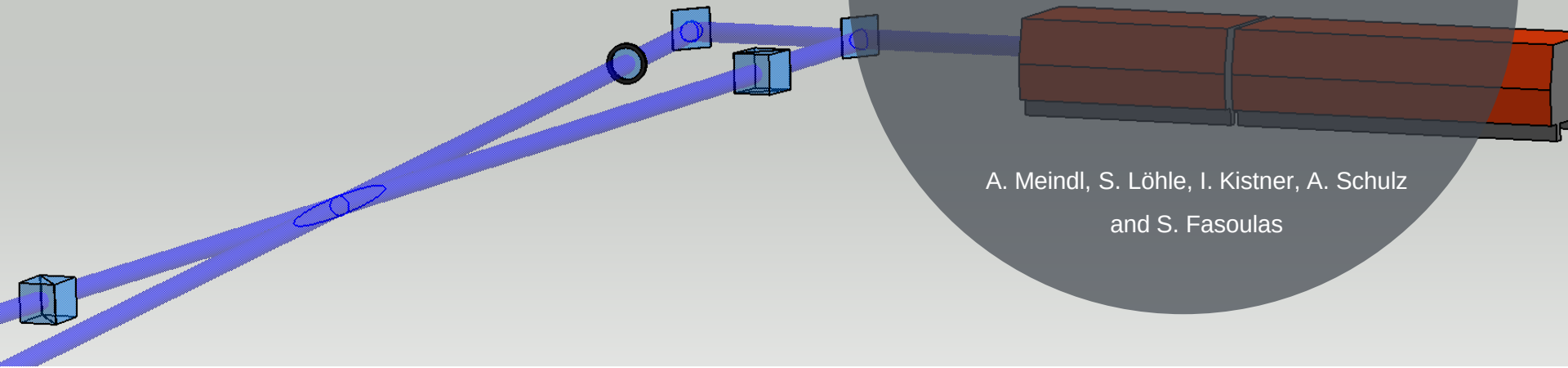
University of Stuttgart
Institute of Space Systems

Two-Photon Induced Polarization Spectroscopy with Atomic Oxygen



A. Meindl, S. Löhle, I. Kistner, A. Schulz
and S. Fasoulas

HEFDiG

Development

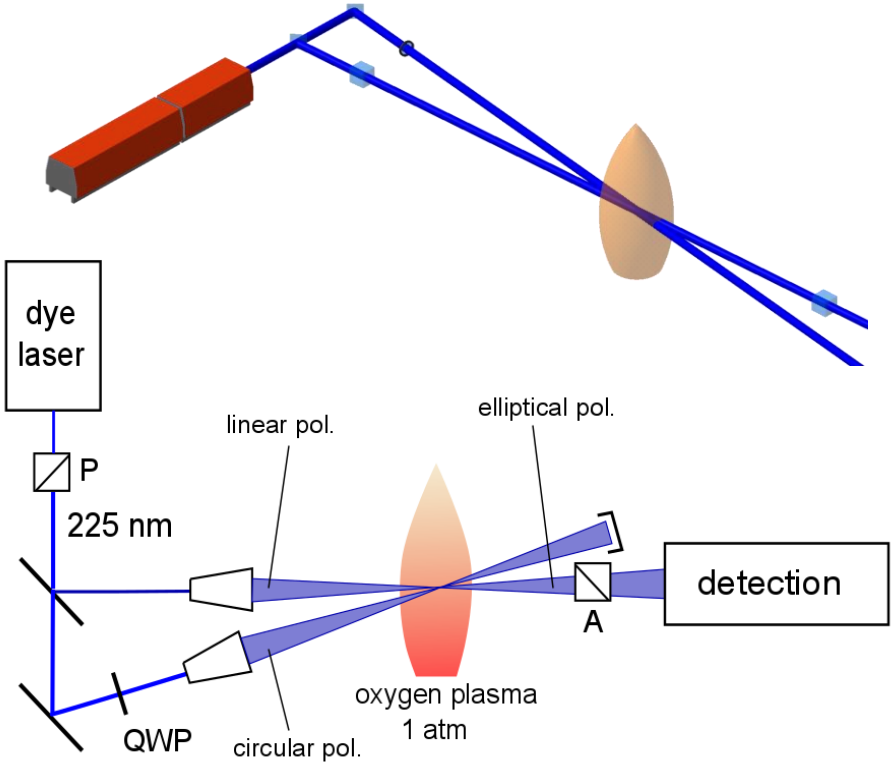
TIPS for atomic oxygen @ HEFDiG

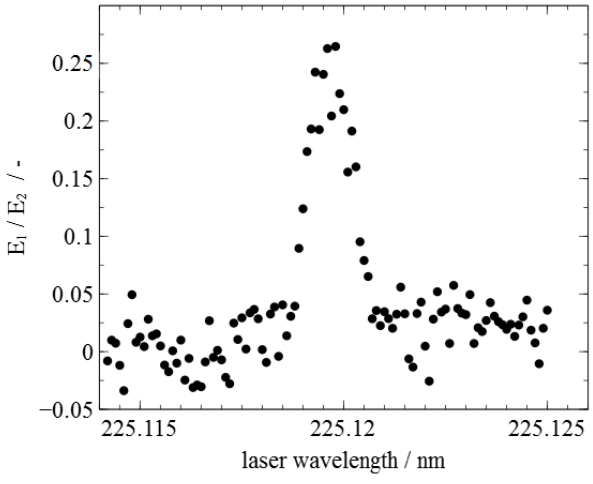
- Last RHTG Workshop (Stuttgart): first xenon profiles; poor signal quality [1]
- October 2018: Detailed study of TIPS with xenon in Applied Optics journal [2]
- AIAA 2019 San Diego: first successful detection of atomic oxygen with TIPS, first absolute number density calibration attempt using xenon [3]

[1] Meindl et al., *8th RHTG Workshop*, 2016
[2] Meindl et al., *Applied Optics*, Vol.57, No. 31, 2018
[3] Meindl et al., *AIAA SciTech Forum*, San Diego, 2019

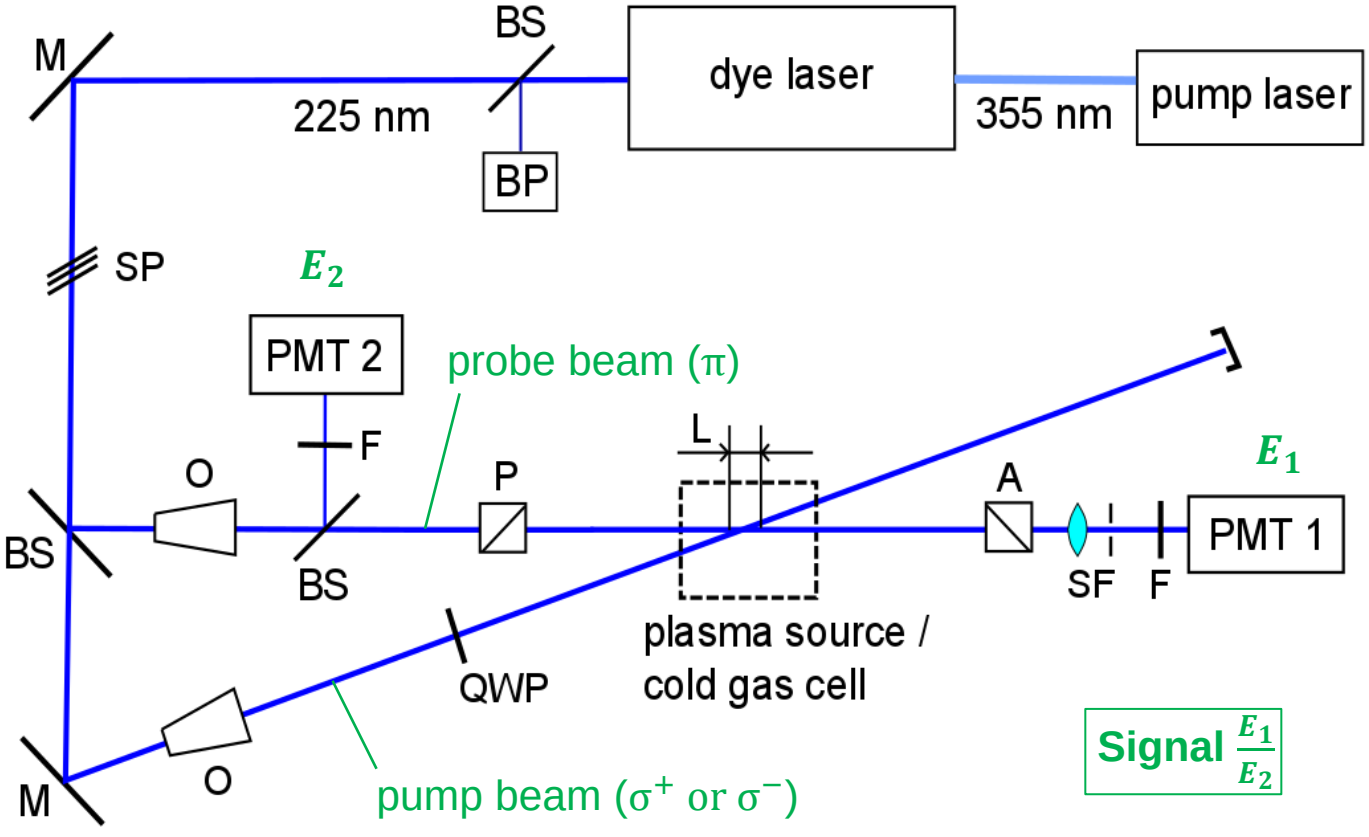
Two-Photon Induced Polarization Spectroscopy

TIPS





TIPS experimental setup



Polarizations:

σ^+

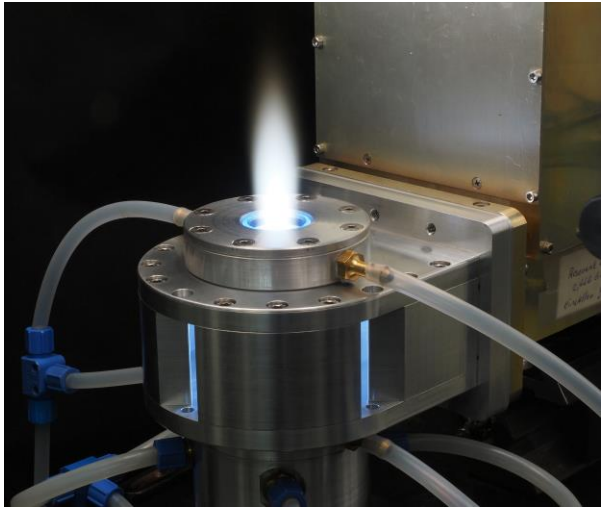
σ^-

π

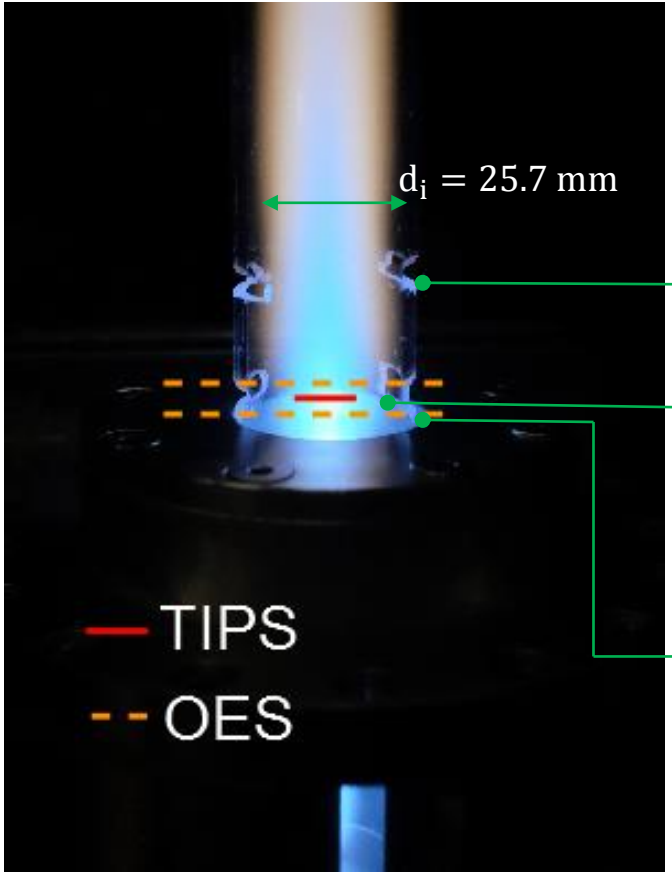
π: superposition of equal parts of σ^+ and σ^-

Goal: absorption of σ^+ (pump) and σ^- (probe) or vice versa

Plasma Torch



- microwave powered; 1 kW & 2 kW, O_2 , $5 \ldots 25\ \mathrm{l/min}$
- TIPS scans: 20 Hz, 0.2 pm per wavelength step, averaged over 20 shots per step



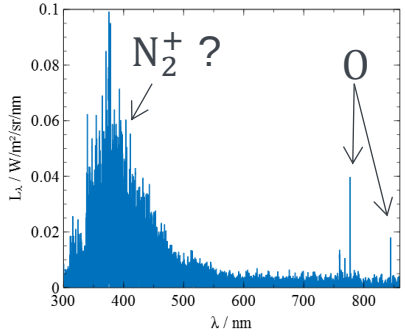
quartz tube, slits

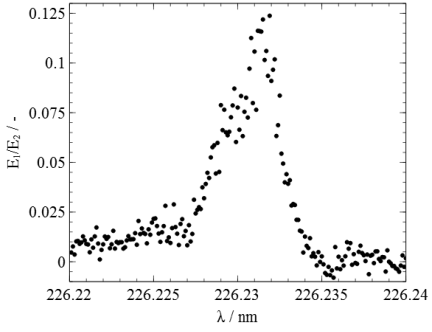
TIPS position:
~3-4mm above exit
9 mm overlap,
centered

Echelle for OES

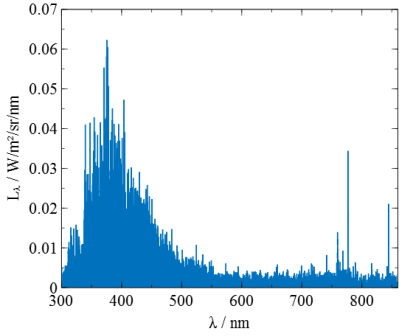
Measurements

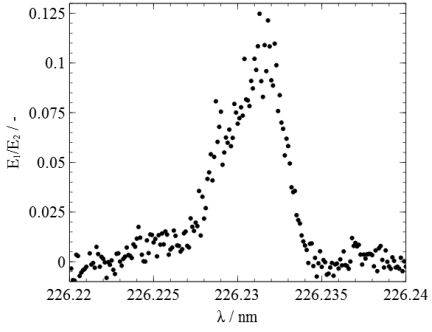
1 kW, 5 l/min



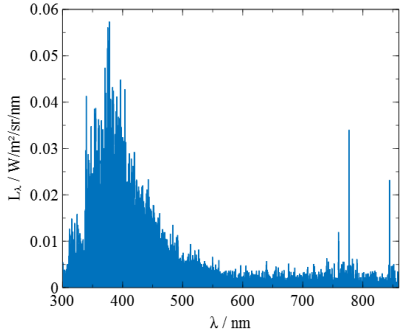


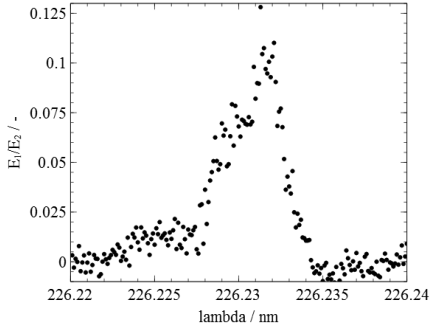
1 kW, 10 l/min





1 kW, 15 l/min

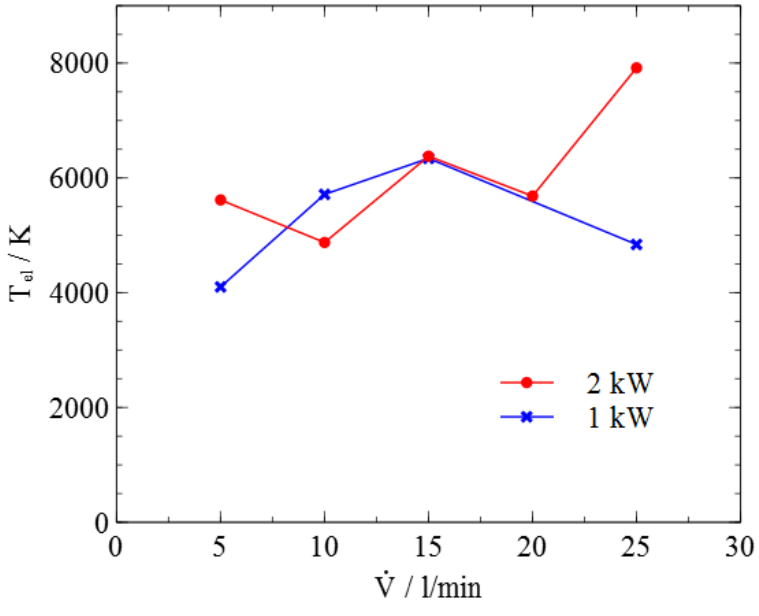




Spectra Analysis

- PARADE [3] fits to red spectral range

  T_{el} from O emission lines around 777 nm and 844 nm



[3] Liebhart et al., *43rd AIAA Thermophysics Conference*, New Orleans, 2012

Polarization Lineshape Modelling

$$P(\Delta\lambda) = \mathrm{X}_{abs}(\Delta\lambda)^2 + \left(\mathrm{X}_{disp}(\Delta\lambda) \pm \alpha\right)^2 \quad [4]$$

$\mathrm{X}_{abs}(\Delta\lambda)$ - absorption lineshape
$\mathrm{X}_{disp}(\Delta\lambda)$ - dispersion lineshape
$\pm\alpha$ - asymmetry (analyzer offset)

co-propagating beams: absorption lineshape is Voigt profile.

$$\mathrm{X}_{abs}(\Delta\lambda) = \frac{1}{\sqrt{\pi}\Gamma'_D} Re[W(x(\Delta\lambda) + iy)]$$

$$\mathrm{X}_{disp}(\Delta\lambda) = \frac{1}{\sqrt{\pi}\Gamma'_D} Im[W(x(\Delta\lambda) + iy)] \quad [5]$$

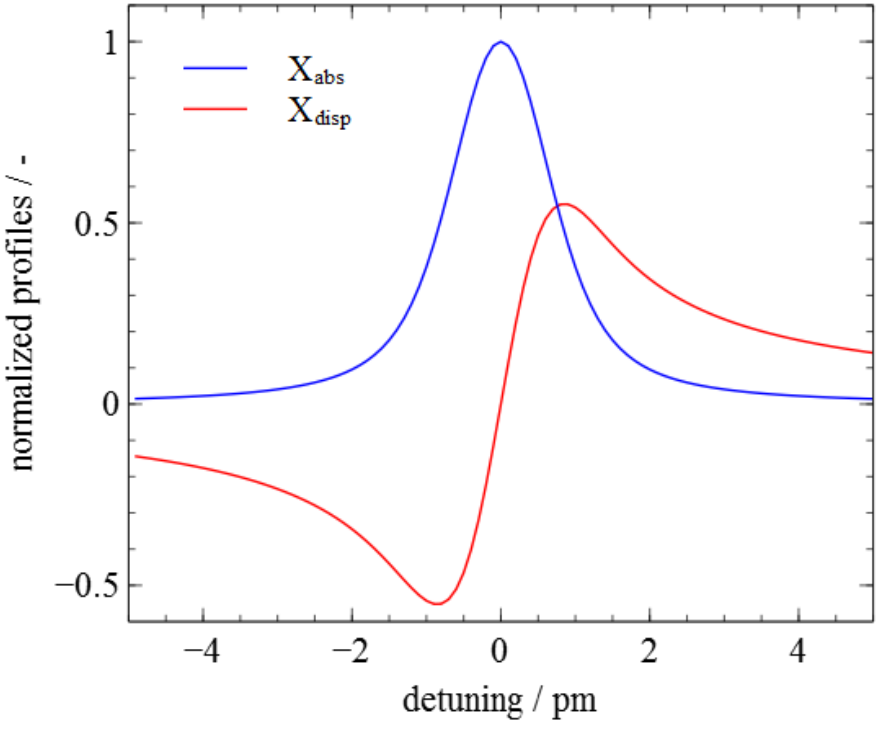
$$x(\Delta\lambda) = \frac{\Delta\lambda}{\Gamma'_D} \qquad y = \frac{\Gamma_L}{\Gamma'_D} \qquad \Gamma'_D = \frac{\Gamma_D}{\sqrt{ln2}}$$

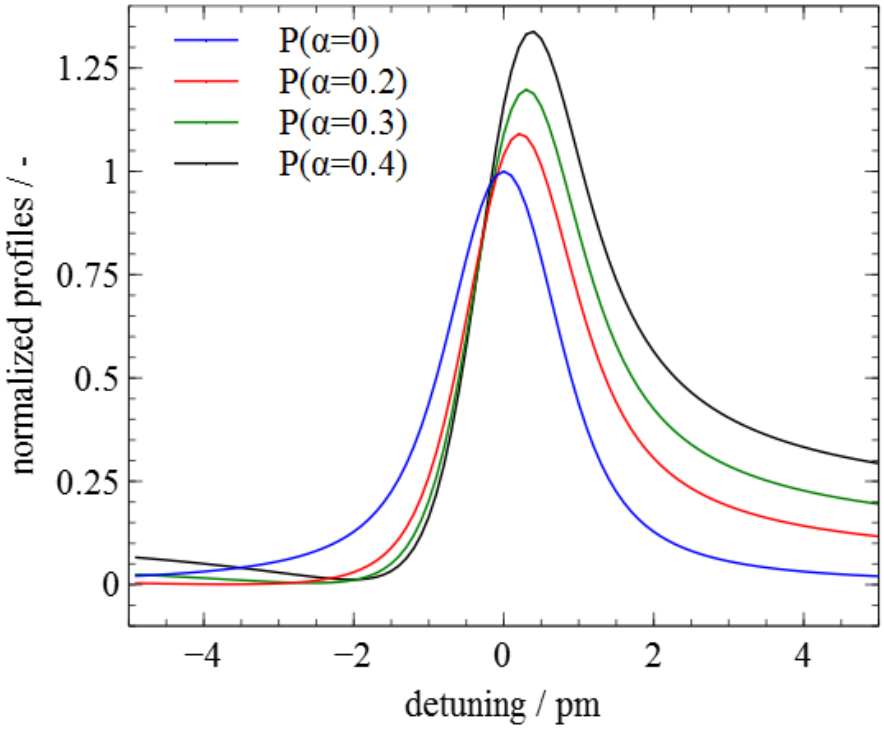
$\Delta\lambda$ - offset from line center
W - complex error function
Γ_D - Gaussian HWHM
Γ_L - Lorentzian HWHM

[4] Steiger et al., *AIP Conference Proceedings*, Vol. 467, 1999.
[5] Ma et al.,*J. Opt. Soc. Am. B*, Vol. 25, No. 7, 2008, pp. 1144–1155.

Polarization Lineshape Modelling

$$P(\Delta\lambda) = \mathrm{X}_{abs}(\Delta\lambda)^2 + \left(\mathrm{X}_{disp}(\Delta\lambda) \pm \alpha\right)^2$$



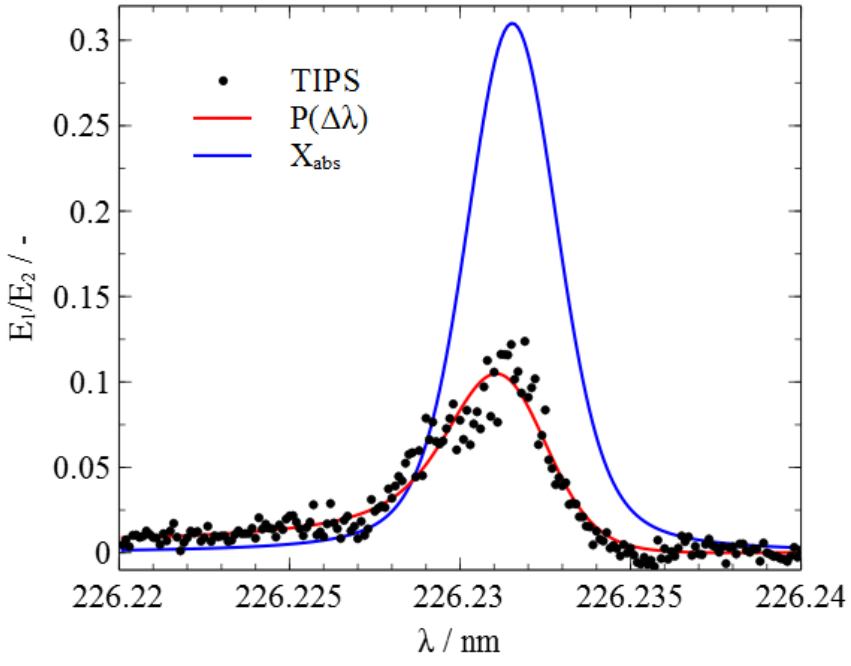


profiles normalized to peak absorption; calculated for $\Gamma_D = \Gamma_L = 0.5$ pm

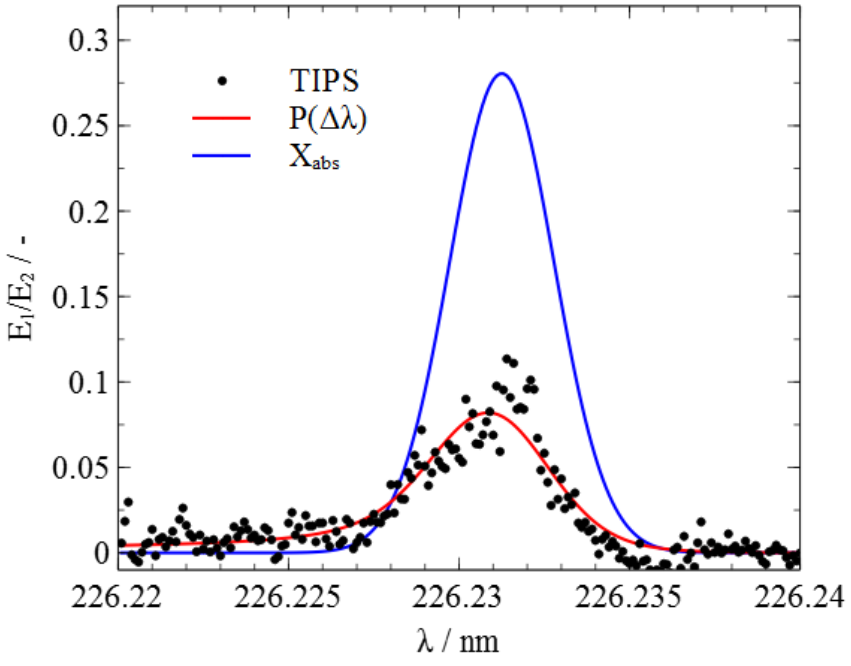
Lineshape Fitting

fitting parameters: Γ_D, Γ_L, λ_0, $\pm\alpha$, scaling factor S

1 kW, 5 l/min



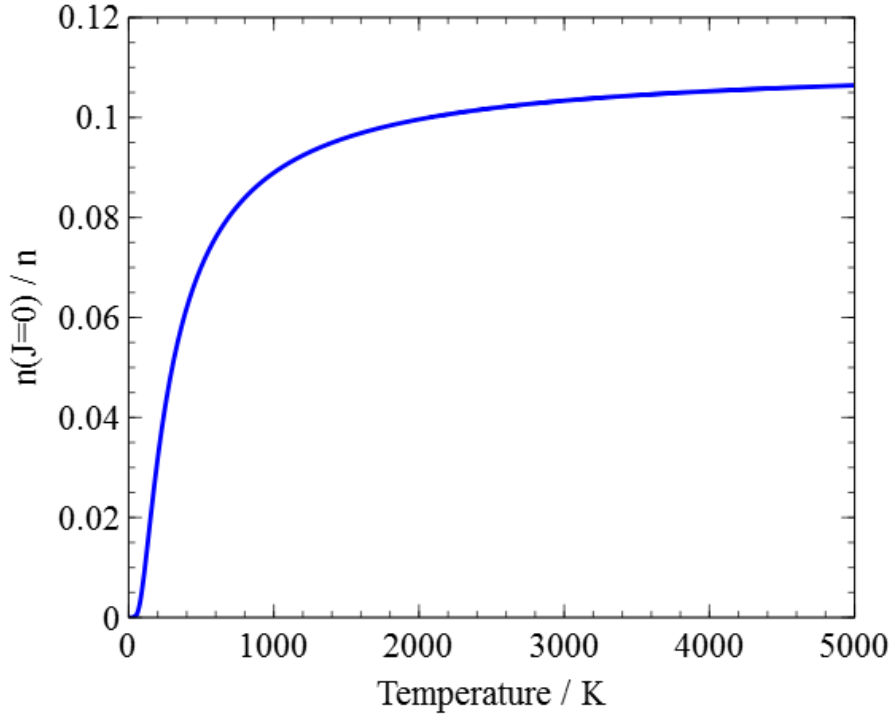
2 kW, 25 l/min



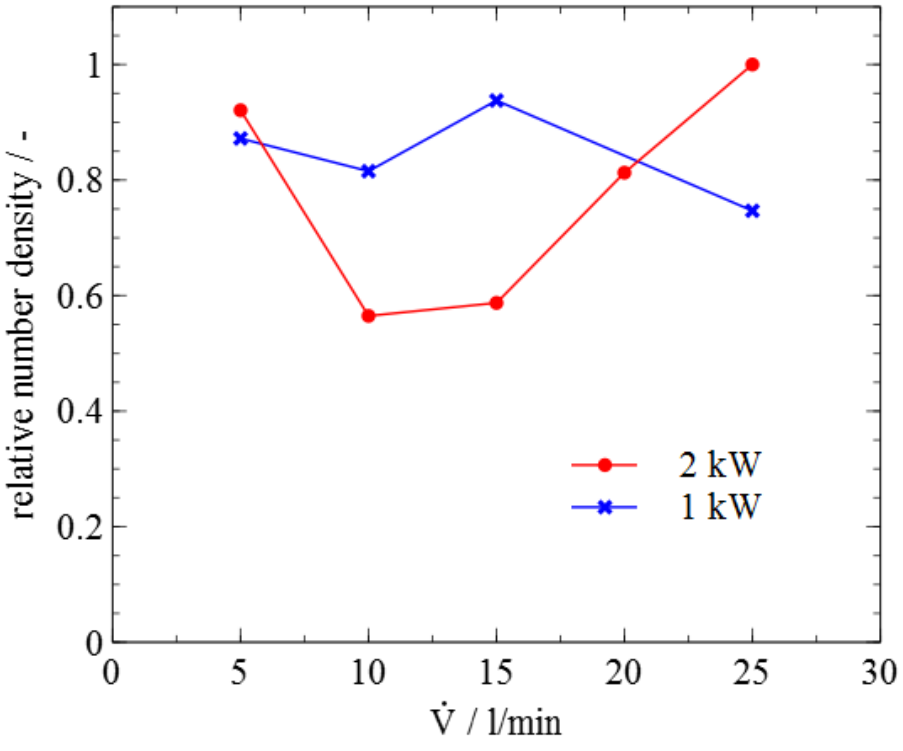
Γ_D calculated from T_{el} with assumption $T_{trans} = T_{el}$ and kept const. during fitting

Atomic Oxygen Ground State Population

$J = 0$ state of the atomic oxygen ground state triplet at $226.98\ \mathrm{cm}^{-1}$



Relative O number densities

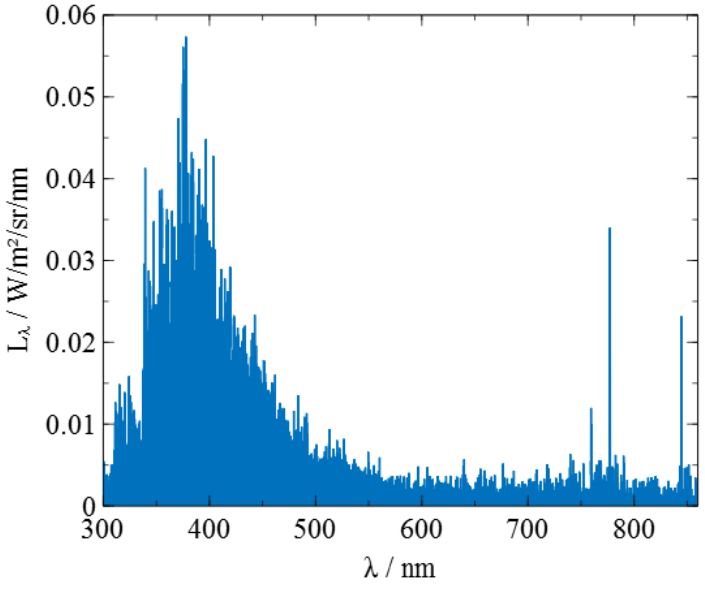


Summary & Outlook

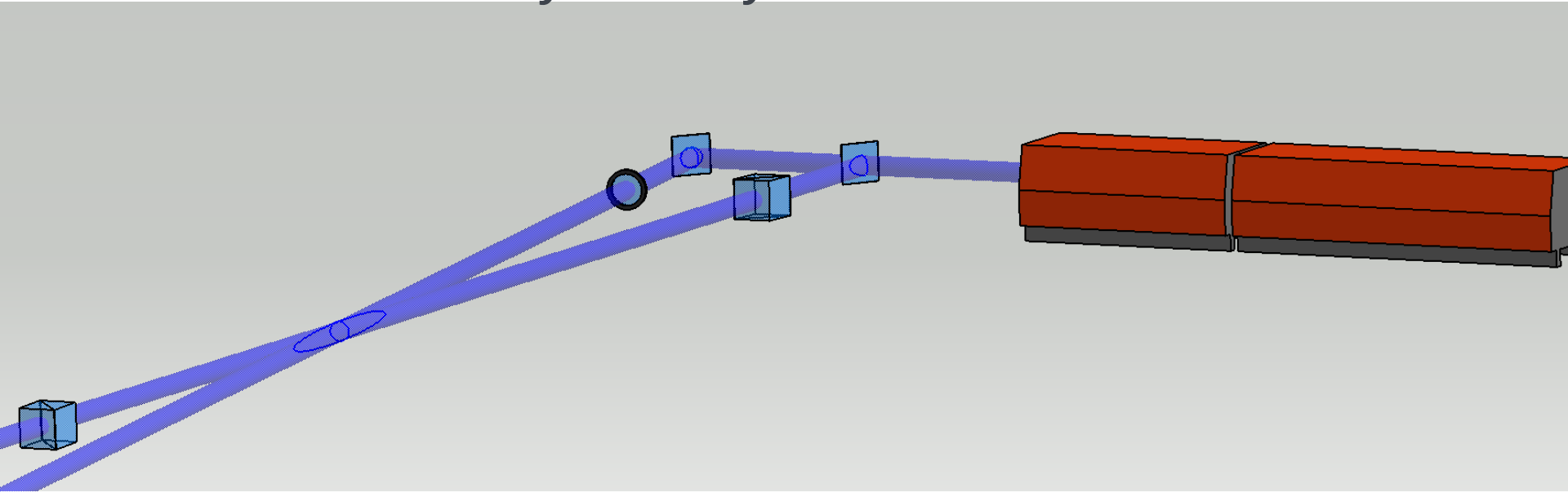
- successful $\mathbf{O}$ detection using TIPS for different plasma conditions in $\mathbf{O_2}$-plasma at 1 atm
- plasma is not well understood (blue spectral range; flow conditions for differing parameters) – Suggestions?

to do:

- absolute number density calibration with xenon



Thank you for your attention!



Questions / Suggestions?