MAX-PLANCK-INSTITUT
FÜR PLASMAPHYSIK

MPG contribution to SP X.1 Atomic and molecular processes in attached/detached plasmas

TASK: Atomic and molecular hydrogen spectroscopy in ionizing and recombining plasmas

D0004: **Interpretation spectroscopy** results using spectra simulation and (CR) modelling with **YACORA** (MPG)

Ursel Fantz, Dirk Wünderlich, Richard Bergmayr

EUROfusion

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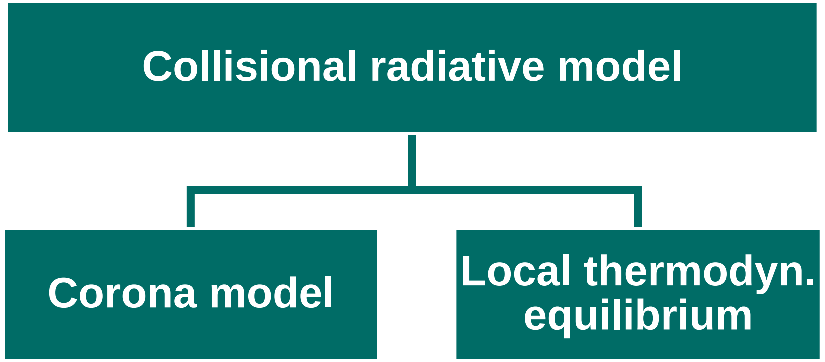
Yacora: a flexible solver for Collisional Radiative models



D. Wünderlich et al, Atoms 4, **2016**, 26

Yacora is a flexible (0D)-solver for CR models:

- Used and improved for more than 20 years
- Many CR models built on that solver, focus here: H and H_2

CR model for…		# states	Comment
H_2	Electronic states only	33	Well benchmarked
	Some vibrational states	214	Well benchmarked
	Vib-rot resolved	>626	Extended Corona models
H		44	**Coupling to H^+, H_2^+, H_3^+, H^-,** very well benchmarked
He		19	Very well benchmarked
Ar			Well benchmarked

- Extensive data base of reaction probabilities
- Drastically increased complexity for molecules
- Data for H based on ADAS and …
- Data for H_2 based on MCCC data and …

  L. Scarlett et al, ADNDT 137, 2021, 101361

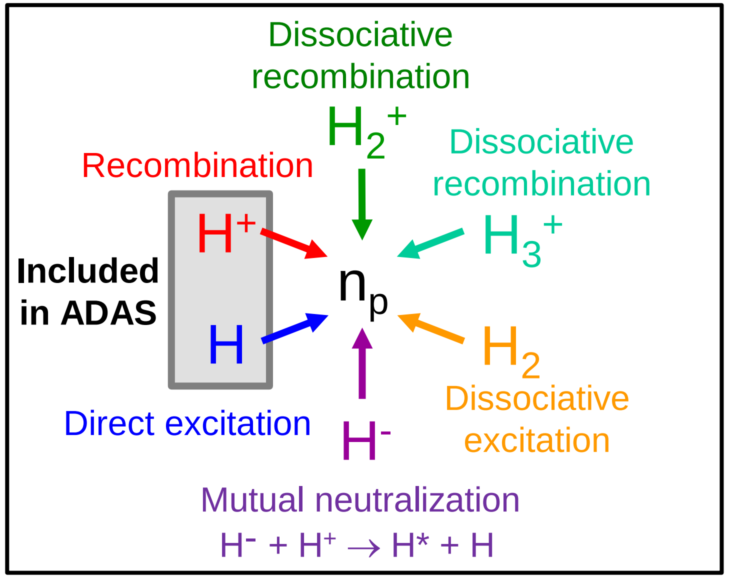
- Dedicated PhD thesis, present status in

  R. Bergmayr et al, Eur. Phys. J. D 77, 2023, 302

Additionally available are: Ar+, Cs, N_2, C_2, CH in different status,

D_2 in preparation

Atomic and molecular hydrogen models



- Ionizing and recombining plasmas
- Opacity is an option

Electron ion recombination — Molecular assisted recombination

EIR: $T_e < .5$ eV, $n_e = 10^{21}$ m^{-3}

MAR: $T_e \sim 2\text{-}5$ eV, n_e $10^{19}\text{-}10^{21}$ m^{-3}

Ionization: $T_e > 10$ eV

H_2 models for different purposes

Electronic states

Population factors,
Effective rate coefficients

For full analysis:
coupling of H and H_2

Vibrationally resolved

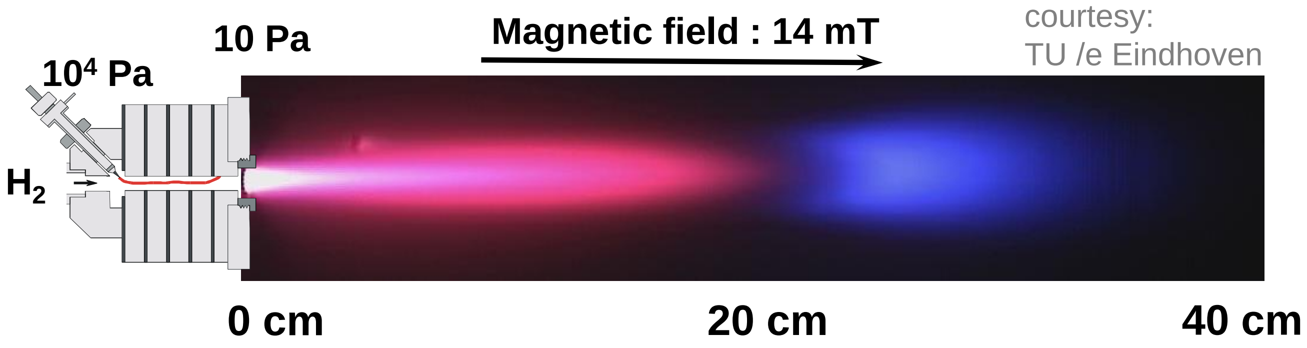
Vibrational population
$H_2(v)$

Ro-vib, resolved
Corona

Simulation of spectra

Example for analysing recombining and ionizing plasmas

Linear plasma device: cascaded arc at TU/e Eindhoven

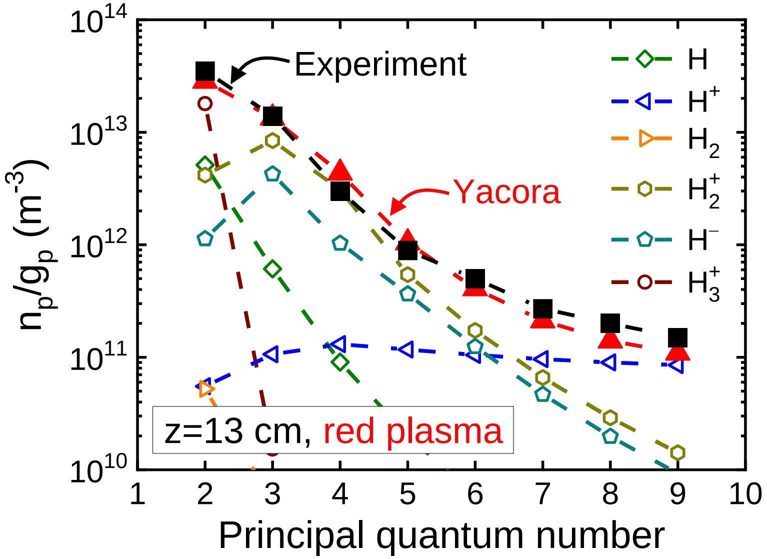


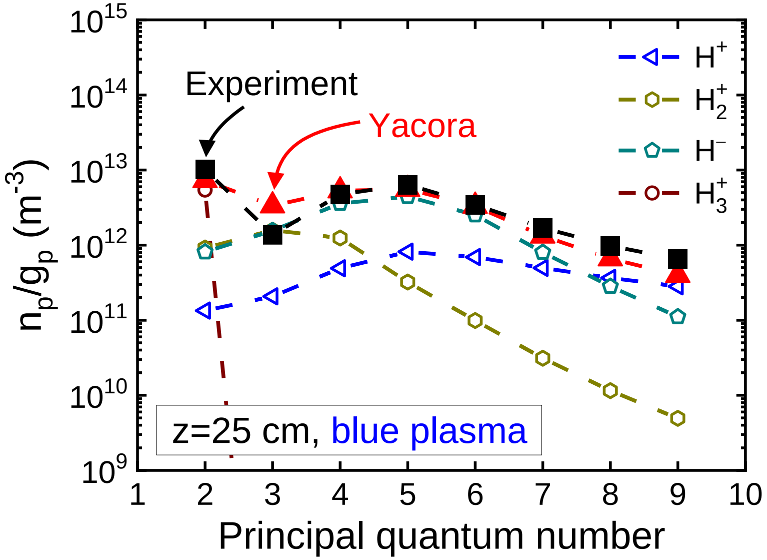
Plasma parameters from Thomson scattering, probes, OES, ...

W.E.N. van Harskamp, Phys. Rev. E 83, 2011, 036412

Excellent agreement experiment ↔ Yacora for red and blue plasma

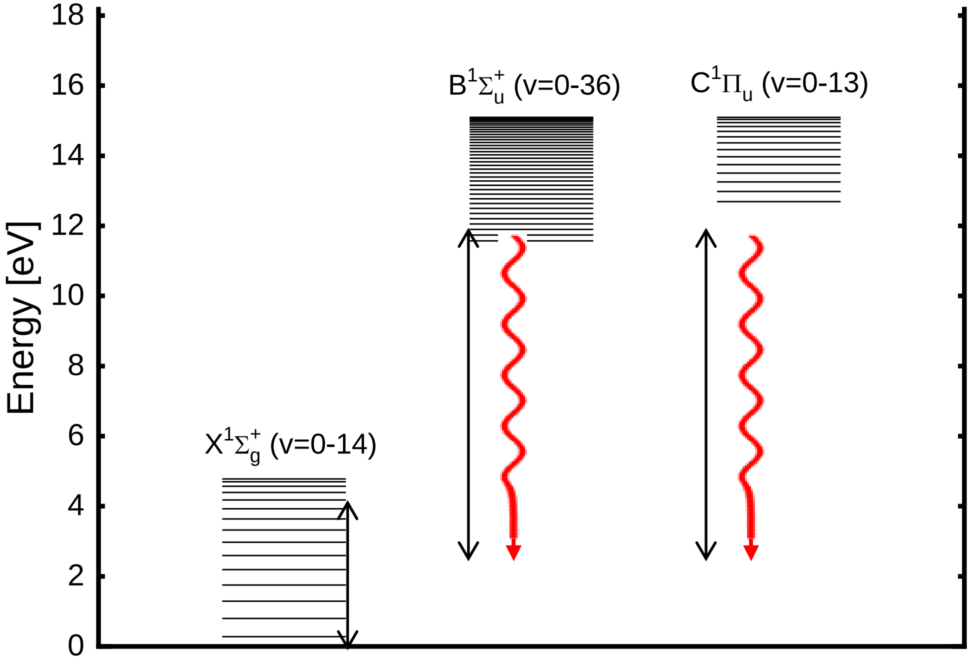
- Atomic and molecular excitation channels play a role
- **Correct prediction of overpopulation of n=4,5 and 6**





Vibrationally resolved CR model, $H_2(v)$ population

Electron collisions, spontaneous emission,
including B^1 and C^1 states
Heavy Particle Collisions (H, H^+, H^-, H_2, H_3^+),



EIE: Electron impact Excitation

EID: Electron Impact Dissociation

H3+DR: Diss. recombination H_3^+

DA: Dissociative Attachment

CX: Charge Exchange

HAID: H Impact Dissociation

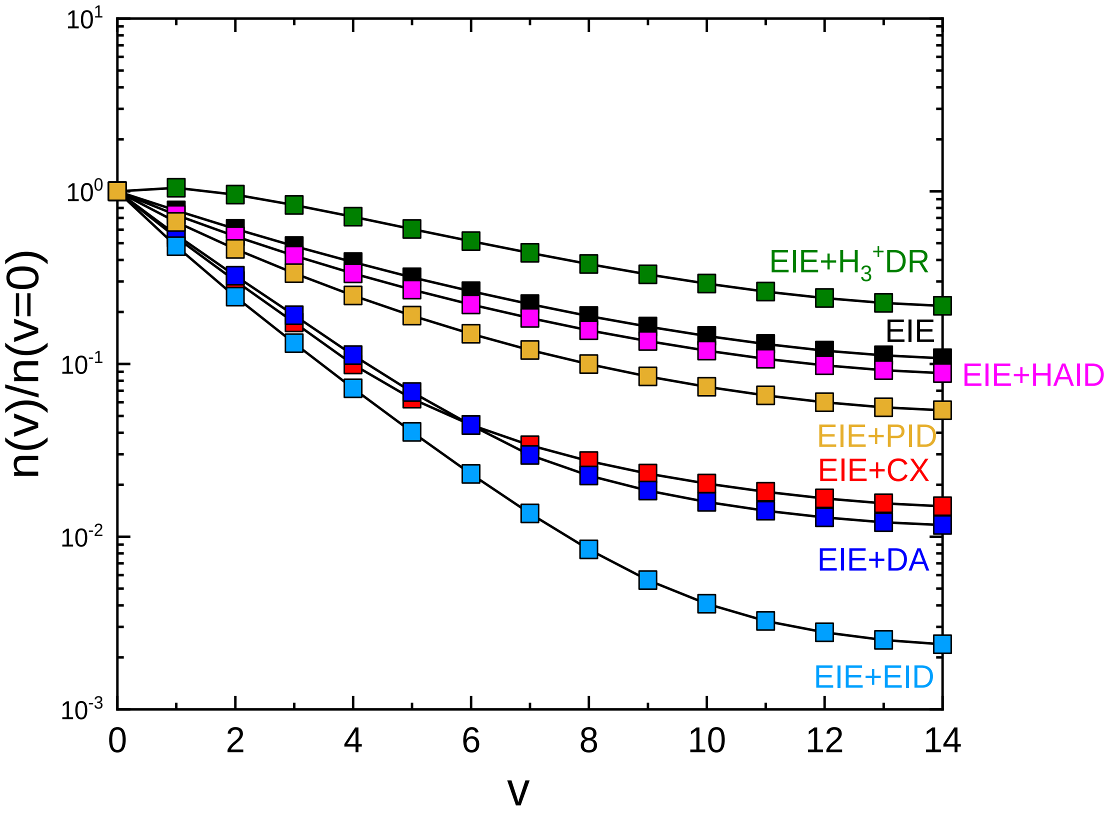
PID: Proton Impact Dissociation

Divertor plasma conditions

$T_e = T_H = T_{H+} = T_{H_2^+} = T_{H_3^+} = 2$ eV, $T_{H_2} = 2/3$ eV

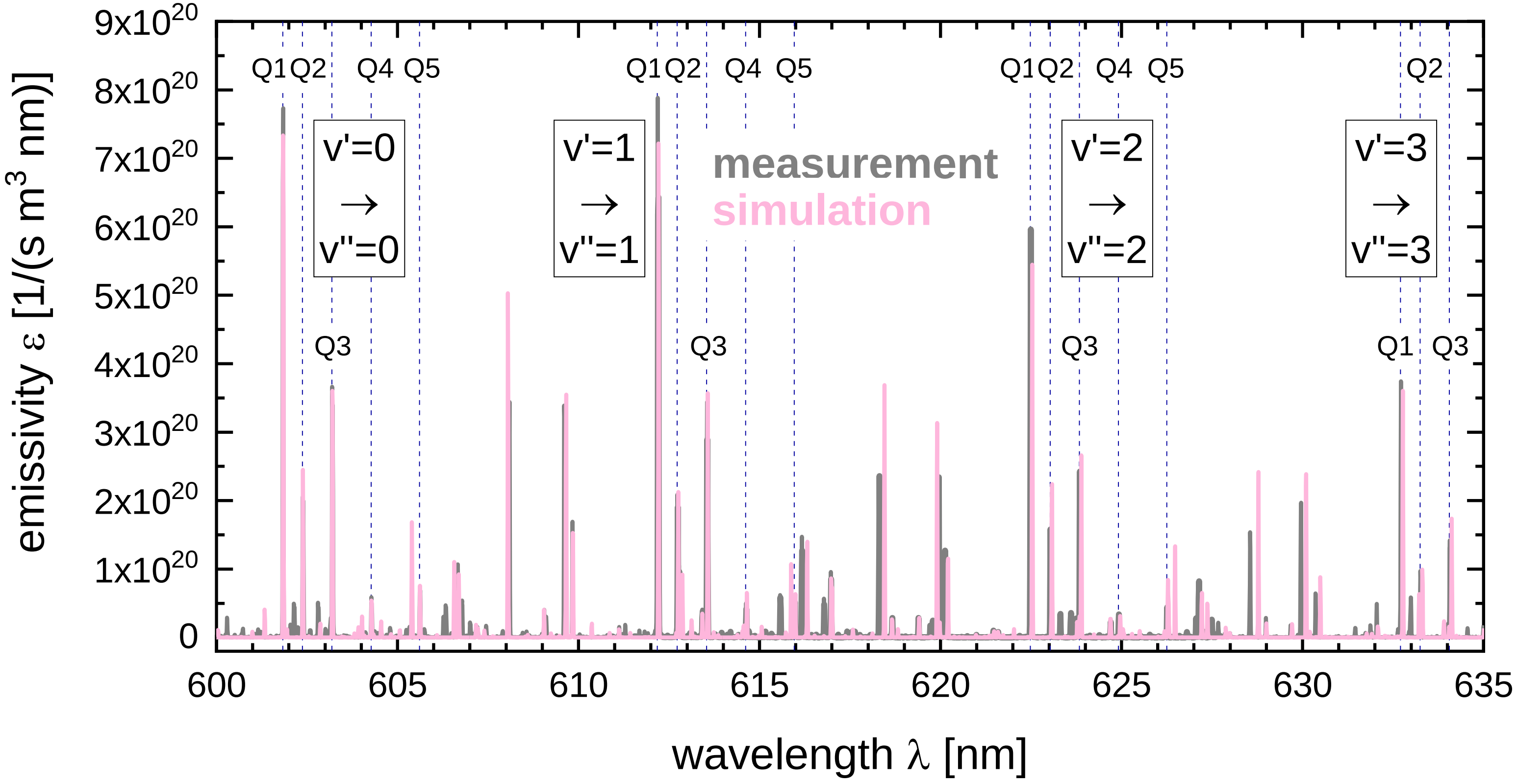
$n_e = 10^{20}$ m^{-3}, $n_{H_2} = 5 \cdot 10^{19}$ m^{-3}, $n_H = 5 \cdot 10^{18}$ m^{-3}

$n_{H+} = 4 \cdot 10^{19}$ m^{-3}, $n_{H_2^+} = 4 \cdot 10^{19}$ m^{-3}, $n_{H_3^+} = 2 \cdot 10^{19}$ m^{-3}



Ro-vibrationally resolved (corona) model
Simulation of spectra

Example: Fulcher transition in a low temperature ICP



T_e = 9 eV

$n_e = 2 \times 10^{16}$ m^{-3}

$T_{rot,1}$ = 500 K
$T_{rot,2}$ = 7500 K
T_{vib} = 4200 K

Closing remark

We look forward to analysing the Magnum PSI data and participating in the measurements.