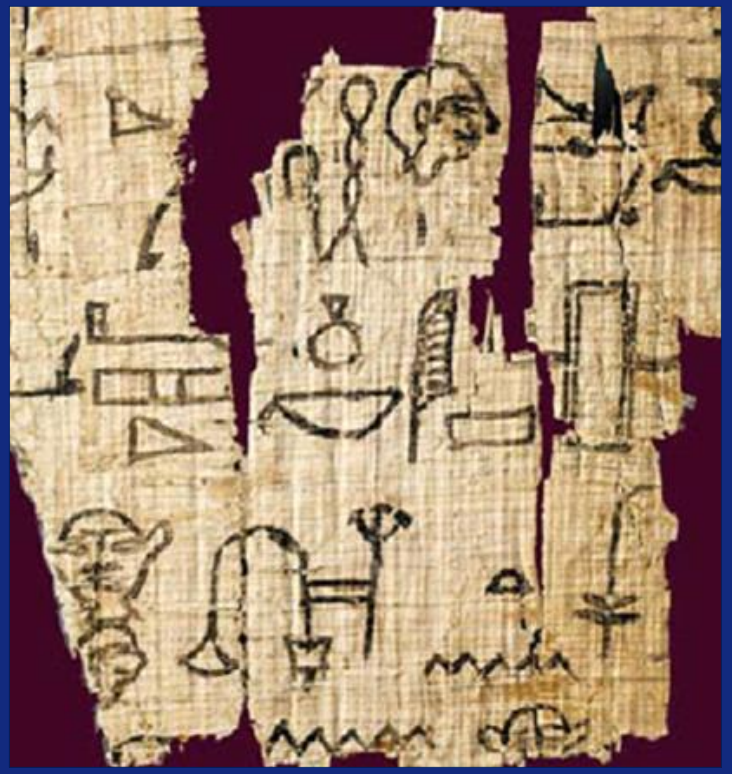
SESAME Cultural Heritage Day, Feb. 16, 2022

# The Elephantine Papyri

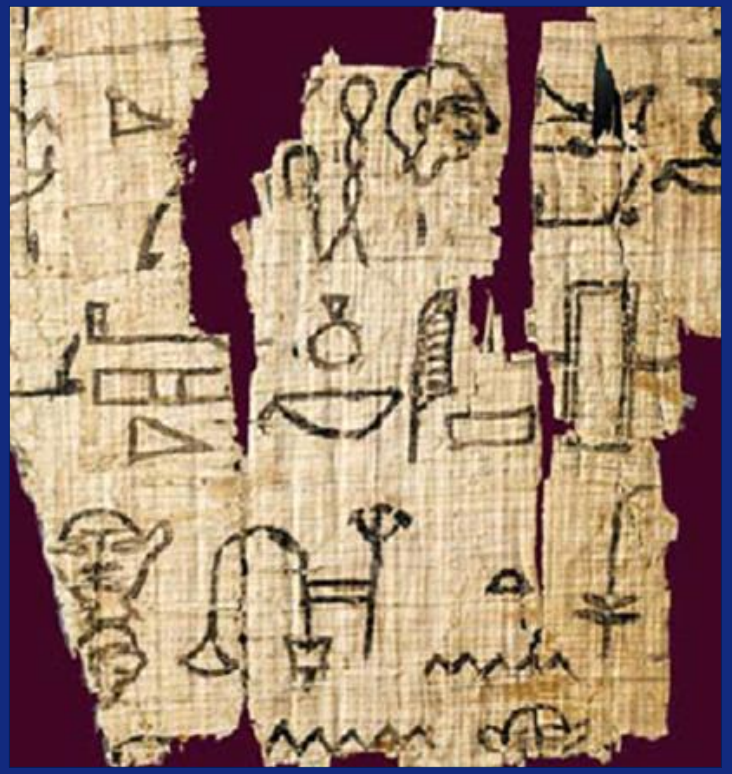
Verena Lepper & Heinz-Eberhard Mahnke
Ägyptisches Museum und Papyrussammlung




Ägyptisches Museum und Papyrussammlung
Staatliche Museen zu Berlin
erc
EINSTEIN ZENTRUM Chronoi
HUMBOLDT-UNIVERSITÄT ZU BERLIN
Freie Universität Berlin
HZB Helmholtz Zentrum Berlin

# Localizing 4000 Years of Cultural History
# Texts and Scripts from Elephantine Island in Egypt

(ERC starting grant “ELEPHANTINE” Verena Lepper)



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# Acknowledgement

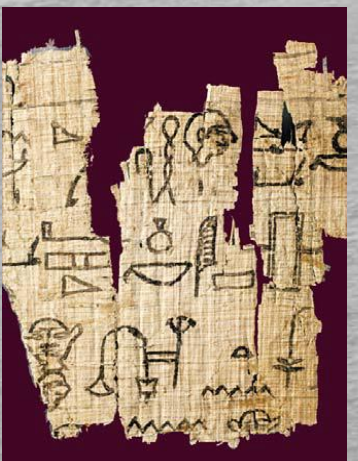

| | |
|---|---|
| ÄMuPapyrus | **T. Angos**, M. Krutzsch, F. Seyfried, as guest E. Menei (Paris), et al. |
| HZB | **T. Arlt** (TU), J. Banhart (TU), N. Kardjilov, I. Manke, L. Puskar, U. Schade |
| ZIB | **D. Baum**, H.-Chr. Hege, **F. Herter**, N. Lindow |
| Louvre | M. Etienne |
| C2RMF (Paris) | E. Laval |
| Rathgen-Forschungslabor | C. Aibeo, R.-R. Pausewein, I. Reiche, S. Röhrs |

Supported by a starting grant ELEPHANTINE (PI Verena Lepper, ÄMP SMB at SPK and HU) of the European Research Council (ERC)

Supported by Einstein Center Chronoi – Exploration ”Folded Time – Ink in Time – Egyptian Papyri“

# Texts and Scripts from Elephantine Island in Egypt

hieroglyphic



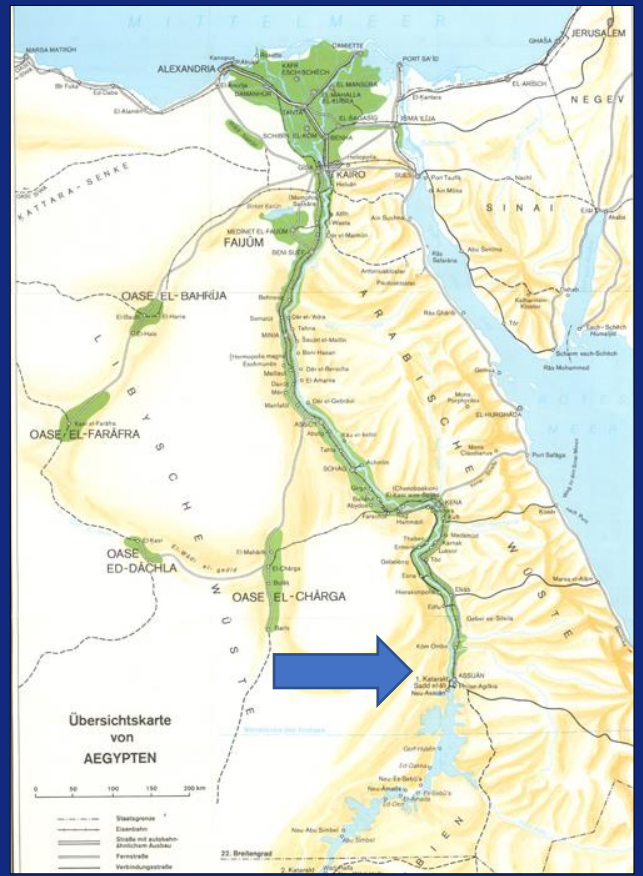
aramaic

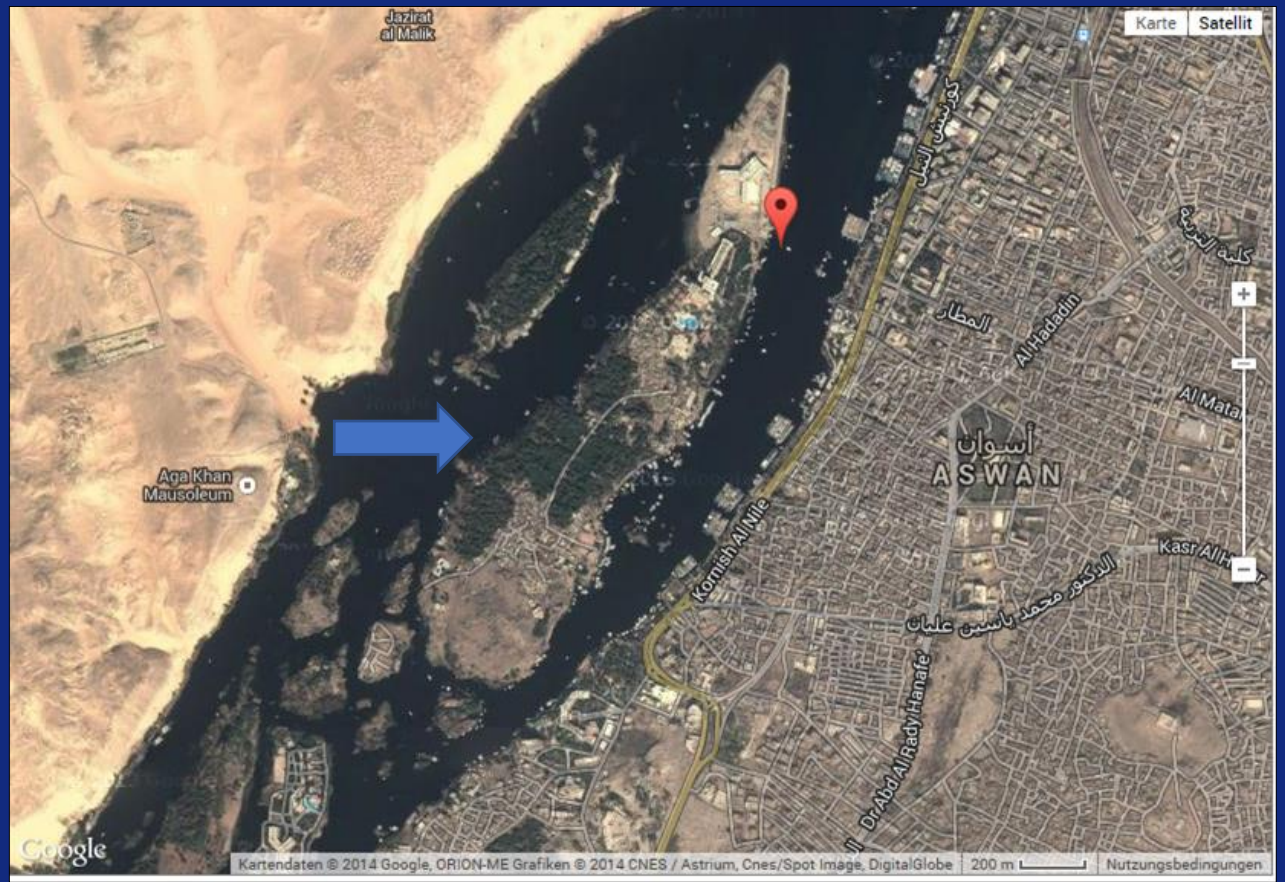
coptic

arabic

# Elephantine Island

- Nile Island at the southern border of Egypt
- Old Kingdom (3rd millenium B.C.) to Arabic times (1000 A.D.)
- Multi-ethnic, Multi-lingual, Multi-cultural, Multi-religious
- Microcosm: “model for big questions in a small place”



# Current State of the Art

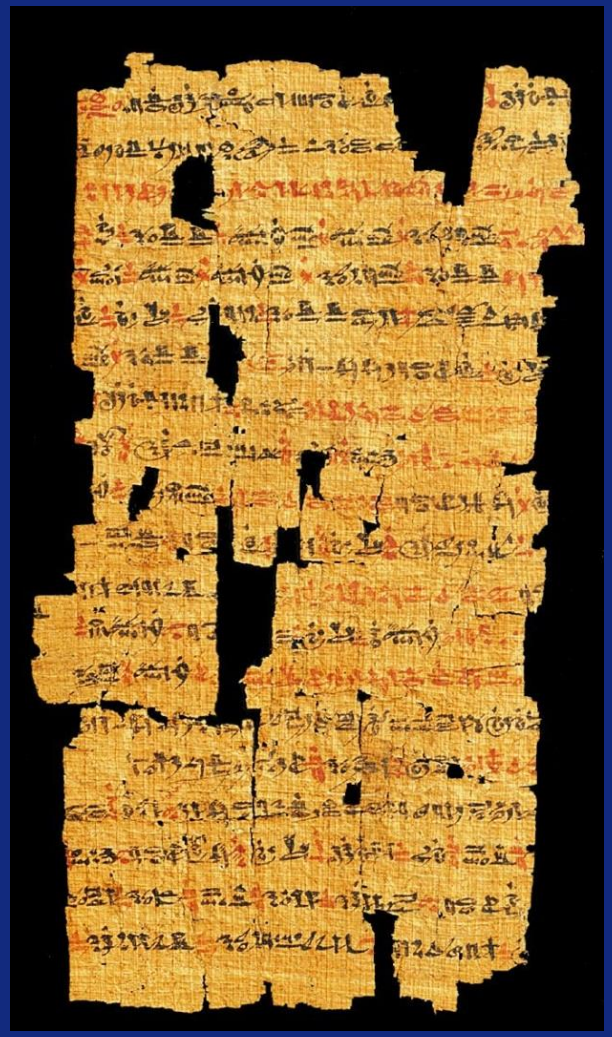
- Turning point concerning research and methodology for papyri from Egypt
- 80% unpublished and unstudied
- In 60 different museums and institutions
- In 24 countries

Brooklyn Museum


Ägyptische Museum und Papyrussammlung

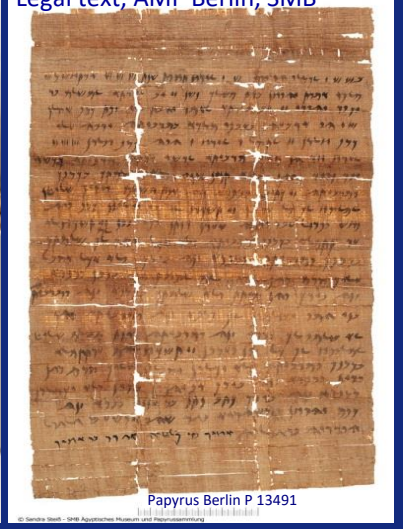
# International Papyrus Puzzle

## Berlin, Paris, Rome, New York, Cairo, Elephantine



# Papyrus collection ÄMP SMB/SPK

Legal text, ÄMP Berlin, SMB



Papyrus Berlin P 13491

**An alternative is needed for the delicate „mechanical“ method !!**

**Tomography**

# Concept

When physical unfolding/unrolling is not possible or too dangerous for preserving the precious object, tomographic approaches may be the appropriate alternative. Requirements are:

- resolution and
- contrast to distinguish writing (ink) and substrate.

**Step 1:**
Select the object of interest (archaeological arguments, cultural background of the object, e.g. Elephantine), x-ray fluorescence

**Step 2:**
Find the proper physical procedure, especially with respect to contrast, take the tomographic data (e.g. by absorption).

**Step 3:**
Computer science treatment of the tomographic data to obtain 2d-planar projections. Optimizing unrolling and unfolding procedures.

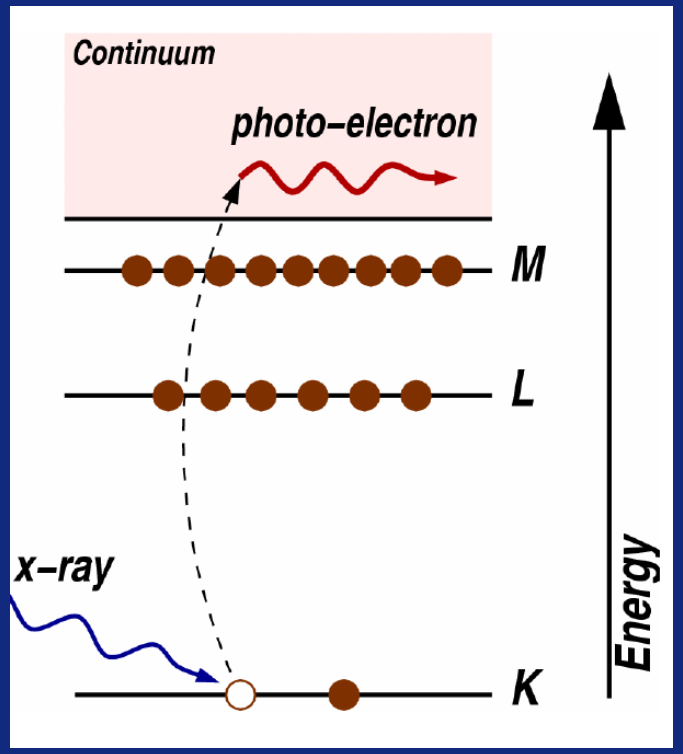
# Step 1: X-ray fluorescence

## Elemental analysis based on photo electric effect

1905

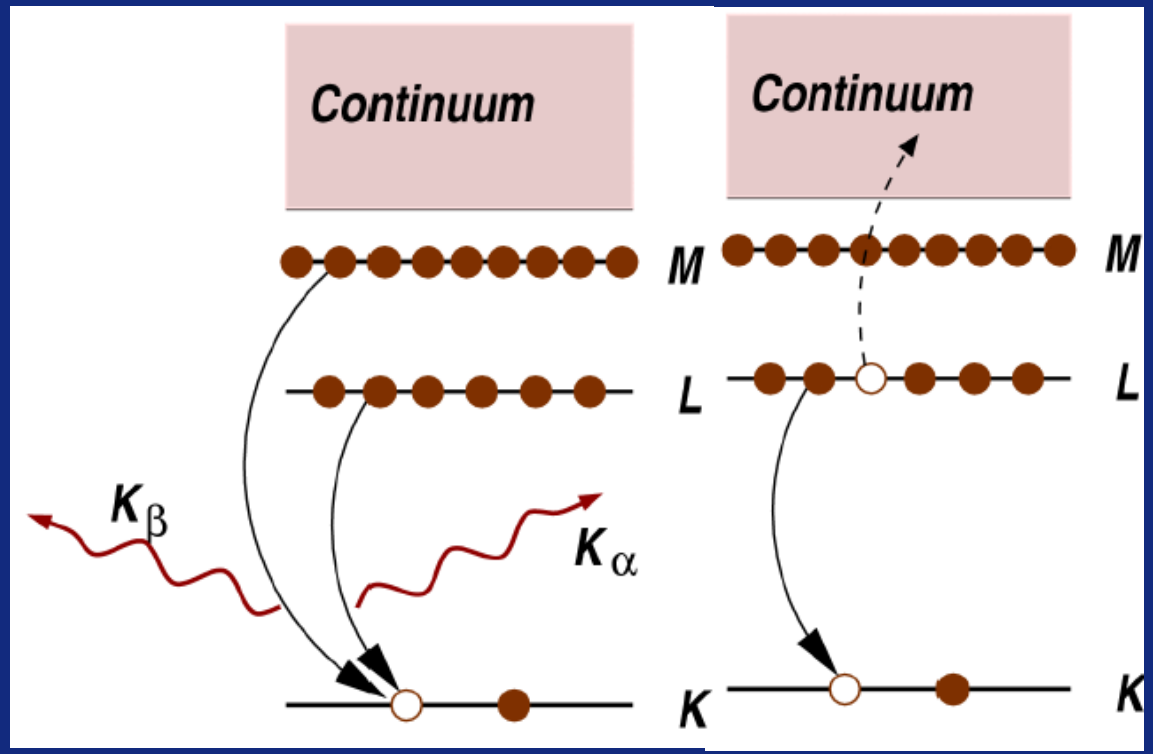
**absorption** | **emission**

an electron is „kicked out“ by a photon




or by an electron (EDX),
or by a proton (PIXE),..

Energy of emitted x-ray is characteristic for element



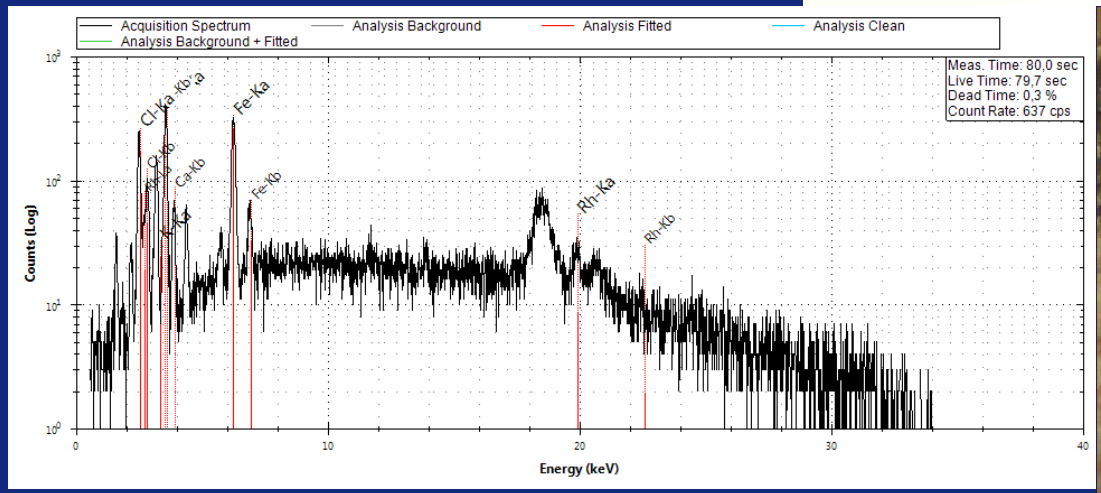

x-ray-fluorescence

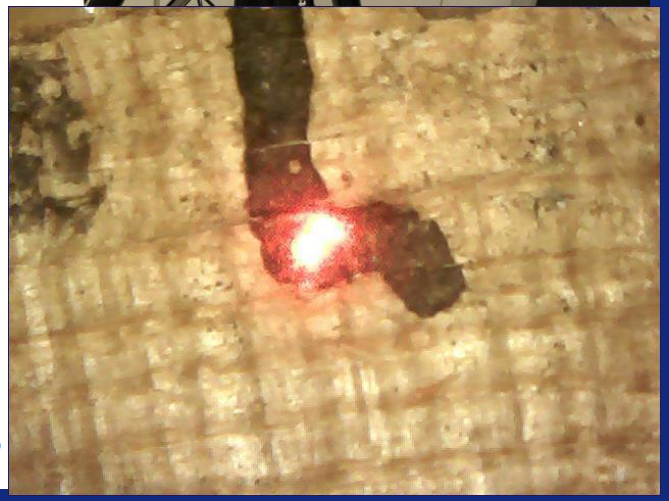
Auger electron

# Step 1: X-ray fluorescence

## Elio

- Portable XRF-spectrometer
- X-ray beam with  about 1 mm diameter
- Non-destructive



**Information on iron (or other high Z) content and distribution (“mapping”)**

# Step 2: X-ray - computer tomography

Contrast based on absorption

due to photo electric effect

$\sigma_{ph} \sim Z^4$

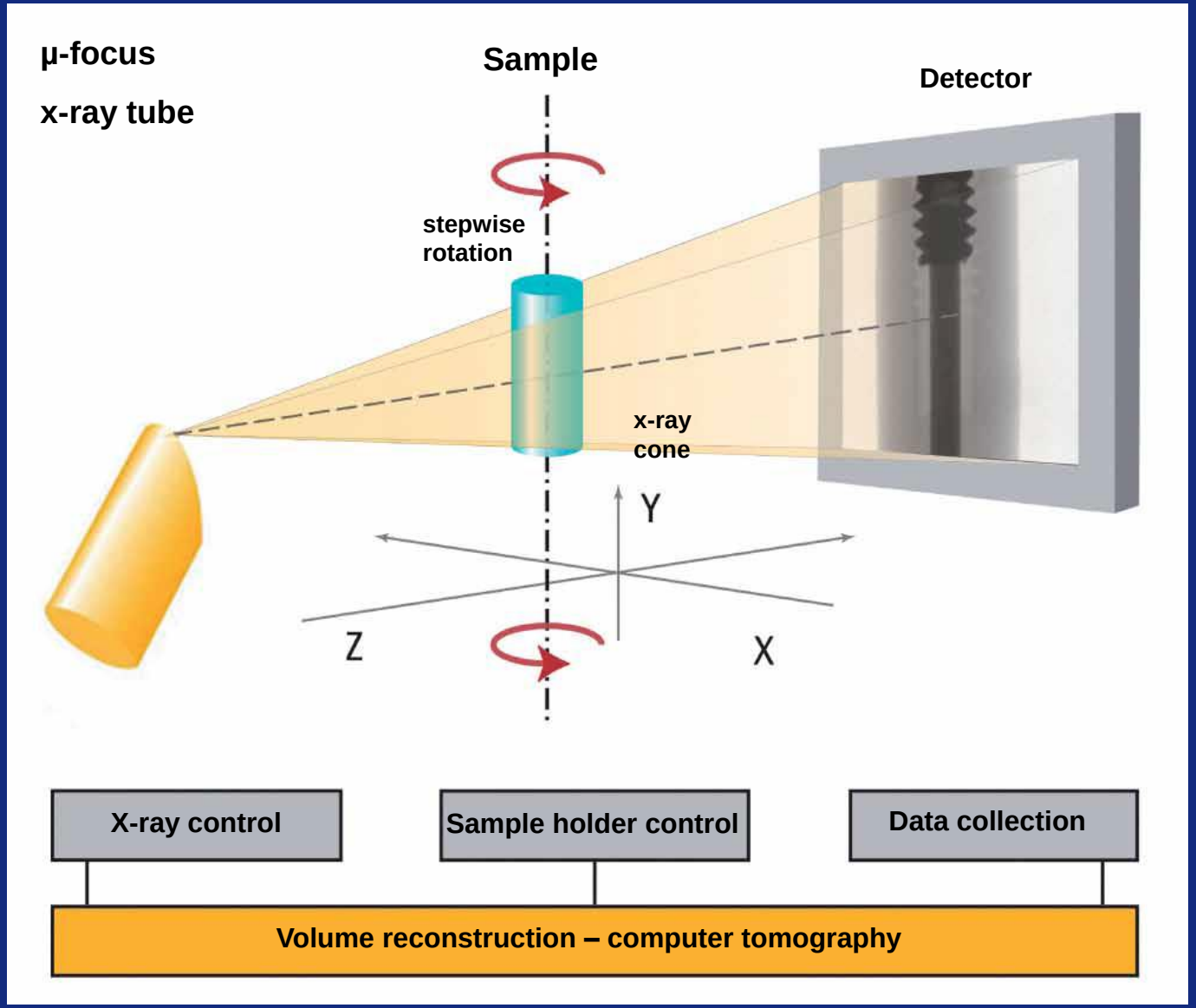
| Element | $\sigma$ ($10^{-24}$ cm$^2$) (at 100 keV) | $\sigma$ ($10^{-24}$ cm$^2$) (at 30 keV) |
|---|---|---|
| C (Z=6) | 3,0 | 5,0 |
| Fe (Z=26) | 34,5 | 763,0 |
| Pb (Z=82) | 1920,0 | 10500,0 |

Energy of emitted fluorescence x-ray is characteristic for element

sorting out for metal ions containing ink (e.g. Fe, Hg, Pb)

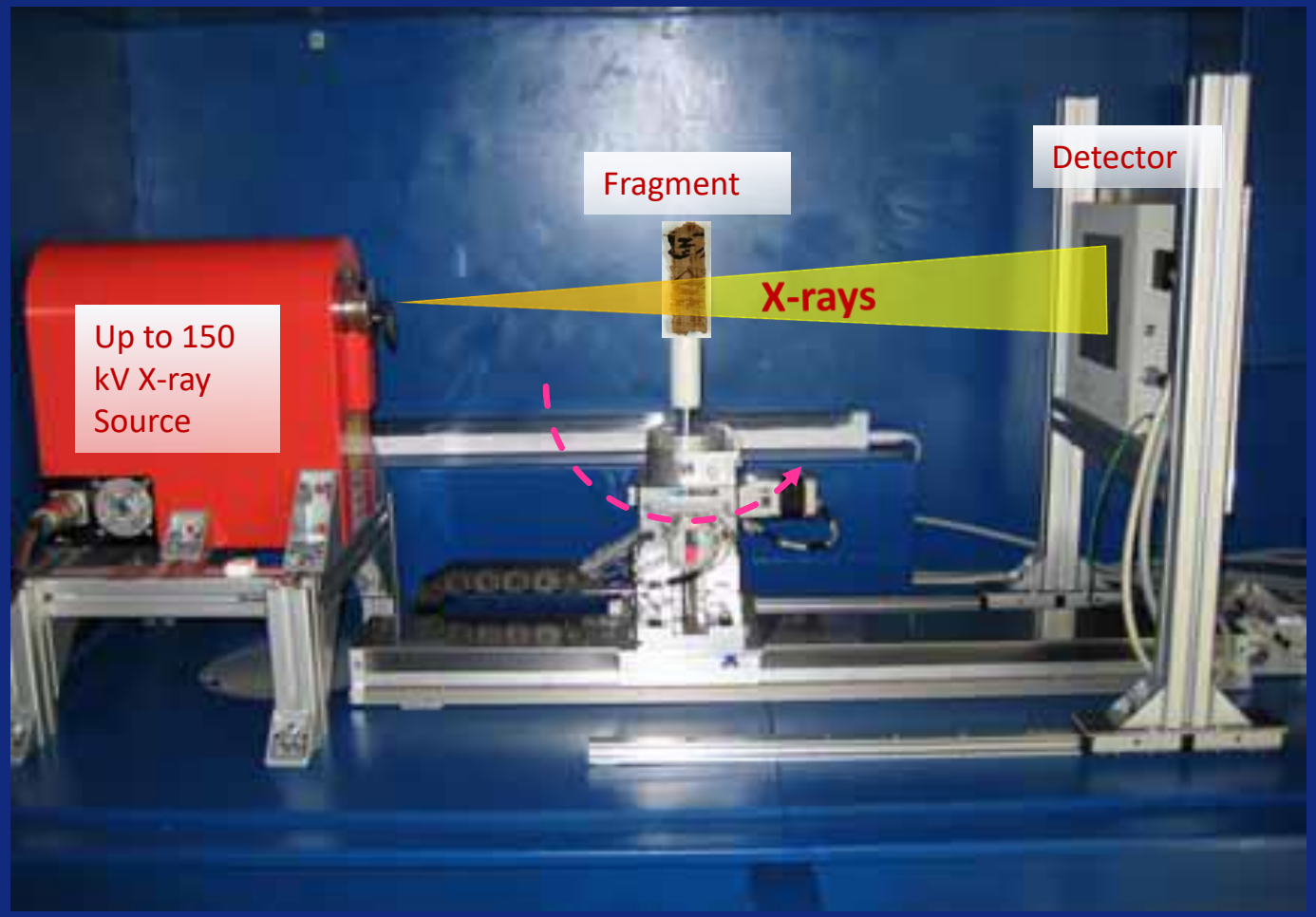
# Step 2: X-ray - computer tomography

## principle: absorption $I = I_0 \cdot \exp(-\mu x)$



# Step 2: X-ray - computer tomography

**principle: absorption $I = I_0 \cdot \exp(-\mu x)$**



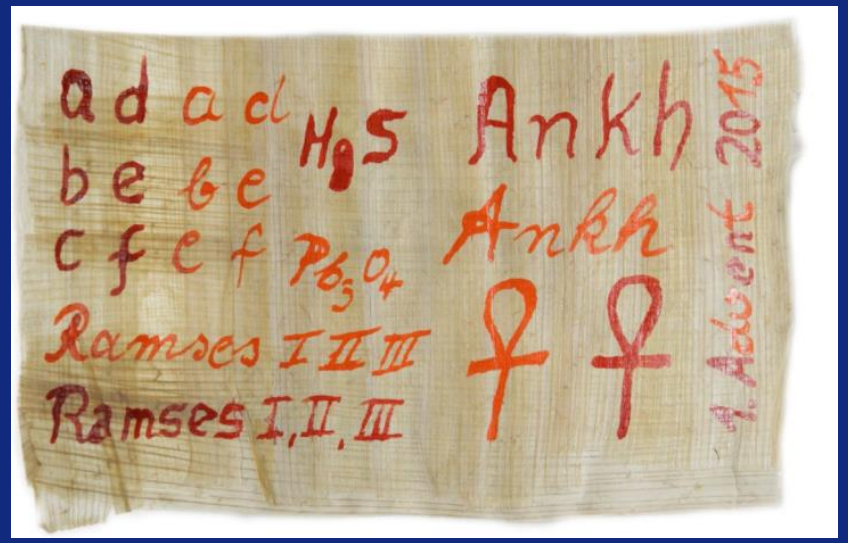

Laboratory system at HZB (micro CT)

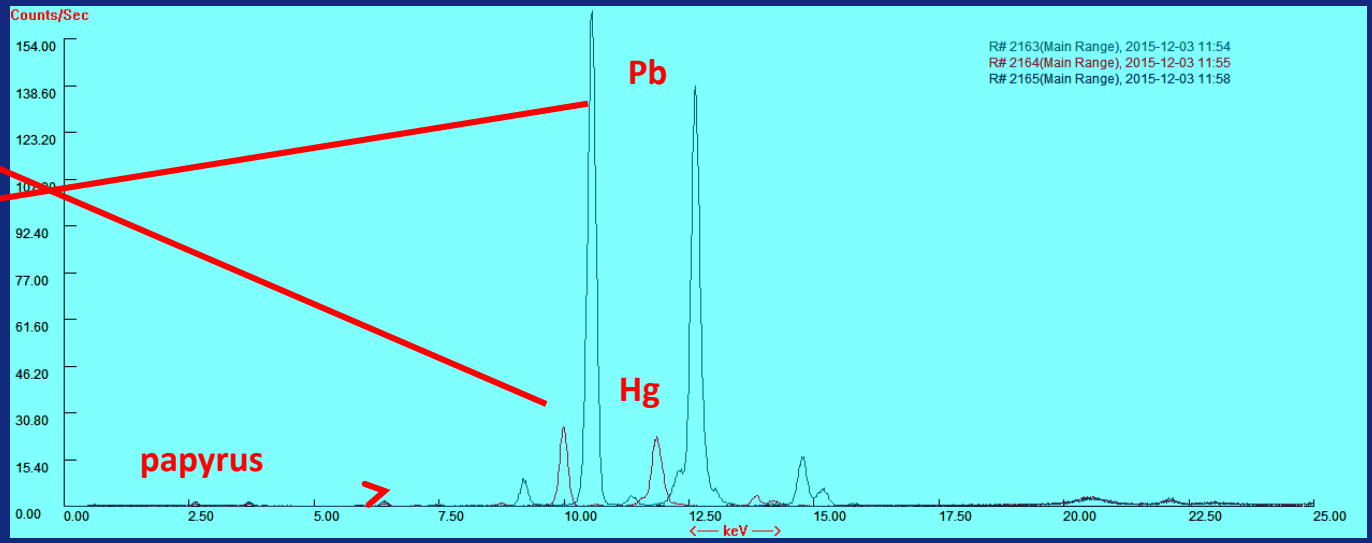
**Alternatives: Commercial CT instruments (various manufacturers) and synchrotrons**

# Step 3: Optimizing the computer science part

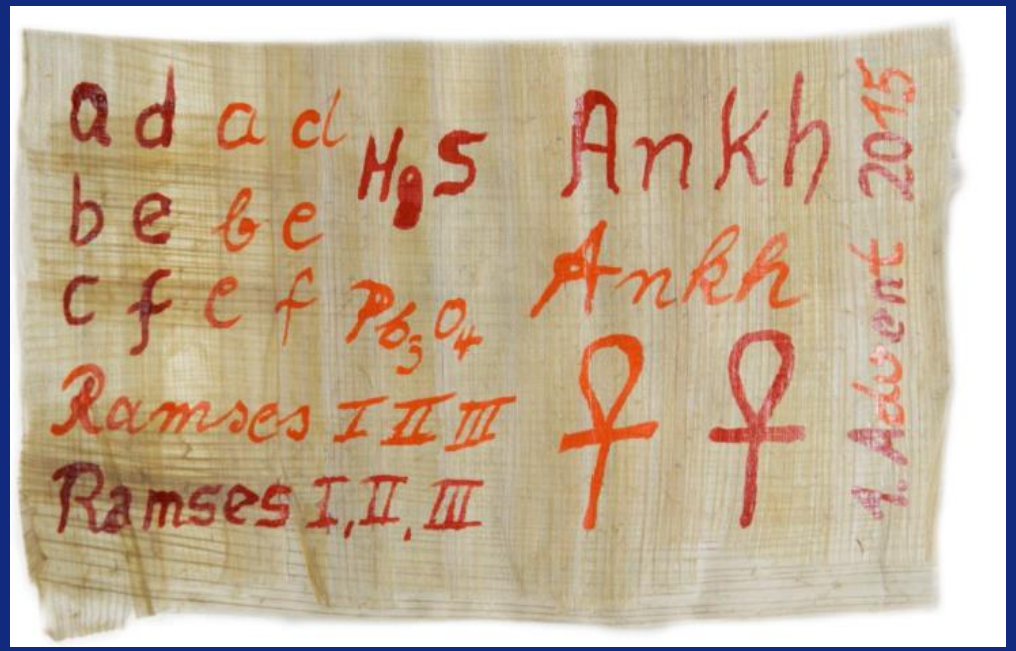
## Preparing objects with high Z element ink

## Ink identification in mockup scroll




Cinnabar (Hg, i.e. HgS) and minium (Pb, i.e. $Pb_3O_4$)

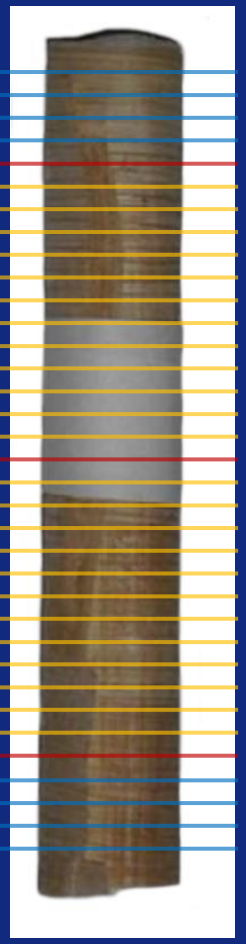



**folded**
*(“magic fold” )*

**rolled**

**volume rendering of 3D images**

# Step 3: (a) Unrolling



extrapolation

slice i

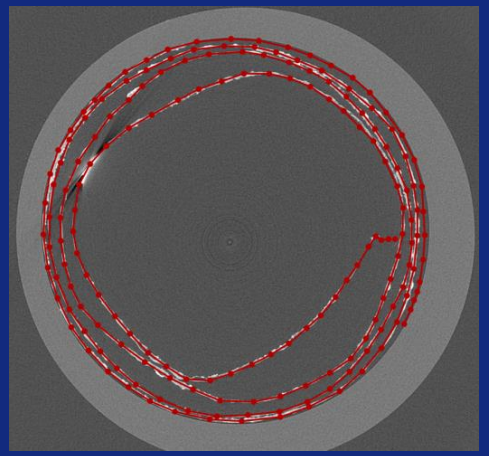
interpolation

slice i+m

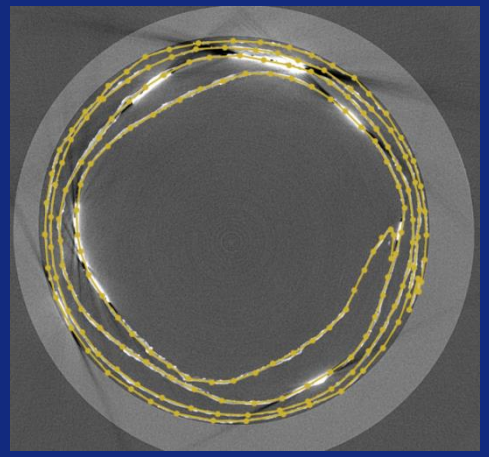
interpolation

slice i+n

extrapolation



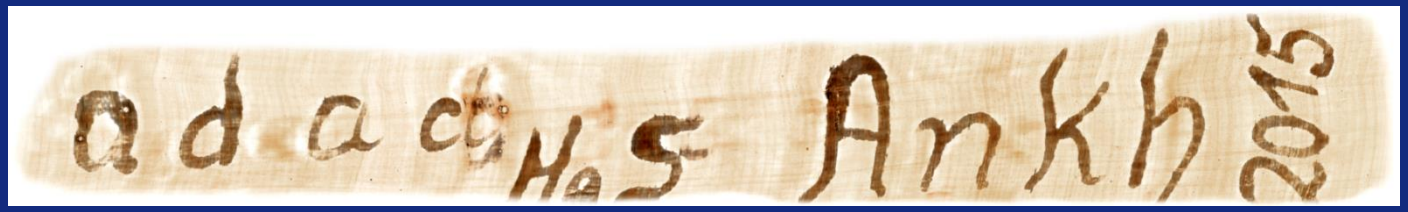
◄ Manually defining a segmentation for spiral contours along the papyrus roll (slices i, i+m, i+n)



◄ Linear interpolation between manual contours and constant extrapolation outside.

A fully virtually unrolled mockup (top part) based on 3 manually placed spiral contours.

Result:



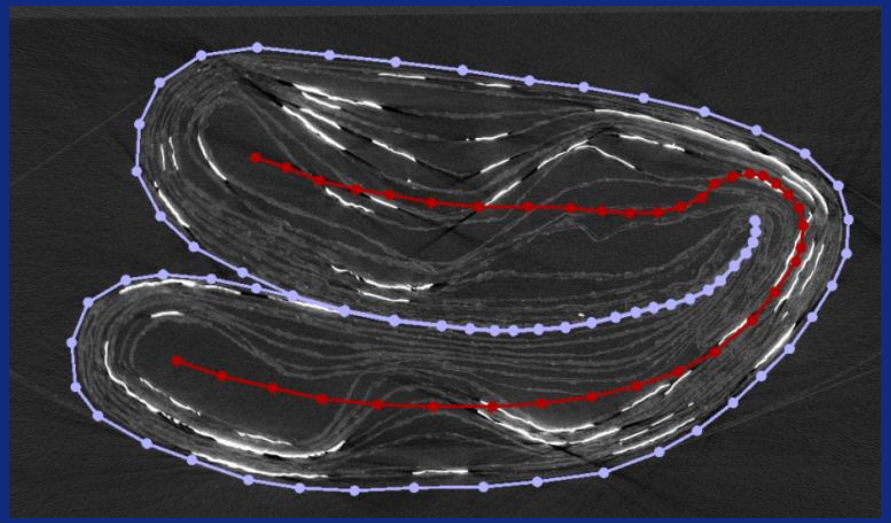
# Step 3: (b) Unfolding

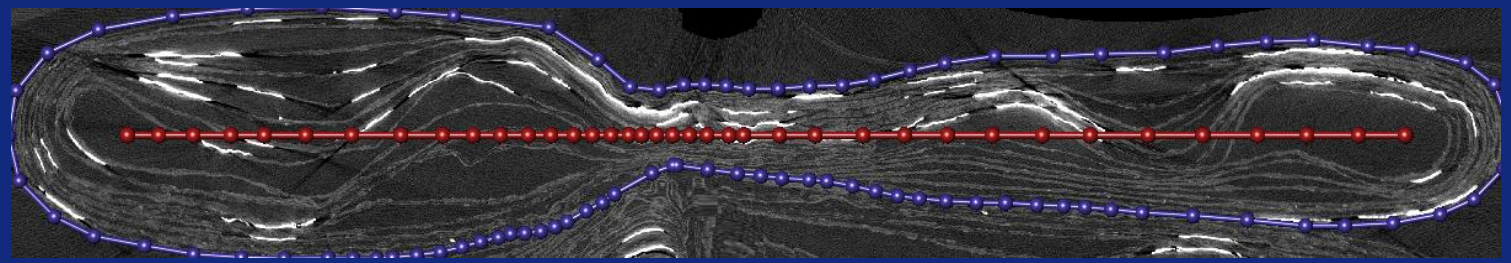
with approximately orthogonal folding lines

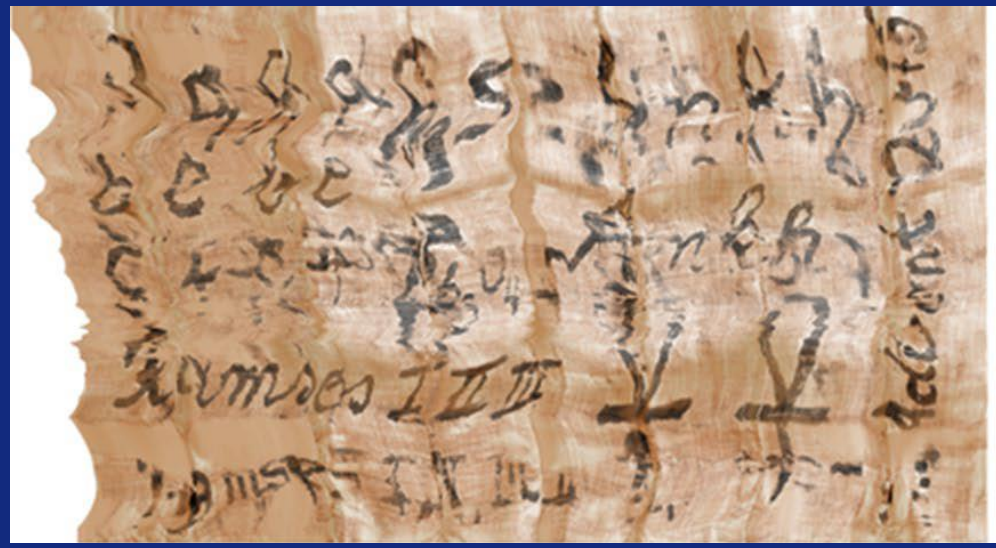

# Step 3: (b) Unfolding

Iterative unfolding using moving least squares until papyrus can be unrolled.

- Set outer contour (blue) and inner fold (red)
- Warp outer contour based on flattened inner folding
- Warp image based on both contours








**D. Baum,** N. Lindow, H.-Chr. Hege, V. Lepper, T. Siopi, F. Kutz, K. Mahlow, H.-E. Mahnke**., Appl. Phys. A (2017) 123: 171**

# Louvre papyrus collection

## Louvre

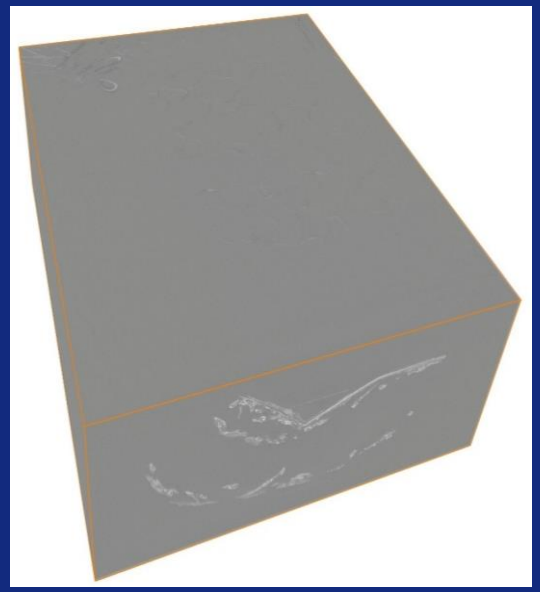


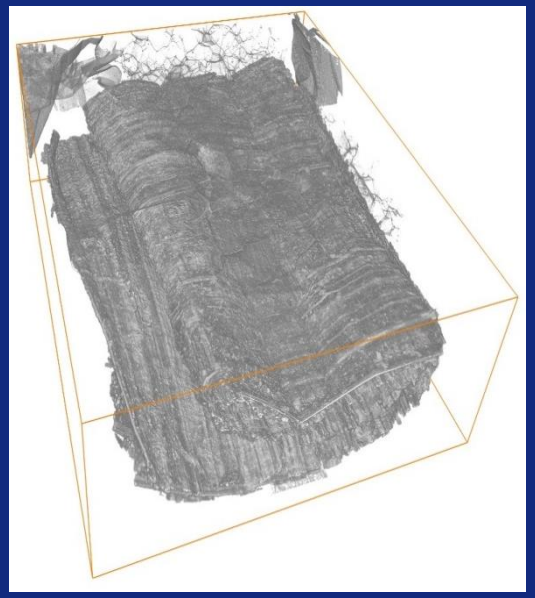

# L/El227b/1-pC

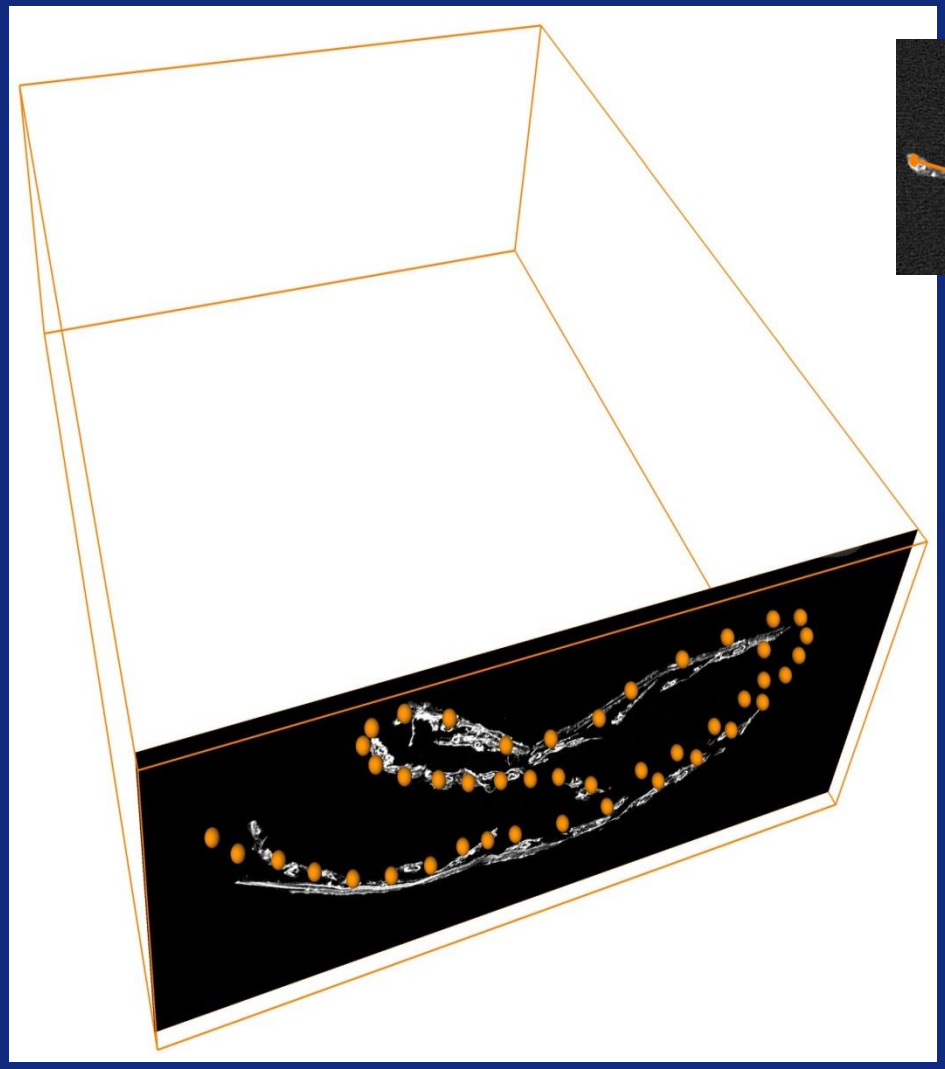
- Folded twice in same direction
- Flattened via single application of unrolling algorithm
- Ink detected

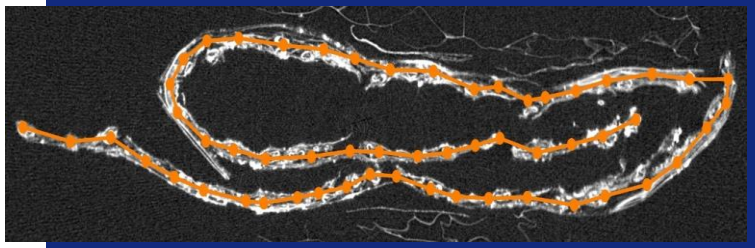
Volume Rendering

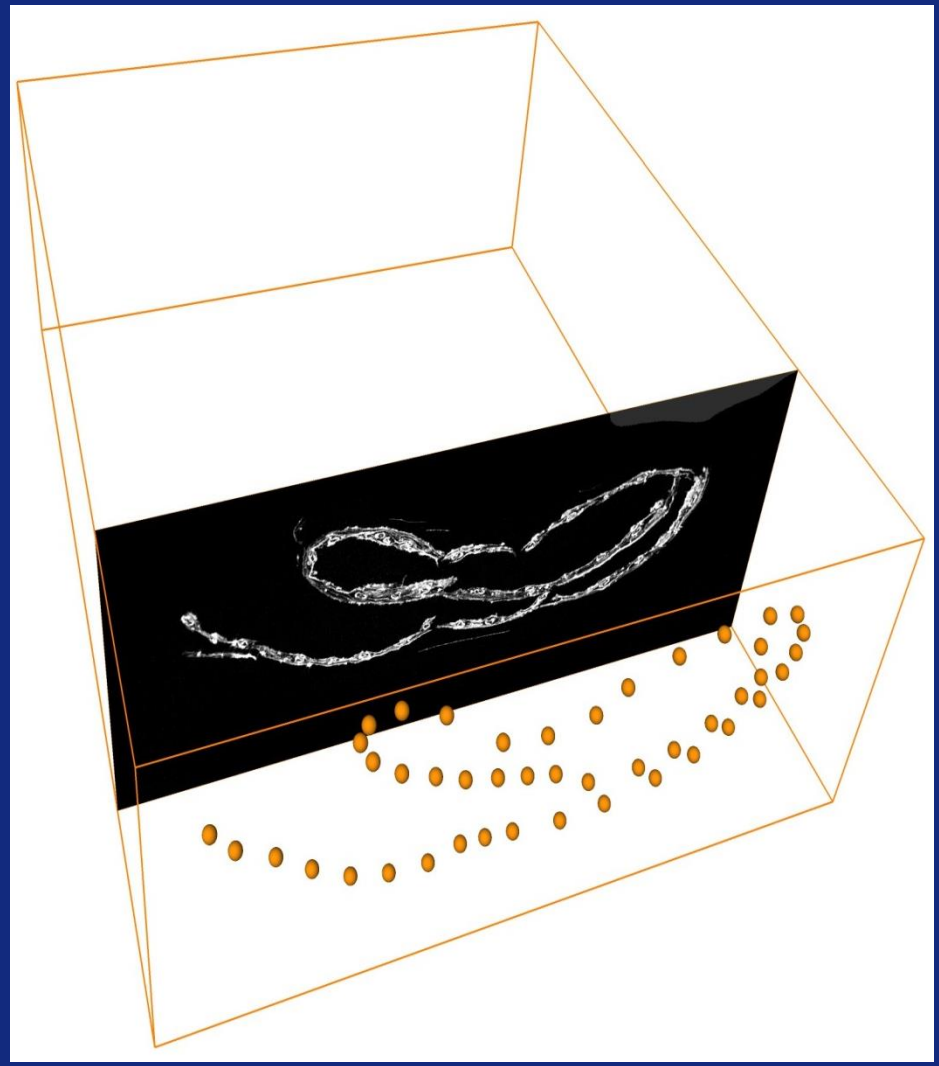
# Volume Rendering of a Tomogram

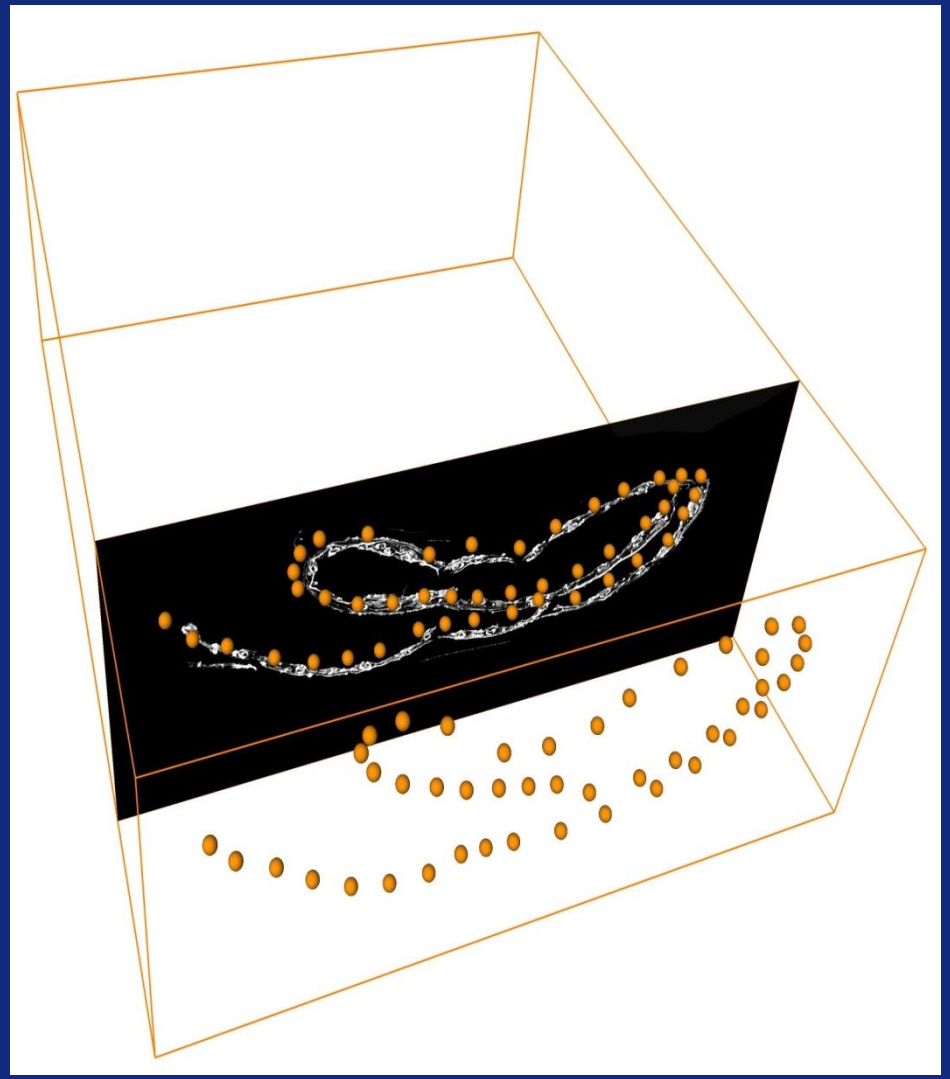


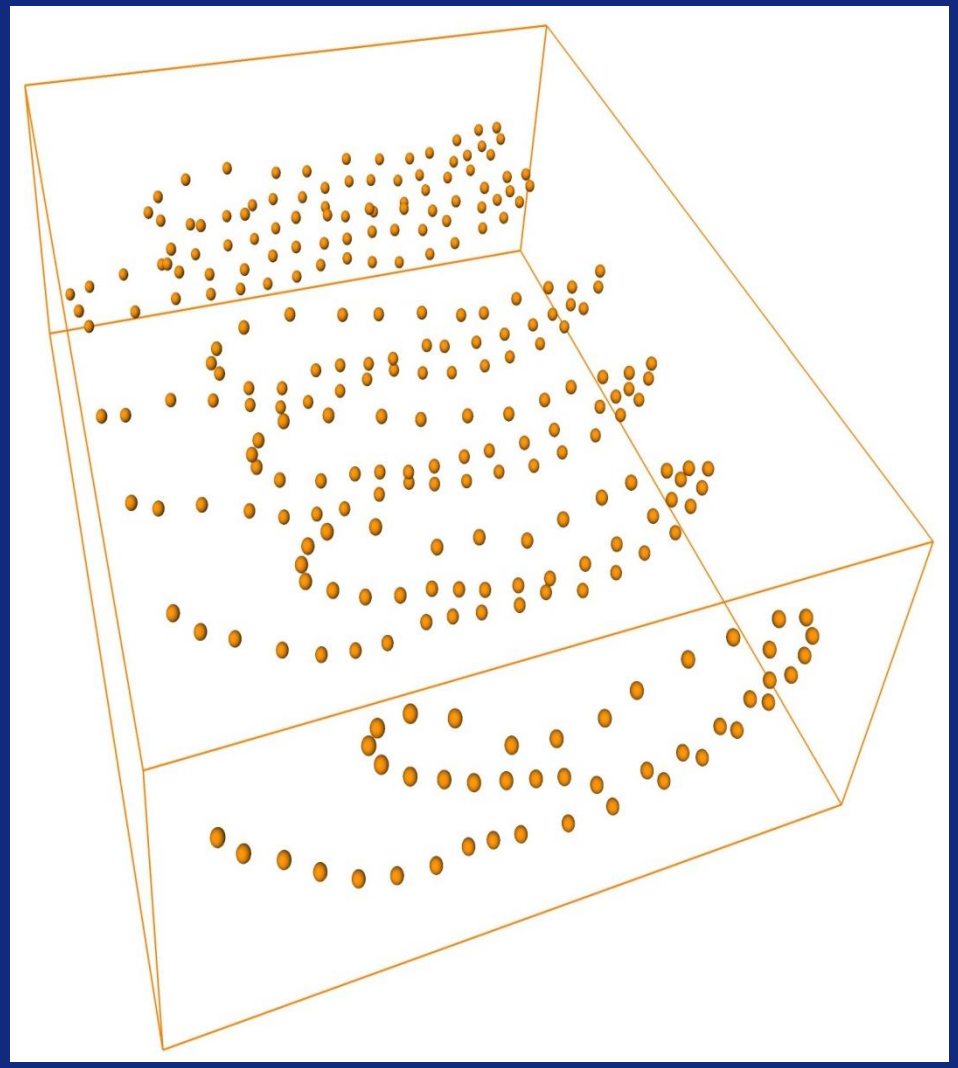


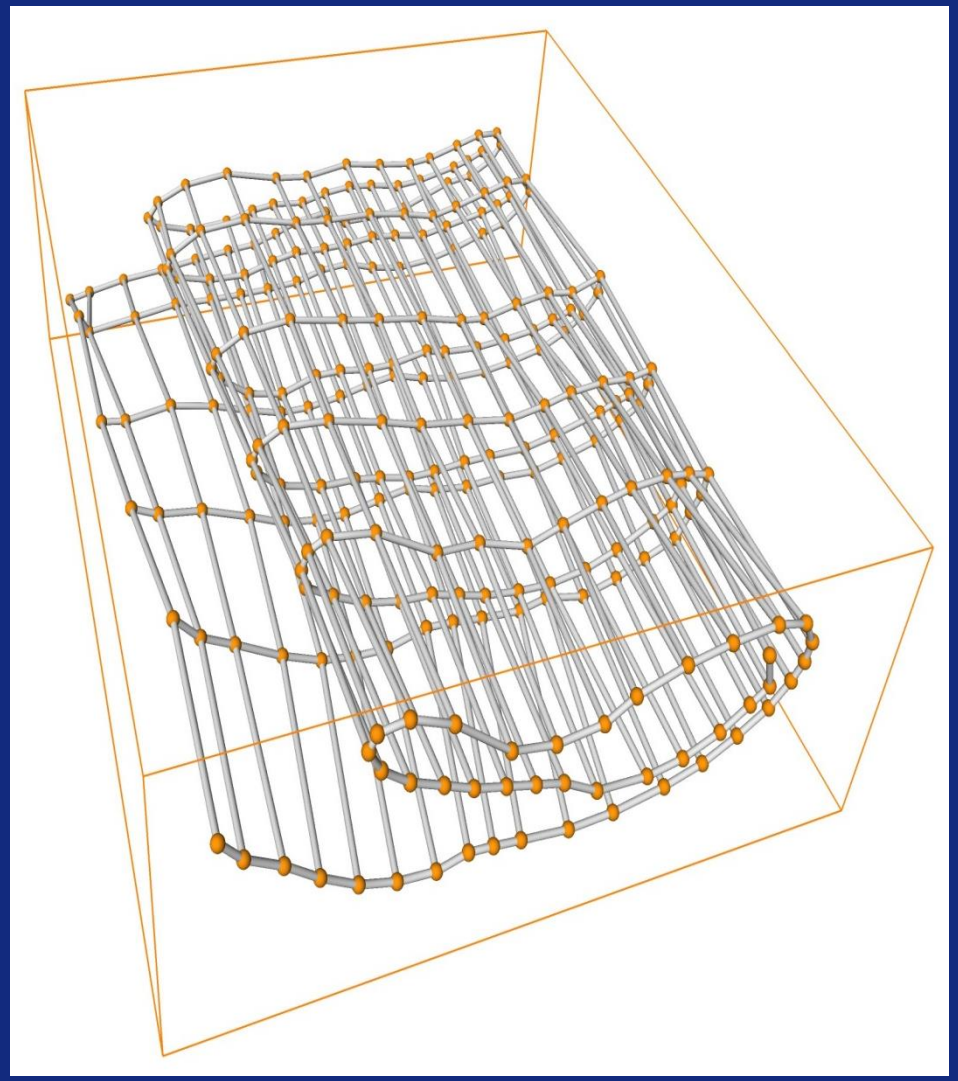


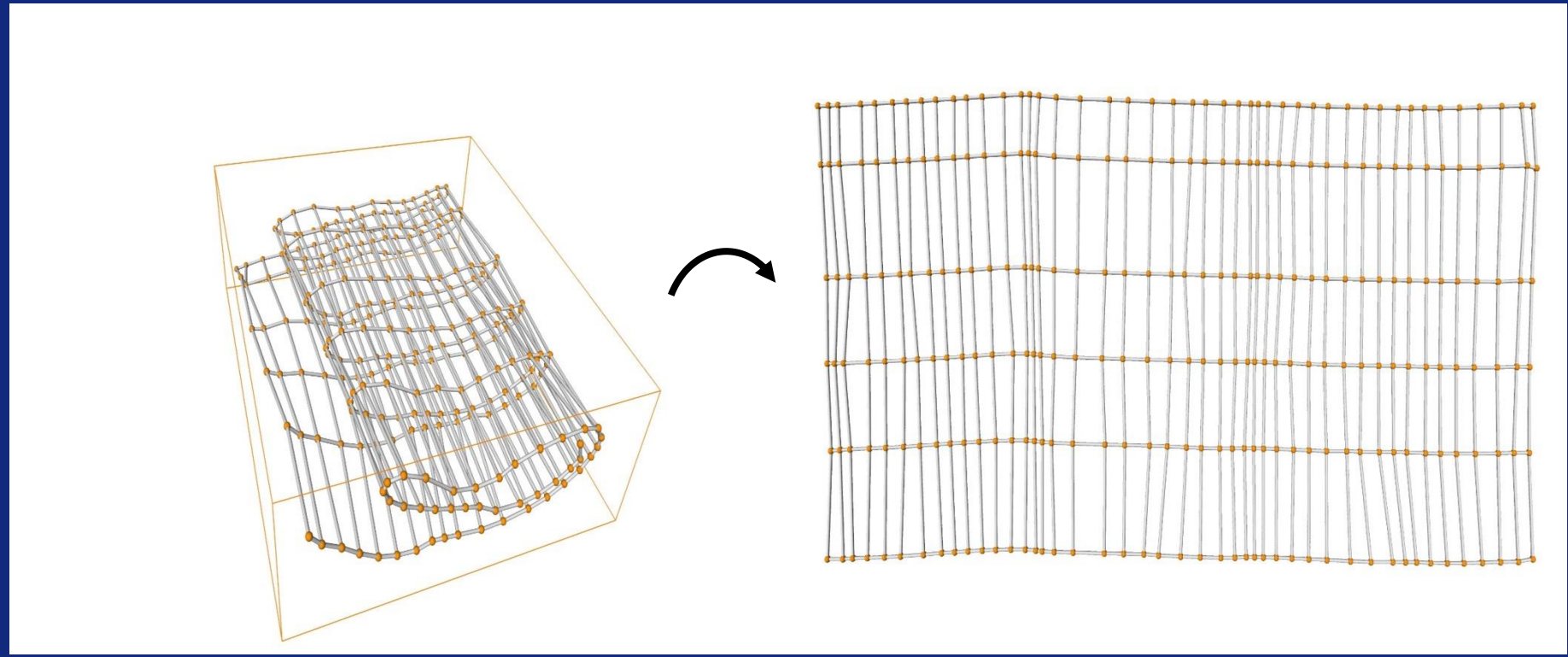


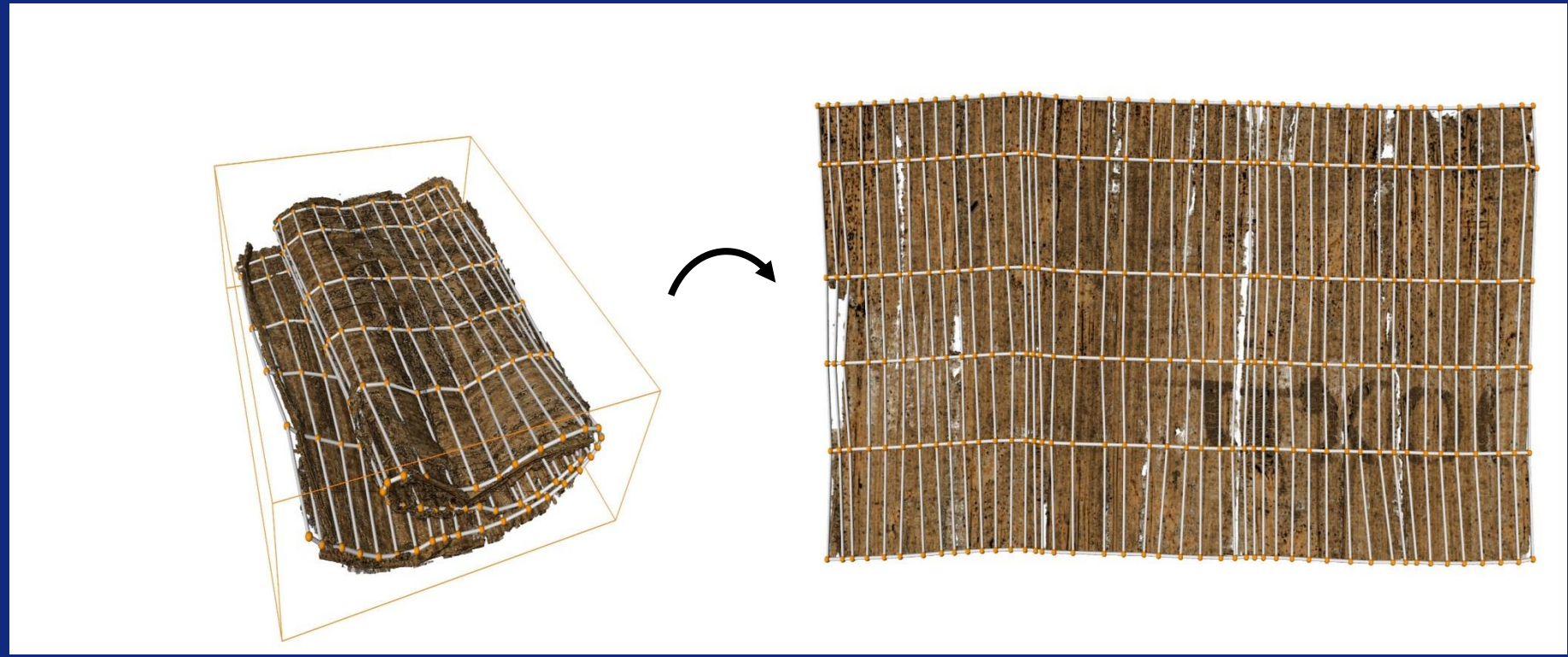












# L/El_227b/1-pC

ⲡⲭⲟⲉ[ⲓⲥ]

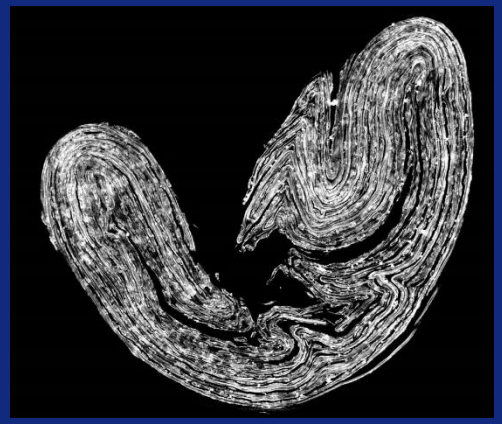
**Coptic for „The Lord“**

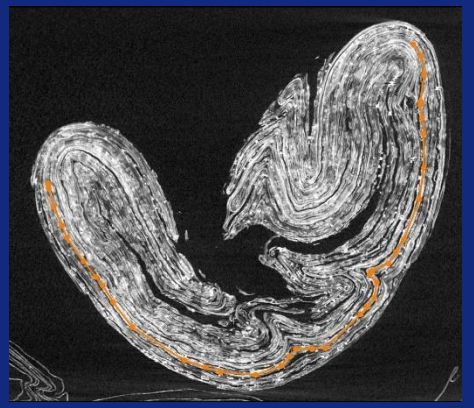
H.-E. Mahnke, T. Arlt, D. Baum, H.-C. Hege, F. Herter, N. Lindow, I. Manke, T. Siopi, E. Menei, M. Etienne, V. Lepper. Journal of Cultural Heritage 41 (2020) 264-269

# L/El_227b/3-pU

## Similar to magic fold

# L/El_227b/3-pU

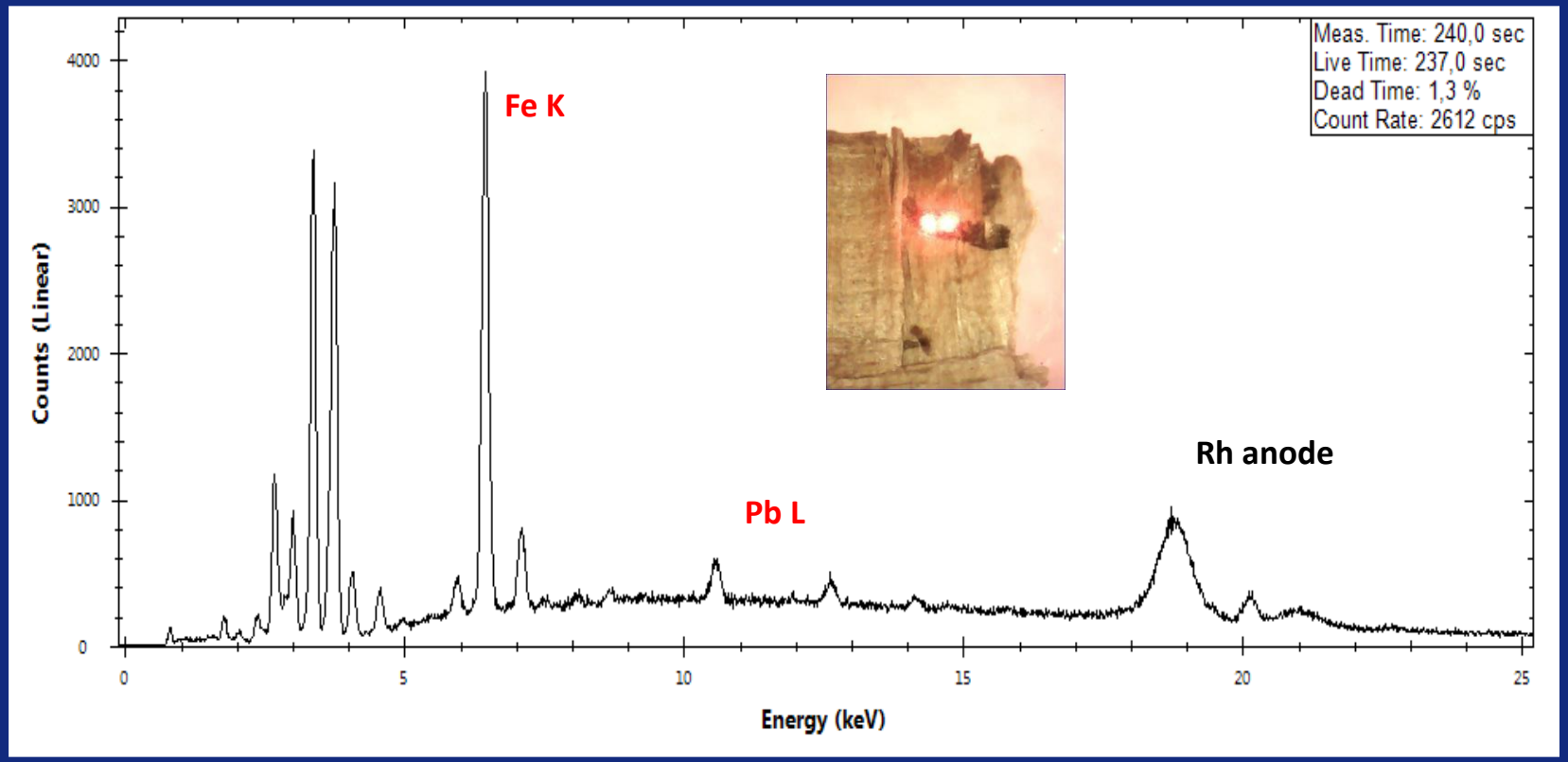




Carbon ink ? !

# L_El 227b_15_pU

## X-ray fluorescence



## Applicable for late hellenistic, early christian, islamic period (i.e. later than 70 AD).

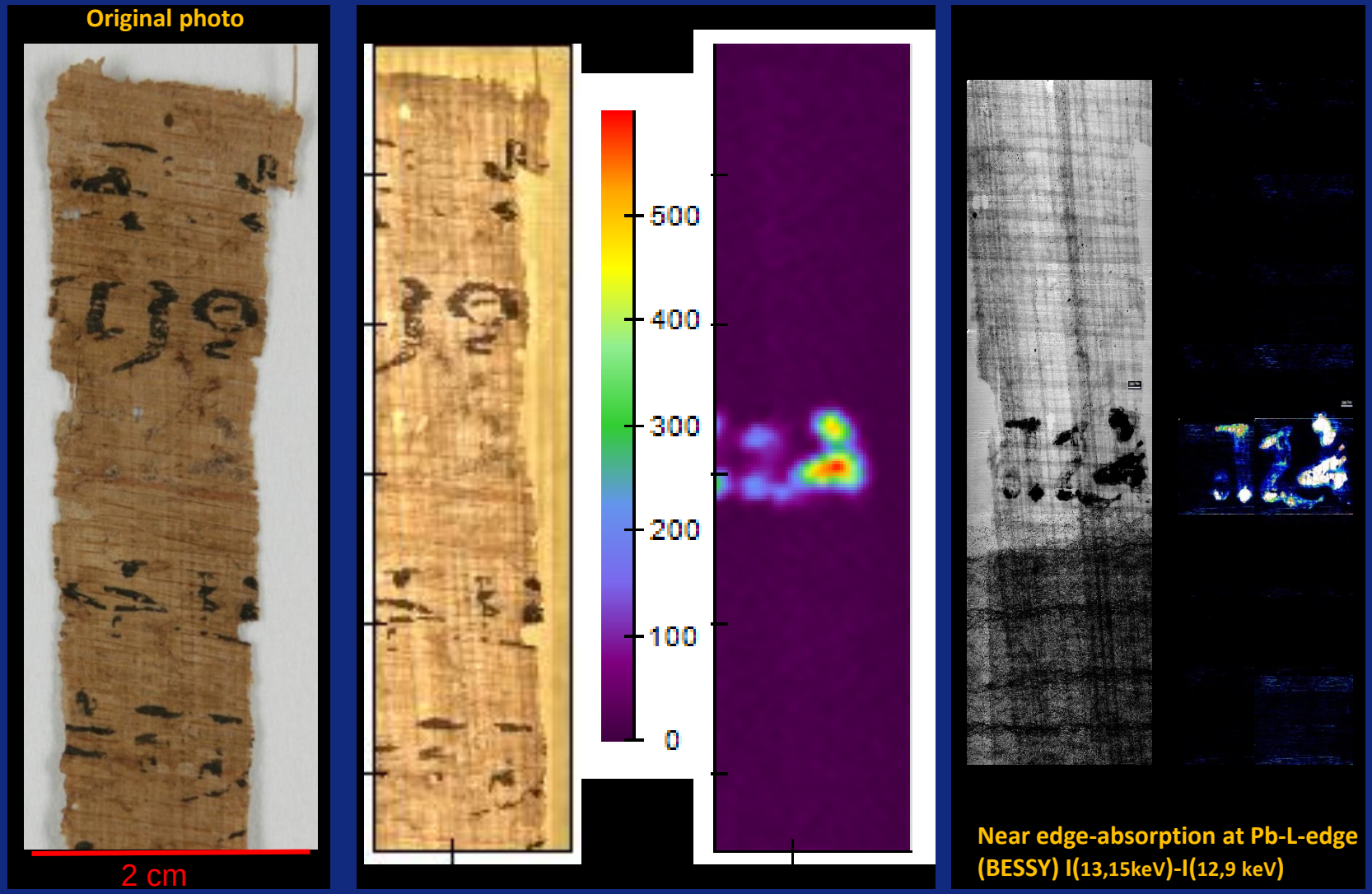
Plinius the Elder describes the identification of iron in his books “Naturalis Historiae” (Book 34) in 77 AD . Therefore one may assume that iron gall ink became available around that time.

## Perspectives for synchrotron use (SESAME)

- For absorption tomography: better sensitivity (contrast) using monochromatic (narrow-band), well-focused x-ray beam

# X-ray spectrum (broad band) versus monochromatic synchrotron

Mapping at 40 keV with x-ray window at Pb-L (10,55 keV) in 0.5 mm steps.




Absorption edge radiography

ÄMP B/Hx352

T. Arlt, H.-E. Mahnke, T. Siopi, E. Menei, C. Aibeo, R.-R. Pausewein, I. Reiche, I. Manke, V. Lepper, Journal of Cultural Heritage 39 (2019) 13-20

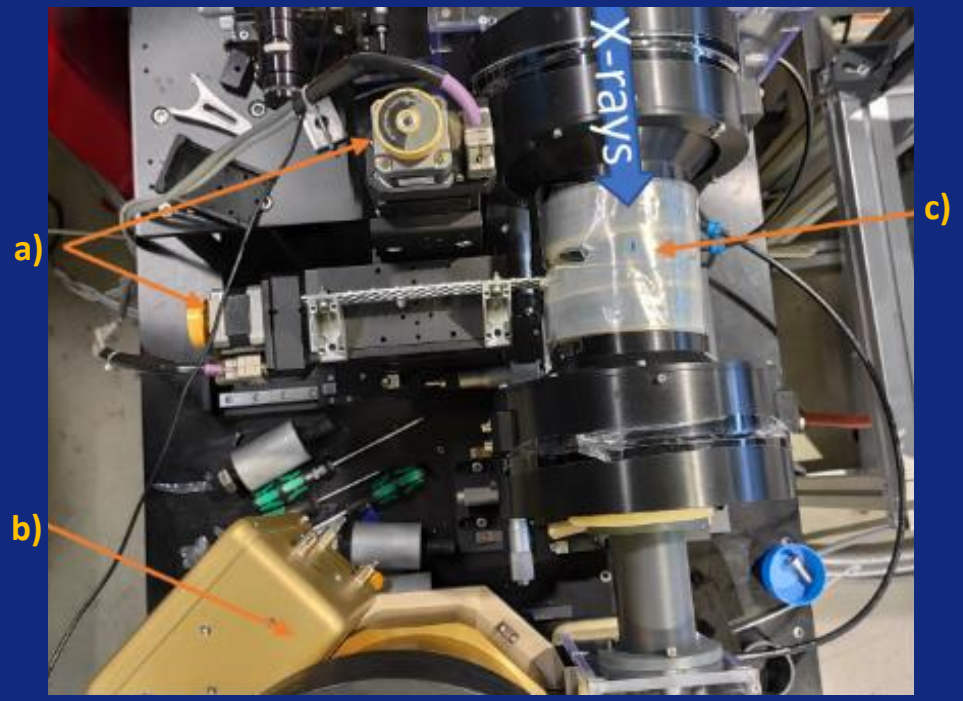
## Perspectives for carbon black ink?

Make use of

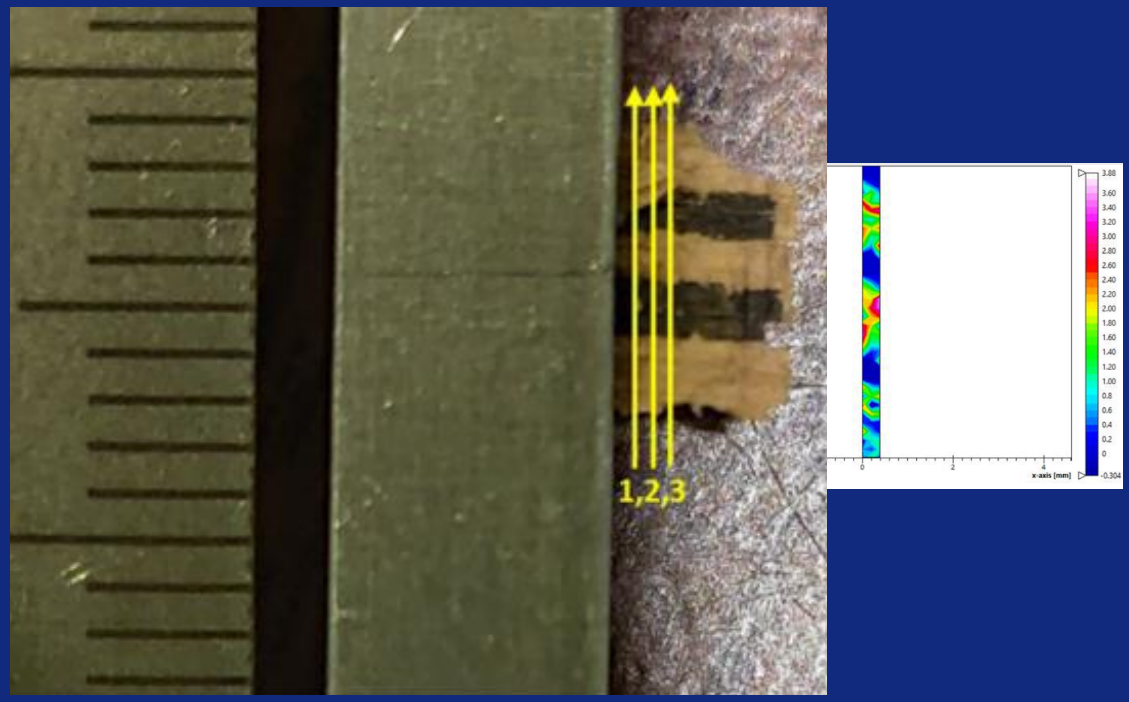
- Crystallinity
- Scattering (fringes)
- Phase contrast
- Index of refraction, carbon bonds ….
- Use of different wave length (IR, THz, …)

## Use synchrotron light (SESAME)

# Carbon ink test with IR at IRIS beam-line BESSY




a) Motors for mapping,
b) Detector (bolometer) at LHe temperature,
c) Papyrus sample under $N_2$-atmosphere.




Papyrus sample and scanning directions and positions
Integrated intensity in interval 185-152 $cm^{-1}$

# Further Challenges

Thank you for your attention !