Comparison of Eirene and Eunomia to the linear plasma linear device Magnum-PSI and outlook to the FE surface model

TSVV VC

J. Gonzalez; 2021-12-10

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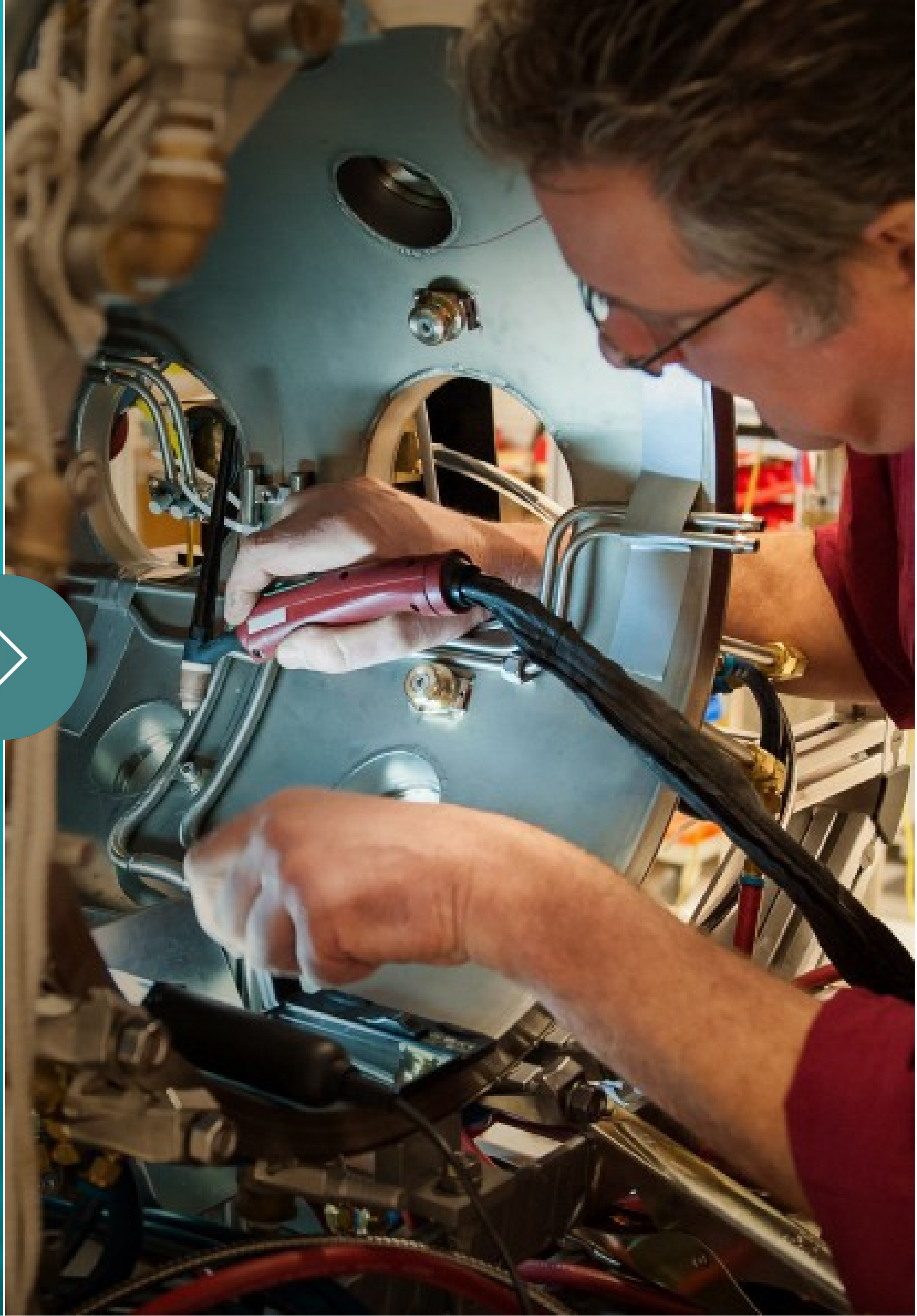

Comparing Eirene and Eunomia

Differences between Eirene-Eunomia

- Main difference is how plasma-neutral collisions are implemented.
- These differences are more relevant in **Electron Impact Ionization/Excitation** (EI), **Molecular Assisted Recombination** (MAR), and plasma-neutral **elastic collision** (EL).
- These differences may produce different neutral distributions, but most important, they calculate different energy and particle **sources** calculated to the plasma code.
- This affect coupled cases through the source/sink of energy and particles.
- First, to analyze these differences, a frozen plasma background is used to compute neutral distributions applying only one collision term per simulation.
- Comparing the “standard” approaches of both codes, although modifications have been done to match sources and reflection model.

Electron Impact Ionization/Excitation

- Main difference is in the database these to processes read in the “standard” operating mode.
  - **Eirene** uses AMJUEL as an effective ionization rate (accounting for excitation). Moreover, the electron energy cooling is non-constant.
  - **Eunomia** uses differentiated processes for ionization and excitation read from HYDHEL with constant energy losses.

Eirene

$e + H \rightarrow 2e + H^+$ AMJUEL 2.1.5 H.4 and H.10

Eunomia

$e + H \rightarrow 2e + H^+$ HYDHEL 2.1.5

$e + H \rightarrow e + H^*$ HYDHEL 2.1.1

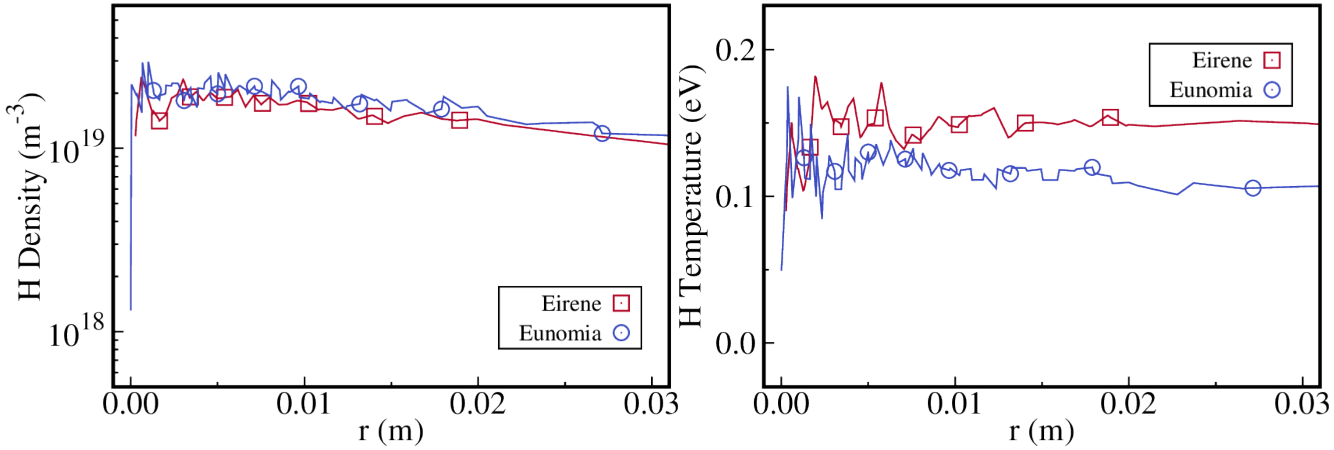

Fig. 1. Radial profiles for H at the TS target position.

Total Source Intensity	Eirene	Eunomia
Electron energy (W)	-589	-193
Ion Particle (part s^-1)	1.3e19	1.9e19

1) Although the collision rate for the processes are read differently, similar profiles are achieved.
2) Similar number of ions are generated.
3) However, quite significant energy electron energy sinks are computed.
4) Eunomia can only use constant energy dependent electron loses.
5) Similar results when HYDHEL 2.1.5 is used in both codes.
6) HYDHEL 2.1.1 possible to implement in Eirene input file but not straight forward.

Molecular Assisted Recombination

- Both codes start with the same CX process. The main difference come from how the H_2^+ molecule is dissociated:
  - **Eirene** uses three processes from AMJUEL leading to different distribution of neutral/ions.
  - **Eunomia** assumes that the dissociation is an spontaneous process that leads to a ground and excited H atoms.

$$H^+ + H_2 \rightarrow H + H_2^+$$ AMJUEL 3.2.3

Eirene

$e + H_2^+ \rightarrow 2e + H^+ + H^+$	AMJUEL 2.2.11
$e + H_2^+ \rightarrow e + H + H^+$	AMJUEL 2.2.12
$e + H_2^+ \rightarrow H + H$	AMJUEL 2.2.14

Eunomia

$e + H_2^+ \rightarrow H + H^*$	Spontaneous

Total Source Intensity	Eirene	Eunomia
Electron energy (W)	-1427	-457
Ion Energy (W)	191	-533
Ion Particle (part s^-1)	-1.3e20	-2.9e20

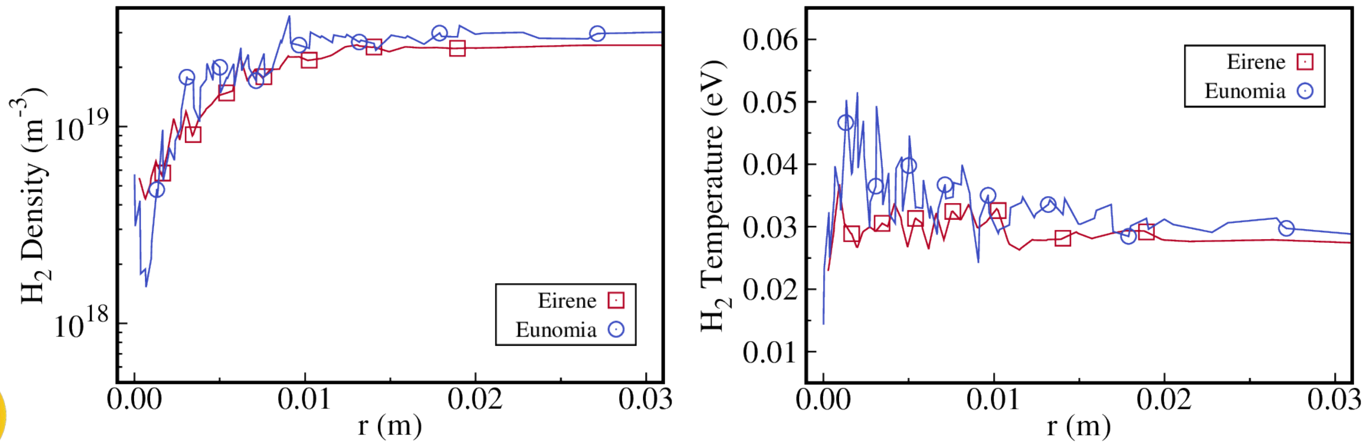

Fig. 2. Radial profiles for H_2 at the TS target position.

1) The resulting profiles agree in the two codes.
2) All sources of energy and particles are completely different.
3) It would require deep modifications to Eunomia to allow Eirene implementation.

Proton-Atom collision

- Eunomia uses CX and EL as individual processes. This should be equivalent to Eirene CX implementation.
- Eirene only uses CX as it assumes both processes are indistinguishable of each other.

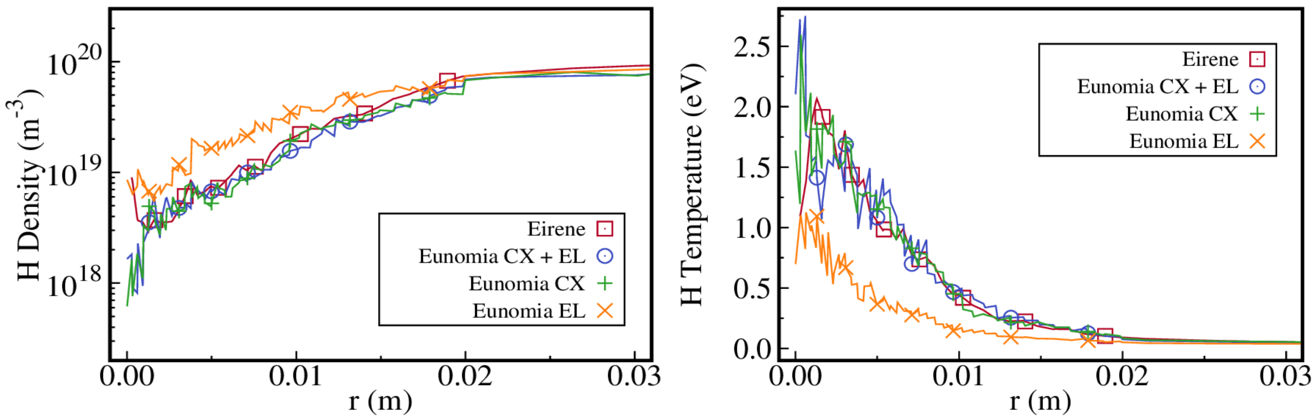

Fig. 3. Radial profiles for H at the TS target position for the different combination of p+H interactions in the two codes.

Code	Ion Energy (W)
Eirene	-479
Eunomia CX	-461
Eunomia CX+EL	-542

1) All observed radial profiles agree, except Eunomia pure EL.
2) However, the EL process adds an additional sink that Eirene does not have.
3) Related with accuracy of processes at low temperatures?

Proton-Molecule collision

- The difference reside in the calculation of the post-collision angle, even when same rate is read by the two codes.

Eirene

Generalized Morse potential from Ref. [1]

Eunomia

$$\cos\theta = \frac{2 + \alpha E_r - 2(1 + \alpha E_r)^R}{\alpha E_r}$$

From Ref. [2]

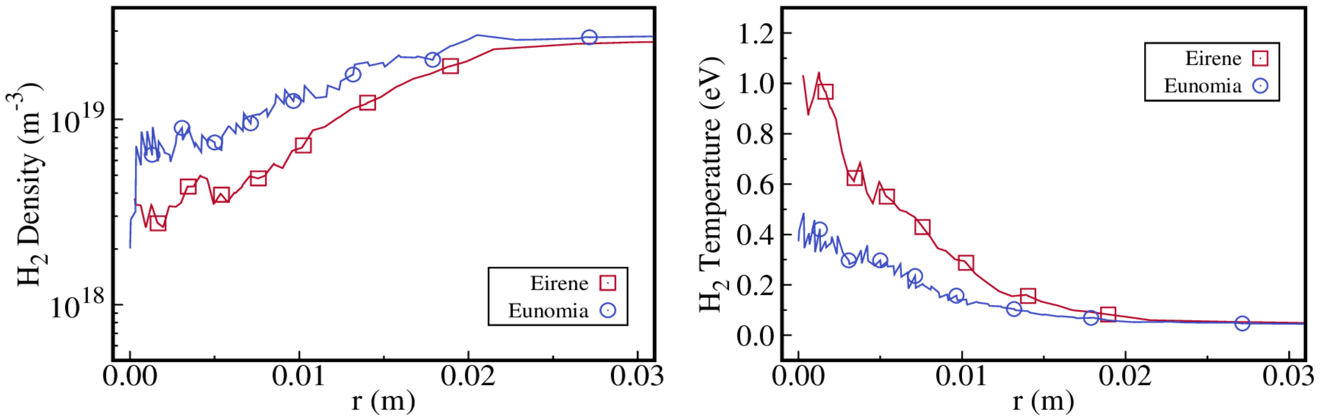

Fig. 4. Radial profiles for H at the TS target position.

1) P. Bachmann, D. Reiter, Kinetic description of elastic processes in hydrogen-helium plasmas, Contributions to Plasma Physics 35 (1) (1995) 45–100.
2) D. Tskhakaya, et. Al, *Self-Consistent Simulations of the Plasma-Wall Transition Layer*, Contributions to Plasma Physics, Wiley Online Library, 2008, 48, 121-125.

Total Source Intensity	Eirene	Eunomia
Ion energy (W)	-370	-490

1) Different profiles are achieved due to the different post-collision angles.
2) Different in ion energy source is significant.
3) In Eunomia $a = 1e6$, but $a = 1$ produces similar results to Eirene.

Comparing a coupled Magnum-PSI run

Differences in coupled runs

- As a result of the different interaction with the neutrals, coupled runs between SOLPS-ITER and B2.5-Eunomia are difficult to compare.
- Moreover, the electric potential at the source, an unknown in our simulations, required to match the temperature profile at the TS target position is completely different between the two codes.
  - It seems that B2.5-Eunomia requires more Ohmic heating as neutrals exchange more energy with the plasma.
- This hinders our capability to reproduce B2.5-Eunomia results as new guesses for the potential need to be performed again for each case.
- Moreover, the relevant collision terms near the target should be re-evaluated as the energy sources differ.
- The SOLPS-ITER potential profile for the High Density case seems to be closer to the reduced experimental data available, but additional measurements are required.

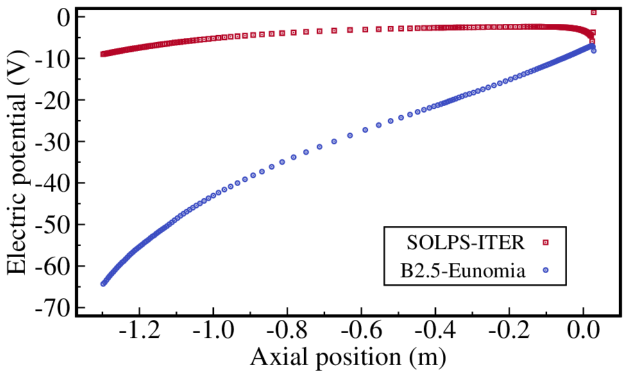

Fig. 5. Electric potential for the High Density case.

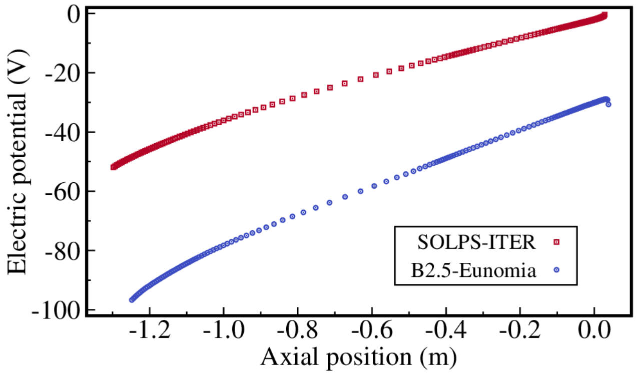

Fig. 6. Electric potential for the Low Density case.

Total Source Intensity	SOLPS-ITER	B2.5-Eunomia
Electron energy (W)	-873	-317
Ion Energy (W)	-46	-1486
Ion Particle (part s^-1)	-6.1e19	-1.0e20

Comparison of Coupled case between SOLPS-ITER and B2.5-Eunomia (plasma)

- With these differences taken into account, quite similar plasma profiles at the TS target position are reached. However, axial profiles are completely different between the two codes.
- This rise from the amount of unknown parameters (transport coefficients, electric potential) and trying to modify those to match measurements at an specific point.
- Additional measurements of plasma and neutrals should be compared to determine the correct distribution.

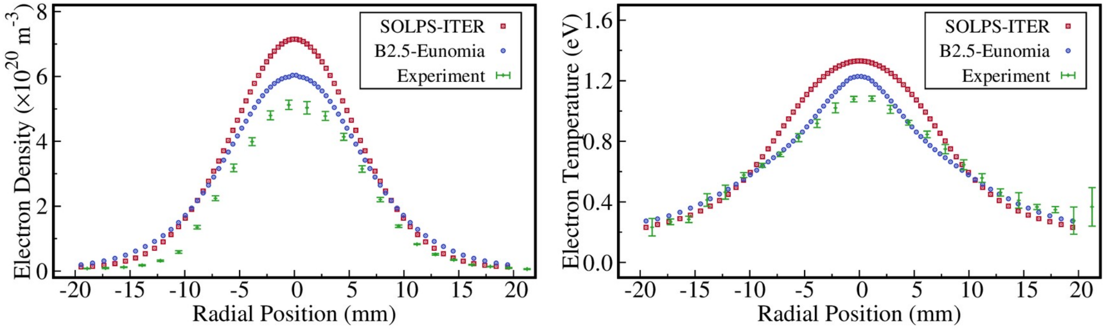

Fig. 7: Comparison SOLPS-ITER (red) and B2.5-Eunomia (blue) with experimental data (green) for a case of high density. Left is electron density and right is electron temperature at TS target position.

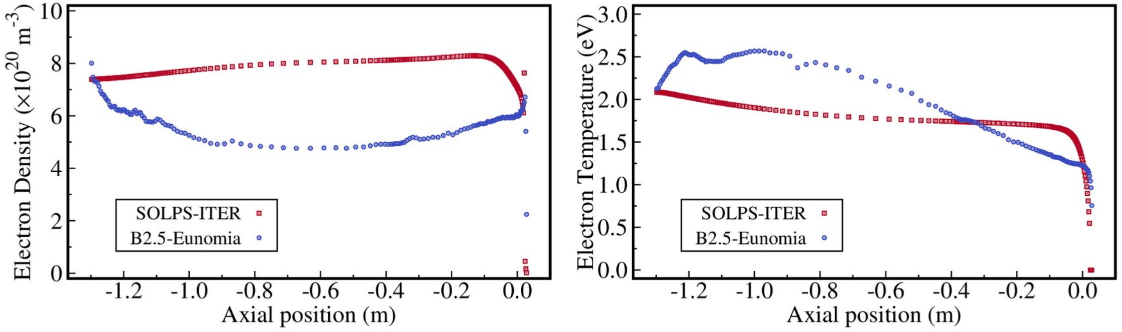

Fig. 8: Comparison SOLPS-ITER (red) and B2.5-Eunomia (blue) for a case of high density. Left is electron density and right is electron temperature at the plasma beam axis.

Comparison of Coupled case between SOLPS-ITER and B2.5-Eunomia (neutrals)

- *Similar* plasma profiles are achieved with quite different neutral distributions:

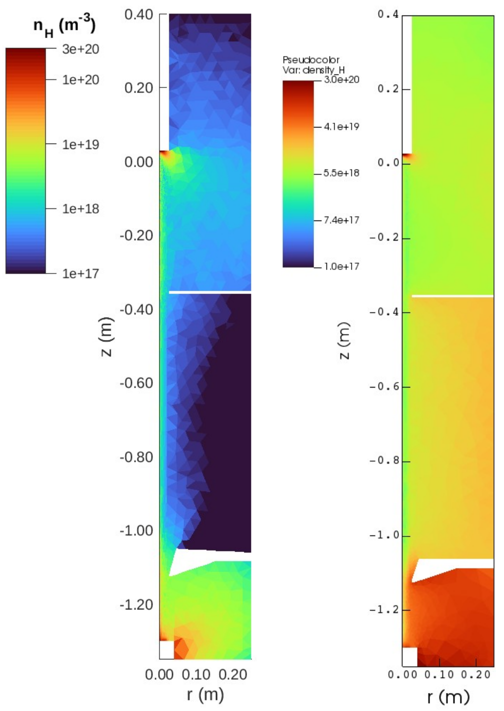

Fig. 9: H density for Eirene (left) and Eunomia (right).

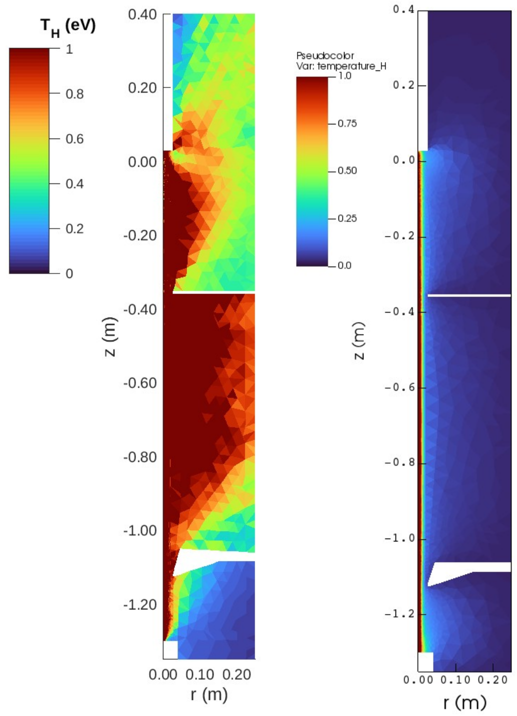

Fig. 10: H temperature for Eirene (left) and Eunomia (right).

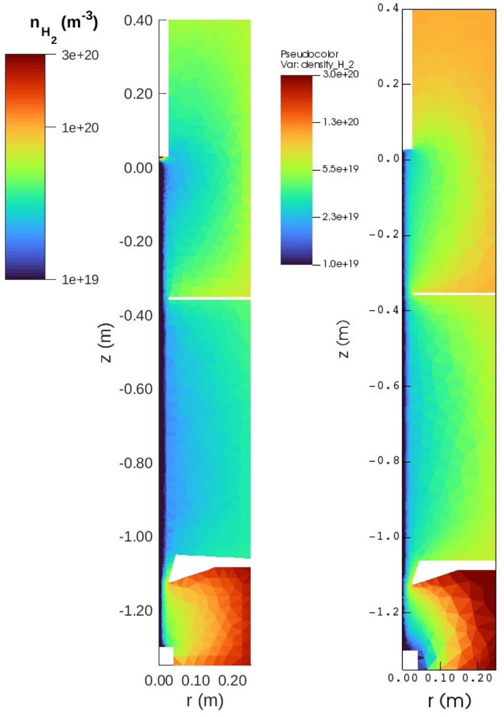

Fig. 11: H_2 density for Eirene (left) and Eunomia (right).

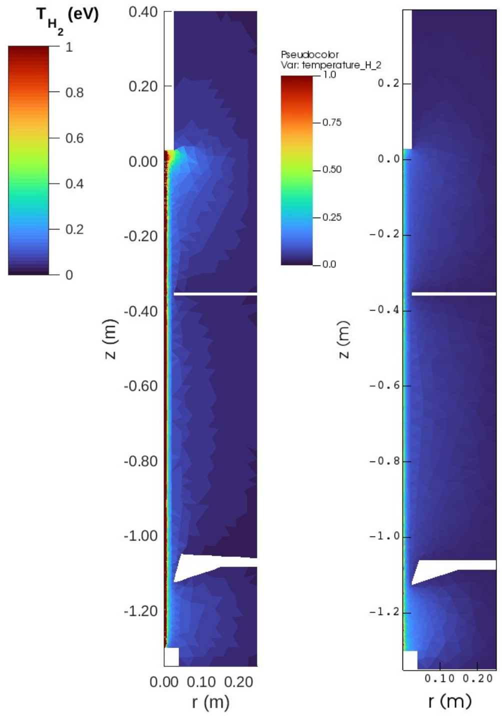

Fig. 12: H_2 density for Eirene (left) and Eunomia (right).

Low density case at low pressure

- Comparing solutions in a regime with low plasma-neutral interaction.
- B2.5-Eunomia results obtained by Ray Chandra [1]
- Both codes agree quite well in radial and axial distributions.
- Differences near the target appear.

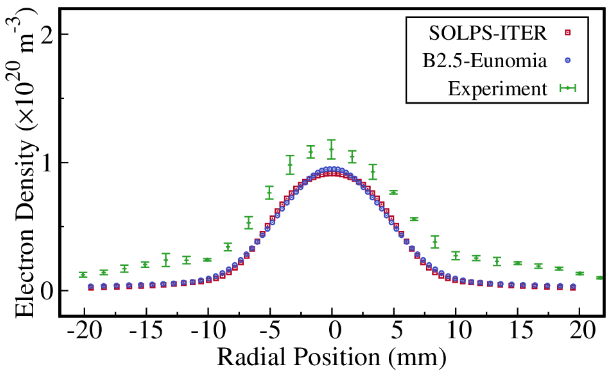

Fig. 13: Electron density for a high density case at a target chamber pressure of 0.27Pa. Radial plot at the target TS position.

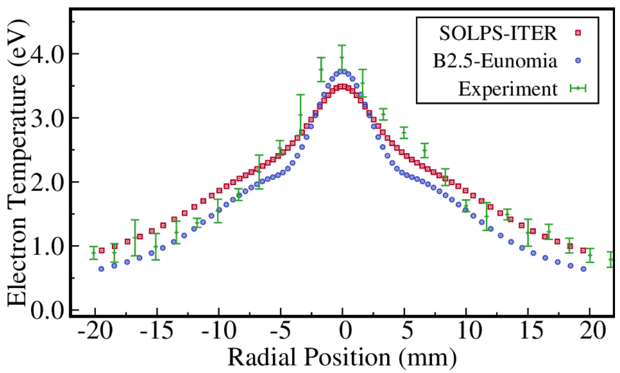

Fig. 14: Electron temperature for a high density case at a target chamber pressure of 0.27Pa. Radial plot at the target TS position.

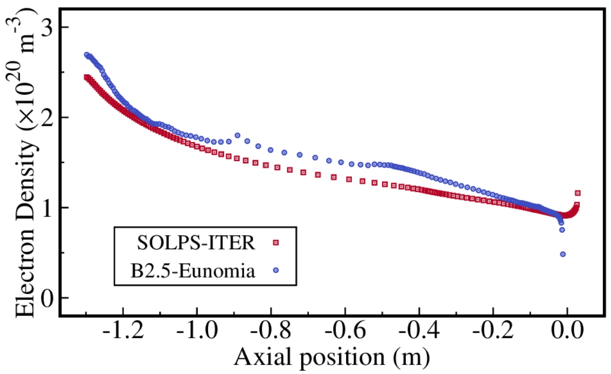

Fig. 15: Electron density for a high density case at a target chamber pressure of 0.27Pa. Axial distribution.

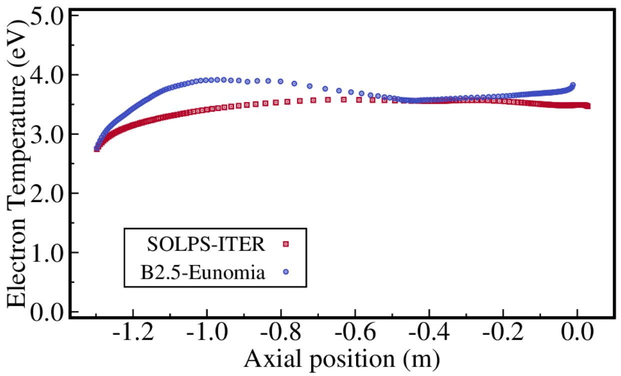

Fig. 16: Electron temperature for a high density case at a target chamber pressure of 0.27Pa. Axial distribution.

[1] Chandra, R., et al. "B2. 5-Eunomia simulations of Magnum-PSI detachment experiments: I. Quantitative comparisons with experimental measurements." *Plasma Physics and Controlled Fusion* 63.9 (2021): 095006.

Conclusions

Conclusions

- Large discrepancies in **neutral modules** (Eirene/Eunomia) regarding collision processes lead to different neutral distributions and sink/sources.
- The **unknown electric potential boundary condition** to obtain similar temperatures at the target TS position is different in SOLPS-ITER than in B2.5-Eunomia.
- Very **distinct plasma/neutral** solutions result in similar profiles at TS target position
- **Additional comparison** with experimental data is required.
- It is unclear the *right* implementation for different processes.
- **Reference cases** of Magnum-PSI in low and high density situations were produced.
  - Higher pressures at the target chamber will be studied to analyse the relevance of collision processes.
- Paper under preparation.

Finite Element Wall model coupled with SOLPS-ITER

Developing of new Finite Element Wall model coupled with SOLPS-ITER

- Currently being developed with the collaboration of Giuseppe Nallo (Politecnico di Torino).
- Only takes into account B2.5 fluxes, but extension to Eirene neutral fluxes is in development.
- This will self-consistently solve the target temperature and overwrite Eirene input parameters for recycling, evaporation, surface temperature…
- Currently the exchange of information is being done in plain text files. Plans to move towards IMAS structure and (possibly) HDF5.
- First steps to make the FEW model to communicate with B2.5 and Eirene.
- Iterative coupling in the next months.

Planning for FEW model

1) Extract relevant neutral fluxes from Eirene and pass them to the wall model.
2) Use a tungsten simplified 2D axial-symmetrical model to check that plasma and neutral fluxes are being correctly read.
3) Check overwriting of Eirene/B.25 parameters.
4) Simple coupled run with Magnum-PSI based on ITER's Monoblock:
    1) Self-consistent temperature and sputtering.
    2) Implement absorption and outgassing.
    3) Involved recycling could be implemented too.

Thank you for your attention

J. Gonzalez | MFEM 2021-11-23

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