XLab Frascati
an X-ray facility

Dariush Hampai

MUSE - General Meeting

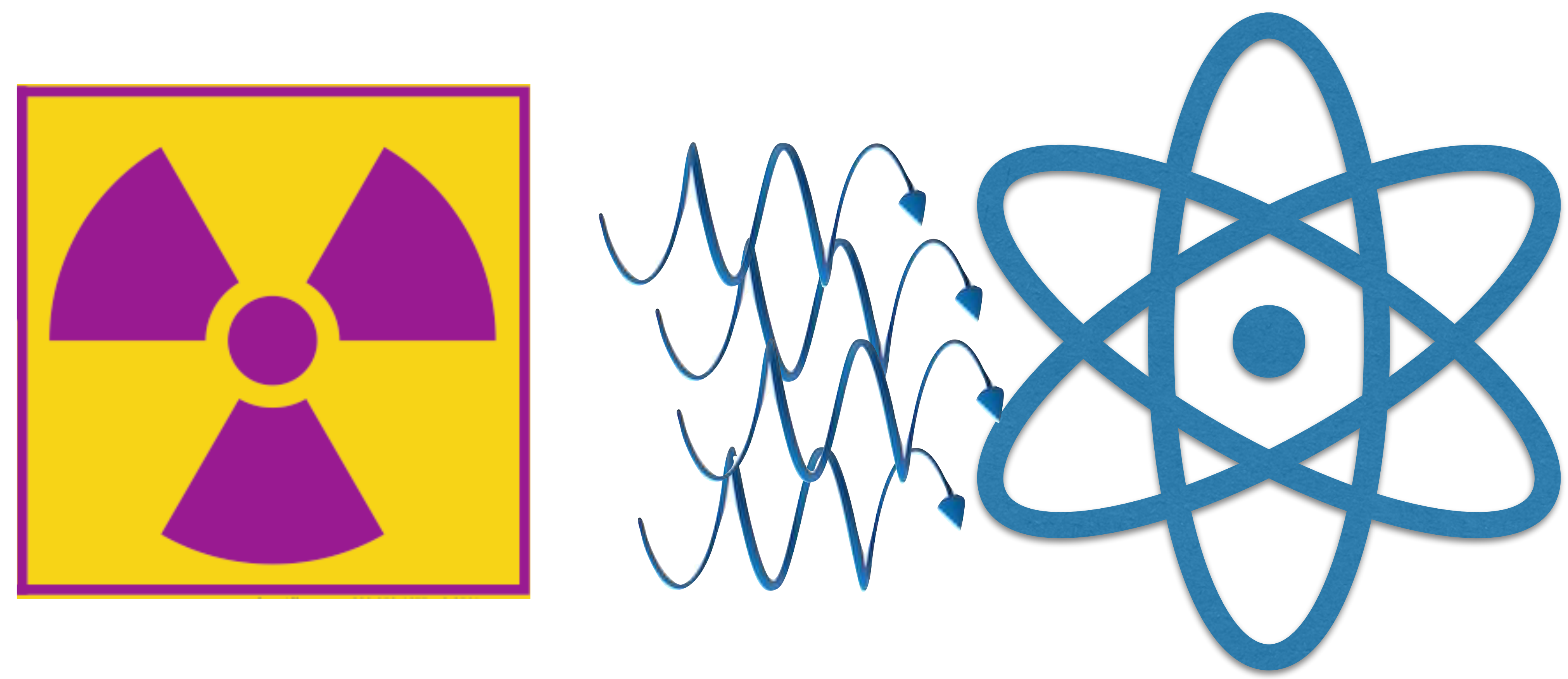
Frascati - 25 October 2019

INFN LNF

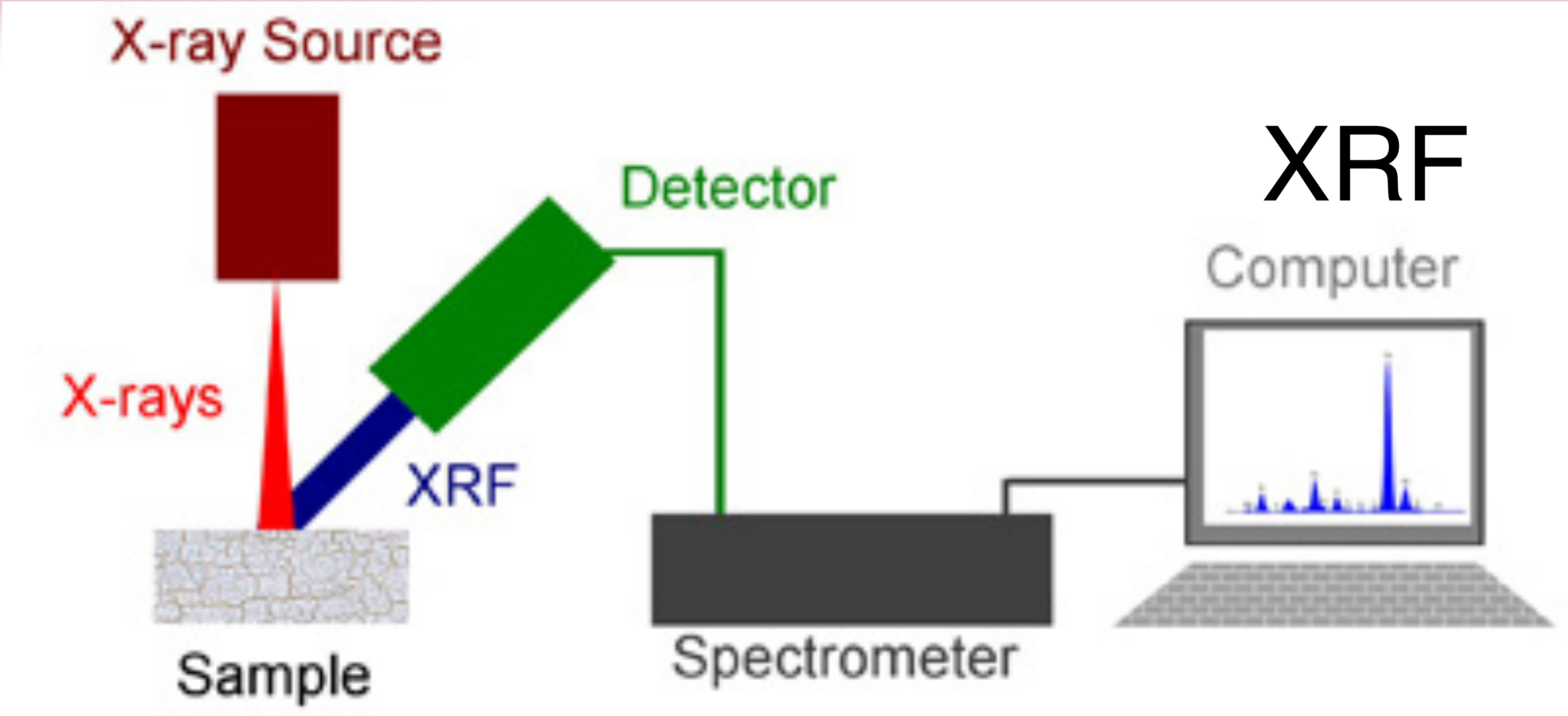
Laboratori Nazionali di Frascati
Xlab-Frascati

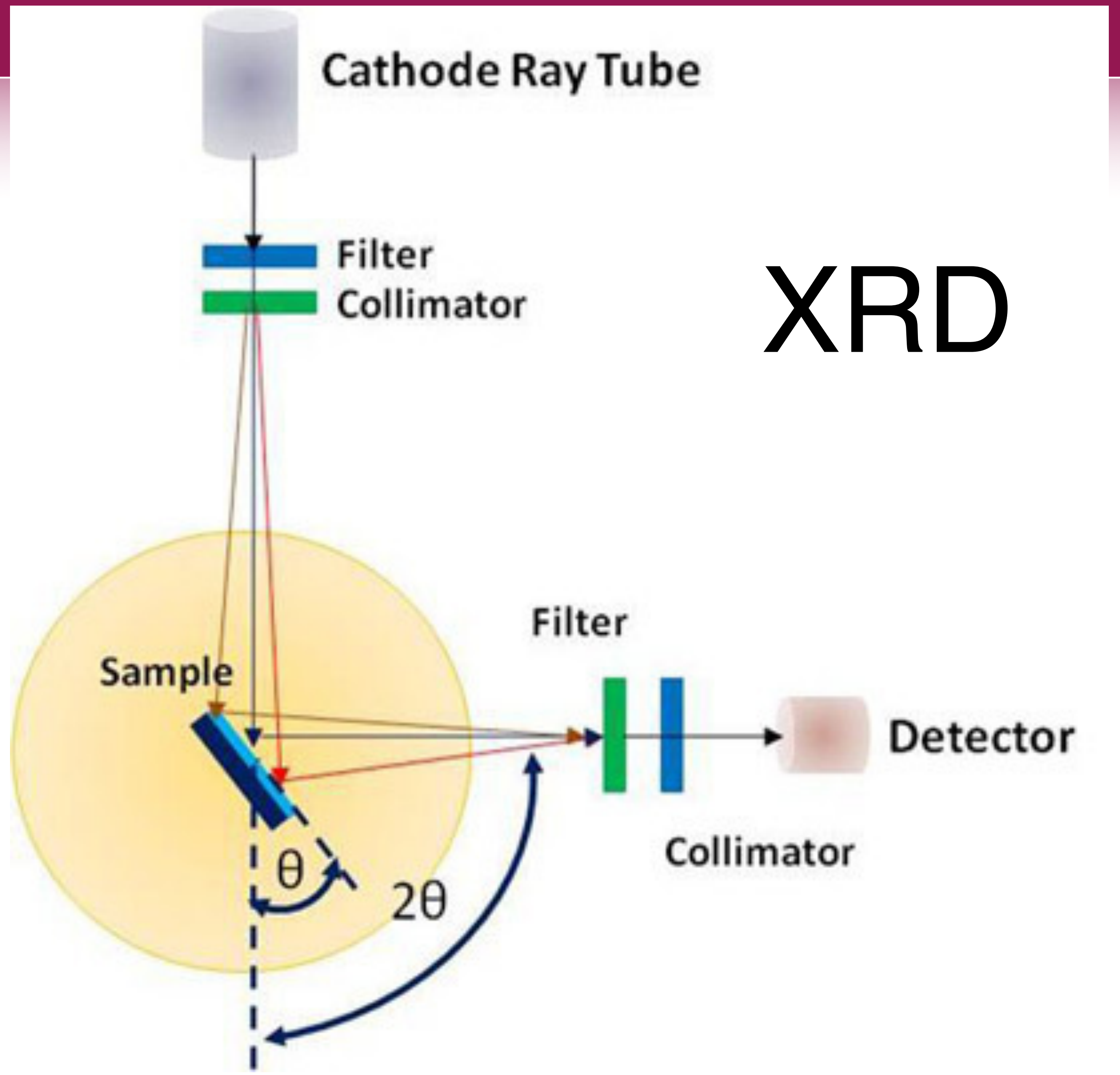
XChannel
x-ray technologies

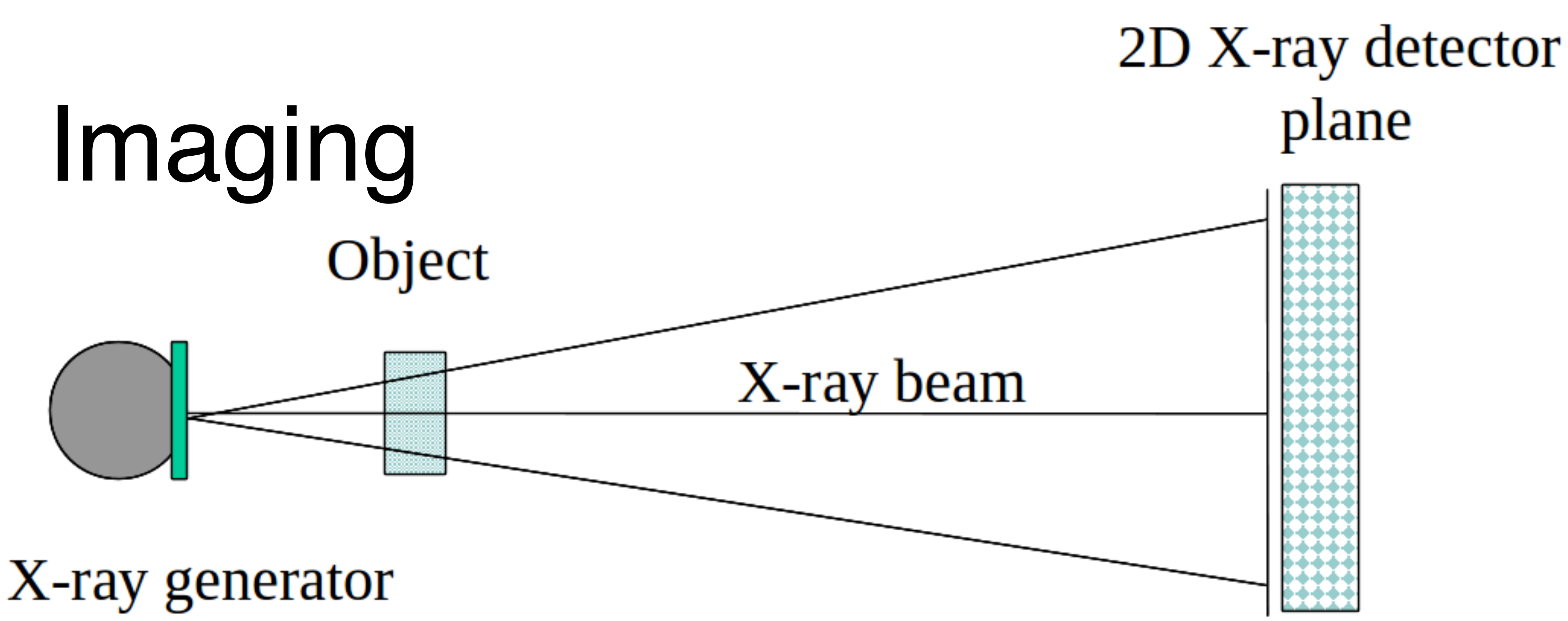
an X-ray experiment sketch



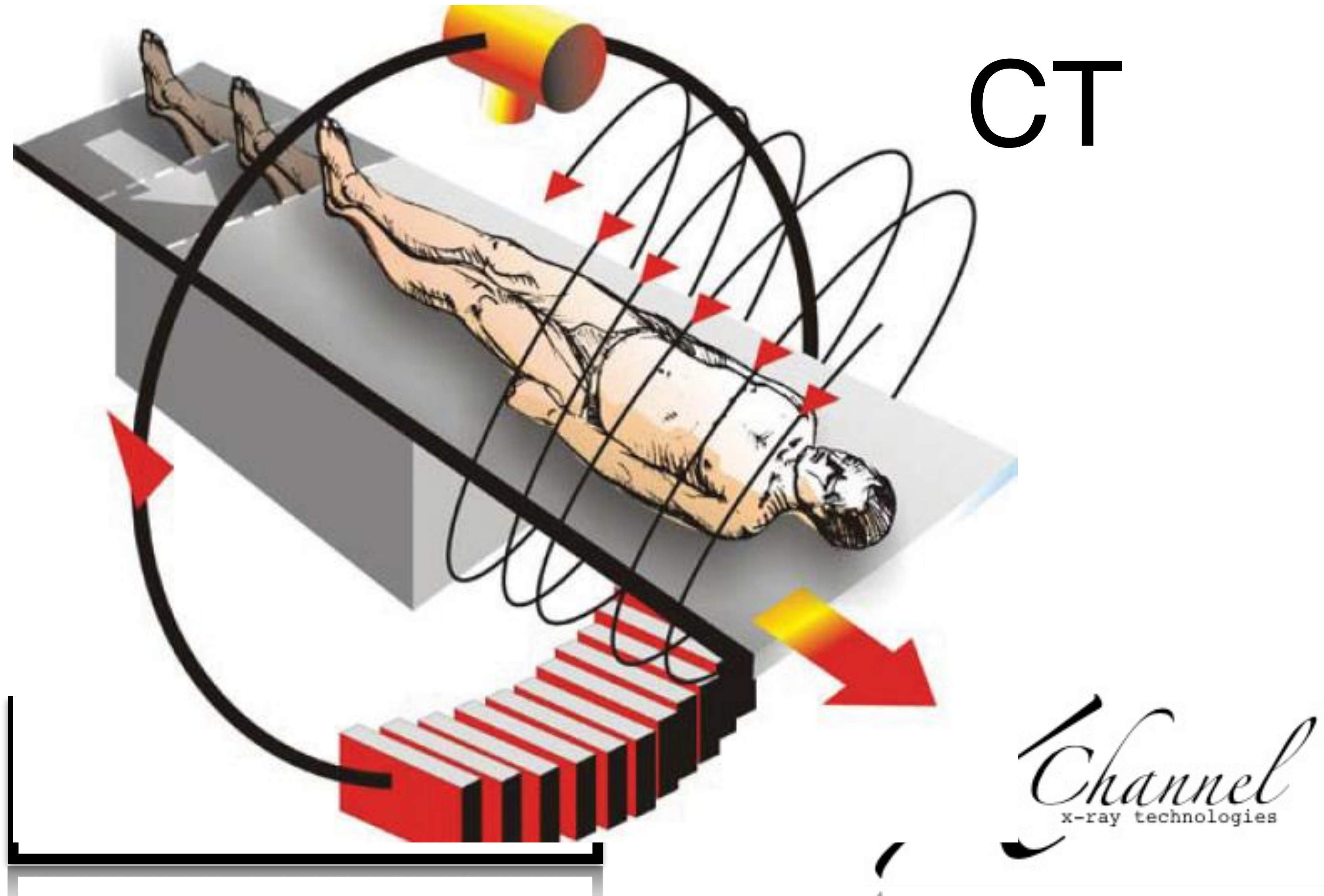
“Classical” X-ray techniques







Object is Magnified



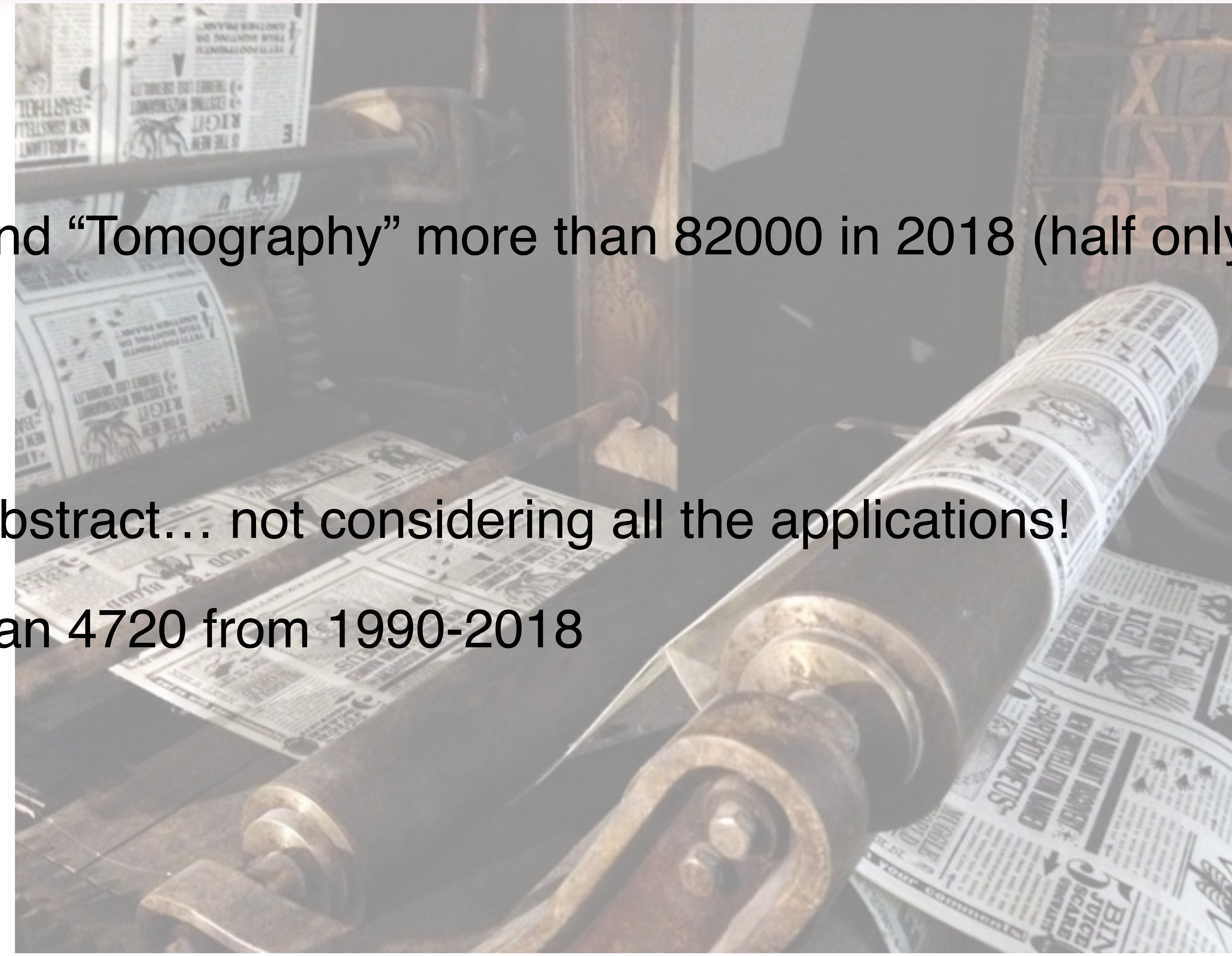
Importance of X-rays

Bibliography trace

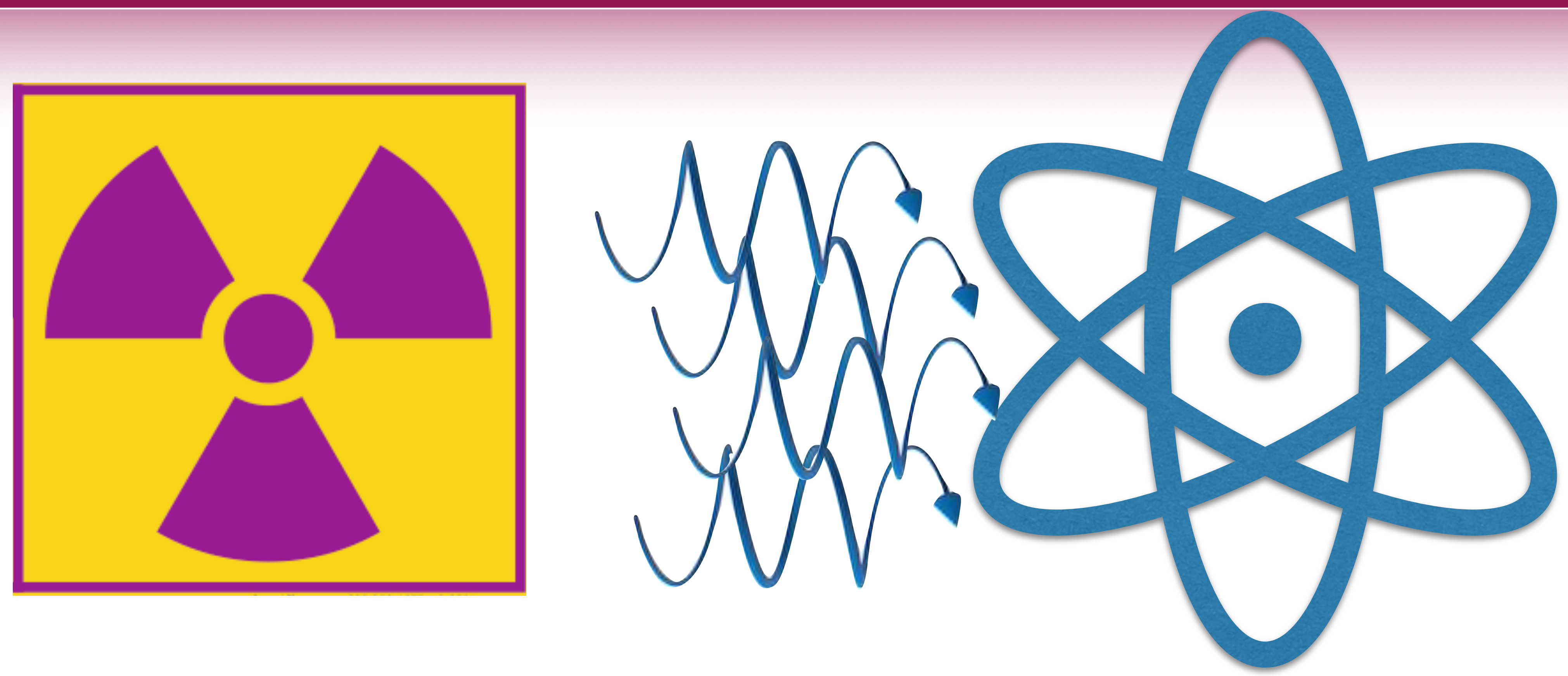
- word “XRF”, “XRD” and “Tomography” more than 82000 in 2018 (half only for Tomography)

- only these words in abstract… not considering all the applications!

- Polycapillary more than 4720 from 1990-2018



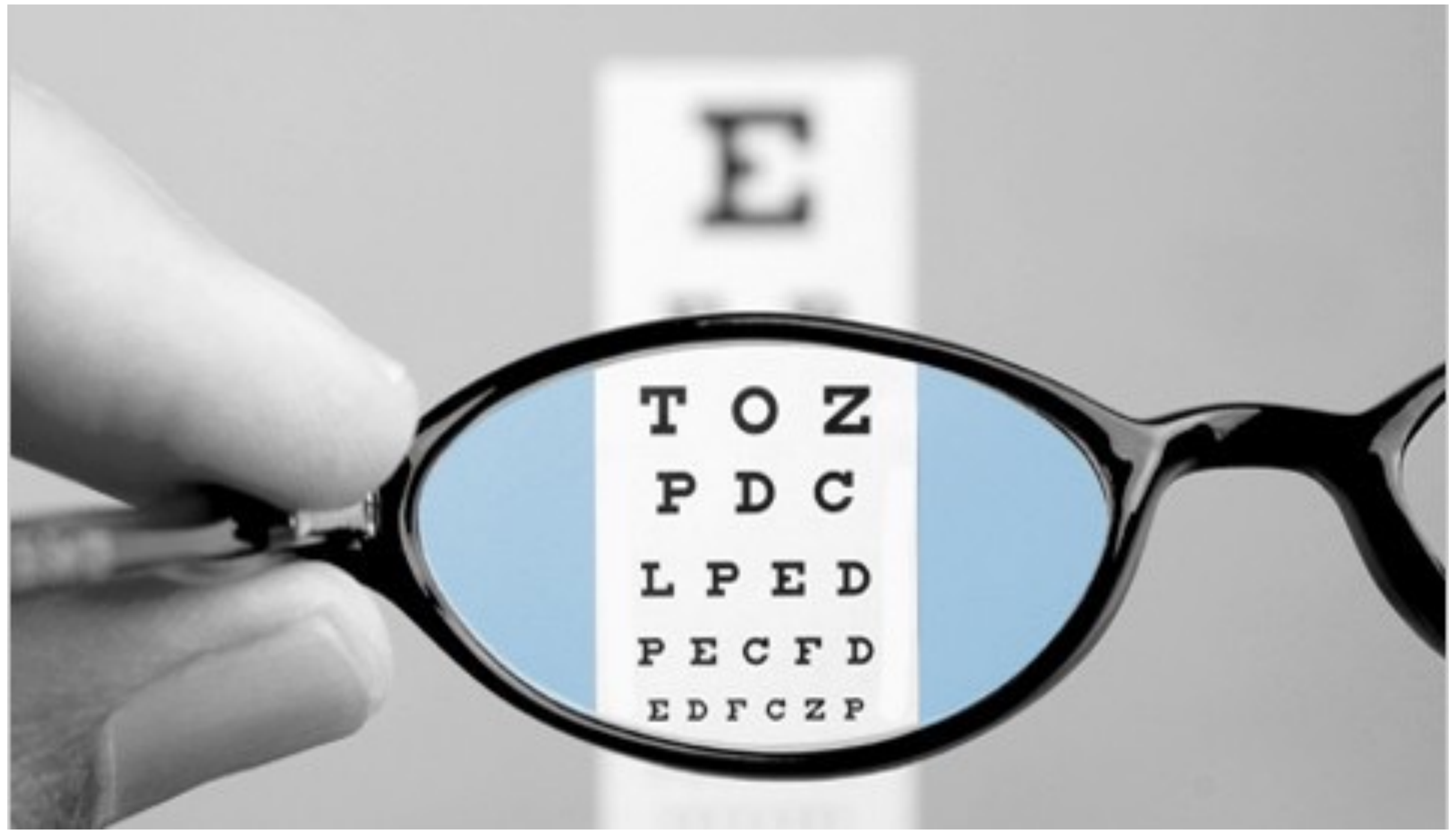
an X-ray experiment sketch



black box = optical device

Optics

- The study of light and the interaction of light and matter is called “Optics”
- Usually for Optics we intend the visible light and all the devices correlated: lens (as glass, telescopes, … - refractive optics), mirrors (reflective optics)



few words about Imaging

a very bad picture...

the problem should be:

1) conditions (luminosity, humidity, ecc..);

2) the camera;

3) the objective;

4) the photographer....

5) etc...

few words about Imaging

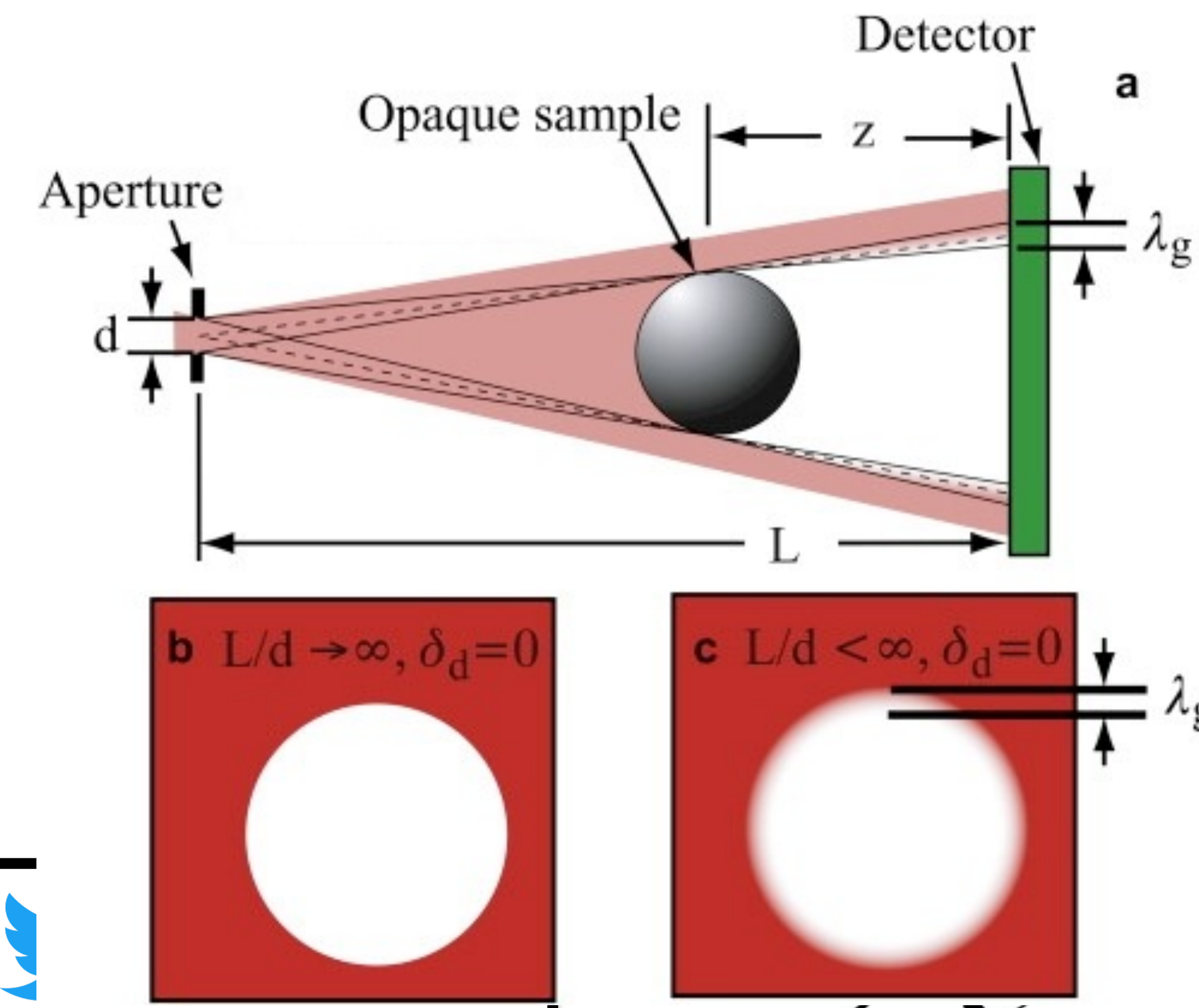
The Blurring effect is caused by many effects, principally by:

1) the source dimension

2) the source aperture

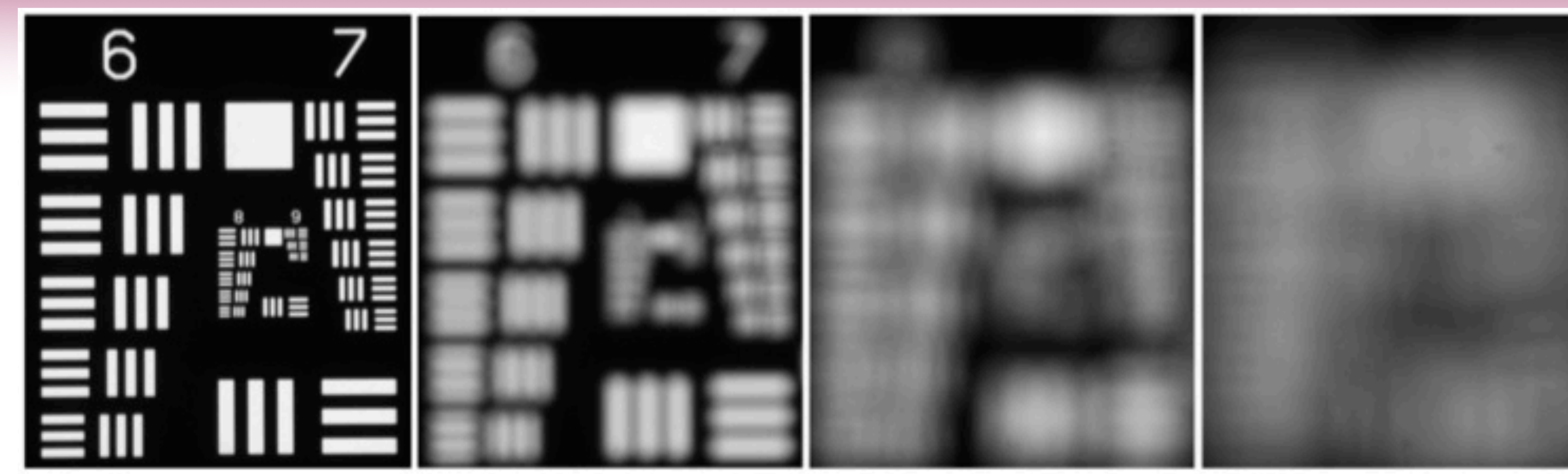
3) the object-detector distance

Moreover, for X-ray beams the optics are not so simple...

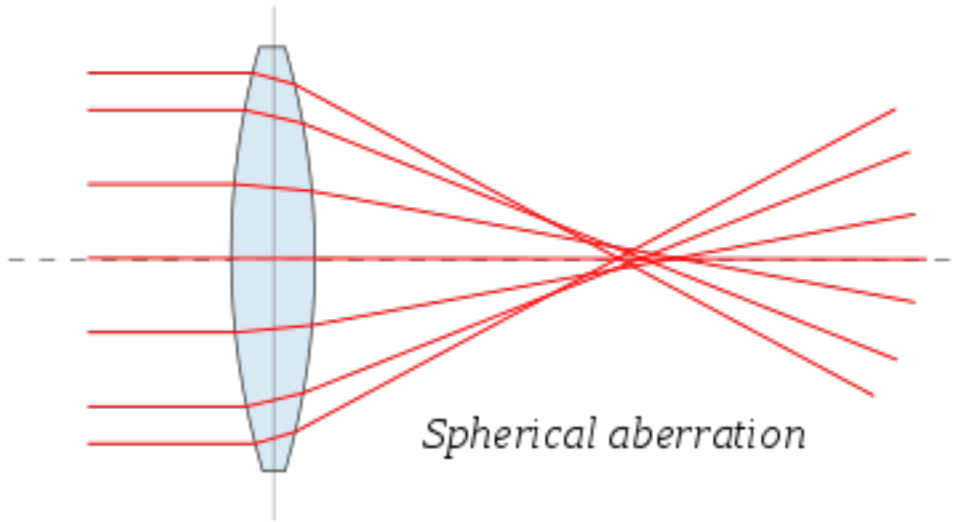


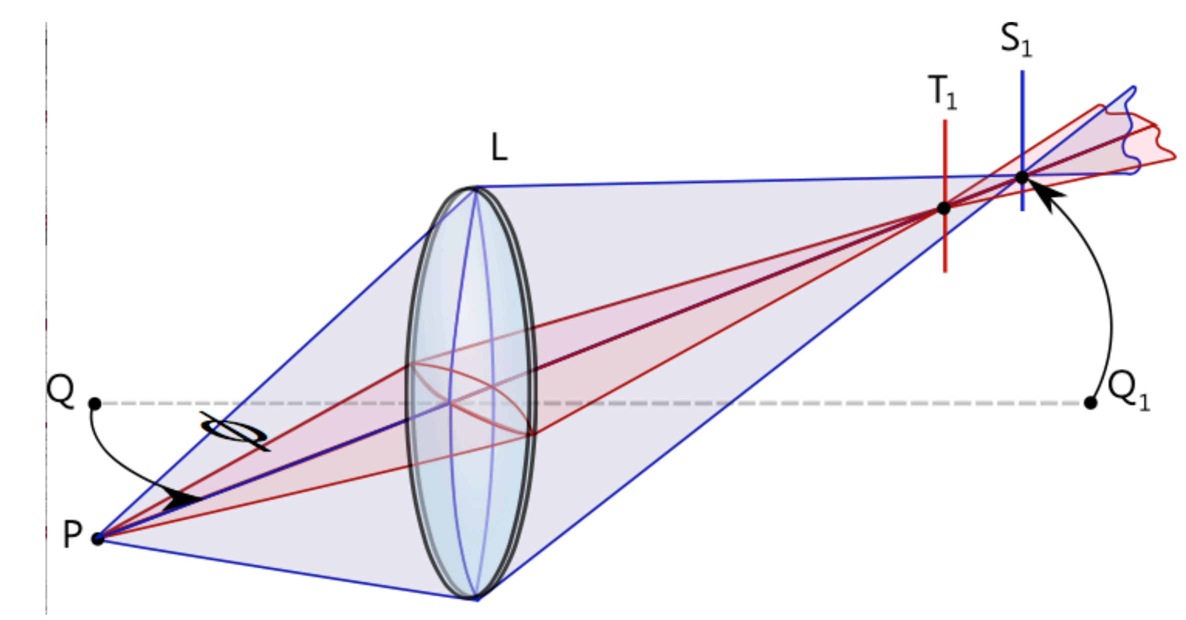
Characteristics of an optical device

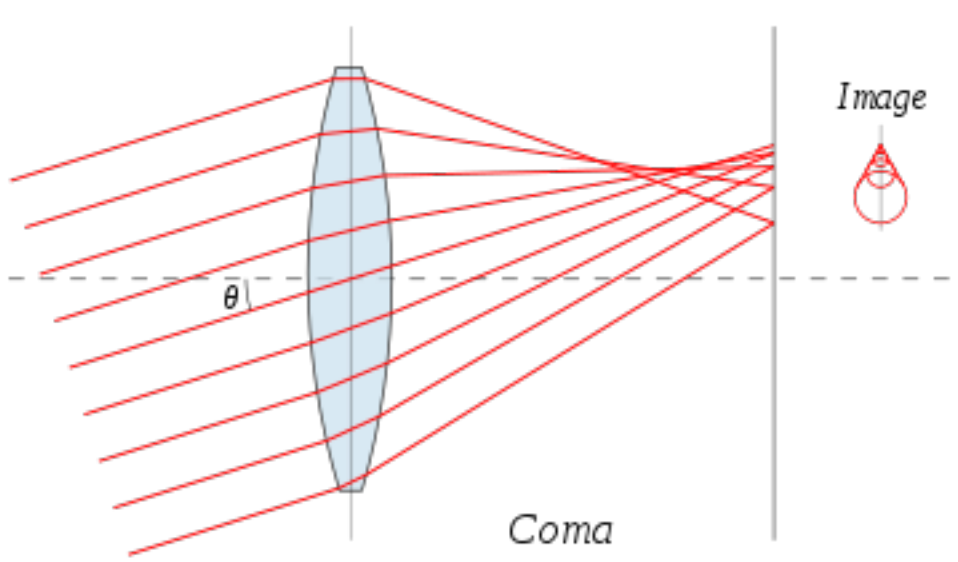
- Resolution
- Magnification

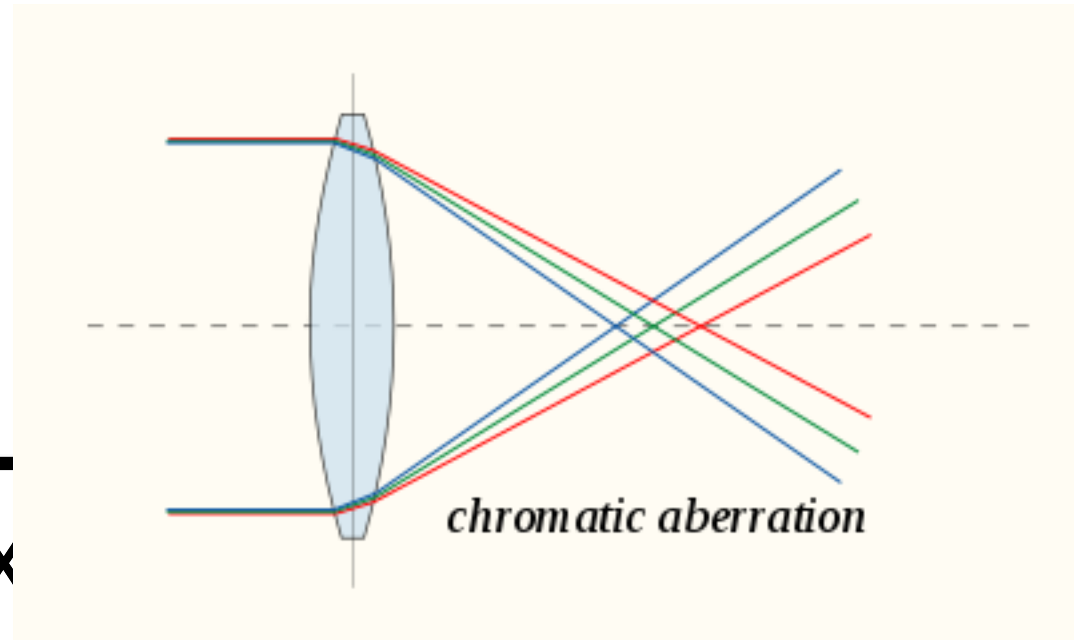


- Aberrations
  - Spherical aberration
  - Astigmatism
  - Coma
  - Chromatic aberration

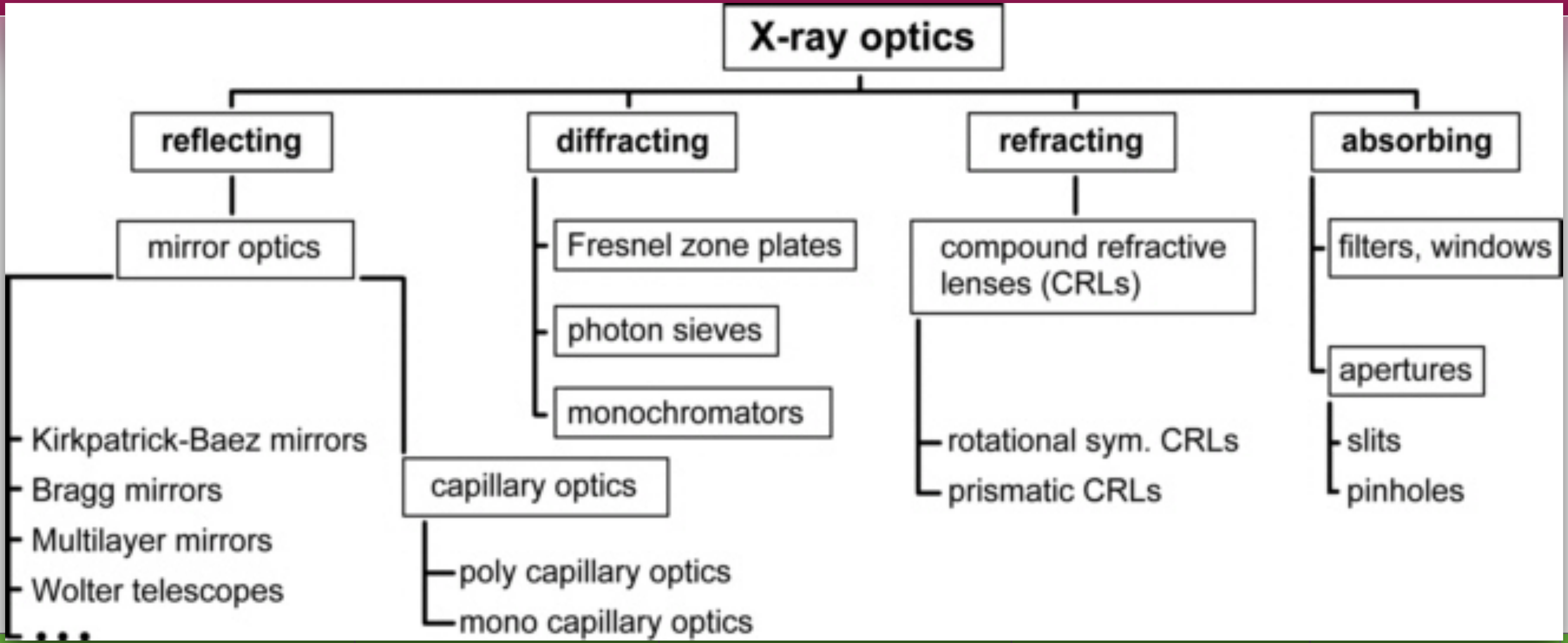






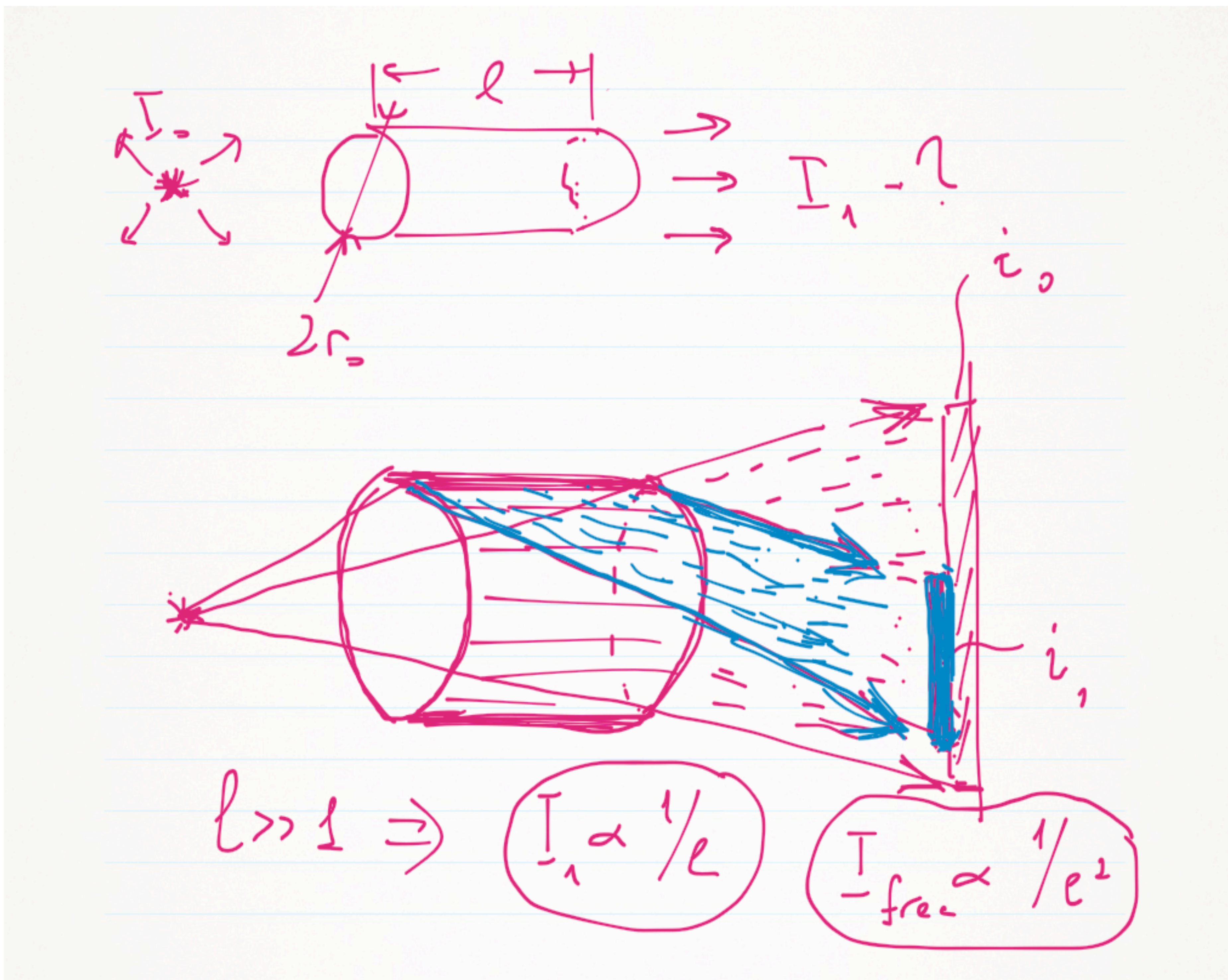


X-ray Optics



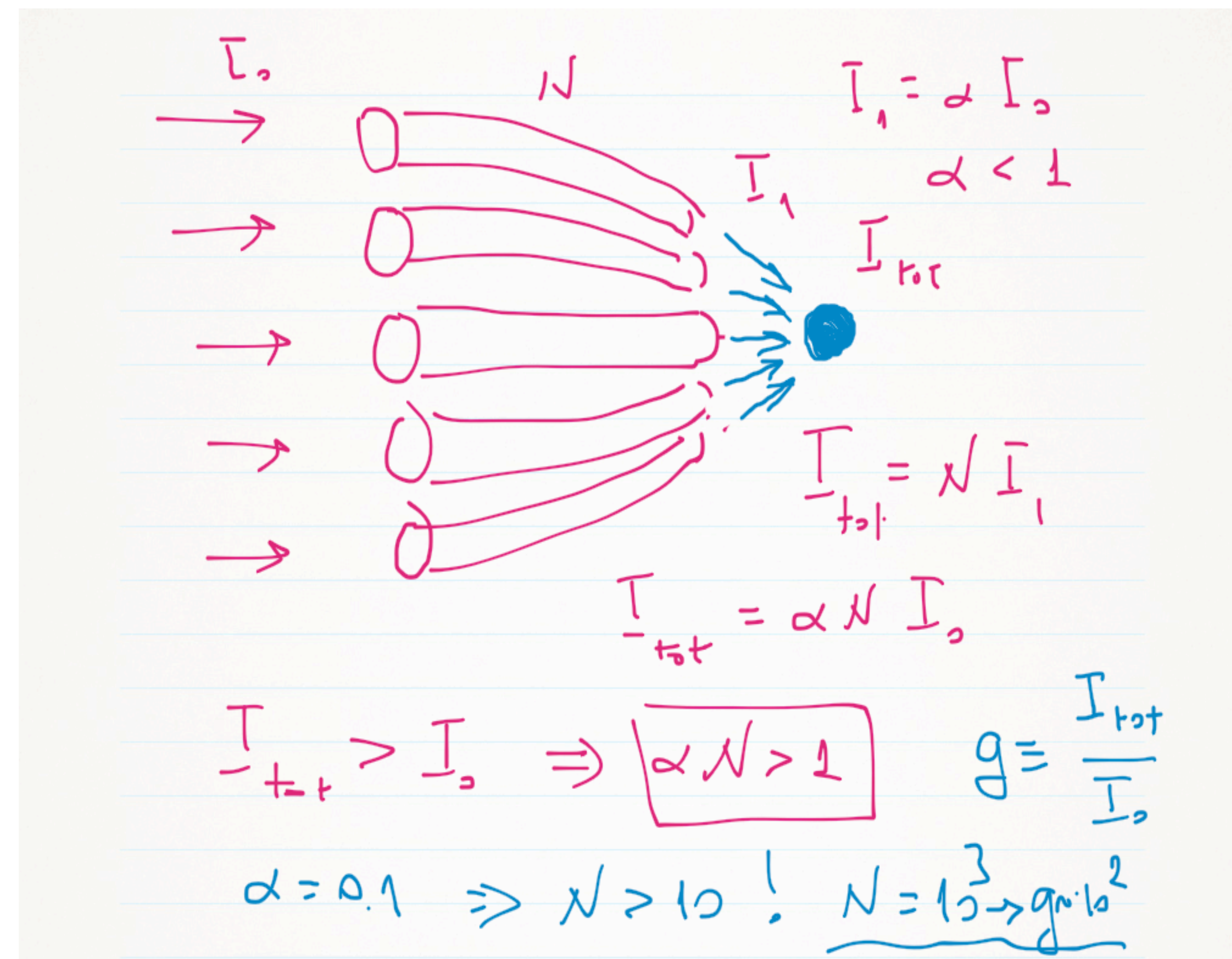
optics type	photon energy range	working distance	min. focal spot diameter	imaging or illumination	achromatic behaviour
mirror optics multi layer / crystal mirror optics	0 - 20 keV 0 - 100 keV	>0.1 m >0.1 m	0.03 µm 0.05 µm	imaging imaging	yes no
polycapillary optics mono capillary optics	0 - 30 keV 0 - 30 keV	0.002 - 0.2 m 0 - 0.2 m	1 µm <1 µm	illumination imaging	yes yes
zone plates	0 - 20 keV	0.001 - 0.1 m	0.015 µm	imaging	no
compound refractive lenses	5 - 1000 keV	>0 m	0.1 µm	imaging	no
coded mask telescopes	all	-	(10 µm)	imaging	yes

@ 1984: first discussion on polyCO at the Minsk's School on charged particles interaction in crystals



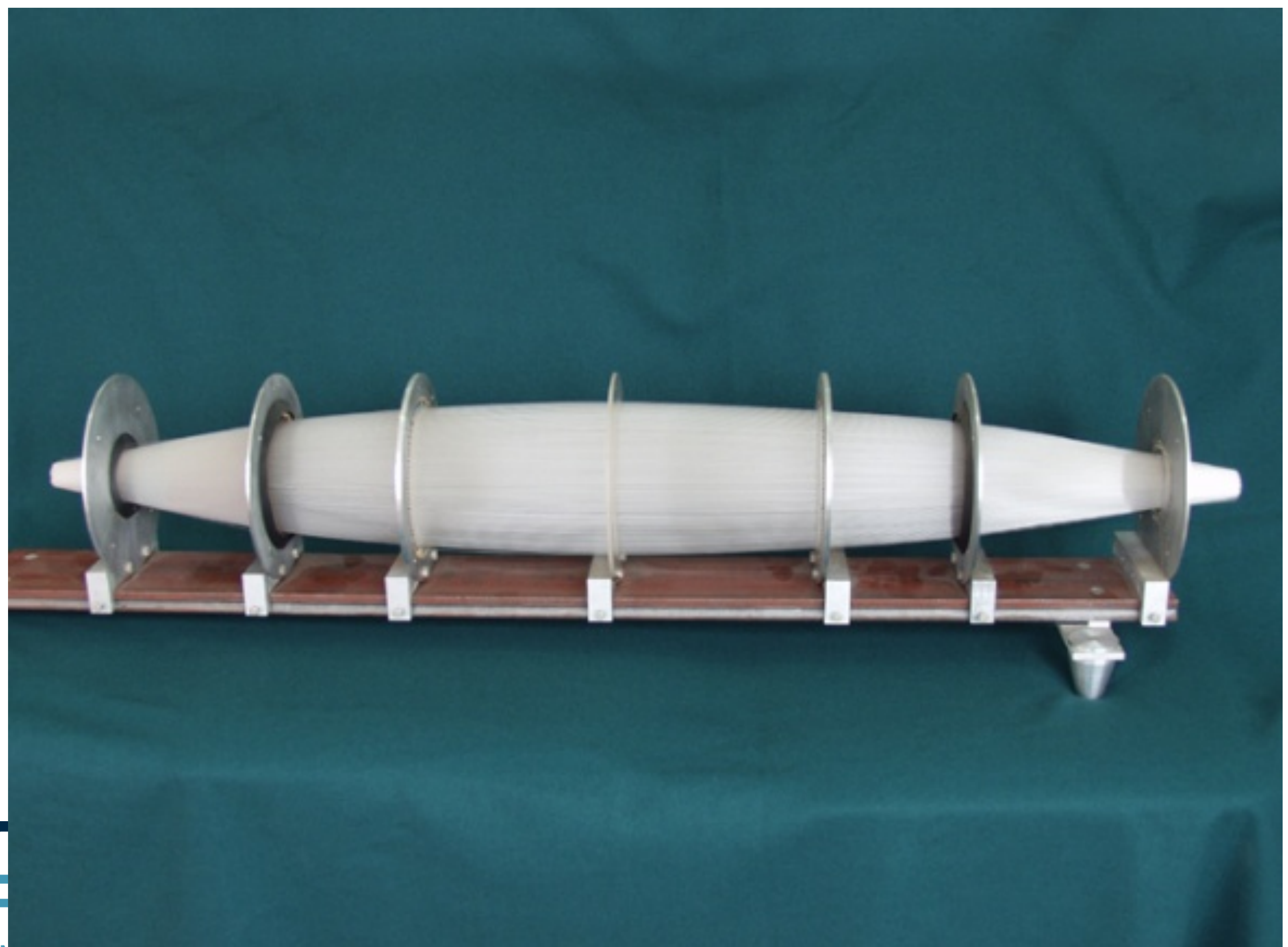
Kumakhov's task:

a night work for the feasibility of mono/ multichannel optics

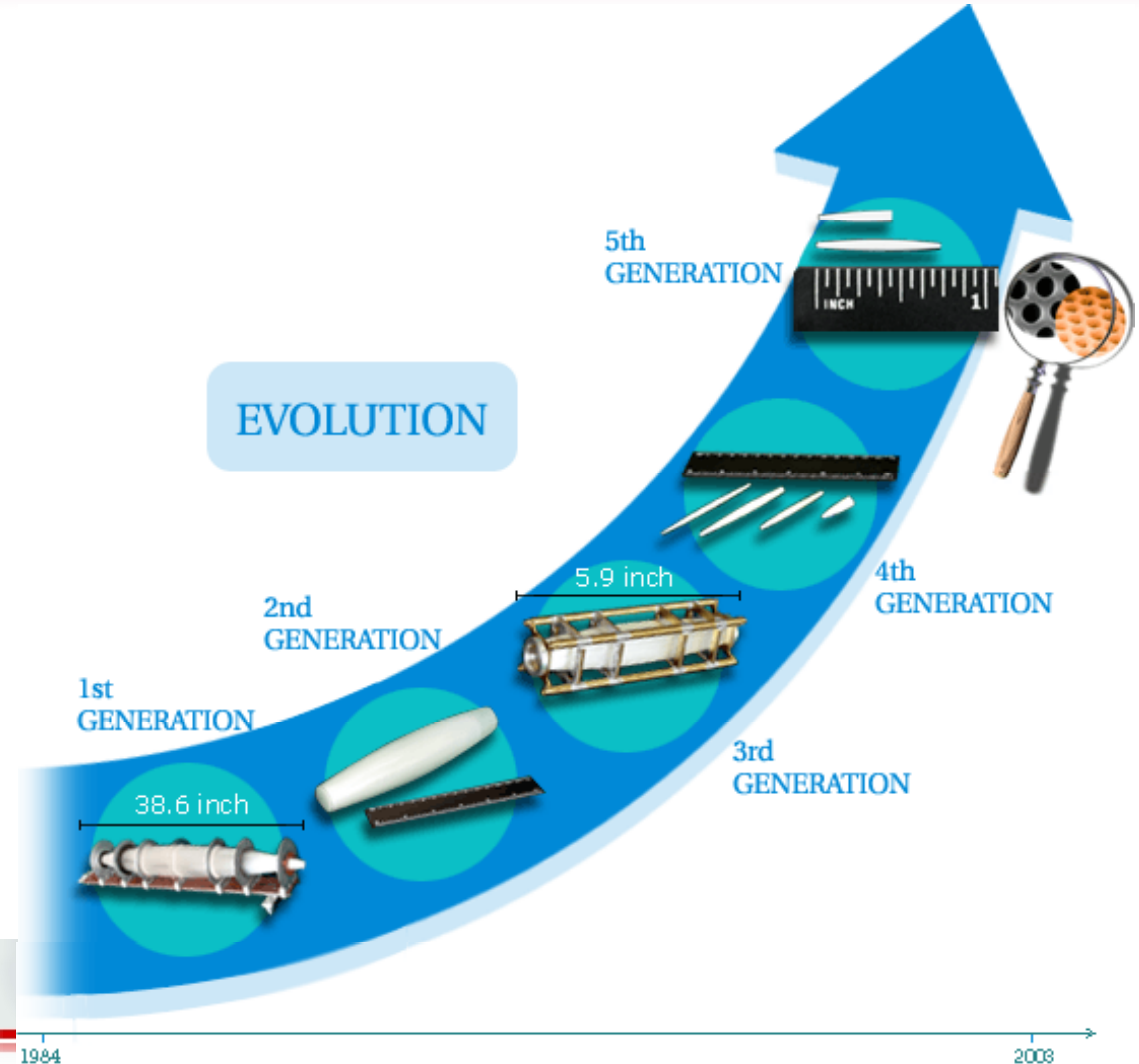


…and after 2 years, the first lens (about 1986)

Prof. Muradin A. Kumakhov
Institute for Roentgen Optics - Mosca



and now… where are we?



Principal characteristics of PolyCO

$$G \equiv \left(\frac{w_p}{w_0}\right)_L = \left(\frac{L\Delta\varphi_p}{\Delta f_p}\right)^2 T_p$$

$$\theta_{max} \approx 2\left(\frac{r_0}{r_{curv}}\right)^{1/2}$$

$$\theta_{max} \leqslant \theta_c\ , \quad \zeta \equiv \frac{r_{curv}\theta_c^2}{4r_0} \geqslant 1$$

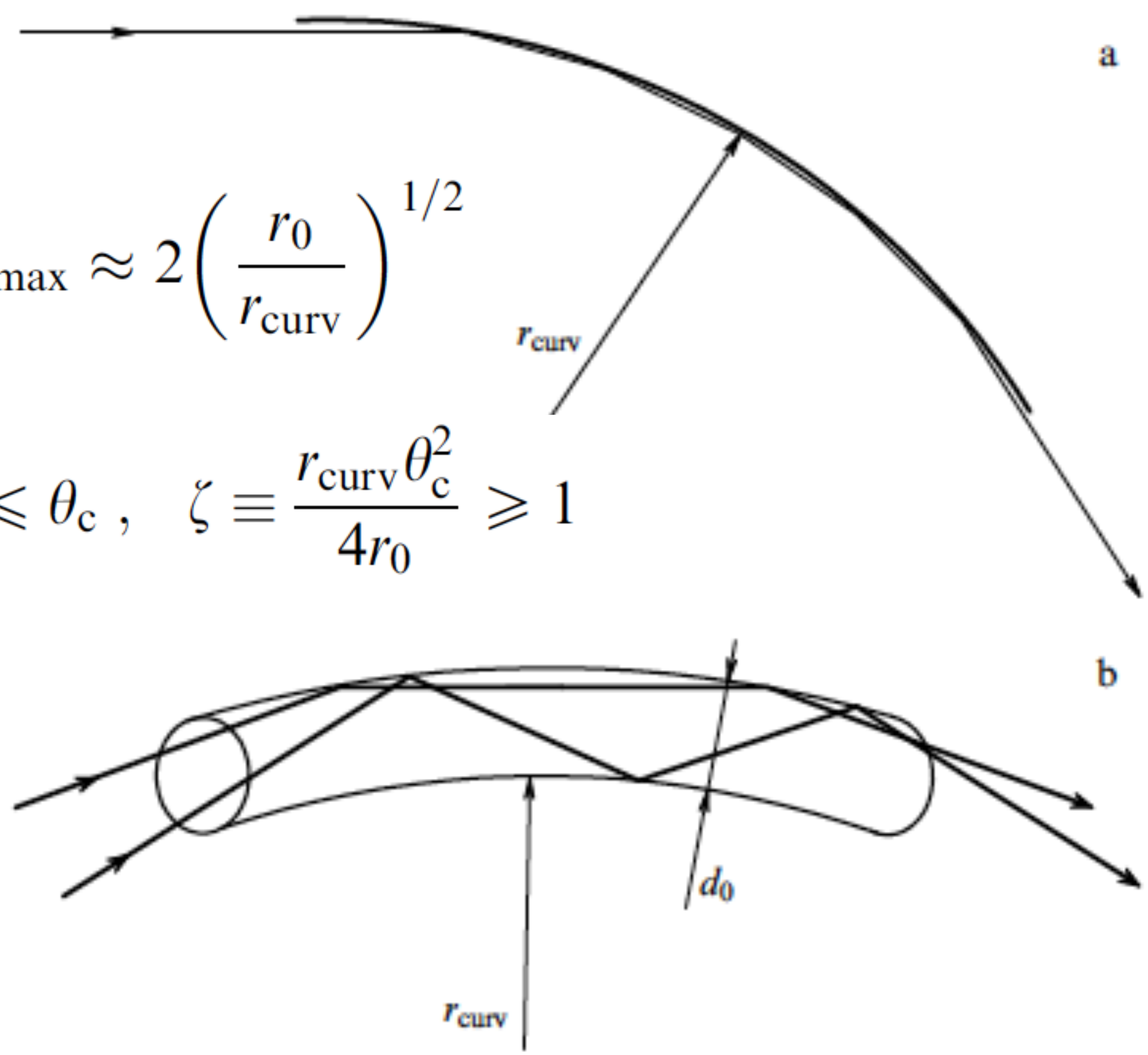


Figure 1. The bending of a beam by a curved surface with a curvature radius r_{curv} (a) and a bent capillary with a diameter d_0 and a curvature radius r_{curv} (b).

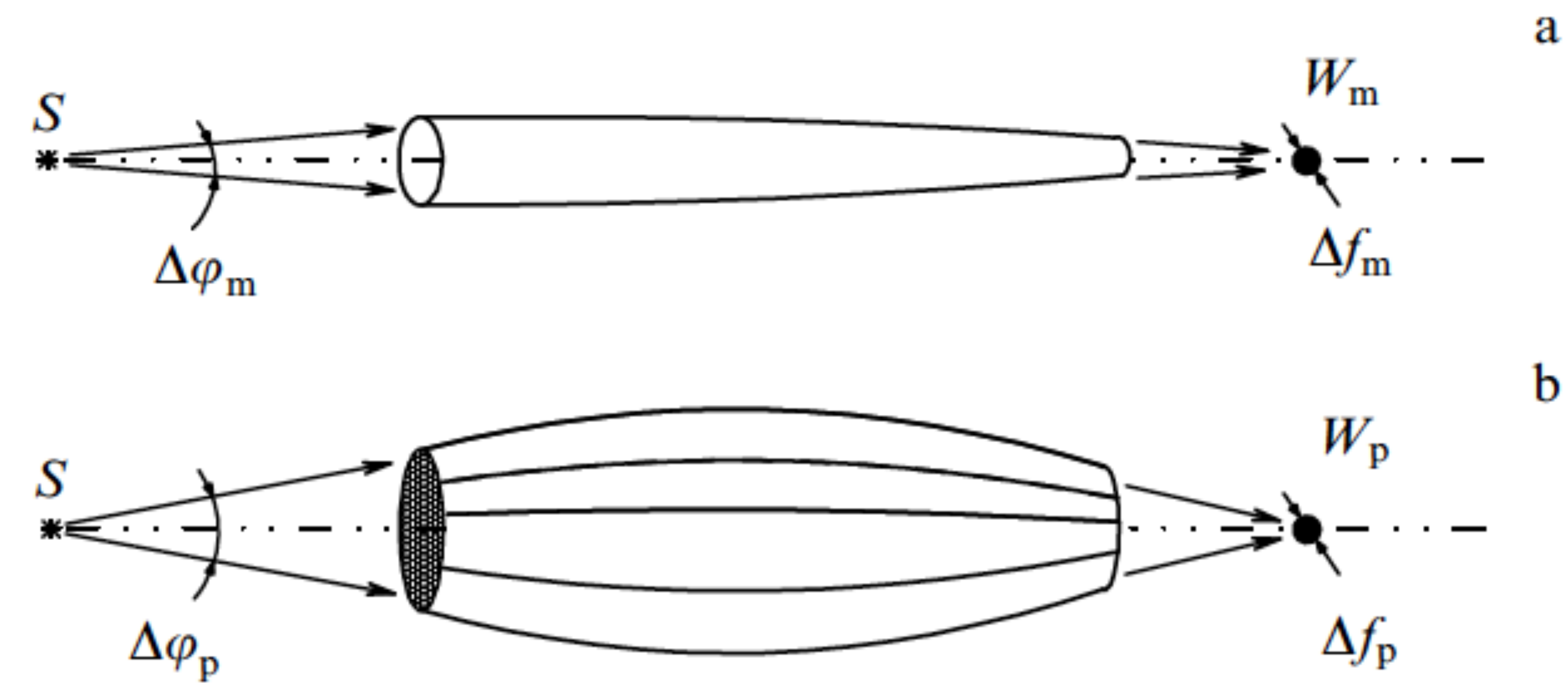


Figure 2. Focusing X-rays by (a) a monocapillary and (b) a system of capillaries (S is the source of X-rays, and Δf is the size of the focal spot).

S.B. Dabagov, Phys. Usp. 46(10), 1053-1075 (2003)

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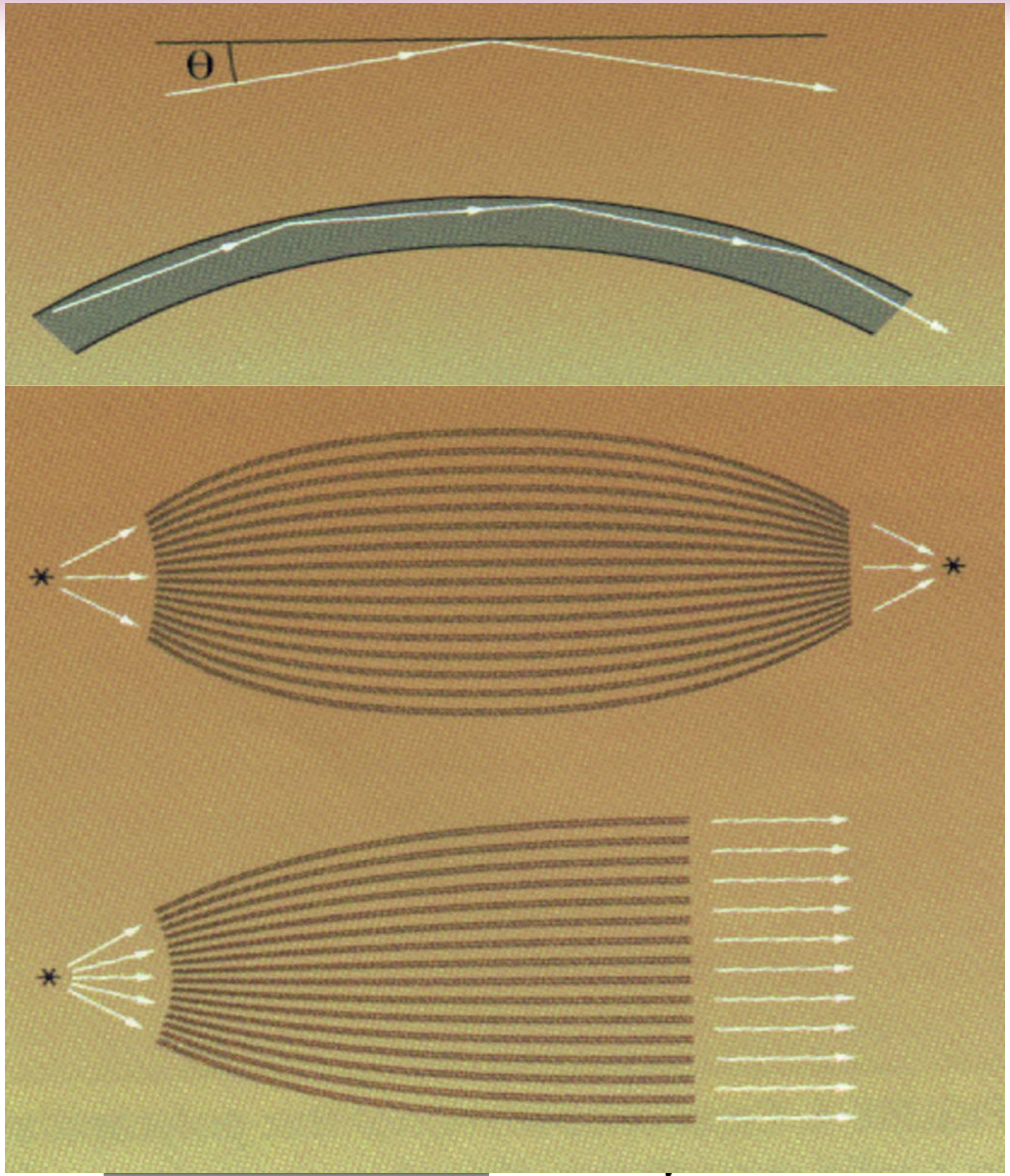
XChannel x-ray technologies

Reflective Optics - (mono/poly) Capillary Optics

- beam bending through large angles
- divergent beam to convergent one
- divergent to quasiparallel & vv
- Number of applications
  - scientific instrumentation (XRF, XRD)
  - elemental/structural analysis
  - medicine (diagnostics, therapy)
  - astrophysics



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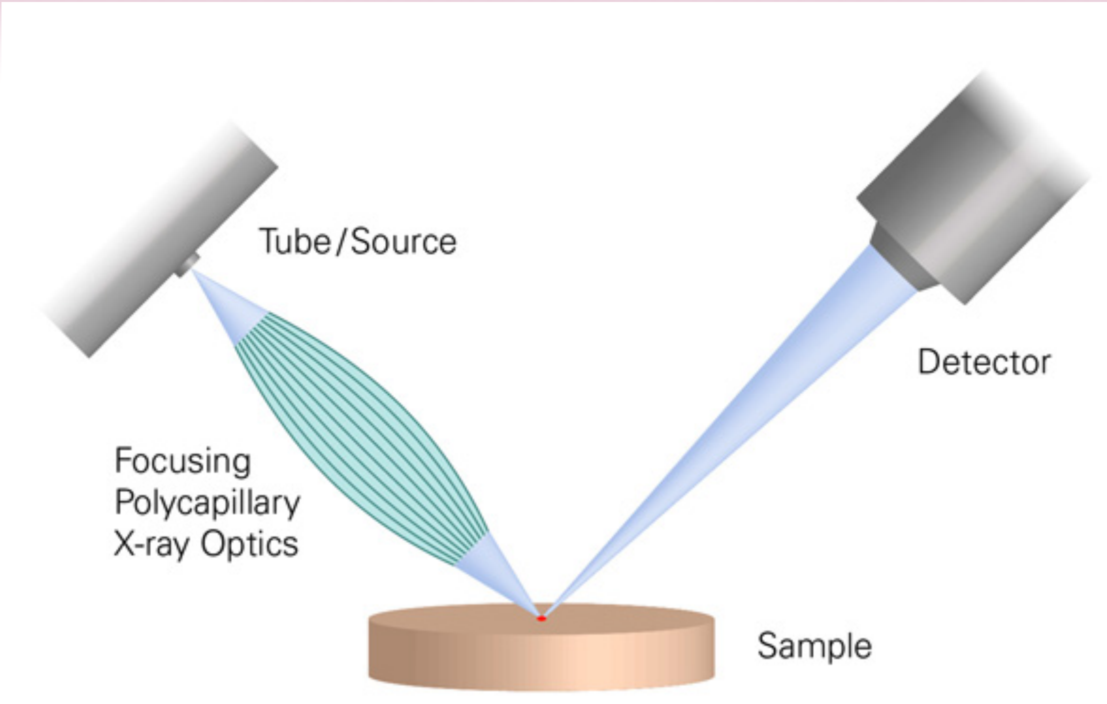
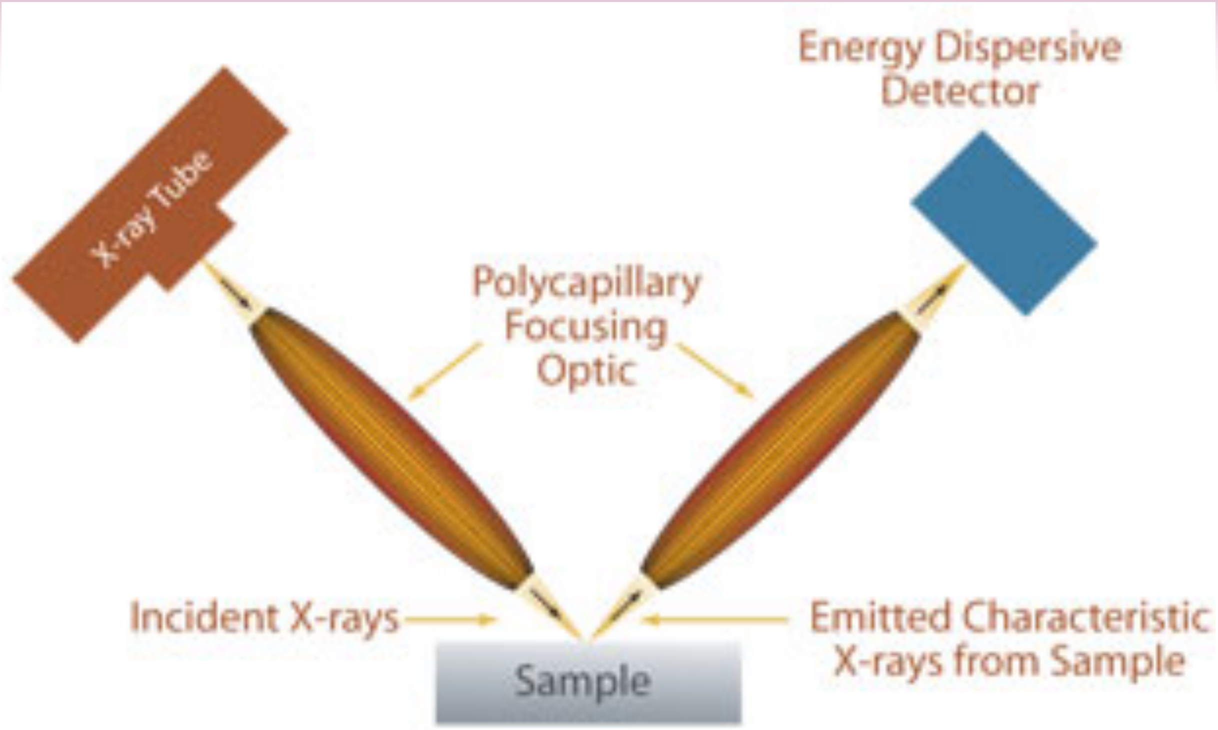
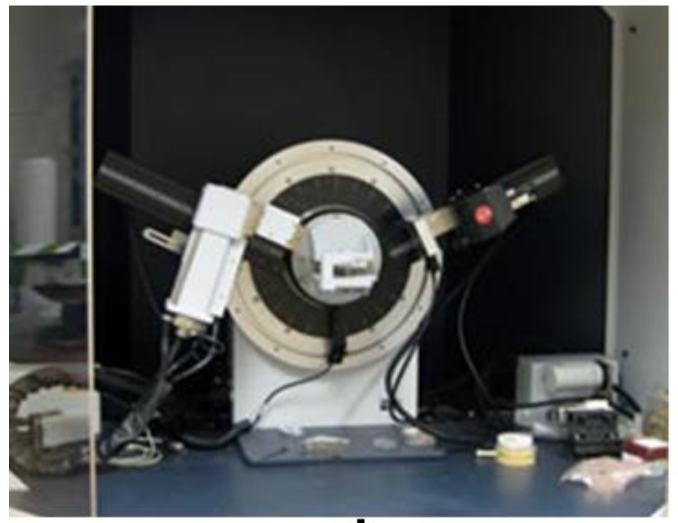
“Non Conventional” X-ray techniques

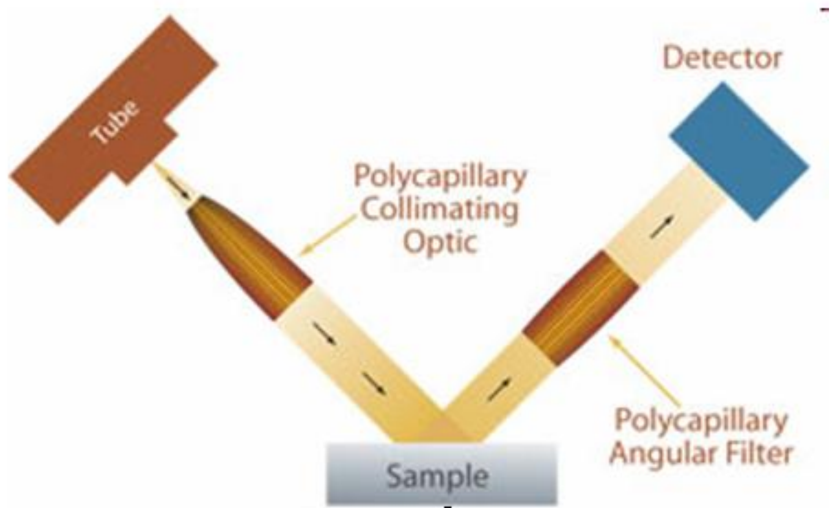
MUSE - GM

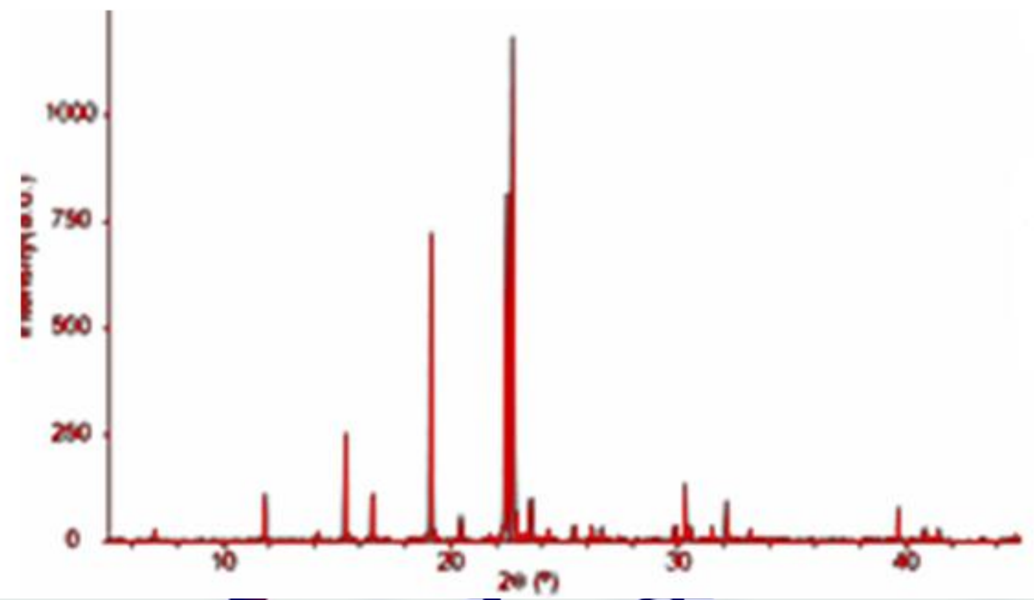


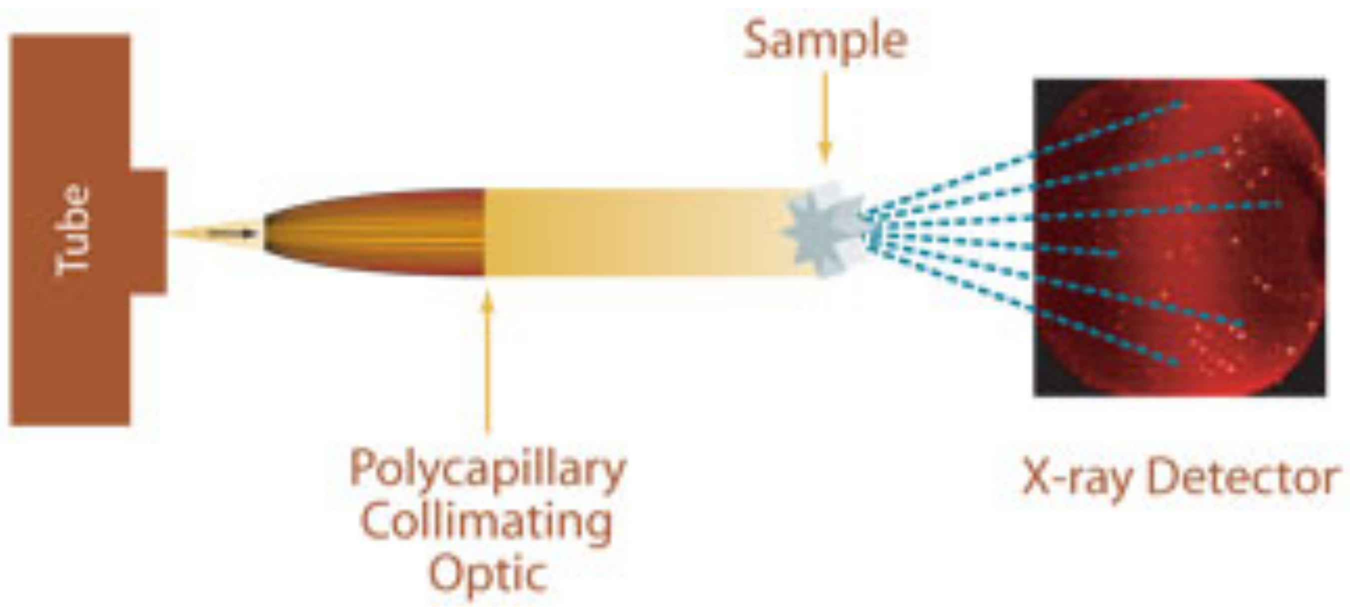


XRF

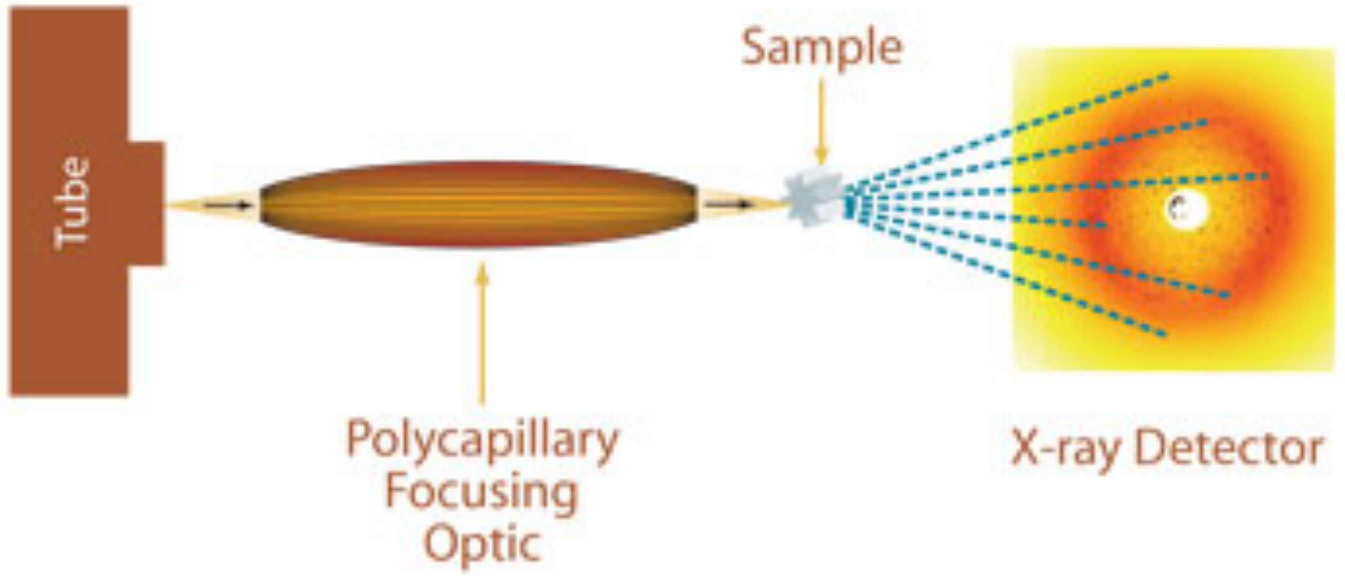








XRD



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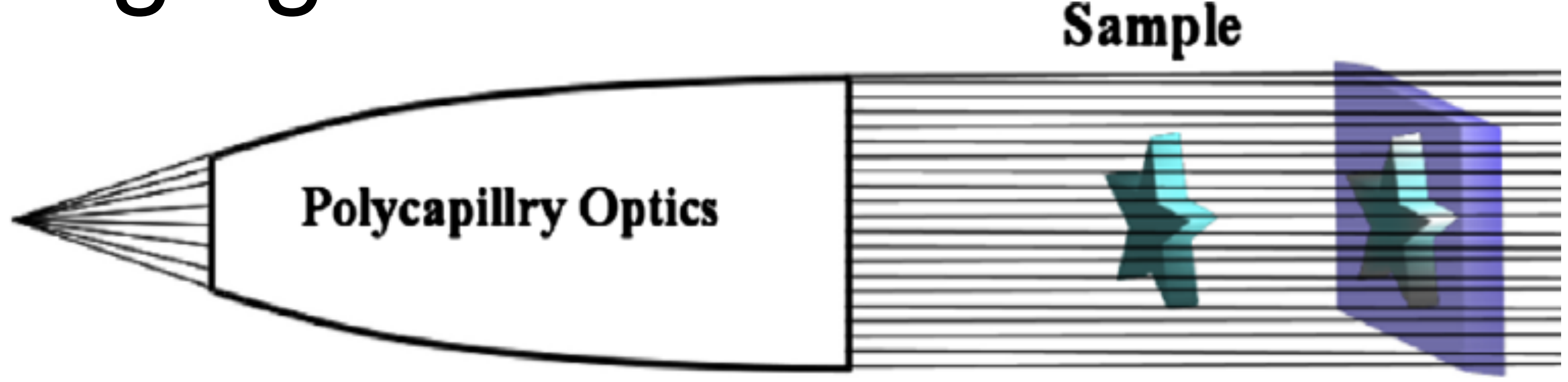
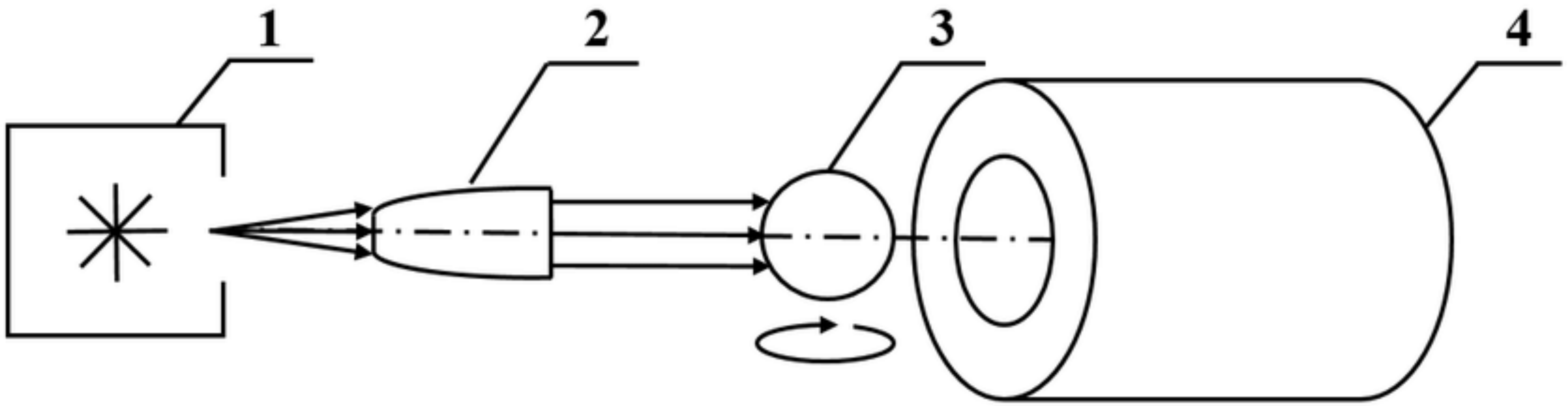
XChannel x-ray technologies

"Non Conventional" X-ray techniques

Imaging



CT



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Polycapillary Optics in the world

- Russia -> studies for novel sources-detectors, diffraction, Imaging and Tomography
- Japan -> studies for μXRF, μXRD, μCT for environmental and archeological applications
- German -> studies for μXRF, μXRD, μCT multipurpose applications
- Portugal -> studies for μXRF, μXRD(principally) archeological applications
- Austria -> studies for μXRF, μXRD, μCT multipurpose applications
- Italy -> (except XlabF) studies for μXRF, μXRD multipurpose applications
- Denmark -> studies for μXRF, μXRD, μCT multipurpose applications
- Belgium -> studies for μXRF, μXRD, μCT multipurpose applications. Theoretical Studies (ray tracing, wave approximation)
- China -> studies for μXRF, μXRD, μCT multipurpose applications. Theoretical Studies (ray tracing, wave approximation)

I apologize if I forgot someone…

MUSE - GM

XENA @ XlabF

- Facility for general X-ray experiments
- HR Imaging - *μ*CT
- Novel Source/Optics/Detectors
- first experimental table… since 2005 @ Xlab

	XENA
Station	X-ray Elemental station for Non-destructive Analysis
Analysis	(1) High resolution imaging (2) µCT (3) X-ray optics characterization (4) Detector characterization (5) Novel sources
Resolution	(1) < 1 µm (with LiF detector) (2) <17 × 17 × 17 μm^3 (CT with spatial resolution CCD camera of 10.4 × 10.4 μm^2)

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XChannel x-ray technologies

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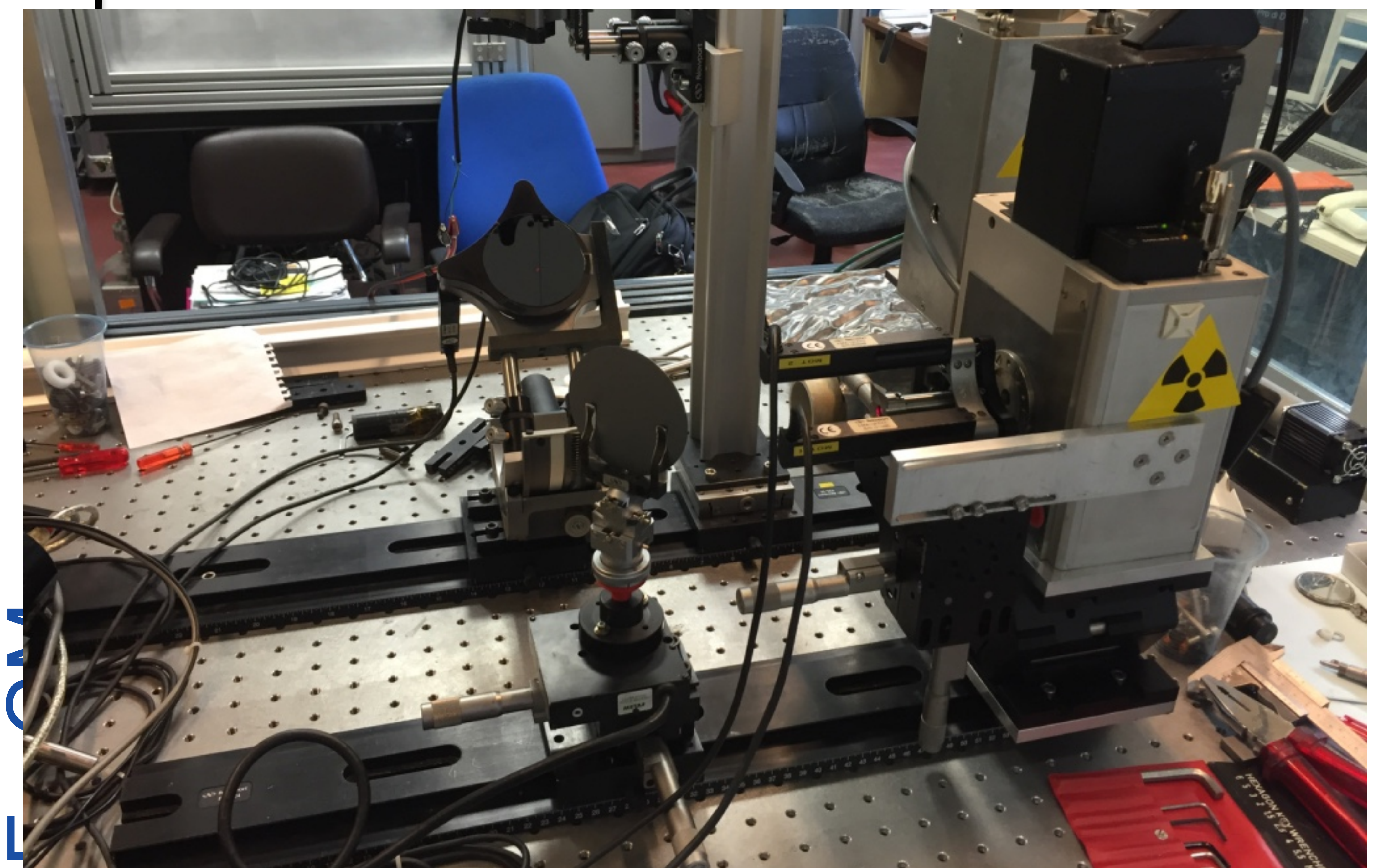
XENA @ XlabF



Nuclear Instruments and Methods in Physics Research B 355 (2015) 264–267

Contents lists available at ScienceDirect

Nuclear Instruments and Methods in Physics Research B

journal homepage: www.elsevier.com/locate/nimb

Advanced studies on the Polycapillary Optics use at XLab Frascati

D. Hampai [a,*], S.B. Dabagov [a,b,c], G. Cappuccio [a]

December 1, 2008 / Vol. 33, No. 23 / OPTICS LETTERS

Elemental mapping and microimaging by x-ray capillary optics

D. Hampai,[1,2,3,*] S. B. Dabagov,[2,4] G. Cappuccio,[2] A. Longoni,[5] T. Frizzi,[5] G. Cibin,[6] V. Guglielmotti,[3] and M. Sala[7]

epl A Letters Journal Exploring the Frontiers of Physics

December 2011

EPL, **96** (2011) 60010

doi: 10.1209/0295-5075/96/60010

www.epljournal.org

High-resolution X-ray imaging by polycapillary optics and lithium fluoride detectors combination

D. Hampai[1,2(a)], S. B. Dabagov[2,3], G. Della Ventura[4], F. Bellatreccia[4], M. Magi[2], F. Bonfigli[5] and R. M. Montereali[5]

International Journal of Multiphase Flow 70 (2015) 15–21

Contents lists available at ScienceDirect

International Journal of Multiphase Flow

journal homepage: www.elsevier.com/locate/ijmulflow

GDI spray structure analysis by polycapillary X-ray μ-tomography

L. Marchitto [a,*], D. Hampai [b], S.B. Dabagov [b,c], L. Allocca [a], S. Alfuso [a], C. Polese [b,d], A. Liedl [b,e]

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High Resolution Imaging - Detector LiF based

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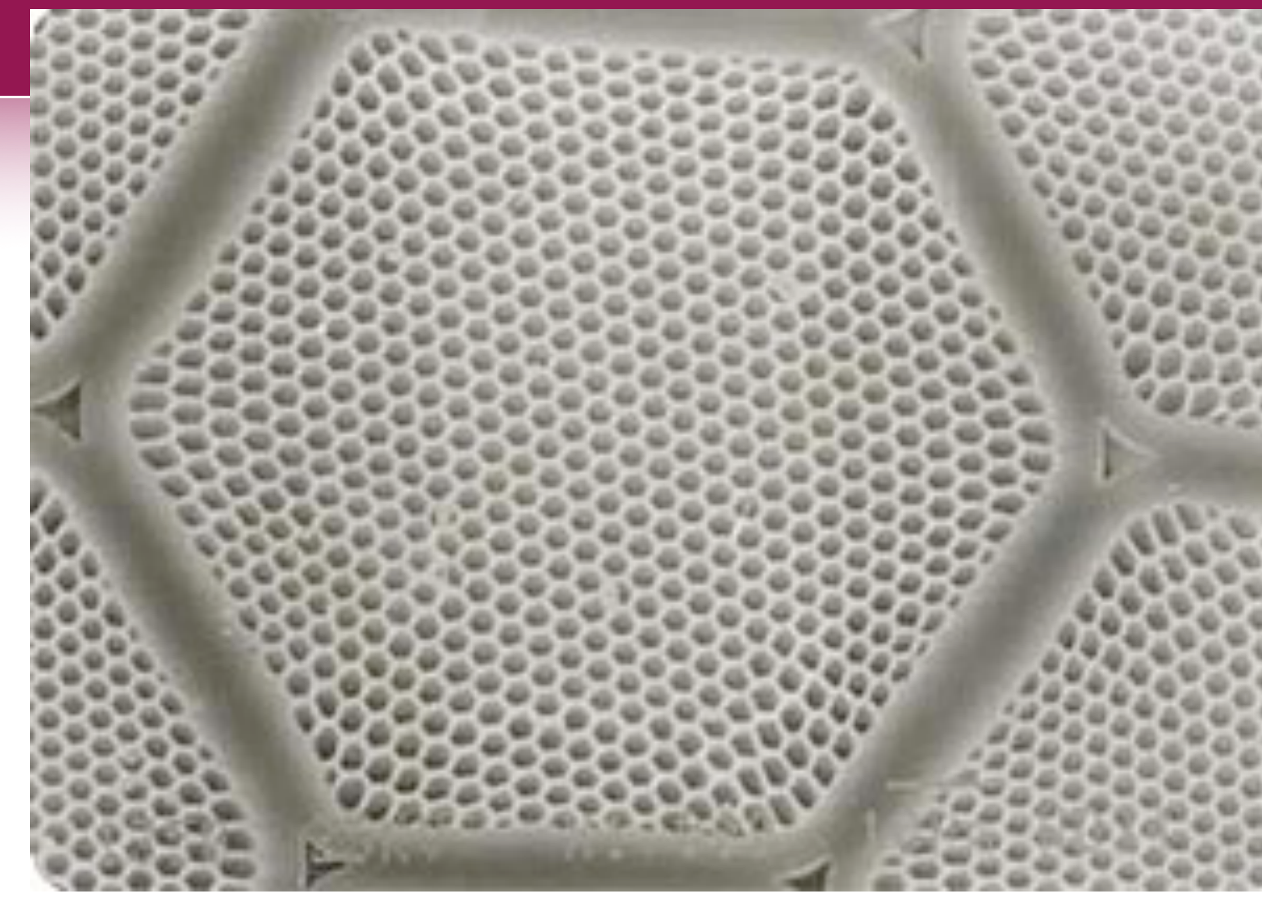
a) Scanning electron microscope image of a typical polycapillary lens transversal section;

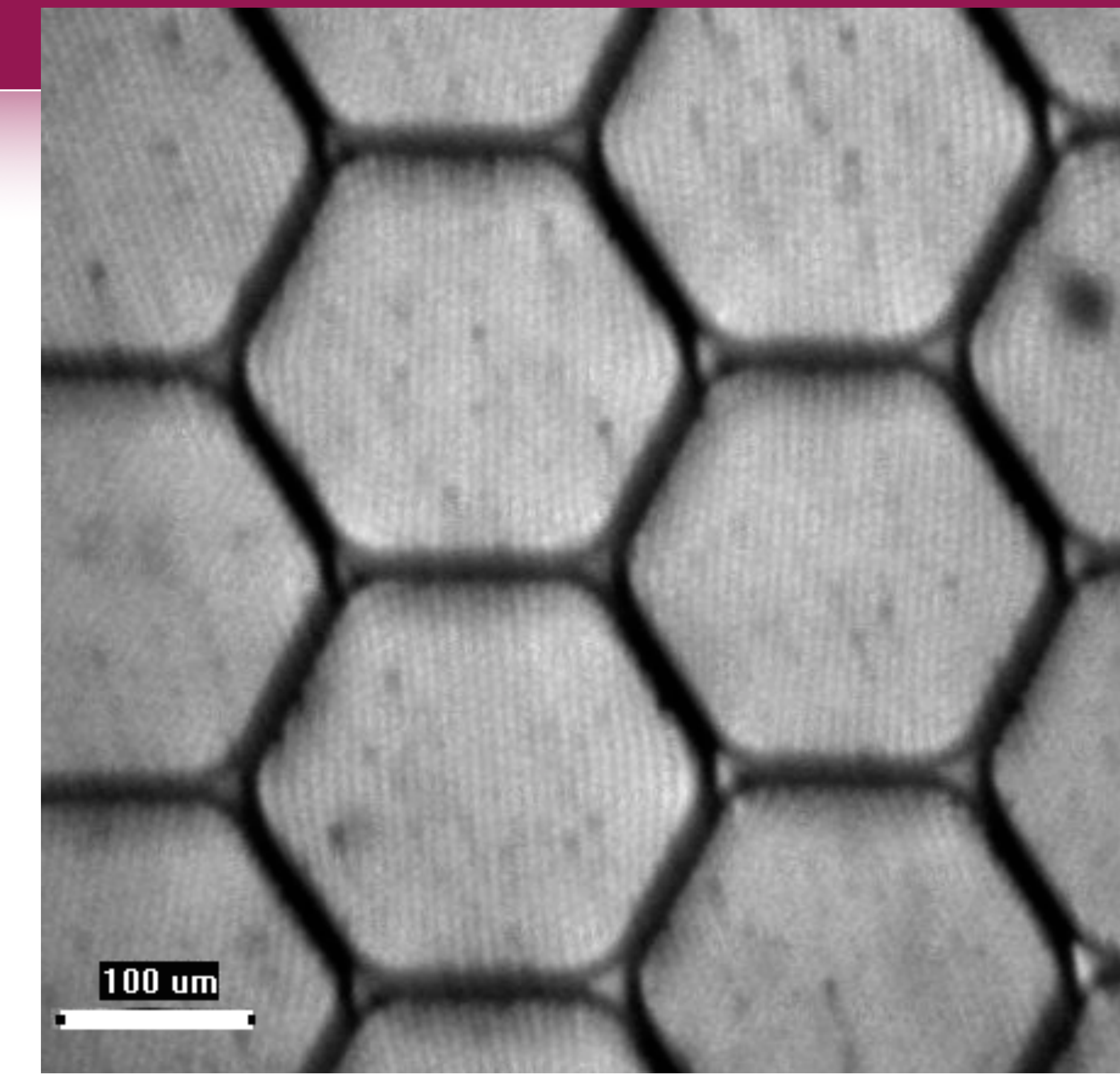
b) X-ray beam transmitted by the polycapillary semi-lens stored in a LiF crystal placed at the lens exit. The image was read by the CLSM system (ob. 20x) in fluorescence mode; scale bar: 100 μm;

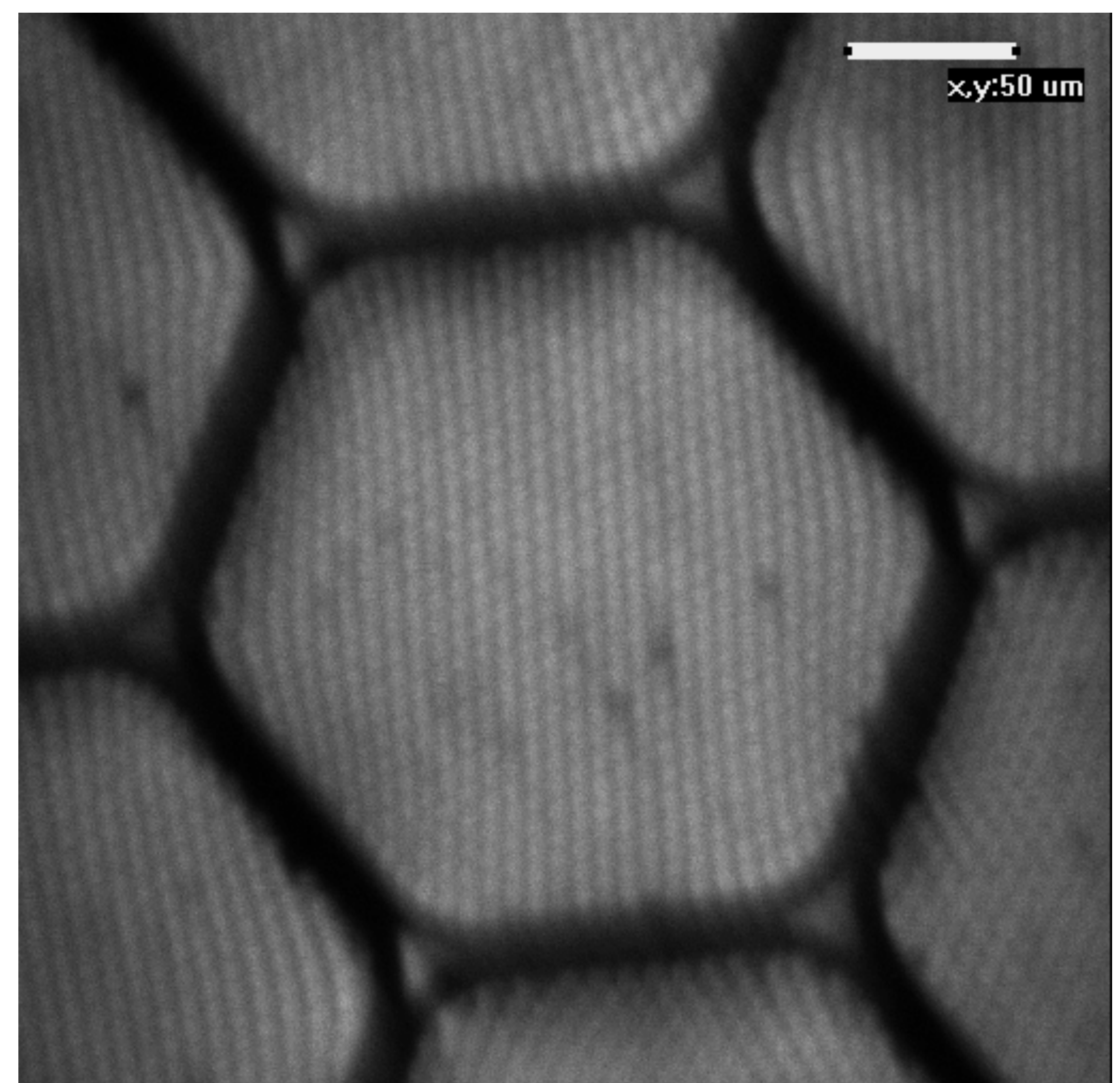
c) Details of the fluorescence image in b) at higher magnification (ob. 40x); scale bar: 50 μm;

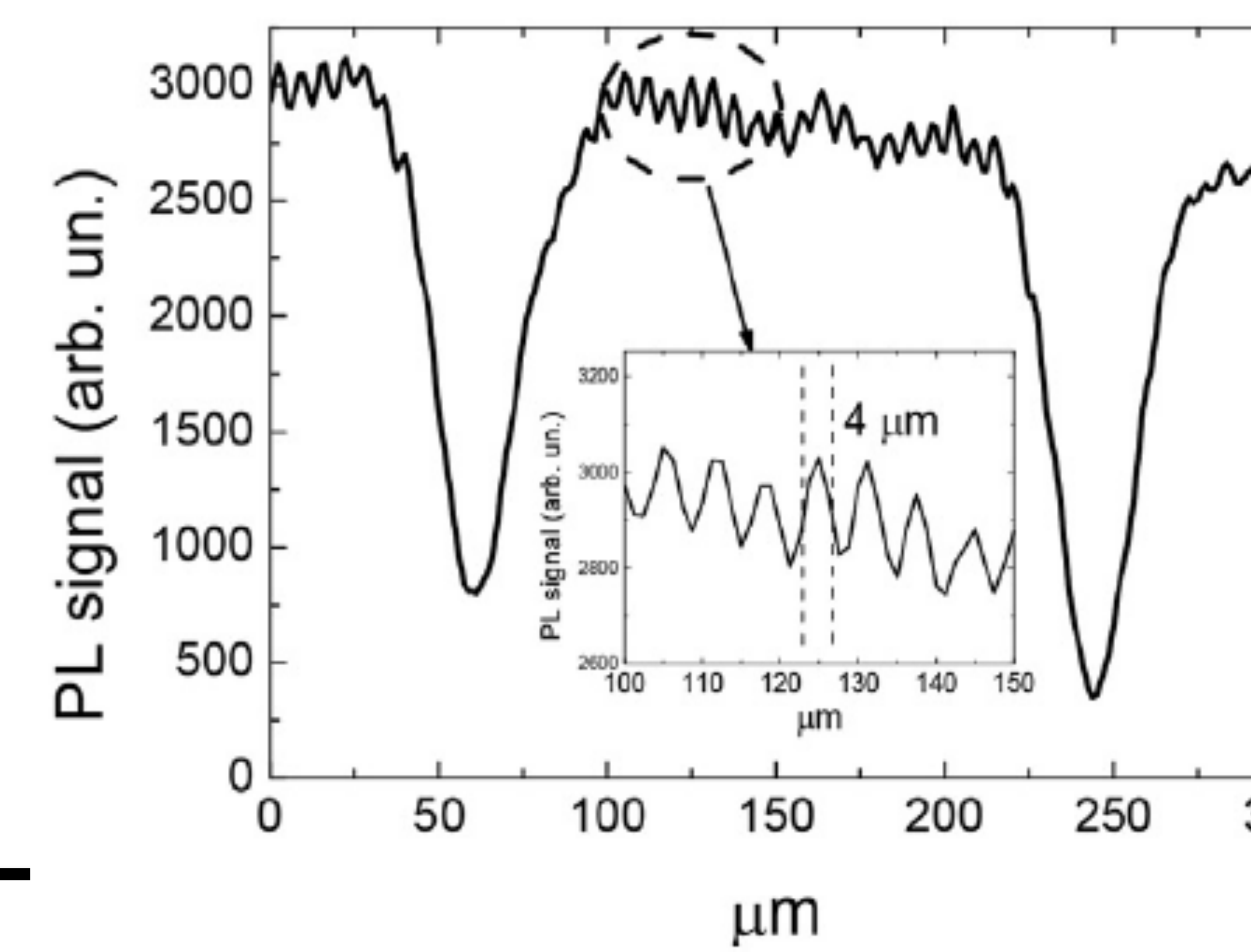
d) intensity profile of photoluminescence signal along the dashed white line.

F. Bonfigli et al., Opt. Mat. 58, 398-405 (2016)









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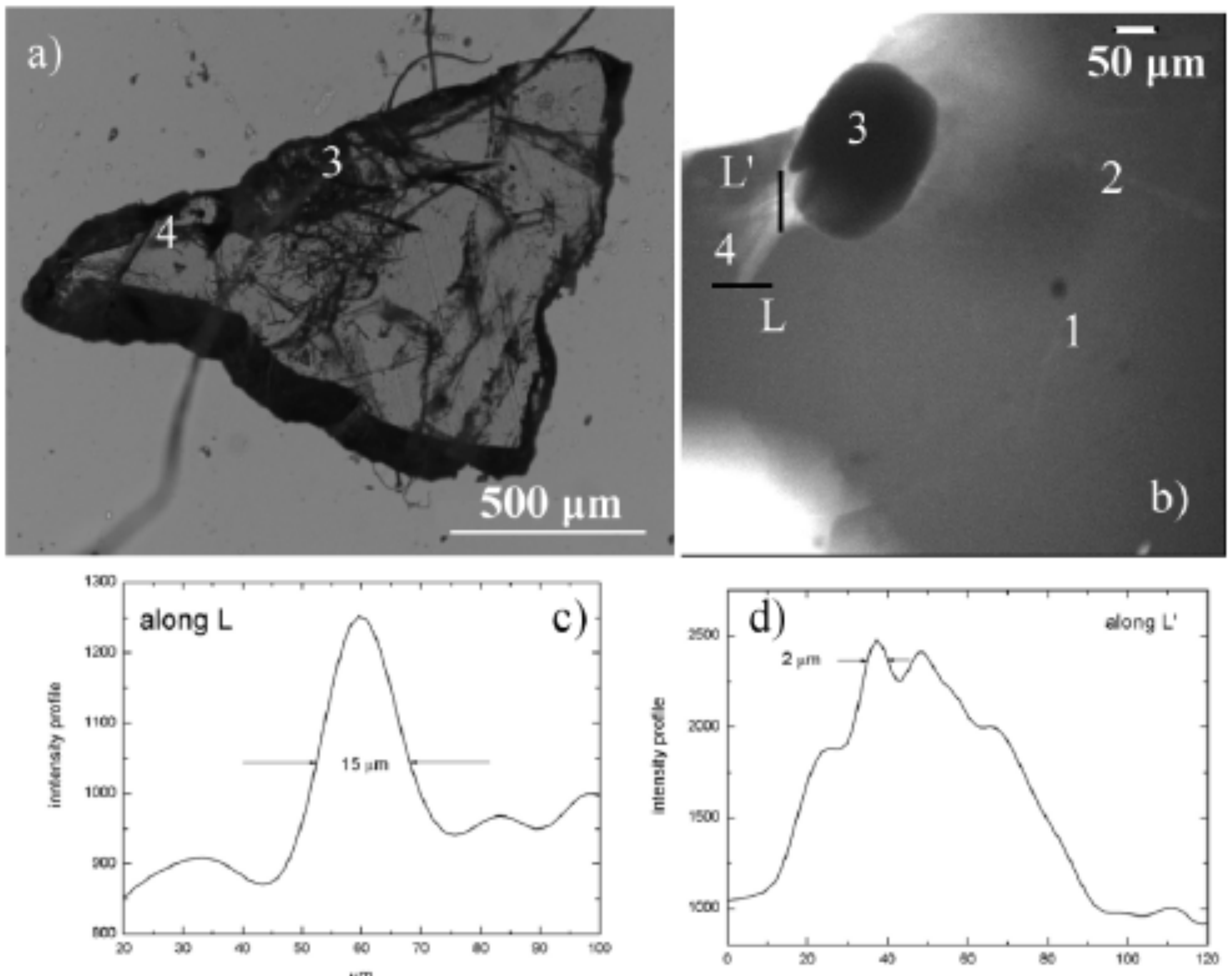
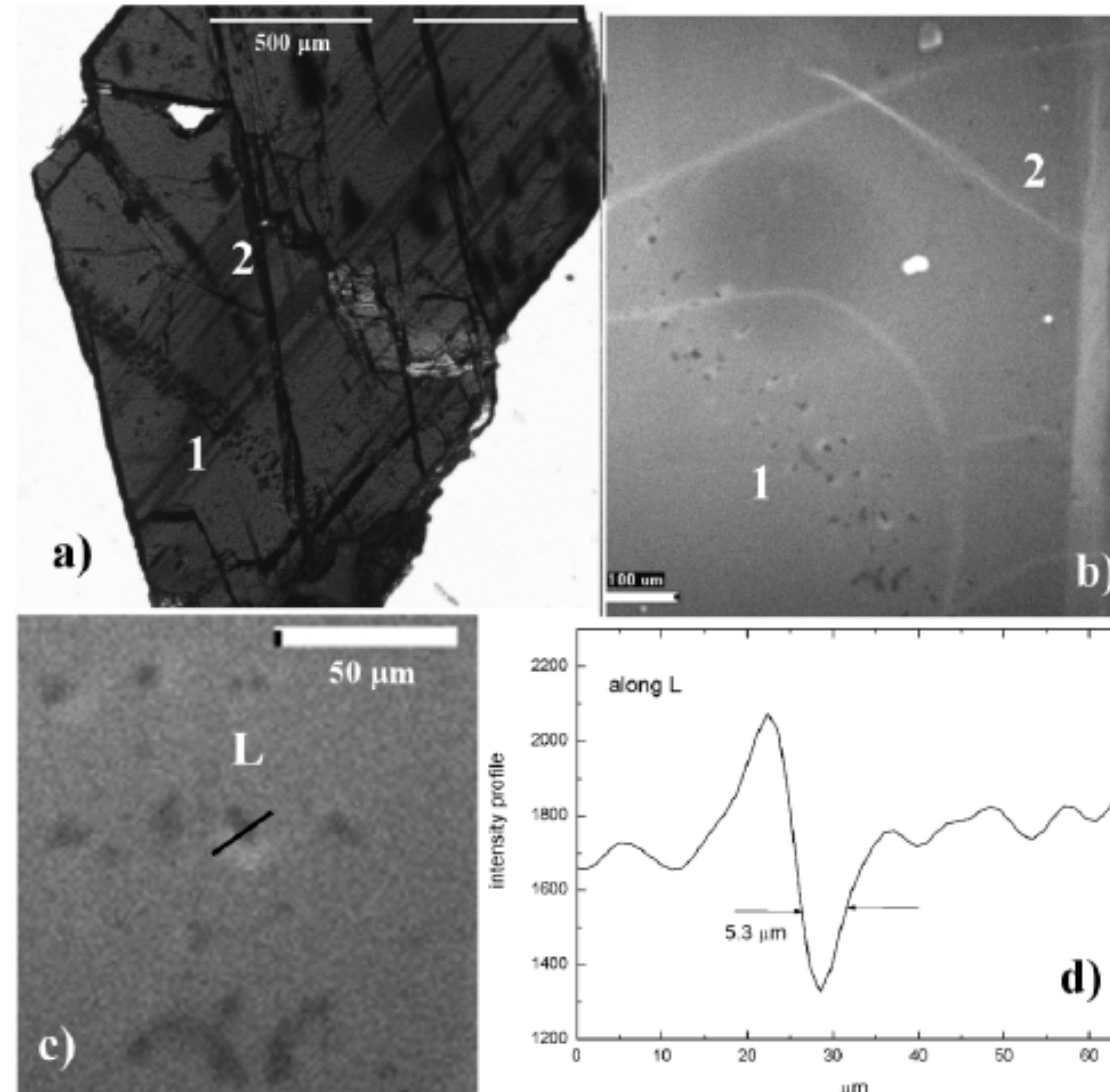
High Resolution Imaging - Detector LiF based

Geological samples
On Left: doubly-polished (010) section of cordierite
On Right: doubly-polished fragment of a magnesium-hastingsite amphibole





D. Hampai et al., EPL 96, 60010 (2011)

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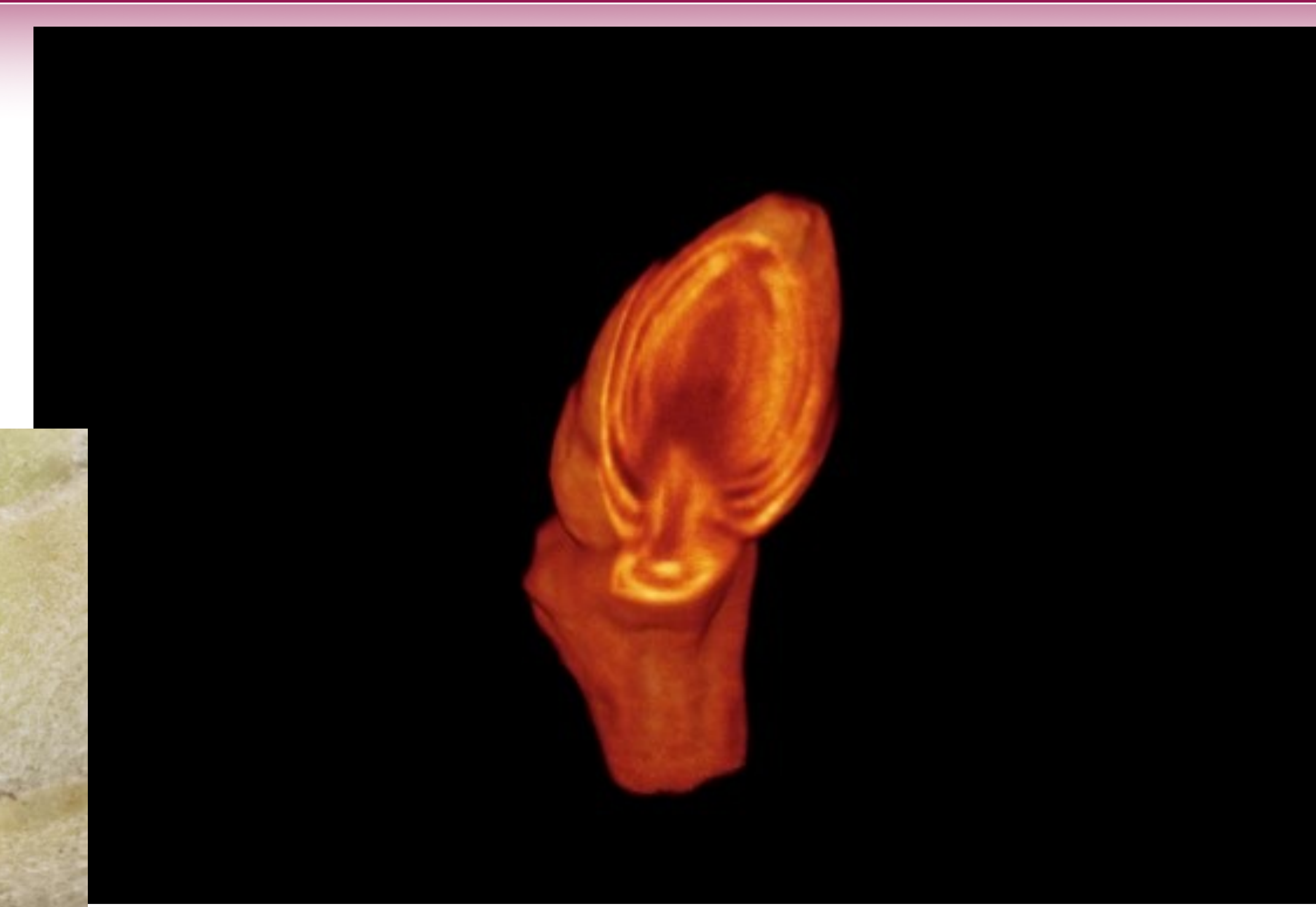
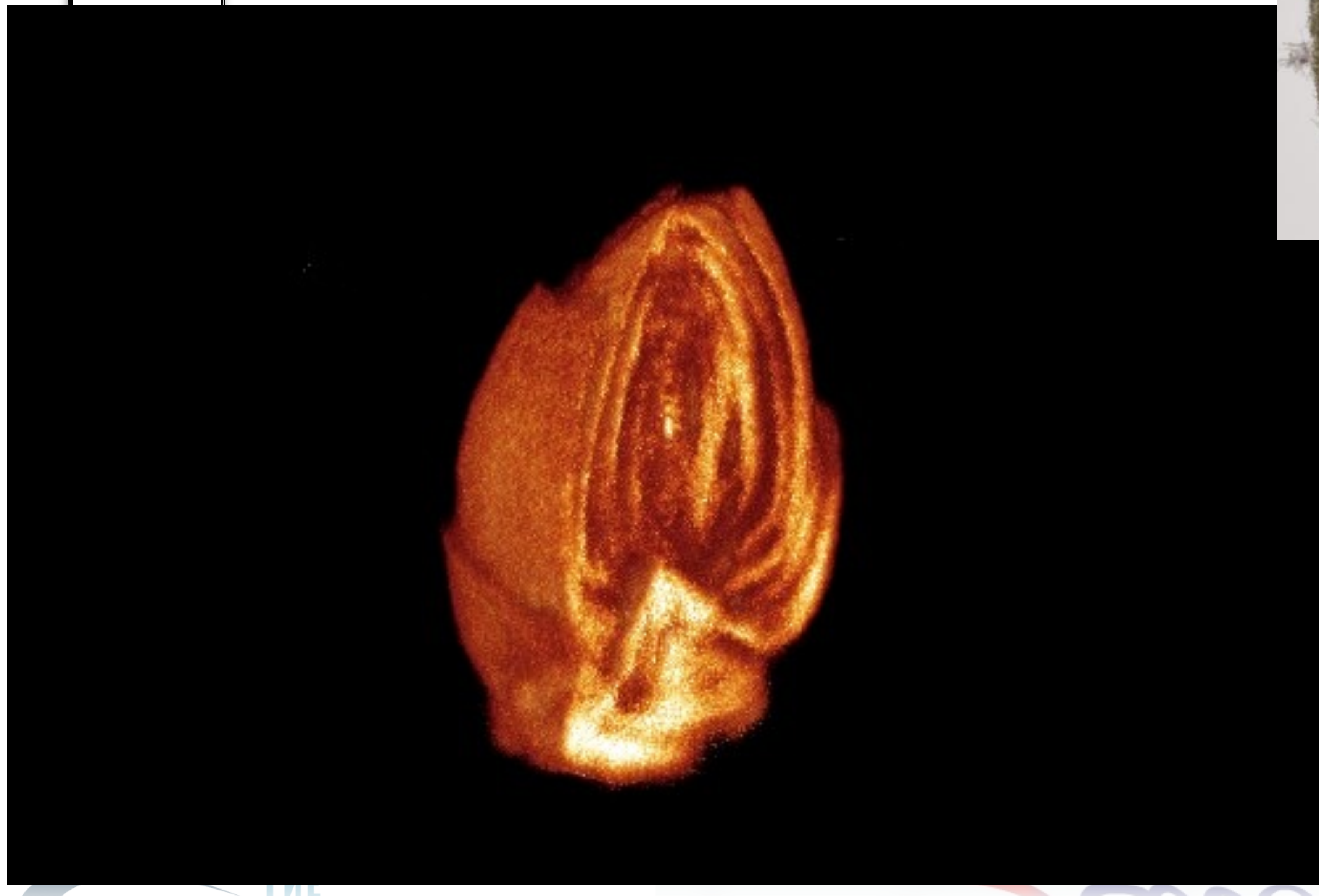
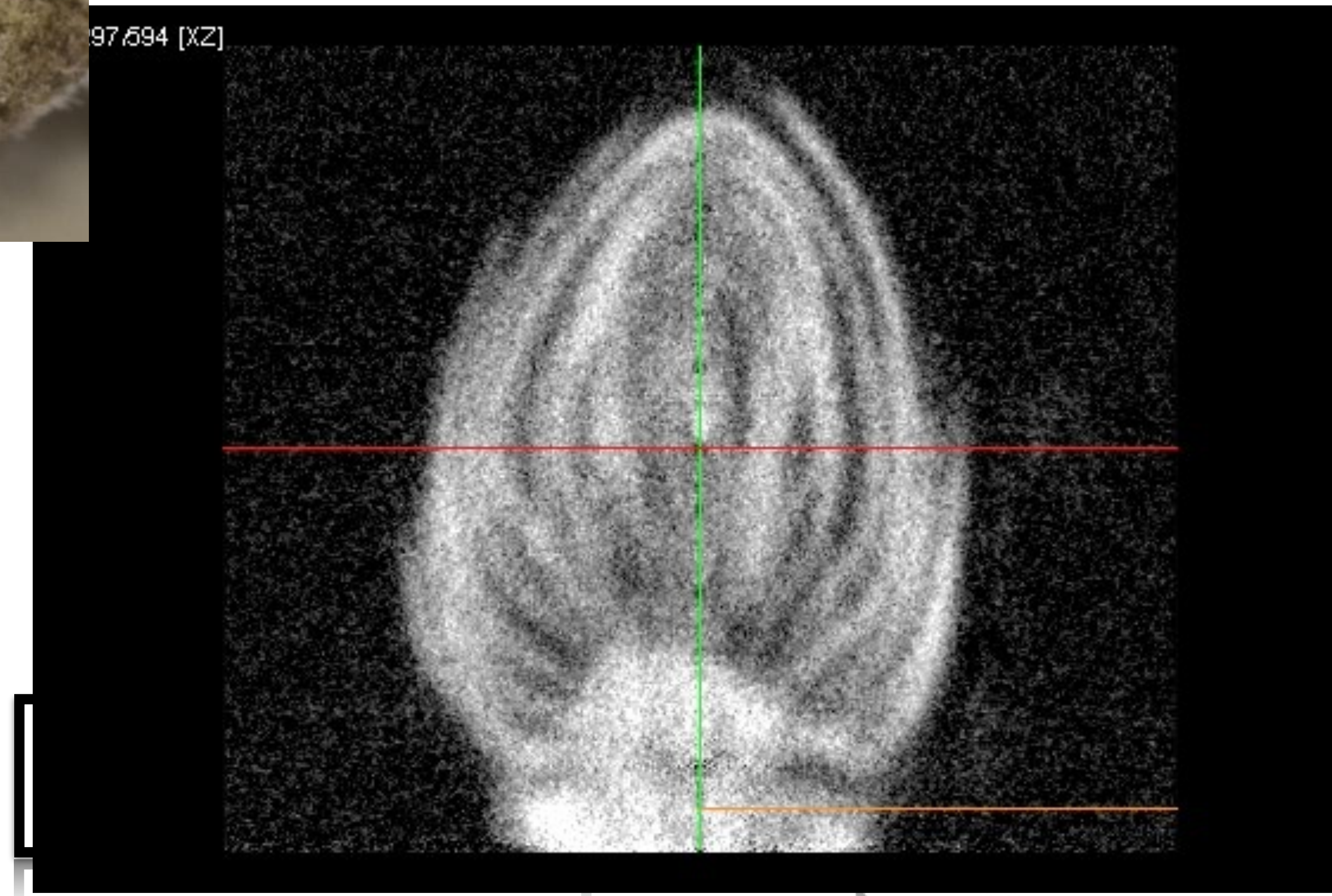
microCT - a flower bud

10x10 µm^2





3.5x3.5 µm^2



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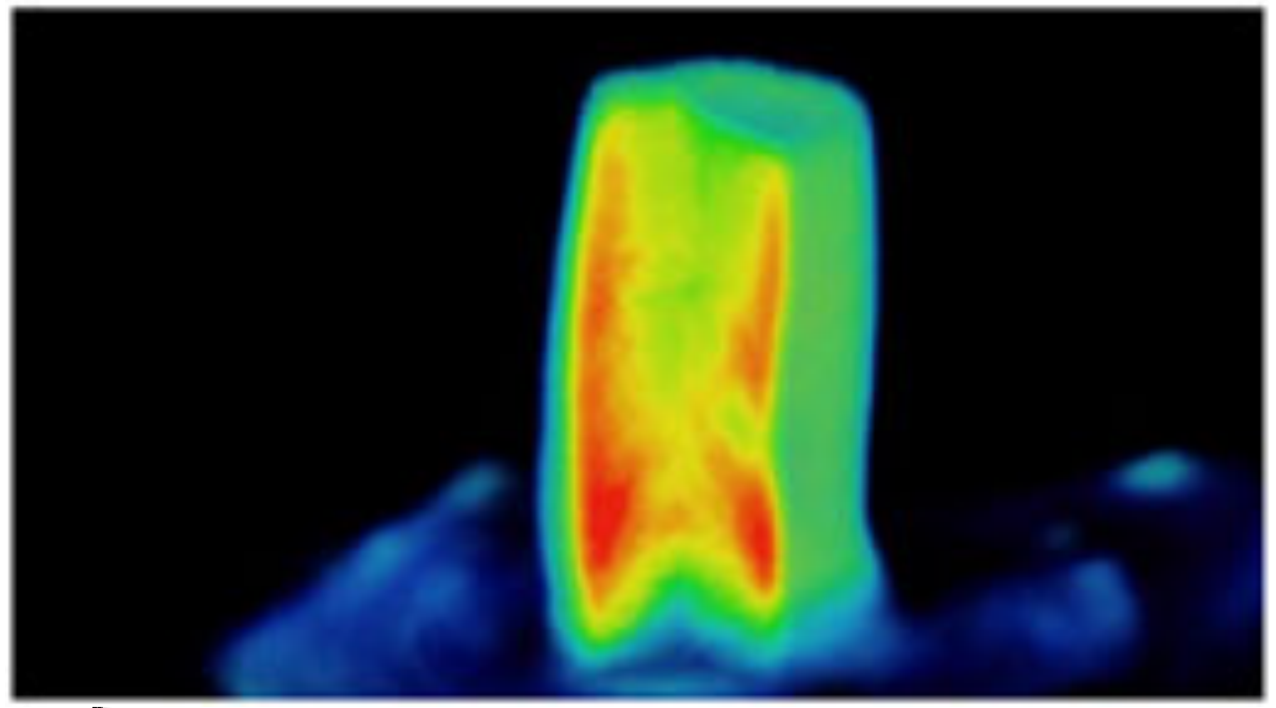
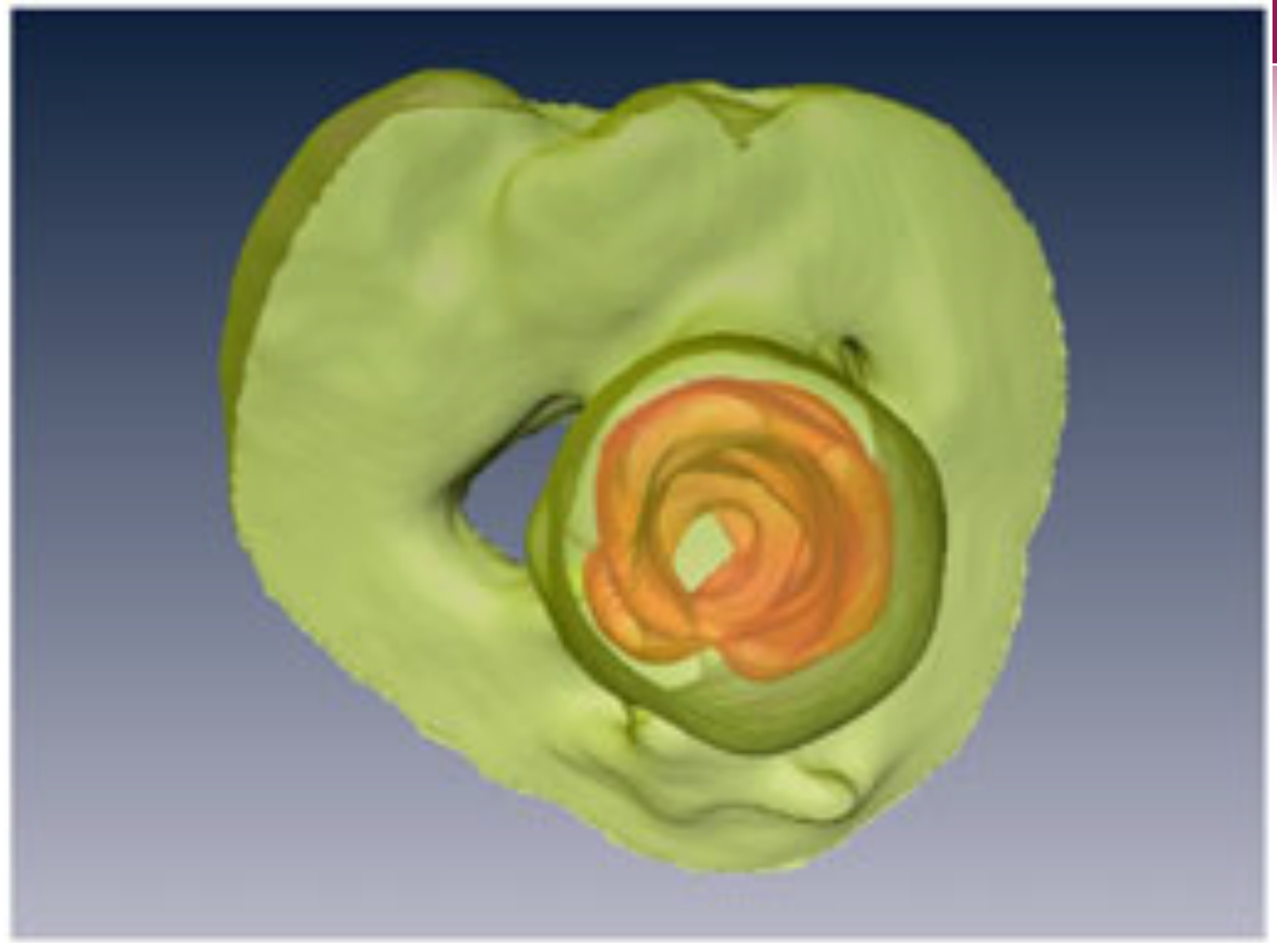
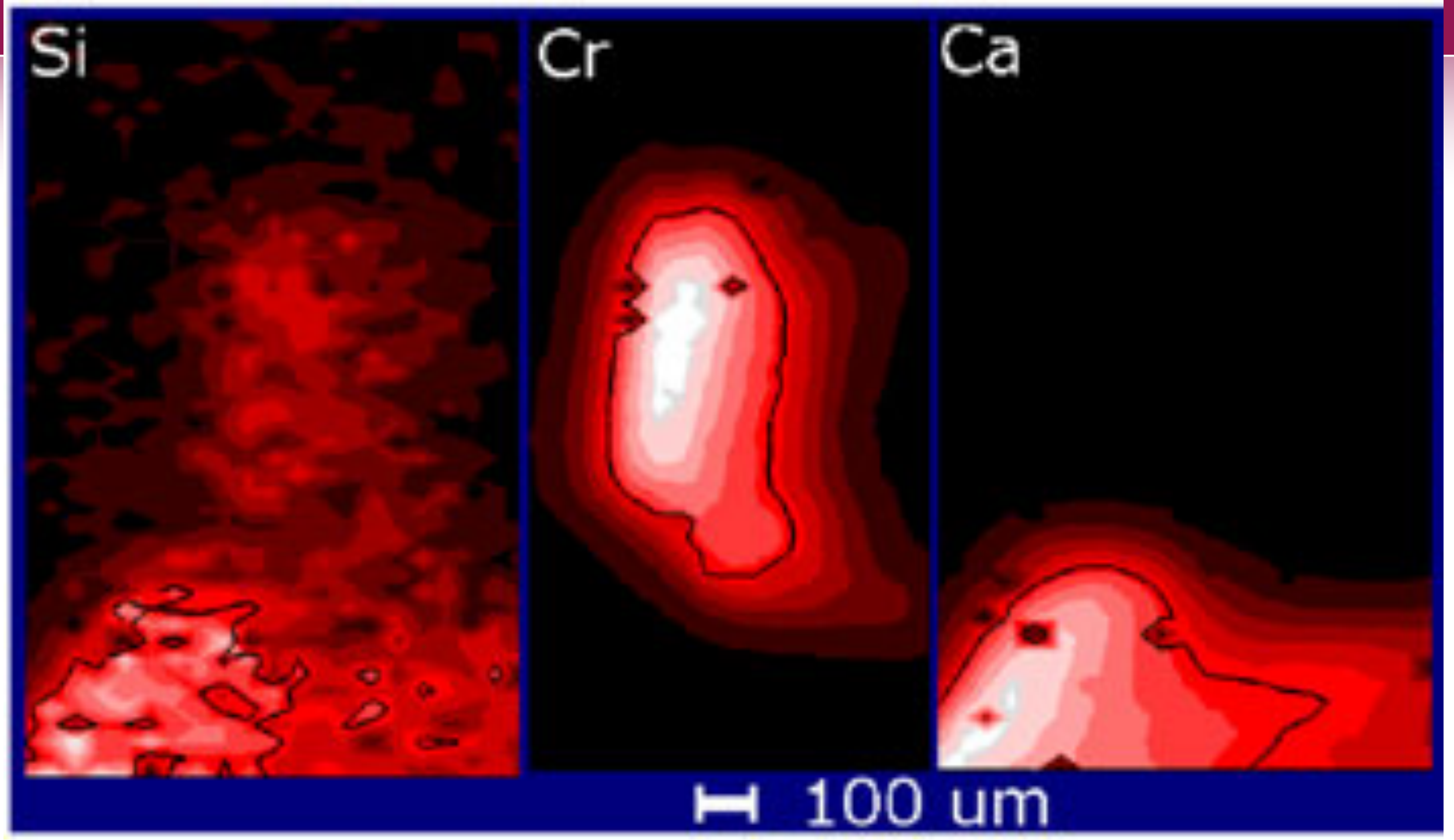
Synthetic Emerald - μXRF and μCT







A. Liedl et al. X-Ray Spectrom. 44, 201-203 (2015)

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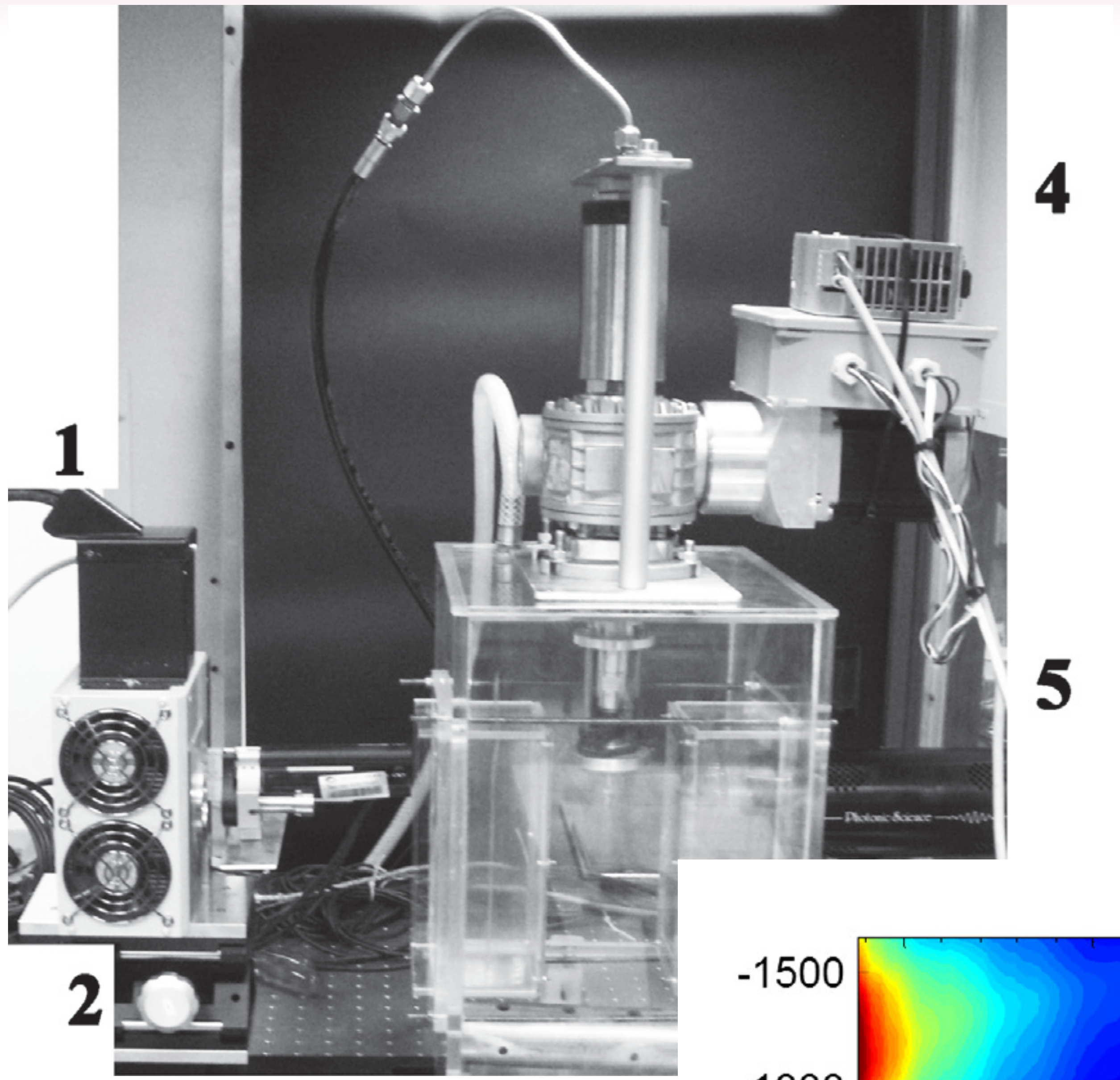
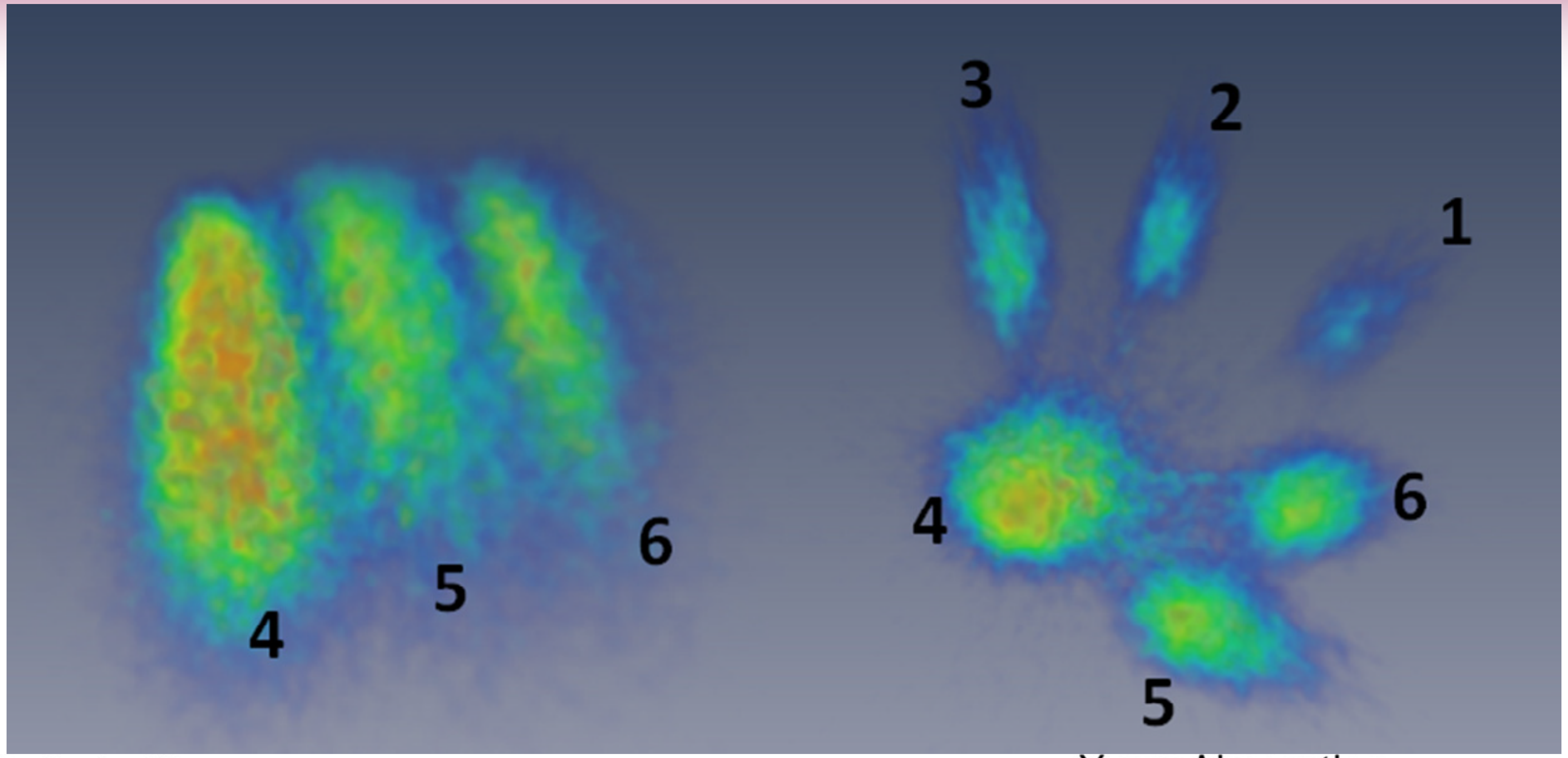
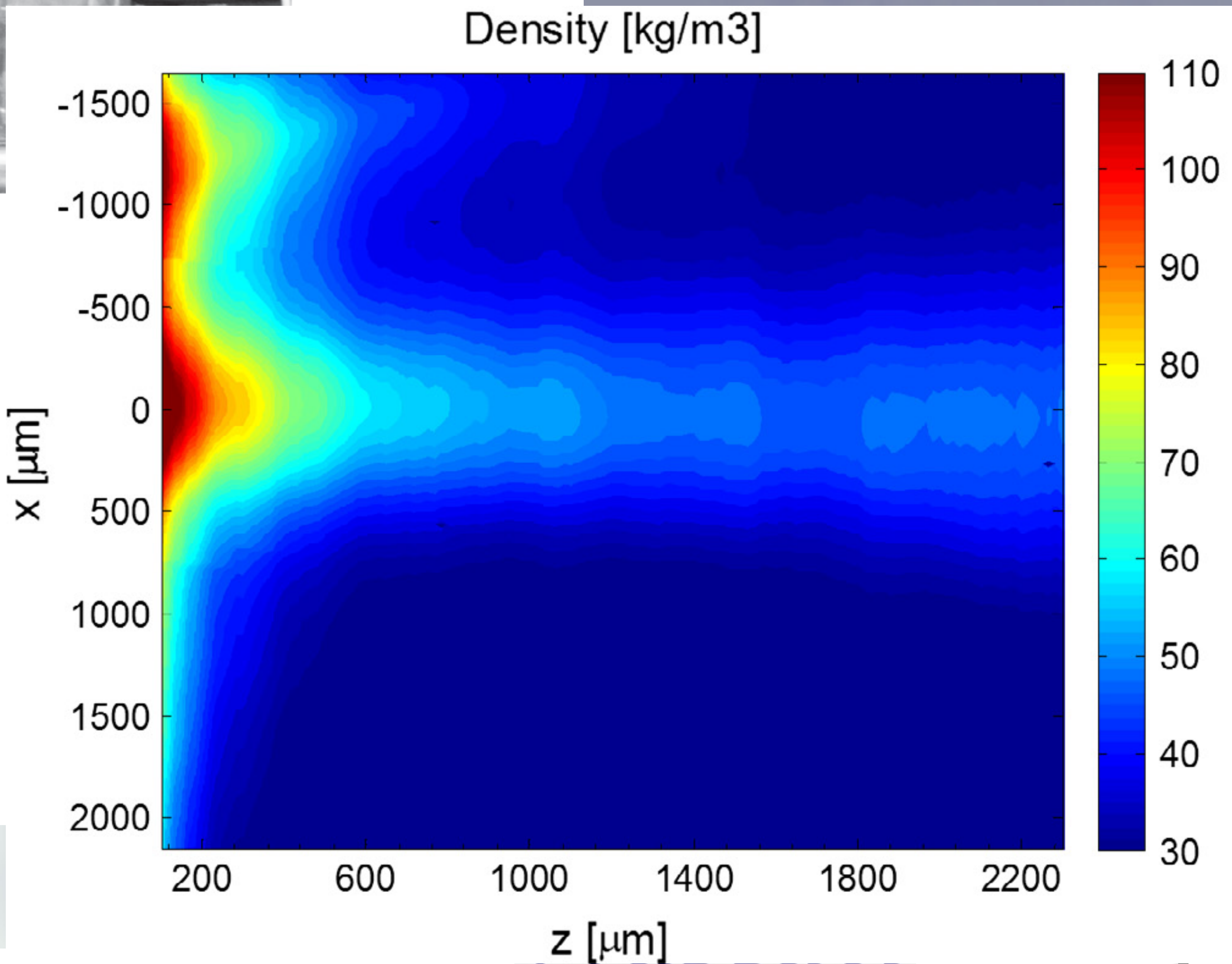
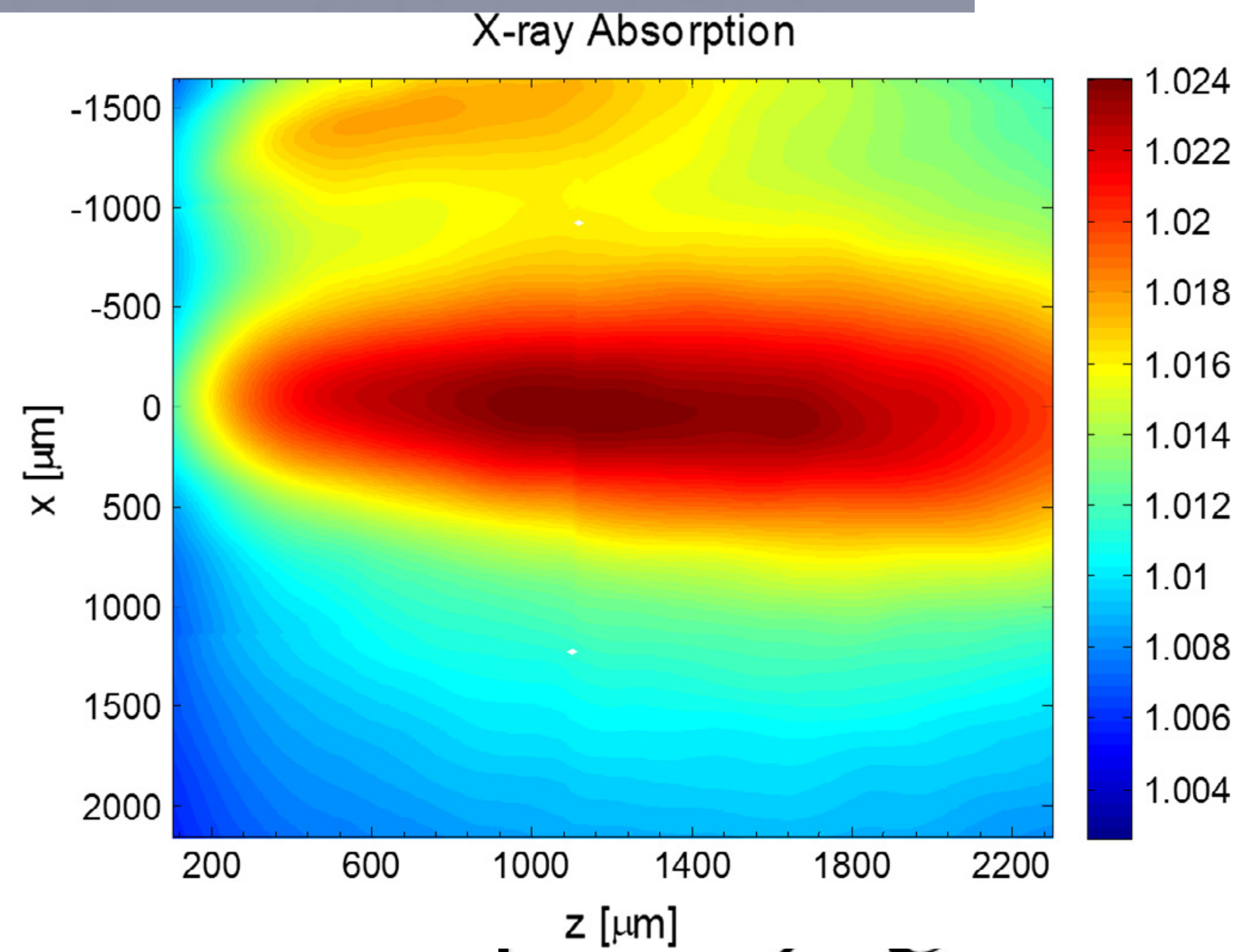
XChannel x-ray technologies

μCT in Dynamic Processes



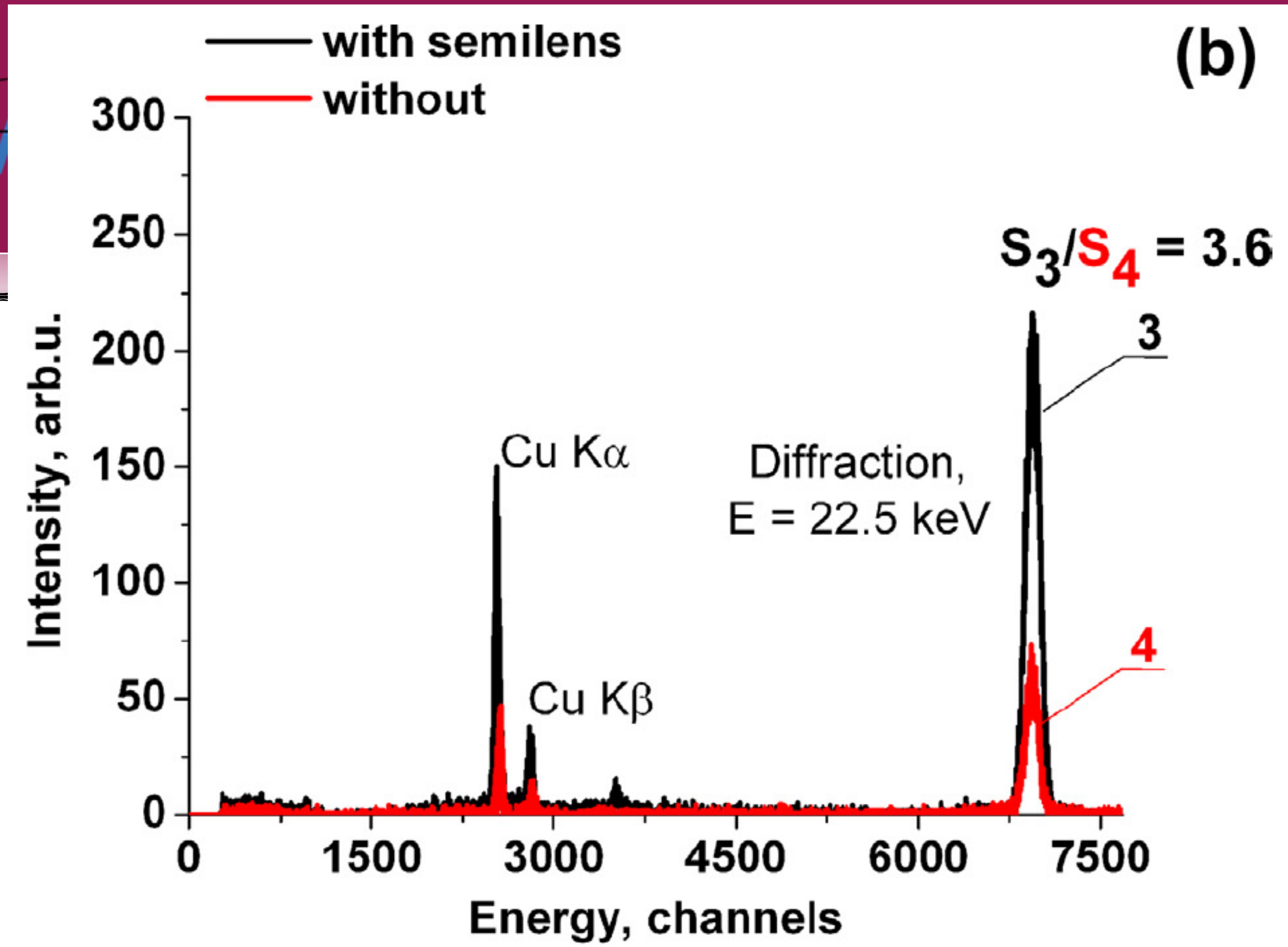


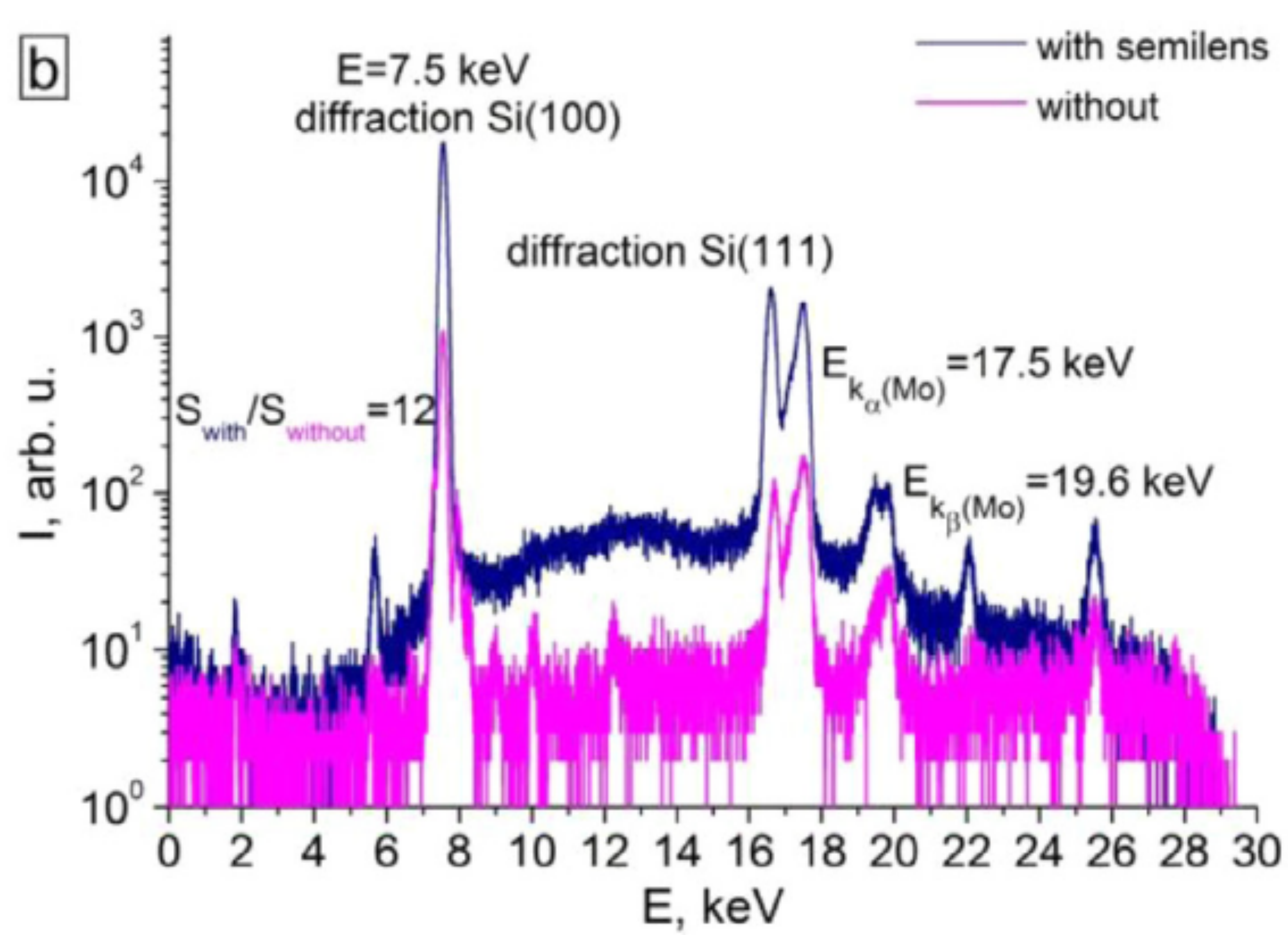


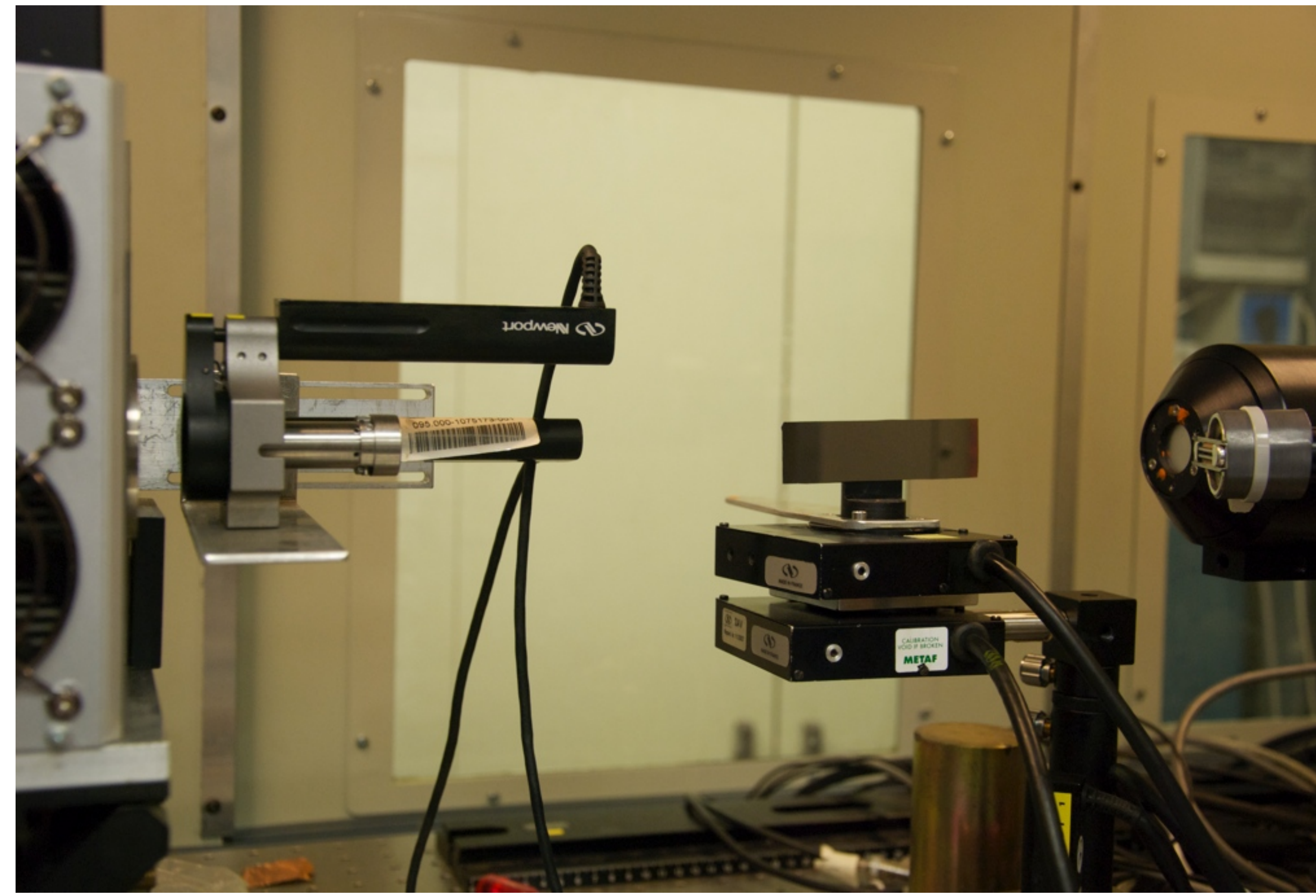


L. Marchitto et al., IJMF 70, 15-21 (2015)

XRD Applications



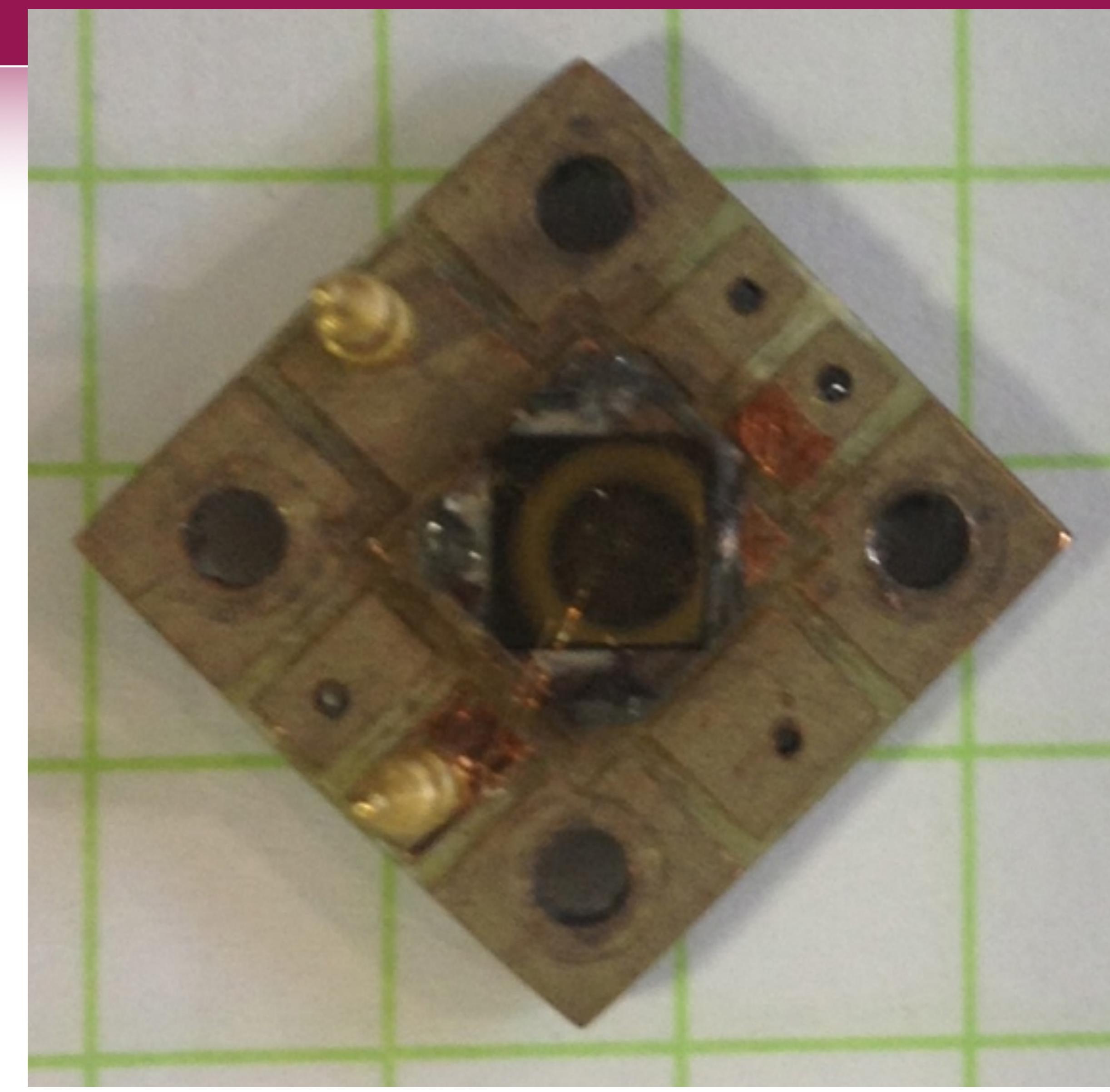


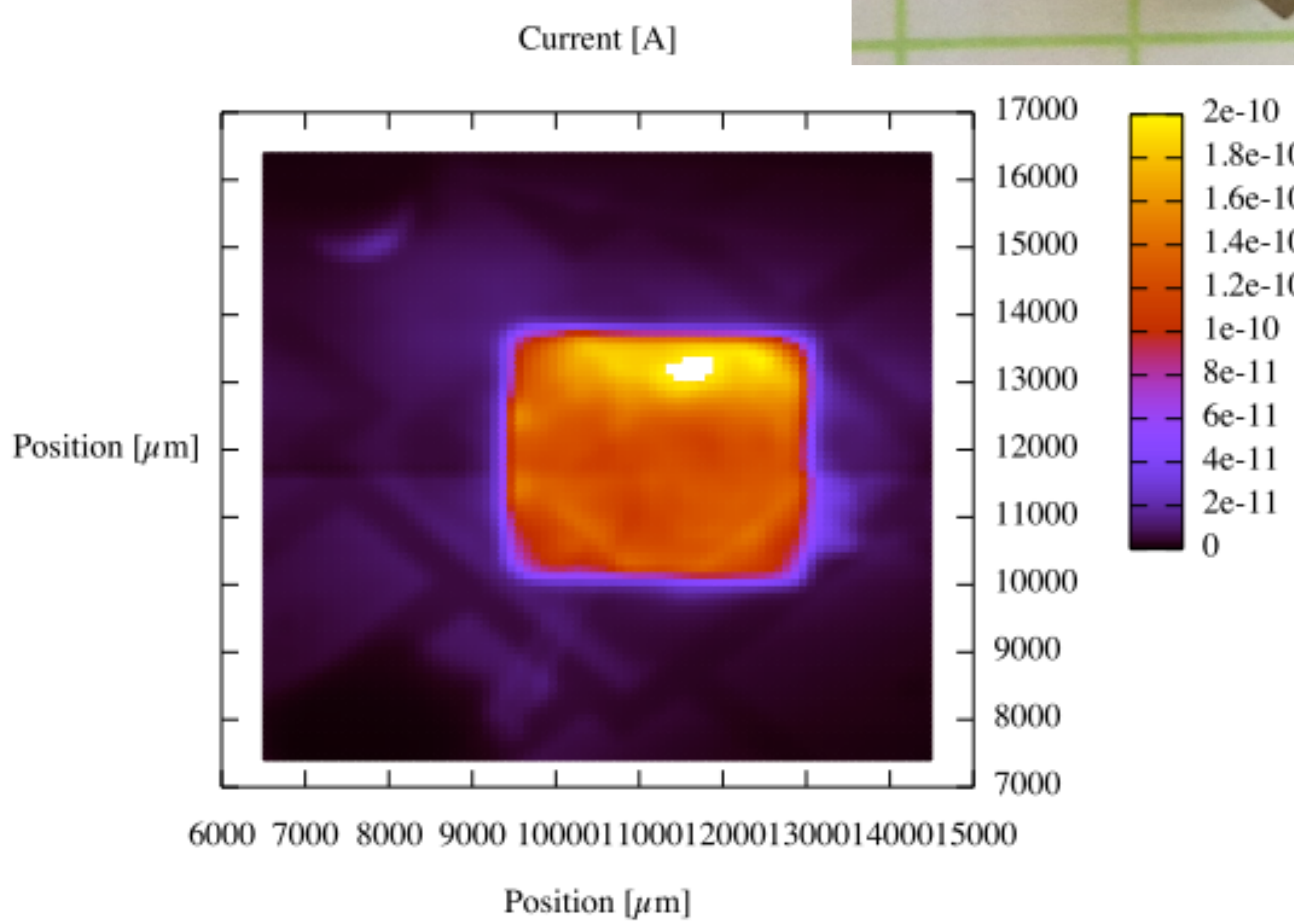


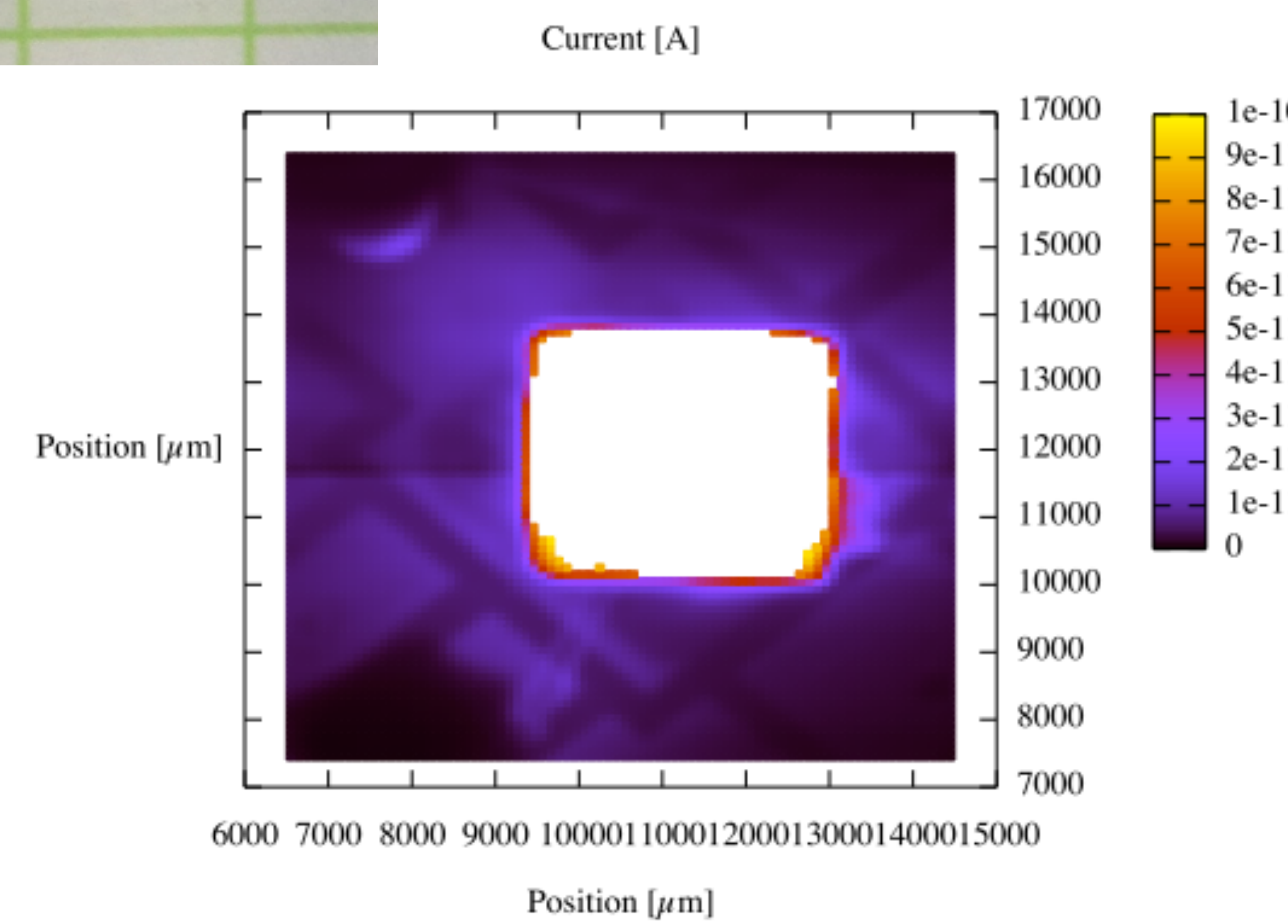
Yu. Cherepennikov et al., NIM B 355, 276-280 (2015)

Yu. Cherepennikov et al., NIM B 402, 278-281 (2017)

Imaging for Diagnostic Diamond Detector

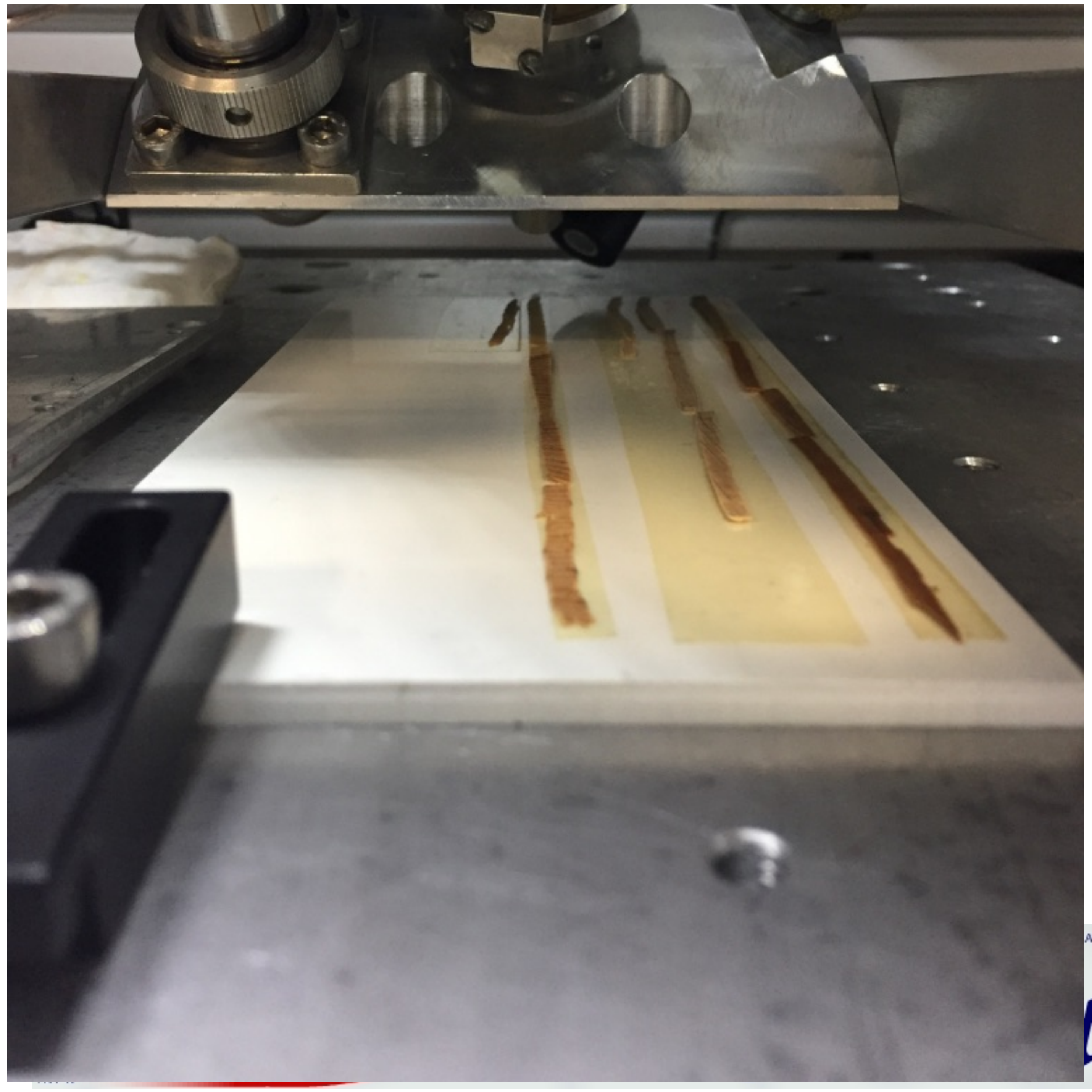






RXR @ XlabF

- Facility for (confocal) μXRF Spectroscopy
- 2D-3D mapping
- Possibility to make Color Tomography
- Presented in 2014 @ EXRS



Analysis	µXRF (2D & 3D mapping) TXRF
X-ray Source	Mo Kα - 50 W source spot ~ 50 µm
primary optics	polycapillary optics 90 µm spot size Transm.: 22% @ Mo-Kα
secondary optics @ high en.	polycapillary semi-lens div. res.: 2.2 mrad Transm.: 58 @ Cu-Kα
secondary optics @ low en.	polycapillary semi-lens div. res.: ~ 5 mrad Transm.: ~ 30 @ Cu-Kα
Detectors	SSD detectors active area: 25 mm^2 En. res.: <135eV @ Mn-Kα
Probe size in the plane *xy*-axis (wire 40 µm)	≤ 77 µm
Probe size in the plane *xy*-axis (wire 40 µm)	≤ 77 µm
Probe size in *z*-axis (sheet 5 µm)	≤ 98 µm
Min. Detectable Concentration	~ 25 ± 1.25 µg/g

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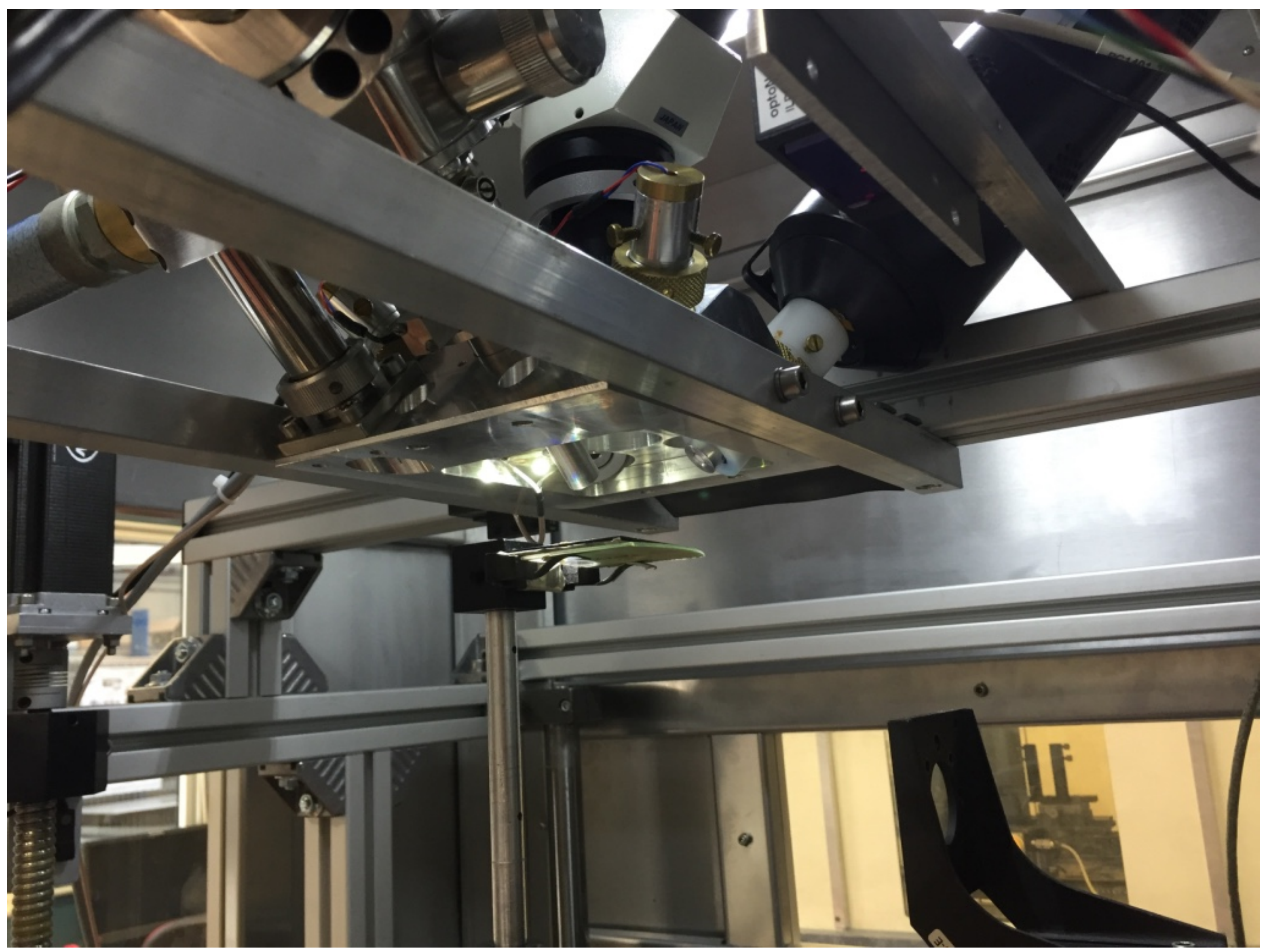
INFN LNF

MUSE

RXR @ XlabF

MUSE - GM



Research article

X-RAY SPECTROMETRY

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RXR: A new X-ray facility at XLab Frascati†

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Nuclear Instruments and Methods in Physics Research B 355 (2015) 264–267

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Nuclear Instruments and Methods in Physics Research B

journal homepage: www.elsevier.com/locate/nimb

Advanced studies on the Polycapillary Optics use at XLab Frascati

D. Hampai [a,*], S.B. Dabagov [a,b,c], G. Cappuccio [a]

Nuclear Instruments and Methods in Physics Research B 402 (2017) 274–277

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2D-3D μXRF elemental mapping of archeological samples

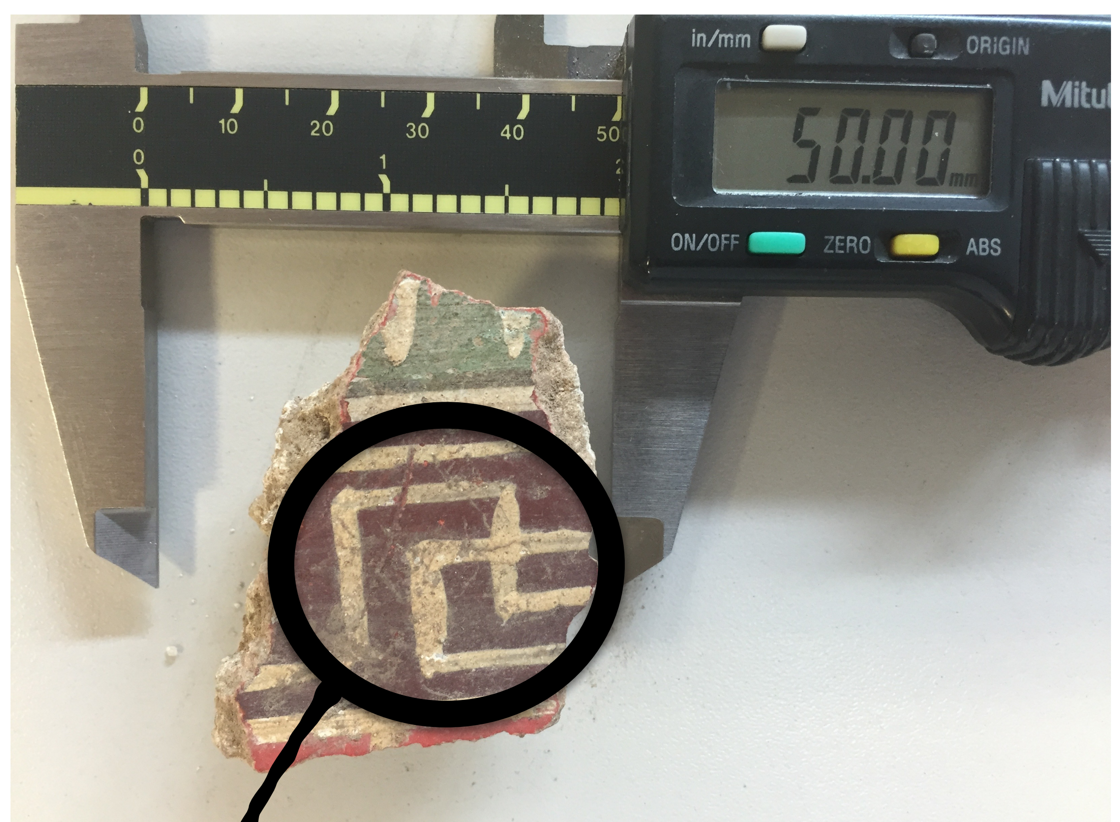
D. Hampai [a,*], A. Liedl [a,b], G. Cappuccio [a], E. Capitolo [a], M. Iannarelli [a], M. Massussi [c], S. Tucci [c], R. Sardella [c,d], A. Sciancalepore [e,f], C. Polese [a], S.B. Dabagov [a,g,h]

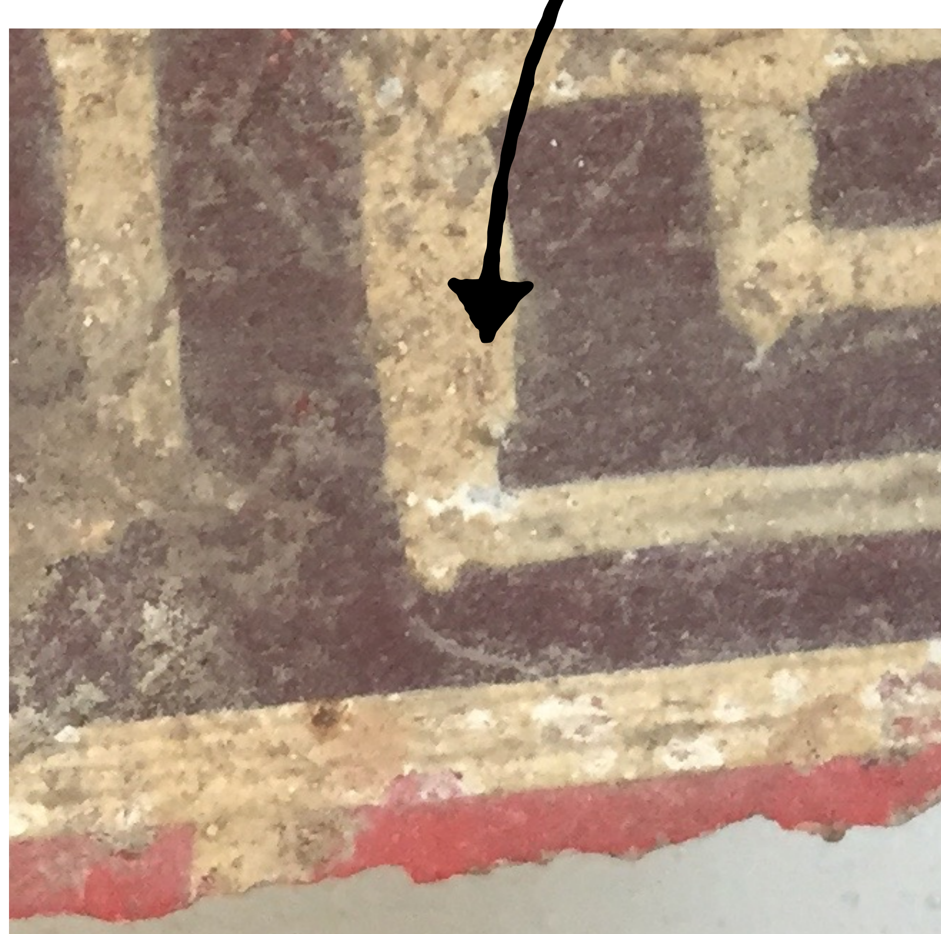
INFN LNF

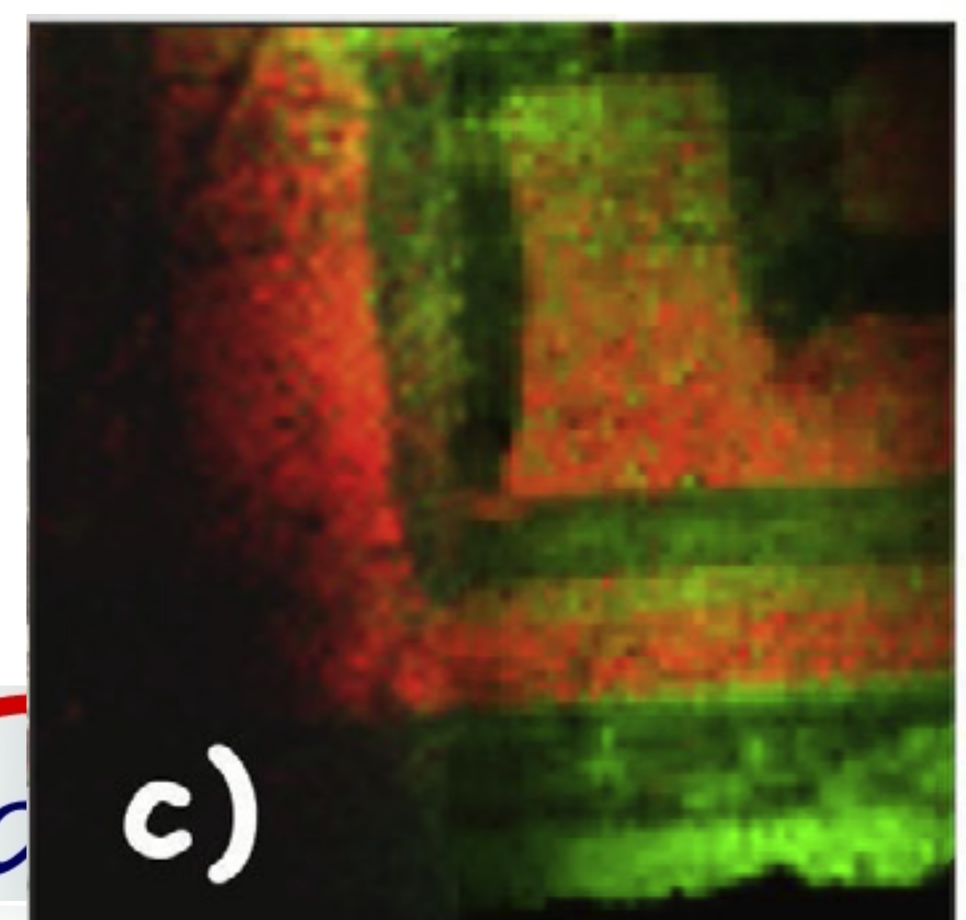
Xlab-Fras

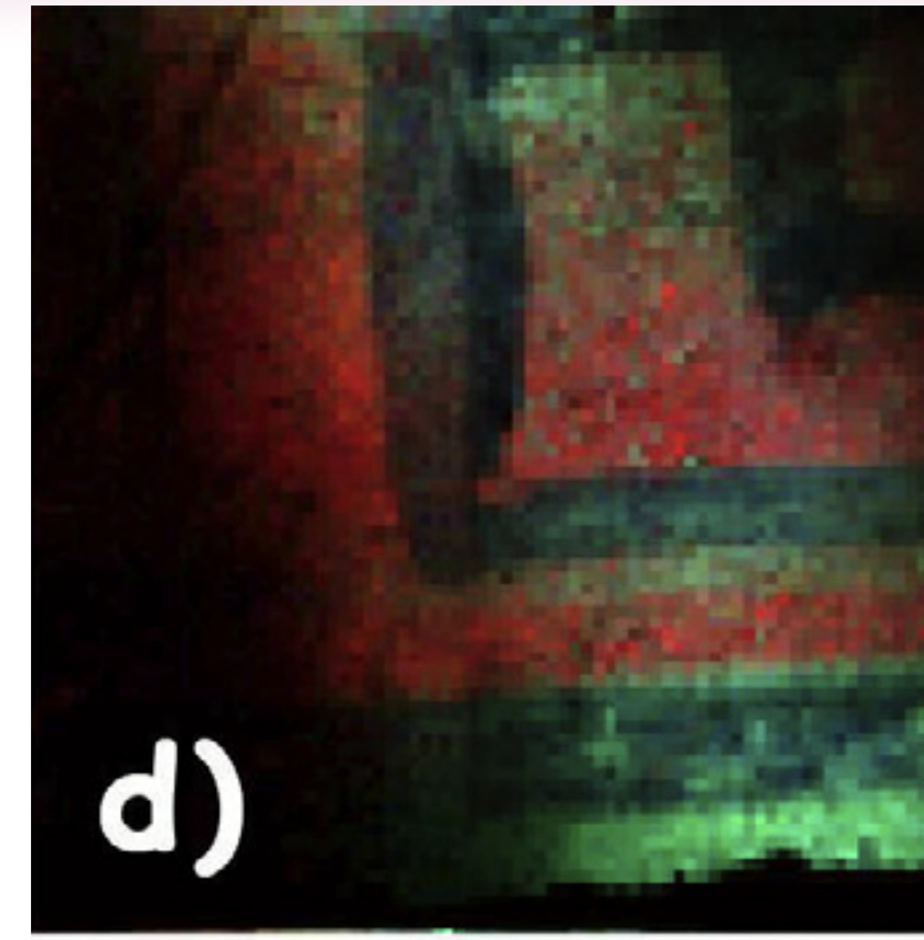
Archeological topic: Villa Fresco

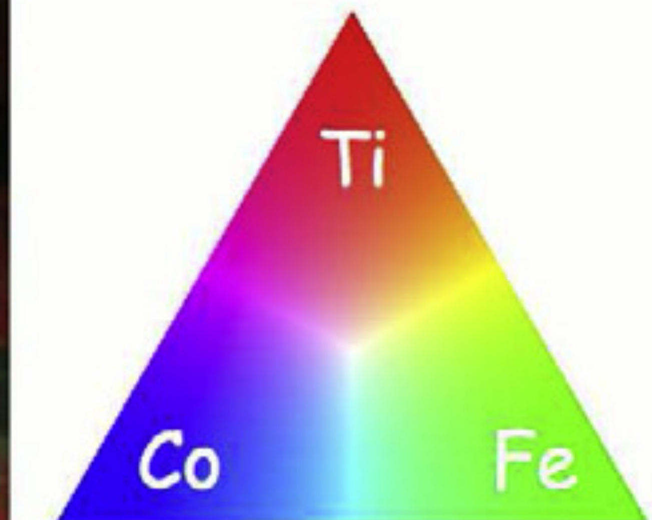
- scan XY ($\Delta x=\Delta y=250\mu m$)
- Acq. time = 5 sec / point
- Area: 20 x 20 mm²

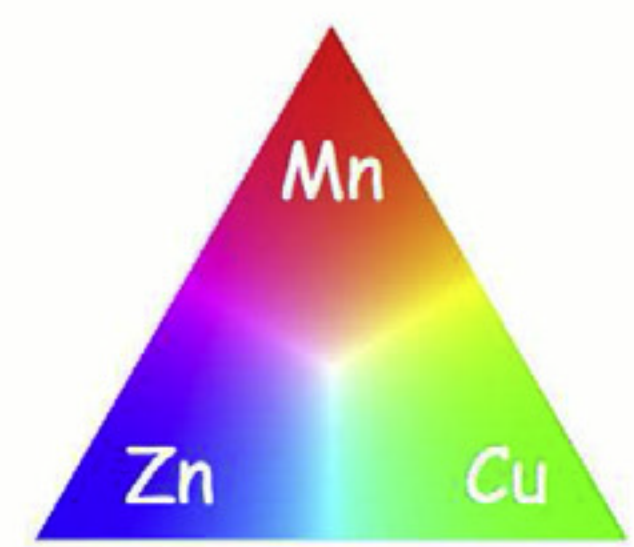


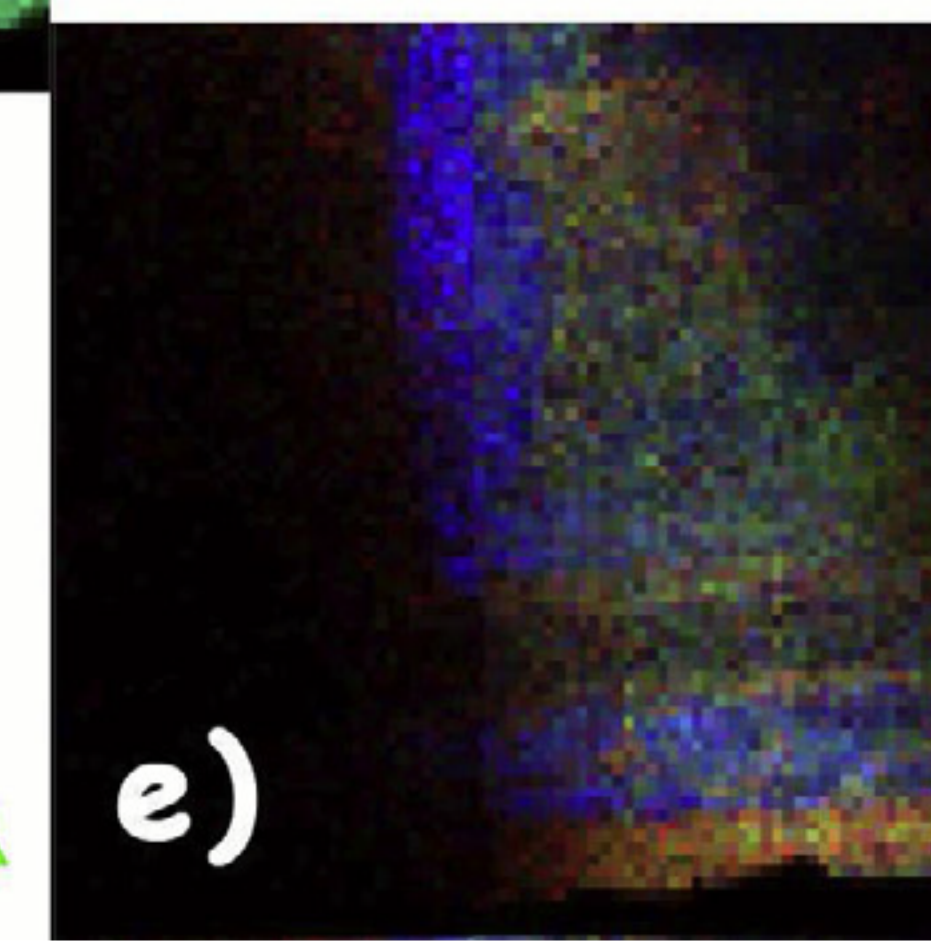






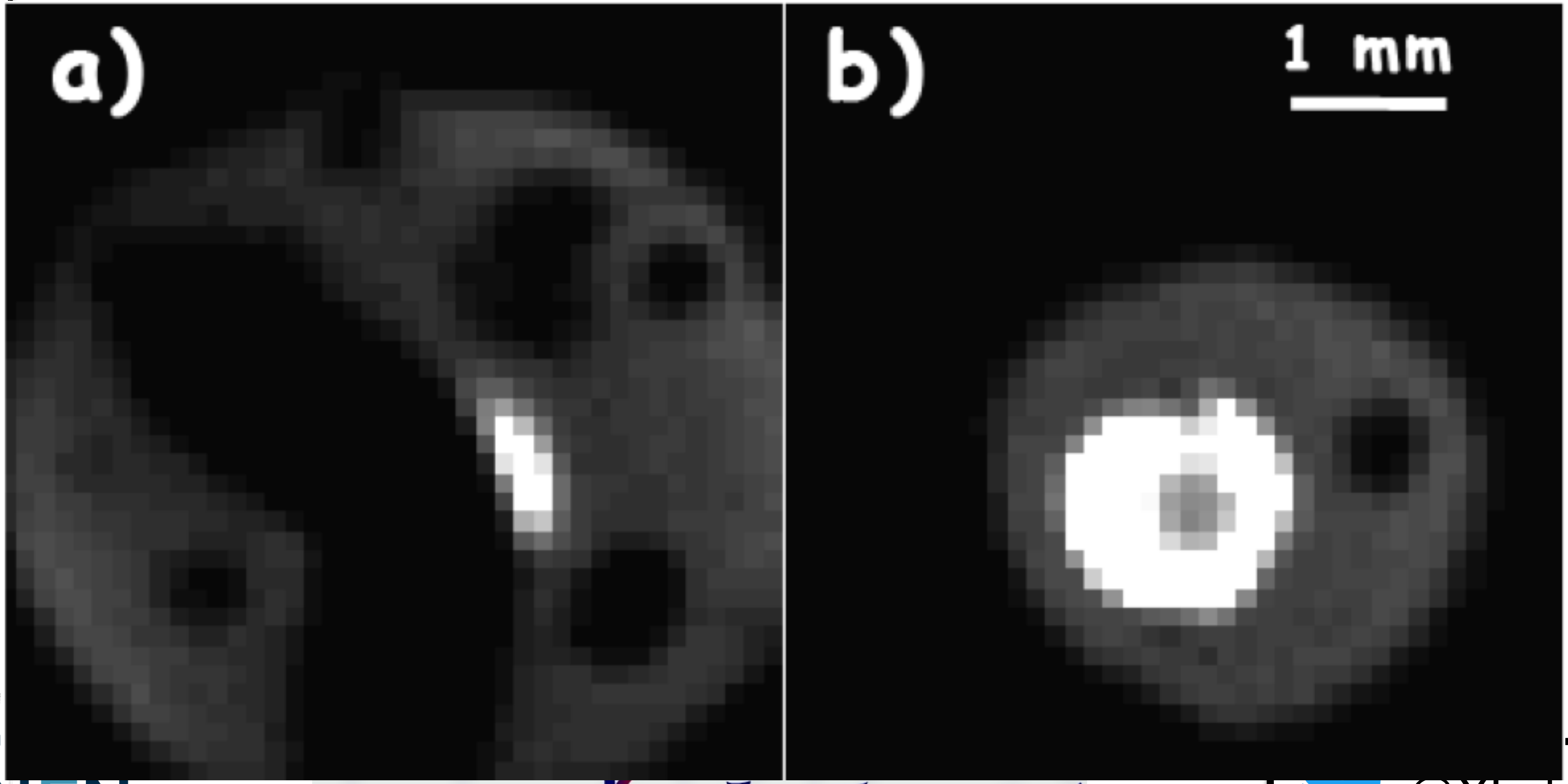


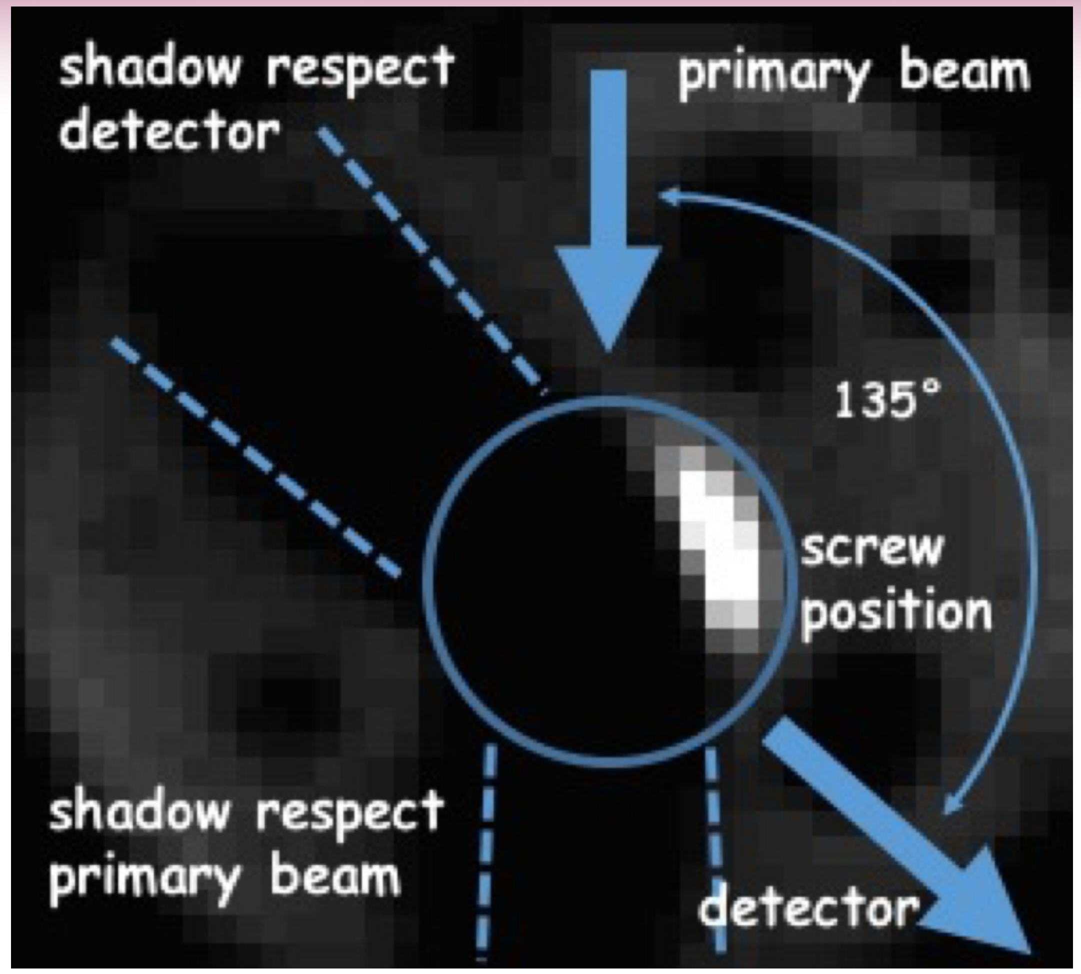




3D Color Tomography

- Simulation biological sample: Methyl acetate, Polyvinyl acetate and Acetone + Steel Screw
- scan Volume 4.1x4.1x2.1 mm^3
- scan XYZ ($\Delta x=\Delta y=\Delta x=100\mu m$)
- Acq. time = 5 sec / point





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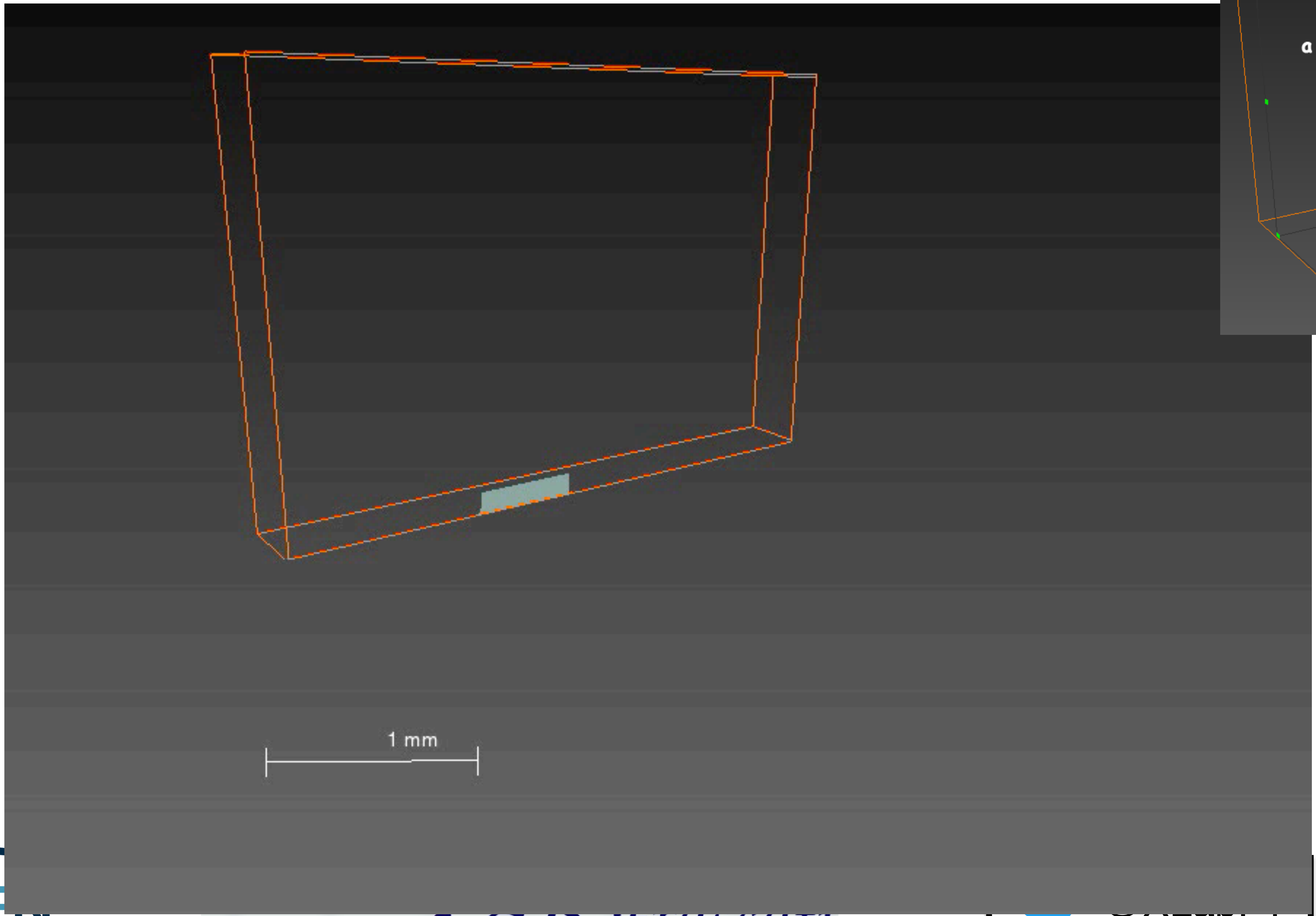
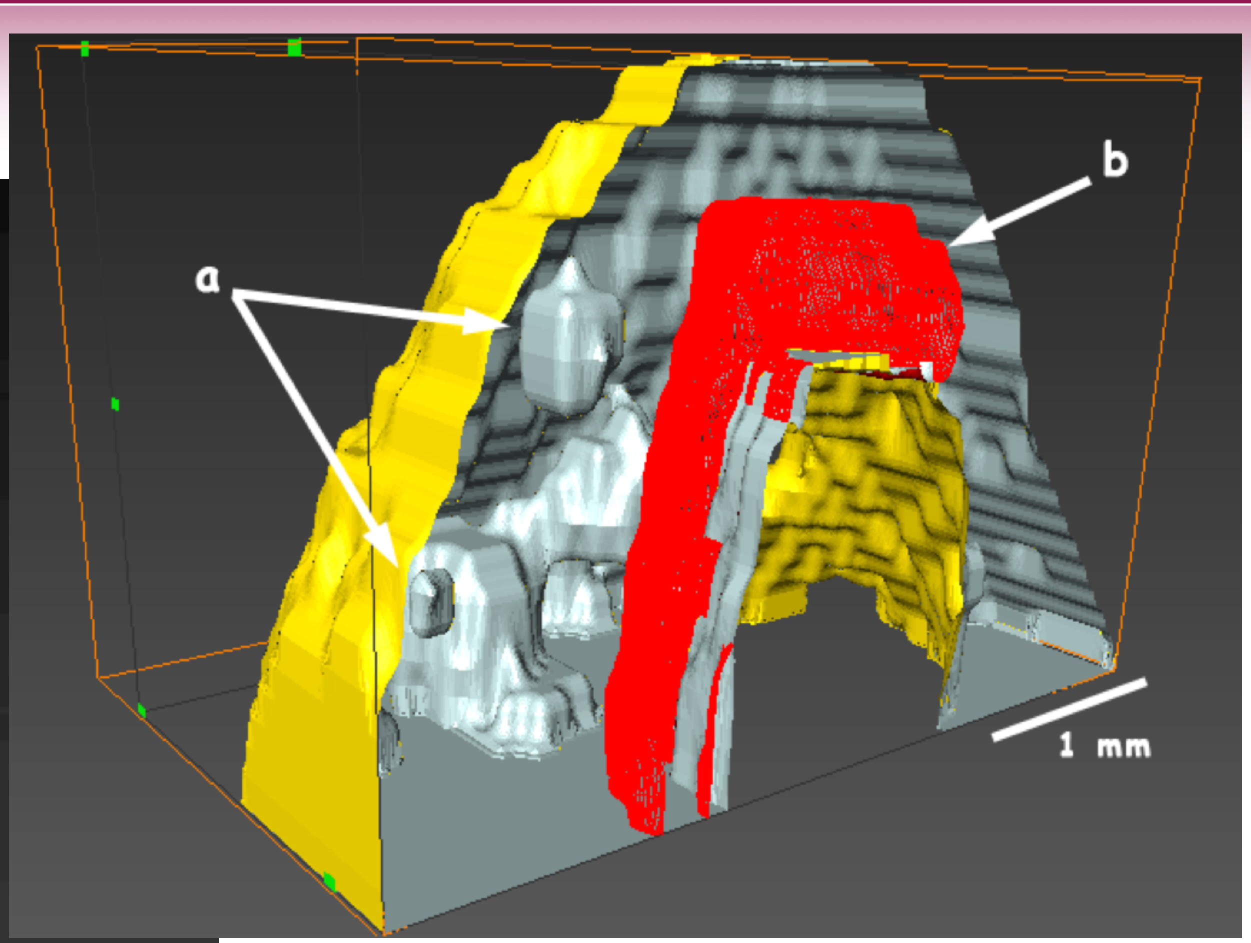
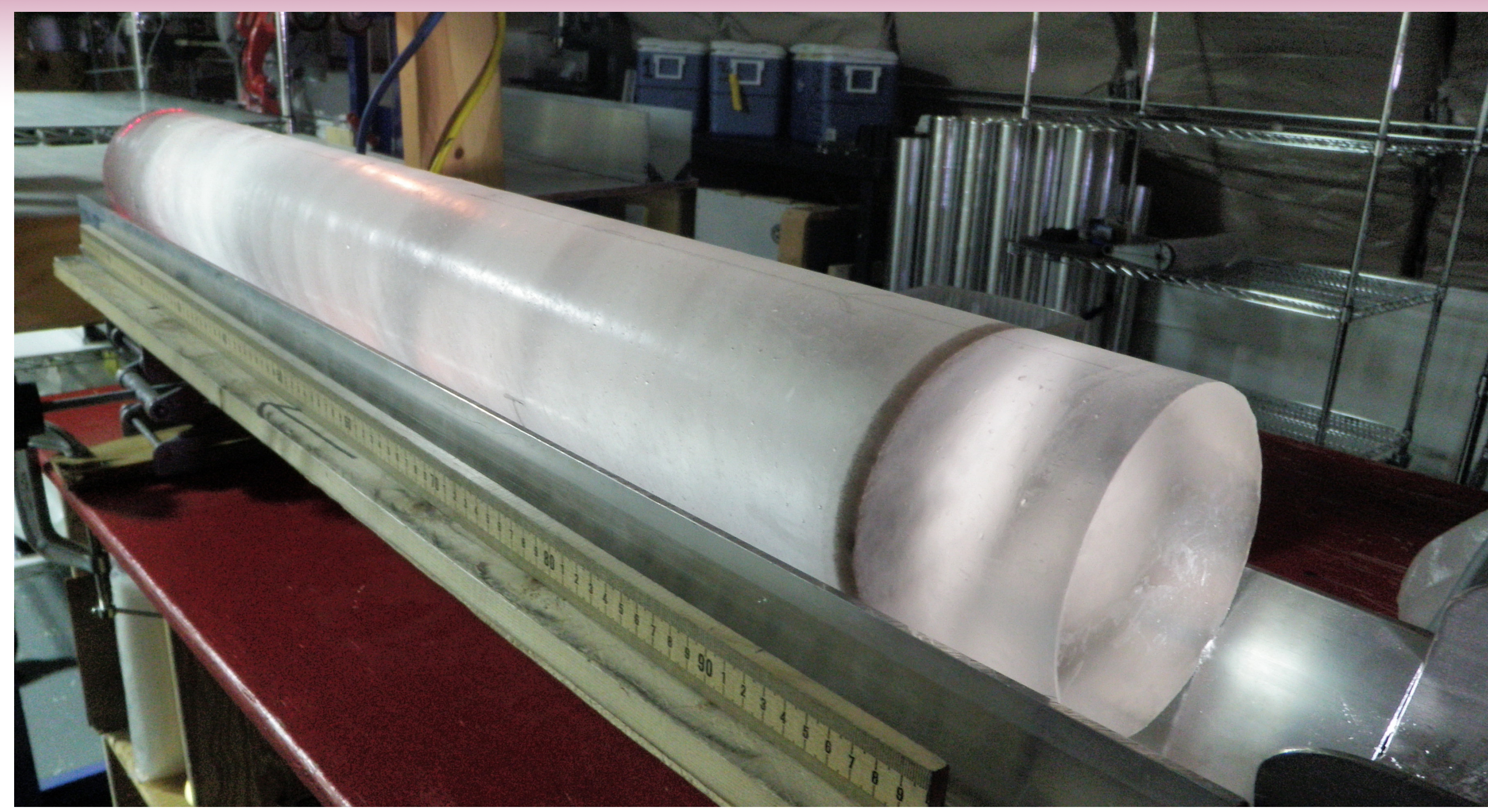
XChannel x-ray technologies

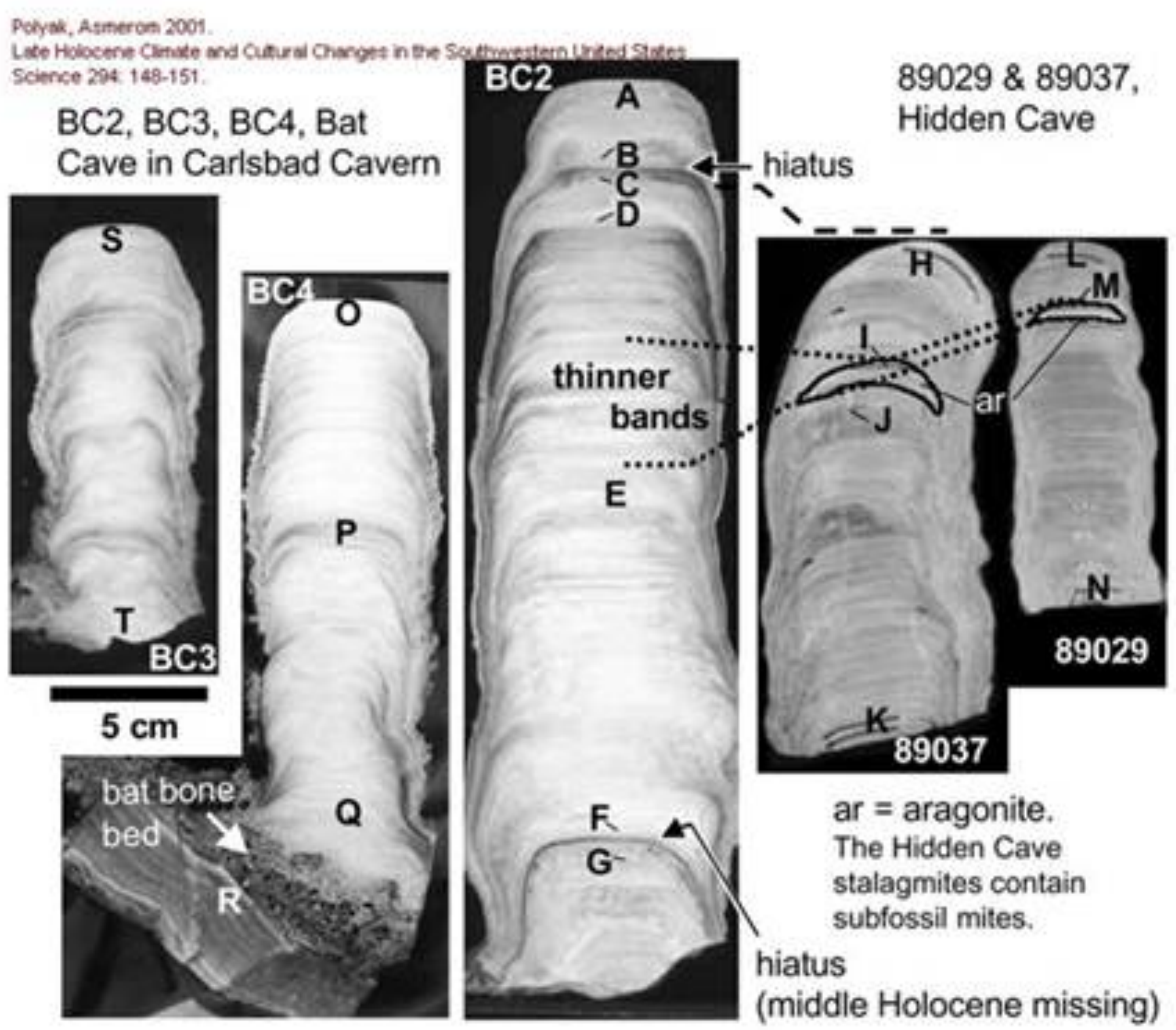
3D Color Tomography

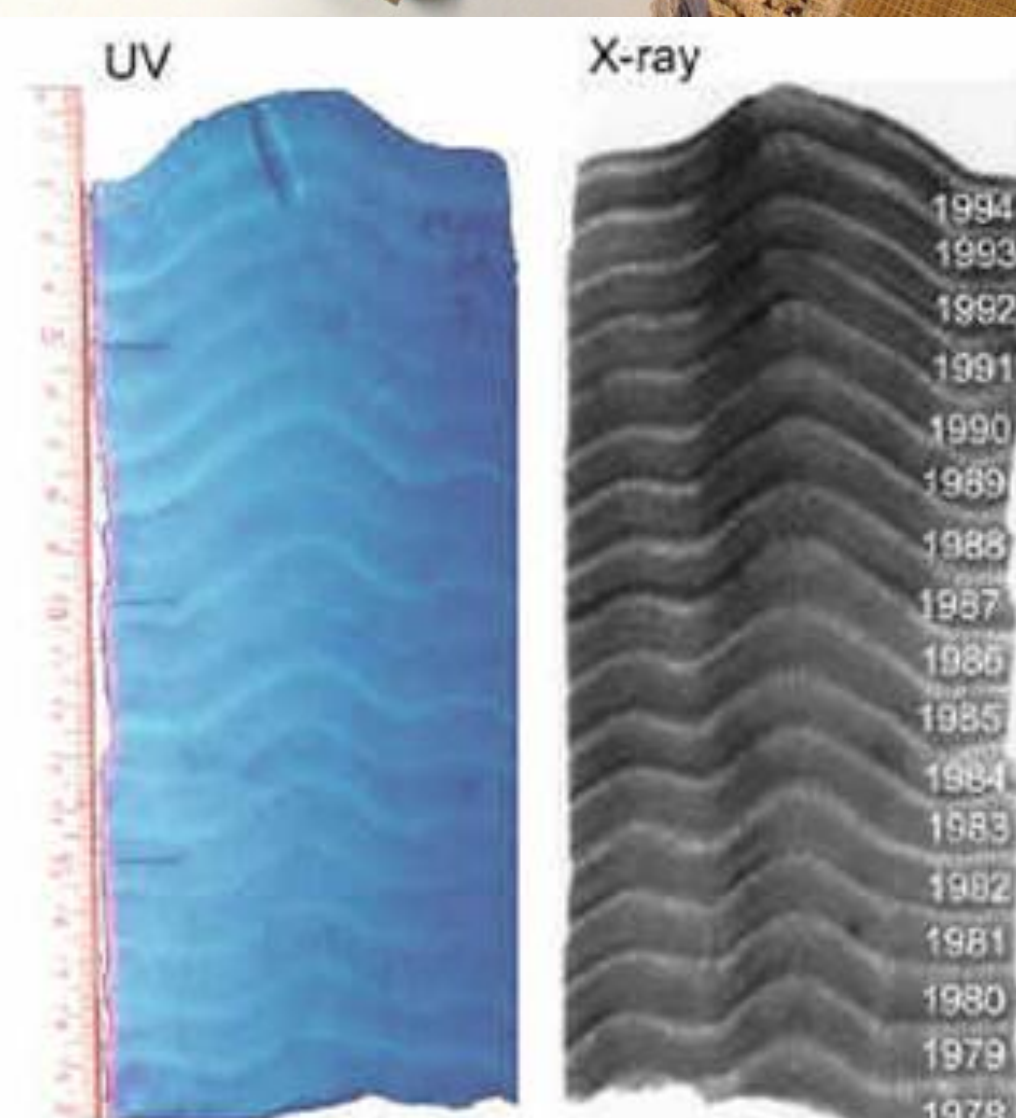




Studies on Natural Archives

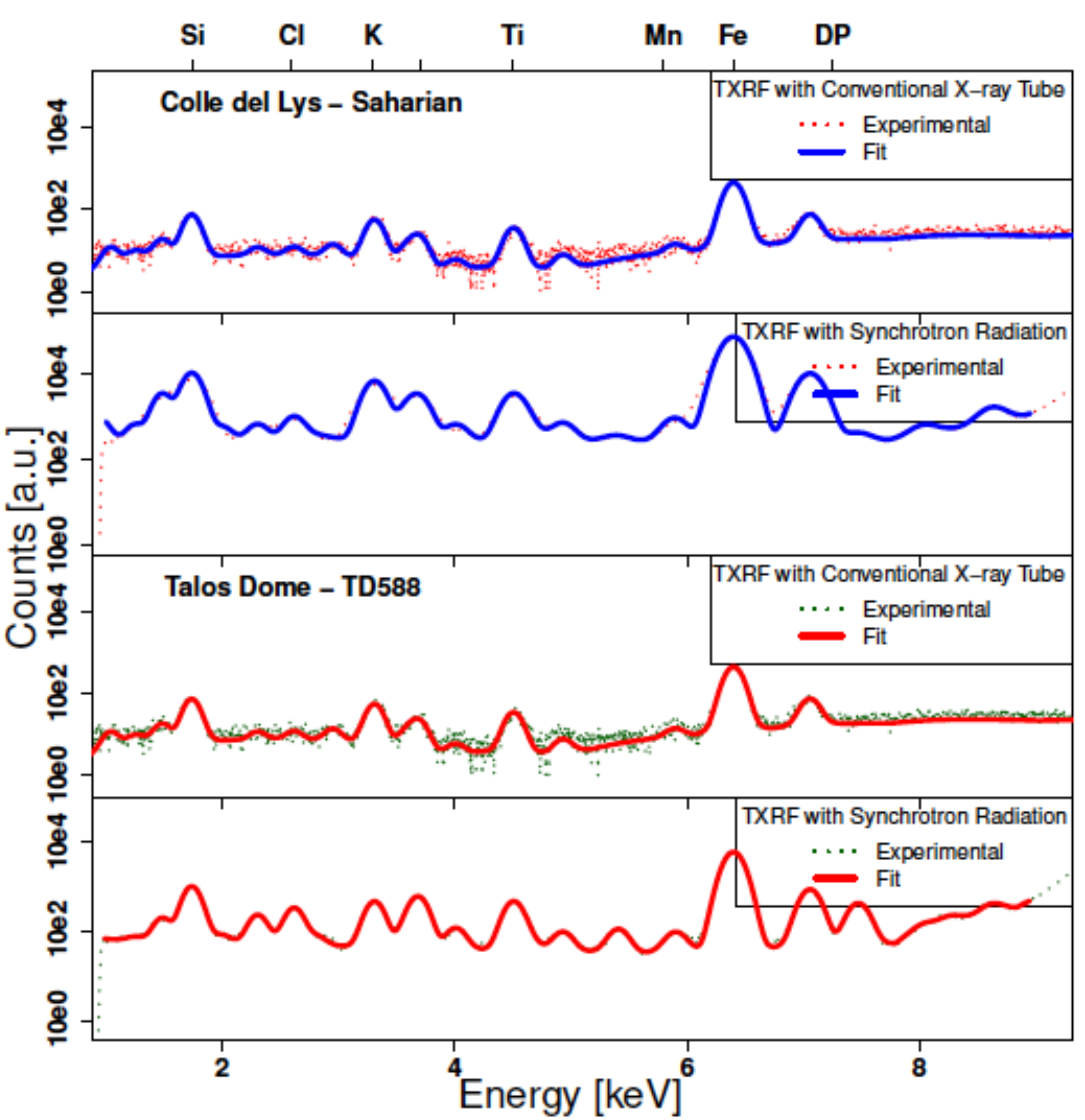


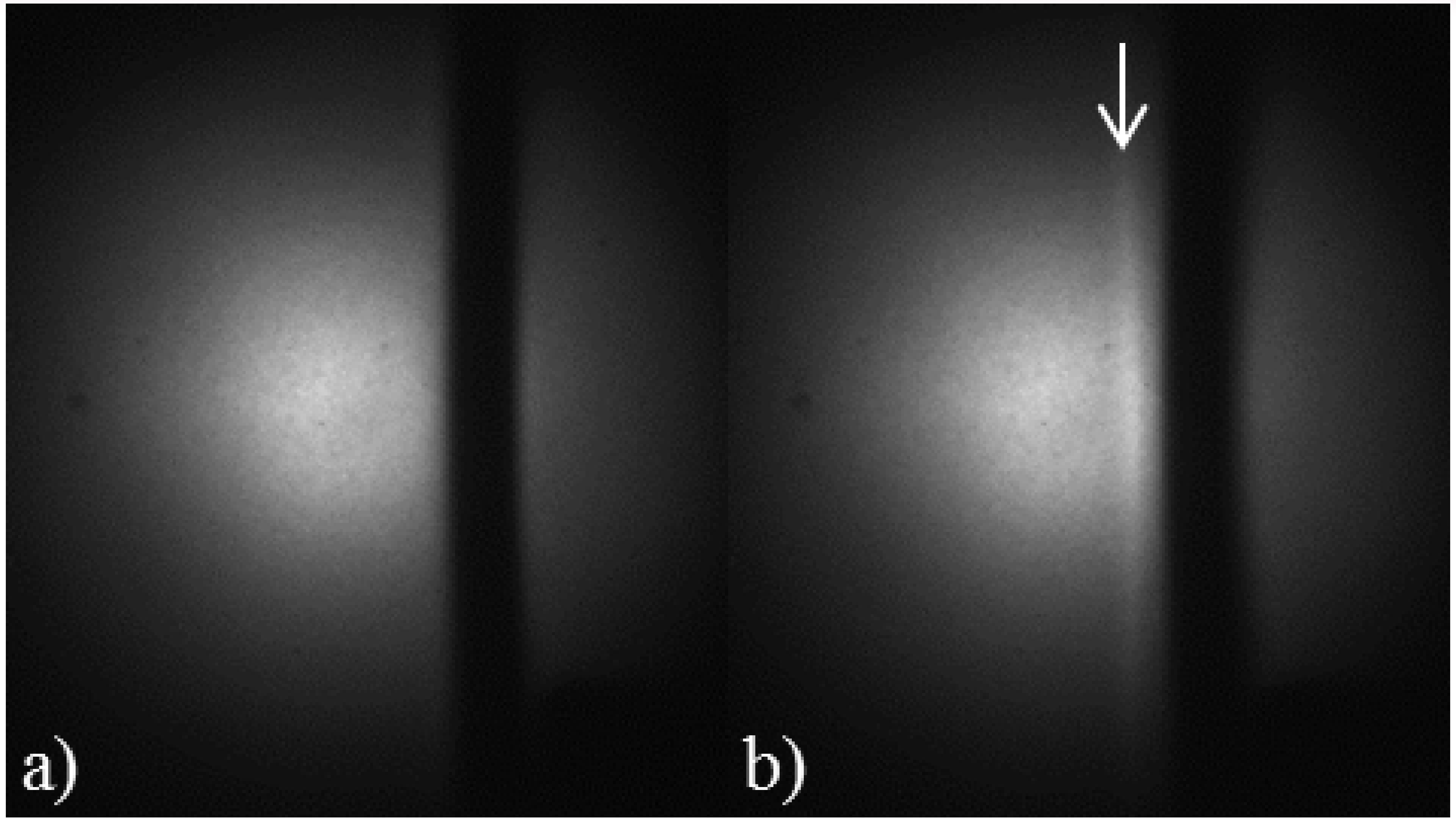


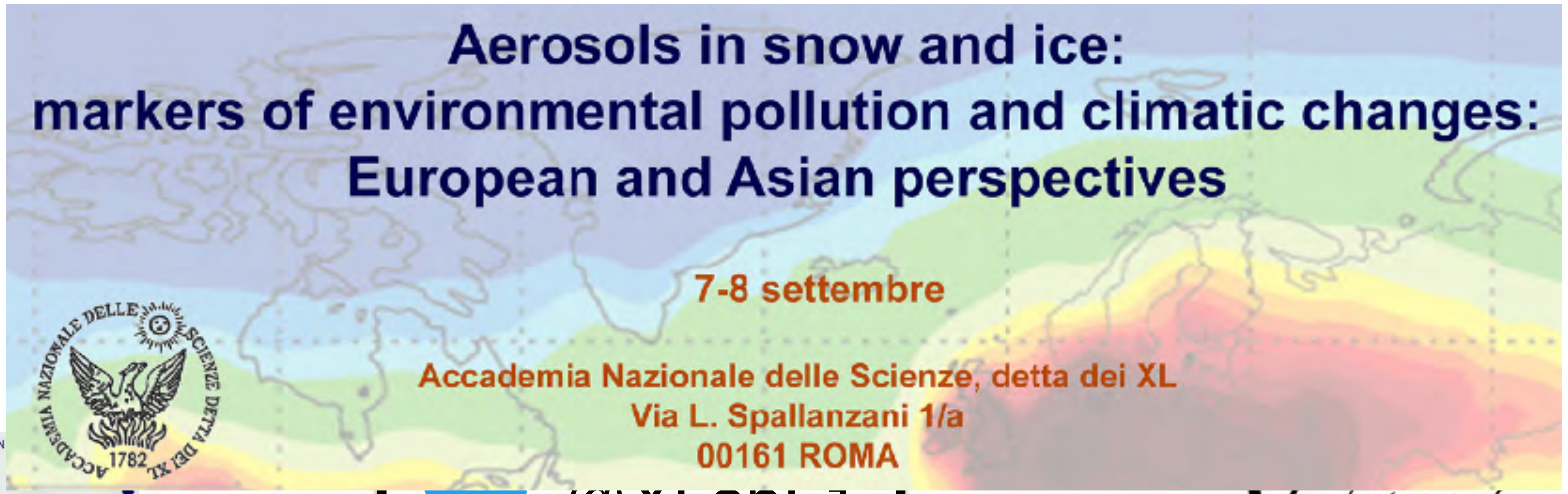


Courtesy of Dr. Rob Dunbar, Stanford University

TXRF @ XlabF - Ice Archives







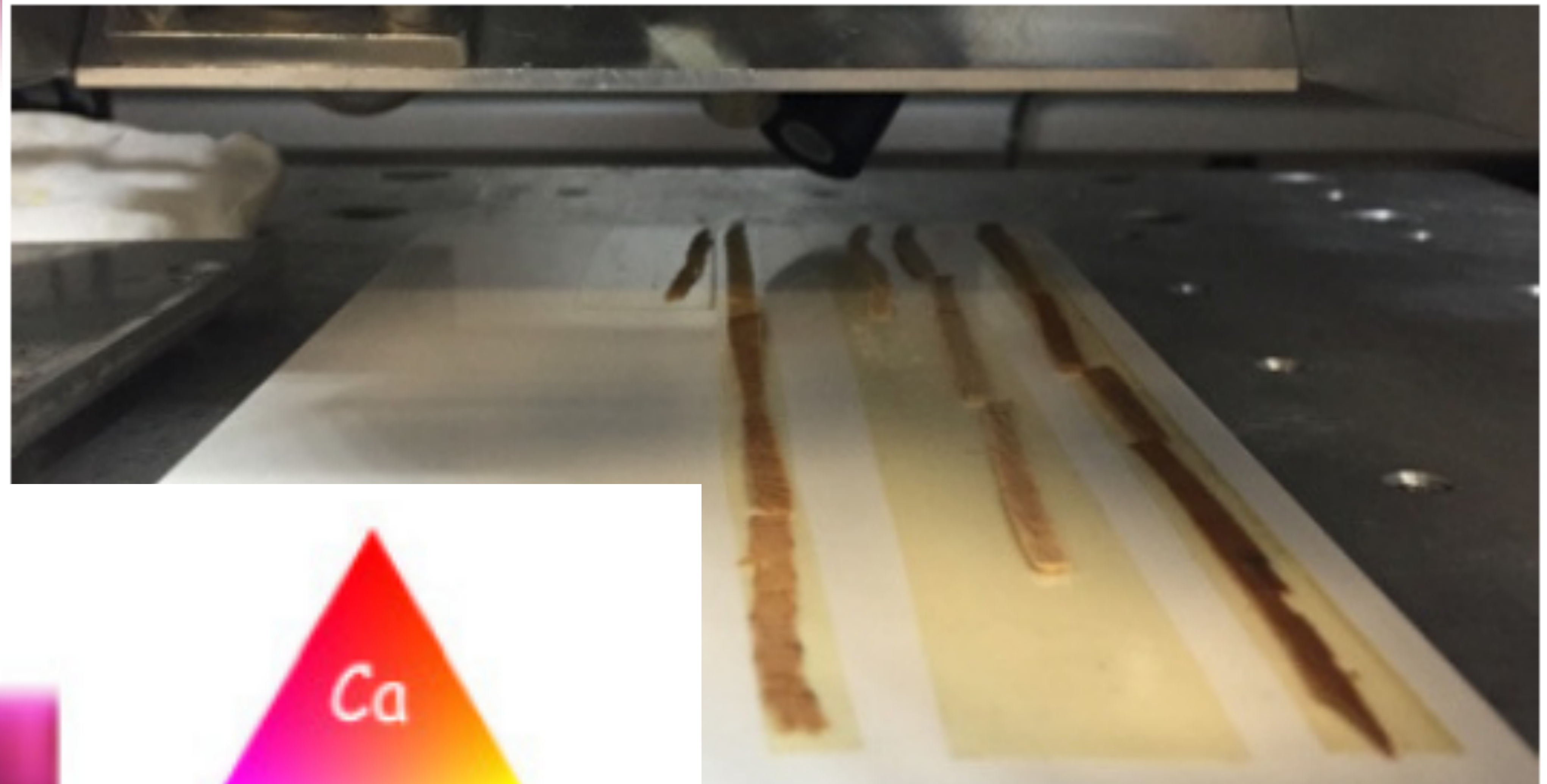
Aleppo pine - Tree Archives

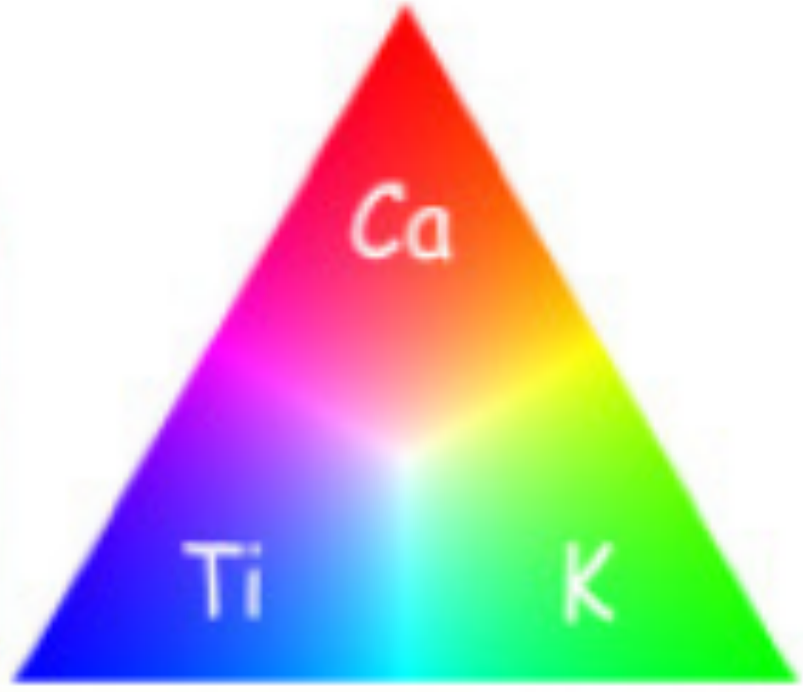
MUSE - GM

- scan XY
- X = 300 mm
- Y = 1 mm
- Δx=100 μm
- Δy=200 μm

- Acq. time = 5 sec / point
- 45 kV
- 0.8 mA

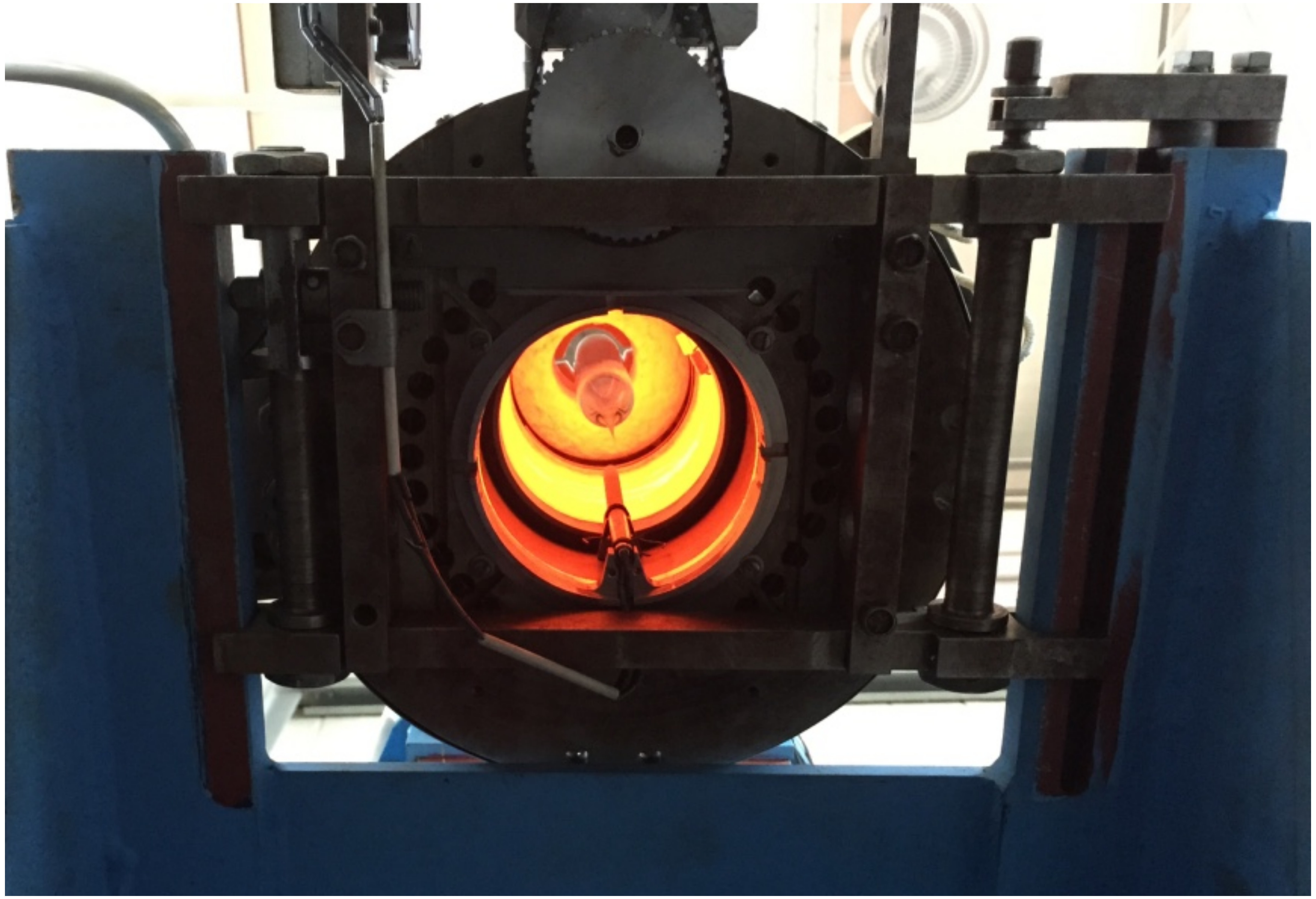
Aleppo pine - Tree Archives





XChannel Techn. - PolyCO Production

- Technological Polo @ LNF
- 3 machine for drawing lens
- 2nd and 4th generations technologies
- full-lens, semi-lens, straight, condenser, monocapillary
- the unique prototype for 5th polycapillary optics (in progress)



XChannel Techn. - PolyCO Production

Typologies
- Full PolyCO Lens
- Semilens PolyCO
- Straight PolyCO
- Full-Semi MonoCO lens
- Single Capillary (shaped - full, semi - straight)

Focal Data	
Focal distance	30- 80 mm
Focal spot (Full Lens)	60-90 μm

Dimensions single channel
- 3-10 μm (PolyCO IV Gen.)
- >20 μm (MolyCO)

Energy range
- PolyCO IV Gen. -> 3-40 keV
- MonoCO -> 1-5 keV

Transmission
- 40-70% 8 keV (PolyCO IV Gen.)
- 20-40% 17 keV (PolyCO IV Gen.)

MUSE

XChannel Techn. vs. Other Companies

MUSE

Who’s @ XLab Frascati

- Frascati (INFN - LNF)
  - Prof. S.B.Dabagov (resp. XlabF)
  - dr. D. Hampai
  - dr. V. Guglielmotti
  - dr. G. Cappuccio
  - E. Capitolo (tec.)
  - dr. A. Marcelli

- ENEA
- Univ. La Tuscia
- Tomsk Polytechnic University / Univ. State of Tomsk
- Univ. Roma La Sapienza
- Univ. Milano Bicocca
- Univ. Roma3
- CNR - IM
- Mephi - Moscow
- De.Tec.Tor. s.r.l.
- PN Detector

@XLabF1

follow us…

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MUSE - GM

thank you
for attention

LABORATORI NAZIONALI DI FRASCATI

Xlab-Frascati

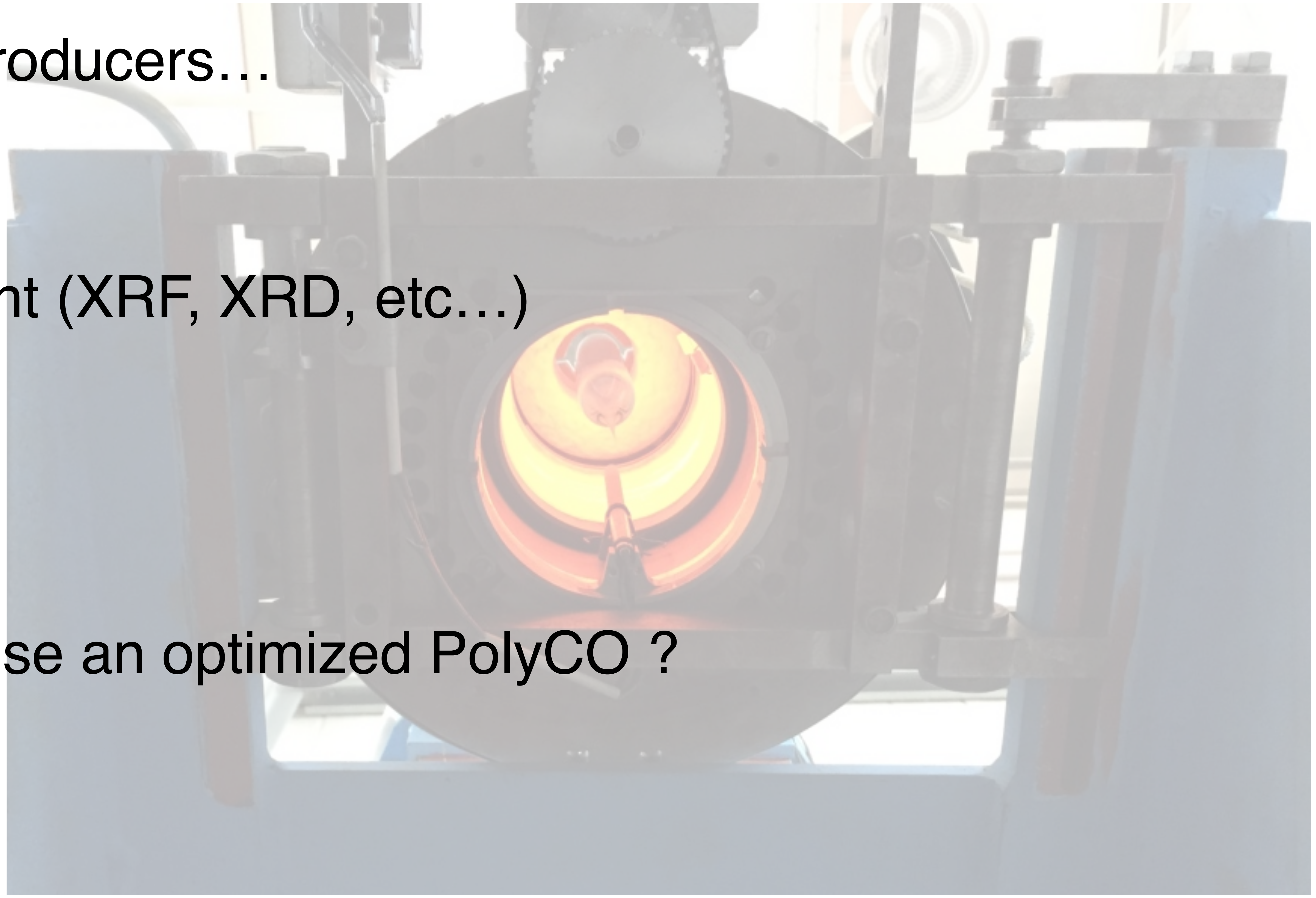
XChannel x-ray technologies

how to choose a PolyCO

we are polycapillary optics producers…

- Which kind of experiment (XRF, XRD, etc…)
- Principal characteristics

→ How to choose an optimized PolyCO ?



how to choose a PolyCO

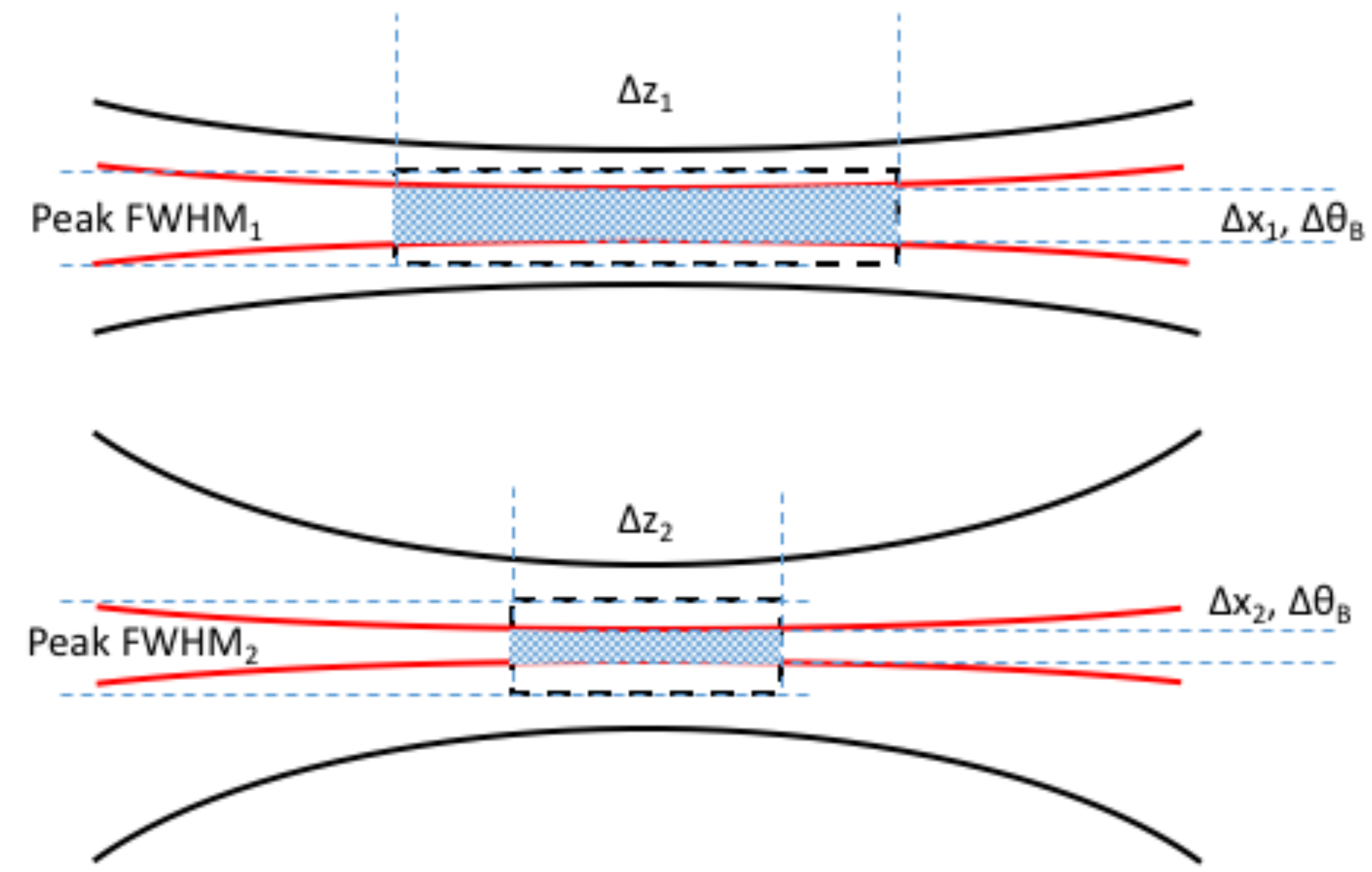
Δx (=Δy for symmetry) is the transversal section dimension of the trajectories with divergence less than the expected maximum allowed divergence $\Delta\theta_B$, while the FOV is determined by Δz.

So the Total Flux in a slice dz is

$$I(dz) = \int_{\Delta x} \int_{\Delta\theta} \rho(dz) d\theta dx$$

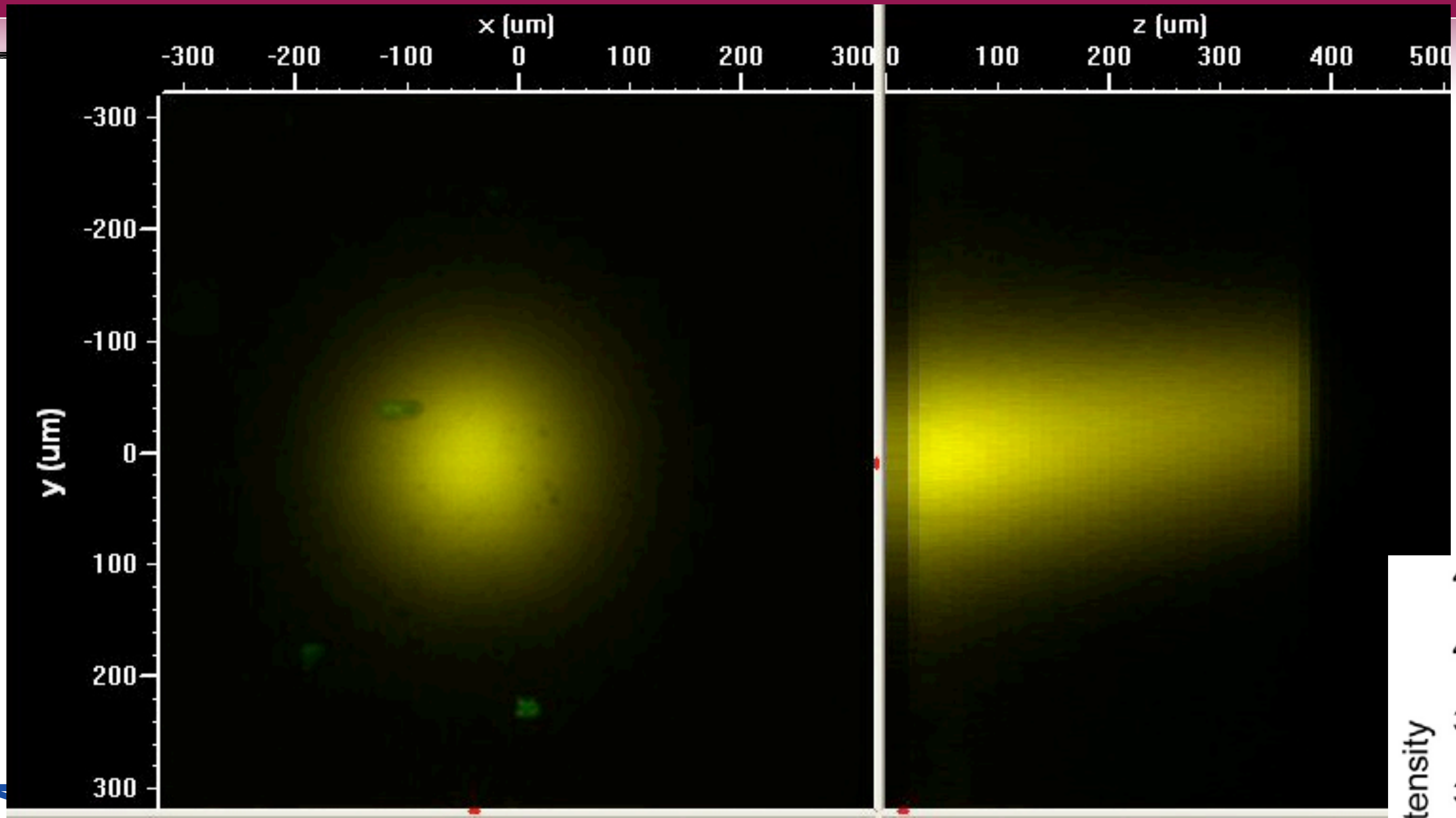
Approximated to:

$$I_{approx} \approx 2\pi N_{photons} \Delta x \Delta z$$

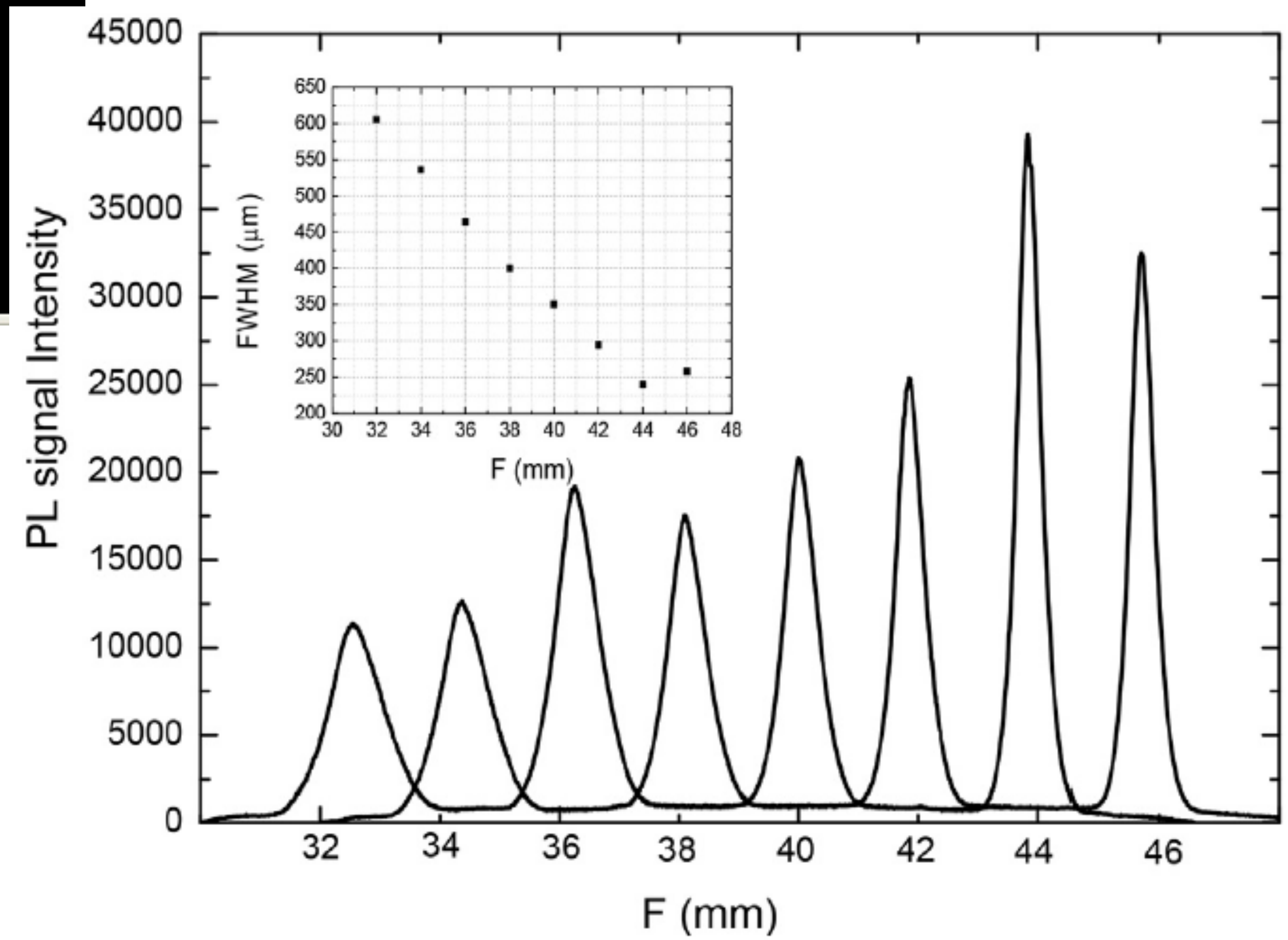


D. Hampai et al., in prep. (2018) to submit to Optics Letters

High Resolution Imaging - Detector LiF based



3D reconstruction performed by CLSM software of the CCs fluorescent volume (640 μm x 640 μm x 500 μm) produced by a the focused X-ray beam along LiF crystal thickness



Graph of the intensity profiles of photoluminescence signal along X direction of the focused beam detected on LiF crystal at different distances F.

F. Bonfigli et al., Opt. Mat. 58, 398-405 (2016)