Accessing hidden text on papyri - Elephantine and beyond

Verena Lepper & Heinz-Eberhard Mahnke

Ägyptisches Museum und Papyrussammlung, SMB/SPK

A multi-disciplinary project

Acknowledgement

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Motivation:

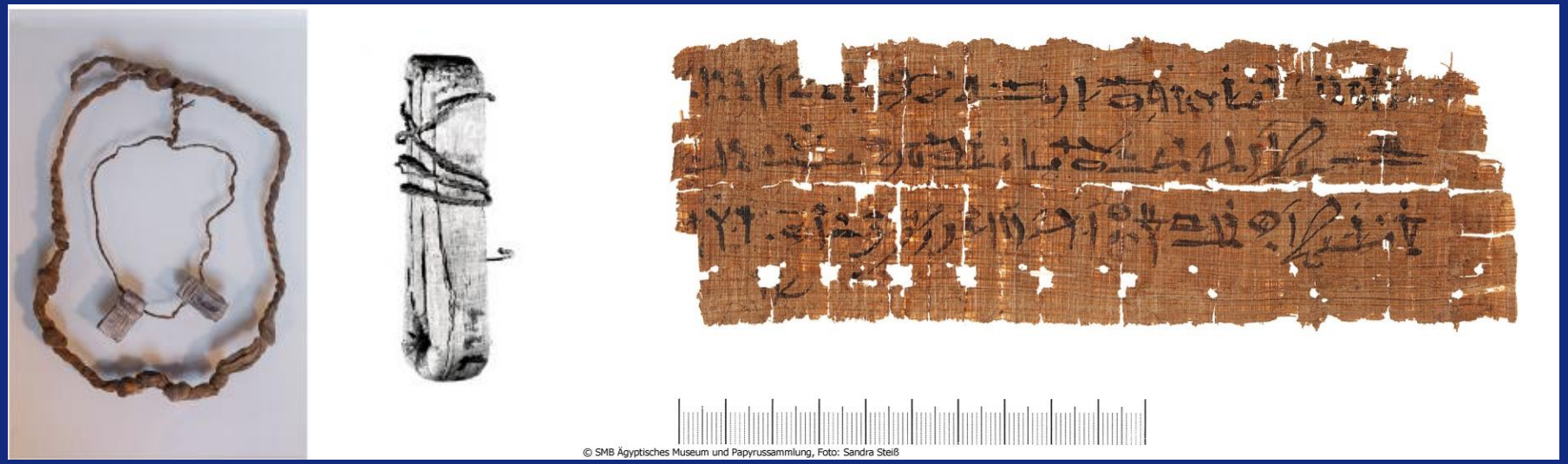
Learning from former cultures by reading their texts

Typical objects suitable for tomography at SESAME/BEATS

Amulettes, folded ‘letters’, or similar

Recent example: documents from Elephantine

Manual unfolding



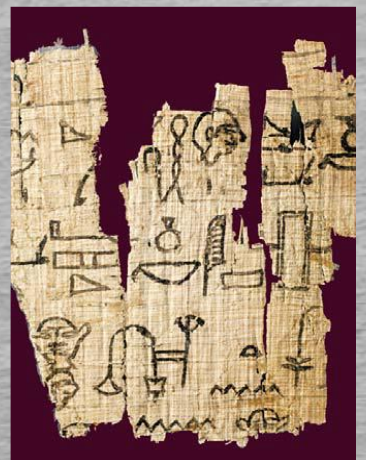
Typical objects suitable for tomography at SESAME/BEATS

Amulets, folded ‘letters’, and similar objects

Texts and Scripts from Elephantine Island in Egypt

over 4000 years

hieroglyphic

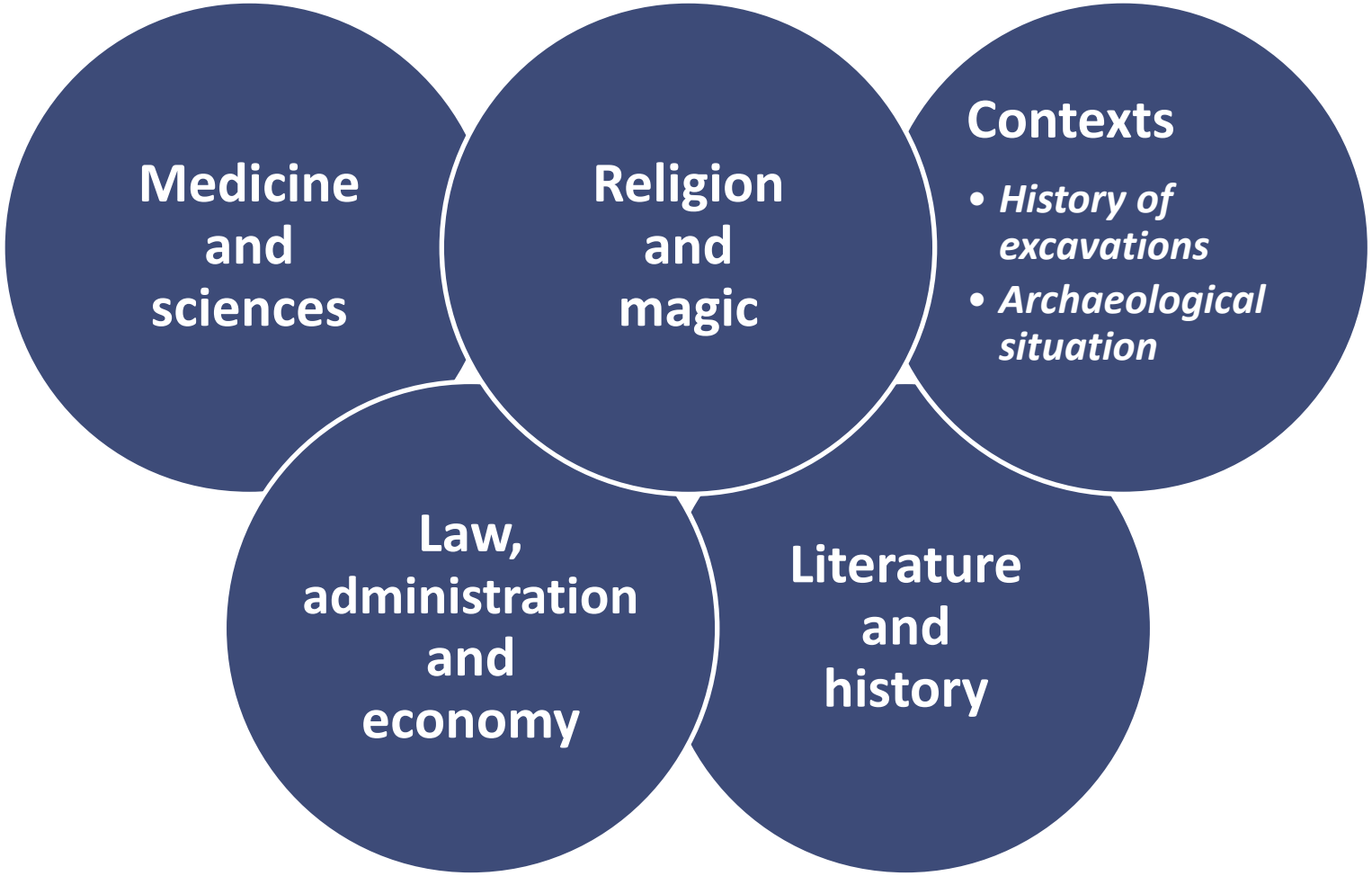


aramaic

coptic

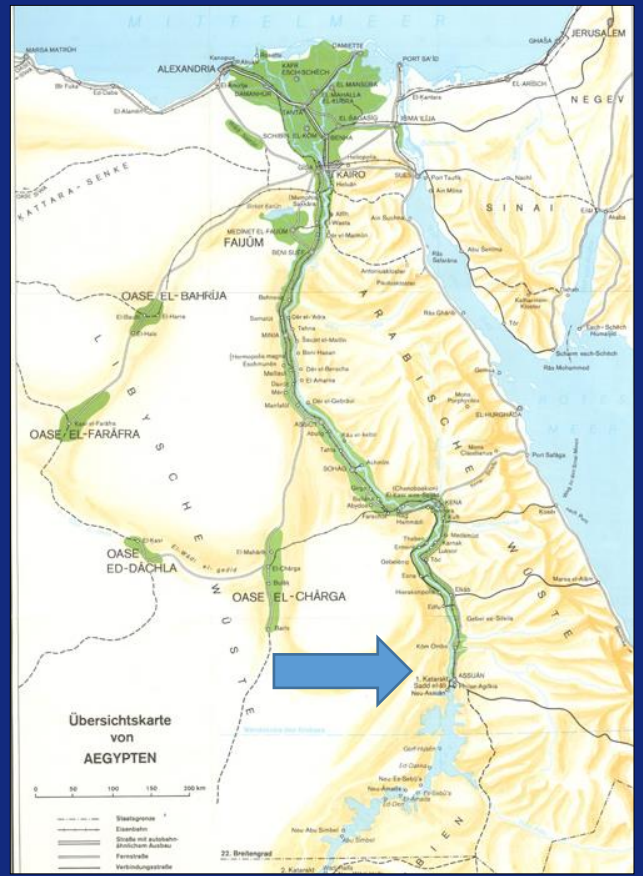
arabic

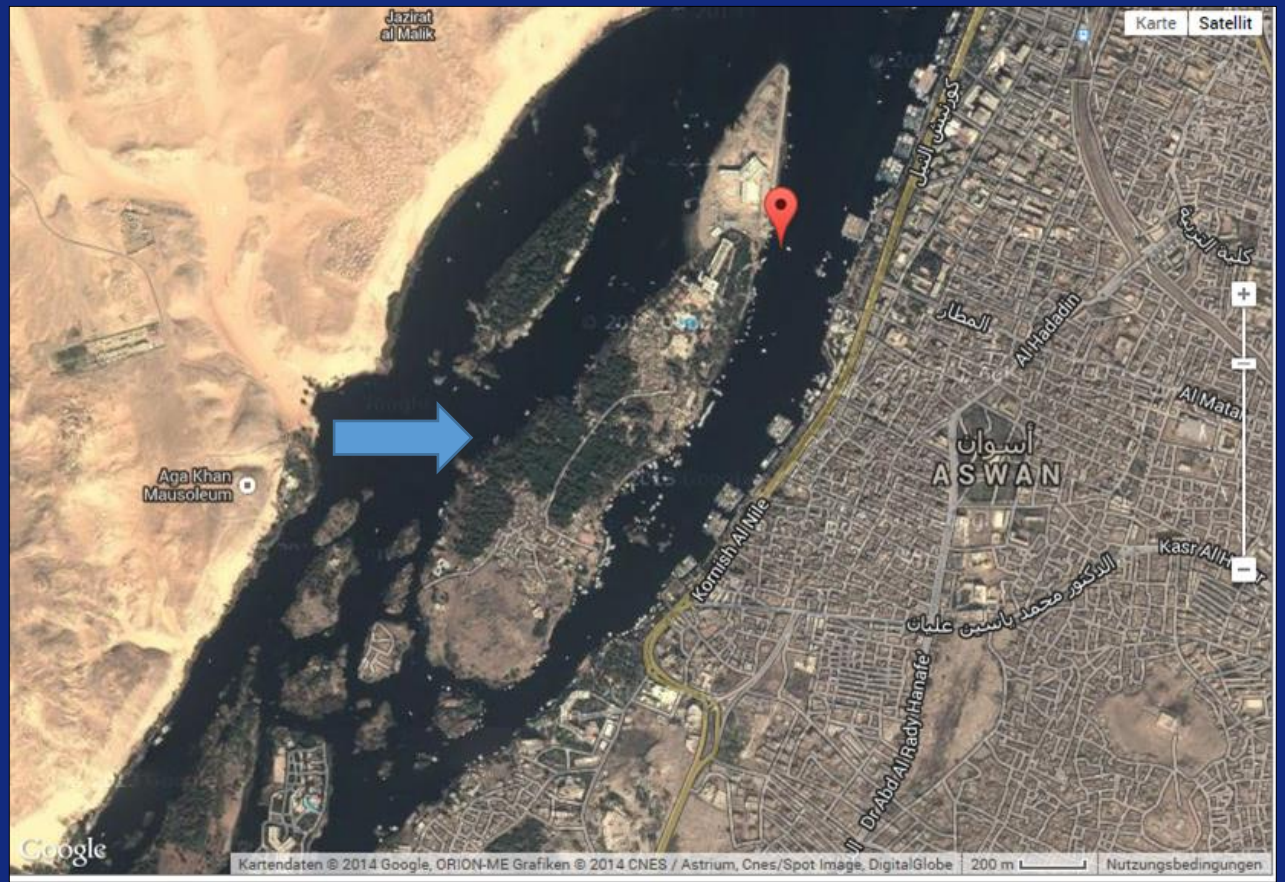
Topics of the Texts

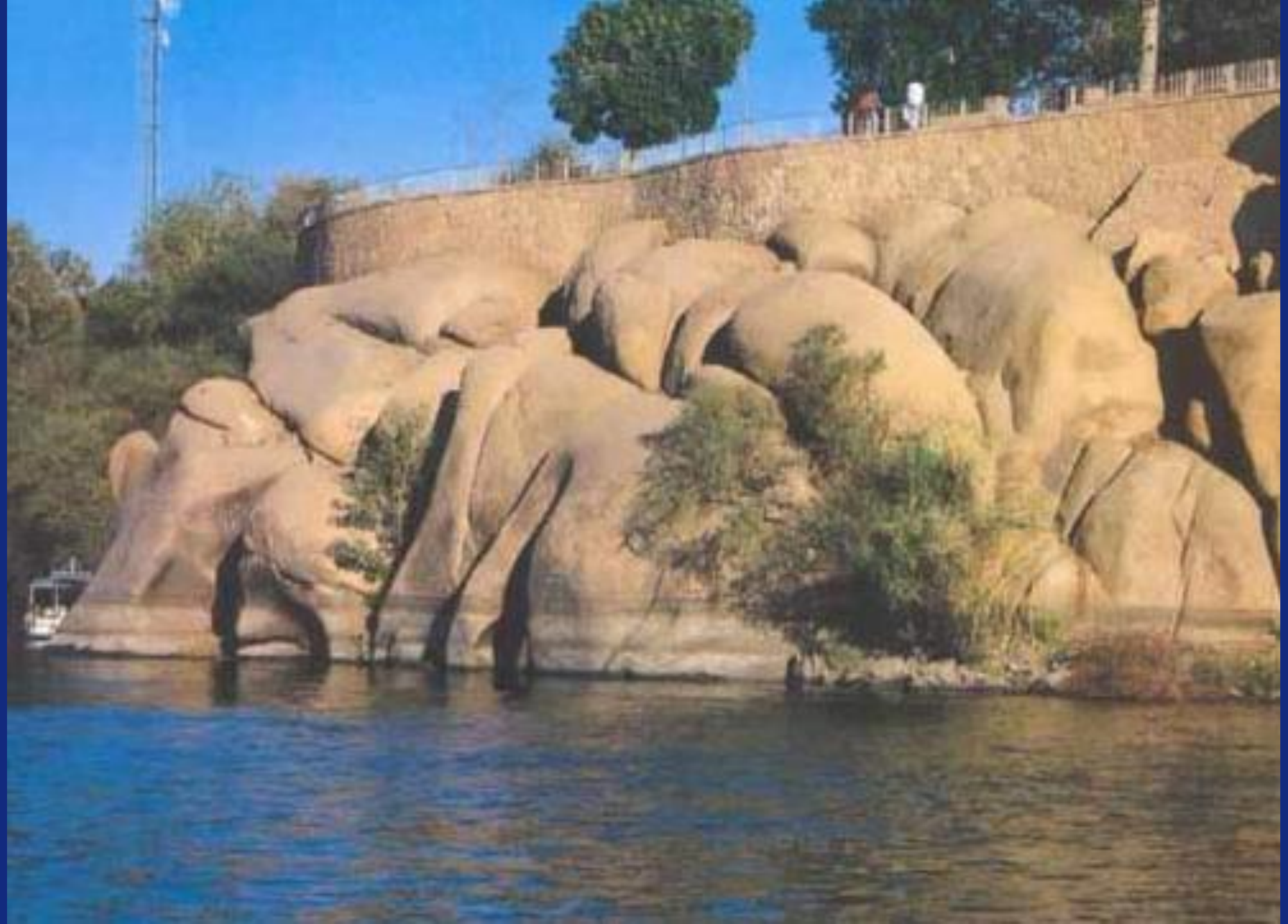


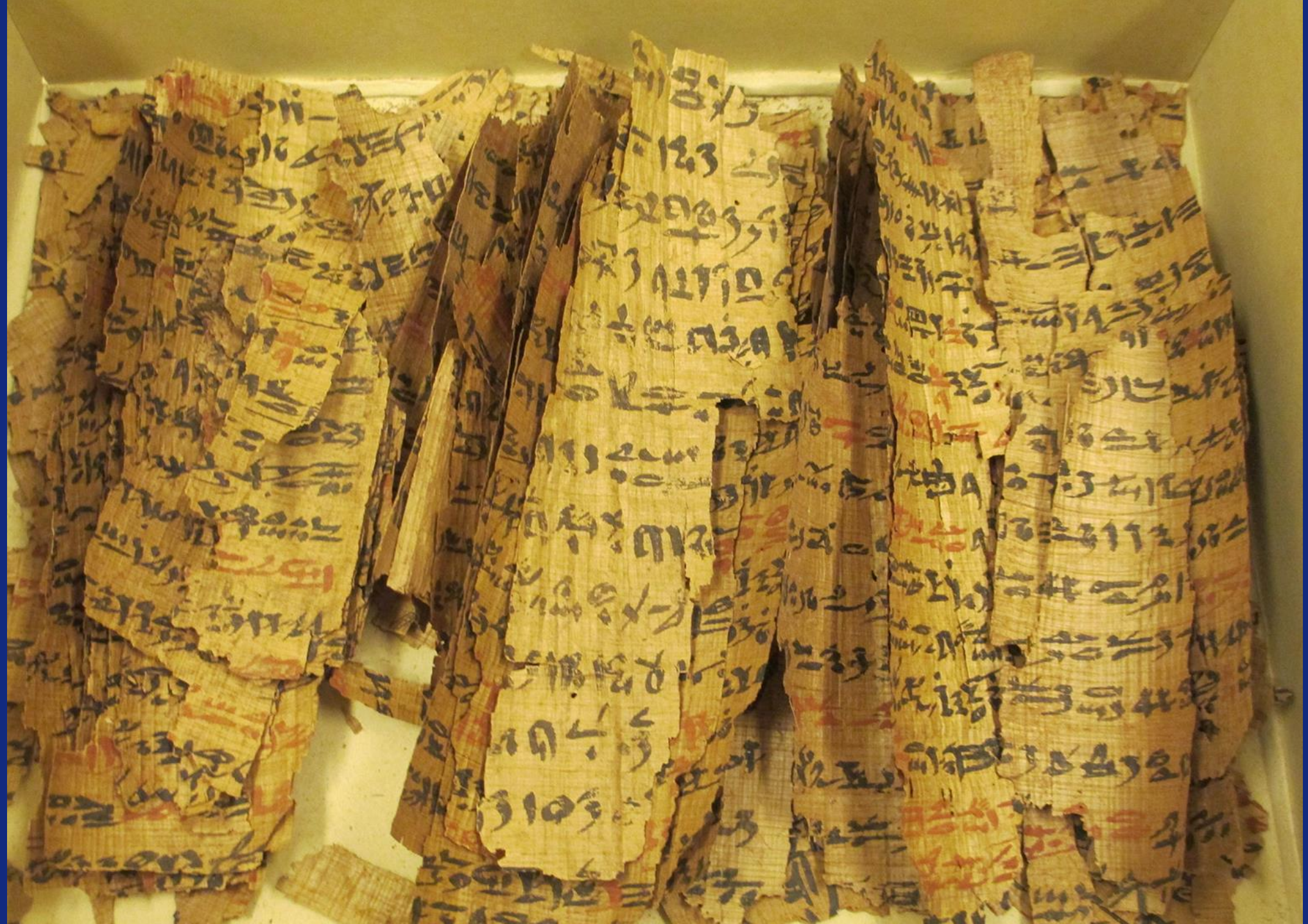
Elephantine Island

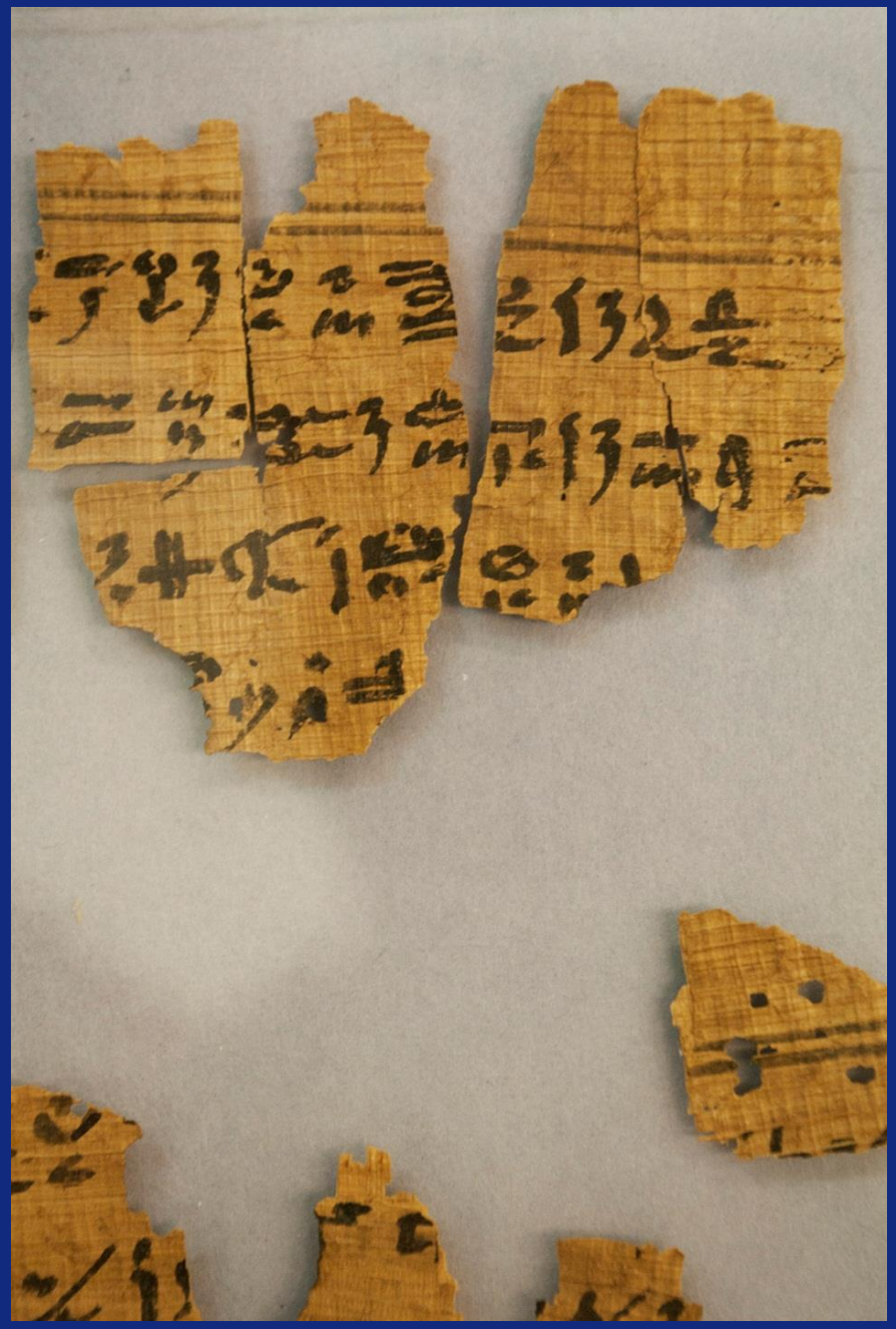
- Nile Island at the southern border of Egypt
- Old Kingdom (3rd millenium B.C.) to Arabic times (1000 A.D.)
- Multi-ethnic, Multi-lingual, Multi-cultural, Multi-religious
- Microcosm: “model for big questions in a small place”





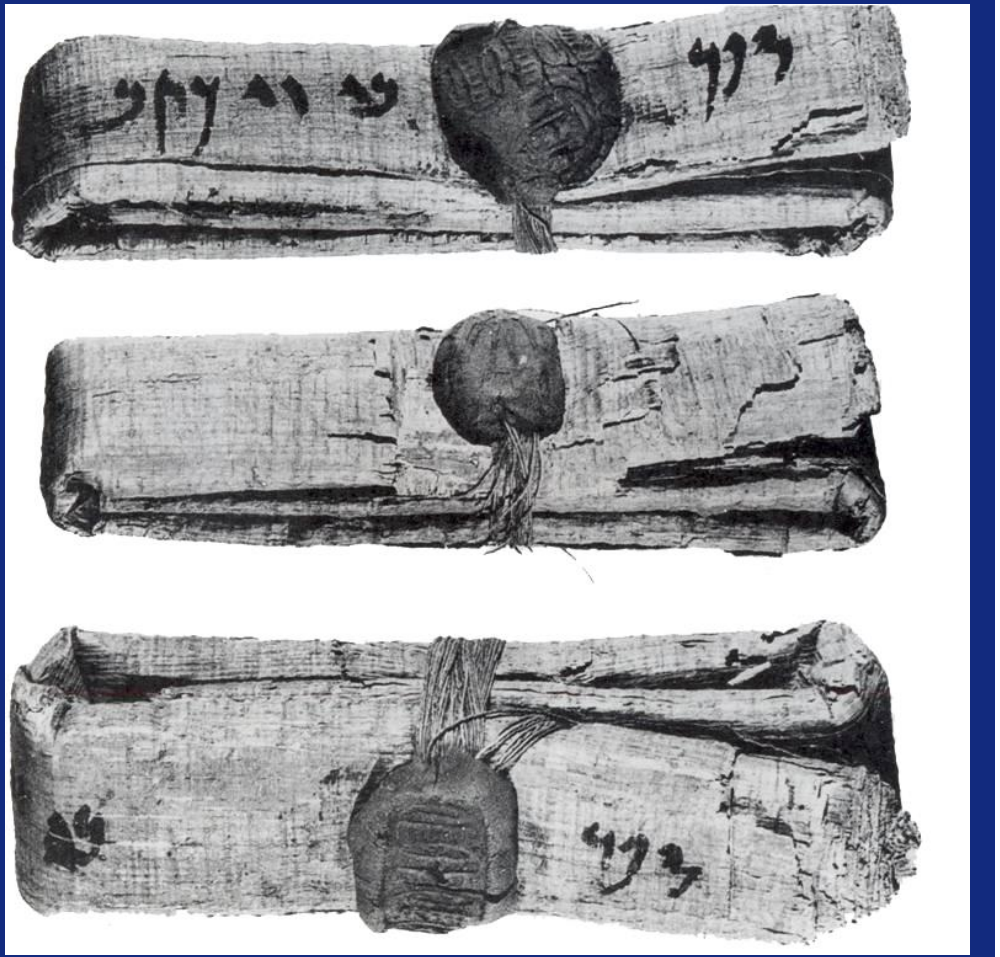






***P.Clermont-Ganneau* 1** (recto)

***P.Clermont-Ganneau* 1** (recto)



Current State of the Art

Example Elephantine (an ERC project 2015 -2022**):**

- **80% unpublished and unstudied**
- **In 60 different museums and institutions**
- **In 24 countries**

Brooklyn Museum

Ägyptisches Museum und Papyrussammlung

Musée du Louvre

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:

- **Contrast to distinguish writing (ink) and substrate,**
- **Resolution (a few µm thickness).**

Various different inks:

- Typical Black: Carbon ink. Later: carbon black with additives, iron gall ink, also with additives (for iron gall ink see recipe given by Plinius the Elder)

- Red: rubrum (ocher, iron oxide), cinnabar (mercury sulfide), minium (lead oxide)

Most texts, especially old ones, are written with carbon black, medieval books often with iron gall ink.

There is practically no contrast for carbon ink against papyrus. Carbon is easily identified by near infrared, but only, when openly accessible.

Additives or other inks are checked by X-ray fluorescence XRF!

Various different inks

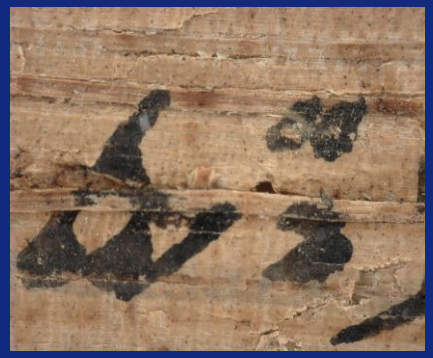
B/Hx247

B/Hx243t

B/Hx130q

B/Hx94g

	B/Hx247	B/Hx243t	B/Hx130q	B/Hx94g
Black:	C	C	C	Fe
Red:	Pb	As + Fe	Pb + Fe	



Carbon identification with NIR

Dino-lite digital microscope

Completed virtual unwrapping for the En-Gedi scroll

(on parchment)

William Brent Seales et al. Sci Adv 2016;2:e1601247

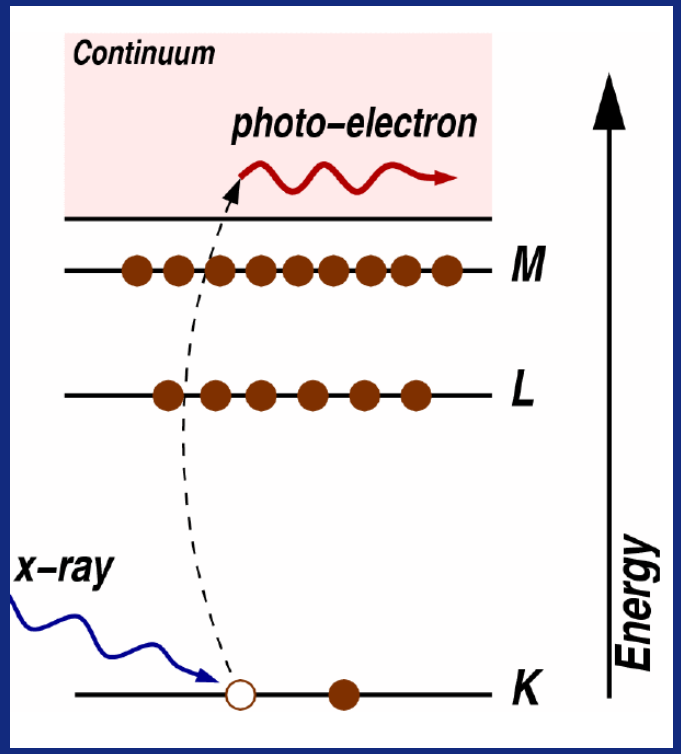
Iron gall ink

Contrast based on photo electric effect

absorption | emission

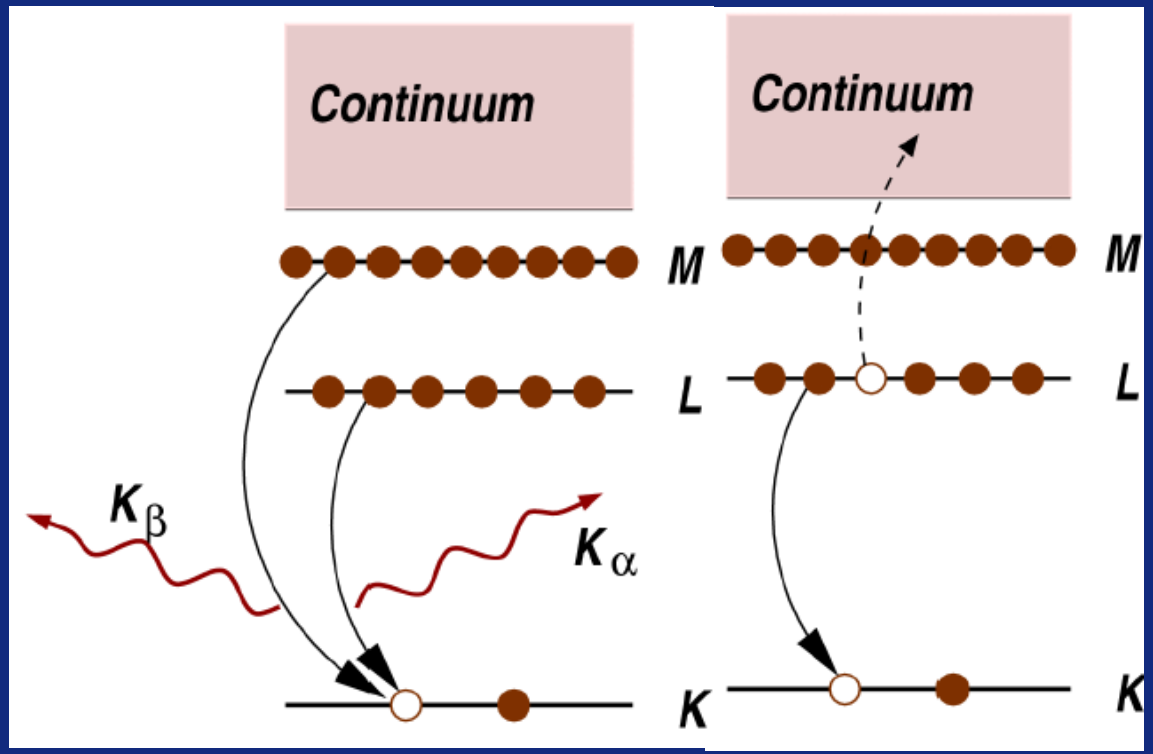
1905

an electron is „kicked out“ by a photon



or by other particles

Energy of emitted x-ray is characteristic for element



x-ray-fluorescence
(dominant for high Z)

Auger electron
(dominant for low Z)

Contrast based on absorption

due to photo electric effect

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

Element	σ (10^{-24} cm^2) (at 100 keV)	σ (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

2. sorting out by XRF for high-Z elements in the ink (e.g. Fe, Hg, Pb)

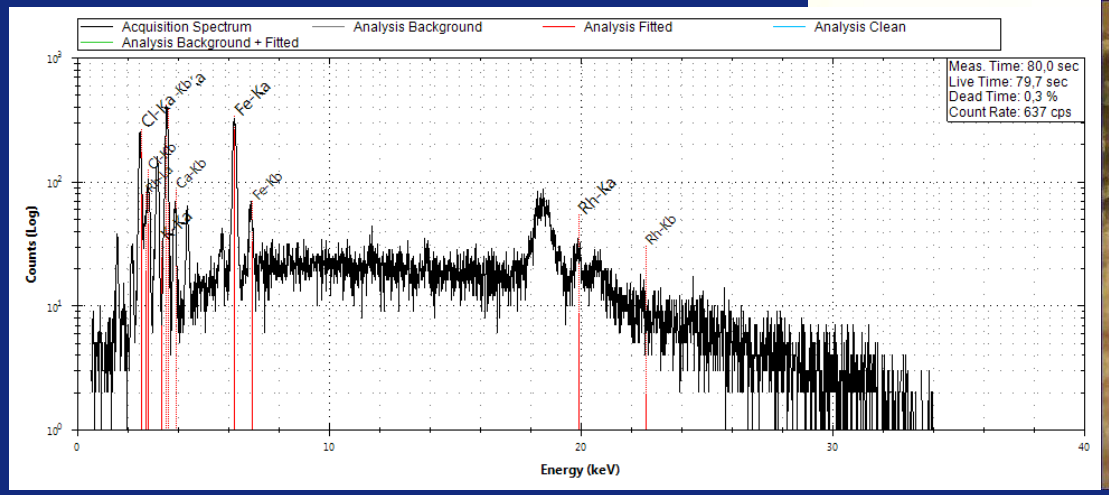
The energy of the emitted x-ray is characteristic for the element : $E_x \sim Z^2$

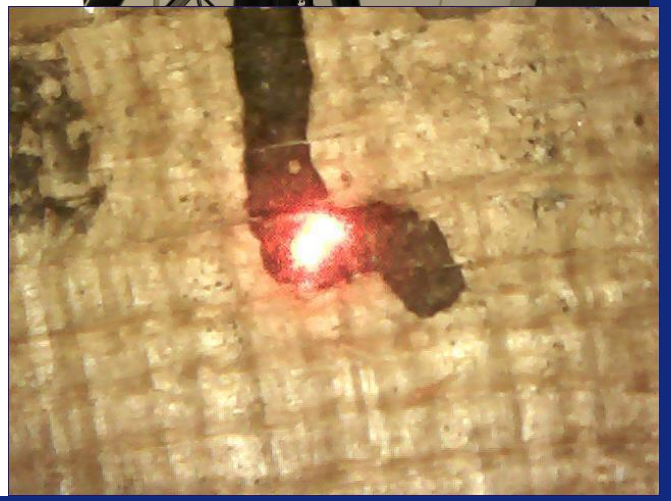
from 10 eV (hydrogen) to 100 keV (above uranium)

X-ray fluorescence

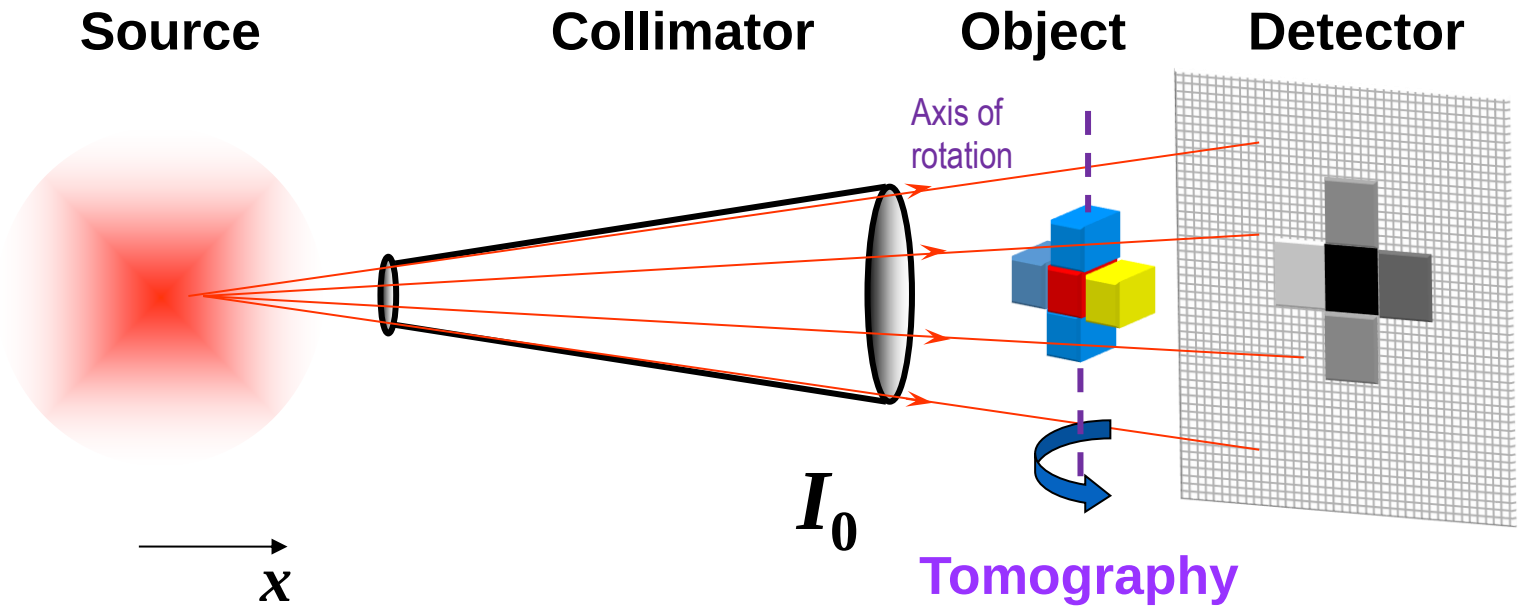
Elio

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





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



Tomography

$$\sim I_0 e^{-\int \Sigma(x)dx}$$

x – **propagation direction**

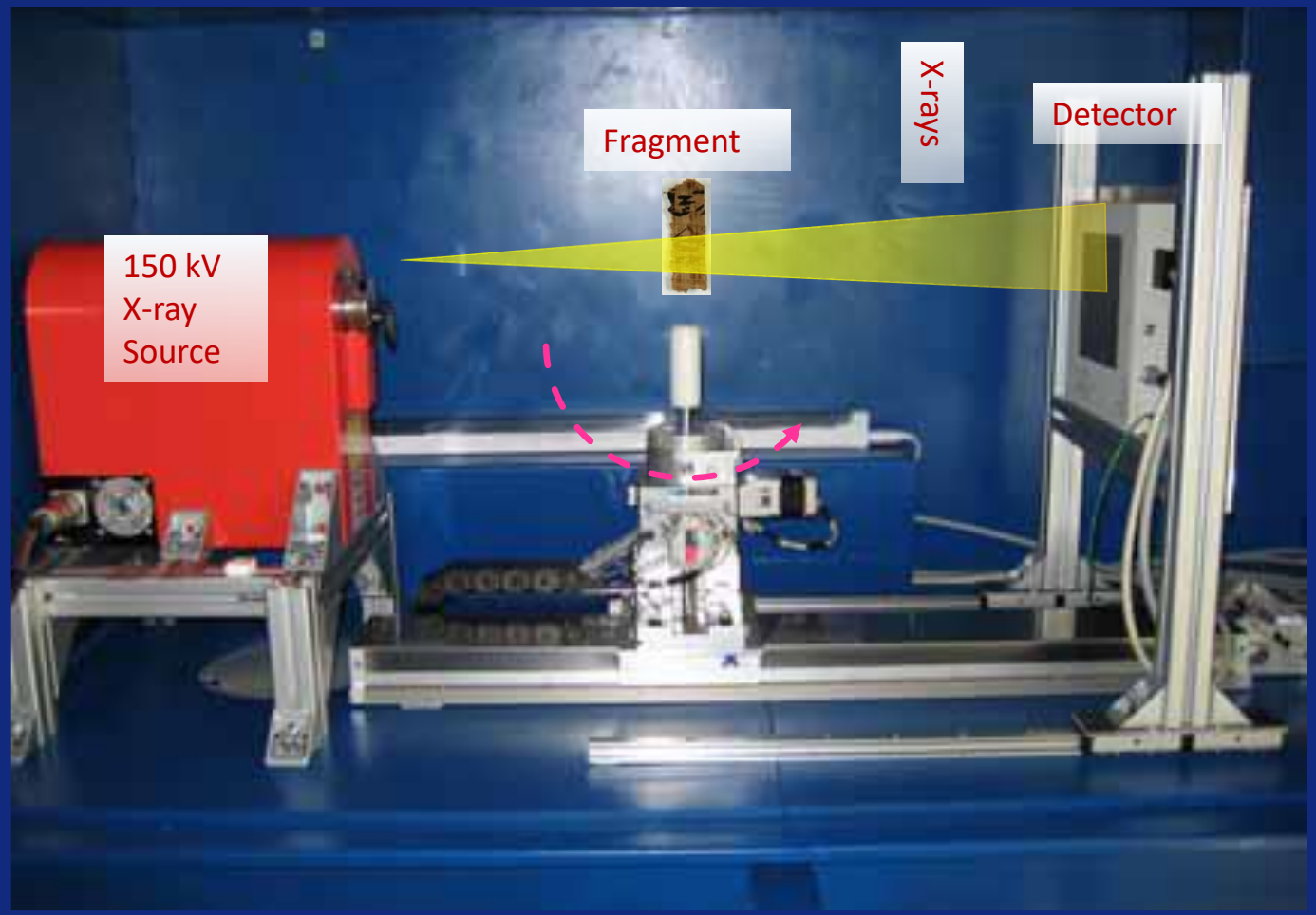
I_0 – **primary beam**

$\Sigma(x)$ – **attenuation coefficient**

Step 3: Volume reconstruction – computer tomography

Step 2: X-ray - tomography

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



Laboratory system at HZB

X-ray tomography

Commercial system

e.g. GE Phoenix nanotom s at Naturkundemuseum,
K.Mahlow, J.Müller

Synchrotron sources

HZB, BESSY

Others: ESRF Grenoble, PETRA at DESY Hamburg,

SESAME Allan, Jordan

Test on a mockup

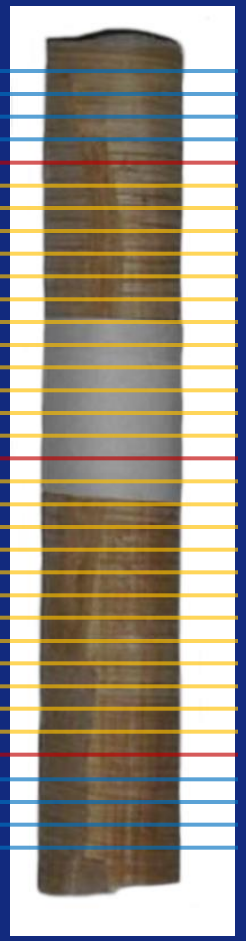
cinnabar (Z=80) and minium (Z=82)

folded
(“magic fold”)

rolled

volume rendering of 3D images

Step 3: (a) Unrolling



extrapolation

slice i

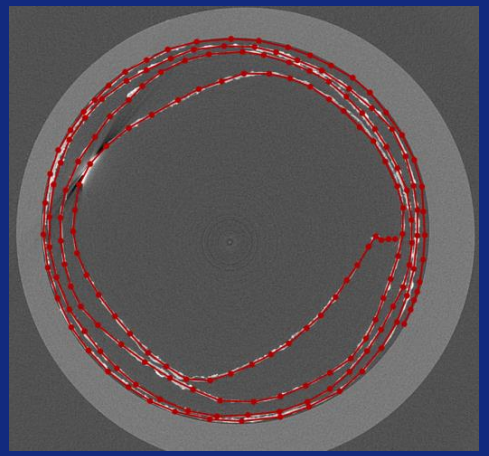
interpolation

slice i+m

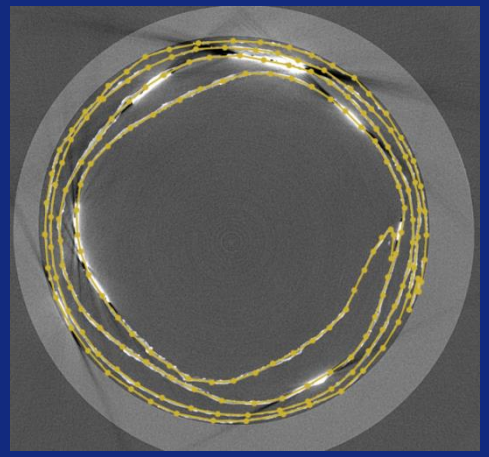
interpolation

slice i+n

extrapolation

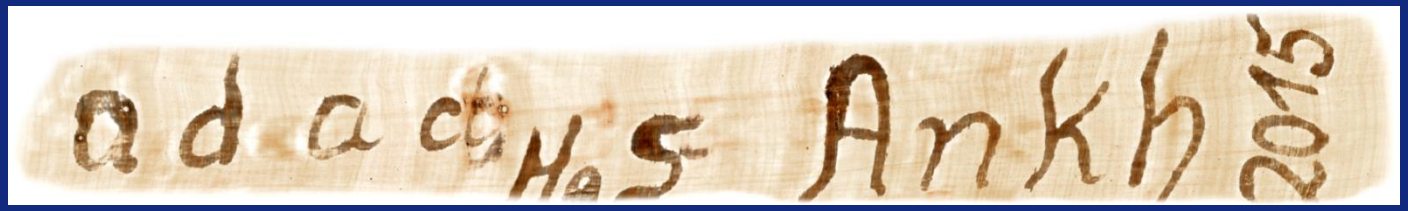


◄ Manually defining a segmentation for spiral contours along the papyrus roll (slices i, i+m, i+n)



◄ Linear interpolation between manual contours and constant extrapolation outside.

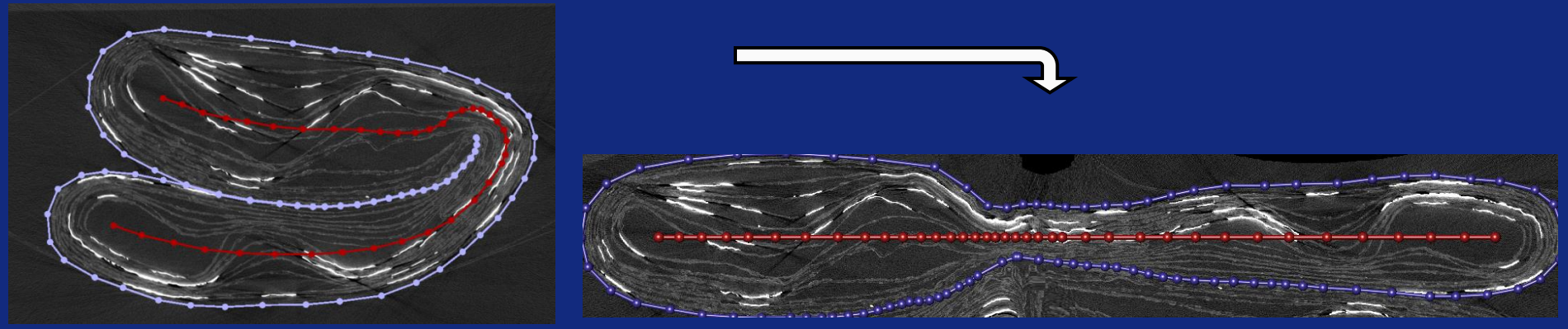
A fully virtually unrolled mockup (top part) based on 3 manually placed spiral contours.

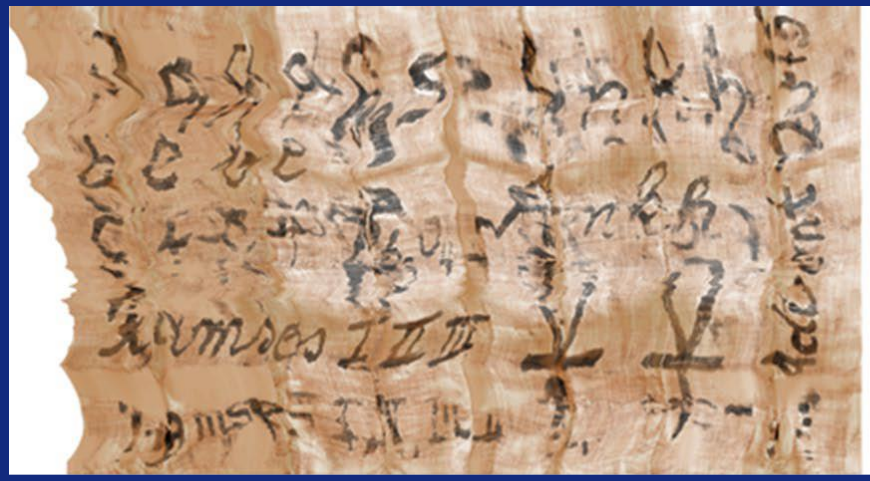


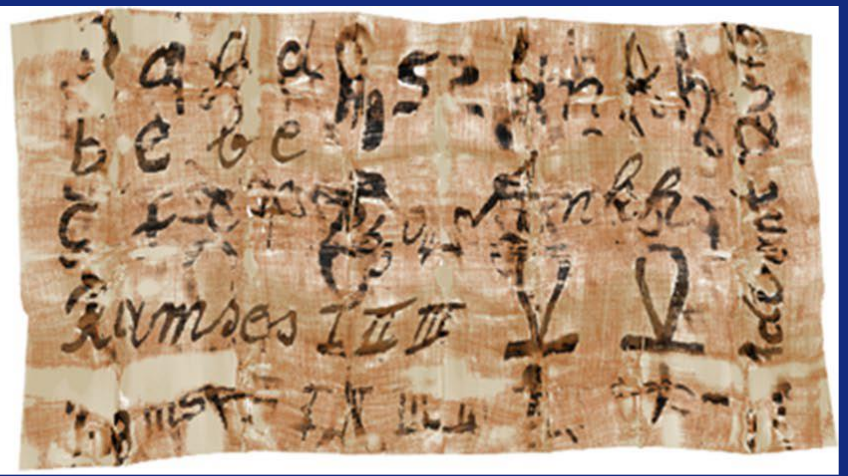
Step 3: (b) Unfolding

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







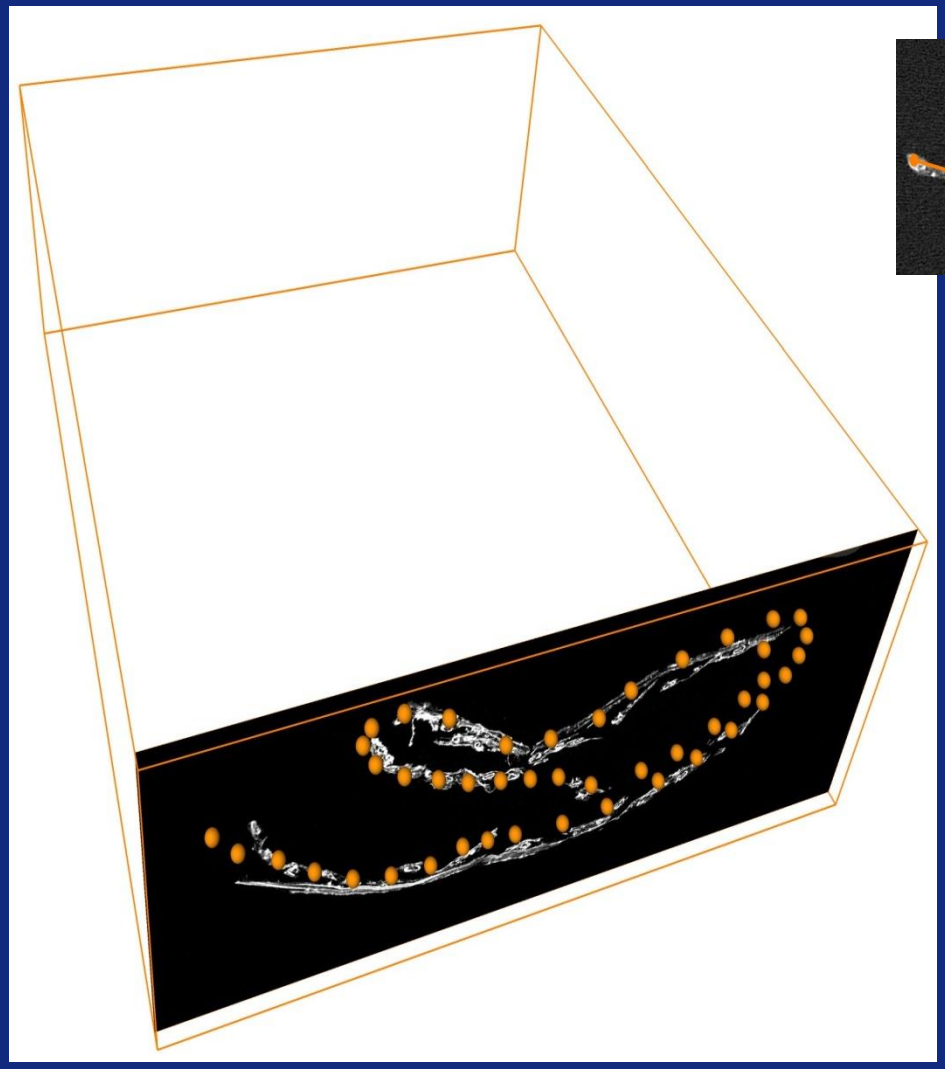

a d a d
b e b e
c f e f
Ramses I II III
Ramses I, II, III
Ankh
Ankh
1. Advent 2015

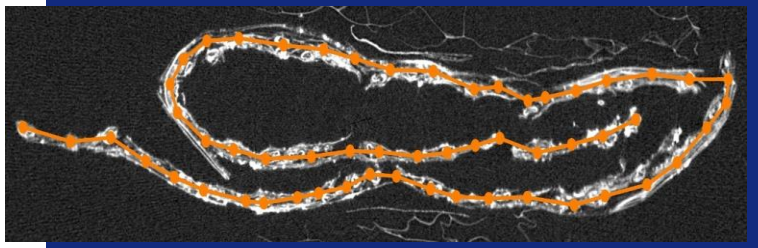
Papyrus L/El227b/1-pC

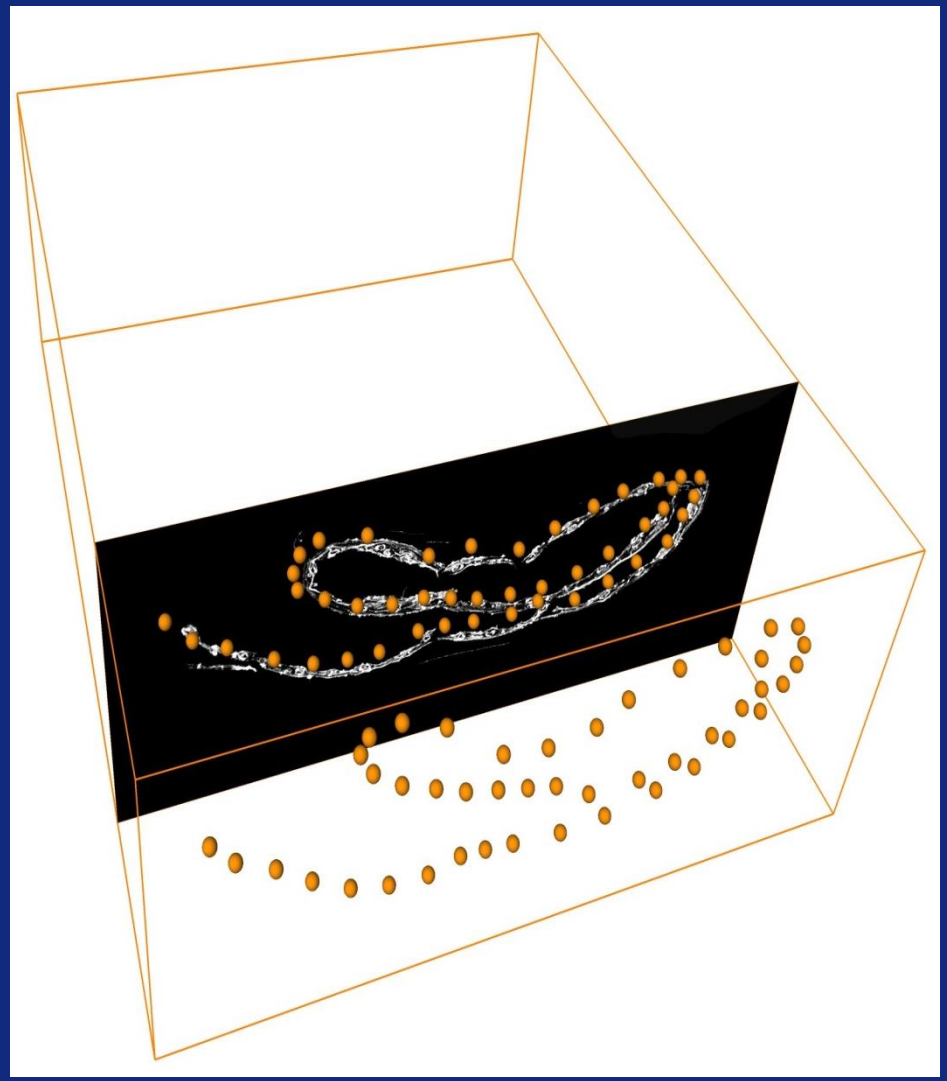
Foto

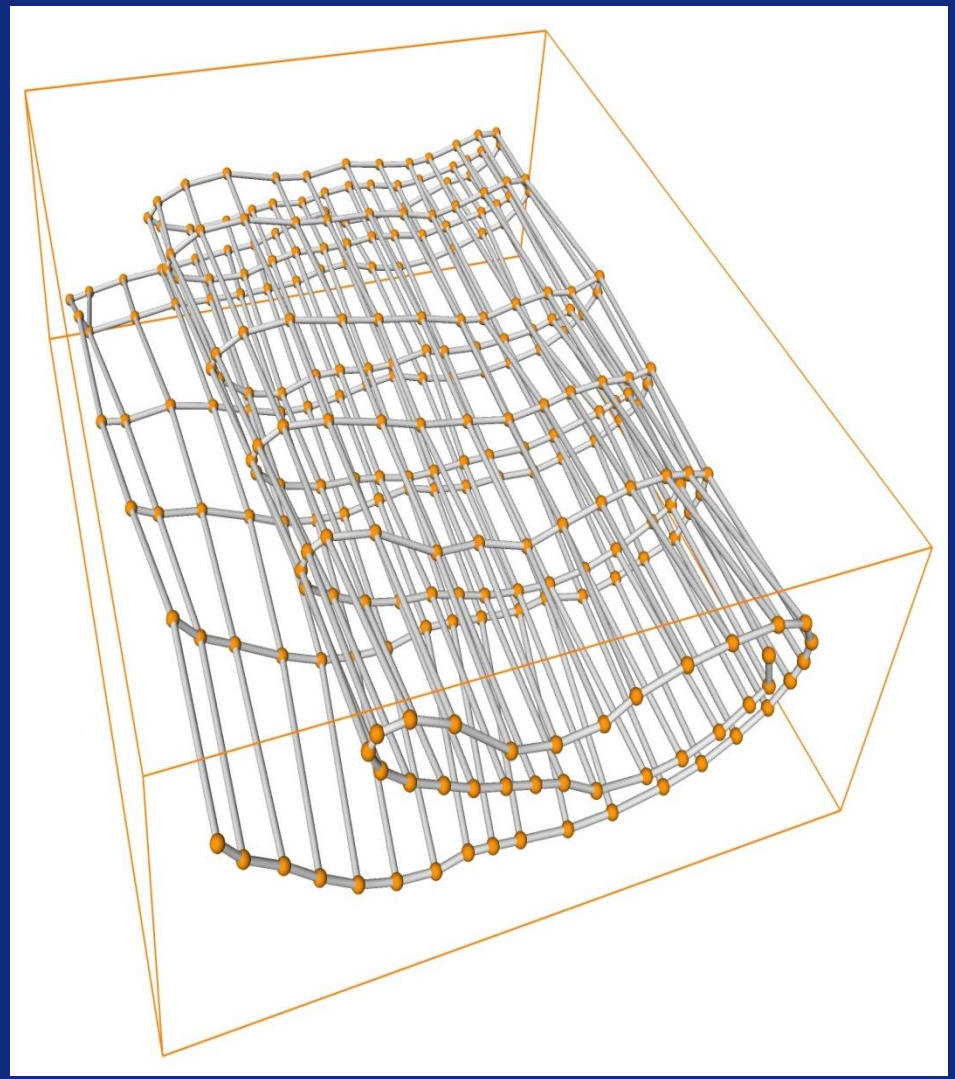
Folded twice in the same direction (equivalent to a scroll)

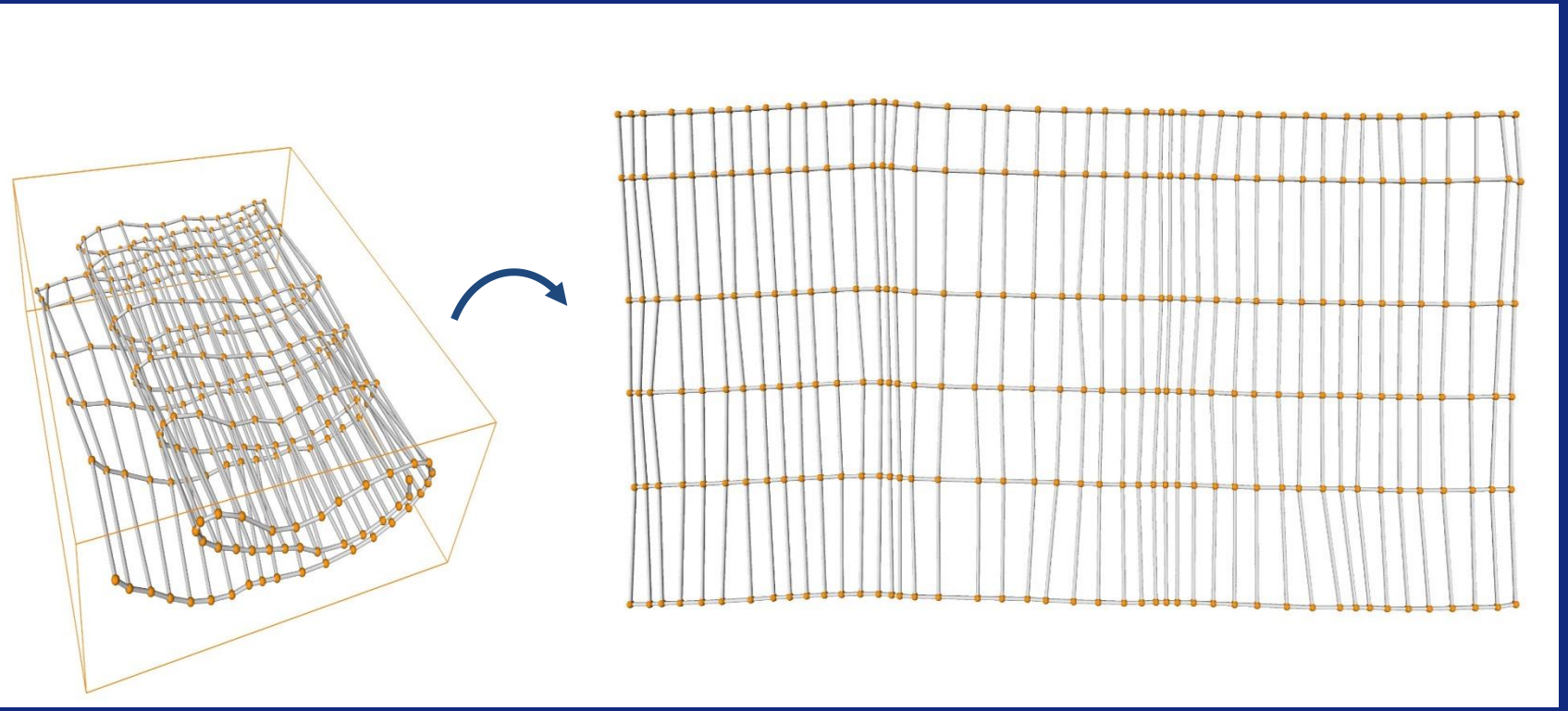
Volume rendering

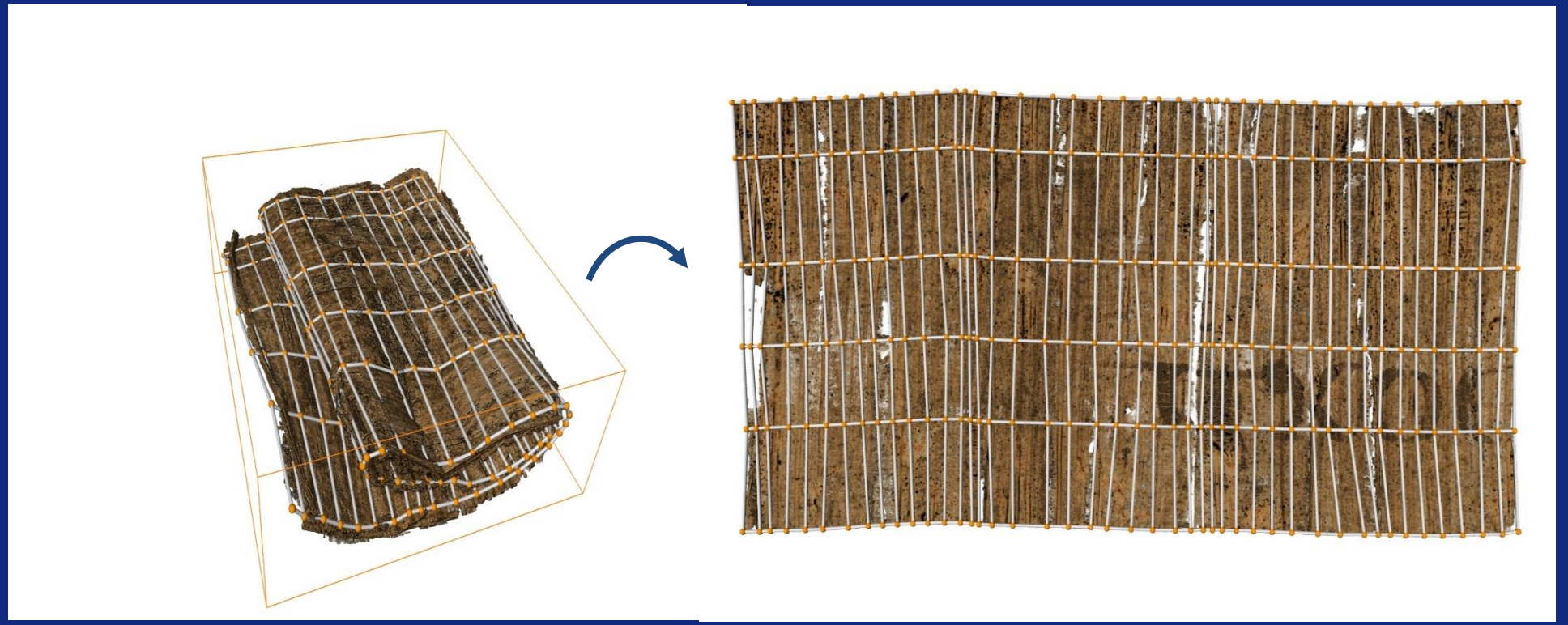












Papyrus L/El_227b/1-pC

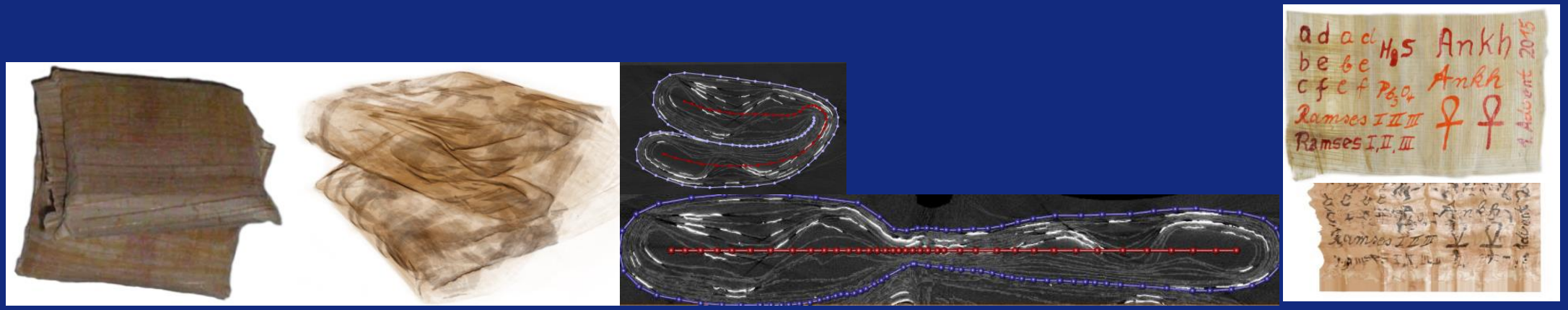
ⲡⲭⲟⲉ[ⲓⲥ]

Coptic for “The Lord“

H.-E.Mahnke et al. Journal of Cultural Heritage, 2019, online

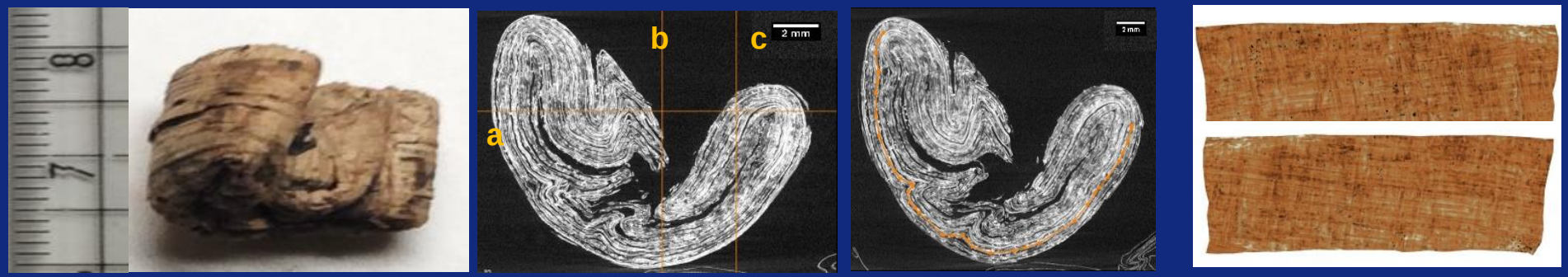
Summary of X-ray – CT results

Test with folded mockup written with cinnabar and minium *(“magic fold”)*



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

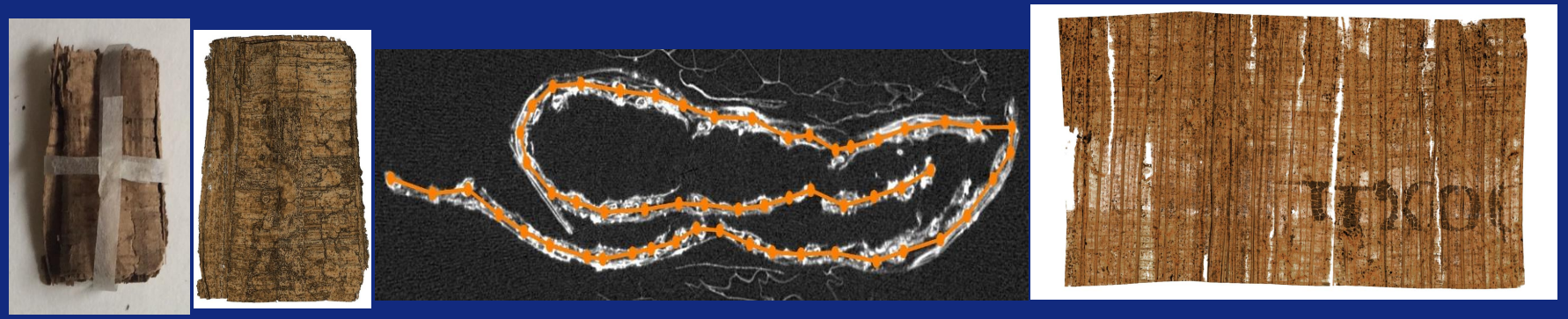
“Magic fold” object (?) from the Louvre collection L/EP227b/2-pU



Summary of X-ray – CT results

“Greek” object from the Louvre collection L/EP227b/4-pG

“Coptic” object from the Louvre collection L/EP227b/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. Jour. Cultural Heritage 41 (2020) 264-269

Applicable for standard text (Fe gall ink) for late hellenistic, early christian, islamic period (i.e. later than 70 AD).

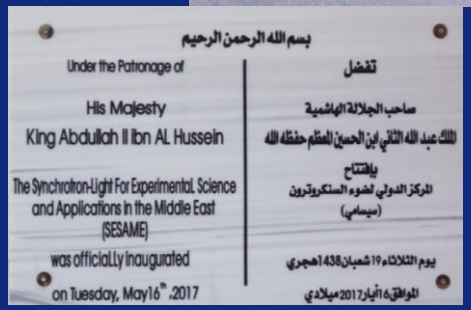
Plinius the Elder describes the identification of iron in his books “Naturalis Historiae” (Book 34) in 77 AD . Therefore, one may assume that iron gall ink became available around that time or somewhat earlier.

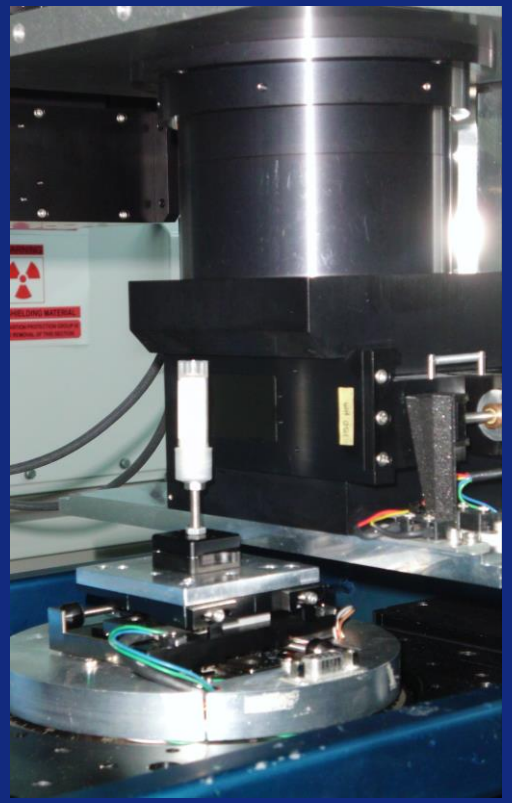
What to do with carbon ink?

SESAME – **S**ynchrotron-light for **E**xperimental **S**cience and **A**pplications in the **M**iddle **E**ast

Model:
CERN:
„Science diplomacy“

SESAME – Synchrotron-light for Experimental Science and Applications in the Middle East

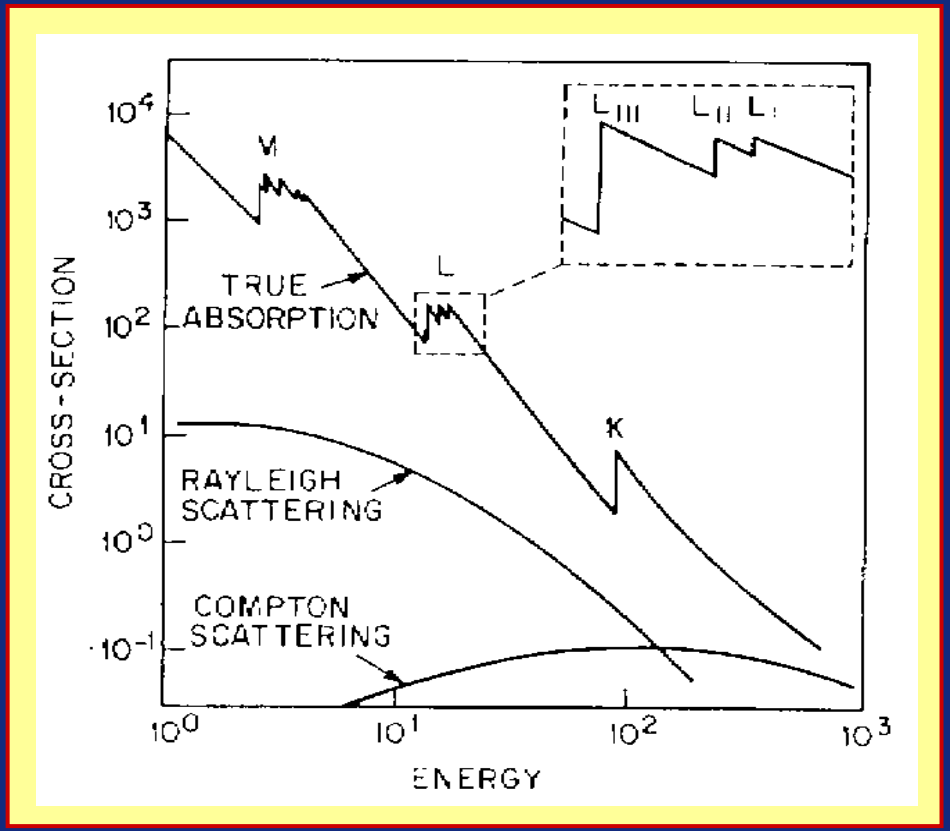




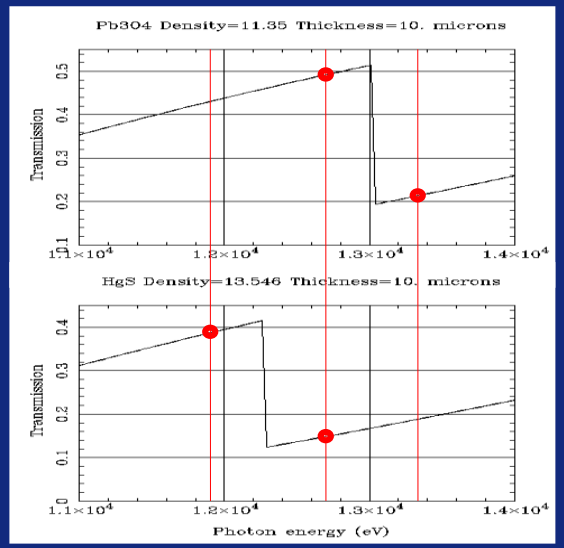
Standard size setup

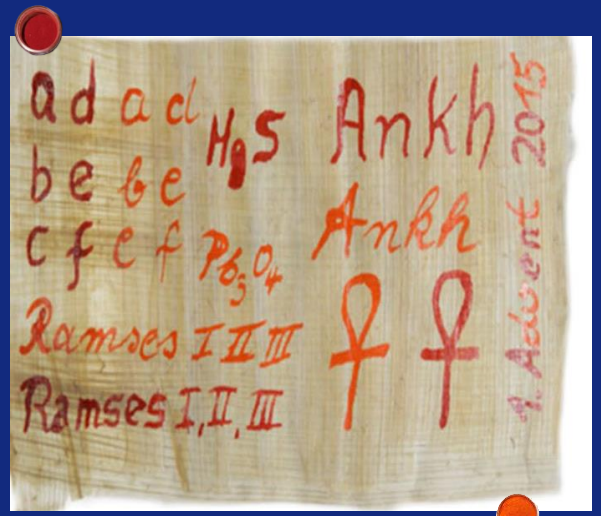
SESAME – Synchrotron-light for Experimental Science and Applications in the Middle East

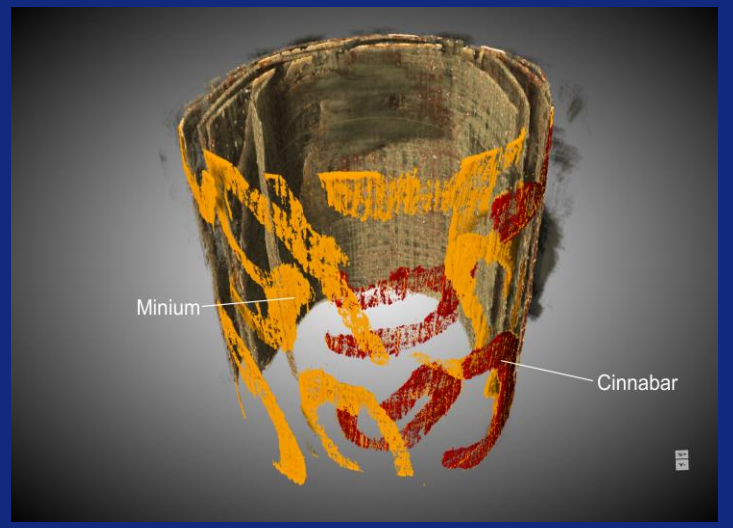
Element specific absorption edges
Test for stability



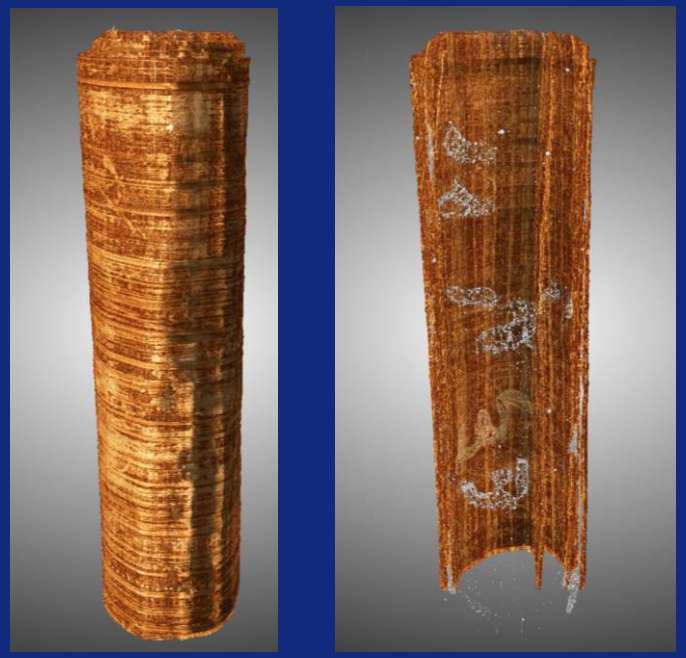
Energies: 11.9, 12.7, 13.35 keV

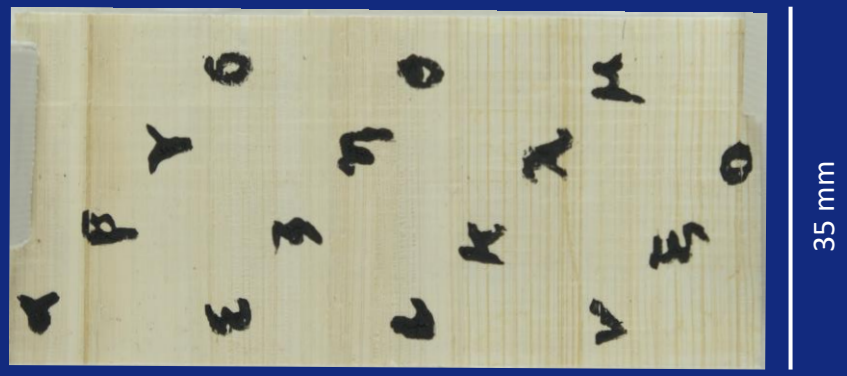


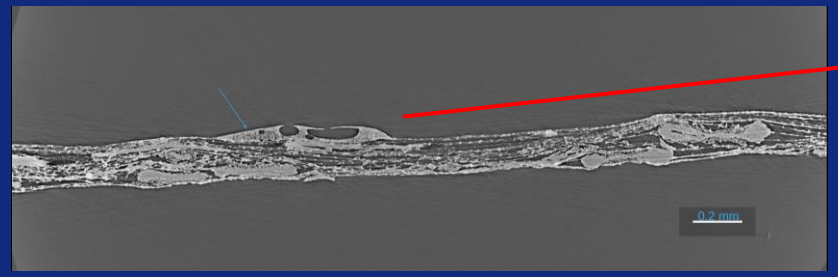


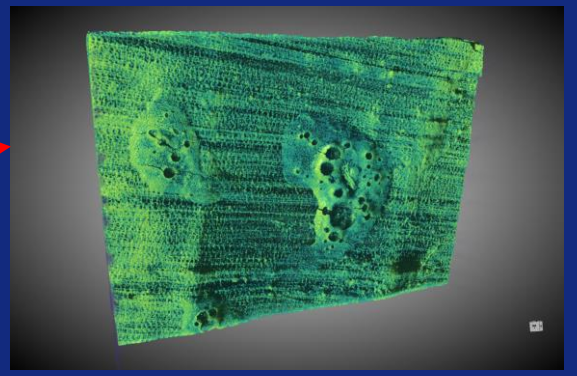


Mixture carbon and 3.5 % (PbS, kohol)









Pure carbon ink

Looking forward for the next bamtime next year on real objects. Thank you

e.g.