INSTITUTE OF PLASMA PHYSICS
OF THE CZECH ACADEMY OF SCIENCES

Modelling of high density collisional sheath

D. Tskhakaya

Institute of Plasma Physics of the CAS, Prague, Czech Republic

Report for TSVV - 7

MINISTRY OF EDUCATION,
YOUTH AND SPORTS

Resume

Proposed tasks (for 2022)

- The study of extremely high density DEMO (and ITER) relevant sheath, ~ $n_e > 5x10^{21}$ m^{-3}
- Two sets of modelling: one with only D^+, another with molecules included (D_2^{+i})

Completed tasks

- BIT1 updated; relevant for TSVV3, 4, 7 and WP-PWIE
- DEMO-relevant plasma sheath with only D^+

Ongoing tasks

- DEMO-relevant plasma sheath including molecules

Publications / Presentations

D. Tskhakaya, 12th International Conference on Atomic and Molecular Data and Their Applications (ICAMDATA), 25-29.09.2022, Mola di Bari, Italy.

2 publications under preparation.

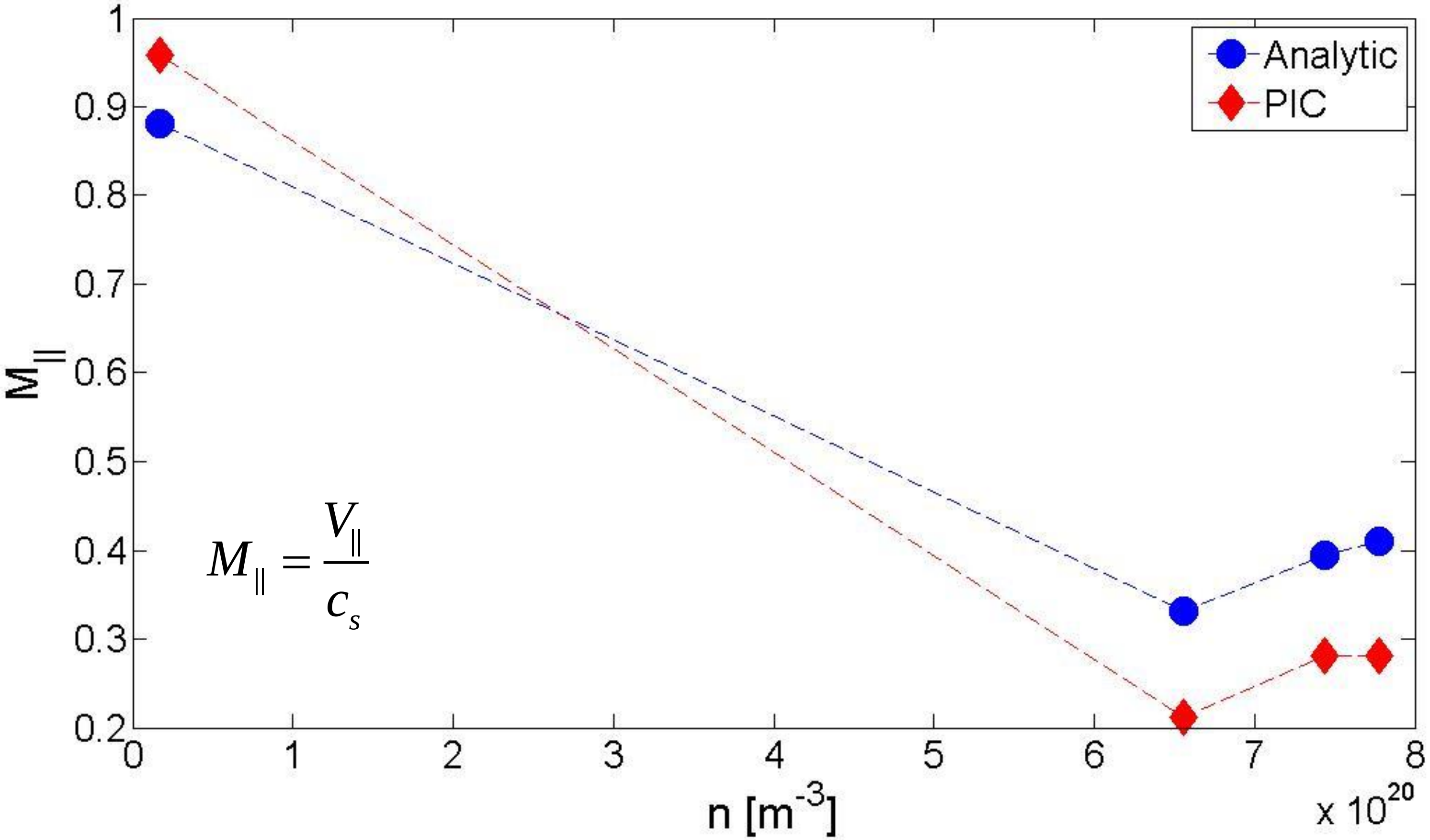
Motivation for HD sheath modelling

	Divertor sheath	
	n_{max} [10^{20} m^{-3}]	T_{min} [eV]
COMPASS	0.3	10
ASDEX-U	2	1
JET	5	1
ITER	50	0.3
EU DEMO	~100	0.2 (?)

Sheath edge:

$$M_{\|} = 1 + \chi - \sqrt{\chi^2 + 2\chi} < 1$$

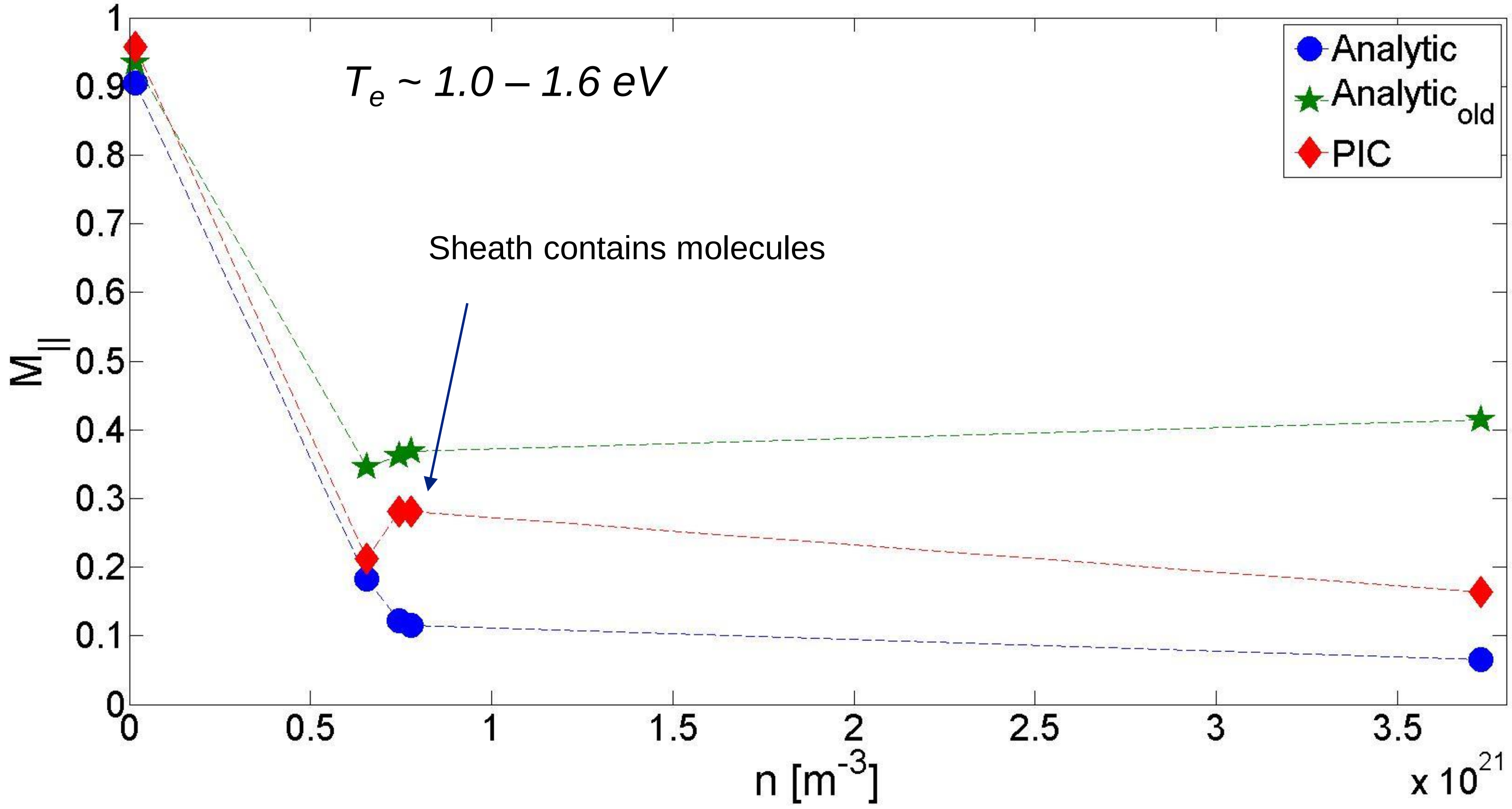
$$\chi = \frac{\upsilon_{mt}\left(1 - V_{\|}^{n} / V_{\|}\right)}{2c_s \sin(\theta)} \; x_{wall}$$



From PIC modelling[1] of the sheath

[1] Tskhakaya, 47th EPS 2021

New results for DEMO relevant sheath



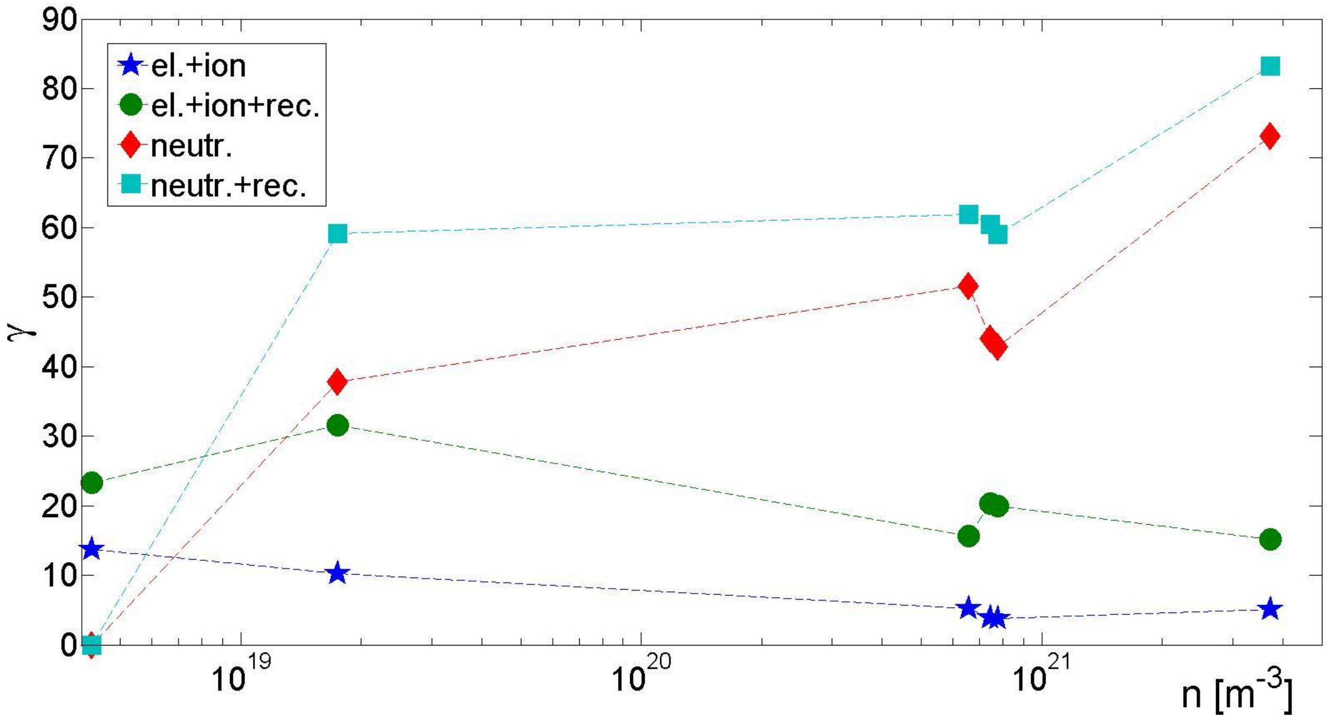
Sheath edge:

$$M_{\parallel} = 1 + \chi' - \sqrt{\chi'^2 + 2\chi'} < 1$$

$$\chi' = \frac{\upsilon_{mt}\left(1 - V_{\parallel}^{n} / V_{\parallel}\right) + \upsilon_{ei}}{2c_s \sin(\theta)} \, x_{wall}$$

What about divertor heat loads?

Power loads to the divertor



$$q_{wall} = \gamma M_{\|} n c_s T_e \sin(\theta)^{[2]}, \quad \gamma = \gamma_e + \gamma_i + \phi + \frac{\chi_i + \chi_m}{T_e}, \quad R_E = 0$$

$$\gamma_e = 2, \quad \gamma_i = 3(1 + 0.5 T_i / T_e) \approx 3.5, \quad \phi \approx 2.9, \quad \chi_i = 13.6, \quad \chi_m \approx 2.2$$

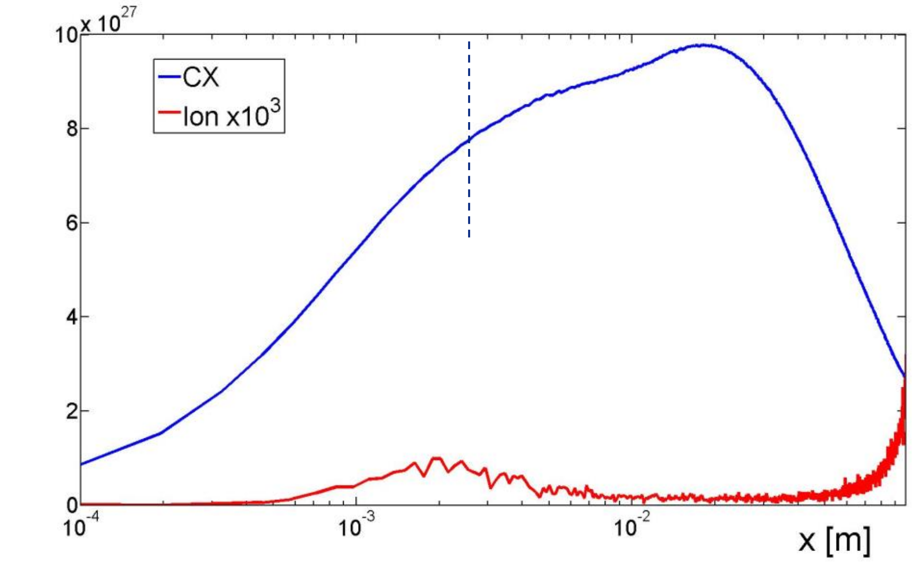
$$q_{wall} = \left(8.4 + \frac{15.8}{T_e}\right) J T_e, \quad \gamma_0 = 8.4, \; J = M_{\|} n c_s \sin(\theta)$$

Contribution of neutrals

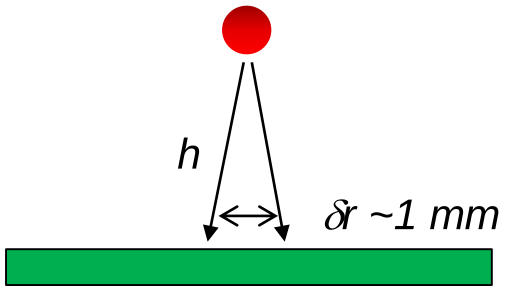
$$q_{wall} = \left(8.4 + \frac{15.8}{T_e} + \gamma_n\right) J T_e, \quad \gamma_n = \frac{q^n}{J T_e} + 2.2 \frac{F^n}{J T_e}$$

[2] P. Stangeby, book, sec. 5 (2000)

Neutral particle loads

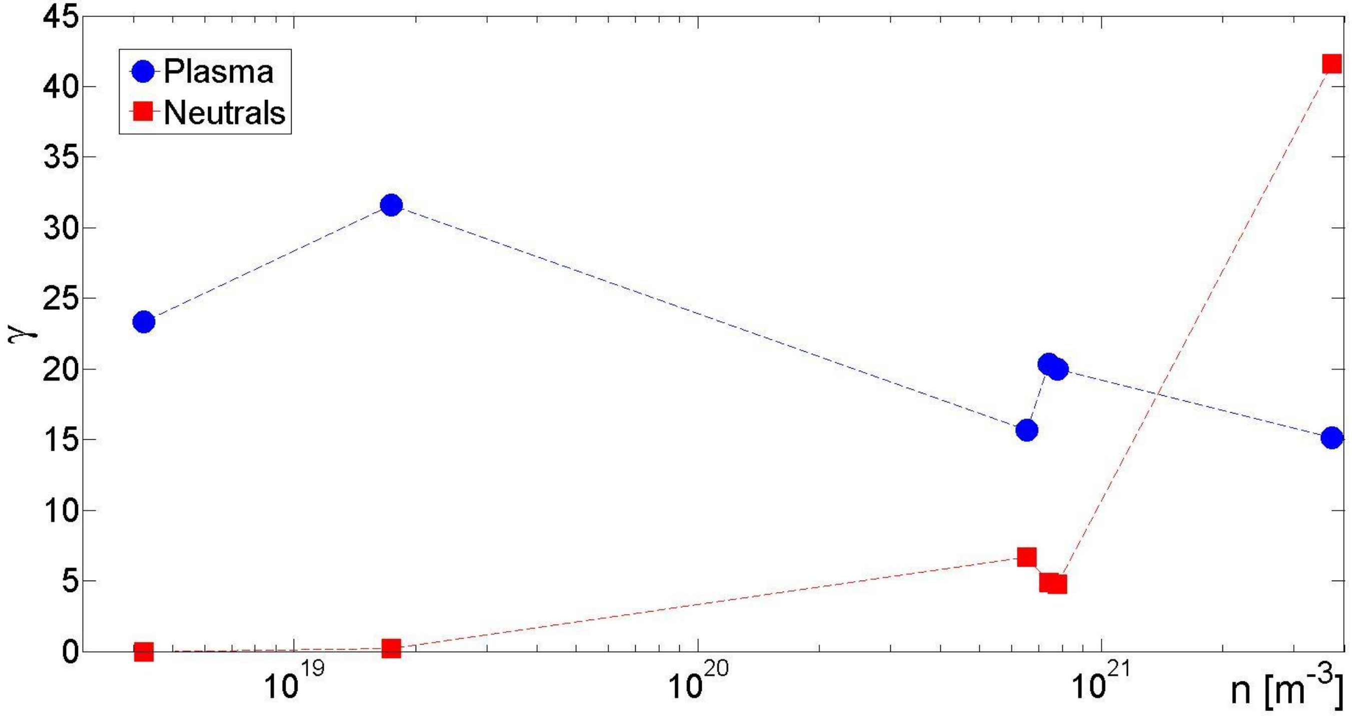


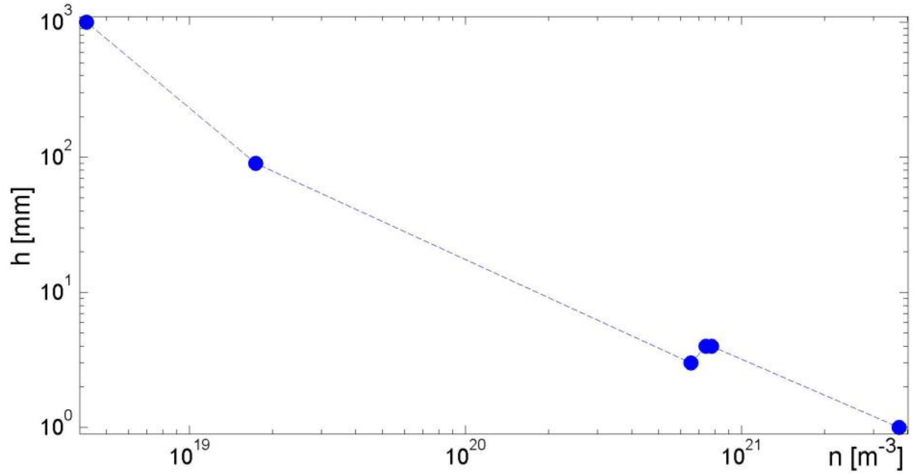
Profiles of CX and ionization collision events across the collisional sheath



$$\delta F = \frac{\arcsin(\delta r / h)}{\pi} F_0$$

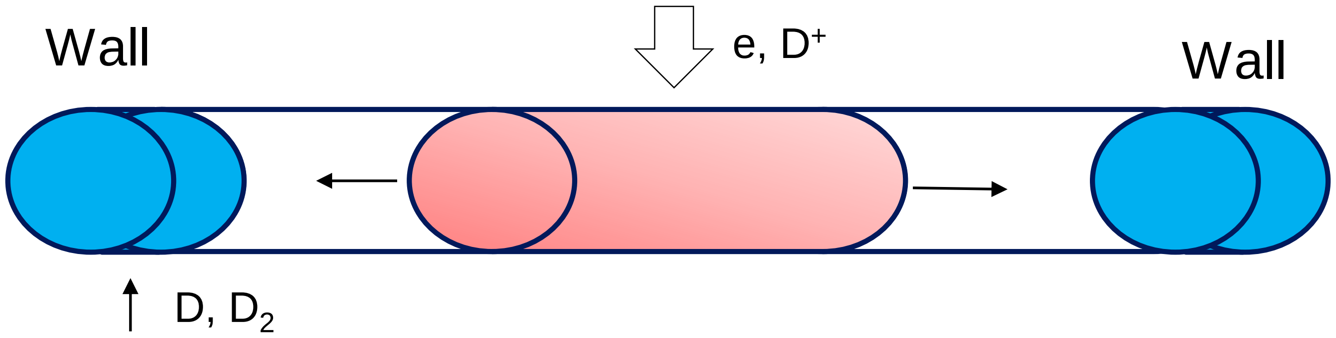
In the DEMO divertor sheath the neutrals can be the main heat curriers





BIT1 modelling of the sheath

Particle and heat source



Plasma recycling, floating conditions

Each simulation takes up to 5 M core hours, 10^{10} particles, 10^{6} (1D) spatial cells

Needs:

- to speed up the simulation (reduce memory usage)
- Incorporate multy-step atomic processes

BIT1 update: memory allocation

Particle memory allocation in the original PIC code

Species 1

Species 2

⋮

Species N_{sp}

Memory is uniformly allocated for different particle species.
Simple implementation, but can lead to significant fraction of **unused memory**.

Particle memory allocation in the updated PIC

Sp. 1

Species 2

⋮

Sp. N_{sp}

Allocated memory is **proportional** to the concentration of given particle species.
More optimized memory usage, but requires **significant update** of the original code. 10% - 30% **faster** than the original code.

Dynamic memory allocation in **the future** code

Sp. 1

Species 2

⋮

Sp. N_{sp}

Time →

Species. 1

Sp. 2

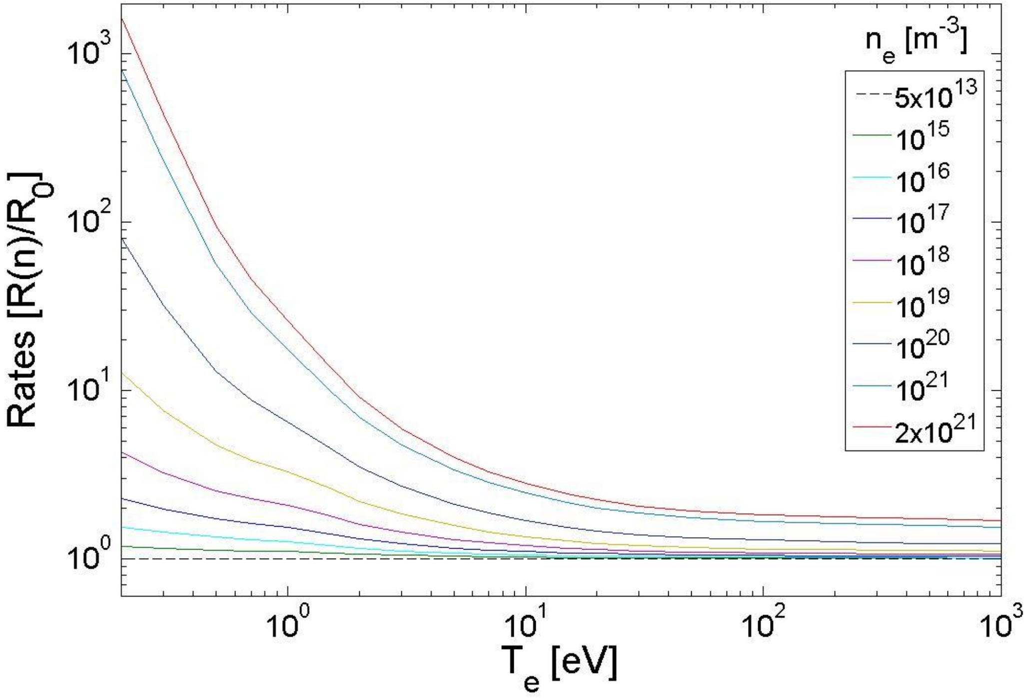
⋮

Sp. N_{sp}

Species memory is allocated dynamically.
Fully optimized memory usage. Requires **major update** of the code.

Update for exascale modelling

BIT1 update: dressed cross-section method



Normalized effective D ionization rate coefficients[2].

Example from ADAS: e + Ne^{+i} → e + $Ne^{+i, (v)}$

Target	states	Number of CS
Ne	89	(N+3)N/2 = 4 096
Ne^+	279	39 339
Ne^{+2}	554	154 289
Ne^{+3}	668	224 114
Ne^{+4}	564	159 894
Total	2 154	**~ 5.8x10^5**

„Dressed“ cross-section method

Kinetic collisional-radiative model?

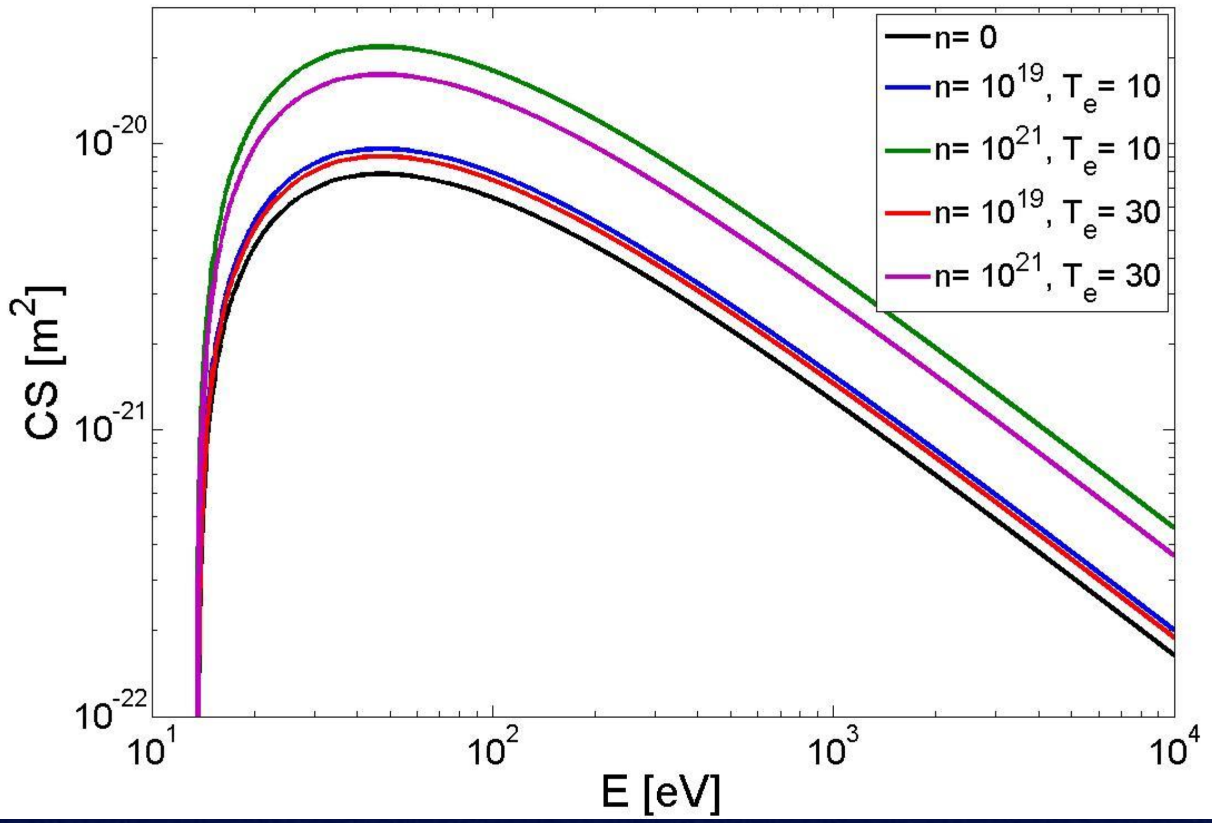
[2] https://open.adas.ac.uk/

Dressed cross-section method (ii)

$$\sigma(E,T,n)=\sigma(E)\frac{R(T,n)}{R_{n=0}(T)}$$

$$\int f_m V\sigma(E,T,n)\,d\vec{V}=R(T,n)$$

$$\sigma(E,T,n\to 0)=\sigma_{n=0}(E)$$



Advantage

i. large number of interaction channels are effectively incorporated

ii. cross-sections and rate coefficients are available

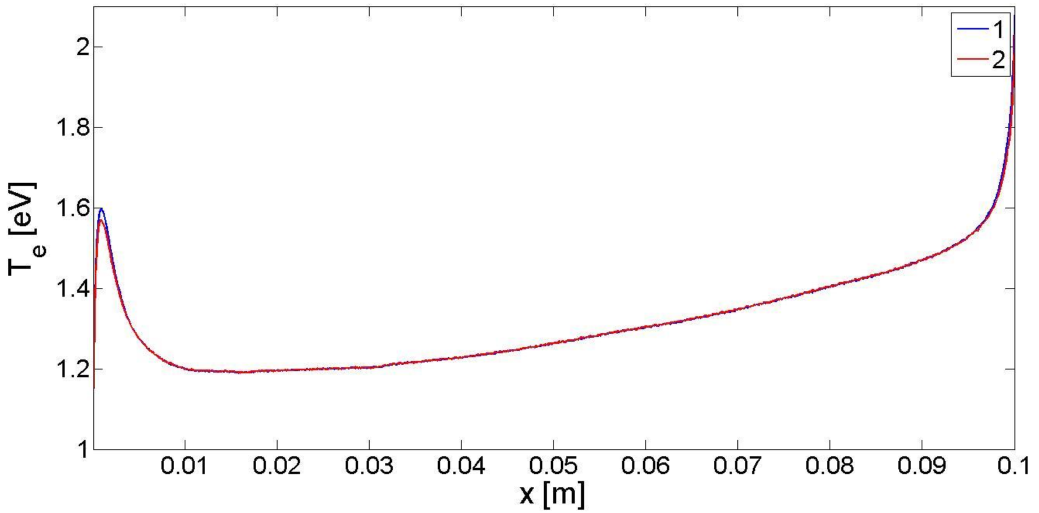
Disadvantage

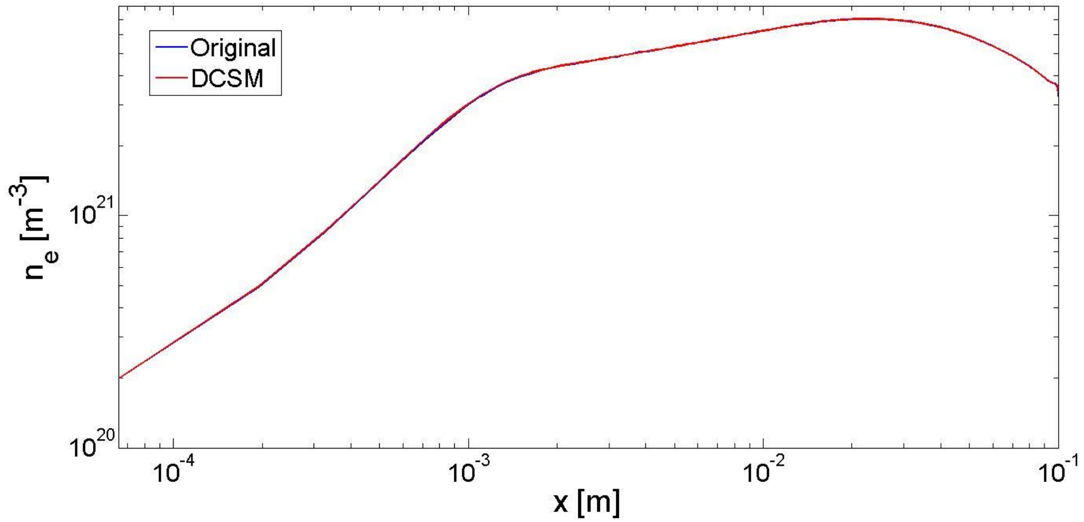
i. needs calculation of temperature → reduction of the run speed (<10%)

ii. Threshold energies E_{th} are density and temperature independent

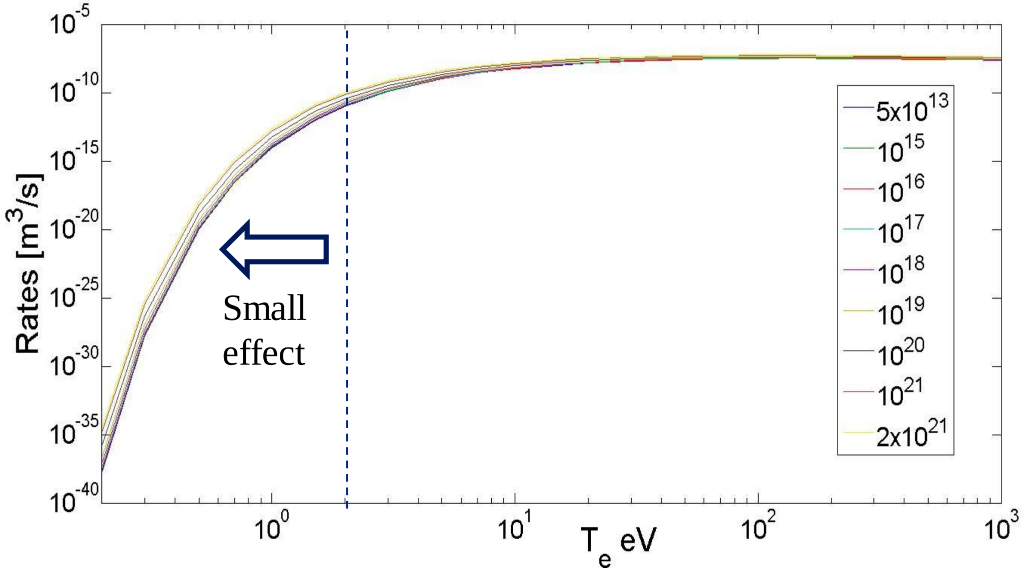
iii. EDFs assumed to be near-Maxwellian

Dressed cross-section method (iii)





Plasma density and temperature in the DEMO-relevant plasma sheath[4]



Low ionization rate for < 2 eV plasma

[4] D. Tskhakaya, ICAMDATA 2022