Theory-based integrated modelling of tungsten transport:
validation in present-day devices and predictions for ITER

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ASDEX Upgrade

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Abstract

- Impurities play crucial roles in the core-edge integration of fusion devices:
  - Core high-Z impurity accumulation must be avoided
  - Impurity seeding will be essential for a tolerable heat exhaust
- We have developed an entirely **theory-based** integrated modelling workflow [1] that self-consistently describes impurity transport and radiation coupled to the plasma
- It has been successfully **validated** against **AUG**, **JET** and **C-Mod** experiments [1-4]
- This provides confidence on its **extrapolation** for predictions of **ITER** plasmas [2,3]

Conclusions

- A validated modelling workflow can be applied to predict the interplay between **impurities**, **auxiliary heating** and **plasma performance**
- In a reactor core, turbulent transport will dominate over neoclassical transport for high-Z impurities, in contrast to present-day devices
- This leads to flat W densities, regardless of ECRH power: W content limited by H-mode sustainment

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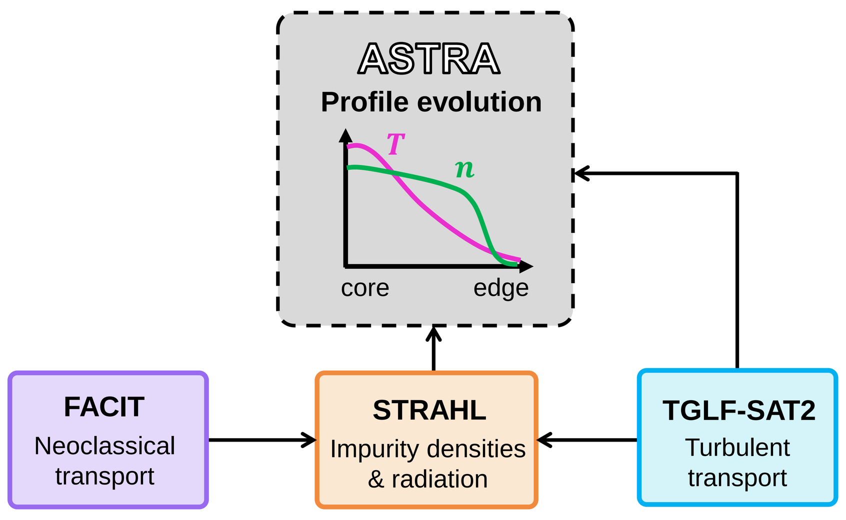
Modelling workflow

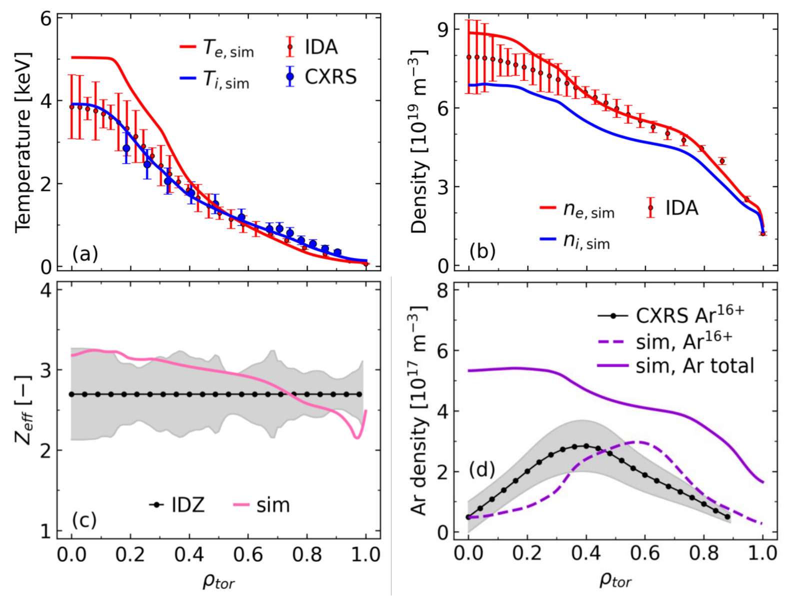
- Couples the impurity code STRAHL to the ASTRA transport modelling suite
- Uses state-of-the-art theory-based transport models **TGLF-SAT2** [5] and **FACIT** [6]
- FACIT was extended to include the effects of **rotation** on high-Z neoclassical transport



- Simulations up to the separatrix for L-modes or H-modes with weak pedestals, or up to the pedestal top in H-mode

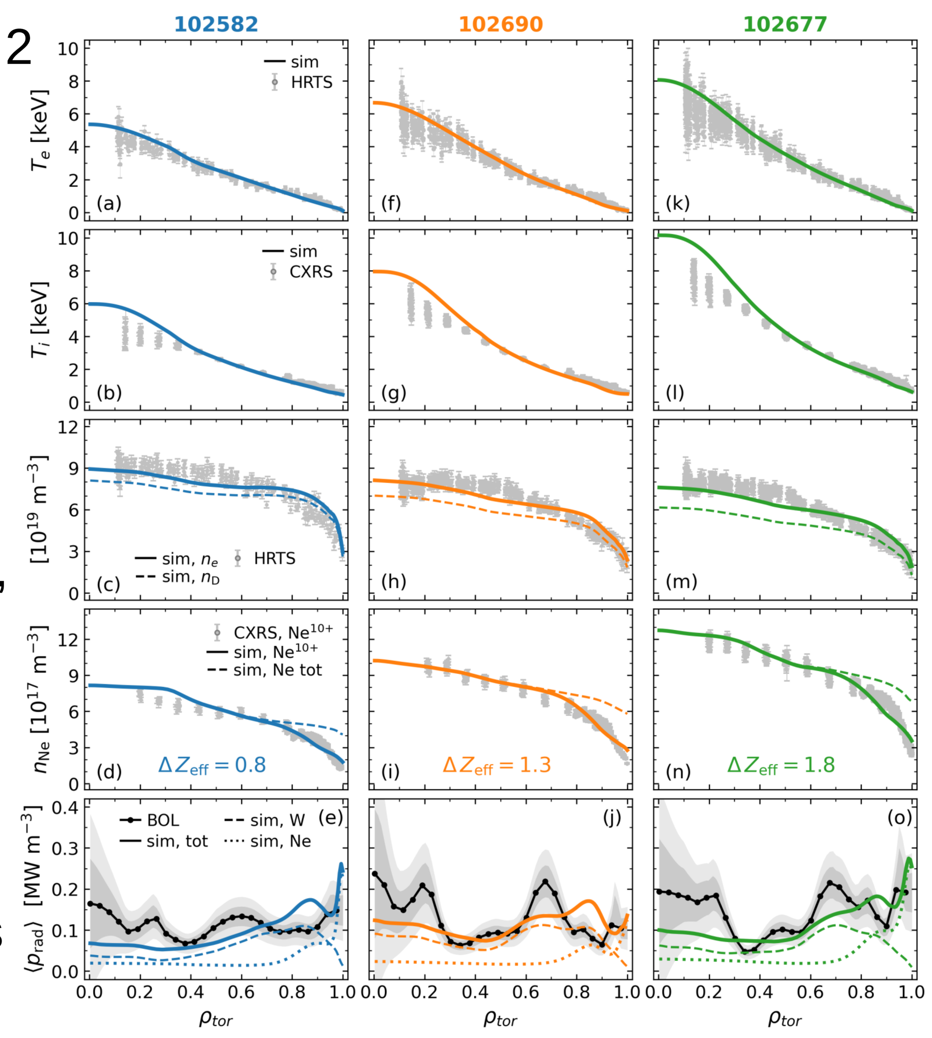
Full-radius modelling of high-power seeded L-modes in AUG and JET

- AUG #37041 with P_{aux} ~ 8 MW but $P_{sep} < P_{LH}$: feedback with **Ar** seeding
- $f_{rad} \approx 70\%$, $H_{98} \approx 0.95$ without ELMs [7]



- Simulation of main plasma with three impurities [1]: **Ar**, **W** and **B**
- High confinement is reproduced
- Simple model for X-point radiation was included

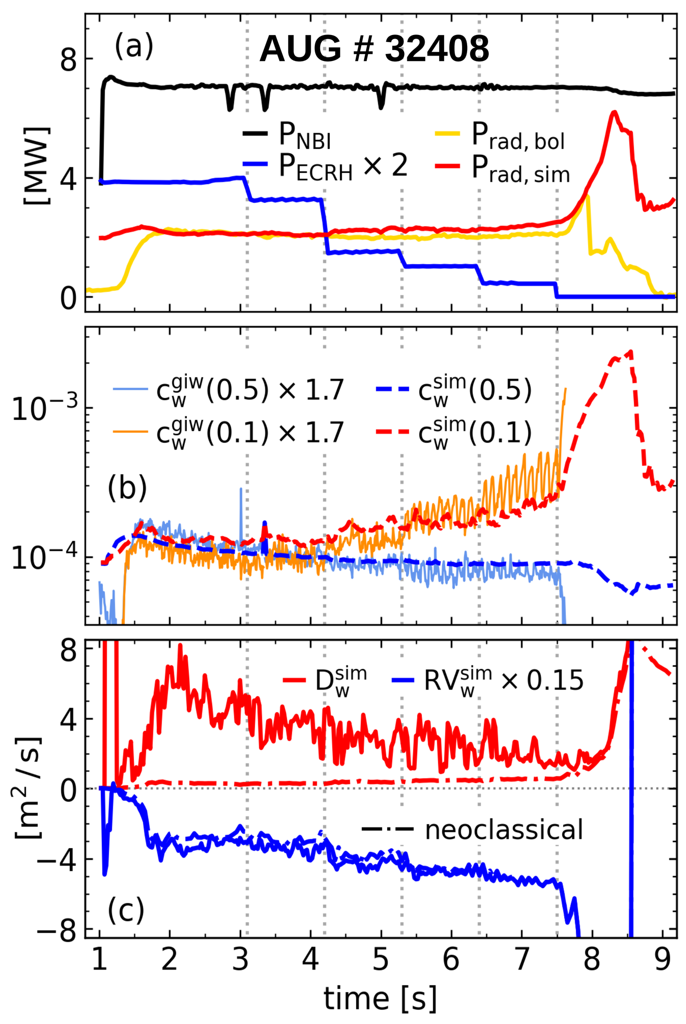
- High current I_p = 3.2 MA at B_t = 3.45 T (q_{95} ~ 3.3) in deuterium [8]
- 28 MW of NBI, 4 MW of ICRH
- Neon seeding: low, intermediate, high
- Excellent agreement with experiment across all transport channels



- Including neon is necessary to reproduce the main profiles and global confinement in the simulations

Control of W accumulation with ECRH in AUG

- **Quantitative** predictions of tungsten **accumulation control** with central **wave heating** in NBI-heated H-modes [2]



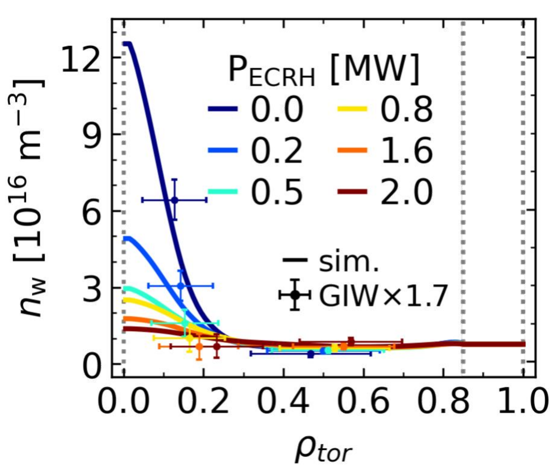
ECRH modifies the competition between neoclassical and turbulent W transport

↓

increases **turbulent diffusion** & reduces **neoclassical pinch**

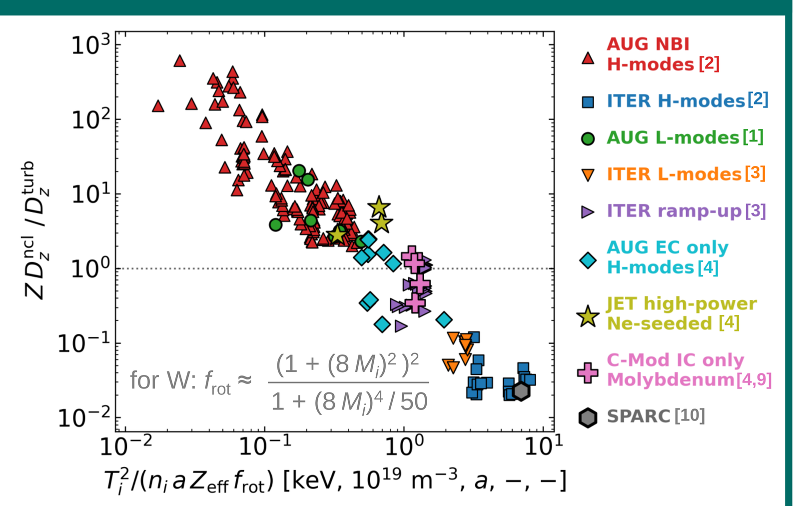
↓

flattening of central W density reproduced by the modelling:



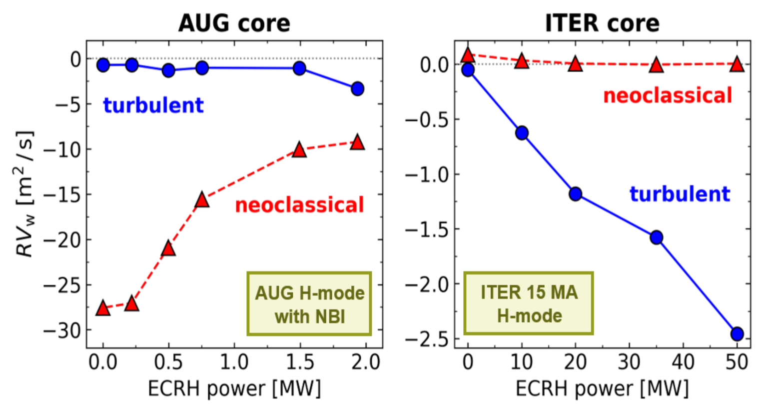
Core high-Z transport in future fusion reactors

A transition in high-Z impurity transport regime takes place, from dominant neoclassical to dominant turbulent convection, as reactor core conditions are approached

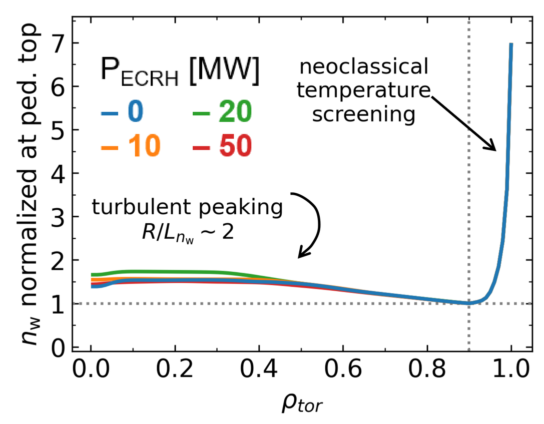


Predictions of tungsten transport in ITER

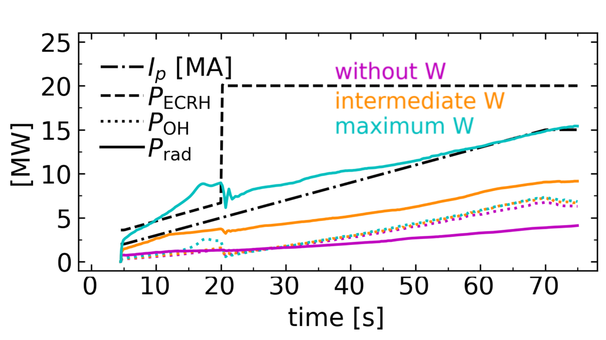
- In the core of ITER, high-Z neoclassical transport is much lower than turbulent transport due to the much lower collisionality and rotation



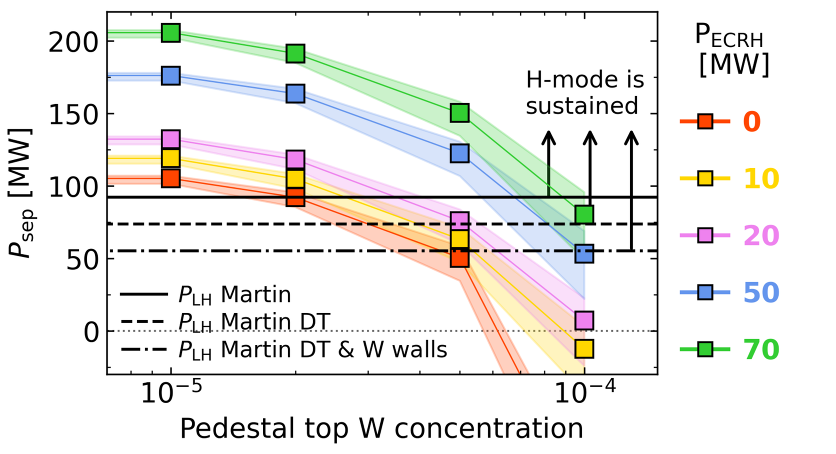
- Turbulent transport does not lead to central accumulation
- W densities are **flat** regardless of ECRH power, in contrast to present devices [2]



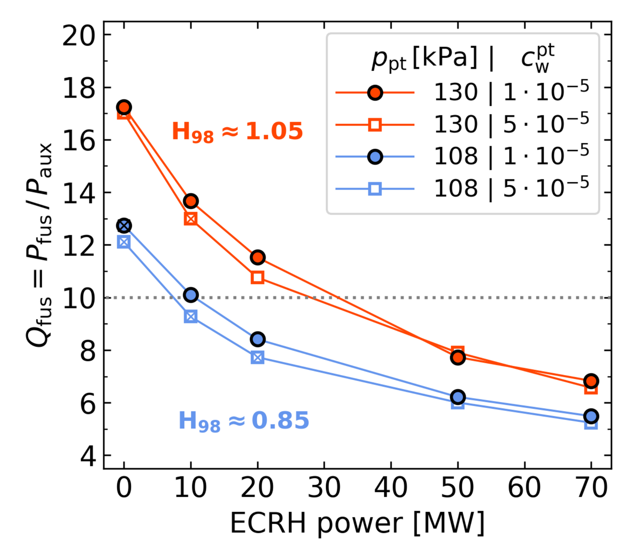
- Max. allowed c_w for survival in the I_p ramp up, and for H-mode access in electron heated L-modes, have also been identified [3].



- In the absence of core accumulation, the maximum tolerable W concentration is limited by the **sustainment of H-mode operation** [2]



- Global radiative losses due to W must be sufficiently compensated with **auxiliary heating**, at a penalty on **performance** in Q_{fus} [2]



- c_w ~ 3 – 5 × 10^{-5} are marginal
- A better confinement also provides a higher margin for H-mode sustainment due to increased alpha heating [3]

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