MAX-PLANCK-INSTITUT
FÜR PLASMAPHYSIK

Ultra-low work function of caesiated surfaces and impact of specific hydrogen plasma species

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This work has been carried out within the framework of the EUROfusion Consortium, funded by the European Union via the Euratom Research and Training Programme (Grant Agreement No 101052200 — EUROfusion). Views and opinions expressed are, however, those of the authors only and do not necessarily reflect those of the European Union or the European Commission. Neither the European Union nor the European Commission can be held responsible for them.

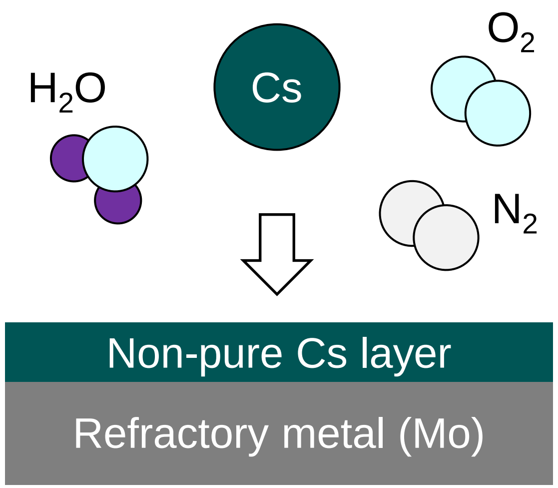
Surface caesiation for the enhancement of H⁻ production

Increase of negative ionization yield of H and H_x^+ on surfaces by decreasing the work function

→ Work function decrease of extraction electrode surface at ion sources via Cs adsorption

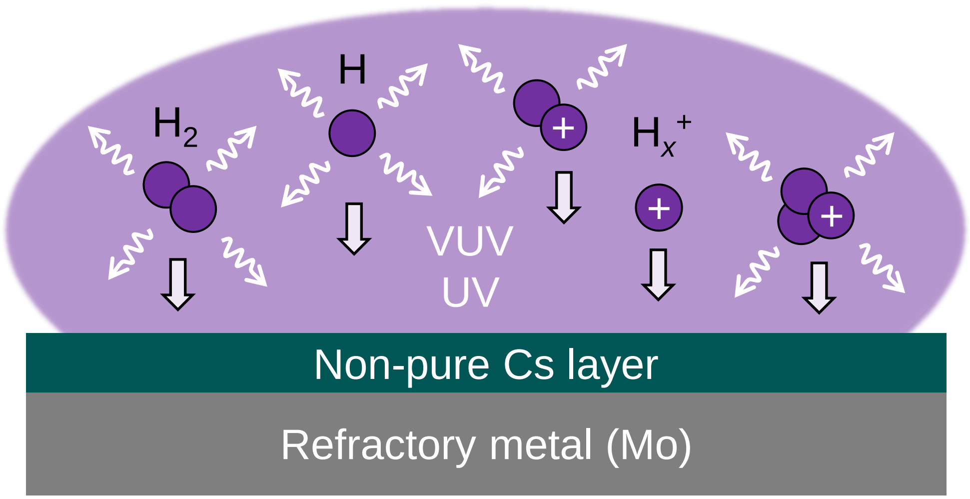
Caesiation in non-UHV:

Co-deposition of Cs and residual gases



Plasma interaction with caesiated surfaces:

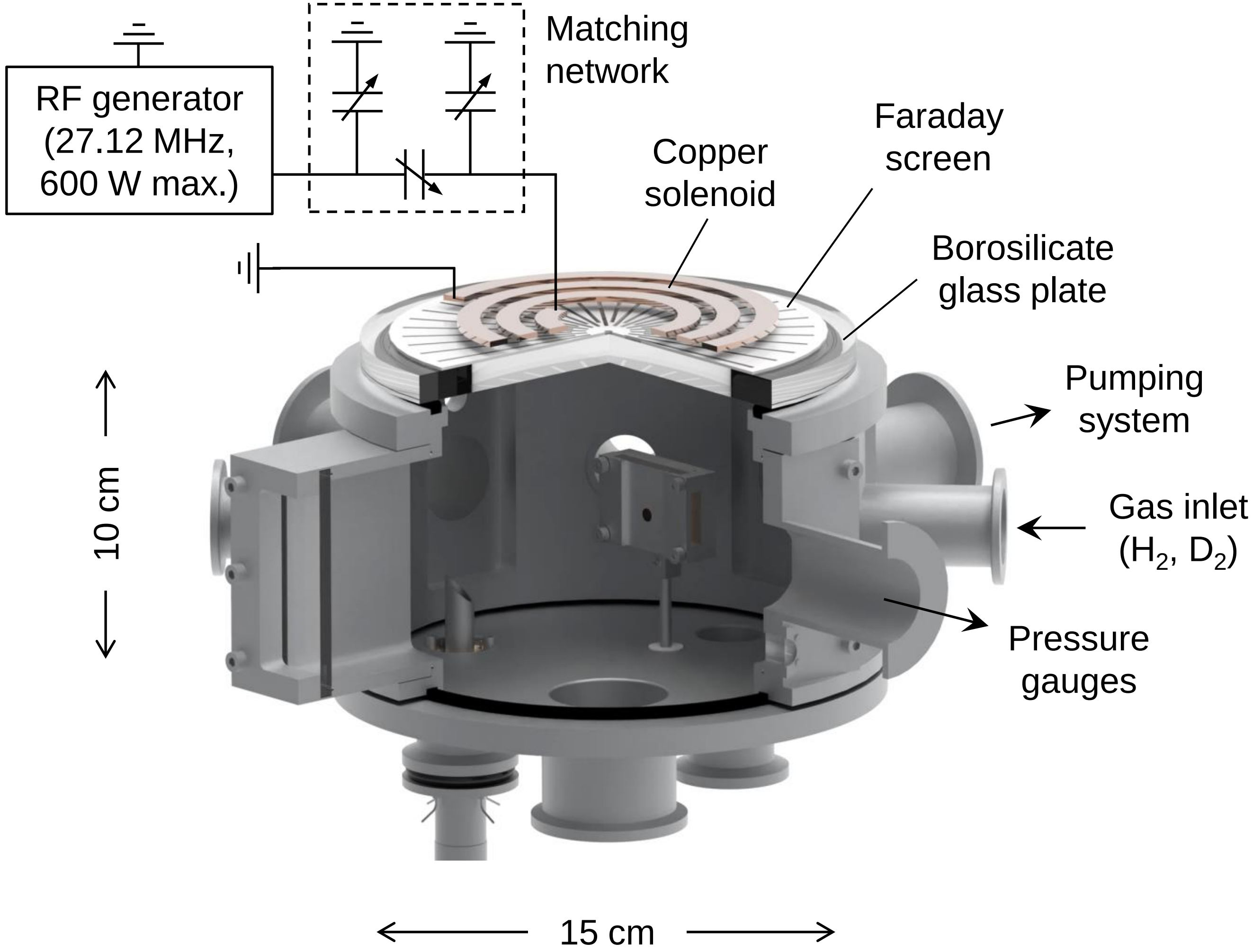
Cs redistribution, change of chemical composition



Pronounced temporal work function dynamics ☞ S. Cristofaro *et al.*, *Plasma Res. Express* **2**, 035009 (2020)

Experimental setup ACCesS

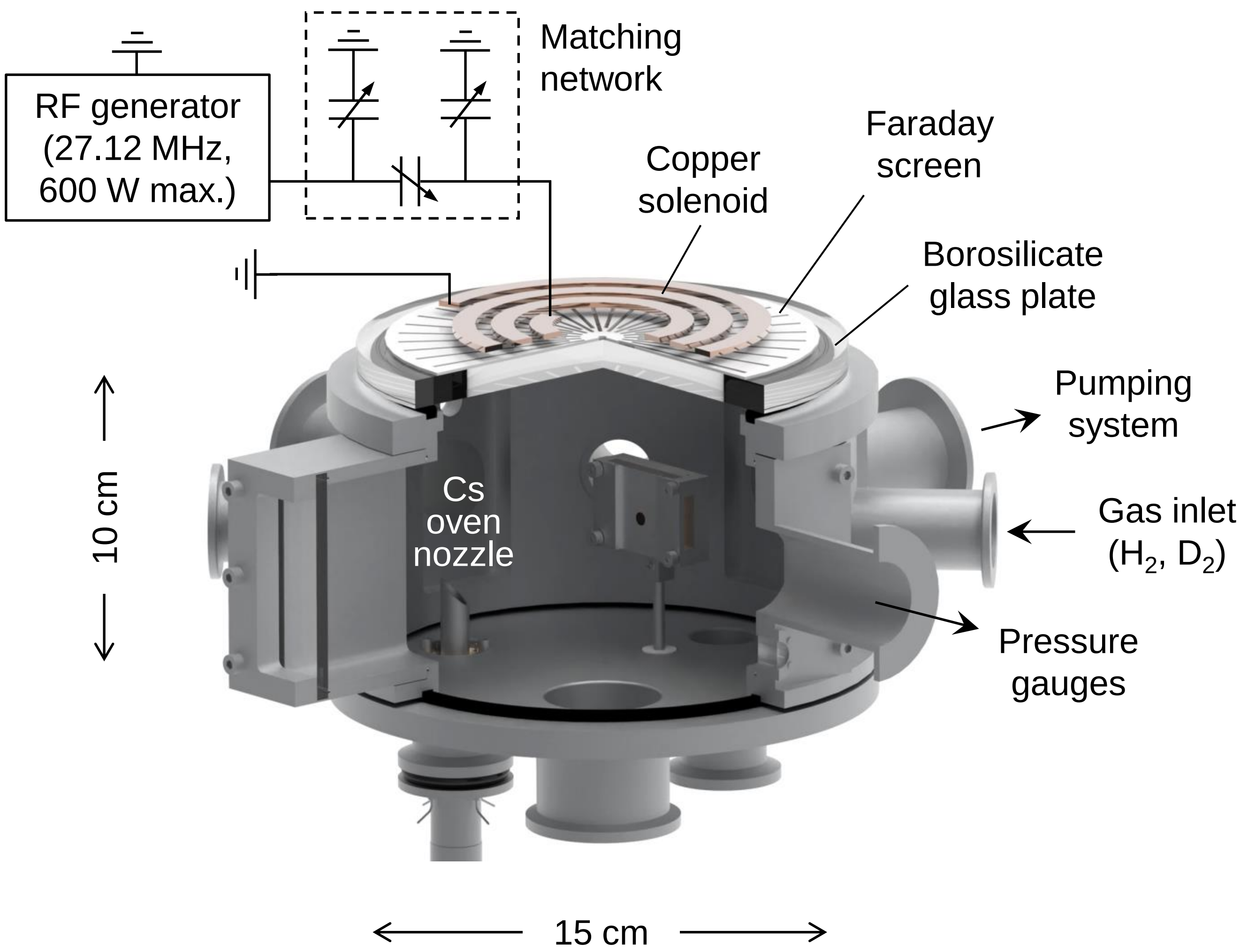
ICP experiment equipped with in situ work function diagnostic



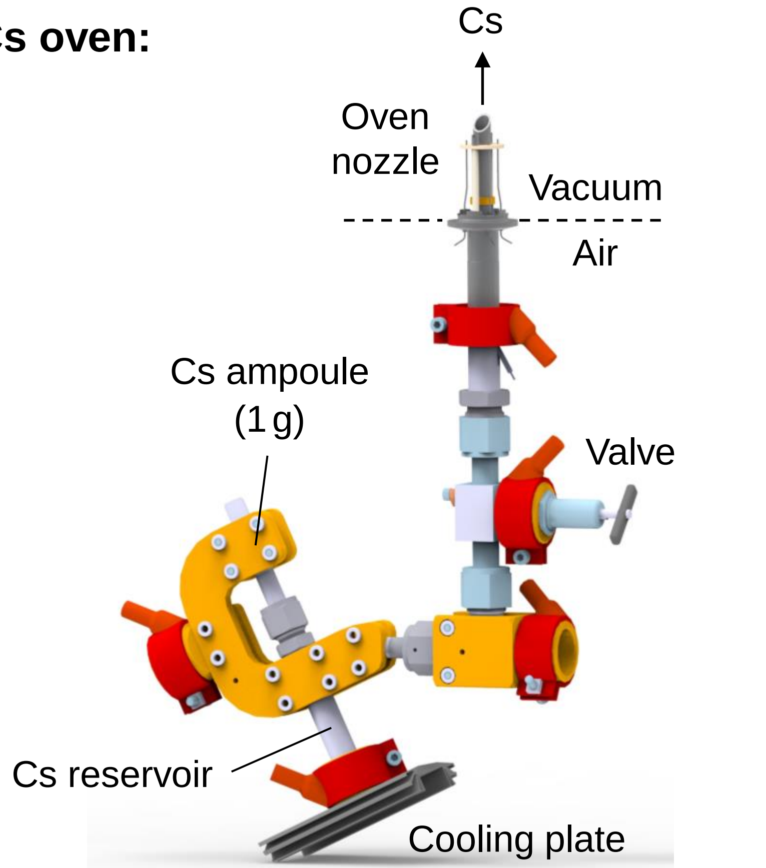
Base pressure: 10^{-6} – 10^{-5} mbar

→ Relevant to ion sources for fusion (BUG and ELISE @ IPP, SPIDER @ NBTF)

Experimental setup ACCesS
ICP experiment equipped with in situ work function diagnostic



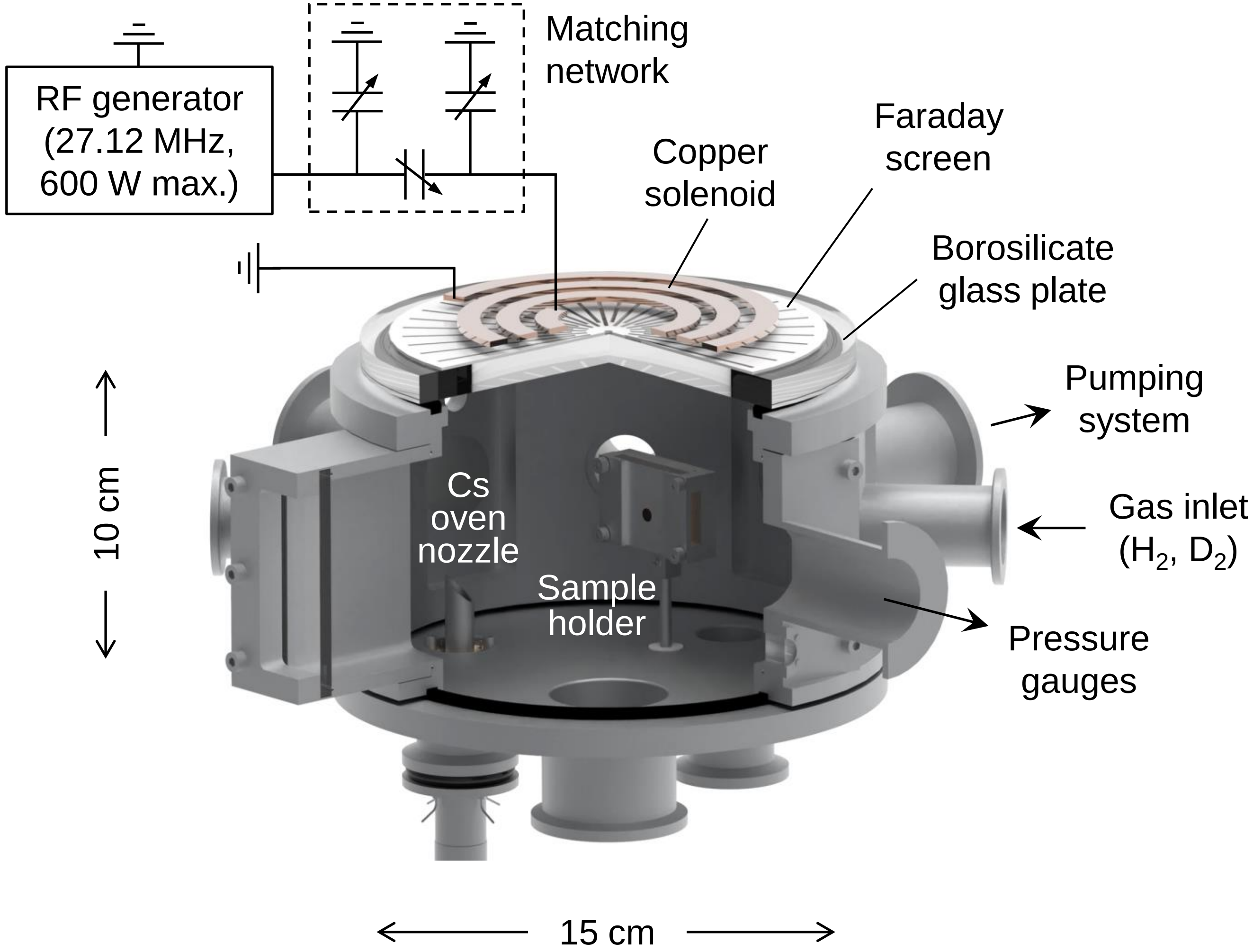
Cs oven:



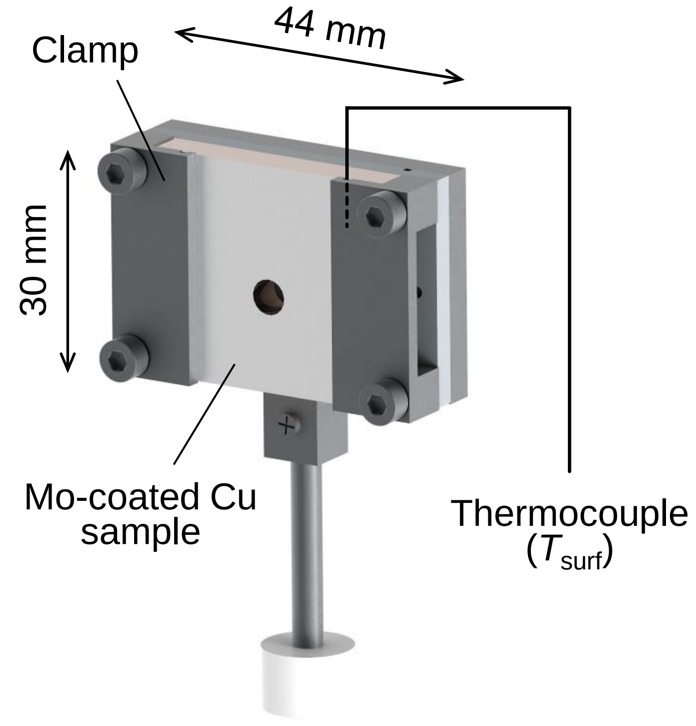
☞ S. Cristofaro *et al.*, *Rev. Sci. Instrum.* **90**, 113504 (2019)

Experimental setup ACCesS

ICP experiment equipped with in situ work function diagnostic



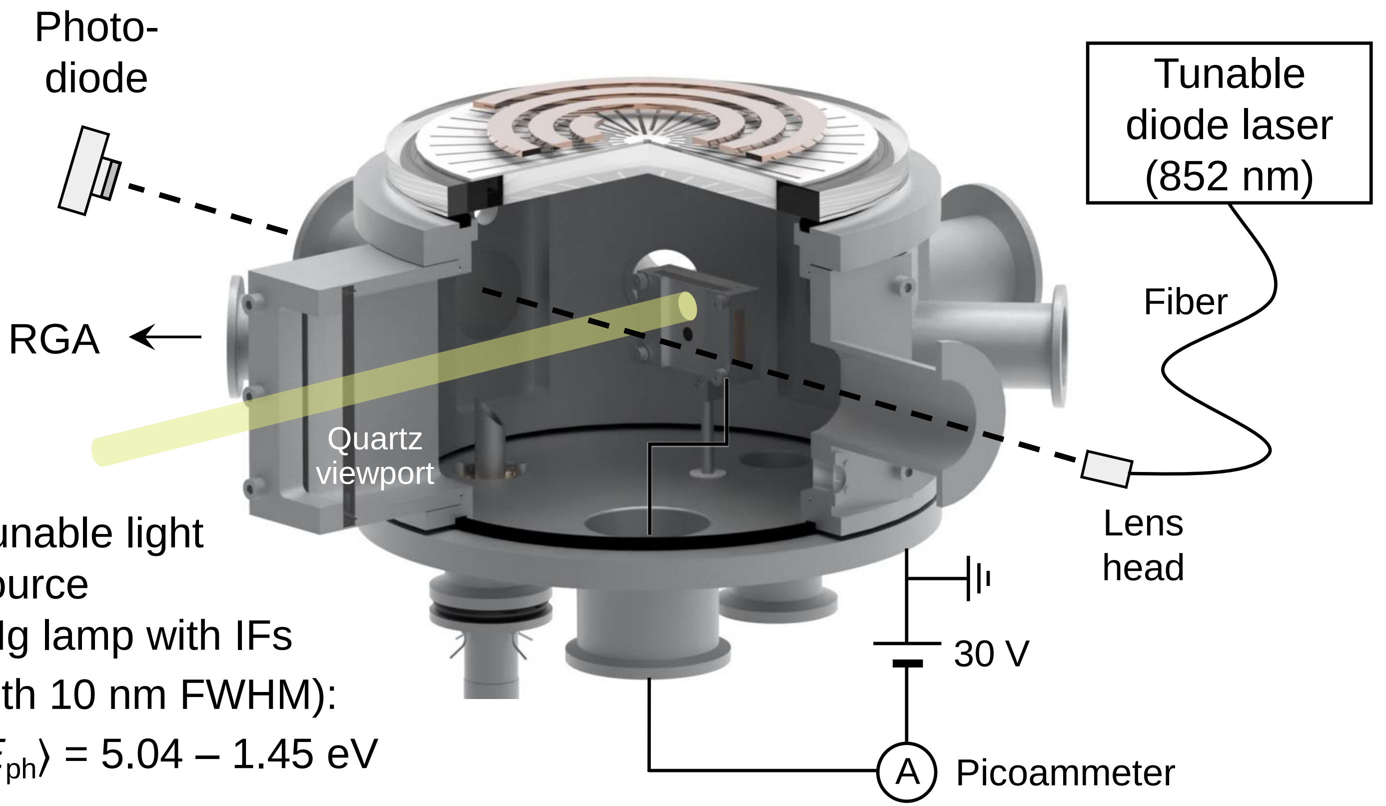
Sample holder:



→ Heatable up to 1000 °C

Experimental setup ACCesS

ICP experiment equipped with in situ work function diagnostic



Tunable light source (Hg lamp with IFs with 10 nm FWHM):
$\langle E_{ph} \rangle = 5.04 – 1.45$ eV

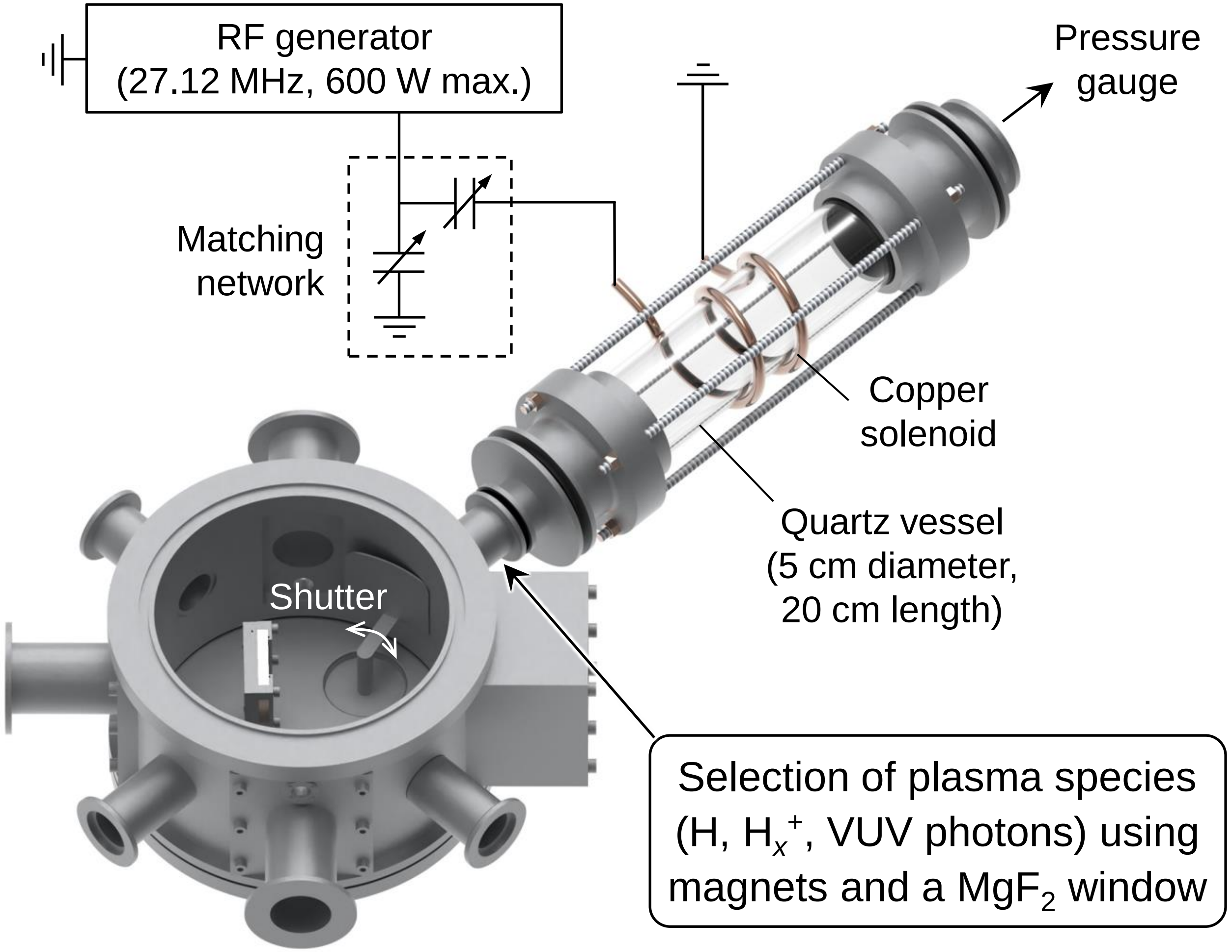
Diagnostics:

- Work function (WF) via photoelectric effect (Fowler method)
  → Improved threshold sensitivity
  ☞ A. Heiler *et al.*, *AIP Adv.* **12**, 035339 (2022)
- Neutral Cs density via TDLAS
- Gas composition monitored with RGA
- Plasma parameters:
  - Langmuir probe (Γ_{i+})
  - OES (Γ_{H})
  - VUV diagnostic (Γ_{VUV})

  ☞ R. Friedl *et al.*, A flexible diagnostic system for the quantification of VUV fluxes emitted from plasmas, submitted to *Meas. Sci. Technol.* (2022)

Upgrade of ACCesS experiment

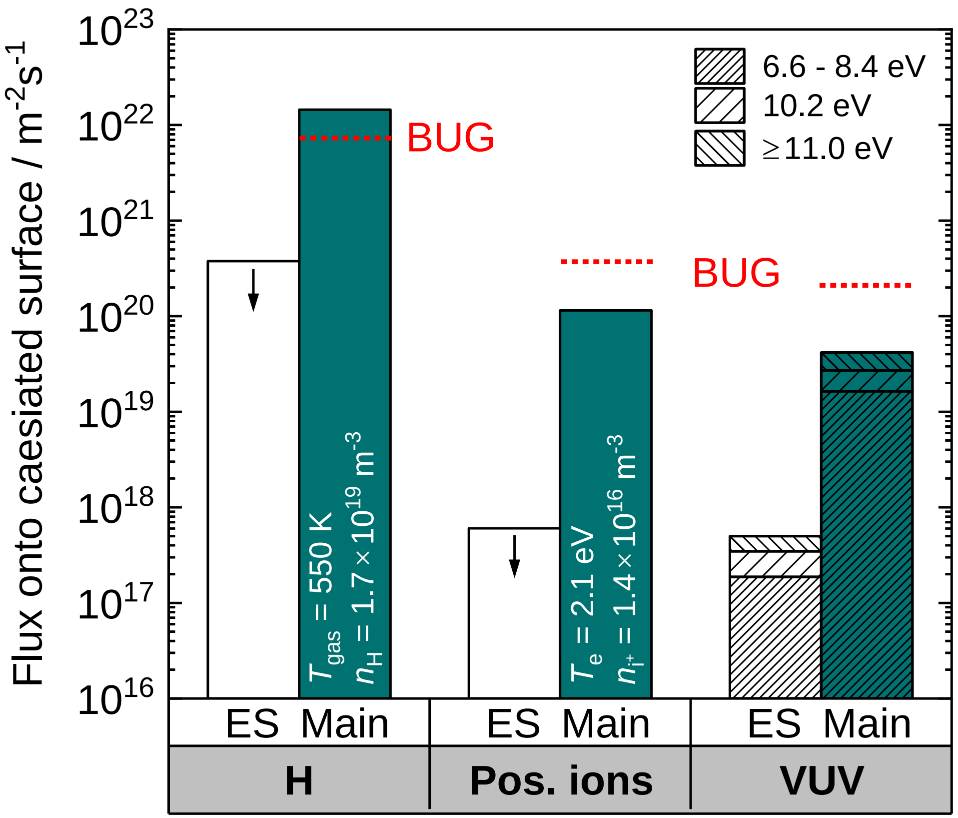
External ICP source for selective exposure to hydrogen plasma species



Selection of plasma species (H, H_x^+, VUV photons) using magnets and a MgF_2 window

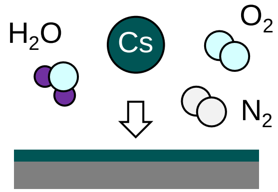
Fluxes onto caesiated surface from

- external source (ES) (10 Pa / 400 W)
- plasma in main vessel (Main) (10 Pa / 250 W)

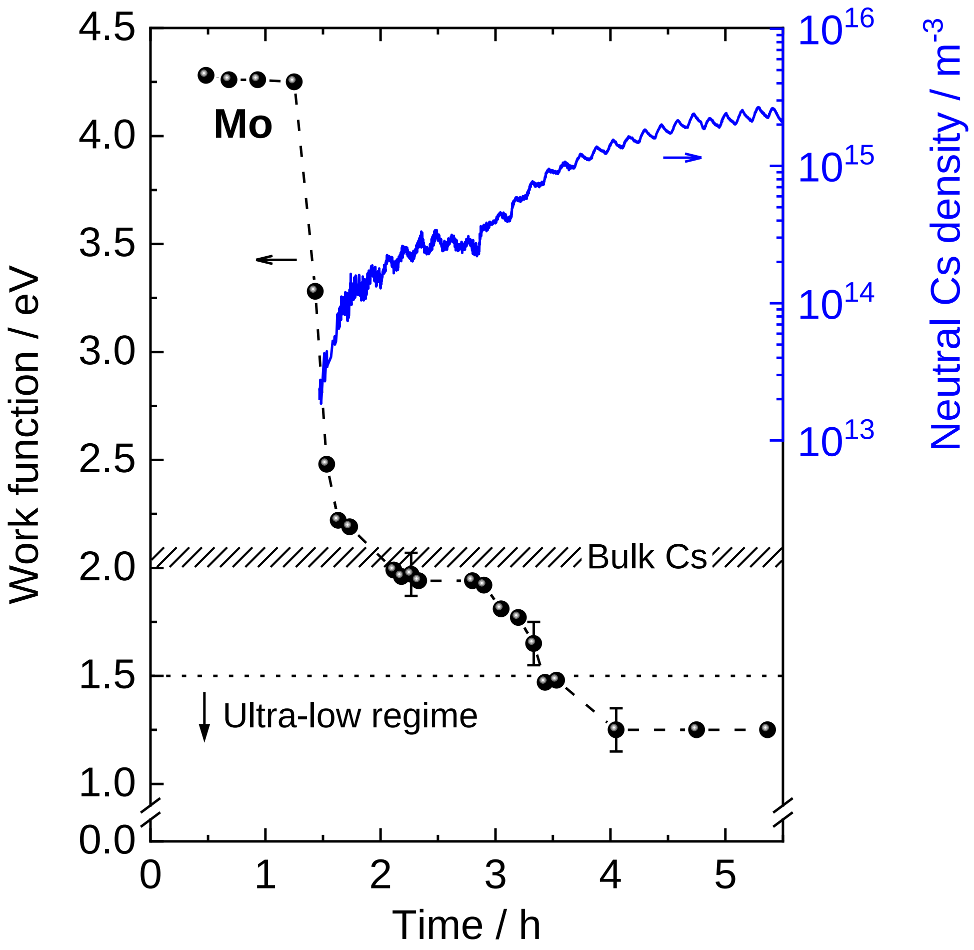


Caesiation under vacuum conditions of 10^{-6} – 10^{-5} mbar

Formation of ultra-low work function layer on Mo



☞ A. Heiler *et al.*, *AIP Adv.* **12**, 035339 (2022)

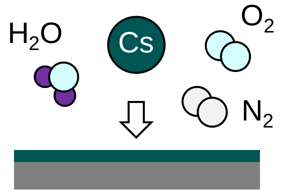


Presence of Cs submonolayer coverage can be excluded:

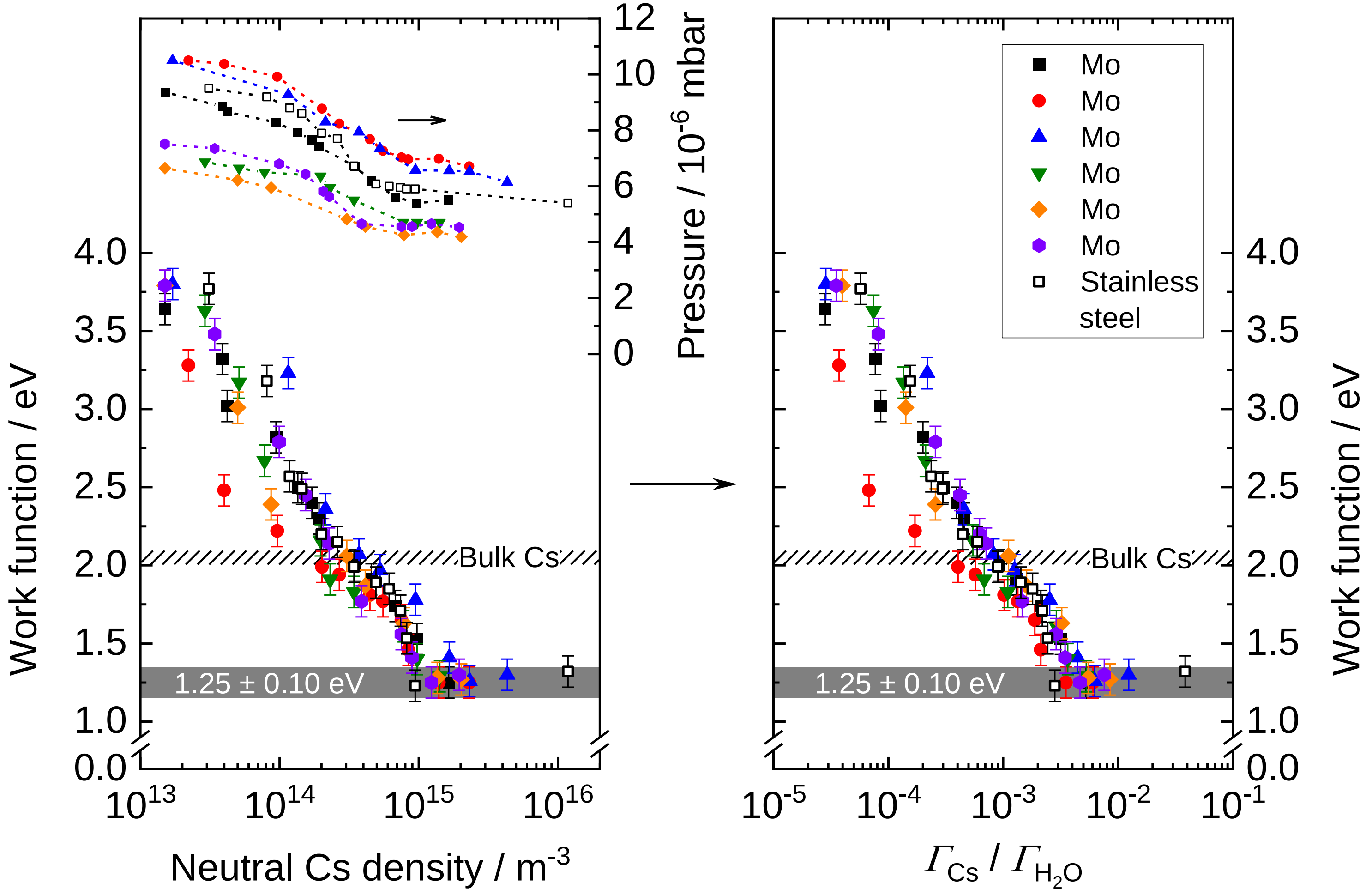
- WF_{min} achievable with Cs coverage < 1 ML = 1.54 eV
  Swanson and Strayer, *J. Chem. Phys.* **48**, 2421 (1968)
- No WF increase with increasing Cs fluence
- Cs coating visible by eye

Growth of thick oxidized Cs layer due to reactions between Cs and residual H_2O

Caesiation under vacuum conditions of 10^{-6} – 10^{-5} mbar
Compilation of various caesiation processes



☞ A. Heiler *et al.*, *AIP Adv.* **12**, 035339 (2022)

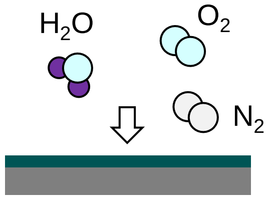


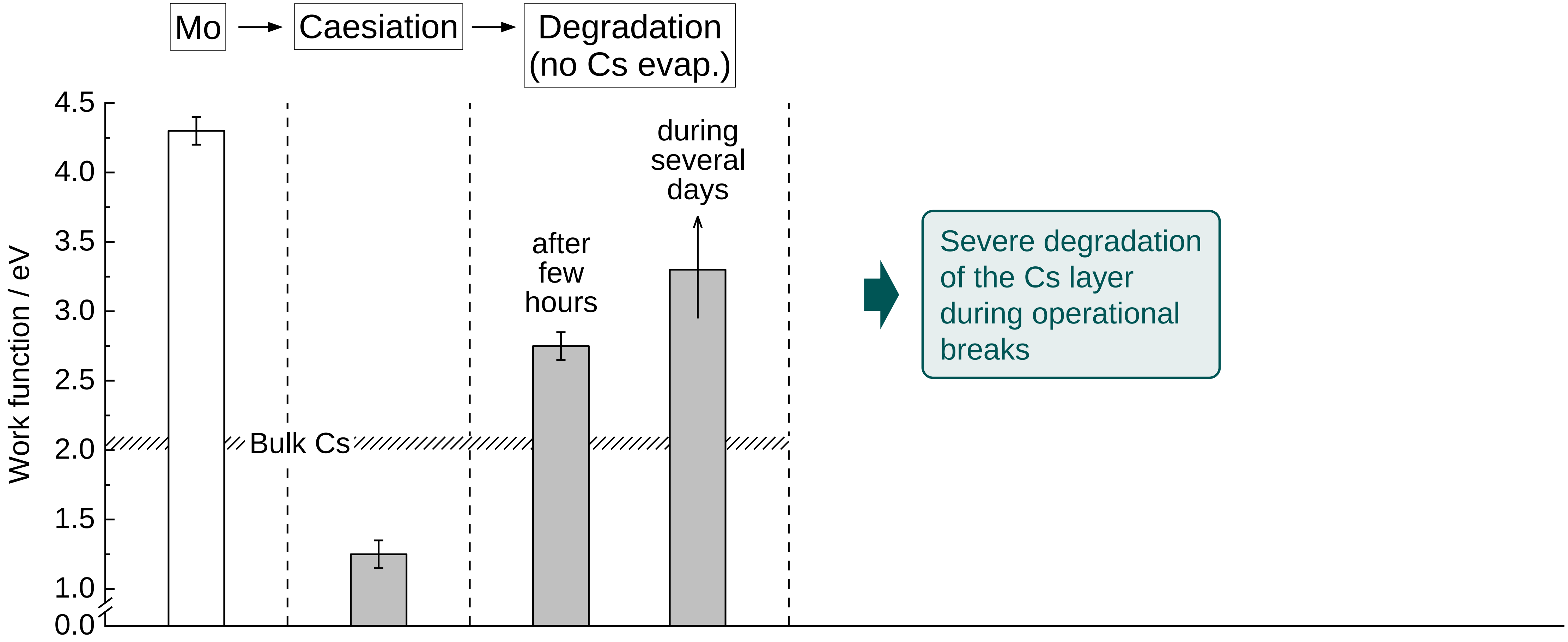
Excellent reproducibility:

- WF ~ 2 eV with Cs densities ~ 10^{14} m^{-3}
- WF = 1.2 – 1.3 eV with Cs densities ≳ 10^{15} m^{-3}, corresponding to a flux ratio of $\Gamma_{Cs}/\Gamma_{H_2O} \gtrsim 5 \times 10^{-3}$

At BUG and ELISE ion sources:
$\Gamma_{Cs}/\Gamma_{H_2O} = 3 – 9 \times 10^{-3}$

Degradation under vacuum conditions of 10^{-6} – 10^{-5} mbar

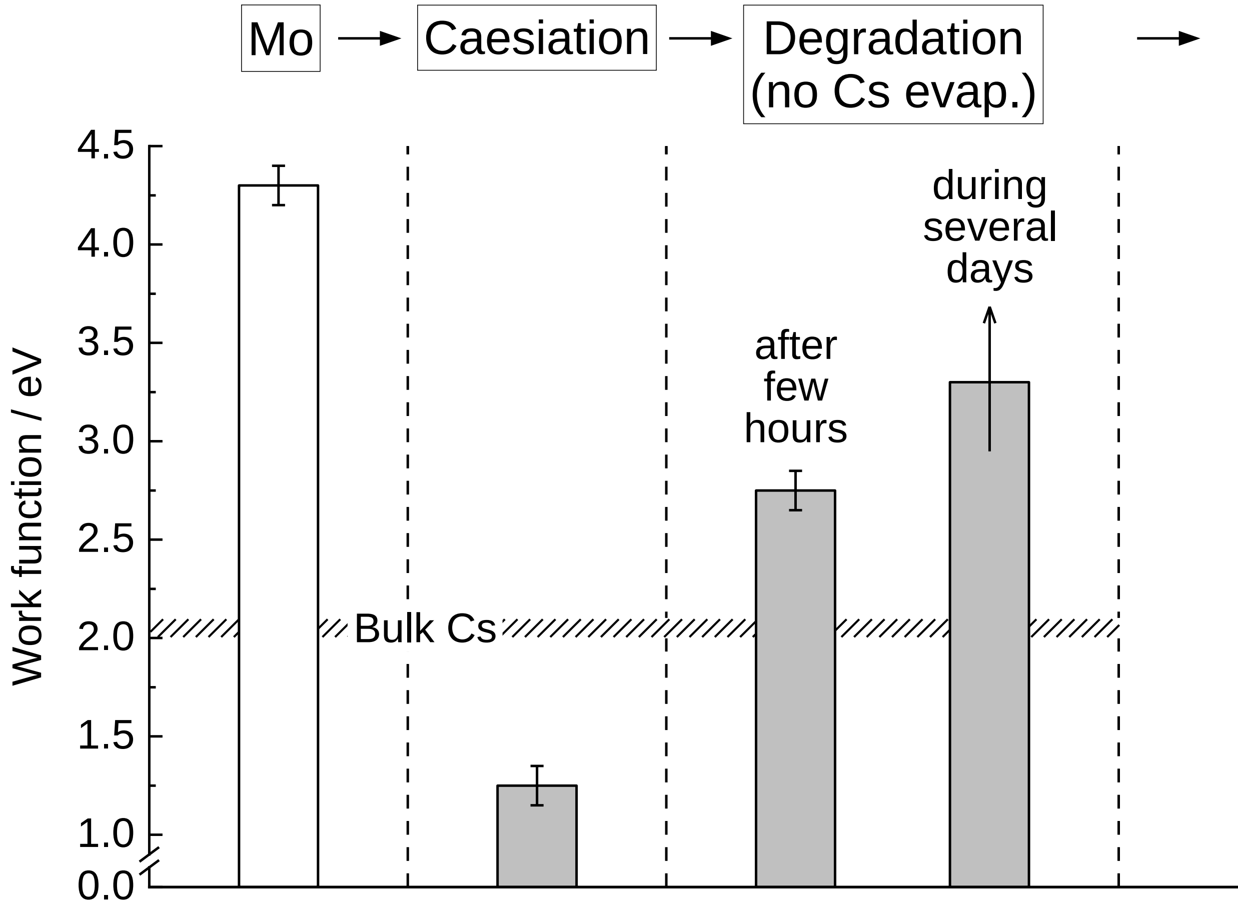




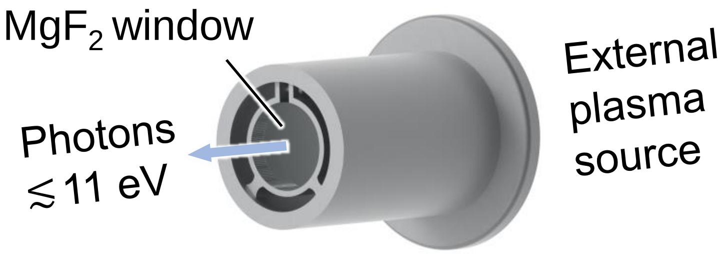
Severe degradation of the Cs layer during operational breaks

A. Heiler, PhD thesis, submitted at University of Augsburg (2022)

Impact of hydrogen plasma species on the WF of caesiated surfaces



VUV photons



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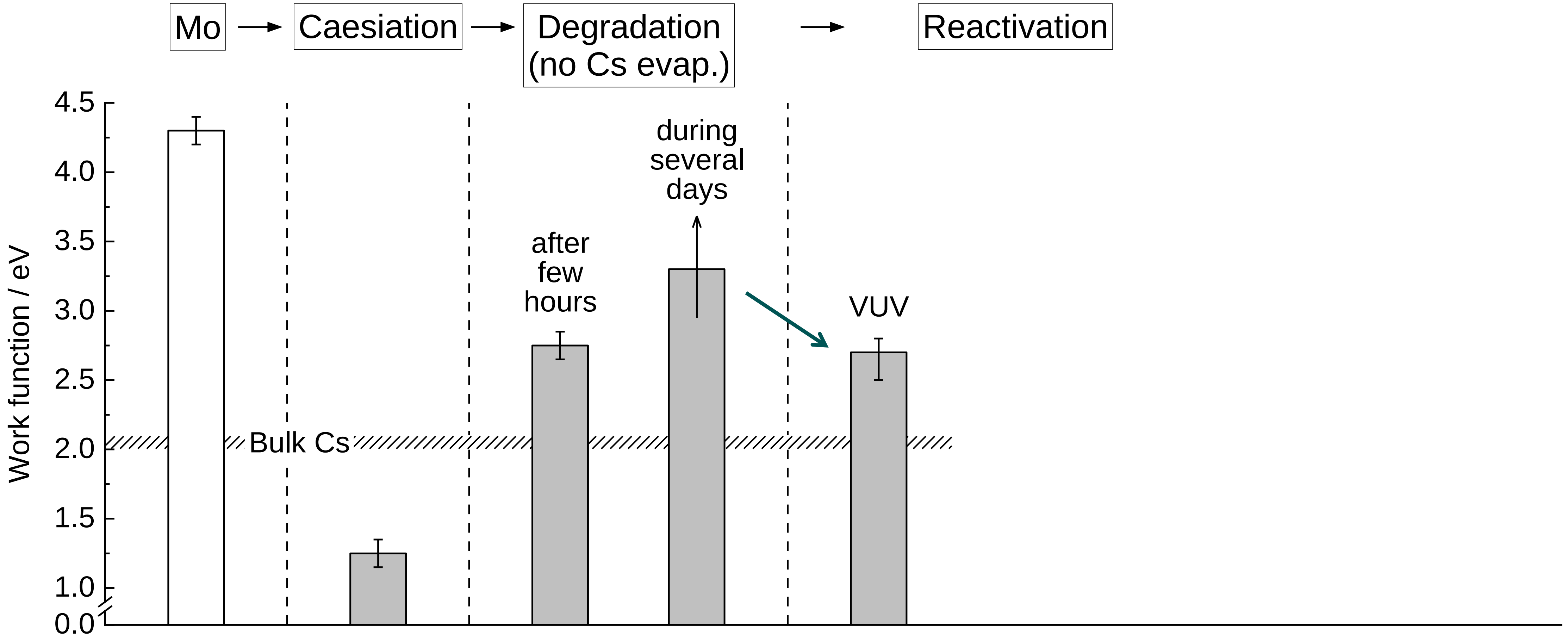

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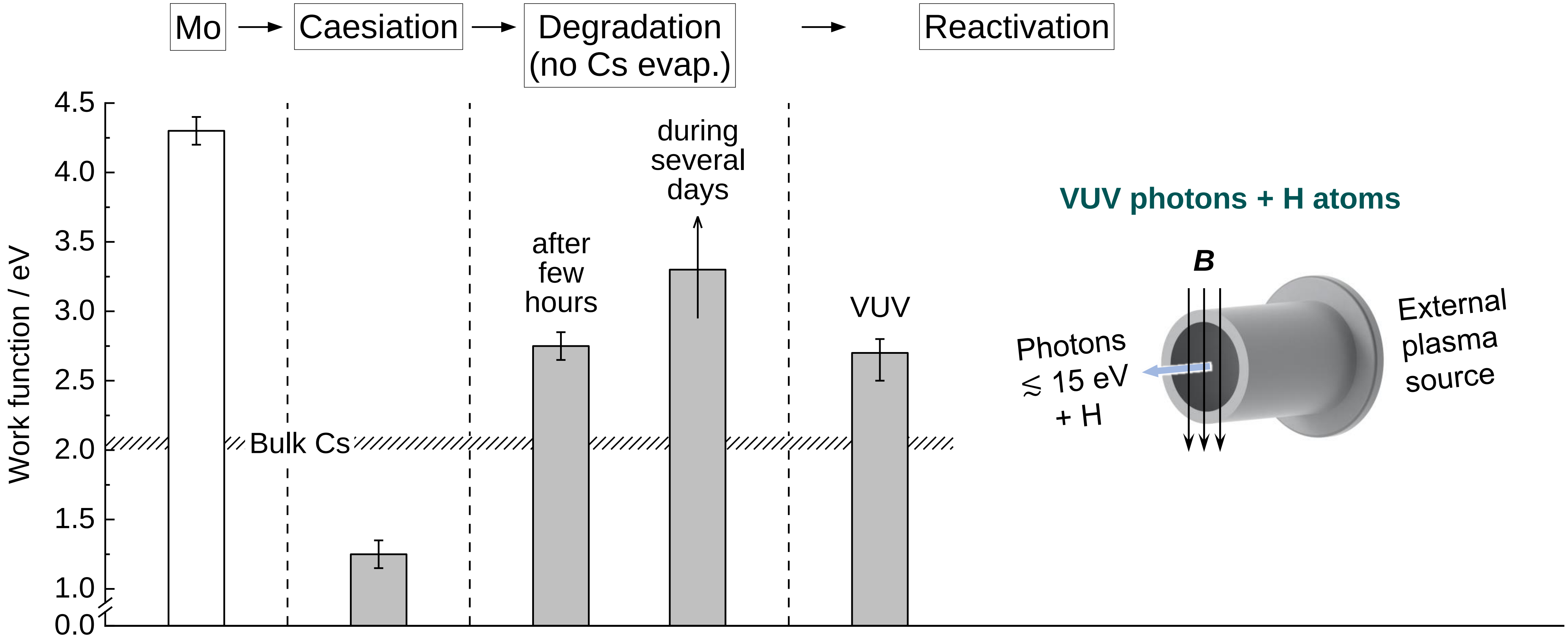

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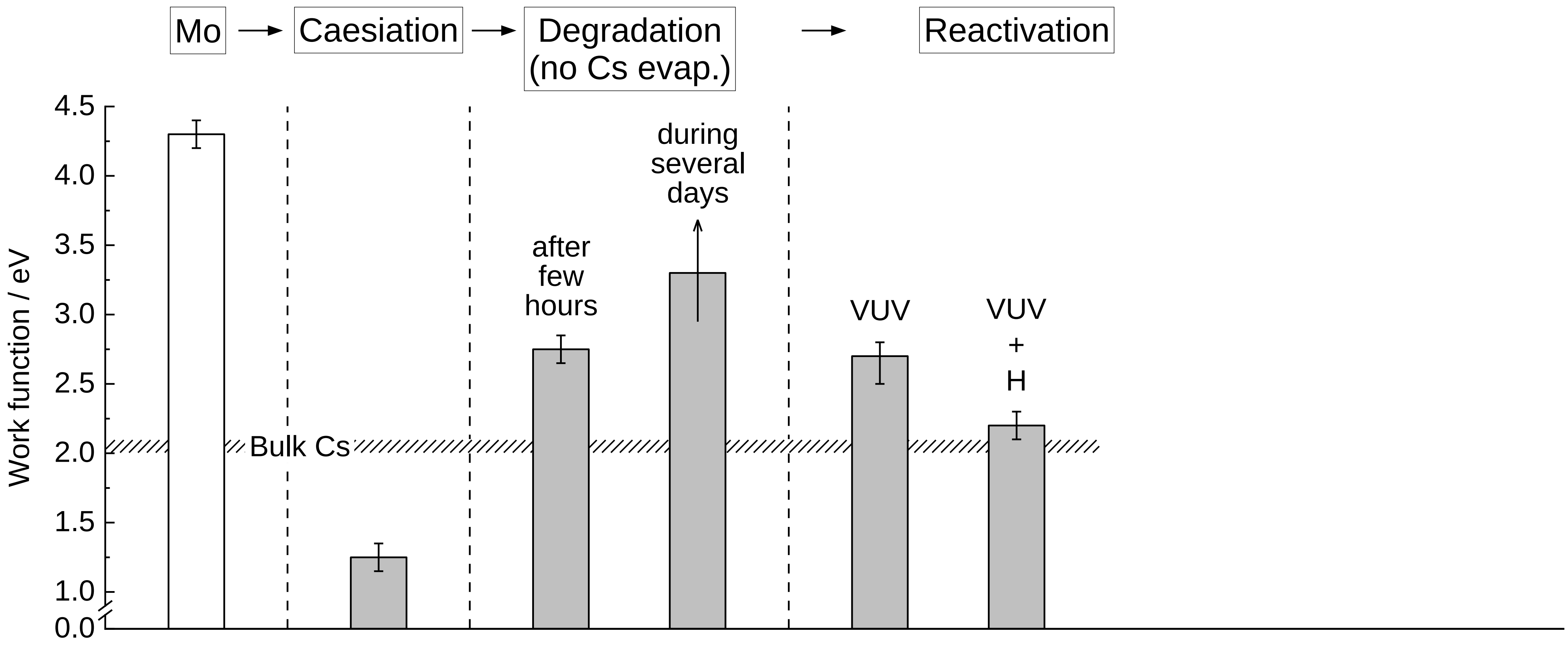

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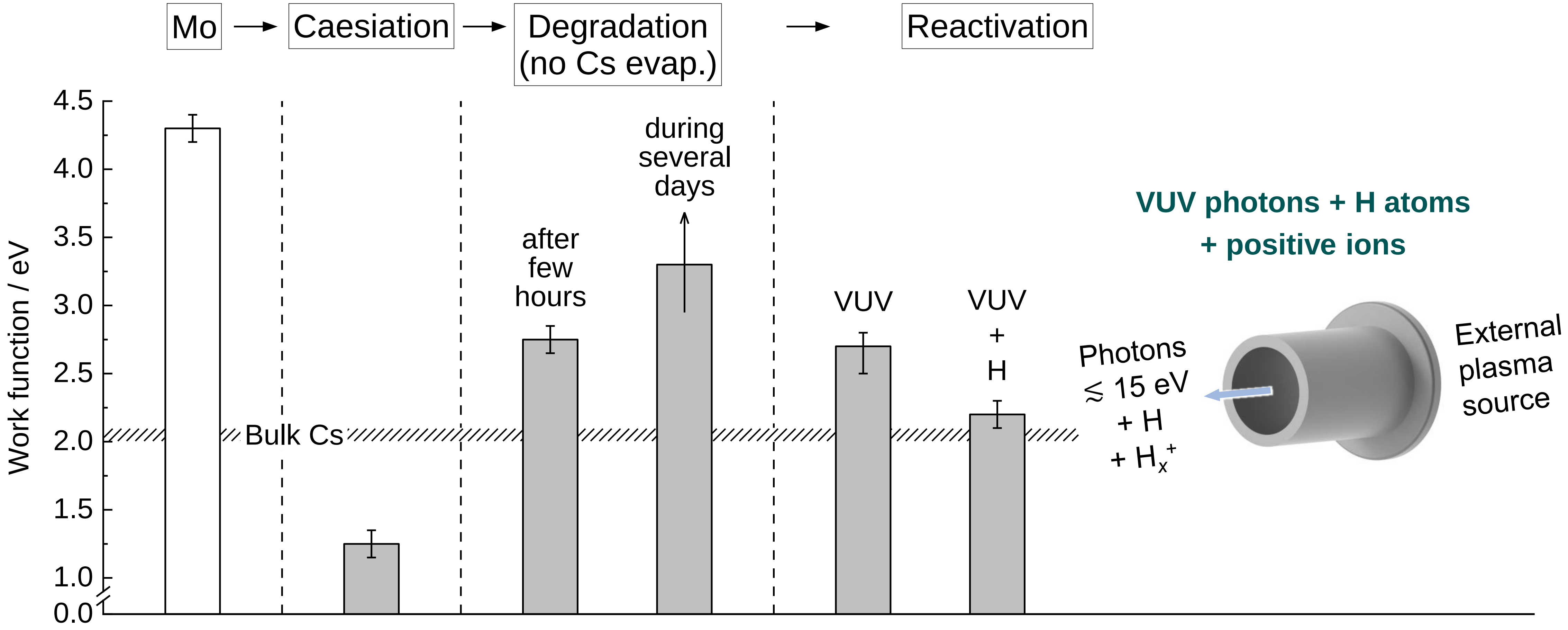

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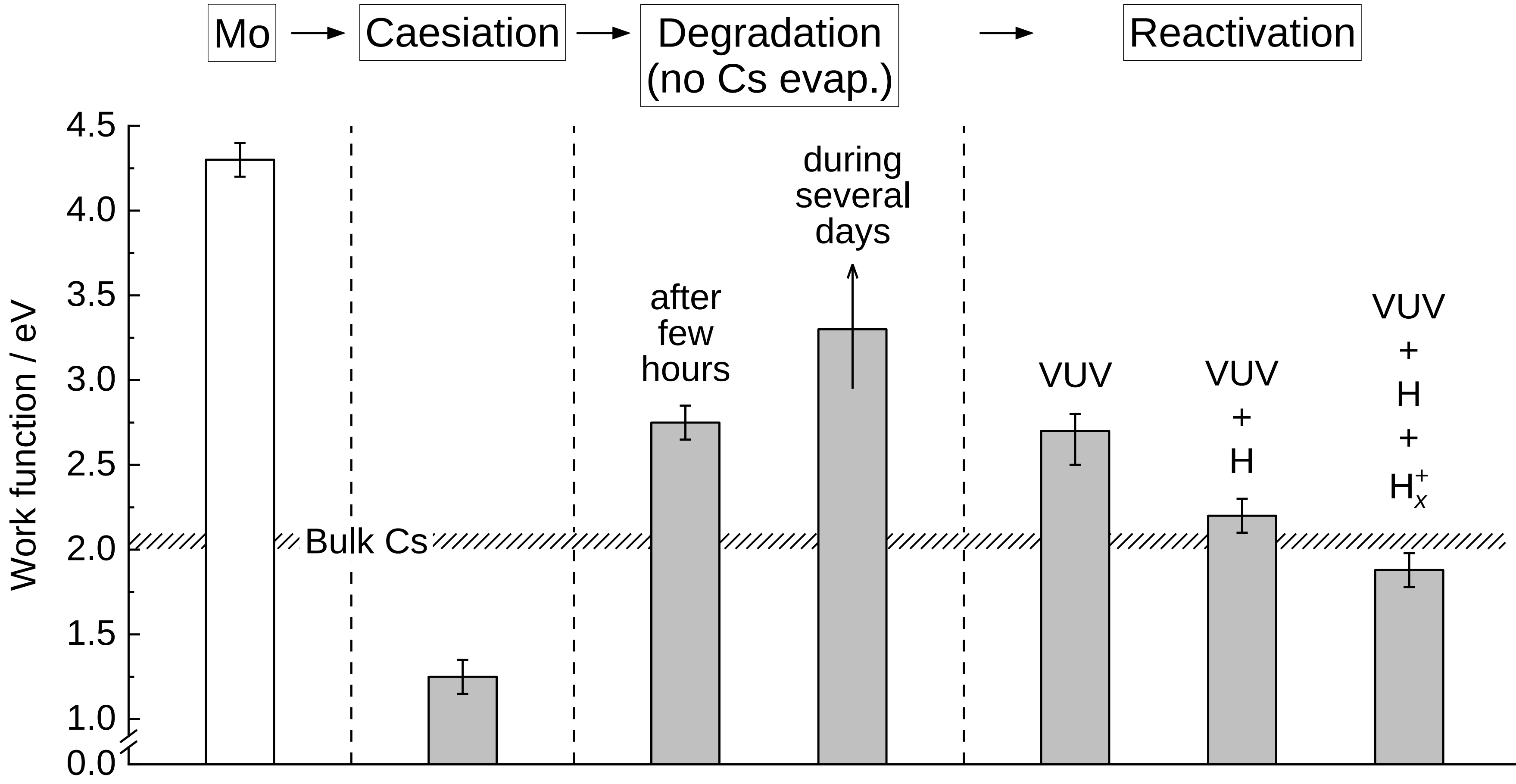
Impact of hydrogen plasma species on the WF of caesiated surfaces

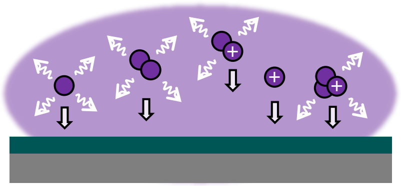


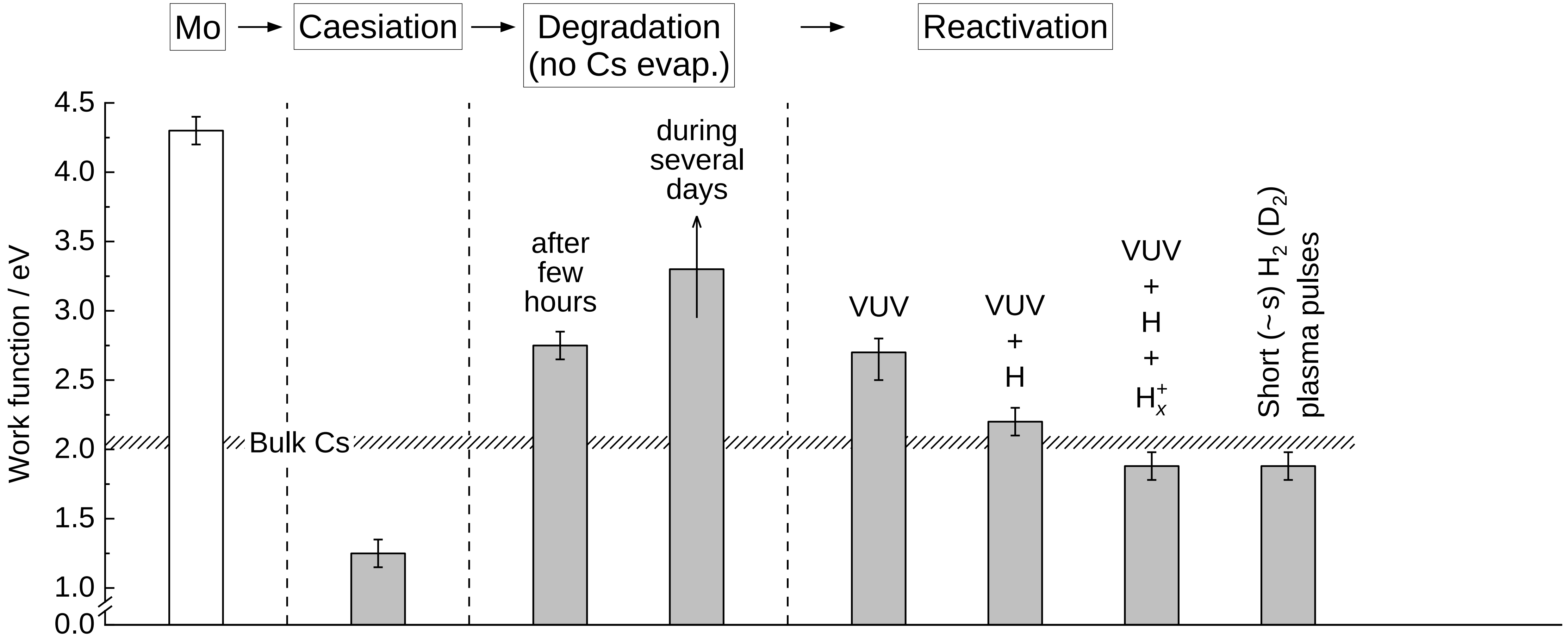
Influence of photonic, atomic as well as ionic interactions on the WF of caesiated surfaces

A. Heiler, PhD thesis, submitted at University of Augsburg (2022)

WF of caesiated surfaces upon H_2 (D_2) plasma exposure

Conditioning with short plasma pulses

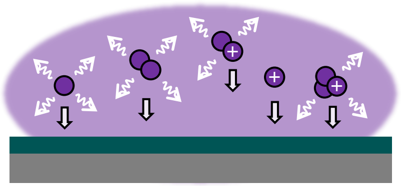


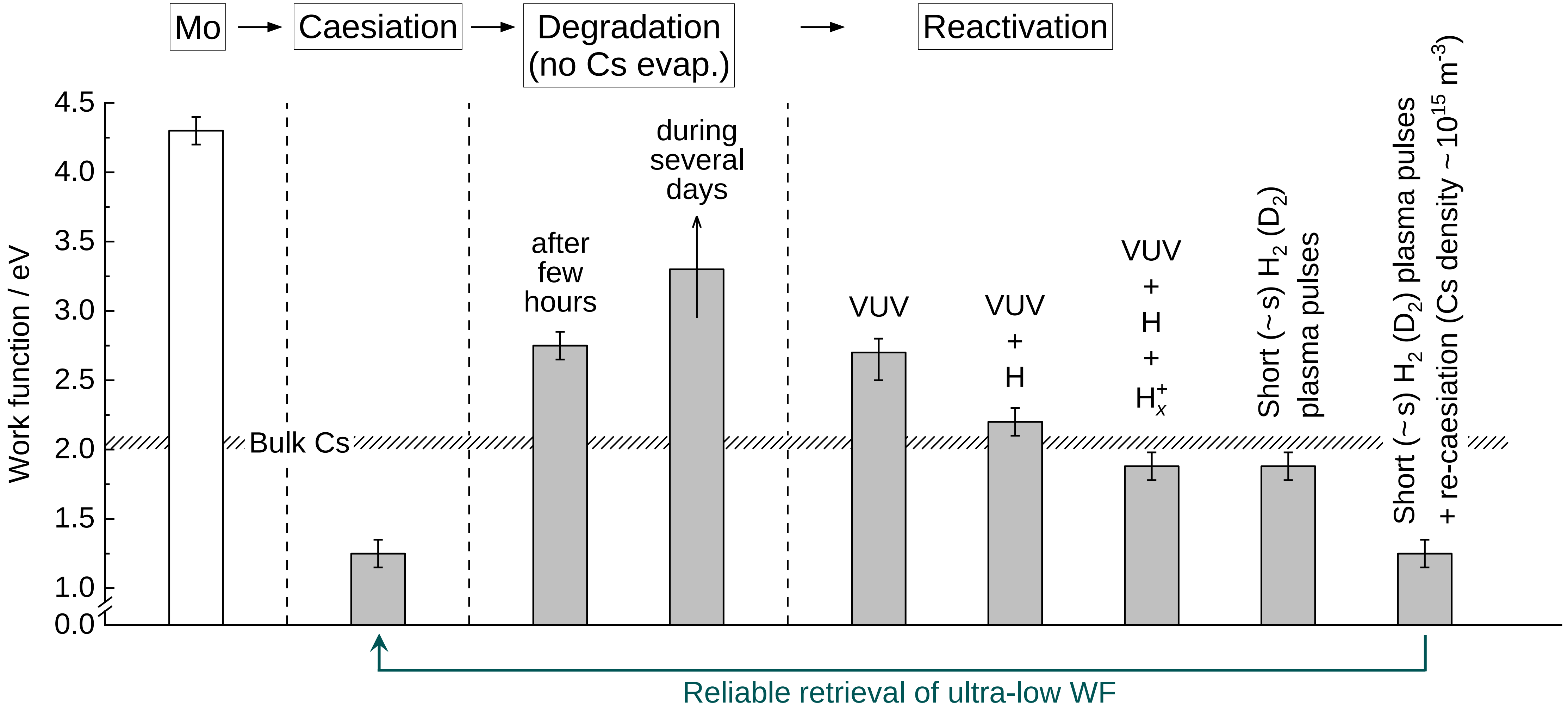


A. Heiler, PhD thesis, submitted at University of Augsburg (2022)

WF of caesiated surfaces upon H_2 (D_2) plasma exposure

Conditioning with short plasma pulses and Cs evaporation





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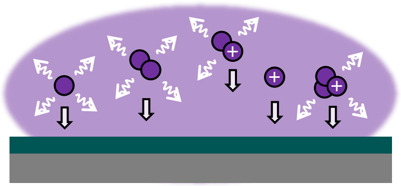
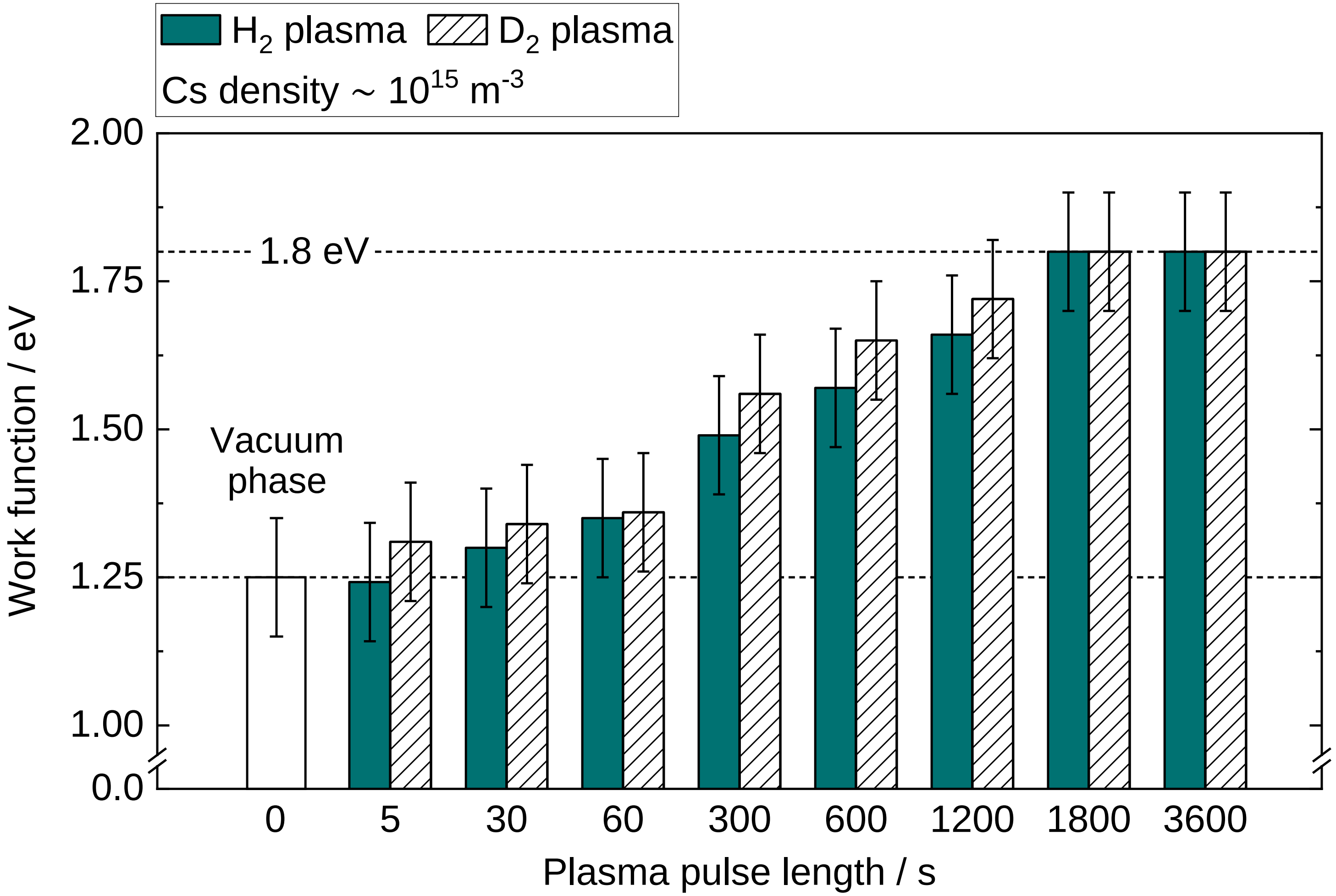
WF of caesiated surfaces upon H_2 (D_2) plasma exposure

Durability of ultra-low work function layer





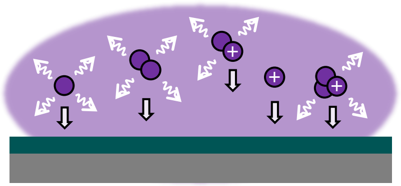
Ultra-low WF layer only stable up to H_2 (D_2) plasma exposures of ~ 1 min

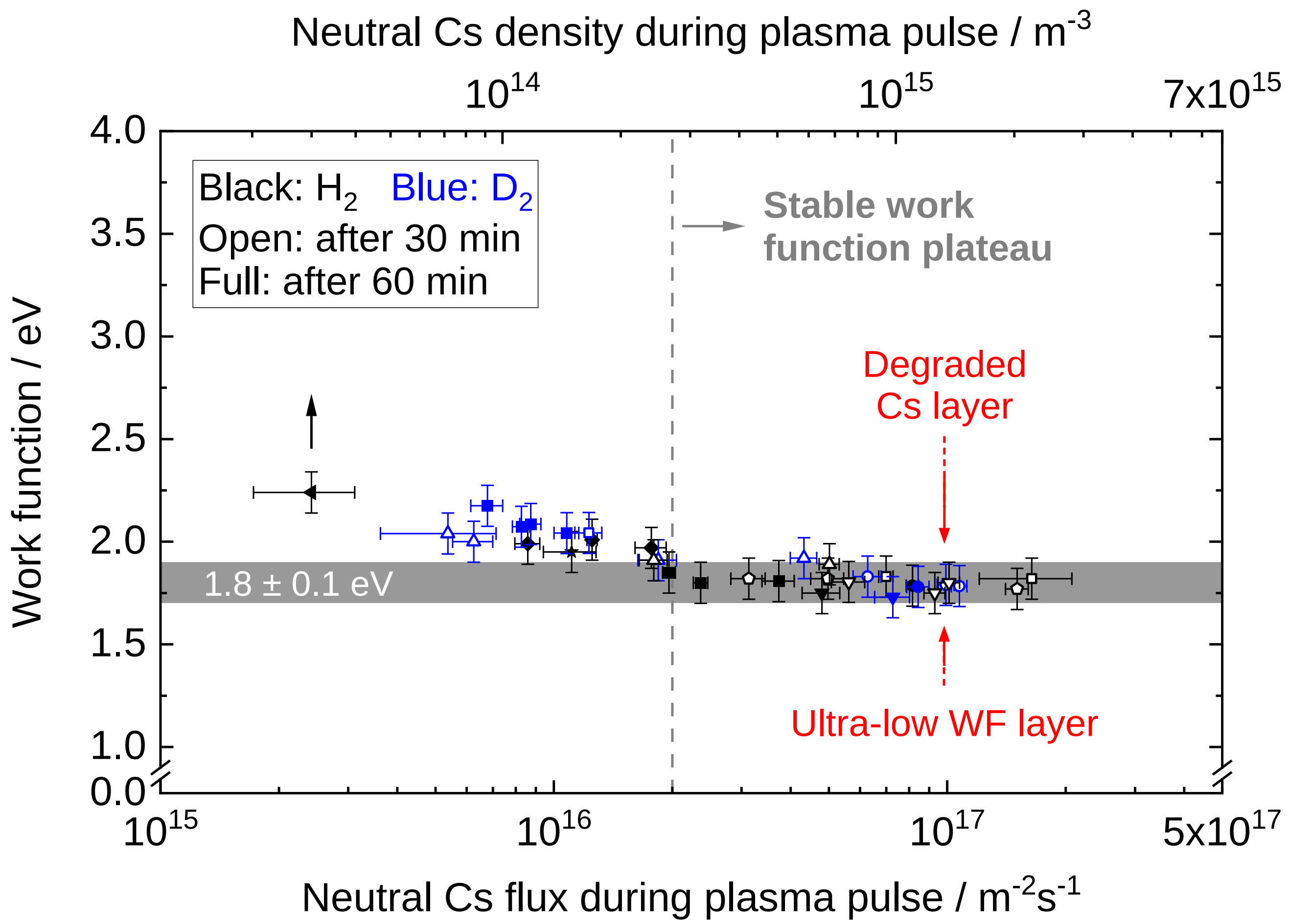
→ Hints for temporal deterioration of ion source performance

A. Heiler, PhD thesis, submitted at University of Augsburg (2022)

WF of caesiated surfaces upon H_2 (D_2) plasma exposure

Steady-state plasma operation





- ➢ Stable WF of 1.8 ± 0.1 eV for Cs densities $\gtrsim 3 \times 10^{14}$ m^{-3} (Cs fluxes $\gtrsim 2 \times 10^{16}$ m^{-2}s^{-1}) during plasma phase
- ➢ Reached WF independent of initial WF in the vacuum phase

A. Heiler, PhD thesis, submitted at University of Augsburg (2022)

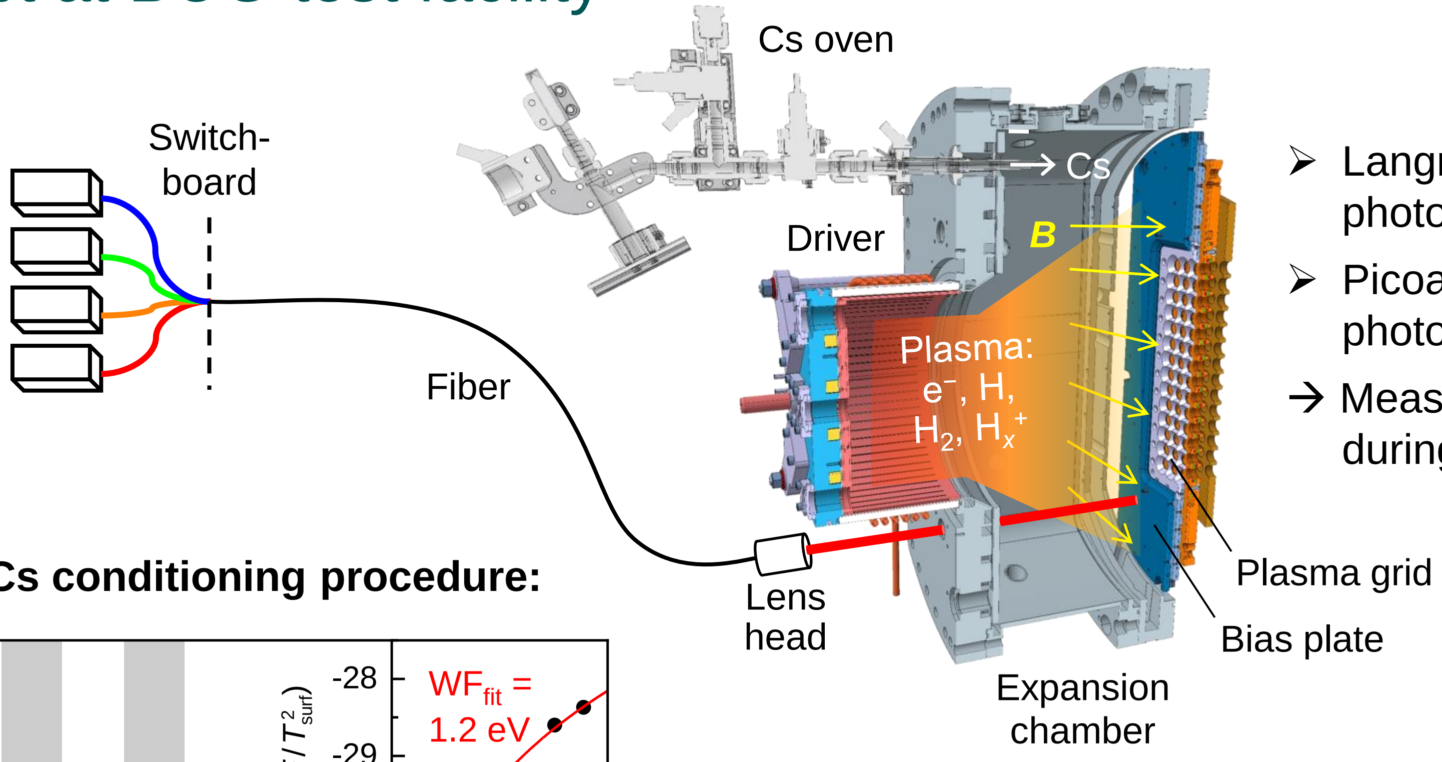
Development of WF diagnostic for ion sources using LEDs
Proof of concept at BUG test facility

Poster by J. Berner (session 2)

Fiber-coupled LEDs:

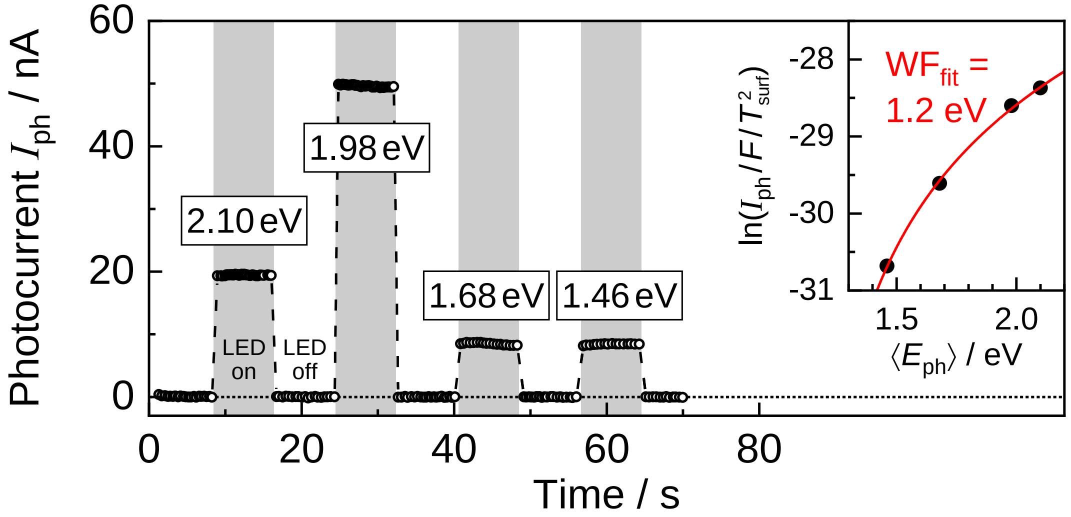
$\langle E_{ph} \rangle$ = 3.22 – 1.13 eV

FWHM = 15 – 30 nm



- ➢ Langmuir probe used as photoelectron collector
- ➢ Picoammeter used for photocurrent measurement
- → Measurements possible during plasma-off phases

Measurement during Cs conditioning procedure:

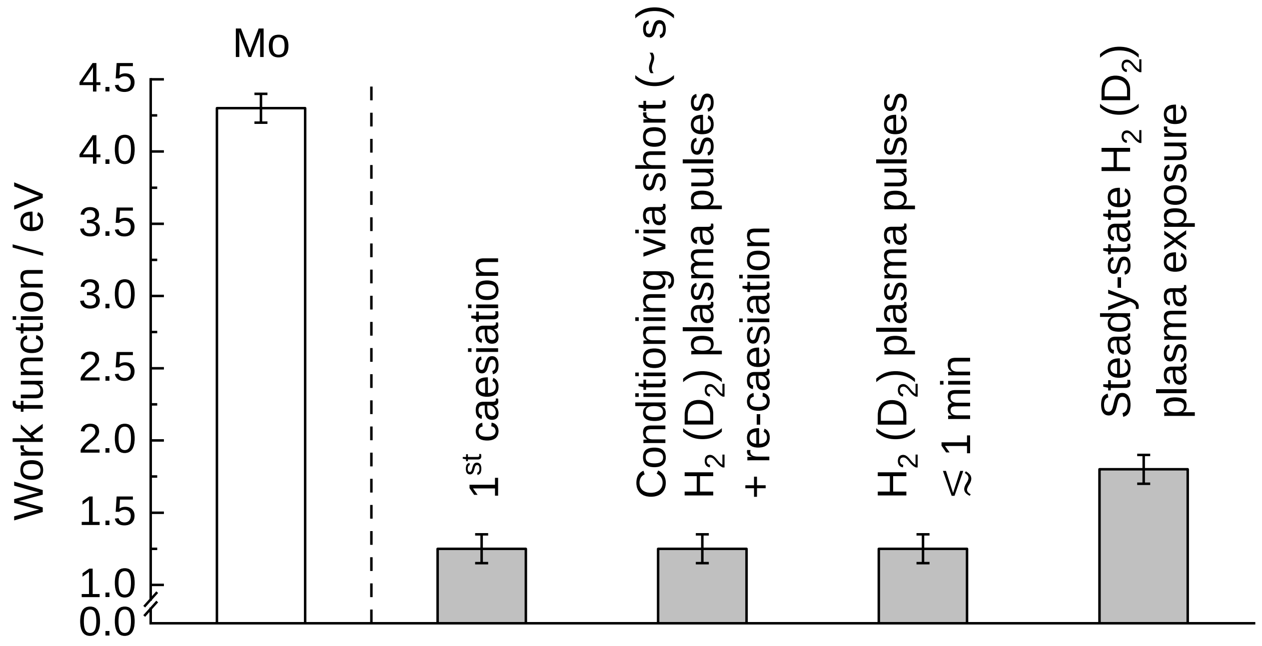


WF < 2 eV confirmed

Proof of concept for absolute WF measurements ✓

Summary and outlook

- **Caesiation under vacuum conditions of 10^{-6} – 10^{-5} mbar:**
  - Reliable formation of Cs layers with ultra-low WF in the range of 1.2 – 1.3 eV
  - Figure of merit: $\Gamma_{Cs} / \Gamma_{H_2O}$
- **WF of caesiated surfaces influenced by impinging VUV, H and H_x^+ species**
- **WF dynamics of caesiated surfaces upon H_2 (D_2) plasma exposure:**



- **Next steps:**
  - Systematic investigations on the correlation between WF, plasma parameters and extracted H^- / e^- currents at BUG test facility
  - Investigations on WF dynamics at lab experiment with lower background pressure (10^{-6} … 10^{-9} mbar)