Investigating the influence of molecules on power/particle/momentum balance in the detached TCV divertor

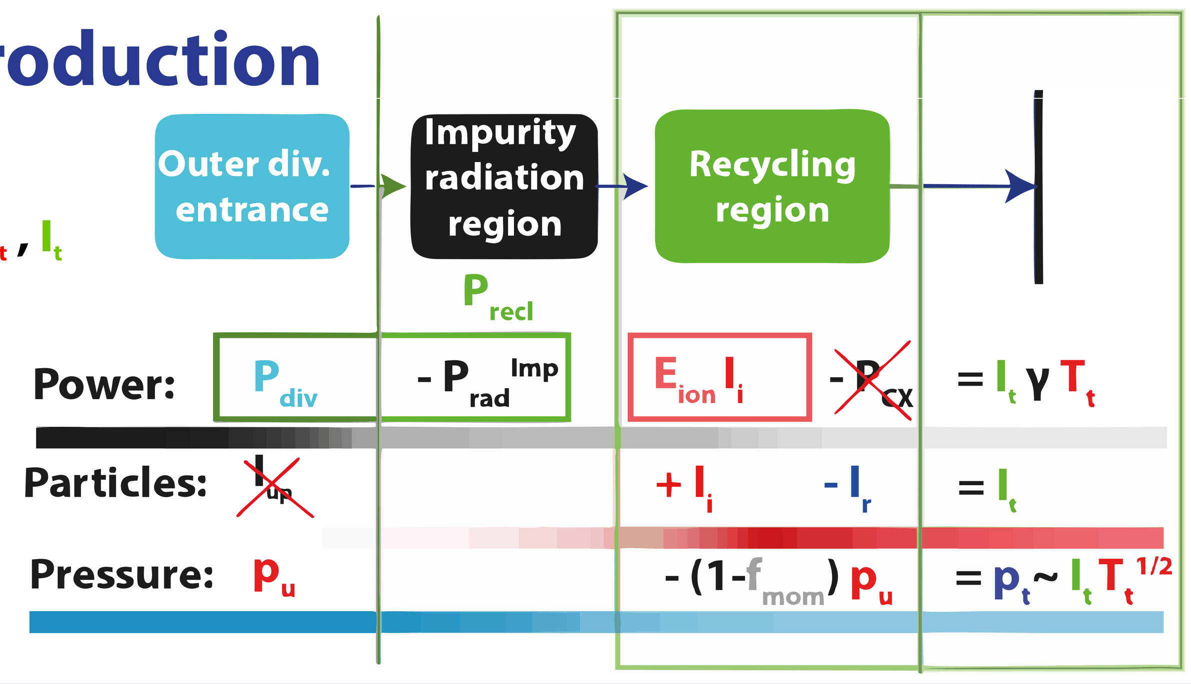
K. Verhaegh[a,b], B. Lipschultz[b], B.P. Duval[c], B. Dudson[b], A. Fil[a], O. Février[c], D.S. Gahle[d,a], J.R. Harrison[a], L. Martinelli[c], D. Moulton[a], O. Myatra[b,a], A. Perek[e], C. Theiler[c], M. Wensing[c] and the TCV[*] and EUROfusion MST1 teams[**]

kevin.verhaegh@ukaea.uk
a Culham Centre for Fusion Energy, Culham, UK
b York Plasma Institute, University of York, UK
c Swiss Plasma Center, EPFL, Lausanne, Switzerland
d University of Strathclyde, Glasgow, UK
e DIFFER, Eindhoven, The Netherlands
* See author list of 'B. Labit, et al 2019, Nucl. Fusion 59 086020'
** See author list of 'S. Coda, et al 2019, Nucl. Fusion accepted'

Detachment introduction

- **Detachment:**
  Simultaneous reduction T_t, I_t

Requires:
- **Particle losses** (ion sink /power limitation
- **Power losses**
- **Momentum losses**



Dα > expected (atomic)

Previously, **atomic** particle/power sources & sinks measured [1,2]

TCV density ramp: 3 phases

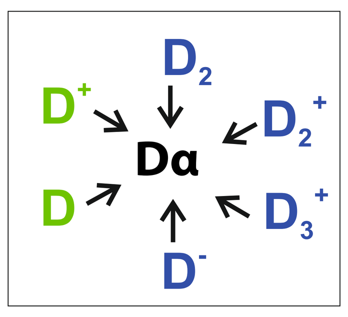
1) Attached
I_t (ion current) & **I_i (ion source)** rise linearly with n_e
P_{recl} >> P_{ion}

2) Detachment start
I_i flattens -> I_t deviates from linear increase with n_e
P_{recl} ~ 2 P_{ion}

3) I_t roll-over
I_i (ion source) rolls over
I_r (recombination) lesser role
P_{recl} ~ P_{ion}

At detachment onset, **Dα rises above atomic estimations**

Cause? **Molecules**?
reaction -> excited atom -> emission

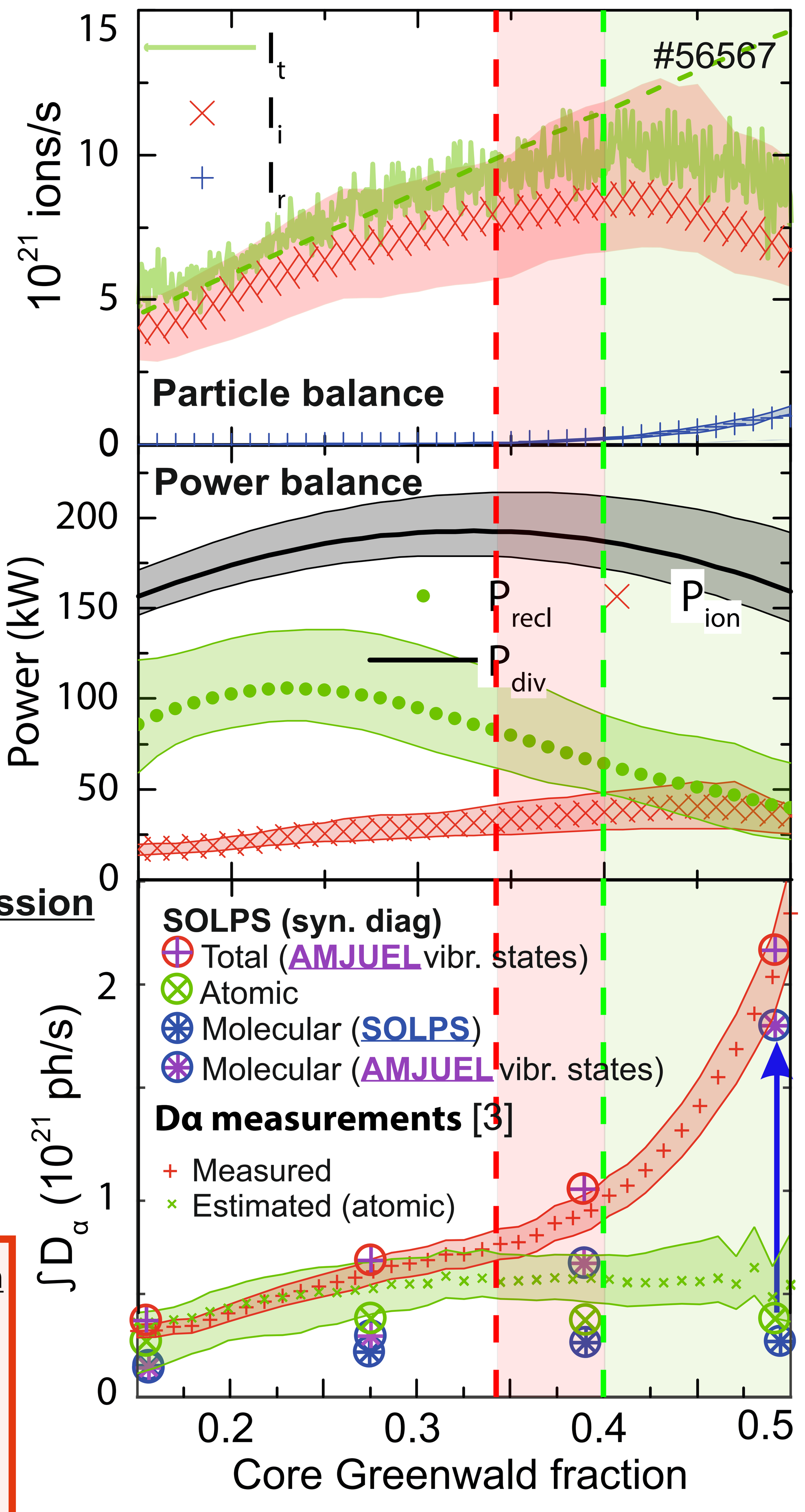


No extra Dα with N_2 seeding

Mol. Dα (D_2^+, D^-) SOLPS too low, but **in agreement** after **post-processing**

- **Mol. Dα -> reactions with D_2^+ D^-**
- **Underestimated by SOLPS**
- **-> Radiation (power losses)**
- **-> Particle gains/losses (MAR/MAI)**

Density ramp
Analysis: Balmer n=5,6 atomic only

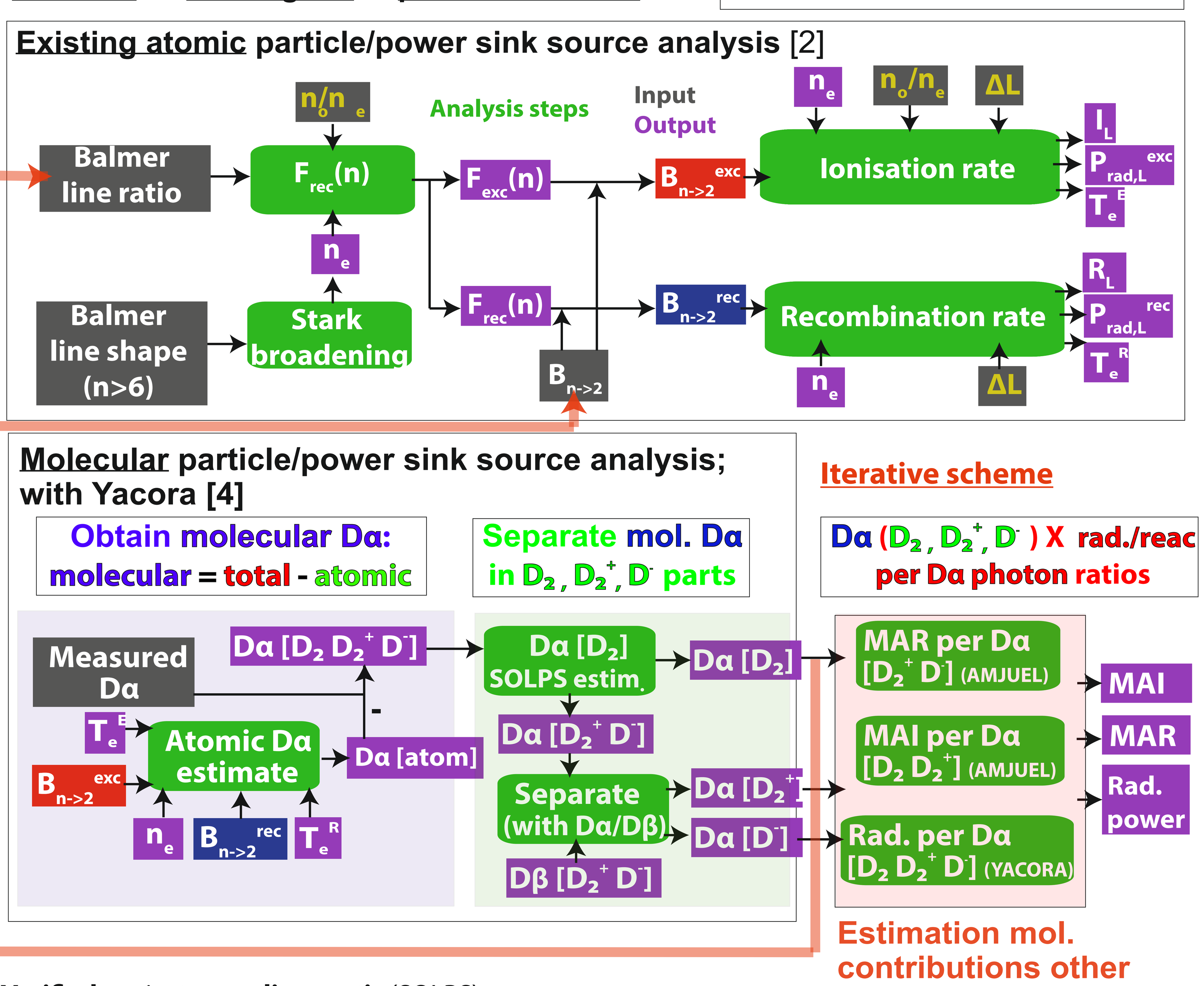


'Post-processed' SOLPS: AMJUEL (vibr. states)

Spectroscopic analysis

Assume all 'missing' Dα -> plasma-molecule

Molecular = Total - Atomic



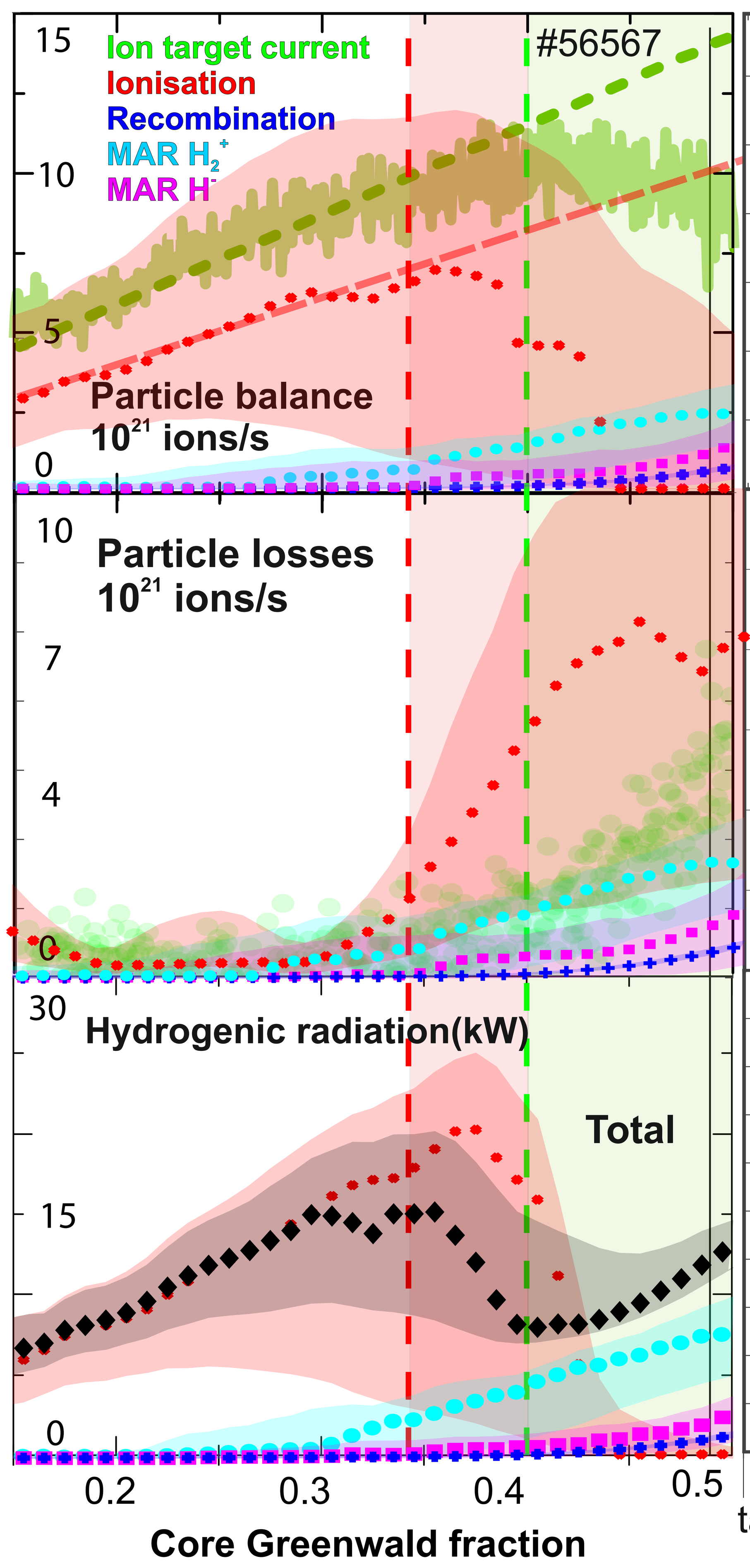
Verified against **syn. diagnostic** (SOLPS)

Estimation mol. contributions other Balmer lines

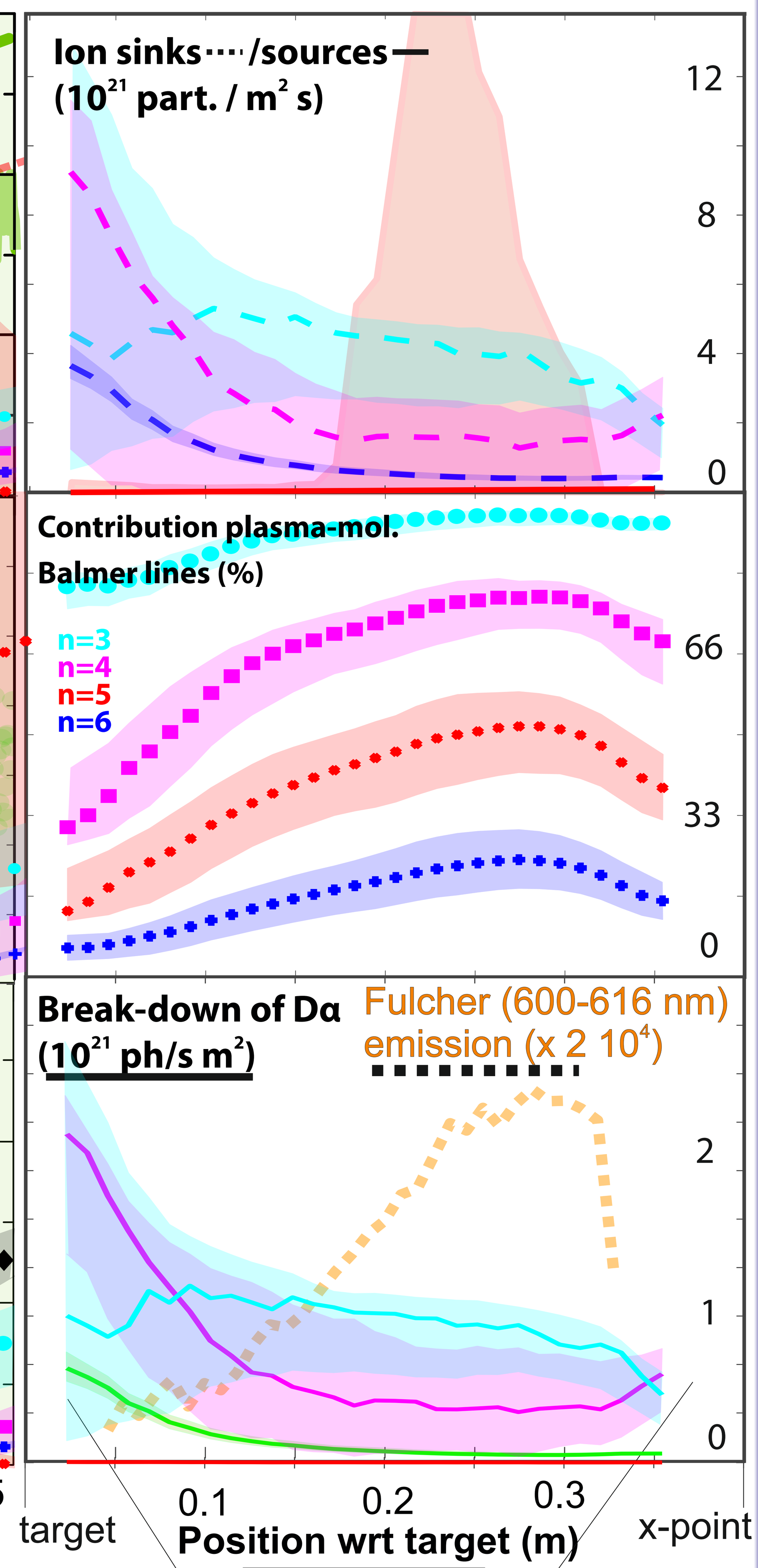
Preliminary results

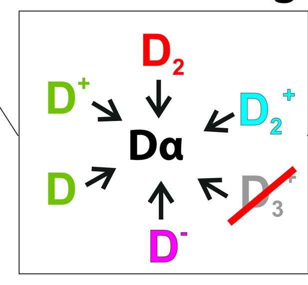
Density ramp

Balmer n=3,4,5,6 - atomic & molecular



Spatial profiles (n_e / n_{GW} ~ 0.48)





- **Increased hydrogenic radiation** (mostly D_2^+)
- **Increased** ion losses **(MAR)** (due to D_2^+ & D^-) - **larger** than electron-ion recombination **(EIR)**
- **Ionisation** - **(MAR+EIR)** < **ion target flux**
- **Onset** of D_2^+ **MAR** near **'power limitation'** /detachment, followed by D^- **MAR** and **EIR**
- Increase ion source (**MAI** D_2^+ & D_2) negligible

- **Significant contributions-> Balmer lines**
- **Mol. Dα** (e.g D_2^+, D^-) near **cold target** -> **D_2^+, D^- associated MAR/rad. loss** near target; below ion. region; wider than EIR region
- **Fulcher (600-616 nm) emission** [5] **at different location than Dα emission** D_2^+ D^-

Preliminary conclusion / DEMO implications :

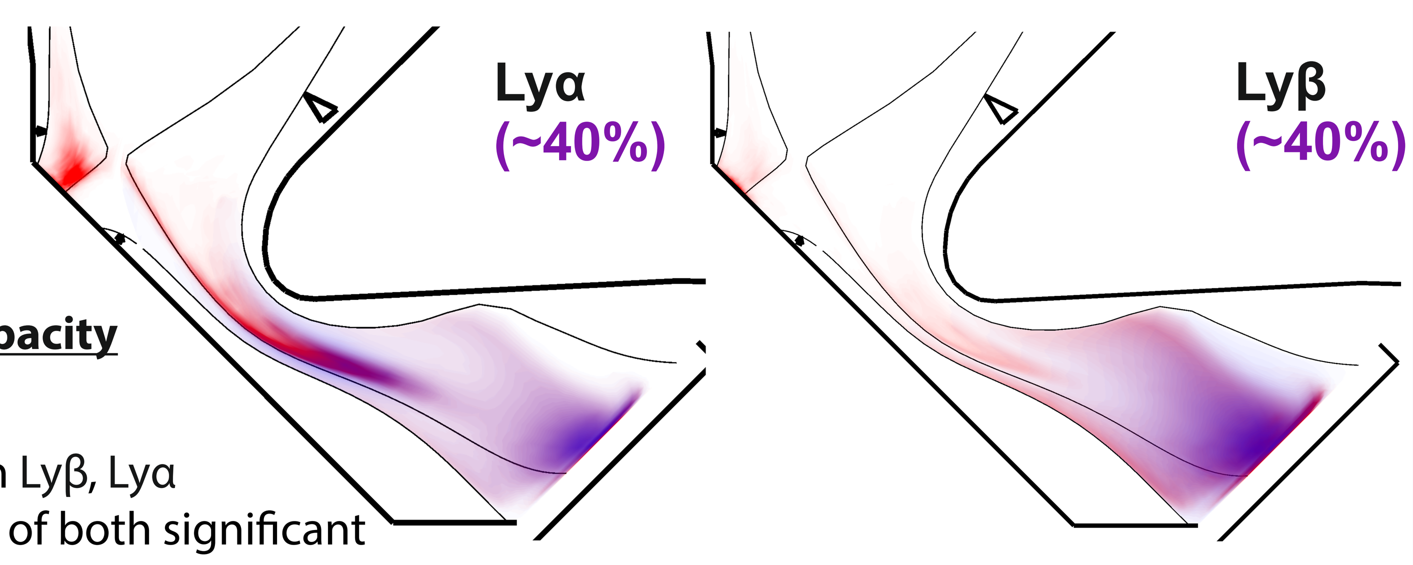
- **Dα** emission & anti-correlation **Dα & I_t** **cannot** be explained with atoms
  - **Additional Dα** could be due to ***D_2^+ (and/or D^-)*** - only high with ***CX & vibr. states***
  - Additional ***Dα does not appear during N_2 seeding***
- **Particle/power losses plasma-mol. interactions** have been **analysed experimentally**

- **Power losses: *significant plasma-mol. rad in hydrogen spectra during detachment*** (similar to atomic excitation radiation); losses mol. bands small [6];
- **Particle losses/gains: *significant MAR larger than EIR***
- **Plasma-mol. interaction can** influence Balmer & Lyman series lines

- **The inclusion of those losses in plasma-modeling codes may be limited -> important for extrapolating to DEMO**

Emission / absorption

Plasma-mol.-> implications for opacity



-> Different location Lyβ, Lyα emission -> opacity of both significant

[SOLPS simulations MAST-U post-processed]

[1]: K. Verhaegh, et al. NF, 2019
[2]: K. Verhaegh, et al. PPCF, 2019
[3]: K. Verhaegh, Thesis, 2019
[4]: D. Wünderlich, U. Fantz; Atoms; 2016
[5]: U. Fantz, et al. 2001, JNM
[6]: M. Groth, et al. 2019, NME

This work has been carried out within the framework of the EUROfusion Consortium and has received funding from the Euratom research and training programme 2018-2019 under grant agreement No 633053. The views and opinions expressed herein do not necessarily reflect those of the European Commission.