

# LA MICROSONDE ÉLECTRONIQUE N'EST PAS MORTE !

Innovations pour les sciences de la Terre et  
l'analyse des matériaux.

Nicolas RIVIDI, CAMPARIS, UAR OMA TERRA

GNMEBA – 2025

**1982**

Camebax,  
SX50



**2011**

Achat  
SX Five



**2002**

Achat  
SX100



**2025**

JXA-  
iHP200F



# CAMPARIS : UN SERVICE UNIQUE EN ILE-DE-FRANCE

**3**

Microsondes  
( 2 Cameca & 1 Jeol)

**43 ans**

au service de la recherche  
& de l'industrie

**2,25 ETP**

et un collaborateur  
bénévole

**16 000+**

heures d'analyse  
chaque année, même  
la nuit !

**40 k€**

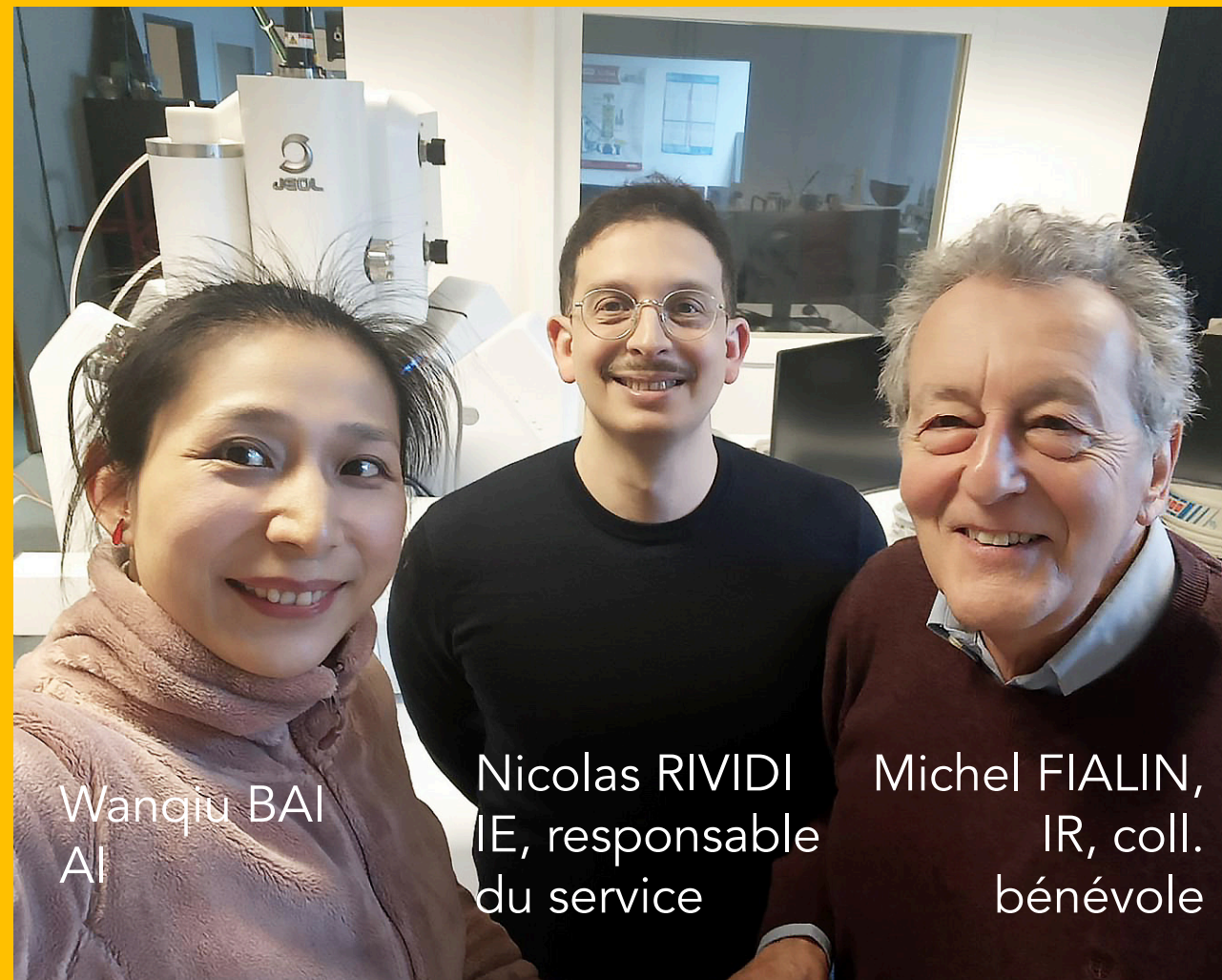
Budget annuel

**~3 M€**

Invest. depuis 2002

**150+**

utilisateurs & utilisatrices  
régulier.e.s



Wanqiu BAI  
AI

Nicolas RIVIDI  
IE, responsable  
du service

Michel FIALIN,  
IR, coll.  
bénévole



A scene from a movie showing a man being carried on a stretcher by two others in a dark, wooded area. The man on the stretcher is looking back over his shoulder. The two carriers are dressed in dark, hooded clothing. The scene is dimly lit, with some light filtering through the trees.

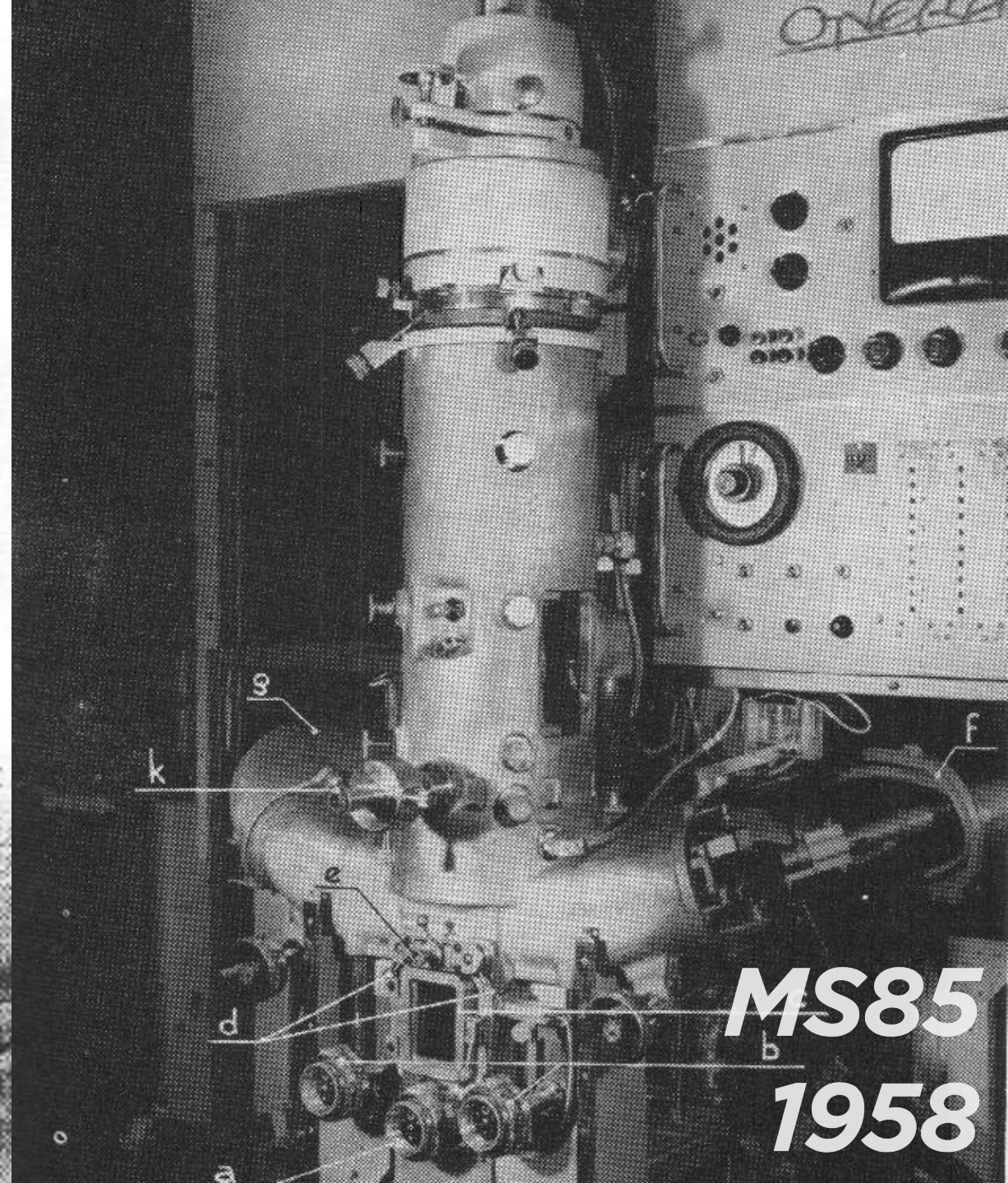
Bring up  
yer dead !

I'm not dead !  
I feel fine

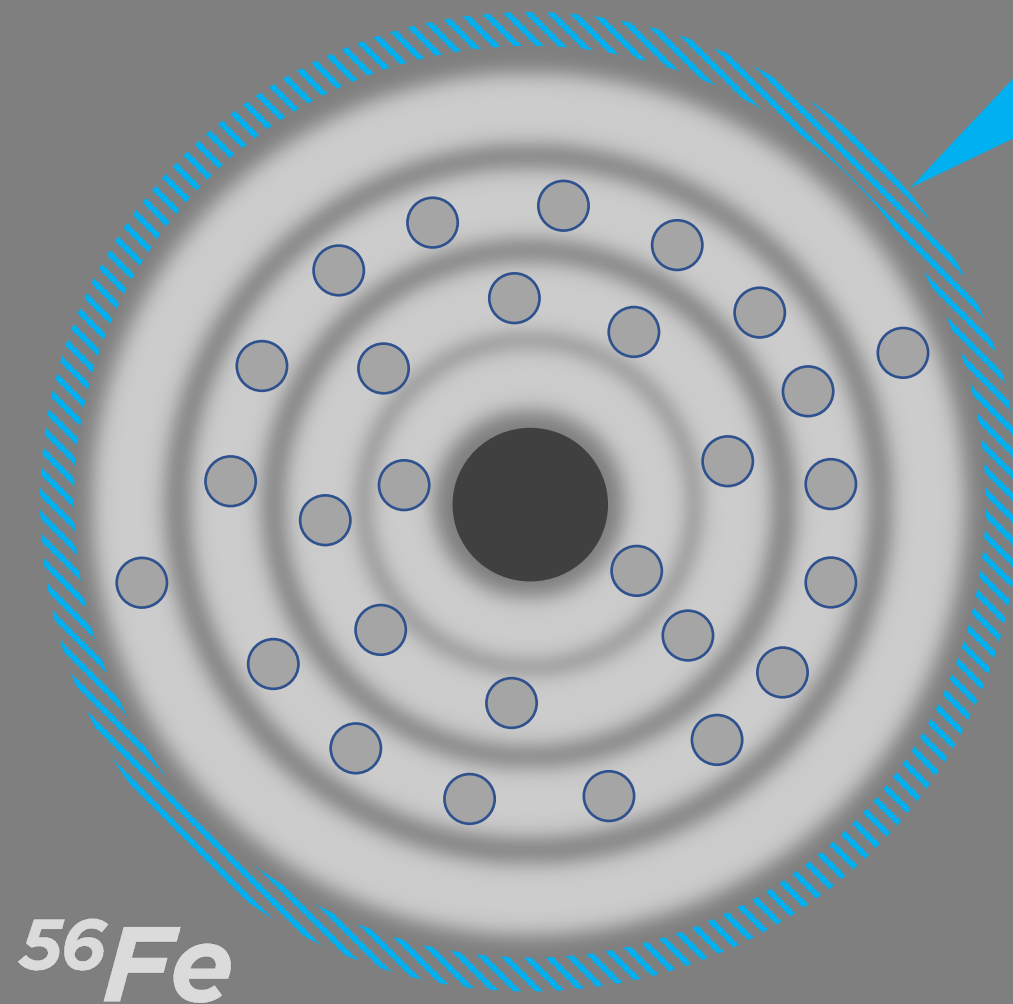




***Raimond CASTAING***  
***1921 – 1998***

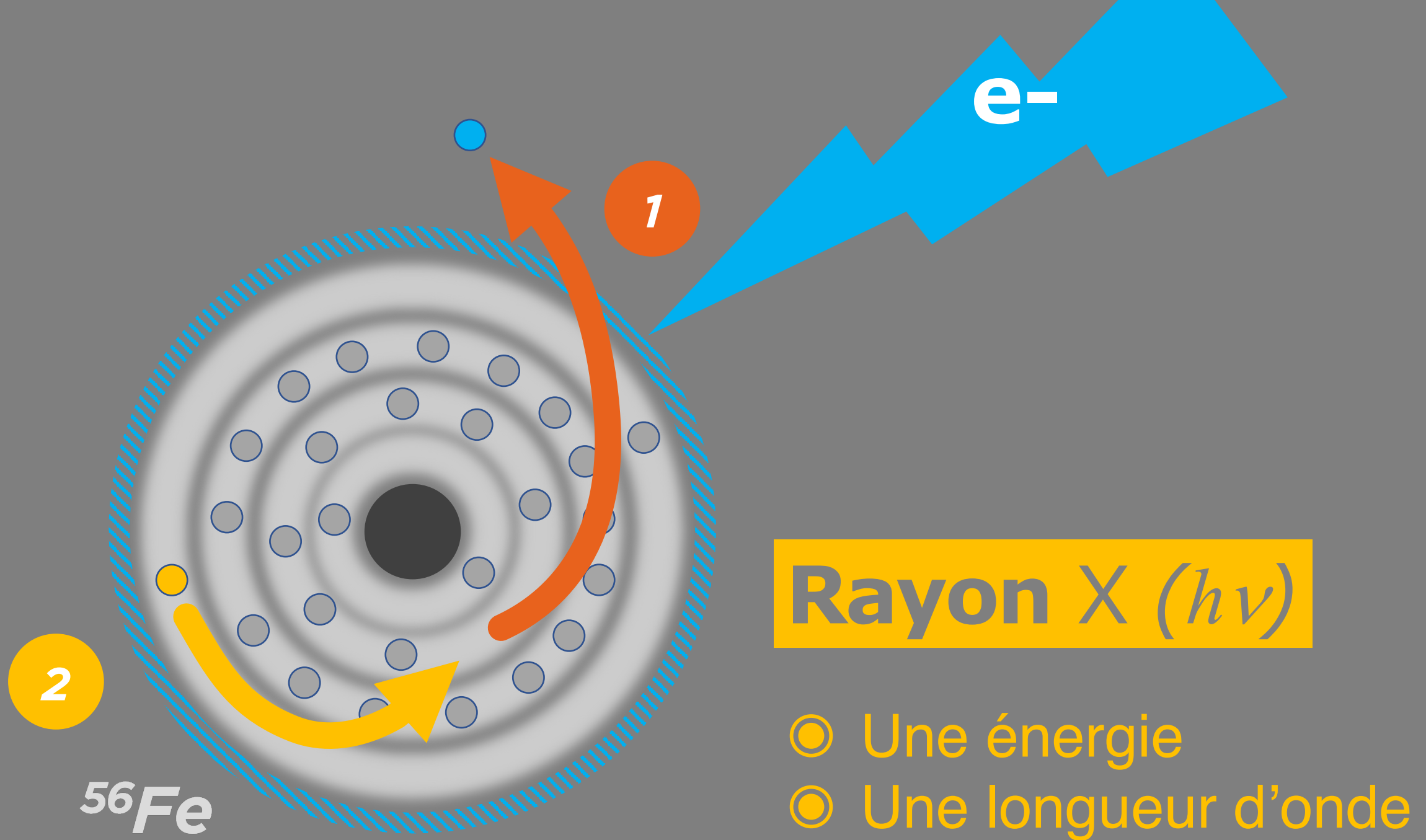


***MS85***  
***1958***

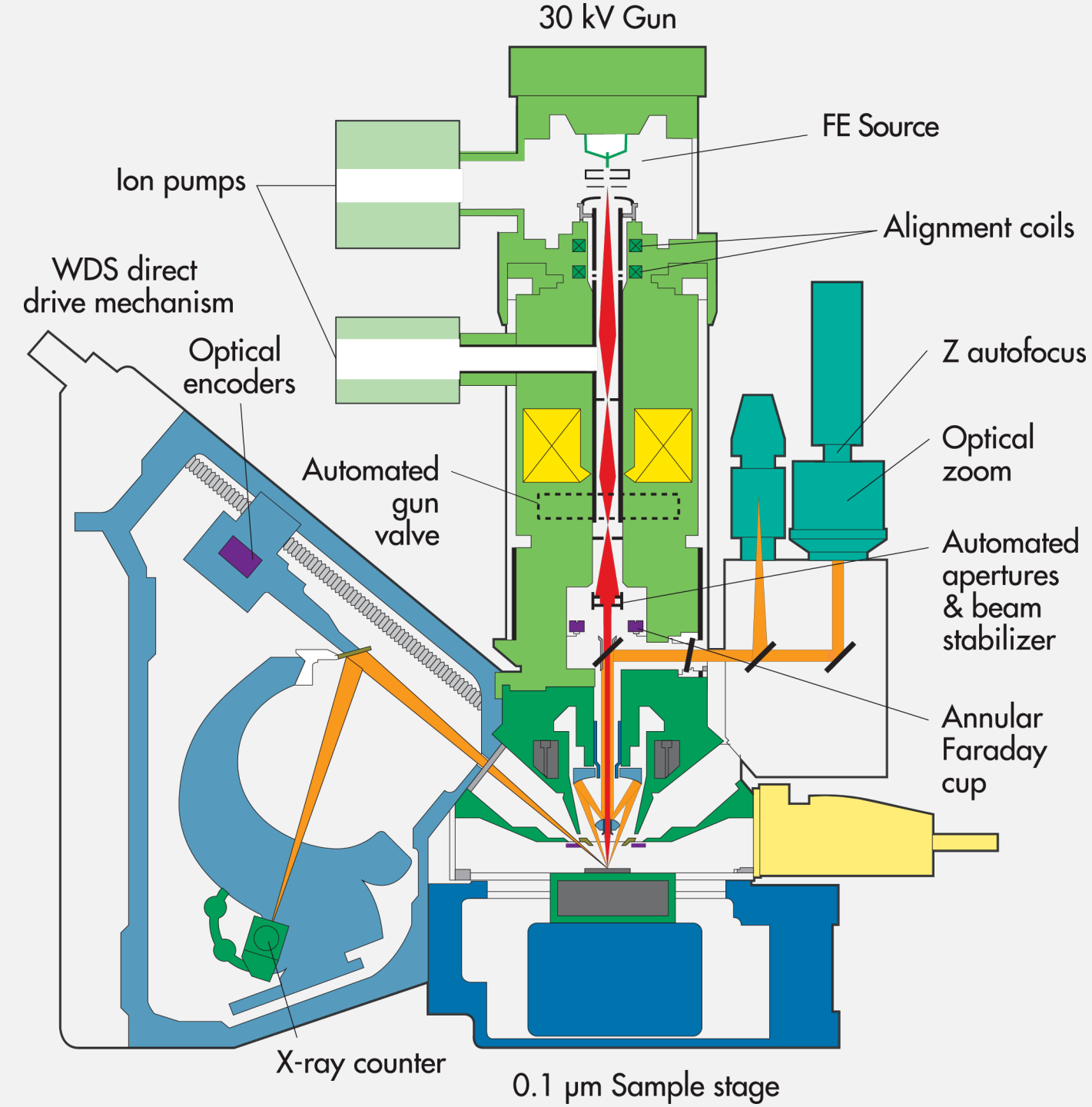


$e^-$

$^{56}\text{Fe}$







Colonne électronique  
de haut voltage et  
haute intensité

Spectromètres WDS  
à haute résolution

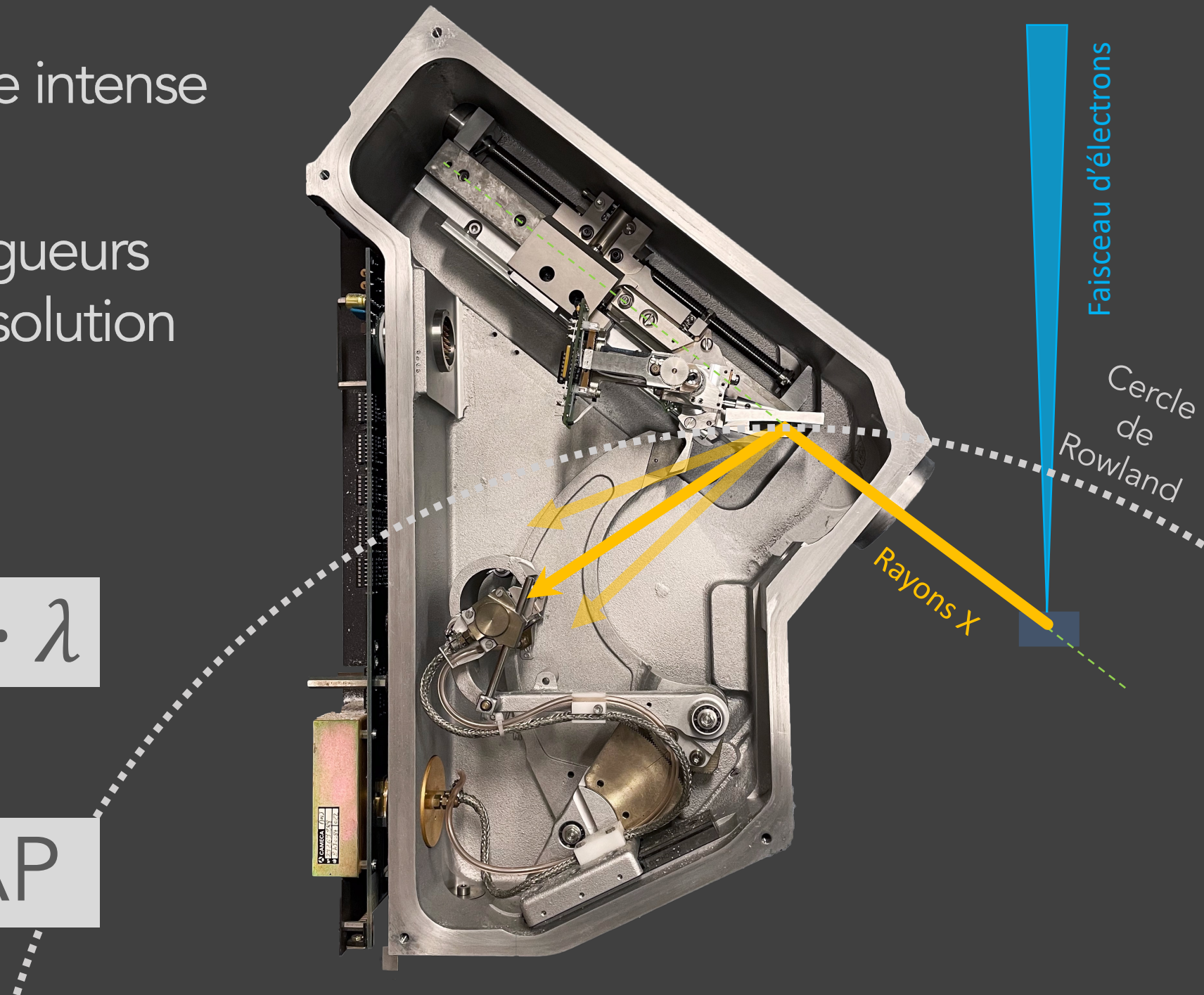
- Sonde électronique intense
- Spectroscopie en dispersion des longueurs d'ondes (WDS) Résolution ~4-5 eV

Loi de Bragg :

$$2d \sin \theta = n \cdot \lambda$$

Quantification :

ZAF,  $\phi\rho z$ , PAP

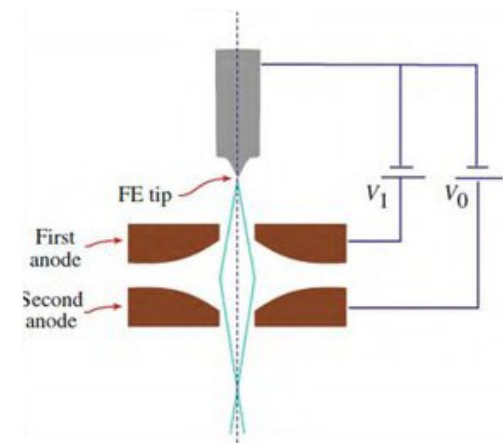
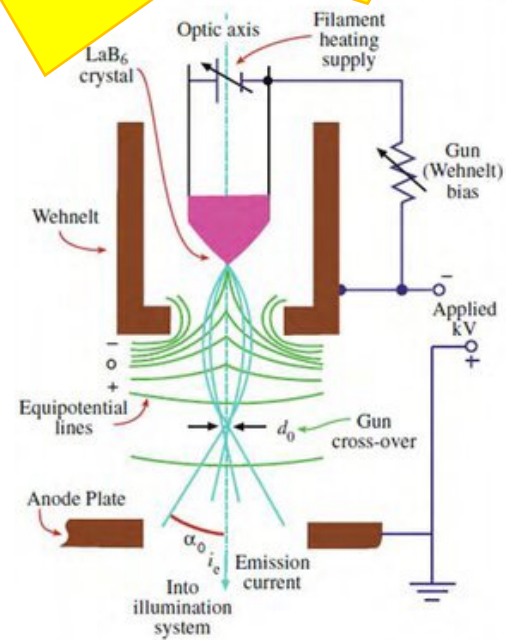
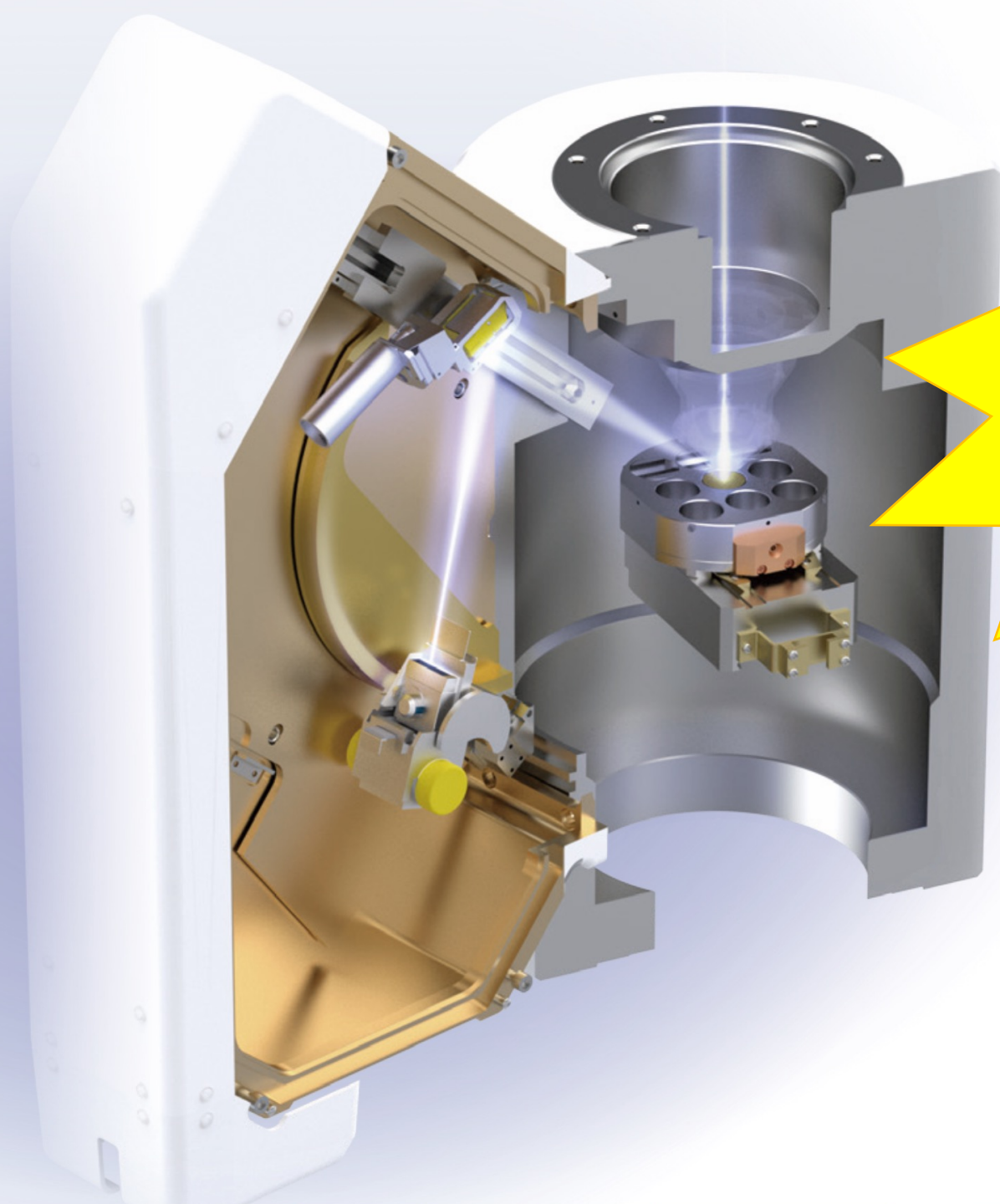


1 H																	2 He		
3 Li	4 Be													5 B	6 C	7 N	8 O	9 F	10 Ne
11 Na	12 Mg													13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr		
37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe		
55 Cs	56 Ba	71 Lu	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn		
87 Fr	88 Ra	103 Lr	104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110 Ds	111 Rg	112 Uub		114 Uuq						

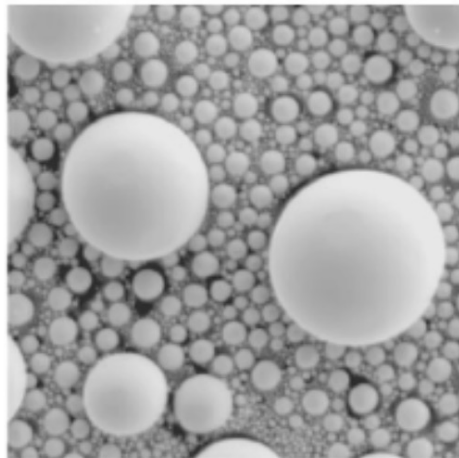
57 La	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb
89 Ac	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No



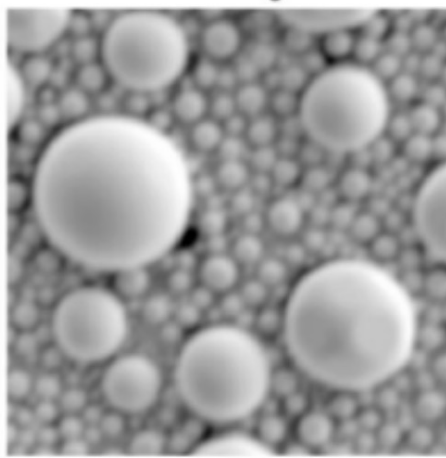
# FEG



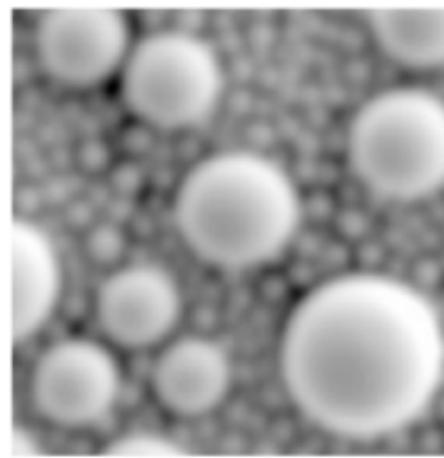
TFE



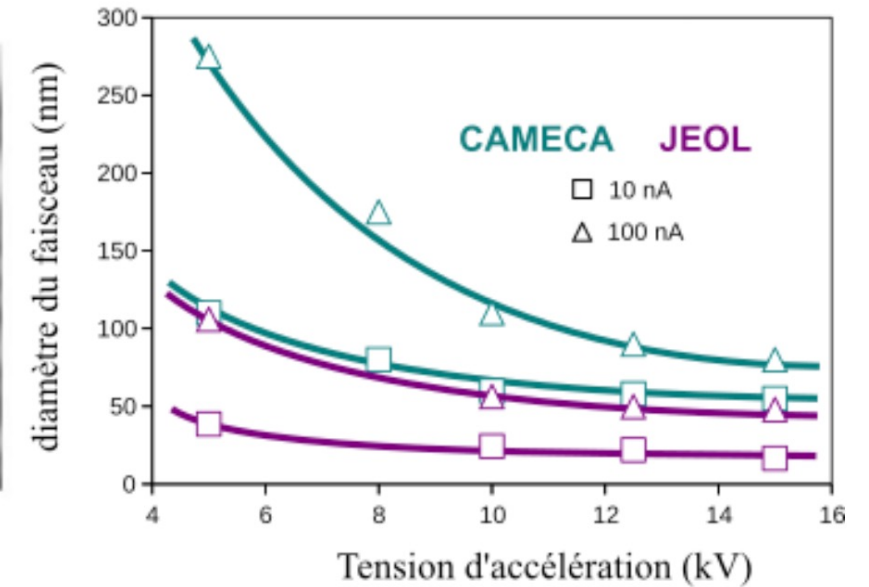
LaB<sub>6</sub>



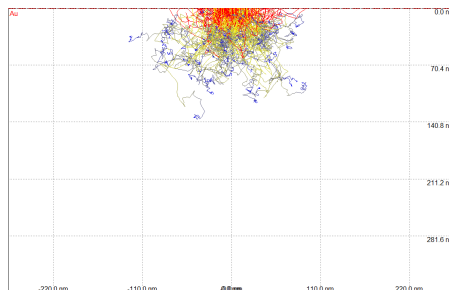
W



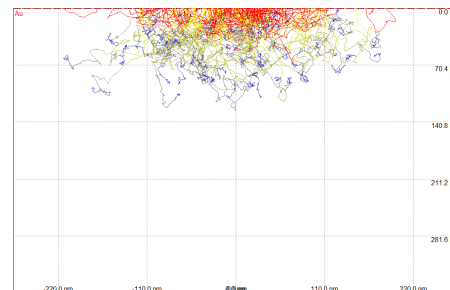
5μm



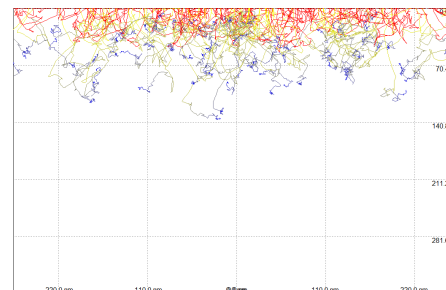
Au (beam 10 kV, 100 nA)



Beam diam. 60 nm



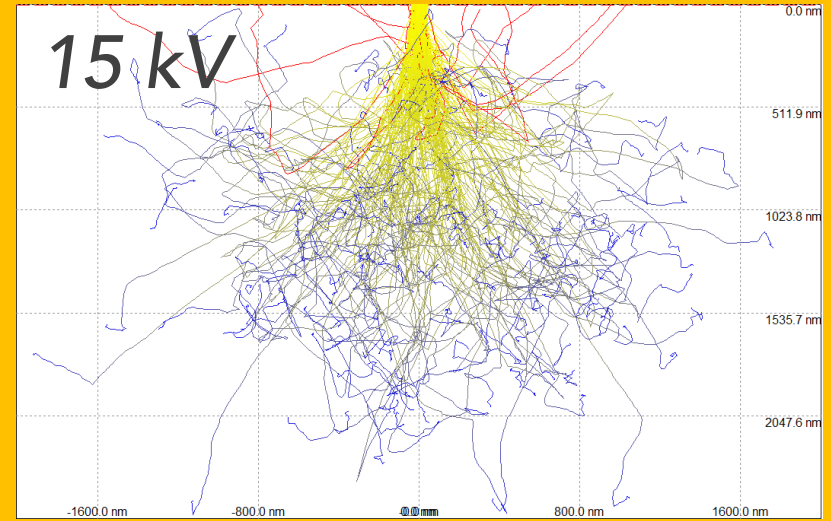
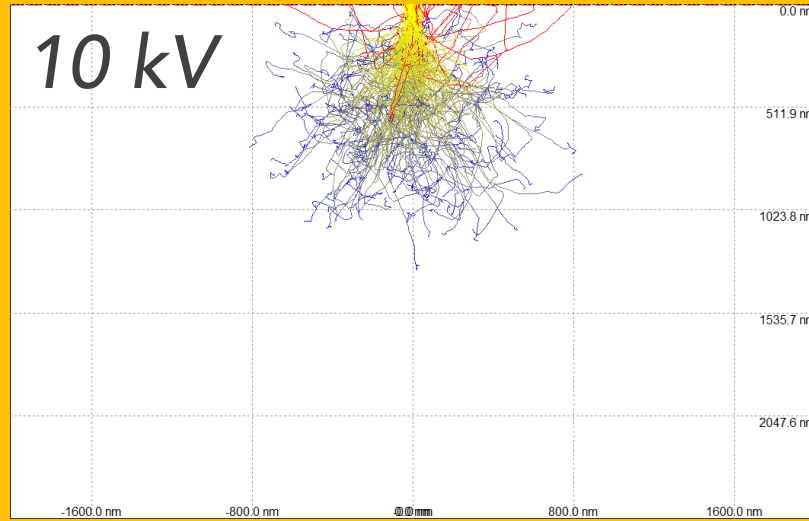
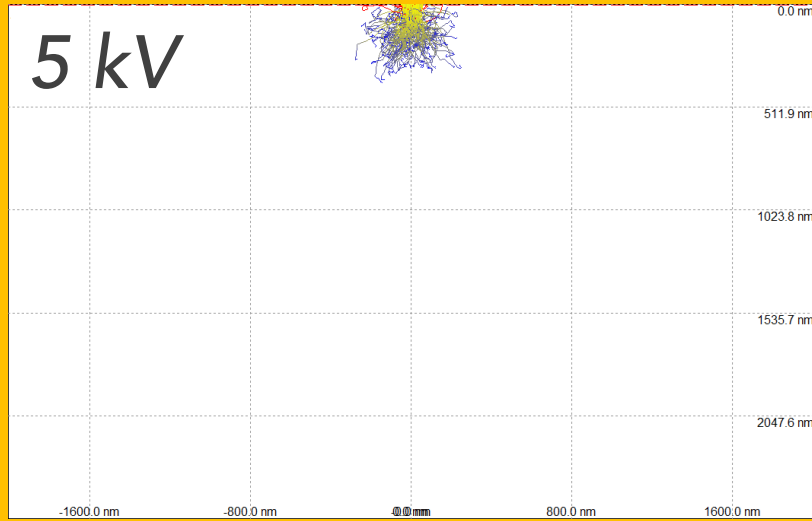
Beam diam. 125 nm



Beam diam. 500 nm

350 nm

*Si (beam 60 nm)*



## Amélioration de la resolution spatiale

- Basses tensions
- Microéchantillonnage



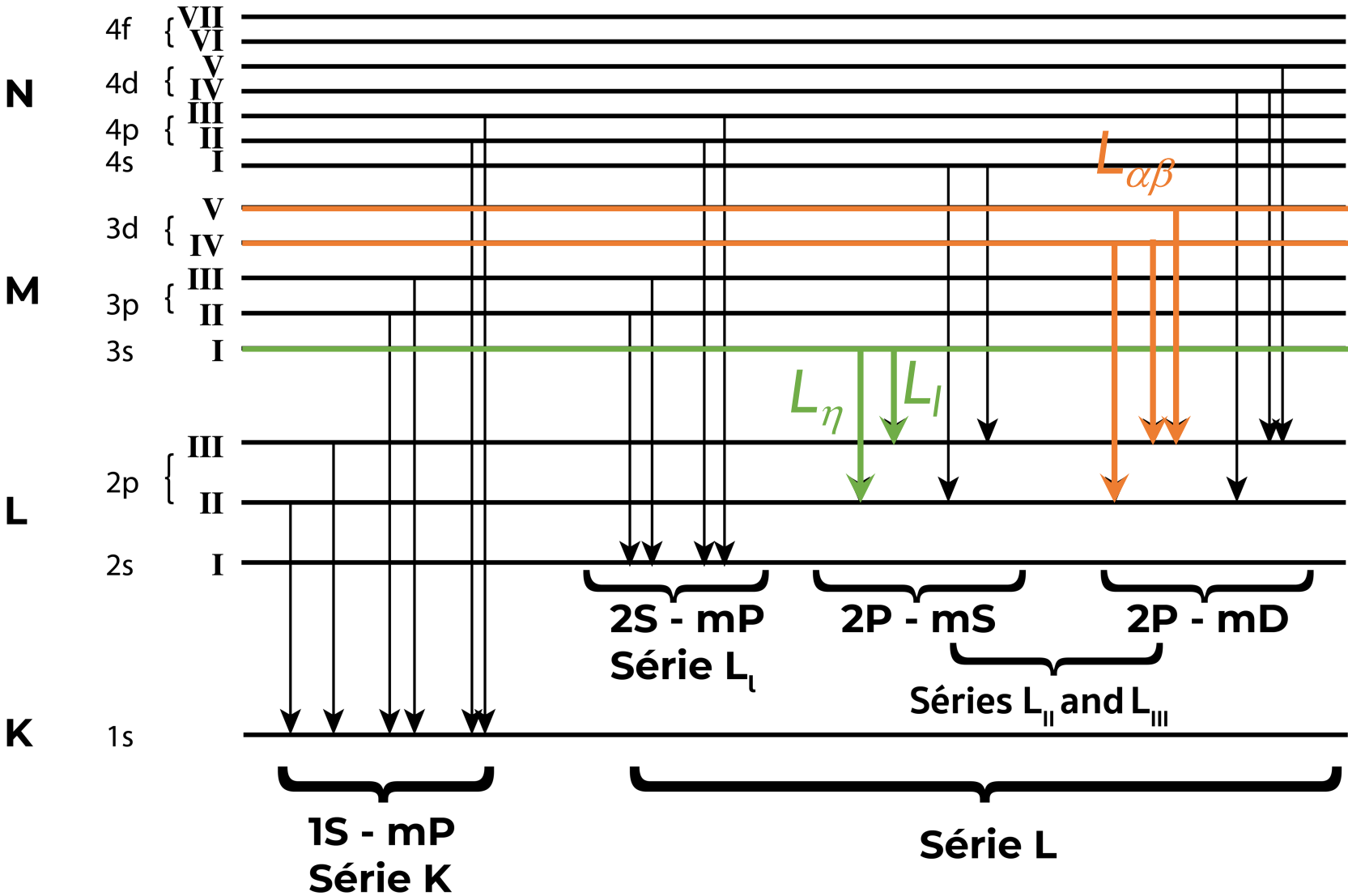
**5 kV**

Raies	Si	Ca	Mg	Fe	Mn	Ti	K	Al	Cr	Na
$K_{\alpha}$ (eV)	1739	3691	1253	6403	5898	4510	3313	1486	5414	1040

26 Fe : [Ar] 3d<sup>6</sup> 4s<sup>2</sup>

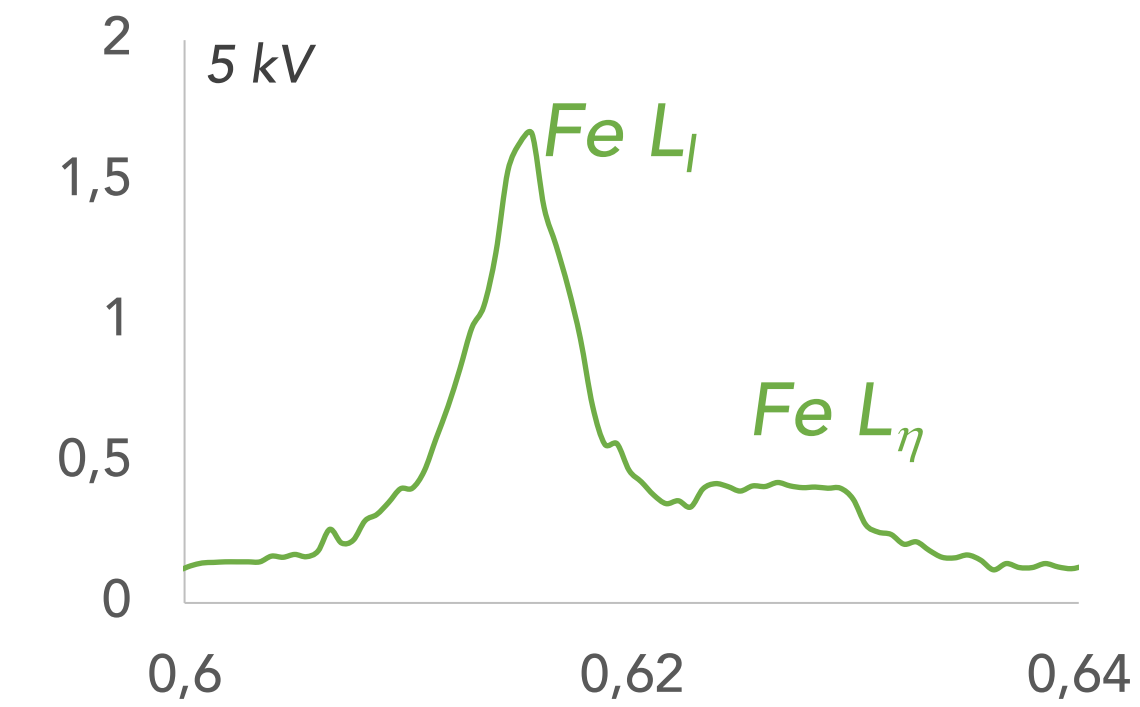
$L_{\alpha\beta}$  : couches de valence

$L_{I\eta}$  : couches atomiques

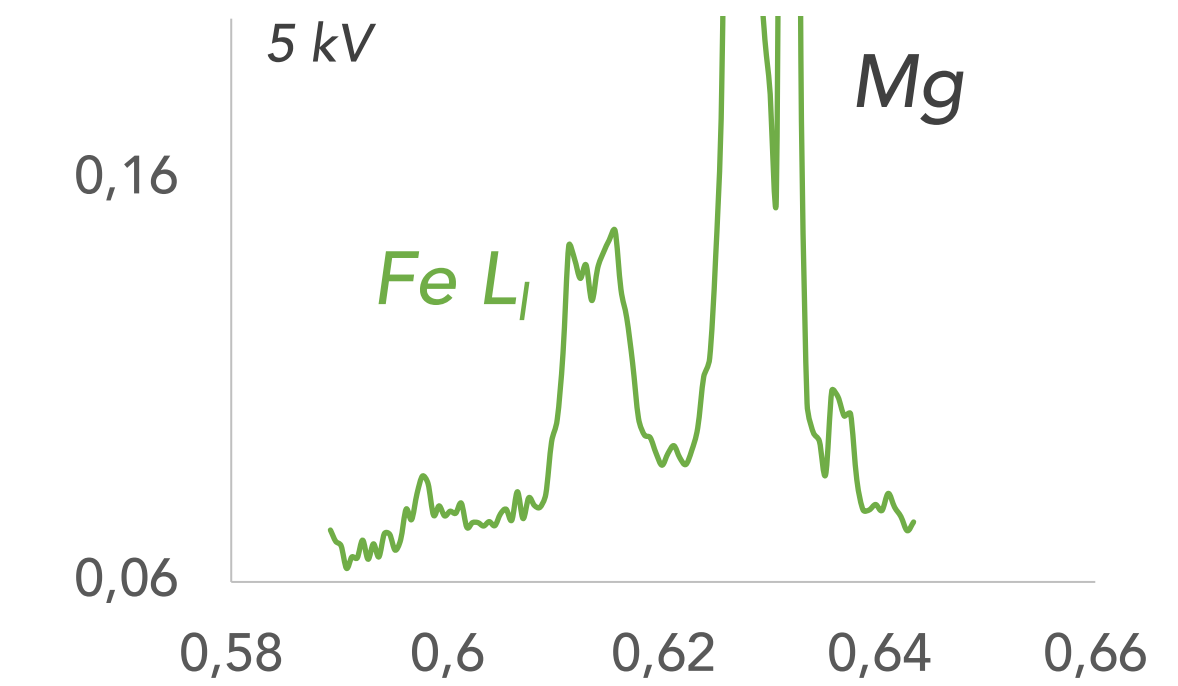


Raies	Si	Ca	Mg	Fe	Mn	Ti	K	Al	Cr	Na
K <sub>α</sub> (eV)	1739	3691	1253	6403	5898	4510	3313	1486	5414	1040
L <sub>I</sub> (eV)				615	556	395			500	

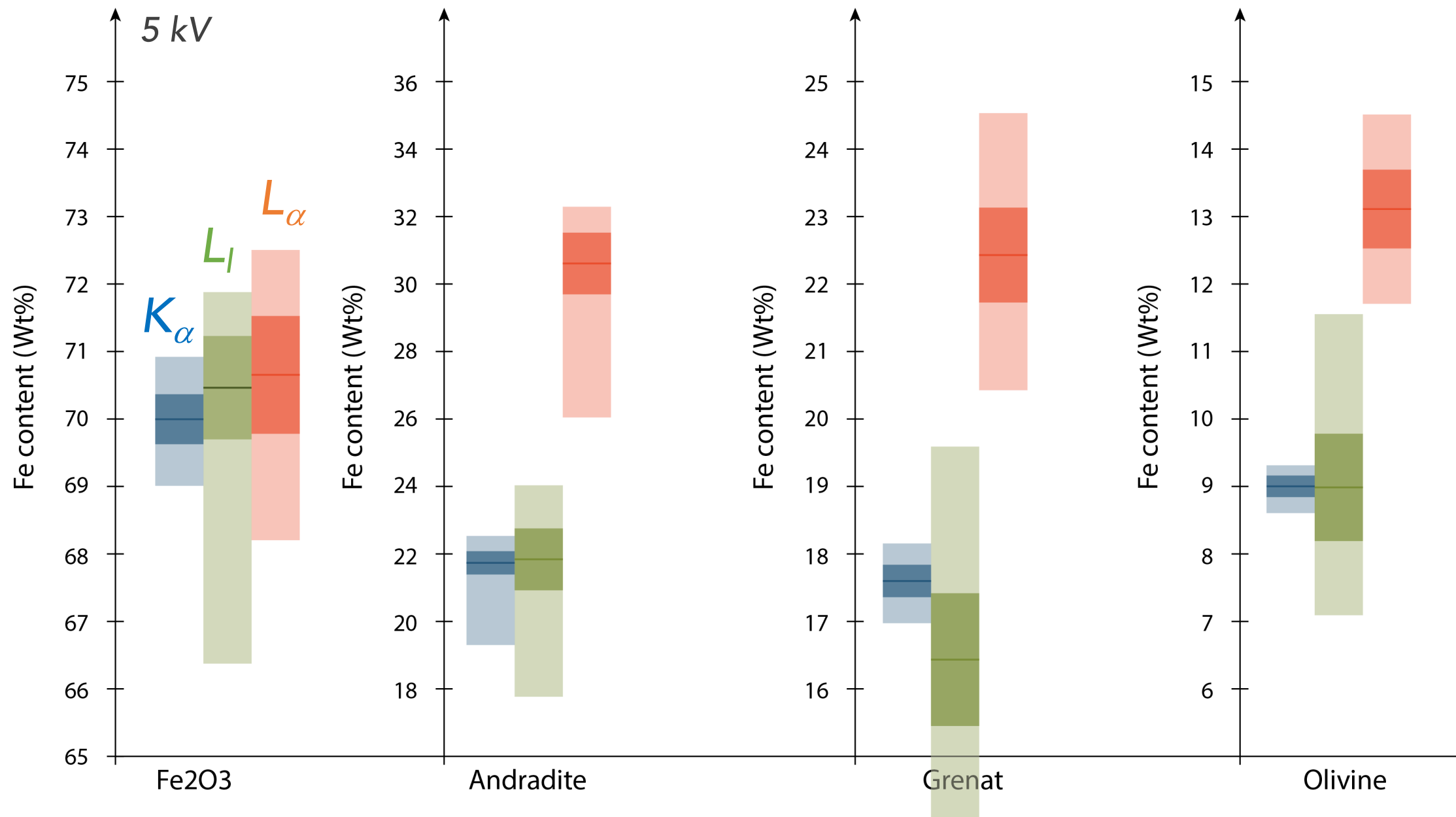
*Hématite (ca. 69 wt% Fe)*



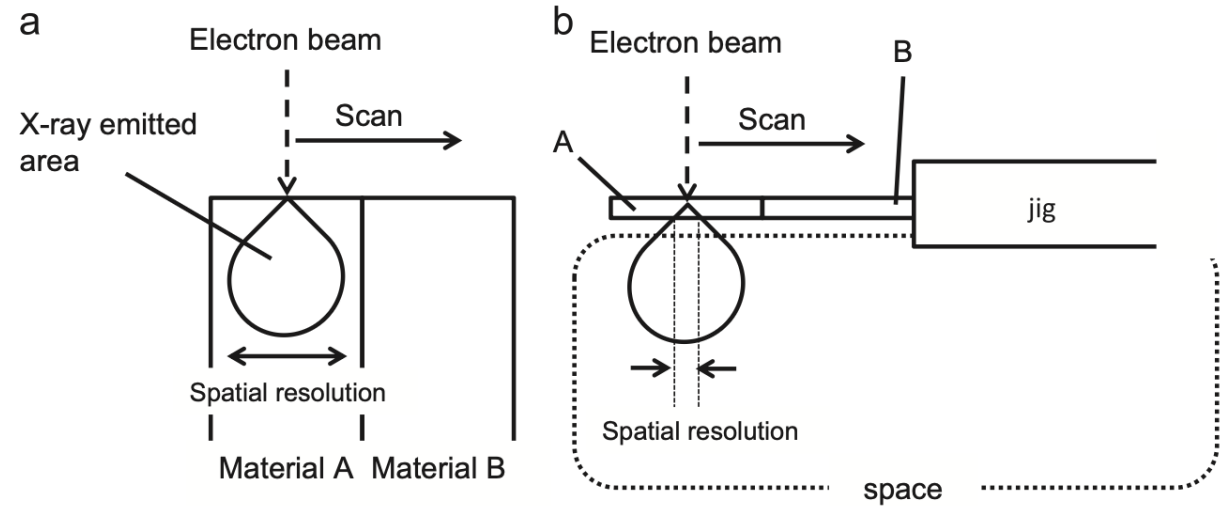
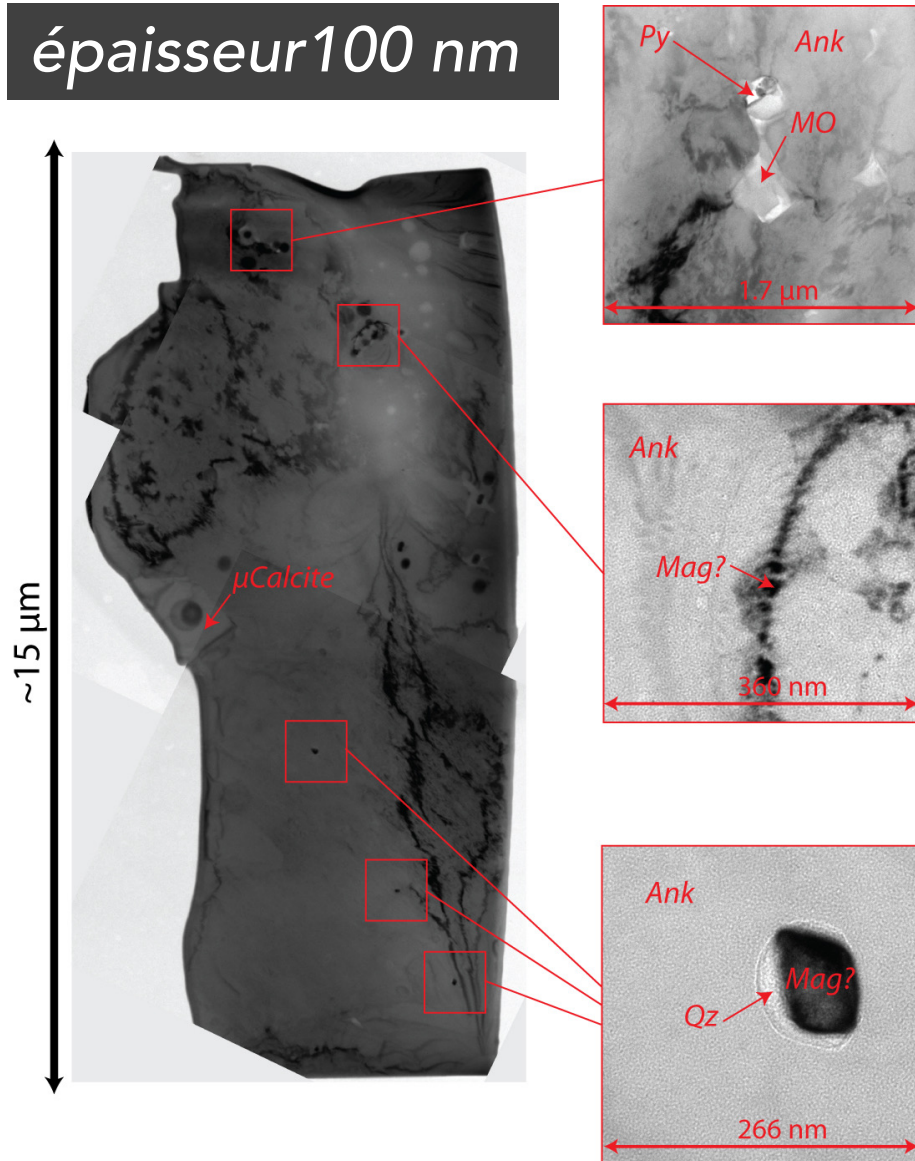
*Diopside (ca. 2 wt% Fe)*



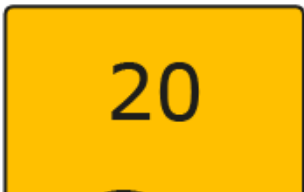
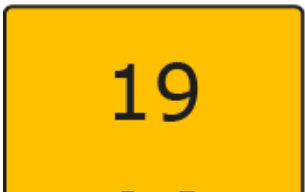
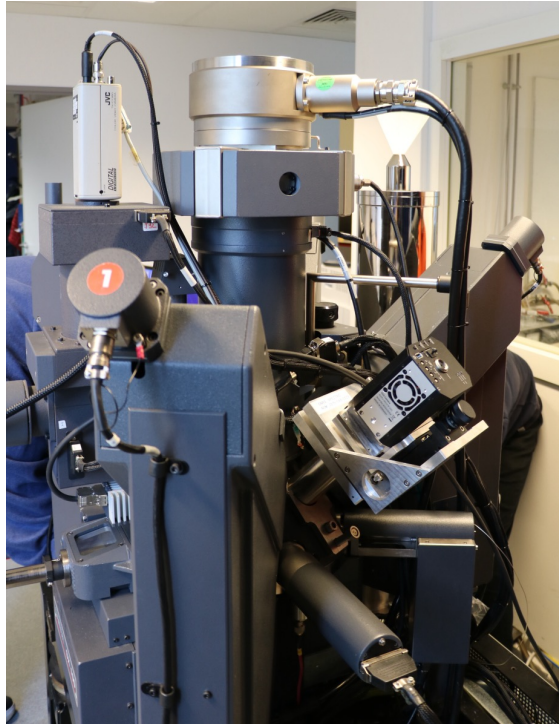
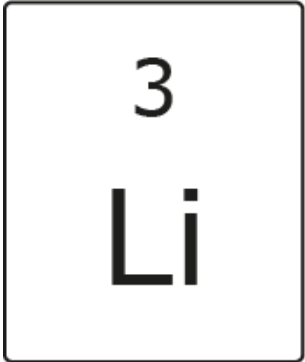
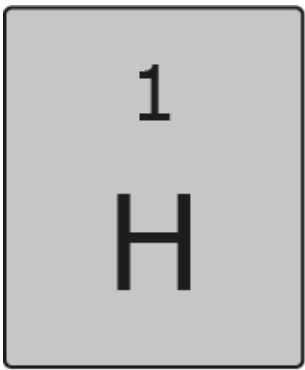




# Microéchantillonnage FIB



- Meilleure résolution haute tension
- Contrôle de l'angle crucial
- Calibration sur des standards en lame FIB identiques

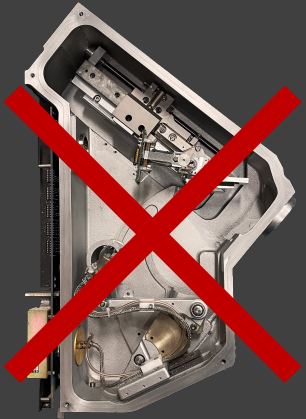


Adaptation d'une microsonde  
électronique de série  
(spectromètre et  
environnement analytique)

2 thèses :

- **Khalil Hassebi** (fin oct. 2024, avec P. Jonnard et A. Verlaquet)
- **Nawel Temmar** (début nov. 2024, avec P. Jonnard)

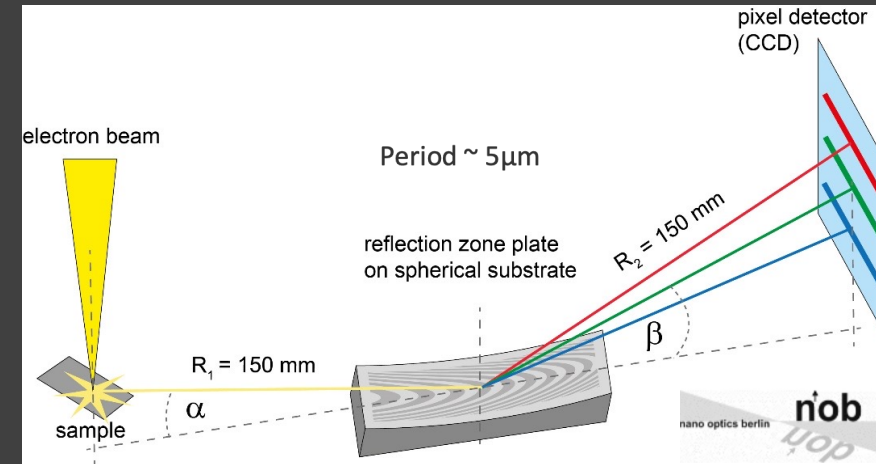
# Gain de résolution spectrale et d'intensité



Cahier des charges d'un spectromètre  
à réseau zone de Fresnel ( $50 \pm 0,3$  eV)

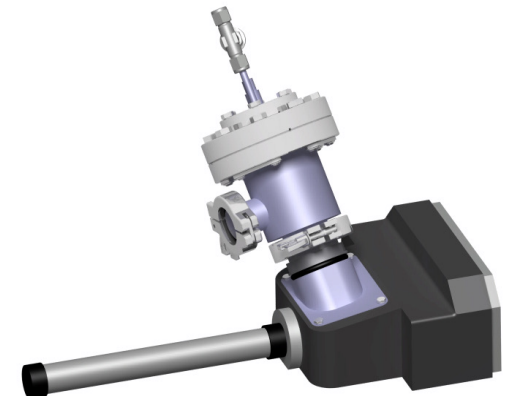
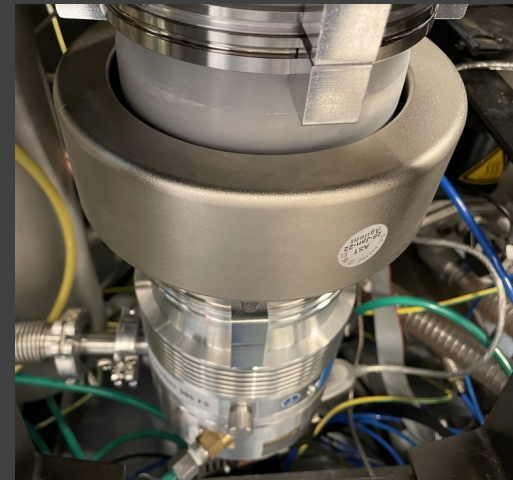
Loi des réseaux :

$$d (\cos \alpha - \cos \beta) = n \cdot \lambda$$



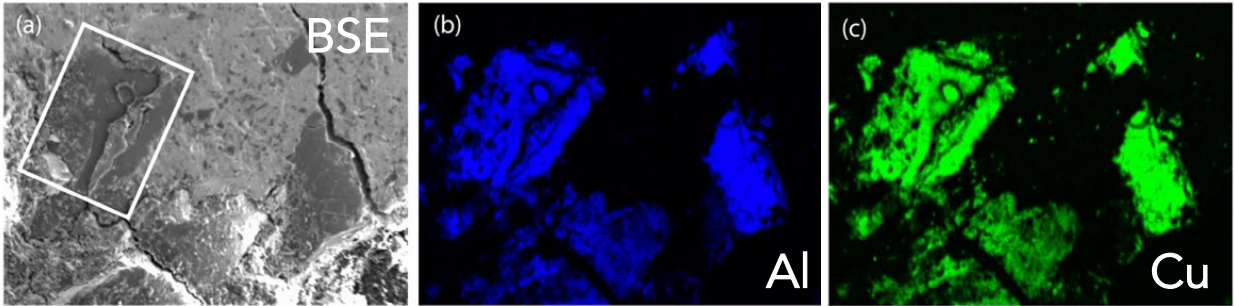
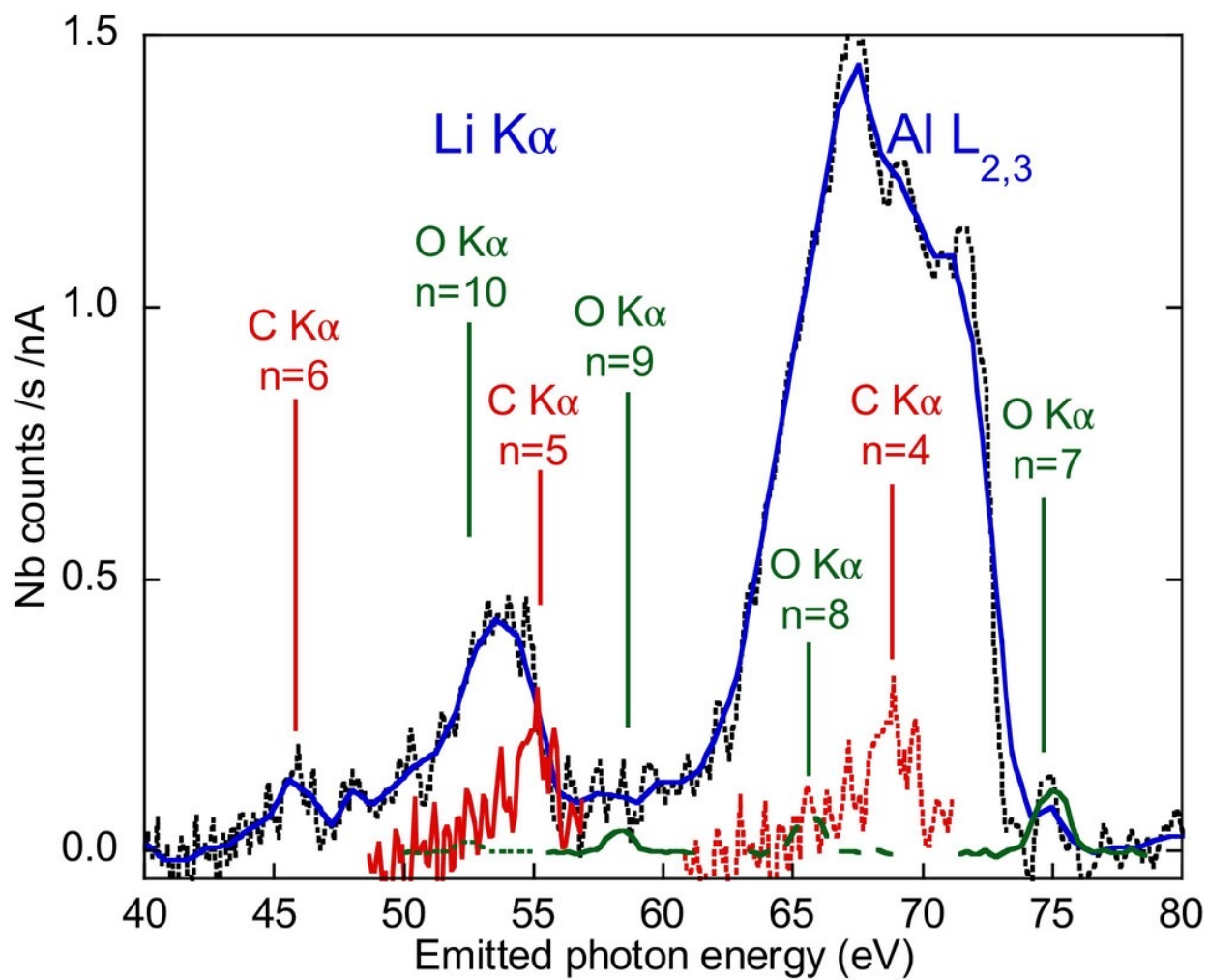
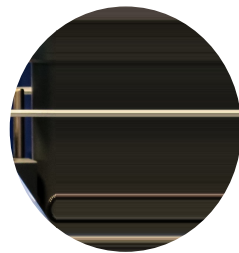
## Propreté de l'environnement analytique

- Installation d'un pompage sec
- Conception d'un décapeur ionique installé sur le sas d'entrée de l'instrument
- Conception d'un sas de transport

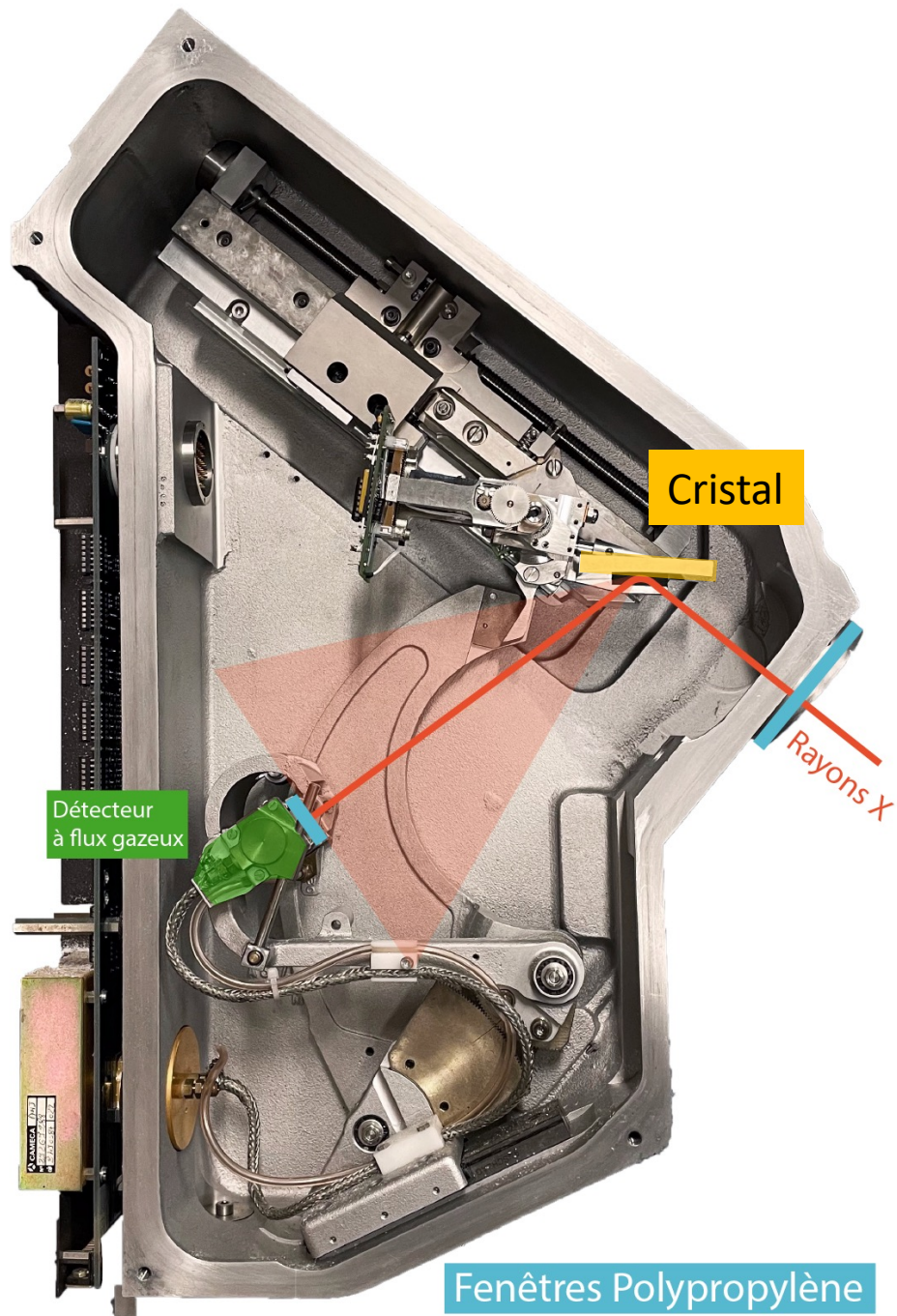




# Khalil Hassebi Spectroscopy and quantification in the Li K emission range using x-ray microanalysis

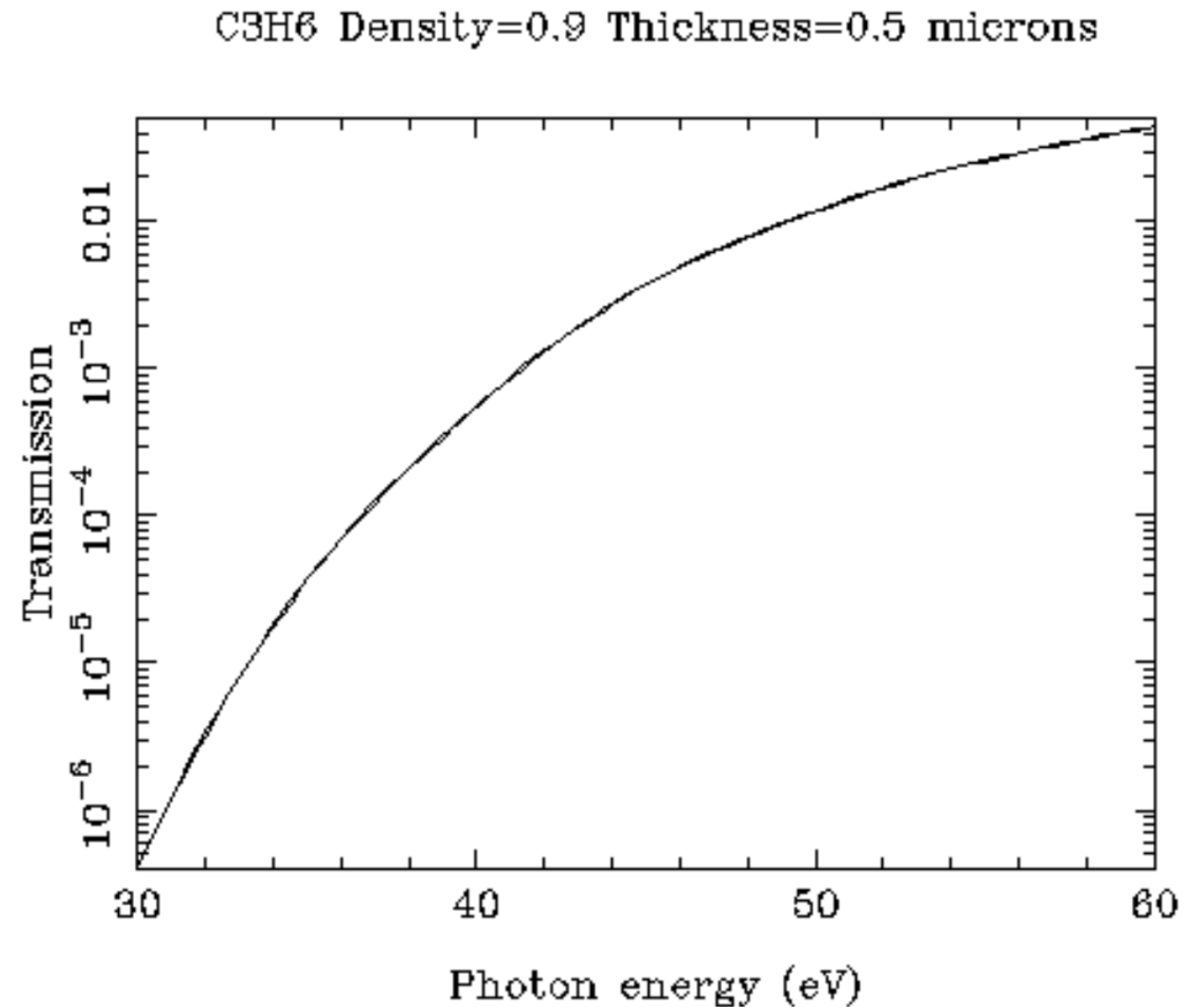


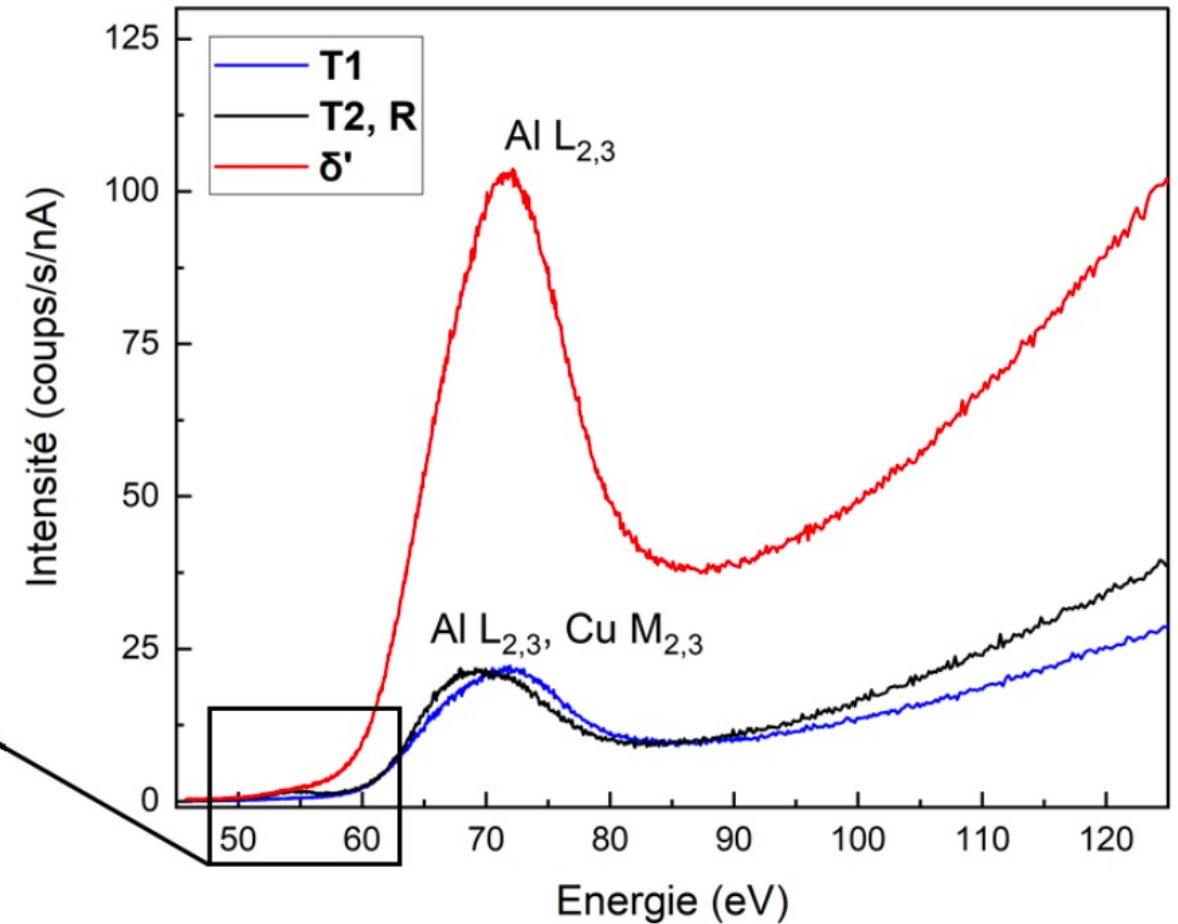
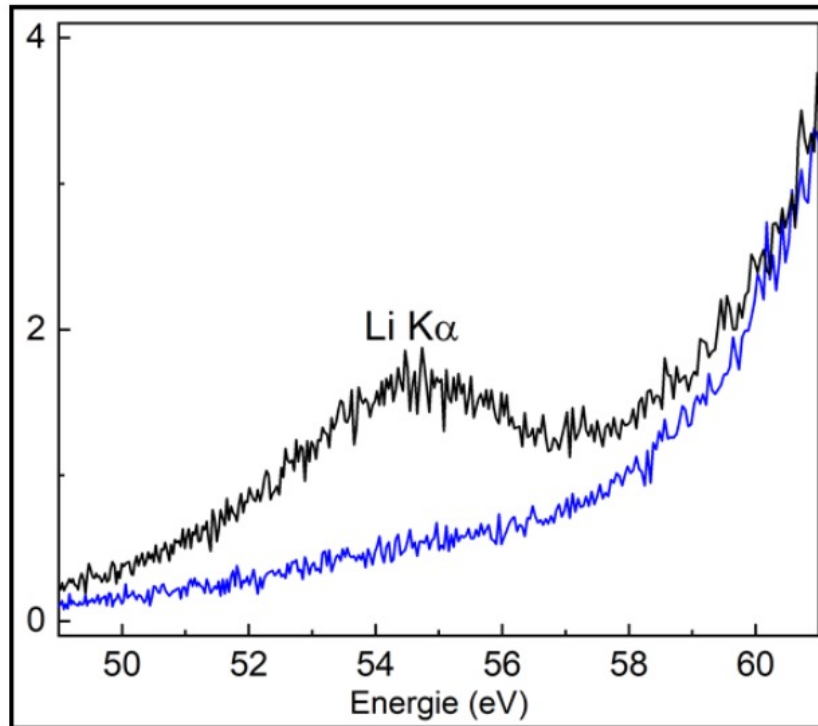
Al (wt%)	Li (wt%)	Cu (wt%)
Soft X-rays (lithium mesuré par difference à 100%)		
59,6	16,9	23,5
Ultra-Soft X-rays (lithium mesuré directement)		
55,5	18,1	26,3



# Absorption des fenêtres

Signal divisé par  $10^6$  à  $10^8$





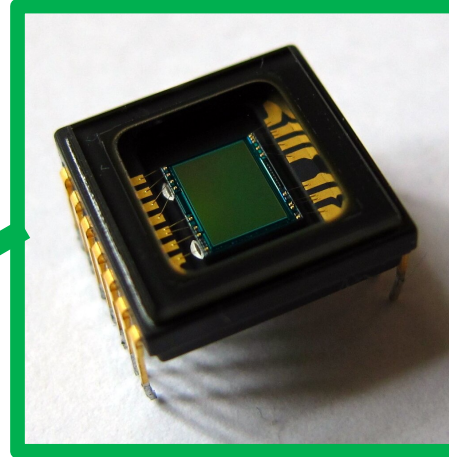
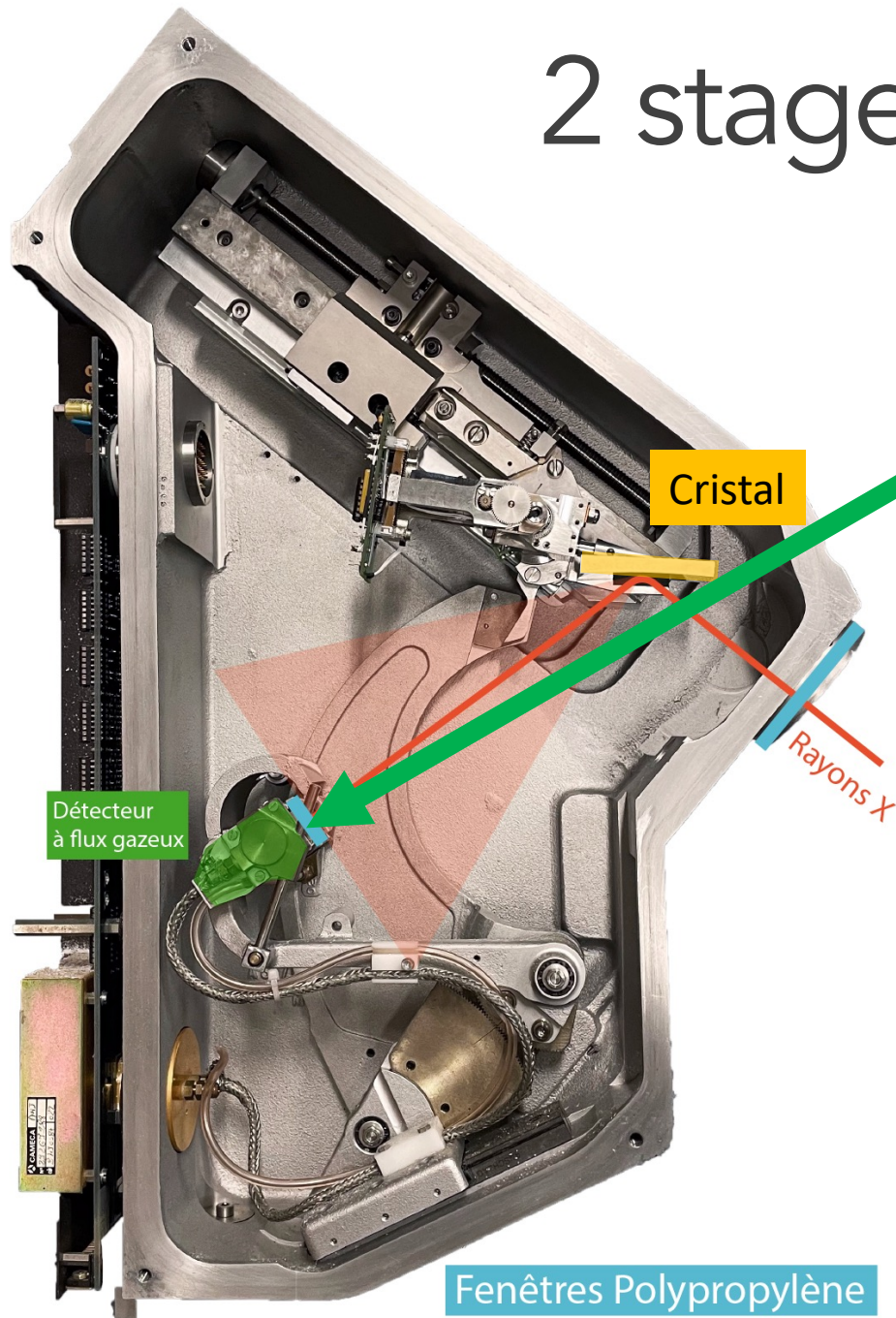
- Faible intensité
- Faible résolution spectrale
- Détermination du fond



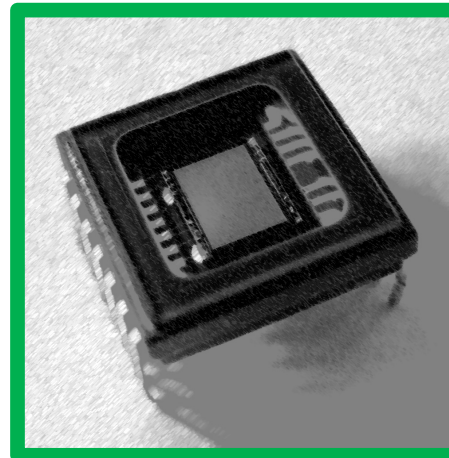
Détection solide



# 2 stages de M1 – 4 mois



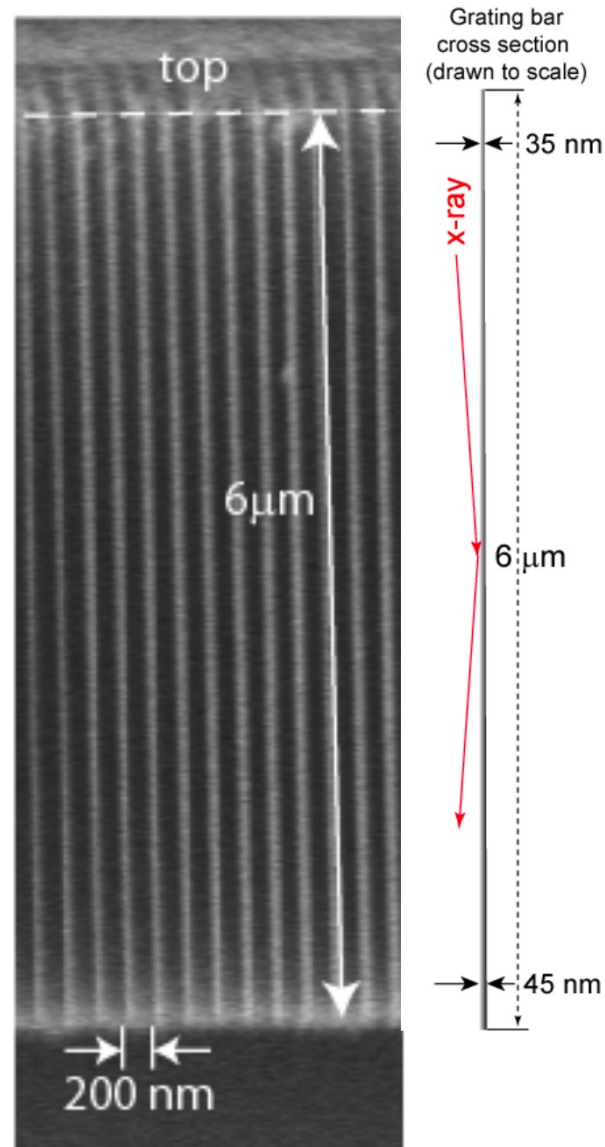
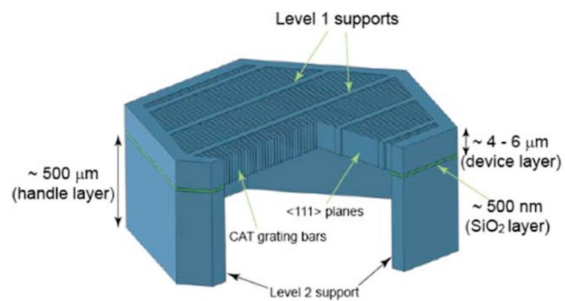
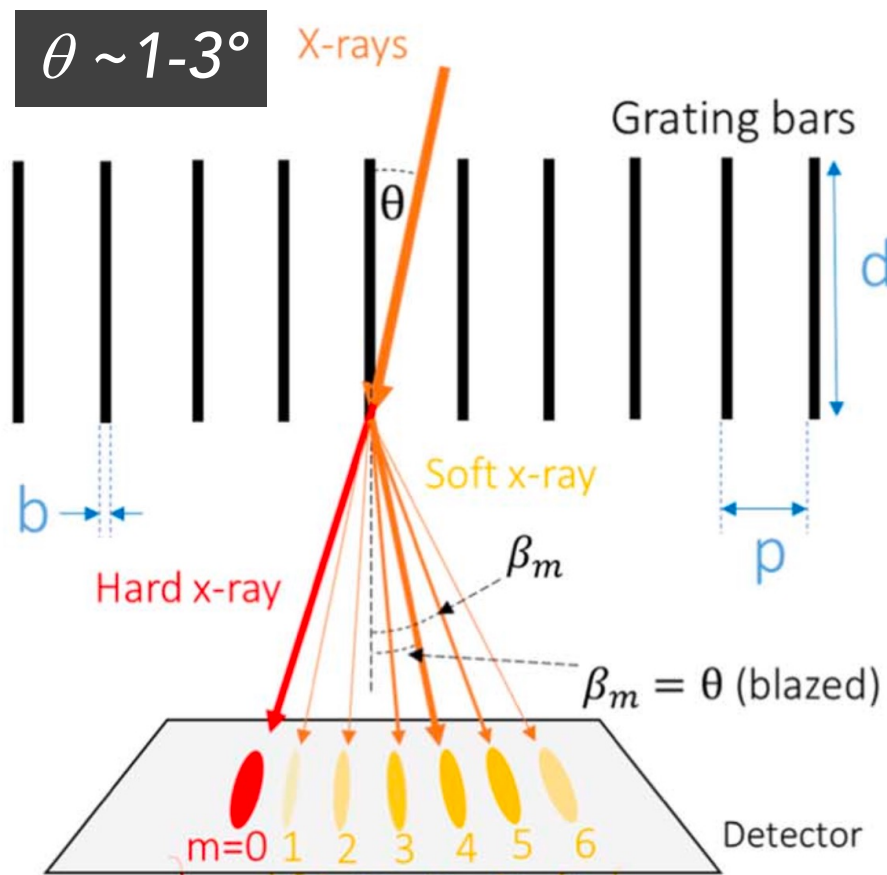
Installation d'un CCD/CMOS  
du commerce dans un WDS  
CAMECA  
exemple : Whurer et al., 2018



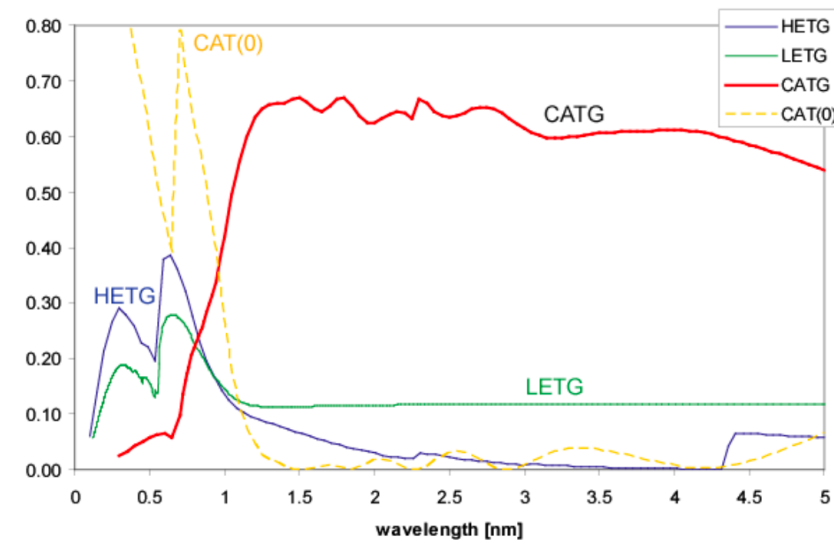
Conception d'un nouveau  
capteur optimisé pour les  
raies  $K\alpha$  du lithium (45-55 eV)



# Réseaux en transmission CAT

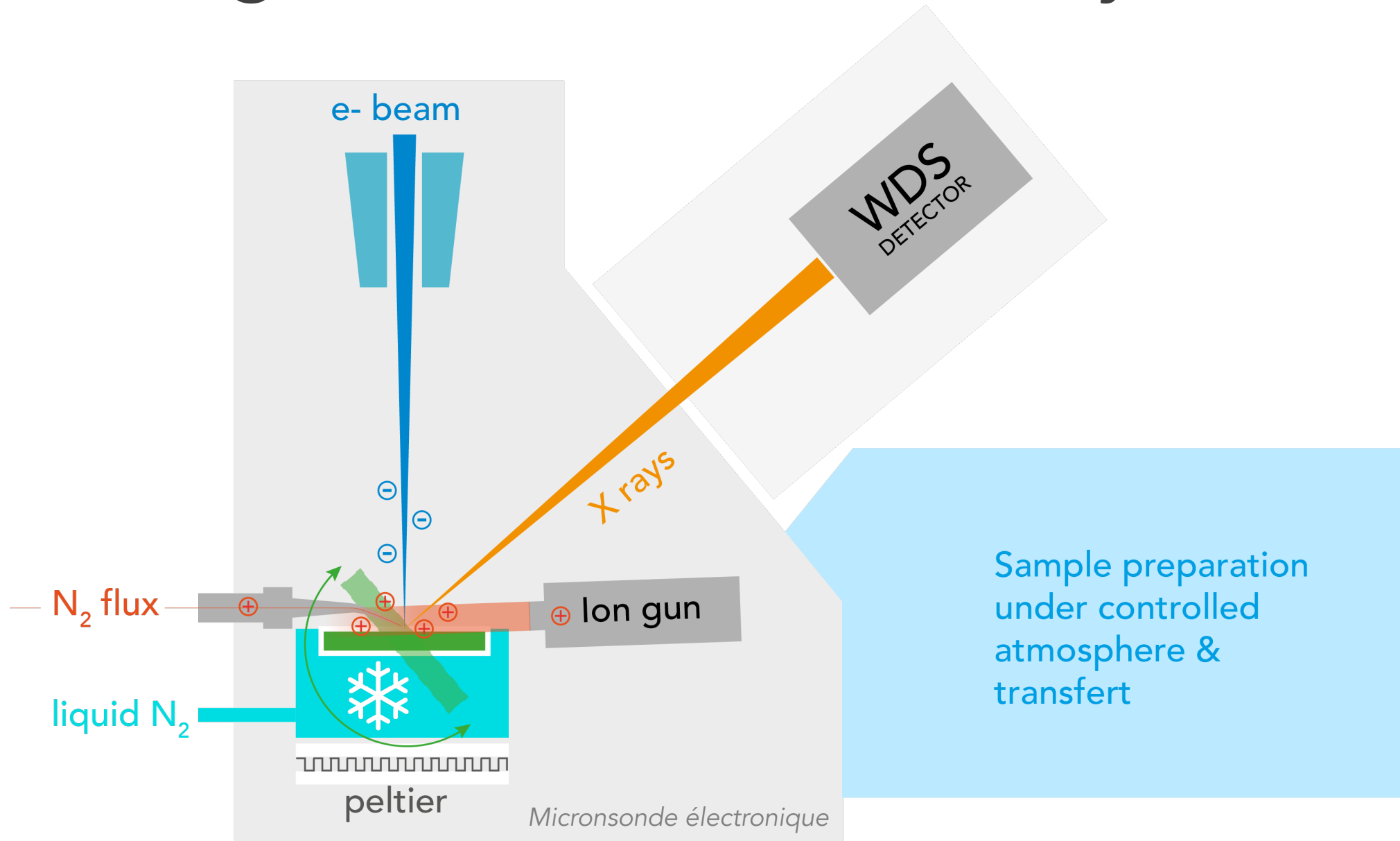


Efficiency comparison with Chandra gratings



Modélisation en cours  
d'un CAT à pas variable  
pour compenser la  
divergence des rayons X

# Charges (e-), Tilt, Clean & Cryo (brrrrr)





*Article sur 'Focus Sciences' CNRS >*



**Bref...**

**la microsonde électronique n'est pas morte !**