Spectroscopy

A Powerful Diagnostic Tool in Source Development

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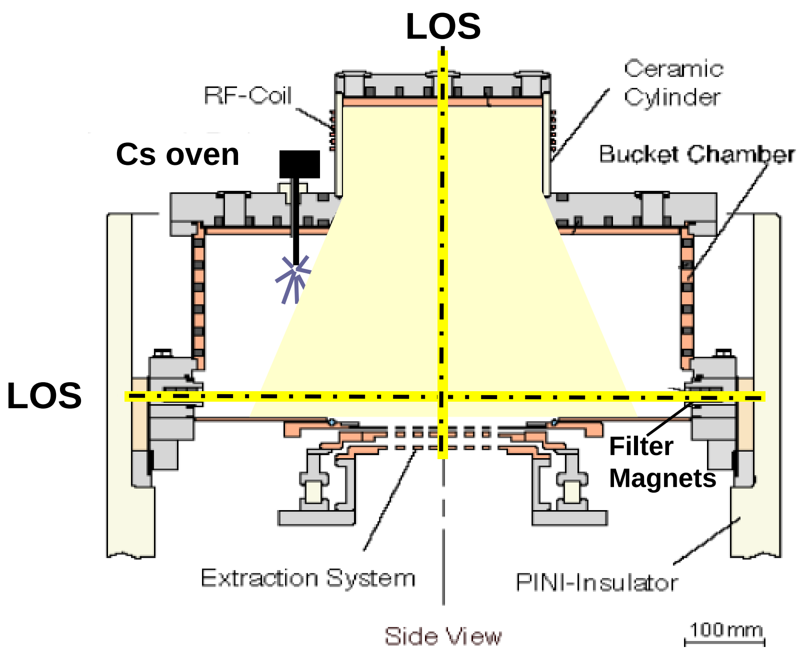


RF sources at IPP, Garching

BATMAN: grid 70 cm^2

MANITU: grid 300 cm^2

Plasma parameter

- n_e, T_e and T_{gas}
- H and H_2 density
- Cs and Cs^+ density
- H^- density
- Time traces

Correlation with j_{H^-} and j_e

Stripping losses

Optimisation of plasma processes

Volume processes

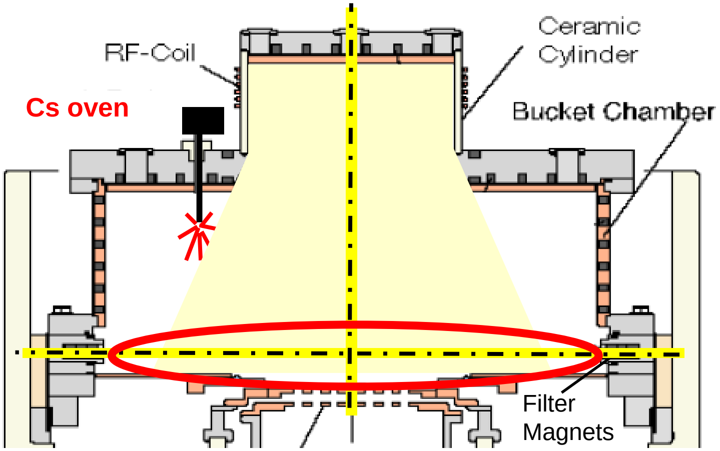
$e^- + H_2 \rightarrow H_2(B,C) + e^- \rightarrow H_2(v) + e^- + h\nu$

Dissociative attachment

$e^- + H_2(v) \rightarrow H^- + H$ Formation $j_{H^-} \approx 4\ mA/cm^2$

$e^- + H^- \rightarrow 2e^- + H$ Electron stripping **Losses** **$T_e < 2$ eV**

$H^+ + H^- \rightarrow H + H$ Mutual neutralisation **Losses** **low n_e**



Surface mechanism

$H\ (H_x^+) + \text{surface}\ e^- \rightarrow H^-$ Cs layer low work function

Formation **high H**

thin and homogeneous coverage of Cs at PG

Cs evaporation, redistribution

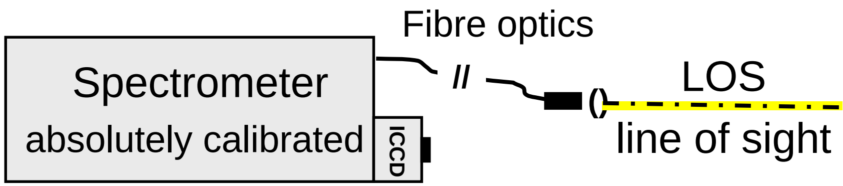
} **temporal behaviour**

Survival length of $H^- \approx$ few cm

Diagnostics of n_e, T_e, T_{gas}, H and H_2, Cs and Cs^+, H^- close to the grid

Optical Emission Spectroscopy (OES)

Simple experimental set-up



Survey spectrometer

- 200 - 900 nm, low resolution $\Delta\lambda \approx 1$ nm, time traces
- 200 - 780 nm, high resolution $\Delta\lambda \approx 0.3$ nm

Analysis (quite complex)

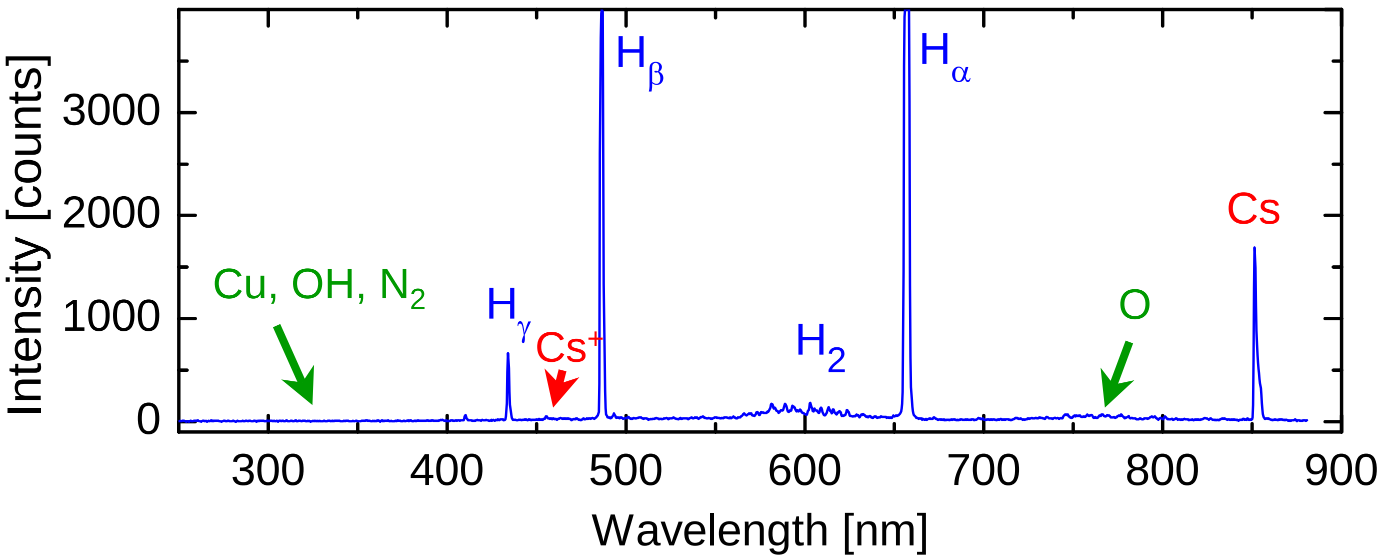
$$\varepsilon_{p,k} = n(p)\, A_{pk}$$

↓

Collisional radiative models

↓

$$\varepsilon_{pk} = n_0\, n_e\, X_{pk}^{eff}(T_e, n_e)$$

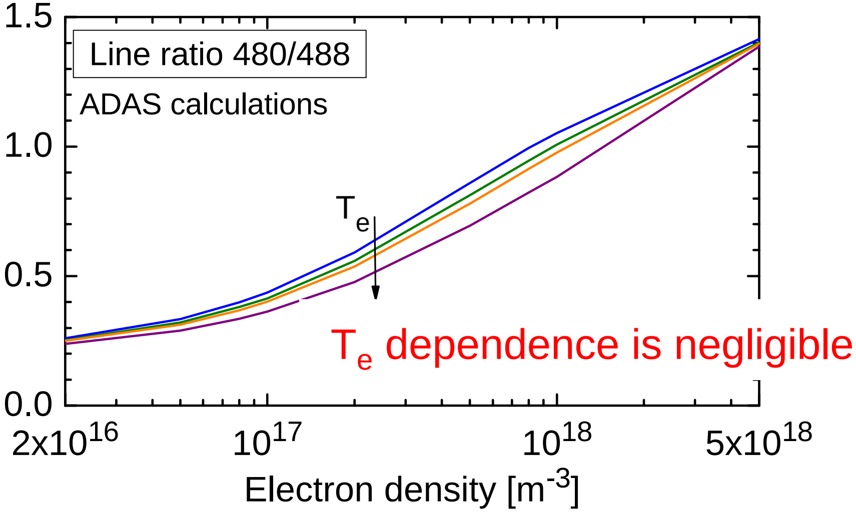


- Impurities
- Cs, Cs^+
- H from H_γ
- n_e from H_β/H_γ
- n_e, T_e diagnostic gas Ar
- H^- from H_α/H_β

Electron density and electron temperature using argon as diagnostic gas

Ar^+ line ratio is sensitive on electron density

$$\frac{\varepsilon_{480}^{Ar^+}}{\varepsilon_{488}^{Ar^+}} = \frac{\cancel{n_{Ar^+}}\ \cancel{n_e}\ X_{480}^{Ar^+}(T_e,n_e)}{\cancel{n_{Ar^+}}\ \cancel{n_e}\ X_{488}^{Ar^+}(T_e,n_e)}$$

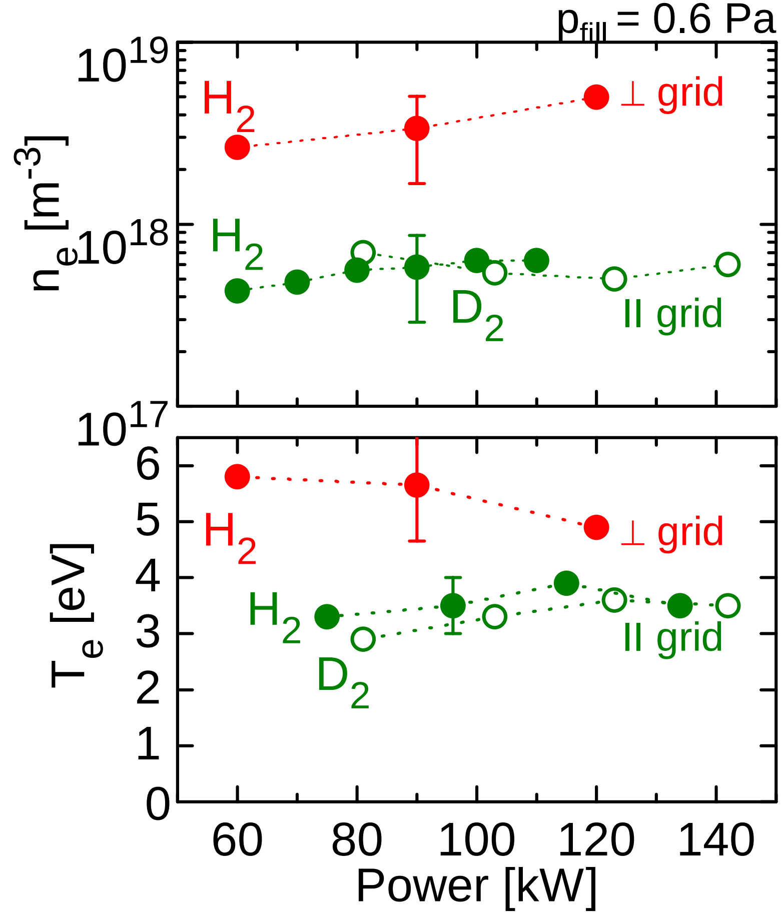


Absolute line intensity for T_e diagnostics

$$\varepsilon_{ph}^{Ar} = n_{Ar}\ n_e\ X_{750}^{Ar}(T_e)$$

needs n_{Ar} and n_e (and EEDF)

BATMAN

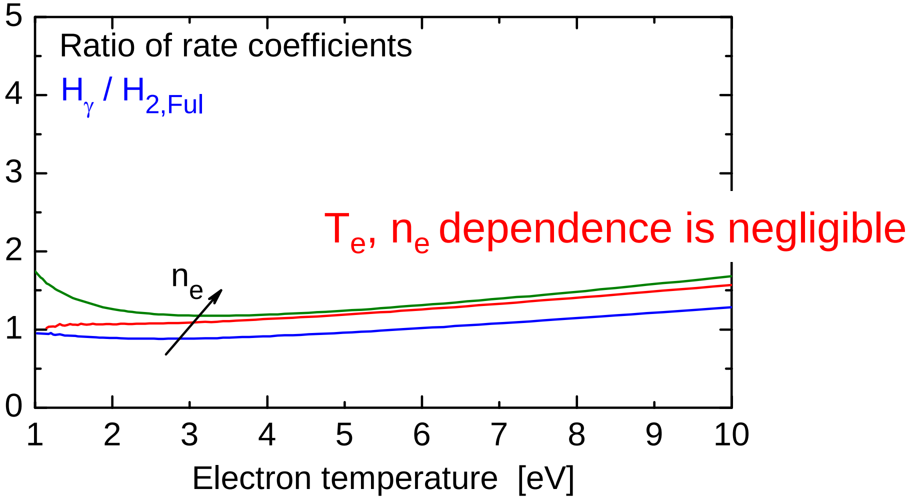


Langmuir probe confirms n_e
but lower T_e II grid : $T_e \approx 1$ eV

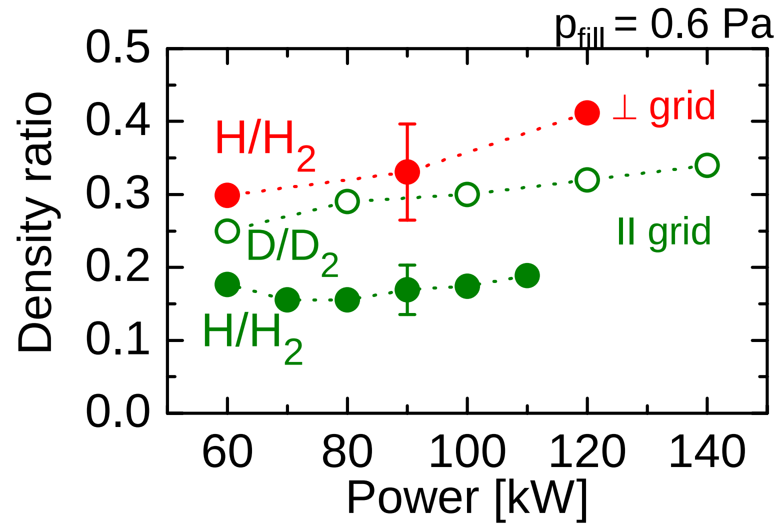
Atomic and molecular hydrogen

Line ratio method ⇨ Density ratio H/H2

$$\frac{\varepsilon^{H}_{H\gamma}}{\varepsilon^{H_2}_{Ful}} = \frac{n_H \, \cancel{n_e} \, X^{H}_{H\gamma}(T_e,n_e)}{n_{H_2} \, \cancel{n_e} \, X^{H_2}_{Ful}(T_e,n_e)}$$



BATMAN



- $H/H_2 \approx 0.15 – 0.2$ (|| grid)
- More atoms in deuterium
- Similar n_e for H_2 and D_2
- Lower T_e for D_2

T_{gas}= 1200 K ± 300 K

|| grid, obtained from H_2 Fulcher radiation

More negative ions expected in D_2 than in H_2

Particle density from line intensity

Cs: $\varepsilon_{852}^{Cs} = n_{Cs}\, n_e\, X_{852}^{Cs}(T_e)$

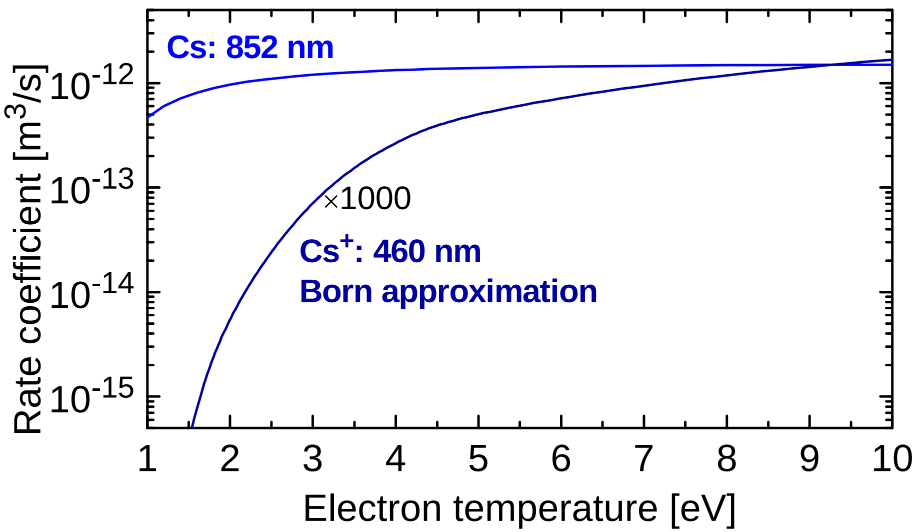
needs n_e, almost independent of T_e

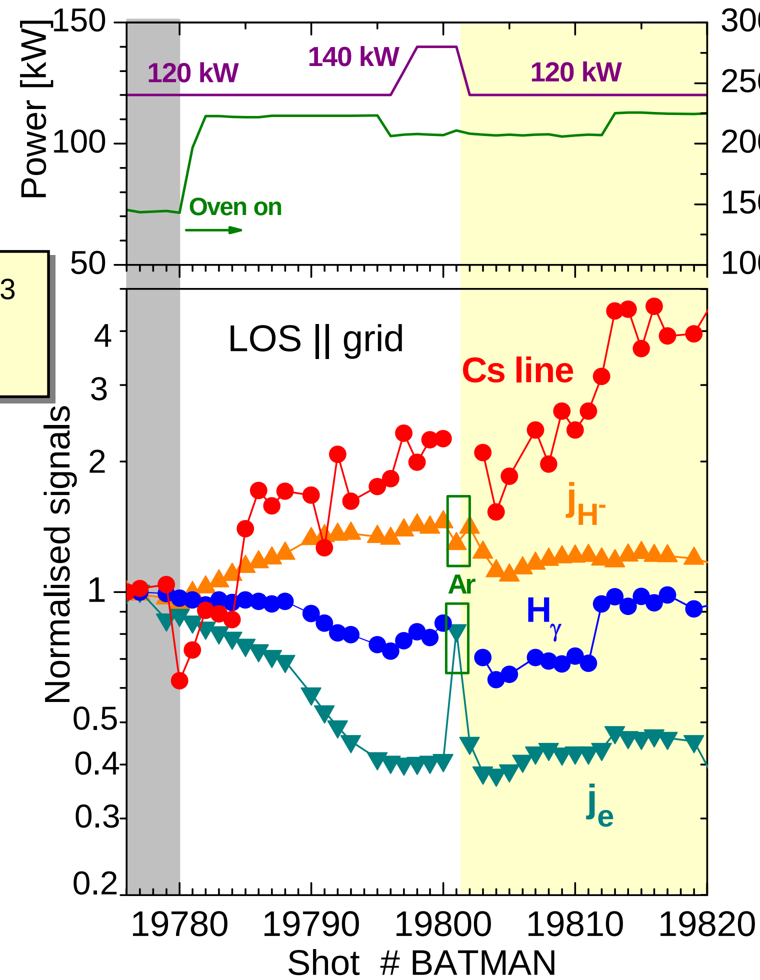
Cs^+: $\varepsilon_{460}^{Cs^+} = n_{Cs^+}\, n_e\, X_{460}^{Cs^+}(T_e)$

needs n_e, strong dependence on T_e

Cs = 10^{14} - 10^{15} m^{-3}

$Cs^+/Cs \approx 30$





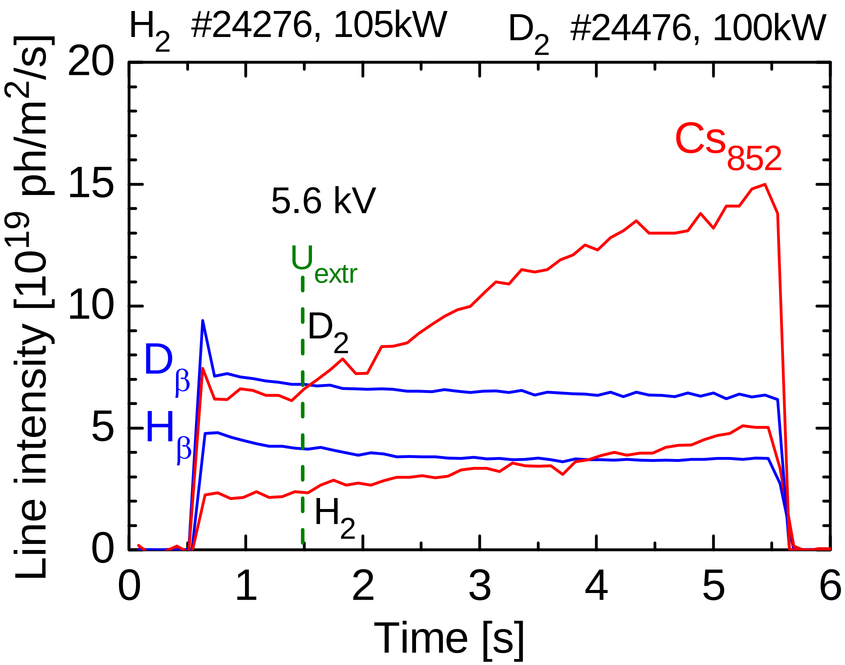
Cs and j_{H^-}:	correlation	no correlation
H_γ and j_e:	correlation	correlation

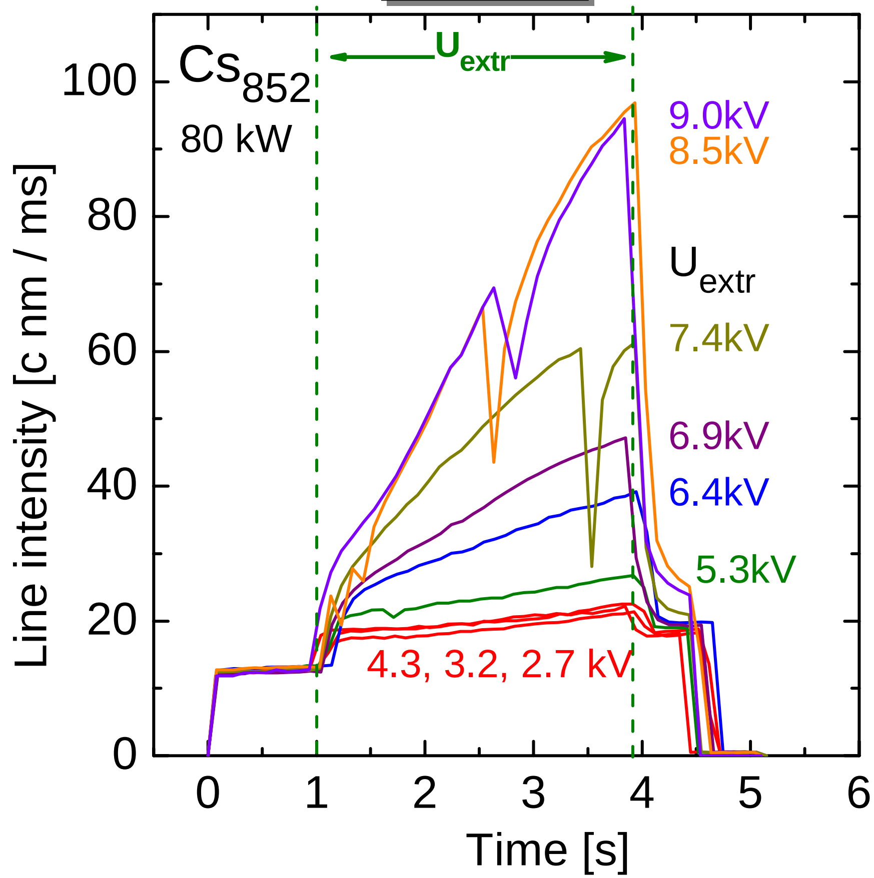
Time traces of cesium and hydrogen lines

BATMAN

LOS II grid

MANITU





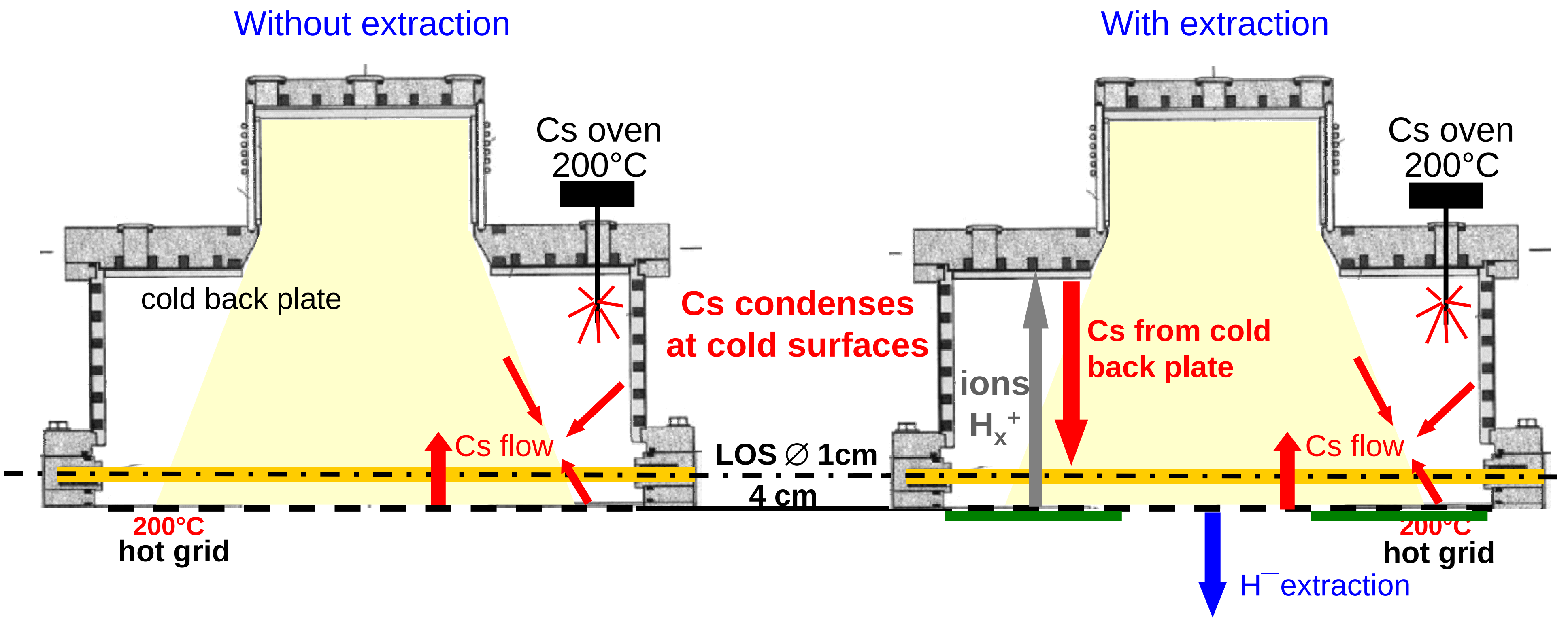
- More Cs and higher H_β in D_2
- Weak dependence on extraction
- Increase typically a factor 2-3
- Ar increases Cs signals by a factor of 10

- Strong dependence on U_{extr}
- Indication of a threshold

Masked grid (20% to length of LOS)

Grid length ≈ length of LOS

Cs dynamics in the RF source



Cs from evaporation and surfaces

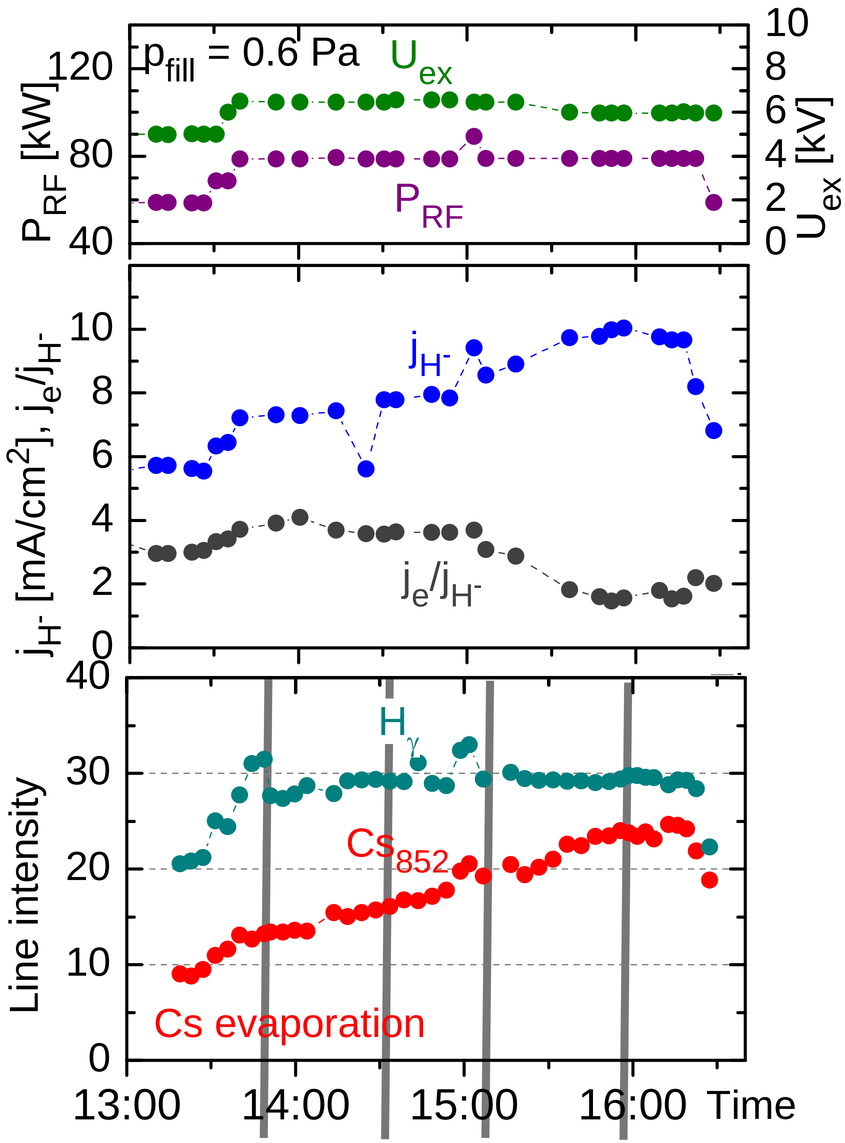
Enhanced Cs sputtering from back plate

H^+, H_2^+, H_3^+, Cs^+

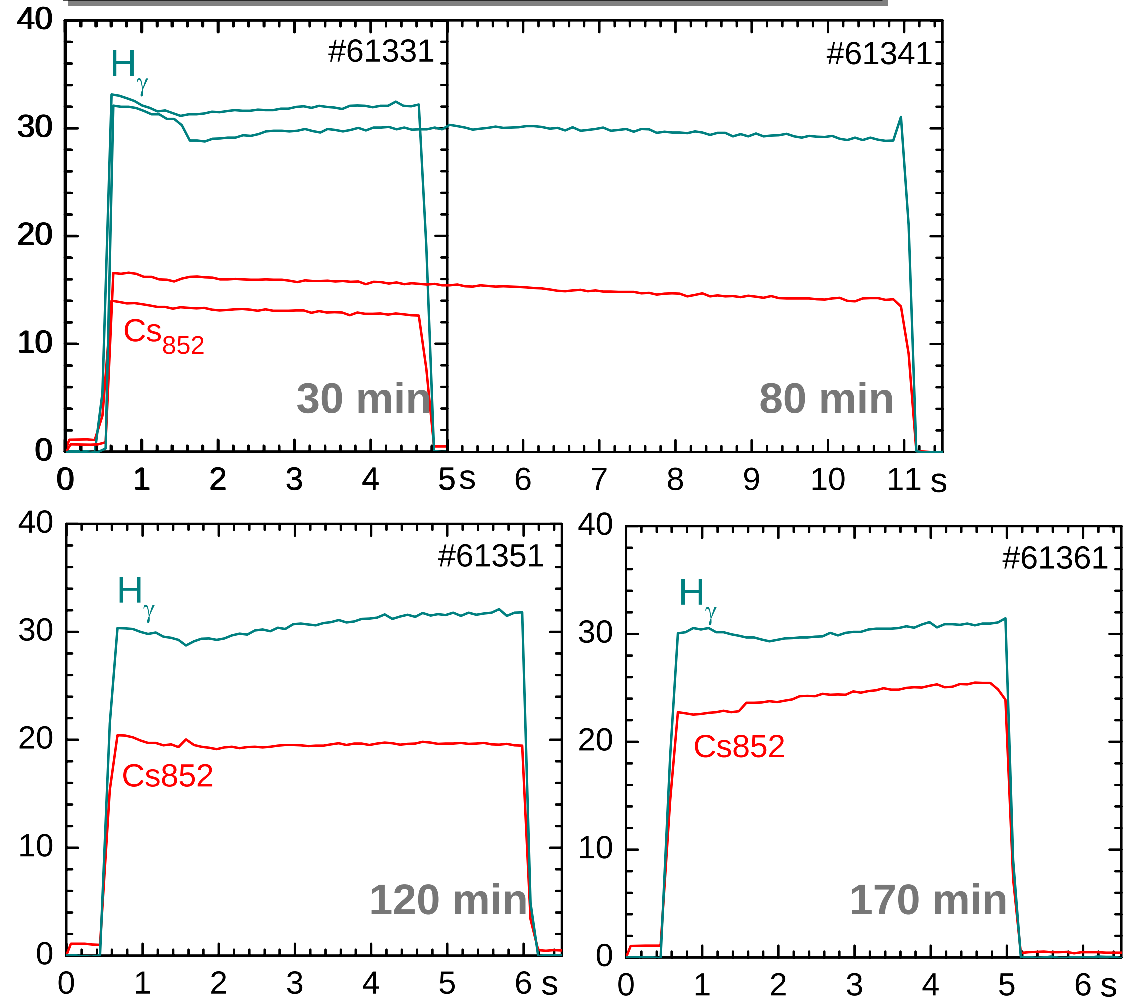
with dependence on $E_{ion} \equiv U_{extr}$

Masked grid of BATMAN prevents ion flux to back plate

Cs intensity parallel to grid used as monitor for cesium balance



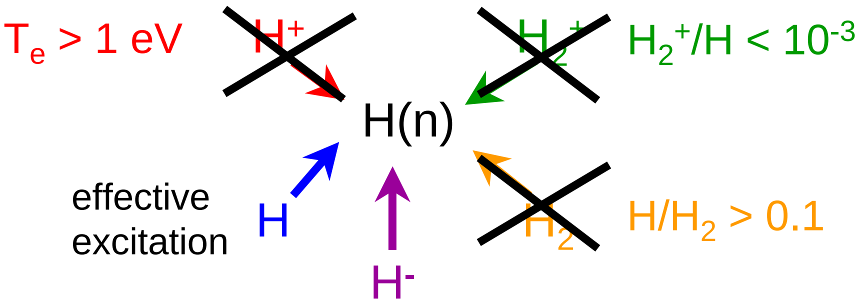
Time traces during evaporation: MANITU



Clear trends in Cs signals

H^- volume density monitored by Balmer line ratios

Population mechanisms for H



mutual neutralisation

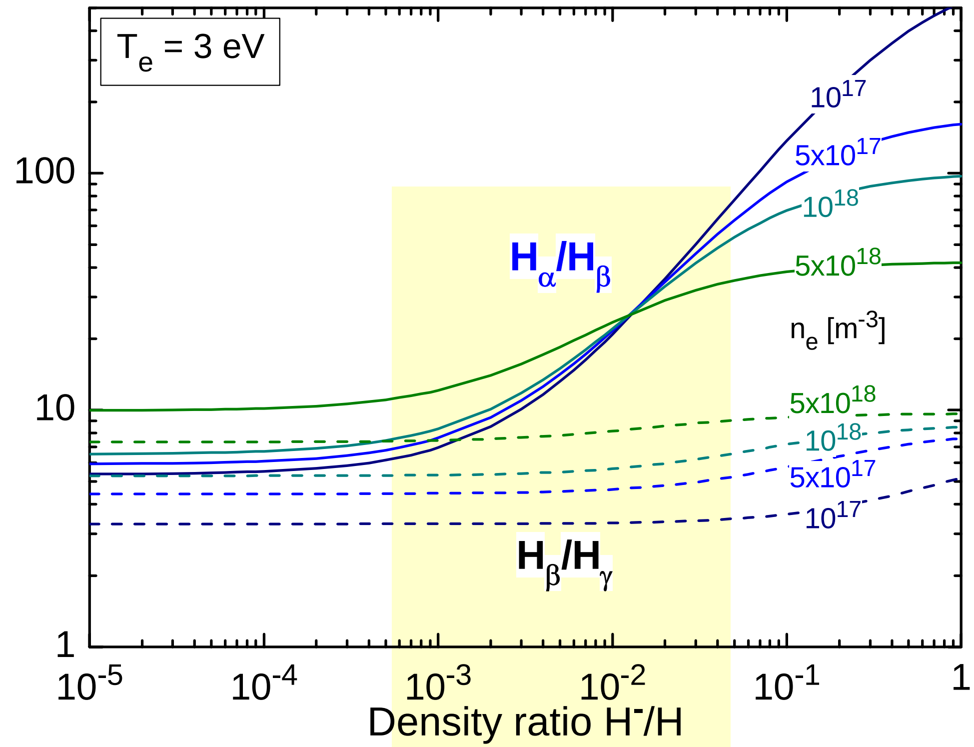
$$H^+ + H^- \rightarrow H(n=3) + H$$

$\downarrow H_\alpha$

Collisional radiative model

Novel diagnostic technique for H^-

Line ratios depend on n_e, T_e and H^-/H



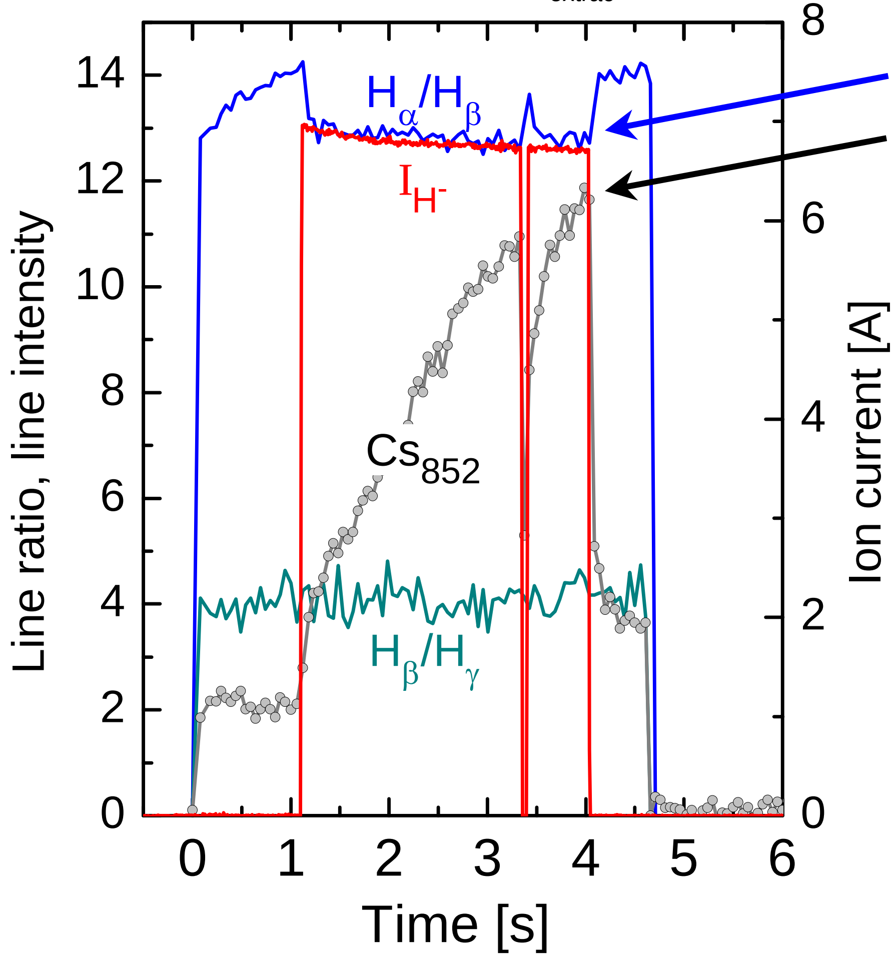
H_α/H_β depends on H^-

H_β/H_γ reflects n_e and T_e

H^- volume density monitored by Balmer line ratios

MANITU

LOS II grid, 4 cm distance



H^- = 1×10^{17} m^{-3}

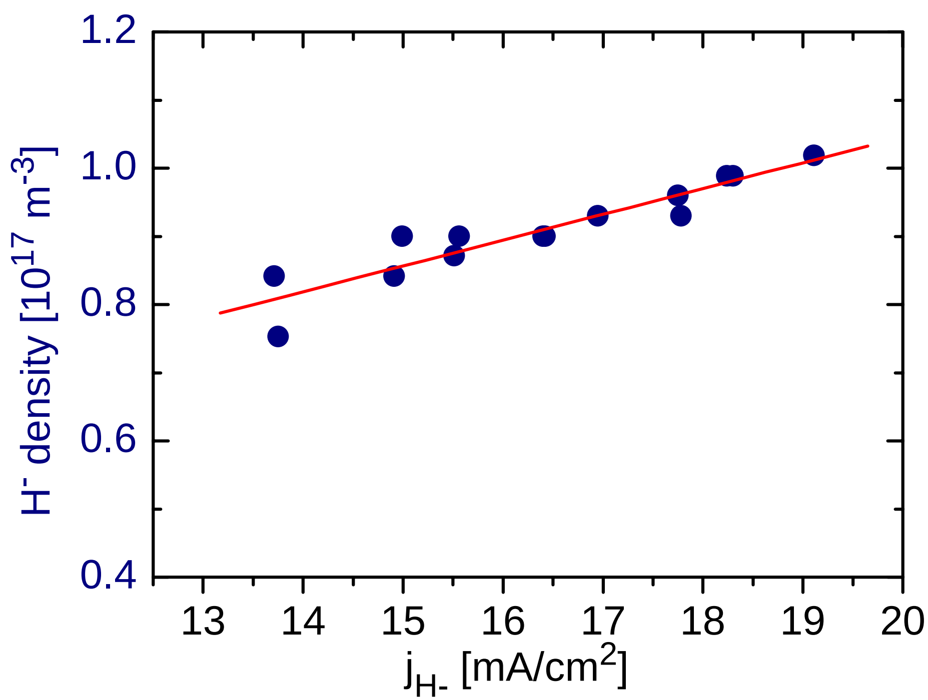
Cs = 1×10^{15} m^{-3}

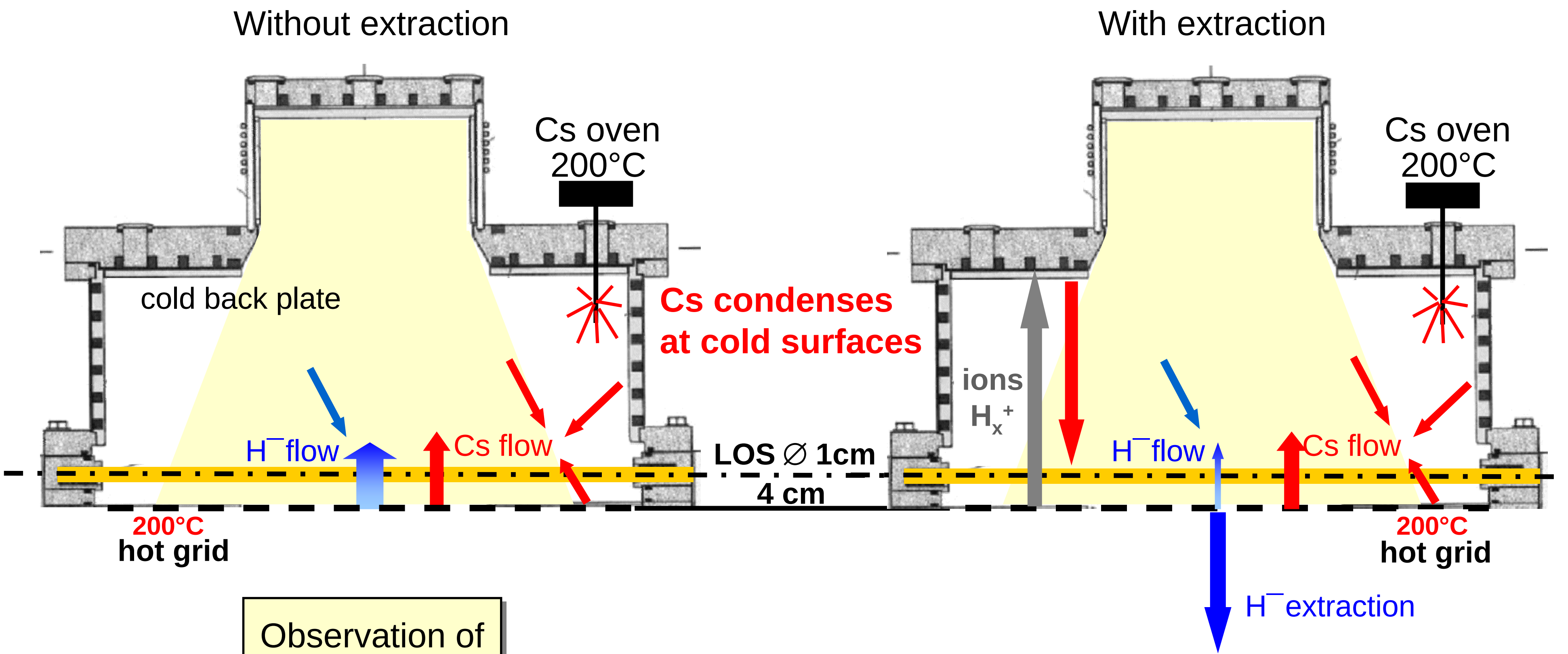
BATMAN: $D^- > H^-$ (factor of 1.5)
LOS (2 cm) > LOS (4 cm)

H^-(w/o Cs) = 1-2$\times10^{16}$ m^{-3} corresponds to j_{H^-} = 2-4 mA/cm^2

H^- formation by volume processes with Cs can be excluded

Correlation of volume density with extracted current





Observation of

- Cs from evaporation and surfaces
- H$^-$ from volume formation
- H$^-$ from surface effect at grid with few cm penetration depth

Less H$^-$ from surface effect

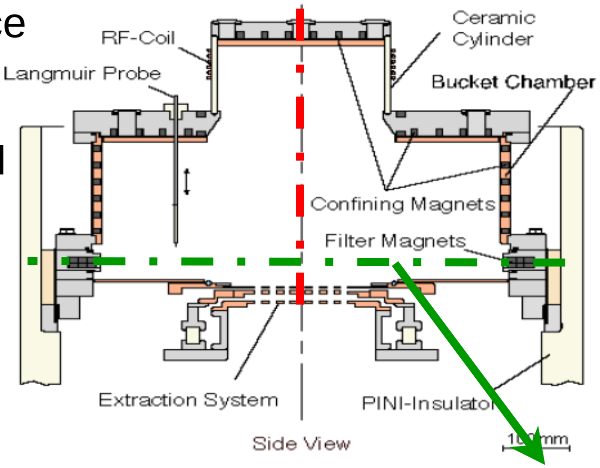
Enhanced Cs sputtering from back plate

in observation volume

Comparison between RF and arc sources

RF source at IPP

BATMAN
MANTU



p = 0.3 Pa

H_2 discharges

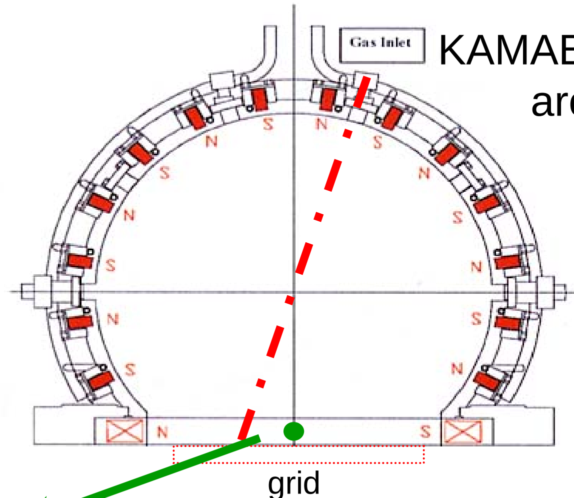
110 kW 45 kW

LOS averaged results

40mm 17mm

KAMABOKO III arc source at CEA

MANTIS

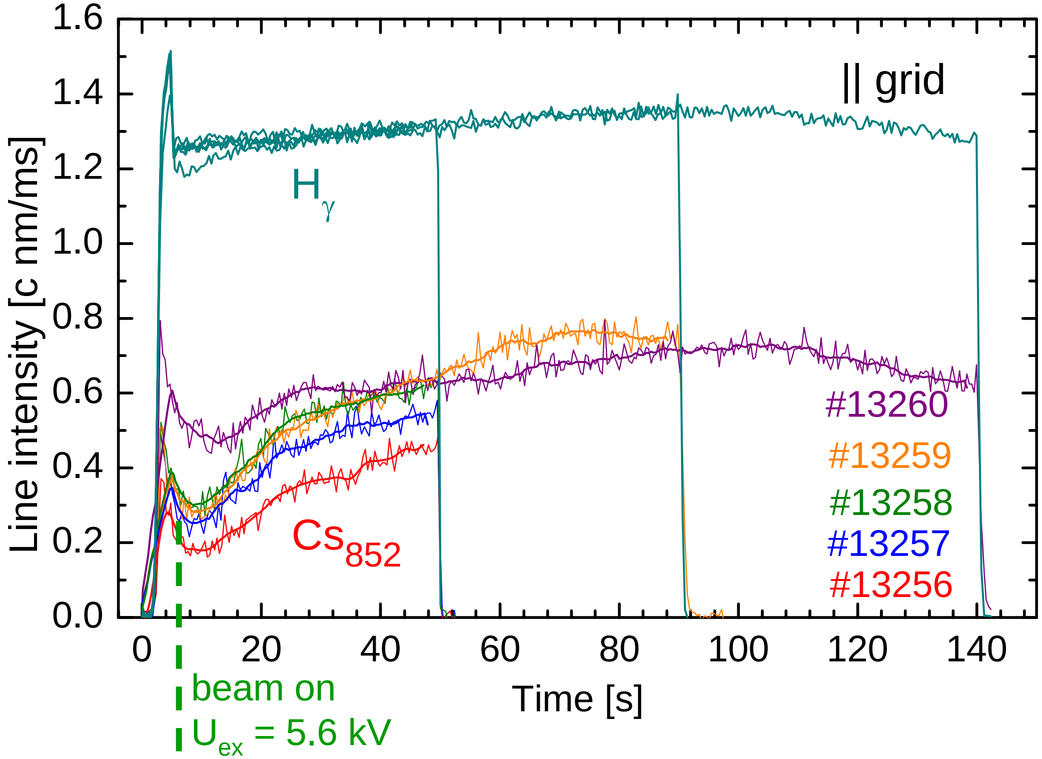


⊥ grid (RF)	II grid (RF)		II grid (arc)	⊥ grid (arc)	
2×10^{19}	4×10^{19}	n_0	1×10^{19}	1×10^{19}	m^{-3}
5×10^{18}	5×10^{17}	n_e	2×10^{18}	5×10^{18}	m^{-3}
5.0	3.0	T_e	2.0	5.0	eV
0.4	0.2	H/H_2	0.7	0.5	
-	1×10^{14}	Cs	5×10^{12}	7×10^{13}	m^{-3}
-	4×10^{15}	Cs^+	2×10^{16}	2×10^{17}	m^{-3}
		W	5×10^{13}	1×10^{14}	m^{-3}
-	2×10^{16}	H^- w/o Cs	2×10^{16}	-	m^{-3}
-	1×10^{17}	H^- with Cs	5×10^{16}	-	m^{-3}

(j_{H^-} = 20mA/cm²) (RF) **(j_{H^-} = 12mA/cm²)** (arc)

Monitoring of cesium in the arc source

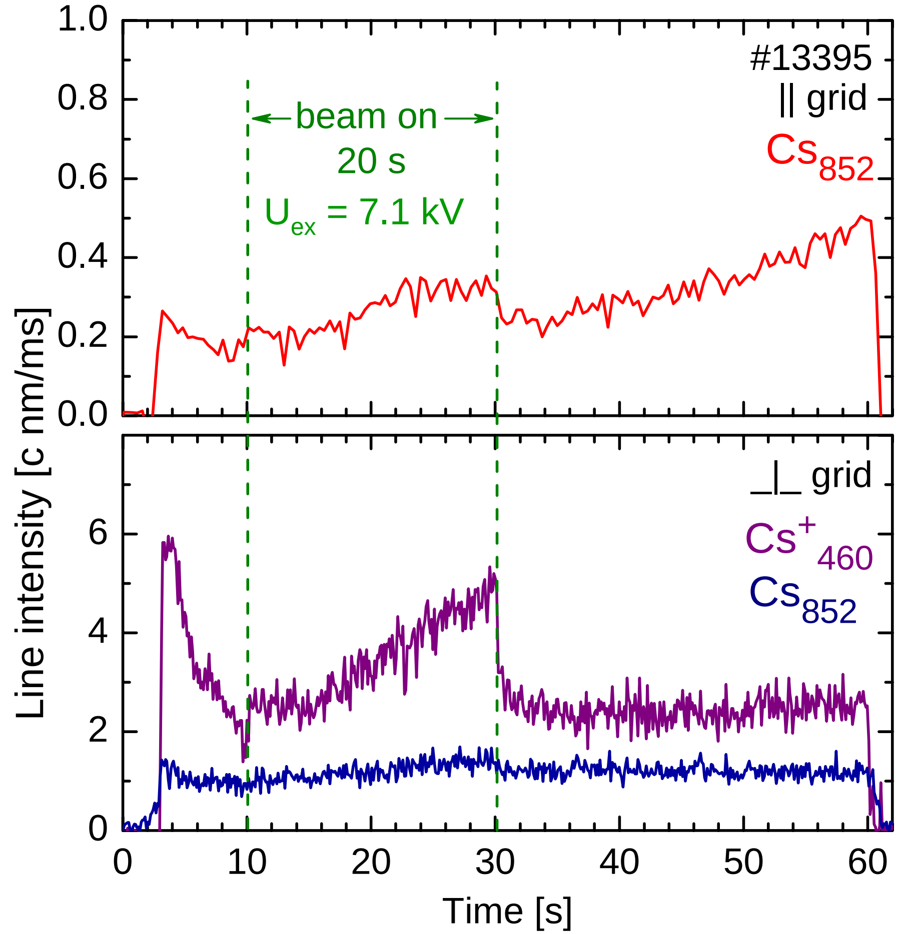
MANTIS: Cs evaporation



- Reproducible H_γ signal
- Increase in Cs signal
- Cs saturates for longer pulses

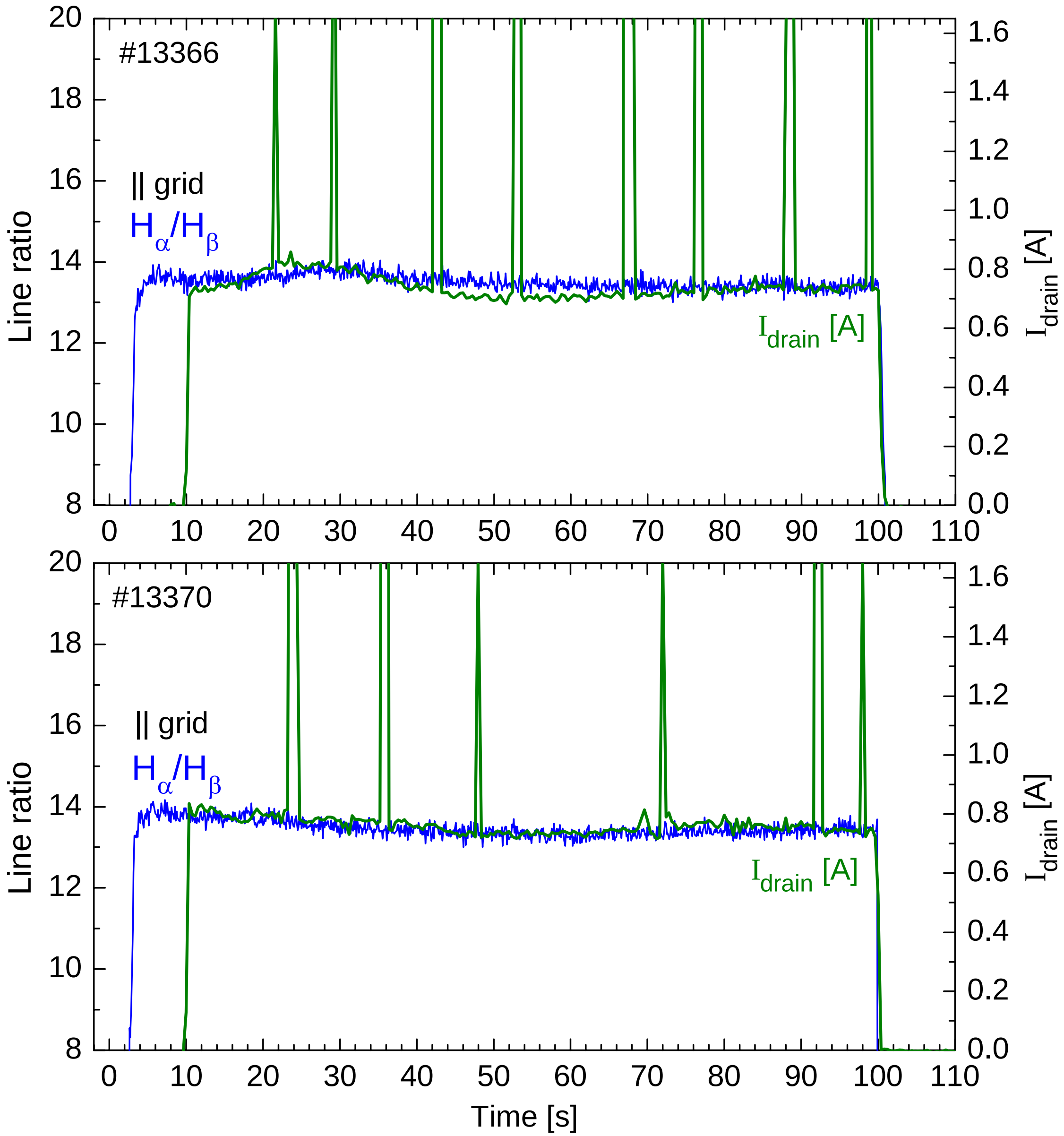
MANTIS: oven closed

- Redistribution during beam on time
- || and ⊥ grid with different shape



Different Cs signals for evaporation and redistribution

Monitoring of H^- in the arc source



H_α/H_β correlates with I_{drain}

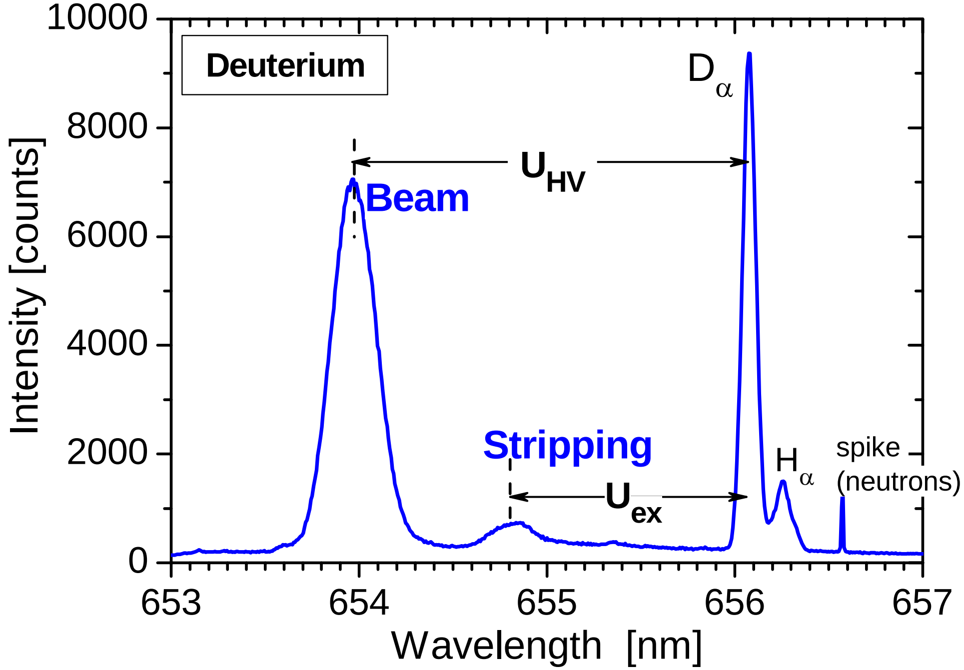
LOS || grid, 17 mm

H^- volume density = 5×10^{16} m^{-3}

j_{H^-drain} = 18 mA/cm^2, j_{H^-cal} = 10 mA/cm^2

H_α beam diagnostics

Analysis of Doppler-shifted peaks



In operation at BATMAN

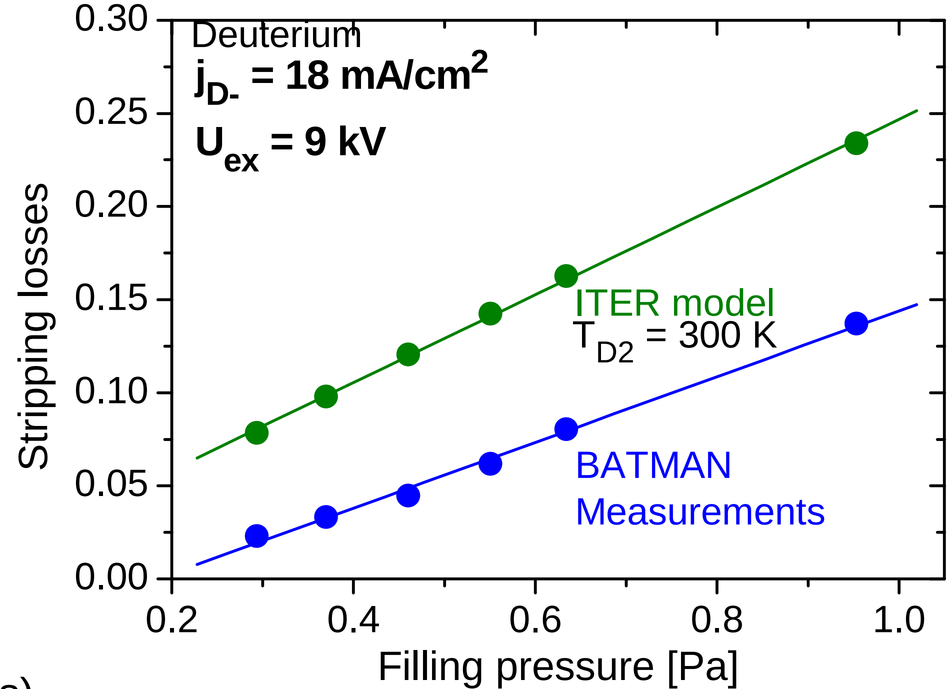
- LOS at 150 cm distance to extraction system
- Mean angle 52° w.r.t. beam axis

Planned as standard diagnostics at MANITU

- Spatially resolved measurements (20 channels)

Results for stripping losses

- Linear dependence on p_{fill}
- Higher values from ITER like model
- Agreement for T_{D2} = 1000 K
- 8% stripping losses at p_{fill} = 0.6 Pa



Spectroscopy – A powerful diagnostic tool in source development

- Diagnostics of plasma parameters n_e, T_e, T_{gas}, densities H, H_2 and impurities

  H$^-$ formation and destruction processes | correlations with j_e | plasma stability

- Monitoring and quantification of Cs, Cs^+ and W in plasma volume

  cesium evaporation and redistribution | tungsten impurities

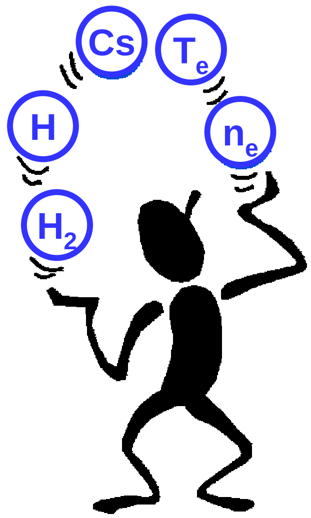
- Novel diagnostic technique for H$^-$ (line ratio method: H_α/H_β)

  correlations with j_{H^-}

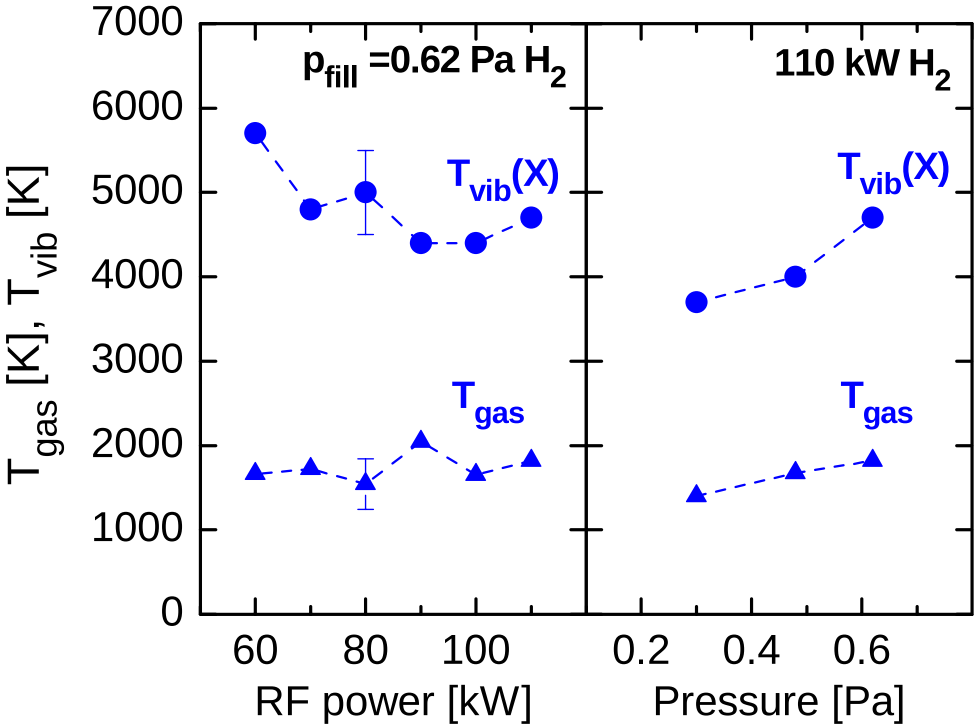
- Valuable results from time traces

- Comparison between RF and arc discharges

- Quantification of stripping losses by H_α beam spectroscopy



Rotational and vibrational population of molecular hydrogen

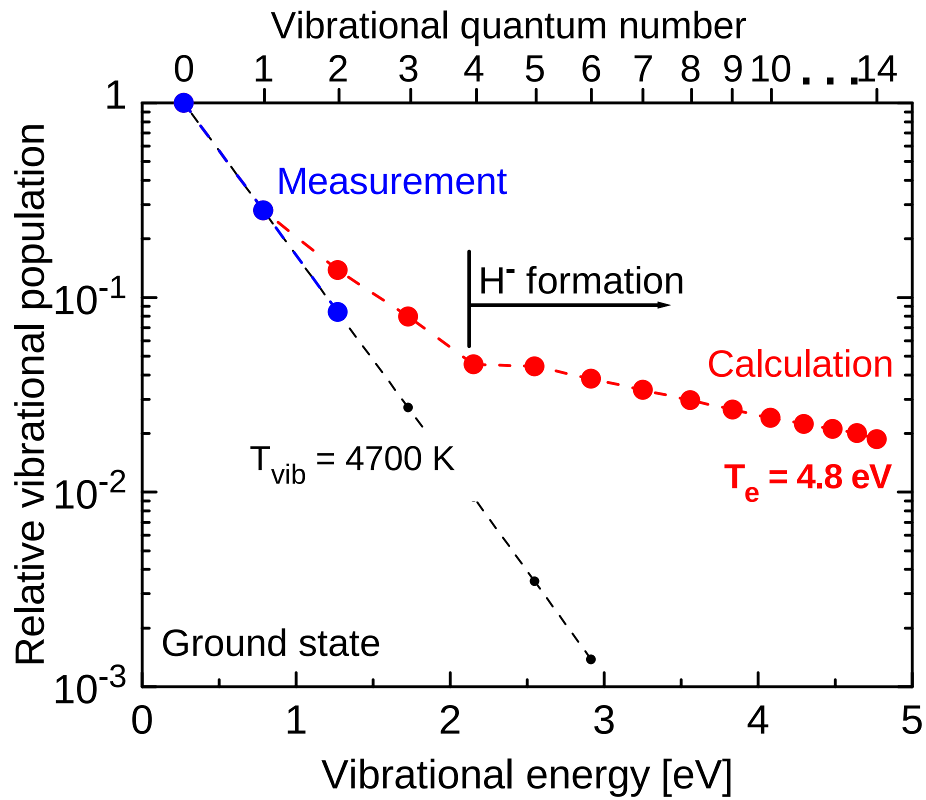


obtained from H_2 Fulcher radiation

T_{gas}= 1200 K ± 300 K

Combination of measurements with modelling

Collisional radiative model for H_2 and D_2



Modelling complete measurements