Two-Photon Induced Polarization Spectroscopy with Atomic Oxygen

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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]
Two-Photon Induced Polarization Spectroscopy

TIPS
Goal: absorption of $\sigma^+$ (pump) and $\sigma^-$ (probe) or vice versa.

Polarizations:
- $\sigma^+$
- $\sigma^-$
- $\pi$: superposition of equal parts of $\sigma^+$ and $\sigma^-$
Plasma Torch

- microwave powered; 1 kW & 2 kW, \( O_2 \), 5 ... 25 l/min
- TIPS scans: 20 Hz, 0.2 pm per wavelength step, averaged over 20 shots per step

\[ d_i = 25.7 \text{ mm} \]

- quartz tube, slits
- TIPS position: ~3-4 mm 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\textsuperscript{[3]} fits to red spectral range

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

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\textsuperscript{[3]} Liebhart et al., 43rd AIAA Thermophysics Conference, New Orleans, 2012
Polarization Lineshape Modelling

\[ P(\Delta \lambda) = X_{abs}(\Delta \lambda)^2 + (X_{disp}(\Delta \lambda) \pm \alpha)^2 \]  
\[ X_{abs}(\Delta \lambda) \] - absorption lineshape  
\[ X_{disp}(\Delta \lambda) \] - dispersion lineshape  
\[ \pm \alpha \] - asymmetry (analyzer offset)

coopropagating beams: absorption lineshape is Voigt profile.

\[ X_{abs}(\Delta \lambda) = \frac{1}{\sqrt{\pi} \Gamma_D'} Re[W(x(\Delta \lambda) + iy)] \]  
\[ W \] - complex error function  
\[ \Gamma_D' \] - Gaussian HWHM

\[ X_{disp}(\Delta \lambda) = \frac{1}{\sqrt{\pi} \Gamma_D'} Im[W(x(\Delta \lambda) + iy)] \]  
\[ \Gamma_L \] - Lorentzian HWHM

\[ x(\Delta \lambda) = \frac{\Delta \lambda}{\Gamma_D'} \quad y = \frac{\Gamma_L}{\Gamma_D'} \quad \Gamma_D' = \frac{\Gamma_D}{\sqrt{\ln 2}} \]  
\[ \Delta \lambda \] - offset from line center  
\[ \Gamma_D \] - Gaussian HWHM  
\[ \Gamma_D' \] - Lorentzian HWHM

Polarization Lineshape Modelling

\[ P(\Delta \lambda) = X_{abs}(\Delta \lambda)^2 + (X_{disp}(\Delta \lambda) \pm \alpha)^2 \]

profiles normalized to peak absorption; calculated for \( \Gamma_D = \Gamma_L = 0.5 \text{ pm} \)
**Lineshape Fitting**

fitting parameters: $\Gamma_D$, $\Gamma_L$, $\lambda_0$, $\pm \alpha$, scaling factor $S$

$\Gamma_D$ 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 cm\(^{-1}\)
Relative O number densities

![Graph showing relative number density vs. flow rate (V) for 2 kW and 1 kW.]
Summary & Outlook

- successful $\text{O}$ detection using TIPS for different plasma conditions in $\text{O}_2$-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?