Magnum-PSI modelling: CRMs and Finite Element model for Plasma-Surface Interaction

TSVV-5 Code Camp

J. Gonzalez; 23-11-2022

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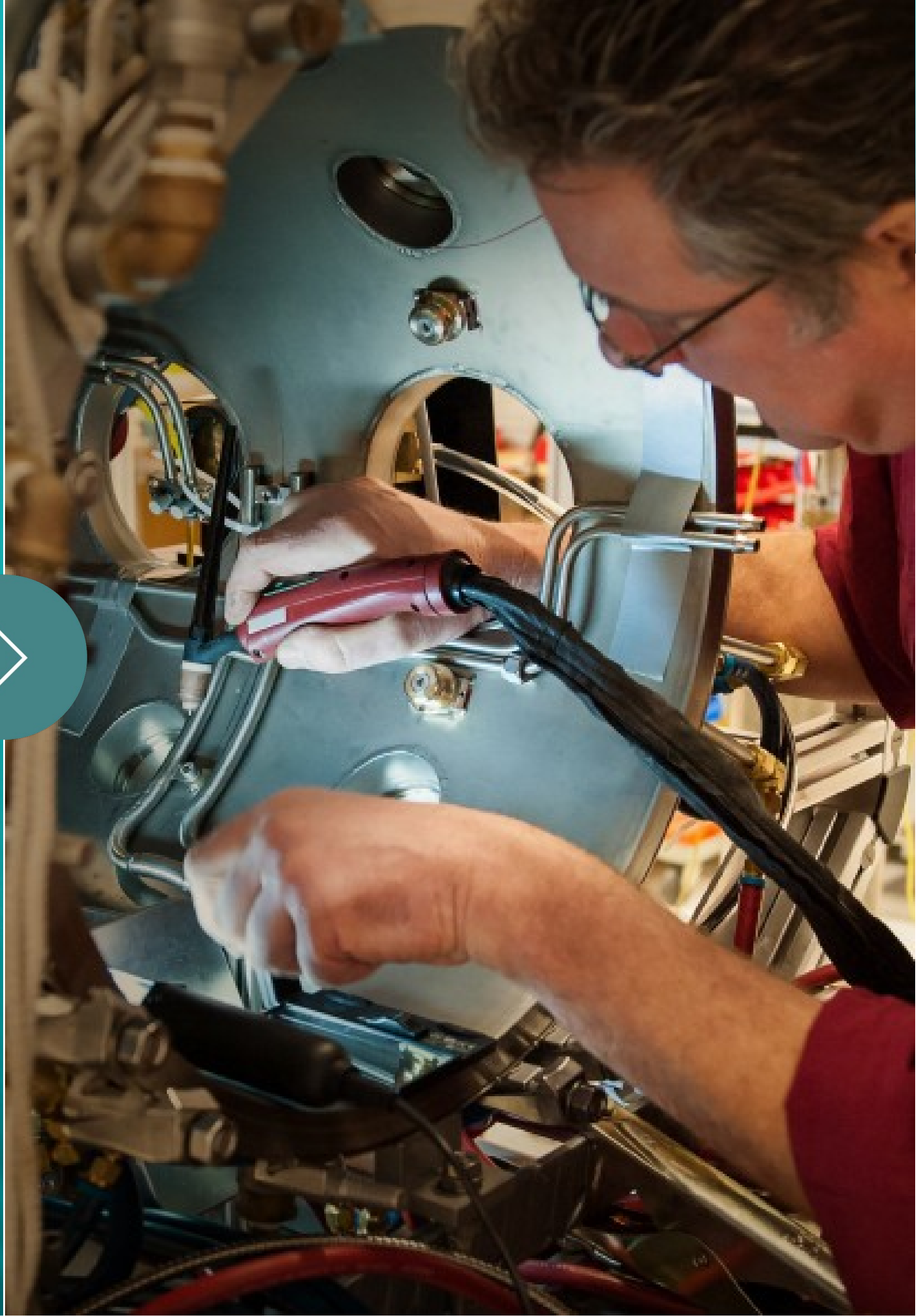

Effect of different CRMs in coupled runs: SOLPS-ITER vs B2.5-Eunomia in detachment experiments

Main differences between Eirene and Eunomia in plasma-neutral collision terms

- Previous work [1] analysing the main differences in **plasma-neutral collision** implementations in Eirene and Eunomia found huge differences in:
  - Electron Impact Ionization.
  - Molecular Assisted Recombination.
  - Plasma-Molecule elastic collisions.
- These lead to significant differences in particle and energy **sources** computed by each code.
- How this translate to coupled cases? (Answer in paper submitted to PPCF)

[1] J Gonzalez et al 2022 Plasma Phys. Control. Fusion 64 105019

Comparison with experimental data (High Density case)

- SOLPS-ITER (solid lines) and B2.5-Eunomia (dashed lines) seems to agree with experimental data.
- **Discrepancies** in density for high neutral pressures.
- SOLPS-ITER seems to show a better trend in the pressure scan.
- Disparate plasma axial distributions.

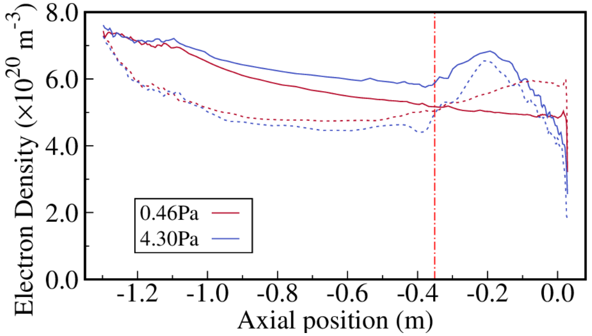

Fig. 1. Axial electron density.

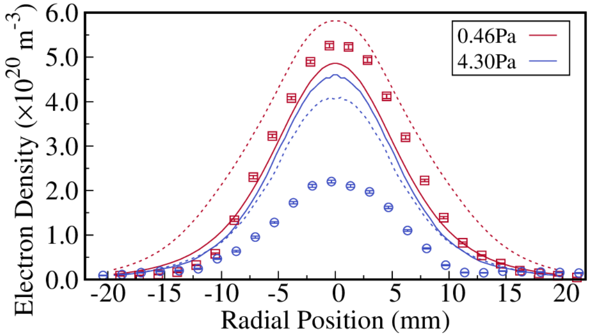

Fig. 2. Radial electron density at TS target position

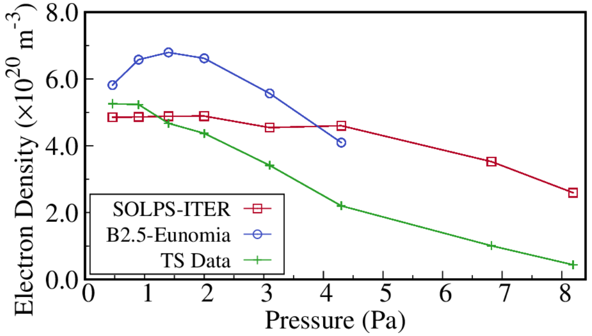

Fig. 3. Peak electron density for a range of pressures

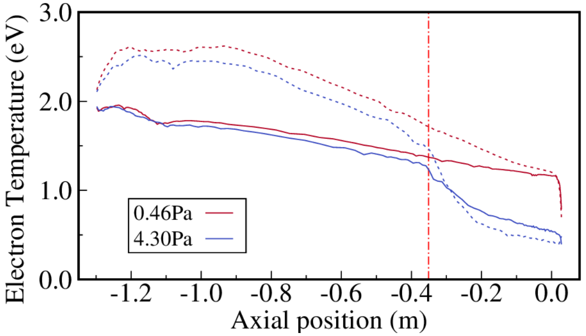

Fig. 4. Axial electron temperature.

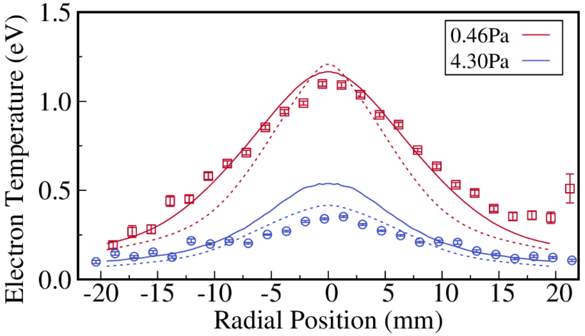

Fig. 5. Radial electron temperature at TS target position

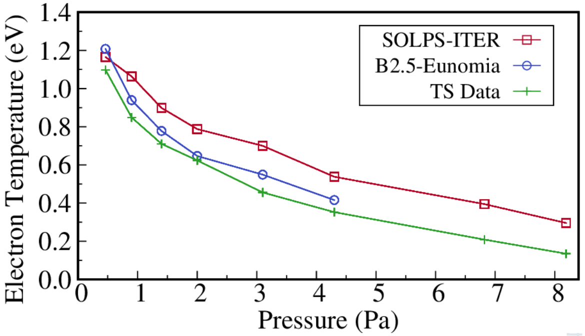

Fig. 6. Peak electron temperature for a range of pressures

Comparison with experimental data (Low Density case)

- SOLPS-ITER (solid lines) and B2.5-Eunomia (dashed lines) seems to agree with experimental data.
- **Discrepancies** in density for high neutral pressures.
- SOLPS-ITER seems to show a better trend in the pressure scan.
- Disparate plasma axial distributions.

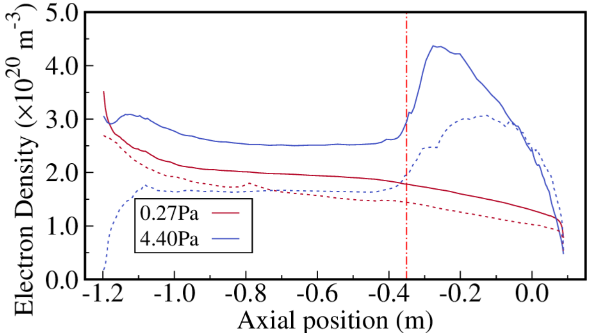

Fig. 7. Axial electron density.

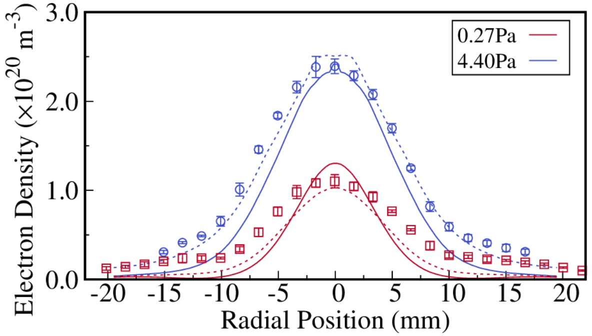

Fig. 8. Radial electron density at TS target position

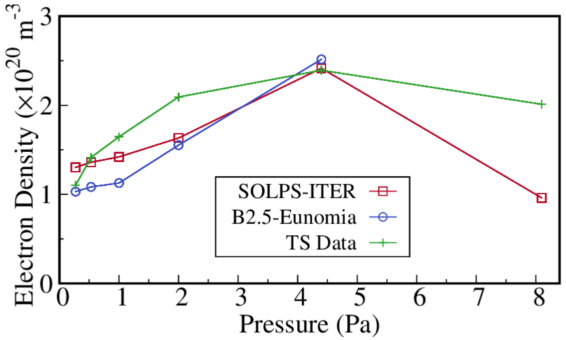

Fig. 9. Peak electron density for a range of pressures

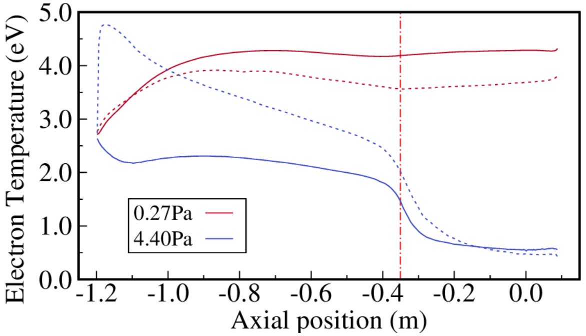

Fig. 10. Axial electron temperature.

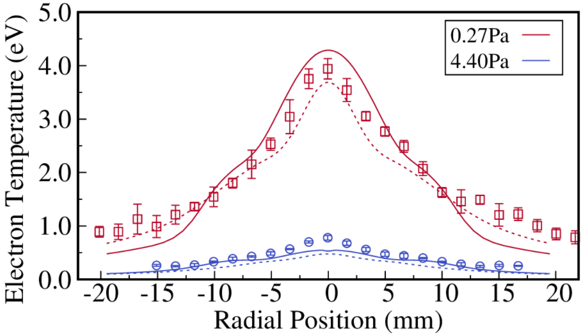

Fig. 11. Radial electron temperature at TS target position

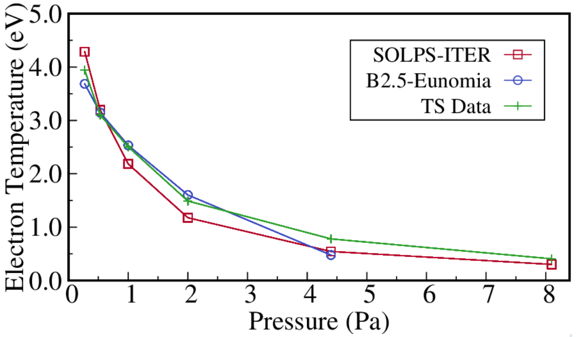

Fig. 12. Peak electron temperature for a range of pressures

Differences in neutral distributions and electric potential

- Significant differences in the neutral distributions obtained by the two modules.
  - Particularly different in the **plasma beam** (r < 20mm).
- Future measurements in Magnum-PSI of atomic density and temperature will allow to determine which distribution is closer.

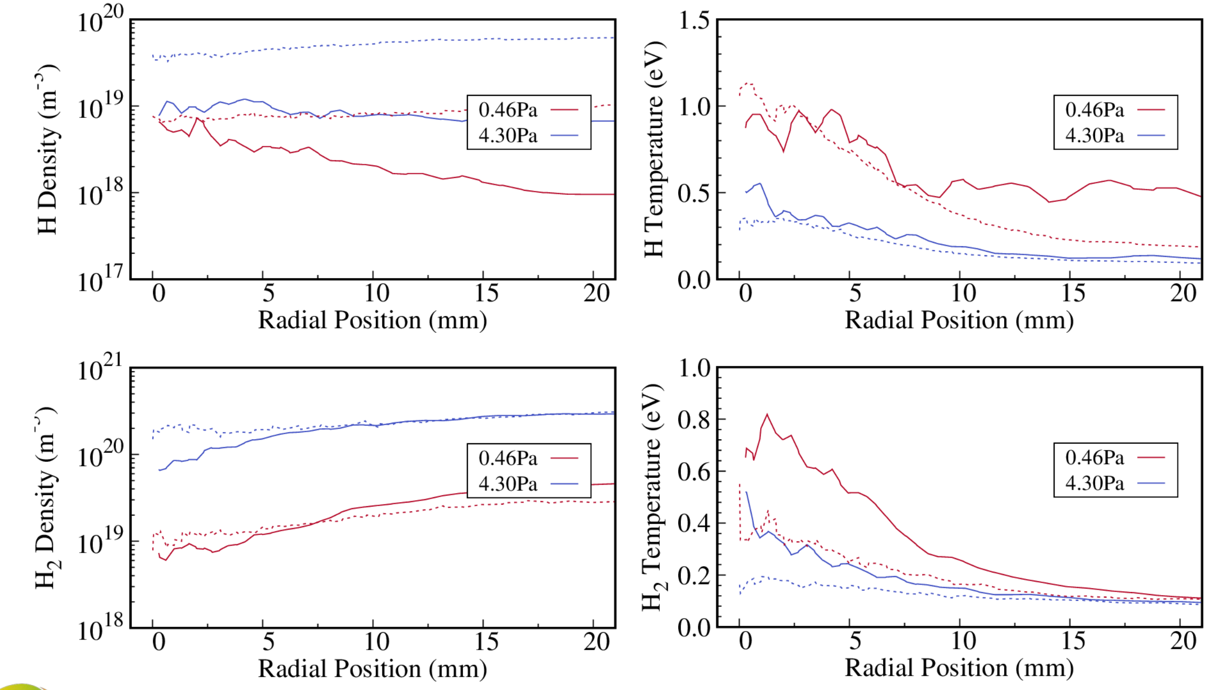

Fig. 13. Neutral distribution of density (left) and temperature (right) for the atomic (top) and molecular (bottom) H species on the low density plasma scenario.

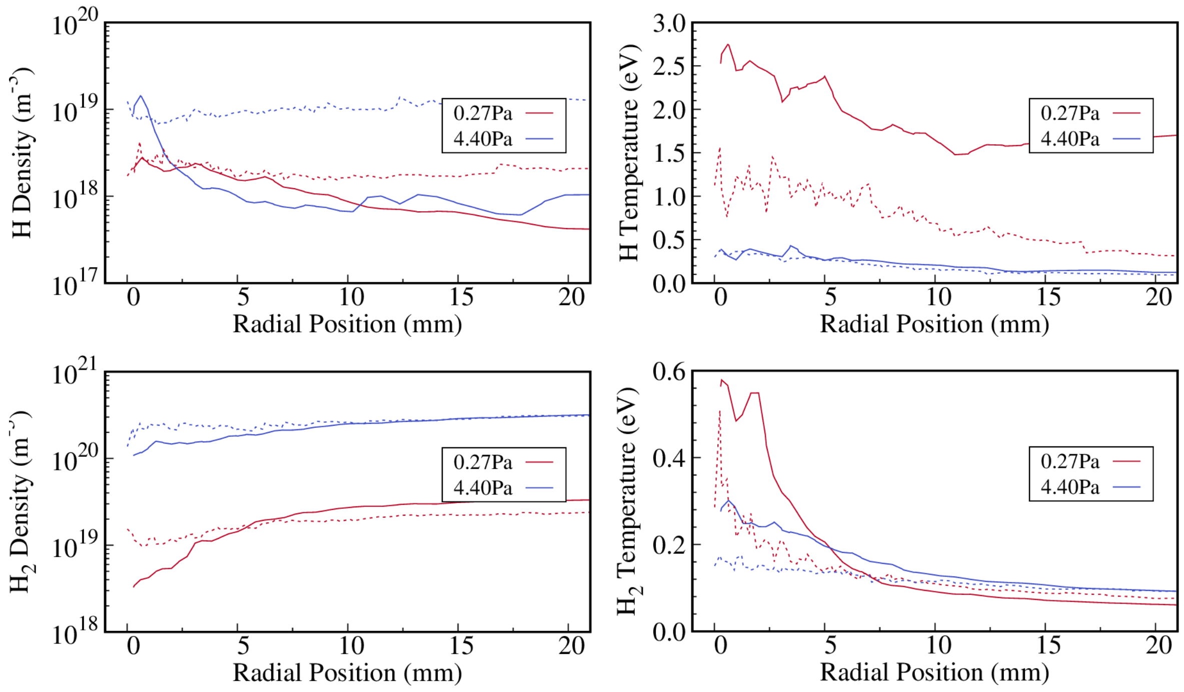

Fig. 14. Neutral distribution of density (left) and temperature (right) for the atomic (top) and molecular (bottom) H species on the low density plasma scenario.

Differences in plasma sources

- The different implementation of plasma-neutral collisions and the differences in electric potential at the source leads to extremely disparate plasma sources.
- These differences change from High to the Low density case, as the relevant collision process in each case are different (different plasma temperature)
- Moreover, the neutral pressure in the target chamber also determines the relevance of some process.

	0.46Pa		4.30Pa		$\Delta(0.46-4.30)$Pa	
	SOLPS-ITER	B2.5-Eunomia	SOLPS-ITER	B2.5-Eunomia	SOLPS-ITER	B2.5-Eunomia
Electron Energy (W)	-543.92	-282.83	-471.33	-186.35	-72.59	-96.48
Ion Energy (W)	-30.97	-1259.50	-271.40	-1470.02	240.43	210.52
Ion particle (part/s)	-1.94e20	-2.22e20	-5.24e20	-5.68e20	3.30e20	3.46e20

Table 3: Integrated sources for electron energy, ion energy and ion particles for the high density case. Last two columns represent the change from the low pressure to the high pressure case. Although the sources calculated by the two neutral modules are quite different, the change between the low and the high pressure case are quite close.

	0.27Pa		4.40Pa		$\Delta(0.27-4.40)$Pa	
	SOLPS-ITER	B2.5-Eunomia	SOLPS-ITER	B2.5-Eunomia	SOLPS-ITER	B2.5-Eunomia
Electron Energy (W)	558.42	-301.13	288.07	-292.09	270.35	-9.04
Ion Energy (W)	-414.84	-901.34	-536.52	-1115.70	121.68	214.39
Ion particle (part/s)	1.59e19	-4.64e19	-1.20e20	-1.56e20	1.36e20	1.10e20

Table 4: Integrated sources for electron energy, ion energy and ion particles for the low density case. B2.5-Eunomia produces larger sinks of ion and electron energy, which means that a higher Ohmic heating is needed to reach the same temperature at the TS target position. Last two columns represent the change from the low pressure to the high pressure case.

Missing processes in Eirene *standard* collision set

- Eunomia implements a collision process that is missing from the *standard* set of reactions in Eirene:

$$e + H_2(v = 0\text{-}14) \longrightarrow H + H^-$$
$$H^- + H^+ \longrightarrow H + H^*$$

- Although the cross section is small, it might become relevant for high pressure-low temperature scenarios.
- Data available in AMJUEL to incorporate this reaction.
- Exact implementation in Eirene input still required.

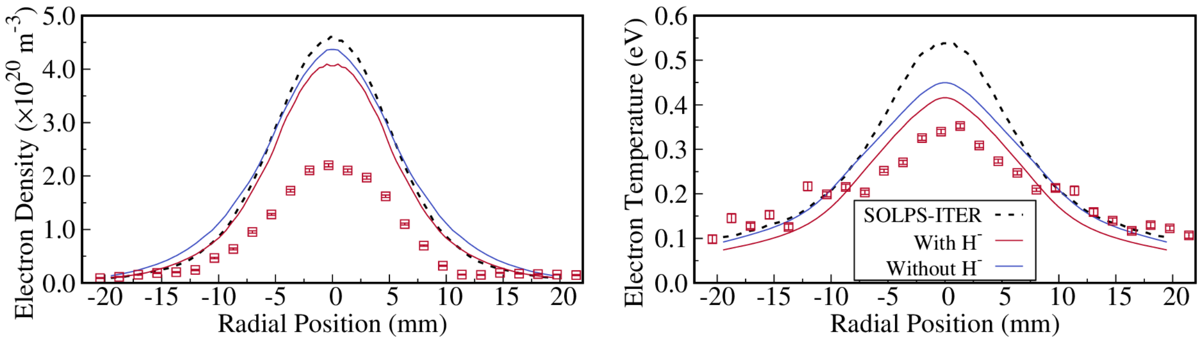

Fig. 15. B2.5-Eunomia simulations with MAR via H^- and without it for the High Density case at 4.40Pa. SOLPS-ITER solution shown in dashed black line as reference.

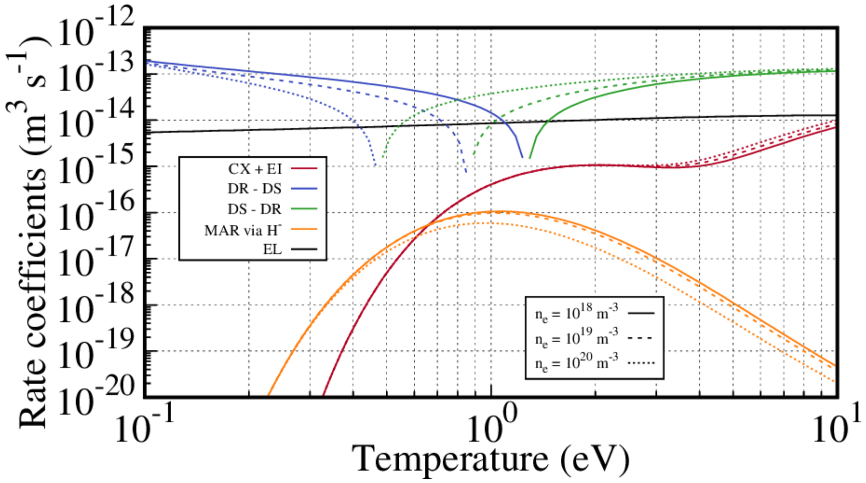

Fig. 16. Rate coefficients of the main molecule collision processes.

Conclusions

- The disparate implementation on plasma-neutral collisions between Eirene and Eunomia directly affects the plasma and neutral distribution and the sources passed to B2.5.
- Similar profiles at TS target position due to *free-parameters*.
- Missing collision term in *standard* Eirene implementation could lead to improvements in low temperature high molecular density situations. (To be implemented)

Coupling of SOLPS-ITER to Finite Element Target Model

Progress in coupling SOLPS-ITER to a Target Model

- Issue: obtaining relevant target properties for the simulation of Magnum-PSI (surface temperature, evaporation flux of LM…) in a **self-consistent** way.
- Solution: Coupling SOLPS-ITER with a Finite Element model (based on FreeFem++).
- First version of interface between the two codes is complete.
  - SOLPS-ITER sends plasma heat flux to target model.
  - Target model returns surface temperature and particle sources fluxes to (possible) overwrite strata in Block 7 via *userfluxparam*.
  - All configured in B2.5 input.
  - Multiple target models possible (currently testing).
- Communication is done via text files.
- New **fort.32** file in Eirene: Contains information about surface temperature and which surface to overwrite the temperature.
- The interface created is quite general and easy to extend for future cases.

Tungsten target in detachment scenarios

- Increasing gas pressure in target chamber => reduces heat flux towards the target.
- Calculation of temperature on the surface self-consistently.
- Bottom surface has a BC that represents Magnum-PSI cooling system.
- Comparison with **pyrometer measurements**.

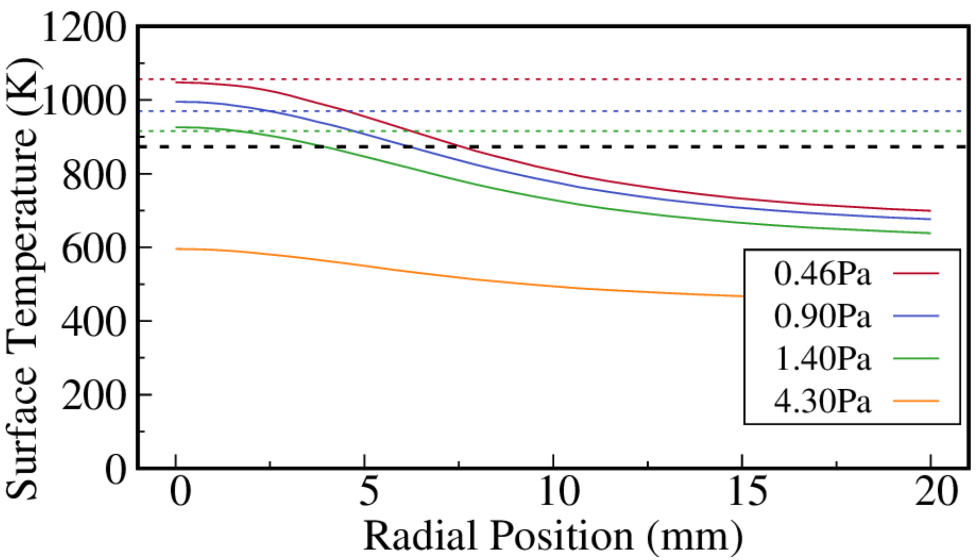

Fig. 17. Surface temperature from SOLPS-FEM (solid line) and pyrometer measurements at the target centre (dashed line) for different neutral pressures in the target chamber.

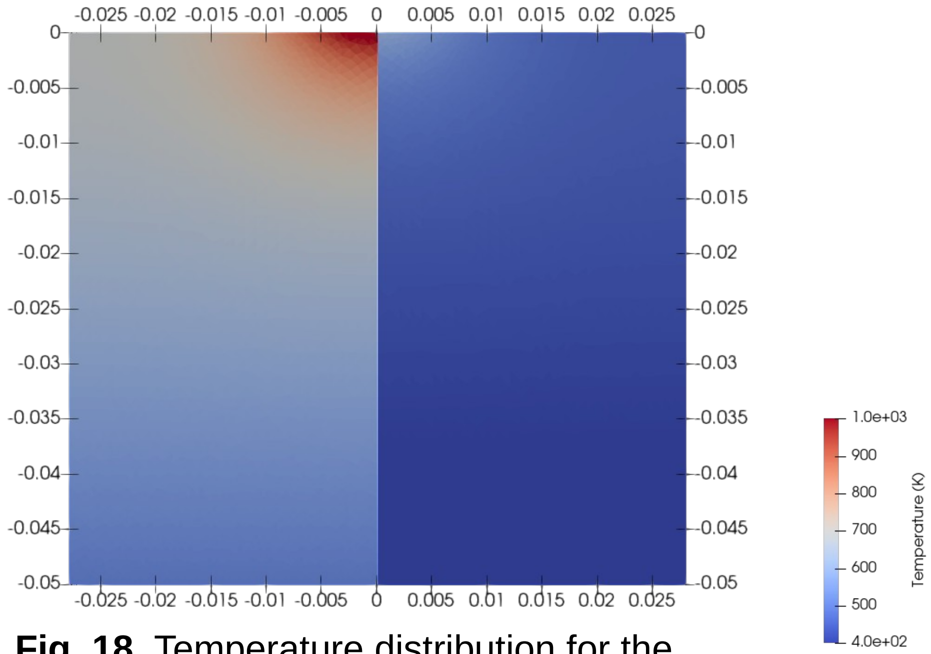

Fig. 18. Temperature distribution for the 0.46Pa (left) and the 4.30Pa (right).

Application to liquid targets

- At DIFFER we are interested in liquid targets.
- This model allows to calculate self-consistently the surface evaporation based on the surface temperature, as well as to account for the thermal properties of the porous structure.
- Still work to do, but first comparison with experimental data seems successful
- However, difficulty in having thermal data for these CPS, which highly affects the surface temperature.
- Accounting for vapour cloud-plasma interaction (SOLPS-ITER) and evaporation heat (Finite Element).

Conclusions

- SOLPS-ITER can be now easily coupled with a finite element target model based on FreeFem.
- Parameters like surface temperature or strata fluxes can be calculated in the FE model and passed back to SOLPS-ITER.
- Current limitation is to E, W surfaces in B2.5. Possible easy extension when wide grids become the standard procedure.
- Allows to validate plasma solutions if target temperatures are measured and thermal properties are know.
  - New experiments in Magnum-PSI to obtain target temperature distribution during wide range of plasma parameters.
- Can be used to test multiple target cooling solutions.
- Extension to liquid targets for self-consistent evaporation flux.

Future works

- Improve the interface to account for possible neutral fluxes.
- Increase the amount of information exchanged.
- Allow to couple with Eirene in standalone mode.
- Extend the coupling options so other target models can be applied.

Thank you for your attention

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Temperature distribution in different CPSs