Production et optimisation de microplasmas pour la génération de l'azote atomique

Kristaq Gazeli

CRCN CNRS (02/2022 - Today)

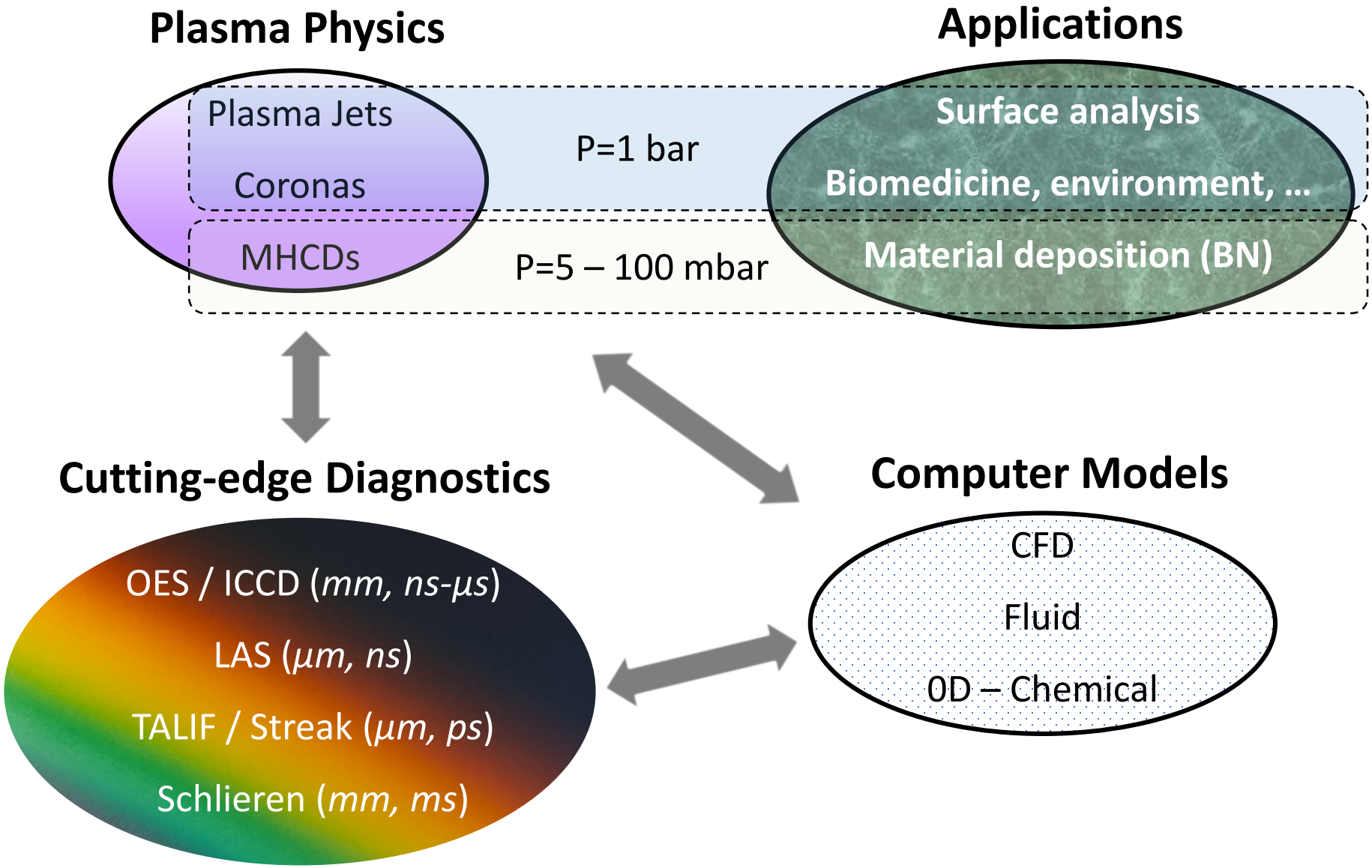
LSPM UPR 3407 – CNRS – Université Sorbonne Paris Nord

23 Octobre 2023

Outline

- ❑ Scientific background
- ❑ Academic posts
  - Representative results
- ❑ Research project

Scientific Background in Plasma Physics/Applications



H2020

Academic posts

09/11 — **International Joint PhD Thesis: Physics – Electrical and computer Engineering**

10/15

08/17 — **1st Post-doc** (ANR *PLASPAMS*)

04/19 — **2nd Post-doc**

(Labex *PHeCell3D* / Inserm *PLASCANCER*)

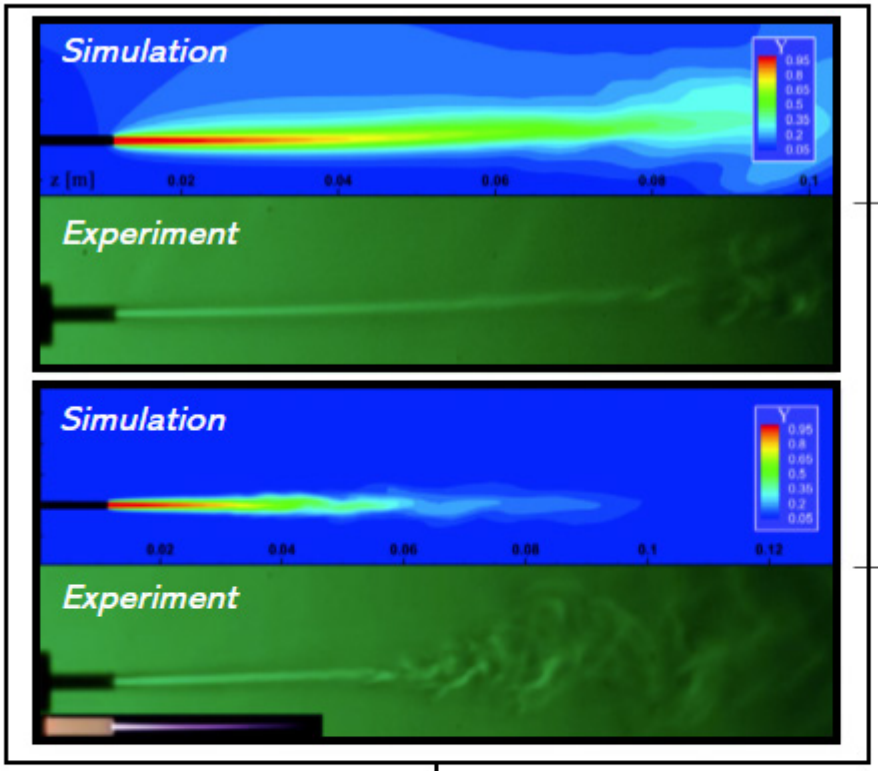
(ANR *DESYNIB* / *EXFIDIS*)

12/20 — **3rd Post-doc (ANR ASPEN)**

01/22 — **Marie Curie Fellow**

02/22 — **Chargé de Recherche CNRS**

Ex. 1: Propagation Mechanism of µs Plasma Jets



Gas Flow Only

Plasma + Gas Flow

Physical Aspects

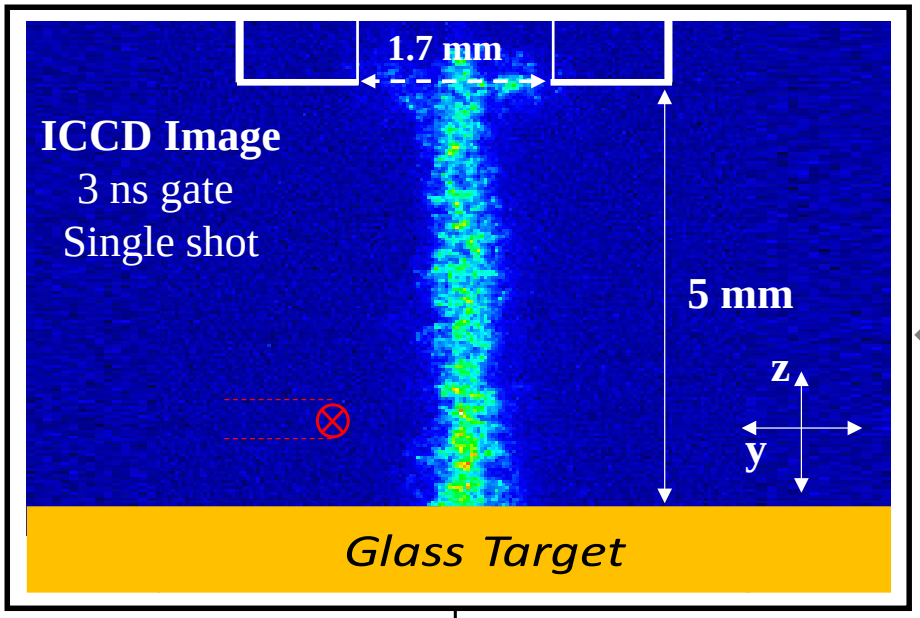
- Insights on the Physicochemical Features of Plasma Jets
- Modification of the Gas Dynamics by the Plasma
- Low Gas Temperature

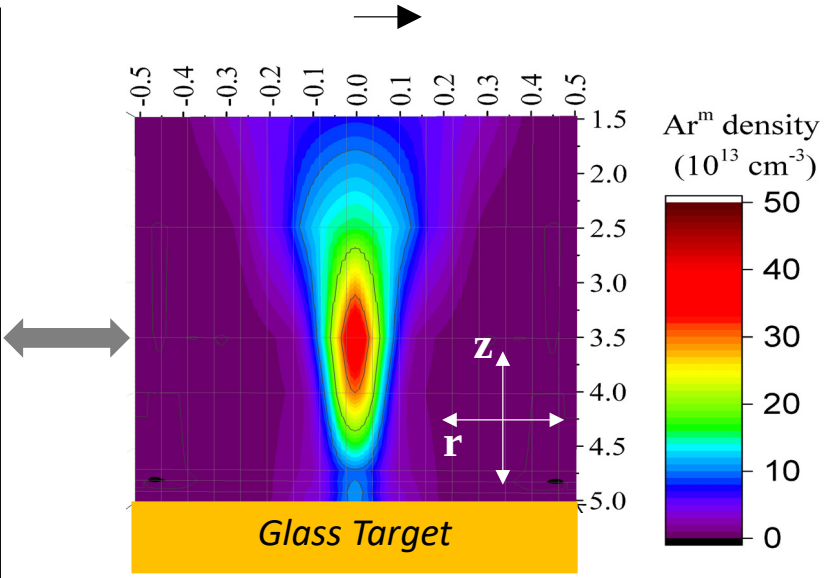
UNIVERSITY OF PATRAS
ΠΑΝΕΠΙΣΤΗΜΙΟ ΠΑΤΡΩΝ

UNIVERSITÉ DE PAU ET DES PAYS DE L'ADOUR

- *K. Gazeli et al., J. Appl. Phys. (2013)*
- *P. Papadopoulos et al., J. Phys. D.: Appl. Phys. (2014)*

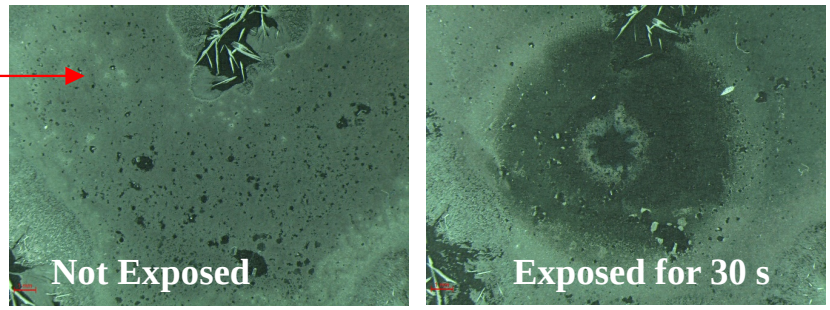
Ex. 2: ns-Pulsed Plasma Jet-Surface Interaction Dynamics

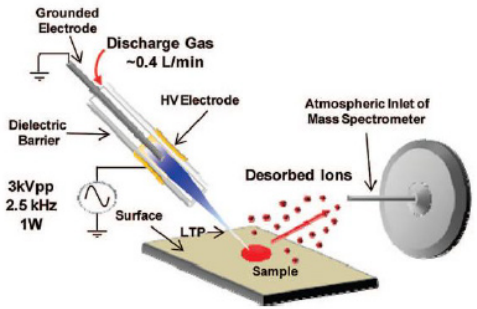




- Effect of the Targets: Diffuse Discharge
- Radial/Temporal Mappings of Ar($1s_5$)
- High Ar($1s_5$) Densities Close to the Target

Desorption of Organic Molecules





K. Gazeli et al., Plasma Process. Polym. (2018)

K. Gazeli et al., Plasma Sources Sci. Technol. (2018)

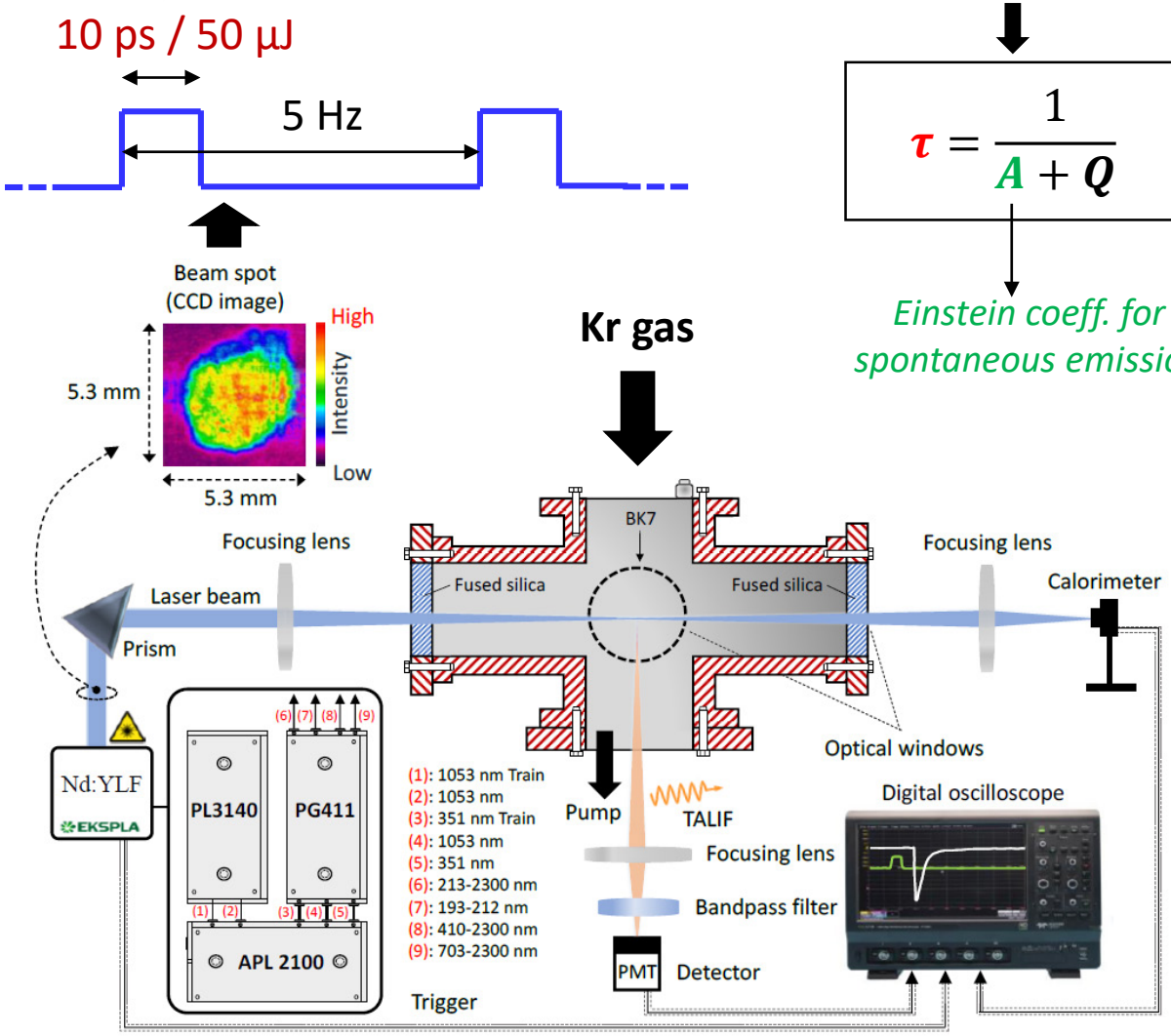
K. Gazeli et al., J. Phys. D.: Appl. Phys. (2020)

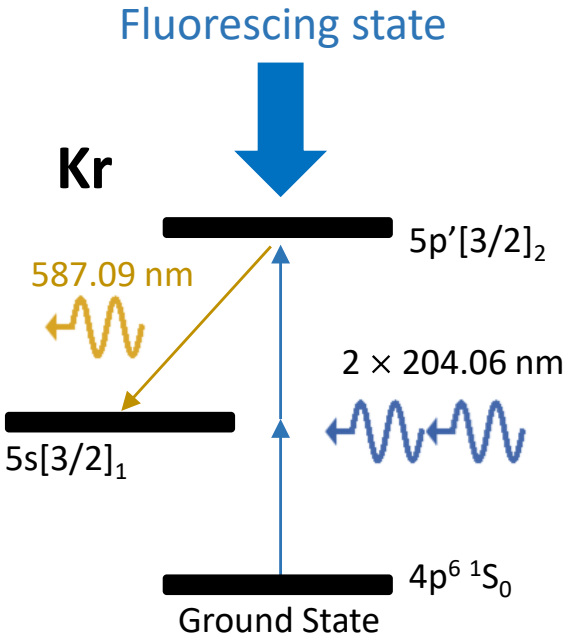
Ex. 3: Development of ps-TALIF Diagnostic in Reactive Plasmas

ps-TALIF: ideal for atomic density measurments in collisional plasmas
(quenching (Q) → **effective lifetime** ~ ns down to 200 ps)

$$\tau = \frac{1}{A + Q}$$

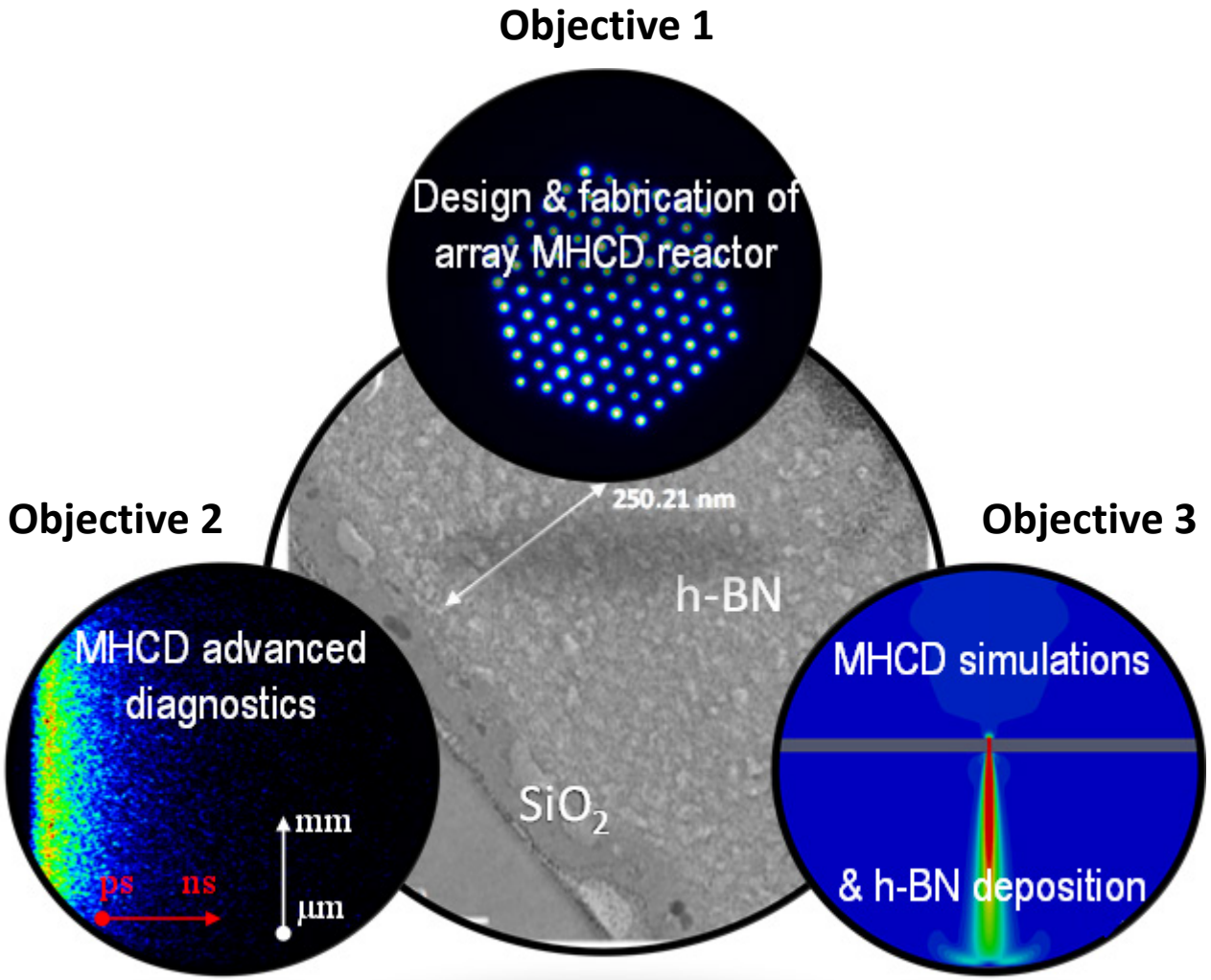
Einstein coeff. for spontaneous emission





K. Gazeli et al. Plasma 4(1), 145-171 (2021) *K. Gazeli et al., Phys. Plasmas (2021)*

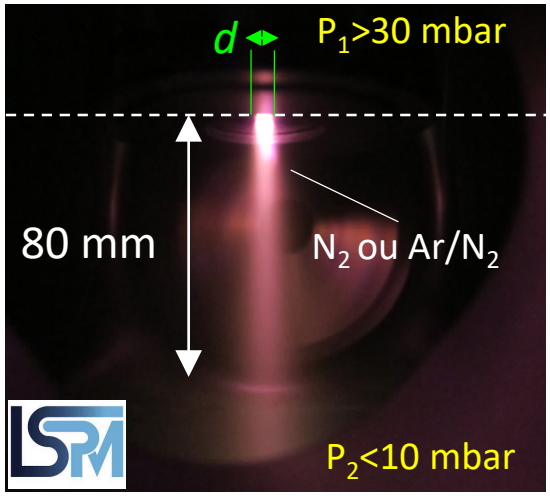
Research Project @ CNRS: MHCDs for h-BN synthesis



Research Project @ CNRS: MHCDs for h-BN synthesis

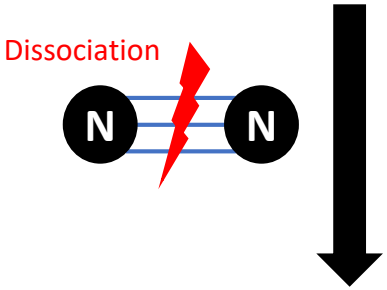
d < 1 mm

Micro-hollow Cathode Discharges

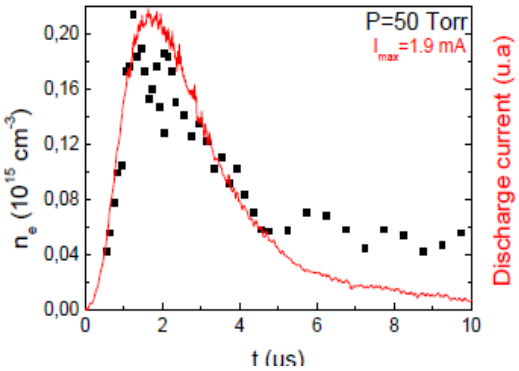


Generated using DC and pulsed voltages

- Very low injected power (< 1 W)
- Small dimensions
- Large power densities (up to 100 kW.cm^{-3})
- Relatively low gas temperatures
- High electron densities (up to 10^{16} cm^{-3})
- Strong gas excitation, ionization and dissociation



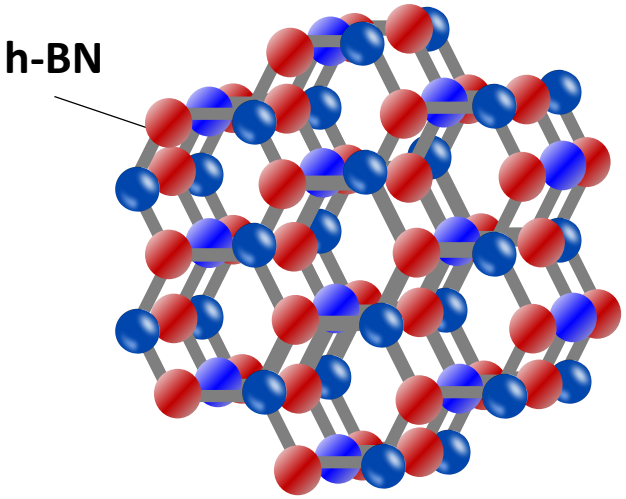
Promising as sources of atomic nitrogen



C. Lazzaroni PhD Thesis

S. Kasri et al., Plasma Sources Sci. Technol. 28 035003 (2019)

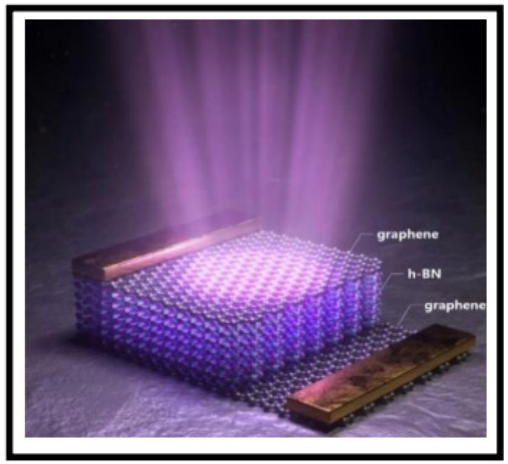
Research Project @ CNRS: MHCDs for h-BN synthesis



Hexagonal Boron-Nitride (h-BN)

- **Large band gap semiconductor** (similar to diamond, 5.9 eV)
- **Dielectric** (breakdown voltage > 0.8 V/nm)
- **Graphene-like** structure, very smooth (r < 0.1 nm)
- **High fusion temperature** (2600 °C)
- **Low thermal expansion, high thermal conductivity**
- **Applications** in photonics, electronics, …

Example : Graphene/h-BN/Graphene Van der Walls heterostructures



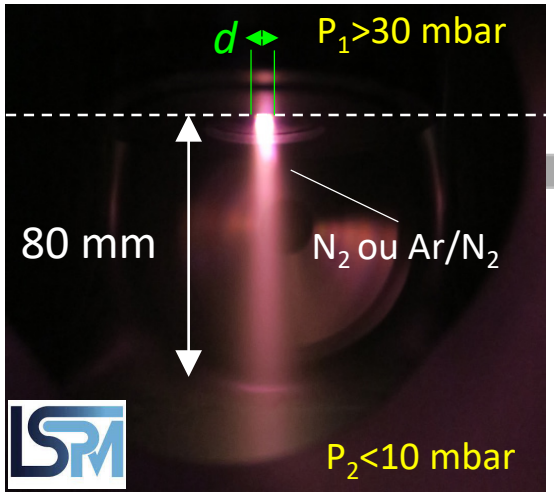
Su-Beom Song et al., Nat. Commun. 12, 7134 (2021)

LED émettant sur le profonde UV

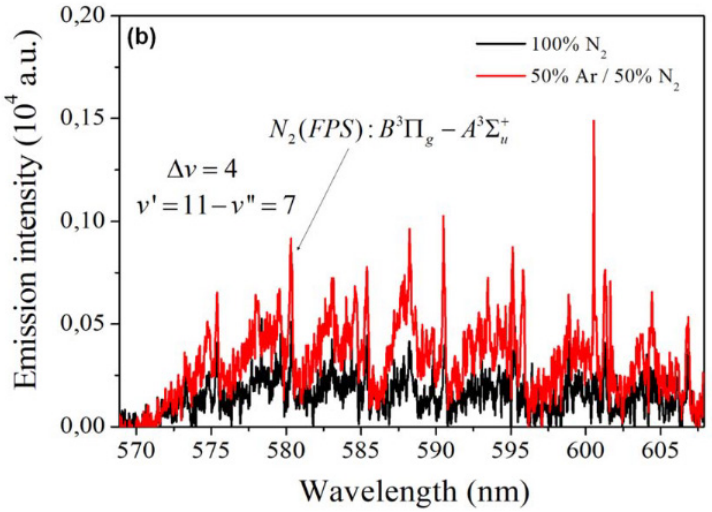
Research Project @ CNRS: MHCDs for h-BN synthesis

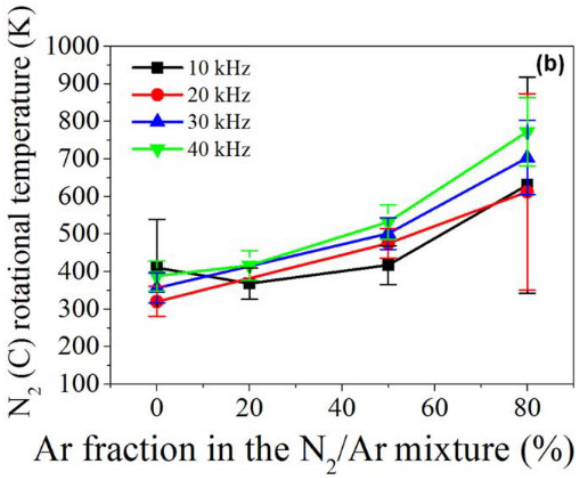
d < 1 mm

Micro-hollow Cathode Discharges



7-hole pulsed MHCD





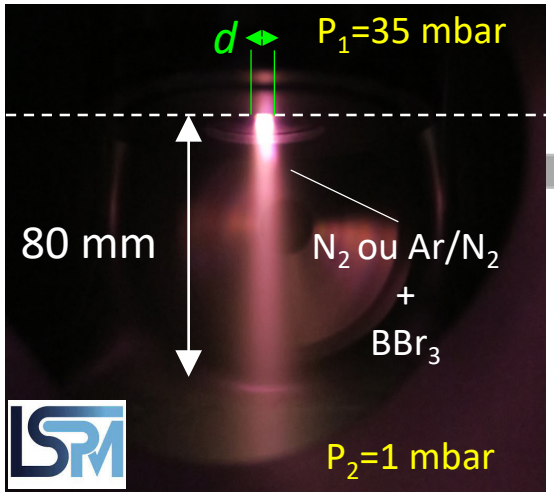
S. Kasri, …, K. Gazeli et al., Plasma Sources Sci. Technol. 28 035003 (2019)

Research Project @ CNRS

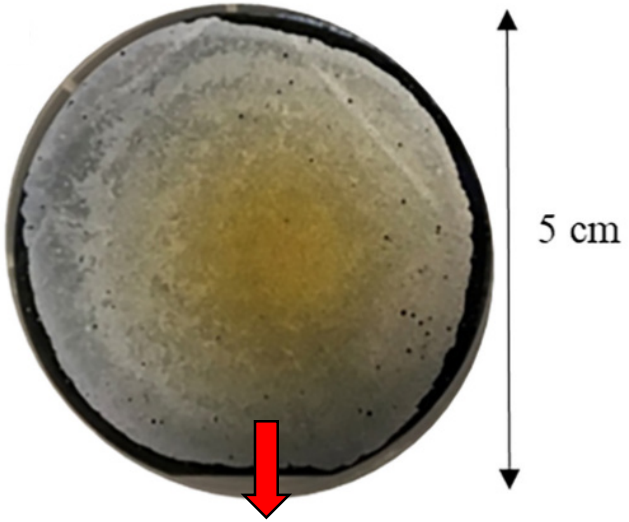
1-hole pulsed MHCD (50%Ar – 50%N_2)

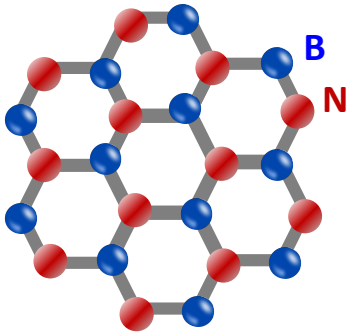
d < 1 mm

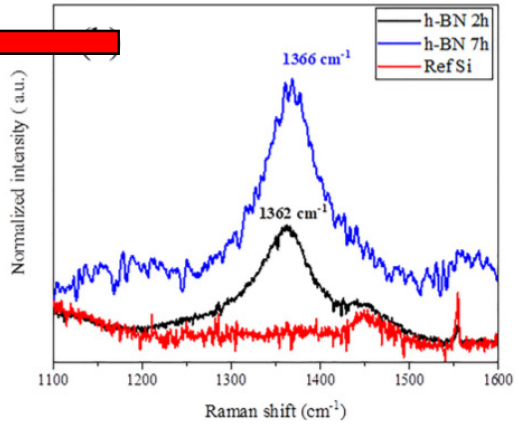
Micro-hollow Cathode Discharges



***h*-BN film**







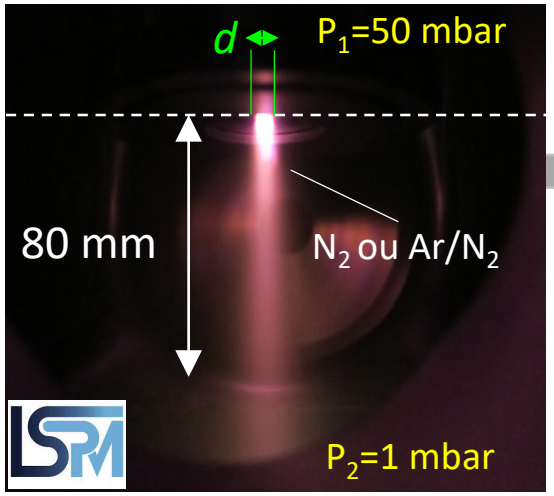
Raman spectrum

H. Kabbara, …, K. Gazeli et al., Appl. Phys. Lett. 116, 171902 (2020)
S. Kasri, …, K. Gazeli et al., Plasma Sources Sci. Technol. 28 035003 (2019)

Research Project @ CNRS

d < 1 mm

Micro-hollow Cathode Discharges



DC MHCD

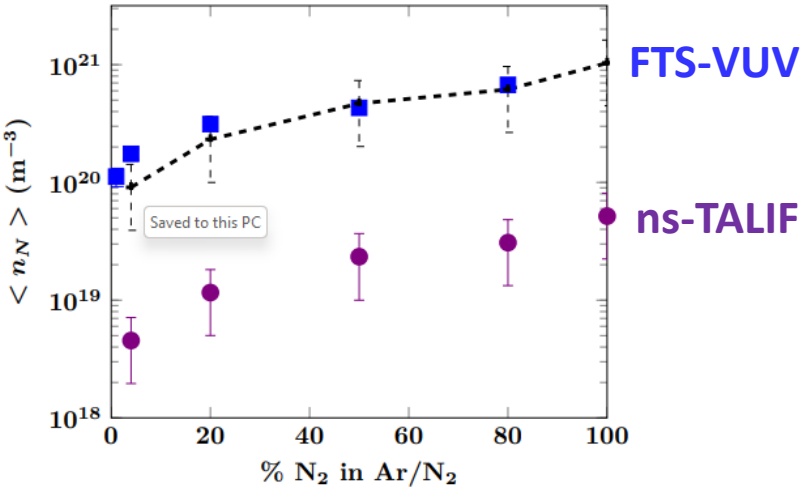
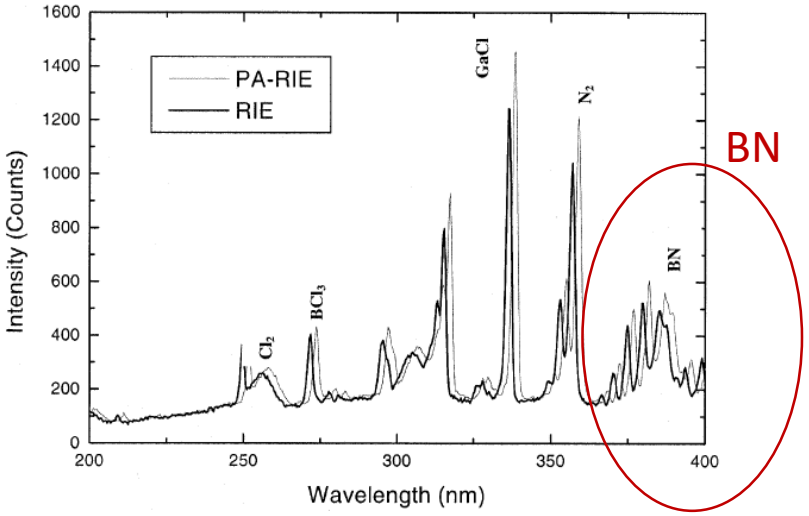


Figure 8: Experimental densities of N atoms measured by FTS VUV (blue squares) [19] and TALIF (purple circles; this work) as a function of the percentage of N_2 in the Ar/N_2 gas mixture. The black dashed line represents the TALIF measurements corrected to take into account the fact that the two techniques are performed at different locations. Conditions: P = 50 mbar in both chambers, I_d = 1 mA. TALIF measurements are plotted with the total uncertainty.

A. Remigy, PhD Thesis

Research Project @ CNRS

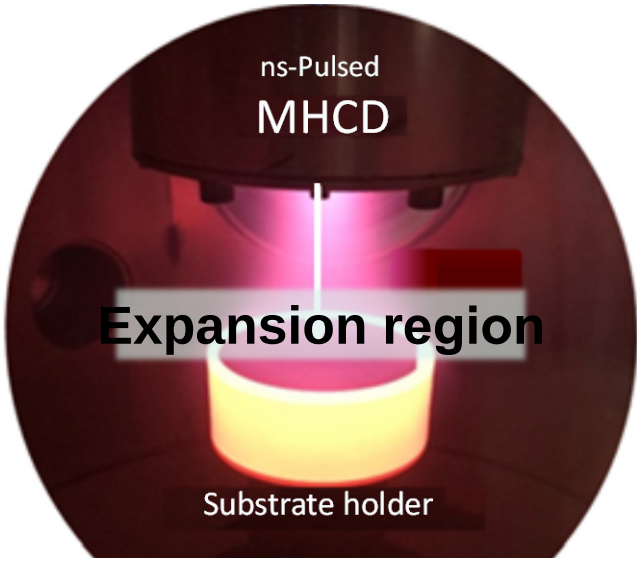
- Generate and investigate pulsed matrix MHCDs (plasma dynamics and chemistry?)
- Improve the quality of the h-BN deposits (control/optimization of N production)
- Improve the accuracy of the N-atom measurements (spatial resolution, …)
- Detect, quantify and control B-atom production (laser diagnostics)
- Detect and quantify BN in the gaseous phase (?)



N. Medelci et al., J. Electr. Mat (2000)

PhD B. Menacer
IPSµP - DMC

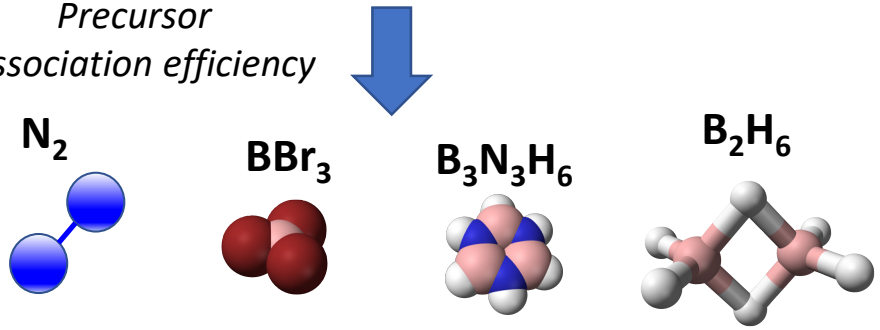
Research Project @ CNRS



Challenge: Micrometric dimensions and stiff voltages

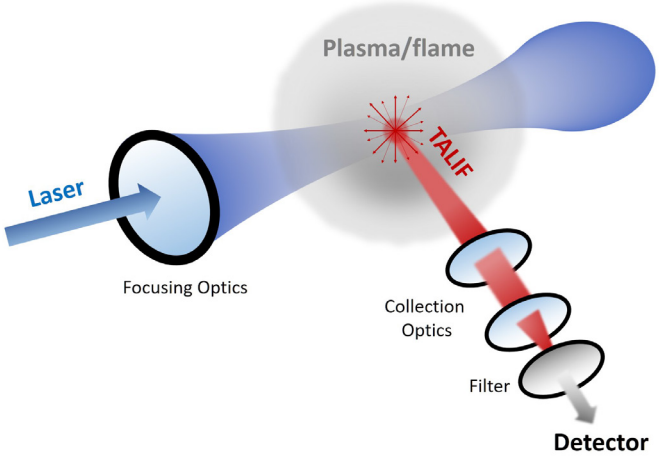
N and B Densities: crucial atoms for fabricating h-BN

Precursor dissociation efficiency

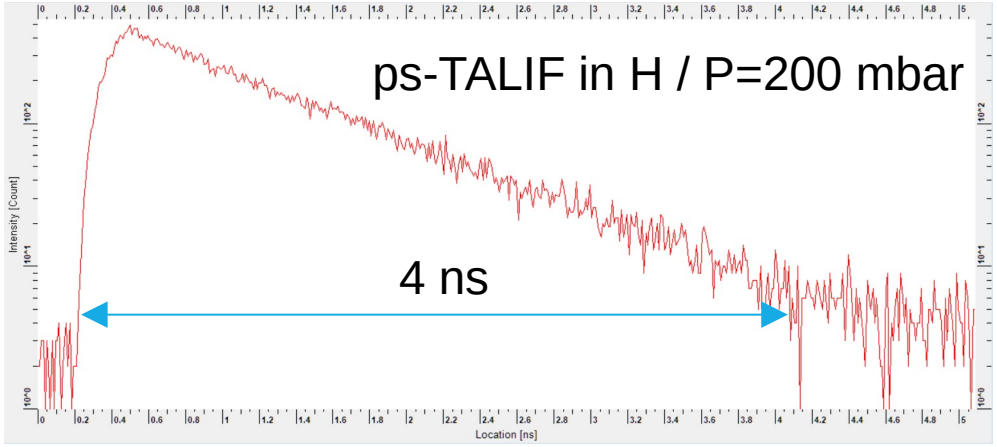


For p>10s mbar → Important Quenching → ns-TALIF/LIF limited

ps-TALIF/LIF (µm – ps)



Streak Camera Signal



Merci pour votre attention !

Remerciements

Membres de l'opération de recherche IPS-µP du LSPM

Financements

- **JCJC SPECTRON (ANR-23- CE51-0004-01)**
- **PRC ULTRAMAP** (ANR-20-CE510020)
- **Labex SEAM** (ANR-10-LABX-0096; ANR-18-IDEX0001);
- IDF projet régional **SESAME DIAGPLAS**