WPPRD-LMD 2024 kick-off meeting

PoliTo activities

G.F. Nallo[1], E. Bray[1], E. Agus[1], A. Costa[1], C. Marchetto[1,2], F. Subba[1], H. Wu[1], R. Zanino[1]

[1]NEMO group, Dipartimento Energia, Politecnico di Torino, Italy
[2]ISC-CNR, Dipartimento Energia, Politecnico di Torino, Italy

Politecnico di Torino
Department of Energy "G.Ferraris"

Nuclear Engineering MOdeling Group

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Outline

- Motivation and aim of the work
- Modelling strategy
- Results of 2023 activities
- Plans for 2024

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Motivation and aim of the work

- LM erosion →
  - Beneficial vapor shielding of the target …
  - … but possibly excessive core plasma cooling/dilution

- Target, SOL and core plasma must all be included in a self-consistent model to:
  - Assess compatibility with EU DEMO plasma scenario and support LMD design
  - Analyze LMD experiments in tokamaks (→ interpretation, model calibration and validation)

→ Aim: to develop and apply the necessary knowledge and tools to simulate the EU DEMO plasma in the presence of an LMD using a state-of-the-art edge plasma and neutrals transport code (SOLPS-ITER) and a core transport code (ASTRA/STRAHL)

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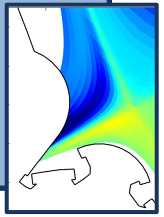
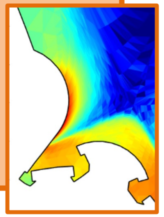
Modelling strategy

- Coupling of state-of-the-art tools to simulate target erosion + transport of plasma and impurities on SOL and core

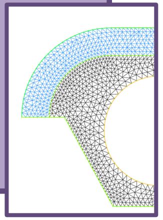
2D SOL plasma model (B2.5 in SOLPS-ITER) →
- SOL plasma temperature and density distributions
- Radiated power in SOL
- Heat flux on divertor target
- Impurity flux to core



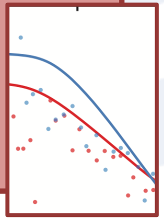
2D neutrals model (Eirene in SOLPS-ITER) →
- Neutrals temperature and density distributions
- Interactions with plasma
- Pumping/redeposition



2D LM erosion model (FreeFem++) →
- Target temperature distribution
- LM evaporation/sputtering rates



1.5D core plasma model (ASTRA+TGLF+STRAHL) →
- Core plasma temperature and density profiles
- Radiated power in core



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Results of 2023 activity (overview)

- First SOLPS-ITER simulations of AUG with liquid Sn module:
  - Simulation of AUG experiments with liquid Sn module → ongoing, will continue in 2024
- Modelling of EU DEMO plasma with liquid Sn divertor:
  - Core plasma impurity transport calculations with new ASTRA/STRAHL/TGLF coupling

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Contact – Email: elisabetta.bray@studenti.polito.it
giuseppefrancesco.nallo@polito.it

Studies on the effect of impurities emitted from a liquid metal divertor on the plasma core for the design of the EU-DEMO

E. Bray, G.F. Nallo, C. Marchetto[2], T. Luda di Cortemiglia[3], C. Angioni[3], D. Fajardo[3] and F. Subba

NEMO group, Dipartimento Energia, Politecnico di Torino, Corso Duca degli Abruzzi 24, 10129 Torino (TO), Italy

[2]ISC-CNR, Dipartimento Energia, Politecnico di Torino, Corso Duca degli Abruzzi 24, 10129 Torino (TO), Italy [3]Max-Planck-Institut für Plasmaphysik, D-85748 Garching, Germany

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RESEARCH

Check for updates

Towards Integrated Target–SOL–Core Plasma Simulations for Fusion Devices with Liquid Metal Targets

Giuseppe Francesco Nallo[1] · Jorge Gonzalez[2] · Elisabetta Bray[1] · Teobaldo Luda di Cortemiglia[3] · Chiara Marchetto[4] · Fabio Subba[1] · Egbert Westerhof[2] · Roberto Zanino[1]

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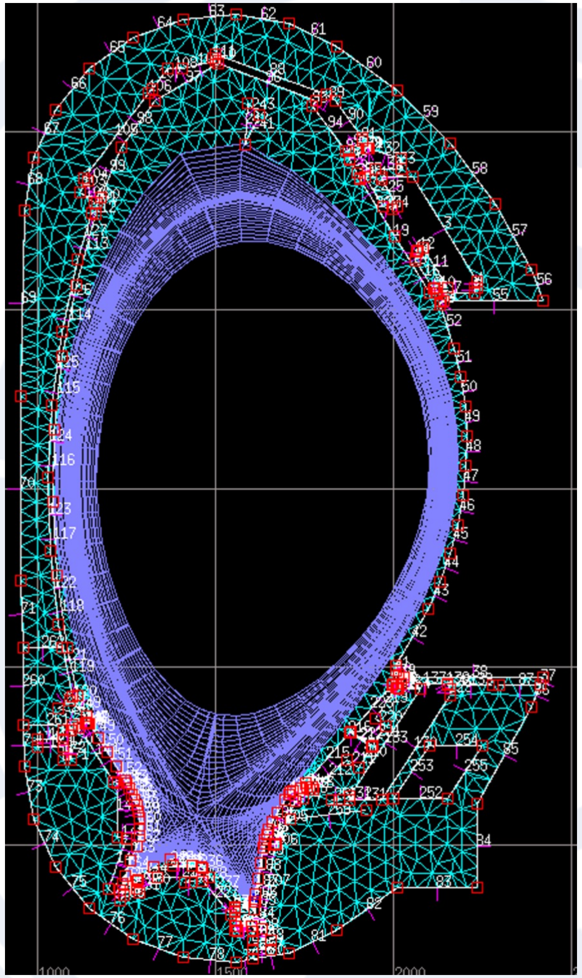
First SOLPS-ITER simulations of AUG with liquid Sn module (I)

- Rationale: use SOLPS-ITER to simulate experimental conditions in AUG (2022 campaign with liquid Sn module [J. Scholte et al., NME 2023])
- Specifically consider H-mode shot #41279
- Plasma species: D, Sn (all ionization states considered)
- Neutral species: D, D^2, Sn^0
- Neutral Sn source: staged approach
  - Impose Sn emission rate predicted by HeatLMD code based on IR target temperature measurement
  - Impose experimentally measured Sn emission rate at outboard target
  - Switch on self-consistent calculation of Sn emission based on computed target temperature

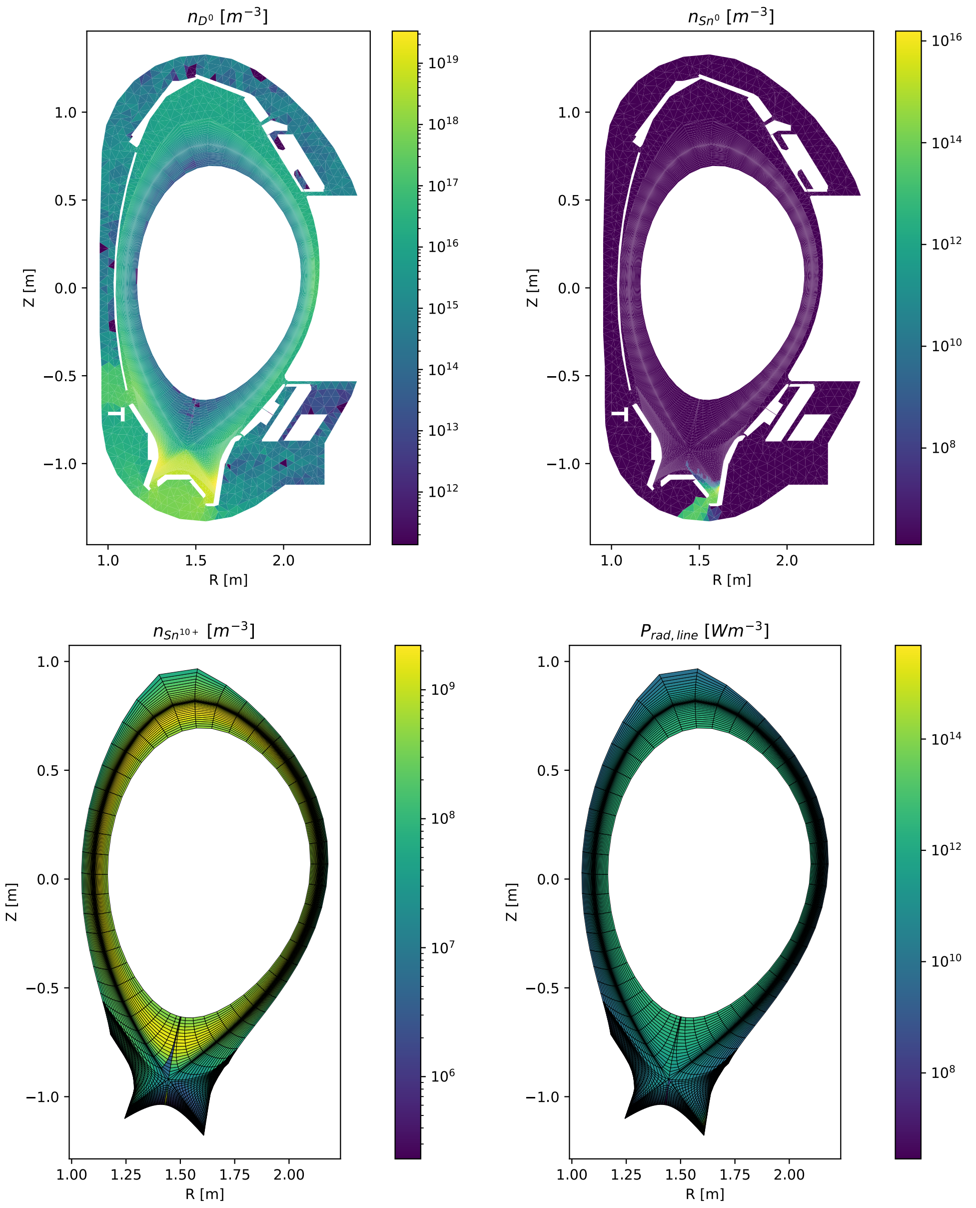


SOLPS-ITER fluid and kinetic grids for the AUG L-mode case

First SOLPS-ITER simulations of AUG with liquid Sn module (II)

- Since these are the very first SOLPS-ITER simulations with Sn and full B2.5-Eirene coupling, a staged approach was adopted
  - Start from a converged pure D, L-mode case
  - Added Sn^0 source of $4 \cdot 10^{17} \# / s$ at outer strikepoint, run up to convergence
  - Verified the correct code behavior in terms of charge states distribution, radiated power density

- *Ongoing: simulations for H-mode case #41279 (see plans for 2024)*
- *Note: the experience gained here allowed us to support SOLPS-ITER modelling for COMPASS-U (see final slide)*



ASTRA simulations of Sn transport in EU DEMO core (I)

ASTRA

Initial conditions

Generic DEMO scenario [Siccinio et al., *FED* 2020]
- Safety factor, T_e, T_i, n_e profiles
- Auxiliary power (250 MW)

Boundary conditions

Outputs of SOLPS-ITER
- T_e, T_i, n_e, n_i, n_{D0}
- Γ of impurities

Interface set at separatrix (*)

(*) treatment of pedestal subject to improvements

$$\Gamma = -D\frac{\partial n}{\partial \rho} + V \cdot n \qquad q = X\frac{\partial T}{\partial \rho} \cdot n$$

ASTRA computes the **main plasma transport equations**, evolving temperatures, densities and current, starting from initial and boundary conditions.

TGLF-NCLASS

The two codes implemented in *ASTRA*, evaluate **turbulent and neoclassical transport coefficients**, starting from the main plasma profiles

STRAHL*

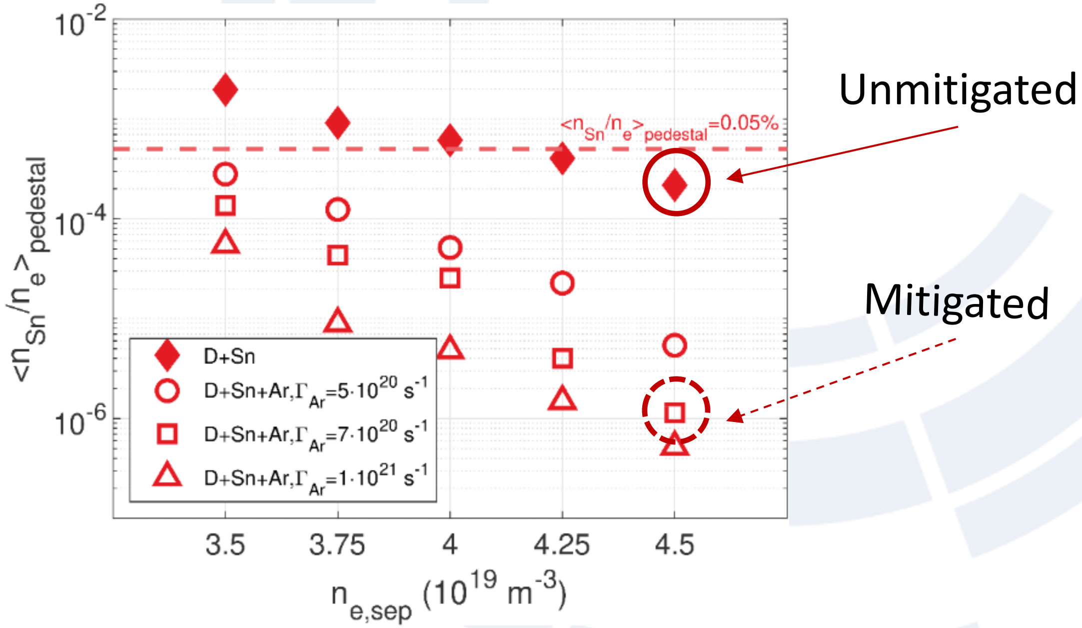
Computes the **impurity density profile** and the **radiated power**

*Not used in the present work

ASTRA simulations of Sn transport in EU DEMO core (II)

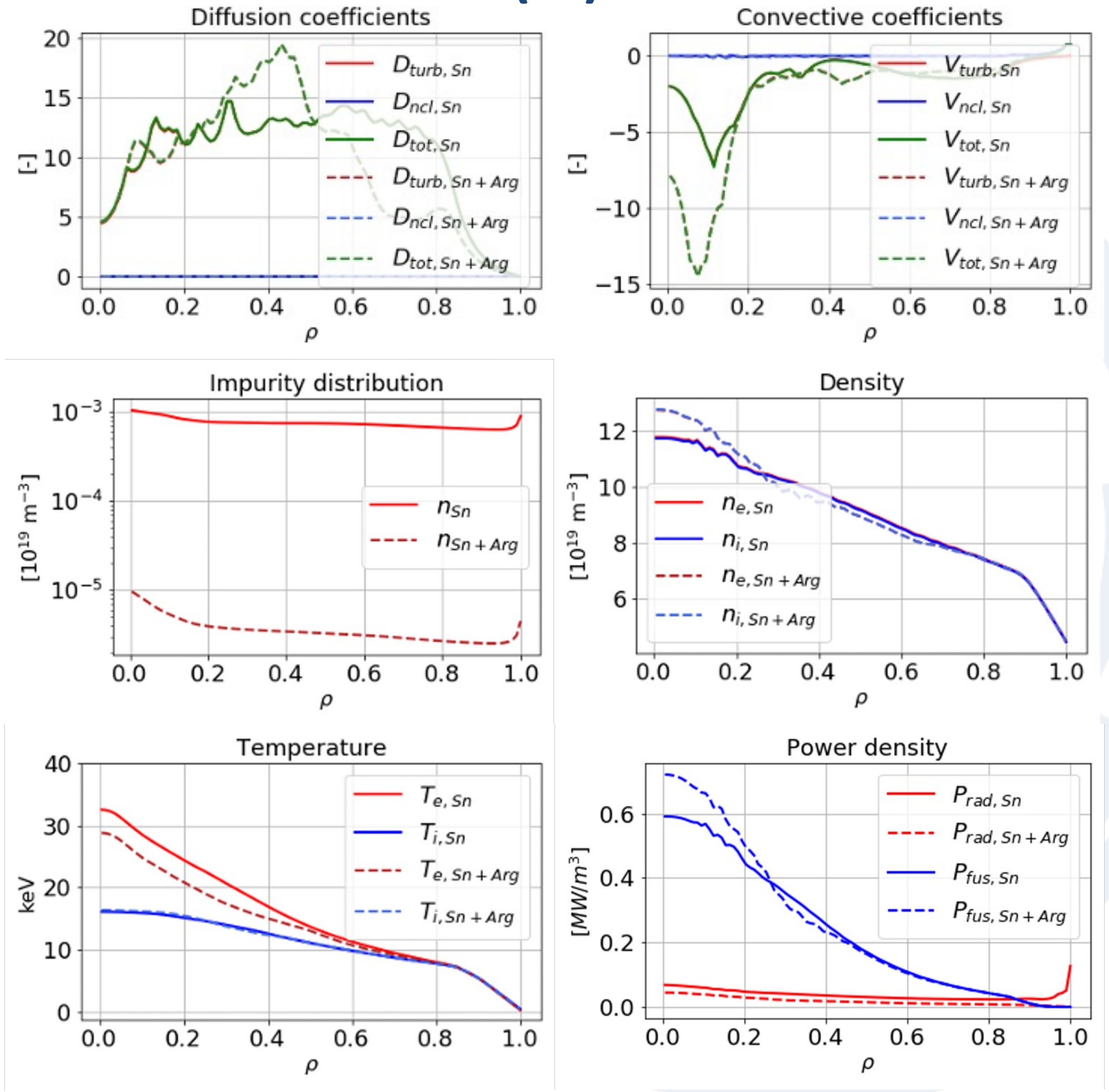
- The ASTRA code was adopted to compute the Sn distribution in the core
- Starting from database of SOLPS-ITER simulations [G.F. Nallo et al., Nucl. Fusion (2022)], one mitigated case and one unmitigated case were considered (see figure)
- Simulation setup:
  - B, I and $q(\rho)$ consistent with SOLPS (EU-DEMO 2017)
  - BCs at ρ=1, ASTRA domain up to ρ=0.85
  - TGLF includes TEM + ITG, NCLASS for neoclassical
  - Input data from SOLPS-ITER (w/ and w/o Ar mitigation), until new SOLPS-ITER calculations for EU-DEMO with Sn divertor become available
  - ASTRA evolved with one impurity (Li or Sn – here only discuss Sn)

Input data for ASTRA	
$T_{e,sep}$	$263\ [eV]$
$T_{i,sep}$	$426\ [eV]$
$n_{e,sep}$	$4.5\ [10^{19}\mathrm{m}^{-3}]$
$n_{D0,sep}$	$2.4 \cdot 10^{13}\ \mathrm{e}[10^{19}\mathrm{m}^{-3}]$



ASTRA simulations of Sn transport in EU DEMO core (III)

- Both mitigated and unmitigated case show Sn accumulation in core
- Turbulent transport dominates over neoclassical transport (opposite behavior wrt. AUG, essentially due to machine size)
- No dilution effects observed but significant radiated power for unmitigated case (concentrated close to the separatrix)
- However, radiation is concentrated close to the separatrix (mostly due to $L_{z,Sn}(T_e)$) – this makes unmitigated Sn appearingly more compatible with EU-DEMO than unmitigated Li
- Sn mitigated case OK



Completion of 2023 activities (before reporting)

- Sn transport in EU DEMO core plasma:
  - Discussed results of core Sn transport with M. Siccinio (DEMO Physics Integration Manager) to align with DEMO baseline studies (mid december)
  - Now need to discuss with E. Fable (IPP Garching) to compare with DEMO results with W.
  - Finally, compare with COREDIV results by I. Ivanova-Stanik.
  - [After reporting: submit a paper on this subject]

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Plans for 2024 (overview)

- Integrated modelling of AUG experiment with LMD module:
  - SOLPS-ITER calculations with self-consistent erosion model activated
  - Core impurity transport calculations including neoclassical transport of heavy impurities (see next slide)

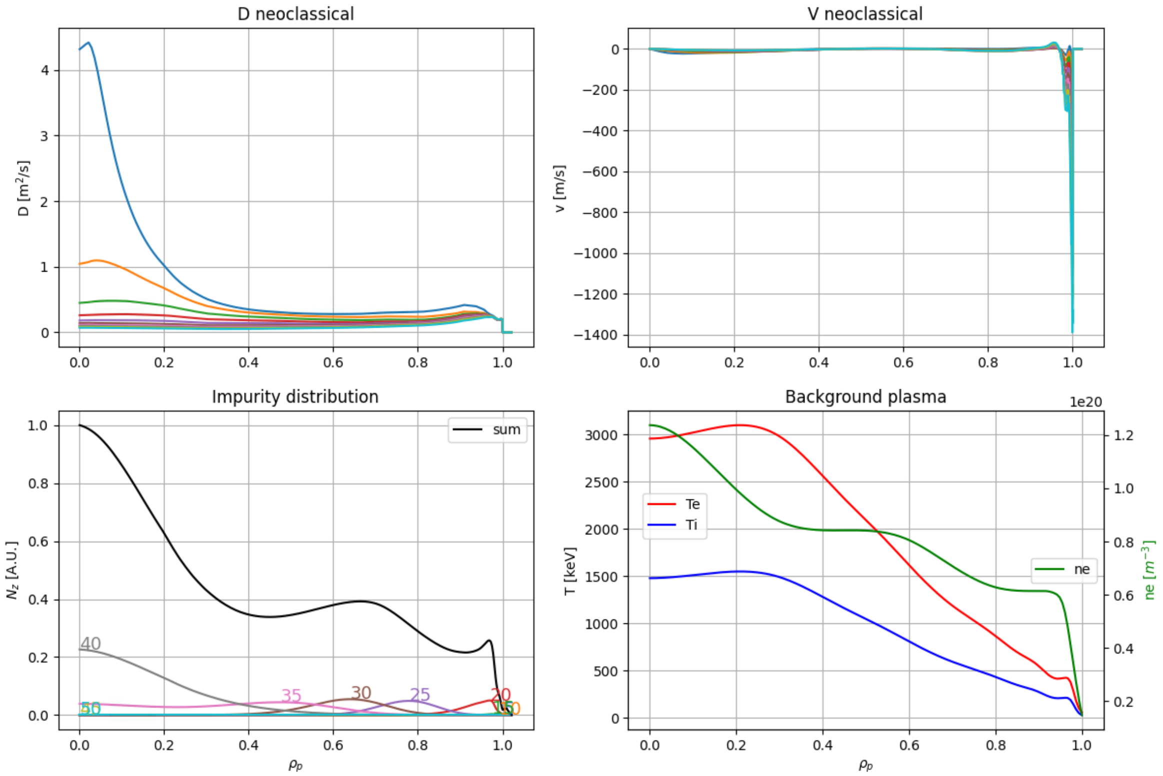
  [Results of both activities will be presented as posters at PSI-24 conference (May 12-17)]

- Update SOLPS-ITER calculations for the EU DEMO with a liquid Sn divertor
  - Refine the treatment of plasma and neutrals based on the activity on AUG
  - Allign with the latest DEMO baseline
  - Take advantage of recent code improvements

  [Aim at presenting first results at ISLA-8 conference (September 7-12)]

First results for AUG integrated modeling

- The work presented in [J.Scholte et al., NME 2023] represents an interpretive analysis of AUG shots with Sn.
- Here focus on shot #41279, with the aum to test the predictive capabilities of the integrated modelling framework developed for liquid metal divertors
- First calculations performed using Aurora (a modern version of STRAHL) instead of ASTRA, for the sake of simplicity
- Neoclassical transport coefficients for Sn computed via the recent FACIT code (specific for heavy impurities)



Acknowledgement of external collaborations

- IPP Garching (C. Angioni, D. Fajardo, E. Fable, T. Luda, R. Dux) – we were supported in setting up core impurity transport calculations for the EU DEMO

- IPP Prague (I. Borodkina) – we are providing support for setting up SOLPS-ITER simulations for Li, in view of the preparation for COMPASS-U operation

- DIFFER (J. Gonzalez, E. Westerhof, H. De Blank, F. Romano) – a Polito MSc student is working on SOLPS-ITER simulations on Magnum-PSI with a Li vapor box to support interpretation of experimental data *[here simulate Li neutrals with Eirene, something on which we can leverage to support COMPASS-U modelling]*