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EUROfusion

The role of plasma-atom/molecule interactions on power, particle and momentum balance during detachment

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University of York

EPFL

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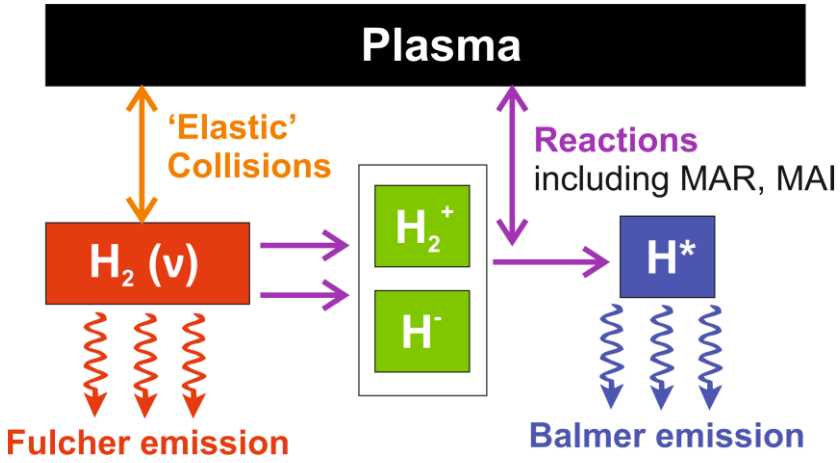
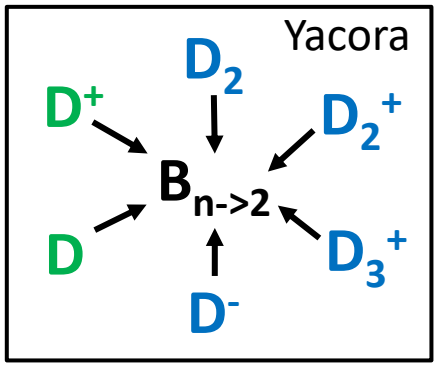
Detachment and plasma-molecule interactions

- Plasma detachment requires: momentum, power and particle losses
- Plasma-molecule interactions (PMI) impact all three balances



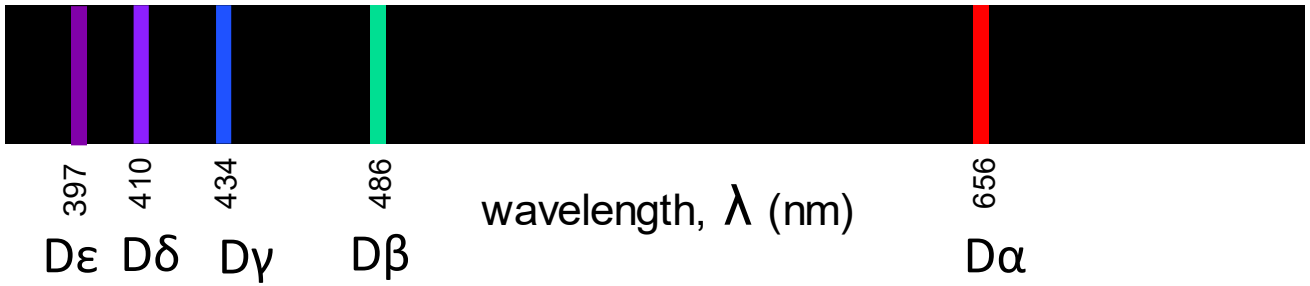
[Wünderlich, et al. *JQSRT* 2020]

'atomic'
'molecular species'



- Plasma-molecule interactions result in **excited atoms** -> **atomic line emission**

Hydrogen Balmer spectrum



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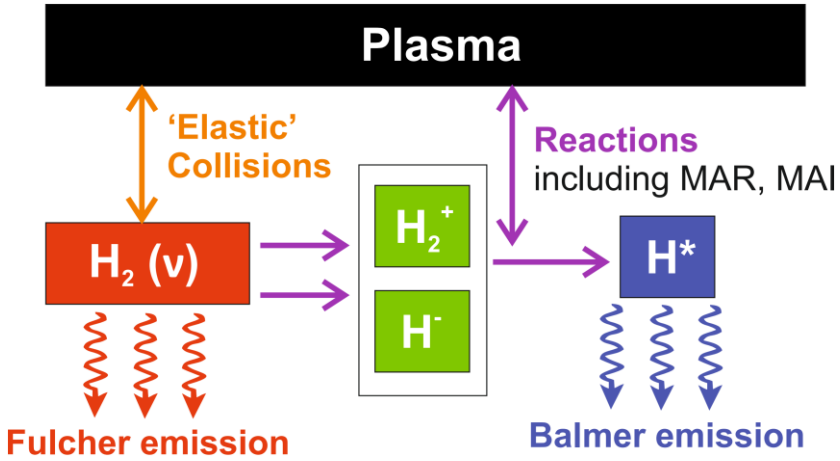

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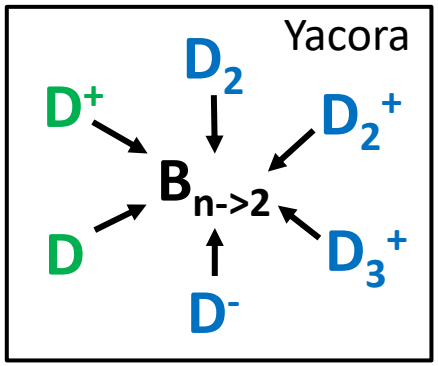


- Plasma-molecule interactions result in **excited atoms** -> **atomic line emission**

Impact plasma-mol. inter. on D emission during detachment relatively unknown

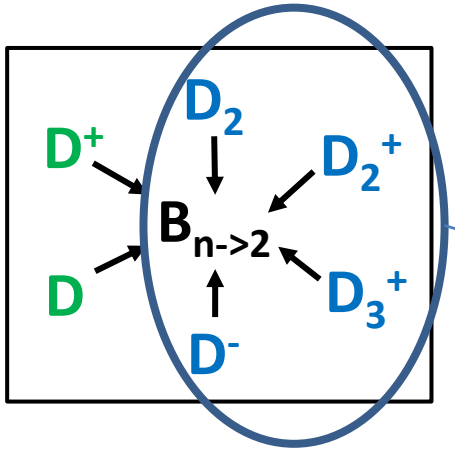
<u>In this work:</u> we investigate this* and use it as a diagnostic to address power & particle losses from plasma-molecule interactions

* [Verhaegh, et al. 2021, PPCF]

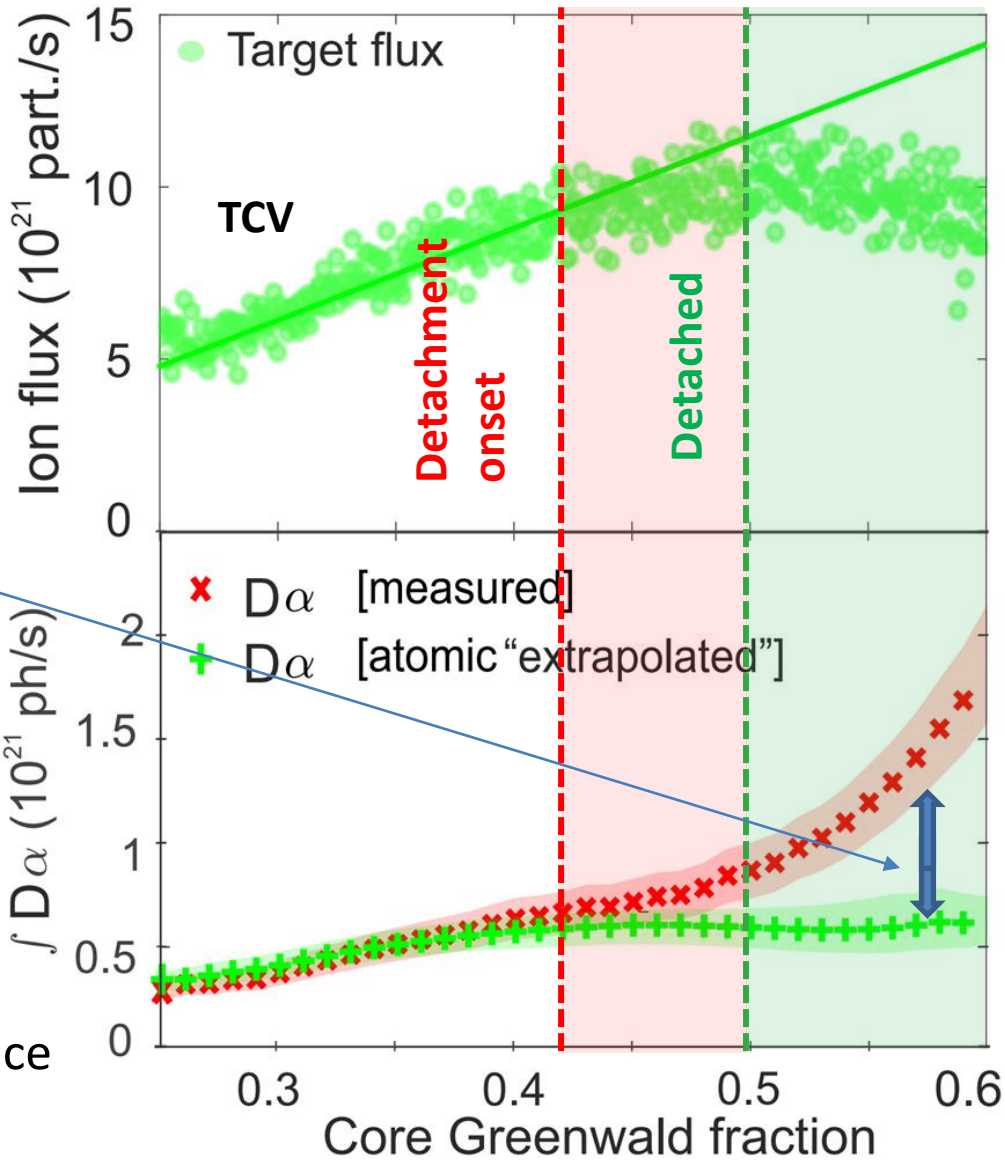
PMI elevates $D\alpha$ emission during detachment

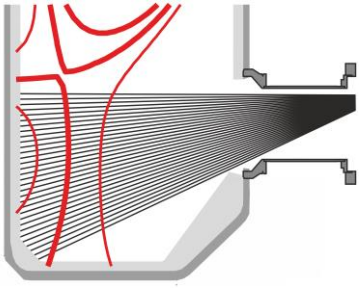
- **$D\alpha$ emission** increases beyond **'atomic' only expectation Da**

-> **$D\alpha$ from excited atoms after PMI**



[Verhaegh, et al. NME 2021]





Results from TCV

- Medium-sized device
- Carbon wall
- Ohmic L-mode

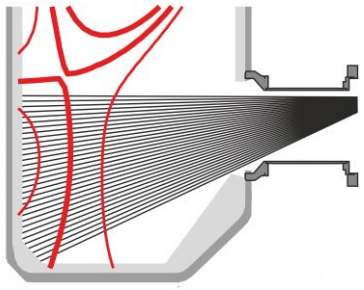
PMI elevates $D\alpha$ emission during detachment

- **$D\alpha$ emission** increases beyond **'atomic' only expectation Da**

-> **$D\alpha$ from excited atoms after PMI**

This suggests:

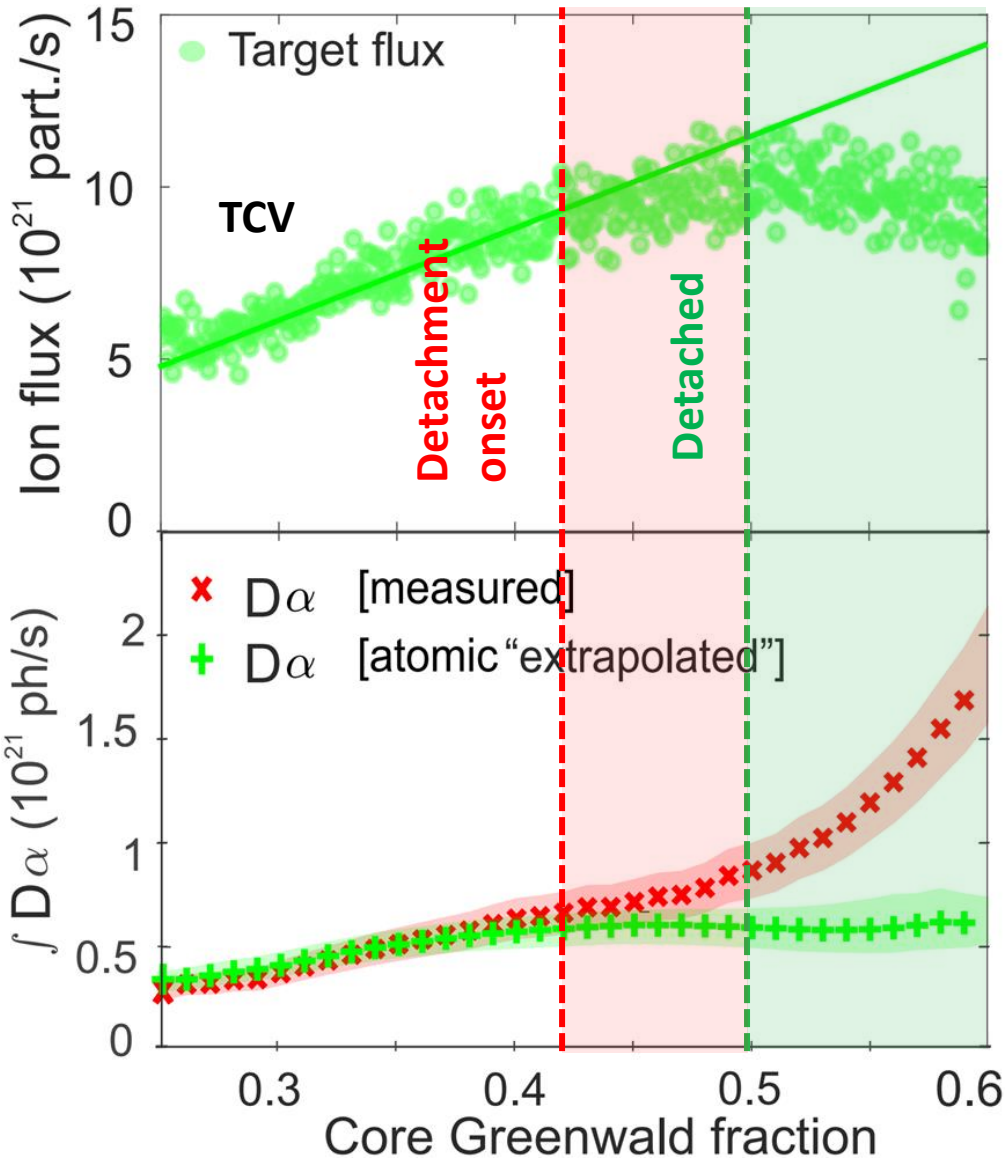
1. **Strong contribution plasma-mol. inter. Balmer lines**
2. **Particle losses through MAR**
3. **Power losses from excited atoms after plasma-mol. interactions**



Contribution (%) PMI to emission

Dα	77
Dβ	50
Dγ	33
Dδ	10

[Verhaegh, et al. NME 2021]



PMI -> power & ion sinks during detachment

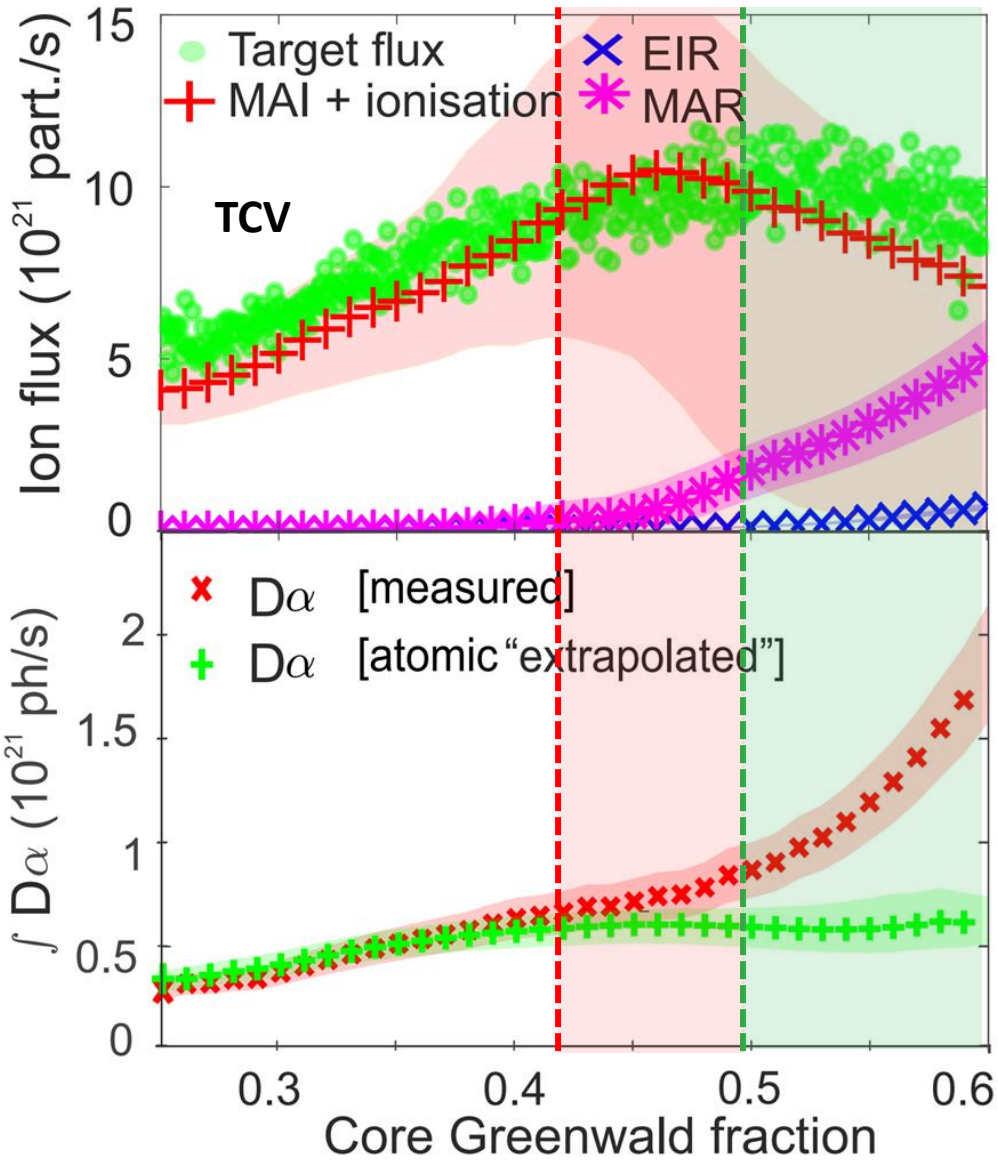
K. Verhaegh, et al. 2021, NME

Detachment onset:

- **MAR** (Molecular Activated Recombination) starts to occur
- **Total ion source** drops

Detached

- **MAR** ~ 50% of ion **target flux** > **electron-ion recombination (EIR)**



MAR – important ion sink

(TCV conditions, n_e = 10^{20} m^{-3})

PMI -> power & ion sinks during detachment

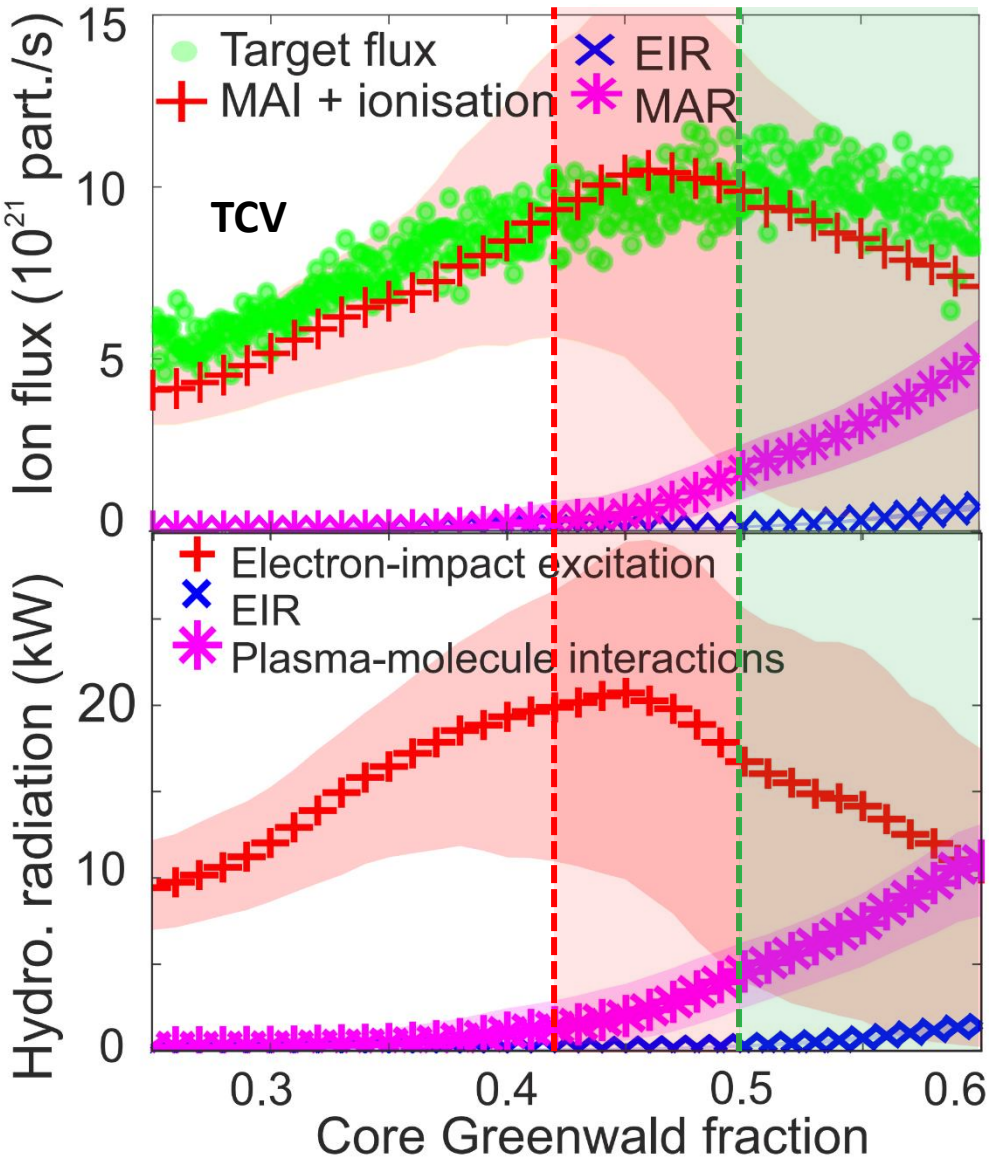
Detachment onset:

- **MAR** (Molecular Activated Recombination) starts to occur
- **Total ion source** drops

Detached

- **MAR** ~ 50% of ion **target flux** > **electron-ion recombination (EIR)**
- **Hydrogenic radiation from PMI** up to ~ 50% of total hydrogenic radiation

MAR – important ion sink & contributes to atomic line radiation (TCV conditions, n_e = 10^{20} m^{-3})

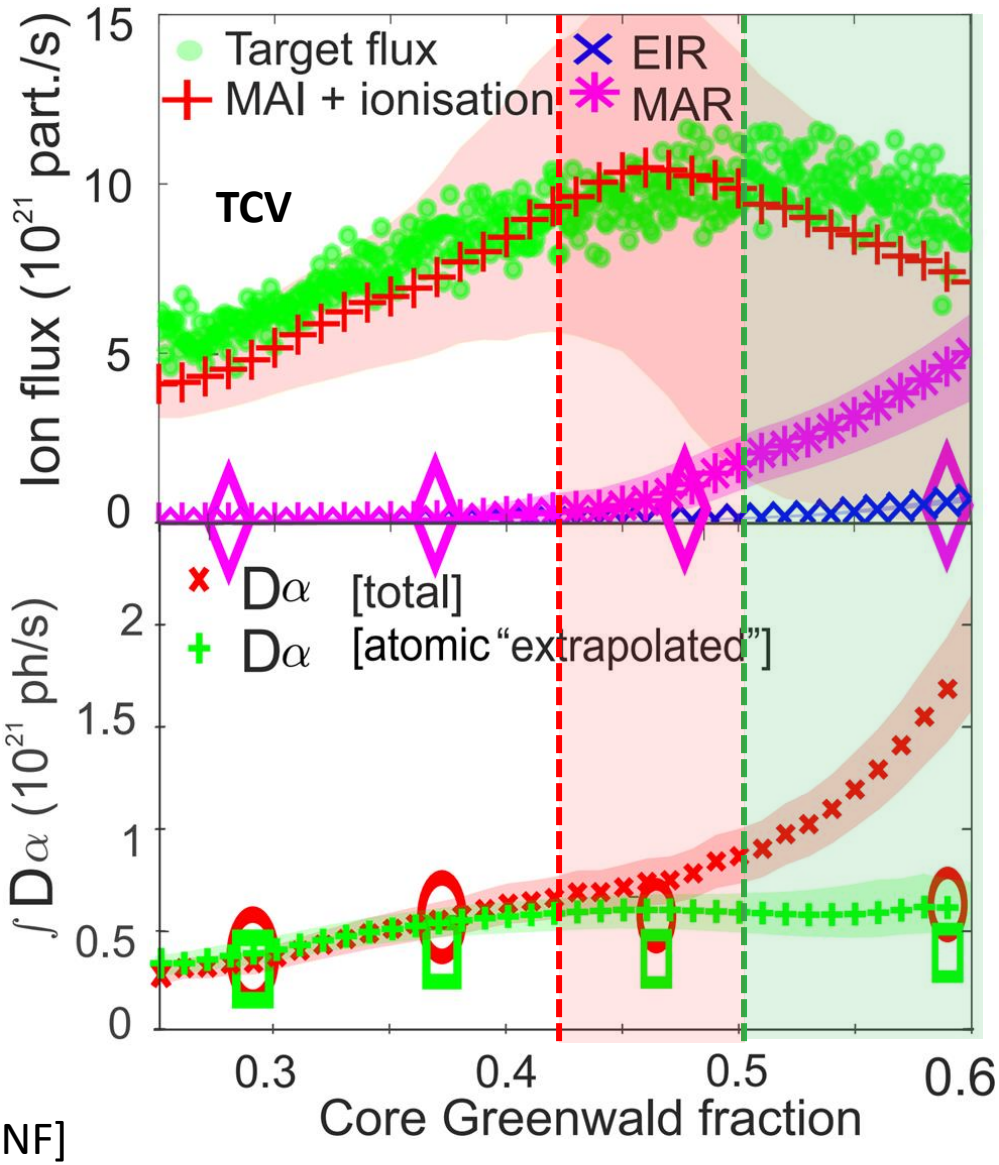


Comparison experiment vs simulation

SOLPS-ITER predictions –
Open symbols

Results obtained using default SOLPS-ITER reactions rescaled for deuterium

The impact of PMI involving D_2^+ underestimated in SOLPS-ITER



SOLPS-ITER in agreement with experiment, except Dα & MAR estimates

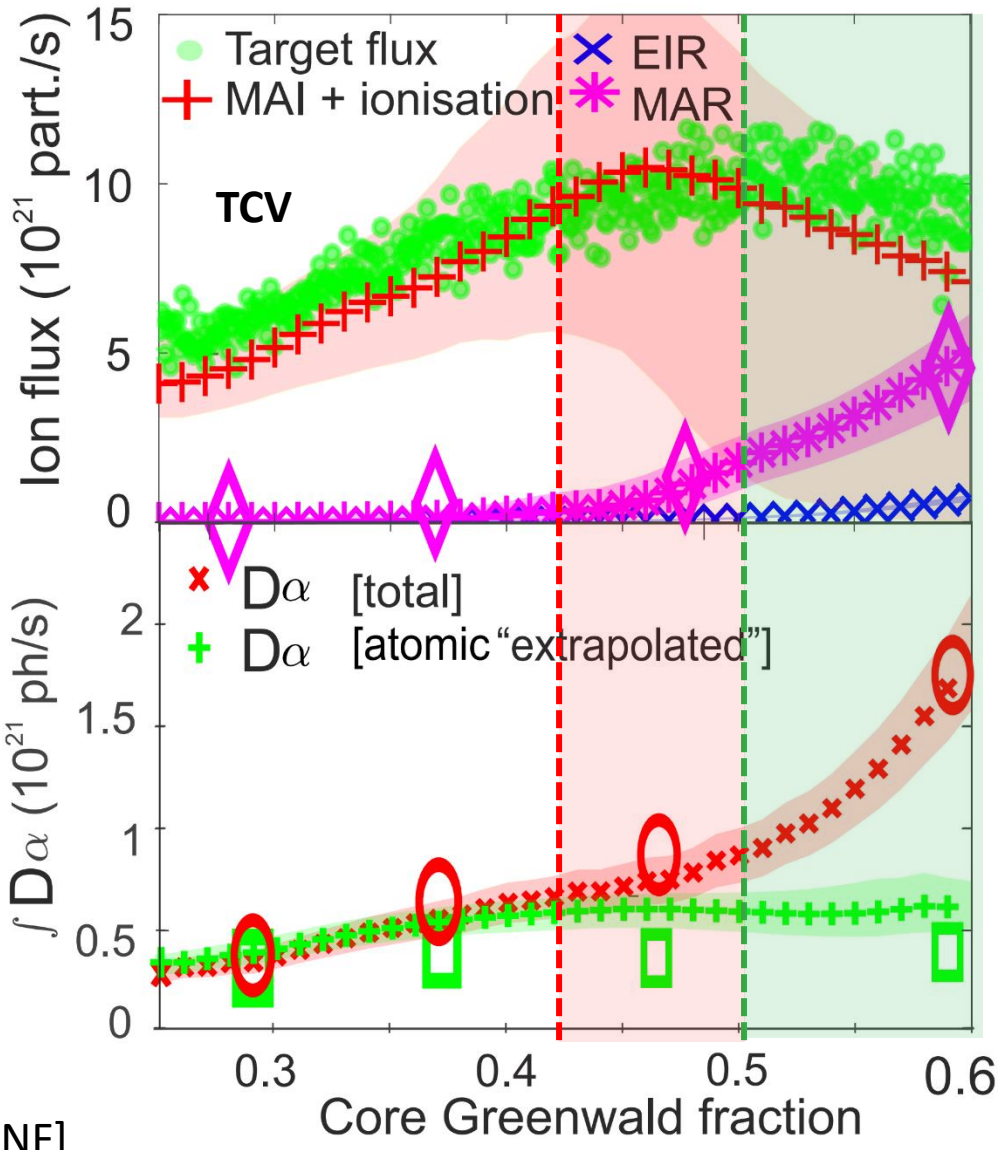
[A. Fil, et al. CPP, 2018, Verhaegh, et al. 2019, NF]

Comparison experiment vs simulation

SOLPS-ITER predictions –
Open symbols

Results obtained by **post-processing** with $D_2 + D^+ \rightarrow D_2^+ + D$ rate derived for D **Kukushkin, et al. 2017, NME**

The impact of PMI involving D_2^+ <u>in agreement</u> between experiment and simulation with post-processing with a revised $D_2 + D^+ \rightarrow D_2^+ + D$ rate



SOLPS-ITER in agreement with experiment, except Dα & MAR estimates

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Conclusion

Plasma-molecule interactions result in **excited atoms**, significantly impacting (T_e = [1.5-3.5] eV):

- Hydrogenic line emission -> **implications for diagnostic analysis**
- Power balance (**50% of total H rad.**)
- Particle balance (**MAR >> EIR** for TCV)

→ **implications for detachment physics**

Such interactions are presently:

- Underestimated in SOLPS simulations
- Not accounted for in spectroscopic analysis

Plasma-molecule interactions (on TCV) have dominant effects on hydrogenic line intensities, power and particle balance during detachment

Further experimental and simulation investigation required