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Determining absolute VUV fluxes for assessing the relevance of photon-surface interaction in ion sources

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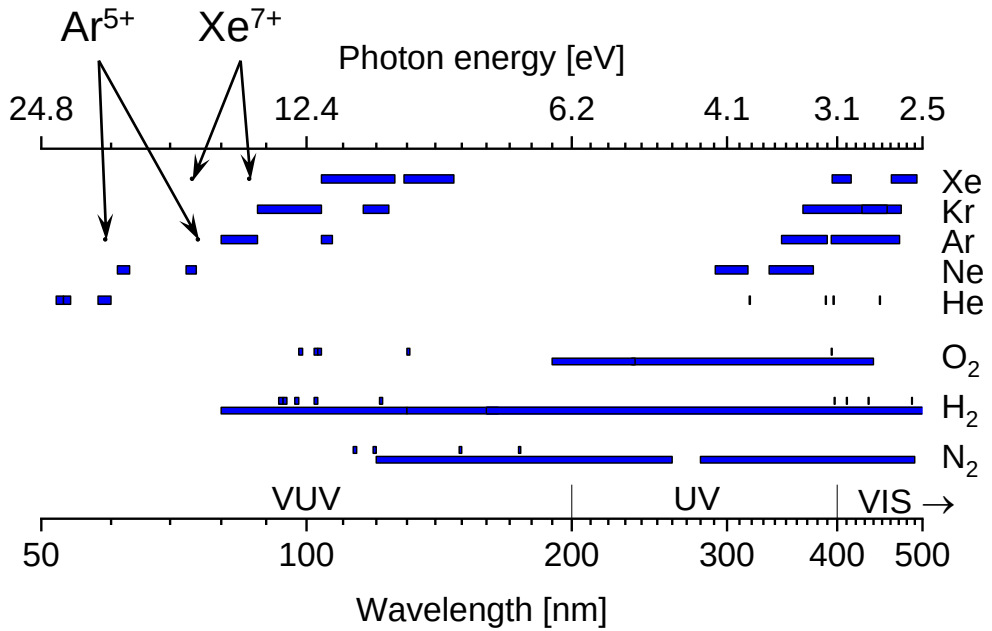
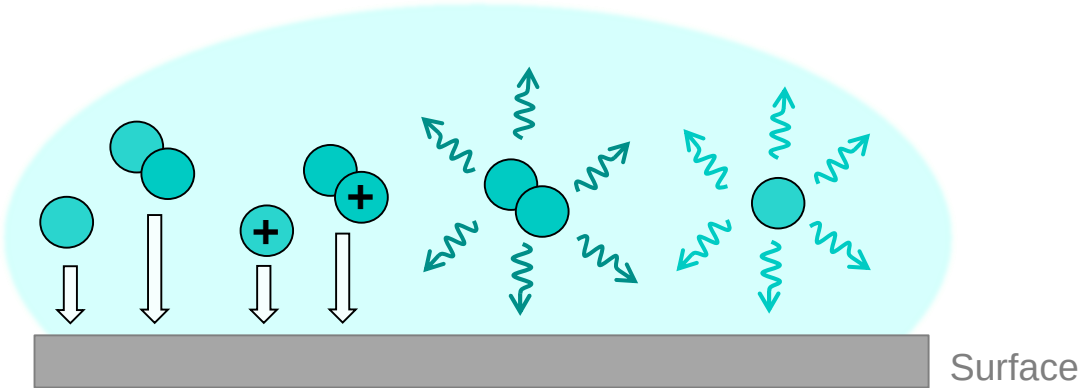
VUV emission in ion sources

- Resonance transitions of neutrals and ions
- Insight into basic plasma physics
- Energetic fluxes towards plasma-facing components



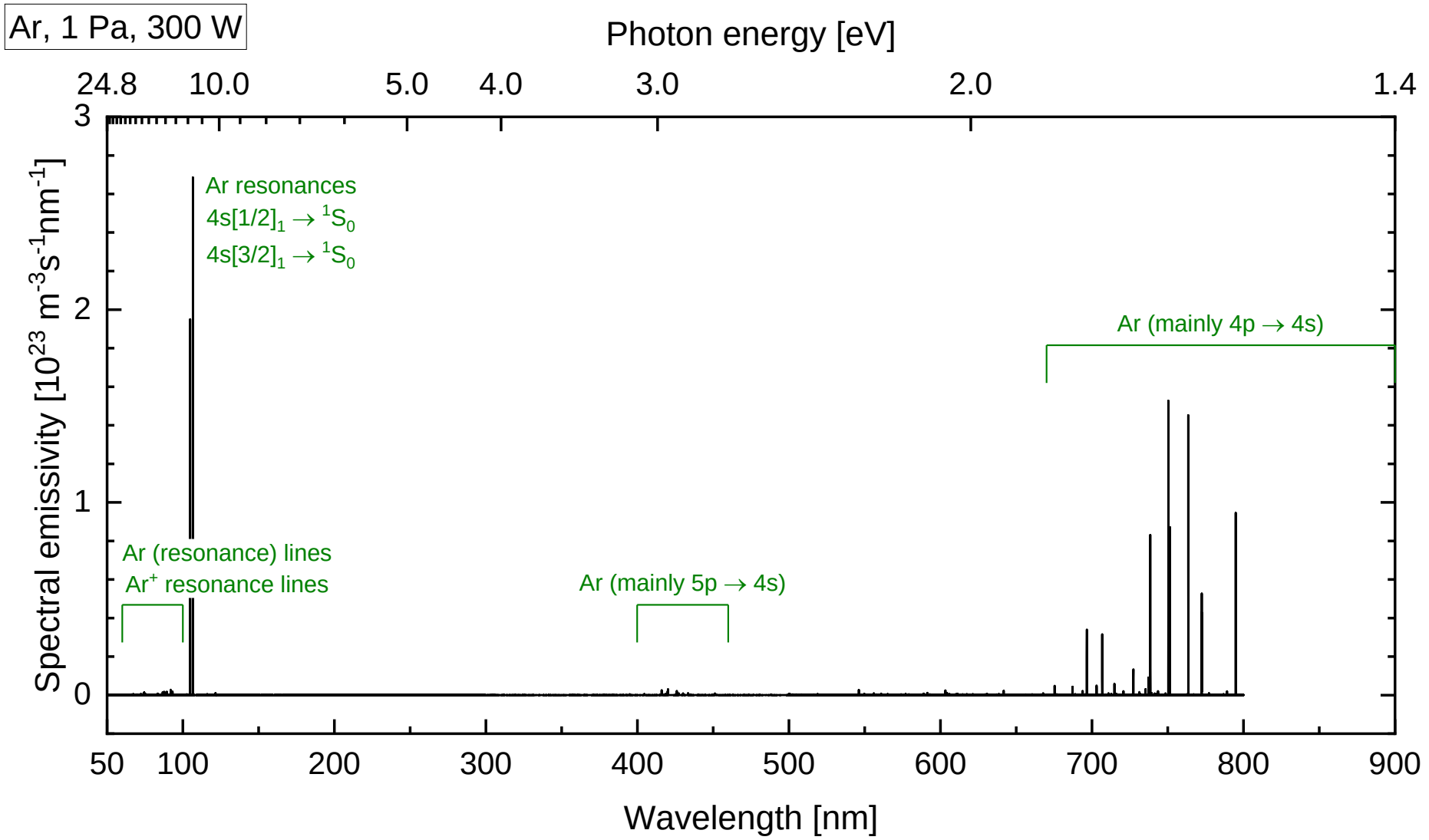


Impact depends on
photon energy and absolute flux

Challenges for VUV spectroscopy:

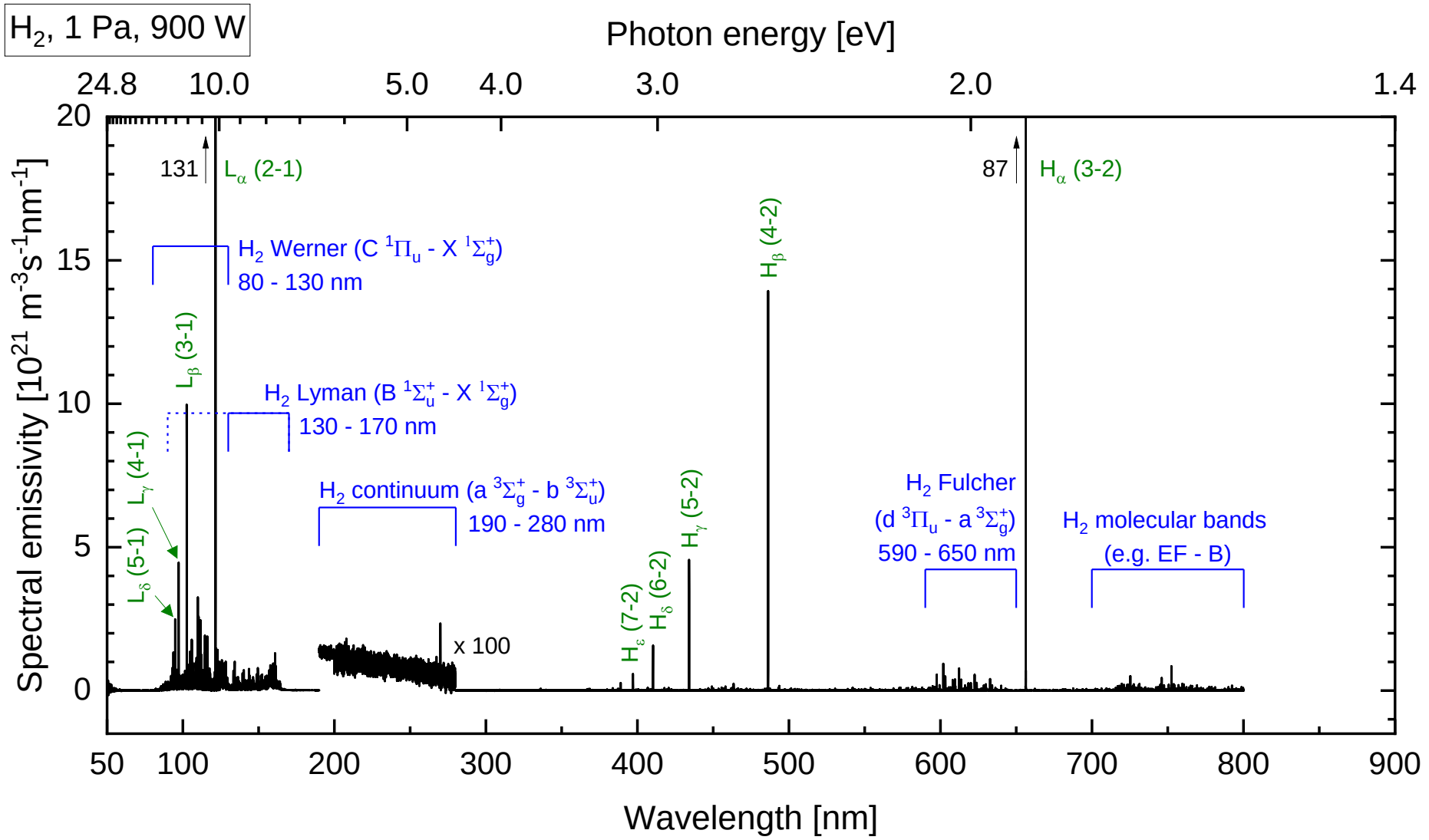
Direct vacuum connection +
Complex calibration procedure

Detecting VUV emission



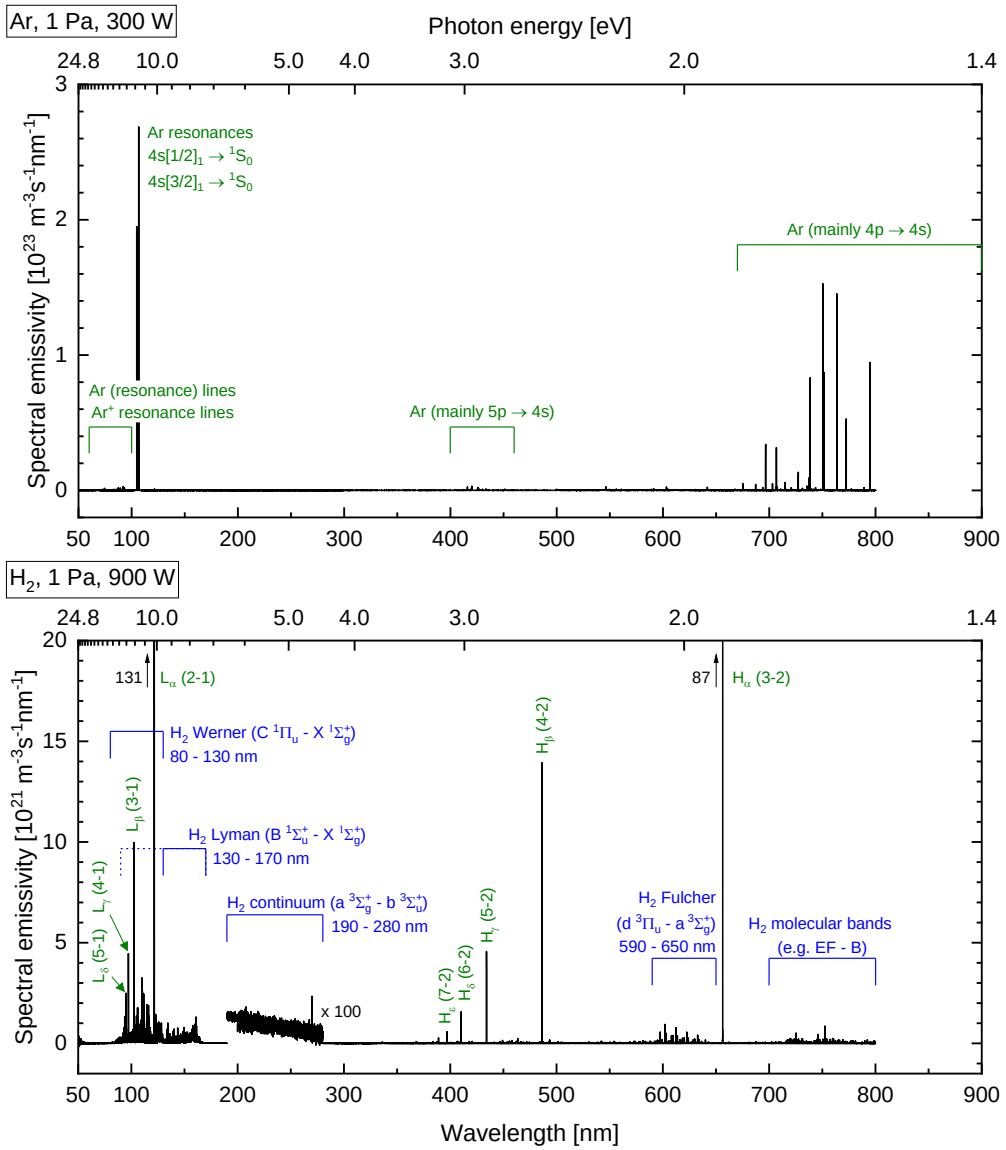
FRIEDL et al., *Meas. Sci. Technol.* **34** (2023) 055501

Detecting VUV emission



FRIEDL et al., *Meas. Sci. Technol.* **34** (2023) 055501

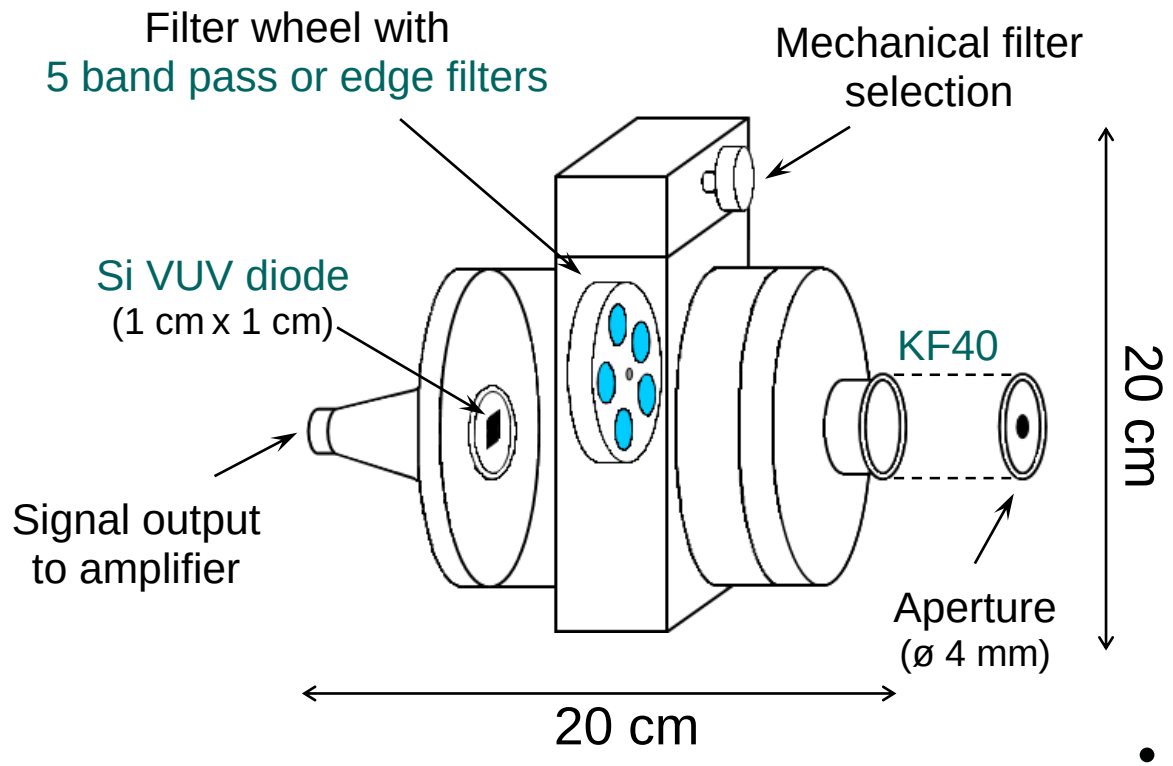
Detecting VUV emission



VUV diode & optical filters

- Simple setup
- Portable & easily attachable
- No separate pumping required

KOMPPULA & TARVAINEN
PSST **24** (2015) 045008

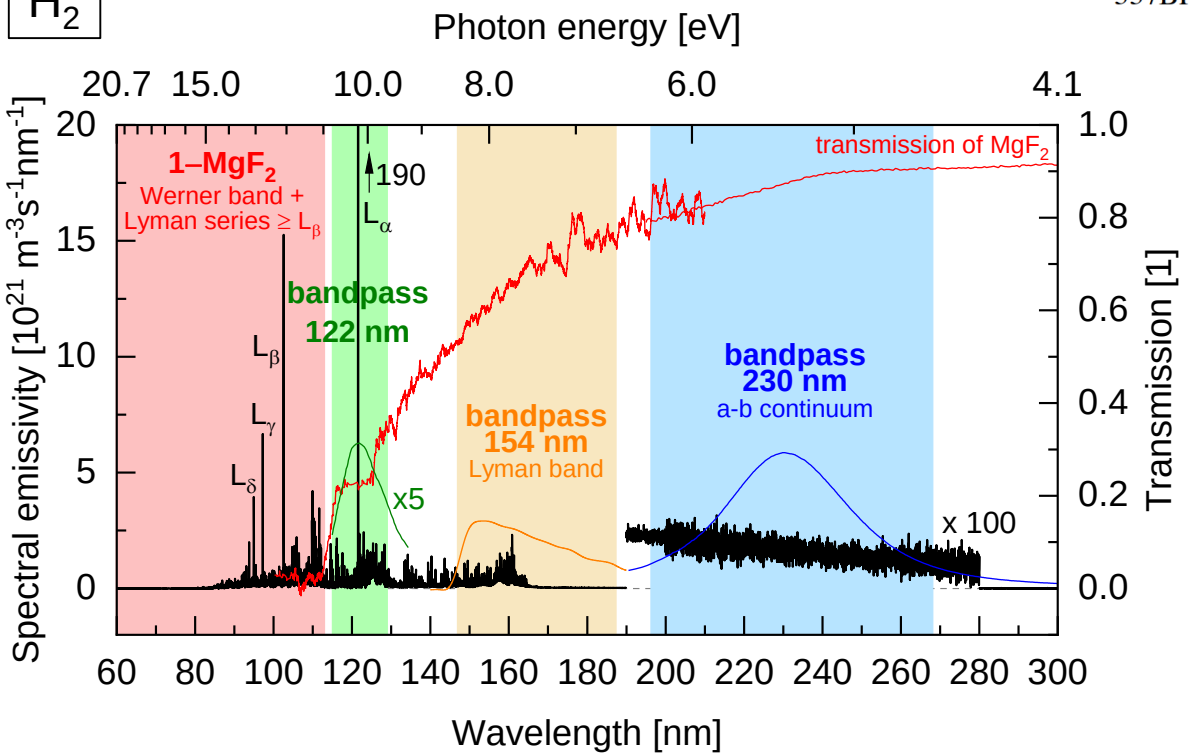


FRIEDL et al., *Meas. Sci. Technol.* **34** (2023) 055501

Detecting VUV emission

VUV diode system – available filter sets

H_2



Band pass filters		
Filter name	Central wavelength	FWHM
122BP	122 nm	14 nm
154BP	154 nm	30 nm
230BP	230 nm	37 nm
313BP	313 nm	10 nm
337BP	337 nm	10 nm

Long pass filters	
Filter name	Cut-on wavelength
MgF_2	113 nm
Fused silica (FS)	153 nm
BK7	281 nm
400LP	397 nm
500LP	500 nm

H_2

Emission system	Filter combination	Filter interval
H_2 Werner band (C-X), H lines $\geqslant L_\beta$	1−MgF_2	$\leqslant$ 113 nm $\geqslant$ 11.0 eV
H line L_α	122BP	115–129 nm 10.2 eV
H_2 Lyman band (B-X)	154BP	147–187 nm 8.4–6.6 eV
H_2 Continuum (a-b)	230BP	196–268 nm 6.3–4.6 eV

➢ Available for Ar, H_2, N_2, O_2, and mixtures

WÜNDERLICH et al., *Rev. Sci. Instrum.* **92** (2021) 123510
FRIEDL et al., *Meas. Sci. Technol.* **34** (2023) 055501

Detecting VUV emission

VUV diode system – absolute calibration

PlanICE (planar ICP, 2 MHz, 2 kW)

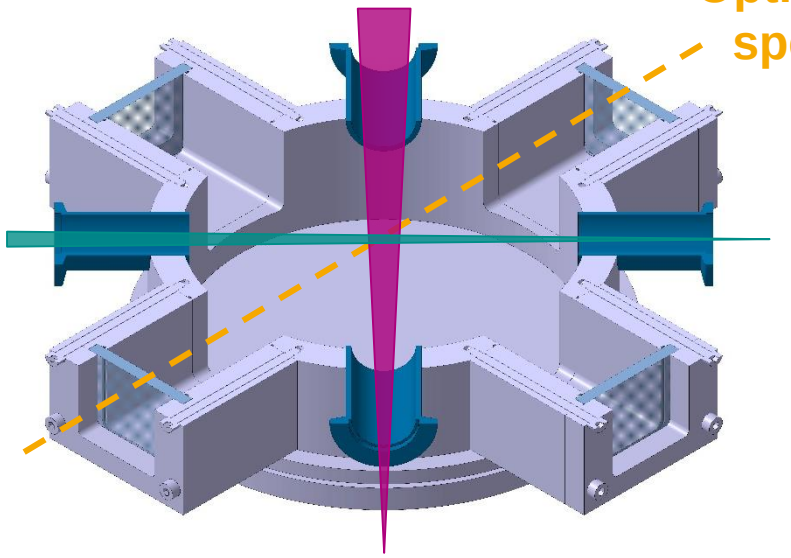
FRÖHLER-BACHUS et al., *JQSRT* **259** (2021) 107427

Absolute radiometric calibration
(→ high current hollow cathode, branching ratios in N_2, D_2 arc lamps, Ulbricht sphere)

Focal length 0.75 m
200–933 nm
FWHM = 16–22 pm

Optical emission spectroscopy

PMT: 116.5–300 nm
CEM: 46–116.5 nm



VUV spectrometer

Focal length 1 m
46–300 nm
FWHM = 30-37 pm

VUV diode system

Sensitive 1 – 1100 nm
Wavelength resolution with filters

- Gas and filter specific calibration factors for Ar, H_2, N_2, O_2 (etc.)
- Energy-resolved absolute VUV flux measurements up to photon energies of 27 eV
- Accuracy better than 25%, Dynamic range > 4 ord.magn.

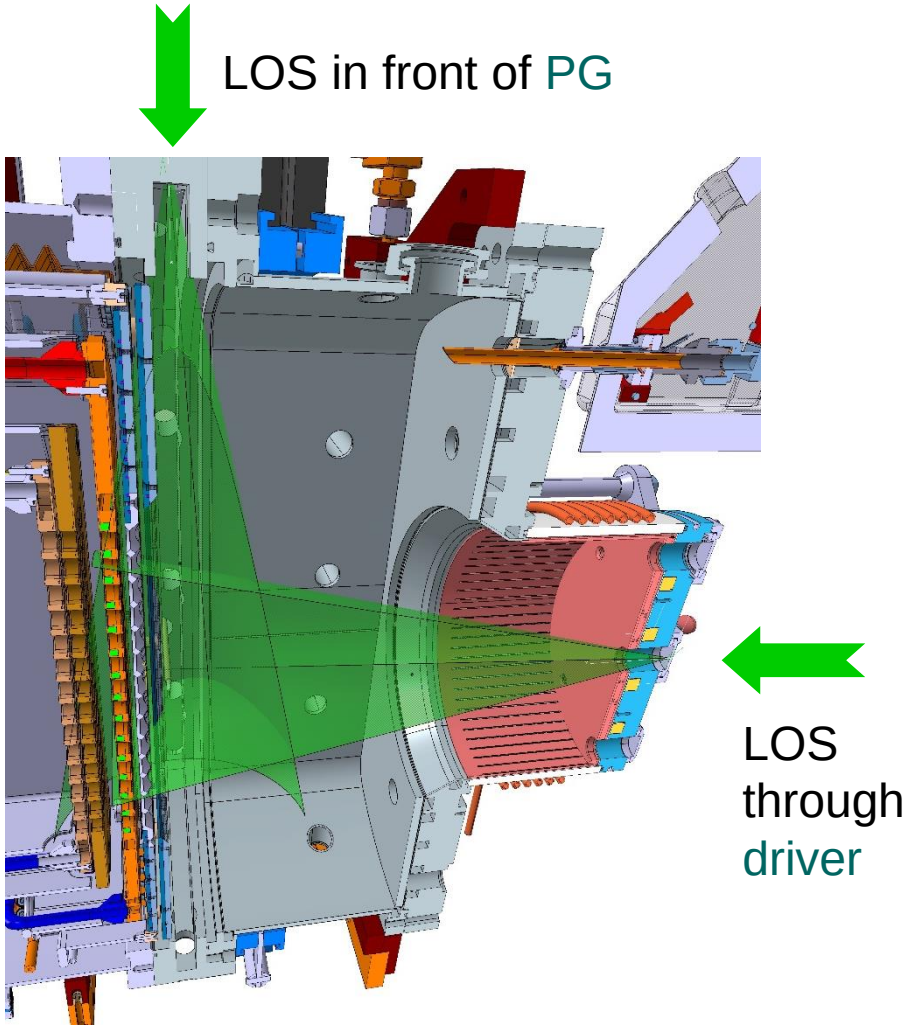
FRIEDL et al., *Meas. Sci. Technol.* **34** (2023) 055501

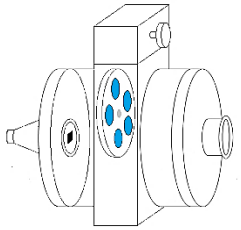
VUV emission in ion sources

Demonstration at negative hydrogen ion source of BUG

- H_2 plasma generated in driver
- H^- produced at caesiated plasma grid (PG) with low WF
- Plasma surface interaction at PG drives strong dynamic of ion source performance, where VUV:

  affects surface WF &
  induces emission of
  photoelectrons
- VUV emission never measured before in BUG





Volt

Calibration factor (specific for filter!)

Ph/(m³s)

Effective volume (specific for setup!)

Ph/(m³s) → Emissivity

VUV emission in ion sources

Demonstration at negative hydrogen ion source of BUG

[1] HURLBATT, *J. Phys. D* **53** (2020) 125204

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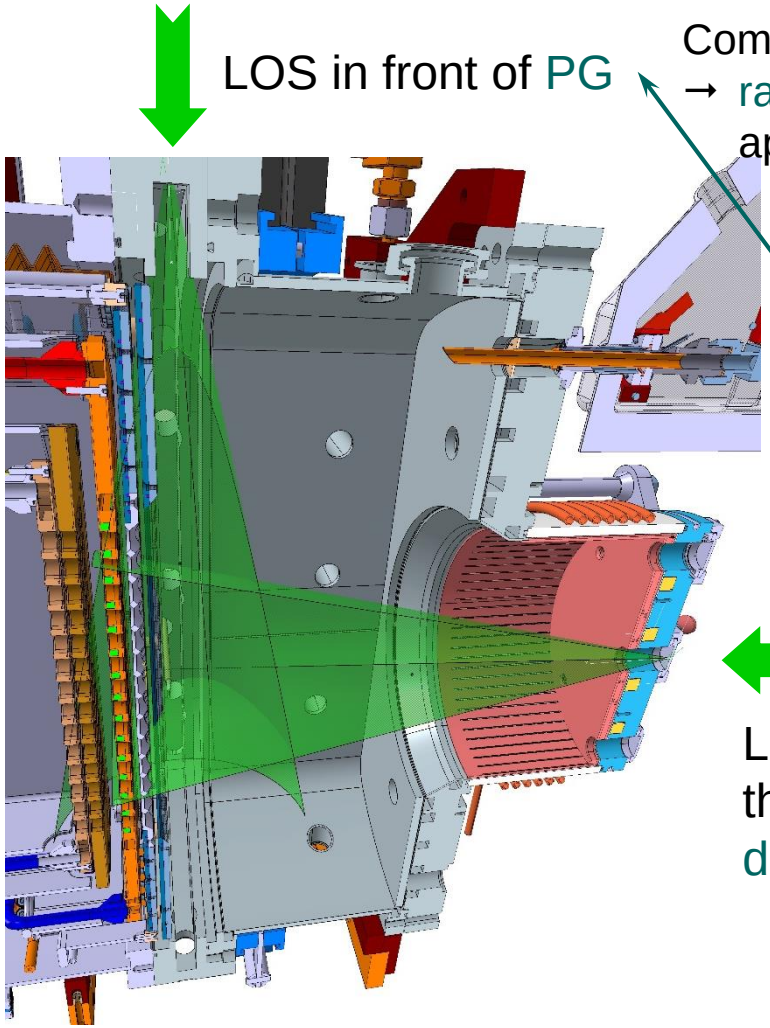
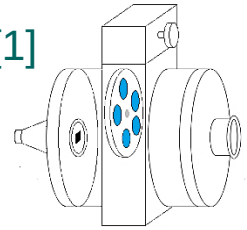


Complex geometry
→ ray tracing code [1] applied



Volt

Calibration factor (specific for filter!)

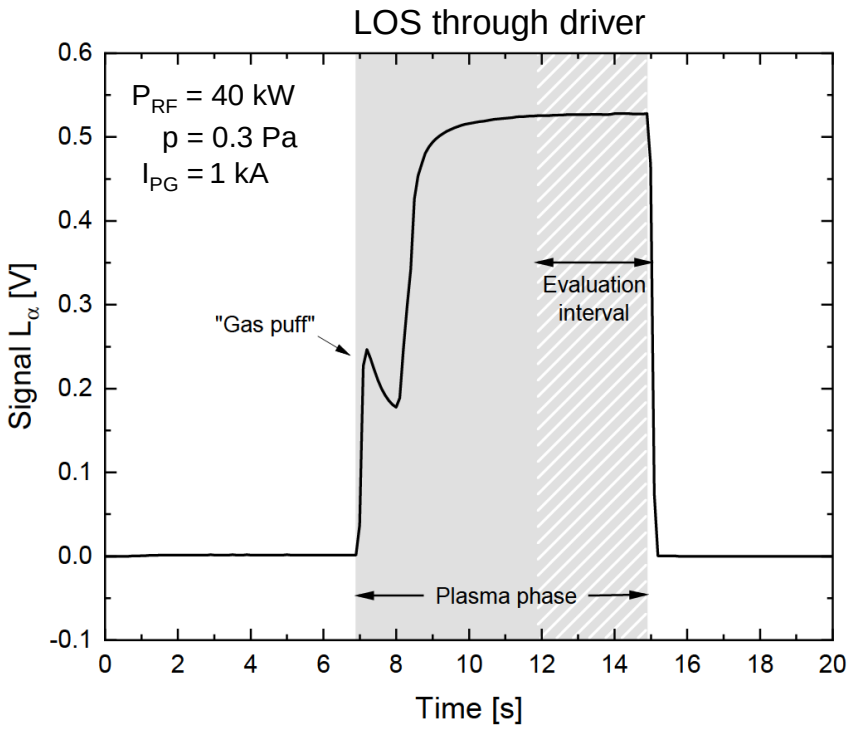
Ph/(m³s)

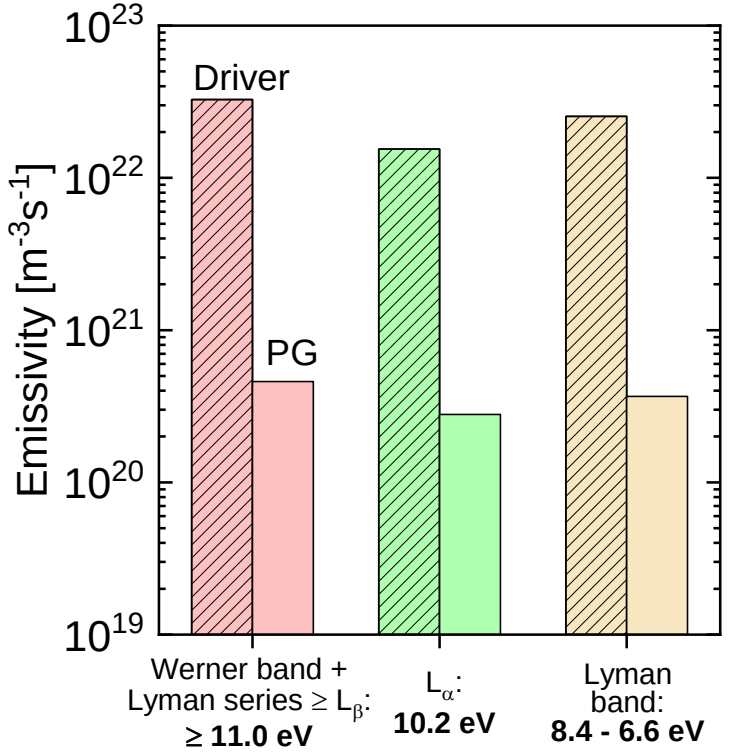
Effective volume (specific for setup!)

Ph/(m³s) → Emissivity

VUV emission in ion sources

Demonstration at BUG (1)





P_{RF} = 40 kW
p = 0.3 Pa
I_{PG} = 1 kA

Driver: T_e = 9.8 eV, n_e = 5×10^{17} m^{-3}

PG: T_e = 2.3 eV, n_e = 6.6×10^{16} m^{-3}

- ✓ Low noise
- ✓ High temporal resolution (here 100 ms)

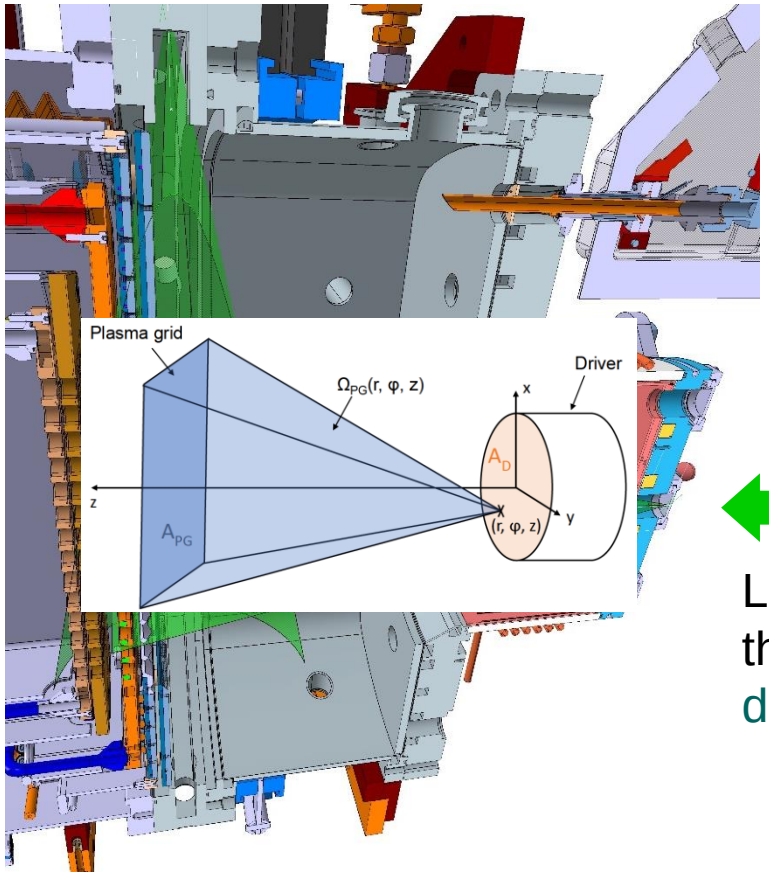
- ✓ VUV in driver almost 2 ord.magn. more intense
- ✓ Dependence on plasma parameters agrees with CR modeling (Yacora)

WÜNDERLICH et al., *Rev. Sci. Instrum.* **92** (2021) 123510

VUV emission in ion sources

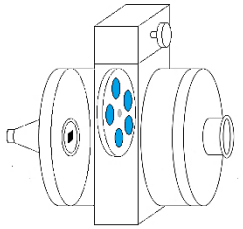
Demonstration at BUG (2)

LOS in front of PG ✓



LOS through driver

Beam widening
→ solid angle calculation required
→ flux reduced by factor ≈10



Volt

Calibration factor (specific for filter!)

Ph/(m³s)

Effective volume (specific for setup!)

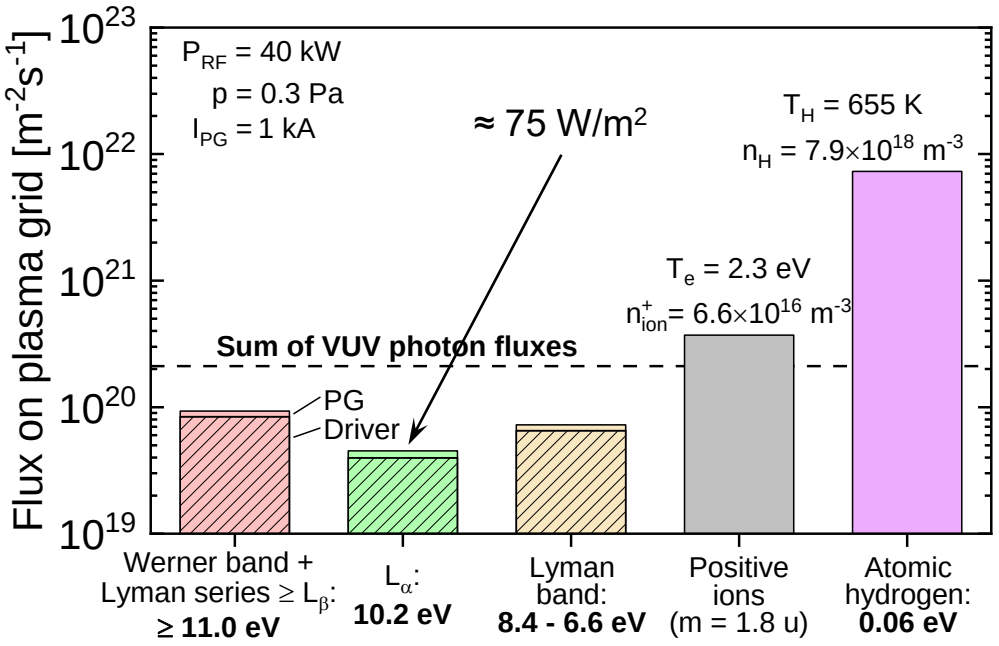
Ph/(m³s) → Emissivity

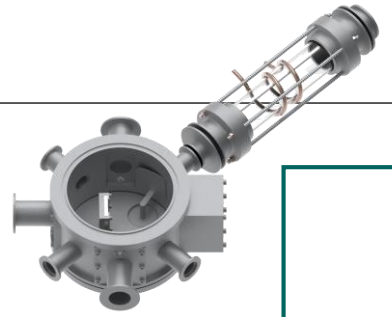
Geometry (Volume/Surface)

Ph/(m²s) → Photon flux

VUV emission in ion sources

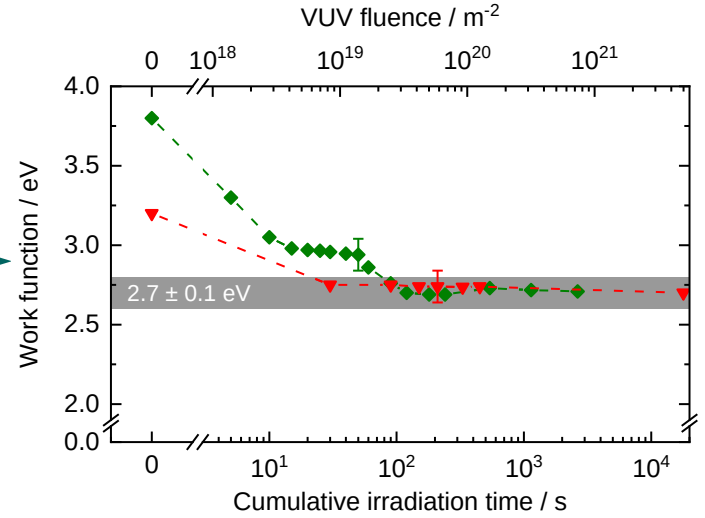
Demonstration at BUG (3)

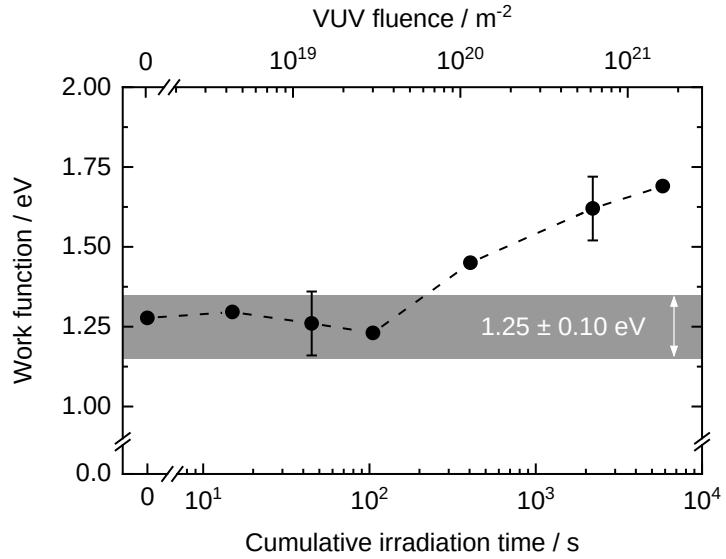




HEILER, *PhD*, UniA 2022
& *NIBS*, Padova 2022

VUV flux < 10^{18} m^{-2}s^{-1}





- VUV flux dominated by driver emission
- Atomic flux dominant but low energy
- Total VUV flux comparable to ion flux
- VUV fluxes high enough to impact the WF

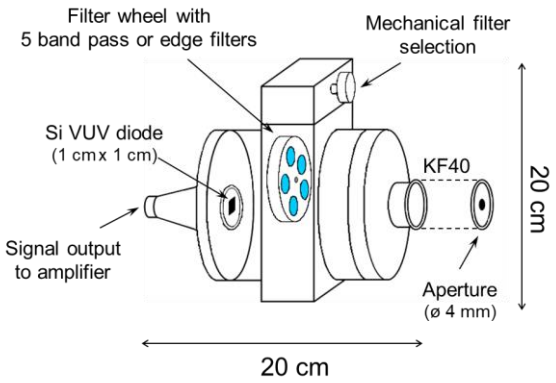
WÜNDERLICH et al., *ICPIG*, Iași 2015

VUV flux > 10^{22} m^{-2}s^{-1}

→ Photoelectrons negligible

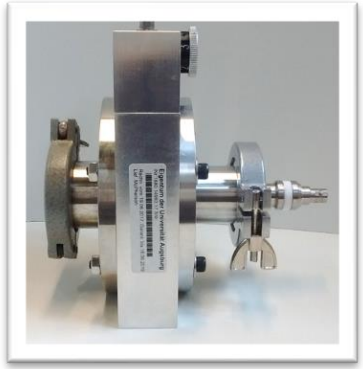
WÜNDERLICH et al., *Rev. Sci. Instrum.* **92** (2021) 123510

Conclusion



VUV detector

Optical filters + VUV sensitive diode
Calibrated against VUV spectrometer



Energy resolution

Absolute VUV fluxes

Variety of discharge gases

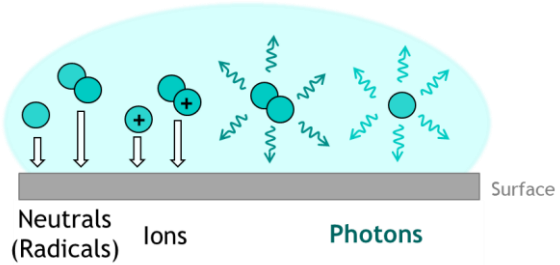
Ar, N_2, O_2, H_2, mixtures (not limited)

Portable and easily attachable

Simple vacuum flange sufficient

VUV fluxes up to 27 eV quantifiable

Insight into basic plasma physics
and plasma-surface-interaction



at BUG

- Comparable photon to ion fluxes onto PG
- Photon energies >11 eV
- Flux magnitude sufficient to change the WF