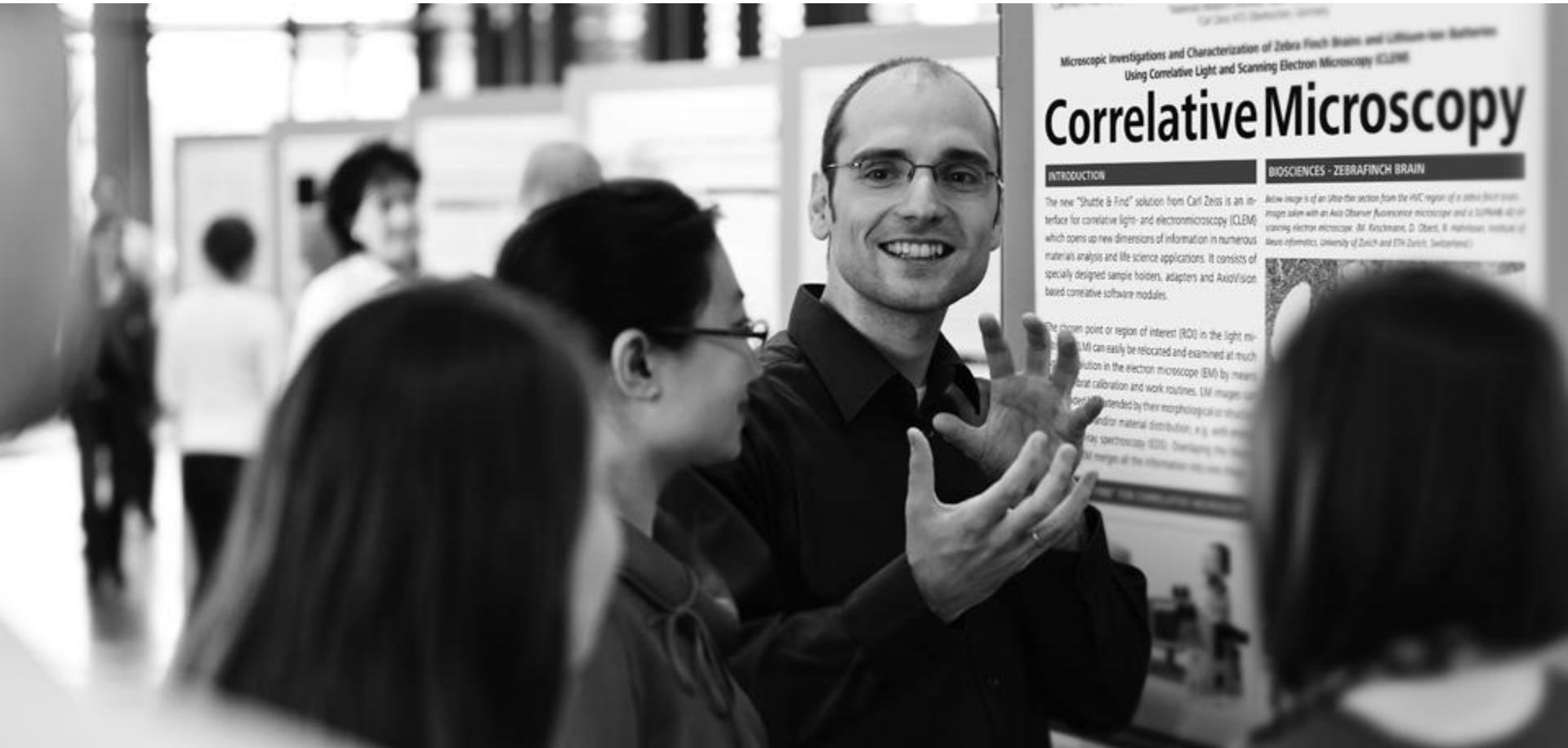


Zeiss Xradia 520 Versa Advanced Training



Carl Zeiss X-Ray Microscopy, Inc.

Rev1 -20131001

Agenda



- 1 Basics of 3D X-Ray Imaging
- 2 Review of Basic Settings
- 3 Advanced Techniques and Settings
- 4 New Features of Xradia 520 Versa

Advanced Topics



- ▣ Sample Preparation/Mounting
- ▣ Reference Image and Multiple Reference
- ▣ Geometric Magnification
- ▣ Sample size Vs. Resolution
- ▣ High Resolution Imaging Considerations
- ▣ Beam Hardening
- ▣ Variable Exposure
- ▣ Vertical Stitching
- ▣ Filtered Secondary Reference
- ▣ Misc. Software Options (XMController and XMReconstructor)
- ▣ Phase Contrast
- ▣ Scout and Zoom

Agenda



- 1 Basics of 3D X-Ray Imaging
- 2 Review of Basic Settings
- 3 Advanced Techniques and Settings
- 4 New Features of Xradia 520 Versa

Basics of X-Ray Imaging



- ☐ X-ray source
- ☐ X-ray spectrum
- ☐ Absorption image
- ☐ Geometric magnifications
- ☐ X-ray microscopic system

Source of X-Ray Radiation



- ❑ X-Rays exist in nature, e.g. in plasmas around stellar nebulae
- ❑ Similar production mechanisms have been mimicked on Earth, in the form of **synchrotron** and **laboratory** X-ray sources.



European Synchrotron Radiation Facility (Grenoble, France)
(source: esrf.eu)



Rigaku Laboratory X-ray Source
(source: directindustry.com)

Synchrotron vs. Laboratory Sources



❑ Synchrotron sources

- Large government installations
- >\$100M USD to build the facility
+~\$10M USD per beamline
- High brightness, high coherence,
tunable spectrum
- Access through proposal process

❑ Laboratory sources

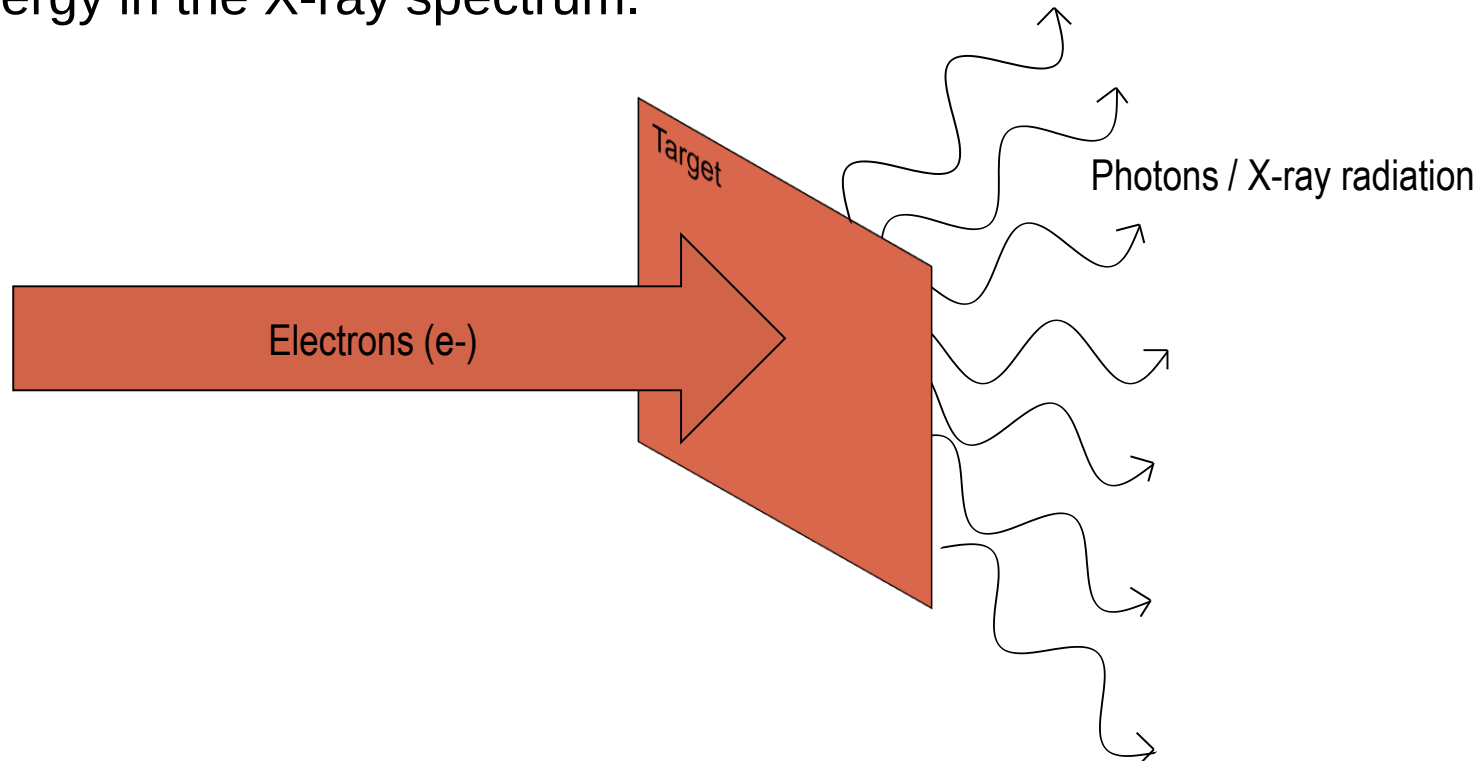
- Compact, cost effective
- Reasonably high brightness
- Access anytime
- May be purchased as integrated
into an imaging system, such as
in the ZEISS Xradia Versa&
ZEISS Xradia Ultra products



Laboratory X-ray Sources



- ❑ Electrons are emitted by a cathode, strike an anode containing a target material.
- ❑ Electrons excite the atoms in the target material, which release energy in the X-ray spectrum.



Target Materials & X-ray Spectra



❑ Different target materials produce different characteristic emission lines, as well as different broad-band emission spectra all the way up to the accelerating voltage (*bremssstrahlung*)

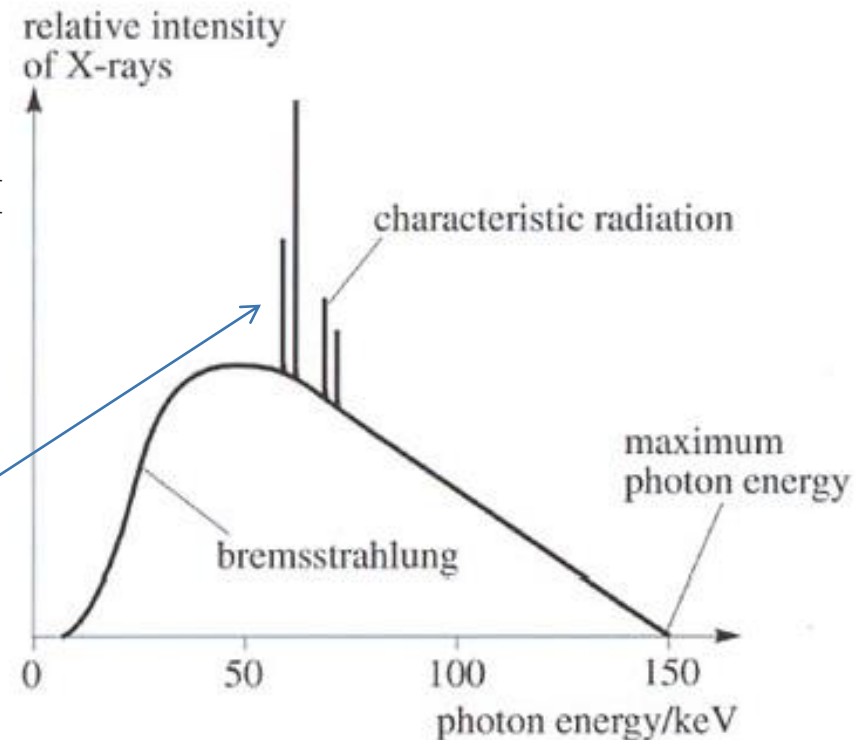
❑ Common target materials:

- W, Cu, V, Cr, Mo

Element	K α_1	K α_2	K β_1	L α_1	L α_2	L β_1	L β_2	L γ_1	M α_1
63 Eu	41,542.2	40,901.9	47,037.9	5,845.7	5,816.6	6,456.4	6,843.2	7,480.3	1,131
64 Gd	42,996.2	42,308.9	48,697	6,057.2	6,025.0	6,713.2	7,102.8	7,785.8	1,185
65 Tb	44,481.6	43,744.1	50,382	6,272.8	6,238.0	6,978	7,366.7	8,102	1,240
66 Dy	45,998.4	45,207.8	52,119	6,495.2	6,457.7	7,247.7	7,635.7	8,418.8	1,293
67 Ho	47,546.7	46,699.7	53,877	6,719.8	6,679.5	7,525.3	7,911	8,747	1,348
68 Er	49,127.7	48,221.1	55,681	6,948.7	6,905.0	7,810.9	8,189.0	9,089	1,406
69 Tm	50,741.6	49,772.6	57,517	7,179.9	7,133.1	8,101	8,468	9,426	1,462
70 Yb	52,388.9	51,354.0	59,370	7,415.6	7,367.3	8,401.8	8,758.8	9,780.1	1,521.4
71 Lu	54,069.8	52,965.0	61,283	7,655.5	7,604.9	8,709.0	9,048.9	10,143.4	1,581.3
72 Hf	55,790.2	54,611.4	63,234	7,899.0	7,844.6	9,022.7	9,347.3	10,515.8	1,644.6
73 Ta	57,532	56,277	65,223	8,146.1	8,087.9	9,343.1	9,651.8	10,895.2	1,710
74 W	59,318.24	57,981.7	67,244.3	8,397.6	8,335.2	9,672.35	9,961.5	11,285.9	1,775.4
75 Re	61,140.3	59,717.9	69,310	8,652.5	8,586.2	10,010.0	10,275.2	11,685.4	1,842.5
76 Os	63,000.5	61,486.7	71,413	8,911.7	8,841.0	10,355.3	10,598.5	12,095.3	1,910.2
77 Ir	64,895.6	63,286.7	73,560.8	9,175.1	9,099.5	10,708.3	10,920.3	12,512.6	1,979.9
78 Pt	66,832	65,112	75,748	9,442.3	9,361.8	11,070.7	11,250.5	12,942.0	2,050.5
79 Au	68,803.7	66,989.5	77,984	9,713.3	9,628.0	11,442.3	11,584.7	13,381.7	2,122.9
80 Hg	70,819	68,895	80,253	9,988.8	9,897.6	11,822.6	11,924.1	13,830.1	2,195.3
81 Tl	72,871.5	70,831.9	82,576	10,268.5	10,172.8	12,213.3	12,271.5	14,291.5	2,270.6

X-ray emission lines for various elements

Source: X-ray Data Booklet (xdb.lbl.gov)



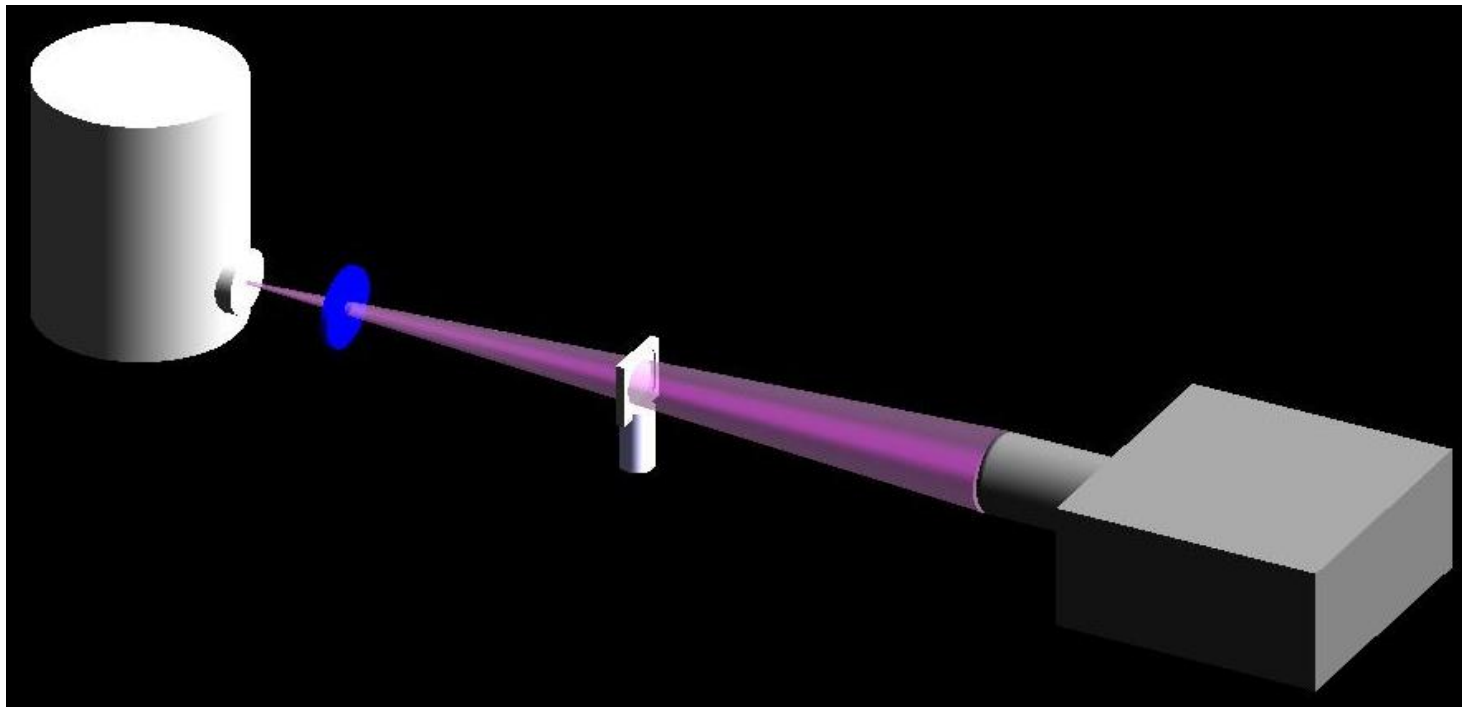
X-ray emission from a W laboratory X-ray source

Source: labspace.open.ac.uk

Imaging with X-rays



- ❑ Full-field X-ray imaging uses the photons produced by an X-ray source to penetrate through a sample.
- ❑ Differential absorptions are picked up by the detector and manifested as X-ray absorption contrast. → 2D X-ray image



X-ray Magnification



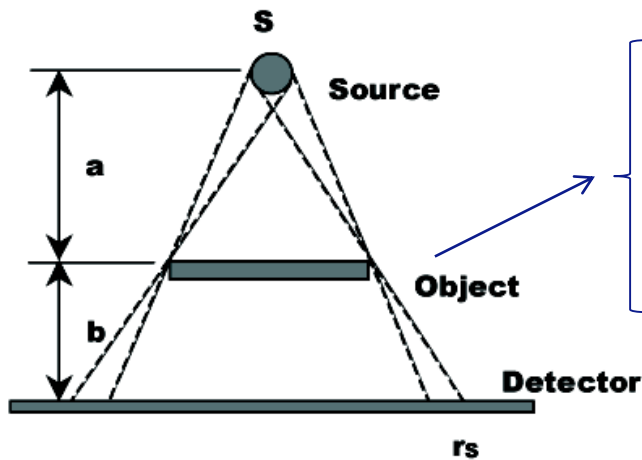
- ❑ Laboratory X-ray sources, by nature, produce a cone of light.
- ❑ Cone angle may be used for imaging magnification
- ❑ Geometric magnification = total beam path / source to object path
- ❑ One method of achieving high resolution is through maximizing geometric magnification, such as when producing a large shadow with visible light.



General System Resolution



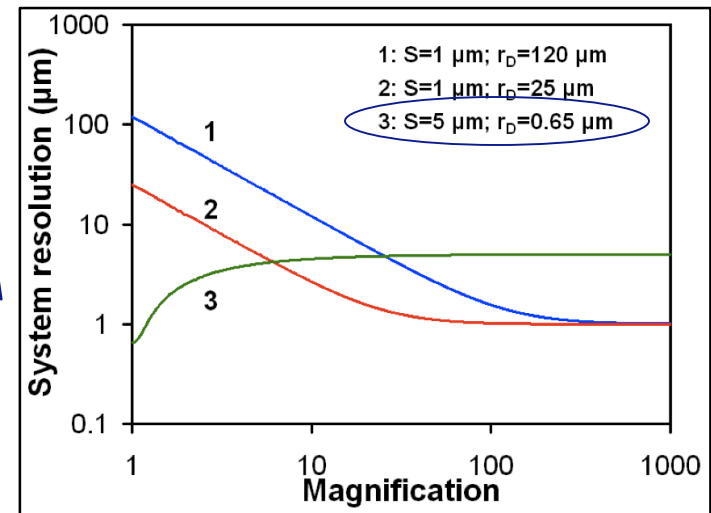
- ❑ Traditional projection-based micro-CT techniques rely on high geometric magnification (M) to achieve high resolution
 - Requires a small spot size (S) to minimize geometric penumbra (r_s)
 - Imposes small working distances $\Rightarrow$ small samples only for high resolution in 3D



$$r_s = S \left(\frac{b}{a} \right)$$

$$M = \frac{a+b}{a}$$

$$r_{total} = \frac{\sqrt{r_D^2 + r_s^2}}{M}$$



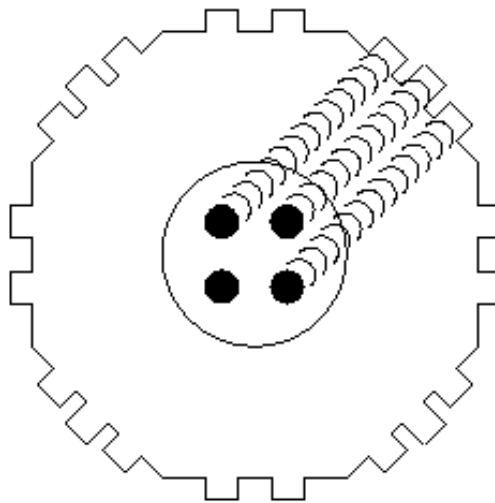
- ❑ The Xradia 520 Versa employs high detector resolution (r_D), allowing samples to be imaged with 0.7 μm resolution without relying on high geometric magnification

X-ray Computed Tomography: Projections and Reconstruction



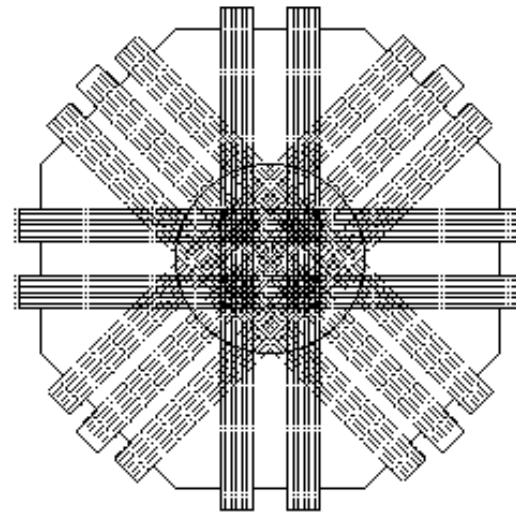
- ❑ The object is rotated, pausing at discrete angles to collect 2D projection images
- ❑ Projection images are combined together to produce a 3D reconstruction of the object's volume

A



Projection

B



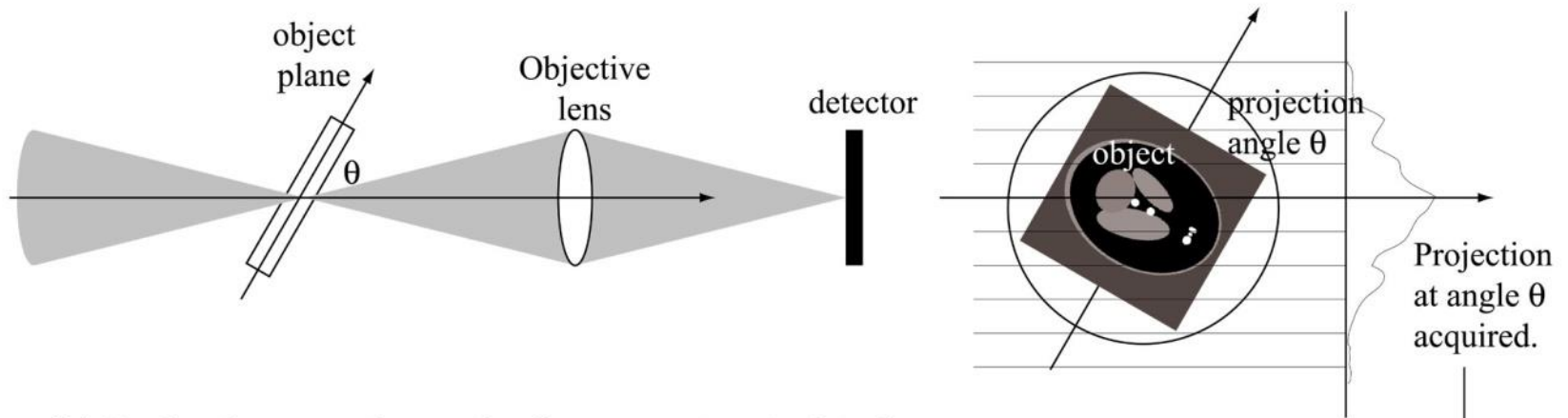
Backprojection

Source: <http://www.owl.net.rice.edu/~elec539/Projects97/cult/report.html>

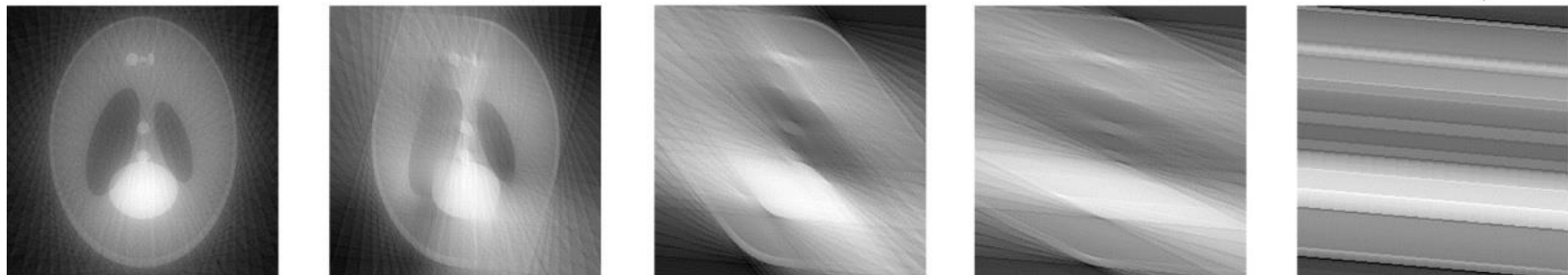
X-ray Computed Tomography: Projections and Reconstruction



(a) Object imaged at various angles to obtain tomographic projections at 50 nm resolution.



(b) Projections mathematically reconstructed to form a 3D volume image that represents the original object.



all 35 projection
reconstructed

25 of 35 projection
reconstructed

10 of 35 projection
reconstructed

5 of 35 projection
reconstructed

1 of 35 projection
reconstructed

Summary



- ❑ X-ray sources may be either large-scale synchrotrons or compact laboratory geometries.
- ❑ Different target materials and source configurations produce different x-ray spectrums for applications in the laboratory.
- ❑ Energy determines penetration depth and imaging contrast
- ❑ Resolution is a combination of geometric magnification, source spot, and detector resolution
- ❑ High resolution detectors allow greater flexibility for many applications

Agenda



- 1 Basics of 3D X-Ray Imaging
- 2 Review of Basic Settings
- 3 Advanced Techniques and Settings
- 4 New Features of Xradia 520 Versa

Review of Basic Settings



▣ Scout-and-Scan

- Sample – Set data directory/folder. Use existing or create new recipes.
- Load – Load the sample and coarsely align ROI using VLC.
- **Scout – Scout the sample, find the ROIs and set imaging parameters:**
 - Coarsely center ROI with low magnification objective and fine tune with high magnification objective
 - Select filter and set energy/power
 - Position source and detector
 - Exposure time, etc.
- Scan – Setup scan parameters: scanning angle, etc.
- Run – Run the recipe for data acquisition

▣ Reconstruction

- Center Shift
- Beam Hardening

▣ 3D Viewer

Agenda



- 1 Basics of 3D X-Ray Imaging
- 2 Review of Basic Settings
- 3 Advanced Techniques and Settings
- 4 New Features of Xradia 520 Versa

Advanced Topics



- ▣ Sample Preparation/Mounting
- ▣ Reference Image and Multiple Reference
- ▣ Geometric Magnification
- ▣ Sample size Vs. Resolution
- ▣ High Resolution Imaging Considerations
- ▣ Beam Hardening
- ▣ Variable Exposure
- ▣ Vertical Stitching
- ▣ Filtered Secondary Reference
- ▣ Misc. Software Options (XMController and XMReconstructor)
- ▣ Phase Contrast
- ▣ Scout and Zoom

Sample Preparation/Mounting



- ❑ Sample to be securely and vertically mounted on sample holders
 - Sample motion results in artifacts
 - High resolution scan is more susceptible to small sample motion
- ❑ Choose appropriate sample holders
- ❑ Align ROI to center of sample holder
 - Allows for maximum flexibility for source and detector positioning



Bad mounting :
Sample holder limits
position of detector
and source



Good mounting: Source and
detector position are only
limited by sample size

For small samples it is
recommended to mount on thin
adapter and use the pin vise

Sample Preparation/Mounting



- ❑ Trim sample down for high-throughput and highest quality scans
 - Determine the desired objective
 - Check the table below for recommended sample size for best performance
 - Ideal sample shape is cylindrical
 - Be aware that trimming may introduce alteration of the sample microstructures.

Objective	Sample Size
40X	0.5-0.7 mm
20X	1-2 mm
4X	2-20 mm
Macro70	30-70 mm

Recommended sample sizes for high throughput/high quality scans.

Sample Preparation/Mounting



❑ Common Tools and Materials

- Tweezers
- 5 min Epoxy
- Superglue
- Al rod
- Razor



Sample Preparation/Mounting



□ Examples of Effective Sample Mounting Strategies



Pin vise (with Al adaptor)
for small samples



Spring clamp for medium
size flat samples



Screw clamp for large flat
and/or heavier samples

Advanced Topics

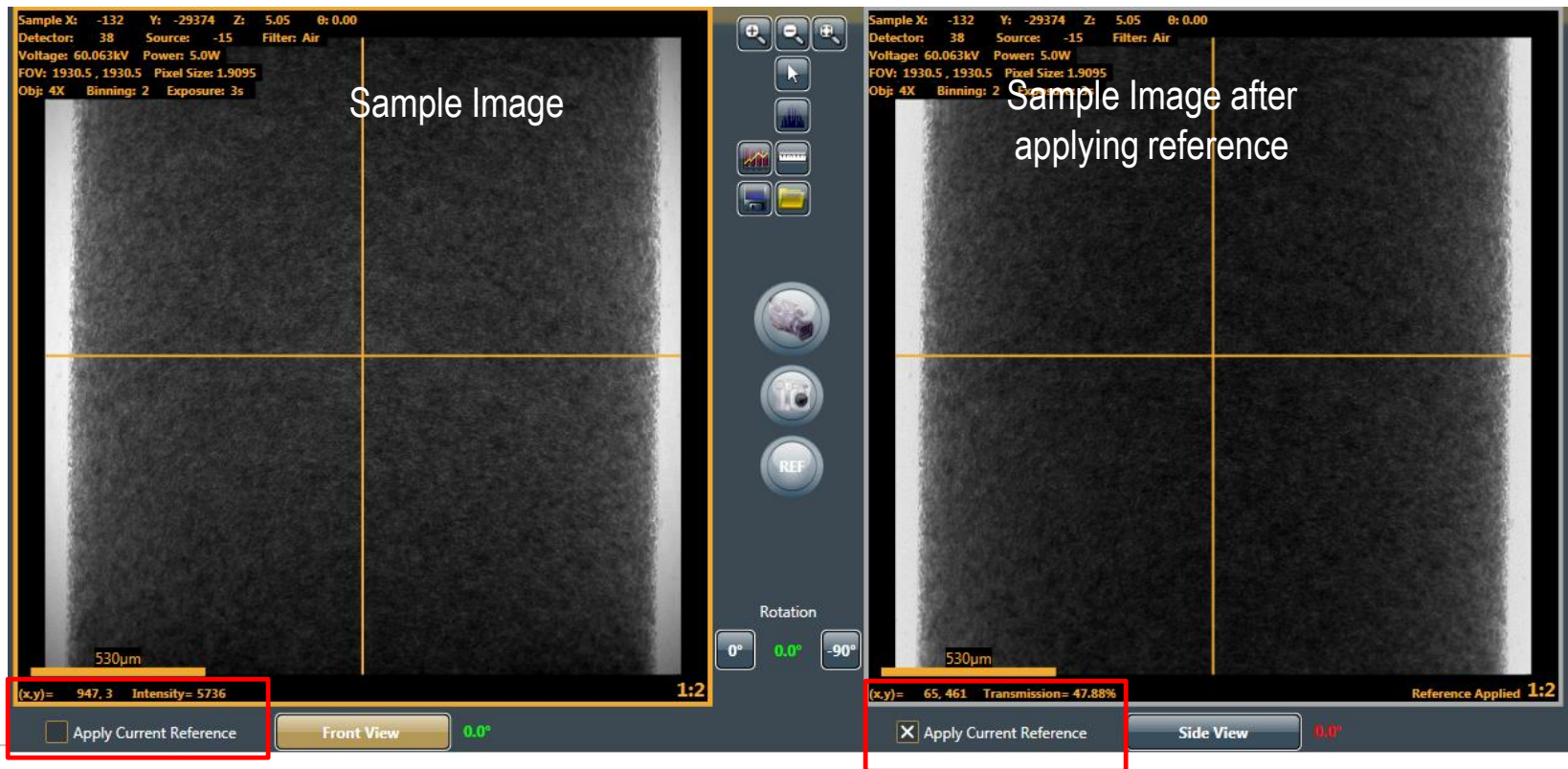


- ▣ Sample Preparation/Mounting
- ▣ Reference Image and Multiple Reference
- ▣ Geometric Magnification
- ▣ Sample size Vs. Resolution
- ▣ High Resolution Imaging Considerations
- ▣ Beam Hardening
- ▣ Variable Exposure
- ▣ Vertical Stitching
- ▣ Filtered Secondary Reference
- ▣ Misc. Software Options (XMController and XMReconstructor)
- ▣ Phase Contrast
- ▣ Scout and Zoom

Reference Image



- A sample image is acquired with the sample in the field of view (FOV).
- A reference image is acquired with the sample out of the FOV using the same acquisition conditions as the sample image.
- Applying a reference to sample image provides the transmission values



Multiple Reference



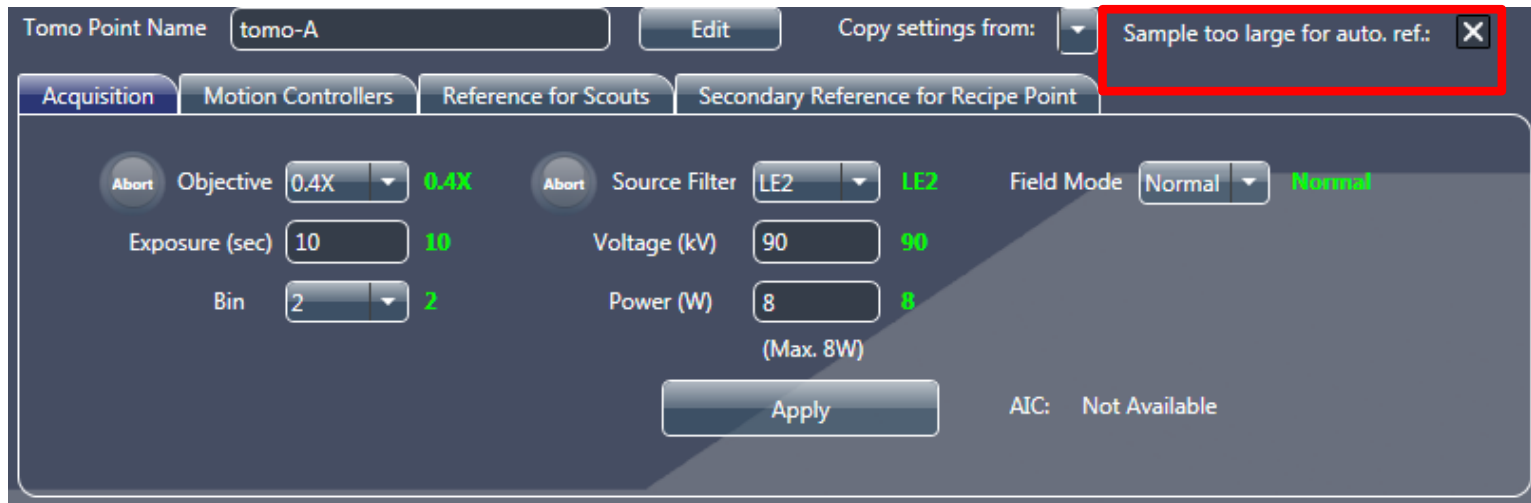
- ❑ Multiple references are automatically acquired throughout the 3D tomography acquisition
- ❑ Improves image quality by having more representative references
- ❑ Disadvantages
 - Slightly longer scan time
 - Does not work for large sample that cannot be moved out of FOV
- ❑ Settings in Recipe
- ❑ Recommended to choose a frequency ~25% total time of tomography
 - e.g. choose reference collection for every 400 frames for a scan with 1,600 projections.

- ❑ Manual reference is used when sample is too large to move outside the FOV for automatic referencing.
 - Automatic referencing relies on clear air images when X or Y axis moves to one of the three limits (positive Y, positive X and negative X) during data acquisition.
 - Manual reference images are taken by physically moving the sample out of the sample stage to allow clear shots for air images.
 - Manual reference is often collected prior to data acquisition. The reference can be automatically applied to projections during tomography.
 - It could be collected after data collection (not recommended). But if collected after tomography, applying reference image to projection images must be done using XMController.

Manual Reference



- ❑ Check “Sample too large for auto ref” in Scout page to start manual reference collection.



- ❑ Set parameters in Scan page (Note: ignore reference parameters in the page)
- ❑ After clicking “Start” in Run page, a window will pop up to assist manual reference collection. Follow the instruction.

Advanced Topics

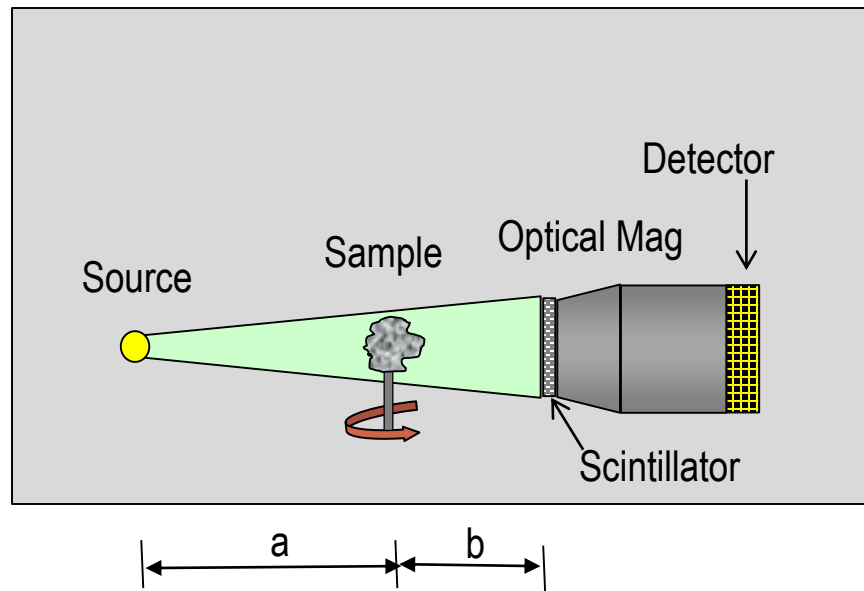


- ▣ Sample Preparation/Mounting
- ▣ Reference Image and Multiple Reference
- ▣ Geometric Magnification
- ▣ Sample size Vs. Resolution
- ▣ High Resolution Imaging Considerations
- ▣ Beam Hardening
- ▣ Variable Exposure
- ▣ Vertical Stitching
- ▣ Filtered Secondary Reference
- ▣ Misc. Software Options (XMController and XMReconstructor)
- ▣ Phase Contrast
- ▣ Scout and Zoom

Geometric Magnification



- ▣ Image resolution is mainly defined by objectives and geometric mag.
- ▣ Geometric magnification can be used to scans using 0.4X and 4X:
 - Geometric Mag. = Source to Detector Distance / Source Distance
= $(a + b)/a$
 - Total Mag. = Objective Mag. x Geometric Mag.



Geometric Magnification



- ❑ Geometric magnification may be used for scans with 0.4X and 4X.
- ❑ Keep source as close to the sample as possible, and pull detector away for max. geometric magnifications.
 - For Macro-70, keep the source and detector distance at least 140 mm to avoid the appearance of source aperture.
- ❑ Refer to the table below for max. geometric magnifications:

Objective	Zeiss Xradia 520 Versa	
	Geo. Mag. Limit	Pixel at limit (µm)
Macro-70	11*	~5
4X	10	~0.7
20X	2.7	~0.5

* Note: the actual max. geometric magnification may vary.

Advanced Topics



- ▣ Sample Preparation/Mounting
- ▣ Reference Image and Multiple Reference
- ▣ Geometric Magnification
- ▣ Sample size Vs. Resolution
- ▣ High Resolution Imaging Considerations
- ▣ Beam Hardening
- ▣ Variable Exposure
- ▣ Vertical Stitching
- ▣ Filtered Secondary Reference
- ▣ Misc. Software Options (XMController and XMReconstructor)
- ▣ Phase Contrast
- ▣ Scout and Zoom

Sample Size vs. Resolution



Xradia 520 Versa (basic rule of thumb)

<u>Objective</u>	<u>Max Physical Sample Size (mm)</u>	<u>Resolution (μm)</u>	<u>FOV (mm)</u>
Macro	100	~65	50*
4X	50	~7	5*
20X	10	~1.5	1
40X	5	~1	0.5

- ☐ Low Mag objectives can have varying resolution and FOV
- ☐ This is general guidance of resolution and FOV. The true resolution depends on other facts: shape of sample, chemical composition, sample porosity and position of ROI, etc.

Xradia 520 Versa

Sample Size vs. Resolution



❑ Rules of Thumb: **For Full Samples and Uniform Diameter Samples**

- FULL SAMPLE → Sample size/1800
 - Ex. 50 mm diameter core → ~ 27 μm voxel res
 - Ex. 12 mm diameter embryo → ~ 6.5 μm voxel res
 - Ex. 2 mm diameter composite → ~ 1.1 μm voxel res

- INTERIOR TOMOGRAPHY → Sample size/5000
 - Ex. 50 mm diameter core → ~ 10 μm voxel res
 - Ex. 12 mm diameter embryo → ~ 2.4 μm voxel res
 - Ex. 2 mm diameter composite → ~ 0.4 μm voxel res

Xradia 520 Versa

Sample Size vs. Resolution



- ❑ Rules of Thumb: **High Aspect Ratio Samples** (i.e. semi package, plate-like sample, etc.)
 - INTERIOR TOMOGRAPHY →
 - 200 mm width (motherboard) → ~ 6-7 μm voxel res *
 - 100 mm small board → ~ 3-4 μm voxel res
 - 50 mm package → ~ 1.5-3 μm voxel res
 - 25 mm package → ~ 0.7-1.5 μm voxel res
 - <15 mm package → ~0.5-1 μm voxel res
- * For large flat samples (motherboard, full wafer, etc) full tomographies are generally not possible and there will be some artifacts due to partial volume effects (limited angle tomography artifacts)

Xradia 520 Versa

Sample Size vs. Resolution



Sample Type	Voxel Resolution	Sample size	Throughput considerations
O&G Rock	0.3-0.7	0.5-3 mm	At a cost of increased noise or lower resolution throughput can be faster
	0.8-2	3-10 mm	
	3-25	10-50 mm	
Bone for osteocyte lacunae imaging	0.5 um Required to see lacunae	3-5 mm max.	Minimize overall sample thickness, including mounting material (i.e. not mounted in several mms of wax)
Polymers	0.3-0.7	0.5-2 mm	Good contrast will require longer scans times than other sample types. Possibly much longer if phase contrast is used
	0.8-2	2-8 mm	
	3-25	8-50 mm	
Metals -- Al	0.3-0.7	0.5-3 mm	At a cost of increased noise or lower resolution throughput can be faster
	0.8-2	3-10 mm	
	3-25	10-50 mm	

Xradia 520 Versa

Sample Size vs. Resolution



Sample Type	Voxel Resolution	Sample size	Throughput considerations
Metals – Cu, Fe	0.5-1	0.5-1.5 mm	Higher absorbing materials, like Iron, will require longer scans and small samples to get good results
	1-3	1.5-4 mm	
	4-15	4-10 mm (max)	
Semiconductor Packaging	0.3-0.6	<10 mm (1-2 mm thick max)	Removing BGA bumps greatly reduces noise and can increase effective throughput
	0.7-2	10-40 mm	
	2.5 - 25	>40 mm	
Bio Mat –Tissue (stained)	0.3-0.7	0.5-3 mm	At a cost of increased noise or lower resolution, throughput can be increased. Non-stained tissue will generally need to be ~1/2 the size to obtain some resolution and scan times will be very long (Phase Contrast)
	0.8-2	3-10 mm	
	3-25	10-50 mm	

Advanced Topics



- ▣ Sample Preparation/Mounting
- ▣ Reference Image and Multiple Reference
- ▣ Geometric Magnification
- ▣ Sample size Vs. Resolution
- ▣ High Resolution Imaging Considerations
- ▣ Beam Hardening
- ▣ Variable Exposure
- ▣ Vertical Stitching
- ▣ Filtered Secondary Reference
- ▣ Misc. Software Options (XMController and XMReconstructor)
- ▣ Phase Contrast
- ▣ Scout and Zoom

High Resolution: General Guidance



- ❑ Make sure that sample is mounted or glued securely
 - It may take several hrs. for newly glued samples to settle
 - If the sample is malleable and has been distorted during sample mounting it may take several hours for the stress in the sample to be relieved
- ❑ Warm up at least 1 hour for best results at highest res
- ❑ Bring both source and detector as close as possible to sample for minimizing scanning time

- ❑ Compare “Sample Drift” correction with the default “Thermal Drift” and choose the one that works the best.
- ❑ Trim sample to minimum size if possible
- ❑ Place ROI close to center of sample holders
- ❑ If very long scan times are necessary overall stability of the sample and the system are even more important.

Sample Drift Correction



- ❑ Sample motion (> 5 pixels) other than rotation throughout scanning can affect image sharpness.
- ❑ Collects a series of sample images at 0° (typical interval: 60-100 frames) during data acquisition to correct sample movements
- ❑ Improves image quality for the environment with temperature fluctuation $> 1^\circ\text{C}$.
- ❑ Source has to be stable (warmed up for > 30 mins)
- ❑ Most useful with high resolution images (i.e. 20X, 40X)

Sample Drift Correction



Open .txrm with
XMController

The screenshot shows the 'Image Control' software window. At the top, there are tabs for Reference, Notes, Navigator, Focus Function, Alignment, and Shifts. Below the tabs is a table with columns: Angle, Total Shift, Stage Shift, Sample Drift, Encoders, Reference ..., and Metrology ... The table contains data for 27 rows (79 to 105). A blue oval highlights the 'Sample Drift' column. Below the table, there is a dropdown menu with 'Use sample drift' selected. To the left of the dropdown is a checkbox labeled 'Stage Shift'. To the right are checkboxes for 'Encoders', 'Reference Shift', and 'Metrology Shift'. At the bottom, there are buttons for 'Export Total Shifts', 'Import Stage Shifts', and 'Import Source Drift .txrm File and Apply'.

	Angle	Total Shift	Stage Shift	Sample Drift	Encoders	Reference ...	Metrology ...
79	-74.844	-2.56,0.50	0.4,0.9	0.1,-0.1	-2.9,-0.3	0.0,0.0	0.0,0.0
80	-74.611	7.75,-0.53	0.4,0.9	-0.1,-0.1	7.5,-1.3	0.0,0.0	0.0,0.0
81	-74.378	-6.17,-0.74	0.4,0.9	-0.1,-0.1	-6.4,-1.5	0.0,0.0	0.0,0.0
82	-74.146	-7.04,1.03	0.4,0.9	-0.1,-0.1	-7.3,0.3	0.0,0.0	0.0,0.0
83	-73.912	-9.51,1.69	0.4,0.9	-0.2,-0.2	-9.7,1.0	0.0,0.0	0.0,0.0
84	-73.679	6.87,0.40	0.4,0.9	-0.2,-0.2	6.7,-0.3	0.0,0.0	0.0,0.0
85	-73.447	3.72,-0.37	0.4,0.9	-0.2,-0.2	3.5,-1.1	0.0,0.0	0.0,0.0
86	-73.213	-2.84,-0.84	0.4,0.9	-0.2,-0.2	-3.0,-1.5	0.0,0.0	0.0,0.0
87	-72.982	5.05,1.95	0.4,0.9	-0.2,-0.2	4.9,1.3	0.0,0.0	0.0,0.0
88	-72.750	-0.68,2.90	0.4,0.9	-0.2,-0.2	-0.8,2.3	0.0,0.0	0.0,0.0
89	-72.517	3.49,1.20	0.4,0.9	-0.3,-0.2	3.4,0.6	0.0,0.0	0.0,0.0
90	-72.284	0.78,-0.49	0.4,0.9	-0.3,-0.2	0.7,-1.1	0.0,0.0	0.0,0.0
91	-72.051	-4.86,0.08	0.4,0.9	-0.3,-0.3	-4.9,0.5	0.0,0.0	0.0,0.0
92	-71.818	6.84,1.64	0.4,0.9	-0.3,-0.3	6.8,1.1	0.0,0.0	0.0,0.0
93	-71.586	-5.16,3.39	0.3,0.9	-0.3,-0.3	-5.2,2.8	0.0,0.0	0.0,0.0
94	-71.353	-10.96,0.10	0.3,0.9	-0.4,-0.3	-11.0,-0.5	0.0,0.0	0.0,0.0
95	-71.119	0.53,1.60	0.3,0.9	-0.4,-0.3	0.6,1.1	0.0,0.0	0.0,0.0
96	-70.887	-9.96,-0.58	0.3,0.8	-0.4,-0.3	-9.9,-1.1	0.0,0.0	0.0,0.0
97	-70.654	3.85,-1.47	0.3,0.8	-0.4,-0.3	3.9,-2.0	0.0,0.0	0.0,0.0
98	-70.421	4.96,2.54	0.3,0.8	-0.4,-0.4	5.1,2.0	0.0,0.0	0.0,0.0
99	-70.189	7.33,-1.27	0.3,0.8	-0.5,-0.4	7.5,-1.7	0.0,0.0	0.0,0.0
100	-69.956	-0.56,-2.17	0.3,0.8	-0.5,-0.4	-0.4,-2.6	0.0,0.0	0.0,0.0
101	-69.722	-2.70,0.63	0.3,0.8	-0.5,-0.4	-2.5,0.2	0.0,0.0	0.0,0.0
102	-69.490	-3.58,2.47	0.3,0.8	-0.5,-0.4	-3.4,2.0	0.0,0.0	0.0,0.0
103	-69.255	-7.91,-0.27	0.3,0.8	-0.6,-0.4	-7.7,-0.7	0.0,0.0	0.0,0.0
104	-69.024	8.93,-0.18	0.3,0.8	-0.6,-0.5	9.2,-0.6	0.0,0.0	0.0,0.0
105	-68.792	2.82,2.98	0.3,0.8	-0.6,-0.5	3.1,2.6	0.0,0.0	0.0,0.0

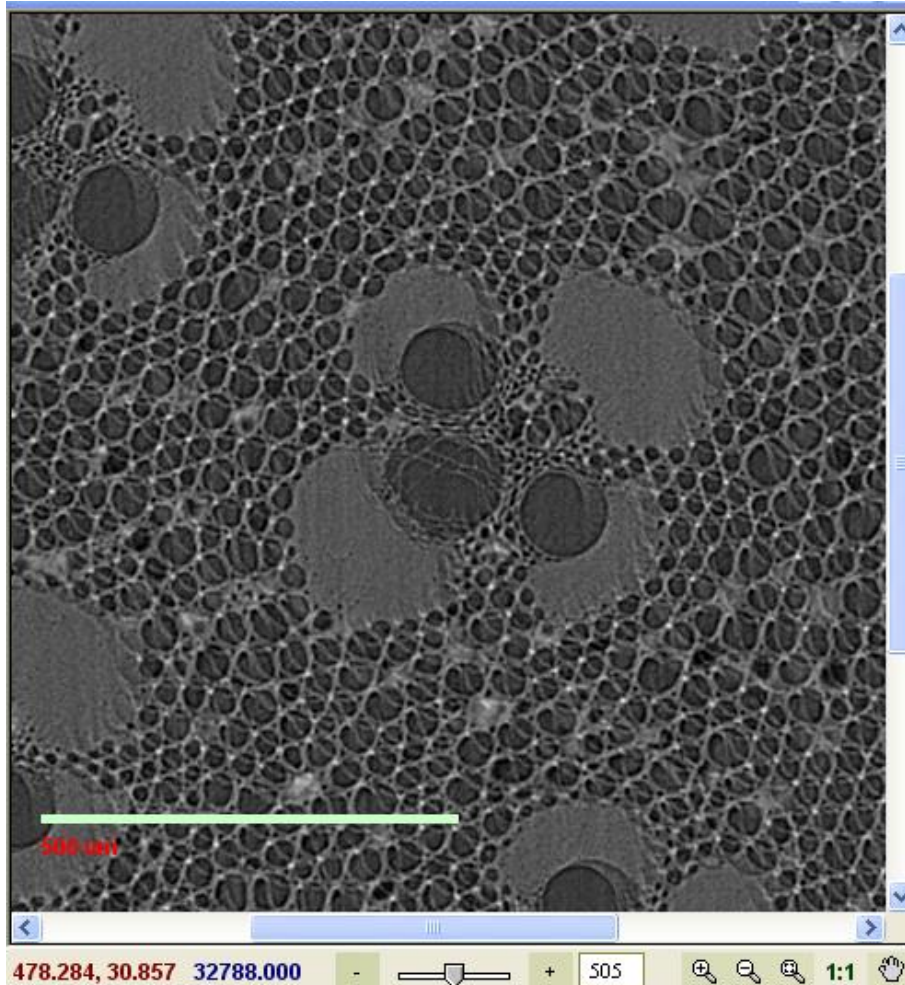
Choose "use sample drift"

Pixels of sample movements

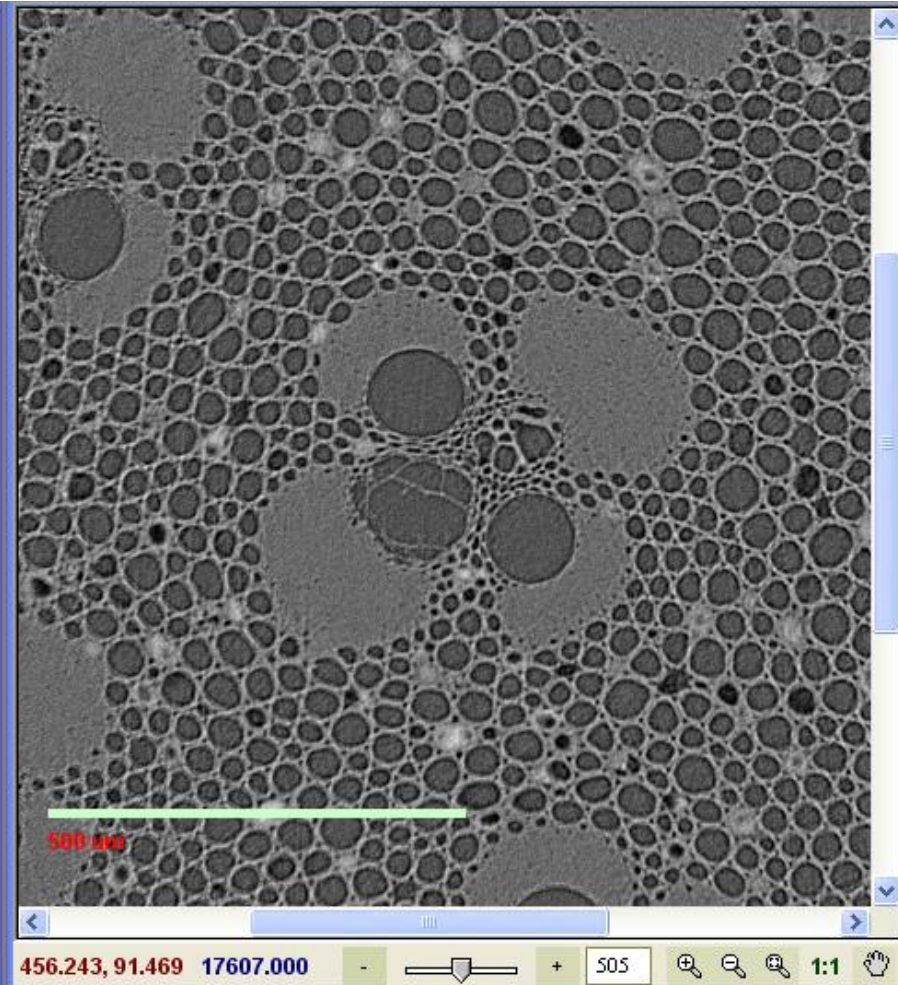
Sample Drift Correction



No sample drift correction



After sample drift correction



Thermal Drift Correction



Image Control

Thermal Reference Notes Navigator Focus Alignment Shifts

	Angle	Total Shift	Stage Shift	Sample ...	Thermal	Encoders	Referenc...	Metrology...
1	-92.999	0.68,-0.36	0.3,0.8	0.0,0.0	0.4,-1.2	-0.0,0.0	0.0,0.0	0.0,0.0
2	-92.770	-8.03,-1.01	0.3,0.8	0.0,0.0	0.4,-1.2	-8.7,-0.7	0.0,0.0	0.0,0.0
3	-92.537	3.75,2.29	0.3,0.8	0.1,0.0	0.4,-1.2	3.1,2.6	0.0,0.0	0.0,0.0
4	-92.303	8.24,-0.10	0.3,0.8	0.1,0.0	0.4,-1.2	7.5,0.2	0.0,0.0	0.0,0.0
5	-92.071	4.81,-2.52	0.3,0.8	0.1,0.0	0.4,-1.2	4.1,-2.2	0.0,0.0	0.0,0.0
6	-91.837	1.94,-0.02	0.3,0.8	0.1,0.0	0.4,-1.2	1.2,0.3	0.0,0.0	0.0,0.0
7	-91.607	6.98,-1.76	0.3,0.8	0.1,0.0	0.4,-1.2	6.2,-1.4	0.0,0.0	0.0,0.0
8	-91.373	-0.16,-1.80	0.3,0.8	0.2,0.0	0.4,-1.2	-0.9,-1.5	0.0,0.0	0.0,0.0
9	-91.140	-1.61,1.53	0.3,0.8	0.2,0.0	0.4,-1.1	-2.4,1.8	0.0,0.0	0.0,0.0
10	-90.907	9.71,-1.25	0.3,0.8	0.2,0.0	0.4,-1.1	9.0,-1.0	0.0,0.0	0.0,0.0
11	-90.674	-3.28,0.65	0.3,0.8	0.2,0.0	0.4,-1.1	-4.0,0.9	0.0,0.0	0.0,0.0
12	-90.440	-8.16,0.73	0.3,0.9	0.2,0.1	0.4,-1.1	-8.9,1.0	0.0,0.0	0.0,0.0
13	-90.209	-7.26,-0.33	0.4,0.9	0.2,0.1	0.4,-1.1	-8.0,-0.1	0.0,0.0	0.0,0.0
14	-89.976	6.01,-0.65	0.4,0.9	0.2,0.1	0.4,-1.1	5.2,-0.4	0.0,0.0	0.0,0.0
15	-89.742	-3.25,-0.75	0.4,0.9	0.2,0.1	0.4,-1.1	-4.0,-0.5	0.0,0.0	0.0,0.0
16	-89.510	-2.01,0.93	0.4,0.9	0.3,0.1	0.4,-1.1	-2.8,1.2	0.0,0.0	0.0,0.0
17	-89.275	10.51,0.08	0.4,0.9	0.3,0.1	0.4,-1.1	9.7,0.3	0.0,0.0	0.0,0.0
18	-89.045	3.46,0.35	0.4,0.9	0.3,0.1	0.4,-1.1	2.7,0.6	0.0,0.0	0.0,0.0
19	-88.811	-9.57,0.11	0.4,0.9	0.3,0.1	0.4,-1.1	-10.4,0.3	0.0,0.0	0.0,0.0
20	-88.578	-5.72,1.60	0.4,0.9	0.3,0.1	0.4,-1.1	-6.5,1.8	0.0,0.0	0.0,0.0
21	-88.346	3.41,-1.78	0.4,0.9	0.3,0.1	0.4,-1.1	2.6,-1.6	0.0,0.0	0.0,0.0
22	-88.113	-1.86,-0.52	0.4,0.9	0.3,0.1	0.5,-1.1	-2.7,-0.3	0.0,0.0	0.0,0.0
23	-87.880	8.29,-0.64	0.4,0.9	0.3,0.1	0.5,-1.1	7.5,-0.5	0.0,0.0	0.0,0.0
24	-87.647	-3.22,-2.33	0.4,0.9	0.3,0.1	0.5,-1.1	-4.1,-2.1	0.0,0.0	0.0,0.0
25	-87.415	2.15,1.49	0.4,0.9	0.3,0.1	0.5,-1.1	1.3,1.7	0.0,0.0	0.0,0.0
26	-87.182	5.74,0.93	0.4,0.9	0.3,0.1	0.5,-1.1	4.9,1.1	0.0,0.0	0.0,0.0
27	-86.950	5.37,-2.45	0.4,0.9	0.3,0.1	0.5,-1.1	4.5,-2.3	0.0,0.0	0.0,0.0

Choose "use temperature"

Use temperature(recommend)

Encoders Reference Shift Metrology Shift

Maximize Reconstruction Volume

Export Total Shifts Import Stage Shifts Select/Deselect images... Import Source Drift .txrm File and Apply

Pixels of thermal movements

Advanced Topics



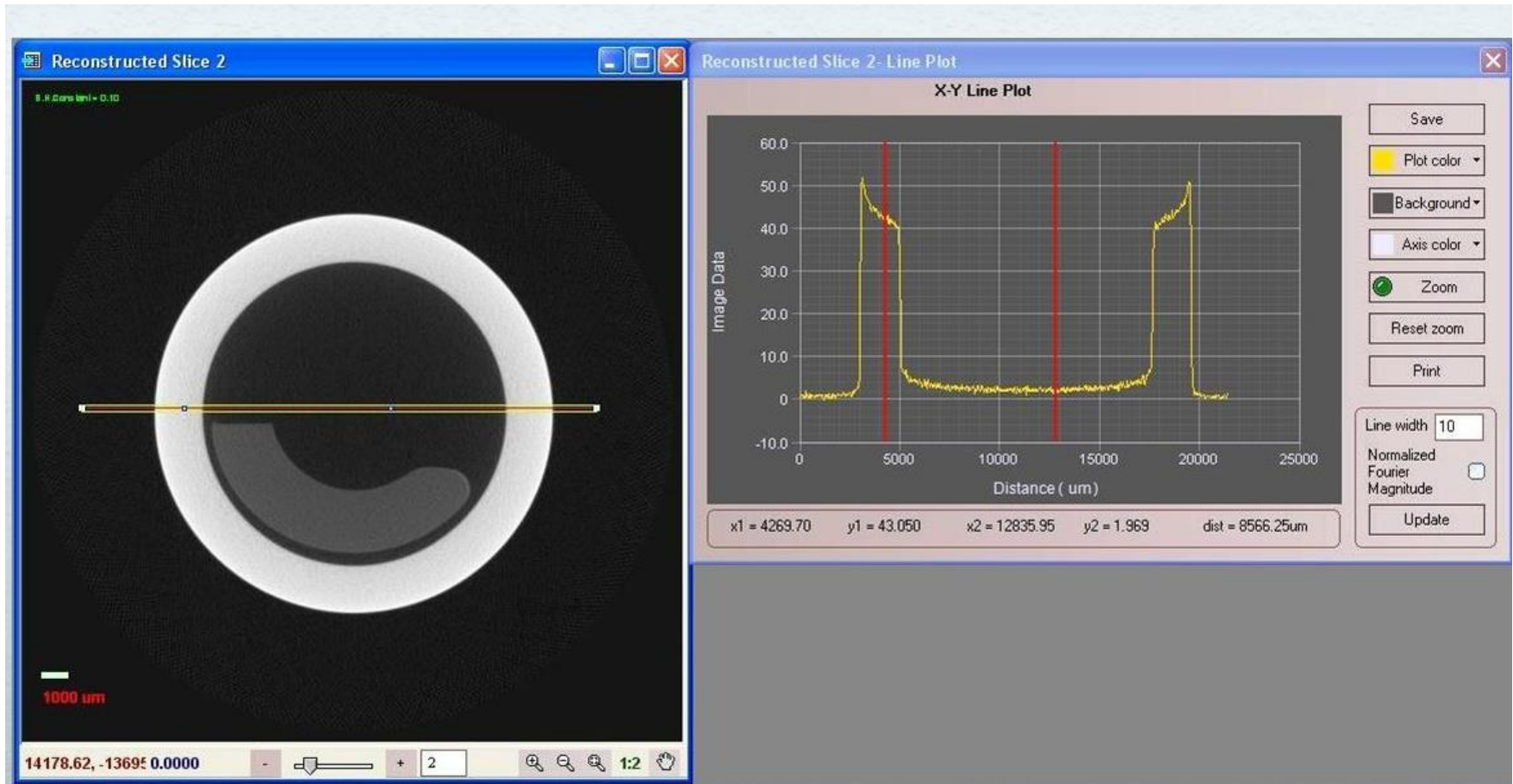
- ▣ Sample Preparation/Mounting
- ▣ Reference Image and Multiple Reference
- ▣ Geometric Magnification
- ▣ Sample size Vs. Resolution
- ▣ High Resolution Imaging Considerations
- ▣ Beam Hardening
- ▣ Variable Exposure
- ▣ Vertical Stitching
- ▣ Filtered Secondary Reference
- ▣ Misc. Software Options (XMController and XMReconstructor)
- ▣ Phase Contrast
- ▣ Scout and Zoom

- ❑ Beam hardening is the phenomenon that a X-ray beam with broad energy spectrum has variable penetrating power as it goes through materials (the beam becomes harder).

- ❑ Source
 - Polychromatic X-ray Spectrum
 - Sample: variance in material thickness in X-ray path
 - Variation in source window, source filter, and detectors.

- ❑ Beam hardening results in non-uniform intensity signals in reconstructed views (cupping artifact is most common)

Example of Beam Hardening

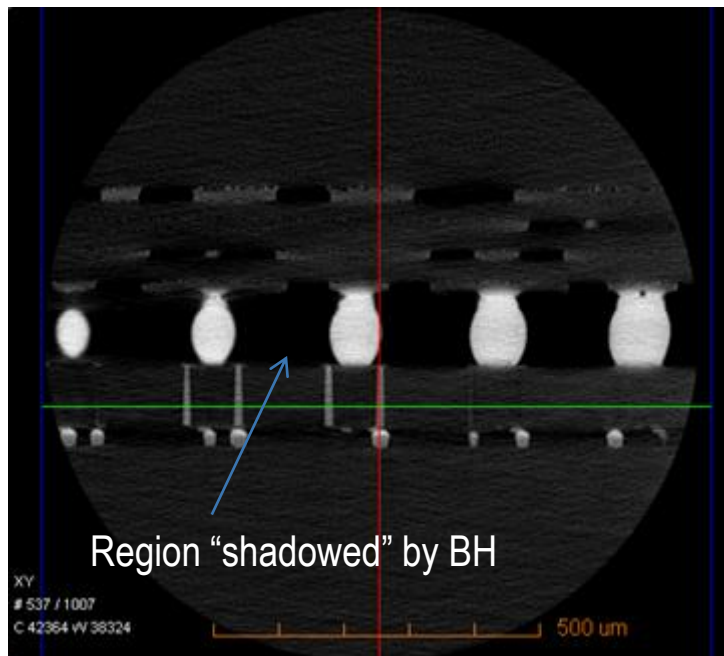
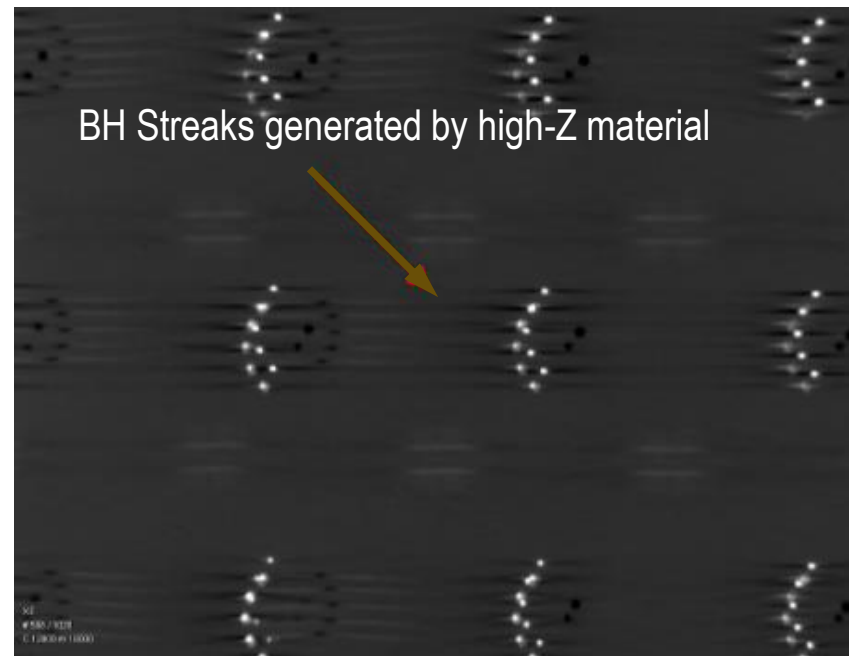


Attenuation varies by the change of material thickness/density.

Challenges to Image Low-Z Materials



- ❑ Beam Hardening (BH) creates artifacts making it difficult to identify low-Z material near high-Z materials (ex. hard to see details of Si or under fill material near Au wires, solder balls and bumps in semi packages)



Challenges to Image Low-Z Materials



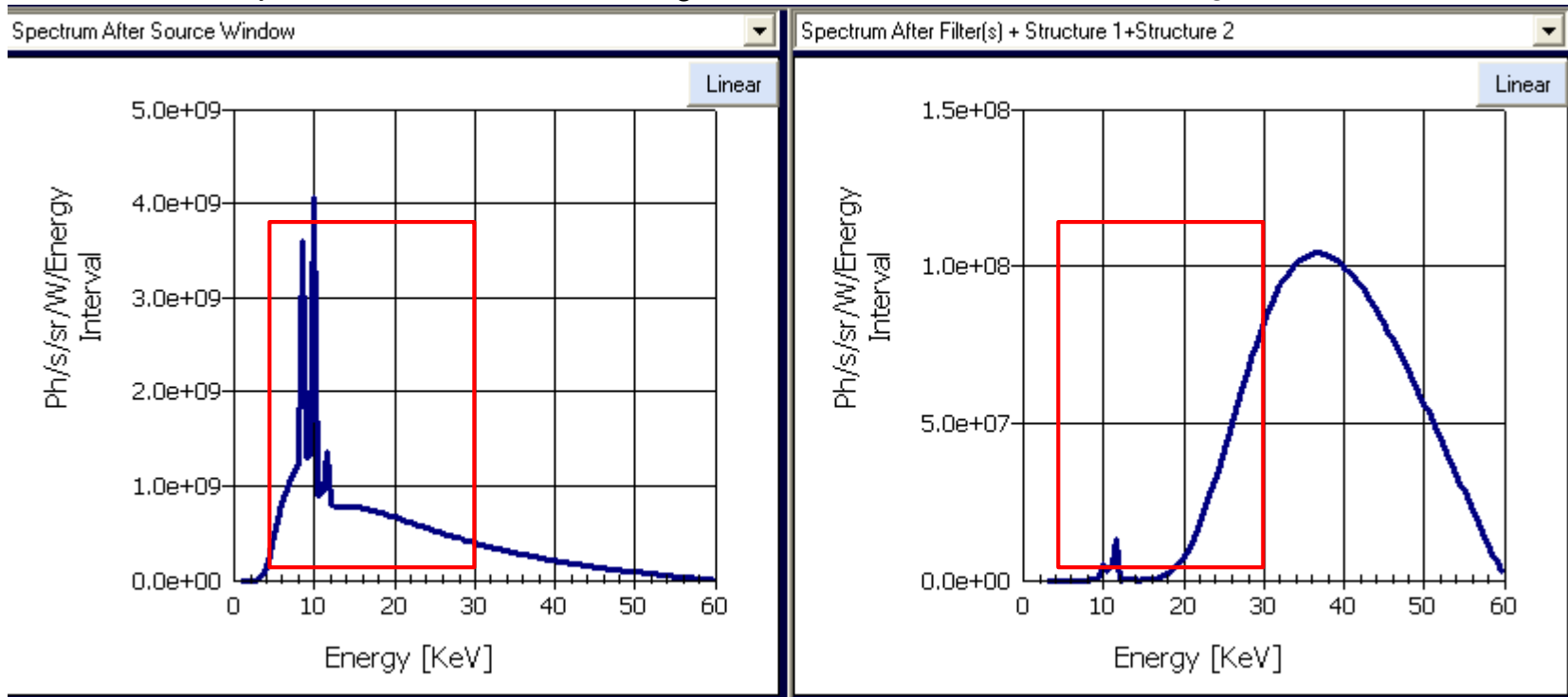
- ❑ To obtain information from images, it is required to achieve good contrast information about the sample.
- ❑ Low Z materials (Si, epoxy, organics, etc.) will only provide contrast if absorption differences is detected with low energy X-ray photons.
- ❑ When imaging through High Z material (Au, Solder, etc.) there are very few low energy photons available, thus making it very difficult to see clear features.
- ❑ The next few slides shows examples of x-ray spectrum and imaging low Z material surrounded by high Z material, which will illustrate the issue more clearly.

Alteration of Spectrum



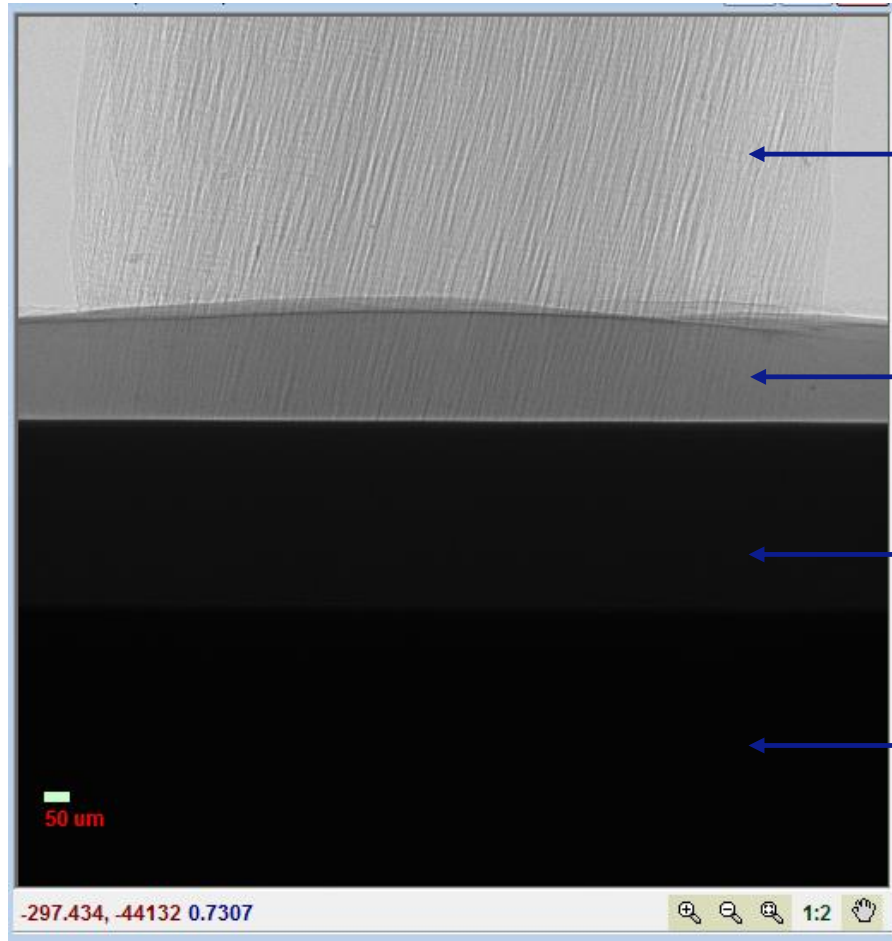
Raw Spectrum with 60 kV setting

Spectrum after 2 mm glass and 30 μm Au



- ❑ 60 kV; 2 mm Si and 30 μm Au (simulated as a filter); The spectrum shifts toward high-energy portion significantly after the beam goes through the filter.
- ❑ The red box indicates the low-energy photons which are needed for obtaining contrast in low-Z materials. After “filtering”, these photons are very limited.

High Attenuation



← Toothpick

← Toothpick + Rubber

← Toothpick + Rubber
+ 1 layer of steel

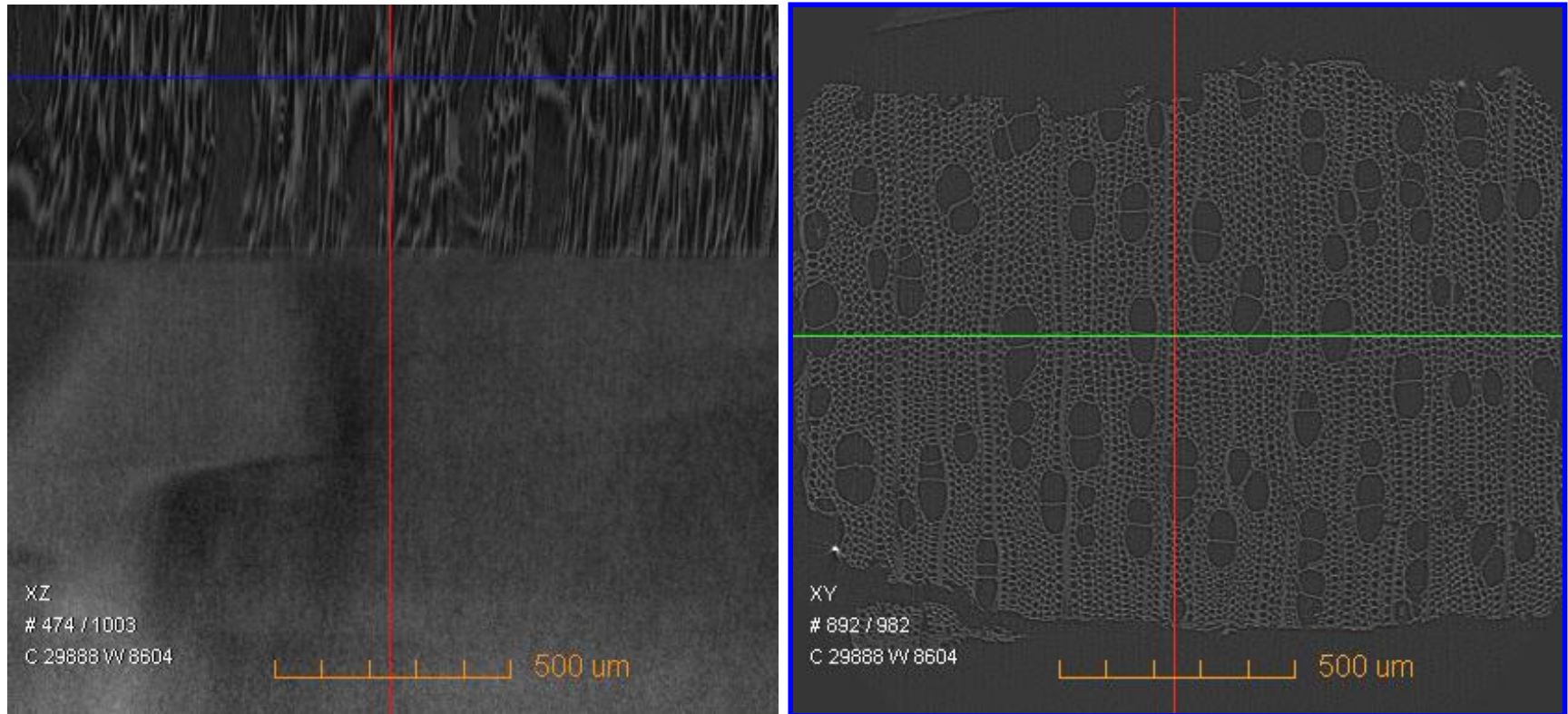
← Toothpick +
Rubber + 2 layers
of steel

Low photo energy needed to resolve soft materials are attenuated by dense materials.

3D Views (toothpick + 50 μm Au)



The sample: a piece of toothpick wrapped with 50 μm Au sheet. 120 kV/10w; 10X; 1.95 μm pixel

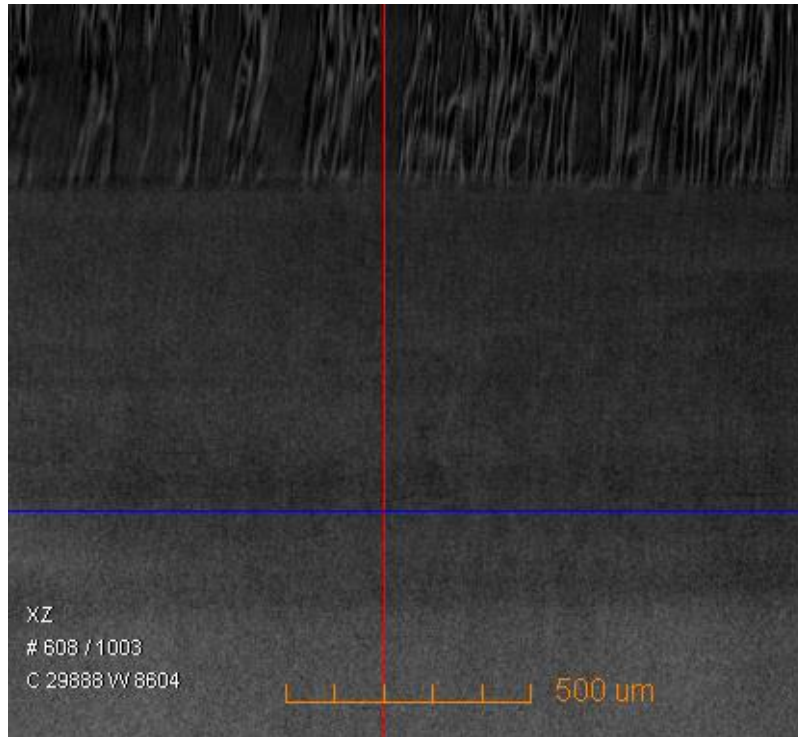
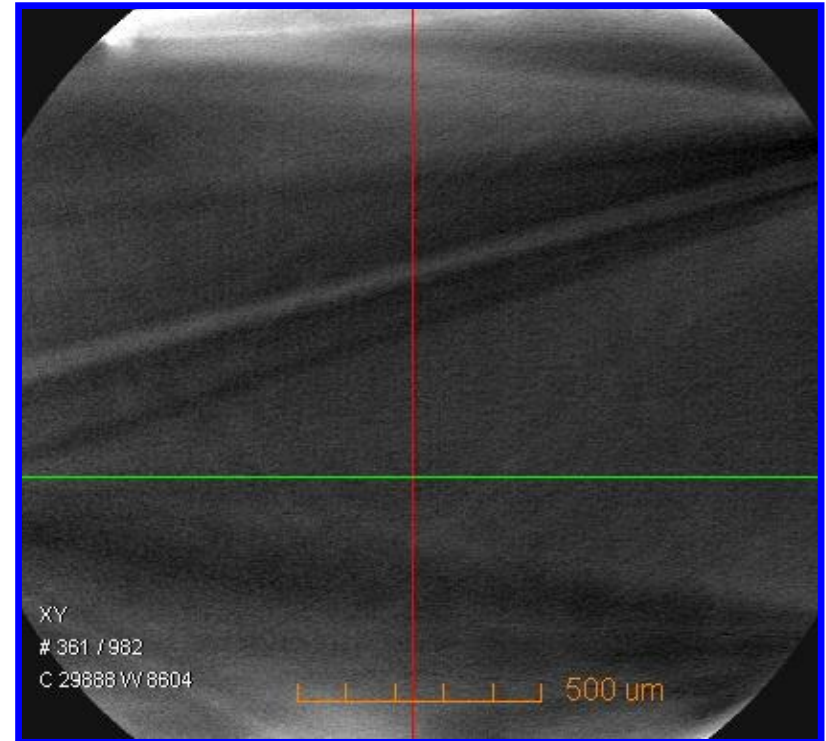


The cross-section (the right image) of the blue line on the left shows that the network structure is clearly imaged because of no significant beam hardening effect on the top slices.

3D Views (toothpick + 50 μm Au)



The same scan as the last page:



The cross-section (the right image) of the blue line on the left shows that the network structure is not visible because of the significant beam hardening effect on the bottom slices, where the Au is present. The Au is acting as a filter preventing the low energy photons from providing any contrast in the wood

Beam Hardening Summary



- ❑ Beam hardening is a physical phenomenon induced by polychromatic X-ray irradiation.
- ❑ ZEISS XRM developed three techniques to reduce beam hardening artifacts: source filters, software correction, and secondary referencing.
- ❑ Beam hardening can be largely corrected by these techniques.
- ❑ Challenges to correct beam hardening exist in the case that low-Z materials are nearby or surrounded by highly absorbing materials.

Advanced Topics

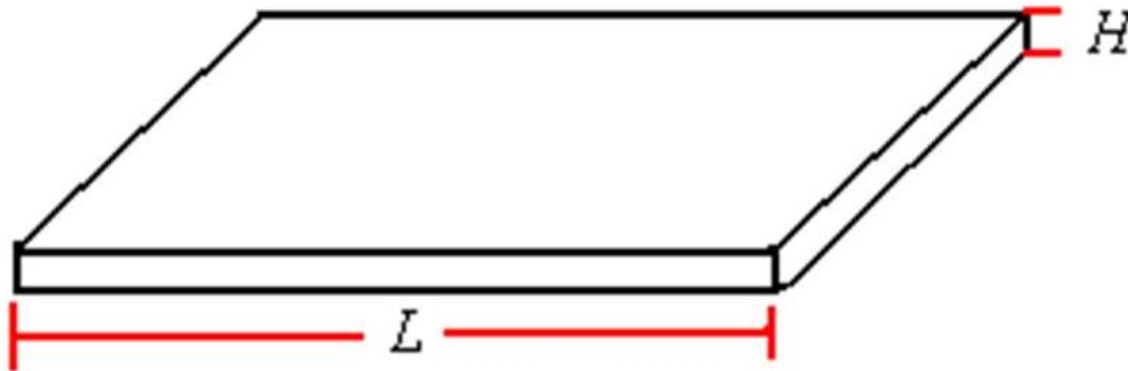


- ▣ Sample Preparation/Mounting
- ▣ Reference Image and Multiple Reference
- ▣ Geometric Magnification
- ▣ Sample size Vs. Resolution
- ▣ High Resolution Imaging Considerations
- ▣ Beam Hardening
- ▣ Variable Exposure
- ▣ Vertical Stitching
- ▣ Filtered Secondary Reference
- ▣ Misc. Software Options (XMController and XMReconstructor)
- ▣ Phase Contrast
- ▣ Scout and Zoom

Variable Exposure



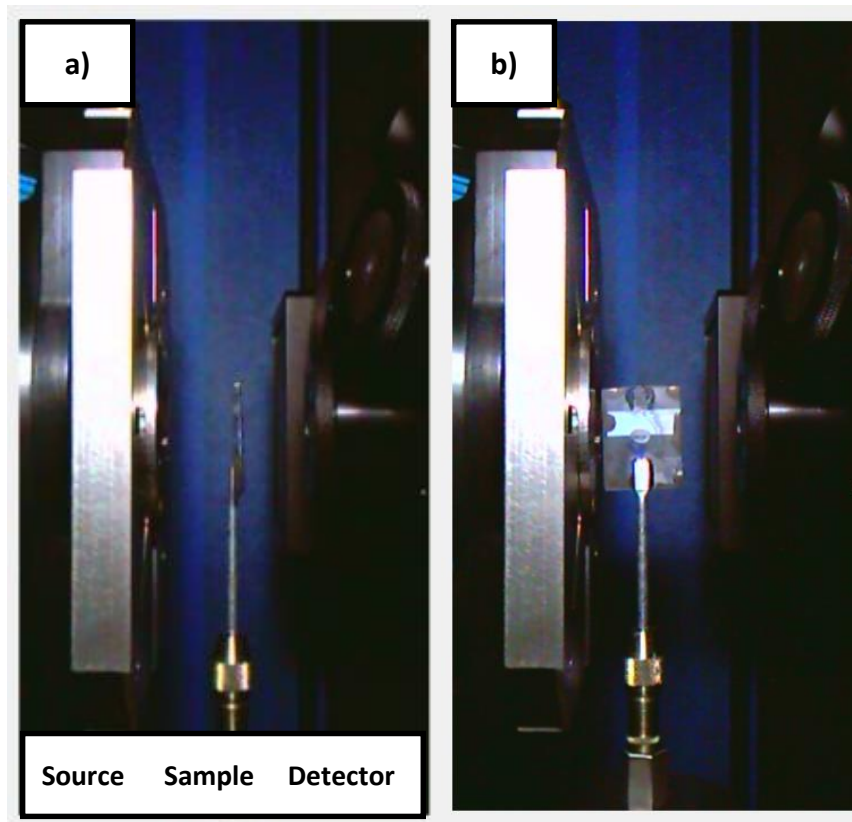
- ❑ Applicable to samples with high aspect ratios, i.e. Semiconductor packages or flat sample types
- ❑ Increases exposure time at Sample theta = +/- 90 degree.
 - Allows for longer acquisition time through thicker parts of the sample. Helps to increase signal for better reconstruction accuracy and reduces photo starvation effects.



Sample Mounting



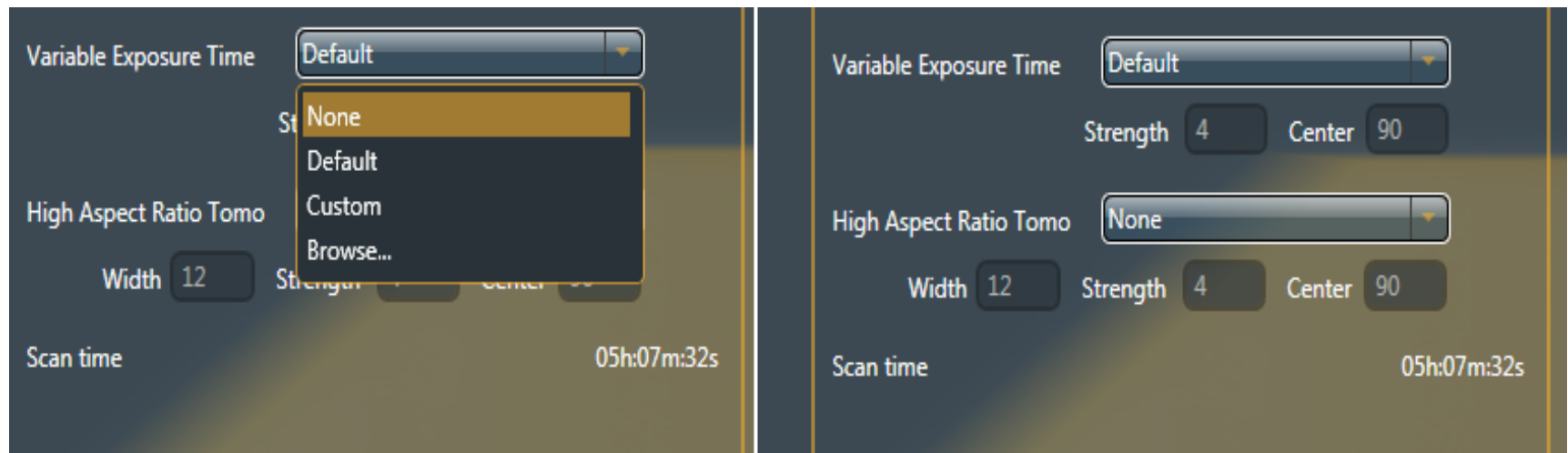
- ❑ It is required to mount the sample facing source or detector; the short views are at 0 degree (a) and long views at ± 90 degree (b).



Select Time factor Table



- Select one of four options in “Variable Exposure Time” in Scan Page.
 - None (the Default option) - equal exposure time tomography
 - Default – Strength 4 (scaling factor), Center 90 (long view angle).
Note: This setting is good starting point for imaging new sample; Center angle being 90 means that two long view regions at 90 and -90 degrees are selected.
 - Customer – allows user to enter non-default parameters.
 - Browse – allows user to load an existing variable time table.



Advanced Topics

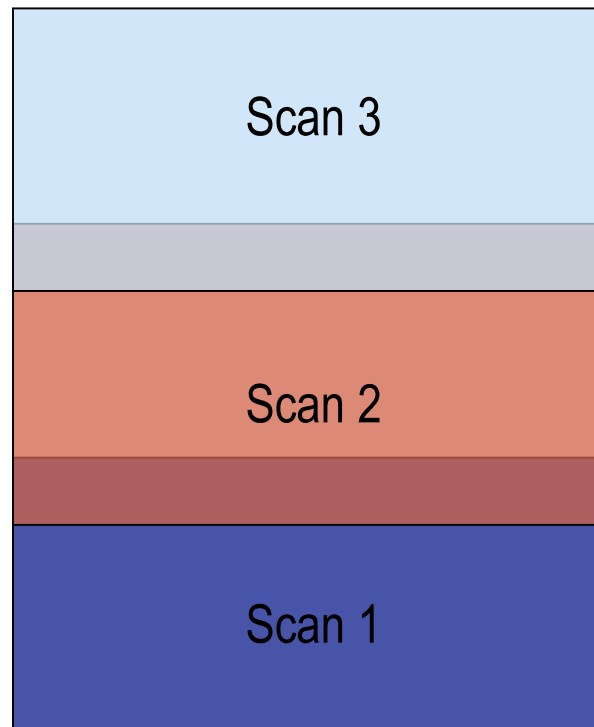


- Sample Preparation/Mounting
- Reference Image and Multiple Reference
- Geometric Magnification
- Sample size Vs. Resolution
- High Resolution Imaging Considerations
- Beam Hardening
- Variable Exposure
- Vertical Stitching
- Filtered Secondary Reference
- Misc. Software Options (XMController and XMReconstructor)
- Phase Contrast
- Scout and Zoom

Vertical Stitching



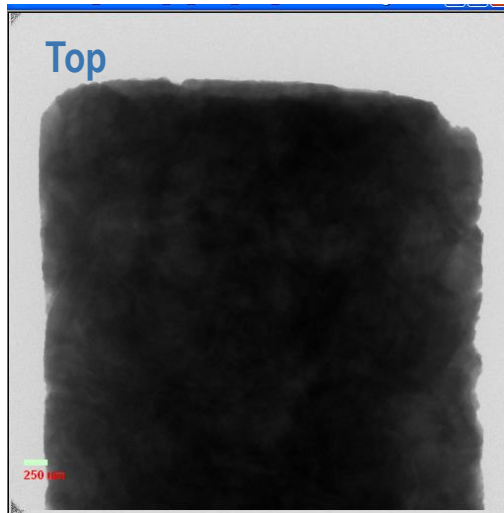
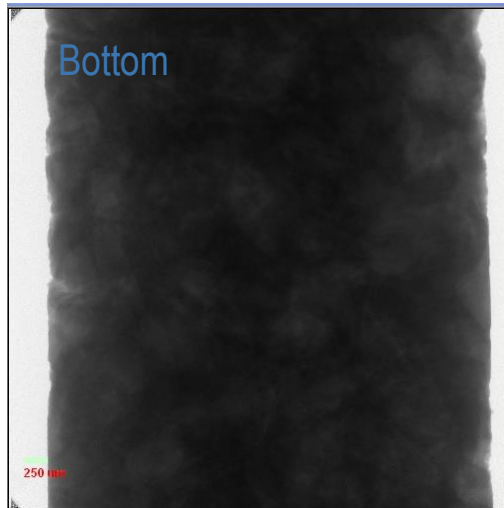
- ❑ Vertical Stitching Plugin
 - Plugin Stitch (Auto Stitch)
- ❑ Allows for larger Field of View along the vertical axis



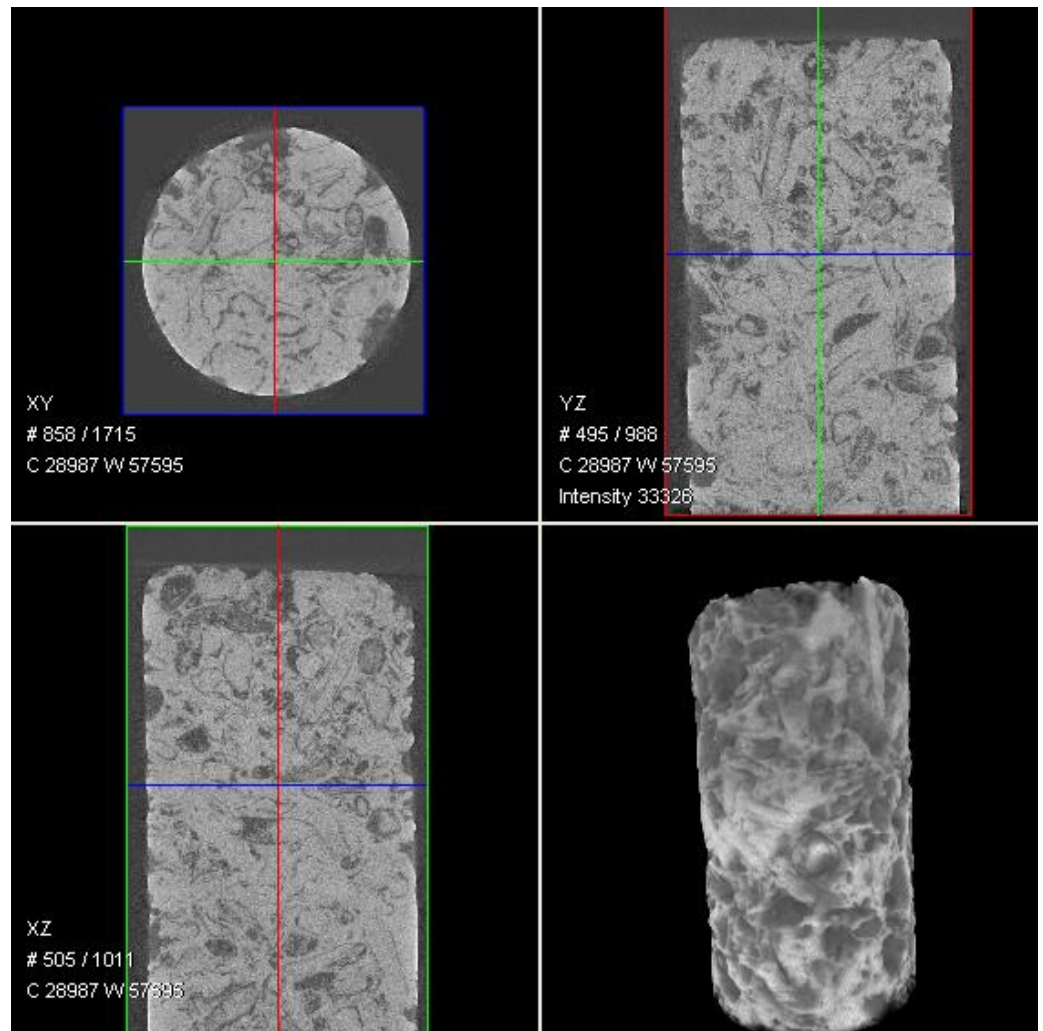
Vertical Stitching



2D Projections



3D Imaging Results



Advanced Topics

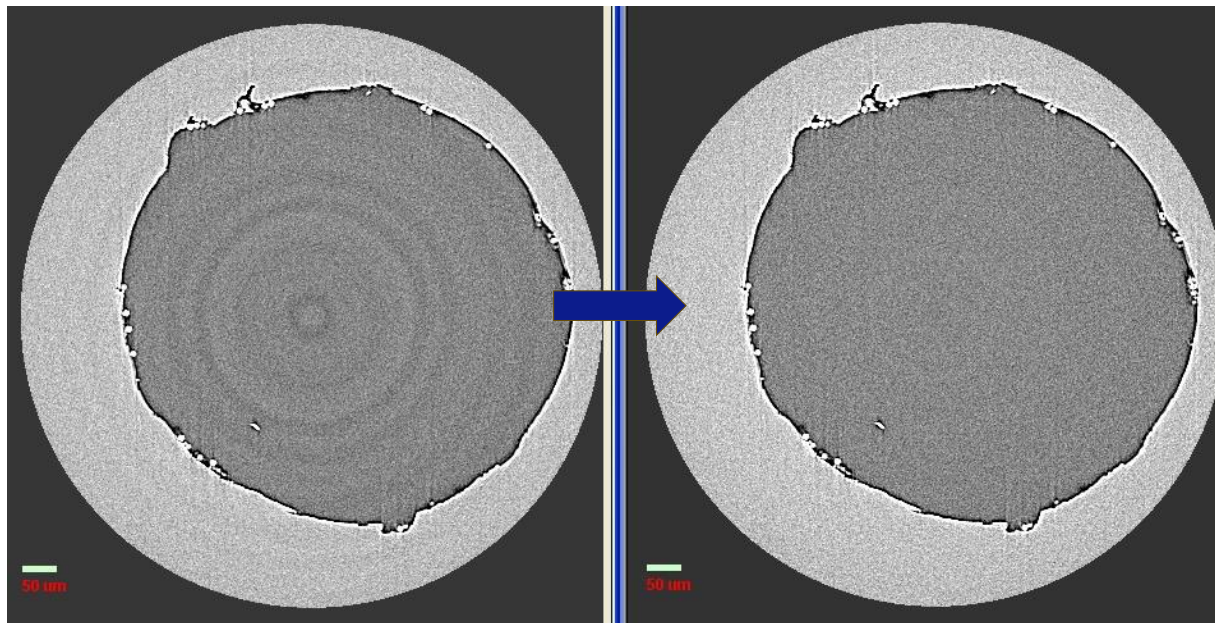


- Sample Preparation/Mounting
- Reference Image and Multiple Reference
- Geometric Magnification
- Sample size Vs. Resolution
- High Resolution Imaging Considerations
- Beam Hardening
- Variable Exposure
- Vertical Stitching
- Filtered Secondary Reference
- Misc. Software Options (XMController and XMReconstructor)
- Phase Contrast
- Scout and Zoom

Filtered Secondary Reference



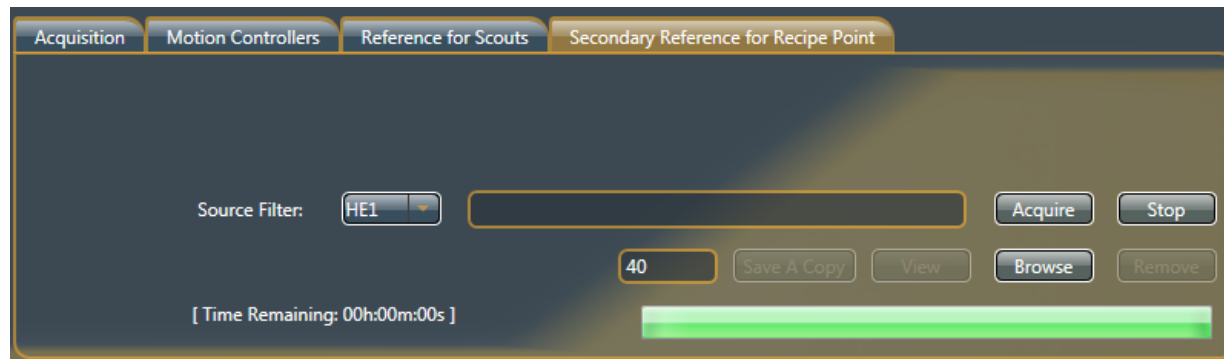
- ❑ When an air reference image contains different BH than the actual sample image, the result will often show up as “diffuse ring” artifacts in the reconstructed data.
- ❑ This phenomenon is most prominent in low attenuating and uniform materials.



Filtered Secondary Reference



- Collect 2nd reference before tomography:
 - Make sure that objective, source filter, energy/power, source/detector positions and exposure time are set. Normally, 2nd reference is the last step in the Scout Page
 - Determine typical counts in the Scout Image
 - Select a filter which provides similar counts (+/- ~20%) with the same exposure time
 - Collect a new “filtered reference” image.



- The 2nd reference image will be automatically saved and applied to the tomography (do not need to apply it with Reconstructor).

Filtered Secondary Reference



- Collect 2nd reference after tomography:
 - Reconstruct .txrm before moving source and detector assembly
 - If diffuse rings are present, a filtered secondary reference is advisable.
 - Select a filter which provides similar counts (+/- ~20%) with the same time
 - Collect a new “filtered reference” image.
 - Apply this new reference in XMReconstructor.

- Refer to technical procedure for detailed explanation

Advanced Topics



- ▣ Sample Preparation/Mounting
- ▣ Reference Image and Multiple Reference
- ▣ Geometric Magnification
- ▣ Sample size Vs. Resolution
- ▣ High Resolution Imaging Considerations
- ▣ Beam Hardening
- ▣ Variable Exposure
- ▣ Vertical Stitching
- ▣ Filtered Secondary Reference
- ▣ Misc. Software Options (XMController and XMReconstructor)
- ▣ Phase Contrast
- ▣ Scout and Zoom

Advanced Software Options



☐ XMController

- Config System (Reference axis, sample drift)
- Image Control/Reference
- 2D/3D Filters
- De-speckle
- Cropping
- Flip and Rotation
- Write to other planes
- Export: tiff, tif, jpeg, bmp, binary

☐ Reconstruction: Rotation, Crop, Filter

☐ 3D View: Binary filter

Advanced Topics

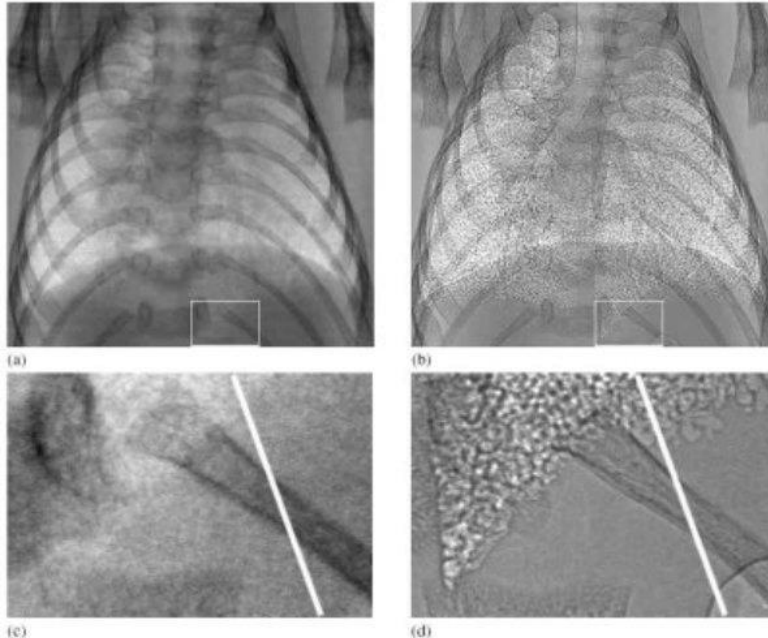


- ▣ Sample Preparation/Mounting
- ▣ Reference Image and Multiple Reference
- ▣ Geometric Magnification
- ▣ Sample size Vs. Resolution
- ▣ High Resolution Imaging Considerations
- ▣ Beam Hardening
- ▣ Variable Exposure
- ▣ Vertical Stitching
- ▣ Filtered Secondary Reference
- ▣ Misc. Software Options (XMController and XMReconstructor)
- ▣ Phase Contrast
- ▣ Scout and Zoom

Phase Contrast Imaging



- ❑ Materials each have x-ray refraction indices that cause the X-ray to bend and phase shift
- ❑ Phase shifted waves interfere with un-shifted waves at the detector
- ❑ Phase information retrieved from detector interference patterns to highlight interfaces & show contrast due to electron density



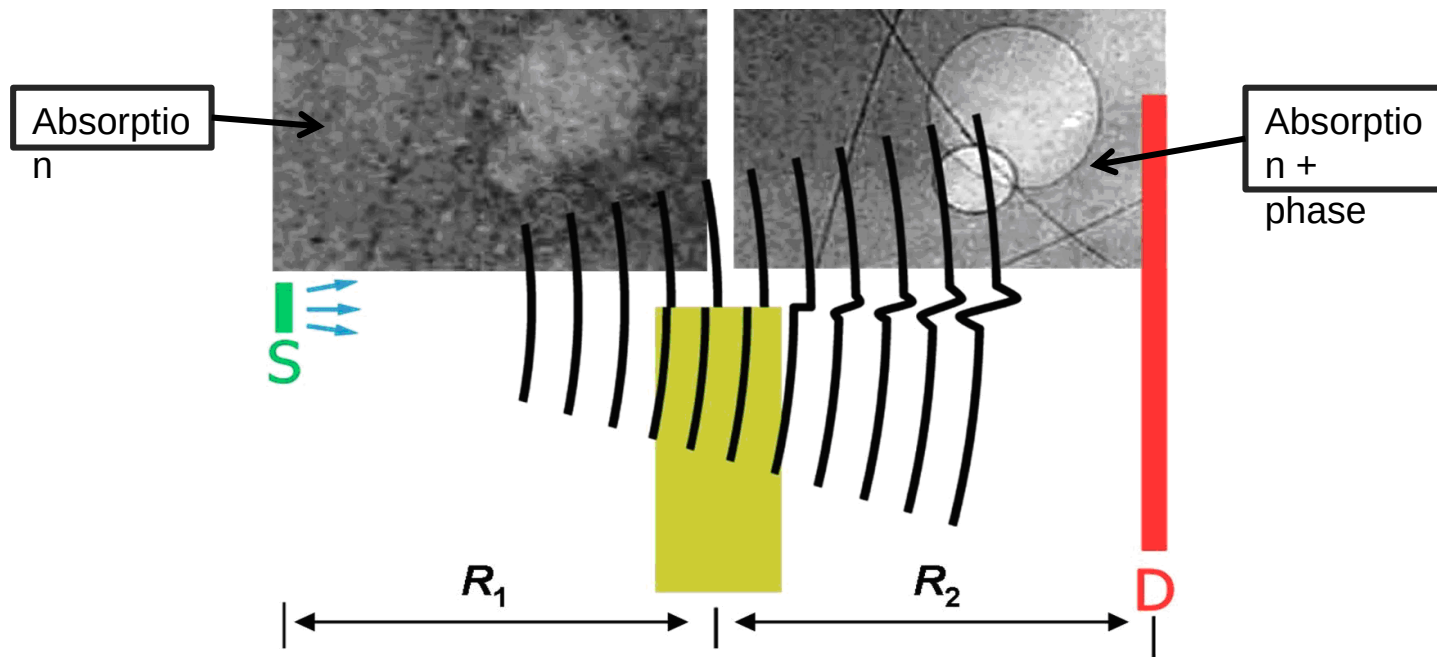
Propagation phase contrast
performed at SPring-8 (Japan)
synchrotron of newborn rabbit
pup

(a) Absorption-based imaging
does not show lung details
(b) Propagation contrast +
absorption details lungs

Xradia 520 Versa: Propagation-based Phase Contrast



- ❑ Several phase contrast techniques
- ❑ **Propagation-based phase** contrast is implemented in Xradia 520 Versa and optimizes source-to-sample (R_1) and sample-to-detector (R_2) distances to maximize phase differences (interference pattern recorded)



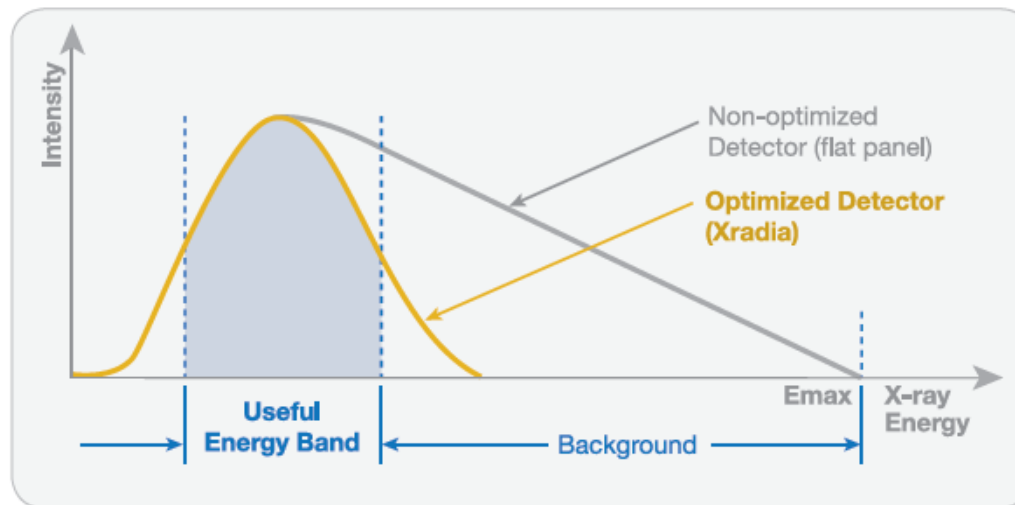
Xradia 520 Versa: Detector Design for Phase Contrast



Phase Enhanced Detector

- ❑ Refractive index is proportional to wavelength: lower energy X-rays offer higher phase contrast
- ❑ Phase Enhanced detectors optimize capture of low energy X-rays

Optimized Spectral Detection



An optimized detector maximizes sensitivity to the band in the X-ray spectrum most sensitive to absorption changes in the sample (useful energy band) and minimizes the capture of higher energy X-ray photons that do not carry a signal (background). Most general purpose, non-optimized detectors such as flat panels are configured to detect a wide range of X-ray spectra and therefore capture significant background noise, reducing image contrast.

Xradia 520 Versa: Detector Design for Phase Contrast



Small Effective Detector Pixel Size

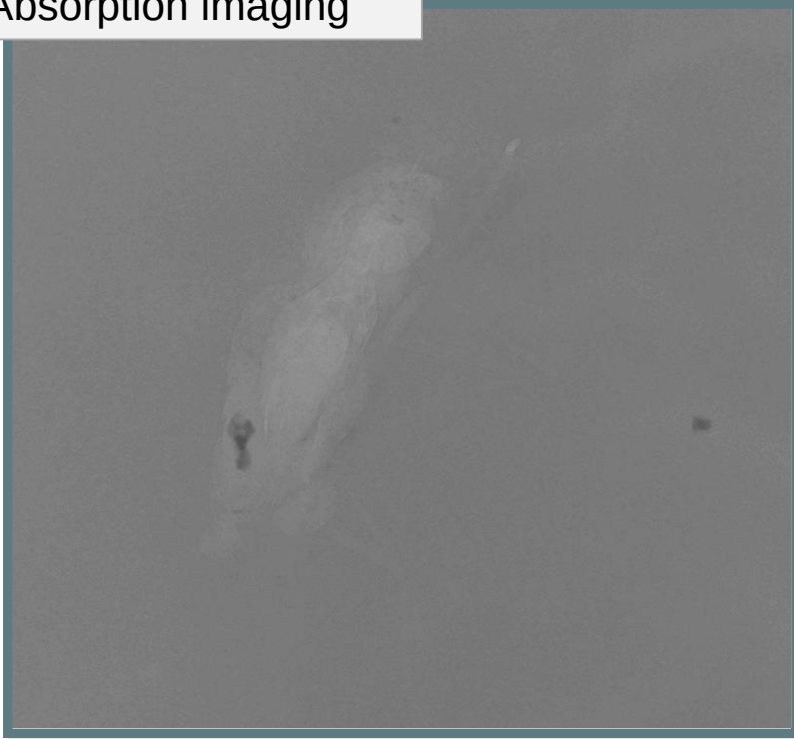
- ❑ Refraction of X-rays is very slight: angle on order of microradians
- ❑ Due to small angle of refraction, projection of phase interference is typically only a few microns on the detector screen (small detector pixels required)
 - Detector pixels larger than a few microns will average out phase interference with other signals, losing critical phase contrast information
 - ZEISS XRM smallest effective detector pixel sizes (down to $\sim 0.3 \mu\text{m}$)

Xradia 520 Versa: Phase Contrast Examples



- ❑ Xradia 520 Versa phase contrast **highlights fractures** & **enables low-Z** (and low delta-Z) **imaging**
- ❑ Fly in amber on ZEISS Xradia MicroXCT (Xradia Versa family)

Absorption imaging



Absorption + phase contrast imaging



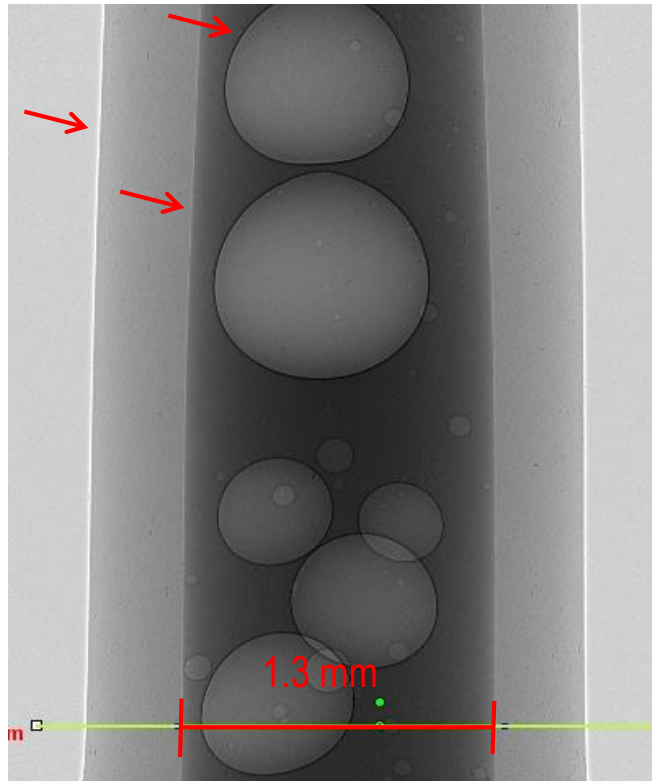
Courtesy: Andrew McNeil, University of Manchester

Phase contrast is edge-enhancing



- ❑ Phase contrast enhances high frequency component and shows up as edge-contrast overlaid in an absorption background.

Arrows point to phase fringes.



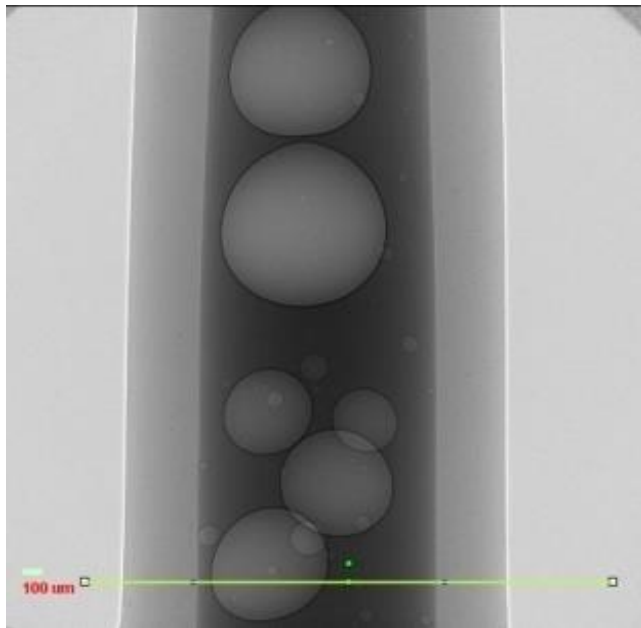
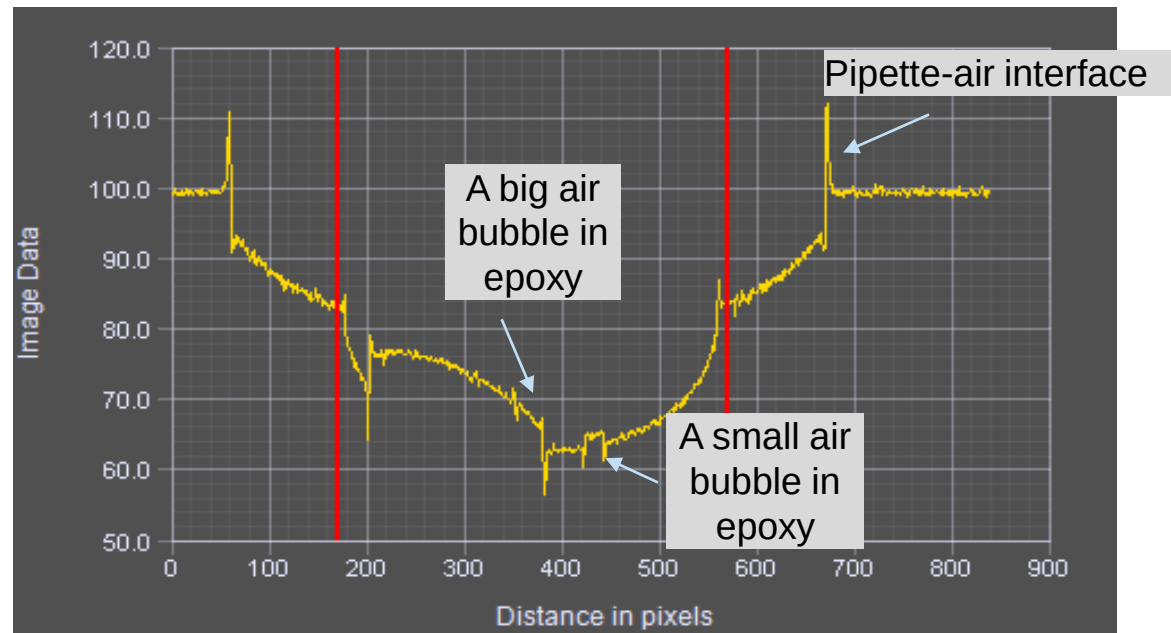
A pipette tip filled with epoxy and air bubbles.

src pos = det pos = 120mm,
4X lens, 40kV,
Exposure time = 1.5 min.

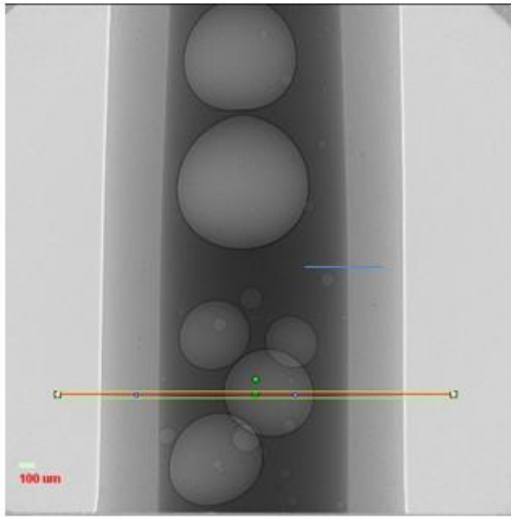
The shape of phase fringes



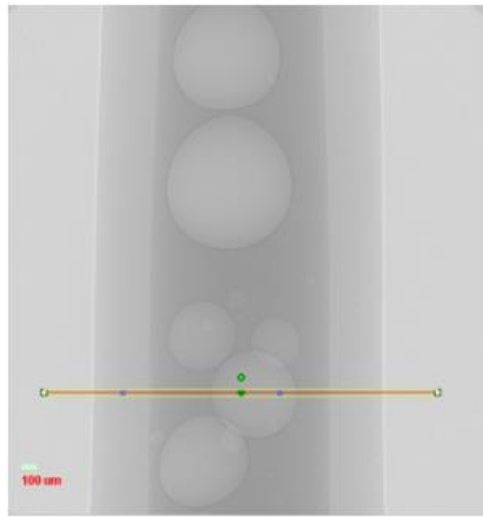
- ❑ The shapes of phase fringes in real data are similar to those produced by the computer simulation.



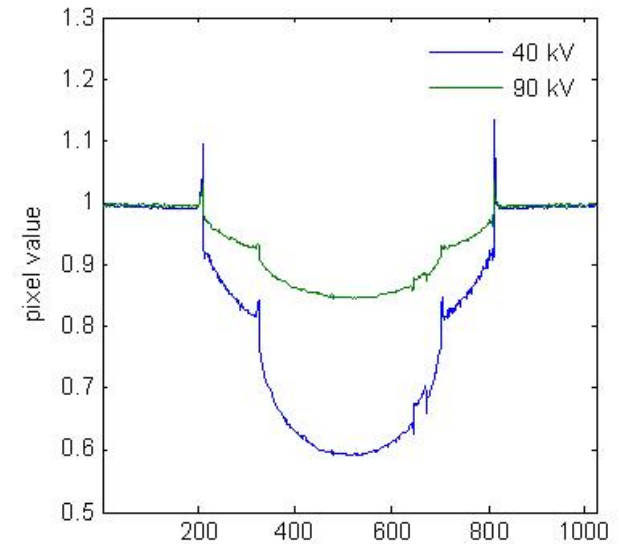
Effect of kV on Phase Contrast



(a) tube voltage = 40 kV



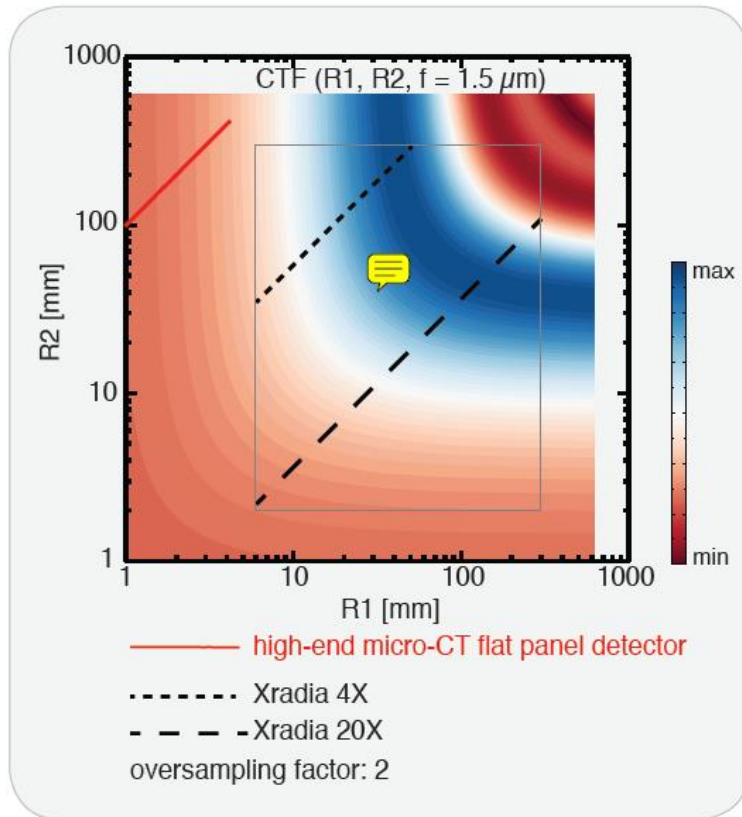
(b) tube voltage = 90 kV



(c) comparison of line profiles

- ❑ Higher kV decreases both phase and absorption contrast.
- ❑ In theory, phase contrast is proportional to $1/E^2$.

Source and Detector Distance



$$\text{phase contrast} \propto \frac{R_1 R_2}{R_1 + R_2}$$

Phase contrast as a function of source-object (R_1) and object-detector (R_2) distance. This plot assumes an ideal imaging system without any resolution degradation.

Advanced Topics

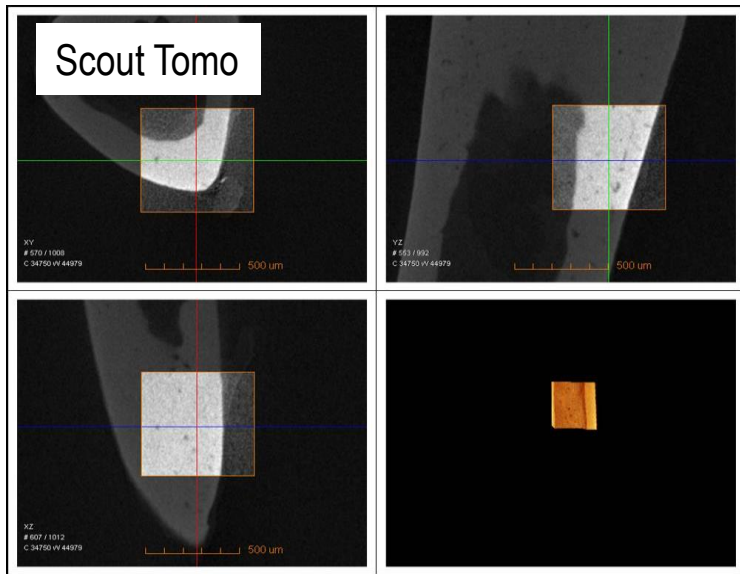
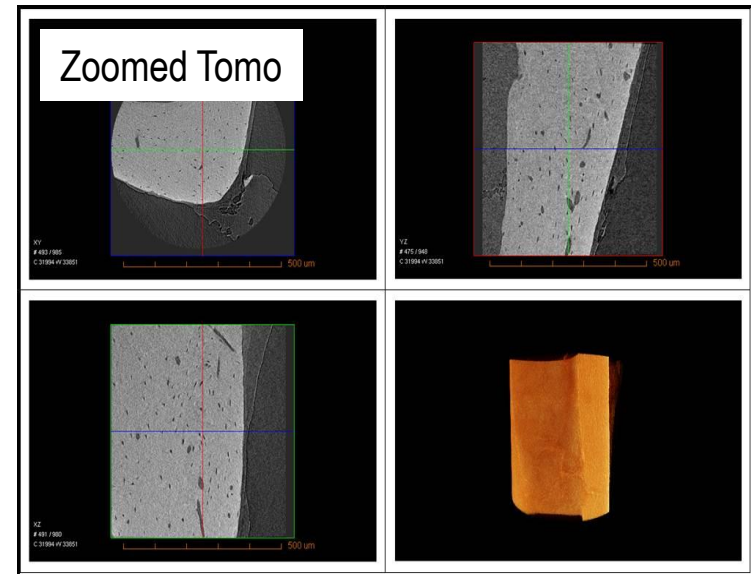
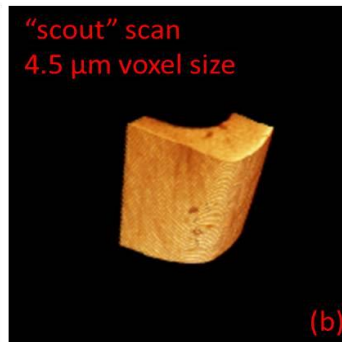


- ▣ Sample Preparation/Mounting
- ▣ Reference Image and Multiple Reference
- ▣ Geometric Magnification
- ▣ Sample size Vs. Resolution
- ▣ High Resolution Imaging Considerations
- ▣ Beam Hardening
- ▣ Variable Exposure
- ▣ Vertical Stitching
- ▣ Filtered Secondary Reference
- ▣ Misc. Software Options (XMController and XMReconstructor)
- ▣ Phase Contrast
- ▣ Scout and Zoom

Scout-and-Zoom



- ❑ Scout and Zoom functionality allows user to setup high resolution interior tomography of any user-defined area.



- ❑ Scout-and-Zoom is a technique to help precisely locate ROIs for high-res scans, based on the results of a quick low resolution scan.
- ❑ Many features and structures of interest are not easy to identify with 2D projections.
- ❑ Two-step procedures:
 - “Scout” step: perform a scout scan, a quick and low resolution tomography
 - “Zoom” step: examine the low-res data in XM3DViewer; identify the co-ordinates for centering a feature or ROI; use a calculator to determine the proper sample stage positions for the Zoom scan

Agenda



- 1 Basics of 3D X-Ray Imaging
- 2 Review of Basic Settings
- 3 Advanced Techniques and Settings
- 4 New Features of Xradia 520 Versa

Highlights of New Features



❑ **Wide Field Mode (Macro-70 and 4X)**

- Improve field of view with a same pixel size
- Improve resolution at same field of view

❑ **High Aspect Ratio Tomography (HART)**

- Better results for a same scan time
- Equivalent or better results for a shorter scan time

❑ **Dual Scan Contrast Visualizer (DSCoVer)**

- Enable sample imaging with two different X-ray spectra
- Provide flexible side-by-side tuning in material contrast of two distinct tomographies
- Allow compositional probing for features normally indistinguishable in a single scan.

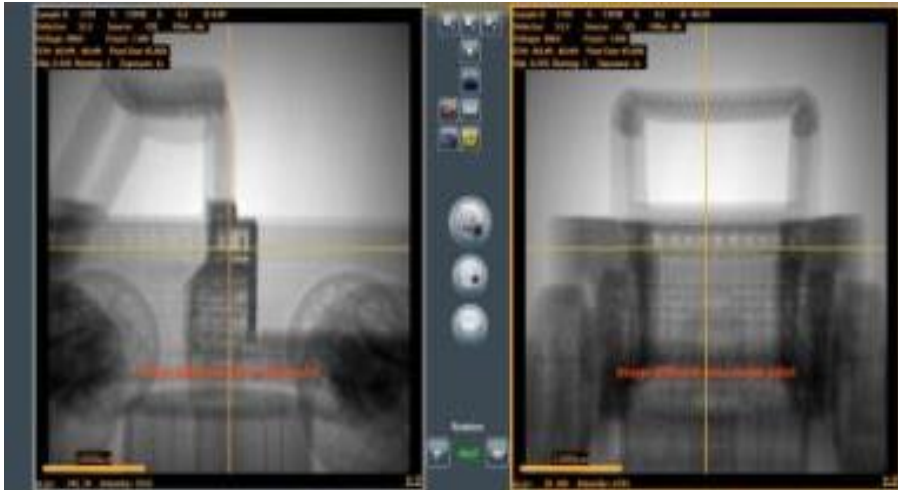
Wide Field Mode



❑ Wide Field Mode (Macro-70 and 4X)

- Run two tomographies at one tomo point. Software automatically stitches projections side-by-side at the end of data acquisition.
- The resulting image from the combined tomographies has a larger field of view.
- Enhance the maximum field of view up to ~ 85 mm. Normal field mode has the max. field of view ~ 50 mm)

NFM:



WFM:



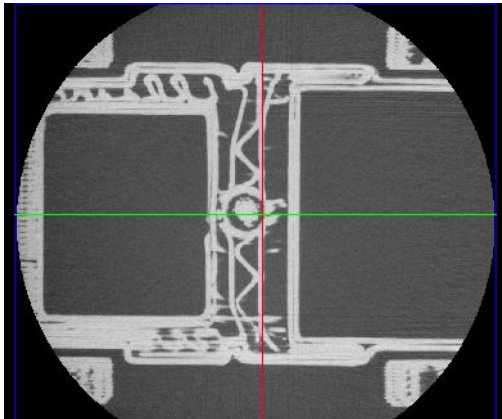
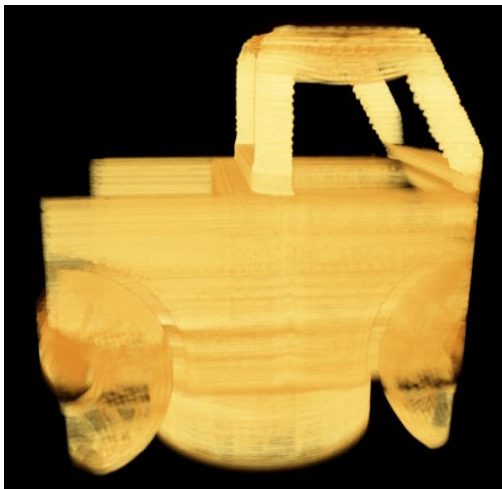
Note: Both 0.4X and 4X WFM are available for Xradia 520 Versa. Only 0.4X WFM is available for Xradia 410/510 Versa.

Wide Field Mode

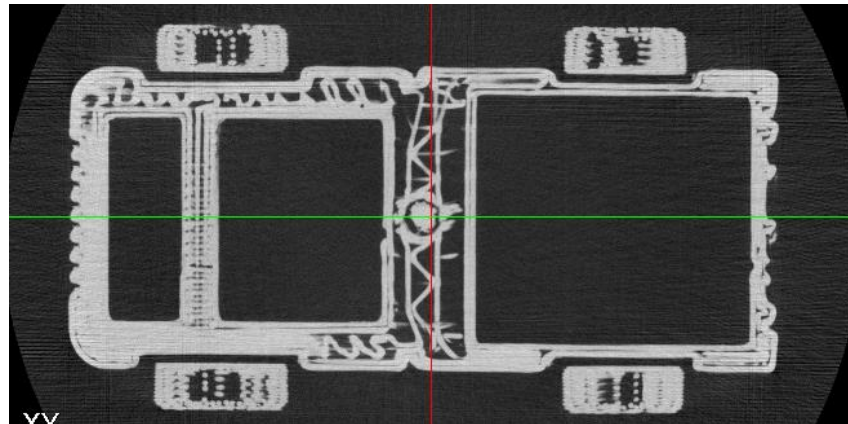


❑ Use Case I: FOV improvement with the same pixel size

NFM: 45 mm; 45 $\mu\text{m}/\text{vox}$



WFM: ~ 86 mm; 45 $\mu\text{m}/\text{vox}$

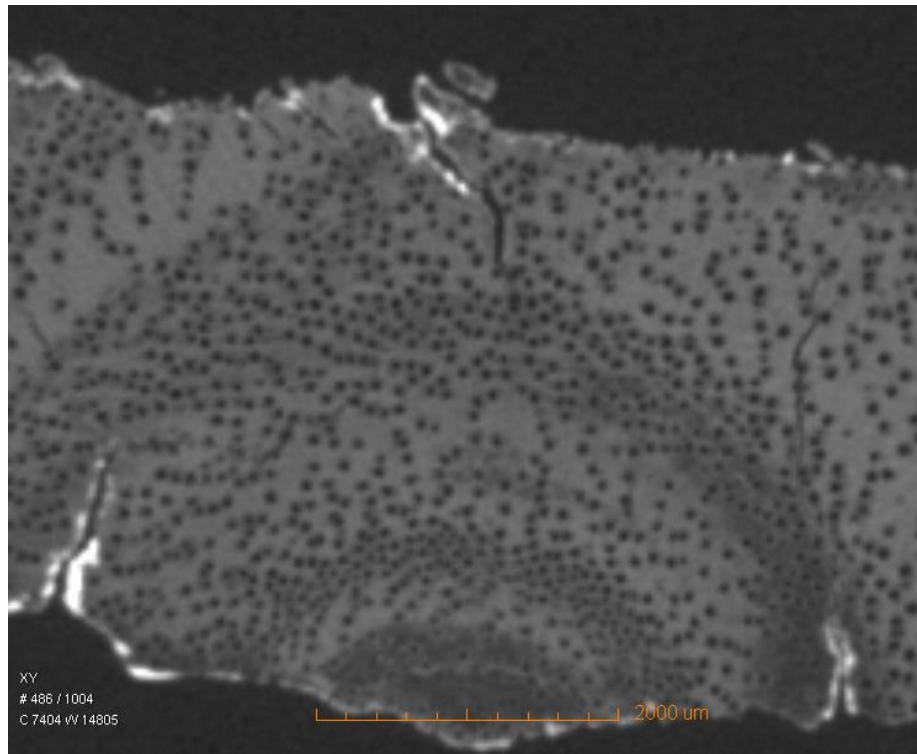


Wide Field Mode

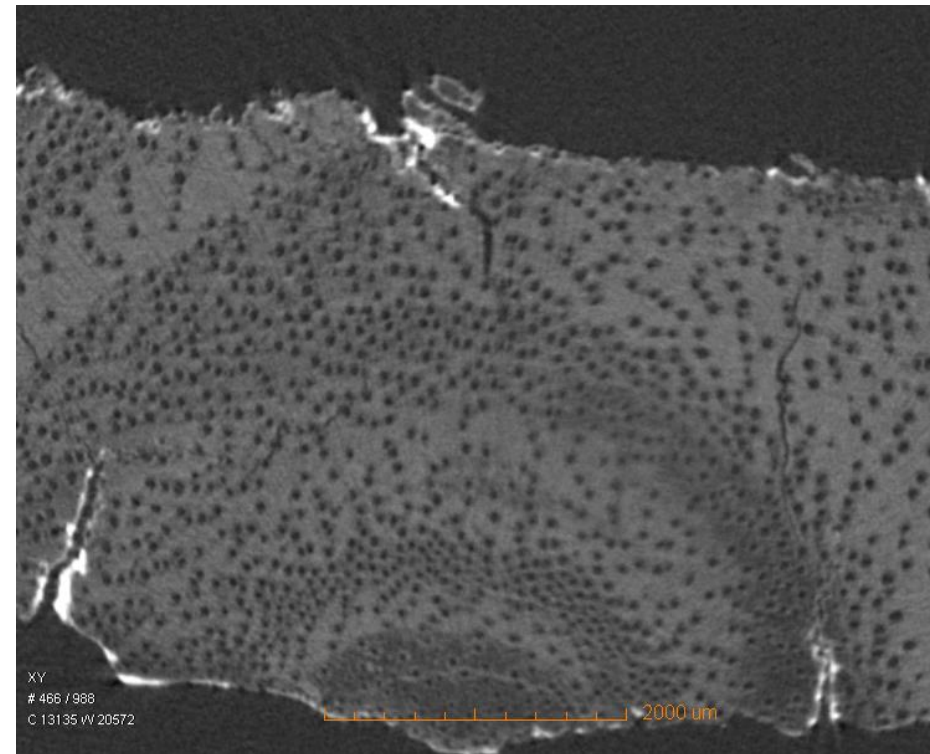


❑ Use Case II: Resolution improvement with the same FOV

NFM: 24.6 mm; 24.6 $\mu\text{m}/\text{vox}$

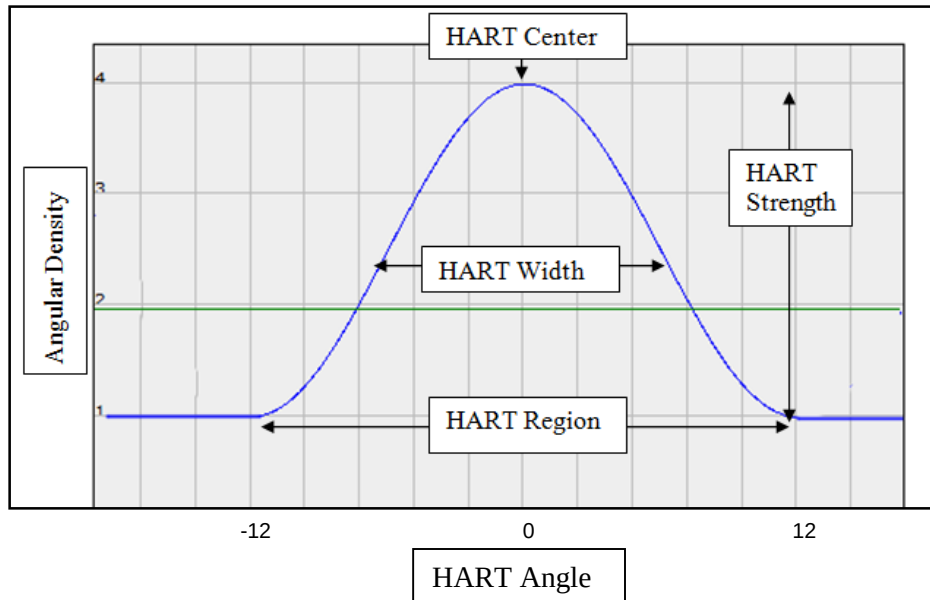


WFM: 24.6 mm; 12.9 $\mu\text{m}/\text{vox}$



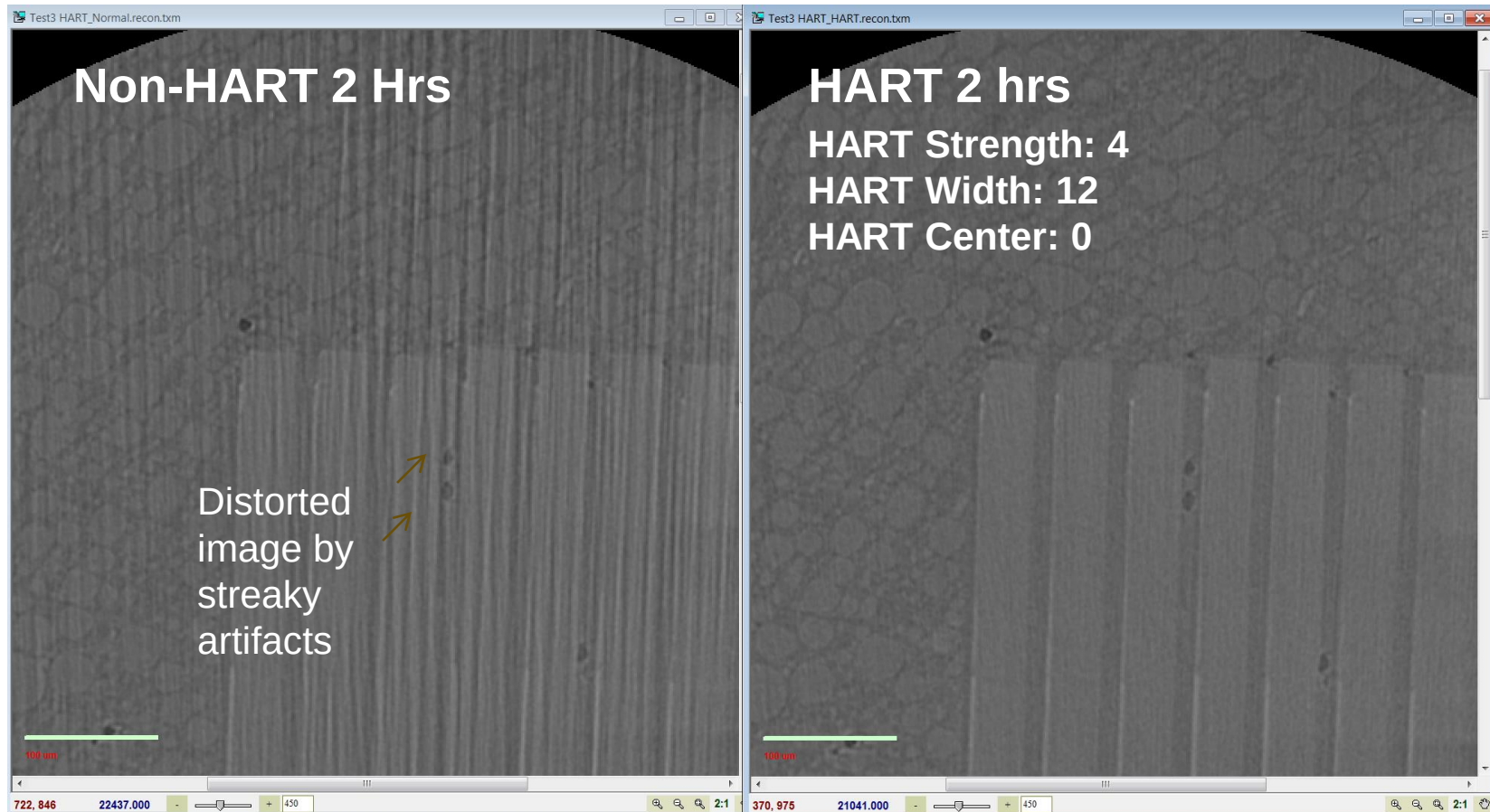
❑ High Aspect Ratio Tomography (HART)

- Better imaging samples that are thin and wide, for example semiconductor packages.
- Higher density of projections is used for long views, resulting in better images for the structure which could be obscured in a normal tomography due to limited number of projections along the long views.



HART region: the angular span with variable angular steps in projections
 HART Width: half of the HART region
 HART Strength: Multiplicative factor over the standard angle increment for each angle
 HART Center = angle and/or projections where angular speed of the theta stage is the slowest (usually longest views)

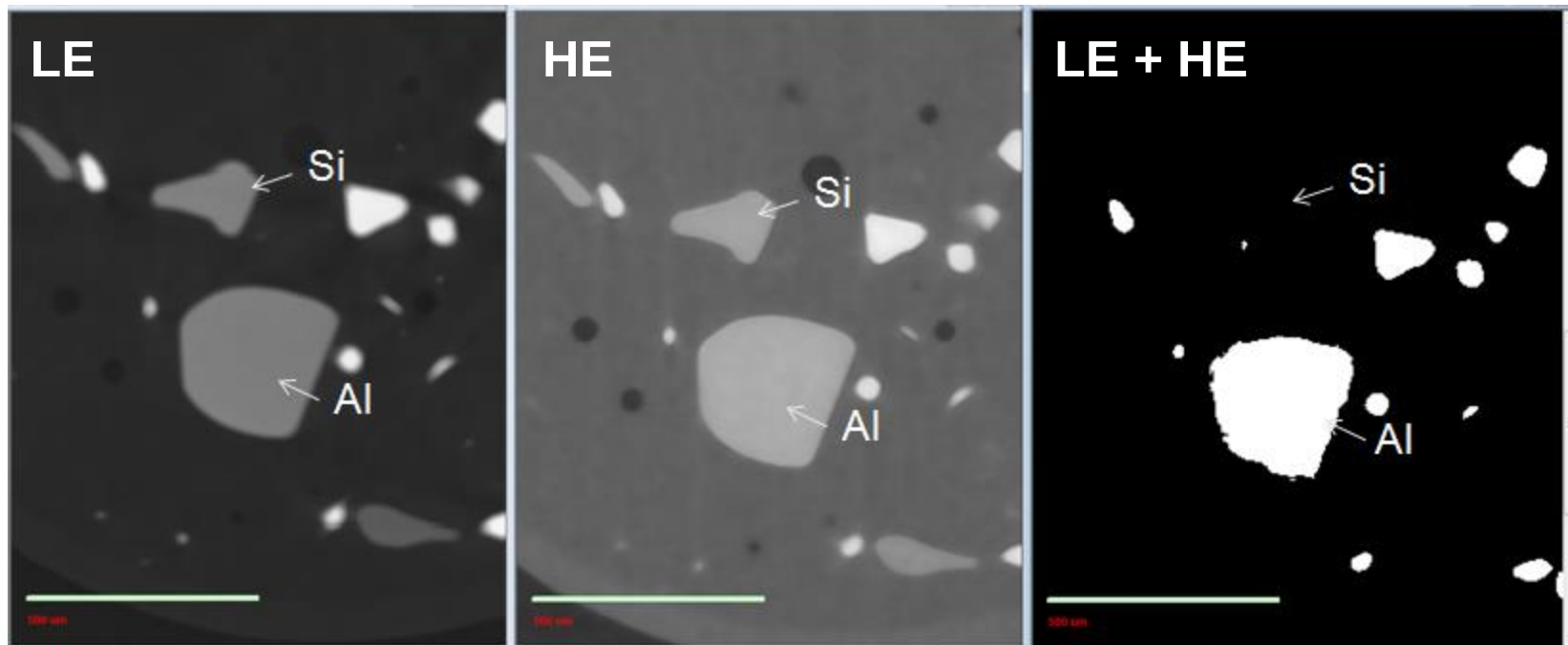
- ❑ **Use Case I: Improvement of image quality with the same scan time (same number of projection and exposure time)**

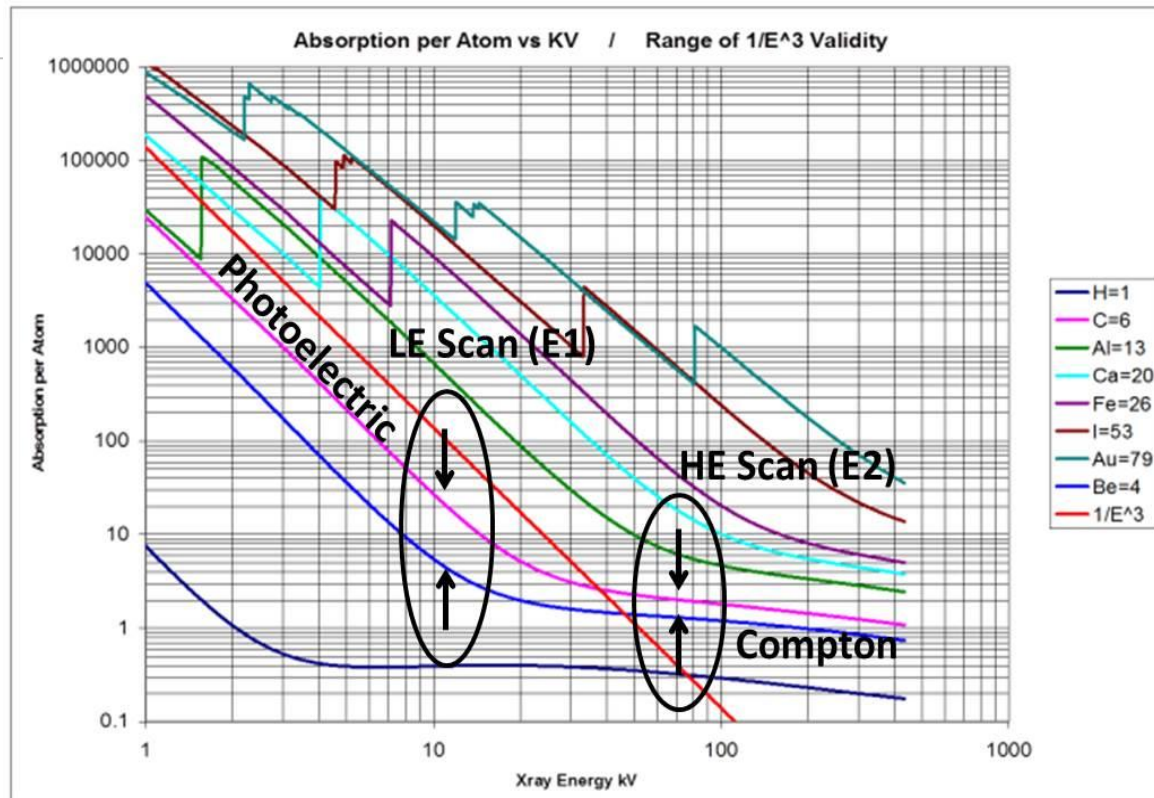


☐ Use Case II: Equivalent or better results in a shorter scan time

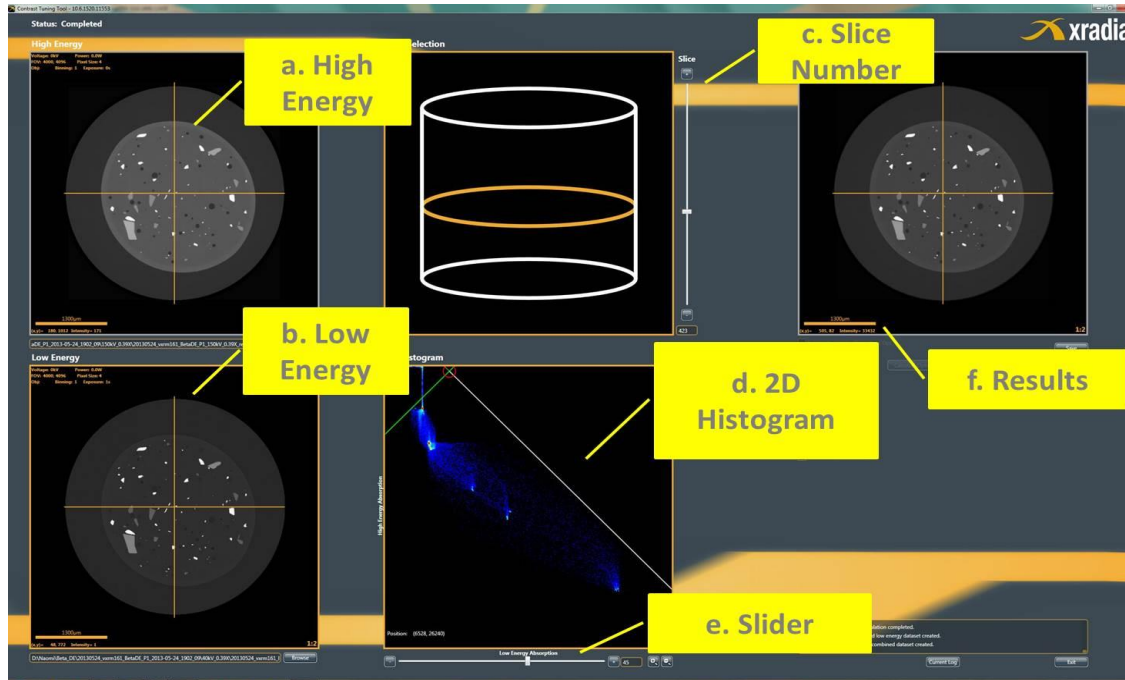
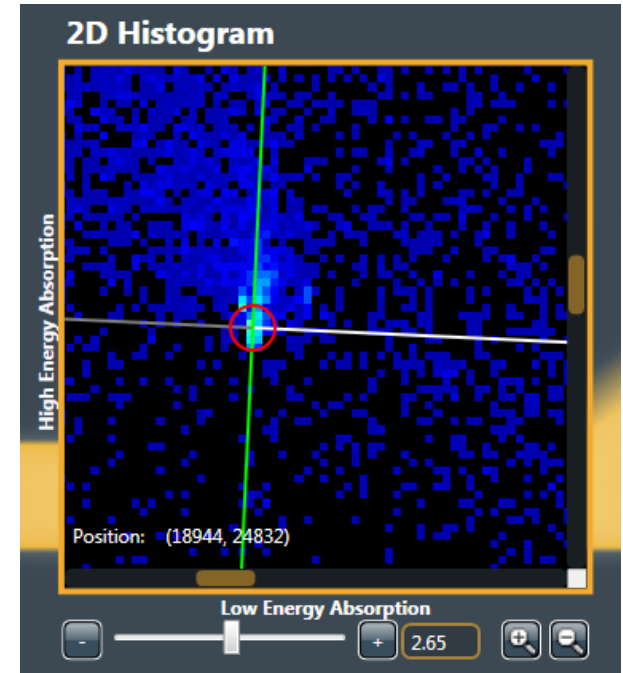


- Tune material contrast of two tomographies side-by-side (acquired with low energy and high energy).
- Enable compositional study of materials and features normally indistinguishable by a single energy scan
- Improve material segmentability by highlighting/masking one or two phases in a chemically complex specimen

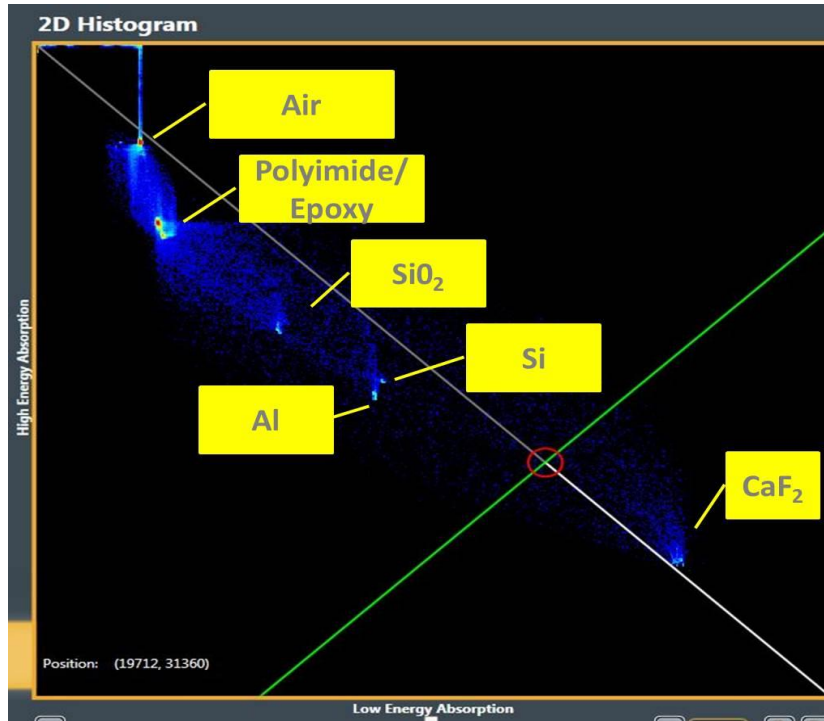
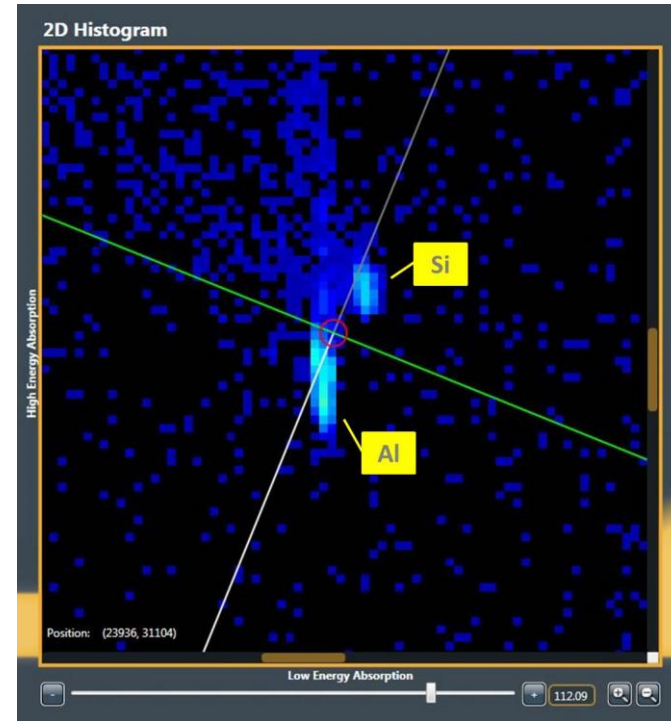




- Low Energy: photoelectric effect is dominant
- High Energy: Compton scattering is dominant
- Low energy scan (ex. 40 kV, no filter) and high energy scan (ex. 150 kV, HE6 filter) to maximize the photoelectric effect and Compton scattering, respectively.



- The 2D histogram plot (part d) is created with LE Absorption on the x-axis and the HE Absorption on the Y-axis.
- Changing the angle with the slider makes it possible to reveal structural compositional information in a blended image (part f).



- The 2D histogram plot (left) shows that the sample has Air, epoxy/polyimide, SiO₂, Al, SiO₂, and CaF₂.
- Appropriate manipulation of the slider (right) allows Si be masked out (the image of Slide 88). The resulting 3D data may be exported.



We make it visible.