

# Diagnosics of pulsed capillary discharges as coherent and incoherent EUV sources

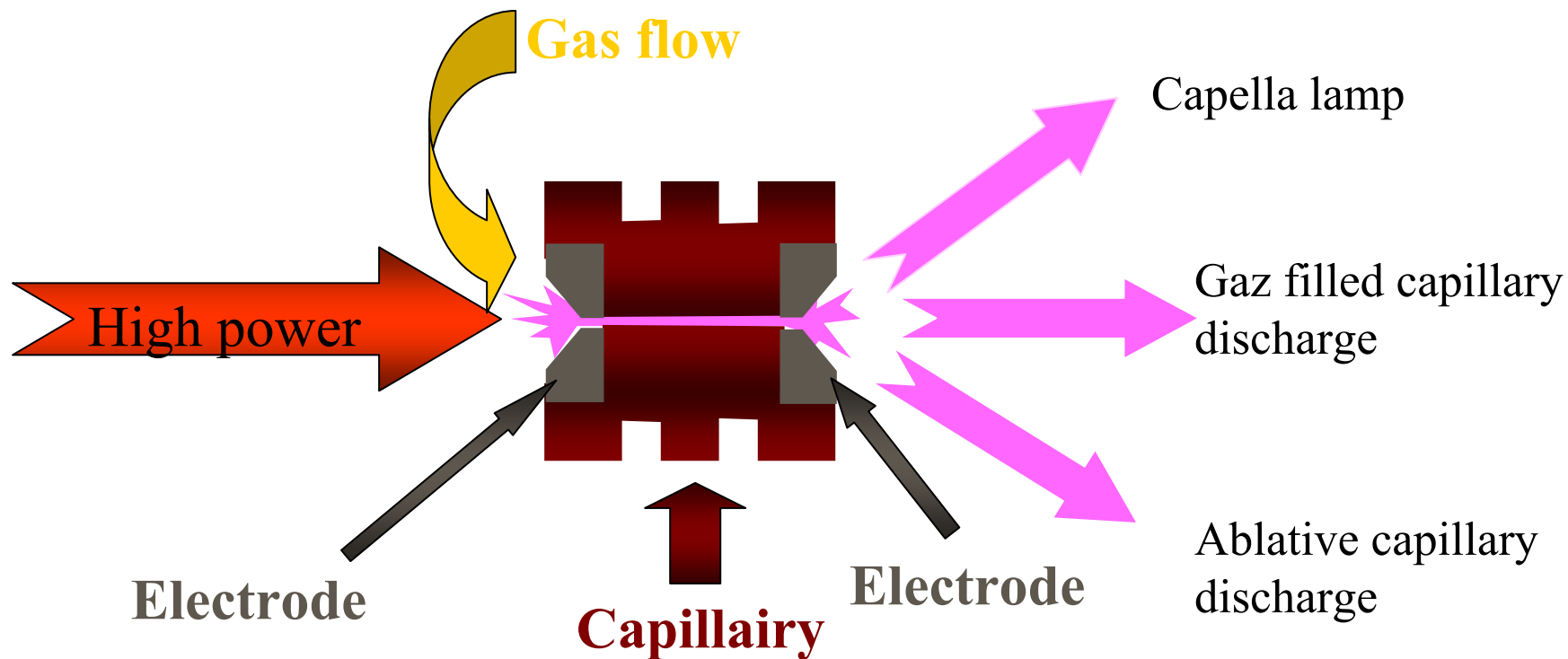
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France

\* CTU Prague

# Pulsed capillary discharges



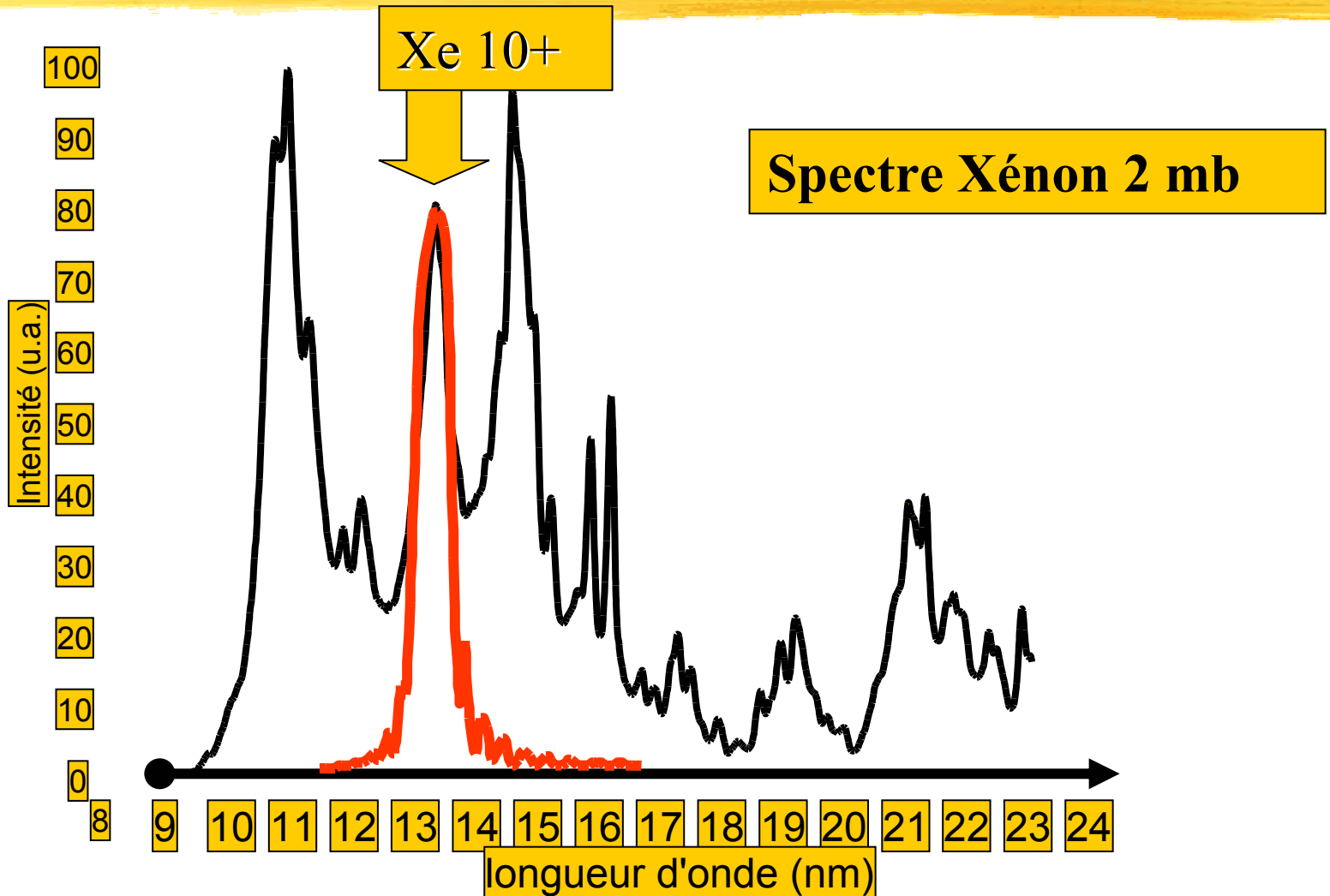
# Capella: a kilohertz EUV Lamp

## CAPELLA:

- 75 m/sr (2%, à 13.5 nm)
- 1 kHz
- Débris OK
- Stabilité < 0.5%
- Rendement: 0.1%
- Stabilité en position < 50  $\mu\text{m}$
- Durée de vie >  $10^8$  tirs

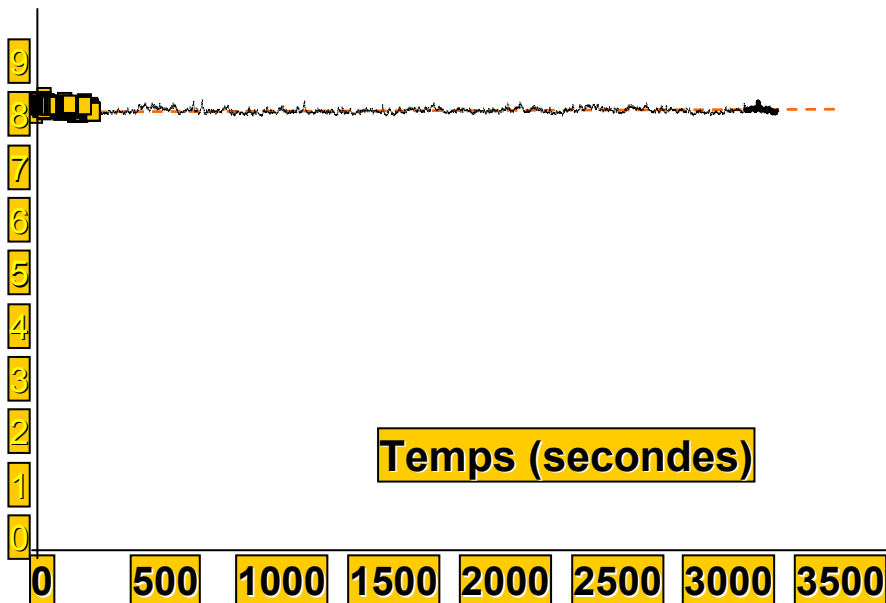


# EUV Xenon spectrum

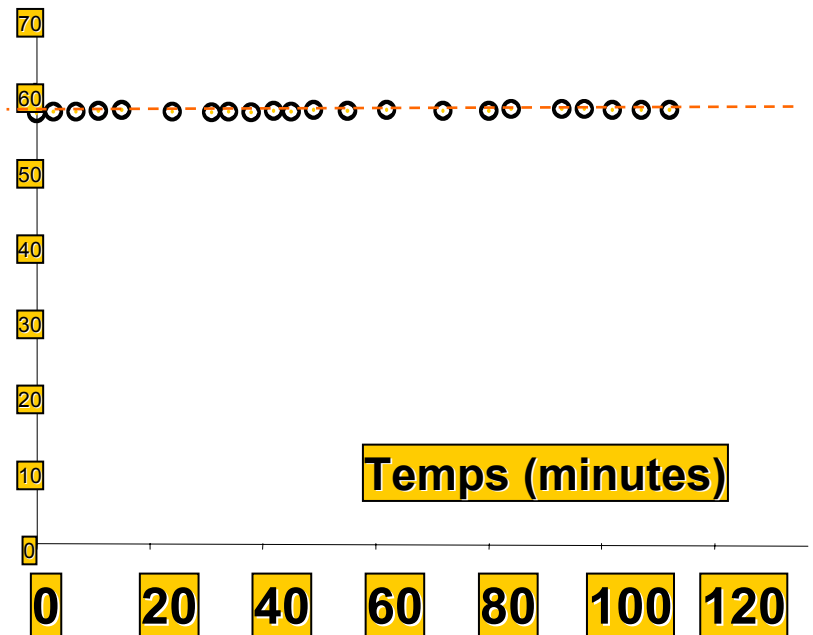


# Capella: a kHz EUV lamp

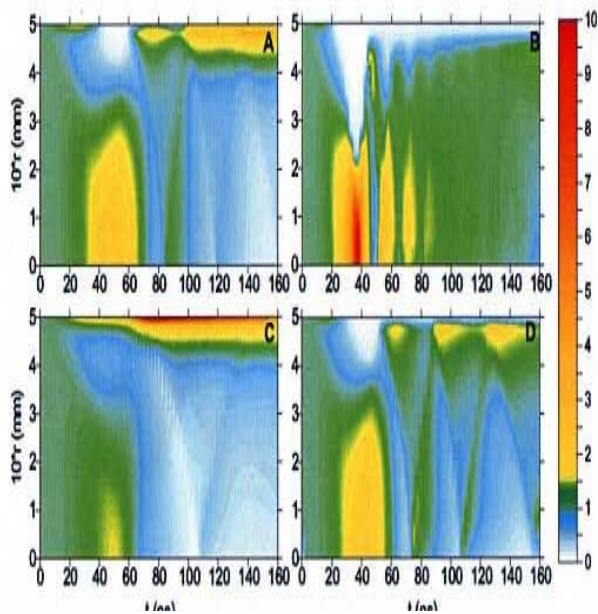
«Continue» à 100 Hz



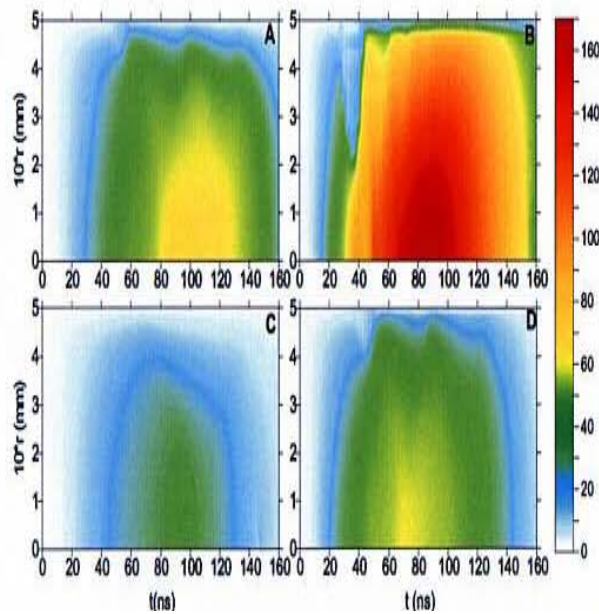
« Rafales » à 1 kHz



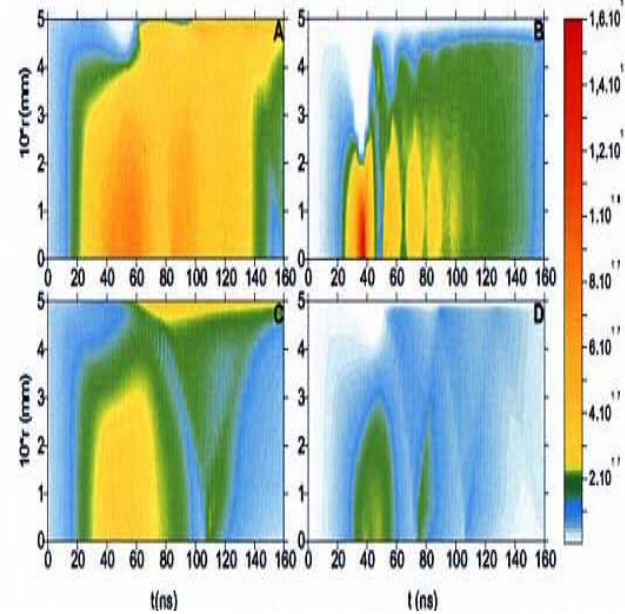
# P. Vrba et al « Modelling of emission characteristics of a xenon capillary discharge »



Compression factor

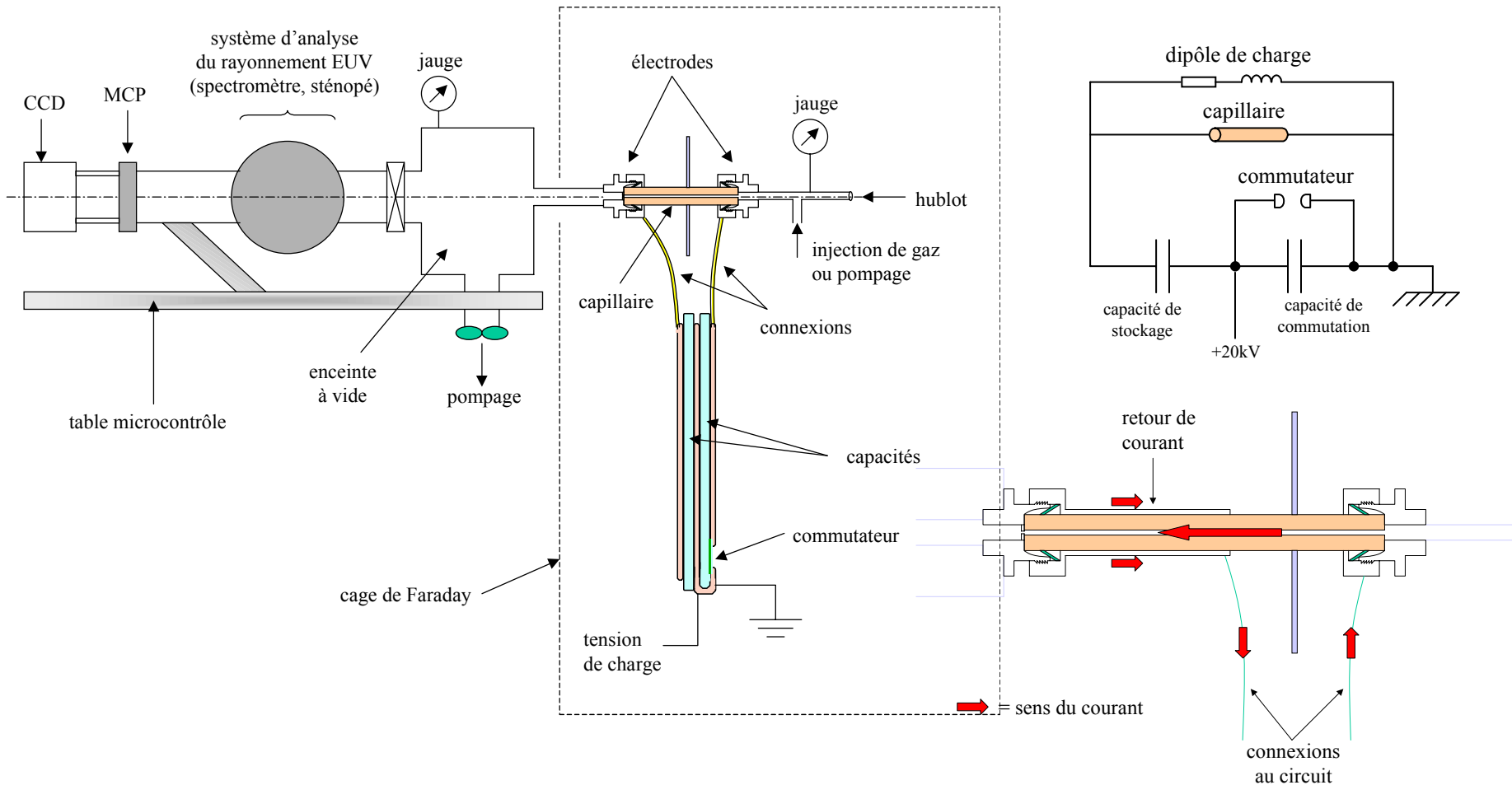


Electronic temperature



Electronic density

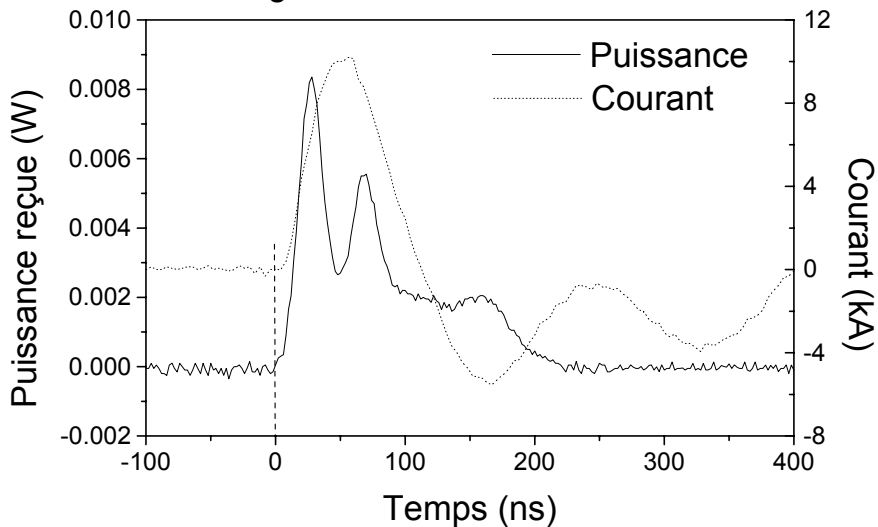
# Experimental setup



# Radiated EUV power

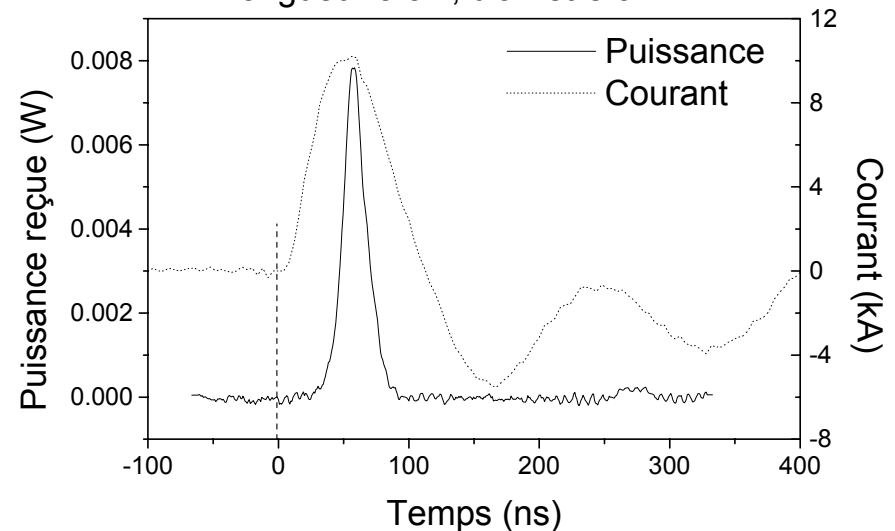
$\Phi$ : 1.5 mm

Longueur 5 cm, diamètre 1,5 mm



$\Phi$ : 3 mm

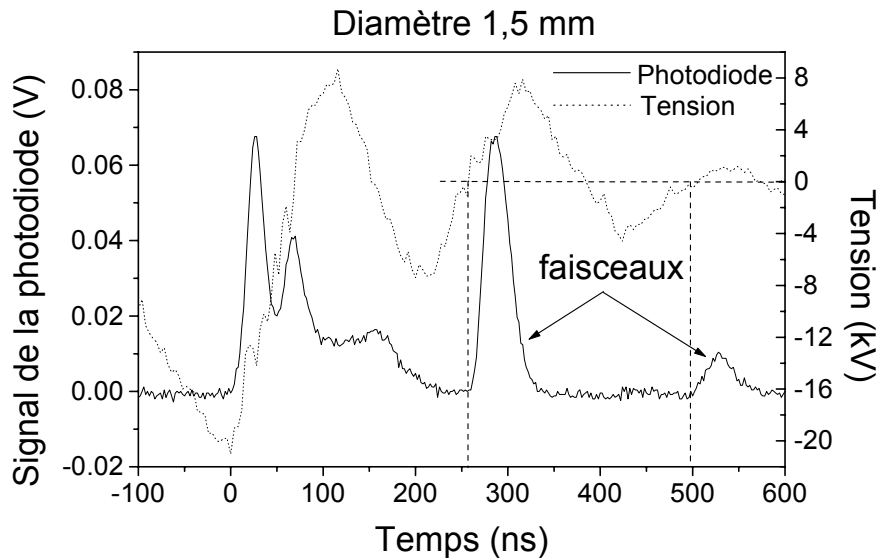
Longueur 5 cm, diamètre 3 mm



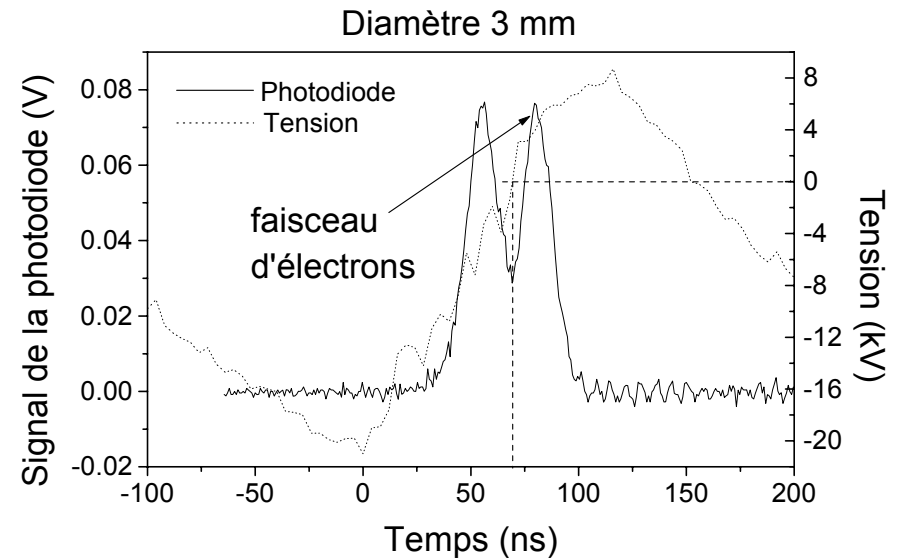


# E-beam génération

$\Phi$ : 1.5 mm

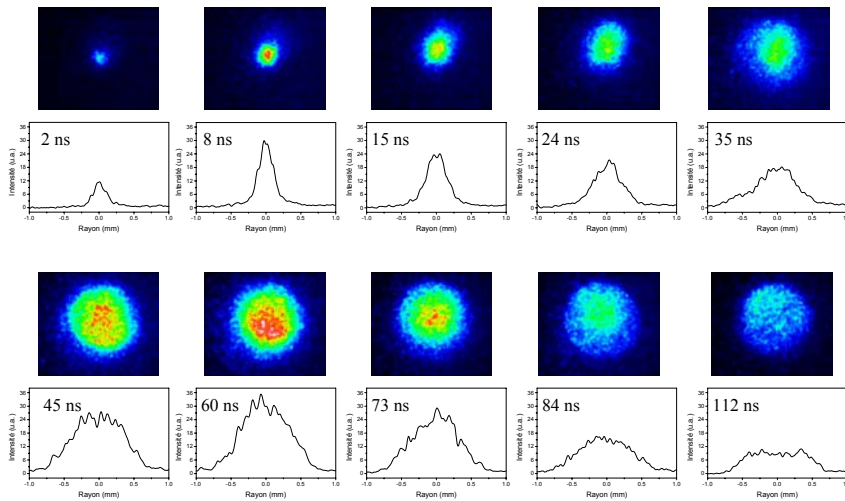


$\Phi$ : 3 mm



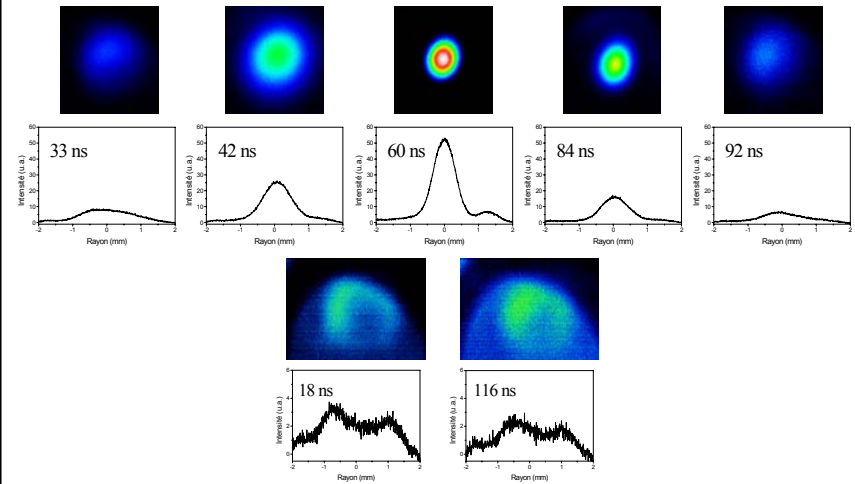
# Plasma dynamics

$\Phi$ : 1.5 mm



IV.1 : images et profils radiaux d'émission aux différents instants pour un capillaire de diamètre 1,5 mm

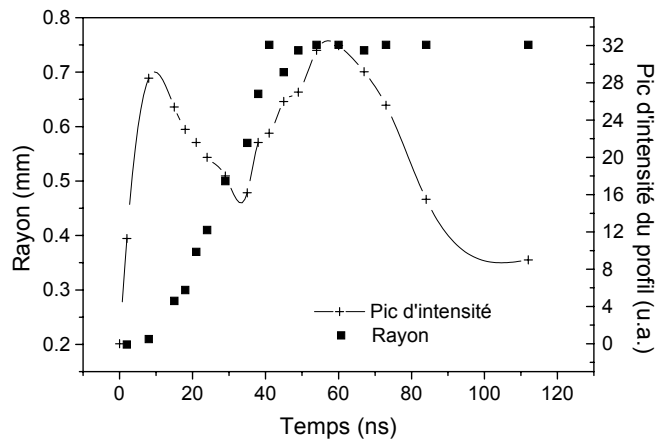
$\Phi$ : 3 mm



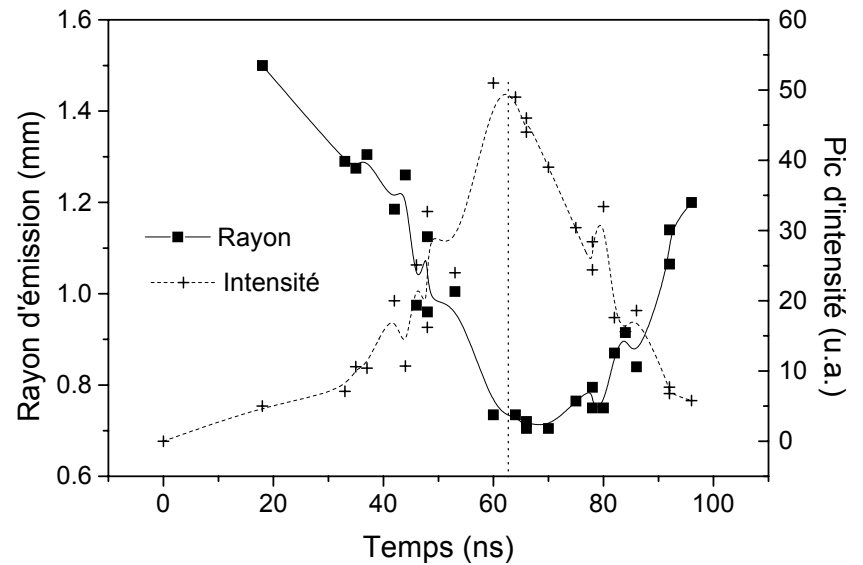
IV.1 : images et profils radiaux d'émission aux différents instants pour un capillaire de diamètre 3 mm et de longueur 5 cm

# Compression factors

$\Phi$ : 1.5 mm



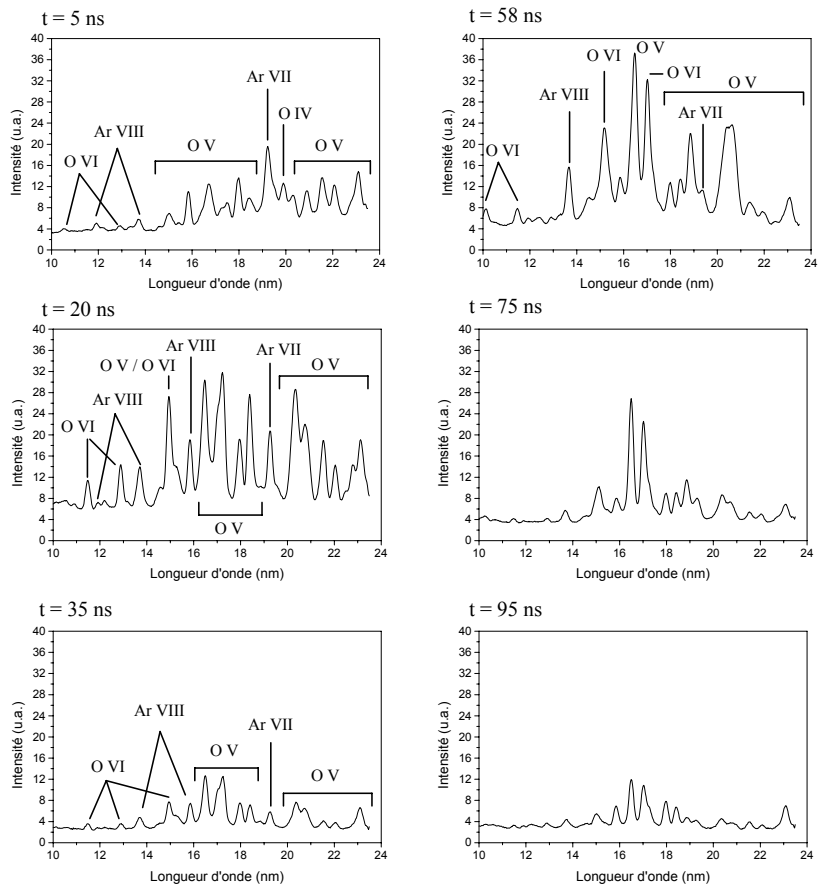
$\Phi$ : 3 mm



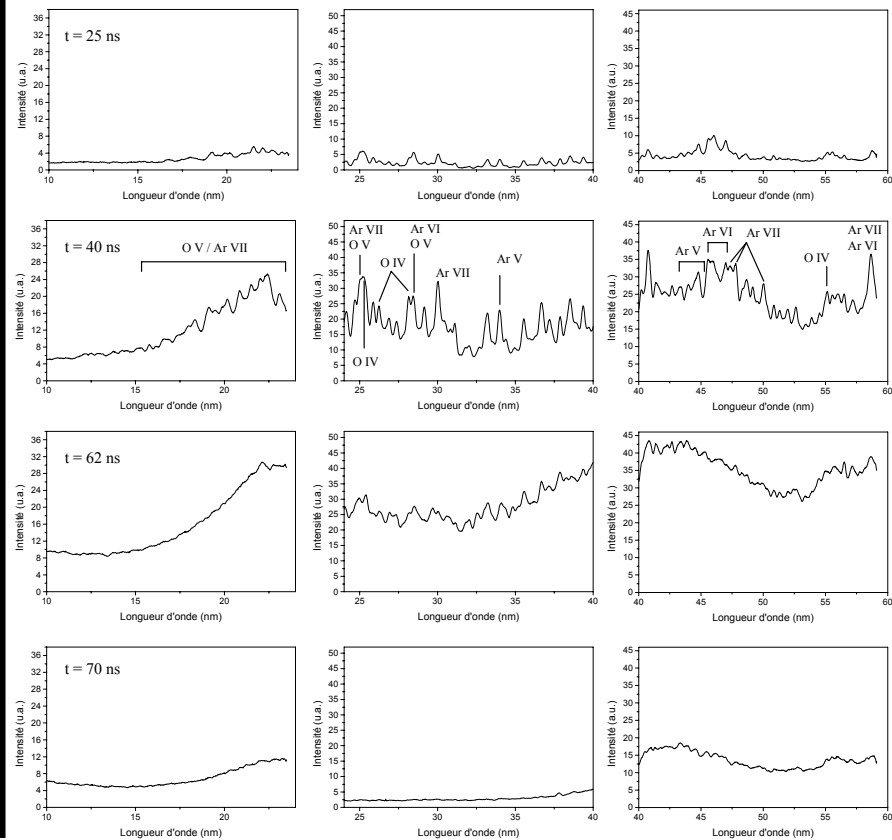
IV.1 : évolution du rayon d'émission du plasma et du pic d'intensité du profil radial

# Time resolved spectroscopie

$\Phi$ : 1.5 mm

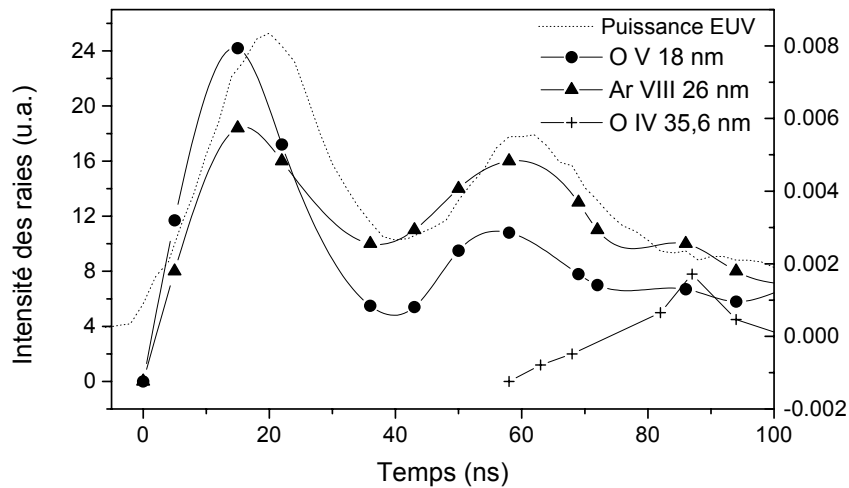


$\Phi$ : 3 mm

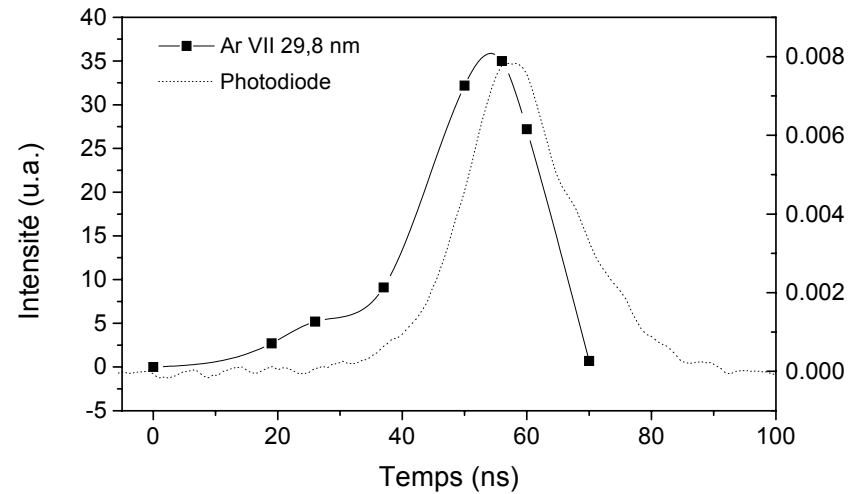


# Line intensity evolutions

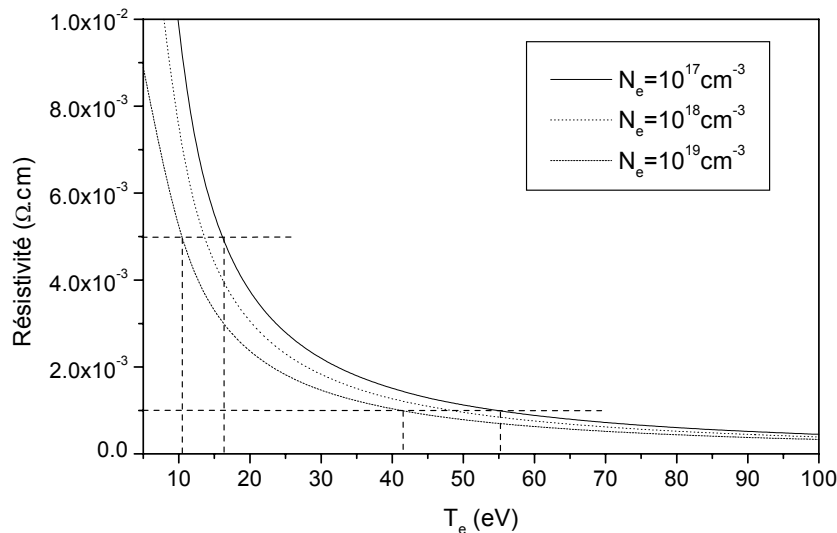
$\Phi$ : 1.5 mm



$\Phi$ : 3 mm



# Temperature estimation: Spitzer formula

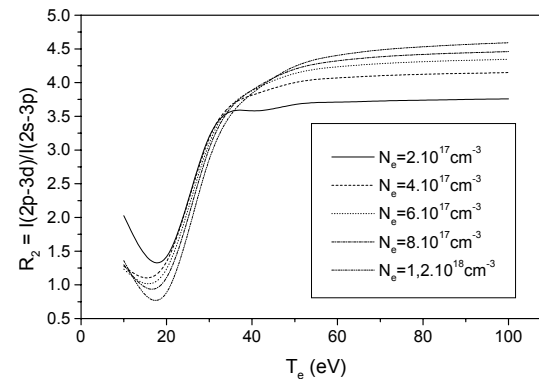
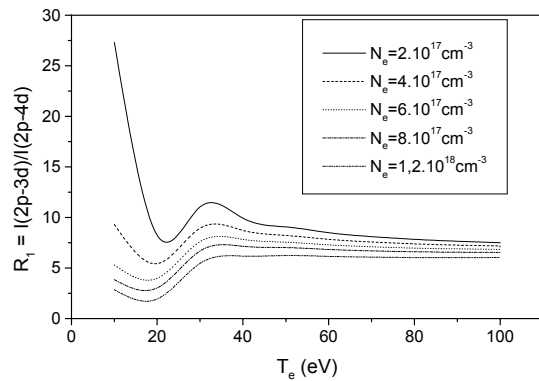
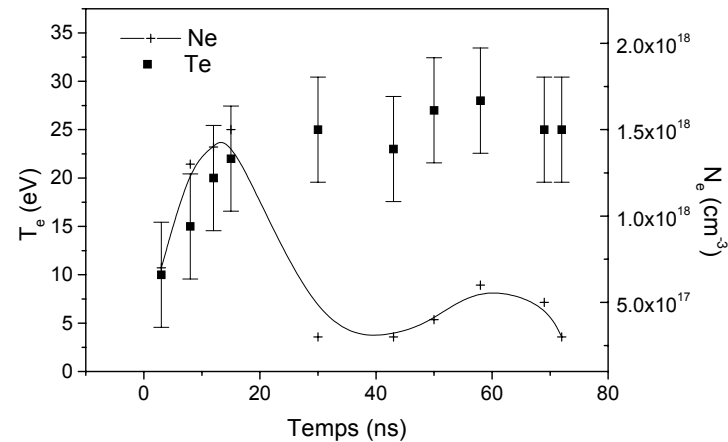
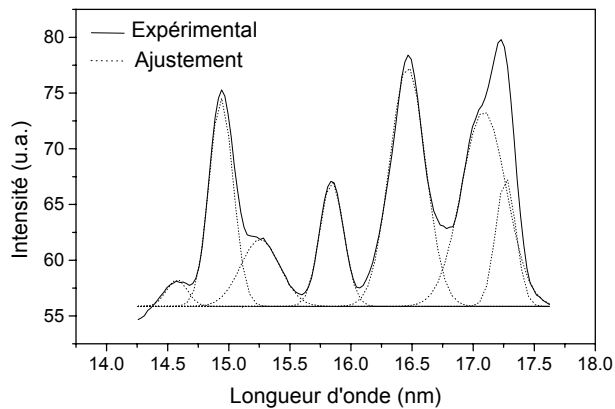


$$\rho = 1,03 \cdot 10^{-2} \frac{Z \ln \Lambda}{T_e^{3/2}} \quad (\Omega \cdot \text{cm})$$

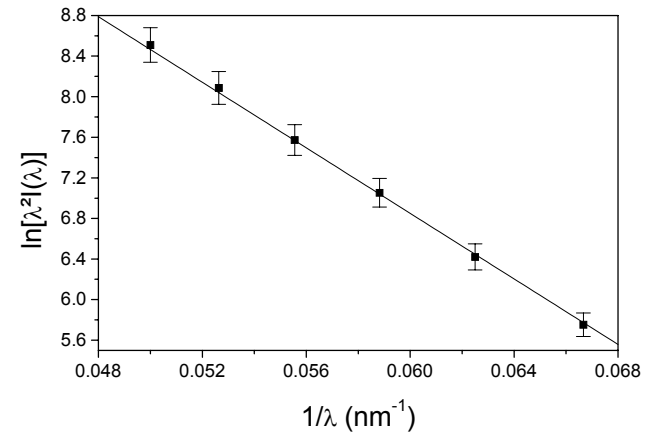
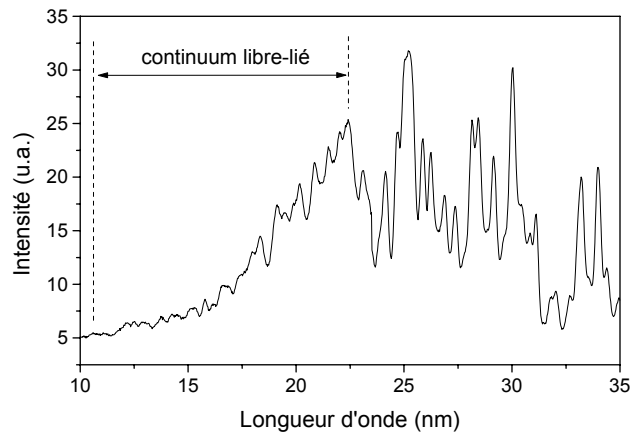
$$\ln \Lambda = 23 - \ln \frac{Z \cdot N_e^{1/2}}{T_e^{3/2}}$$

Capillary dimension	Resistivity	Mean temperature
5 cm × 1,5 mm	2,1 · 10 <sup>-3</sup> Ω.cm	20-30 eV
5 cm × 3 mm	8,5 · 10 <sup>-3</sup> Ω.cm	5-15 eV
5 cm × 4,5 mm	1,9 · 10 <sup>-2</sup> Ω.cm	~ 5 eV
12,5 cm × 3 mm	1,1 · 10 <sup>-2</sup> Ω.cm	5-10 eV

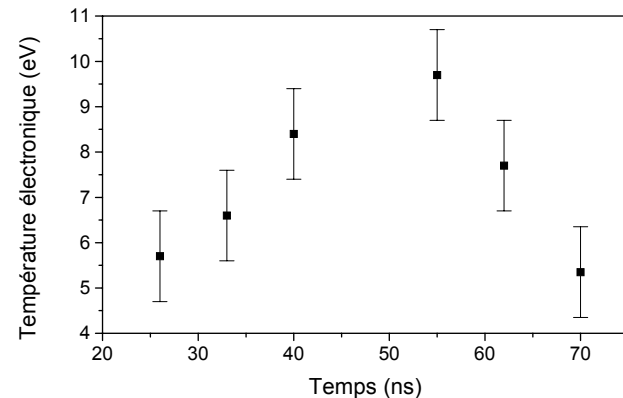
# Temperature estimation: Fly code



# Temperature estimation: electronics recombination

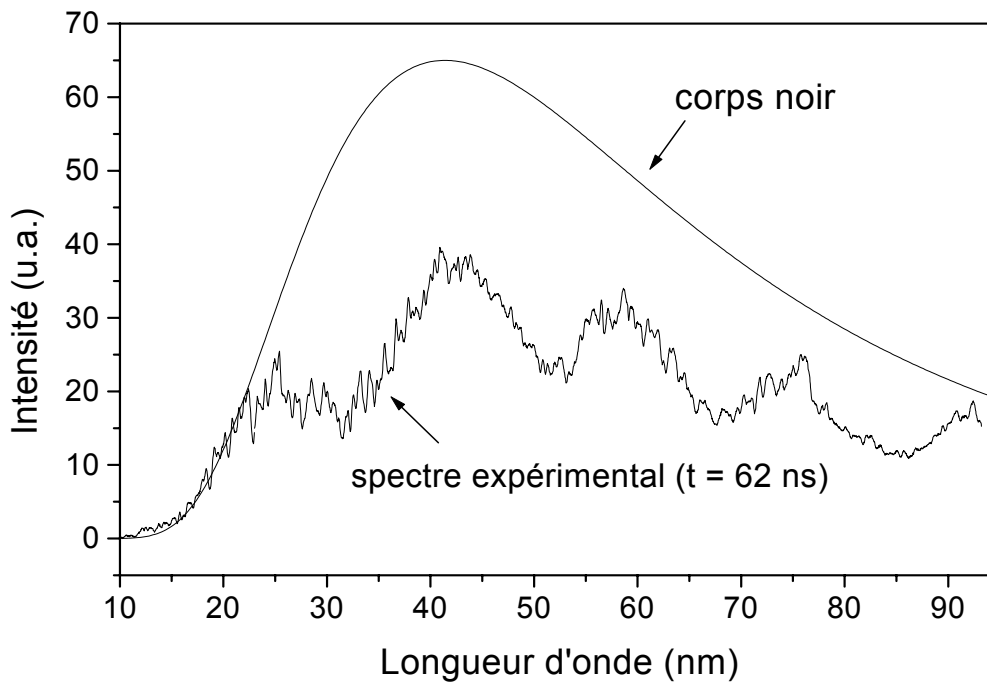


$$I(\lambda) = \frac{I_0}{\lambda^2} \exp\left(-\frac{hc}{\lambda k T_e}\right)$$

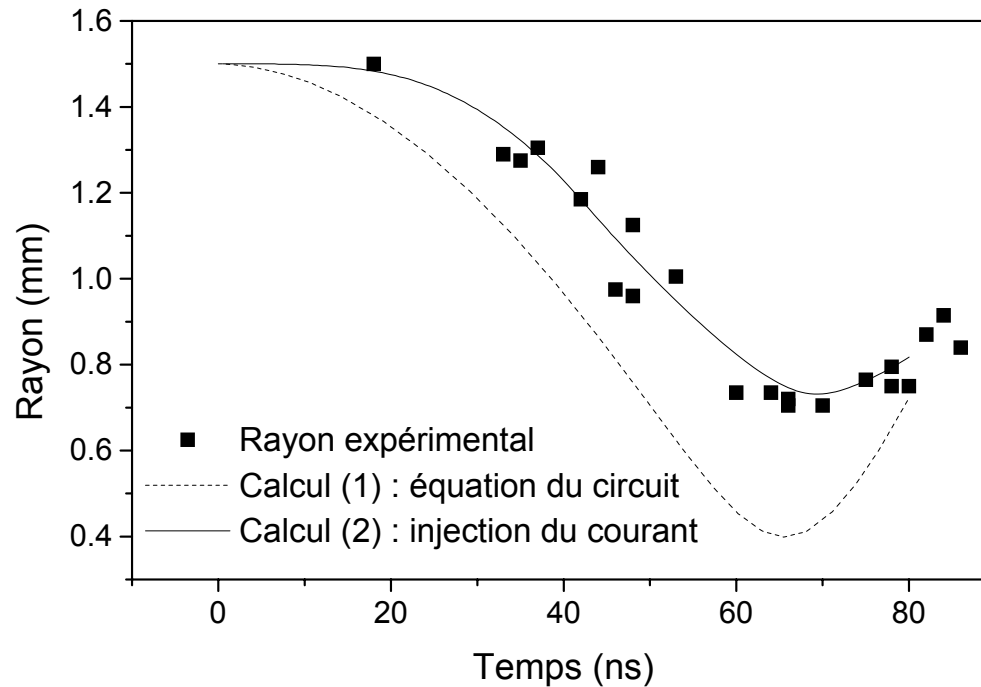




# Temperature estimation: Blackbody radiation



# Pinch time



V.1 : rayon théorique et expérimental pour le capillaire de longueur 5 cm et de diamètre 3 mm

# Toward coherent shortwavelength discharge source

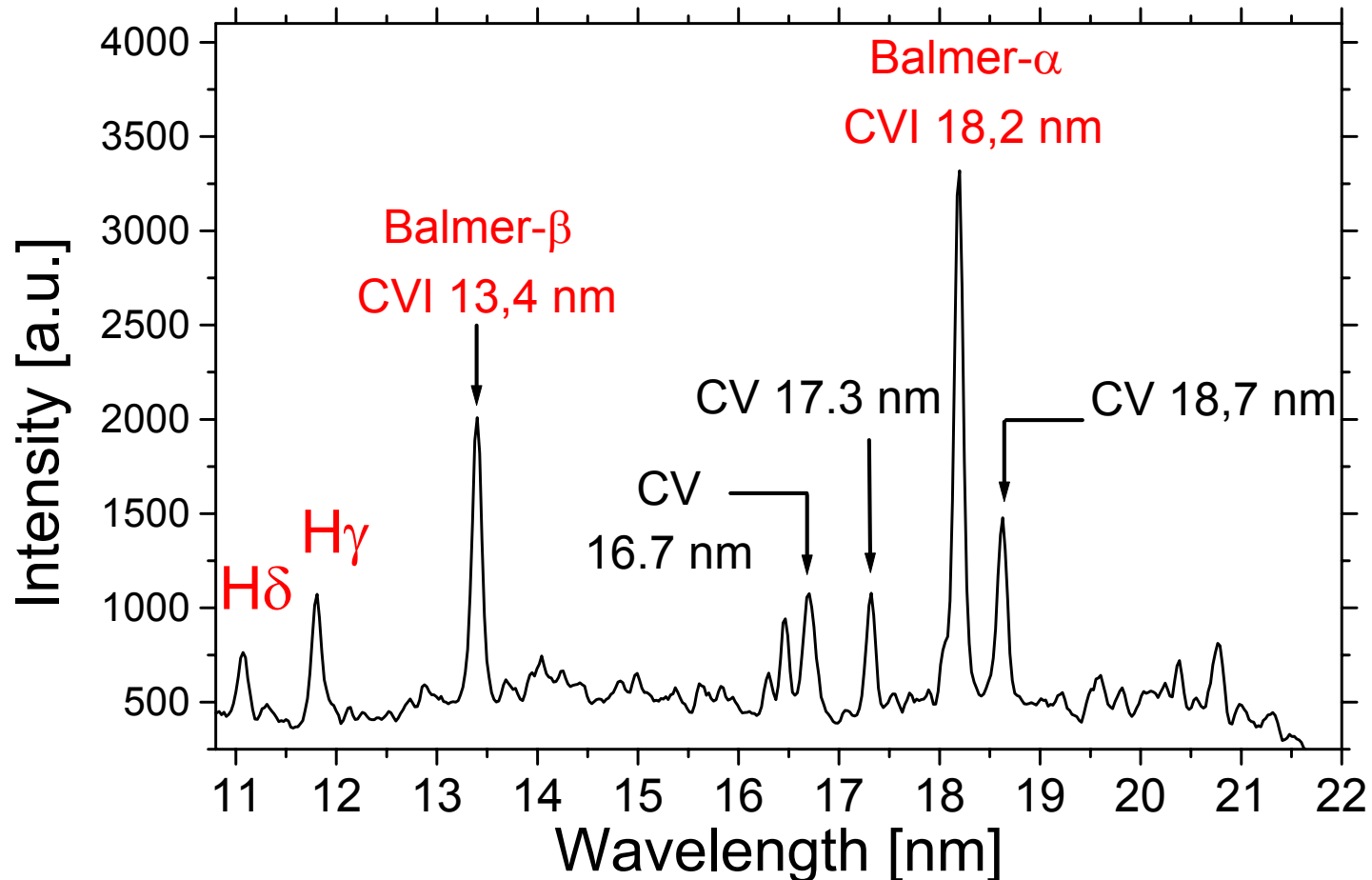


Carbon ablative capillary discharge  
for the production of

Hydrogen-like carbon  $H\alpha$  at 18,2 nm  
and  $H\beta$  at 13.5 nm

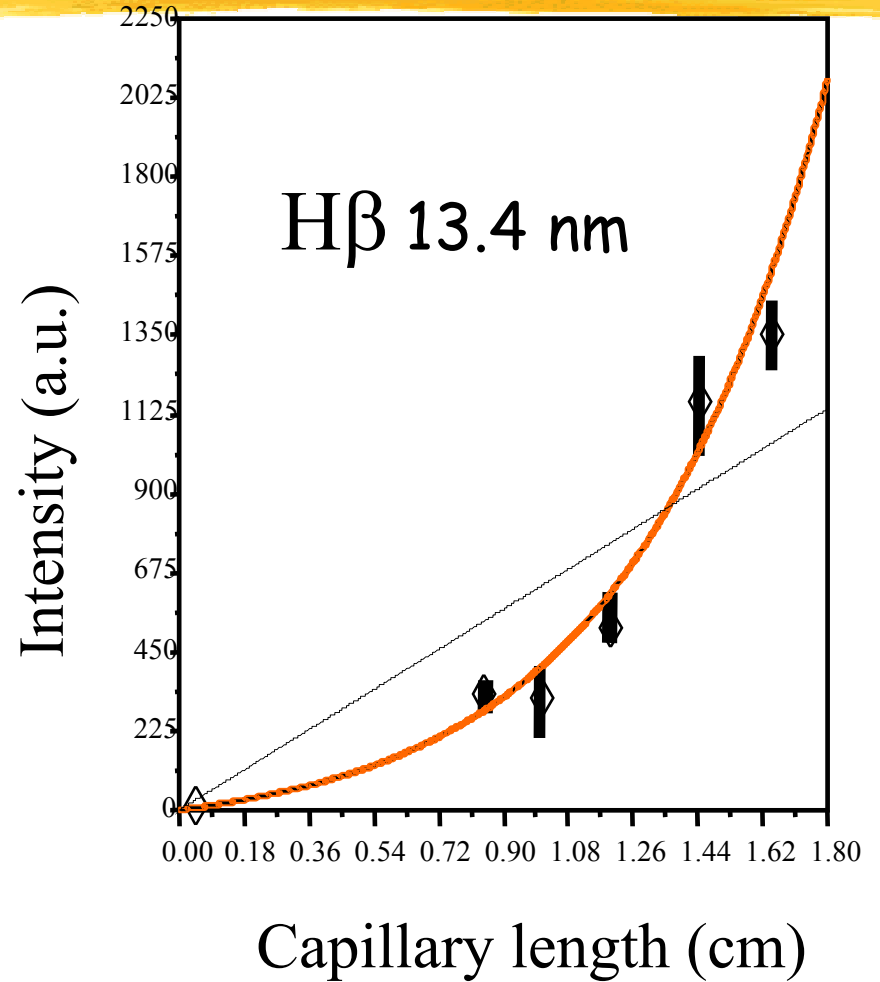
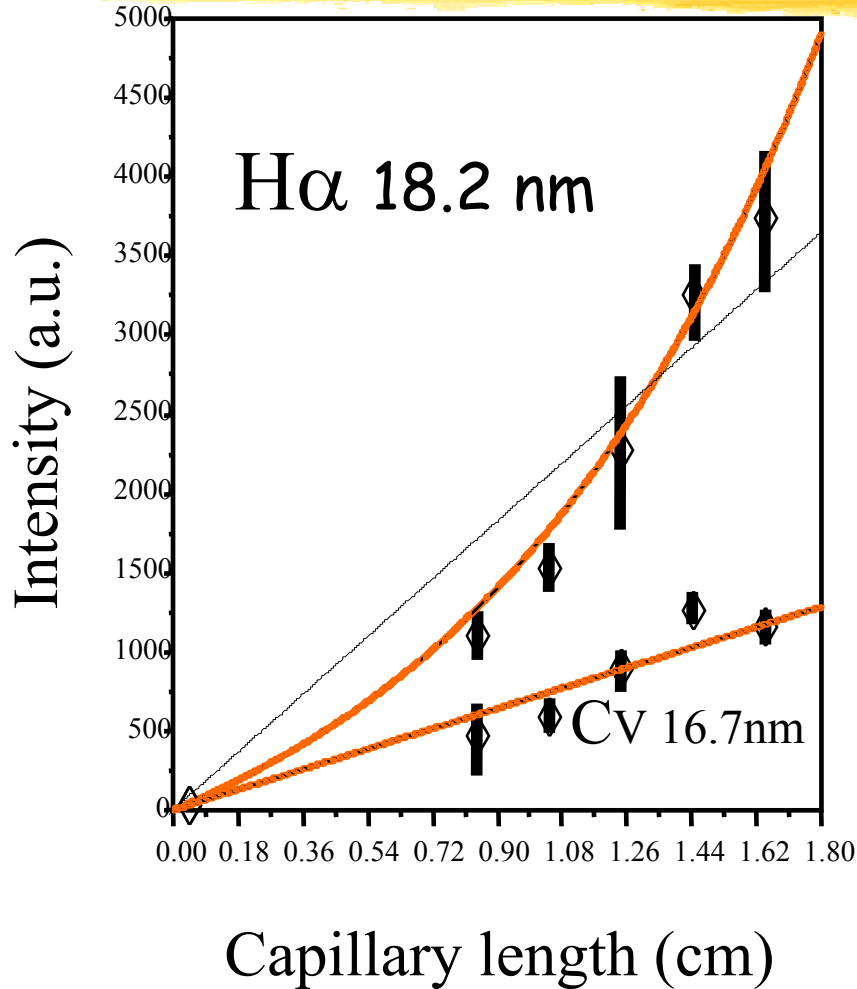
Transitions of the Balmer serie of CVI

# Ablative capillary discharge



$gl=1.6$

$gl=3$



# Perspectives



⌘ **Uncoherent sources:** still needs of powerfull lamps for EUV Lithography.

⌘ **Coherent sources:** Gas filled capillary: carbon plasma can lead to gain at 18.2 and 13.4 nm