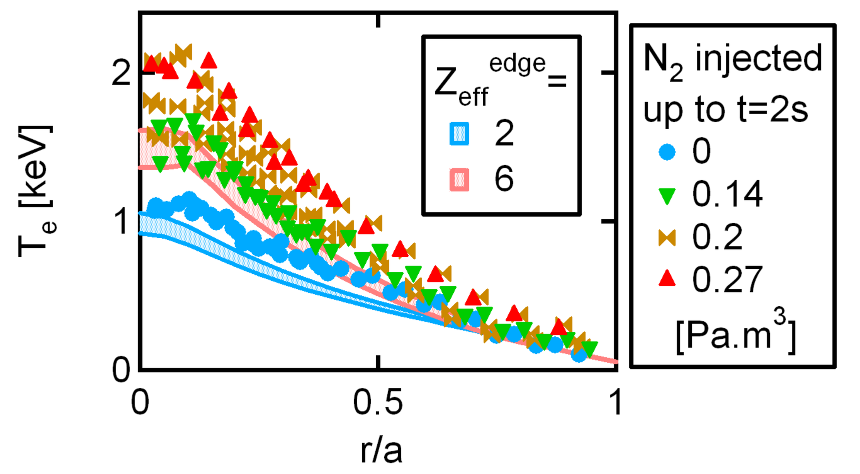

Fig.6 : Temperature profiles at t=2s

Main trends are recovered (fig.7)

- Current profile peaking
- Limited radiation increase
- Reduction of ohmic power
- Limitation by global radiation
  - *f_{rad}>1 with Tungsten & large N_2 seeding*
- MHD stability is improved (fig.8)

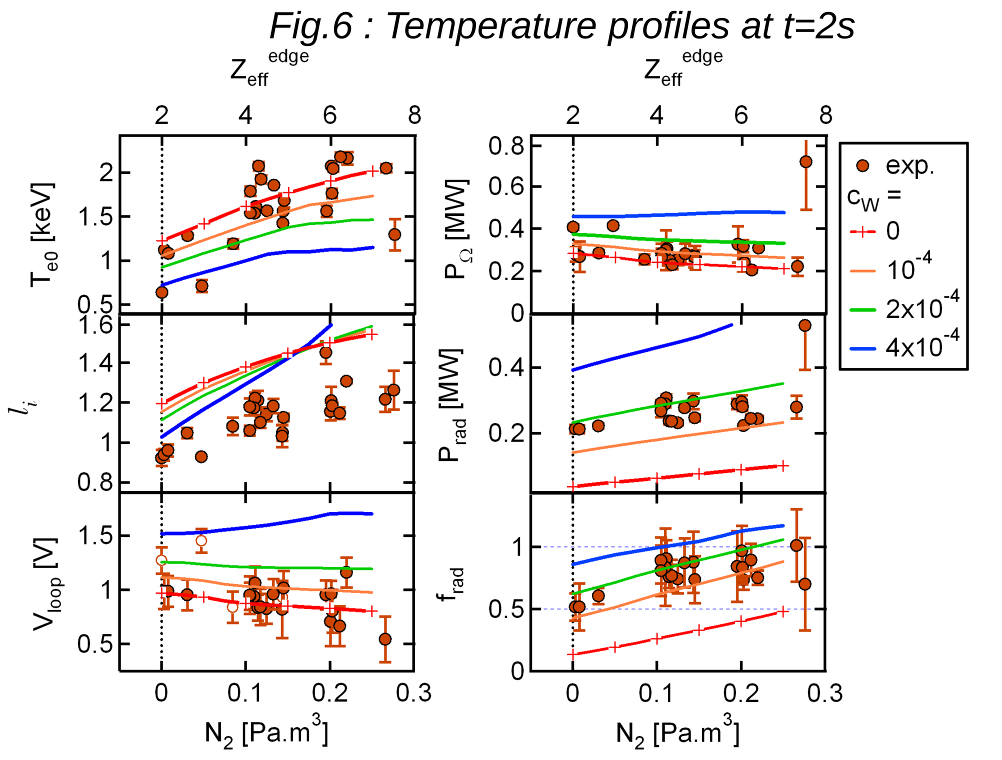

Fig.7 : Plasma parameters versus edge Z_{eff}

Physics mechanisms (fig. 9 & 10)

- Increase of R/L_{Te} via two mechanisms
  - equilibrium modification
  - (ITG/TEM threshold ~ s/q [7])
  - dilution effect [6]
- At low to medium W-contamination (as in dataset)
  - The net power decreases with N_2 in the outer region due to Nitrogen radiation
- At large W-contamination
  - The net power also increases in the very core due to large ohmic heating variation with N_2 seeding

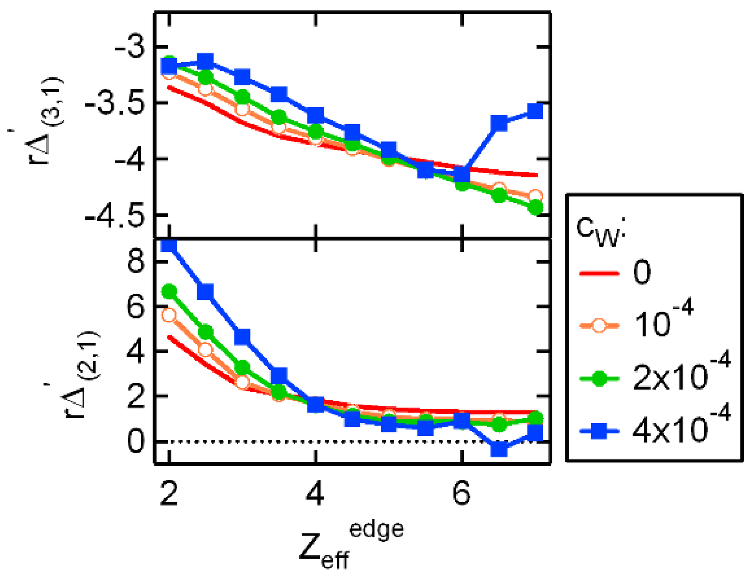

Fig.8 : Tearing stability at q=2 and q=3 versus edge Z_{eff}

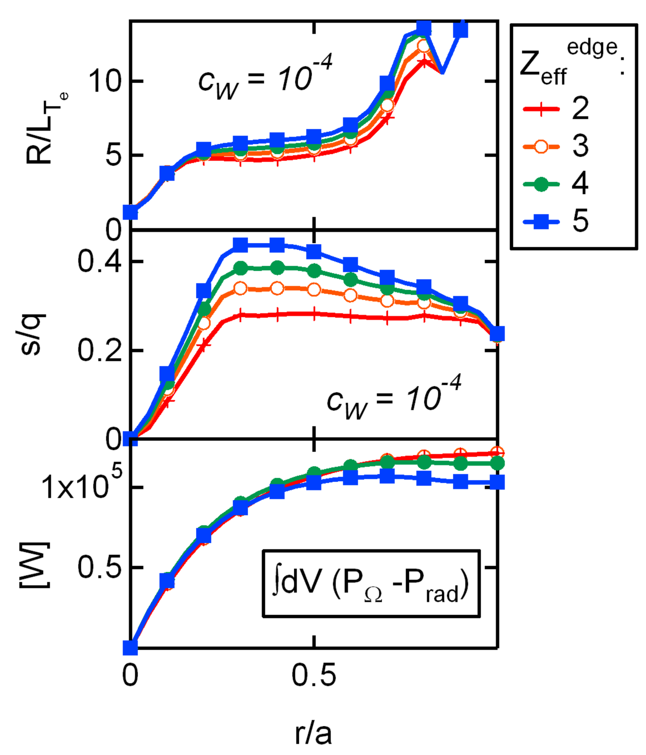

Fig.10 : Normalized temperature gradient, s/q and cumulated net power at t=2s for $c_W=10^{-4}$ and # edge Z_{eff}

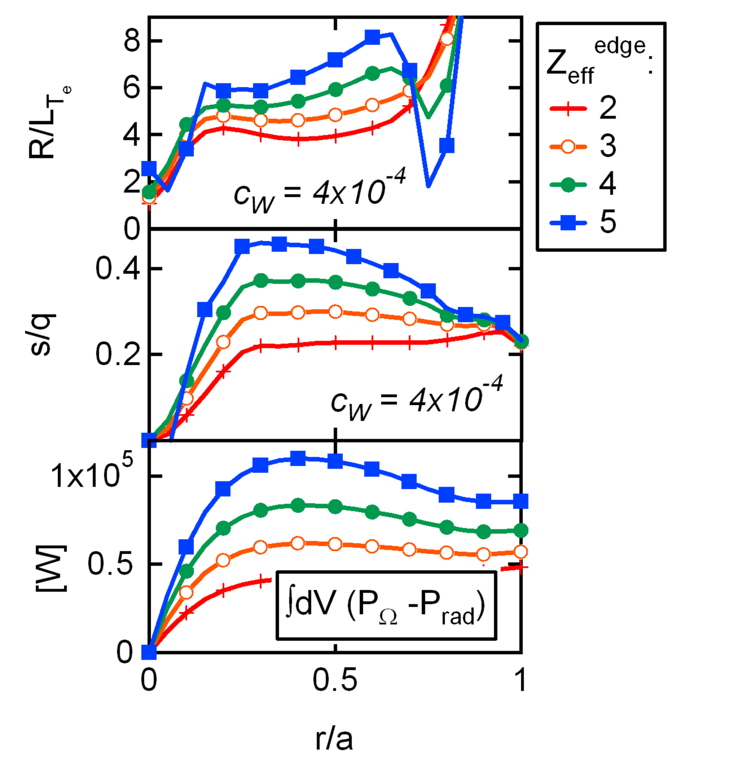

Fig.9 : Normalized temperature gradient, s/q and cumulated net power at t=2s for $c_W=4 \times 10^{-4}$ and # edge Z_{eff}

Acknowledgements

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