# Advanced Studies on the PolyCO Optics use at XLab-Frascati

dr. Dariush Hampai

Channeling 2014
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# XLab Frascati Collaboration Network

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- Prof. S.B. Dabagov (Resp.)
- Dr. D. Hampai
- Dr. G. Cappuccio
- Dr. A. Liedl
- Dr. C. Polese
- Ing. F. Lucibello
- Dr. A. Marcelli

**Detectors**

INFN - ENEA - CERN - Univ. Tomsk

**X-ray Spectroscopy – X-ray Imaging**

INFN – Diamond Light Source - ENEA – University of Rome "Sapienza" - CNR – University of Bicocca – University of Florence – University of Minsk - Lebedev Physical Institute

**Novel Source – Nanoray (Eur. Proj.)**

Labor, University of Rome "Sapienza" - University of Rome "Tor Vergata"

INFN Istituto Nazionale di Fisica Nucleare

Russian Academy of Sciences P.N.Lebedev Physical Institute LPI

diamond

LABOR

CERN

ISMN Istituto per lo Studio dei Materiali Nanostrutturati

KIT Karlsruhe Institute of Technology

Università degli Studi di Milano Bicocca

DISAT

CADARACHE

SAPIENZA Università di Roma

ENEA Centro Ricerche Frascati

Agenzia nazionale per le nuove tecnologie, l'energia e lo sviluppo economico sostenibile

Laboratori Nazionali di Frascati

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# Main Activity at XLab - Frascati

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**X-ray Optics** – Polycapillary and Compound Refractive Optics

**Material Analisys** - The X-ray Spectroscopy:

- X-ray Fluorescence (normal and total reflection modes)
- X-ray diffraction
- X-ray Imaging
- X-ray Tomography amd micro-Tomography

**Diagnostic Applications**

- X-ray Imaging for large object with high spatial resolution

**Crystal Characterization for hadron beam collimation through crystal channeling**

**Novel technologies and experimental setup**

- Prototype for XRF – TXRF and X-ray Imaging
- X-ray tube based on Carbon Nanotube Cold Cathode

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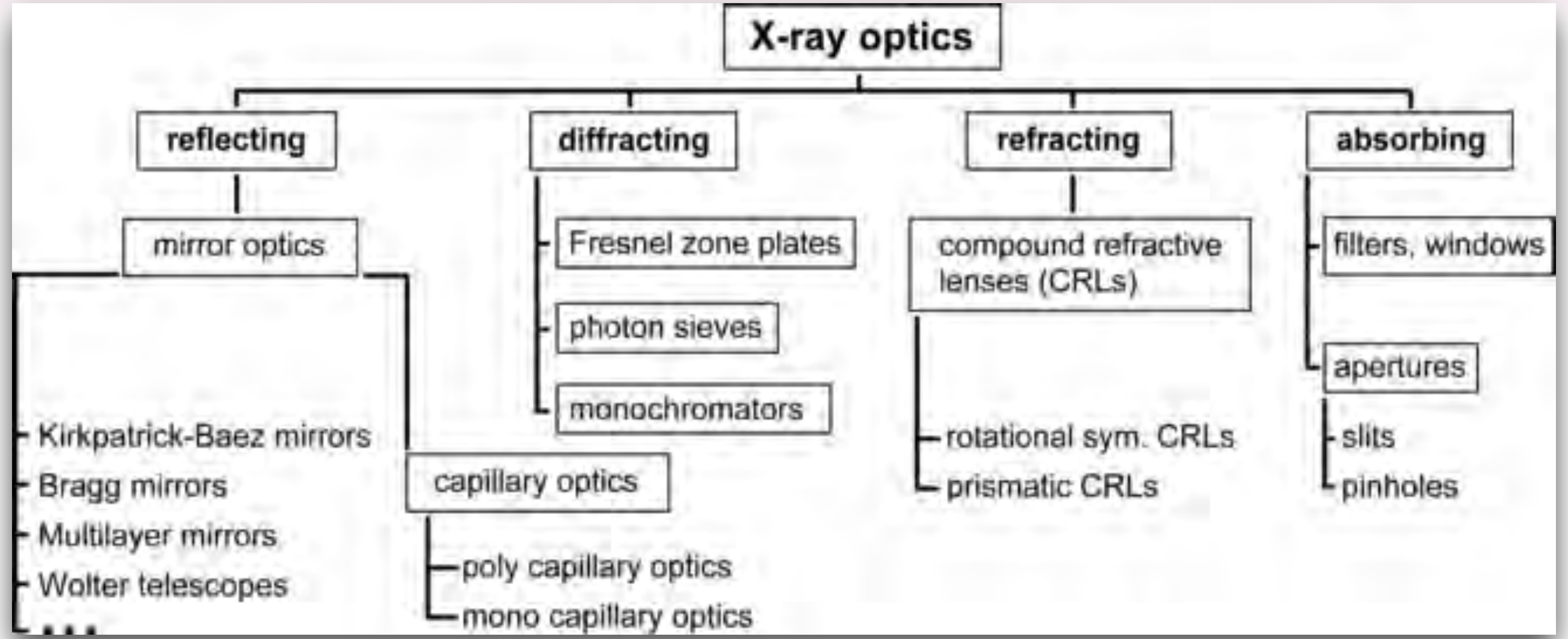
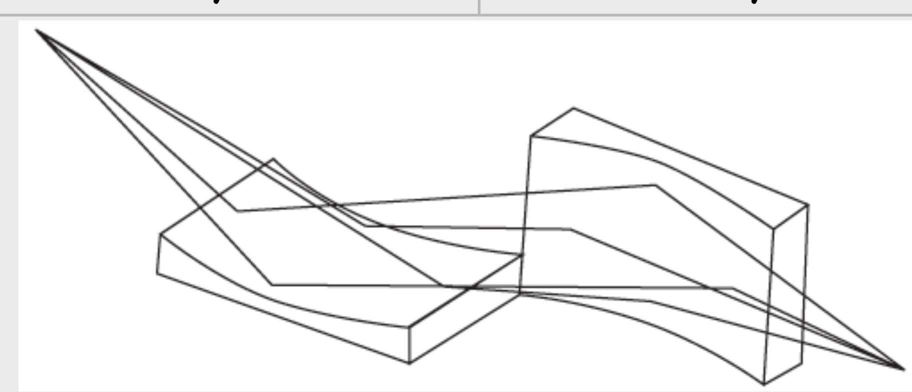
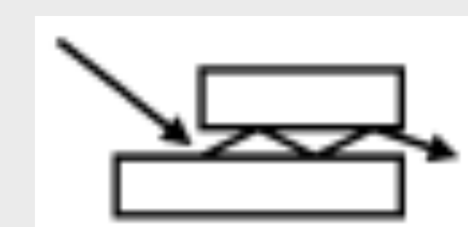
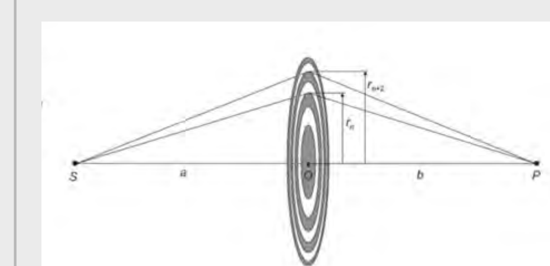
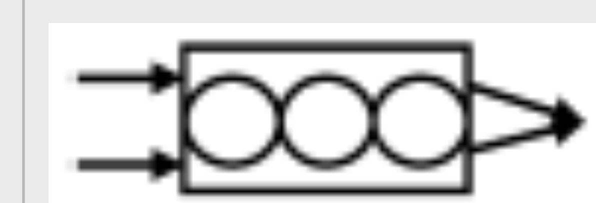
# Overview on X-ray optics




| physical effect | types of optics using this effect |
|---|---|
| reflection | (crystal) mirror optics; capillary optics |
| diffraction | zone plates |
| refraction | compound refractive lenses |
| absorption | windows; filters; pin holes and coded mask telescopes |

# μ-Focusing Optics

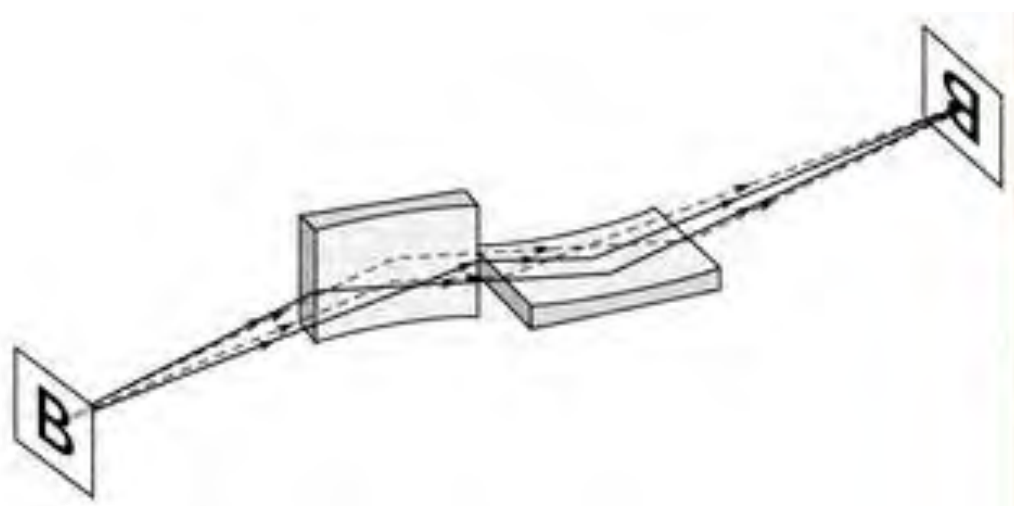
| | Reflective | | | | | Diffractive | Refractive |
|---|---|---|---|---|---|---|---|
| | Kirkpatrick-Baez | | Capillaries | | Waveguides | Zone Plates | Refractive Lens |
| | mirrors | multilayers | multi-capill. | mono-capill. | | | |
| | Kirkpatrik Baez, 1948 | Undewood Barbee, 1986 | Kreger, 1948 | Balaic, 1995 | Feng et al., 1993 | Baez, 1952 | Snigirev et al., 1996 |
| |  | |  |  |  |  |  |
| E | < 20 keV | < 100 keV | < 30 keV | | < 20 keV | < 30 keV | < 1 MeV |
| ΔE/E | white beam | $10^{-2}$ | white beam | | $10^{-3}$ | $10^{-3}$ | $10^{-3}$ |
| Δx | 25 nm | 41 nm | 50 nm | 250 nm | $40 \times 25$ nm$^2$ | 30 nm | 50 nm |
| ref. | H. Minura et al. | O. Hignette et al. | D.H. Bilderback et al. | A. Snigerev et al. | A. Jarre et al. | H.C. Kang et al. | C.G. Schroer et al. |

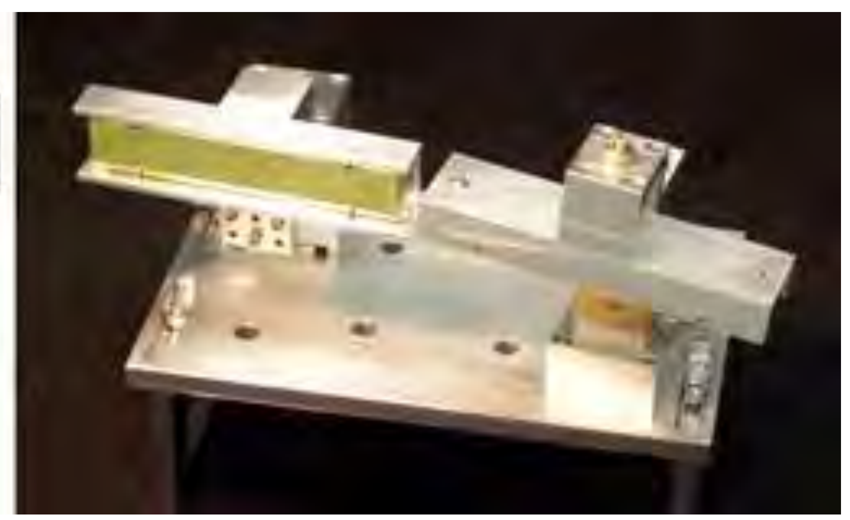
# Reflective Optics - Kirkpatrick–Baez

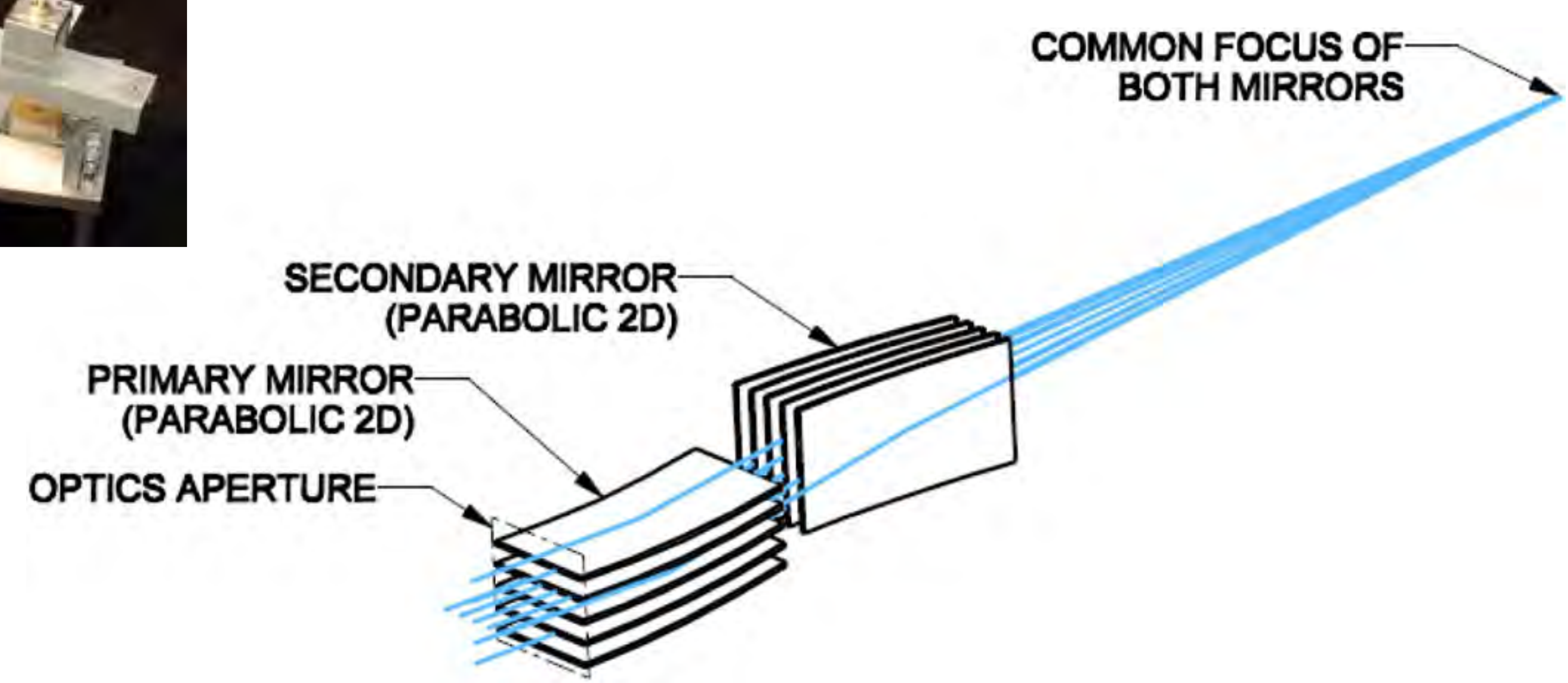


Kirkpatrick-Baez-optics [P. Kirkpatrick, A.V. Baez, 1948] consist of two mirrors. The surface of the first mirror is e.g. aligned horizontally, the second mirror is aligned vertically. In order to achive a common focal point, both mirrors have to be curved elliptically in a way, that leads go the horizontal focus line of the first mirror and the vertical focus line of the second mirror coinciding in the same plane.
KB-mirrors are expensive (up to several 100 k€).

Some example:
AXO Dresden - Radiation Cu Ka < 100 μm and focal length 90 mm
Agilent SuperNova - Beam size: 140 microns

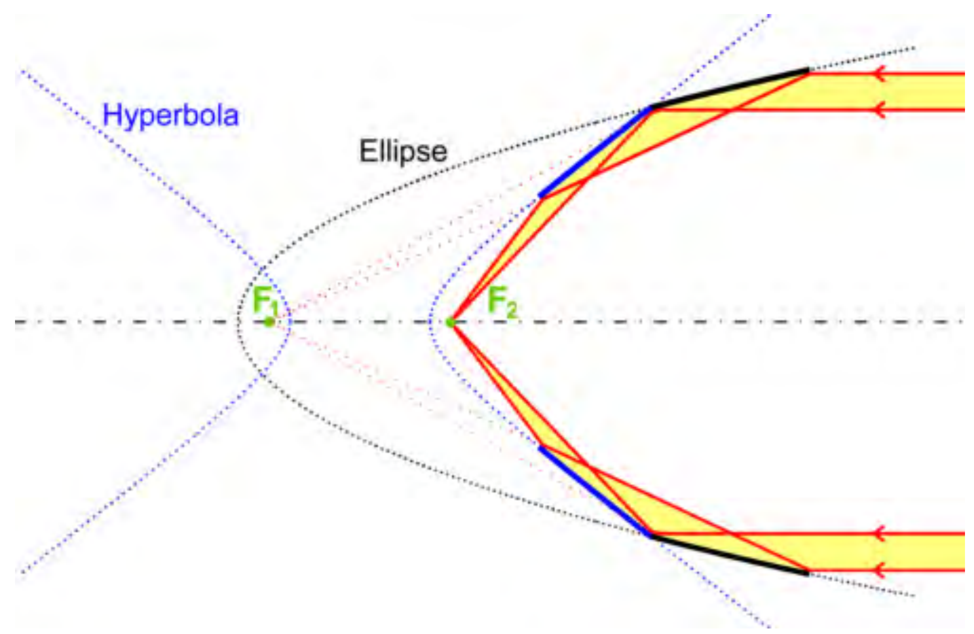




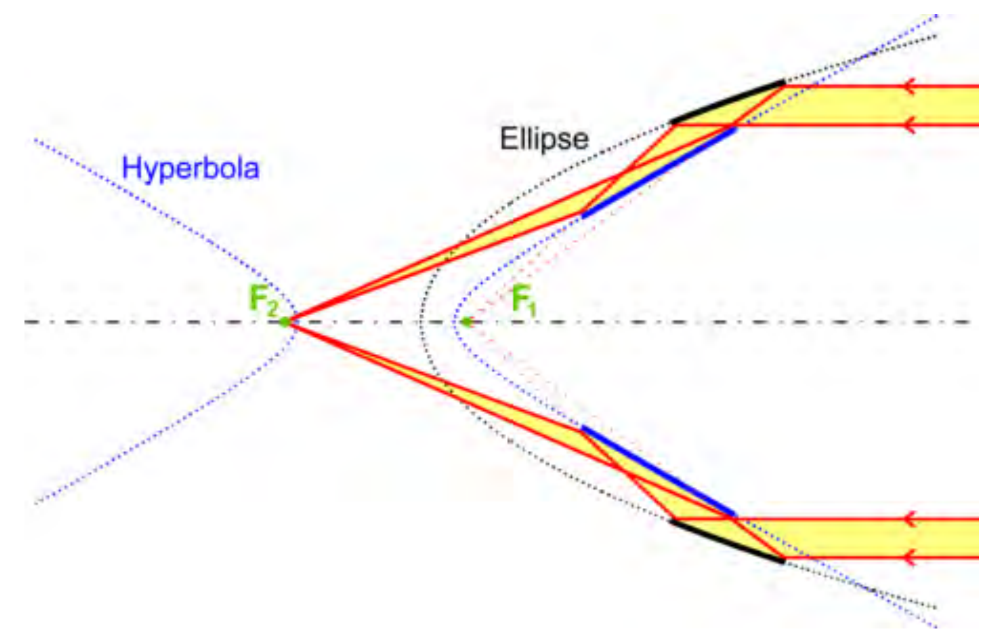


# Reflective Optics - Wolter Optics

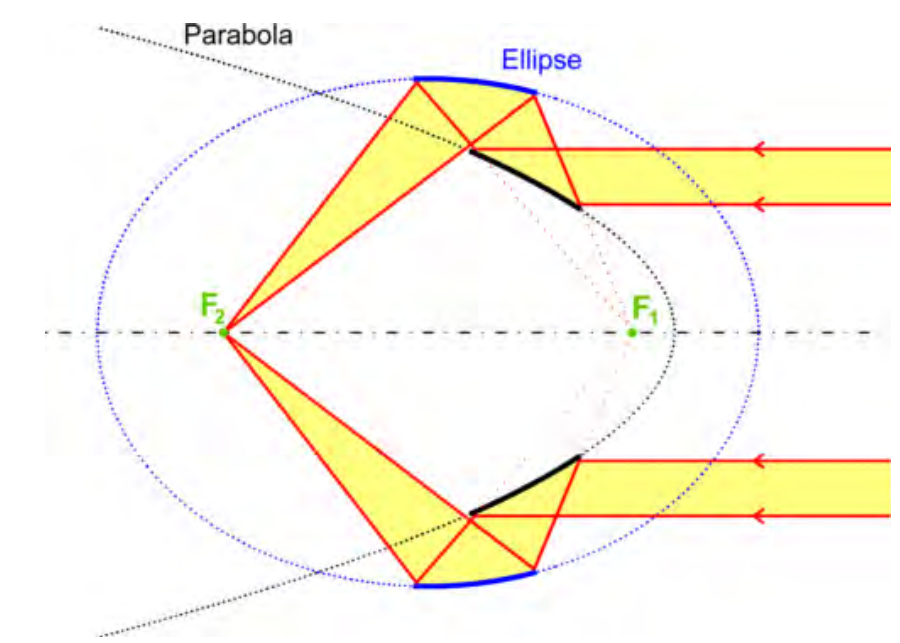
Type I Wolter optics, nowadays, are used for telescopes, and they consist of an elliptical or parabolic mirror followed by a hyperbolic mirror. The mirrors mostly are tubular, rotationally symmetric TER-mirrors. Wolter optics roughly fulfill the above mentioned Abbé criterion and therefore can be used as imaging optics. As the light is only reflected under grazing incidence, a single tubular mirror set does not catch much of the incoming light.




Wolter Optics Type I




Wolter Optics Type II




Wolter Optics Type III

Wolter optics are used in X-ray telescopes in astrophysics like the orbiting X-ray observatories Chandra and XMM-Newton, as well as in the Swift Gamma-Ray Burst Mission.

# X-ray Telescopes based on Wolter Optics

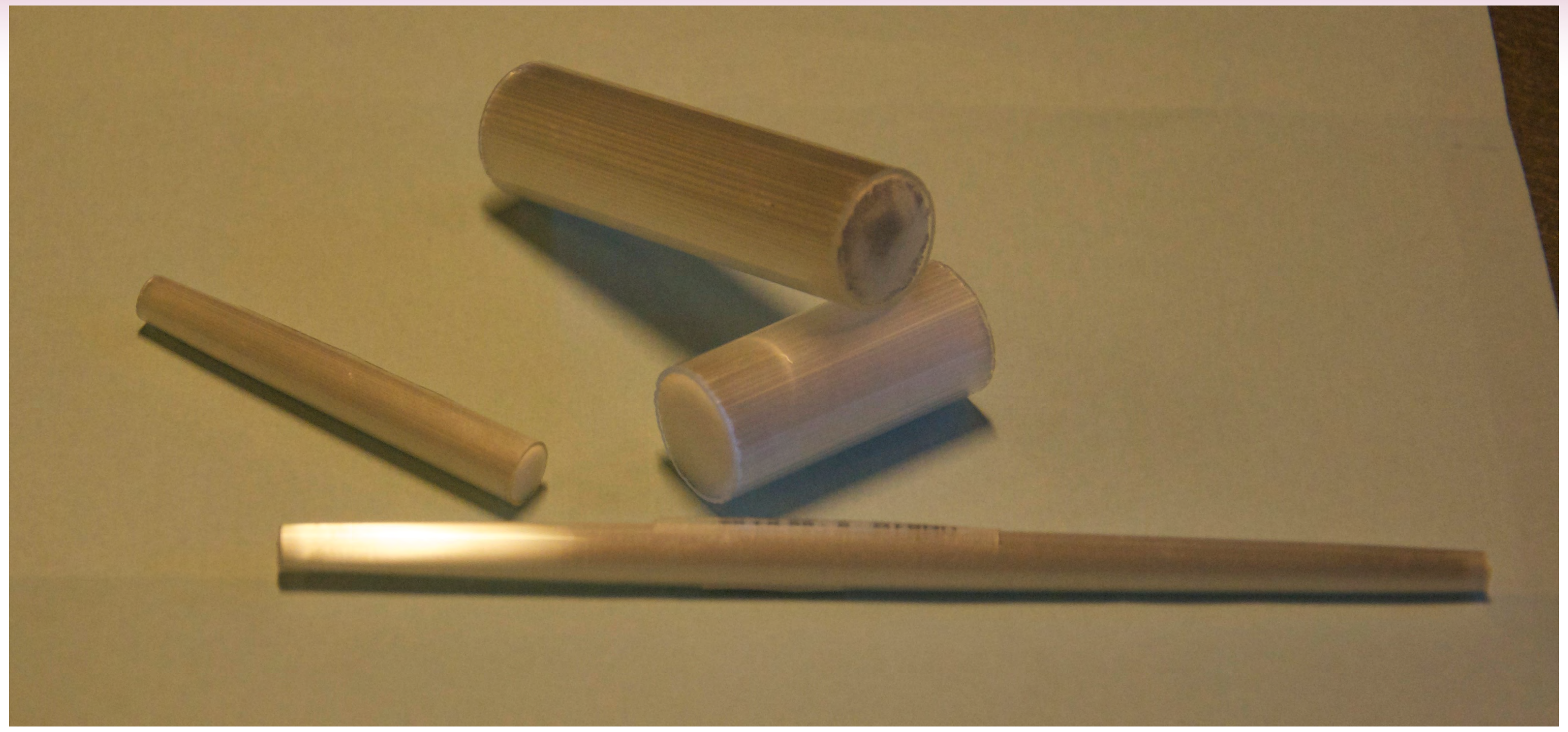
Chandra and XMM Newton

- **Chandra (NASA)**
  Launch: July 1999
  Orbit: 64 hours
- Two Transmission Grating Spectrometers
- Angular resolution ~ 0.5"

- ***XMM-Newton*** **(ESA)**
  Launch: December 1999
  Orbit: 48 hours
- Reflaction Grating Spectrometer
- angular resolution ~ 15"

| Mirror Characteristic | Chandra | XMM |
|---|---|---|
| aperture diameter | 1.2 m | 70 cm one module |
| mirrors | 4 nested | 58 nested |
| grazing angles (arcmin) | 27-51 | 18-40 |
| focal length (m) | 10 | 7.5 |
| mirror coating | Ir | Au |
| highest energy focused (keV) | 10 | 10 |
| on axis resolution | 0.5 | 20 |
| Mirror Weight (kg) | several hundred kilograms | 425 |
| roughness | 1.95 – 3.58 Å | 3.5 – 6 Å |

# Chandra & XMM-Newton vs. PolyCO



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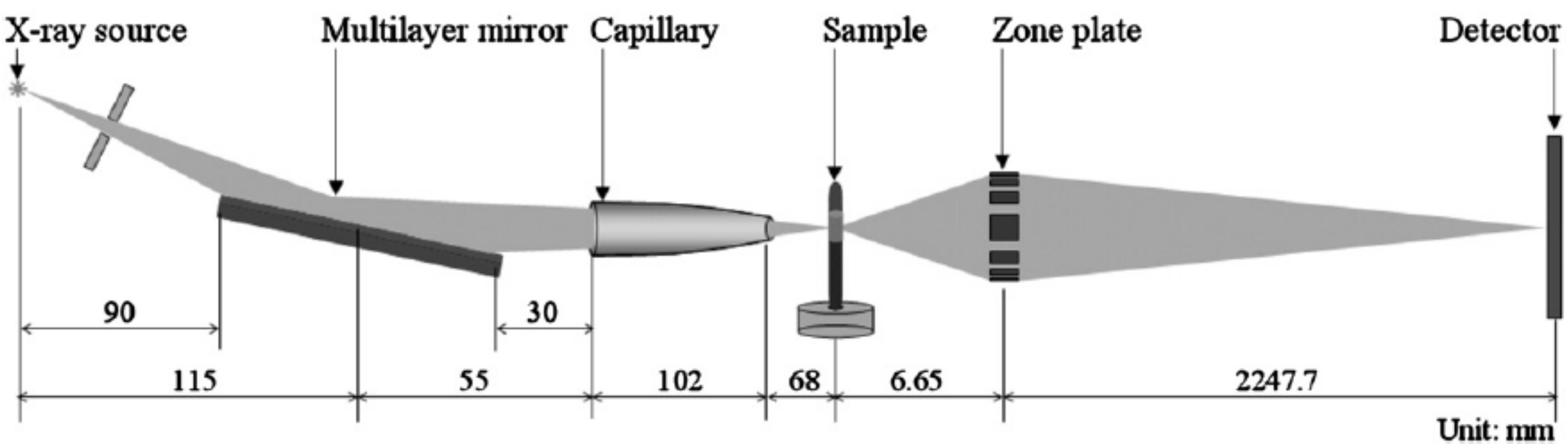
# Diffractive Optics - Zone Plates

In the soft x-ray range FZPs can reach a resolution down to below 20 nm [W. Chao et al. 2005], and sub-100 nm values are routinely achieved. The efficient focusing of hard X-rays is more difficult, since in order to obtain acceptable diffraction efficiencies:

1) the zone plate structures should be made from heavy materials;
2) the required height of the structures needs to be a micron or more.

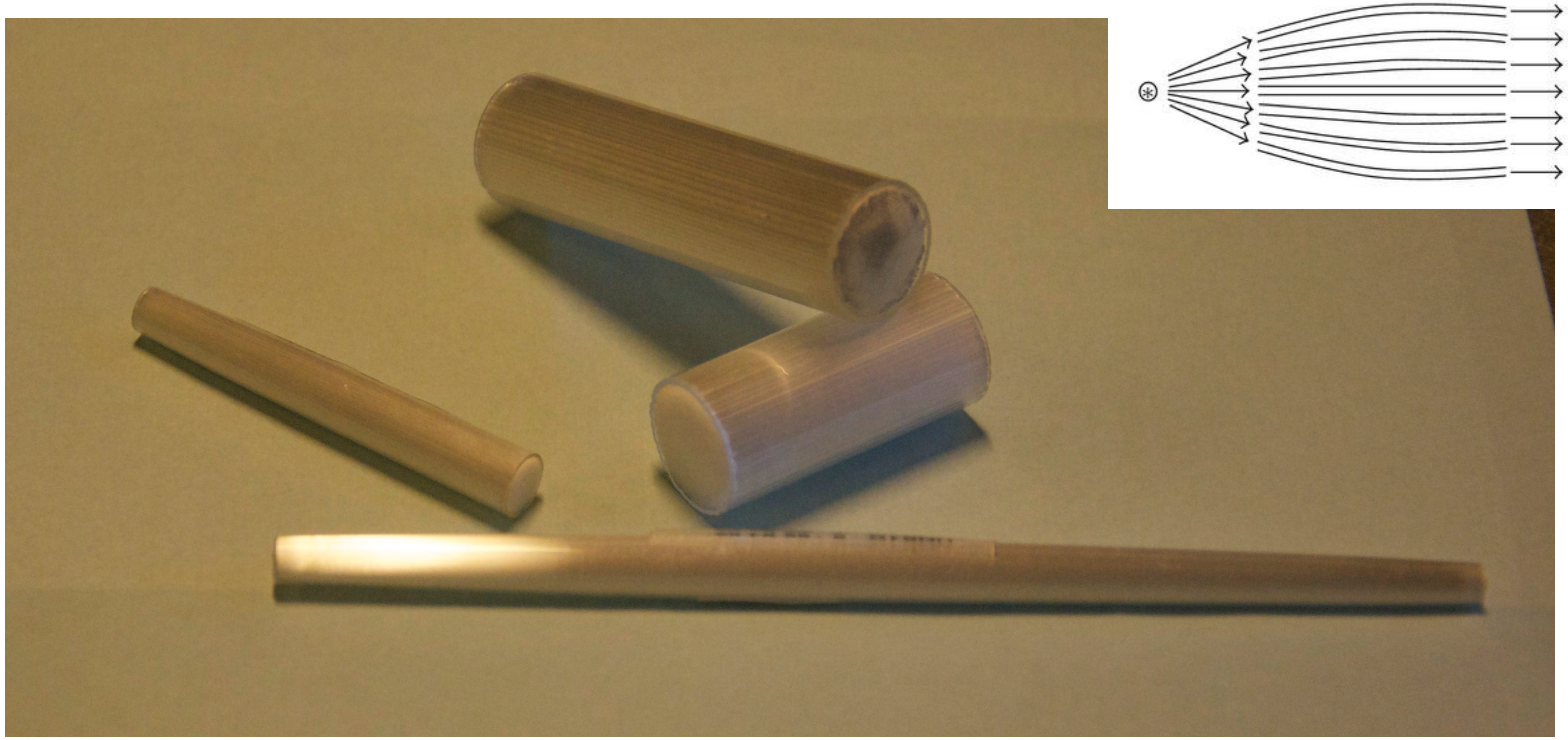
This is the reason why the high resolution potential of FZPs could not be exploited in the hard X-ray regime [B. Nöhammer et al., 2005].

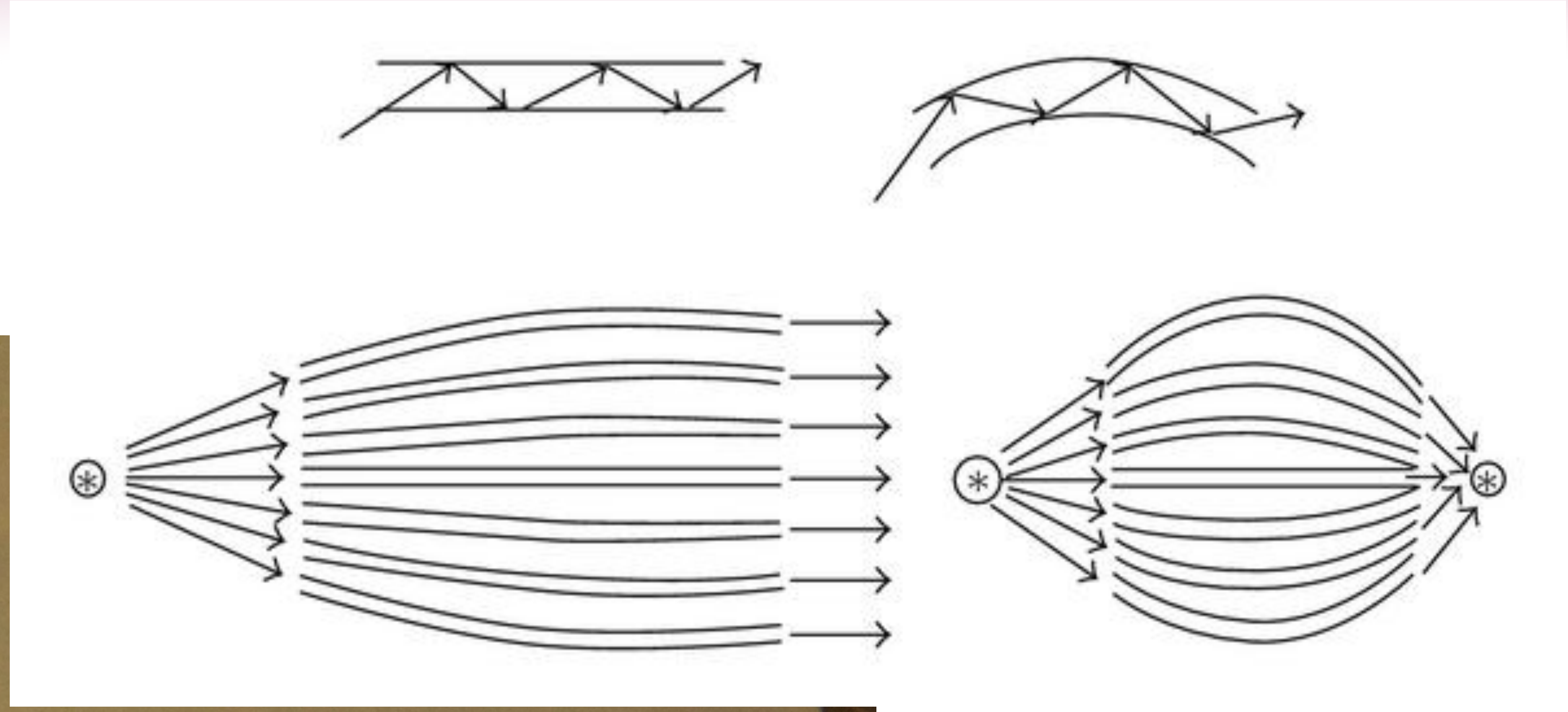
XRadia - True spatial resolution <700 nm
High resolution down to 50 nm is maintained for imaging of samples within in situ devices
Switchable field-of-view ranging from 15 to 60 μm




Chon et al., 2012

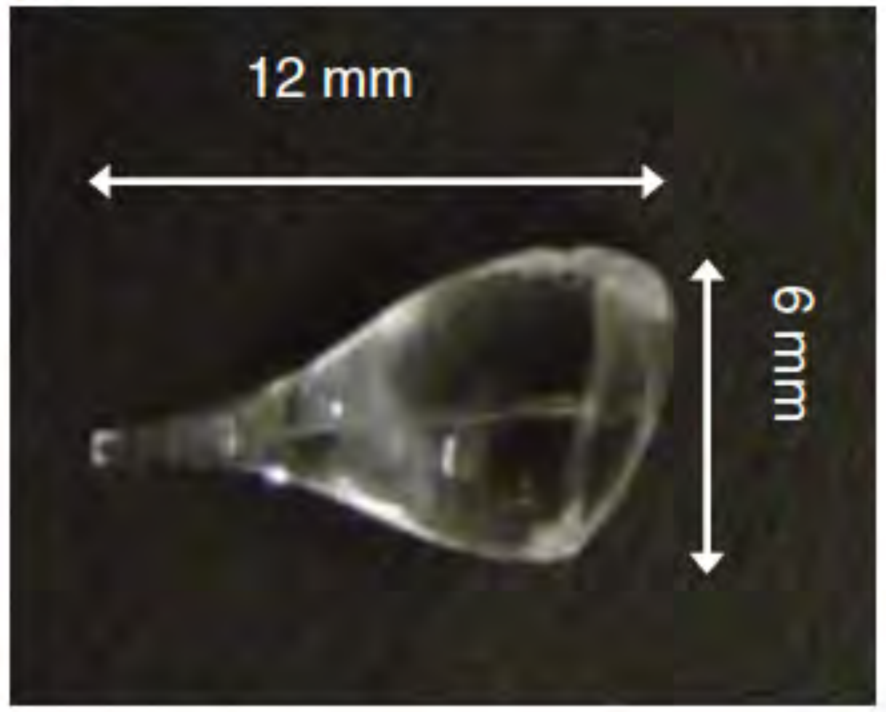
# Reflective Optics - (mono/poly) Capillary Optics

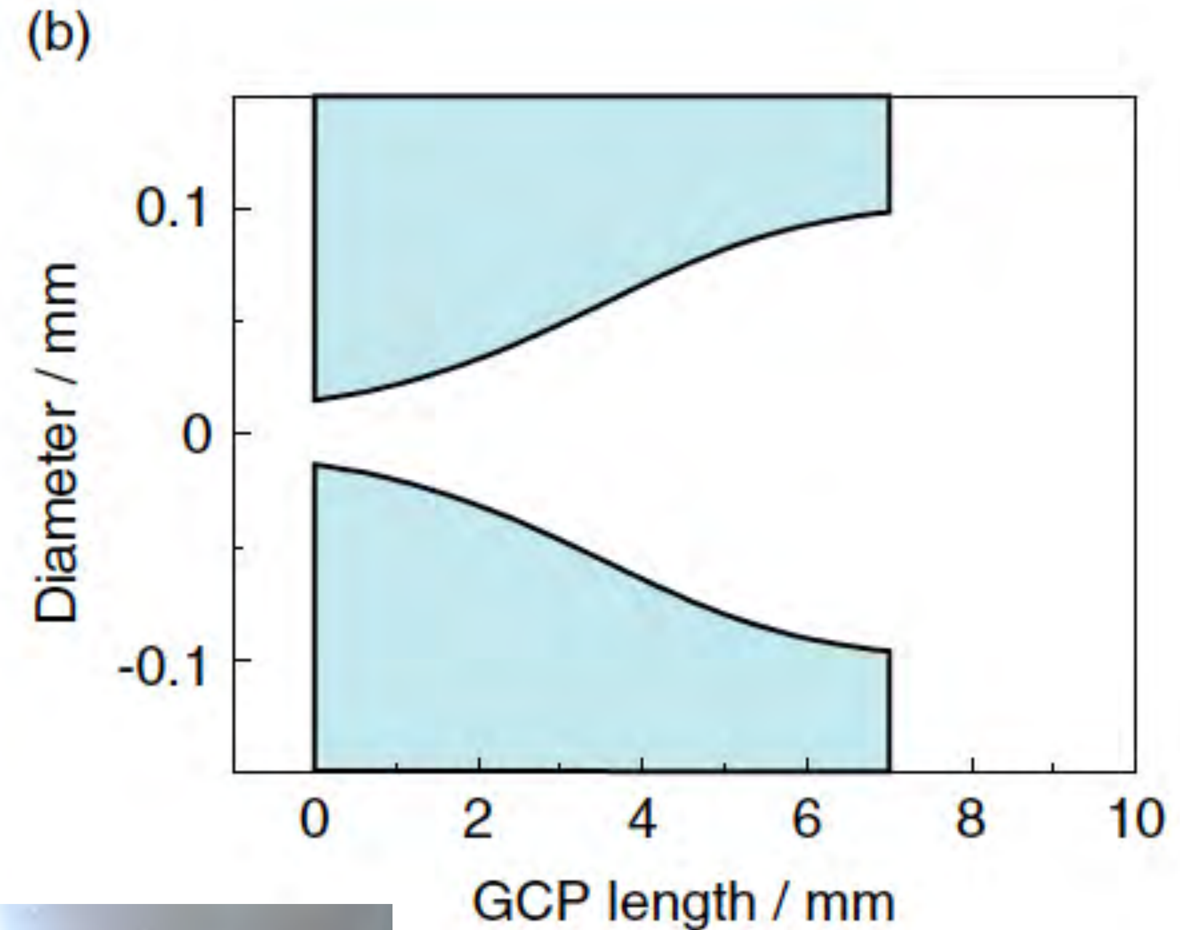




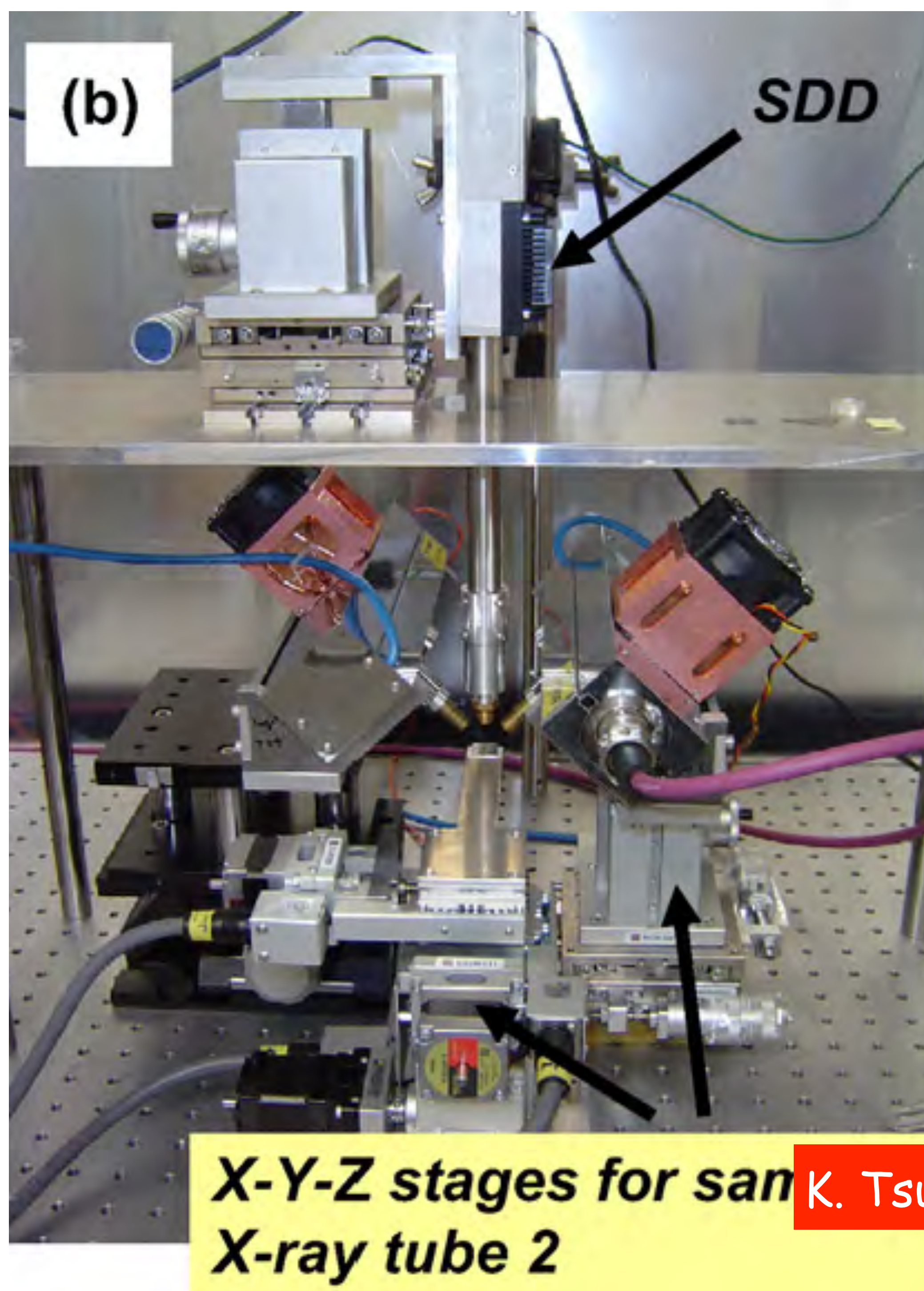
R. Hudec, 2010

# Reflective Optics - (mono/poly) Capillary Optics

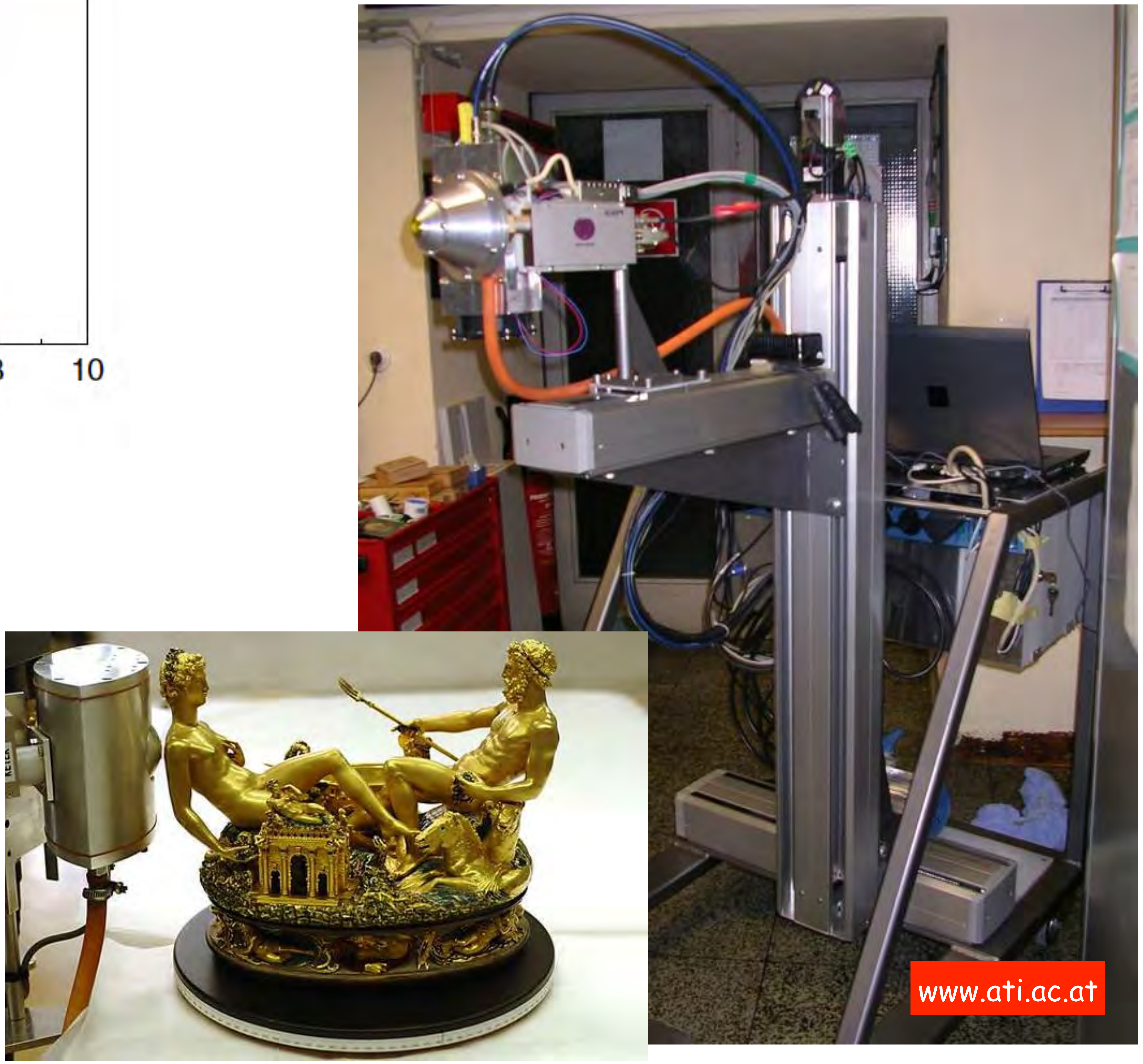



A. Matsusada et al., 2008




K. Tsuji et al., 2007



# XLab-Frascati

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- High Resolution Imaging
- $\mu$CT
- X-ray Optics Characterization
- Detector Characterization
- Study on Novel Sources

RXR - rainbow X-ray

XENA - X-ray Elemental station for Non-destructive Analysis

- $\mu$XRF (2D and 3D mapping)
- TXRF
- Detector Characterization
- in future: High Resolution Imaging and $\mu$CT

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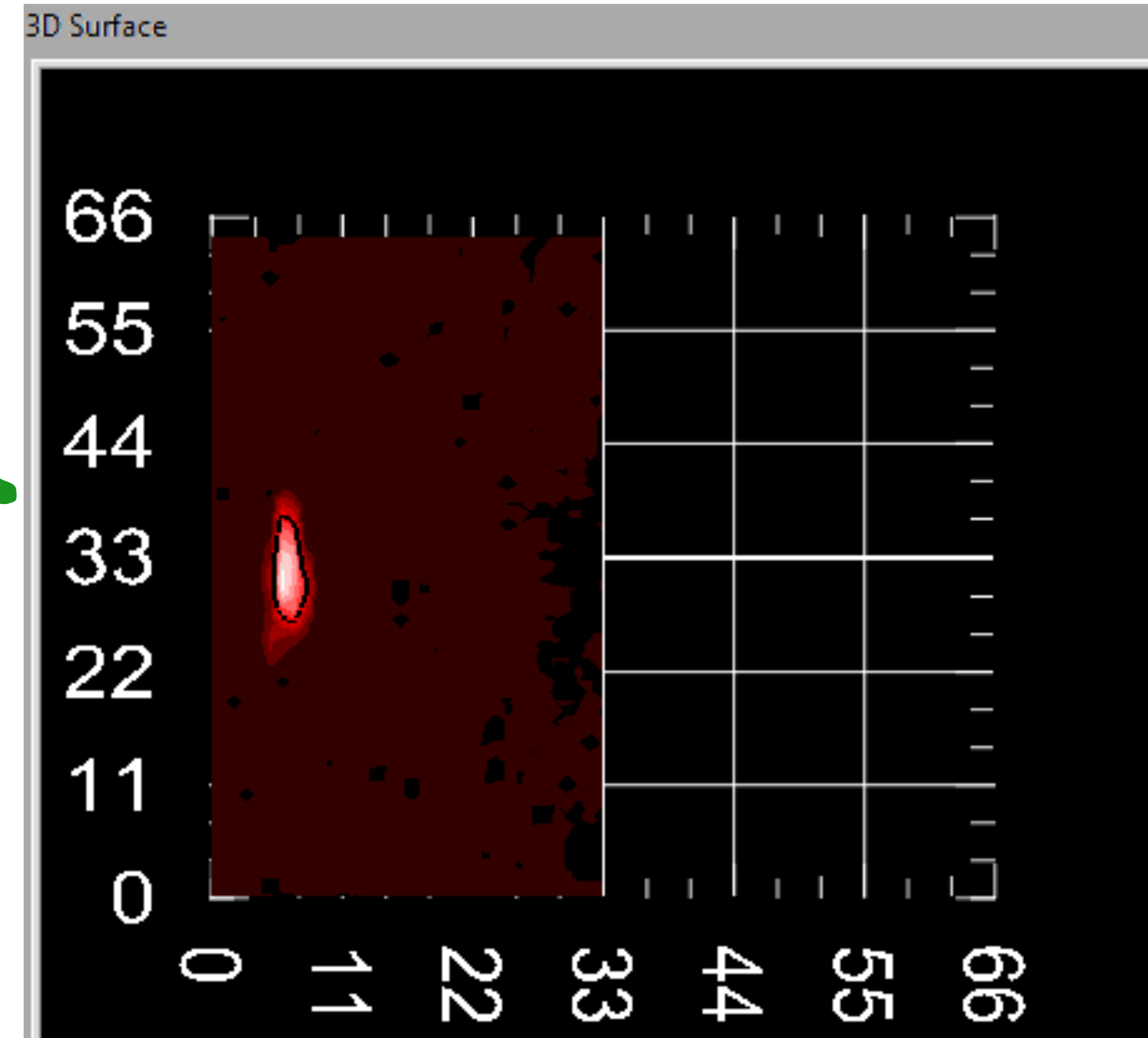
# RXR: a cultural heritage sample

## Middle Age Earthenware Jar from XVI Tuscan Furnace
## μXRF Mapping

- 21 x 7 steps (in low resolution)
- 66 x 35 steps (in high resolution)
- 50 x 50 $\mu m^2$ spatial resolution
- 35 kV / 750 μA
- $T_{acq}$ = 20 / step

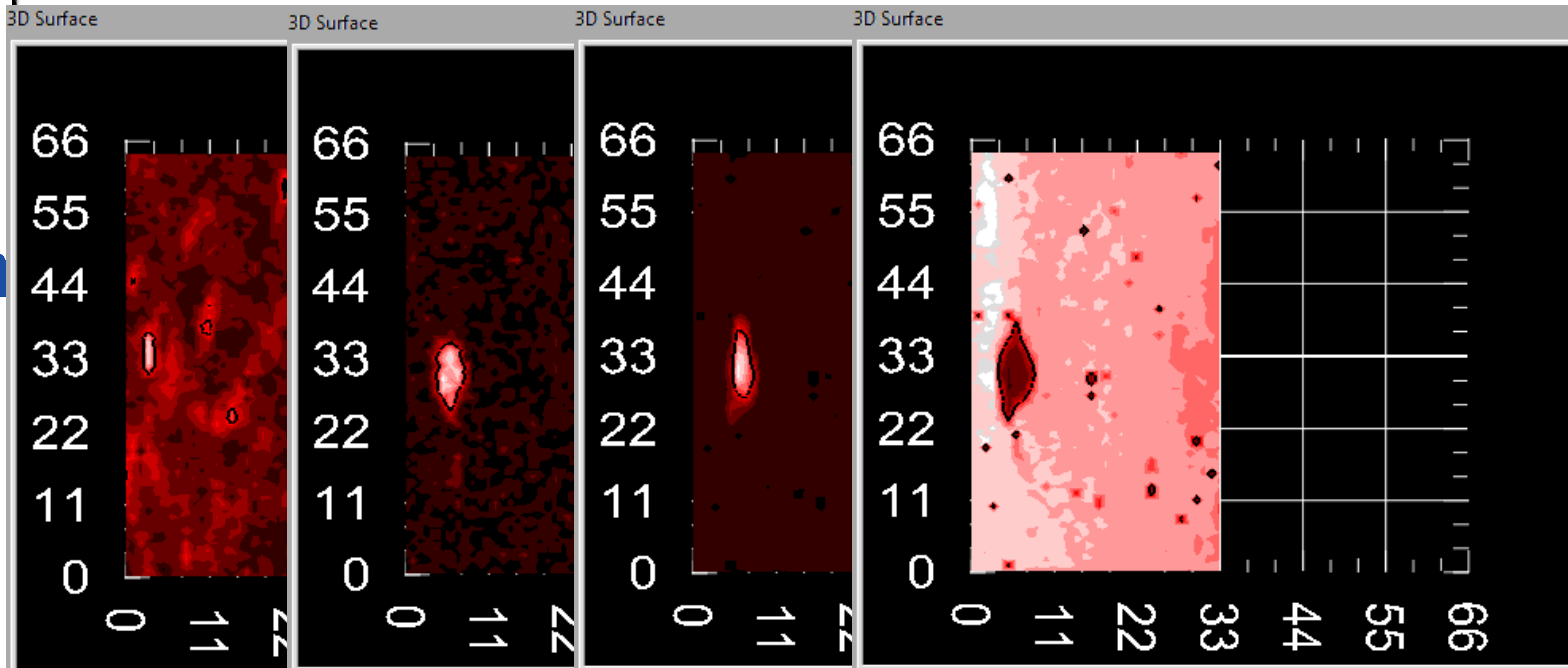




Fe mapping

# RXR: a cultural heritage sample



K S Fe Pb

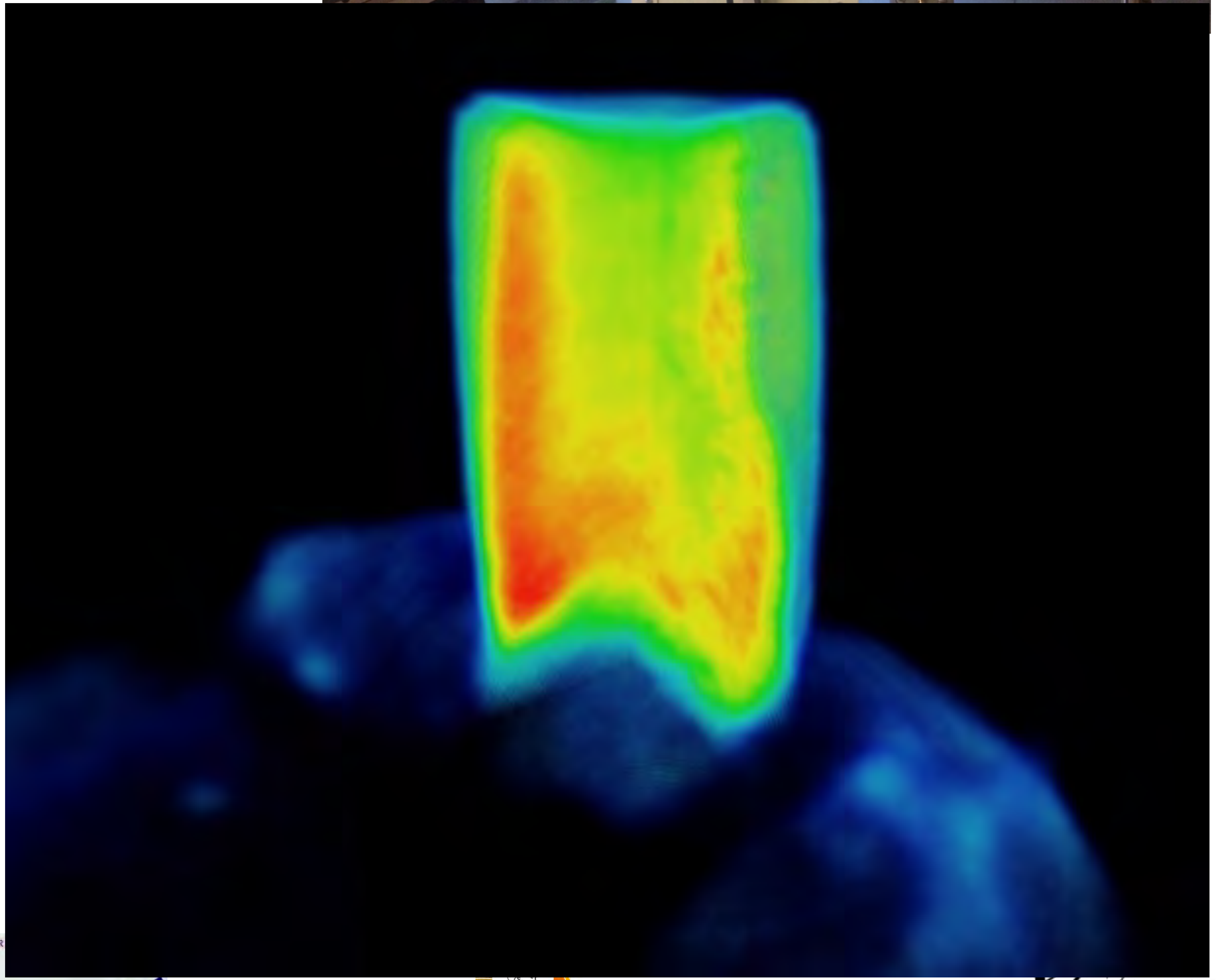


# XENA - Emerald - μCT

## μCT

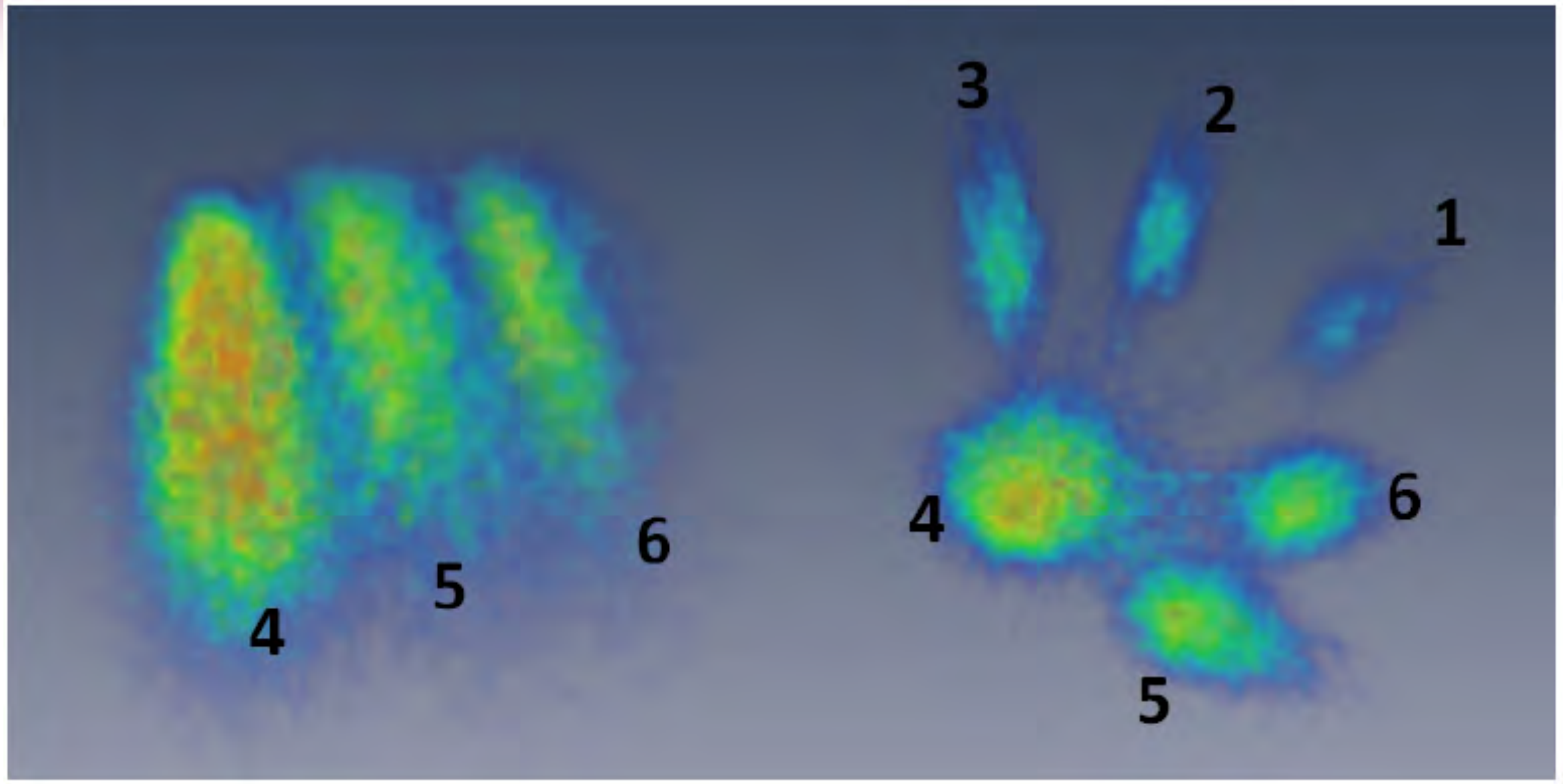
- 720 images for 360 degree
- 120 ms / image
- 35 kV / 700 μA
- about 600 s of total exposition
- 15 μm Resolution





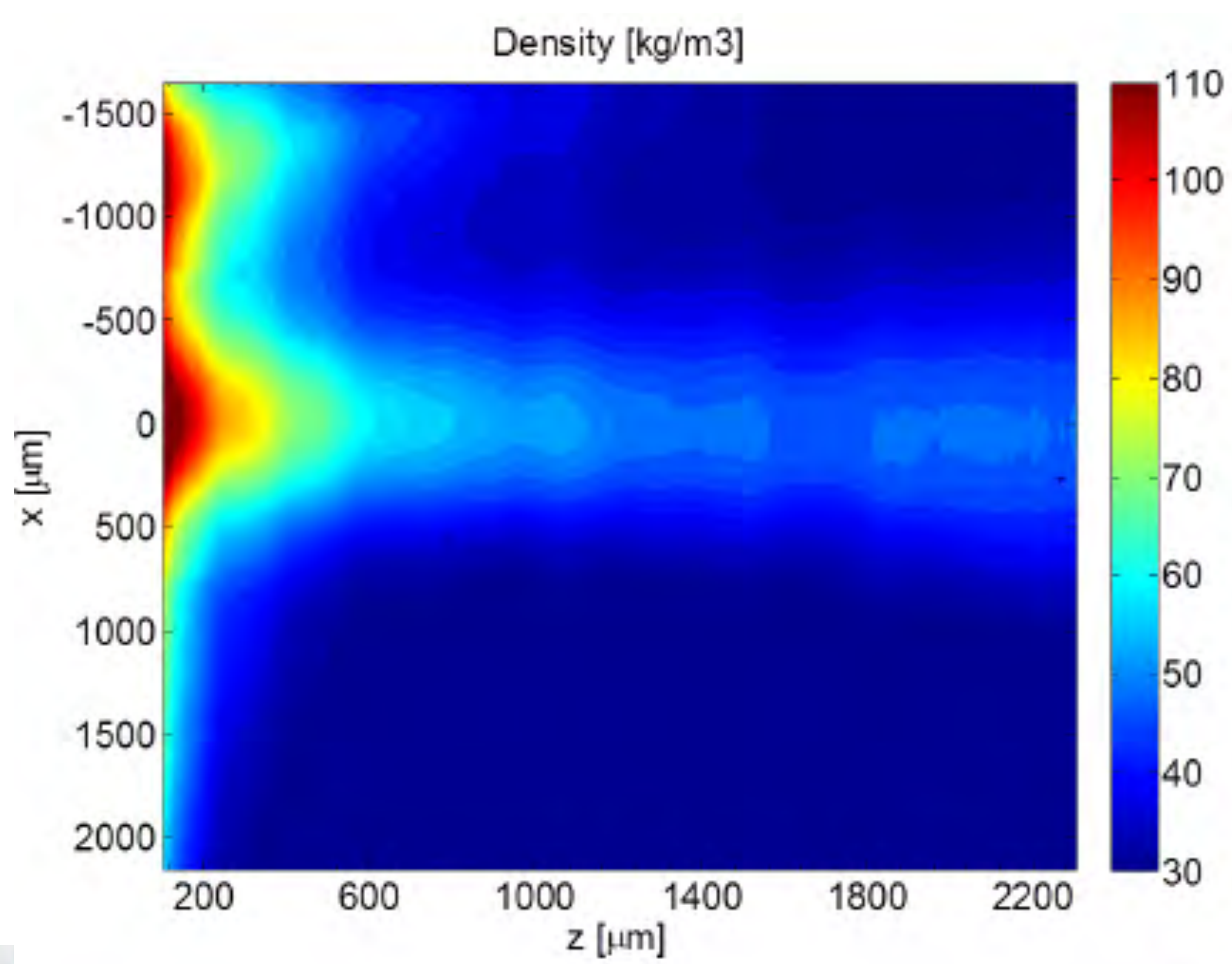
# Xena - Density Fuel Jet Maps by μCT

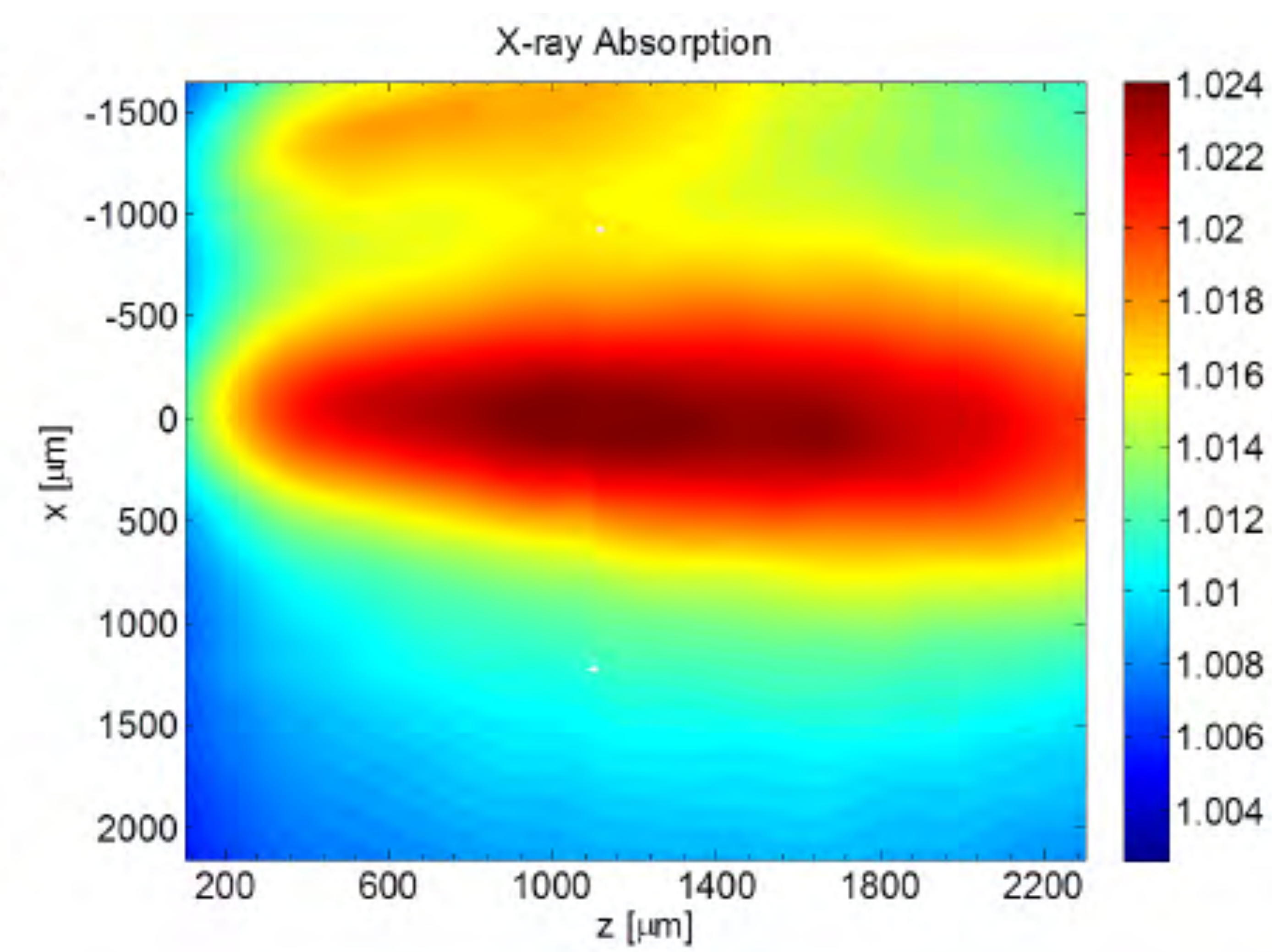





### μCT

- 100 images for degree for 360 degree
- 2 ms / image
- 35 kV / 700 μA
- 16,7 μm Resolution



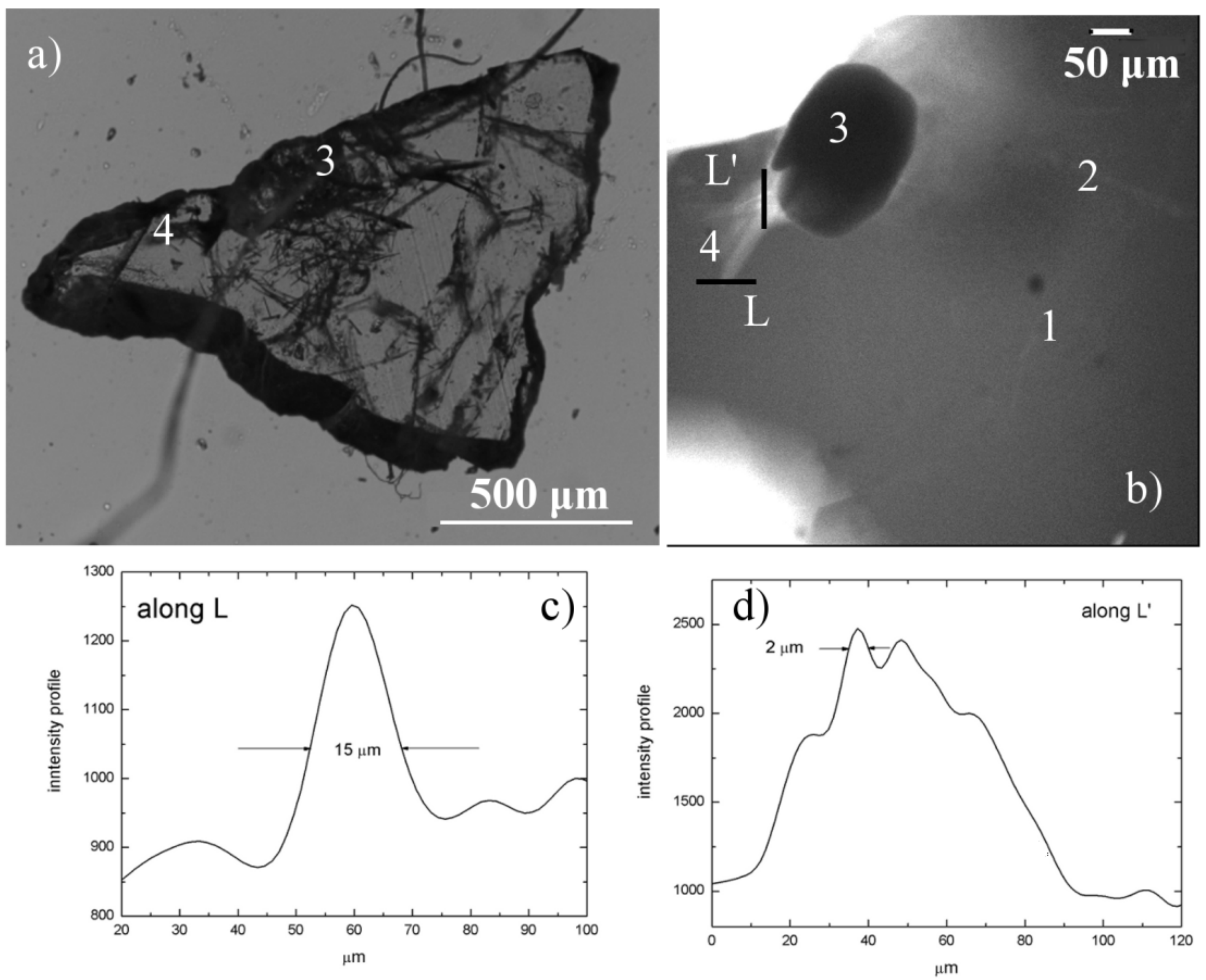
# XENA - High Resolution Imaging with LiF

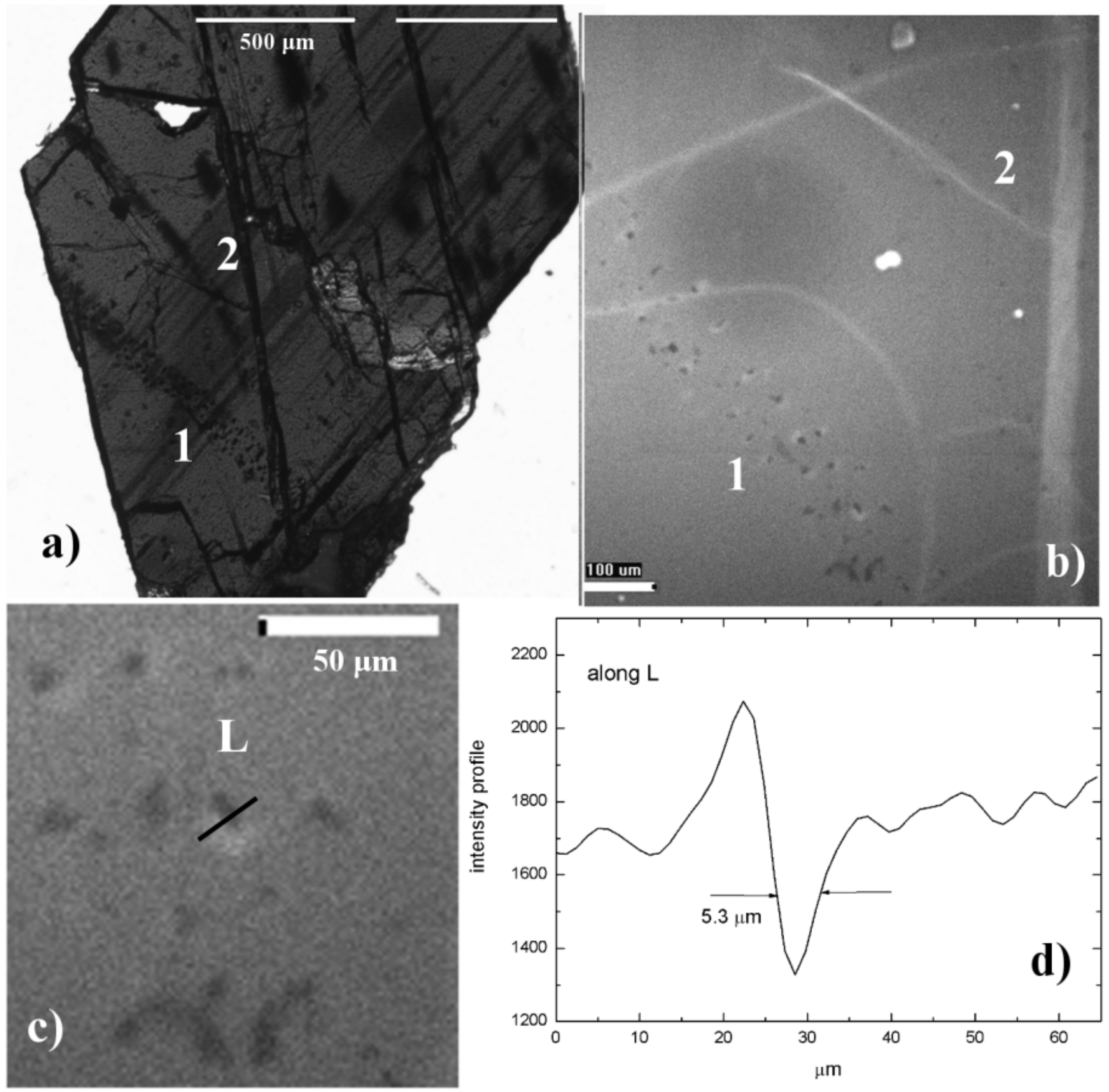


**Geological samples**

**On Left**: doubly-polished (010) section of cordierite

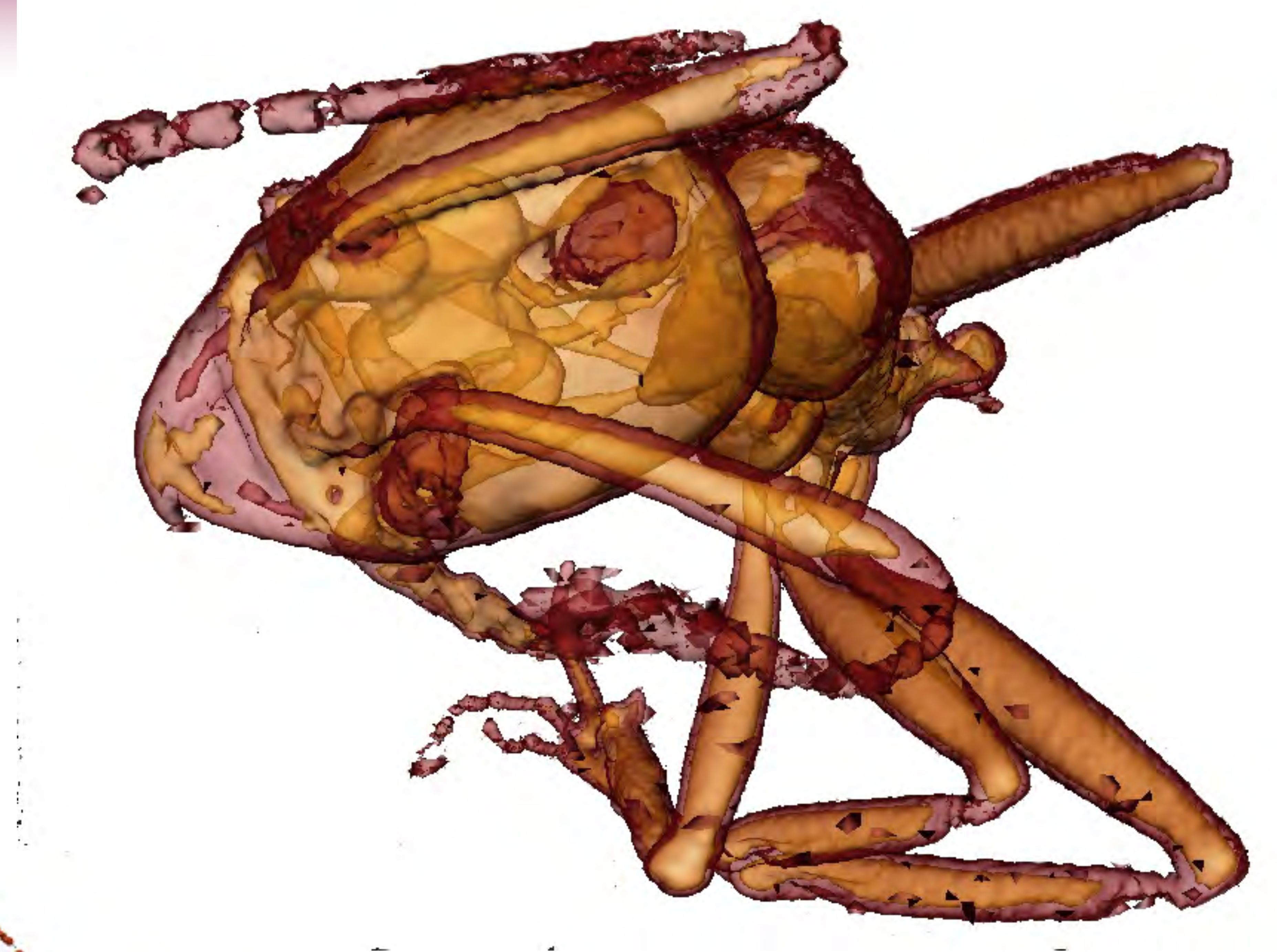
**On Right**: doubly-polished fragment of a magnesium-hastingsite amphibole



# Conclusions

- a very short review on X-ray Optics
- Advantage and disadvantage on PolyCO
- Our Results on
  - XRF (2D mapping, 3D mapping, TXRF)
  - $\mu$CT and High Resolution Imaging



# Vitruvio XLOS

**Thank you for your attention**