EUROfusion

WPPRD-LMD 2023 KoM: PoliTo

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Outline

- PoliTo task
- Overview of the modelling strategy
- Summary of 2022 activities
- Plans for 2023
- Perspective

PoliTo task

- 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)

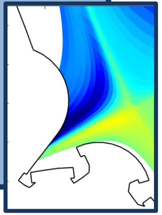
Aim: to develop and apply the necessary knowledge and tools to simulate the EU DEMO plasma in the presence of an LMD using a state-of-the-art **edge plasma code** (SOLPS-ITER) and a **core transport code** (ASTRA).

Methodology

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

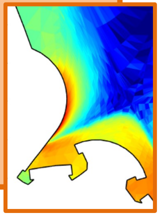
2D SOL plasma model (B2.5 in SOLPS-ITER) →

- SOL plasma temperature and density distributions
- Radiated power in SOL
- Heat flux on divertor target
- Impurity flux to core



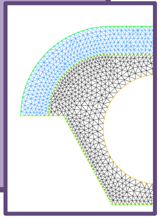
2D neutrals model (Eirene in SOLPS-ITER) →

- Neutrals temperature and density distributions
- Interactions with plasma
- Pumping/redeposition



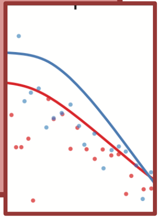
2D LM erosion model (FreeFem++) →

- 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



Summary of 2022 activities

- Coupling of **target evaporation/sputtering model to EIRENE**:
  - Modelling developments:
    - Target emission profile is now consistent with the impinging power/particle fluxes also when using a kinetic model for the neutral species (EIRENE)
    - LM condensation on FW is currently simulated via a species-specific pump
  - First studies performed:
    - Application to Magnum-PSI (to focus on target-plasma interactions)
- **Integration of core plasma** in the model:
  - Use ASTRA/STRAHL with impurity fluxes computed by SOLPS-ITER (imposed at the separatrix) to assess core plasma contamination
  - For the time being, the coupling is not self-consistent (fluxes from SOLPS-ITER are used as a boundary condition for ASTRA/STRAHL, but no feedback on the SOL plasma is considered)

Overview of modelling strategy (I)

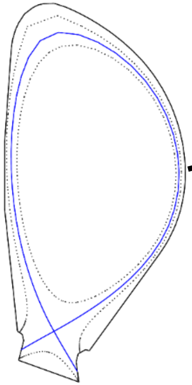
Core plasma: couple to ASTRA.

- One-way (FP9-2022)
- Self-consistent coupling (IMAS?)

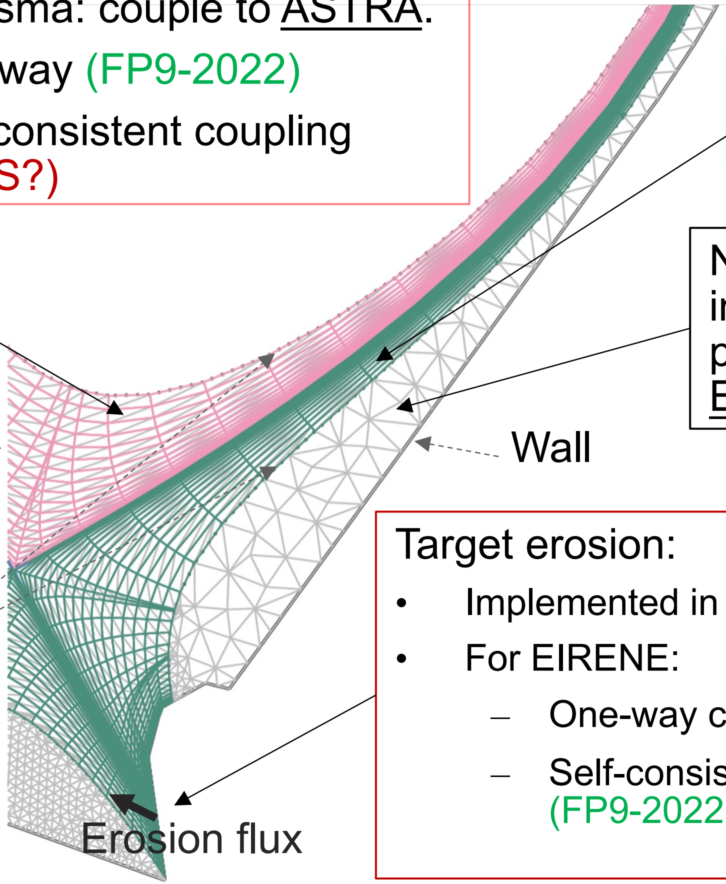
Pedestal: use ASTRA/STRAHL with parametric studies on transport coefficients

SOL plasma: B2.5 (FP8 – 2018/2019)

Neutral transport, interaction with plasma, pumping/redeposition: EIRENE (FP8 – 2020)



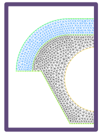
SOLPS-ITER (B2.5 + EIRENE) simulation domain



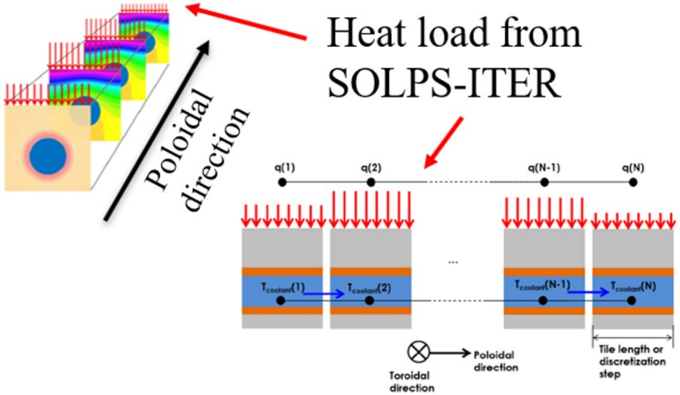
Target erosion:

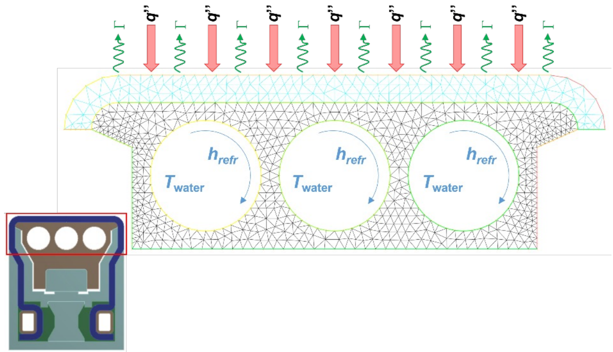
- Implemented in B2.5 (FP8-2018/2019).
- For EIRENE:
  - One-way coupling (FP9-2021).
  - Self-consistent coupling: ongoing (FP9-2022)

2D Target erosion: FreeFem++

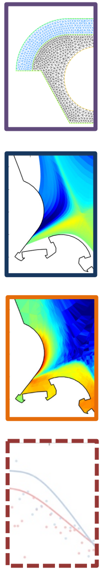


- 2D FE model for heat conduction in each section
  - Specified heat transfer coefficient and coolant temperature
  - Imposed heat flux from SOLPS-ITER on PFS
  - Consider evaporation, thermal sputtering
  - Temperature-dependent properties
- Simplified treatment of LM-filled CPS layer on top of substrate:
  - Solid layer with averaged thermal properties evaluated by law of mixtures
  - Pure Li/Sn
- Output:
  - Temperature distribution in divertor target (assess temperature limits for material compatibility)
  - Evaporation flux of metal for each poloidal location
- Notes:
  - Uncertainties in actual thermal properties of the LM-filled CPS
  - In principle, transient simulatios are possible

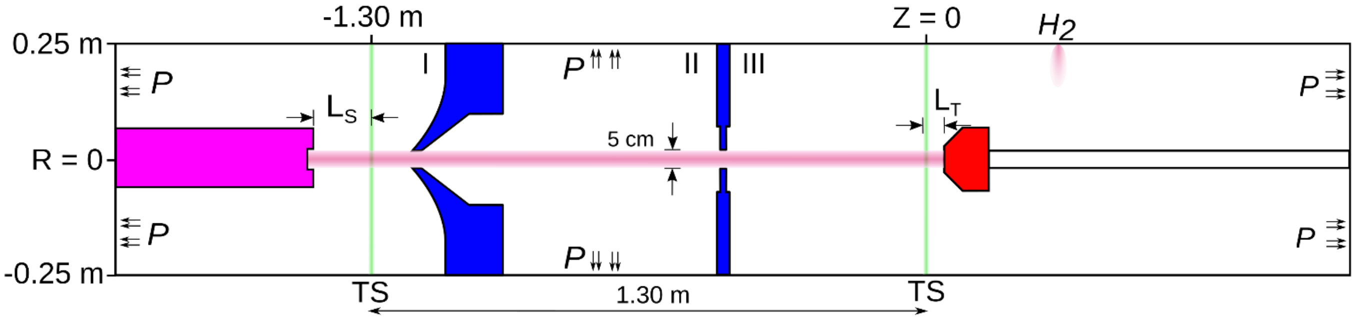




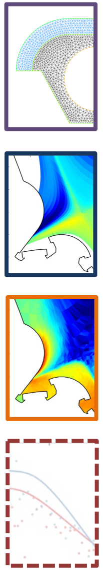
Application #1: Magnum-PSI



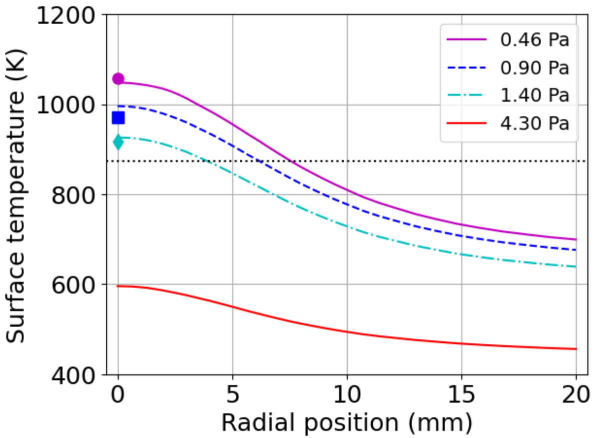
- Application of the model to linear plasma device (LPD):
  - Can perform validation of simulations against experimental data
  - Relatively short simulation times
  - Capability to easily switch targets and change plasma conditions
  - Similar heat and particle fluxes to those expected at ITER



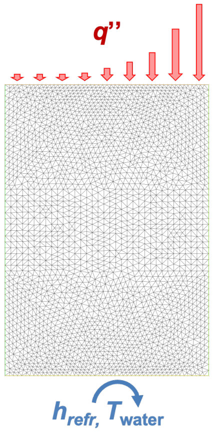
#1: Magnum-PSI, solid target

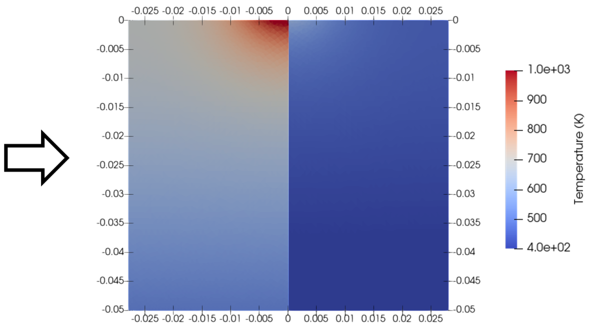


- Increasing gas pressure in target chamber → reduced target heat flux
- Comparison with pyrometer measurements shows good results, compatibly with the lower temperature measurable by the pyrometer (black dashed line)
- New experiments planned in the future to extend validation



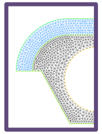
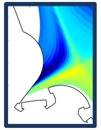
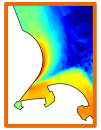
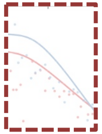
Computed temperatures (lines) and pyrometer measurements at target center (markers) for different neutral pressures in the target chamber.





Target temperature distribution for the 0.46Pa (left) and the 4.30Pa (right).

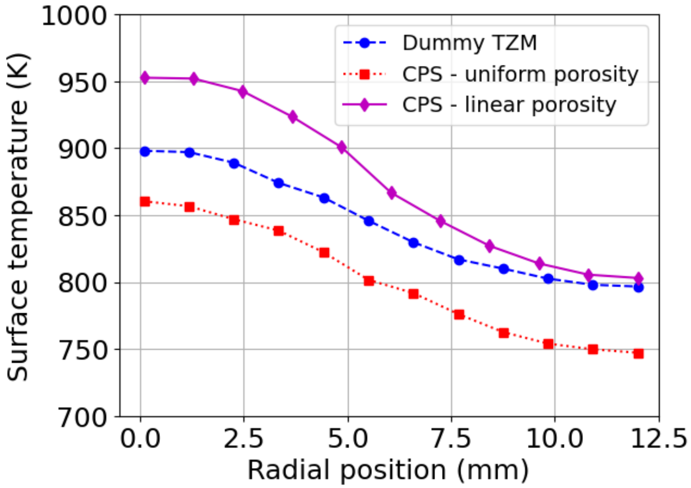
#1: Magnum-PSI, CPS target

- First results considering LM target show that evaluating thermal properties of 3D printed or sintered W is crucial to correctly evaluate surface temperature

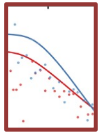
- In experiments $T_{CPS} > T_{Dummy}$ → the system here considered appears to be characterized by linear porosity

- Agreement with solid target (dummy) but discrepancies in CPS based on how the porous structure is defined



Surface temperature distribution for the dummy target, a CPS model based on the 3D printed design and a model with linear axial porosity (0.4 to 0.0 at the top).

1.5D Core plasma: ASTRA+STRAHL



Initial conditions

Generic DEMO scenario [Siccinio et al., *FED* 2020]
- Safety factor, T_e, T_i, n_e profiles
- Auxiliary power (50 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

ASTRA

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

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

TGLF-NCLASS

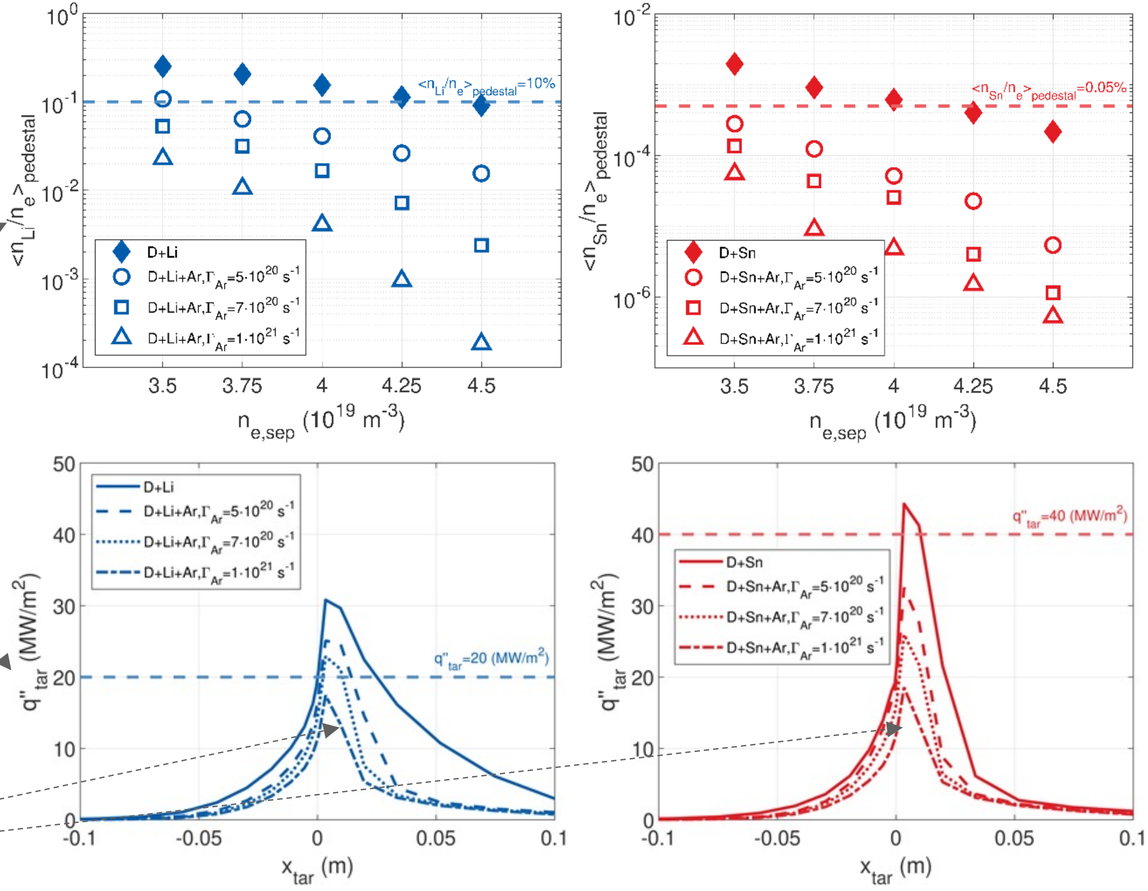
The two codes implemented in *ASTRA*, evaluate **turbulent and neoclassical transport coefficients**, starting from the main plasma profiles

STRAHL

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

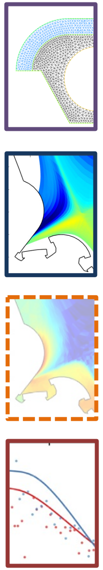
Application #2: EU DEMO

- Operational window significantly widened thanks to Ar seeding, for both Li and Sn, in terms of:
  - Core plasma contamination (but need more detailed assessment → couple to ASTRA in FP9)
  - Target peak heat flux (to be compared to power handling capability of different LMD designs)
- For sufficiently large Ar seeding rates, same heat flux profile for Li and Sn (Ar radiation dominates the power balance)



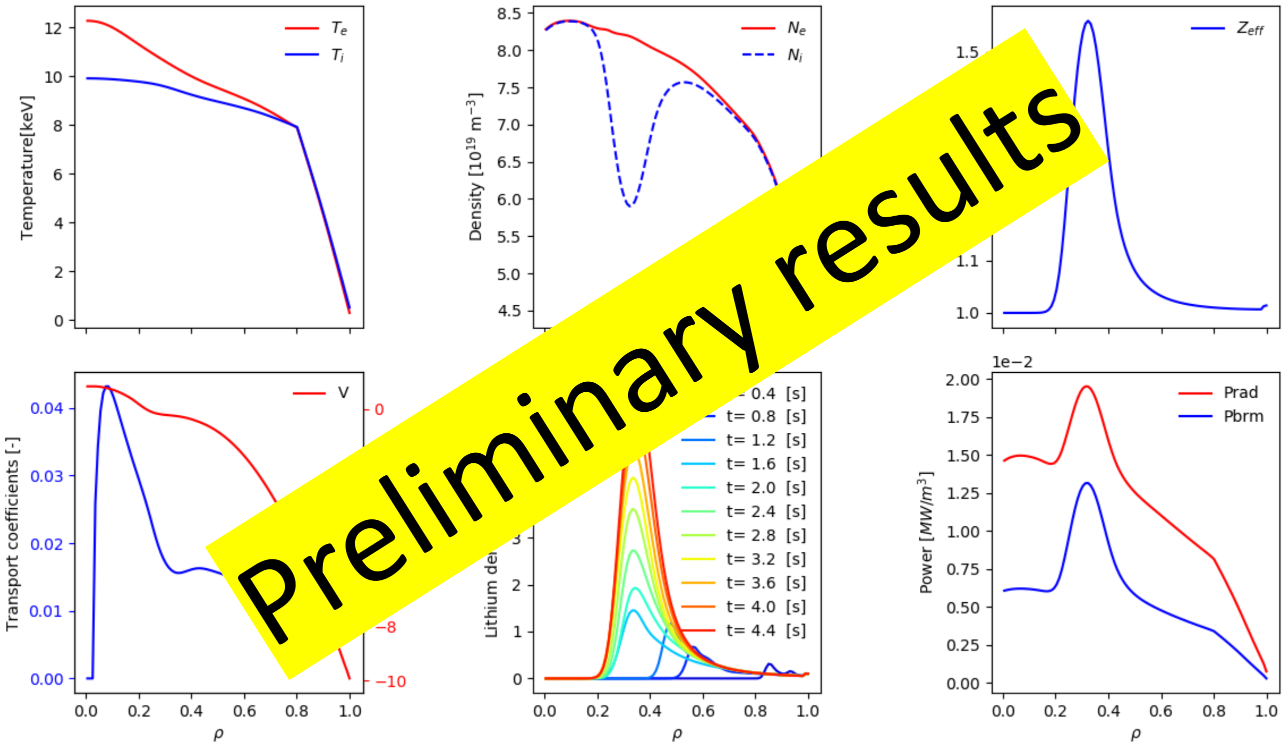
#2: Li impact on core plasma (preliminary)

Li	Boundary conditions
$T_{e,sep}$	$286.9\ [eV]$
$T_{i,sep}$	$501.6\ [eV]$
$n_{e,sep}$	$4.5\ [10^{19}\mathrm{m}^{-3}]$
$\Gamma_{imp,sep}$	$5.38 \cdot 10^{20}\ [1/s]$
$n_{D0,sep}$	$9.18 \cdot 10^{7}\ [10^{19}\mathrm{m}^{-3}]$



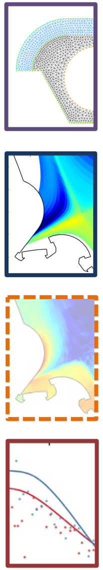
- Inward flux of impurities driven by pinch velocity
- Result is dilution of core plasma, as expected

Results at *4.4 [s]* of discharge



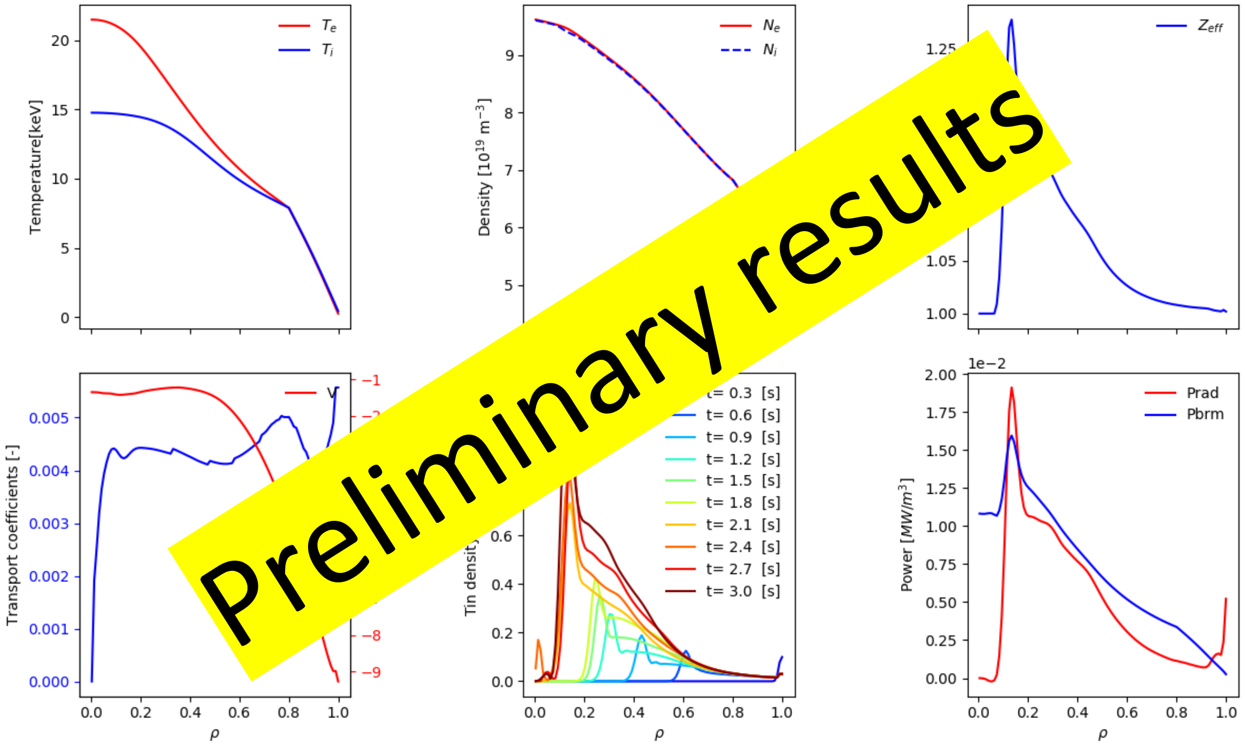
#2: Sn impact on core plasma (preliminary)

Results at *4 [s]* of discharge



Sn	Boundary conditions
$T_{e,sep}$	$248.9\ [eV]$
$T_{i,sep}$	$428\ [eV]$
$n_{e,sep}$	$4.5\ \ [10^{19}\mathrm{m}^{-3}]$
$\Gamma_{imp,sep}$	$1.45 \cdot 10^{18}\ [1/s]$
$n_{D0,sep}$	$2.37 \cdot 10^{13}\ [10^{19}\mathrm{m}^{-3}]$

- No dilution, as expected
- But similar Z_{eff}…
- … and resulting total radiation, with respect to Li



Plans for 2023

- SOLPS-ITER modelling of liquid Sn divertor for DEMO:
  - **Revise preliminary core plasma calculations** with new ASTRA/STRAHL/TGLF coupling (C. Angioni, D. Fajardo – IPP Garching)
  - Application of SOLPS-ITER (including self-consistent evaporation/sputtering) + ASTRA/STRAHL (one-way coupling) to the EU DEMO, considering different liquid Sn divertor designs, to assess core plasma contamination
- Benchmark against previous activities:
  - Compare with COREDIV calculations
- Preliminary validation:
  - More careful comparison with Magnum-PSI data
  - Simulation of AUG experiments with liquid Sn module

Summary of collaborations

- Ongoing collaborations:
  - Self-consistent coupling of EIRENE to surface erosion model (J. Munoz, E. Westerhof - DIFFER)
  - Using ASTRA-STRAHL with fixed fluxes computed by SOLPS-ITER (C. Marchetto – IFP-CNR Turin + C. Angioni – IPP Garching)
  - AUG experiments (J.G.A. Scholte - DIFFER)

- Perspective collaborations:
  - Preparation for Compass-Upgrade LMD experiments (J. Horáček, J. Čečrdle – Prague)

Thanks for your kind attention.

Comments or Questions?