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TSVV 6 – Impurity Sources, Transport, and Screening

G. Ciraolo on behalf of the TSVV 6 team

3rd WP PWIE Project meeting– February 2023

IRFM
JÜLICH Forschungszentrum
Aalto University
EPFL École Polytechnique Fédérale de Lausanne | Swiss Plasma Center
TU Graz Graz University of Technology
FR FCM

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Aims

- **Establish an integrated modelling suite to predict the W impurity distribution** in DEMO, including W source generation, W screening, W transport, W exhaust and its impact on the plasma performance.

- Develop **3D kinetic transport models for heavy impurities** (including W) and seeding species like Ar, Kr, Xe in the SOL and pedestal regions of DEMO.

- **Assess the effects of 3D perturbations** and ELM suppression techniques **on the W impurity distribution in ITER** reference scenarios, along with their implications for DEMO.

Key Deliverables

1. **Validated suite of 3D codes** and **transport models to describe in an integrated way the W content** and its distribution in metallic devices, in particular DEMO and ITER, with discrimination of main chamber and divertor sources, screening, transport, and exhaust along with its impact on the main plasma dynamics and performance.

2. **Assessment of** the W influx, W screening, and **W transport** in **ITER plasmas envisaged for pre-fusion and fusion power** operation with **semi-detached divertor** and **application of resonant magnetic perturbations for ELM suppression**. Discussion of the impact on a potential loss of semi-detachment and ELM suppression on the W influx, W screening, and W transport in those ITER scenarios.

3. **Applications of the developed model**. Assessment of the **seeding impurity screening and transport** in DEMO and **ITER scenarios**

CONSORTIUM AND PARTICIPANTS

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Commitment of the TSVV Task team members during the period 2021-2023, and indication beyond 2023

The table below summarizes the commitment of team members **in terms of pm** for each year between 2021 and 2025, with values beyond 2023 being indicative. **Table received on IMS**

Team member	Beneficiary	2021	2022	2023	2024	2025
G Ciraolo	CEA	8	8	8	8	8
H Bufferand	CEA	6	6	6	6	6
E Gravier	CEA/UL	5	5	5	5	5
M Raghunathan	CEA/AMU	6	6	6	0	0
Y. Marandet	CEA/AMU	4	4	4	4	4
D. Harting	FZJ	8	6	6	6	6
S. Rode	FZJ	6	6	6	6	6
J. Romazanov/A Knieps	FZJ	0	4	6	6	6
H. Kumpulainen	VTT (Aalto Univ)	6	6	6	6	6
Postdoc/PhD	EPFL	0	0	0	6	6
M. Eder	OEAW (Graz TU)	6	6	6	0	0
ACH resources	**ACH**	**1**	**1**	**1**	**6**	**6**
TOTAL		59+1	59+1	59+1	54+6	54+6

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Aalto University

EPFL ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE | SWISS PLASMA CENTER

TU Graz — Graz University of Technology

TEAMS AND NUMERICAL TOOLS

Expertise / codes

- CEA / FR FCM : SOLEDGE3X-EIRENE, GYSELAX
- FZJ : EMC3-EIRENE and KIT module, ERO2.0
- GRATZ TU: kinetic modeling of ion transport with GORILLA code
- AALTO UNIV. : integrated modeling core-edge JET plasma, W transport with JINTRAC-ERO2.0 package
- EPFL: theoretical framework, tungsten impurity transport in 3D equilibria (VENUS-LEVIS code)
- Aalto Univ. : integrated modeling core-edge JET plasma

- **PROJECT ORGANIZED WITH RESPCT TO THE 3 KEY DELIVERABLES WITH MILESTONES AND DELIVERABLES**

KEY DELIVERABLE 1, TASK 1 AND SHORT TERM MILESTONES

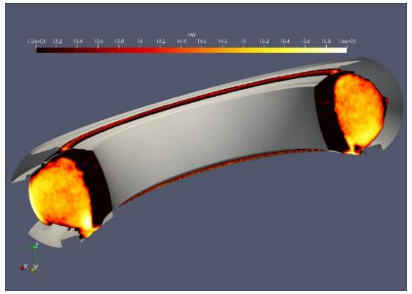
- **Task 1** for **key deliverable 1**: **numerical development** and verification of **SOLEDGE3X, EMC3-EIRENE and ERO2.0** codes

ID	Milestone-description	participants	Target date
M1.1	**Implementation of a 3D** wall (i.e. with objects toroidally localized) **in SOLEDGE3X-EIRENE**	H. Bufferand, M. Raghunathan	12/2021
M1.2	**Integrating Gorilla orbit tracing code into EIRENE**, first step: test of the efficiency of resulting combination in axisymmetric tokamak geometry	M. Eder, M. Raghunathan Y Marandet	12/2021
M1.3	Develop interface for importing **SOLEDGE3X** plasma backgrounds into **ERO2.0**	H. Bufferand, J. Romazanov, PhD student CEA (funded by other means)	06/2022

- Ongoing simulations with a 3D wall with SOLEDGE3X using **fluid neutrals**
- Ongoing work (K Galazka, Y Marandet) for coupling SOLEGDE3X and EIRENE with a 3D wall

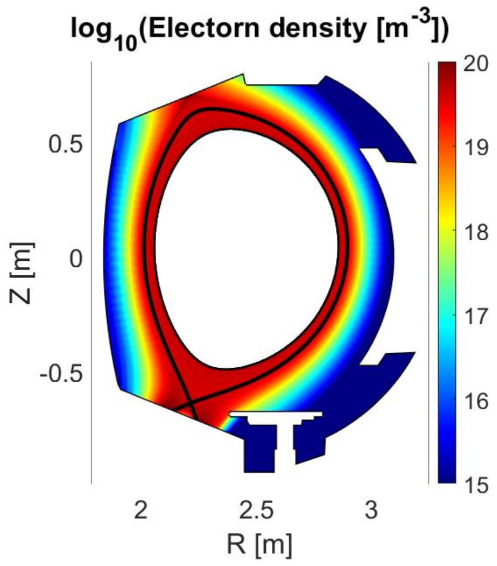
- very promising results on Gorilla, now to see how to integrate in EIRENE (Y Marandet and D Harting)

- Done

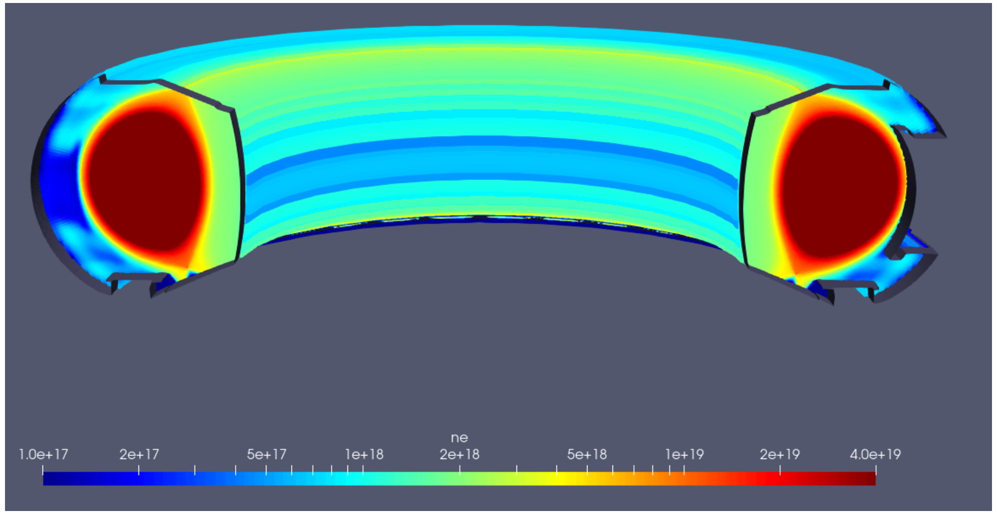


Milestone 2021: **Implementation of a 3D wall** (i.e. with objects toroidally localized) **in SOLEDGE3X-EIRENE**

2D Axysimmetric wall



3D simulation with Non-Axysimmetric wall



SOLEDGE plasma background using fluid neutrals

Status for modeling neutrals in 3D:

- Coupling with EIRENE still ongoing for non-axisymetric wall
- Rely on fluid neutral models

Description of the fluid model for transport of neutrals :

- « Crude » model (ad-hoc constant diffusivity)

$$\partial_t n_n + \vec{\nabla} \cdot \left(-D\vec{\nabla} n_n\right) = S_{n_n}$$

- Improved 1 equation model (CX dominated regime based on Horsten et al., Nucl. Fusion 2017)

$$\partial_t n_n + \vec{\nabla} \cdot \left(n_{n,eq} v_{i,\parallel} \vec{b} - D_p \vec{\nabla} p_n\right) = \mathrm{S}_{\mathrm{n_n}}$$

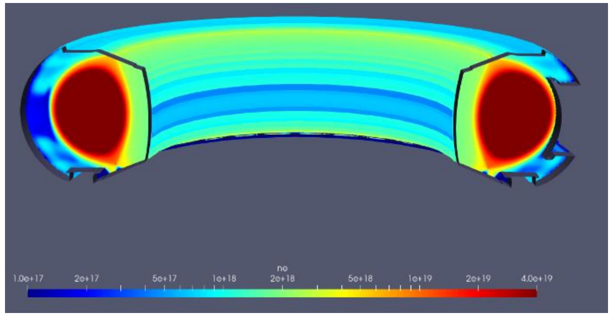
$$D_p = \frac{1}{m(n_i\langle\sigma v\rangle_{cx} + n_e\langle\sigma v\rangle_{iz})} \quad \text{and} \quad n_{n,eq} = n_i \frac{n_e\langle\sigma v\rangle_{rec} + n_n\langle\sigma v\rangle_{cx}}{n_i\langle\sigma v\rangle_{cx} + n_e\langle\sigma v\rangle_{iz}}$$

Assumption for now : $T_n = T_i$

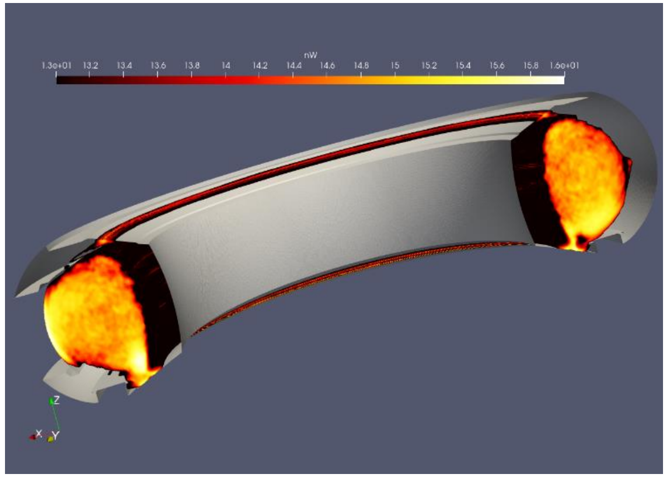
MODELING TRANSPORT OF TUNGSTEN IN A 3D PLASMA BACKGROUND

Milestone June 2022: Develop interface for importing SOLEDGE3X plasma backgrounds into ERO2.0 for W transport

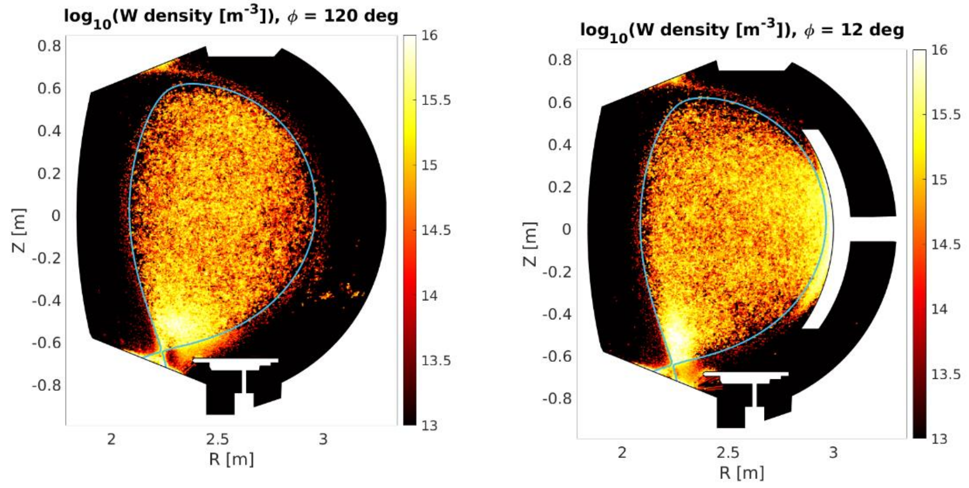
3D simulation with Non-Axysimmetric wall



SOLEDGE plasma background with fluid neutrals



3D density map of W obtained with ERO2.0 using the soledge backrgound



Poloidal maps of W density at two different toroidal angle

→ Comparison between W transport in 2D vs 3D plasma background (**S. Di Genova, PSI 2022**)

Improving W migration description

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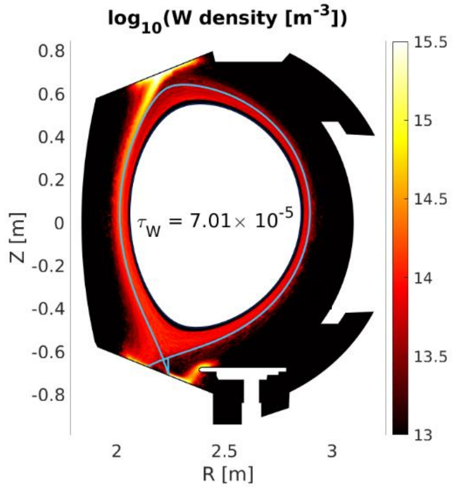
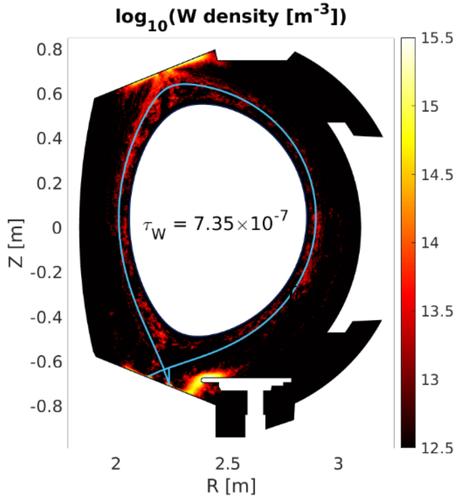
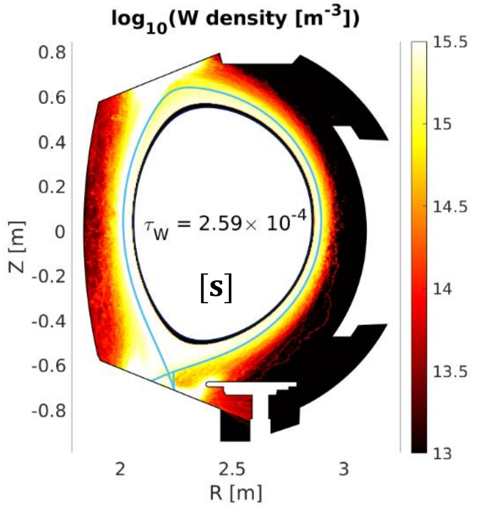
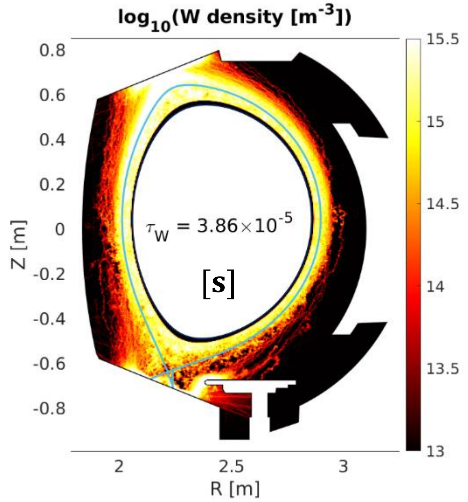
I year simulations





II year simulations

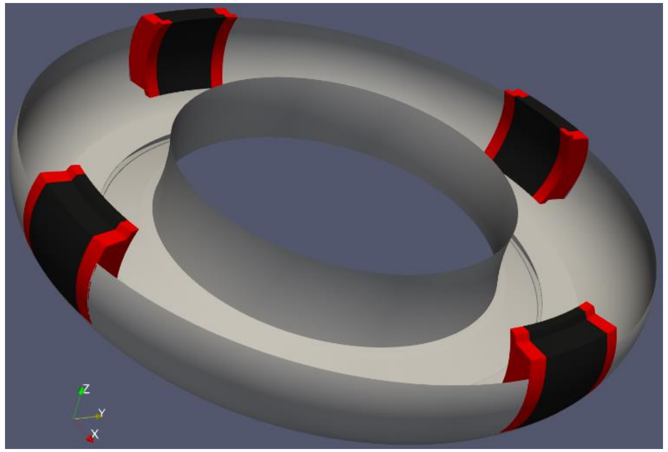




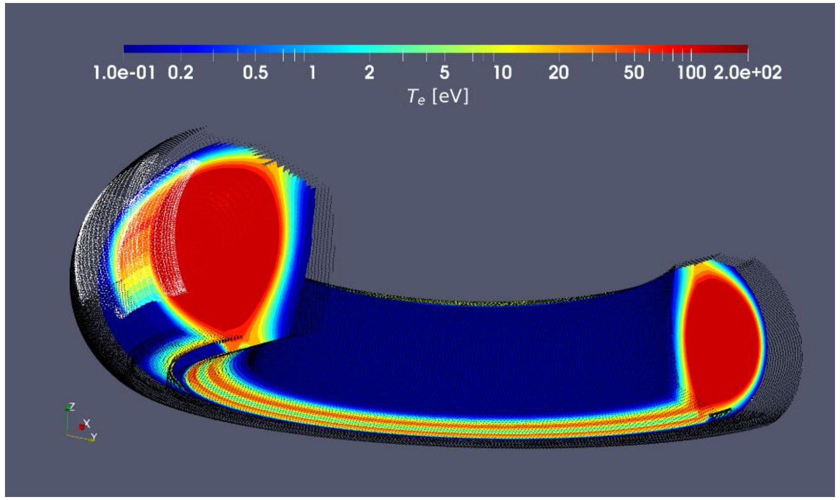
Model physical features	
Anomalous transport	Diffusive process with $D_{an} = 0.3\ \mathrm{m}^2/s$
CODE UPDATE **Collisional forces**	friction forces F_0, thermal forces $F_{\nabla T}$
CODE UPDATE **Sheath physics**	Electron density with Boltzmann factor: $n_\mathrm{e} = n_0 \exp\left(\frac{e\phi}{k_\mathrm{B} T_\mathrm{e}}\right)$
Plasma impurities	From uniform 3% Oxygen to possibility of considering the distribution of ionized states computed by SOLEGDE (mixture from O^{1+} to O^{8+})

Penetration of W into the core region increases accordingly to experimental measurements (**S Di Genova et al, in preparation**)

INVESTIGATION OF W CORE CONTAMINATION IN WEST GEOMETRY DUE TO ANTENNA LIMITER WITH 3D SOLEDGE-ERO2.0 SIMULATIONS

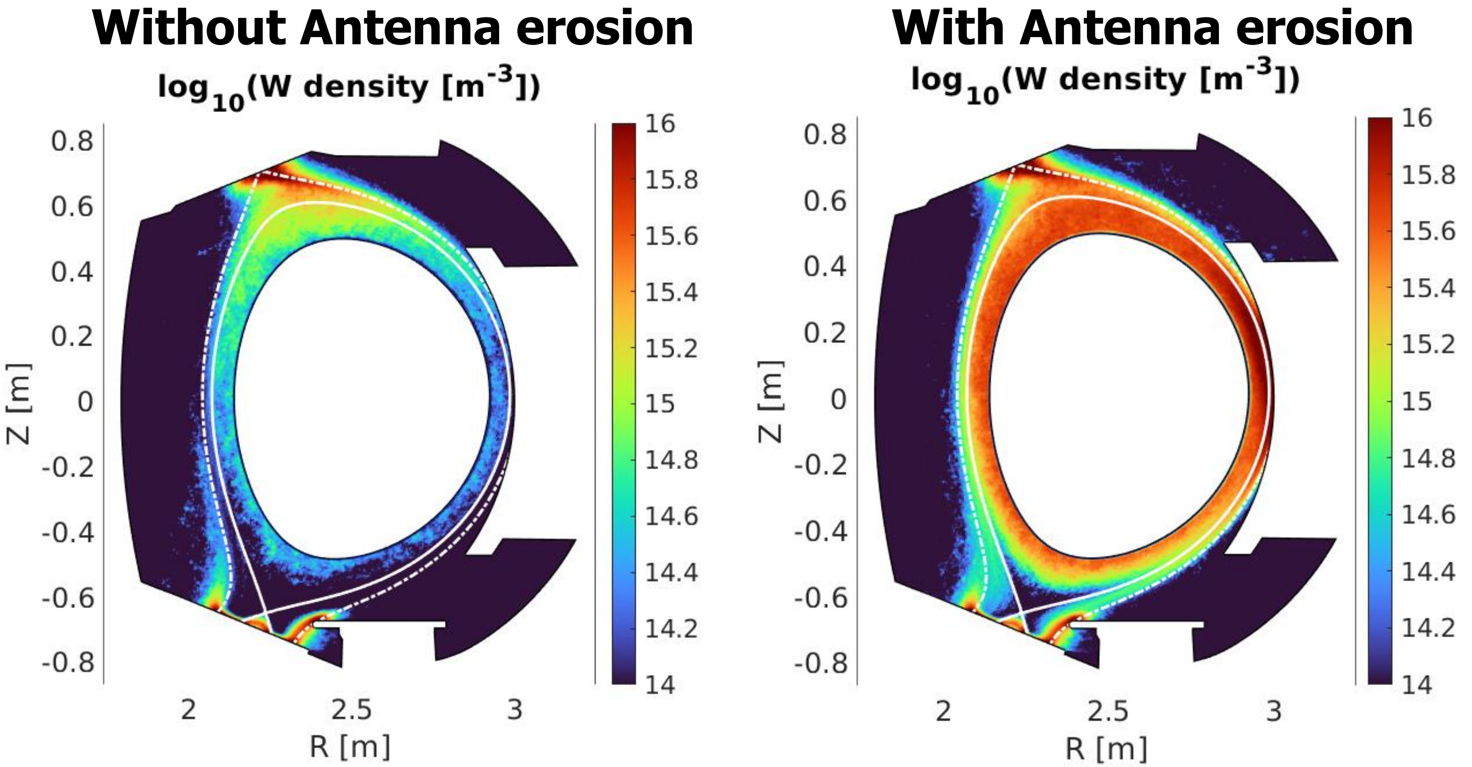


3D asymmetric wall model:Radial Outer Gap: 1.5 cm



SOLEDGE background plasma

(S Di Genova, NME 2023)

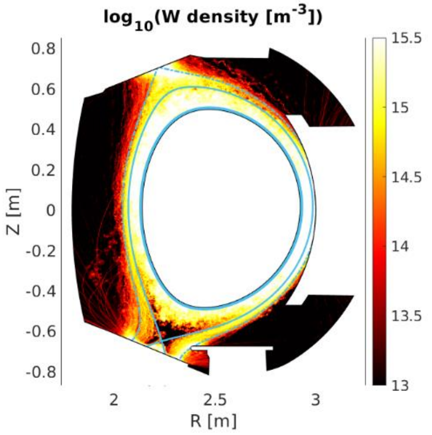


Results in this configuration	Antenna protections	Other PFCs
Erosion rate Q [# s^{-1}]	3.27×10^{19}	2.54×10^{20}
Contribution core W content N_W [#]	9.00×10^{16}	9.95×10^{15}
	90% of contamination	85% of erosion

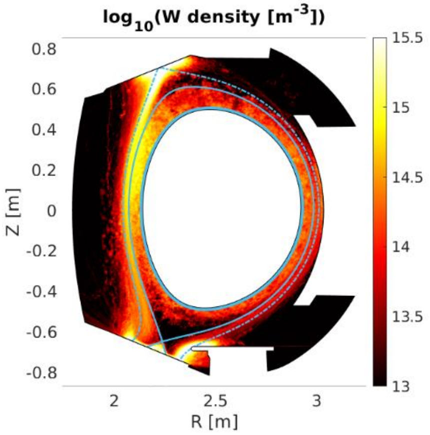
ONGOING INVESTIGATION ON ANTENNA POSITION AND W CORE CONTAMINATION USING 3D SOLEDGE-ERO2.0 SIMULATIONS

Radial Outer Gap (ROG) = R_{Ant} - R_{Sep}

Here an example of ROG scan in SOLEDGE3X and ERO2.0 in thin SOL conditions ($\lambda_n^{SOL} \approx 1$ cm)

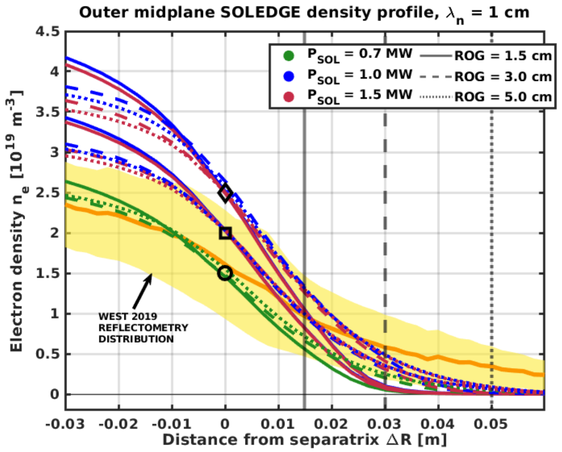


ROG = 1.5 cm



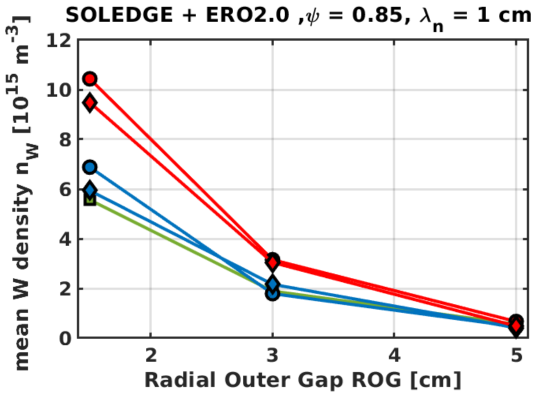
ROG = 5 cm

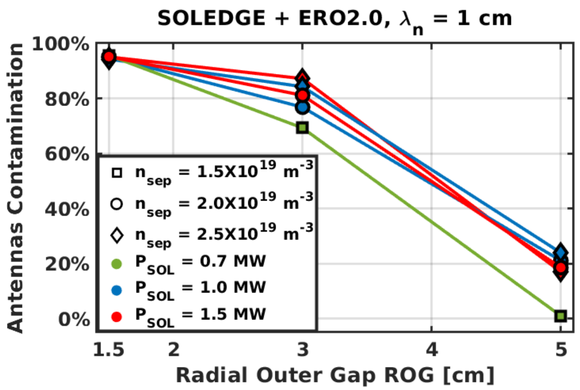
- n_W at the core-edge interface is strongly influenced by the P_{SOL}, and slightly by n_{sep}
- When ROG $\approx 2\lambda_n^{SOL} - 3\lambda_n^{SOL}$ antennas are the predominant cause of contamination.
- When ROG $\approx 5\lambda_n^{SOL}$ The antennas impact on contamination is negligible (comparable with 2D)



We study the impact of:

- $\mathbf{ROG\ (1.5, 3,\ and\ 5\ cm)}$
- $\mathbf{n_{sep}}$
- $\mathbf{P_{SOL}}$

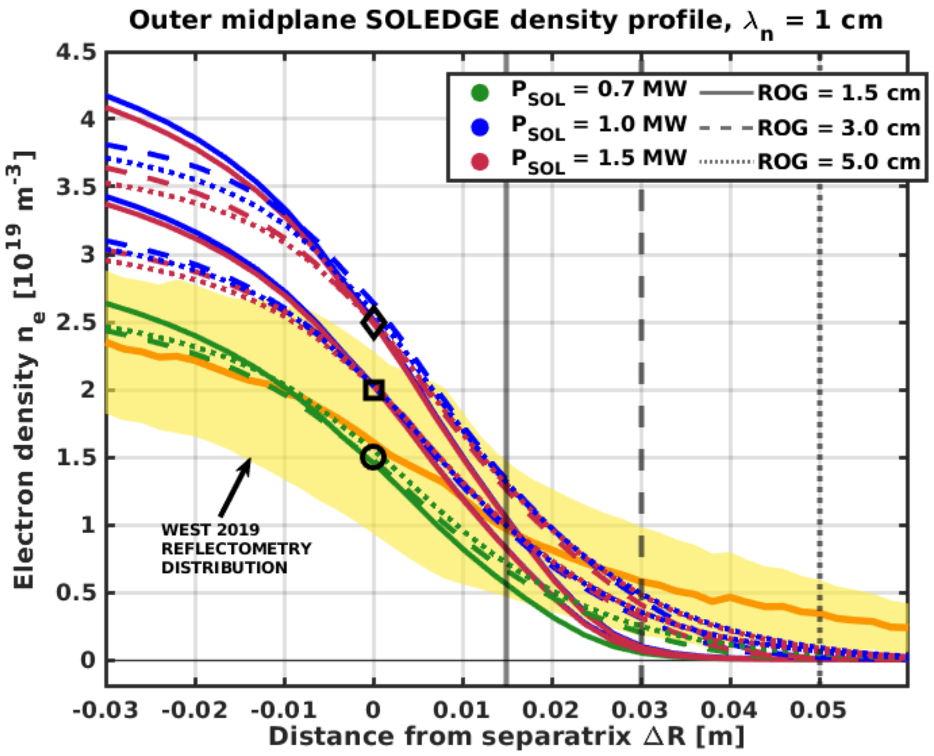


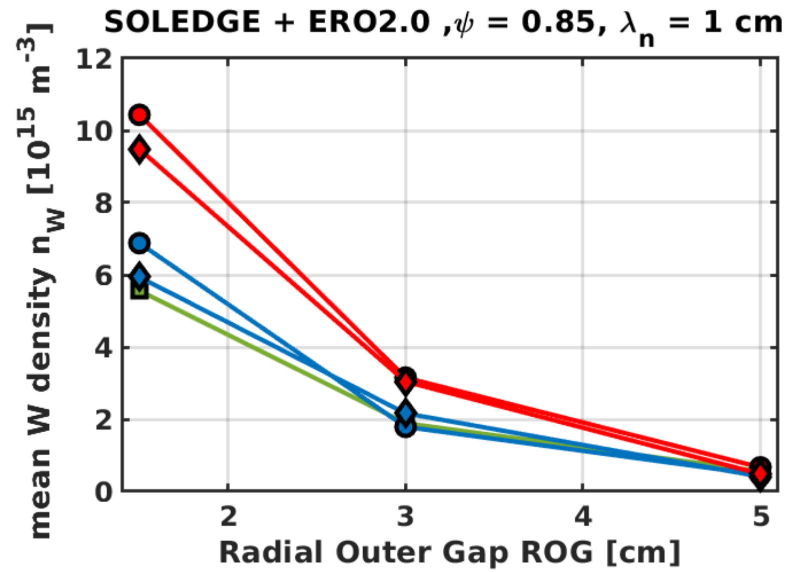


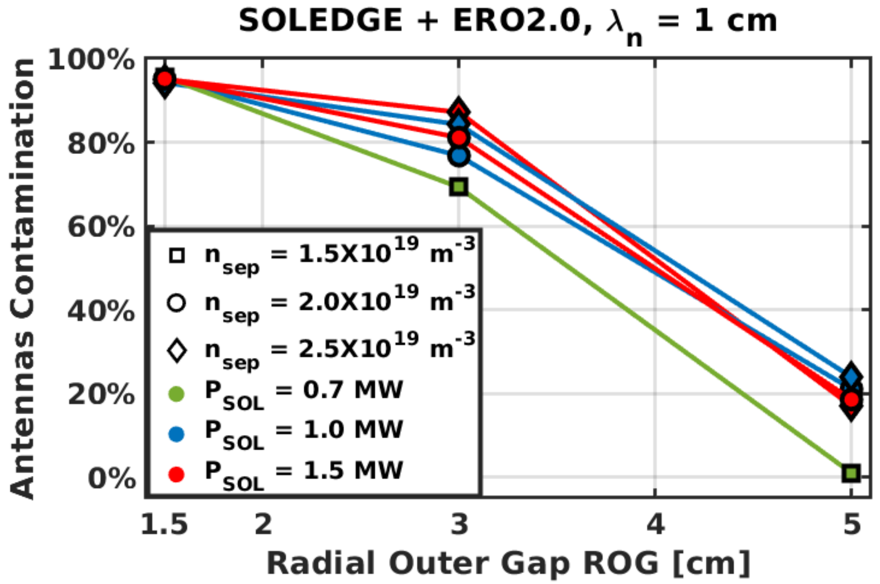
WEST 2019 Campaign reflectometry indicate an average $\lambda_n^{SOL} \approx 3$ cm (Yellow are in figure).

A similar study with larger transport coefficient helps gaining insight in “large” SOL conditions.

ONGOING INVESTIGATION ON ANTENNA POSITION AND W CORE CONTAMINATION USING 3D SOLEDGE-ERO2.0 SIMULATIONS



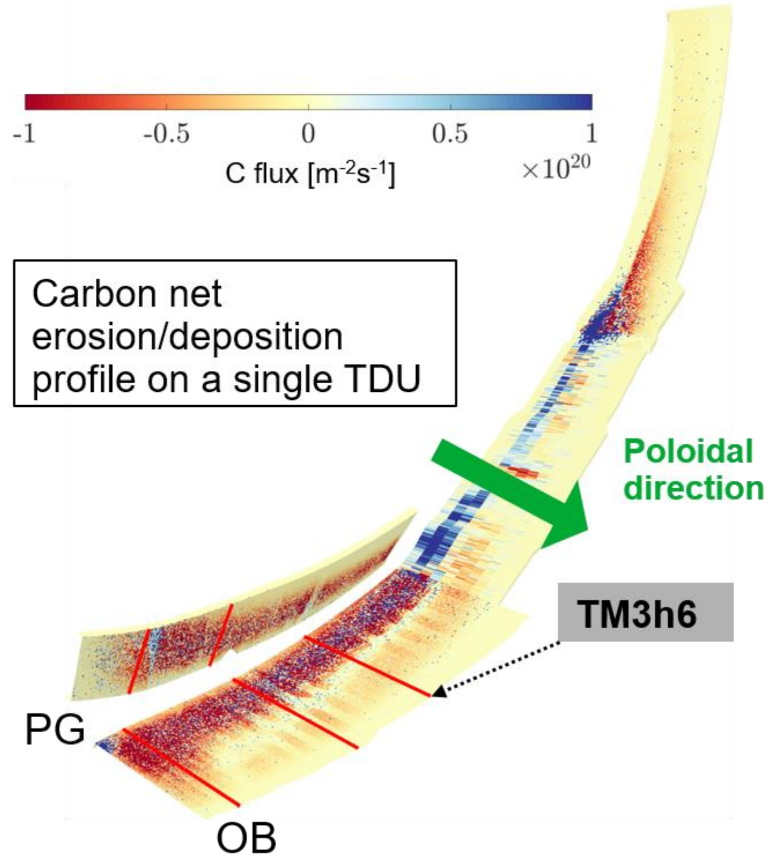




- n_W at the core-edge interface is strongly influenced by the P_{SOL}, and slightly by n_{sep}
- When $\mathrm{ROG} \approx 2\lambda_n^{SOL} - 3\lambda_n^{SOL}$ antennas are the predominant cause of contamination.
- When $\mathrm{ROG} \approx 5\lambda_n^{SOL}$ The antennas impact on contamination is negligible (comparable with 2D)

- **W7-X simulations:**
  - **Develop EMC3-EIRENE + ERO2.0 integrated 3D workflow**
  - **Validate the workflow using W7-X experiments** (intrinsic ^{12}C erosion: spectroscopy, markers tiles; ^{13}C tracer experiment: post-mortem analysis)

- ^{12}C erosion and transport:
  - Simulations done + benchmarked with post-mortem, see *M. Zhao et al., NF-2022*
- ^{13}C tracer injection and transport:
  - Simulations done + benchmarked with post-mortem, see *E. Wüst et al., NME-2022*
- More simulations are planned (taking into account erosion by neutrals and various other model improvements) to achieve better match with experiment
- Simulation of W tiles from OP1.2 and comparison with experiment (M. Mayer): work in progress, need to repeat with higher statistics



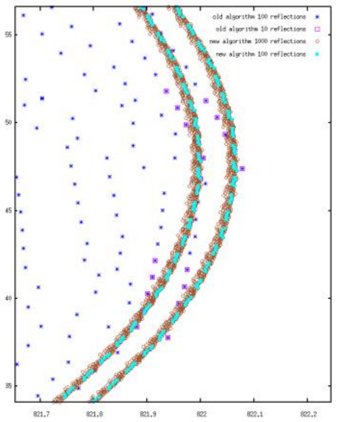
Milestone 2021: **Implementation of Kinetic Ion Transport module in EMC3-EIRENE for low Z impurities**

ID	Milestone-description	participants	Target date
M1.13	**Implementation of EIRENE Kinetic Ion Trace module in EMC3 for low Z impurities**	**D. Harting, Postdoc FZJ**	**12/2021**
M1.14	Assess applicability of EIRENE-KIT with EMC3 for recycling and sticky impurities (for low Z species)	D. Harting, Postdoc FZJ	06/2022

HARTING D. et al., Nucl. Mater. Energy **33,** 101279 (2022)

Current Status of EMC3-EIRENE Kinetic Ion Transport Module

- New accurate implementation of grad-B and curvature drift-movement
  - Completely redesigned core part of KIT with EMC3 (field aligned local curvilinear coordinate system of the EMC3 cell)
  - Banana orbit correctly described
- Re-designed treatment of anomalous diffusion
  - Add time step limit to avoid huge diffusion steps
- Currently improving coulomb collision description



Examples of new results on banana orbits: very small numerical diffusion

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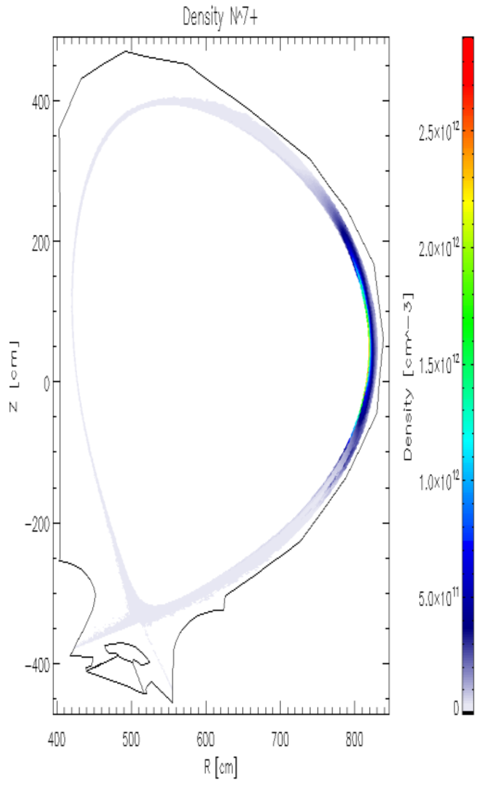
FIRST STABLE SIMULATION FOR NITROGEN SEEDING WITH AN ITER PLASMA BACKGROUND

- **ITER background plasma** with P_{SOL} = 20MW and n_{sep} = $1x10^{19}$ m^3
- **Nitrogen puffed from top of machine**
- **N^{1+} – N^{4+}** mainly located in divertor due to recycling
- **N^{5+}** trapped in magnetic mirror on HFS of X-point
- **N^{6+} – N^{7+}** need higher T_e and thus are trapped in magnetic mirror at OMP
- Improvements to be made on the treatment of coulomb collisions

N7+ density map



HARTING D. et al., Nucl. Mater. Energy **33,** 101279 (2022)

Key Deliverable 2: Assessment of the W influx, W screening, and W transport in ITER plasmas

ID	Milestone-description	participants	Target date
M2.2	**2D Plasma background in semi-detached conditions** (no RMP)	D. Harting, H. Bufferand, G. Ciraolo, N. Rivals	12/2021

- **20MW (PFPO-1)**
- **L-mode** transport
- Pure H
- **Advanced options in EIRENE** (elastic ion col., MAR, neutral-neutral col.)

SOLEDGE3X computational domain

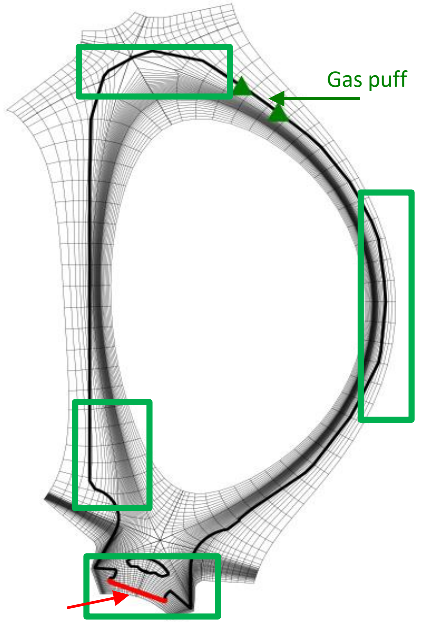
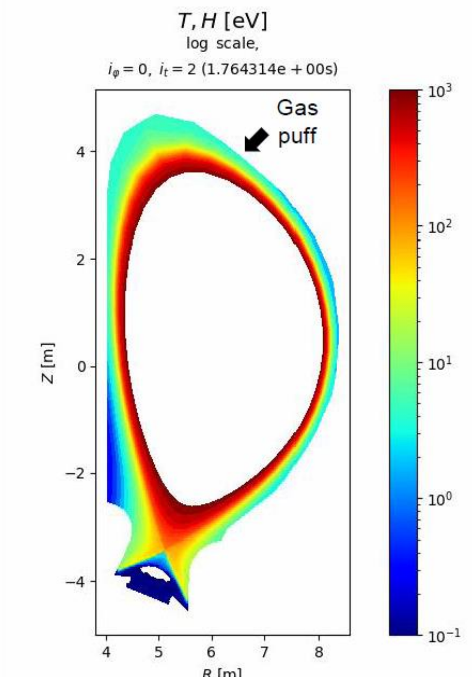


Illustration of case 2297
(mid-upper part of the gas puff scan)



Temperature and density in the divertor region

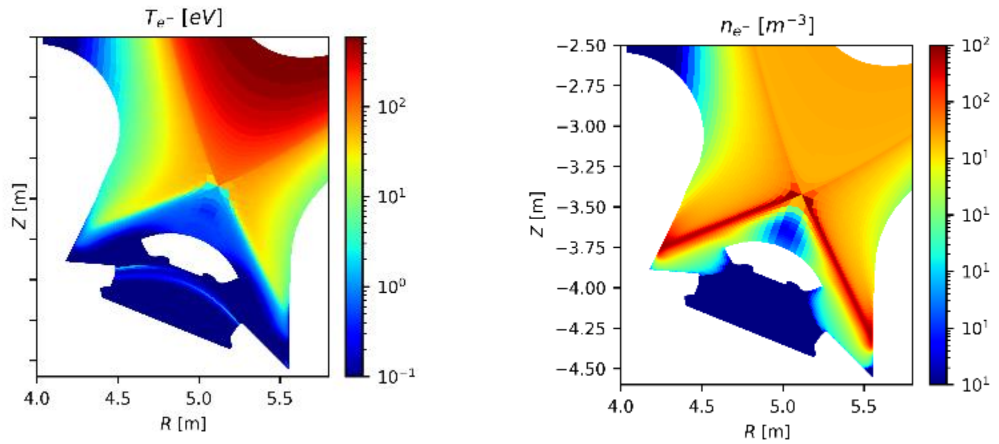
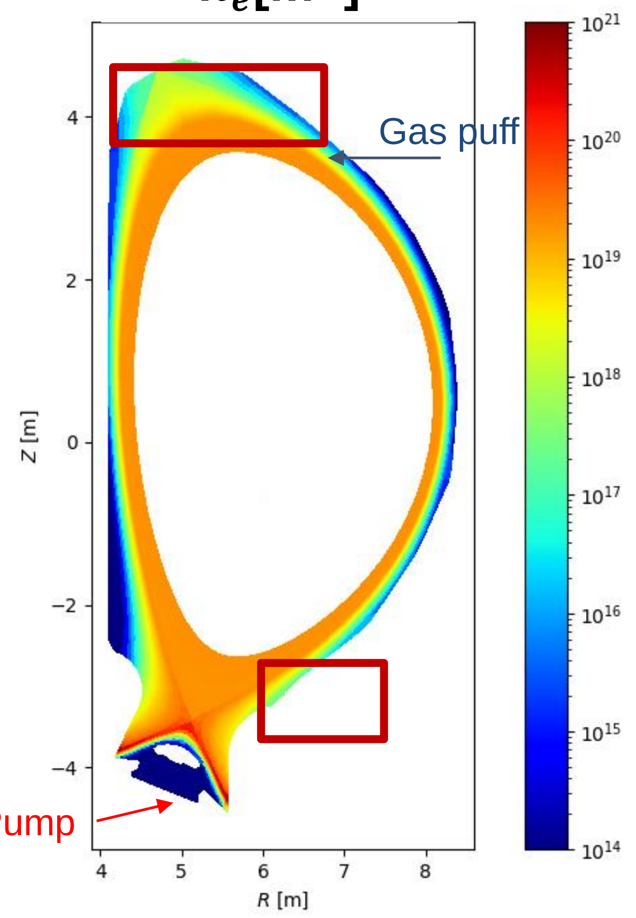
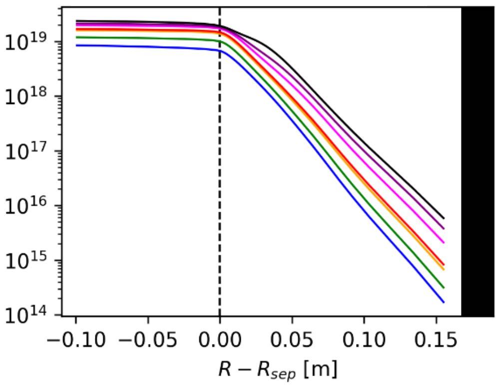


Illustration case at medium throughput (3.31 x 10^{22} $e^{-}.s^{-1}$):

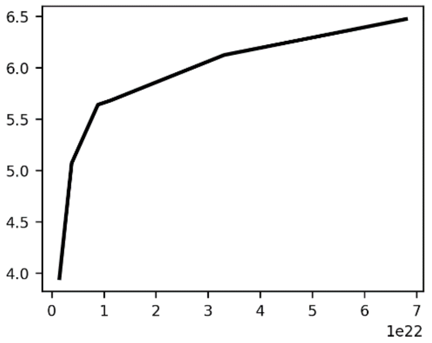
n_e[m^{-3}]



n_e[m^{-3}] OMP

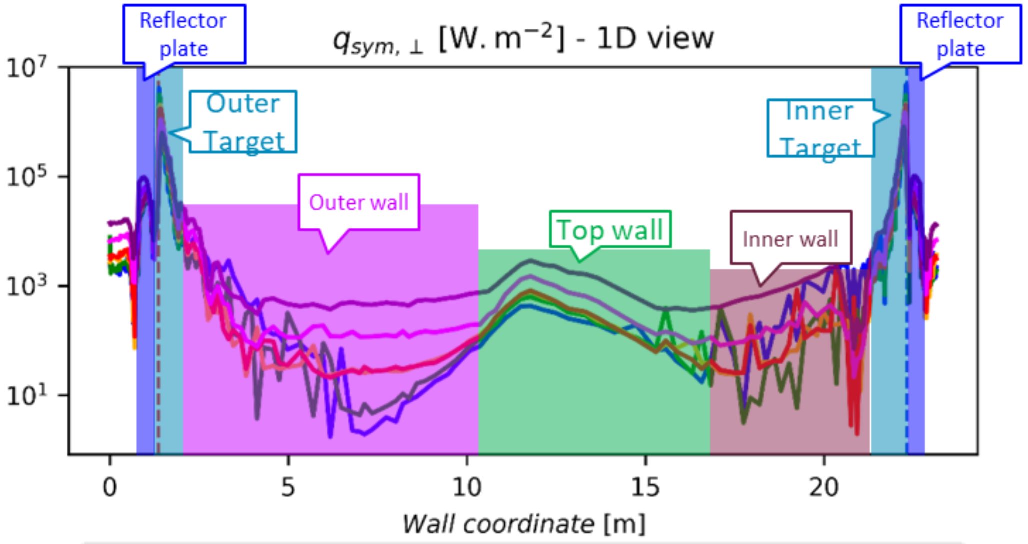


λ_q[mm]



Throughput [$e^{-}.s^{-1}$]:

- 1.46e+21 s^{-1}
- 3.81e+21 s^{-1}
- 8.85e+21 s^{-1}
- 1.13e+22 s^{-1}
- 3.31e+22 s^{-1}
- 6.80e+22 s^{-1}
- 1.76e+23 s^{-1}



- λ_q increase with throughput
- **Strong plasma-wall interaction**:
  - Top
  - Outer lower wall

- *[N. Rivals et al, NME 2022]*

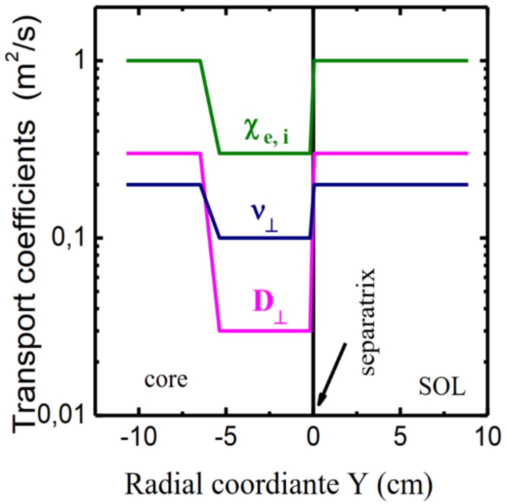
ONGOING 2D SOLEDGE SIMULATIONS FOR ITER H-MODE PLASMA IN FPO PHASE WITH 100MW INJECTED POWER AND Ne SEEDING AND He ASHES

KEY DELIVERABLE 3: ASSESSMENT OF THE SEEDING IMPURITY SCREENING AND TRANSPORT IN ITER SCENARIOS.

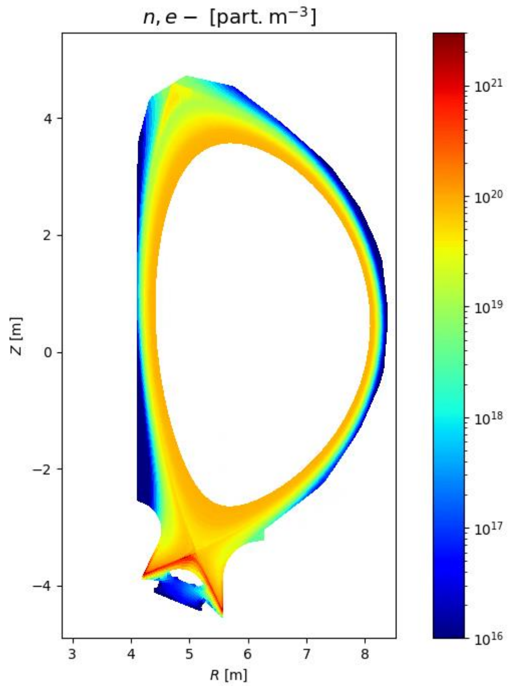
- **Pin = 100MW FPO Q=10 plasma**
- D
- Neon seeded
- Helium fusion products
- H-mode transport barrier
- Advanced neutral modelling (MAR, neutral-neutral collisions)

(N Rivals et al, in preparation)

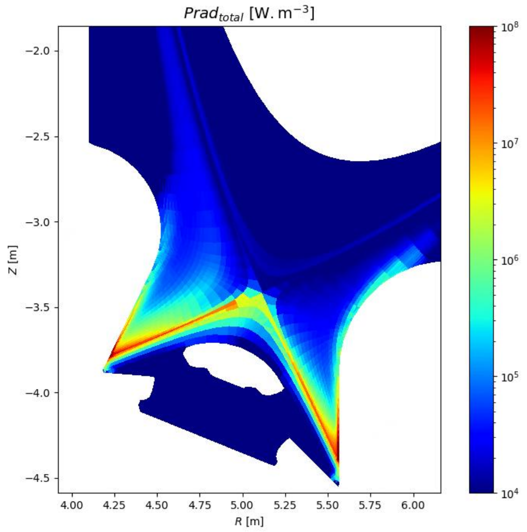
RADIAL PROFILE OF TRANSPORT COEFFICIENTS



ELECTRON DENSITY



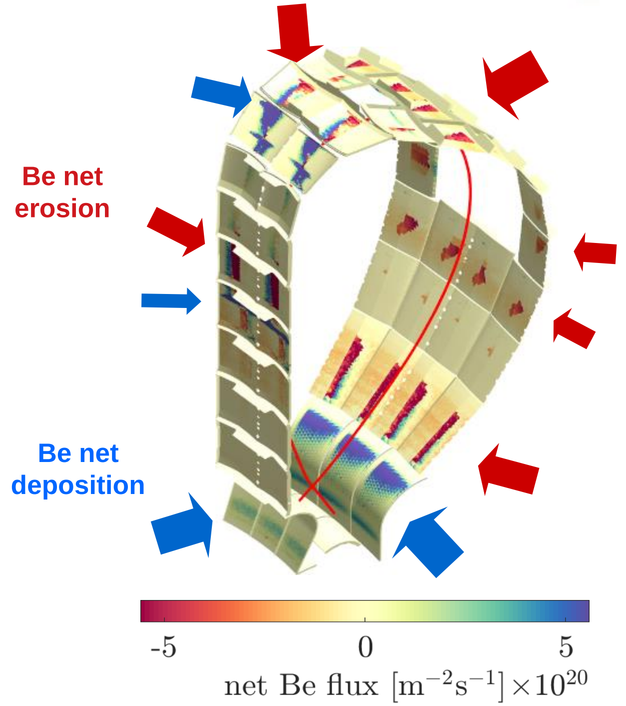
RADIATED POWER



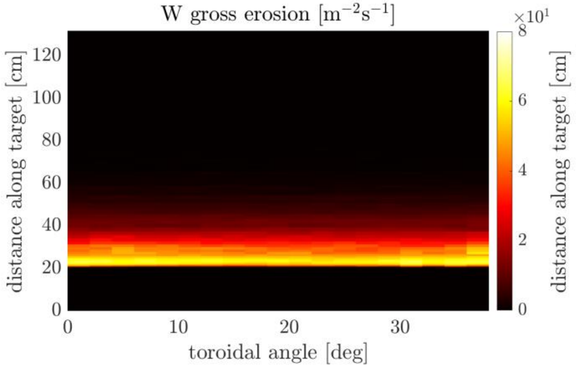
M3.2	2D ITER Plasma background in semi-detached conditions (no RMP) and N/Ne/… seeding (both with EMC3-EIRENE and SOLEDGE3X with fluid impurities as reference case)	**milestone expected for 03/2023**

Key Deliverable 2: Assessment of the W influx, W screening, and W transport in ITER plasmas

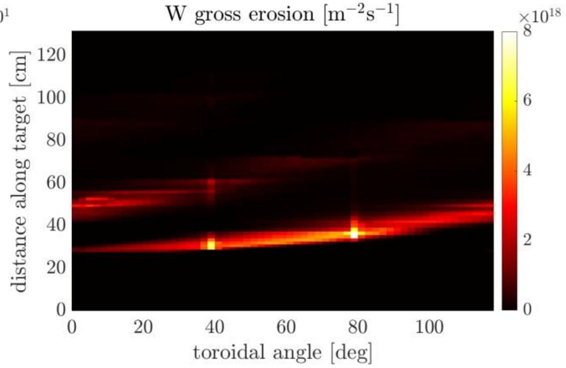
- **ERO2.0 runs using 2D ITER plasma backgrounds (OEDGE):**
  - Previous work (*J. Romazanov et al. CPP-2019, NME-2021, NF-2022*) focused on Be FW erosion
  - Next step: repeat with considering the W divertor
- **ERO2.0 runs using 2D/3D ITER plasma backgrounds with+w/o RMPs (EMC3-EIRENE)** is work-in-progress:
  - 4 EMC3-EIRENE PFPO plasma backgrounds by Heinke Frerichs: 2 with and w/o RMPs, each in low + high density
  - Implementation of EMC3-EIRENE to ERO2.0 data transfer was adapted to tokamaks
  - **First preliminary W gross erosion obtained on inner target for low-density case**
  - Under investigation: improvement of B-field interpolation



no-RMP case



RMP case



Deliverables for 2022-2023

D2.1	**Characterization of W transport on 2D ITER plasma backgrounds obtained in M2.2 using ERO2.0 (post processing)**	**01/2023**
D2.2	Analysis of EMC3-EIRENE ITER plasma background with 3D perturbation in semi-detached conditions (full 3D solution)	12/2022

SUMMARY AND NEXT STEPS

- Project overall in line with the objectives set out in the intial proposal

- Next steps (end of 2023)
  - **Implement complex magnetic geometries into SOLEDGE3X (first with ripple effects)**
    - Operators aligned with $\vec{b}$ no-longer lie in the flux surface (parallel diffusion so far treated as a 2D operator in the $[\varphi,\theta]$ plane)
    - New generic operator class now defined in SOLEDGE3X enables general 3D diffusion (parallel diffusion now 3D operator coupling all mesh points)
    - Advection was already treated in 3D

  - **SOLEDGE3X 3D plasma background with fluid impurities and validation on WEST experiment in double null configuration**

  - **ERO2.0 runs on SOLEDGE3X WEST plasma backgrounds and comparison with experimental results**

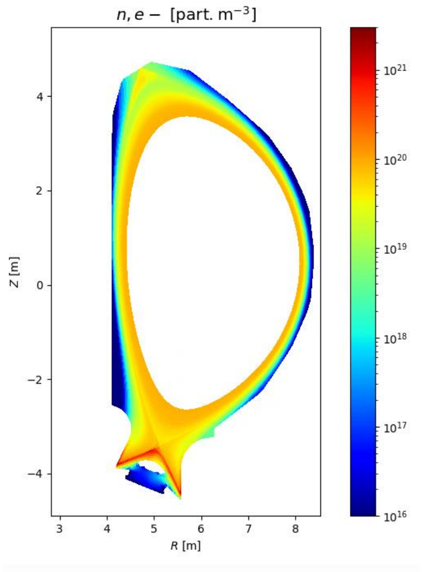
NEXT STEPS ON KINETIC IMPURITY MODELING

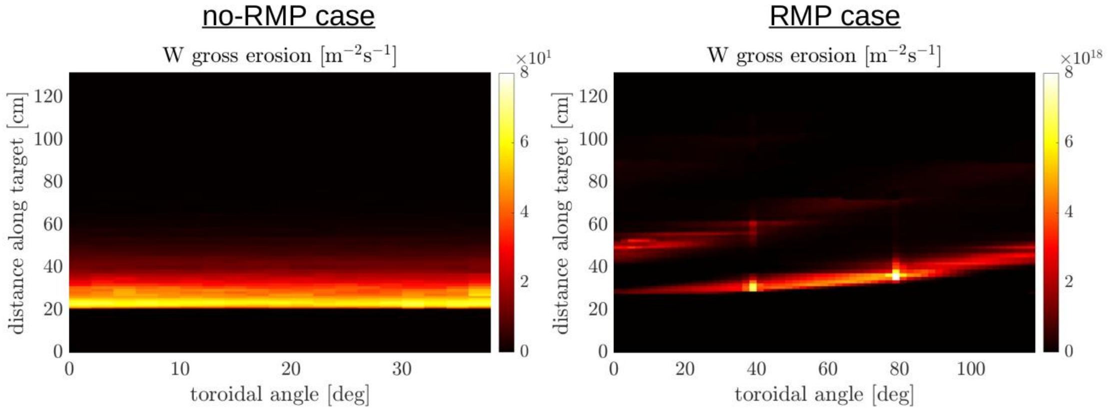
- **2023 milestone for Code development:**
  - **EIRENE-KIT module**: Assessment on the applicability of EIRENE-KIT with EMC3 for recycling and sticky impurities
  - **ERO2.0**
    - Erosion in multi-component plasma (e.g. D^0, D^+, T^0, T^+, He^0, He^+, He^{2+}, + seeding species)
    - Assist merging of developments from CEA + Aalto: improved W sputtering; CX energy distributions
  - **Benchmark between ERO2.0 with EIRENE-KIT:**
    - Consistent usage of Fokker-Planck collision term
    - Cross-check individual trajectories + ensembles in selected cases (e.g. ITER)

- **Comparison with experiments and validation**
  - **W7-X simulations:**
    - Develop EMC3-EIRENE + ERO2.0 integrated 3D workflow
    - Validate the workflow using W7-X experiments (intrinsic ^{12}C erosion: spectroscopy, markers tiles; ^{13}C tracer experiment: post-mortem analysis)

MILESTONES ON ITER SIMULATIONS

Characterization of W transport on 2D ITER plasma backgrounds obtained in M2.2 using ERO2.0 (post processing)	10/2023
Analysis of EMC3-EIRENE ITER plasma background with 3D perturbation in semi-detached conditions (full 3D solution)	12/2023
characterization of W transport using ERO2.0 runs on 3D ITER plasma backgrounds obtained in M2.4	08/2023





ID	Milestone-description	Target date
M1.1	**Implementation of a 3D** wall (i.e. with objects toroidally localized) **in SOLEDGE3X-EIRENE**	12/2021
M1.3	Develop interface for importing **SOLEDGE3X** plasma backgrounds into **ERO2.0**	06/2022
M1.5	Implement complex magnetic geometries into SOLEDGE3X (first with ripple effects)	03/2023

MOVING TOWARDS 3D MAGNETIC FIELD

- Account for ripple / RMPs
- The grid remains based on axi-symetric flux surfaces (3D field treated as perturbation of axi-symetric field)

Progress:

- Operators aligned with $\vec{b}$ no-longer lie in the flux surface (parallel diffusion so far treated as a 2D operator in the $[\varphi, \theta]$ plane)
- New generic operator class now defined in SOLEDGE3X enables general 3D diffusion (parallel diffusion now 3D operator coupling all mesh points)
- Advection was already treated in 3D (almost nothing to do)

Purpose: Simulate non-axisymetric magnetic field in SOLEDGE3X

ID	Milestone-description	Target date
M1.1	**Implementation of a 3D** wall (i.e. with objects toroidally localized) **in SOLEDGE3X-EIRENE**	12/2021
M1.3	Develop interface for importing **SOLEDGE3X** plasma backgrounds into **ERO2.0**	06/2022
M1.5	Implement complex magnetic geometries into SOLEDGE3X (first with ripple effects)	03/2023

- Account for ripple / RMPs
- The wall remains axi-symetric (non necessarily)
- The grid remains based on axi-symetric flux surfaces (3D field treated as perturbation of axi-symetric field)

Progress:

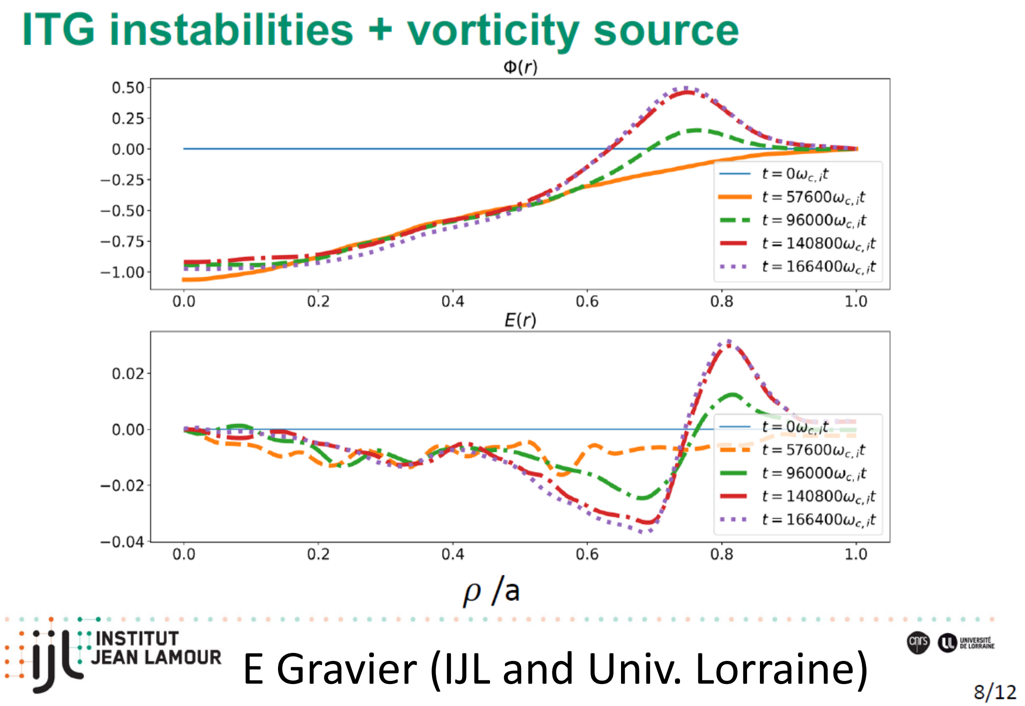
Operators aligned with $\vec{b}$ no-longer lie in the flux surface (parallel diffusion so far treated as a 2D operator in the $[\varphi, \theta]$ plane)

- New generic operator class now defined in SOLEDGE3X enables general 3D diffusion (parallel diffusion now 3D operator coupling all mesh points)
- Advection was already treated in 3D (almost nothing to do)

EUROfusion

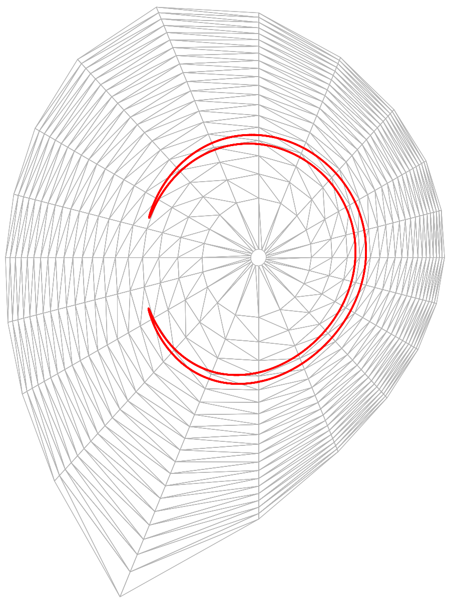
Task 2 for key deliverable 1: GyselaX (and VENUS-LEVIS) code development for investigation for W transport in the pedestal region

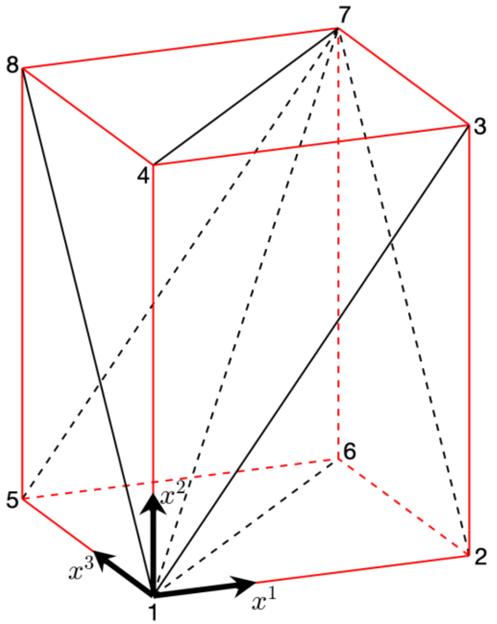
ID	Milestone-description	participants	Target date
M1.19	**Implementation of a source term in the vorticity equation of GyselaX code**	E. Gravier, PhD student CEA/UL (funded by other means)	12/2021
M1.20	**Generation of transport barriers by sheared poloidal flows, triggered by a vorticity source** (poloidal momentum), with GyselaX code.	E. Gravier, PhD student CEA/UL (funded by other means)	12/2022



Fully achieved

Purpose: modelling of impurity transport in Soledge3X-EIRENE
GORILLA: mesh-based symplectic integration method for guiding-center orbits





Tetrahedral mesh used in GORILLA

Advantages of GORILLA:

- **Computational efficiency** (up to 10x faster than RK4)
- **Physically correct long time orbit dynamics**
  - Symplectic: preserved total energy, magnetic moment, phase-space volume, …
- Formulation in general curvilinear coordinates
  - Well-suited for edge plasma (**no flux coordinates**)

Objective:

- Computation of guiding-center orbit statistics in Soledge3X-EIRENE domain (particle and flow densities)

Principal achievement within 1st year of TSVV 6:

- **Correct Hamiltonian time dynamics (necessary for statistics)**

$$\frac{\mathrm{d}t}{\mathrm{d}\tau} = \left(\sqrt{g}B_\parallel^*\right)^{(L)}$$

Integration of kinetic ion tracers into EIRENE and SOLEDGE3X

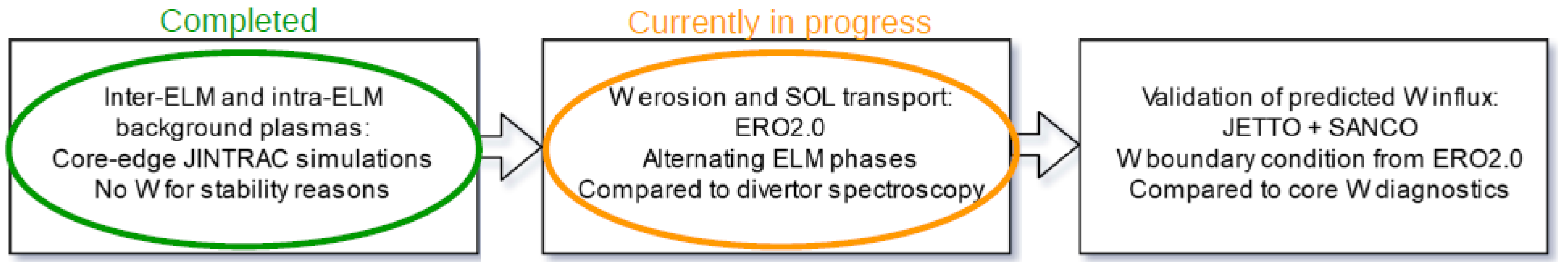
- EIRENE-KIT: Extending field line tracing by drift and mirror force [1,2]
- GORILLA: Mesh-based 3D symplectic guiding-center tracer [3]

- Two coupling approaches in Monte-Carlo codes
  - Compute fluid quantities from statistics of ion tracer
  - Directly hand particle between neutral and ion tracer on (de-)ionization

[1] F. Schluck, Contributions to Plasma Physics, vol. 60, p. e201900144, 2020.
[2] D.V. Borodin and EIRENE-NGM-DEVELOPERS, 28th IAEA Fusion Energy Conference, May 2021.
[3] M. Eder et al., Phys. Plasmas 27, 122508, 2020.

JINTRAC and ERO2.0 W transport modelling and validation using JET type-I ELMy H-mode plasmas

- Two scenarios:
  - M18-18: good diagnostic coverage, validated divertor conditions
    - JPN 94605 at 50 s
  - M18-02: highest fusion performance, speculative divertor conditions
    - JPN 96947 at 48 s: peak D-D neutron record
- W erosion validated by comparing predicted W I and W II divertor emission to spectroscopy
- Core W concentration will be predicted by JINTRAC using the W influx from ERO2.0, and validated against core W measurements (M. Sertoli)



- ERO2.0 test runs to verify the simulation setup are completed for the ELM and inter-ELM phases
  - Technical issues have been resolved
  - Larger runs with better statistics are ongoing, to validate the predicted W erosion
- Once the ERO2.0 W predictions are validated, they will be used as an edge boundary condition for core W transport in JINTRAC

M1.31	Execute and validate JINTRAC simulations in JET ELMy H-mode plasmas, characterise dominant transport process leading to core W accumulation, including ELMs	H. Kumpulainen	03/2023

Improving W migration description

the simulations were updated in order to reduce prompt re-deposition and get closer to experimental estimations of n_W ($\sim 10^{15}\ m^{-3}$)

CODE UPDATE:

Ion thermal force:

$$\vec{F}_{\nabla T_i} = -\frac{\Lambda}{10\sqrt{\pi^3}}\left(1+\frac{m_i}{m}\right)\left(\frac{ZZ_i e^2}{\varepsilon_0}\right)^2 \frac{e^{-\chi_i^2}}{u_i T_i^2}\left(\vec{q}_i - 2(\vec{q}_i\cdot\vec{\chi}_i)\,\vec{\chi}_i\right)$$

$$\vec{\chi} = \frac{\vec{v}-\vec{v}_i}{u_i}$$

$$u_i = \sqrt{\frac{2T_i}{m_i}}$$

$$\vec{q}_i \approx -60\ T_i^{\frac{5}{2}} \nabla T_i\ [\mathrm{W\ m^{-2}}]$$

CODE UPDATE:

Electron density Boltzmann distribution inside the Magnetic pre-sheath**:**

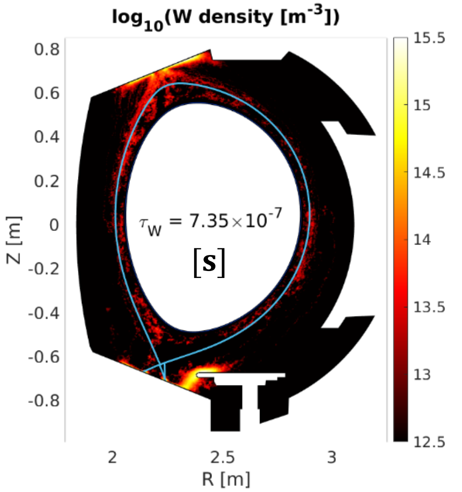
$$n_e(x) = n_e^0 e^{\frac{\phi(x)}{k_b T_e}}$$

NEW SIMULATION SETTINGS:

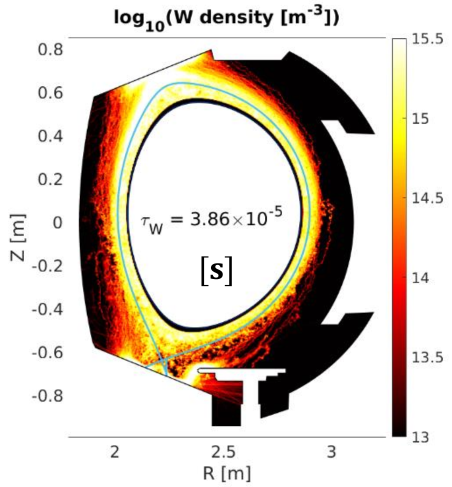
3% Oxygen mixture from O^{1+} to O^{8+}. O^{n+} concentration coming from an educated guess based on SOLEDGE modelling (Increases erosion as well!)

New simulations present separatrix average n_W up to 150 times higher than old ones
But the erosion rate is only 3 times higher

Old simulation



Updated simulations



Kinetic model [D. Reiser, NF, 1998-Y. Homma et al.,JCP, 2013]

Friction forces:

$$\vec{F}_0 = -\frac{\Lambda}{4\pi}\left(1+\frac{m_i}{m}\right)\left(\frac{ZZ_ie^2}{\varepsilon_0}\right)^2 \frac{n_i}{2T_i}\left(\frac{\mathrm{erf}(\chi_i)-\chi_i\,\mathrm{erf}'(\chi_i)}{\chi_i^3}\right)\vec{\chi}_i$$

$$\vec{\chi} = \frac{\vec{v}-\vec{v}_i}{u_i}$$

$$\vec{q}_i \approx -60\,T_i^{\frac{5}{2}}\nabla T_i\ [\mathrm{W\,m^{-2}}]$$

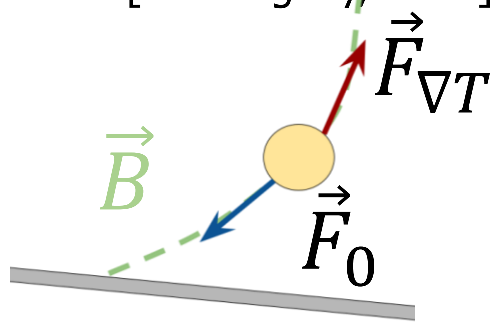
[P. Stangeby, 2001]

If Temperature gradients are non-negligible:

Ion thermal force:

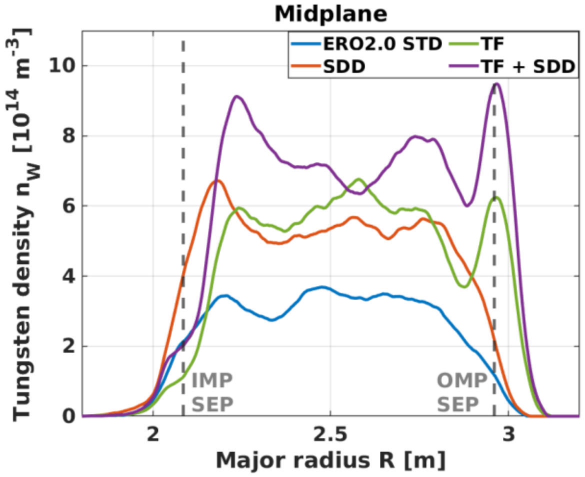
$$\vec{F}_{\nabla T_i} = -\frac{\Lambda}{10\sqrt{\pi^3}}\left(1+\frac{m_i}{m}\right)\left(\frac{ZZ_ie^2}{\varepsilon_0}\right)^2 \frac{e^{-\chi_i^2}}{u_iT_i^2}\left(\vec{q}_i - 2(\vec{q}_i\cdot\vec{\chi}_i)\,\vec{\chi}_i\right)$$

$$u_i = \sqrt{\frac{2T_i}{m_i}}$$

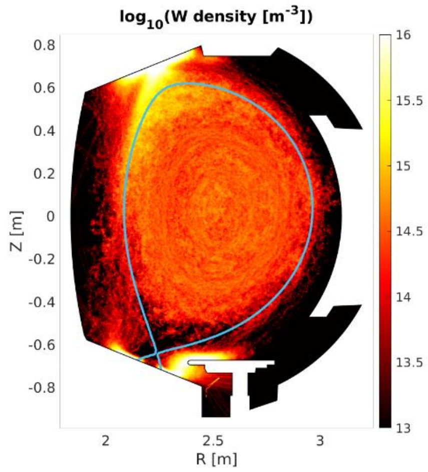


Electron density inside the MPS:

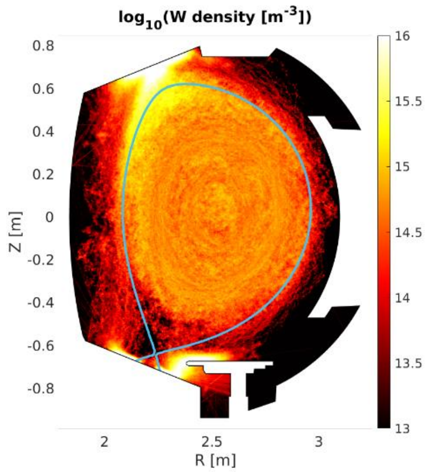
$$n_e(x) = n_e^0 e^{\frac{\phi(x)}{k_bT_e}}$$



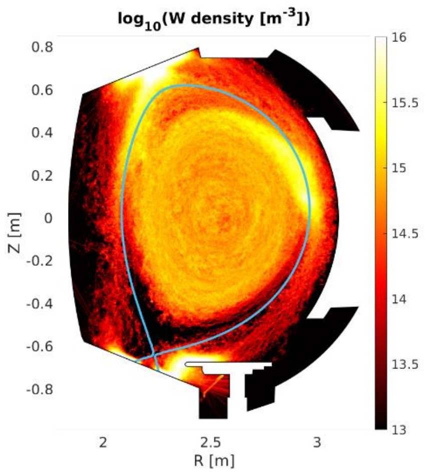
ERO2.0 STD



ERO2.0 + MPS el. density drop

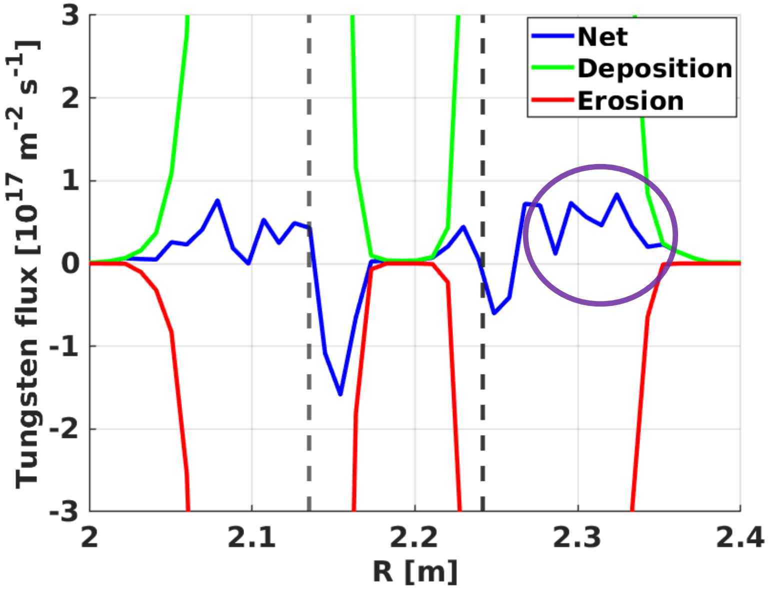


ERO2.0 + Thermal forces + MPS el. density drop

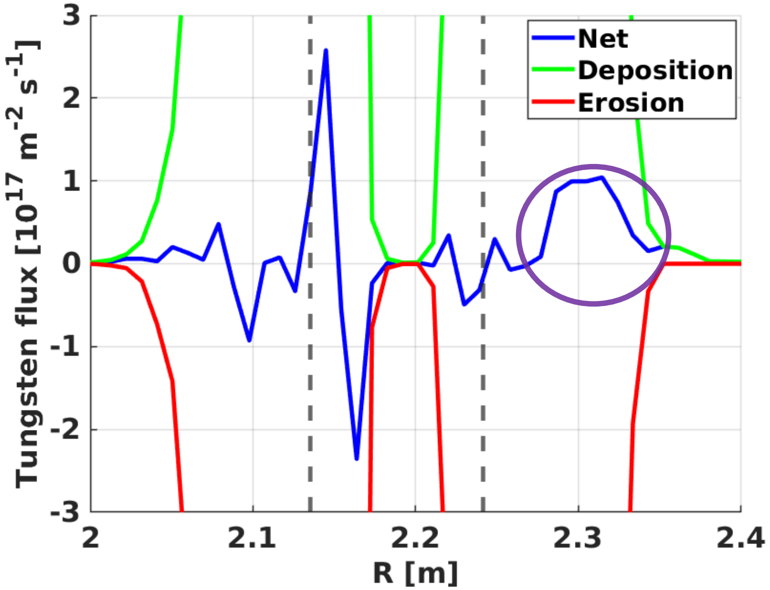


Divertor targets: strong local redeposition

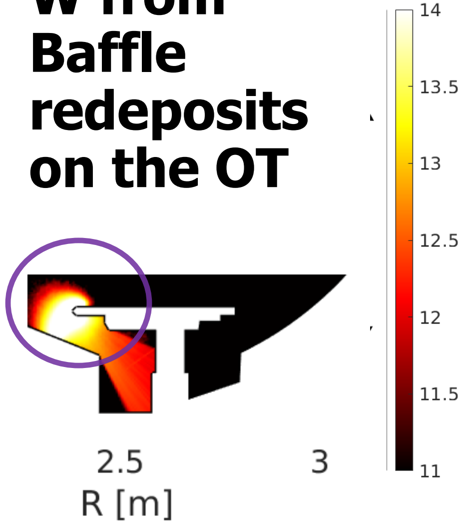
Low density background

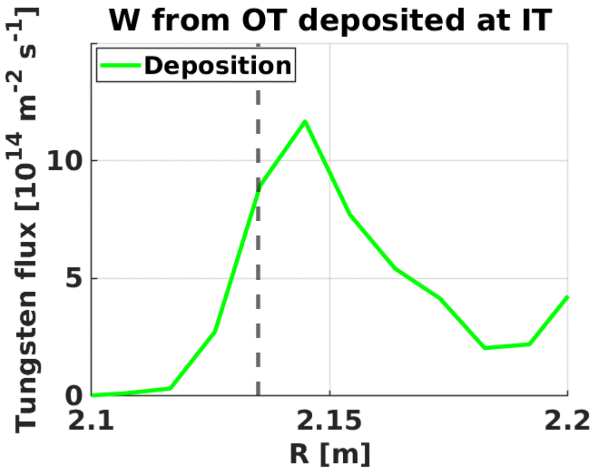


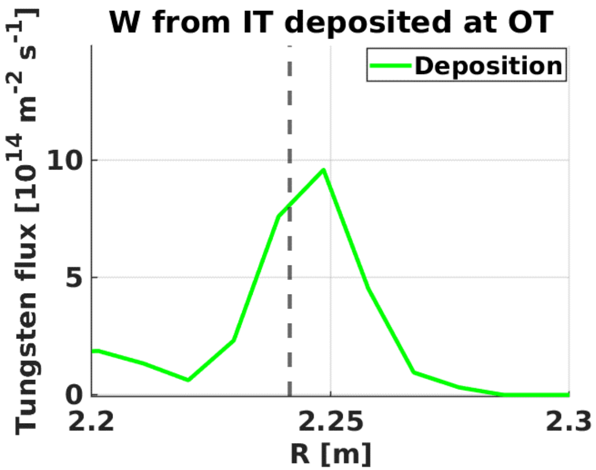
High density background

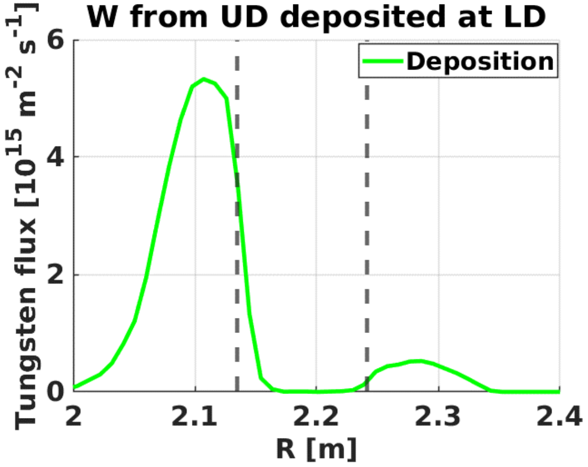


W from Baffle redeposits on the OT



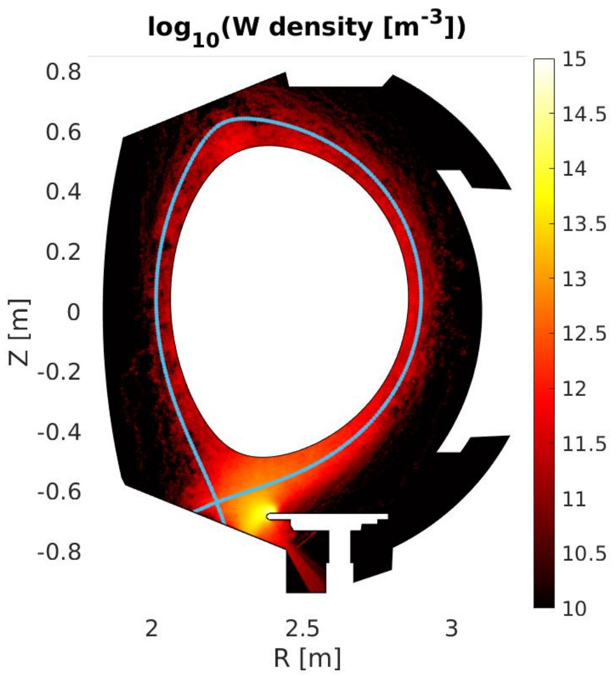






Non-local dep. < 1%

Baffle contamination: two different magnetic configurations

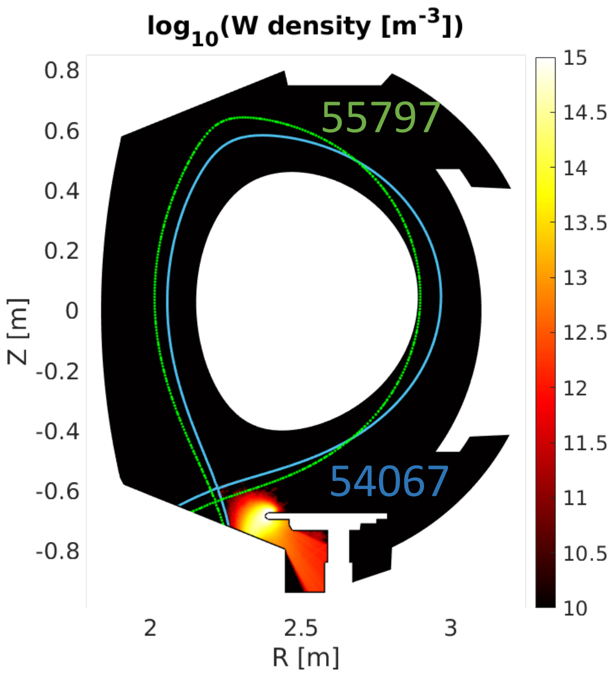


#55797: low X-point

Simulation power 2.5 MW

Separatrix density: 2.1e19 m-3

Penetration factor τ_W: 1e-6 s



#54067: high X-point

Simulation power 3 MW

Separatrix density: 2.5e19 m-3

Penetration factor τ_W : 1e-11 s

ERO2.0 Input parameters:

$$D_\perp^{an} = 1\ \mathrm{m}^2/s$$

Future simulations to investigate X-point height influence on W contamination