

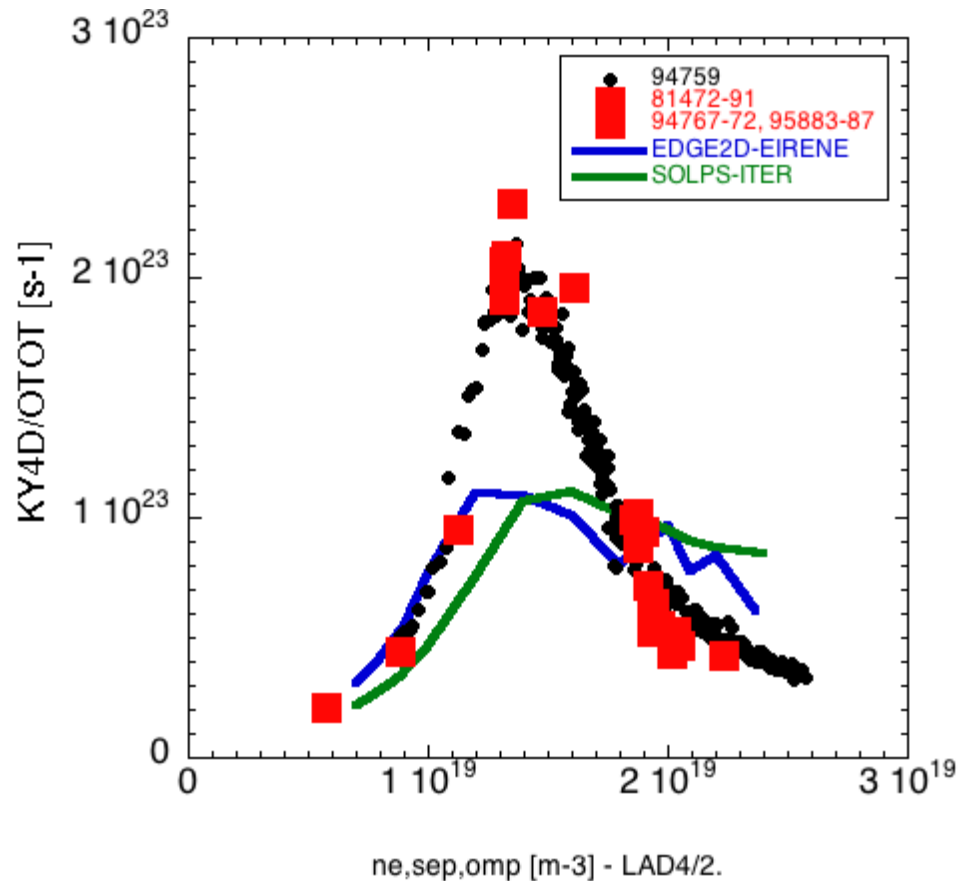
Status of radiation transport in EIRENE

Ray Chandra

24 August 2023

Several outstanding issues with code runs and physics models currently investigated

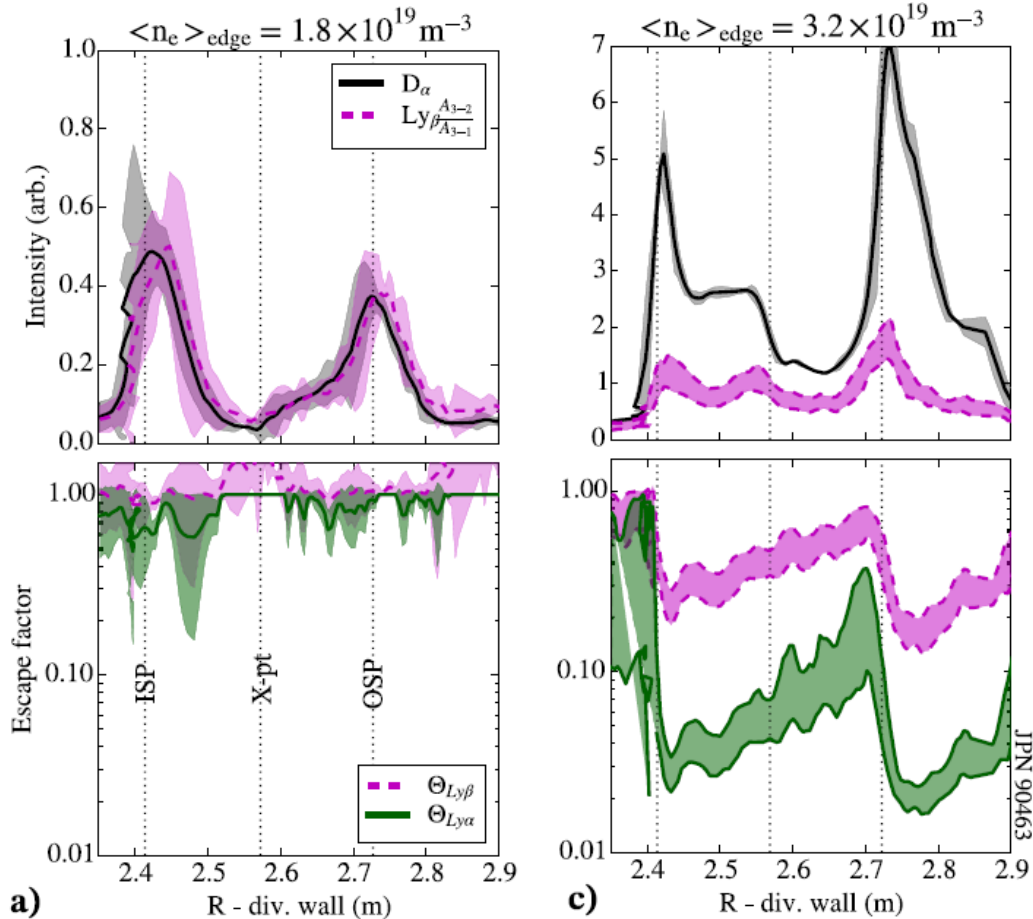
N. Horsten et al.



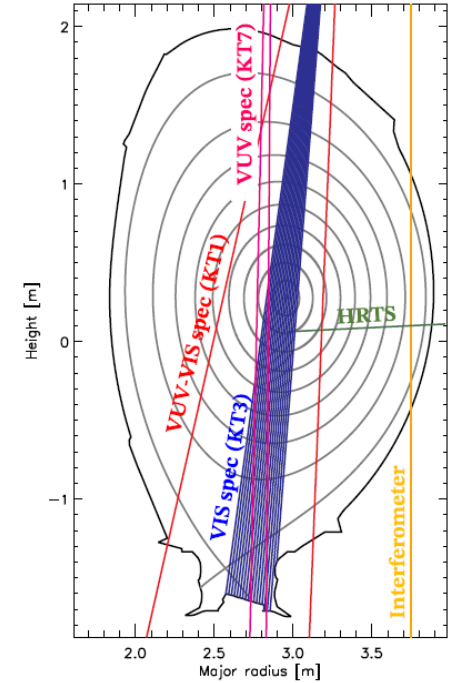
- Separatrix location $\rightarrow n_{e,sep,omp}$
- Fixing $n_{e,sep,omp}$ vs fuelling/pumping
- Impact of vibrationally resolved molecules (c.f., U. Fantz, JNM 2001)
- Increase of I_{div} due to inclusion of Ly- α opacity (c.f., B. Lomanowski, PPCF 2020)
- Transport of molecular ions
- Necessary grid resolution for detached conditions

M. Groth, IAEA-TM CR Properties W & H, Vienna, Austria (2021)

Ly- α opacity experimentally observed with KT1 in JET D L-mode



- Constant $\frac{Ly\beta}{D_\alpha}$ in the optically thin case
- 94-98% $Ly\alpha$ absorption at high densities
- Ad-hoc opacity factors in the model (constant, not self-consistent):



Photon transport using EIRENE!

B Lomanowski et al., Plasma Physics and Controlled Fusion 62, 6:065006 (2020)

Line radiation trapping in EIRENE by including Line photons as test-particles

- Analog description → *D. Reiter et al., Plasma Physics and Controlled Fusion 44, 8:1723–37 (2002)*
- Requirements:
 1. Photon sources – for line radiation, excited species of atoms
 2. Rate coefficients – spont. Emission, absorption: line shape
 3. Reflections – simple specular model
- Result → line absorption tallies Q_{ext}

Solving the population of H excited states with collisional-radiative model within EIRENE – h_colrad.f

- Based on *K. Sawada et al., Journal of Applied Physics 78, 2913 (1995)*

$$\begin{bmatrix} \frac{dn_{D_2}}{dt} \\ \frac{dn_{D_3}}{dt} \\ \vdots \\ \frac{dn_{D_n}}{dt} \end{bmatrix} + \underbrace{\begin{bmatrix} M_{22} & M_{23} & \dots & M_{2n} \\ M_{32} & & \ddots & M_{3n} \\ \vdots & & & \vdots \\ M_{n2} & \dots & & M_{nn} \end{bmatrix}}_{\mathbf{M}} \begin{bmatrix} n_{D_2} \\ n_{D_3} \\ \vdots \\ n_{D_n} \end{bmatrix} = \underbrace{\begin{bmatrix} C_1 \\ C_2 \\ \vdots \\ C_n \end{bmatrix}}_{\mathbf{C}} n_{D_1} + \underbrace{\begin{bmatrix} F_1 \\ F_2 \\ \vdots \\ F_n \end{bmatrix}}_{\mathbf{F}} n_{D^+} + \begin{bmatrix} \Gamma_{D_2} \\ \Gamma_{D_3} \\ \vdots \\ \Gamma_{D_n} \end{bmatrix}$$

- In steady-state:

$$\begin{bmatrix} n_{D_2} \\ n_{D_3} \\ \vdots \\ n_{D_n} \end{bmatrix} = \mathbf{CM}^{-1}n_{D_1} + \mathbf{FM}^{-1}n_{D^+} + \begin{bmatrix} \Gamma_{D_2} \\ \Gamma_{D_3} \\ \vdots \\ \Gamma_{D_n} \end{bmatrix} \mathbf{M}^{-1} = \mathbf{R}_1 n_{D_1} + \mathbf{R}_0 n_{D^+} + \mathbf{R}_{ext}$$

- \mathbf{M} , \mathbf{C} , \mathbf{F} are n_e, t_e dependent rate coefficients, explicitly coded in h_colrad.f up to $n=34$
- Q_{ext} inserted as Γ_{D_n}

New plasma ionization balance and neutral H mfp from modified effective ionization rate coefficient, S_{eff}

$$S_{\text{eff}} = S_1 + \underbrace{\sum_n \left(C_{1,n} - R_{1,n} \left(F_{n,1} + \frac{A_{n,1}}{n_e} \right) \right)}_{S_{\text{eff},cr}} + \underbrace{\sum_n \left(Q_{\text{ext},n} - R_{\text{ext},n} \left(F_{n,1} + \frac{A_{n,1}}{n_e} \right) \right)}_{S_{\text{eff},ph}}$$

- ‘Extra’ ionization contribution from photon re-absorption, $S_{\text{eff},ph}$
- $S_{\text{eff},cr}$ normally read from AMJUEL or ADAS files, in this case S_{eff} calculated internally

Individual test cases for photon tracing and h_colrad

Testing h_colrad:

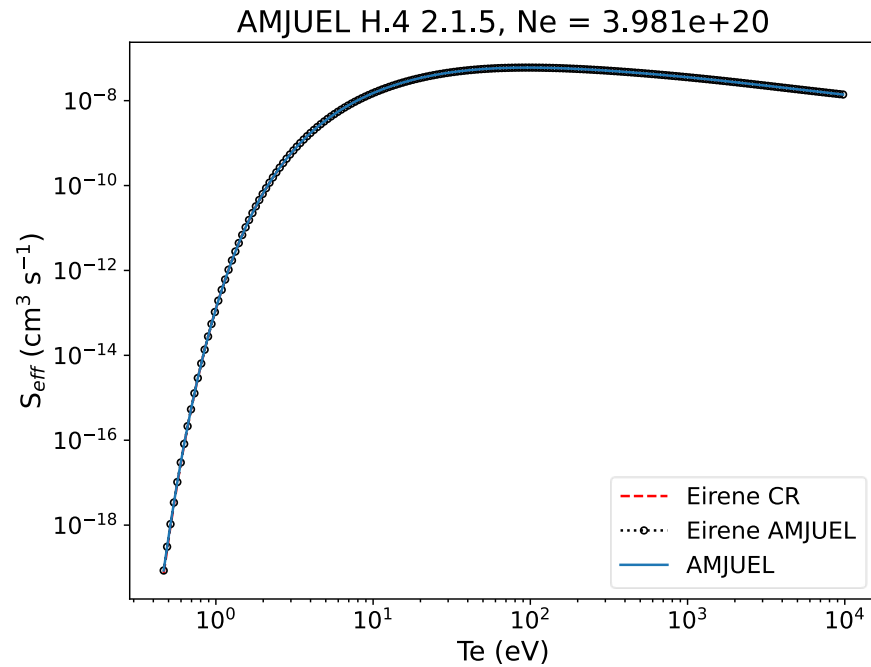
- EIRENE 2D grid with n_e and T_e varied along x and y dimensions
- Ne, 20 points, $\sim 1e8 - 1e16 \text{ cm}^3$
- Te, 200 points, $\sim 0.5 - 1e4 \text{ eV}$

Testing photon tracing:

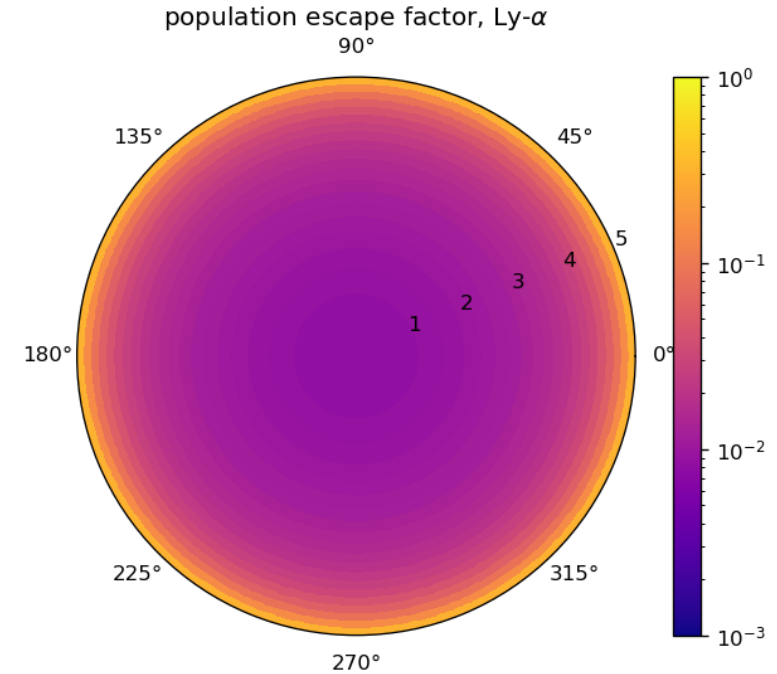
- EIRENE 1D cylindrical grid with 20 radial points
- Homogeneous $T_H = 1 \text{ eV}$, $n_H = 10^{14} \text{ cm}^{-3}$, $R = 5 \text{ cm}$
- Simulated Ly-a and Ly-b photons ($2e6$) with volumetric sources ($H_{(n=2,3)}$ as bulk ions)
- Line shape only doppler broadening

Individual test cases for photon tracing and h_colrad

Testing h_colrad:

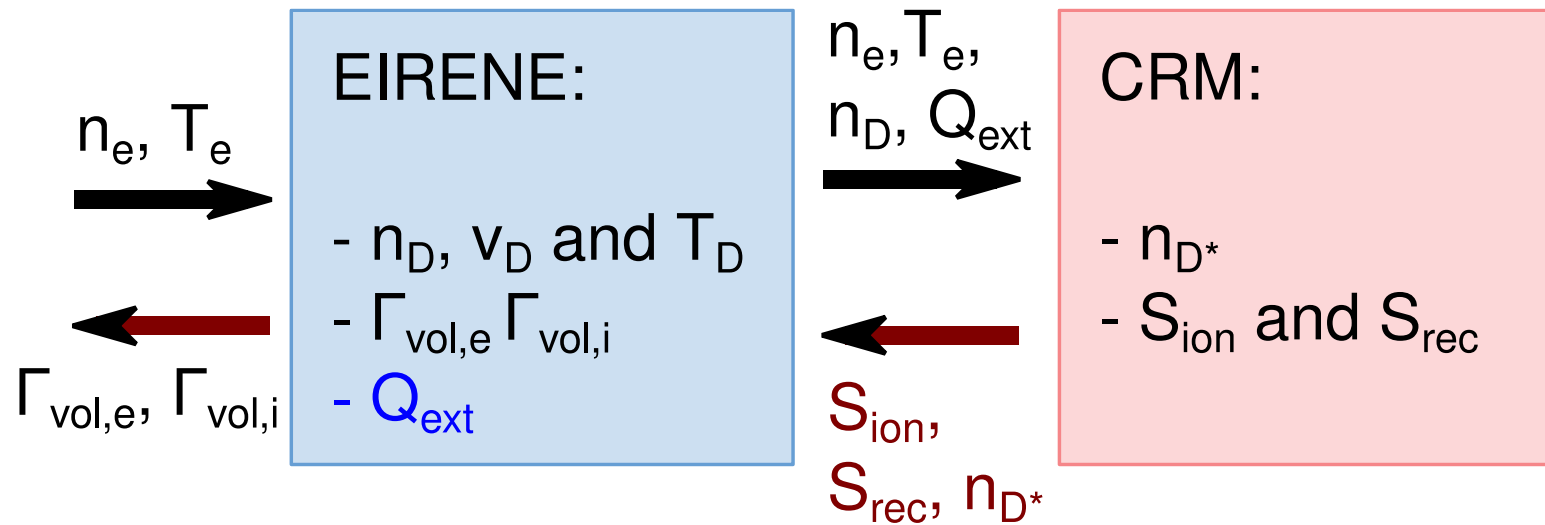


Testing photon tracing:



TSVV-5 Code Camp 21-25 November 2022

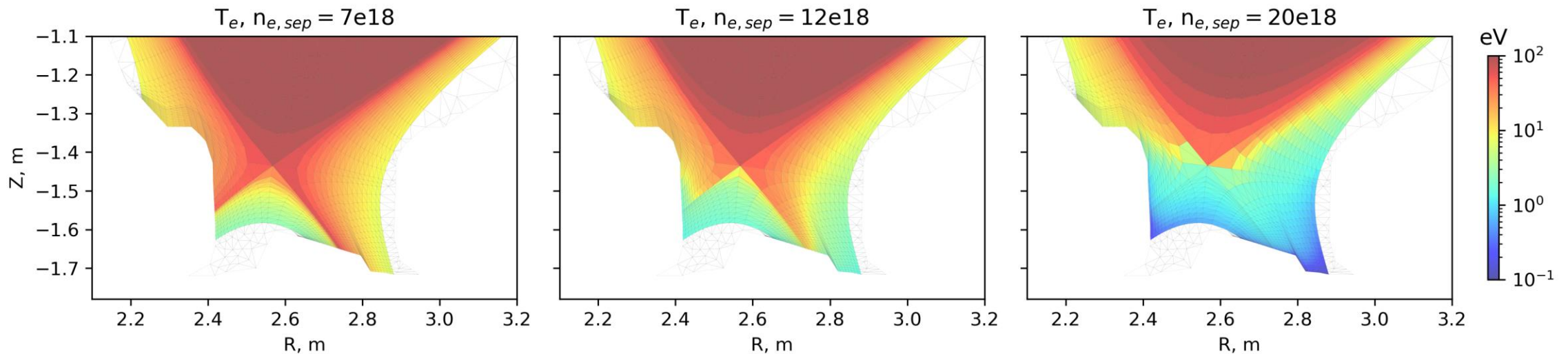
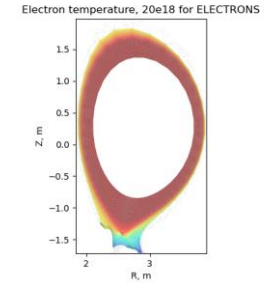
Photon-gas coupling for self-consistent $Q_{\text{ext}} \rightarrow S_{\text{eff}} \rightarrow n_{\text{H}}$



- EIRENE provides Q_{ext} to CRM, CRM provides S_{eff} and n_{D^*} (photon sources) to EIRENE
- First implementation in EIRENE version coupled to EDGE2D (March 2023)

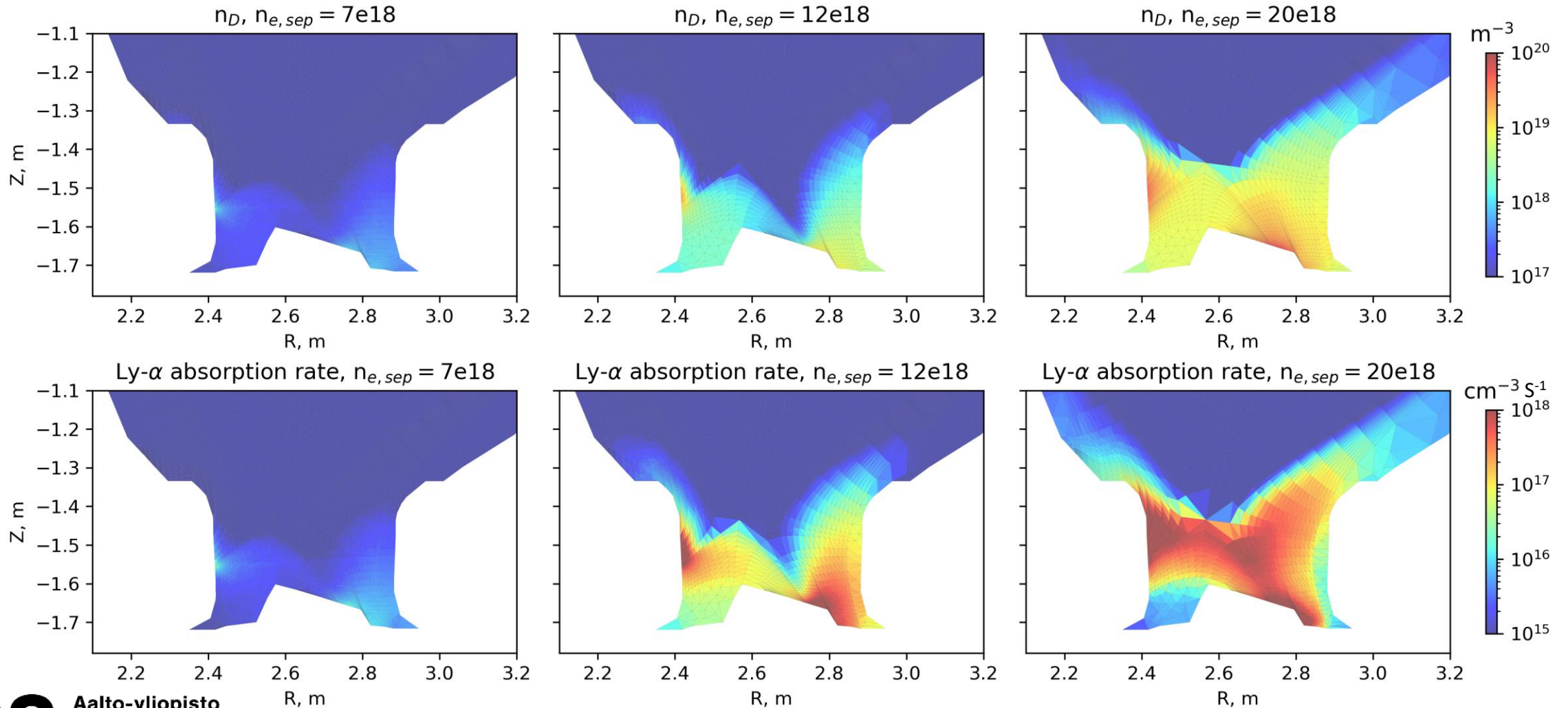
Radiation transport applied to static plasma solutions from JET81472 D+Be EDGE2D-Eirene runs¹

- $n_{e,sep} = 0.6e19 - 2.2e19$
- Ly-alpha and Ly-beta as test-particles
- Shown for low-recycling, high-recycling and detached ($n_{e,sep} = 0.7e19, 1.2e19, 2.0e19$)



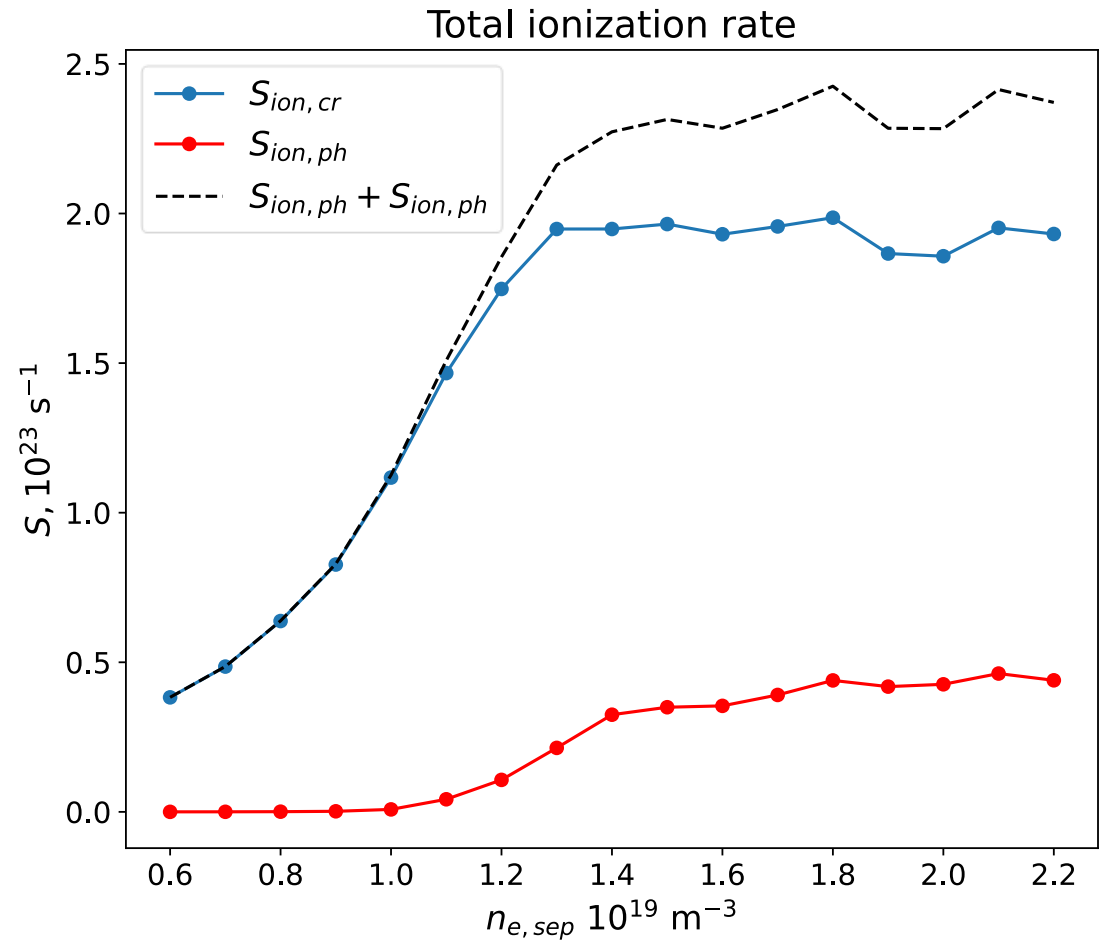
¹M. Groth et al., *Journal of Nuclear Materials* 463 (August 2015): 471–76, <https://doi.org/10.1016/j.jnucmat.2014.12.030>.

Expected high Ly-alpha absorption rate at high neutral D density



Photon absorption adds up to ~20% of total CR ionization rate in detached conditions

- Ionization rate integrated over the whole plasma volume
- No effect in low recycling regimes
- EPS 2023 poster contribution (July 2023)



Next: Photon-gas coupling module in SOLPS-ITER

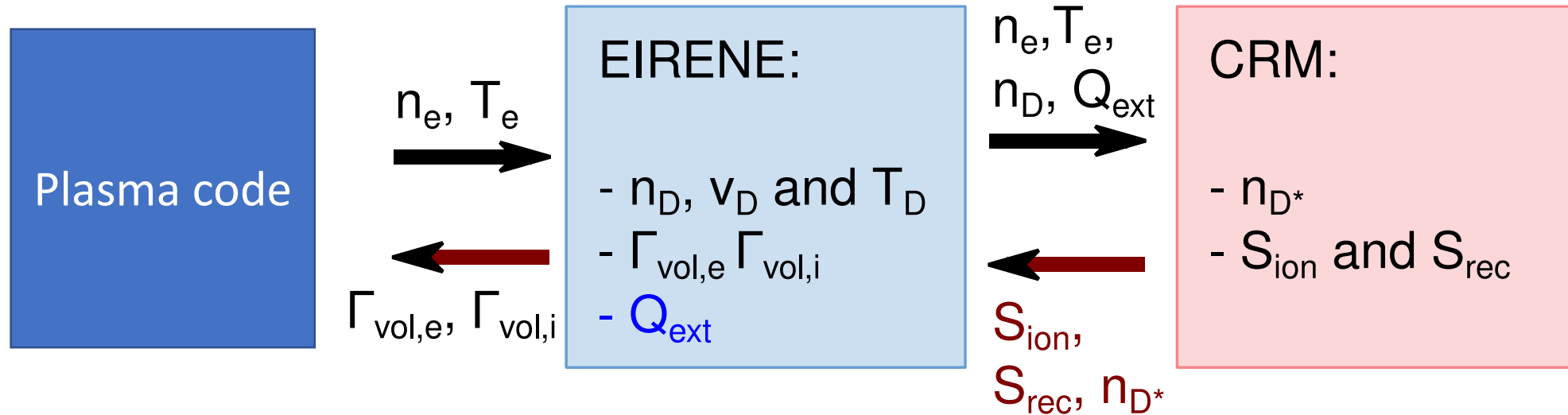
- Cherry-pick necessary components for photon-gas coupling from EDGE2D-EIRENE version into release/3.0.8
- New branch in git.iter.org → feature/rchandra/photontrace
- Testing standalone EIRENE
- Status:
 1. Compilation in triton.aalto.fi ✓
 2. h_colrad and photon tracing tests ✓
 3. 1 iteration run with static plasma (JET81472) ✓
 4. Multiple iteration run



Next: similar study with static plasma solutions from SOLPS-ITER JET81472 D runs

- Comparison with EDGE2D-EIRENE photon solutions
- S_{eff} comparison with modified ADF11 accounting opacity (Lomanowski 2020)
- Expanding h_{colrad} for H2 and H2+ contribution to H*
- planned publication for EDGE2D-EIRENE and SOLPS-ITER photon simulation with static plasma (Q4 2023)

Next²: Plasma-photon-gas coupling



- Self-consistent $n_e, T_e \rightarrow$ new high-recycling, detached dynamics (hopefully better I_{div} prediction)
- Connect with EIRENE input parallelization work (Yannick, next code camp?)