Atelier diagnostics laser

Laurent Invernizzi

Research Engineer

28/10/2025

LaSPM platform

Laser and **S**pectroscopy diagnostics in **P**las**M**as

Many tools for many applications…

Spectrometers

Space/time resolved optical emission spectroscopy

500 pm | 50 pm | **Spectral resolution** | 20 pm | 4 pm

Global spectrum
E.g.: *species identification*

Molecular band spectrum
E.g.: *ro-vibrational temperature*

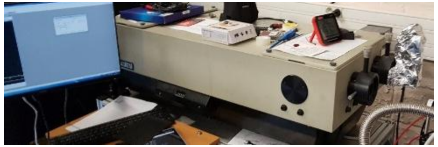
Atomic line spectrum
E.g.: *electron density*

4096

AVANTES
MEMBER OF THE NYNOMIC GROUP

Shamrock 500i

OXFORD INSTRUMENTS
ANDOR



THR1000

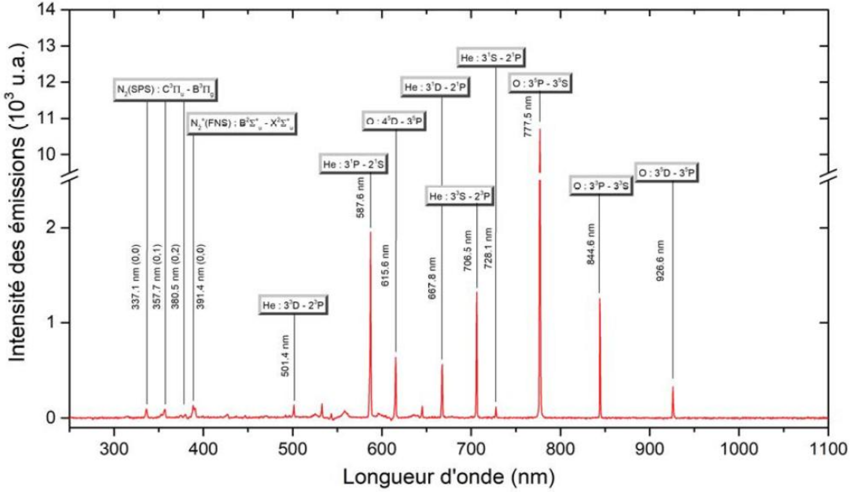
JOBIN YVON HORIBA

Sopra

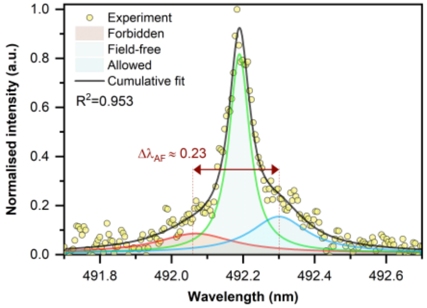
Réseau Plasmas Froids

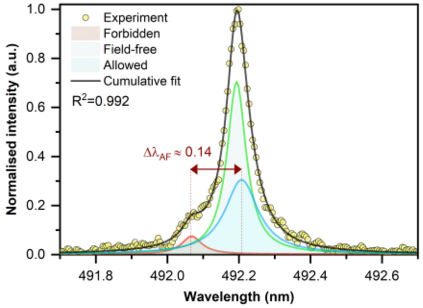
Spectrometers (short focal)

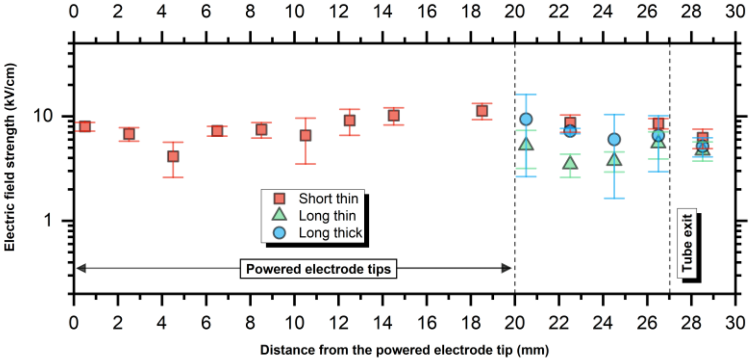
Species identification



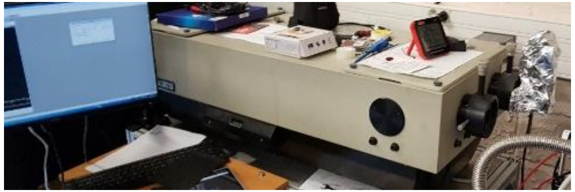
Electric field intensity measurement (Stark polarisation)





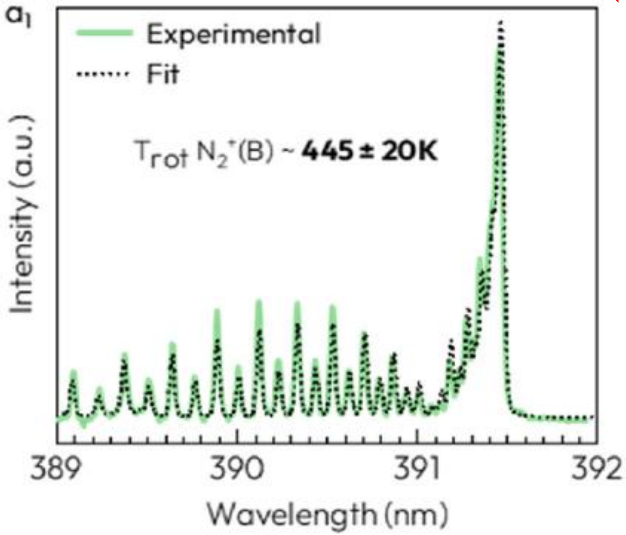


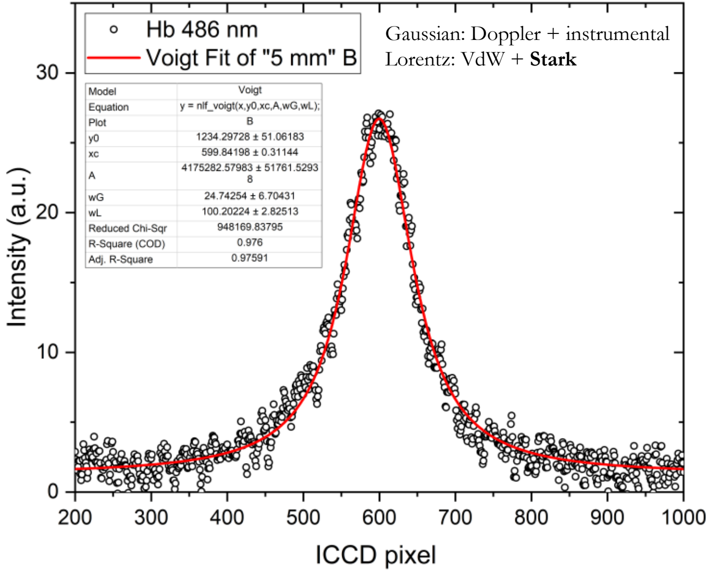
Spectrometers (long focal)



Electron density (Stark broadening)

Rotational temperature

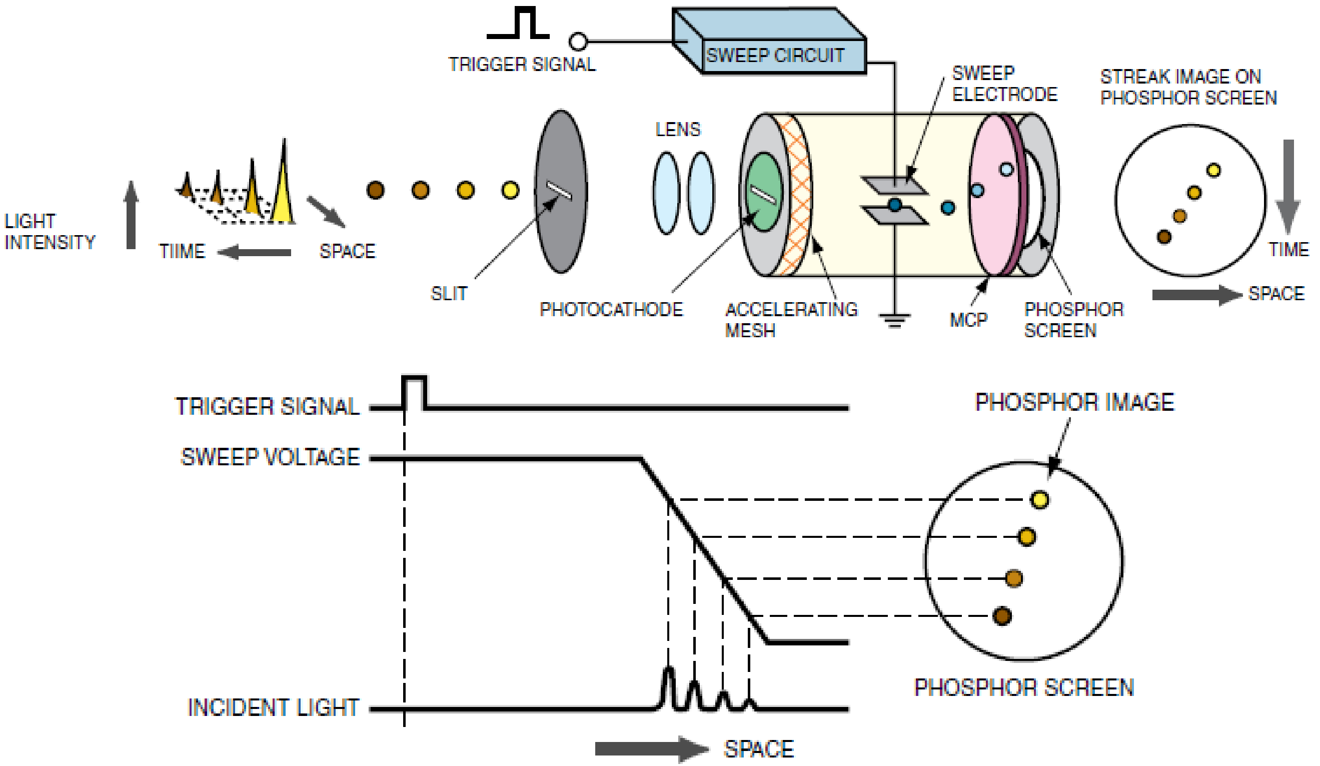




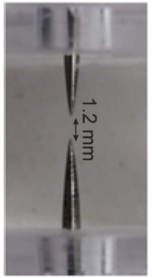
Ultra-fast imaging (streak camera)

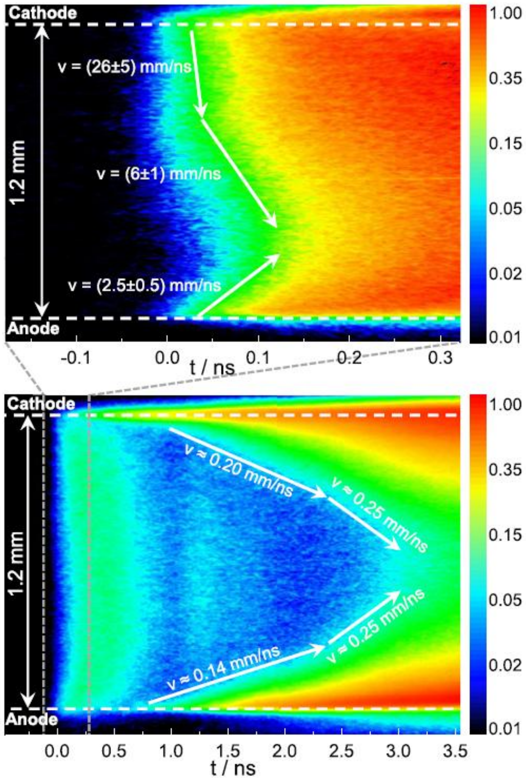
HAMAMATSU

Streak camera: minimal temporal resolution = 1 ps



Ultra-fast imaging (streak camera)



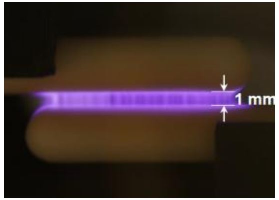


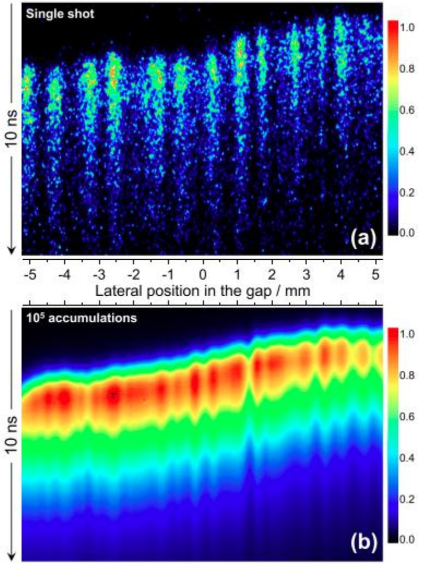
- Enables **1D time-resolved tracking** of the discharge evolution, revealing its **ultrafast propagation velocity**

- Demonstrates **all propagation phases** (fast and slow stages)

- Shows the temporal delay between plasma formation at the cathode and the anode

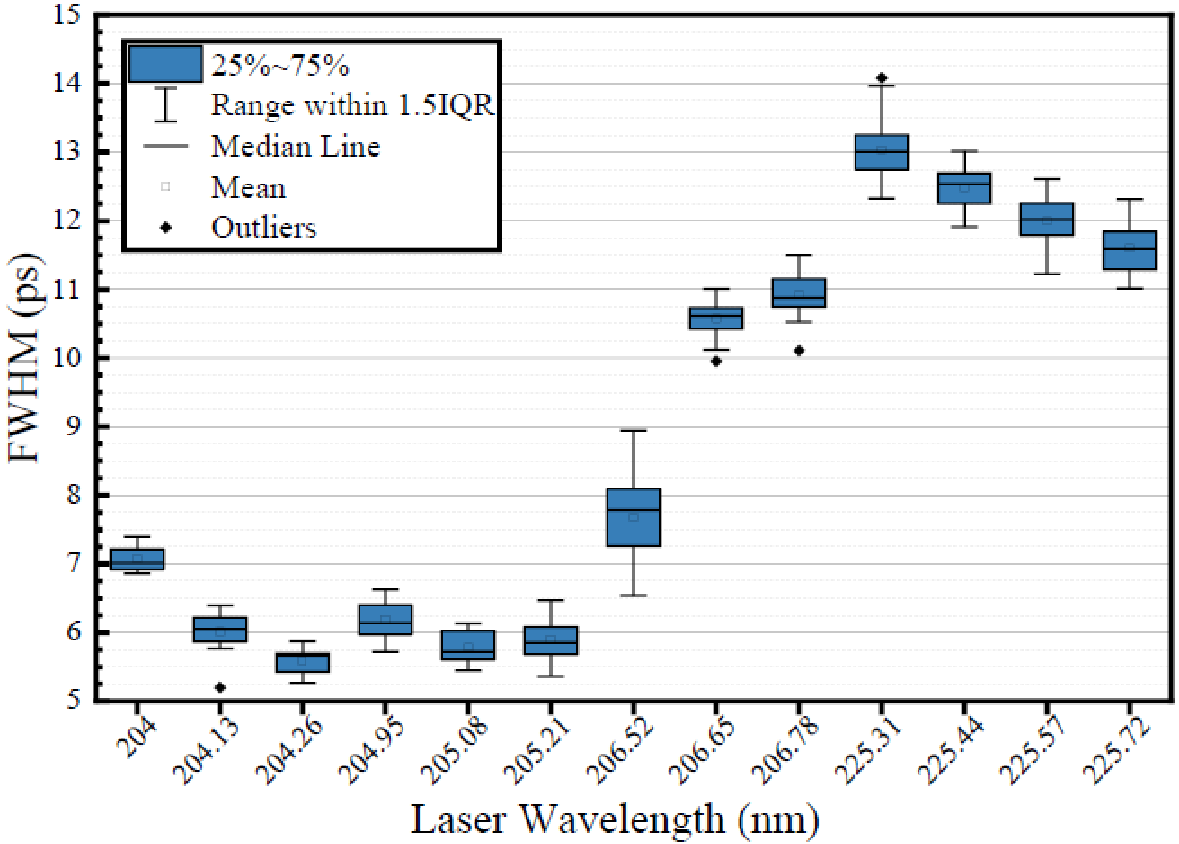
- Reveals the sequence of filament formation





Ultra-fast imaging (streak camera)

Measurement of the duration of our ps-laser!

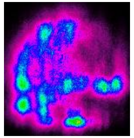


Ps-system (laser + streak camera)

Picosecond system

Highly collisional plasmas

EKSPLA



Picosecond pump laser: Nd:YLF

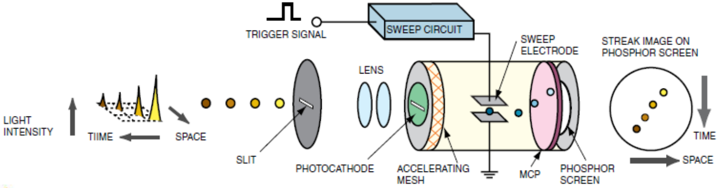
$\tau_{laser} \approx 10$ ps FWHM

$f_{laser} = 5$ Hz

Optical parametric oscillator (OPO): 193-2000 nm

HAMAMATSU

Streak camera: minimal temporal resolution = 1 ps



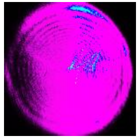
Z-translation: spatial resolution = 1 µm

LABVIEW: automated measurement

PYTHON: data processing (including deconvolution)

Ns-system (laser + PMT)

SPECTRA PHYSICS and SIRAH
Nanosecond pump laser: Nd:YAG
$\tau_{laser} \approx 10$ ns FWHM
$f_{laser} = 10$ Hz
Dye + crystals KPD/BBO: 197-900 nm



PRINCETON INSTRUMENTS
Monochromator: spectral resolution = 0.4 nm

HAMAMATSU
PMT with gate function: temporal resolution = 2 ns

3-axis translations: spatial resolution = 1 µm

LABVIEW: automated measurement

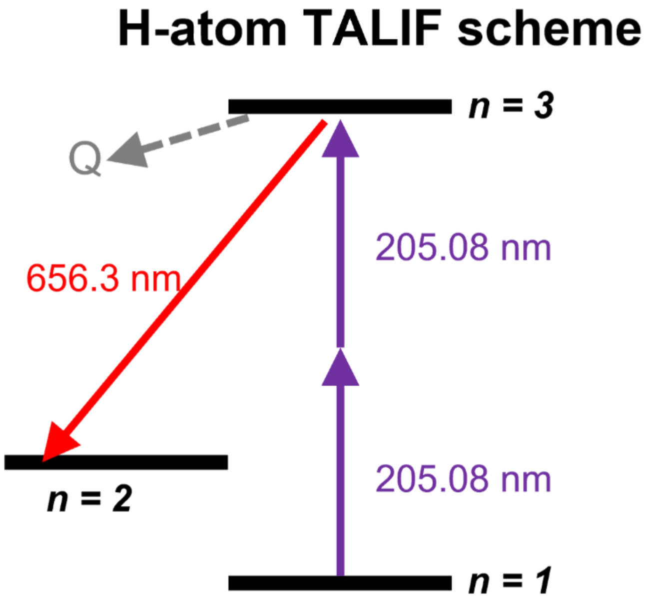
PYTHON: data processing

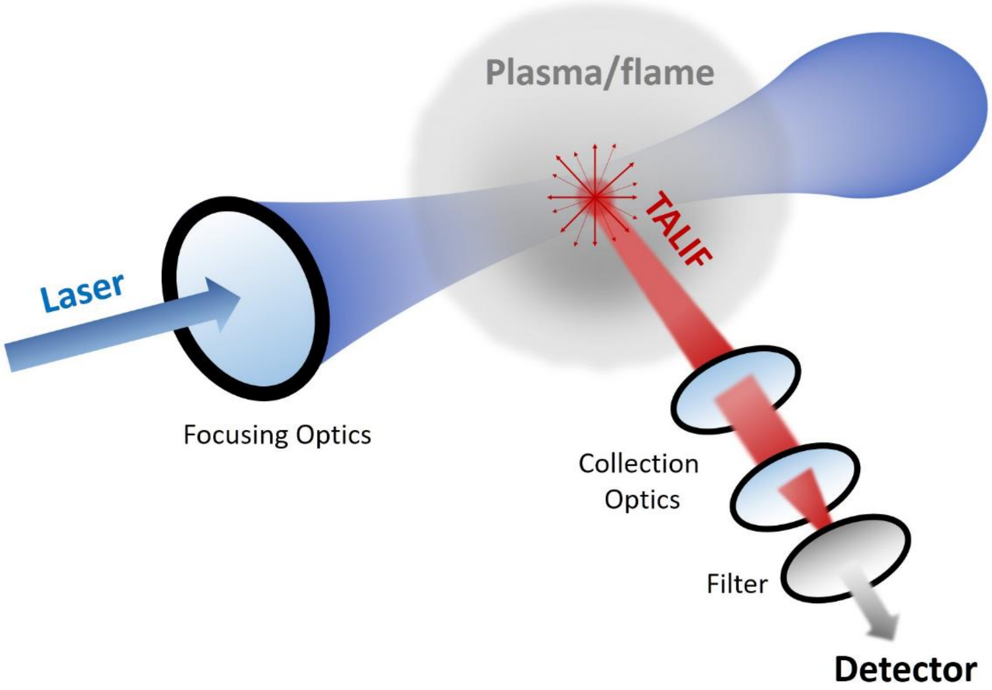
Nanosecond system

Weakly collisional plasmas

TALIF (ps- ns-systems)

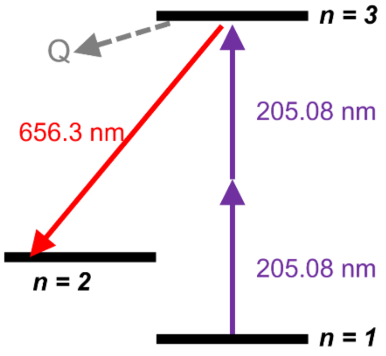
TALIF: **T**wo-photon **A**bsorption **L**aser **I**nduced **F**luorescence
→ Absolute density measurements of **H, O, N**, etc. in plasmas!



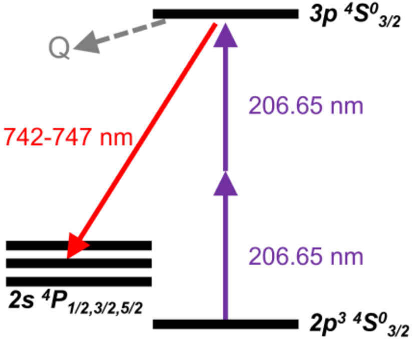


TALIF (ps- ns-systems)

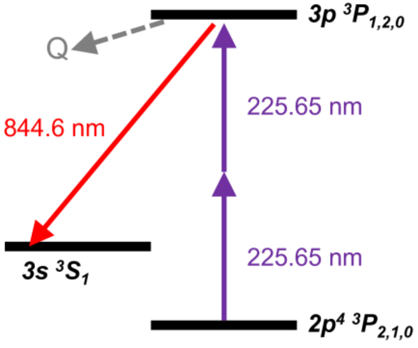
H-atom TALIF scheme



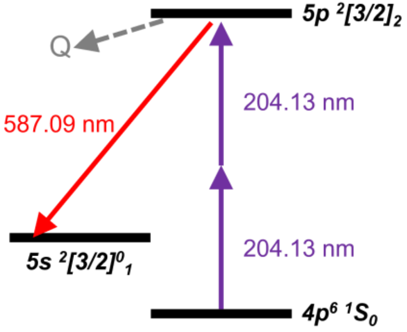
N-atom TALIF scheme



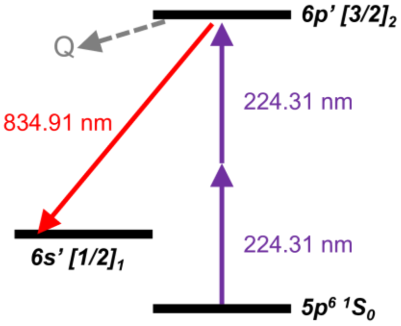
O-atom TALIF scheme



Kr-atom TALIF scheme



Xe-atom TALIF scheme



TALIF equation

To be determined

Calculated/litterature/data sheet

Measured

$$n_X = n_{cal}\,\frac{\int_t \int_\lambda S_{F_X}}{\int_t \int_\lambda S_{F_{cal}}}\,\frac{\eta_{cal}}{\eta_X}\,\frac{T_{cal}}{T_X}\,\frac{\sigma_{cal}}{\sigma_X}\,\frac{A_{cal}}{A_X}\,\frac{\tau_{cal}}{\tau_X}\,\frac{E_{cal}{}^2}{E_X{}^2}\,\frac{\lambda_{cal}{}^2}{\lambda_X{}^2}$$

Species of interest density (H, N, O, etc.)

Calibration species density (Kr, Xe)

Ratio of temporally and spectrally (and spatially) integrated fluorescence signals

Quantum efficiency ratio of the detector at the fluorescence wavelength

Optical transmission ratio at the fluorescence wavelength

Two-photon excitation cross-section ratio

Einstein coefficient ratio of the transition from the laser-excited level to the lower state

Experimentally-measured fluorescence decay time ratio of the laser-excited state

Laser energy ratio

Laser wavelength ratio

Plasmas already probed!

1 bar

10^{-4} bar | 10^{-3} bar | 10^{-2} bar | 10^{-1} bar

Weakly collisional → Highly collisional

Radiofrequency

Material deposition

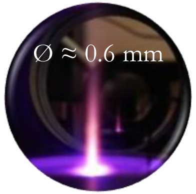
Microwave

Depopulation mechanisms of H

Radiofrequency

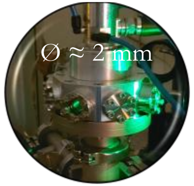
Diagnostics comparison

Pulsed



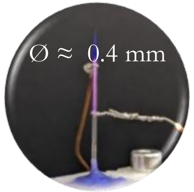
Material deposition

Microwave



Gas temperature measurement

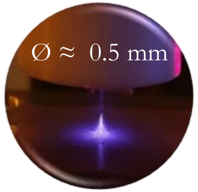
Pulsed



University of Cyprus

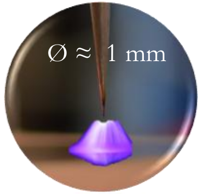
Mass spectrometry

Pulsed



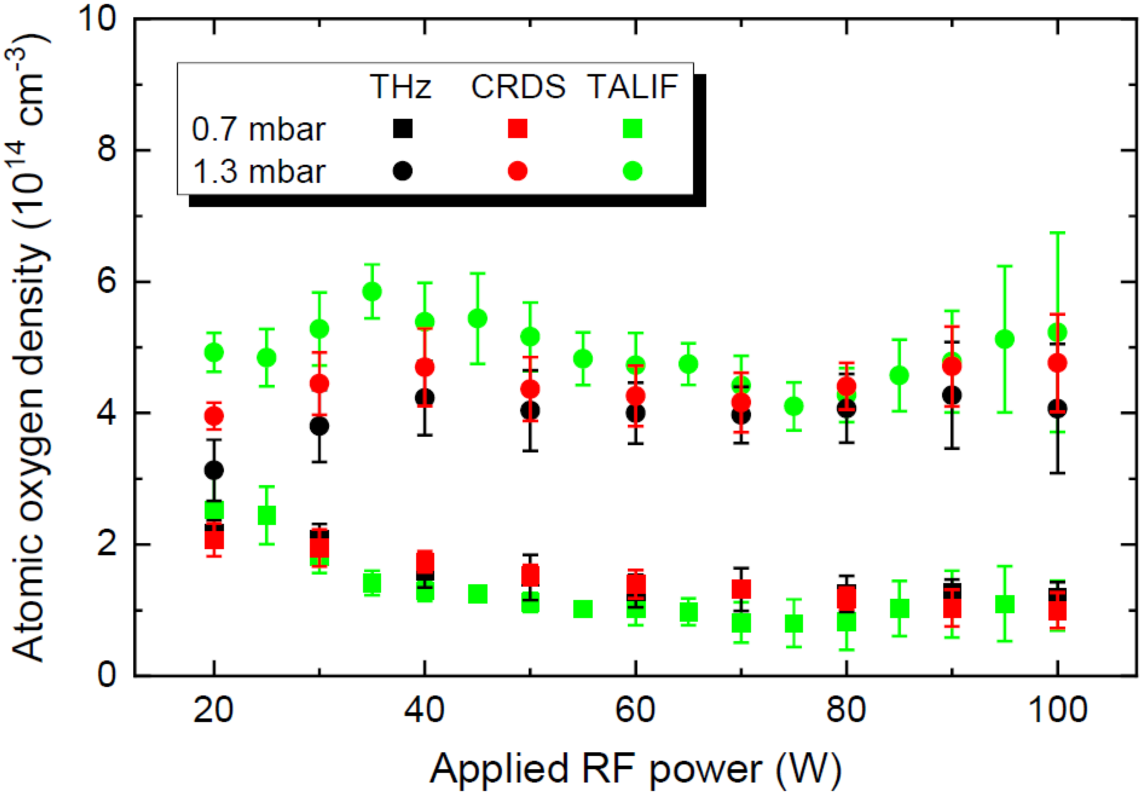
N-production mechanisms

Pulsed



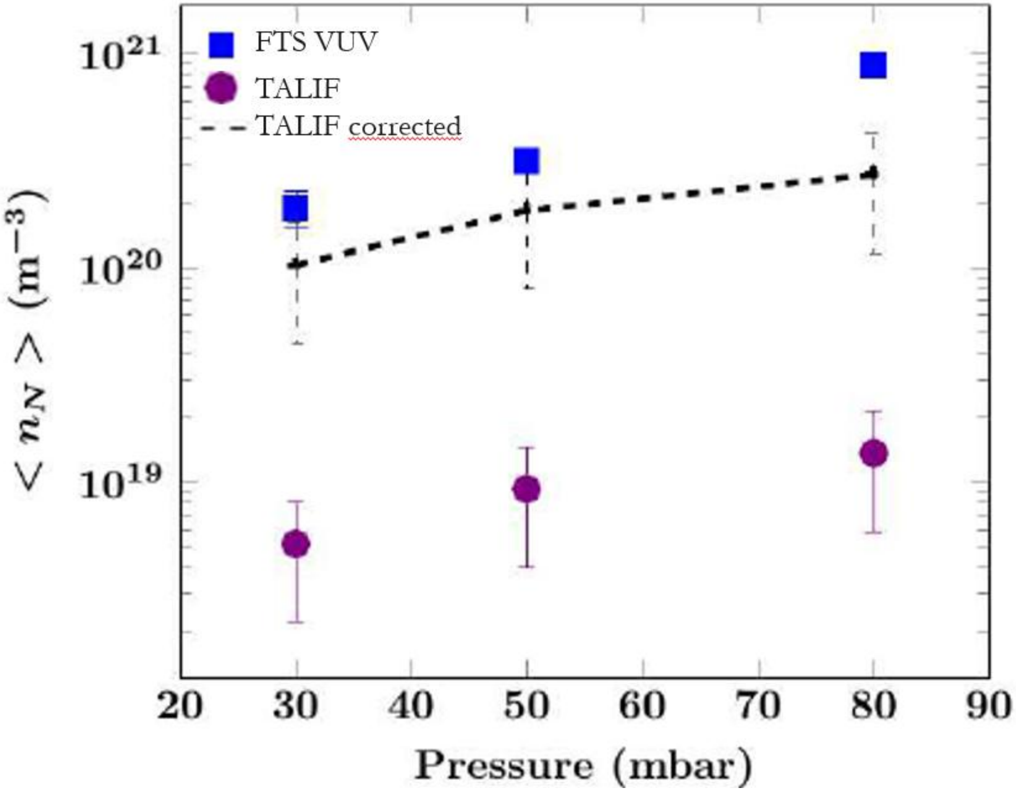
Analytical chemistry

Plasmas already probed!



Pressure ~ 1 mbar
Feeding gas: oxygen
Power supply: radiofrequency
Picosecond system

Plasmas already probed!



Pressure ~ 10s mbar
Feeding gas: argon + nitrogen
Power supply: pulsed
Nanosecond system

LaSPM operation

	Rate Summary – Excl. VAT			
Billing basis	CNRS clients (CNRS units)	Partner clients (universities, INSERM, etc.)	External academic clients (public hospitals, etc.)	Private clients
Week	2719.95 €	2719.95 €	2719.95 €	5000 €

Keep it in mind **well in advance**:
- to include it in your ANR submissions (e.g., platform to be listed in Webcontrat).
- to take into account that the platform is used continuously during the following 12 months.

A new website now lists the "**CNRS Ingénierie**" **platforms**: https://plateformes.insis.cnrs.fr/
You will find a **contact form** available there.

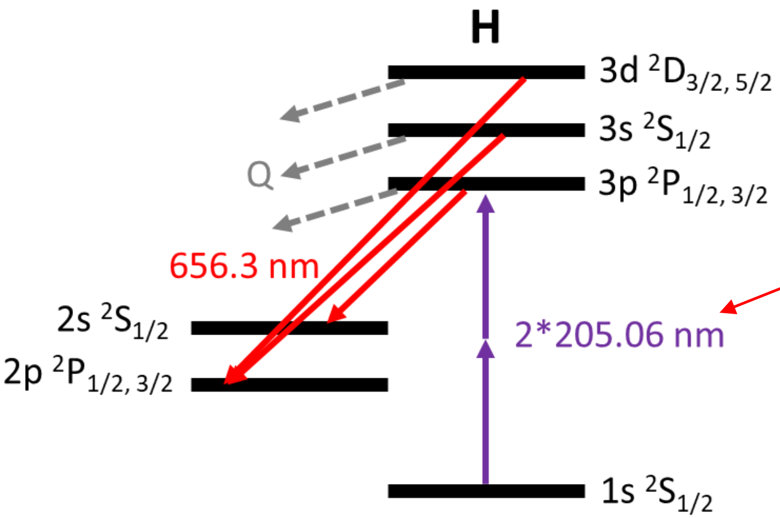
Additonals

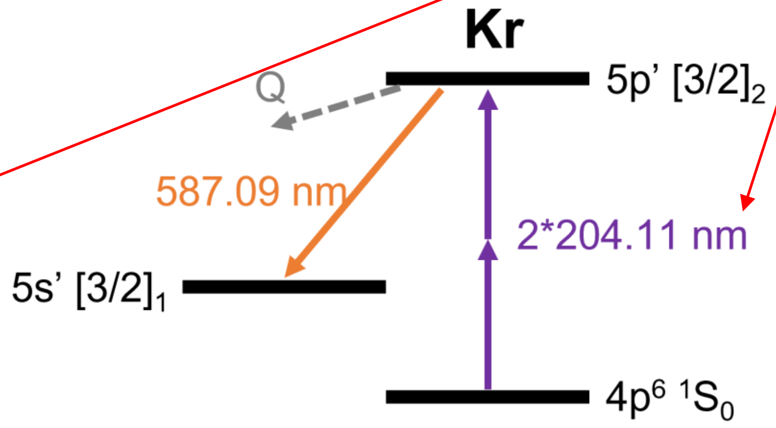
Wavelength

Measured

Laser wavelength ratio

$$n_X = n_{cal} \frac{\int_t \int_\lambda S_{F_X}}{\int_t \int_\lambda S_{F_{cal}}} \frac{\eta_{cal}}{\eta_X} \frac{T_{cal}}{T_X} \frac{\sigma_{cal}}{\sigma_X} \frac{A_{cal}}{A_X} \frac{\tau_{cal}}{\tau_X} \frac{{E_{cal}}^2}{{E_X}^2} \boxed{\frac{{\lambda_{cal}}^2}{{\lambda_X}^2}}$$



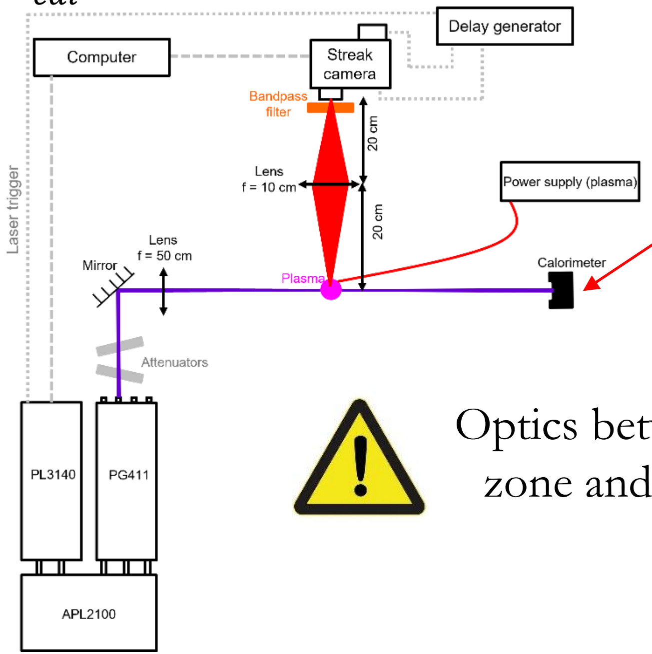


Laser energy

Measured

Laser energy ratio

$$n_X = n_{cal} \frac{\int_t \int_\lambda S_{F_X}}{\int_t \int_\lambda S_{F_{cal}}} \frac{\eta_{cal}}{\eta_X} \frac{T_{cal}}{T_X} \frac{\sigma_{cal}}{\sigma_X} \frac{A_{cal}}{A_X} \frac{\tau_{cal}}{\tau_X} \boxed{\frac{{E_{cal}}^2}{{E_X}^2}} \frac{{\lambda_{cal}}^2}{{\lambda_X}^2}$$



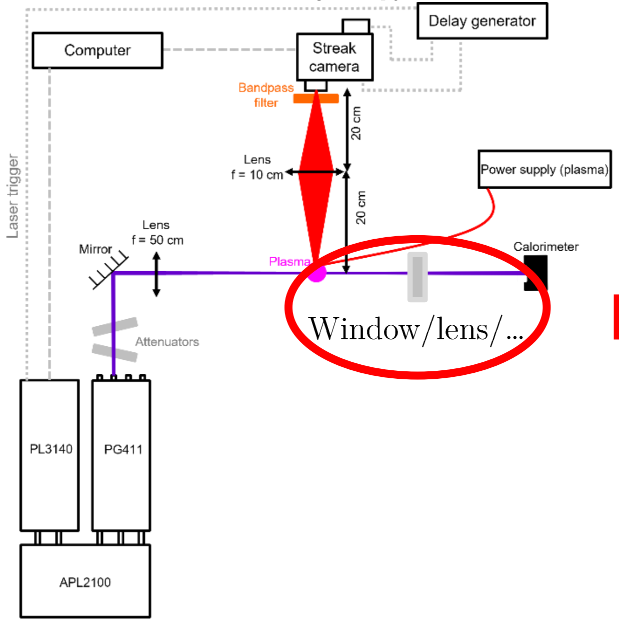
Optics between the probed zone and the calorimeter

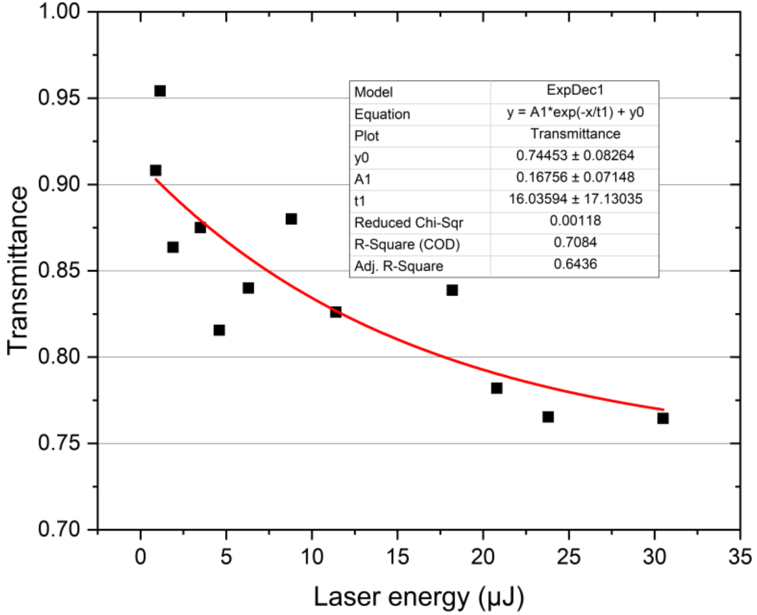
Laser energy

Measured

Laser energy ratio

$$n_X = n_{cal} \frac{\int_t \int_\lambda S_{F_X}}{\int_t \int_\lambda S_{F_{cal}}} \frac{\eta_{cal}}{\eta_X} \frac{T_{cal}}{T_X} \frac{\sigma_{cal}}{\sigma_X} \frac{A_{cal}}{A_X} \frac{\tau_{cal}}{\tau_X} \boxed{\frac{{E_{cal}}^2}{{E_X}^2}} \frac{{\lambda_{cal}}^2}{{\lambda_X}^2}$$



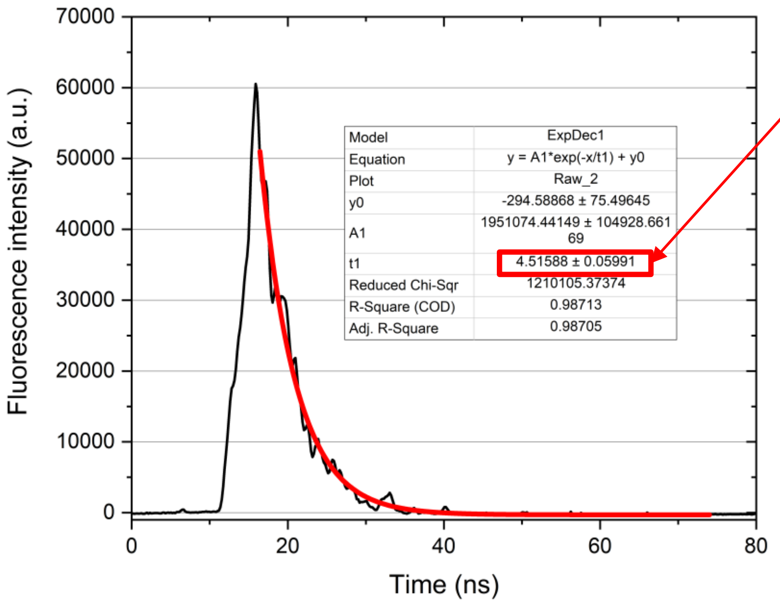


Effective lifetime

Measured

Experimentally-measured fluorescence decay time ratio of the laser-excited state

$$n_X = n_{cal} \frac{\int_t \int_\lambda S_{F_X}}{\int_t \int_\lambda S_{F_{cal}}} \frac{\eta_{cal}}{\eta_X} \frac{T_{cal}}{T_X} \frac{\sigma_{cal}}{\sigma_X} \frac{A_{cal}}{A_X} \boxed{\frac{\tau_{cal}}{\tau_X}} \frac{{E_{cal}}^2}{{E_X}^2} \frac{{\lambda_{cal}}^2}{{\lambda_X}^2}$$



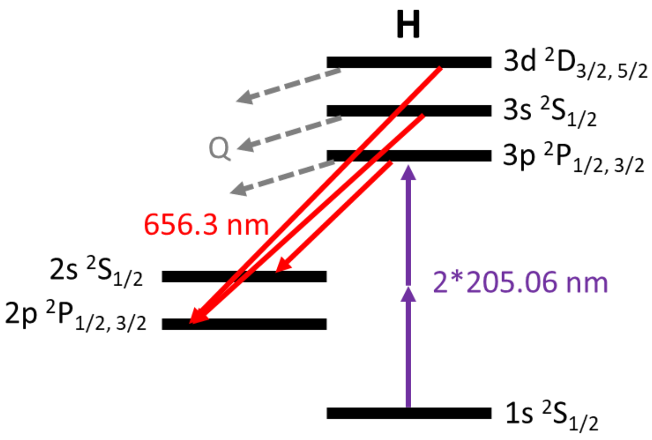
Deconvolution

Einstein coefficient

Calculated/litterature/data sheet

Einstein coefficient ratio of the transition from the laser-excited level to the lower state

$$n_X = n_{cal} \frac{\int_t \int_\lambda S_{F_X}}{\int_t \int_\lambda S_{F_{cal}}} \frac{\eta_{cal}}{\eta_X} \frac{T_{cal}}{T_X} \frac{\sigma_{cal}}{\sigma_X} \boxed{\frac{A_{cal}}{A_X}} \frac{\tau_{cal}}{\tau_X} \frac{{E_{cal}}^2}{{E_X}^2} \frac{{\lambda_{cal}}^2}{{\lambda_X}^2}$$



- NIST database

Or

- $A_X = \frac{b\ (purely\ optical\ branching\ ratio)}{\tau_{natural_X}}$

2-photon absorption cross section

Calculated/litterature/data sheet

Two-photon excitation cross-section ratio

$$n_X = n_{cal} \frac{\int_t \int_\lambda S_{F_X}}{\int_t \int_\lambda S_{F_{cal}}} \frac{\eta_{cal}}{\eta_X} \frac{T_{cal}}{T_X} \boxed{\frac{\sigma_{cal}}{\sigma_X}} \frac{A_{cal}}{A_X} \frac{\tau_{cal}}{\tau_X} \frac{{E_{cal}}^2}{{E_X}^2} \frac{{\lambda_{cal}}^2}{{\lambda_X}^2}$$

Niemi 2001: $\frac{\sigma_{Kr}}{\sigma_H} = 0.62 \pm 50\%$ $\frac{\sigma_{Kr}}{\sigma_N} = 0.67 \pm 50\%$

Niemi 2005: $\frac{\sigma_{Xe}}{\sigma_O} = 1.8 \pm 11\%$

Drag 2021 + Bamford 1987: $\frac{\sigma_{Xe}}{\sigma_O} = 0.73 \pm 32\%$

Shu 2024: $\frac{\sigma_{Xe}}{\sigma_O} = 1.9 \pm 20\%$

Starikovskiy 2025: $\frac{\sigma_{Kr}}{\sigma_H} = 0.027 \pm 20\%$

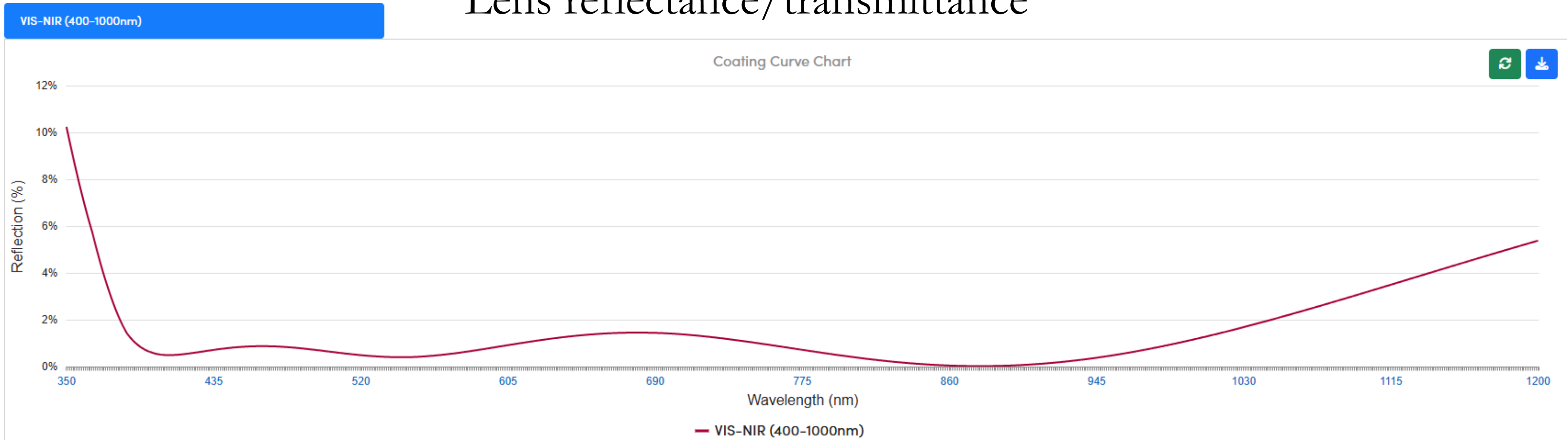
Transmittance

Calculated/litterature/data sheet

Optical transmission ratio at the fluorescence wavelength

$$n_X = n_{cal} \frac{\int_t \int_\lambda S_{F_X}}{\int_t \int_\lambda S_{F_{cal}}} \frac{\eta_{cal}}{\eta_X} \boxed{\frac{T_{cal}}{T_X}} \frac{\sigma_{cal}}{\sigma_X} \frac{A_{cal}}{A_X} \frac{\tau_{cal}}{\tau_X} \frac{{E_{cal}}^2}{{E_X}^2} \frac{{\lambda_{cal}}^2}{{\lambda_X}^2}$$

Lens reflectance/transmittance



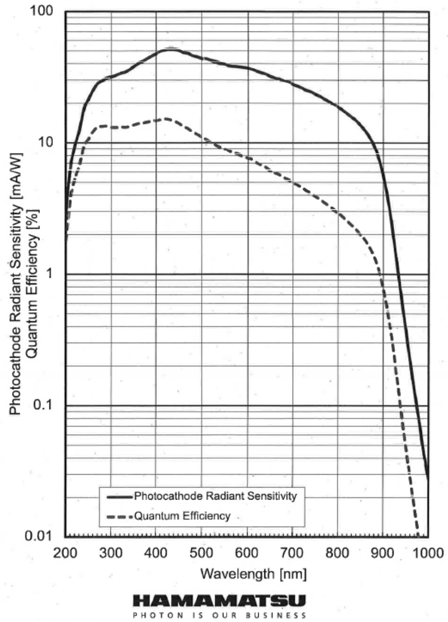
Quantum efficiency

Calculated/litterature/data sheet

Quantum efficiency ratio of the detector at the fluorescence wavelength

$$n_X = n_{cal} \frac{\int_t \int_\lambda S_{F_X}}{\int_t \int_\lambda S_{F_{cal}}} \boxed{\frac{\eta_{cal}}{\eta_X}} \frac{T_{cal}}{T_X} \frac{\sigma_{cal}}{\sigma_X} \frac{A_{cal}}{A_X} \frac{\tau_{cal}}{\tau_X} \frac{{E_{cal}}^2}{{E_X}^2} \frac{{\lambda_{cal}}^2}{{\lambda_X}^2}$$

Given in the datasheet of the detector



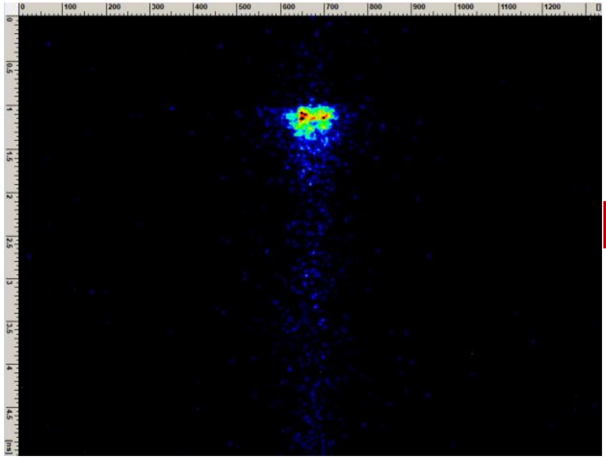
Fluorescence signal

Measured

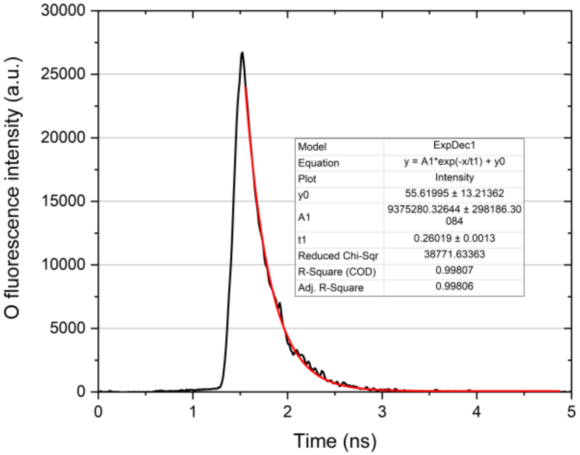
Ratio of temporally and spectrally (and spatially) integrated fluorescence signals

$$n_X = n_{cal} \boxed{\frac{\int_t \int_\lambda S_{F_X}}{\int_t \int_\lambda S_{F_{cal}}}} \frac{\eta_{cal}}{\eta_X} \frac{T_{cal}}{T_X} \frac{\sigma_{cal}}{\sigma_X} \frac{A_{cal}}{A_X} \frac{\tau_{cal}}{\tau_X} \frac{{E_{cal}}^2}{{E_X}^2} \frac{{\lambda_{cal}}^2}{{\lambda_X}^2}$$

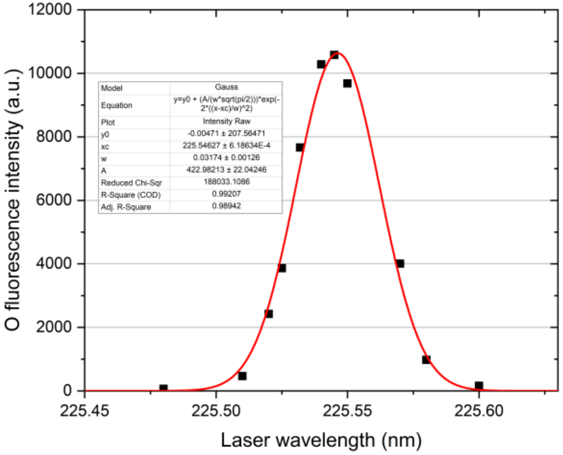
Raw signal



Space-integrated



Time-integrated



Density calibration

Calculated/litterature/data sheet

Calibration species density (Kr, Xe)

$$n_X = \boxed{n_{cal}} \frac{\int_t \int_\lambda S_{F_X}}{\int_t \int_\lambda S_{F_{cal}}} \frac{\eta_{cal}}{\eta_X} \frac{T_{cal}}{T_X} \frac{\sigma_{cal}}{\sigma_X} \frac{A_{cal}}{A_X} \frac{\tau_{cal}}{\tau_X} \frac{{E_{cal}}^2}{{E_X}^2} \frac{{\lambda_{cal}}^2}{{\lambda_X}^2}$$

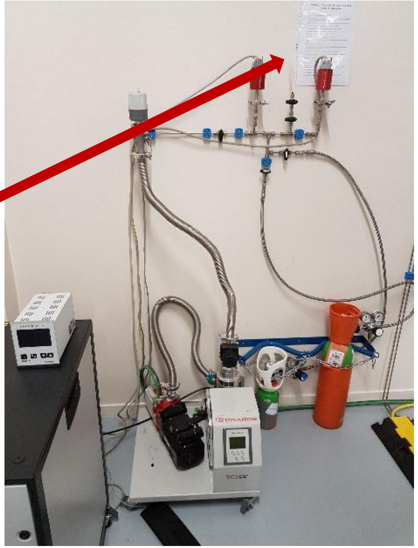
Ideal gas low: $P = Nk_BT$

P = pressure

N = n_{cal}

k_B = Boltzmann coefficient

T = gas temperature



Thank you for your attention

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