EUROfusion PWIE SP 4 D
Plasma background modelling, neutral wall fluxes and upgraded A&M data

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The background plasma conditions determine the migration of impurities in magnetic fusion devices

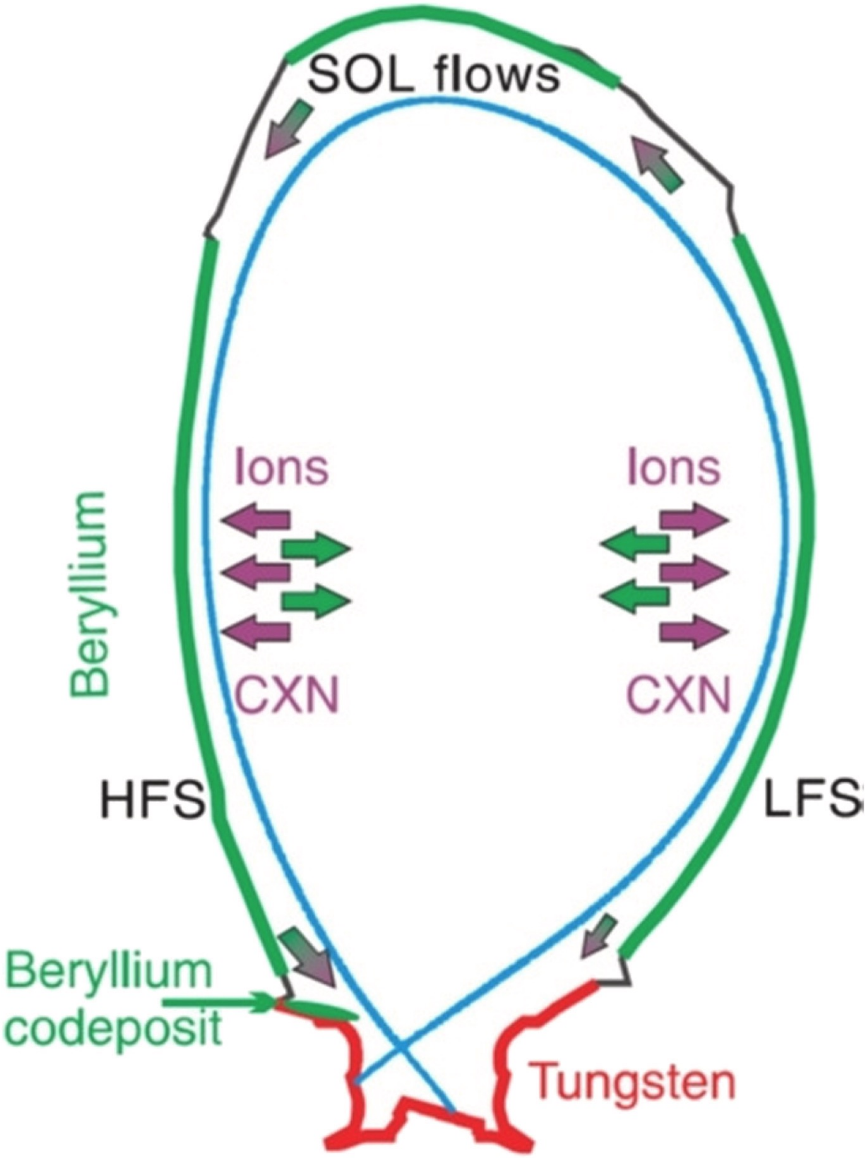


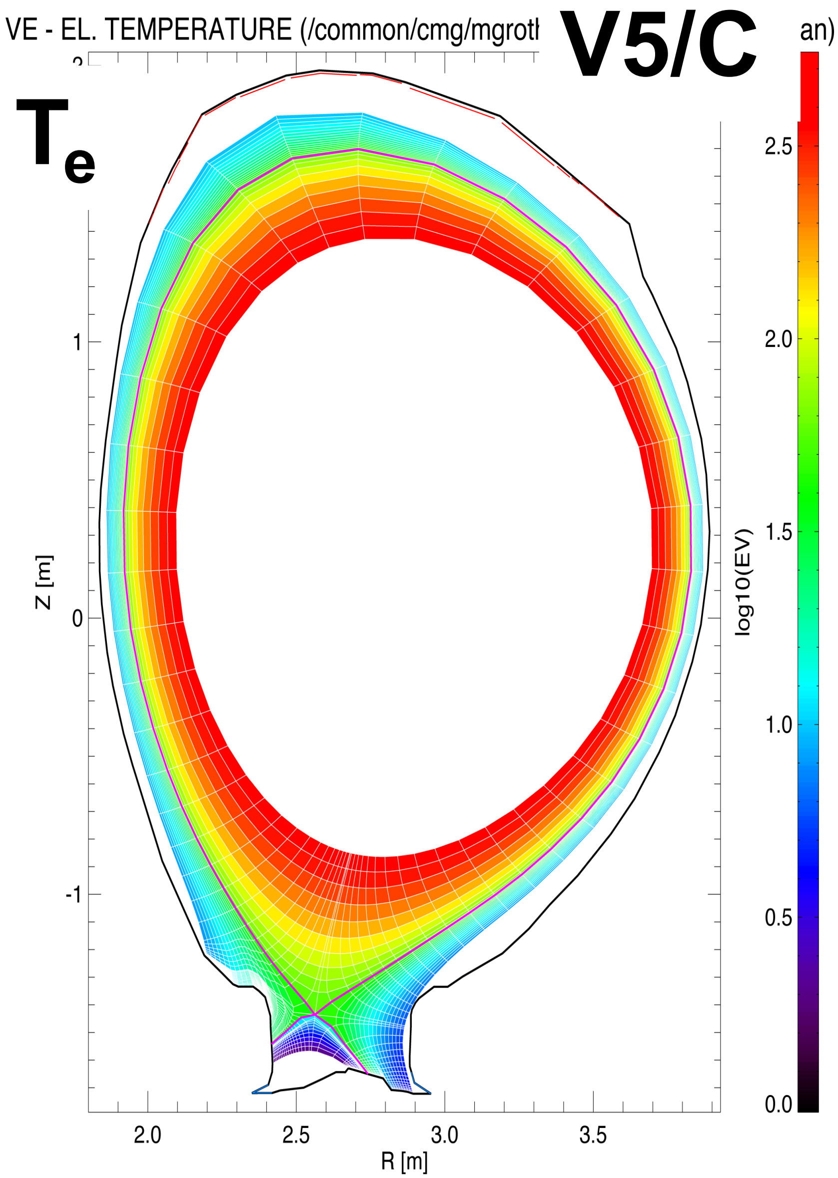
Fig. from S. Brezinsek et al., NF 2015

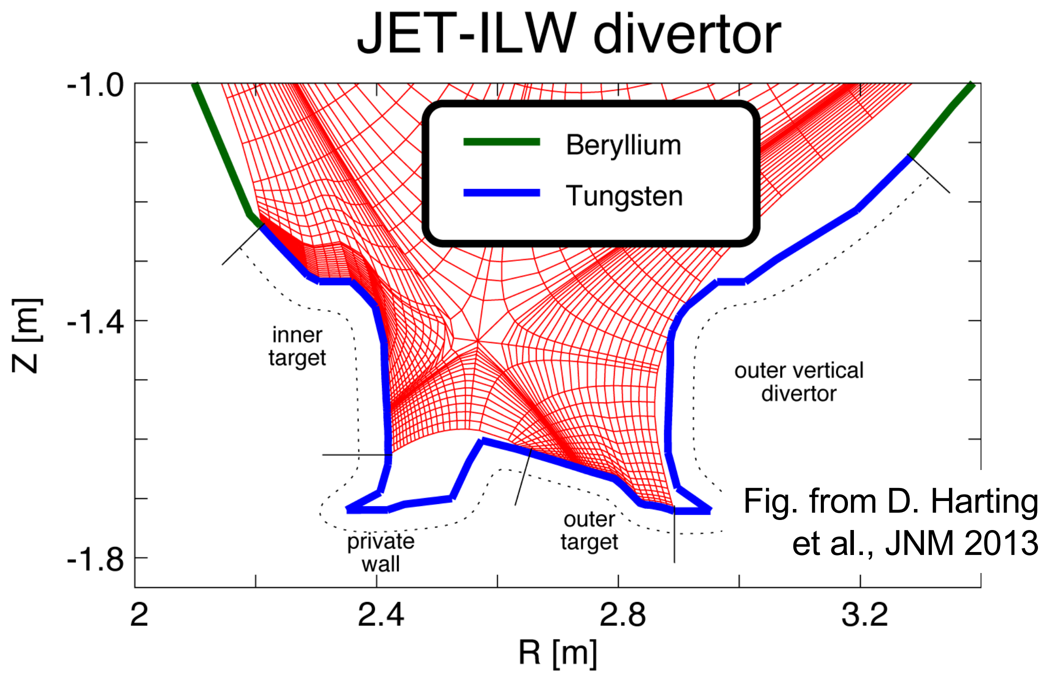
- Ion and (charge-exchange) neutral fluxes = sputtering source
- Divertor plasma conditions + plasma flows = divertor retention, short-range migration
- Main SOL plasma conditions and flows = wall sources, long-range migration
- Ideally, seek **validated** 3D maps of fluxes, T, n, potential flows, etc. across the entire SOL up to the main wall

⇒ In reality, 2D maps of plasma conditions in near-separatrix SOL, several λ_n for edge-modelling optimised configurations, partially validated, known issues, e.g., reproducing SOL flows

⇒ SOLPS-ITER, EDGE2D-EIRENE, SOLEDGE2D-EIRENE, OEDGE, …

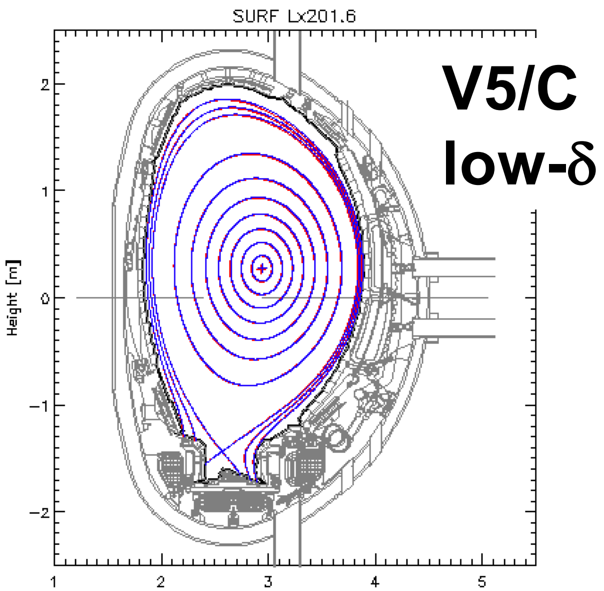
EDGE2D-EIRENE in the JET-ILW configuration for V5/C has been used to provide the background plasma for ERO2.0

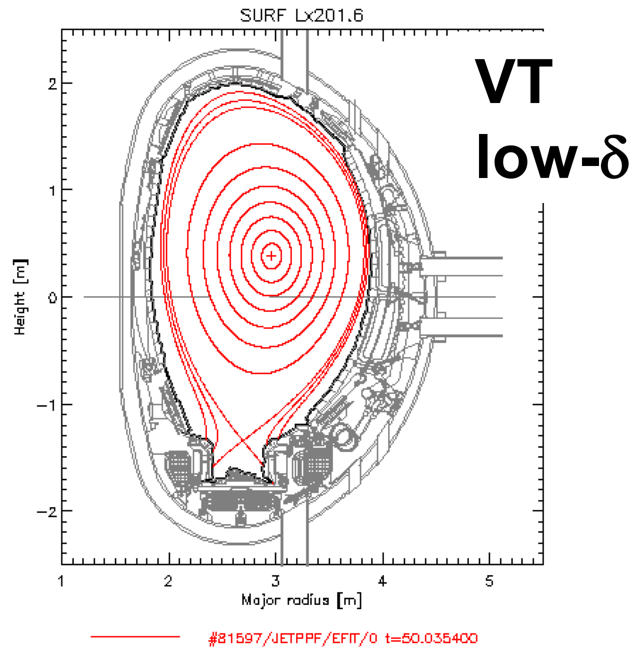


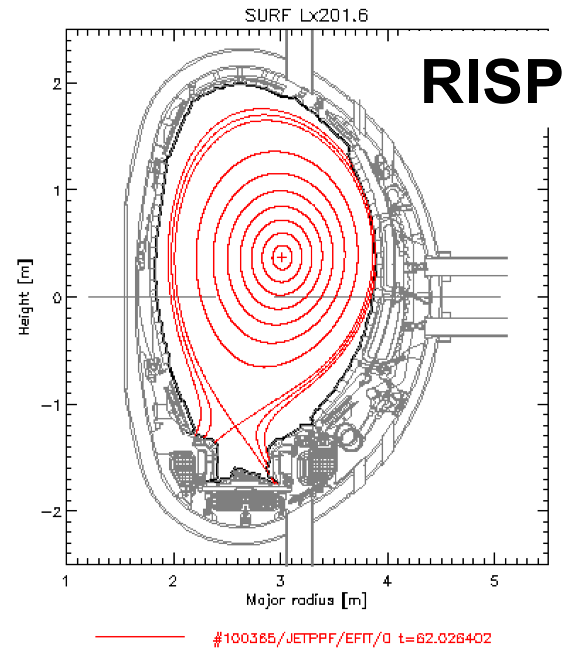


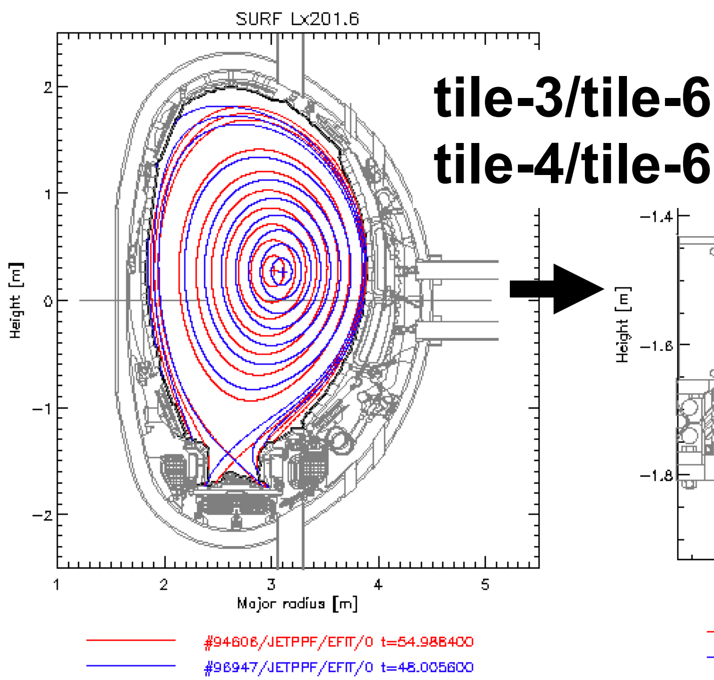
- Physical sputtering of Be at MC wall; Be = non-recycling impurity, omit W (run W with ERO2.0)
- Vacuum region between physical wall and EDGE2D grid edge
- Power and density scans corresponding to experiments, carried out on same grid

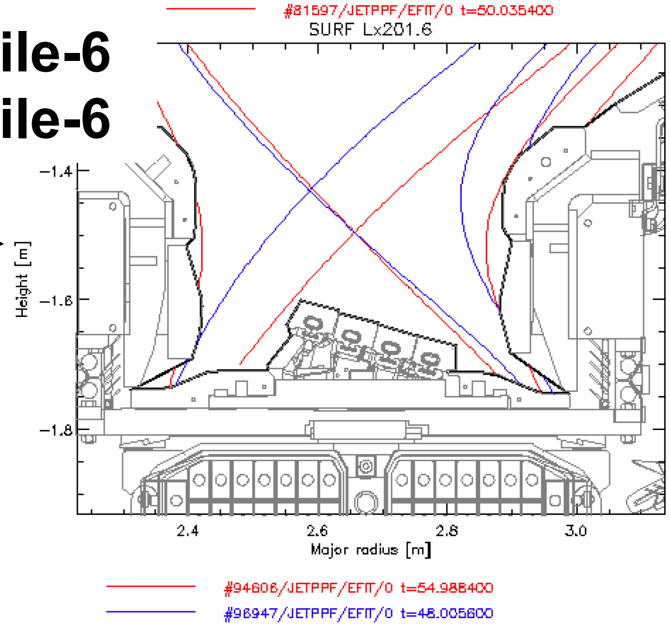
Portfolio of PWI relevant JET-ILW equilibria has been developed since start of ILW campaign in 2011











Experimental setup and data analyses tailored toward validation of edge codes ⇒ used in impurity migration codes

- Focus of work on JET-ILW → comparison to AUG via 2022 He and D experiments
- Systematic changes to plasmas to investigate both the trends and the absolute values of the plasma parameters
  - Parameter scans: core density ($n_{sep,LFS\text{-}mp}$) and input power (P_{SOL}) for divertor conditions
  - Plasma movements for spatial resolution, repeat discharges for diagnostics, e.g., hydrogenic molecules
  - Change of hydrogenic isotope species → helium in 2022
  - Ohmic → L-mode → inter-ELM H-mode → intra-ELM H-mode
- Synergy between general SOL physics experiments (e.g., detachment, power exhaust) and impurity generation and migration experiments:
  - Same or similar equilibria
  - Same or similar plasma conditions

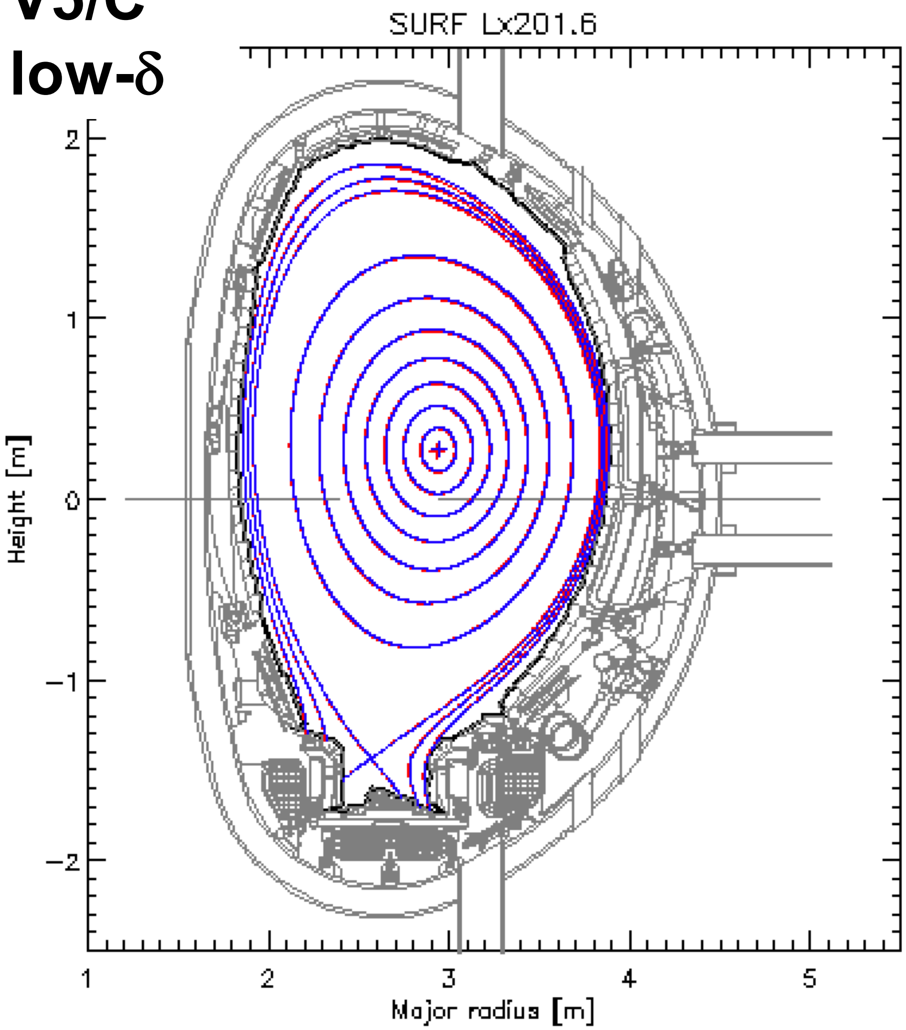
Simulations of background plasma conditions in JET-ILW, V5/C low-δ configuration

$\Rightarrow$ CXN into LFS midplane port

$\Rightarrow$ Isotope effect on SOL

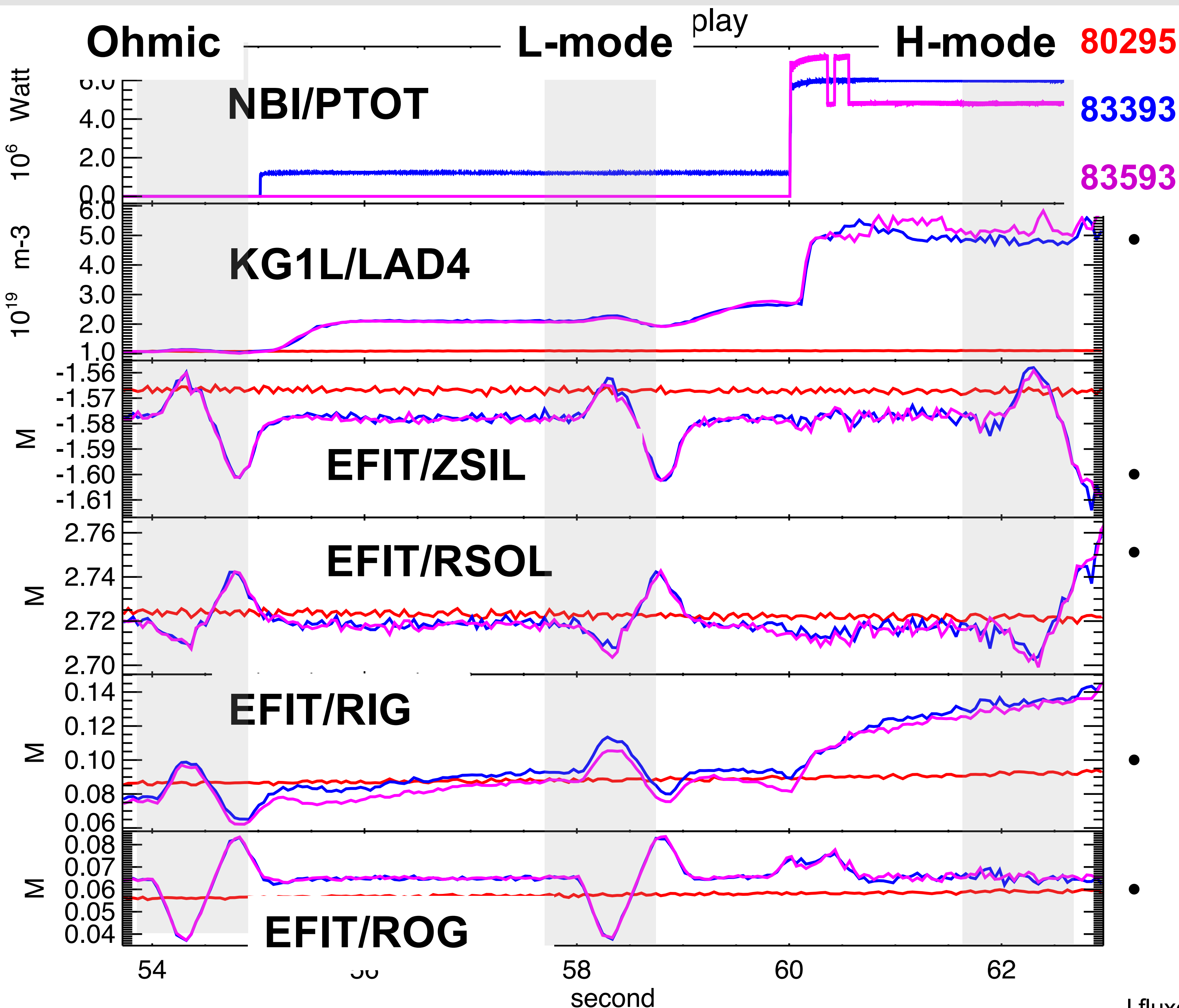
Vertical-tile-3, horizontal-tile-5, stack C (V5/C) configuration most used, most diagnosed config.

V5/C low-δ



JET equil. / time	Type/purpose	Edge fluid codes
80295 / 59.0 s	2.0 MA, 2.0 T, V5/C, low-δ, drifts: **Initial Be migration exp.**, ohmic, density and power scans **BeMP: ohmic, L-mode, H-mode (C30c)**: D+Be+W, H+Be, T+Be, He **CXN to outer midplane port for mirror assembly**	EDGE2D-EIRENE OEDGE
81472 / 50.0 s	2.5 MA, 2.5 T, V5/C, low-δ, drifts: **L-mode, density and power scans** H+Be, D+Be, T+Be, D+N → He in 2022	EDGE2D-EIRENE SOLPS-ITER OEDGE

The Ohmic, L-mode and H-modes phases of the BeMP were simulated based on EDGE2D-EIRENE



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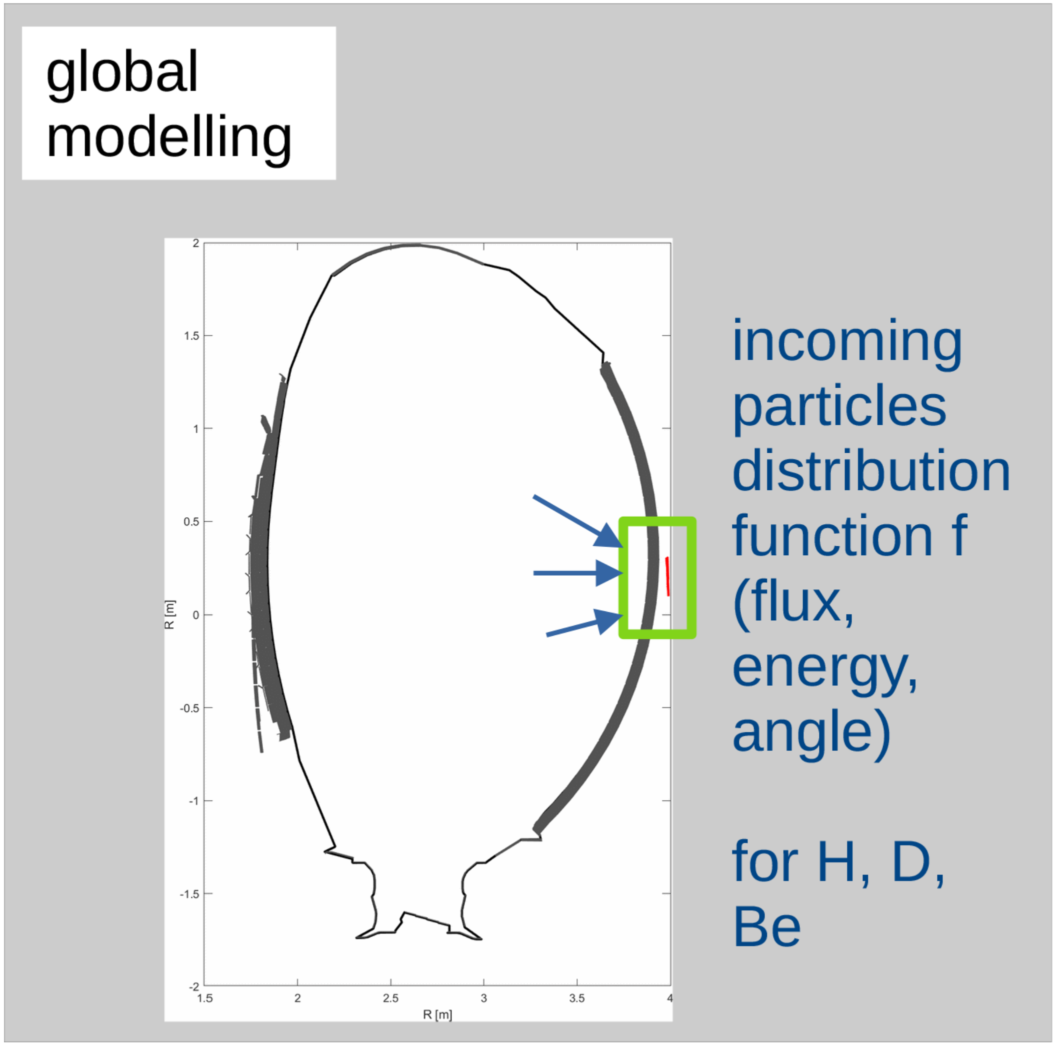
- LAD4 ≈ 1.1e19 m^{-3} (Ohmic), 2.3e19 m^{-3} (L-mode)
- ZSIL within 1cm
- RSOL within 0.5 cm
- RIG moved during pulse
- ROG within 1 cm

Revisited EDGE2D-EIRENE simulations for EIRENE energy and angle resolved neutral fluxes into OMP port



In collaboration with FZJ (Juri Romazanov, Sebastian Rode, Sven Wiesen), figure courtesy of Juri Romazanov

- FZJ/ERO2.0 project to assess performance of mirrors installed inside an outer midplane port
- Simulations of JET Be monitoring pulse ⇒ extension of outer midplane region to estimate charge-exchange neutral (CXN) fluxes
- EIRENE energy and angle resolved spectra of atomic and/or molecular fluxes to designated tally surface

A port and a EIRENE diag. surfaces at the OMP vessel was introduced to measured D0 CX fluxes to a mirror assembly

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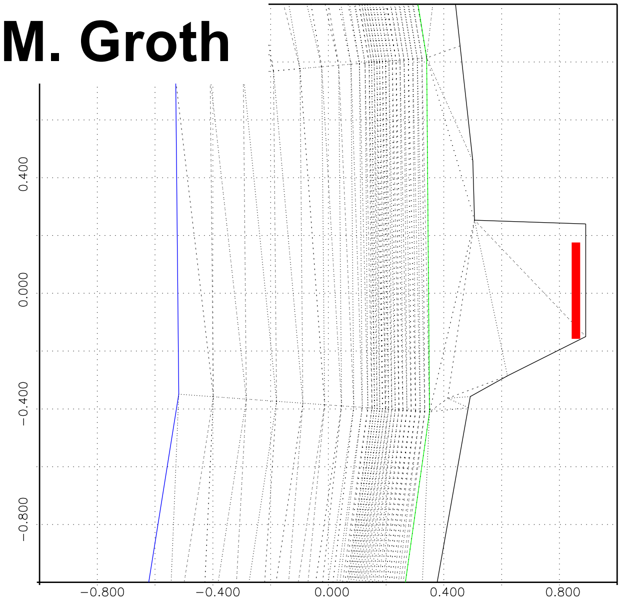
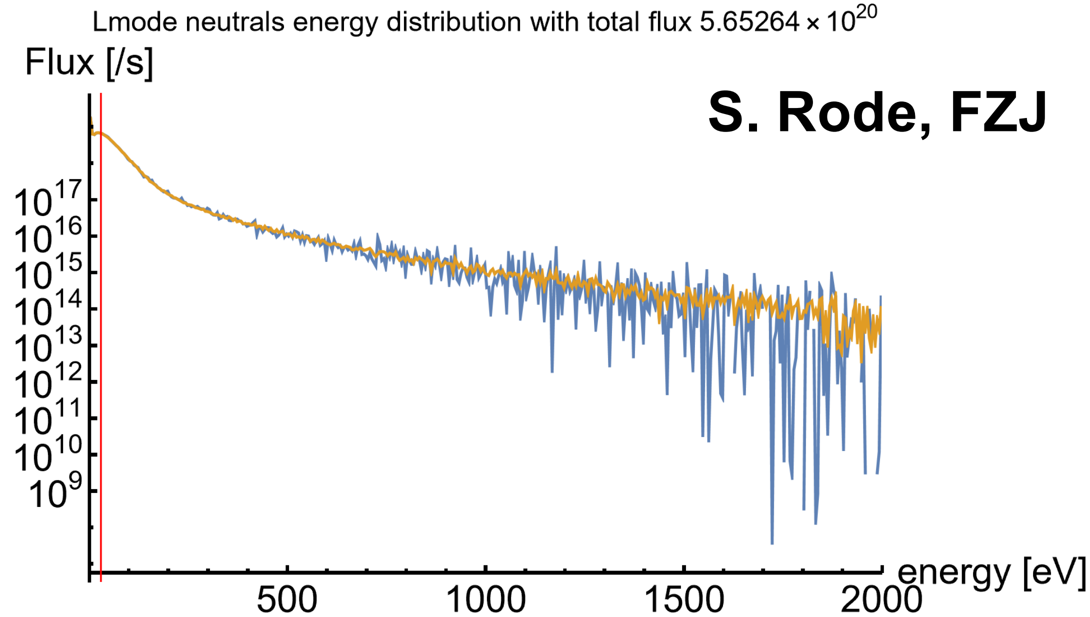
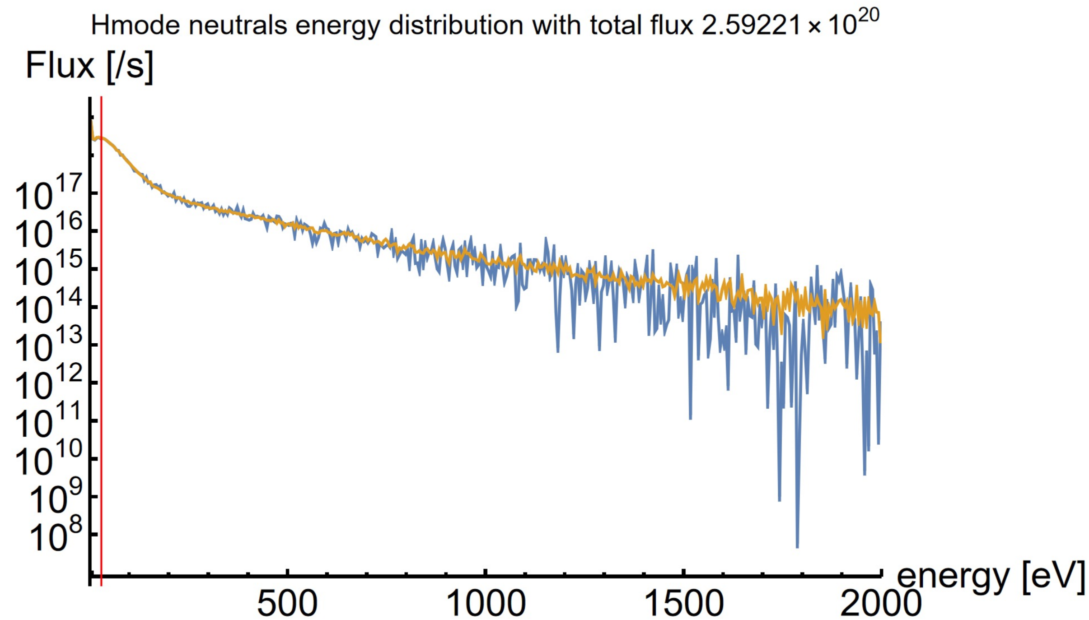


S. Rode, FZJ

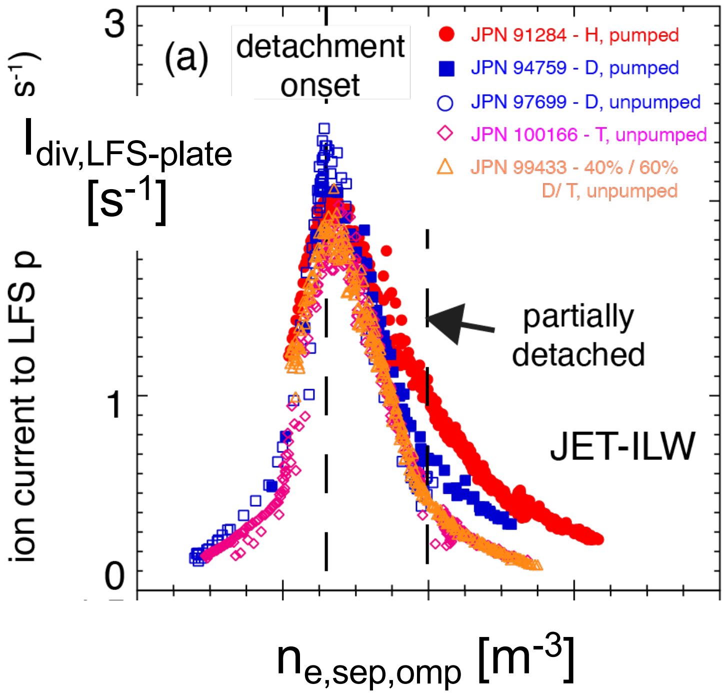




- Standalone EIRENE with imported E2D solution for plasma grid
- EIRENE energy spectrum of D0 in 150 bins, equi-spaced 0 to 1 keV → 400 bins, equi-spaced 0 to 2 keV

⇒ As of last week: **impact angle = polar angle wrt. surface normal**

Density scans in H, D and T were simulated with EDGE2D-EIRENE for the different SOL regimes



H, D, T, DT

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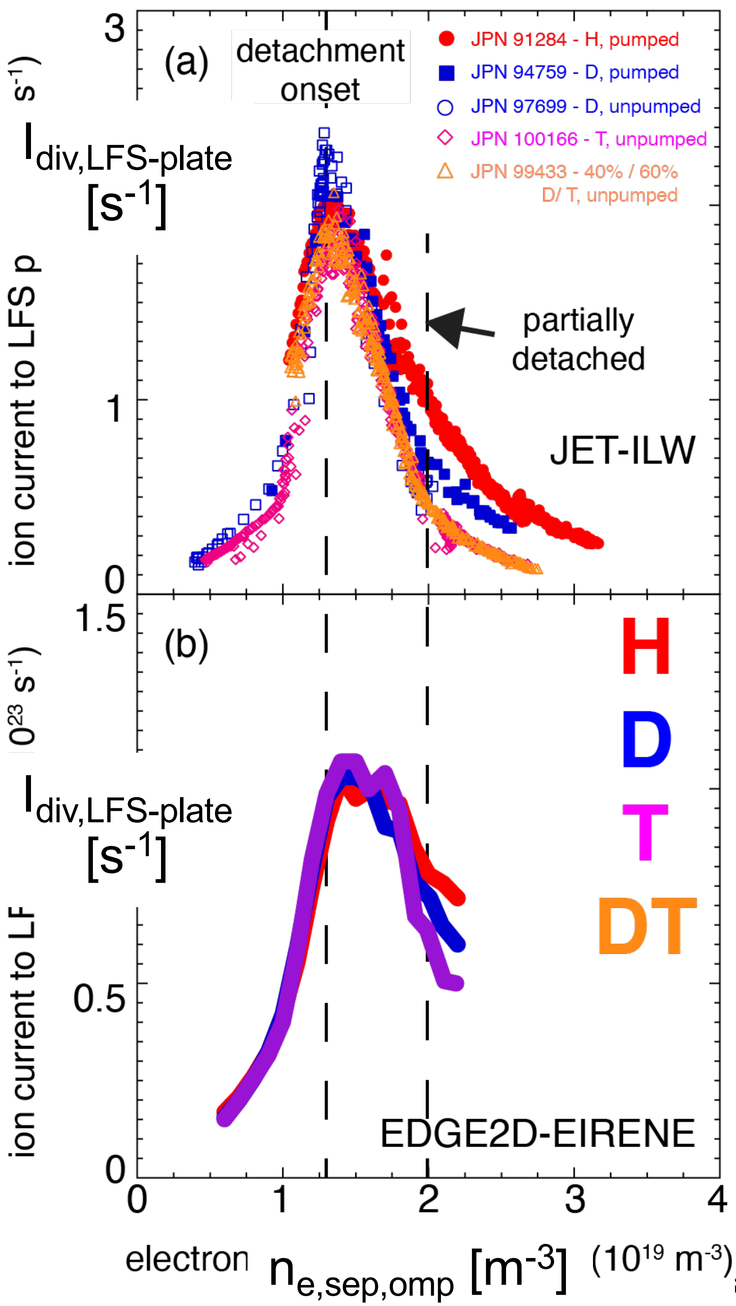
Density scans in H, D and T were simulated with EDGE2D-EIRENE for the different SOL regimes



H, D, T, DT

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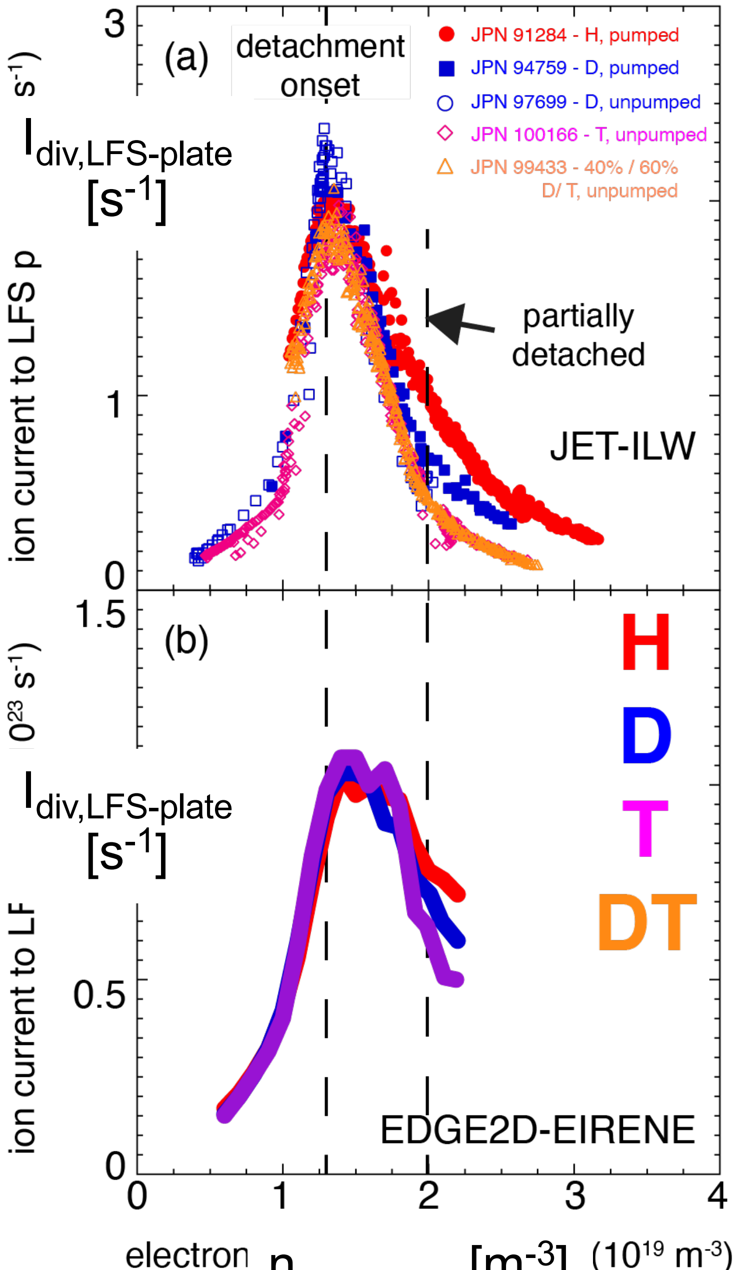
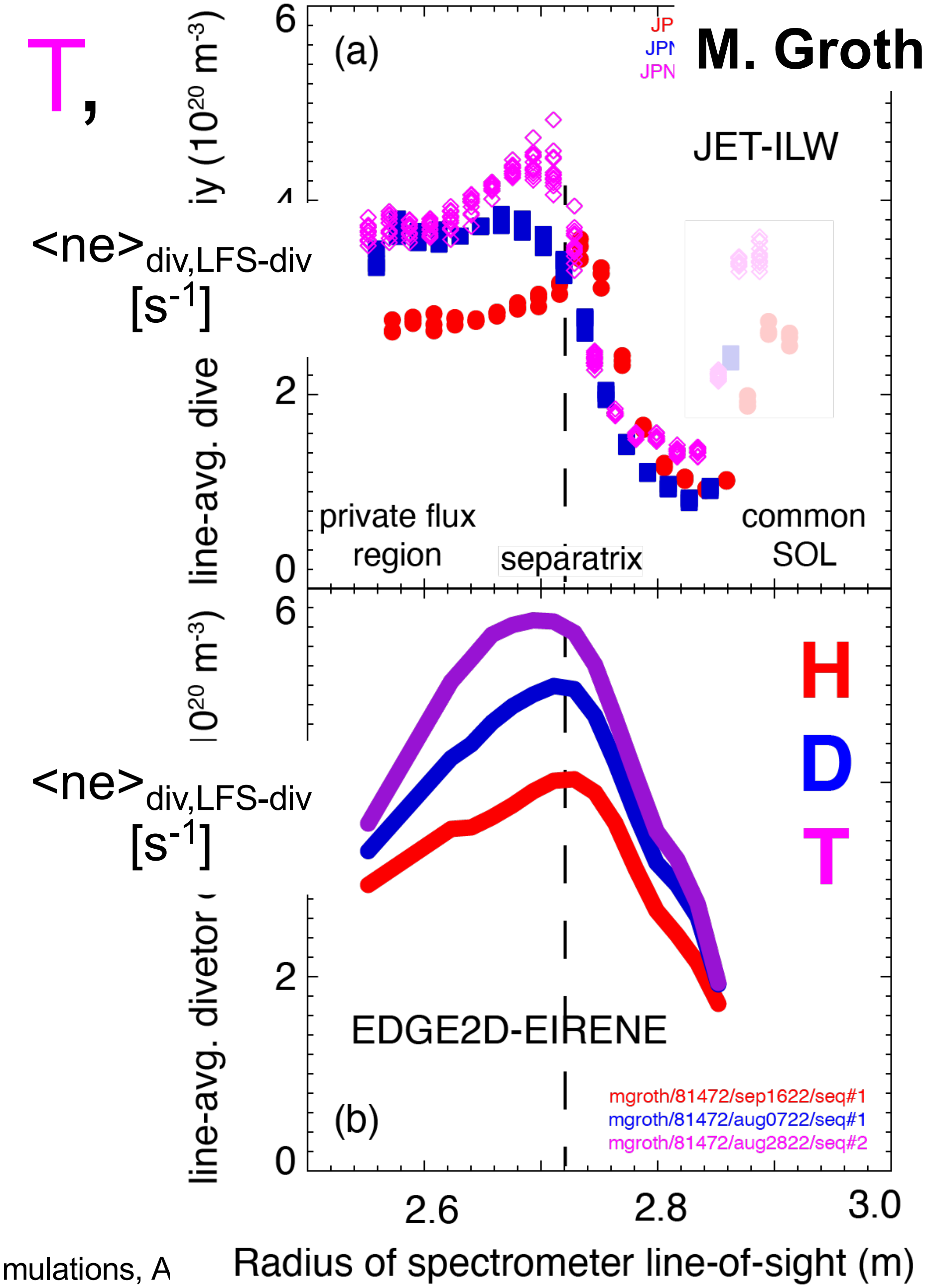
- **Generic density scan** with identical transport coeffs., same input power, physics models, etc.
- Stronger reduction in ion current to outer plate for T than for H and D, consistent with measured currents, LFS divertor densities

EDGE2D-EIRENE predicts higher div. densities in T than in H and D in high-recycling and partially detached conds.



H, D, T, DT

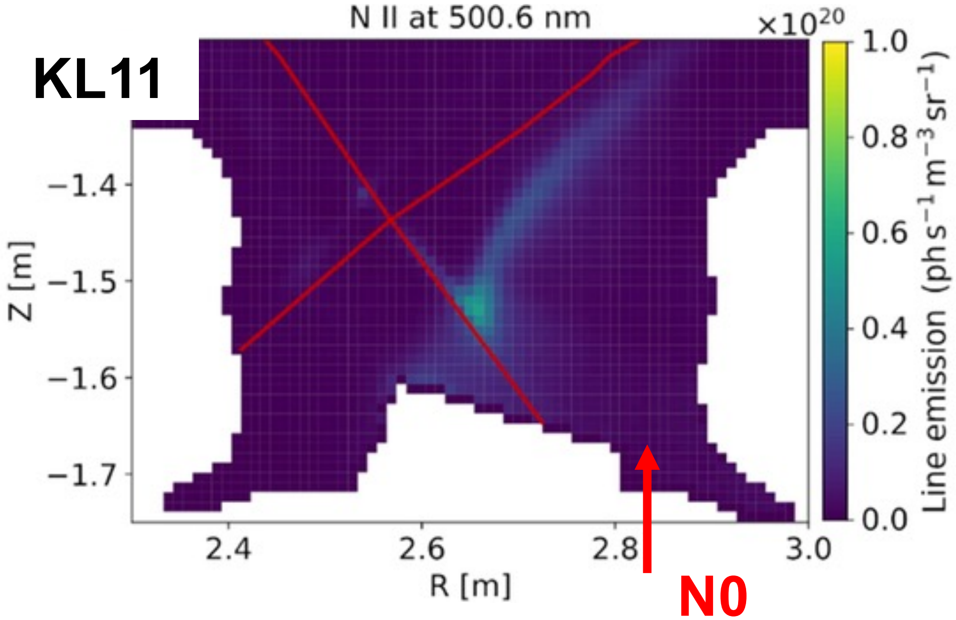
M. Groth

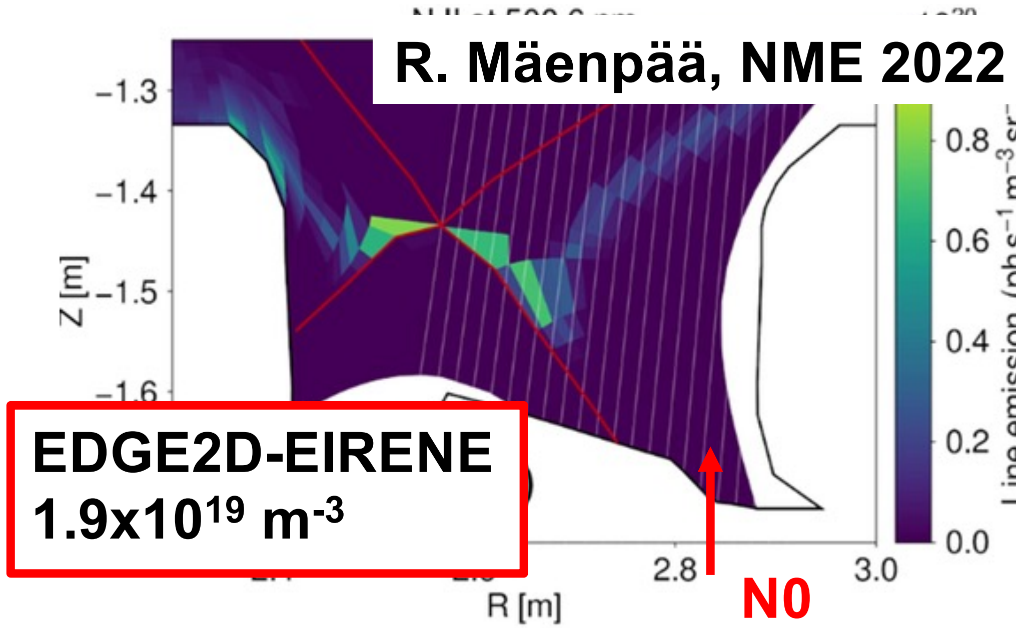


ma background simulations, A

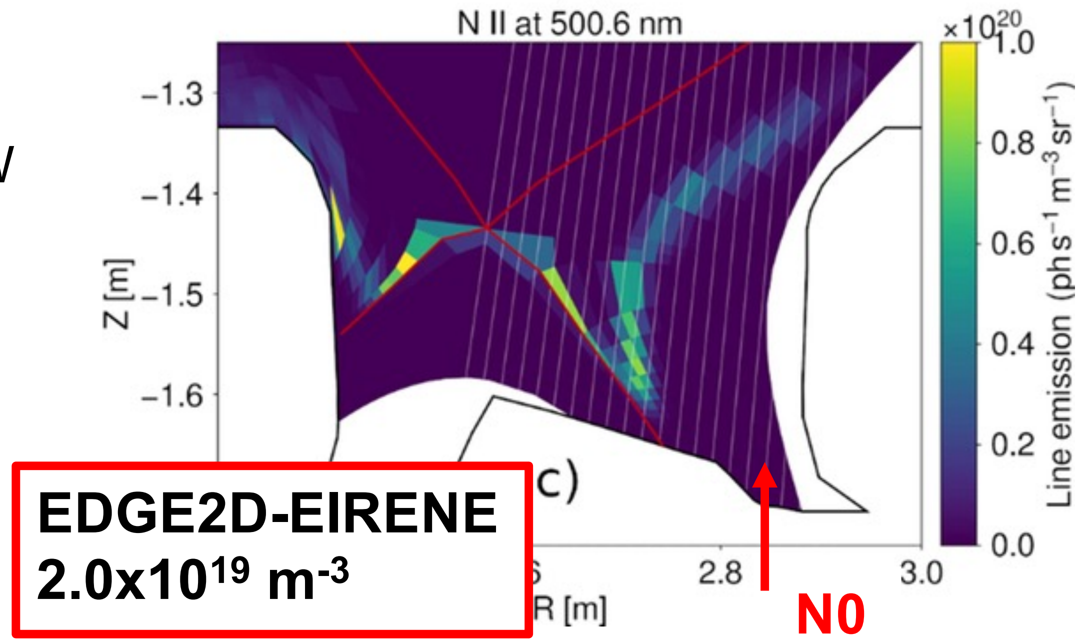
Nitrogen recycling and transport studies in JET-ILW L-mode plasmas

Location of N II emission (divertor conditions) strongly depends on EDGE2D-EIRENE assumed $n_{e,sep,LFS\text{-}mp}$



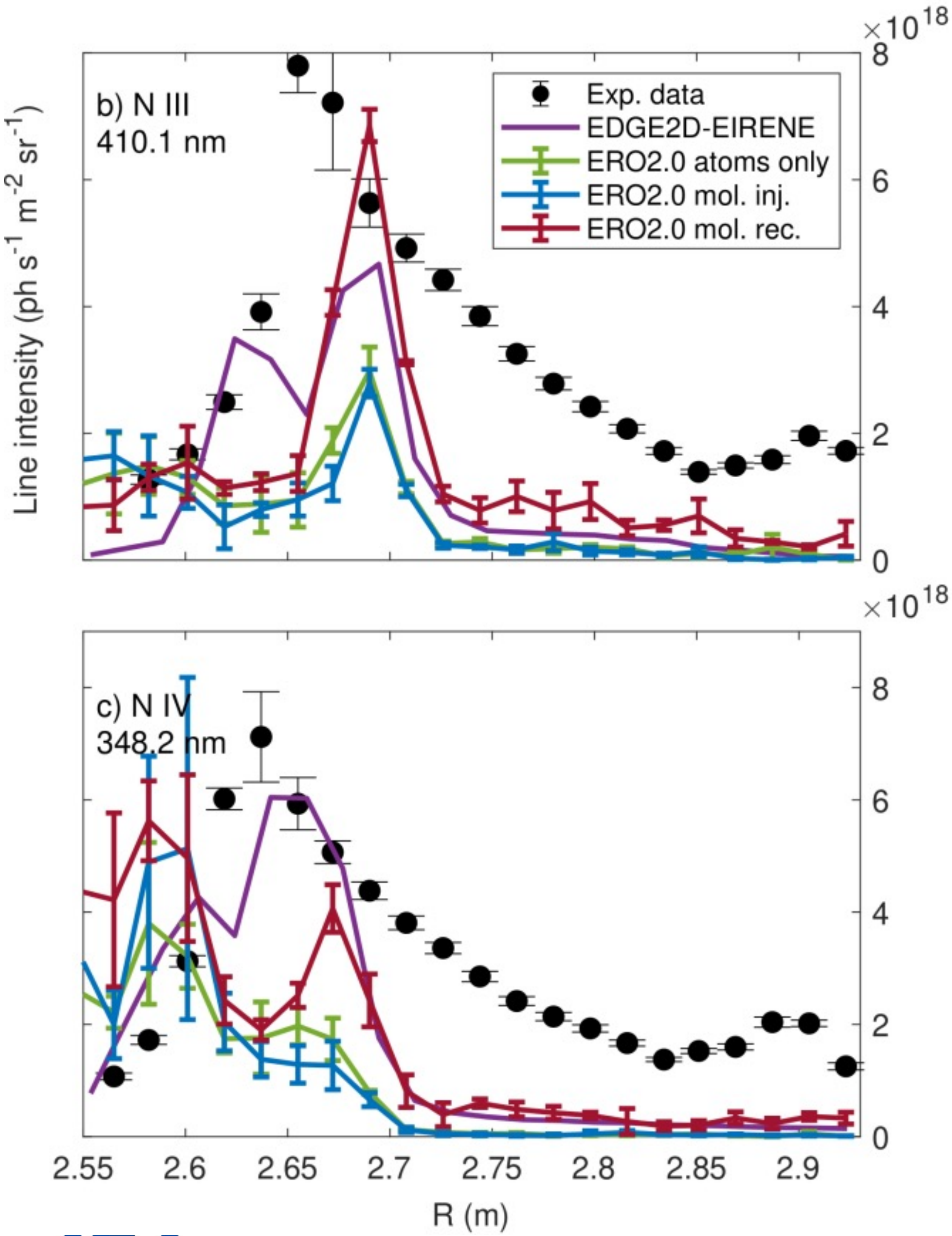


- EDGE2D-EIRENE and ERO2.0 simulations of N transport in JET-ILW high-recycling L-mode plasma
- Injection of nitrogen as atoms in EDGE2D-EIRENE ⇒ as atoms and molecules, recycling as molecules in ERO2.0



Molecular recycling of N ions in ERO2.0 increases N II - N IV intensity in the divertor, reduces N I intensity

R. Mäenpää, NME 2022



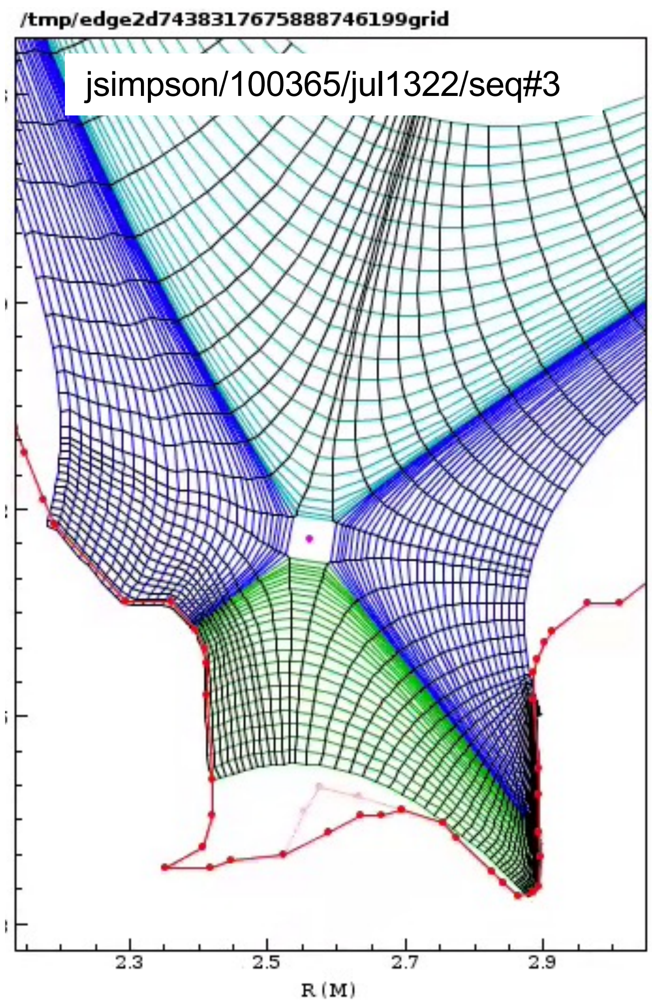
- Translational energy gain by N_2 dissociation fragments increases plasma penetration

⇒ Atomic and molecular injection of nitrogen produce similar predictions of N III and N IV line intensities, radial distributions across floor

- Molecular recycling of N_2 increases penetration of nitrogen away from strike point ⇒ improved agreement with experiment

Plasma conditions for Raised Inner Strike Point configuration for fuel retention studies

To expedite hydrogenic background plasma production, OEDGE was used for the RISP config.



- Equilibrium from JPN 100365 at 60.1802 s

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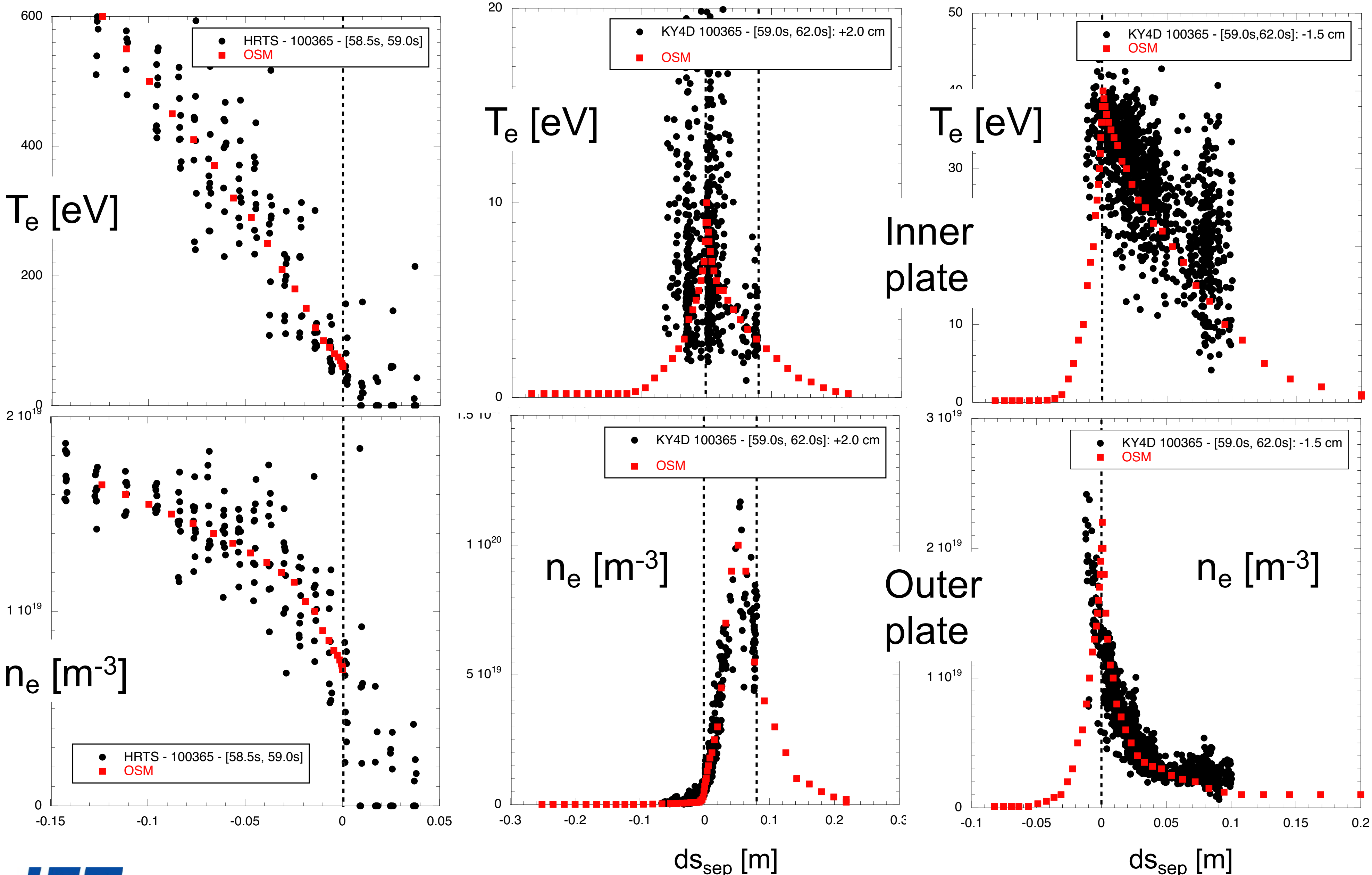
- OEDGE code: T_e, T_i, n_e and $v_{||}$ are predicted for individual flux tubes using the **measured** T_e, T_i, n_e at the target by Langmuir probes at both plates, and the measured core plasma profiles (e.g., HRTS)
- Grid from GRID2D (as EDGE2D-EIRENE)
- Plasma iterated with EIRENE for atomic and molecular densities, temperatures, etc.
- Code runs for 20-30 mins, but setup depends on assumed/fitted LP profiles
- OEDGE (EIRENE) parameters stored in netCDF files for further processing in ERO2.0

Utilize HRTS outer midplane, and inner and outer plates data for T_e and n_e as inputs to OEDGE grid

M. Groth



OEGDE predicts the anticipated D^+ flow to the inner plate in the inner SOL, to the outer plate in the outer SOL

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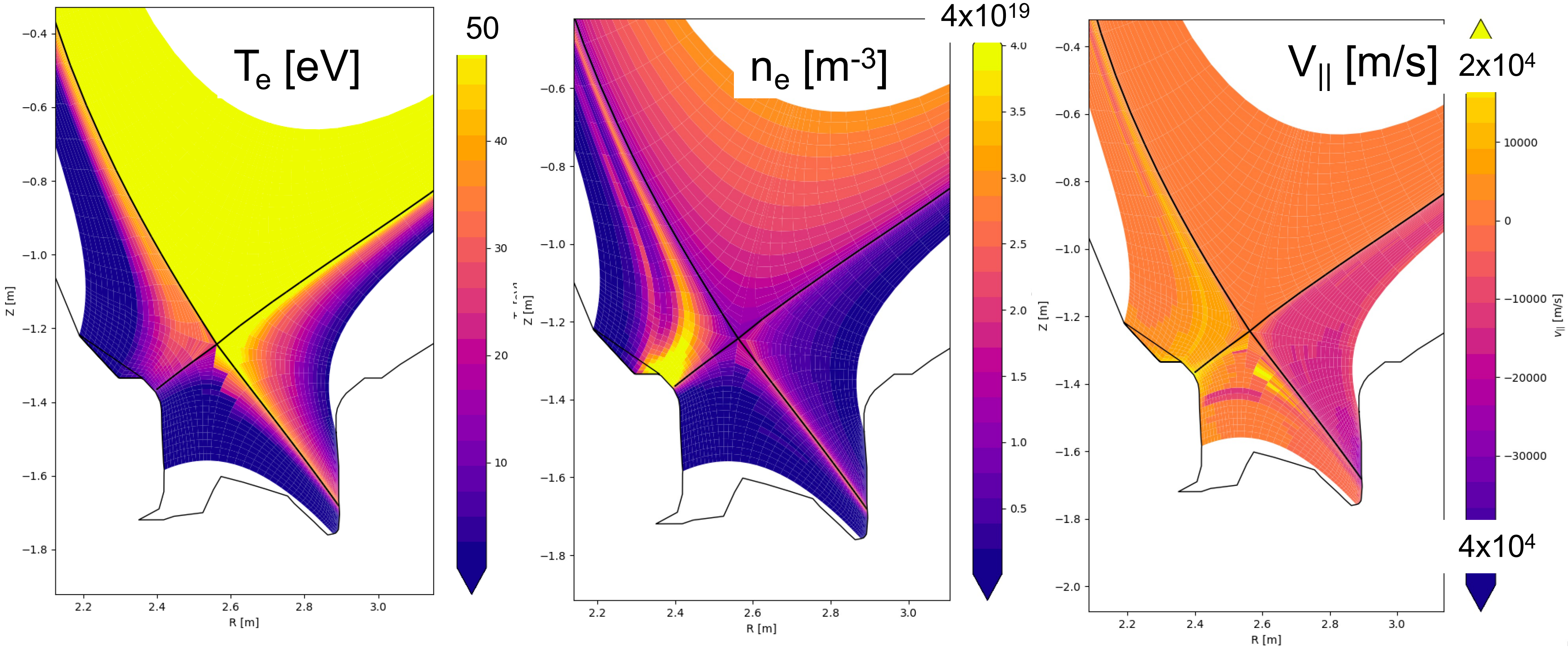
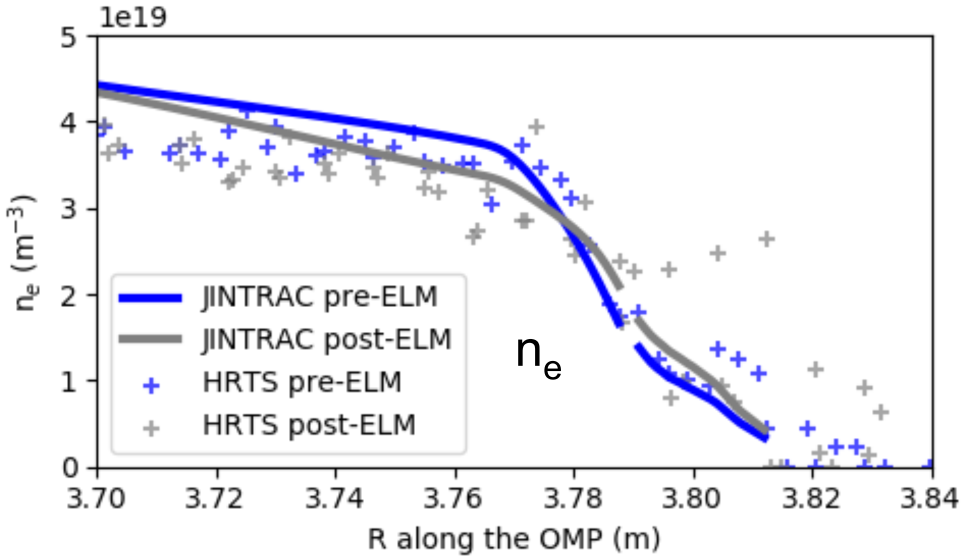


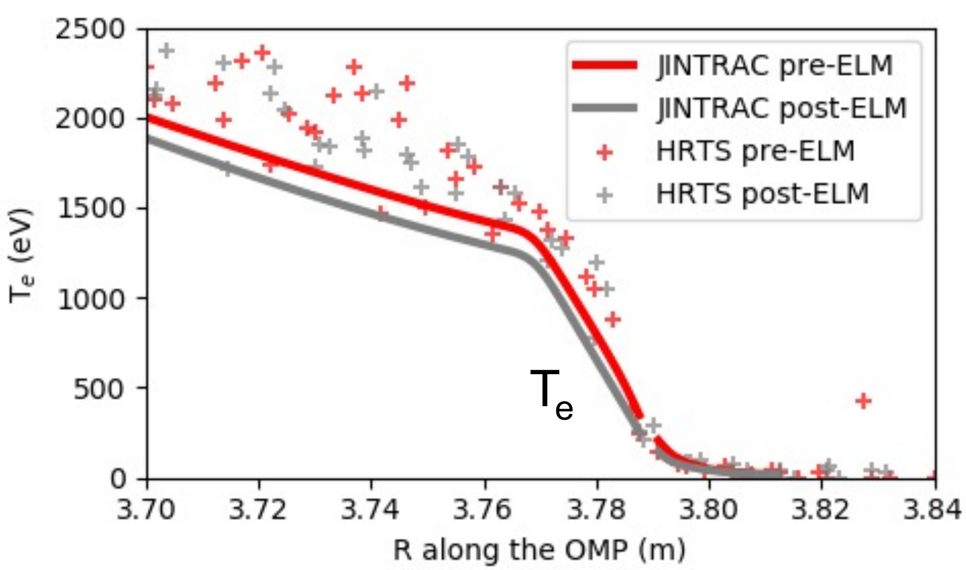
- Strongly peaked density near the corner of the flat and 45-deg tile on tile 1 ⇒ to be confirmed against KS3 and KL11 D_α measurements
- Systematic variations in LP parameters to test sensitivity of background plasma conditions on assumed profiles

JINTRAC / ERO2.0 inter and intra-ELM simulations of JET-ILW H-mode plasmas for whole-device W transport studies

Validated ELMy H-mode EDGE2D-EIRENE and JINTRAC solutions produced for W transport modelling

H. Kumpulainen





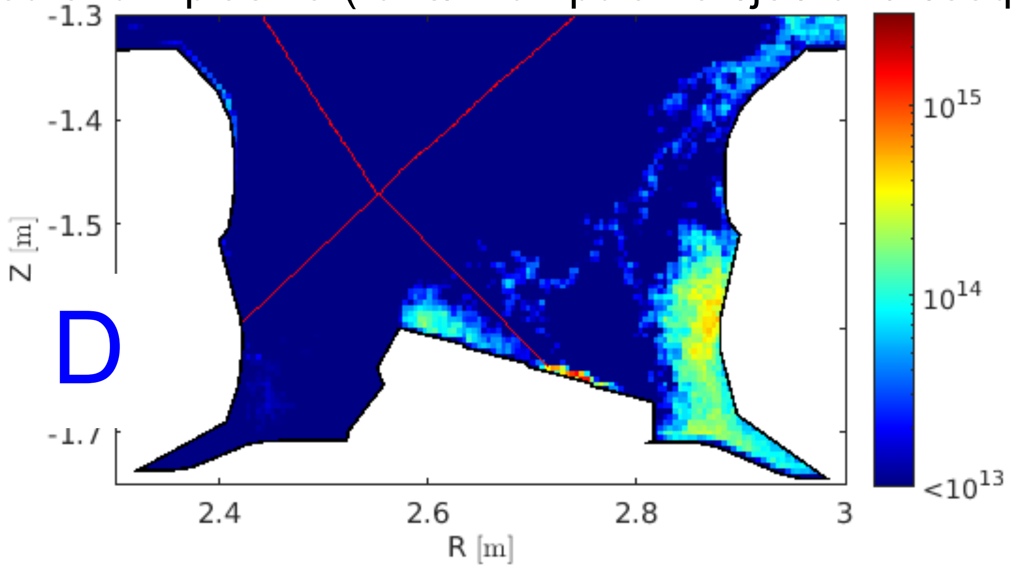
JPN 96947 (8 s), hkumpul/runs/run098x,run098y

- The studied scenarios include:
  - 18-36 MW of heating power
  - Vertical-horizontal and corner-corner divertor configurations
  - Deuterium and tritium plasmas
- Time-dependent solutions validated against:
  - Upstream n_e, T_e, T_i profiles
  - LFS target n_e, T_e, j_{sat} profiles
  - ELM-resolved time-evolution of:
    - Pedestal n_e, T_e
    - Plasma stored energy
    - Heat loads on targets
    - Divertor D-alpha and Be II emiss.

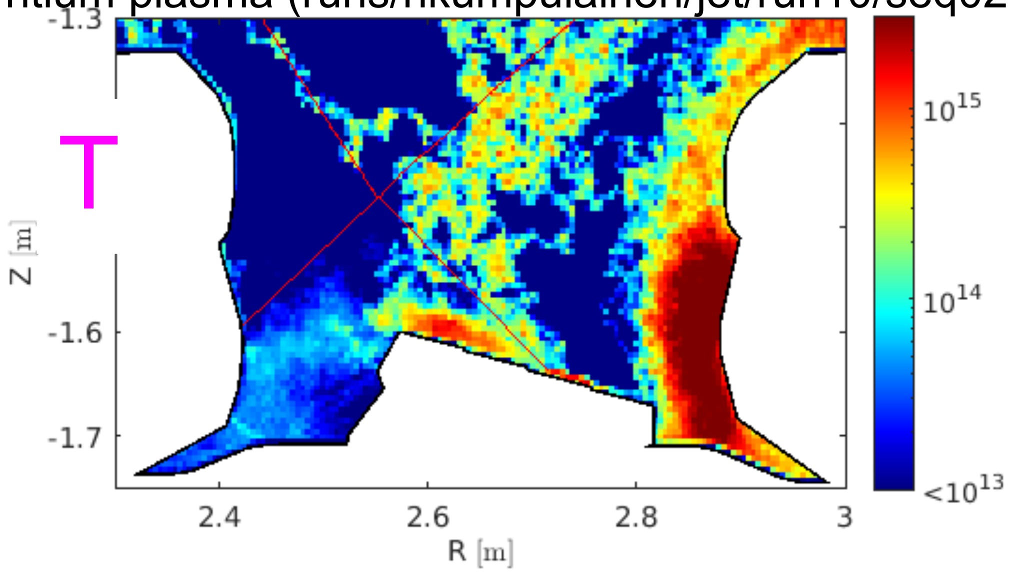
ERO2.0 predicts a factor-of-2 higher gross W erosion in tritium than in deuterium ELMy H-mode plasmas

H. Kumpulainen

Deuterium plasma (runs/hkumpulainen/jet/run02/seq17)



Tritium plasma (runs/hkumpulainen/jet/run10/seq02)



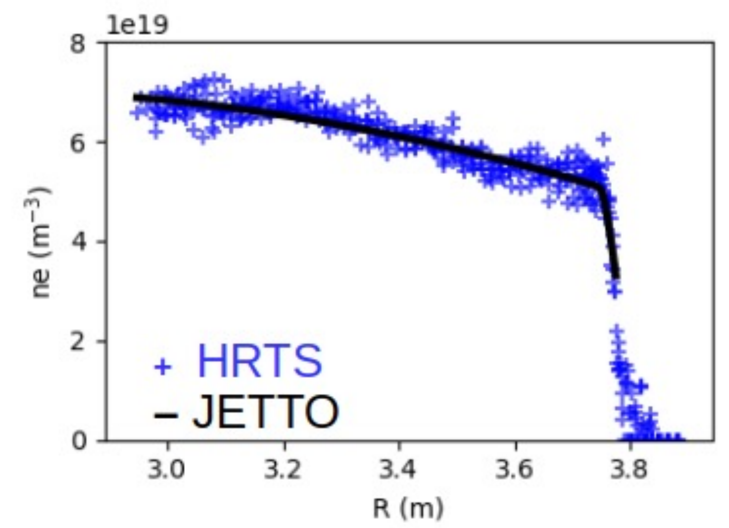
JPN 94605 (10 s), W density, inter-ELM phase

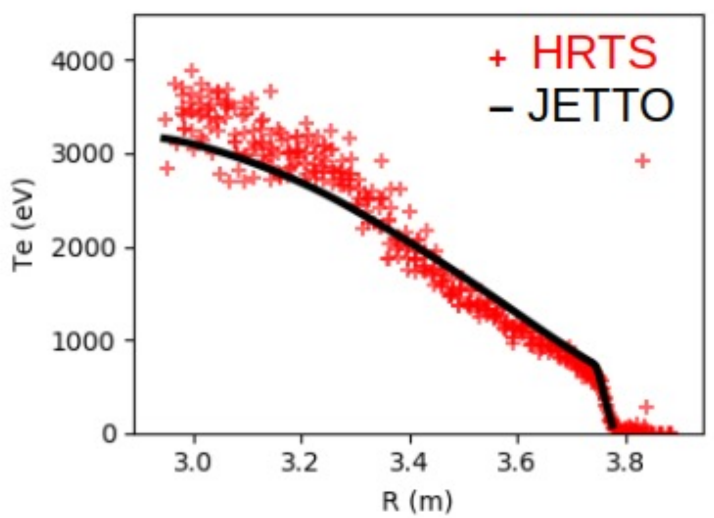
- Impact of D/T isotope on predicted Be concentration less than 30% → increased W erosion mostly due to:
  - T ions (esp. during ELMs)
  - T atoms (esp. inter-ELM non-plasma-wetted W surfaces)

- Very effective screening predicted at both divertor targets → primary cause of W influx to the main plasma is erosion by CX atoms near the outer divertor entrance

JINTRAC modelling with NEO aims to predict the core W density based on edge plasma ERO2.0 W predictions

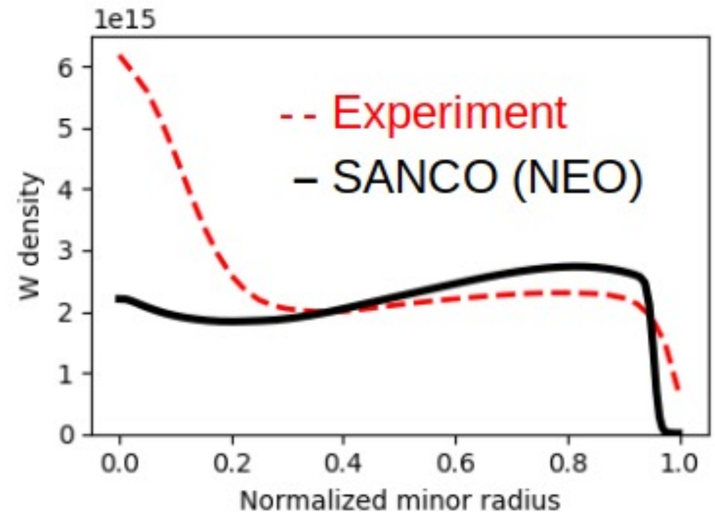
H. Kumpulainen





JPN 94606 (10 s), hkumpul/jetto/runs/run111

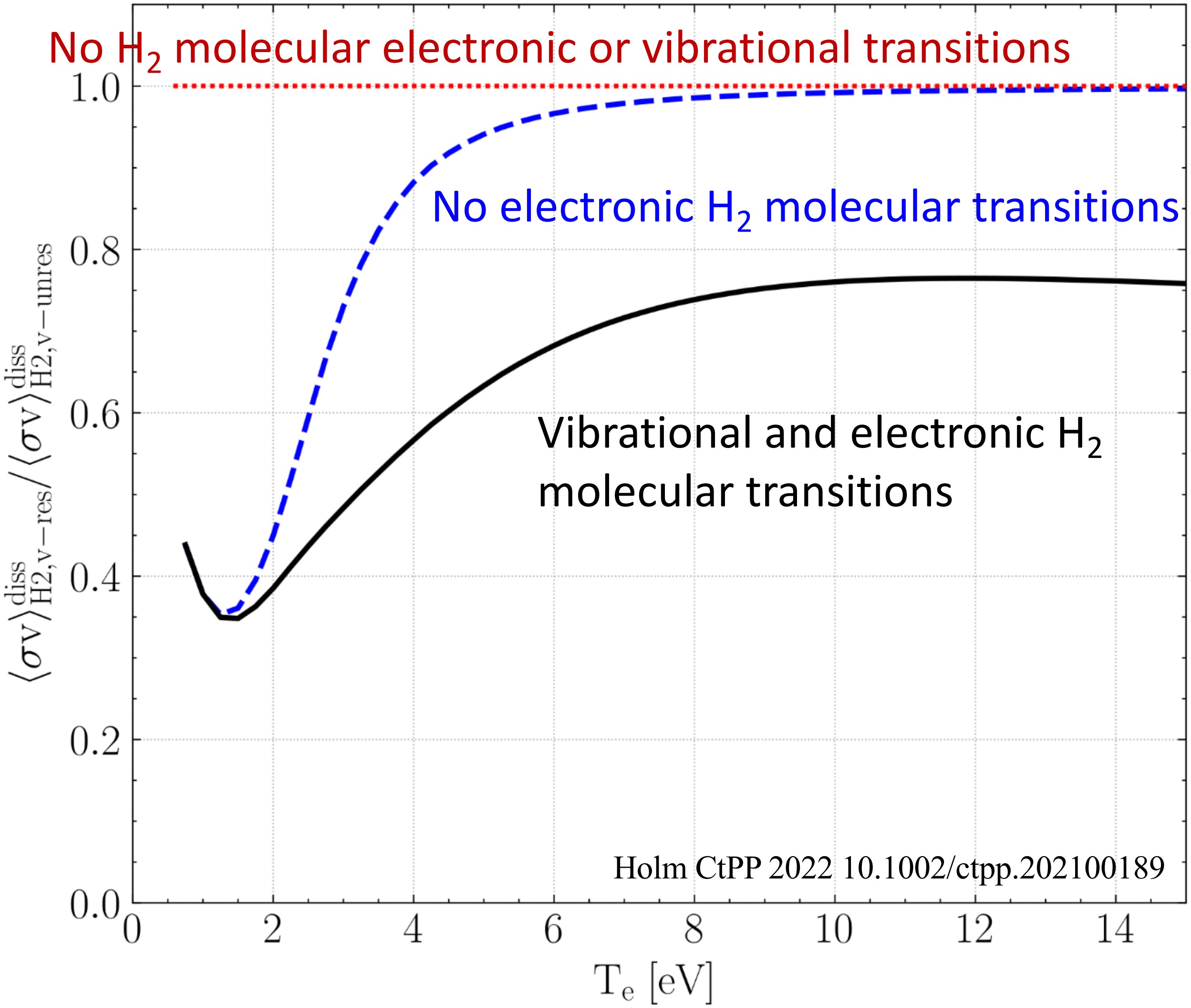
- Main ion conditions from Bohm/gyro-Bohm and neoclassical transport, fitted to measurements
- W boundary condition iterated to match ERO2.0 predictions of W density at the pedestal top
- More turbulent transport than expected in the core, work in progress



Assessment of Jülich AM databases for hydrogenic molecules, comparison to more up-to-date IPP Garching AM databases

Vib. resolved EIRENE data considers different collisional-radiative (CR) processes than vib. unresolved data

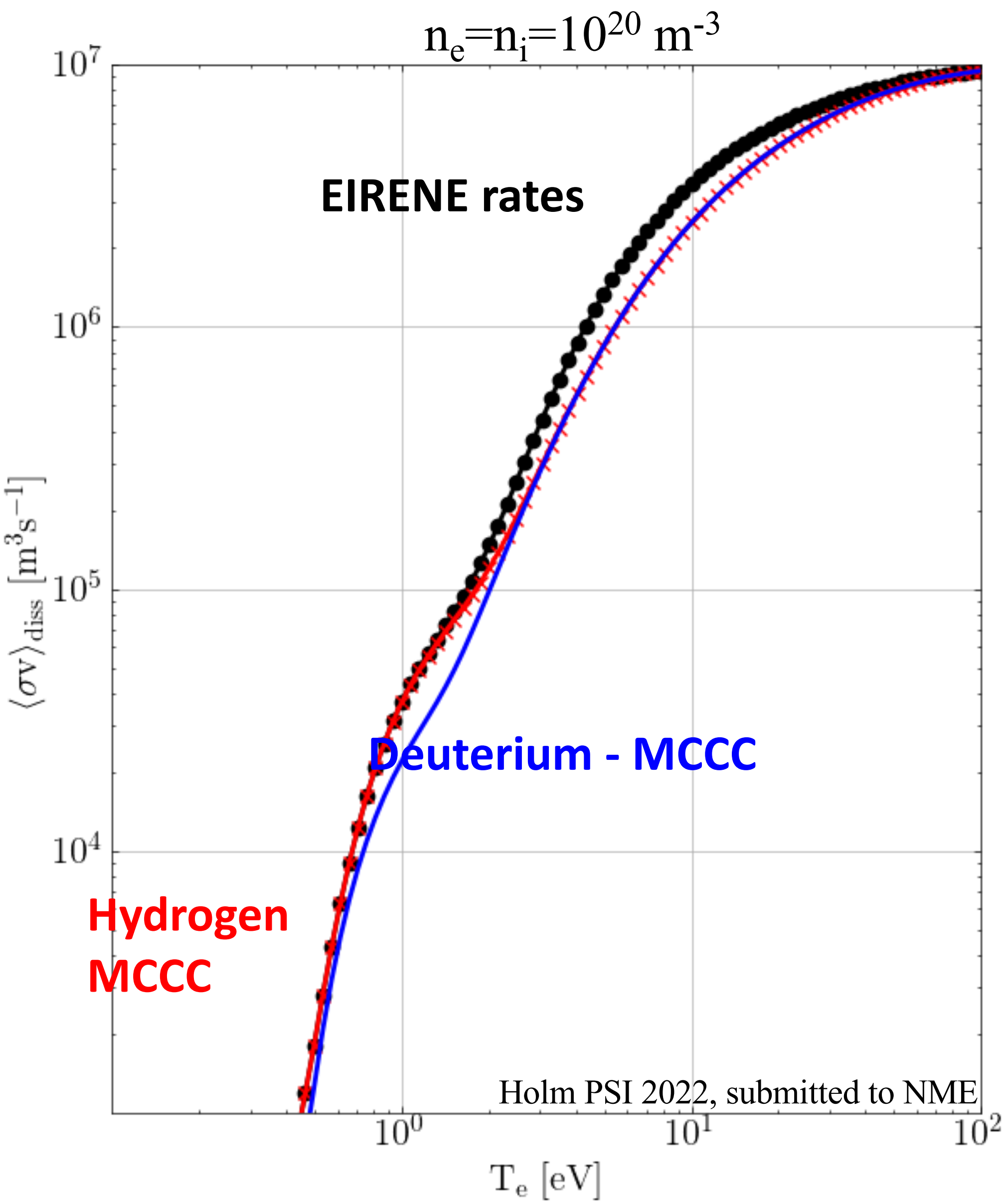
A. Holm



- Adding vibrational processes cause up to 60% difference in dissociation rates
- Impact strongest in the T_e=0.5–4 eV range, where molecular processes strongest
- Electronic transitions affect T_e>4 eV
- Vibrational transitions affect T_e<4 eV

Molecular-convergent close-coupling (MCCC) data [1] predicts an isotope effect on dissociation for T_e=0.7-3 eV

A. Holm



- Predicted isotope effect strongest for temperatures associated with detachment onset and detached conditions
- MCCC data indicates weaker dissociation of both H_2 and D_2 for T_e>3 eV compared to EIRENE data (AMJUEL, HYDHEL, H2VIBR)

⇒ Task moved to TSVV-5 as part of EIRENE (re)development

[1] mccc-db.org, accessed July 6th 2022

Summary of simulated plasmas for JET-ILW

- Comprehensive exp. data analyses and EDGE2D-EIRENE, ERO2.0 Be and W and standalone EIRENE simulations for V5/C equilibria, Ohmic, L-mode and H-mode (Ex. 1.1.2, Ex. 3.1.2, Ex. 1.2.5, B15-09, M18-27, M21-15, …)

  ⇒ dedicated plasmas for (interpretative) edge fluid code validation, BeMP, isotope effect, nitrogen (recycling, transport), He, **CXN fluxes**, W sputtering, ELMs, …

  - SOLPS-ITER for L-mode plasmas, D and D+N_2+N

- Dedicated JINTRAC (EDGE2D-EIRENE) and ERO2.0 W simulations for high-performance H-mode plasmas in corner-corner (tile-3/tile-6 and tile-4/tile-6) configurations (hybrid experiments under M18-02, M21-01)

  ⇒ predictive edge fluid code simulations, D vs T, W sputtering, ELMs, …

- Detailed exp. data analyses and EDGE2D-EIRENE simulations for VT configuration in L-mode (under M13-18 → RT22-05-Det)

- Dedicated exp. data analyses and OEDGE simulations of RISP (in lieu of EDGE2D-EIRENE) in support of Be migration/fuel retention experiments (under M18-30 and M21-27)

Work plan for 2023 (and beyond)

- Continue interpretative studies with EDGE2D-EIRENE of L-mode plasmas for H, D, T and DT plasmas (Mathias Groth → IAEA-FEC 2023)
  - SOLPS-ITER for L-mode plasmas and updated EIRENE (Mathias Groth, Ray Chandra, Niels Horsten, TSVV-5)
  - V5/B and GIM14 for calibrated D_2 influxes
- Revisit EDGE2D-EIRENE simulations for VT configuration in L-mode (Mathias Groth, experiment RT22-05-Det ⇒ potential M.Sc. thesis)
- SOLPS-ITER simulations of D+N / D+N2, ammonia formation and transport (Roni Mäenpää, PhD thesis 2021-2025)
- OEDGE simulations of RISP (Mathias Groth) → Dmitri Matveev ERO2.0
- Interpretative and predictive JINTRAC simulations of JET H-mode plasmas (Henri Kumpulainen → EPS 2023, PhD thesis, Aug 2023)
- Interpretative studies of JET-ILW (and AUG) He plasmas, L-mode, attempt of H-mode (David Rees → PhD thesis 2022-2026, separate M.Sc. thesis)

Discussion items

- Validation of plasma solutions in the far SOL, all the way to main chamber wall: usage of wall Langmuir probes for fluxes, plasma conditions, shadowing effects in 2D

⇒ SOLPS-ITER with extended grids to wall, SOLEDGE2D-EIRENE

- 3D background plasma simulations ⇒ EM3C-EIRENE
- Cross-machine simulations for and comparisons to AUG, WEST, TCV, MAST-U
- …