BEATS

Microtomography Beamline for Science, Engineering and Industry

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and Applications in the Middle East
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https://www.sesame.org.jo/beamlines/beats

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OUTLINE

- BEATS beamline description and specifications
- Detection systems available at BEATS
- Modes of imaging available at BEATS
- Experiment design
- Data acquisition
- Introduction of the reconstruction tools at BEATS
- Introduction to ImageJ/Fiji
- Beamtime preparation - bring enough storage memory
- Suitable sample size, shape
- Some results from previous experiments

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EXPERIMENTAL SCIENCE
AND APPLICATIONS IN
THE MIDDLE EAST

BEAmline for **T**omography at **S**ESAME (BEATS)

- Hard X-ray full-field radiography and micro-CT station
- Layout based on TOMCAT (Swiss Light Source)
- Funded by the EU's Horizon 2020 program
- First received general users in 2024
- Monochromatic energy: 8 – 50 keV
- A state-of-the-art computing infrastructure for data collection, three-dimensional (3D) image reconstruction and data analysis
- Adjustable propagation distance between sample and detectors

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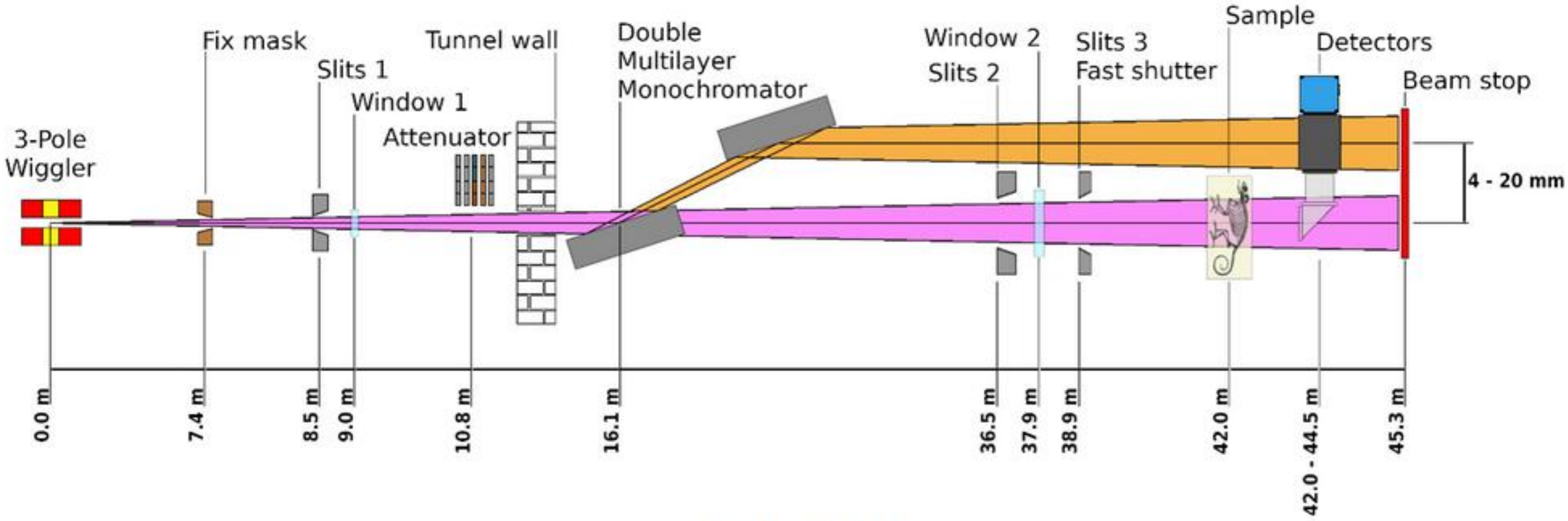
ID10 – BEATS (BEAmline for Tomography at SESAME) beamline

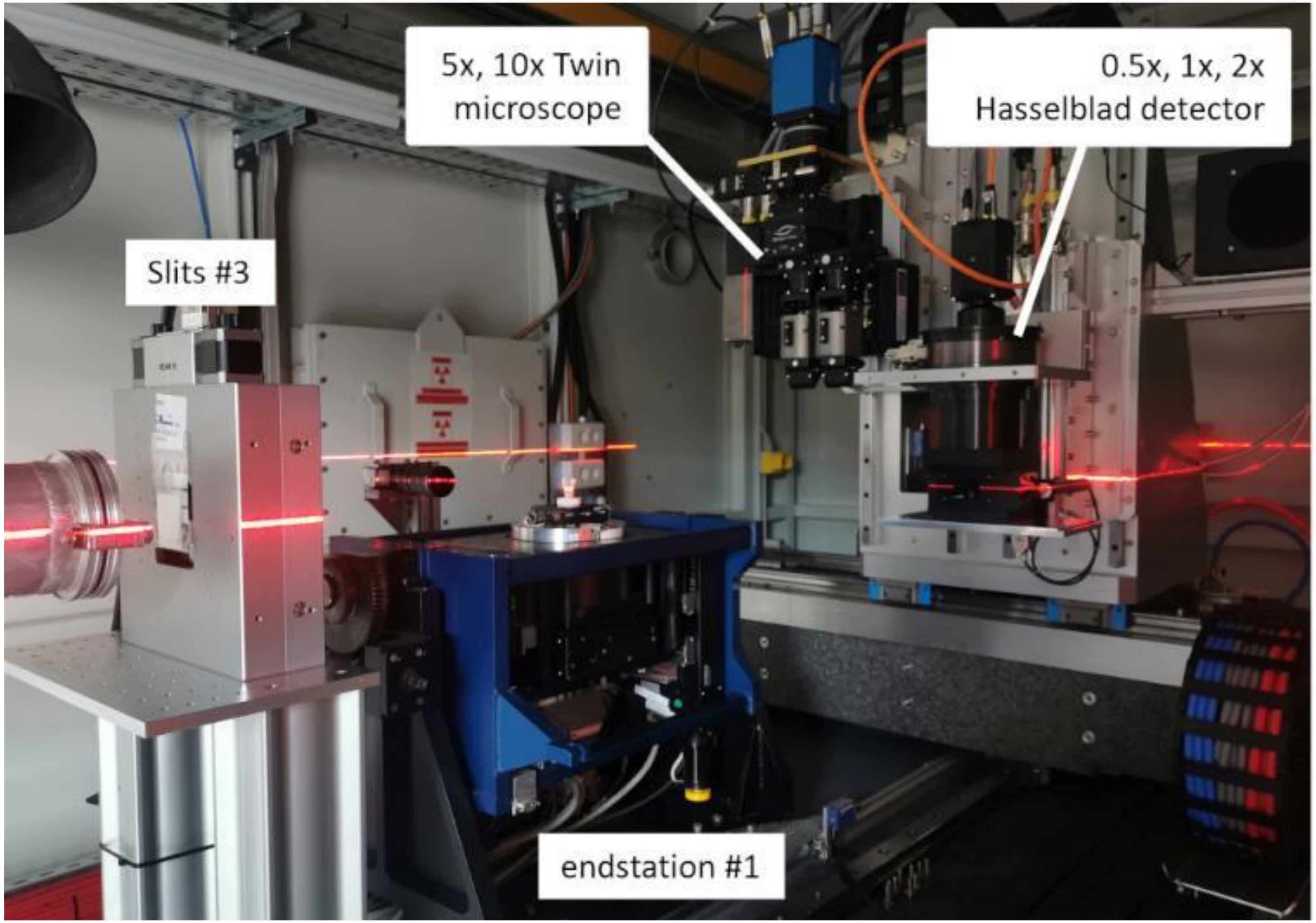


BEATS beamline layout

Advantages over laboratory-based X-ray systems

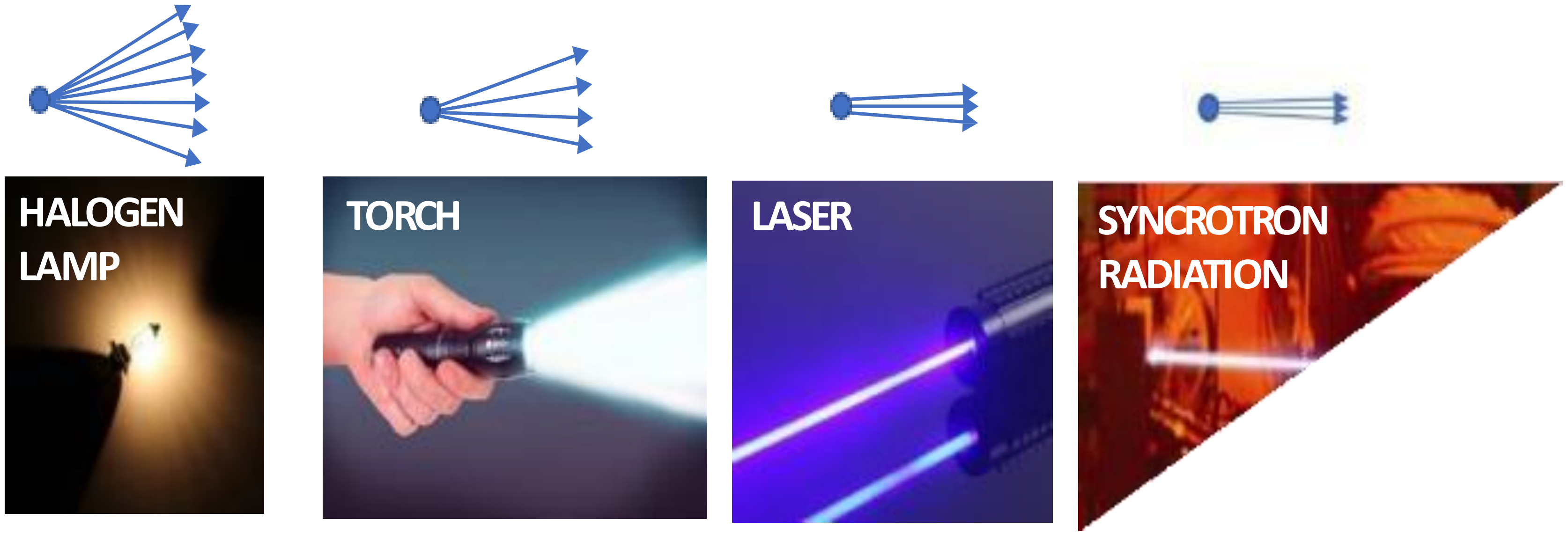
- Greater brilliance of X-ray source
- High photon flux on small sample area – enables short acquisition time and time-resolved scans
- Superior contrast and image quality
- Higher spatial resolution
- Higher sensitivity to light elements (2-3 orders of magnitude)
- Superior signal-to-noise ratio

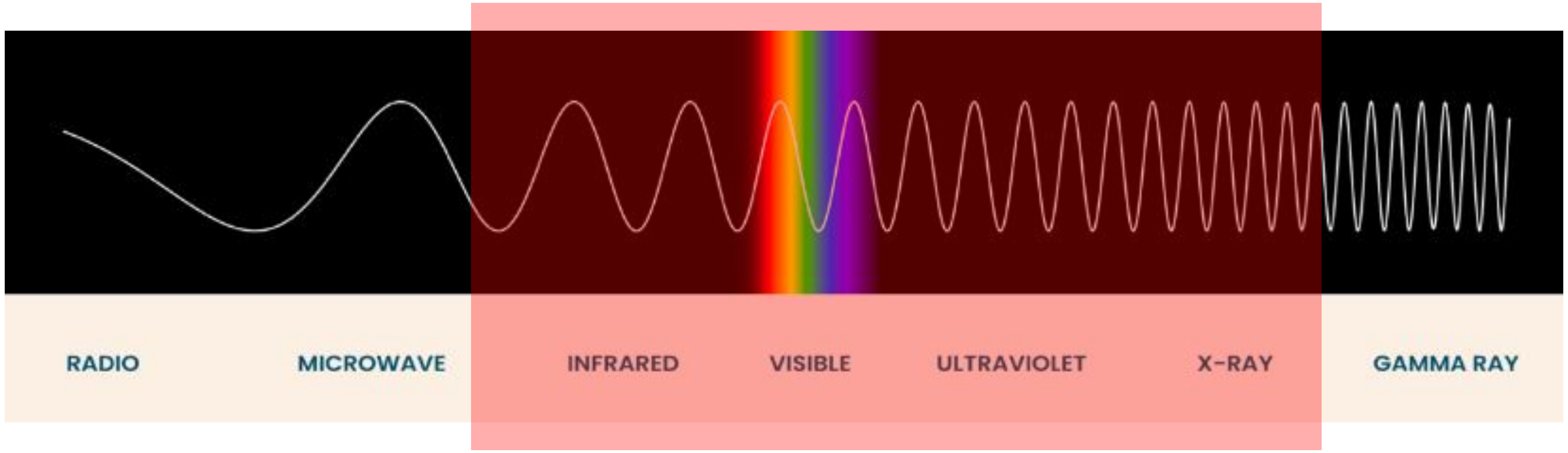
BEATS tomography endstation



Advantages of synchrotron radiation

High collimation

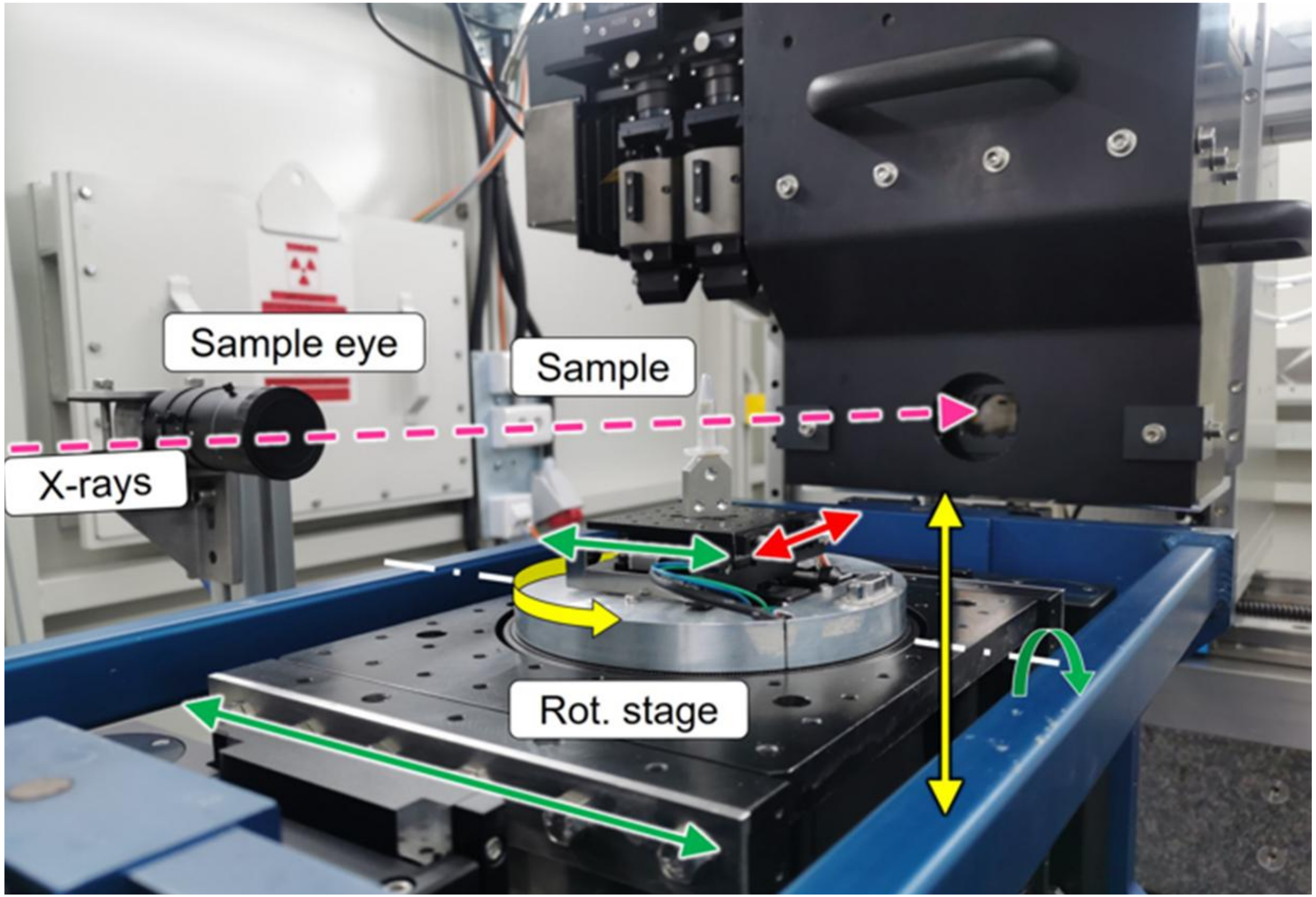




Broad spectrum from IR to hard X-rays

Images courtesy M. Cestelli Guidi, XFEL

View of the tomography sample manipulator



ID10 – BEATS (BEAmline for Tomography at SESAME) beamline

Detectors

	DETECTOR 1	DETECTOR 2	DETECTOR 3
Type	White-beam medium resolution detector	White-beam Twin microscope	Monochromatic microscope
Manufacturer	ESRF (France)	Optique Peter (France)	Optique Peter (France)
Lens type	Hasselblad H system	Mitutoyo M Plan Apo(Radiation hardened)	Olympus PLAPO/UPLAPO
Magnification	0.5×; 1×; 2×	5×; 7.5×; 10×	10×; 20×
Available voxel size (with PCO edge 5.5)	13 – 3.25 µm	1.3 – 0.65 µm	0.65 – 0.33 µm

The DMM allows to select a photon energy between 8 and 50 keV

Max Flux On Sample 4.8 * 10^{13} [ph/s] @ 20 [keV]

ID10 – BEATS (BEAmline for Tomography at SESAME) beamline

	CAMERA 1	CAMERA 2
Sensor type	sCMOS - Mono	CMOS - Mono
Manufacturer	PCO (Germany)	Teledyne FLIR (US)
Model	edge 5.5	Oryx 10GigE
Megapixels	5.5	7.1
Sensor size	2560 × 2160	3208 × 2200
Pixel size	6.5 µm	4.5 µm
Max frame rate (full frame)	100 fps	112 fps
Shutter	Rolling / Global	Global
Exposure time	500 µs - 2 s	10 µs - 30 s
Bit-depth	16 bit	8 bit / 16 bit
ADC	16 bit	8 bit / 10 bit / 12 bit
Dynamic range	88.6 dB	71.7 dB

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Resolution and field of view

	Detector 1	Detector 2	Detector 3
Type	White-beam microscope	White-beam microscope	Monochromatic microscope
Magnification	0.5x, 1x, 2x	5x, 7.5x, 10x	10x, 20x
Available pixel size	13 -3.25 μm	1.3 – 0.65 μm	0.65 – 0.33 μm
Field of view	34 x 29 mm 7.9 x 6.7 mm	3 x 2.8 mm 1.7 x 1.4 mm	1.7 x 1.4 mm 0.8 x 0.7 mm

Max Flux On Sample 4.8 * 10^{13}[ph/s] @ 20 [keV]

Reconstruction for datasets

Test dataset	Dataset 1	Dataset 2	Dataset 3
Sinogram shape	1376×1000×1000	2560×1000×1000	4371×1000×2000
Raw data size (16-bit)	6.0 GB	28.2 GB	42.3 GB
Reconstruction shape	1376×1376×1000	2560×2560×1000	4371×4371×1000
Reconstruction size (32-bit)	7.6 GB	26.2 GB	76.4 GB
Gridrec			
FBP CUDA			

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TECHNIQUES AND MODES

- Radiographic (absorption) imaging
- Phase-contrast XCT
- Absorption-Edge Subtraction Imaging
- Dynamic – In situ experiments
- Monochromatic
- White Beam/Pink Beam

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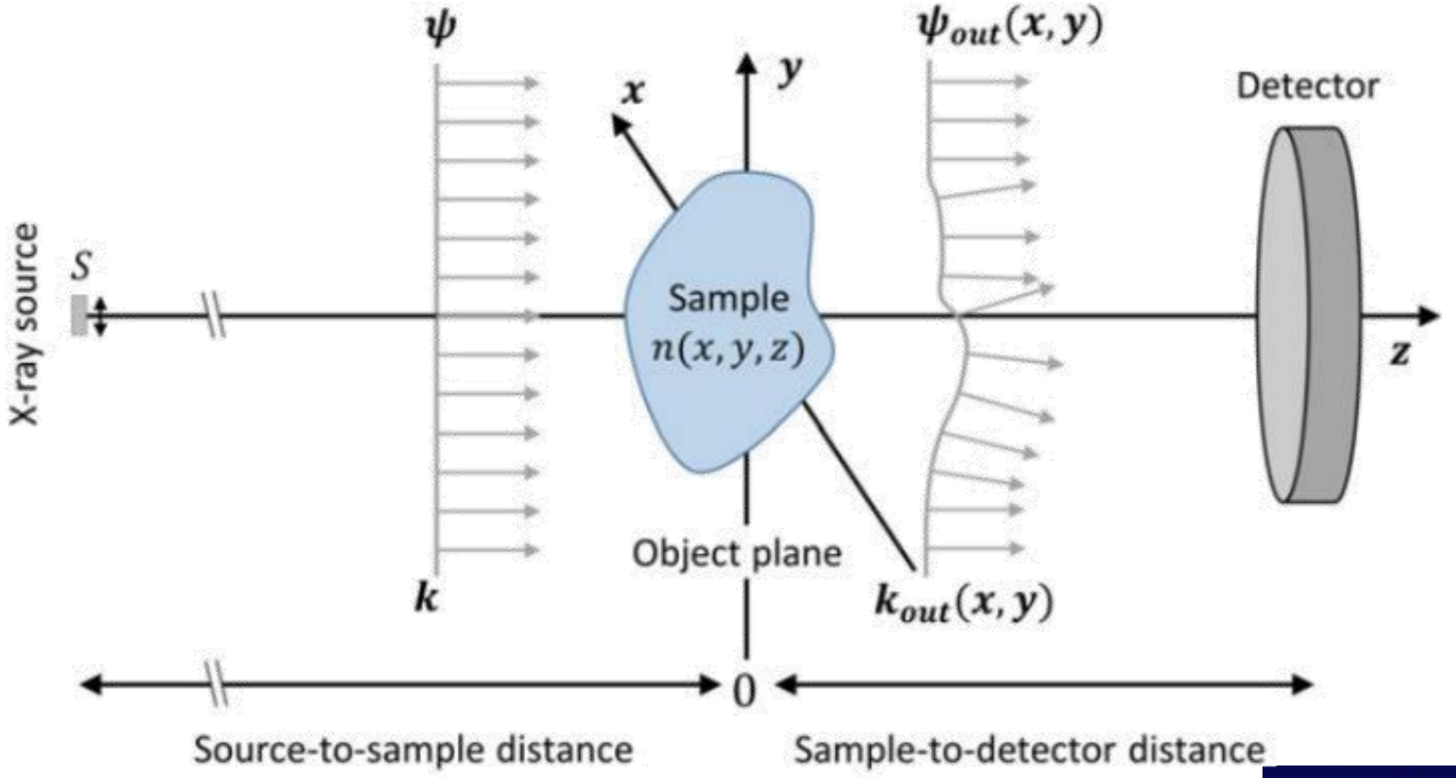
A brief introduction to phase contrast (PC) X-ray imaging

- Conventional X-ray imaging / CT measures decreases in X-ray intensity as the beam crosses a sample
- PC imaging instead measures the beam's phase shift



Attenuation contrast CT

Beer–Lambert's law:

$$I = I_0 e^{-\sum_{i=1}^{n} \mu_i x_i}$$

Interaction of X-rays with matter

Several contrast modes are possible

When X-ray wave passes through an object

both the intensity and the phase change vary according to the refractive index, *n*:

$$n = 1 - \delta + i\beta$$

imaginary part (β) controls the attenuation (absorption)

and the real part (δ) the phase shift

The linear attenuation coefficient, μ, expresses the attenuation of X-rays as they pass through the material and is given by $4\pi\beta/\lambda$

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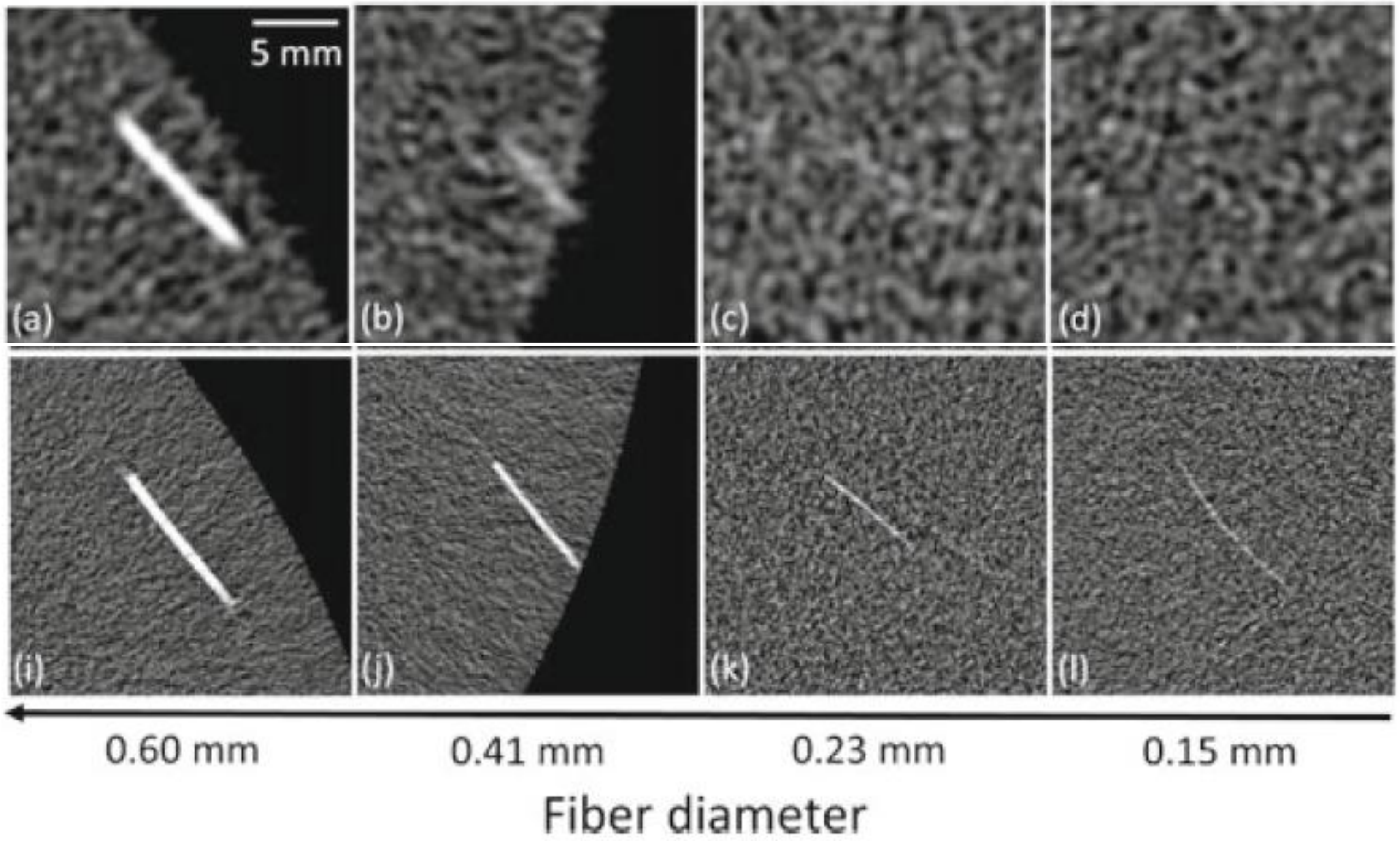
PC imaging improves spatial resolution

Traditional CT

PC tomography



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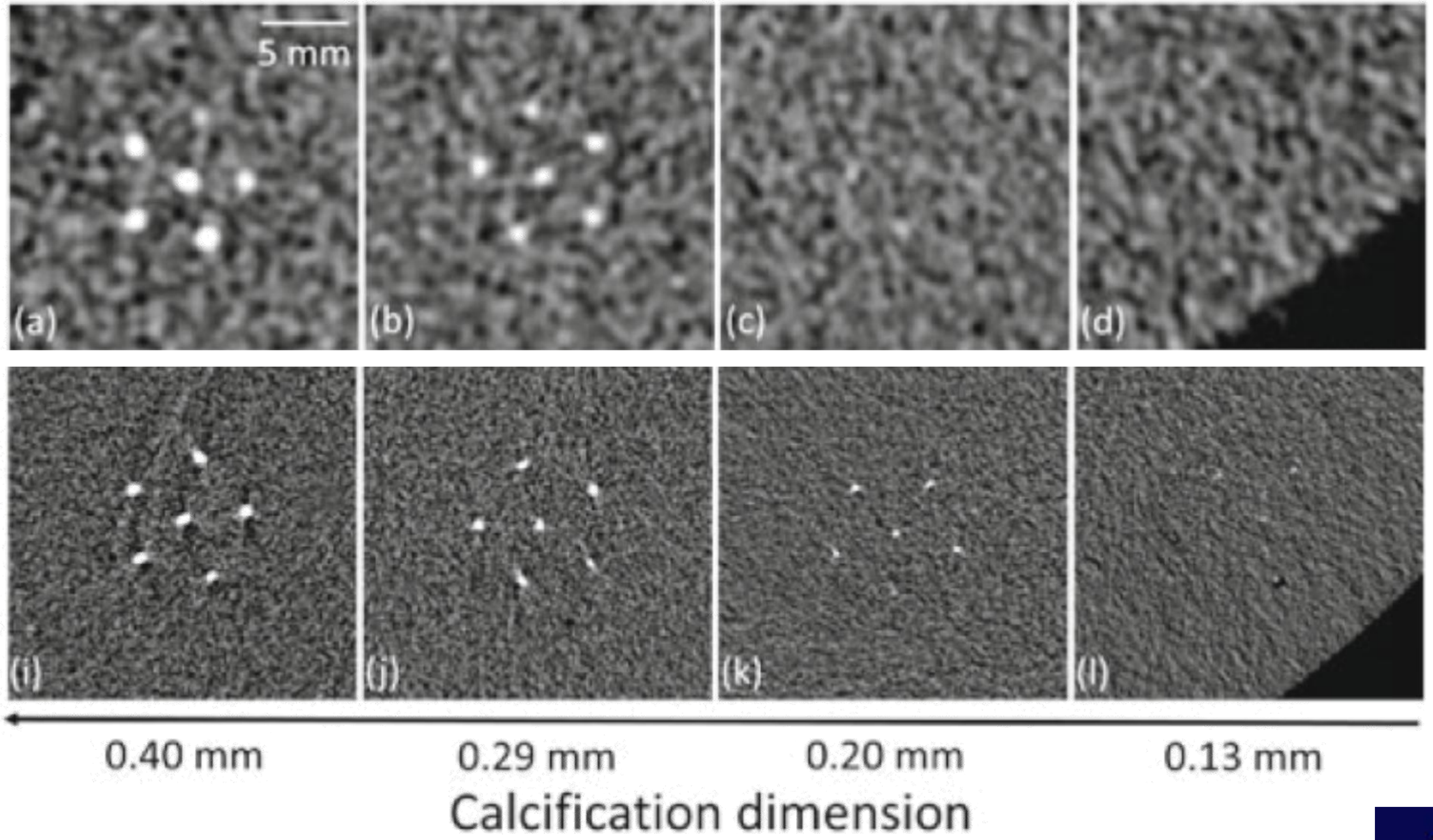
Small calcifications are better resolved using PC

Traditional CT

PC tomography

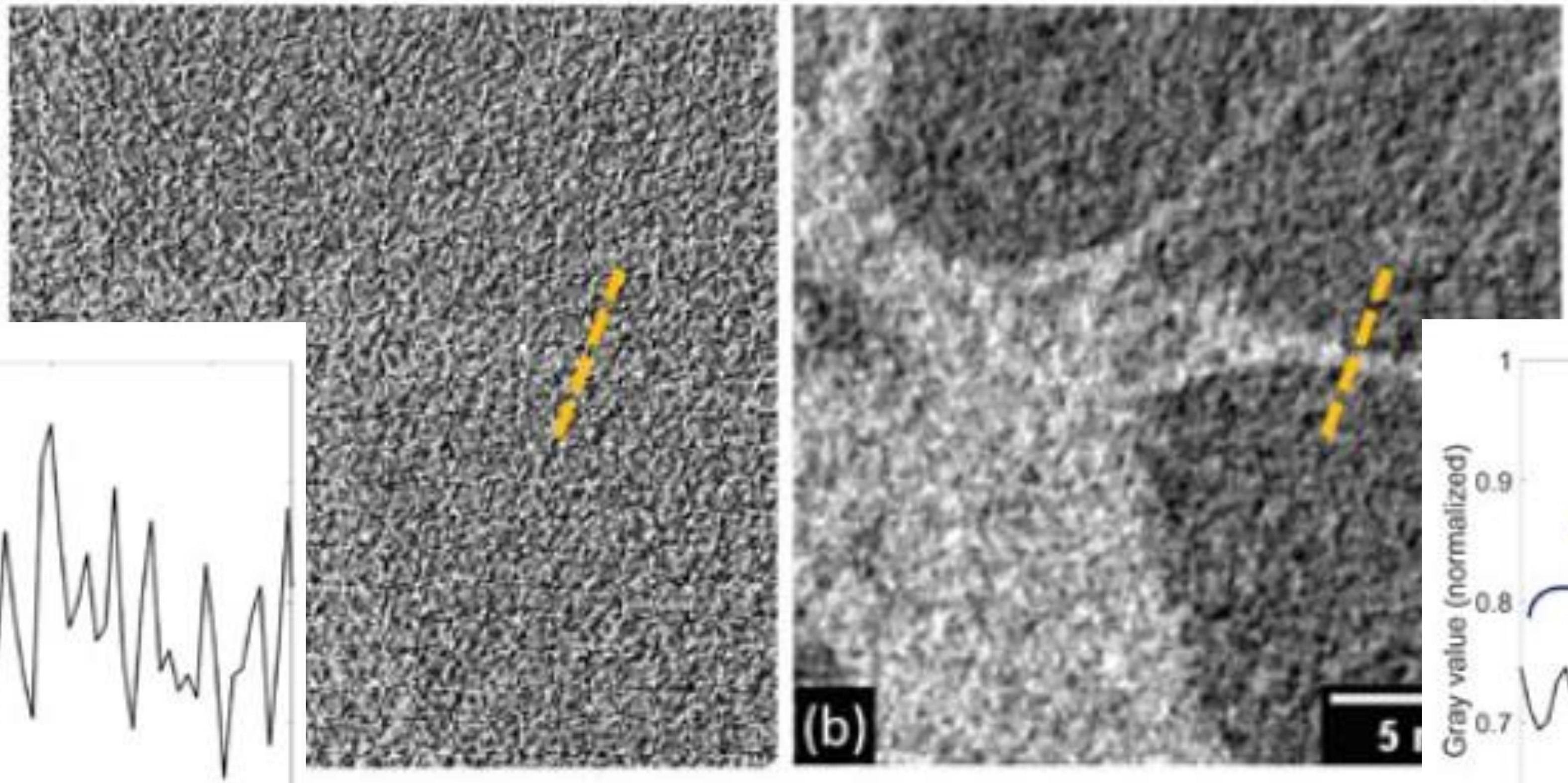


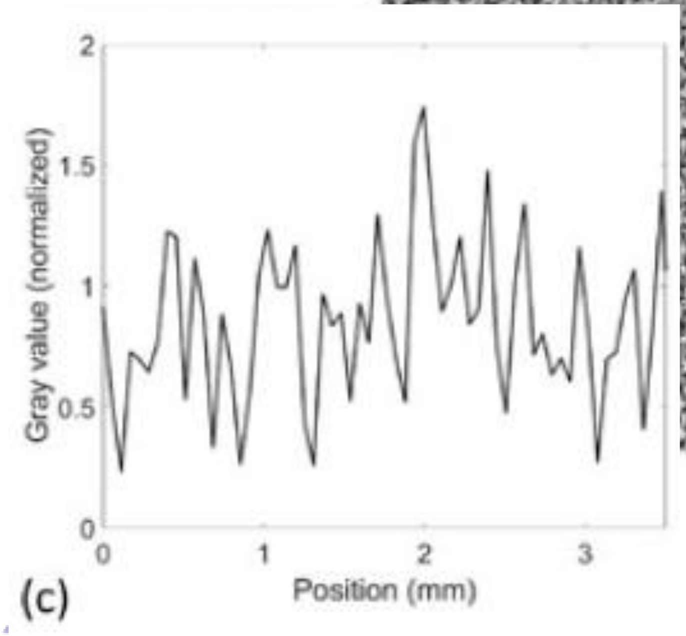
X-Ray Phase-Contrast Tomography, Springer, 2020

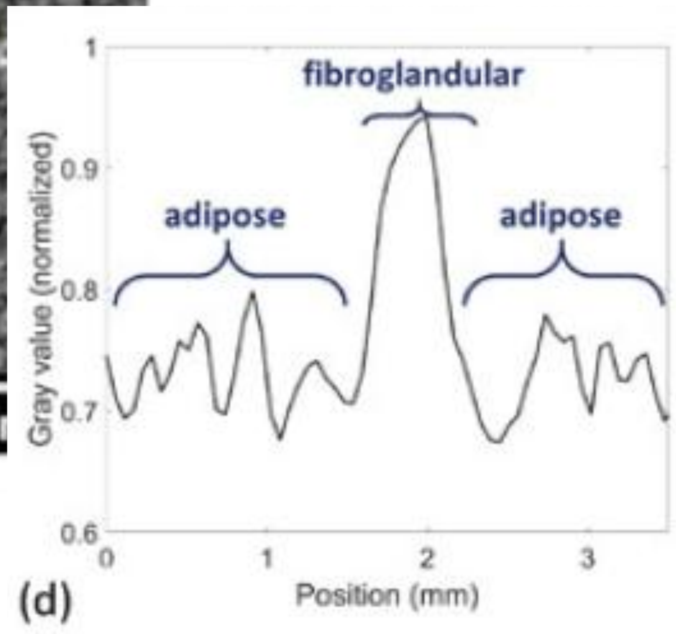
PC imaging improves resolution of fibrous detail

Without PC

With PC

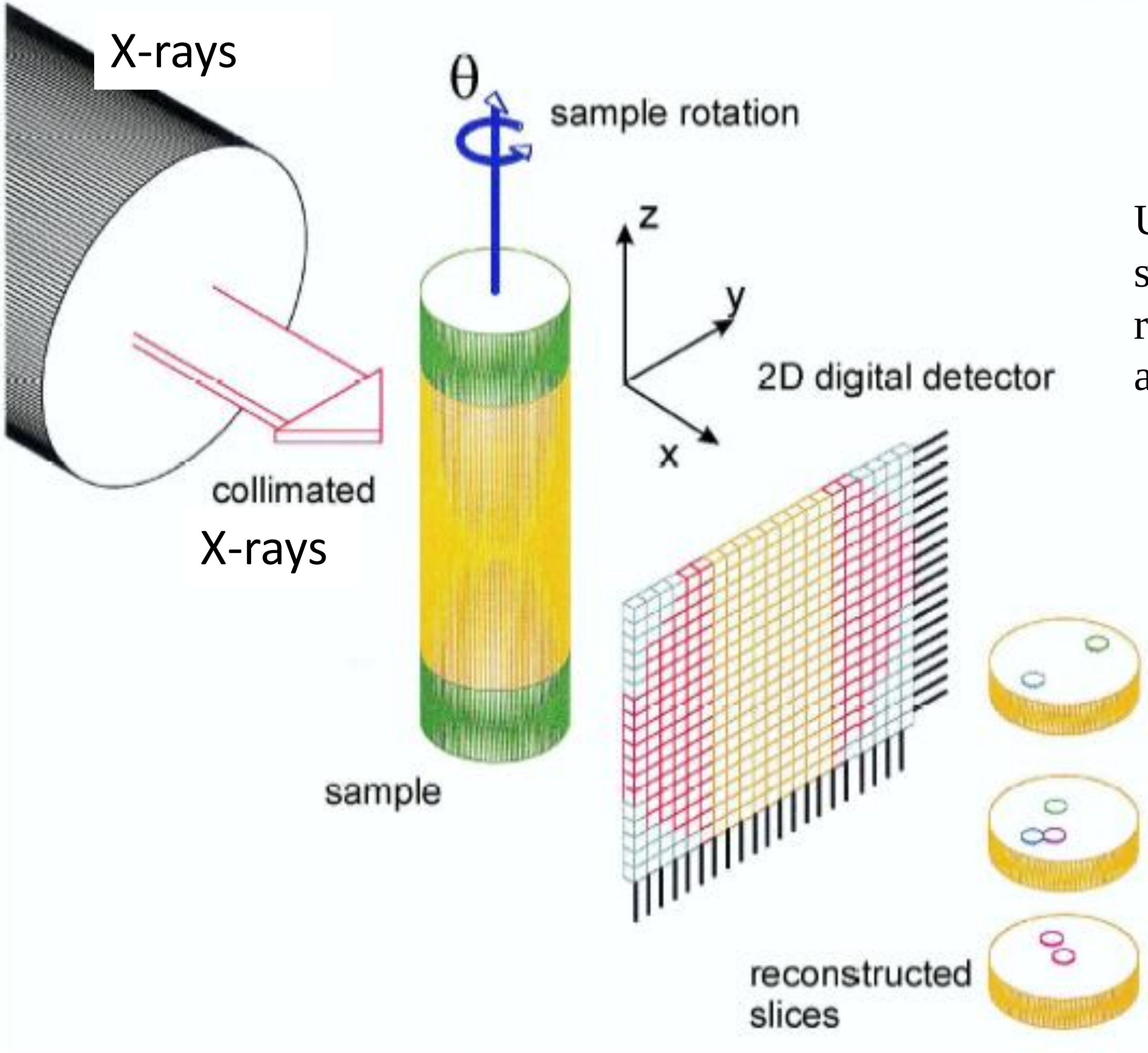






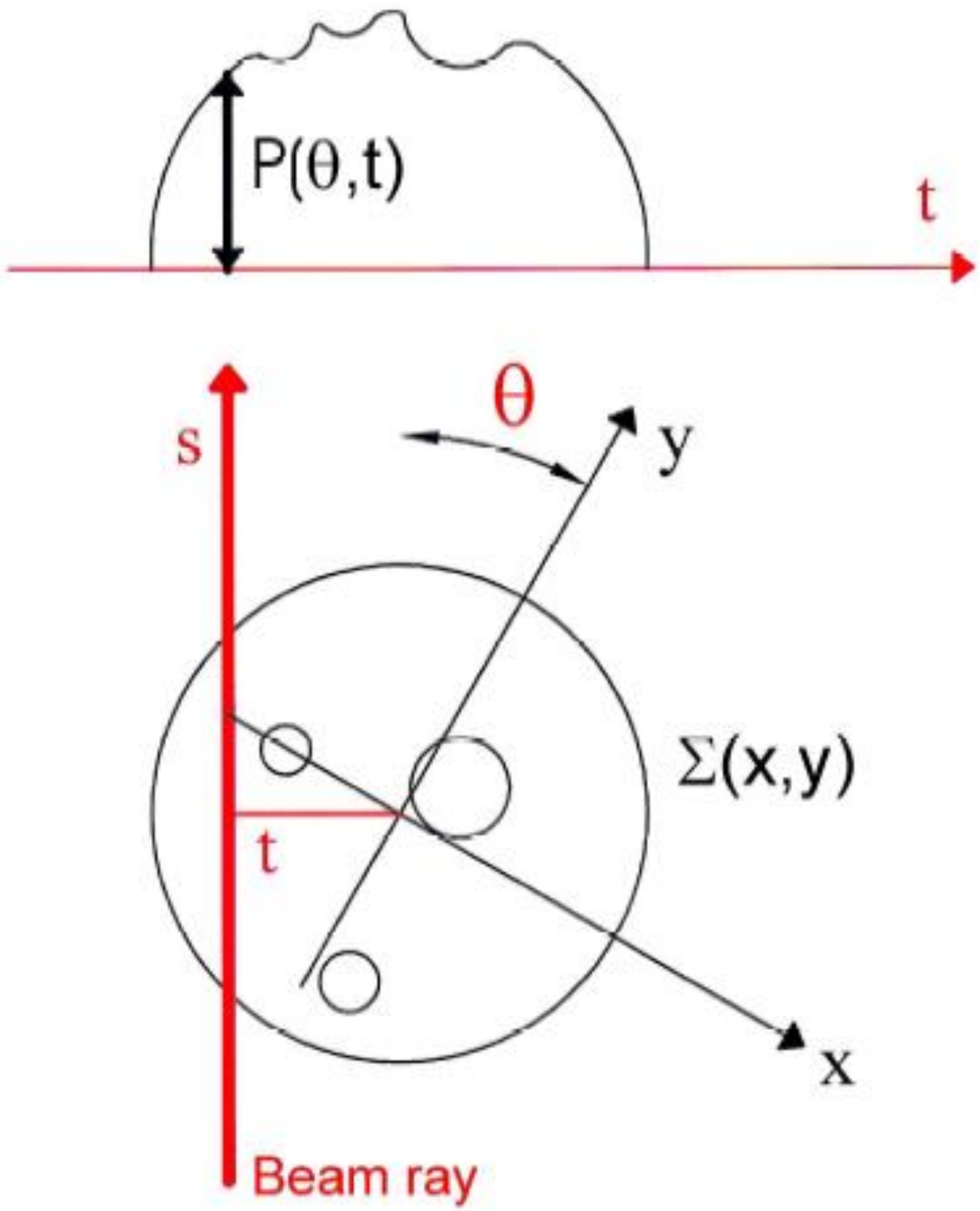
Breast tissue including solid carcinoma

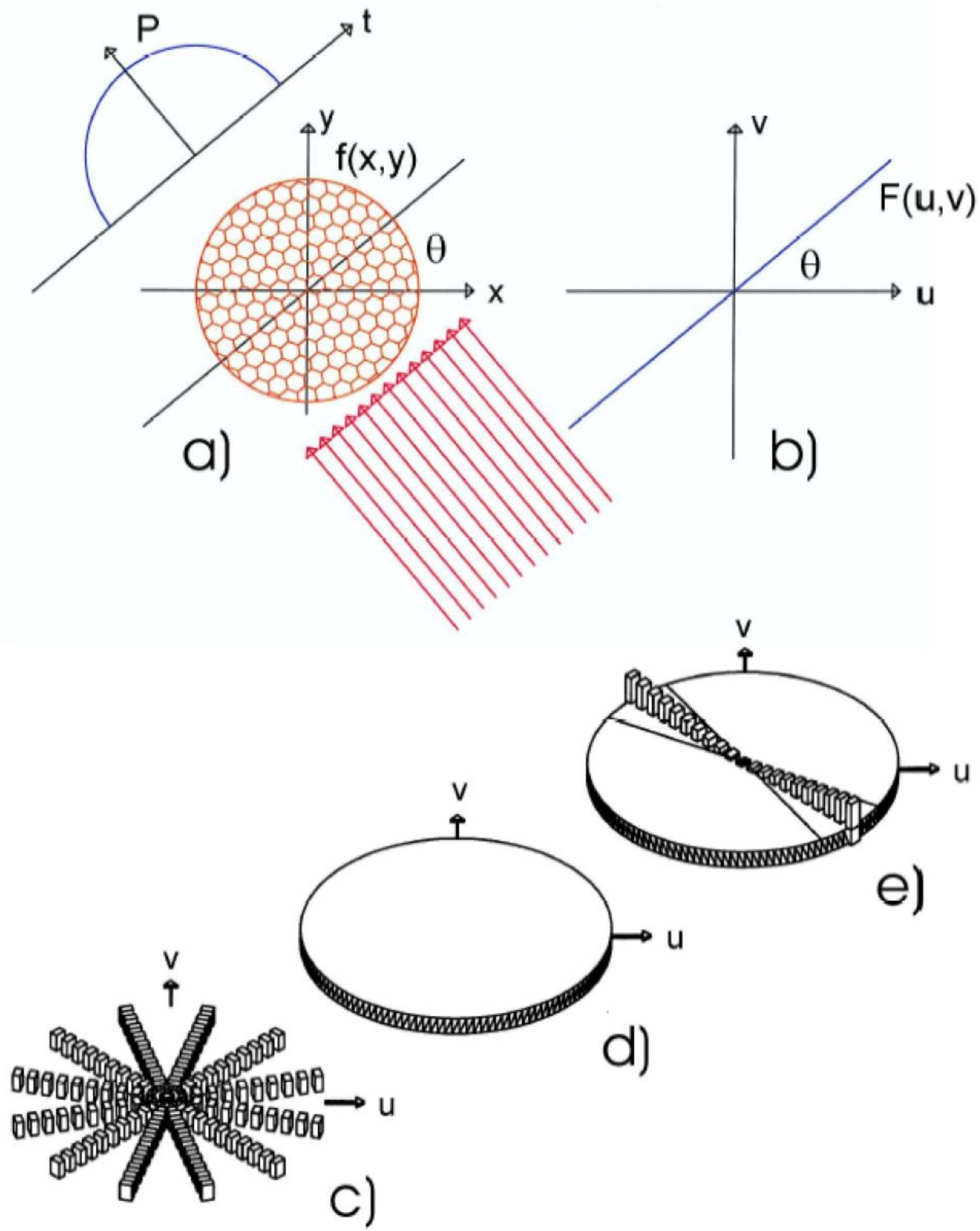
The Method of Filtered Backprojection



Utilization of the transmission signal for the tomographic reconstruction of the linear attenuation coefficient

Principle of tomographic projection





Tomographic Reconstruction with filtered backprojection:

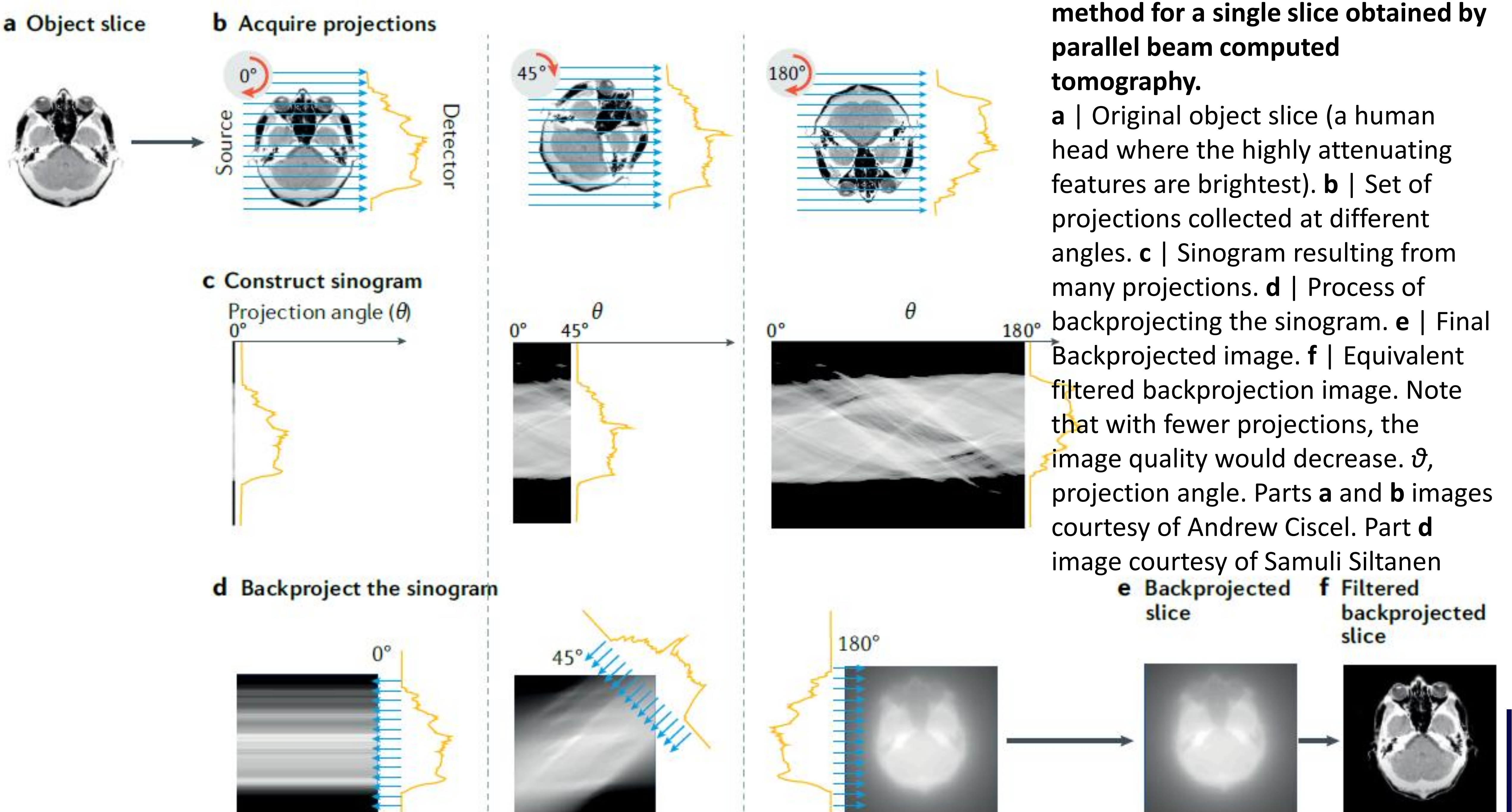
a) Calculation of the projection data.

b) +c) each projection defines a line in Fourier space.

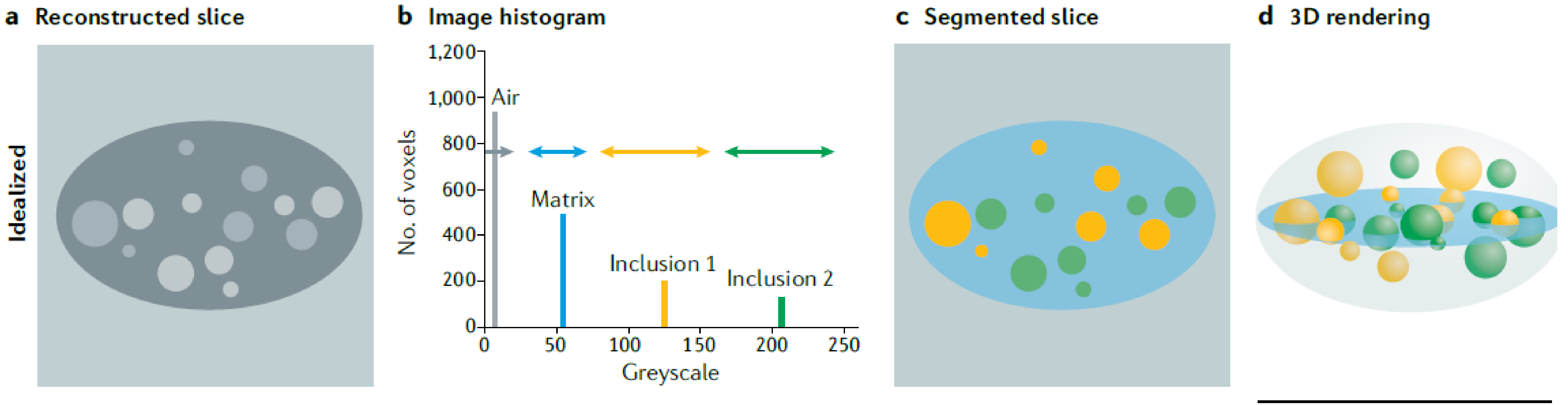
d) Ideal occupation of the Fourier space in the limit of a large number of projections.

e) The high-frequency part from the backprojection is amplified.

Backprojection reconstruction method for a single slice obtained by parallel beam computed tomography.
a | Original object slice (a human head where the highly attenuating features are brightest). **b** | Set of projections collected at different angles. **c** | Sinogram resulting from many projections. **d** | Process of backprojecting the sinogram. **e** | Final Backprojected image. **f** | Equivalent filtered backprojection image. Note that with fewer projections, the image quality would decrease. ϑ, projection angle. Parts **a** and **b** images courtesy of Andrew Ciscel. Part **d** image courtesy of Samuli Siltanen



Segmentation processes for an idealized sample



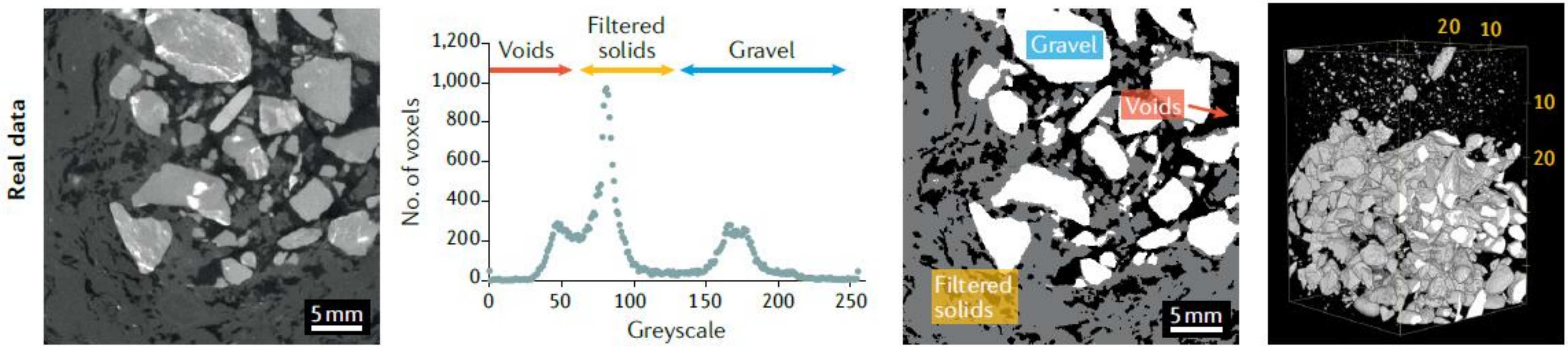
a | Reconstructed tomographic slice showing different phases according to the grey levels.

b | Greyscale histogram of the volume with the segmentation ranges used to segment the phases.

c | Segmented slice showing the segmented regions.

d | Three- dimensional (3D) rendering of the segmented objects with the matrix phase rendered semi- transparent. Bottom row adapted

Segmentation processes for a gravel filter pack



Segmentation processes for an for a filter pack for wetland water treatment recorded as 8- bit images.

a | Reconstructed tomographic slice showing different phases according to the grey levels.

b | Greyscale histogram of the volume with the segmentation ranges used to segment the phases.

c | Segmented slice showing the segmented regions.

d | Three- dimensional (3D) rendering of the segmented objects with the matrix phase rendered semi- transparent. Bottom row adapted

BEAmline for Tomography at SESAME

Funded by the EU's H2020 framework programme under grant agreement n°822535

BEAmline for Tomography at SESAME

Semester	Submitted	Approved	Approval %age		Shifts	
SEM 6	23	17	74		156	
SEM 7	28	18	64		144	
SEM 8	23				153	shifts requested

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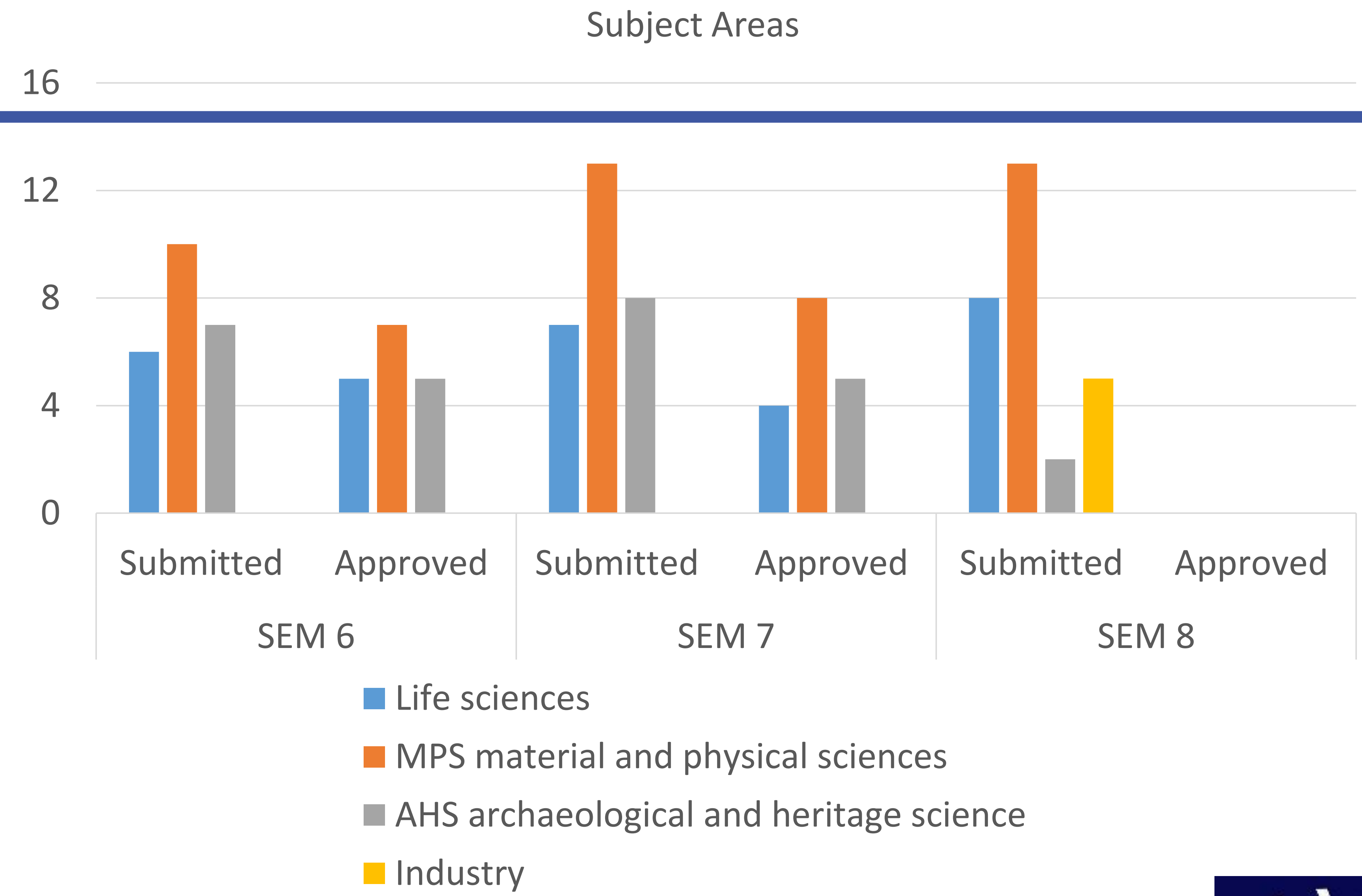
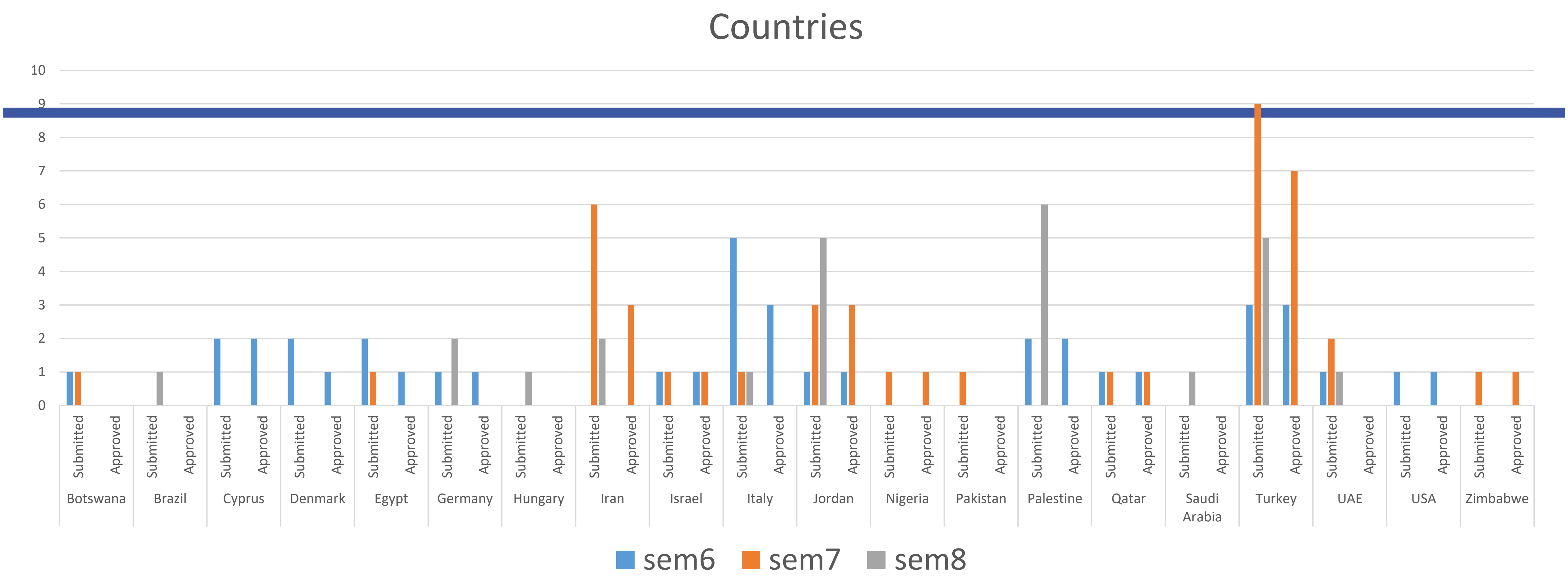
BEAmline for Tomography at SESAME



Funded by the EU's H2020 framework programme under grant agreement n°822535



Countries
10
9
8
7
6
5
4
3
2
1
0
Submitted
Approved
Botswana
Brazil
Cyprus
Denmark
Egypt
Germany
Hungary
Iran
Israel
Italy
Jordan
Nigeria
Pakistan
Palestine
Qatar
Saudi Arabia
Turkey
UAE
USA
Zimbabwe
sem6
sem7
sem8

BEAmline for Tomography at SESAME

RECENT USER ACTIVITIES

- 3 groups successfully performed beamtime (July)
  - Cyprus (Life Sciences)
  - Italy (MPS)
  - Turkey (in situ) (MPS)
- 3 groups have successfully performed beamtime (October)
  - Nigeria (MPS)
  - Qatar (in situ) (MPS)
  - Turkey (in situ) (MPS)
- Dec – Feb
  - Turkey AHS
  - Jordan – 2 groups - Life Sciences
  - Iran Life Sciences
  - Iran AHS

Funded by the EU's H2020 framework programme under grant agreement n°822535

1. SETUP CONTROL STATION

2. CHANGE THE BEAMLINE ENERGY

3. STREAM DETECTOR DATA

4. BEAMLINE SETUP

5. SCAN SETUP

6. SILX – CHECK THE PROJECTIONS

7. RECONSTRUCTION

8. CONVERT TO 8 BIT

9. IMAGE J – BINARY IMAGE

10. 3D RENDERING - DRAGONFLY

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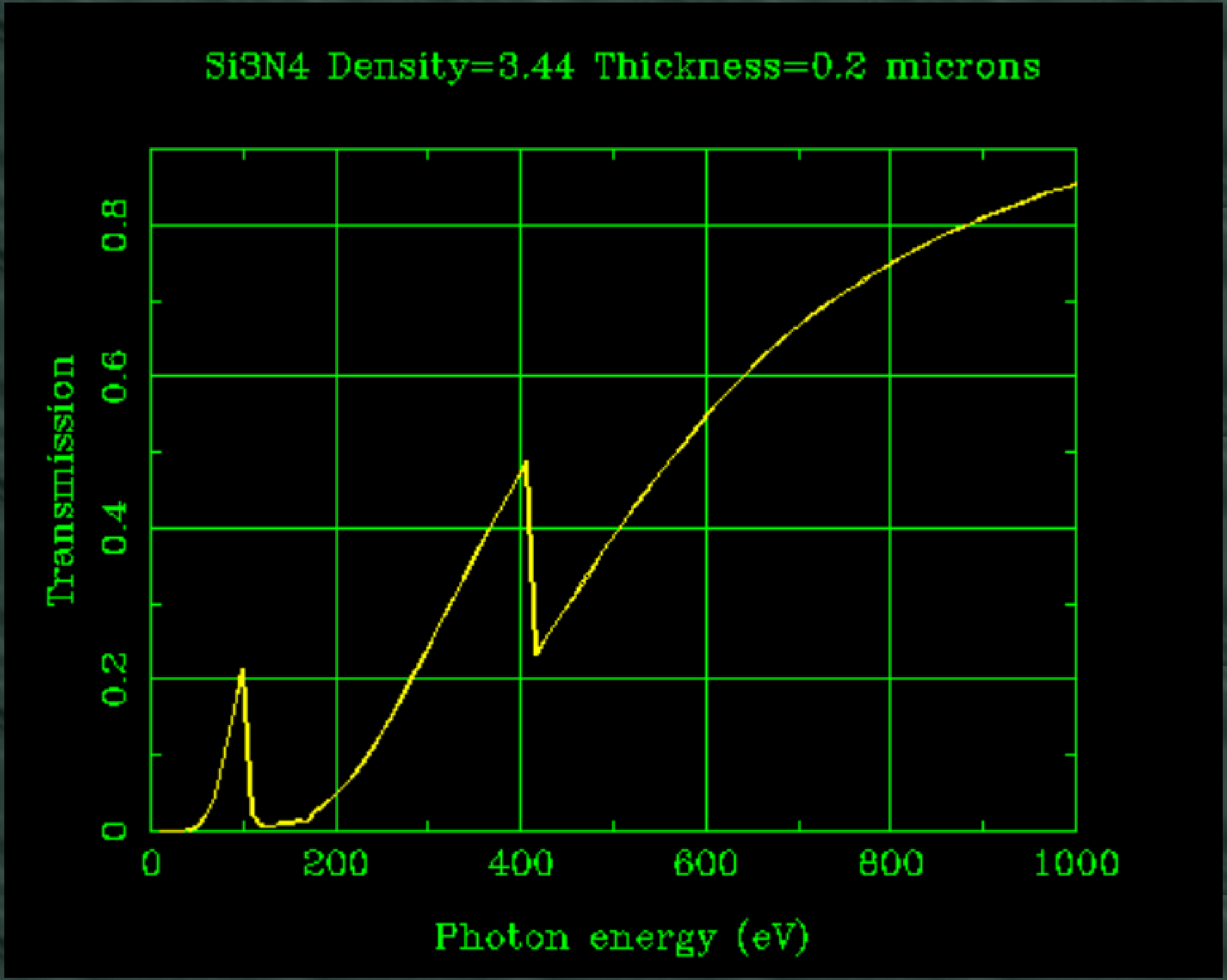
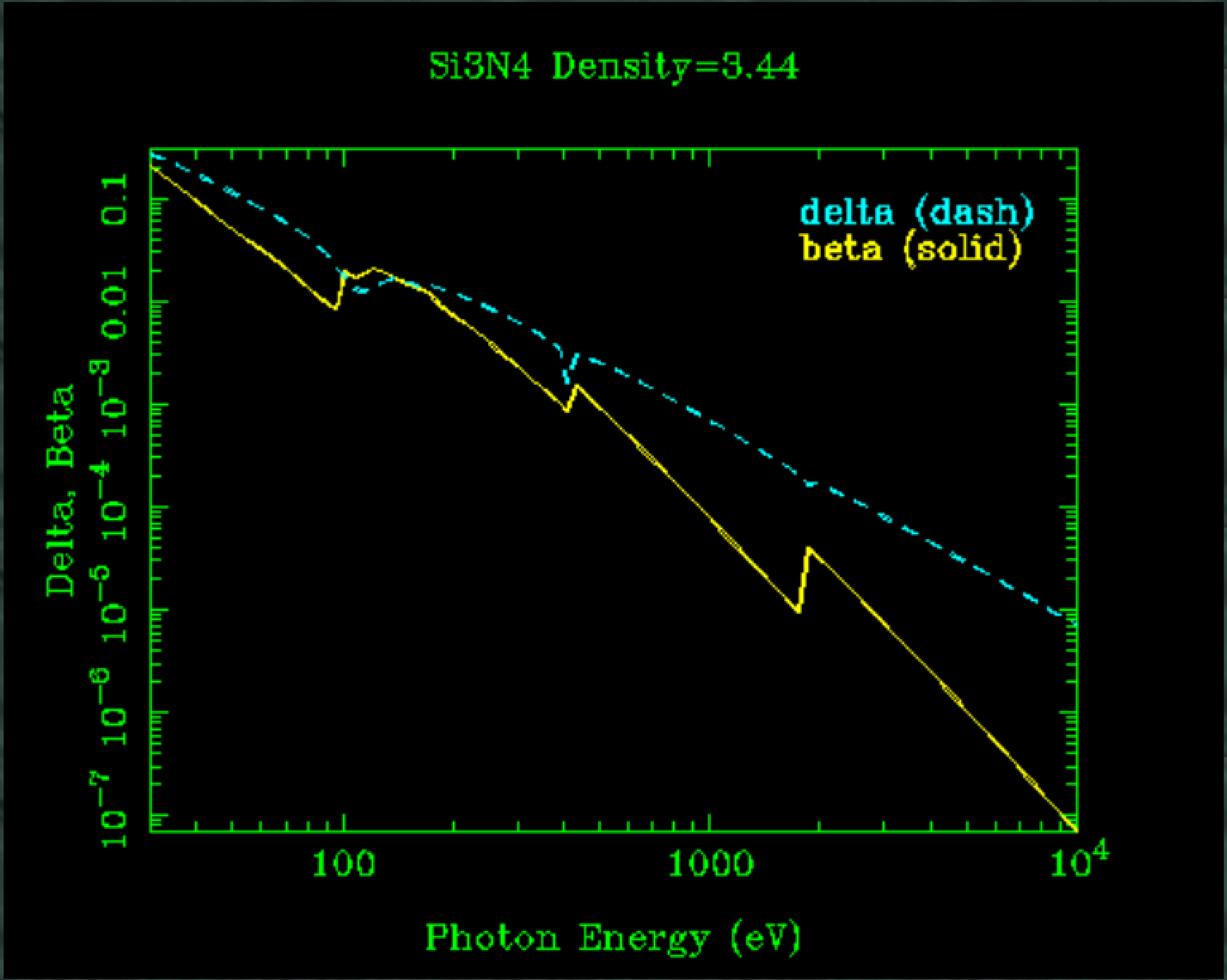
https://henke.lbl.gov/optical_constants/

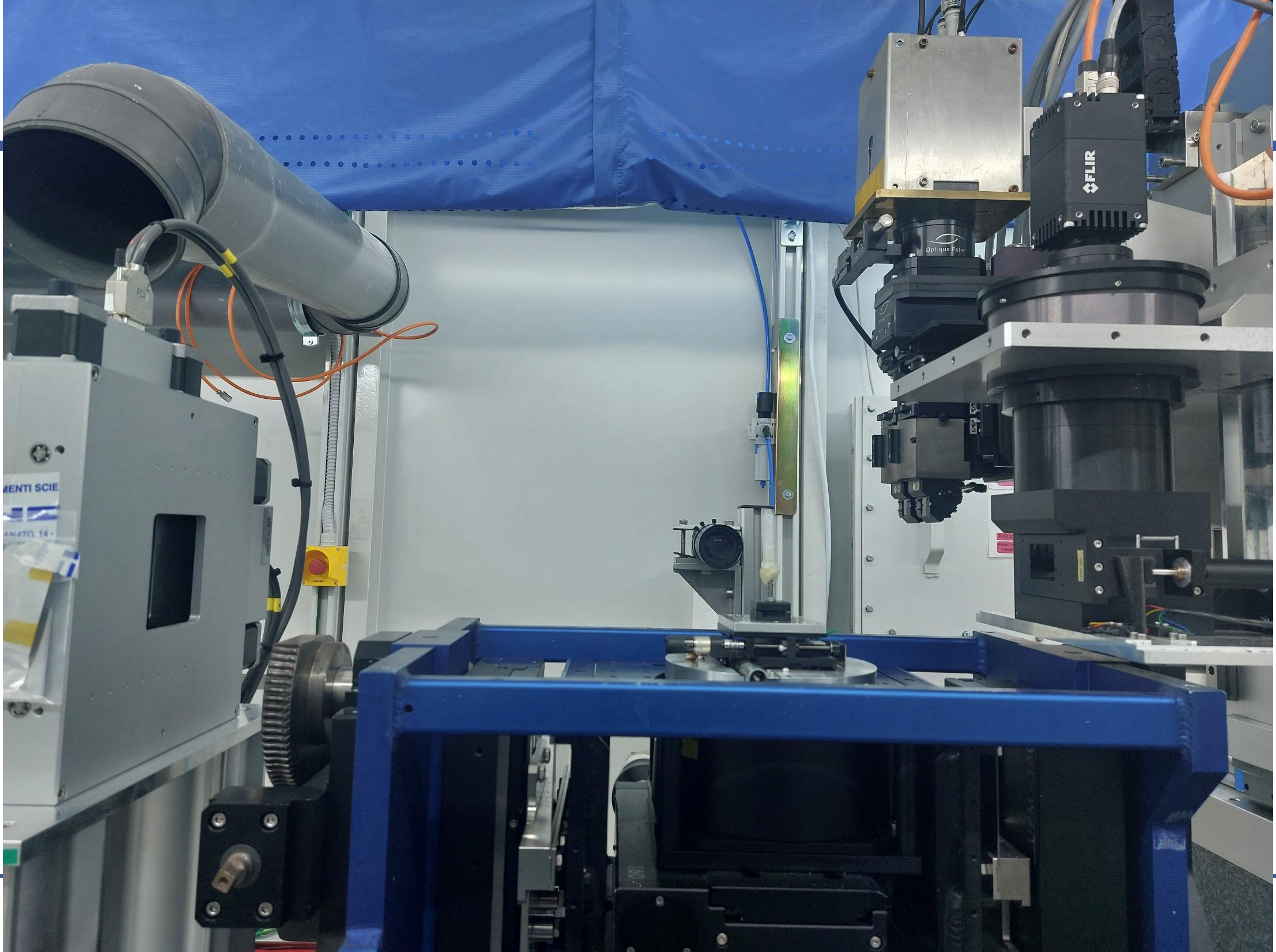
Filter Transmission: data file here

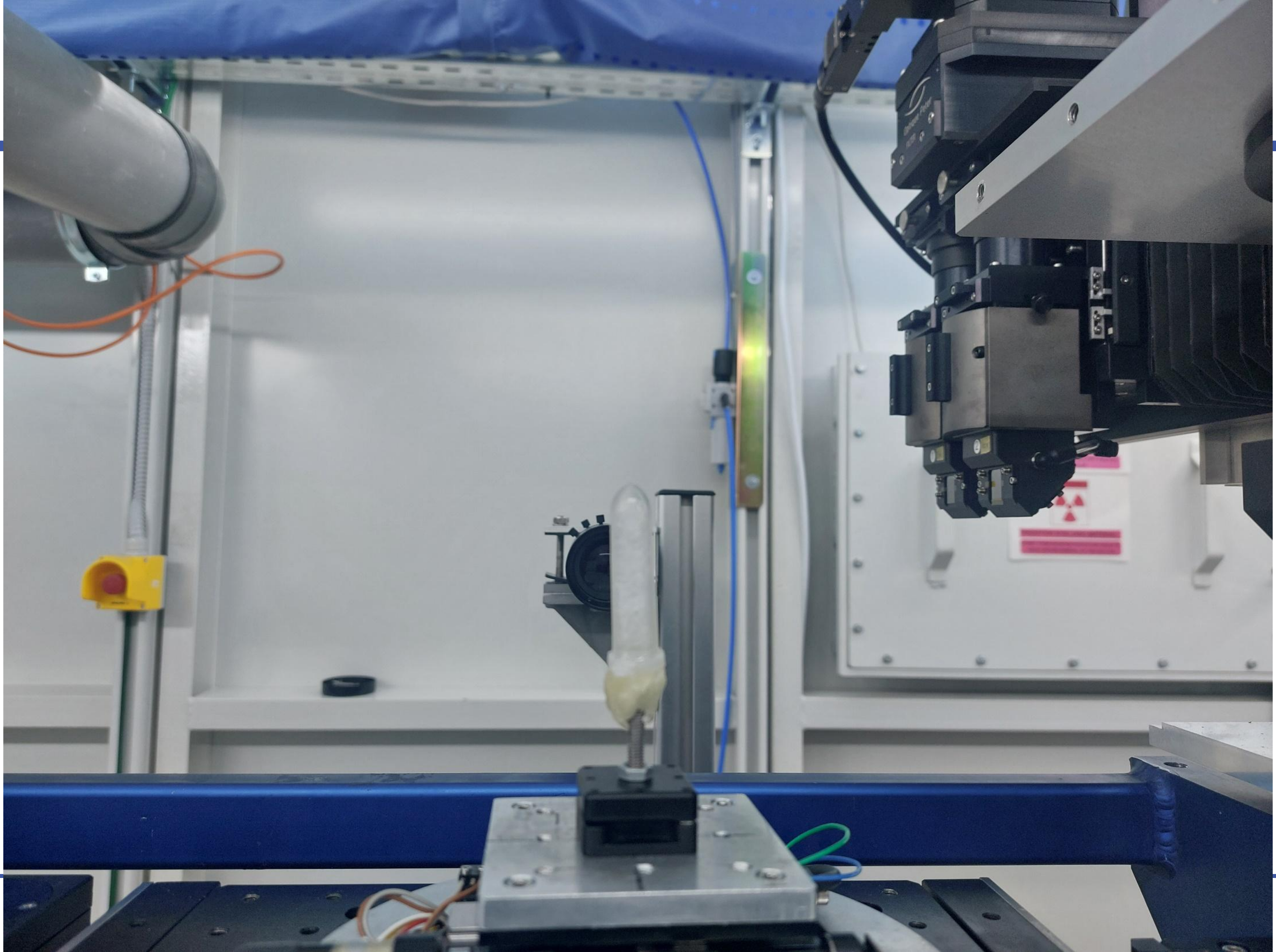
Print

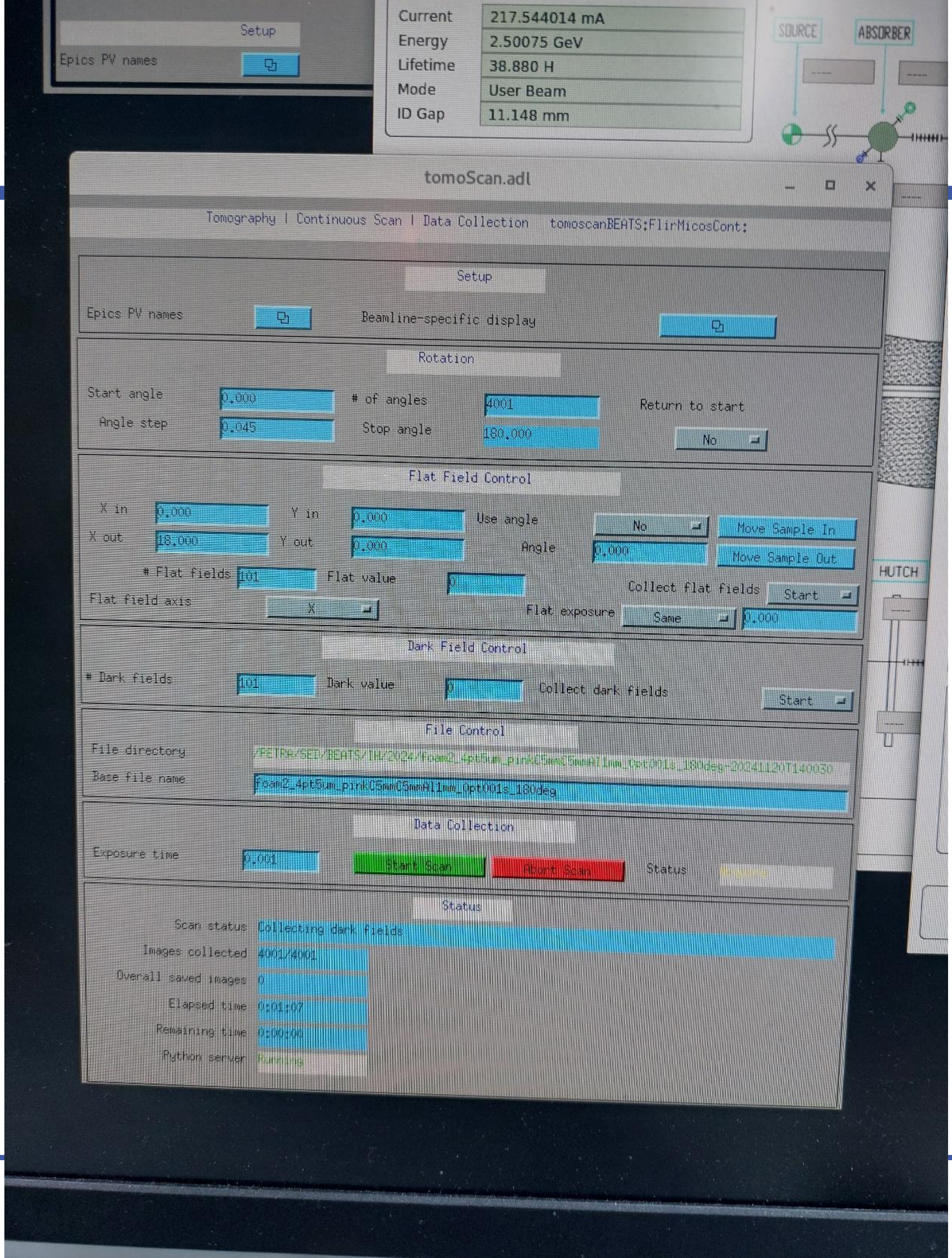


Index of Refraction = (1-delta)-i(beta)




Optique Peter
FLIR





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Current
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Energy
2.50075 GeV
Lifetime
38.880 H
Mode
User Beam
ID Gap
11.148 mm
SOURCE
ABSORBER
tomoScan.adl
Tomography | Continuous Scan | Data Collection
tomoscanBEATS:FlirMicosCont:
Setup
Epics PV names
Beamline-specific display
Rotation
Start angle
0.000
# of angles
4001
Return to start
Angle step
0.045
Stop angle
180.000
No
Flat Field Control
X in
0.000
Y in
0.000
Use angle
No
Move Sample In
X out
18.000
Y out
0.000
Angle
0.000
Move Sample Out
Flat fields
101
Flat value
Collect flat fields
Start
Flat field axis
X
Flat exposure
Same
0.000
HUTCH
Dark Field Control
Dark fields
101
Dark value
Collect dark fields
Start
File Control
File directory
Base file name
Data Collection
Exposure time
0.001
Start Scan
Abort Scan
Status
Status
Scan status
Collecting dark fields
Images collected
4001/4001
Overall saved images
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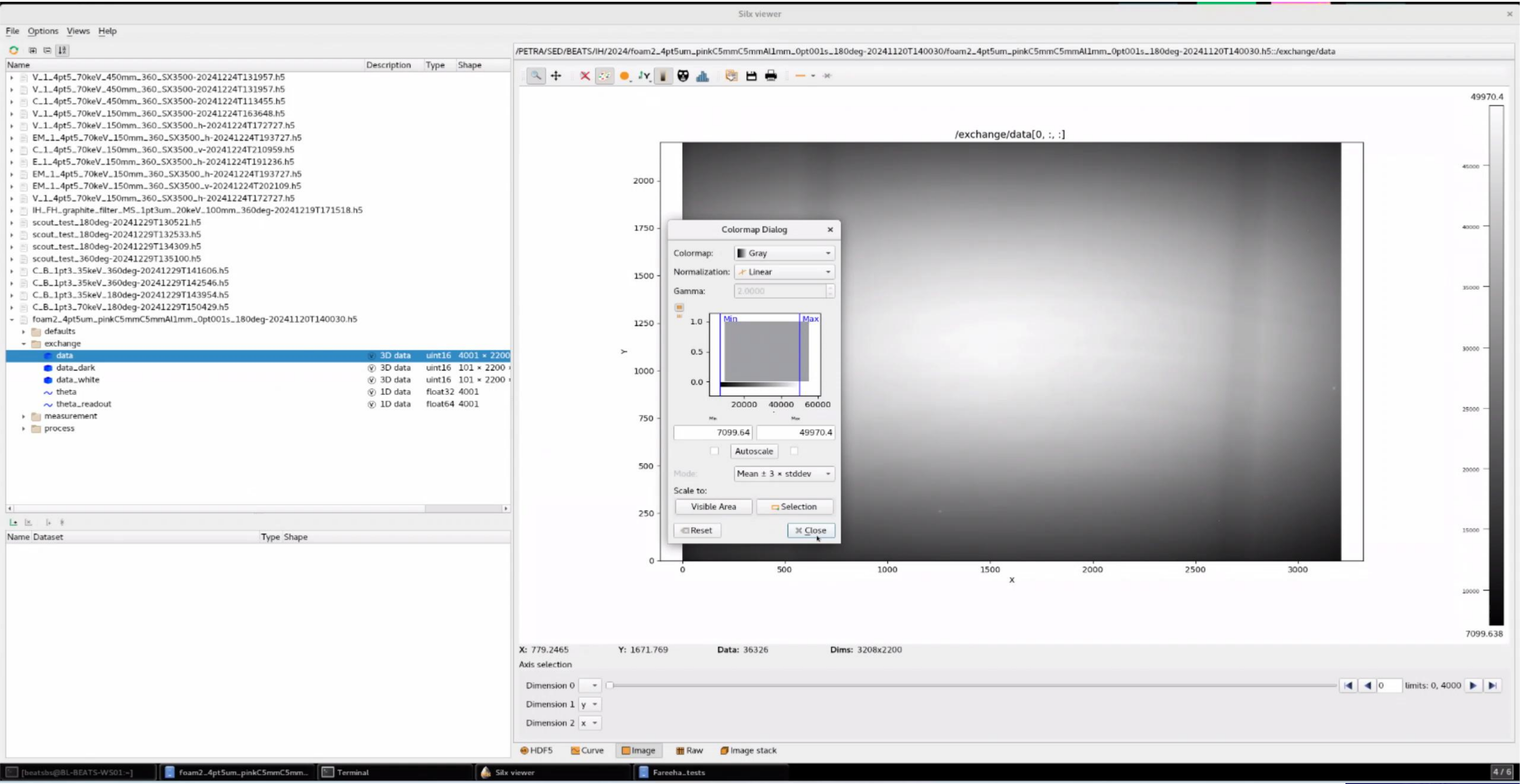
Elapsed time
0:01:07
Remaining time
0:00:00
Python server

SILX



Silx viewer
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V_1_4pt5_70keV_150mm_360_SX3500_h-20241224T172727.h5
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C_B_1pt3_70keV_180deg-20241229T150429.h5
foam2_4pt5um_pinkC5mmC5mmAl1mm_0pt001s_180deg-20241120T140030.h5
defaults
exchange
data 3D data uint16 4001 × 2200
data_dark 3D data uint16 101 × 2200
data_white 3D data uint16 101 × 2200
theta 1D data float32 4001
theta_readout 1D data float64 4001
measurement
process
Name Dataset Type Shape
/exchange/data[0, :, :]
Colormap Dialog
Colormap: Gray
Normalization: Linear
Gamma: 2.0000
Min Max
7099.64
49970.4
Autoscale
Mean ± 3 × stddev
Scale to:
Visible Area
Selection
Reset
Close
49970.4
7099.638
X: 779.2465 Y: 1671.769 Data: 36326 Dims: 3208x2200
Axis selection
Dimension 0
Dimension 1 y
Dimension 2 x
limits: 0, 4000
HDF5 Curve Image Raw Image stack
Terminal
Silx viewer
Fareeha_tests
4 / 6

Fiji and ImageJ

- Artifacts – COR
- Ring removal
- 8-bit conversion
- Comparison of absorption and phase contrast images
- Cropping
- Noise filtering
- Segmentation – binary
- Analysis – measurements
- Skeleton

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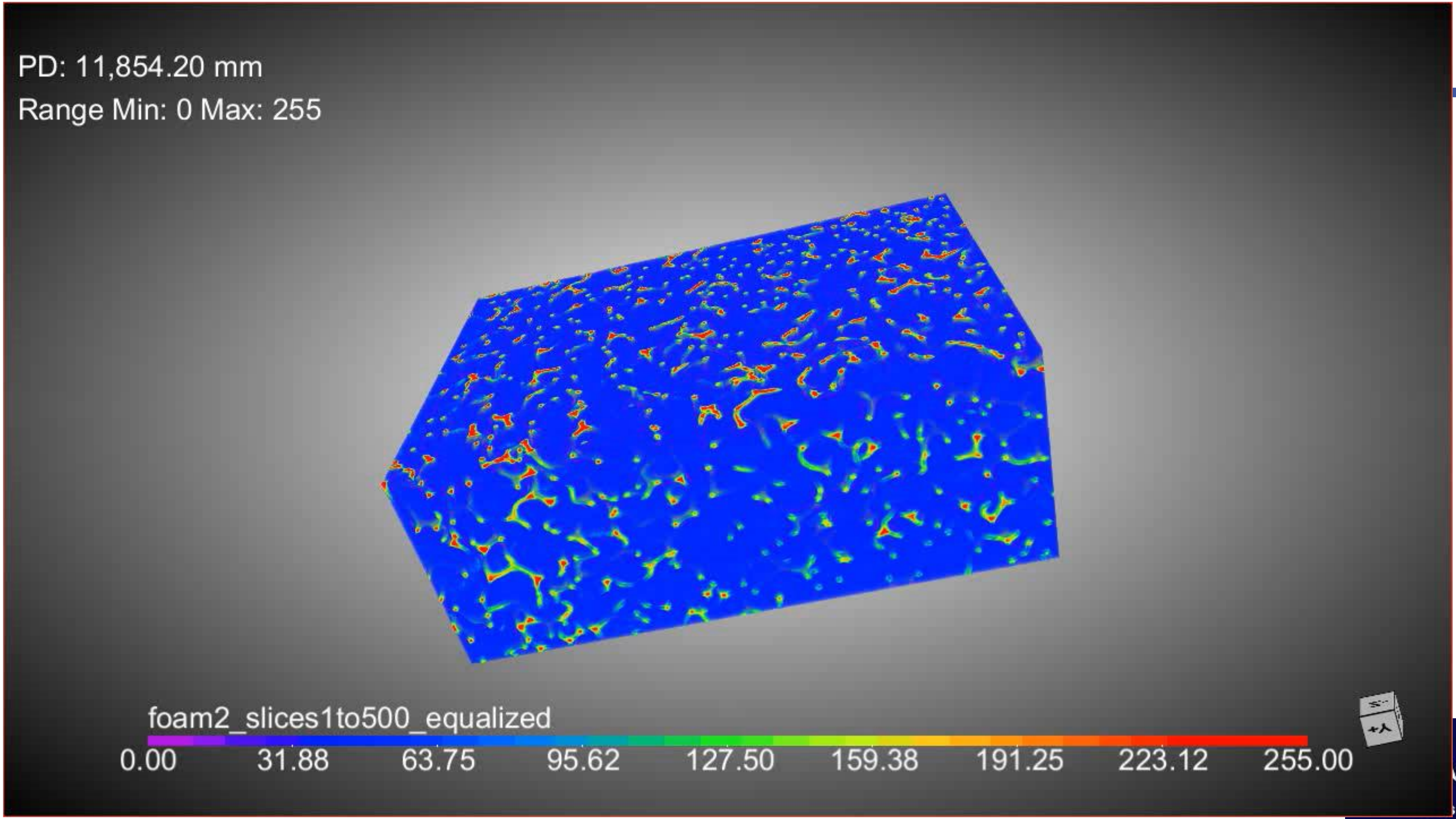
Video



PD: 11,854.20 mm
Range Min: 0 Max: 255
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223.12
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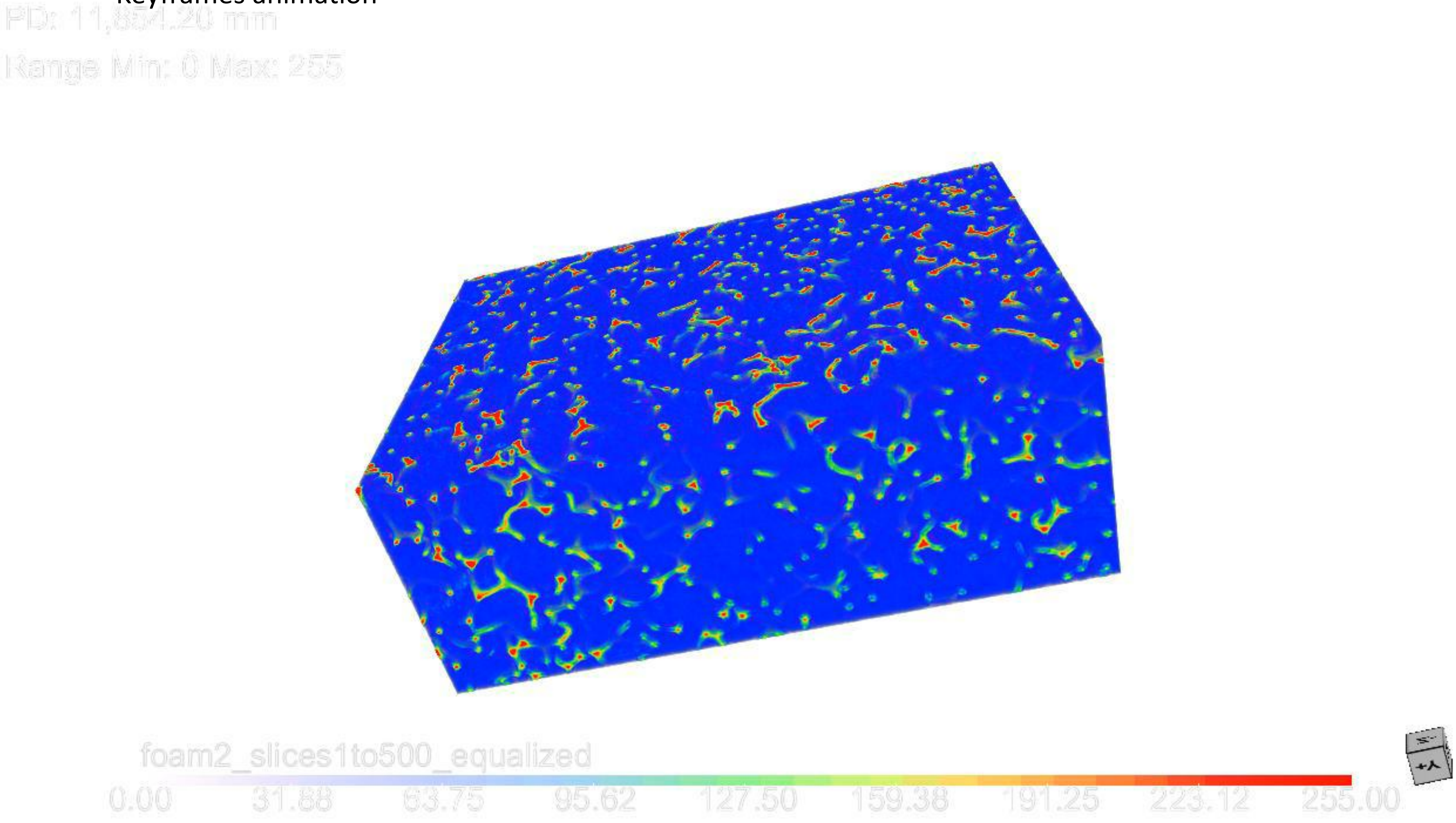
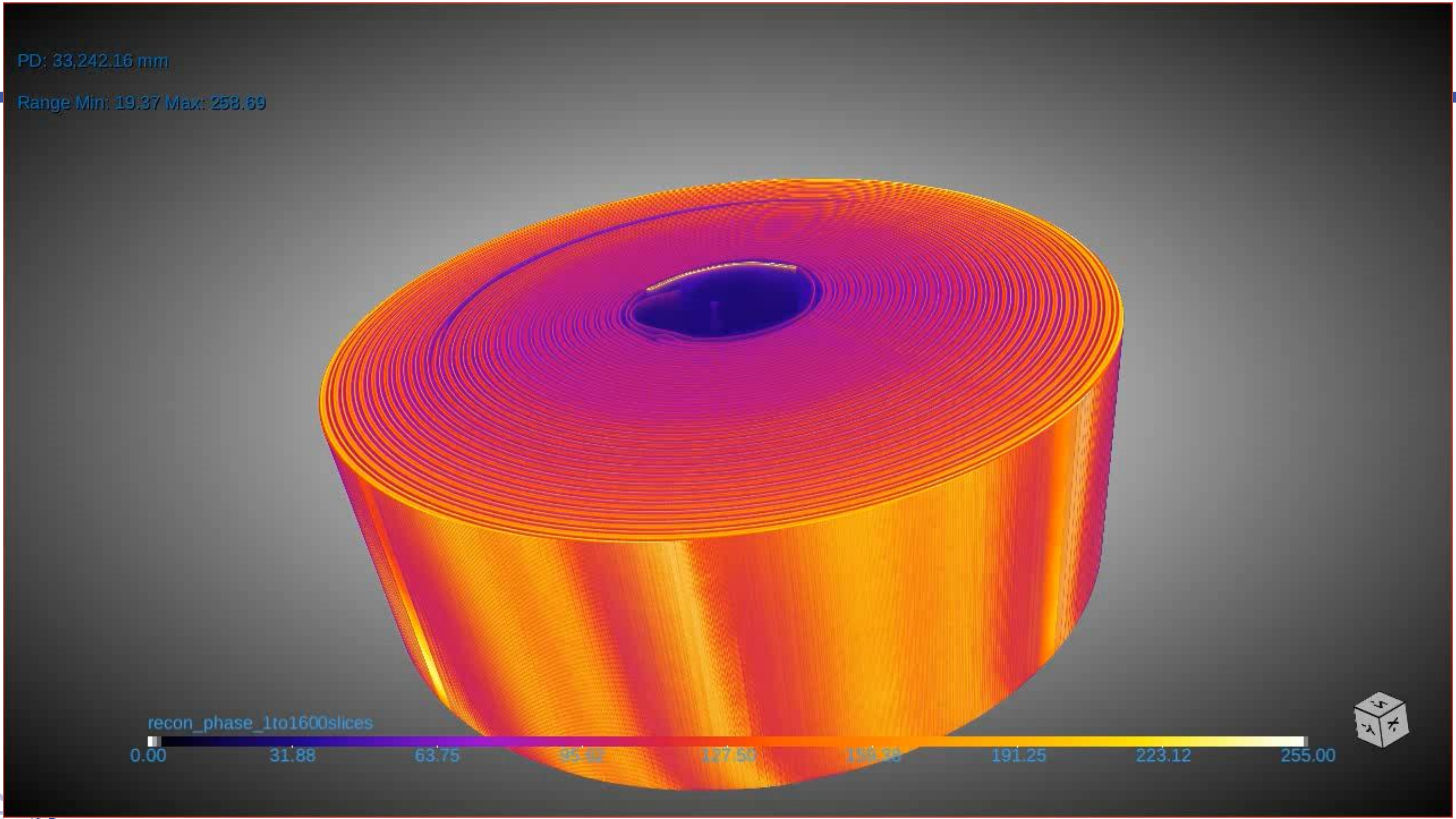
Keyframes animation

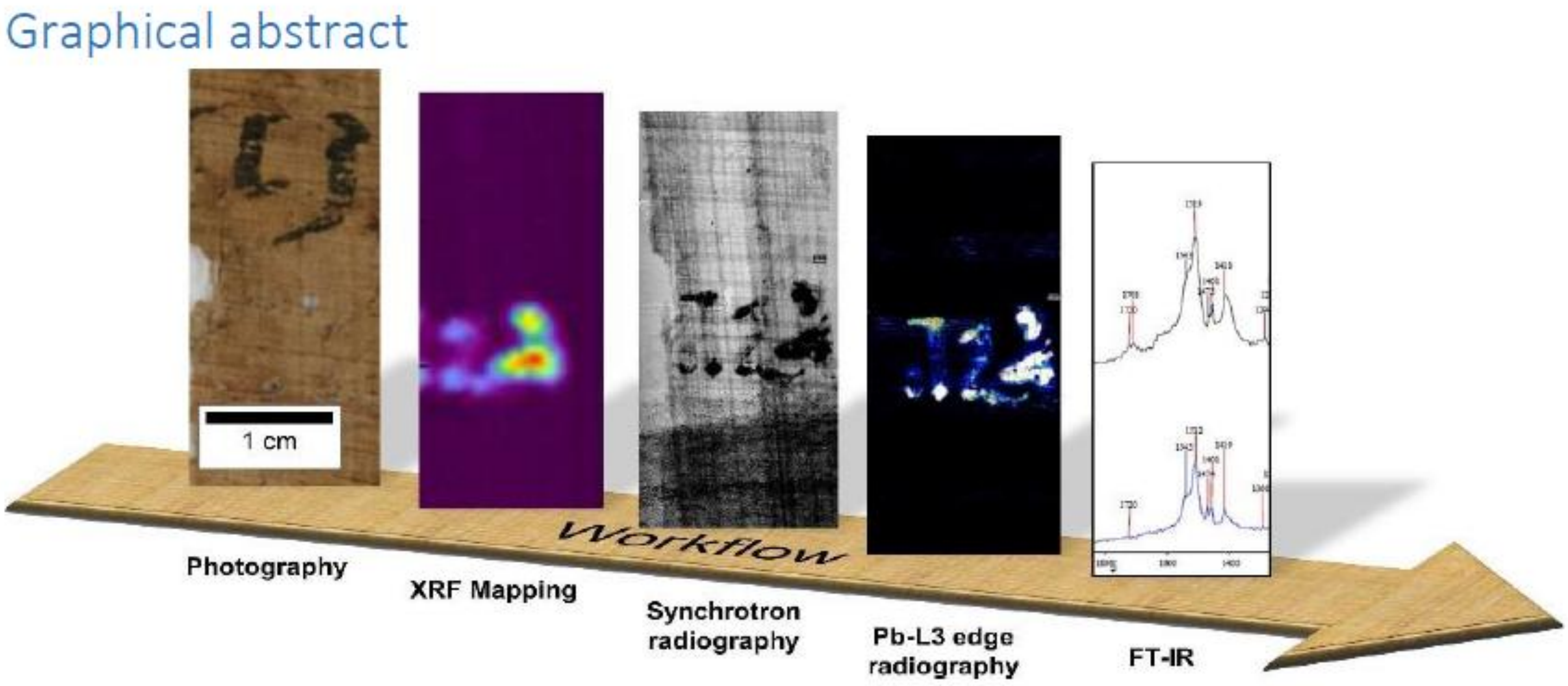


ATES Mehmet Nurullah, ALTIN Serdar, KUCUKKOYLU Sedat, , NASIROV Hasan, Turkey

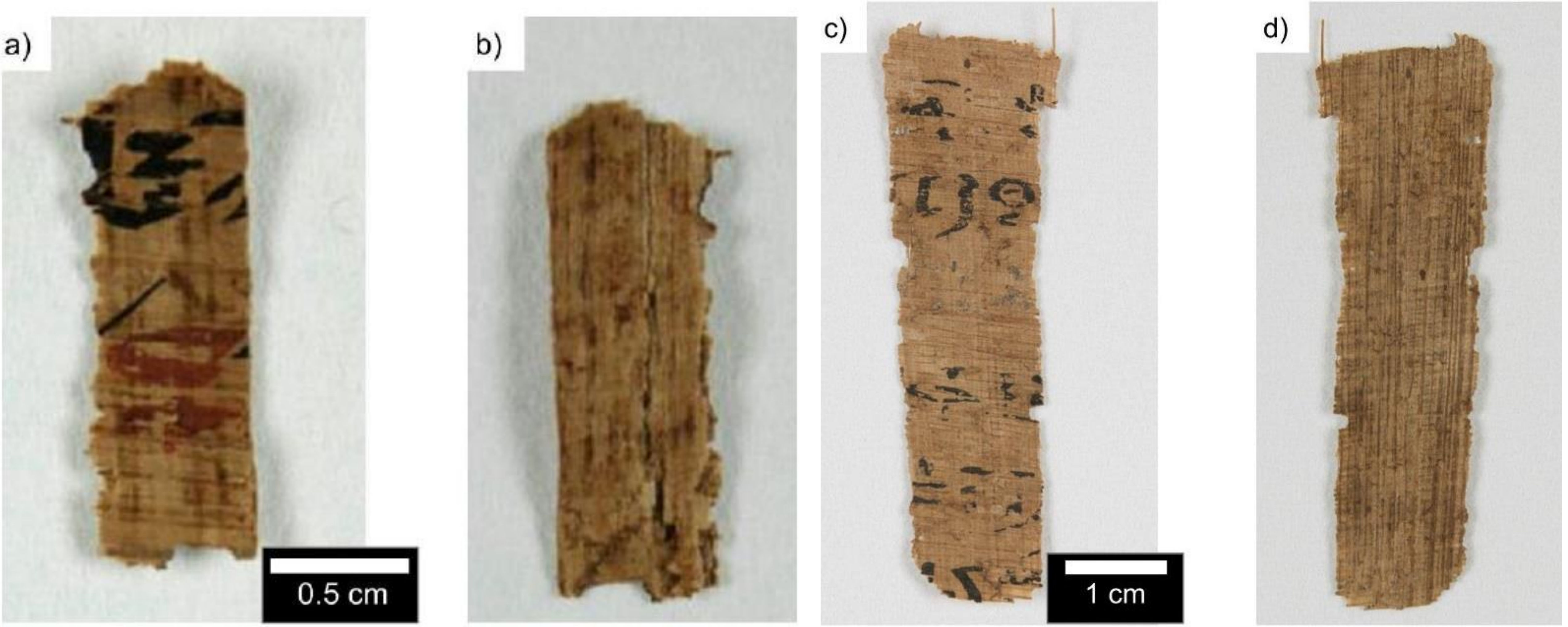


Turkey, Bogazici University, Inonu University, TUBITAK The Scientific and Technological Research Institution of Turkey, Eskisehir Technical University

Absorption Edge Sensitive Radiography and Tomography of Egyptian Papyri

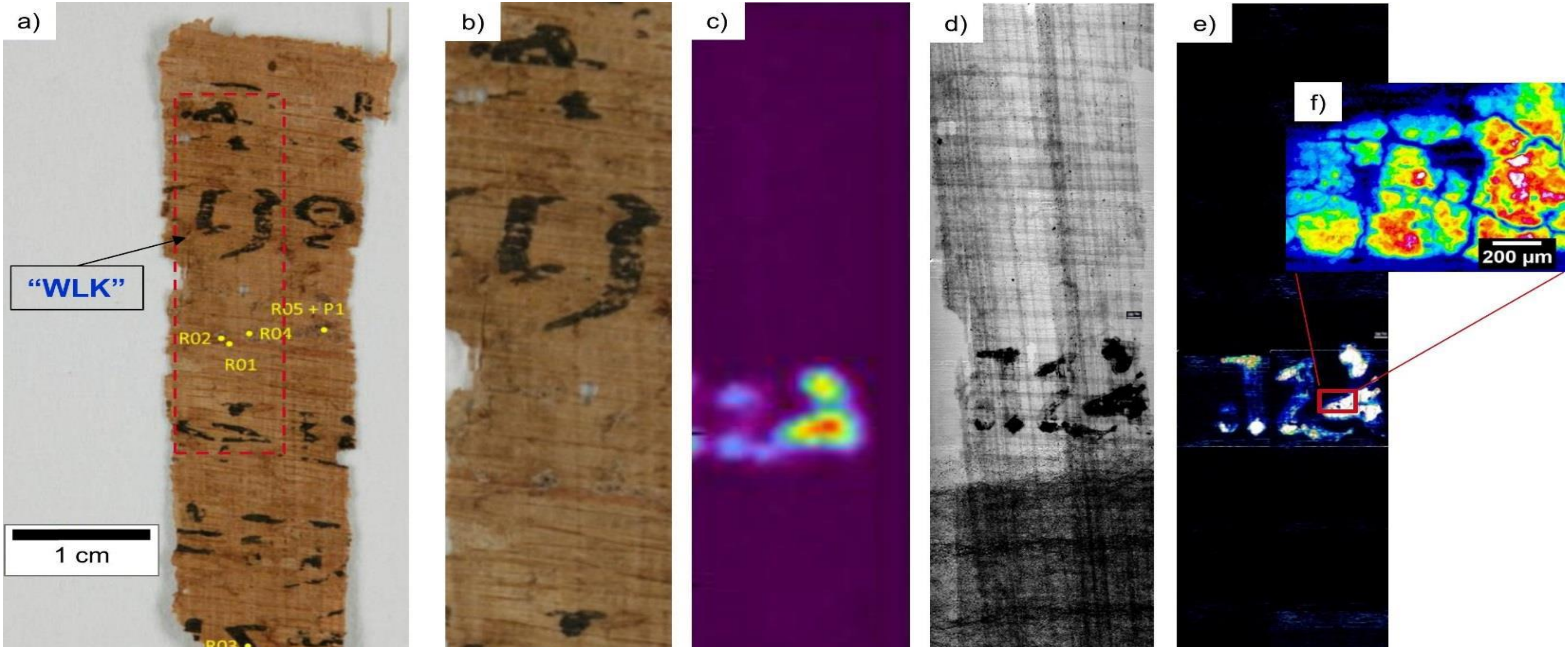


Arlt, Tobias, Heinz-Eberhard Mahnke, Tzulia Siopi, Eve Menei, Cristina Aibéo, Regine-Ricarda Pausewein, Ina Reiche, Ingo Manke, and Verena Lepper. "Absorption edge sensitive radiography and tomography of Egyptian papyri." *Journal of cultural heritage* 39 (2019): 13-20.



a) Recto and b) verso side of fragment "ÄMP B/H x 133g", c) recto and d) verso side of fragment "ÄMP B/H x 352". All pictures were taken by T. Siopi (AMP)

Arlt, Tobias, Heinz-Eberhard Mahnke, Tzulia Siopi, Eve Menei, Cristina Aibéo, Regine-Ricarda Pausewein, Ina Reiche, Ingo Manke, and Verena Lepper. "Absorption edge sensitive radiography and tomography of Egyptian papyri." *Journal of cultural heritage* 39 (2019): 13-20.



Fragment "ÄMP B/H x 352". a) Photo of the fragment with marked area that is enlarged in b) and indication of the Raman measurement's spots (R) and the sampling spot (P). Subfigures b)-e) show the same area. c) XRF mapping for Pb. d) Transmission radiography and e) absorption edge radiography at Pb_{L3} edge with enlarged cutout

Arlt, Tobias, Heinz-Eberhard Mahnke, Tzulia Siopi, Eve Menei, Cristina Aibéo, Regine-Ricarda Pausewein, Ina Reiche, Ingo Manke, and Verena Lepper. "Absorption edge sensitive radiography and tomography of Egyptian papyri." *Journal of cultural heritage* 39 (2019): 13-20.

An energy of 19 keV was chosen for standard radiographic measurements while 7.0 keV and 7.2 keV (Fig. 3b) and 12.90 keV and 13.15 keV were chosen for measurements at the absorption edges of Fe (K-edge) and of Pb (L23 -edge), respectively.

With the versatile detector system, different magnification optics can be combined with different CCD cameras and scintillator screens.

For the pre- sented work, a 20-m thick CWO 4 scintillator was combined with
a 10-fold magnification optics and a pco4000 CCD camera, resulting
in a pixel size of 440 nm

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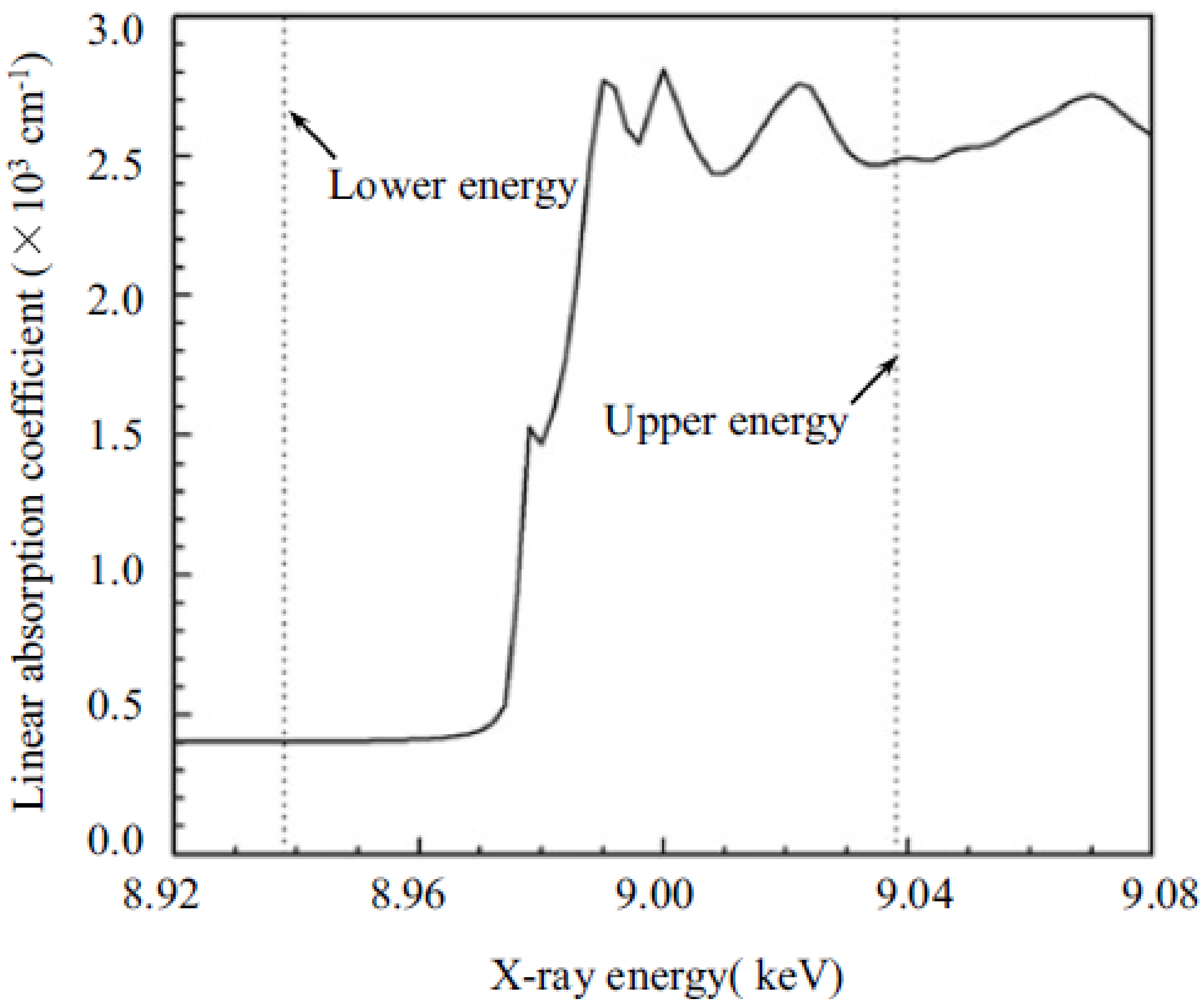
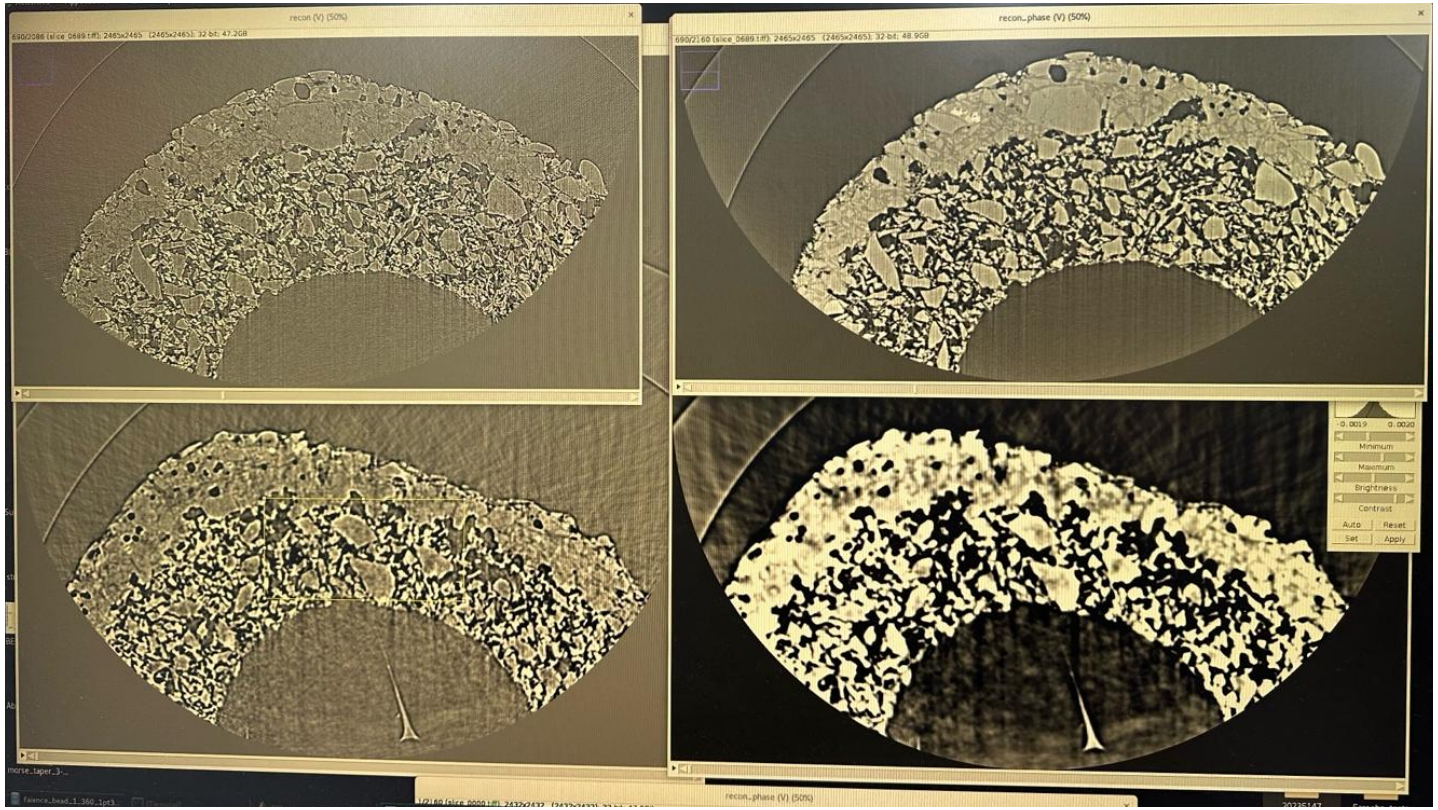
Fig. 5.37 X-ray absorption spectrum near the K absorption edge of copper; copper with a purity of 99.99% was used and measurements were made with an X-ray beam size of 8 × 0.6 mm [69]



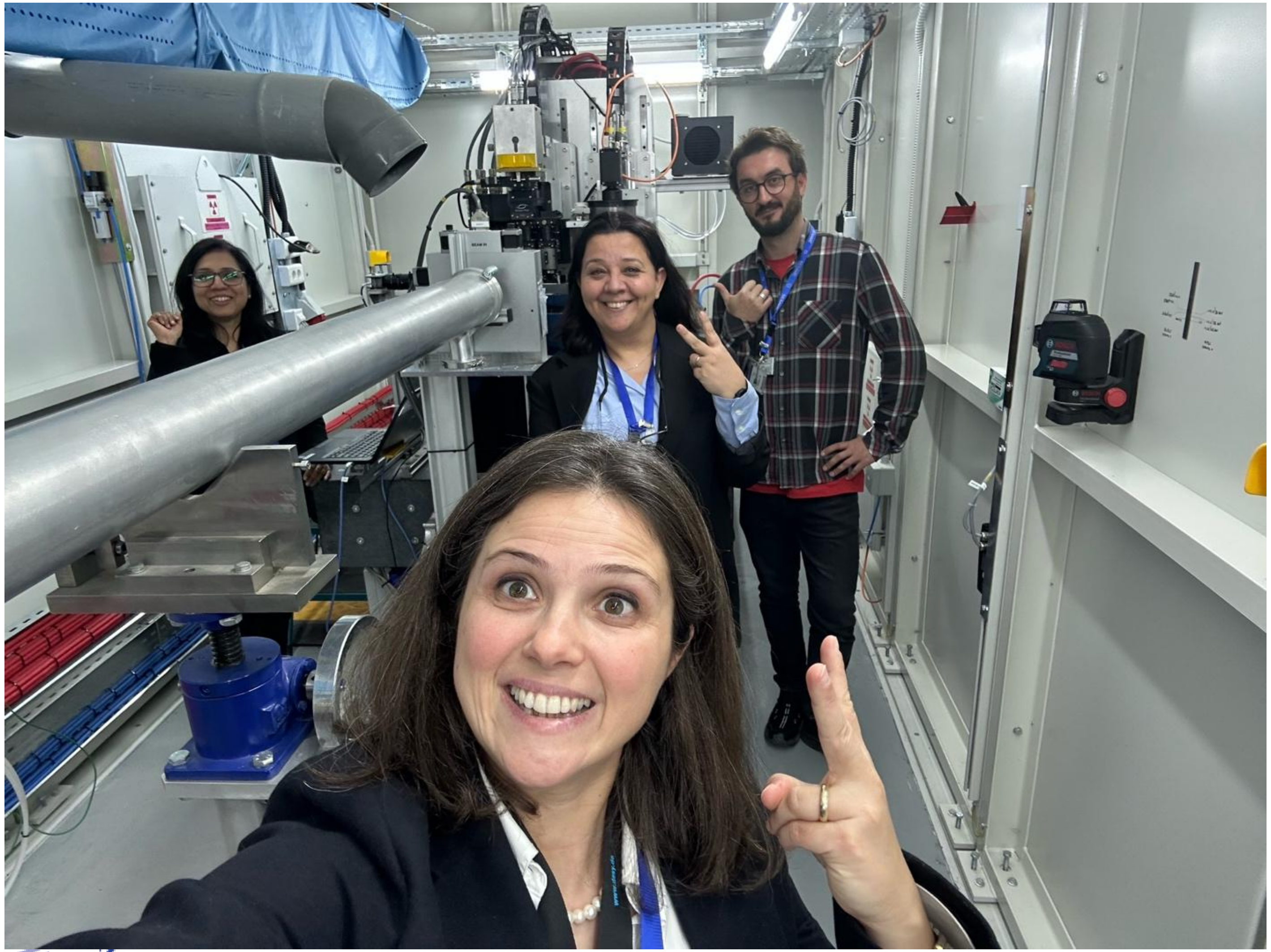
Toda, Hiroyuki. "X-Ray CT." (2021).

Phase-Contrast Synchrotron Tomography of Faience and Egyptian Blue

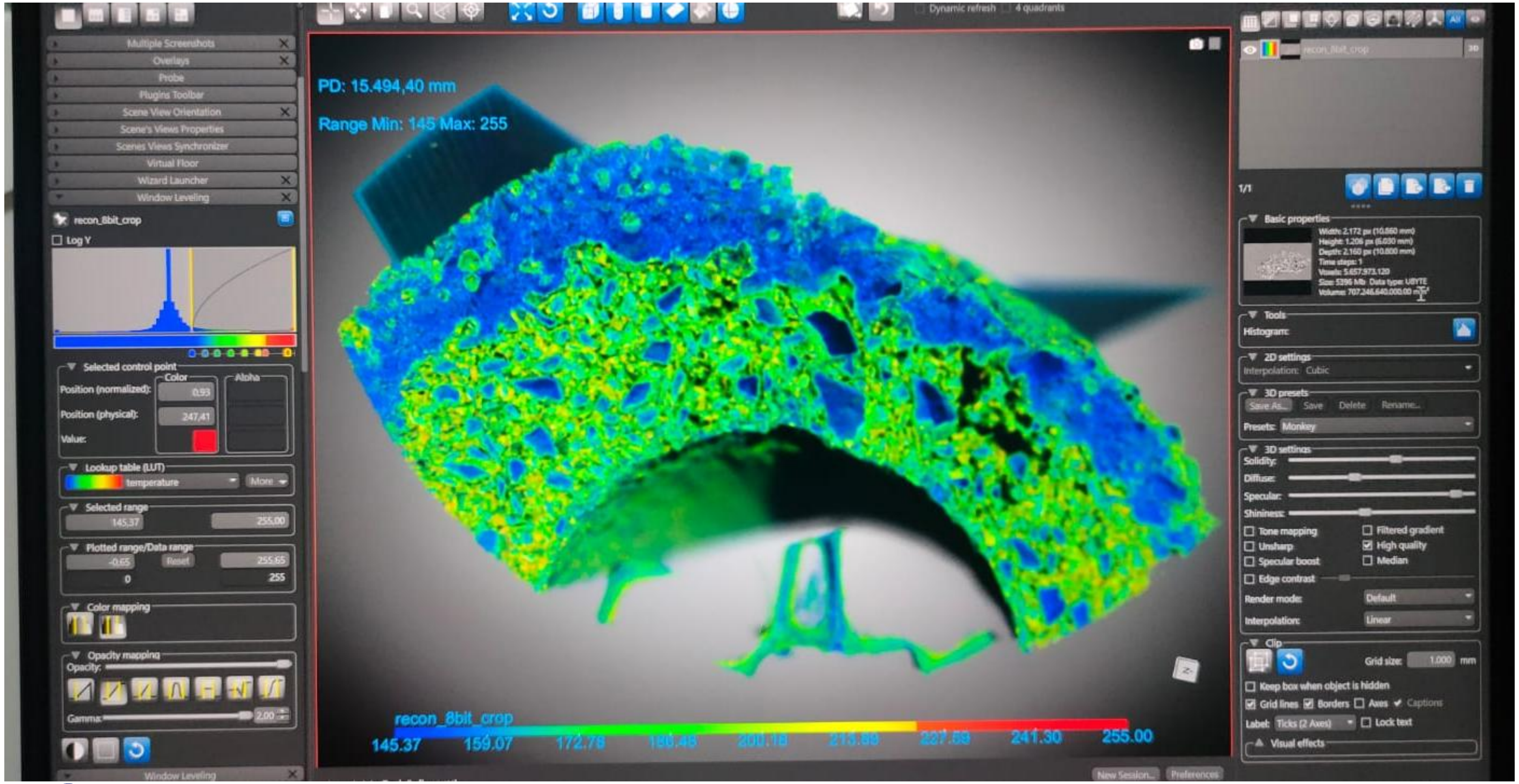


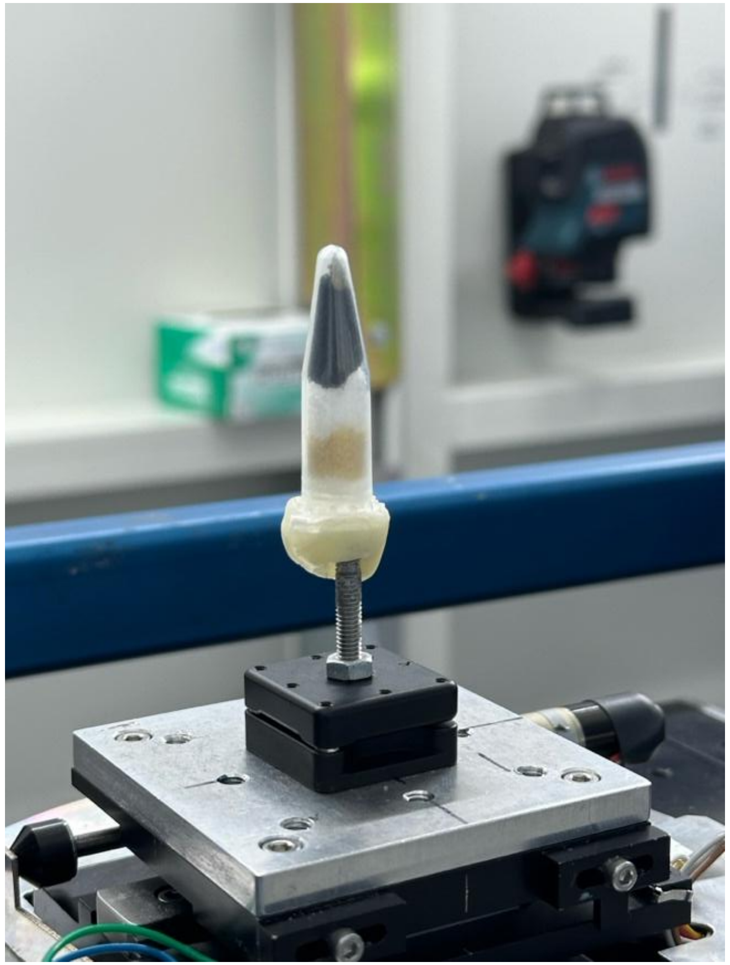
https://www.sesame.org.jo/news/synchrotron-x-ray-phase-contrast-microtomography-faience-beads-and-egyptian-blue-pigment

Dardeniz, G., Büyükgedik, G., Kaya, O., Özkorucuklu, S., Hameed, F., & Iori, G. (2025). Synchrotron computed tomography of 5000 years old faience beads from Southeastern Anatolia (Türkiye). *Tomography of Materials and Structures*, *7*, 100056.



Dardeniz, G., Büyükgedik, G., Kaya, O., Özkorucuklu, S., Hameed, F., & Iori, G. (2025). Synchrotron computed tomography of 5000 years old faience beads from Southeastern Anatolia (Türkiye). *Tomography of Materials and Structures*, *7*, 100056.





SESAME

BEATS

Conclusions

- Very beneficial for archaeology and cultural heritage
- Non-destructive
- Qualitative as well as quantitative

Conclusions

- Successful functioning of the BEATS beamline
- Proposals from several different countries
- Beamtimes performed for two semesters
- 3rd semester – now in progress
- Next call for proposals will be announced soon
- Website – for dates/deadlines, new activities, and highlights

https://www.sesame.org.jo/beamlines/beats

ACKNOWLEDGEMENTS

AND

THANKS

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https://www.sesame.org.jo/beamlines/beats