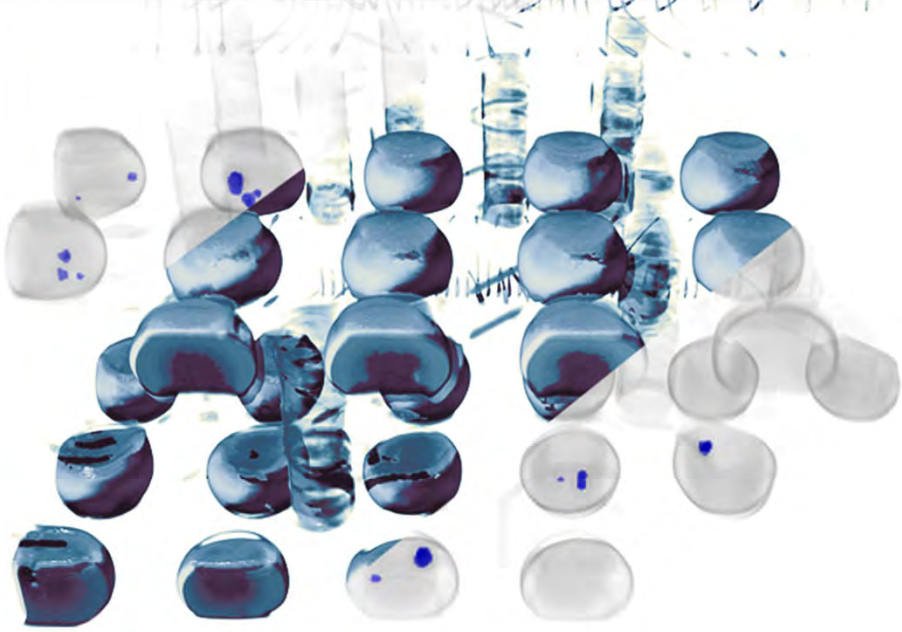
X-RAY COMPUTED TOMOGRAPHY

The Superpower System

Guest Speaker:

Aya Takase
Director of
X-Ray Imaging,
Rigaku Americas Corp.

May 7, 2020 11am PDT



COVALENT ACADEMY

Advancements in Instrumentation Series

RSVP at:
https://bit.ly/covalent06

Rigaku
COVALENT METROLOGY

Covalent Metrology



- **Founded 2016**
- **Testing, measurement & characterization Platform**
- **30 team members (13 PhDs)**
- **9,500 ft² lab in Sunnyvale**
- **1-Stop-Shop Source for Answers**
  - 30 instruments in-house
  - 6 partnerships with instrument makers
  - 11 partner labs
  - 6 corporate “tool shares”
- **>275 customers** (80% repeat)

Covalent Technical Groups and Organization

hello@covalentmetrology.com

Electron & Scanning Probe Microscopy

(SEM/TEM, AFM, EDS, EELS, Nanoindent, acoustic microscopy)

Surface Analysis

(XPS, Auger, ToF-SIMS, dSIMS)

Optical Microscopy & Spectroscopy

(Laser Confocal, White Light, Chromatic Dispersion, Spectral Ellipsometry, UV-Vis-NIR Spectroscopy)

Materials/ PC Board FA

(Cross Sections, Inspections, Dye & Pry)

X-Ray Characterization

(XRD/XRR, XRF, µCT)

Chemical Analysis

(ICPMS, GCMS, FTIR, Raman, Solid & Solution NMR, 2D NMR)

Nanoparticle Analysis

(DLS, PSA, Particle Zeta Potential)

Bulk Properties Characterization

(DSC, TGA, DMA, Rheometry, Tensile Test, Pencil Test, Surface Zeta Potential)

Covalent's Instrument Partners

Rigaku

COVALENT METROLOGY

- **Partnership established in Fall 2018**
- **Covalent is home to Rigaku's**
  Silicon Valley Semiconductor Division Metrology lab:
  - SmartLab XRD w/ full set of optics + heated stage
  - AZX-400 WDXRF with 200mm and 300mm cassette / FOUP (in clean booth)
  - CT Lab HX micro-CT
  - New system June 2020 (to be announced)

Other Partners

J.A. Woollam
Ellipsometry Solutions

Anton Paar

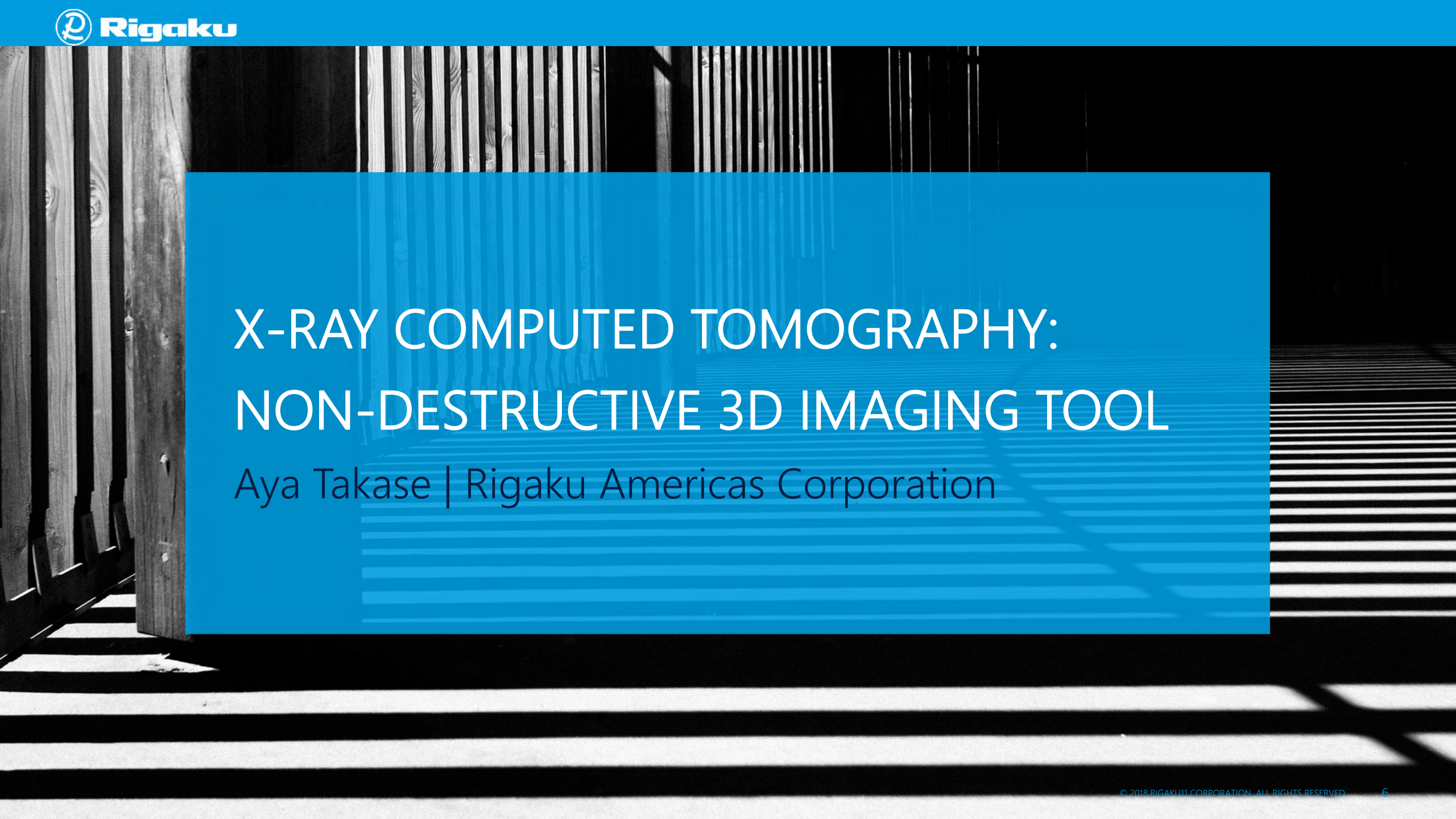
KEYENCE

PVA TePla

Aya Takase, Rigaku Americas Corporation



Aya Takase is the Director of X-ray imaging at Rigaku Americas Corporation. She helps X-ray users to develop analysis and testing methods. Aya believes user-friendly X-ray tools can greatly help materials science research and has worked with Rigaku engineers to design automated and user-friendly X-ray CT scanners and diffractometers for over twenty years. Aya holds a MA in physics from Tokyo University of Science.



X-RAY COMPUTED TOMOGRAPHY: NON-DESTRUCTIVE 3D IMAGING TOOL

Aya Takase | Rigaku Americas Corporation

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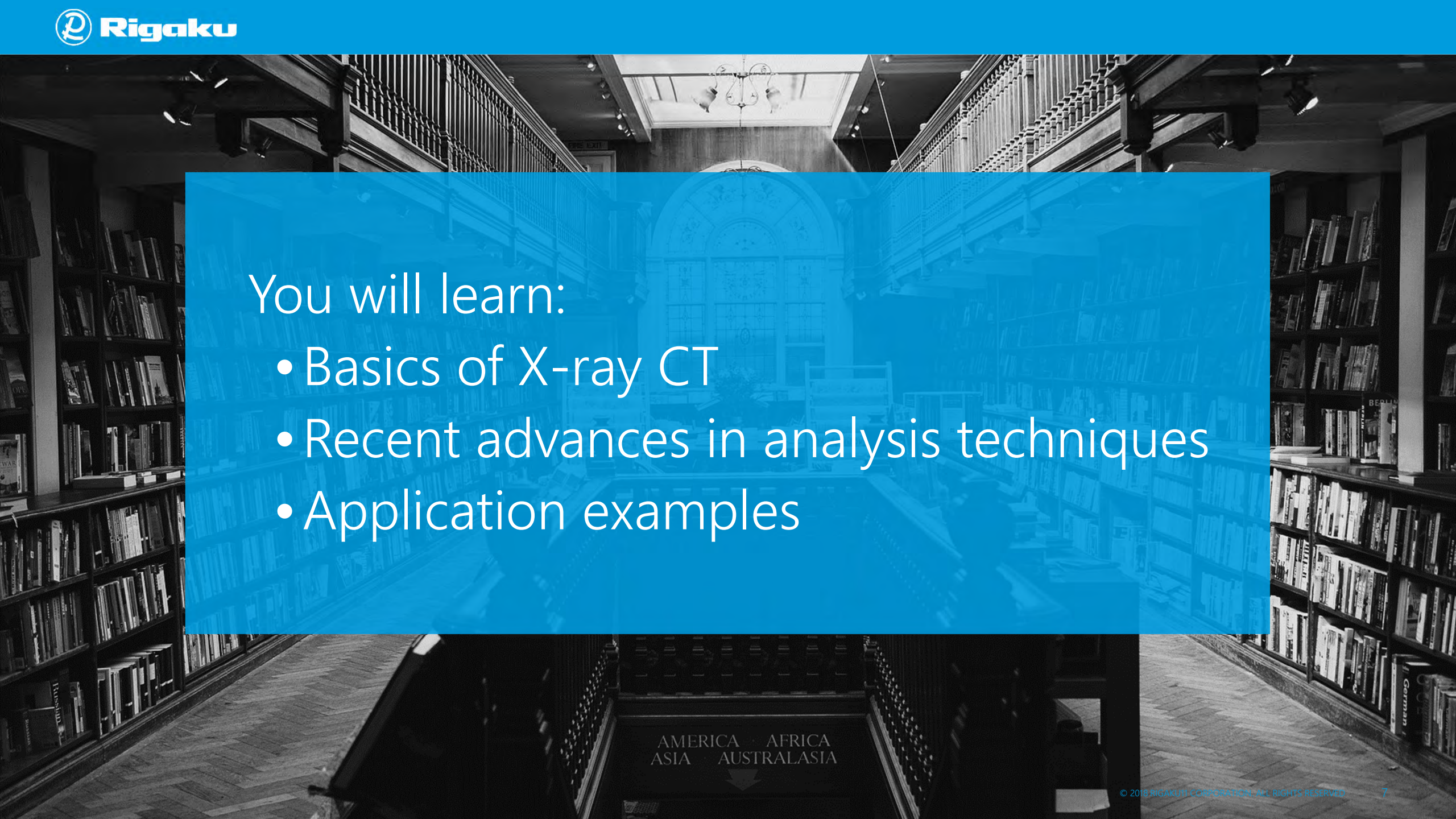

You will learn:

- Basics of X-ray CT
- Recent advances in analysis techniques
- Application examples

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WHAT IS X-RAY CT?

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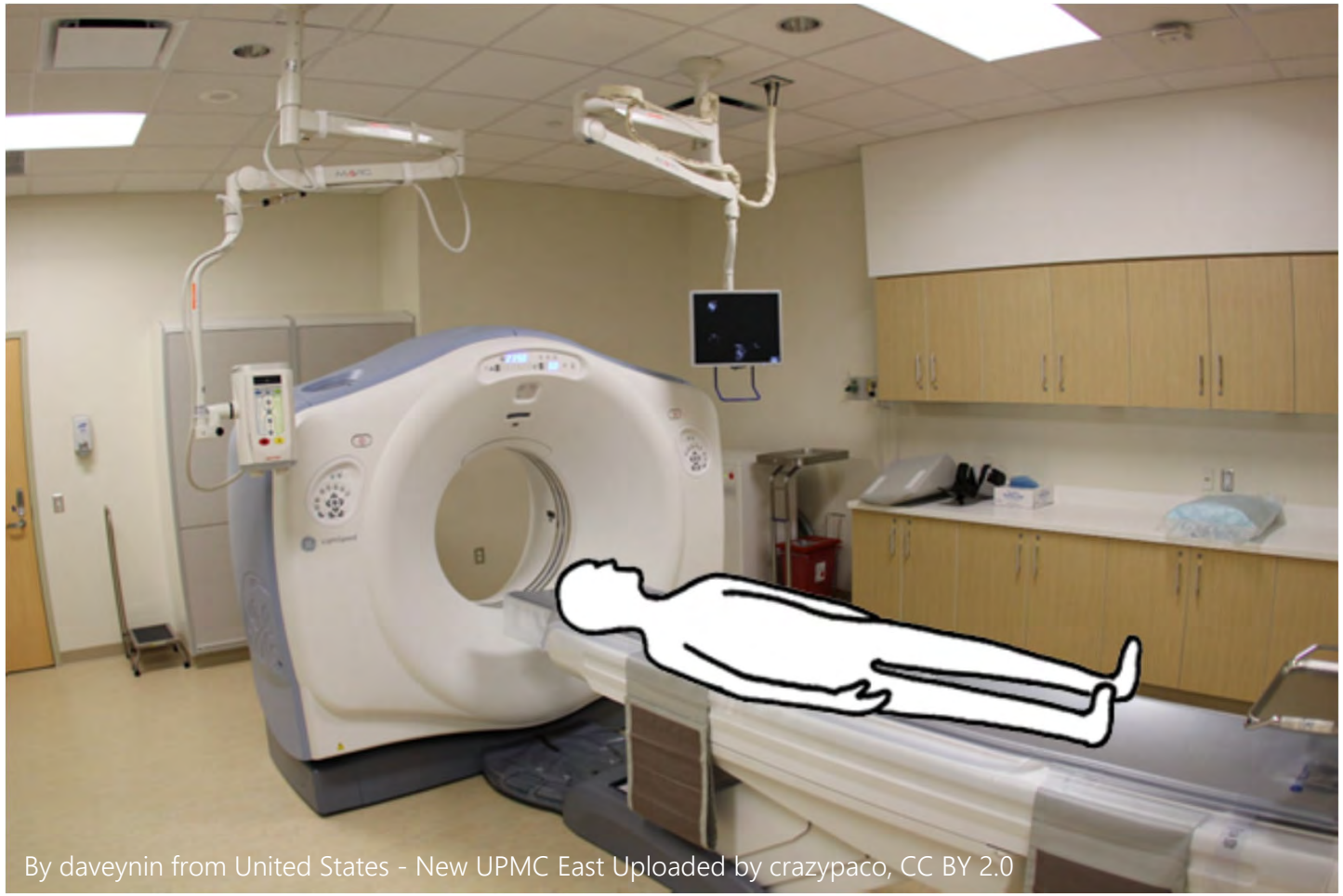

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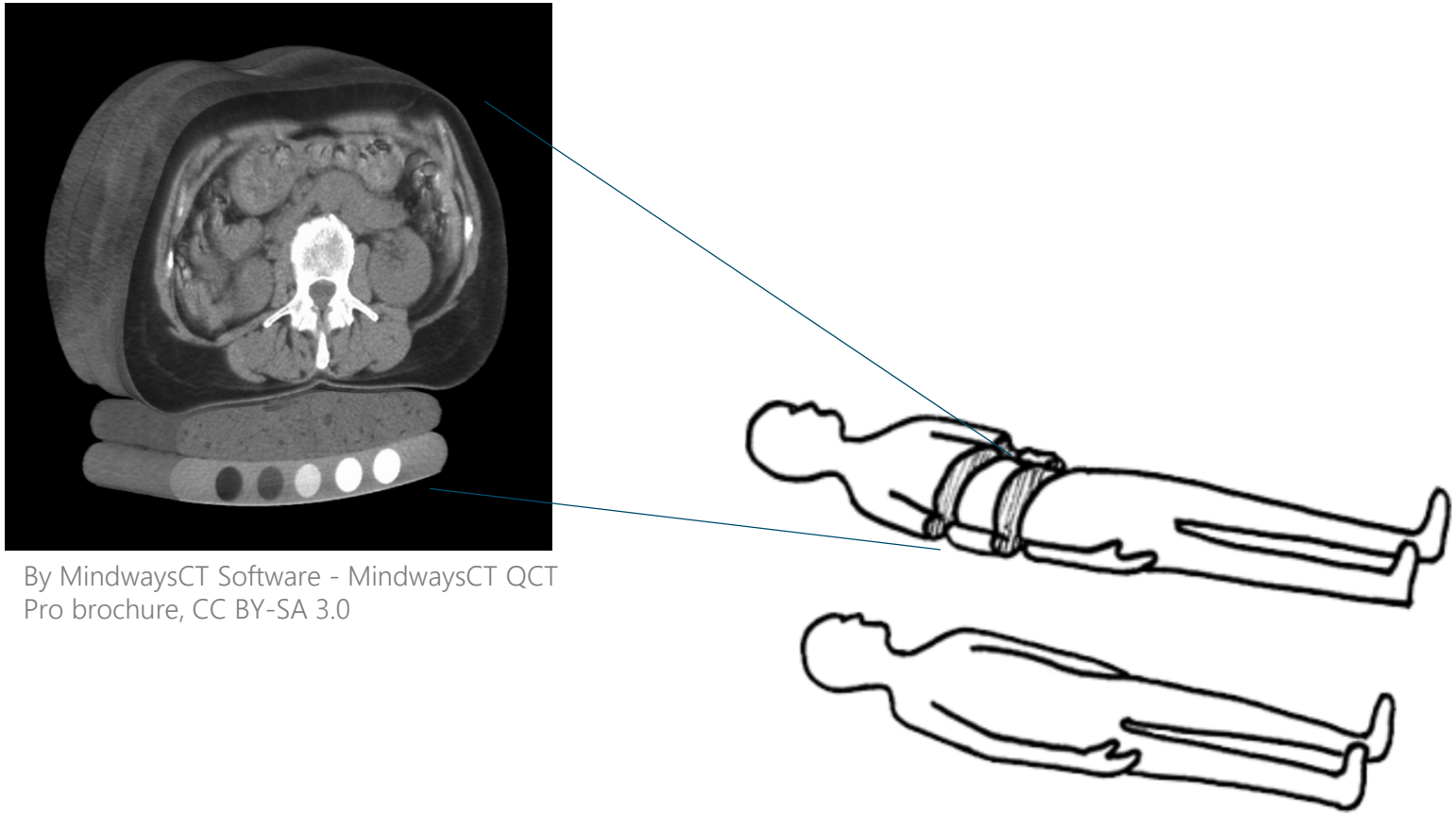

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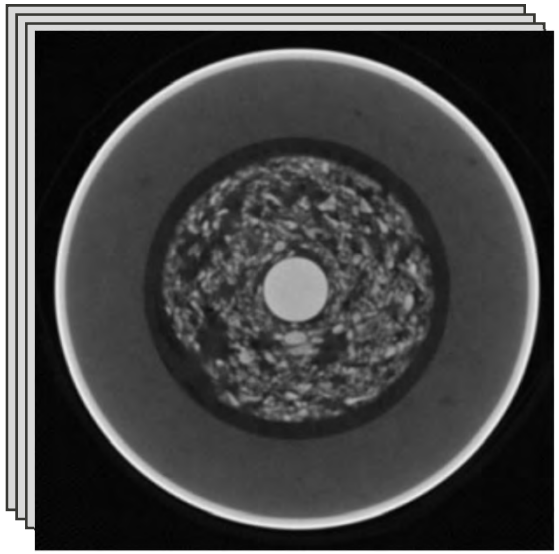

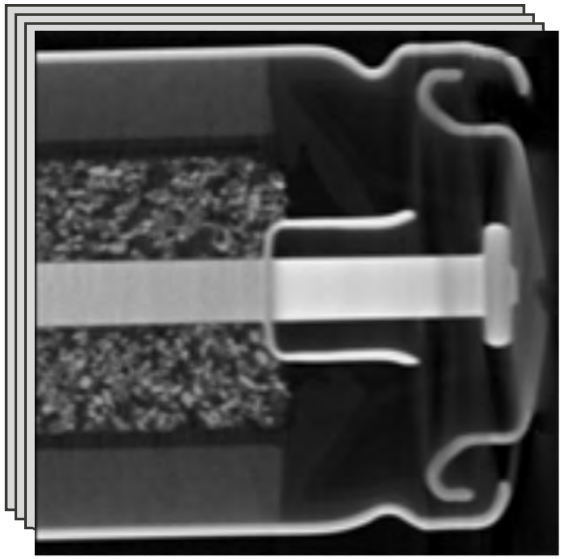

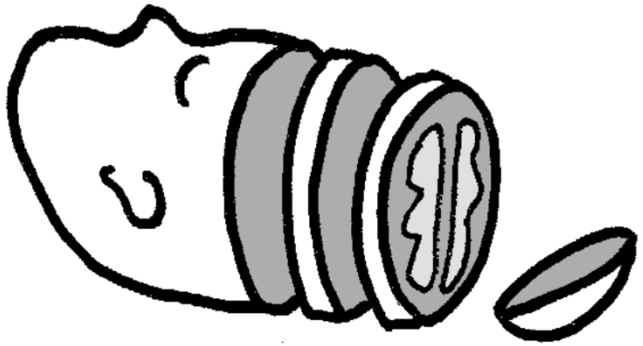

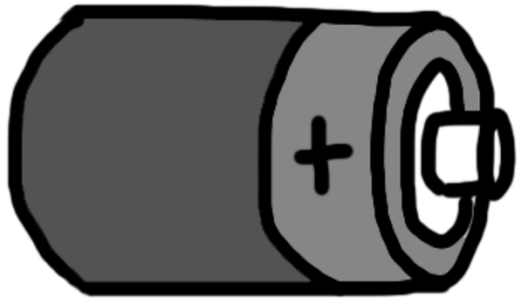

CAT Scan

X-ray Microtomography/Microscope

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HOW DOES IT WORK?
– LET'S START WITH 2D –

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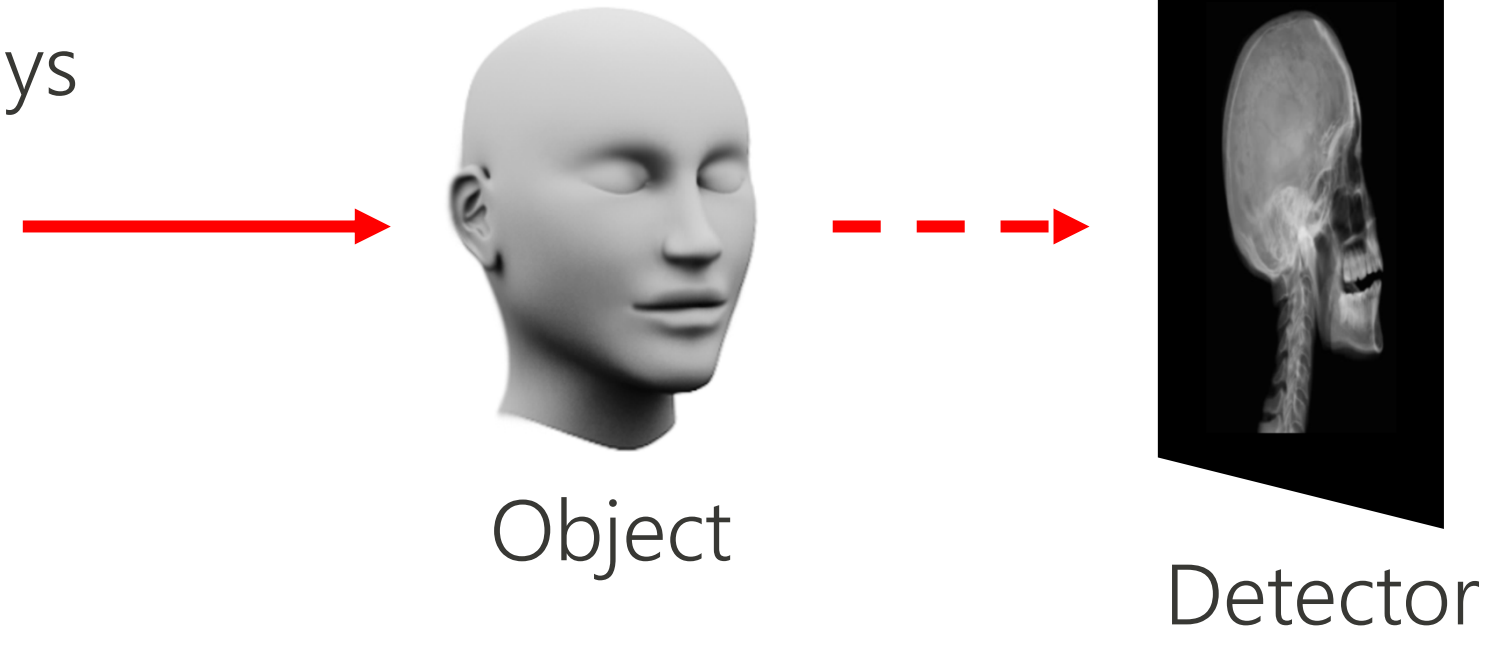
2D projection

X-rays



Object

Detector

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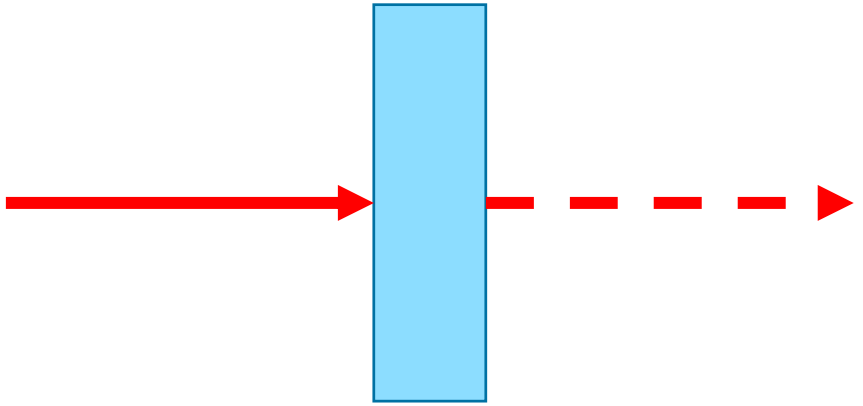

Things absorb X-rays.

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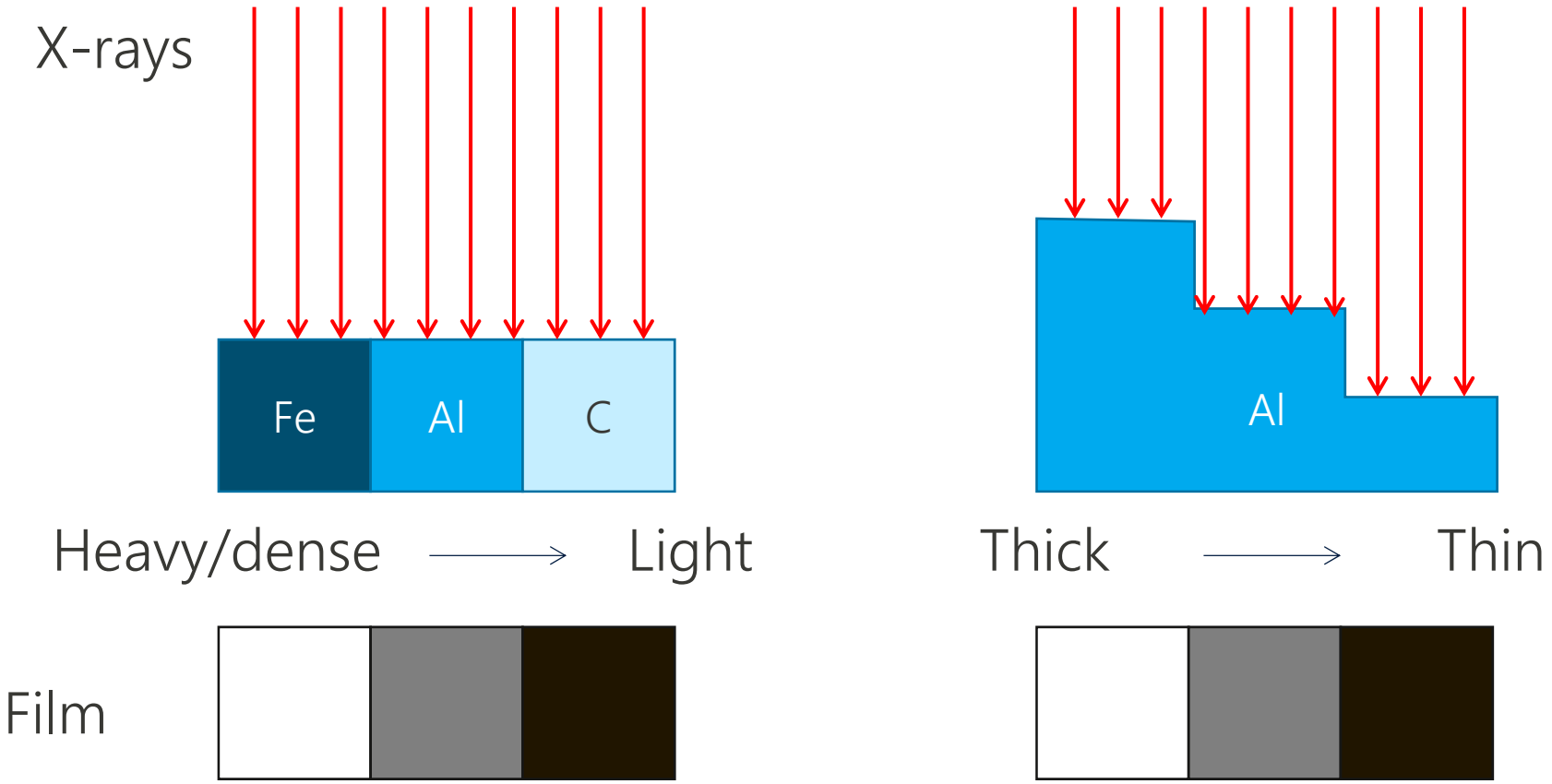

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HOW DO YOU GET 3D VIEW?

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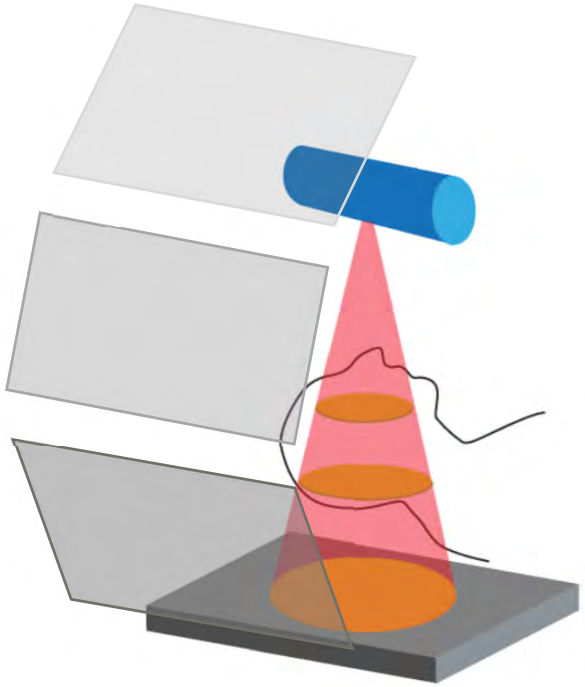
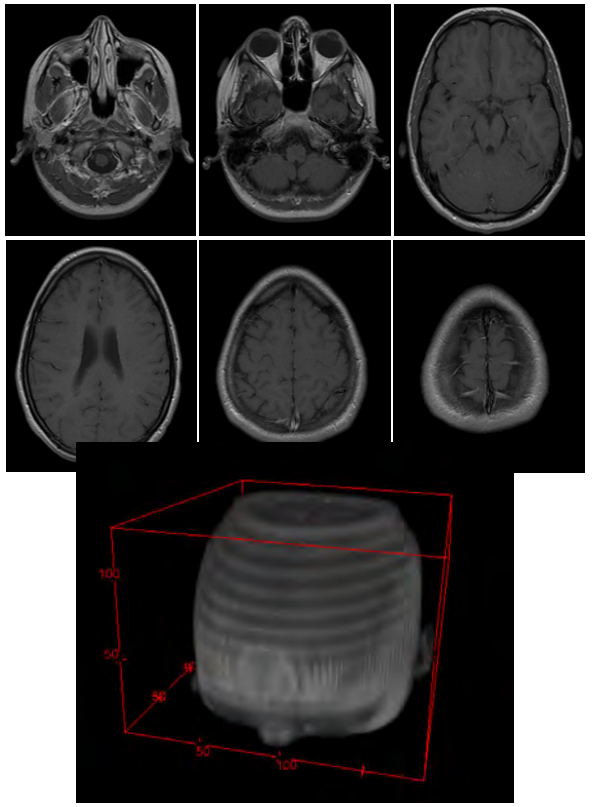


Scan

Reconstruction





Tomographic cross sections
3D rendering

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HOW DOES RECONSTRUCTION WORK?

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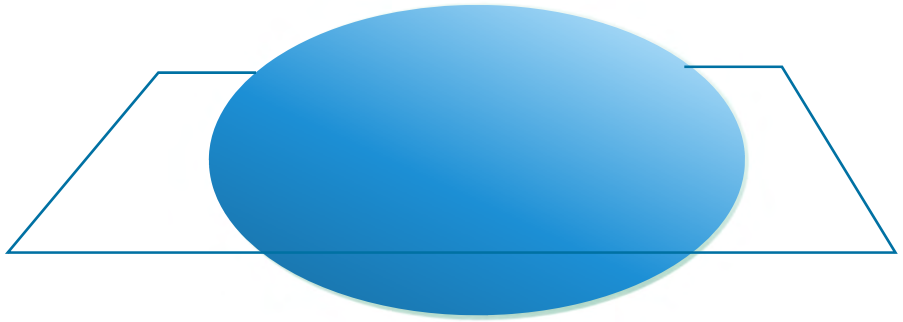
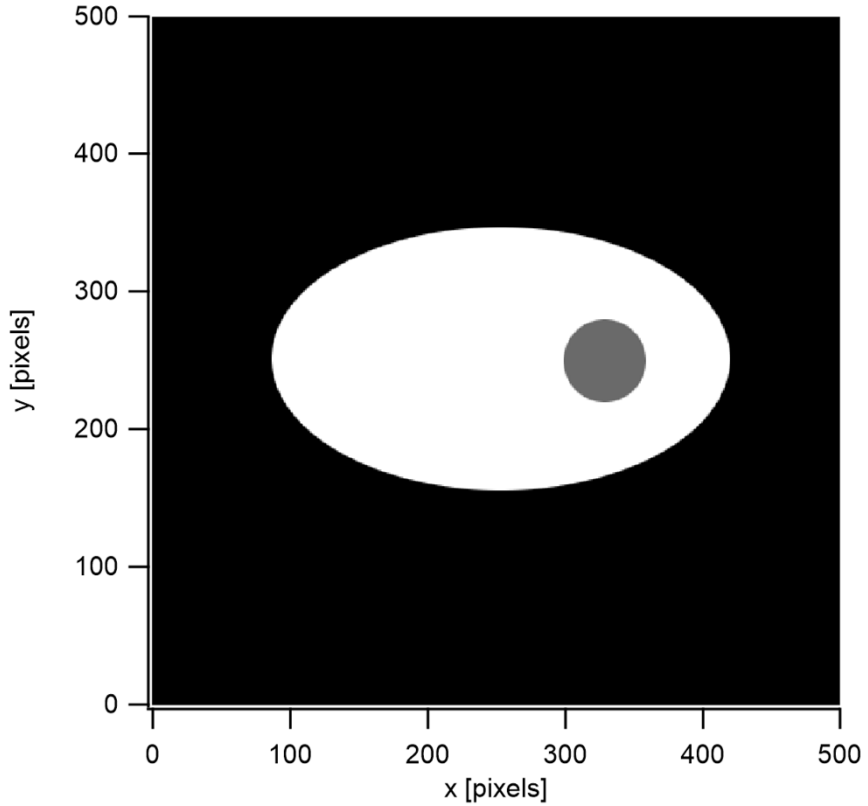


Tomographic cross section



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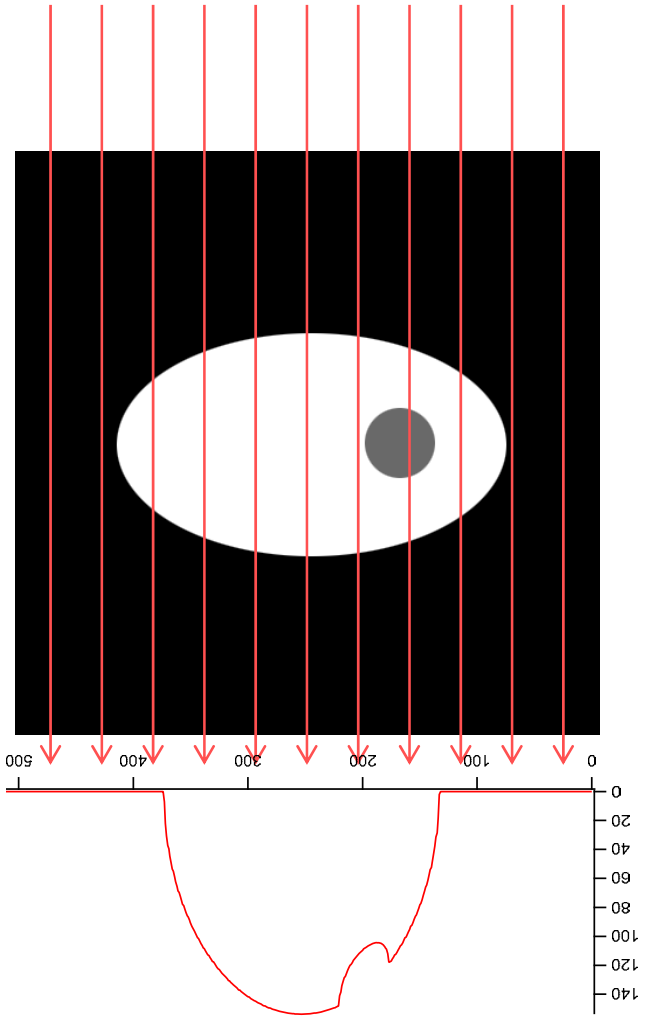

Integrated density projection angle 0°

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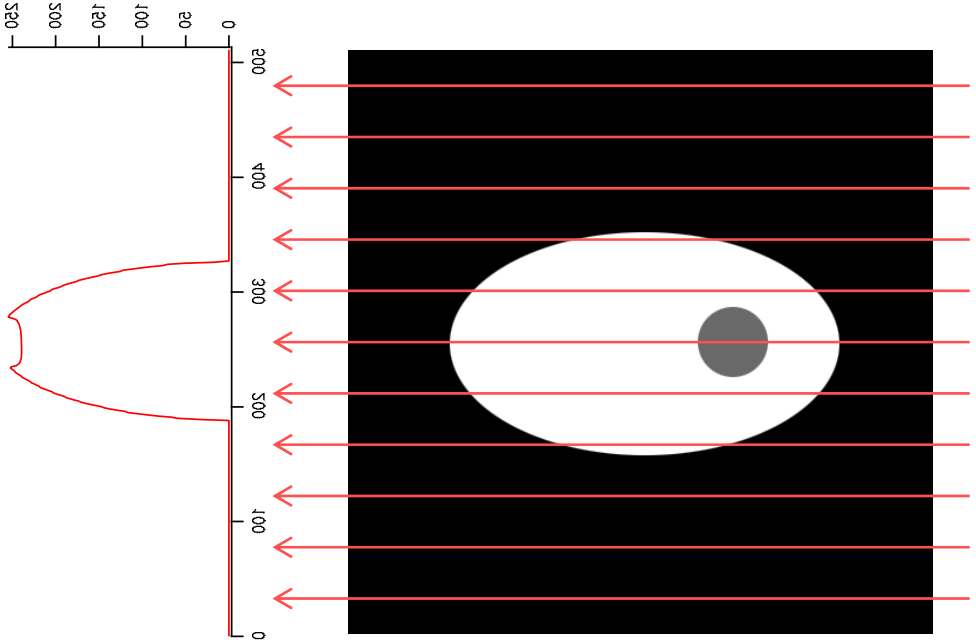
90°



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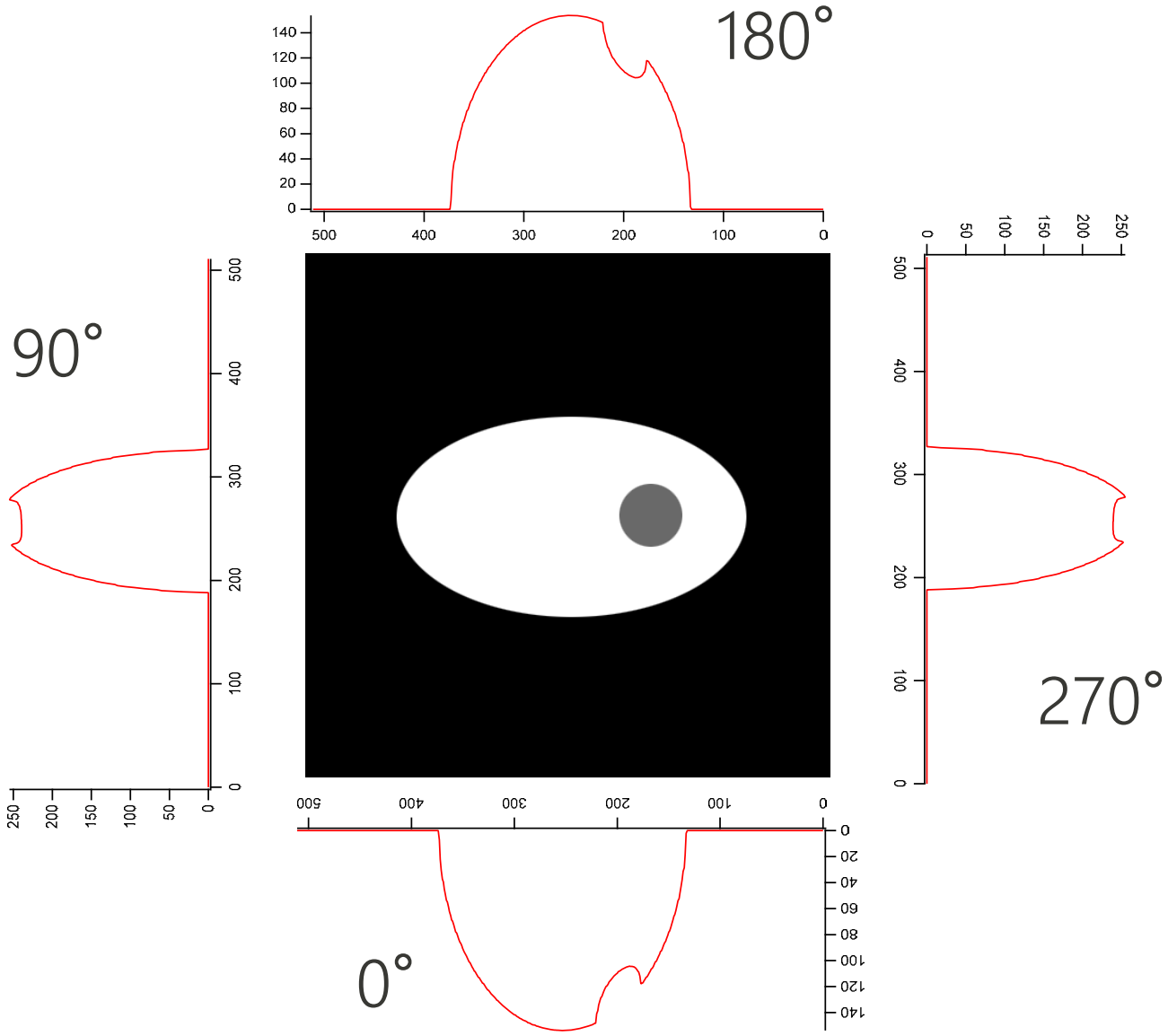

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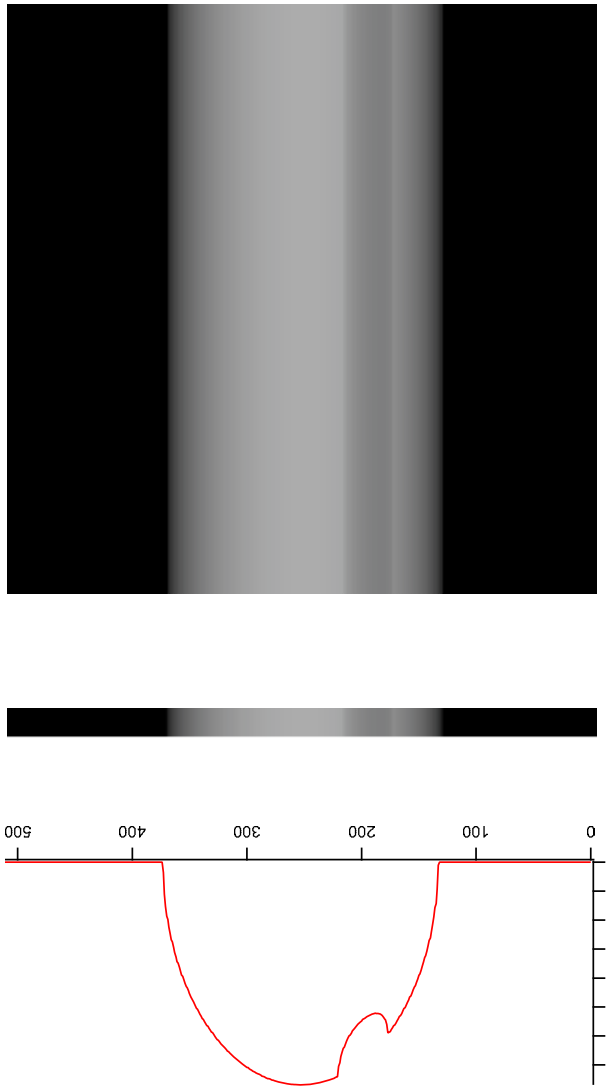

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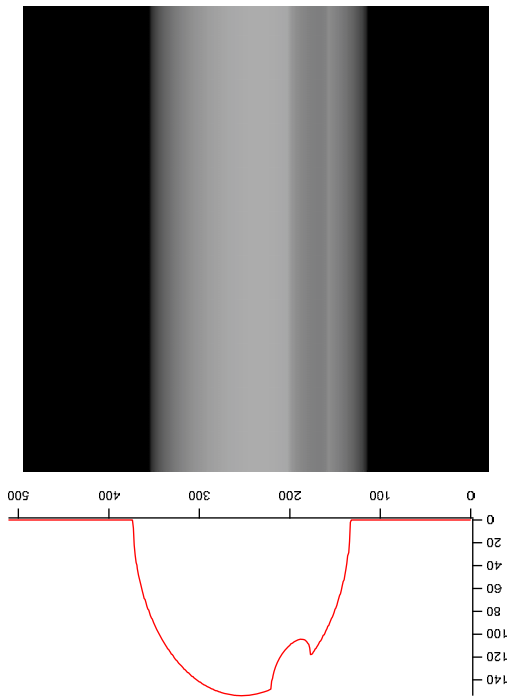

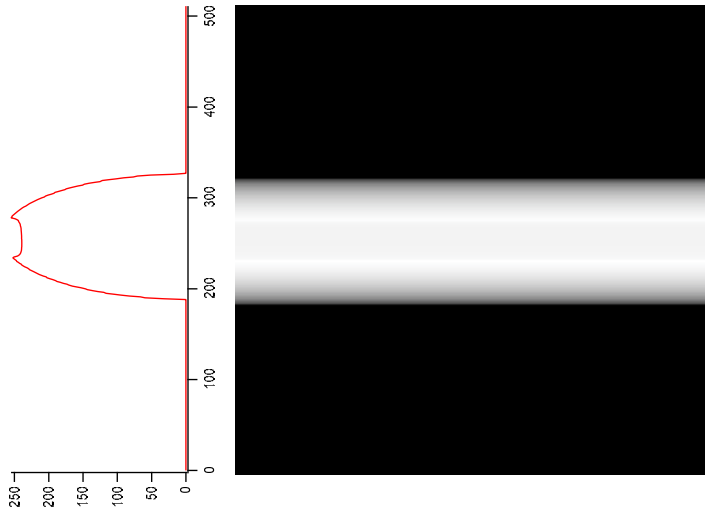

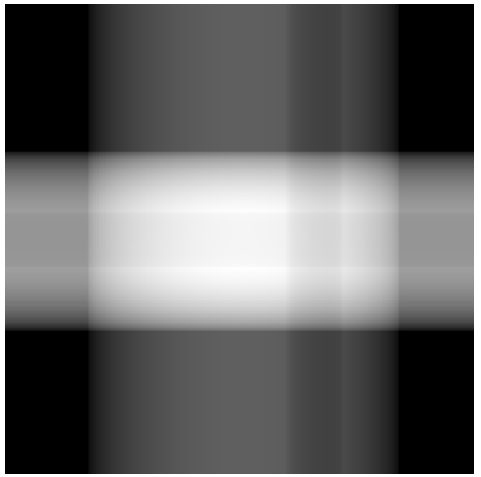

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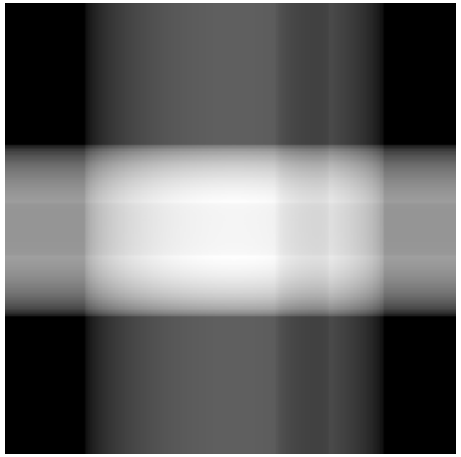
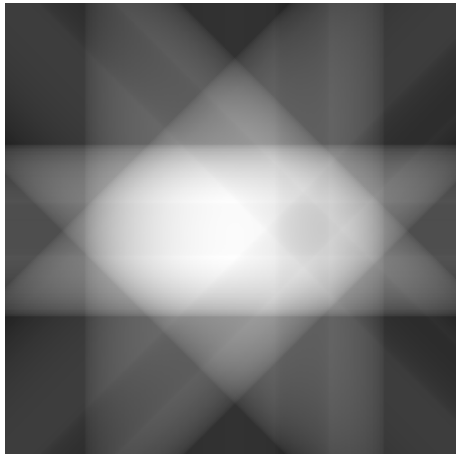
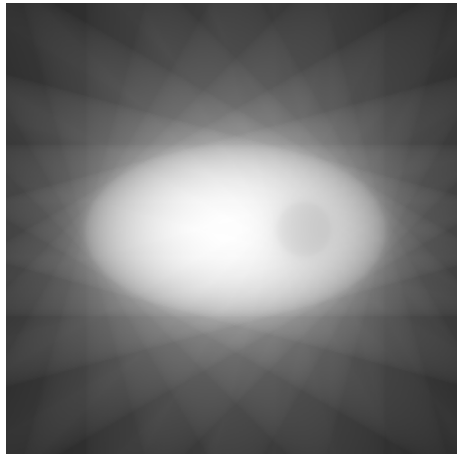


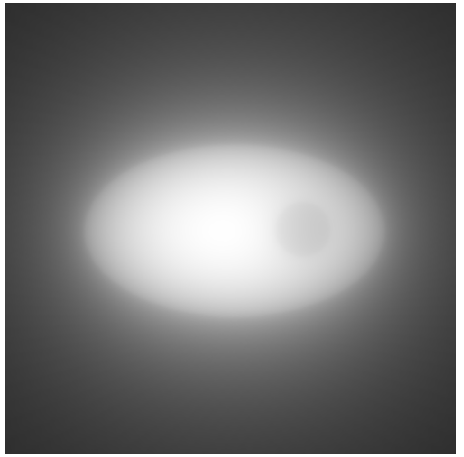
4 projections



8 projections



24 projections



120 projections

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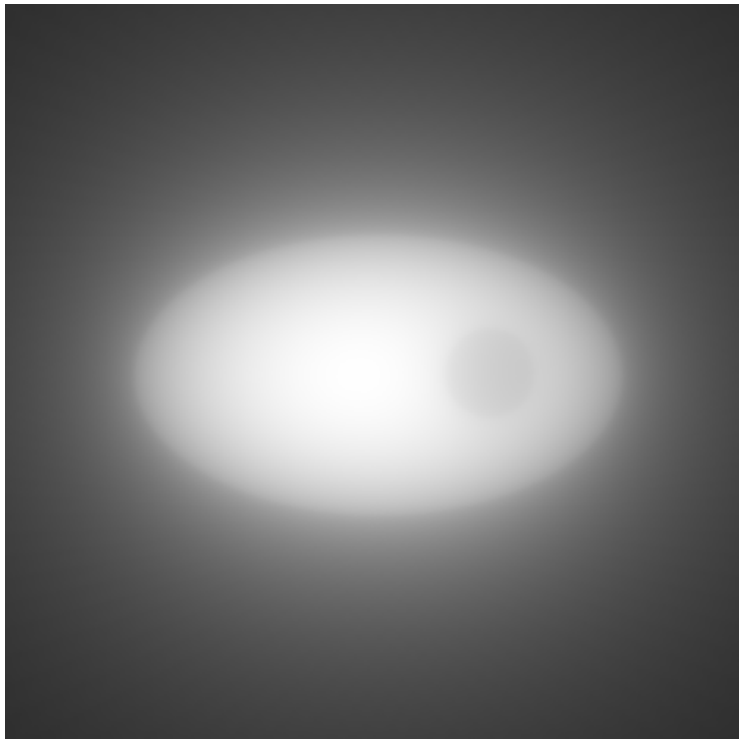
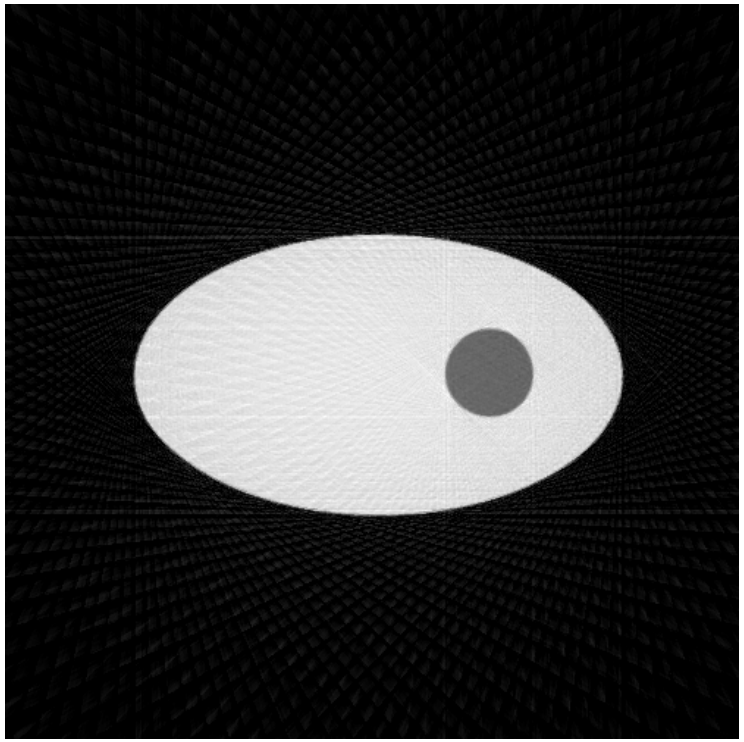


120 projections



120 projections
With ramping filter

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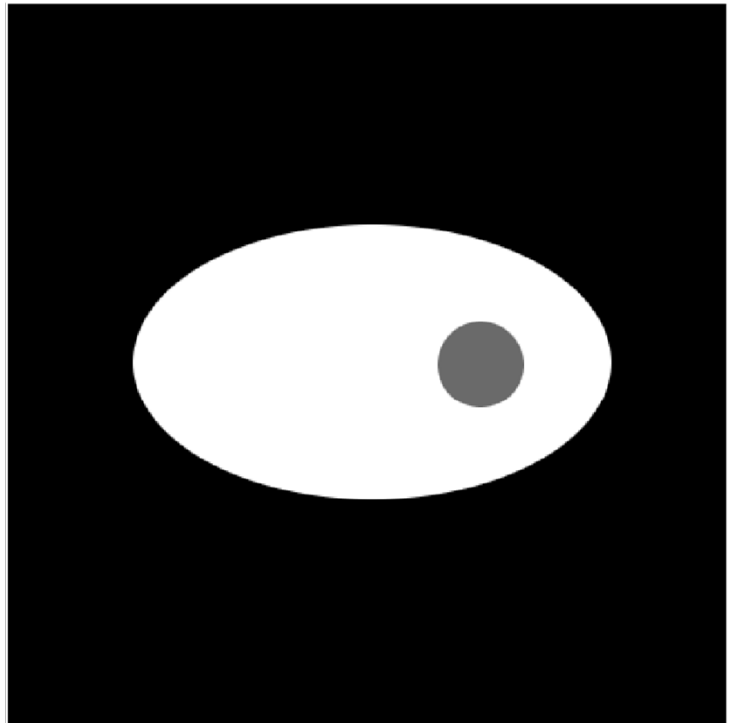
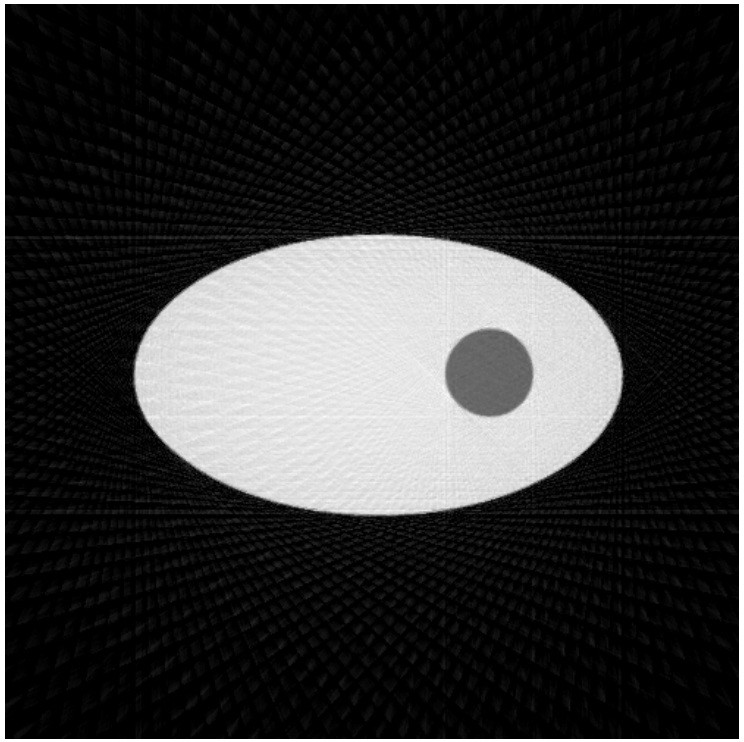


Original



Reconstructed

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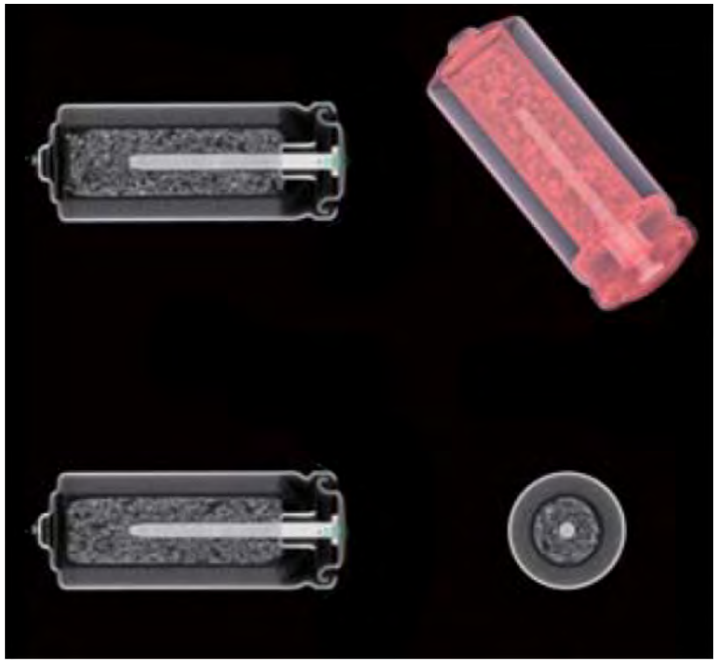

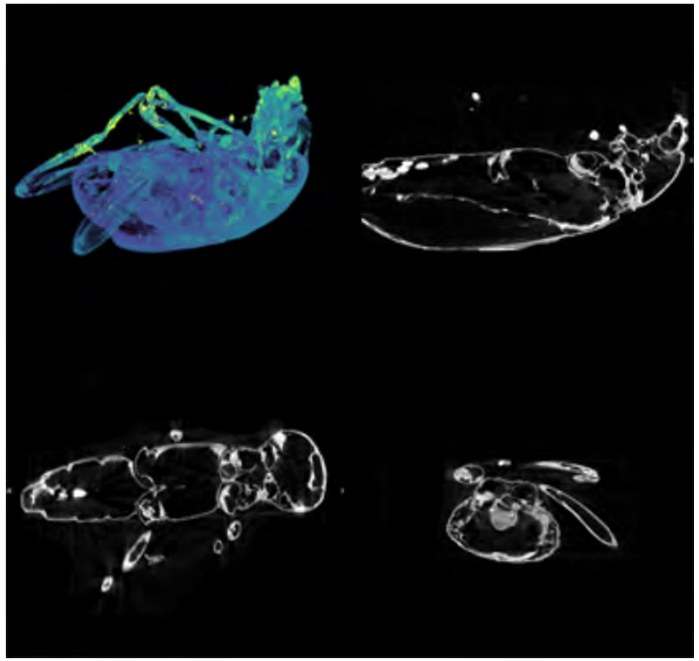

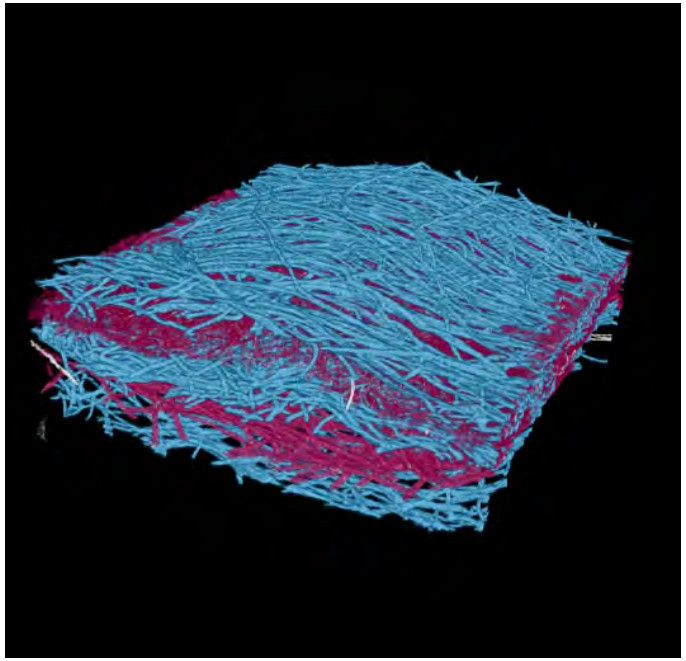

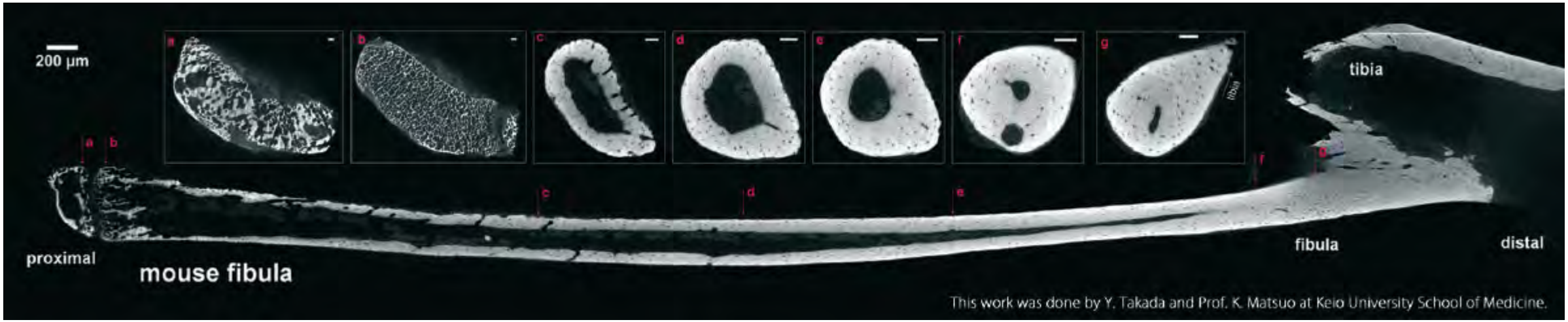

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WHAT ARE THE COMMON CHALLENGES?

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- Limited resolution compared to EM
- Too light/heavy absorbing materials
- Artifacts



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- Limited resolution compared to EM
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- Artifacts



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WHAT'S THE RESOLUTION?

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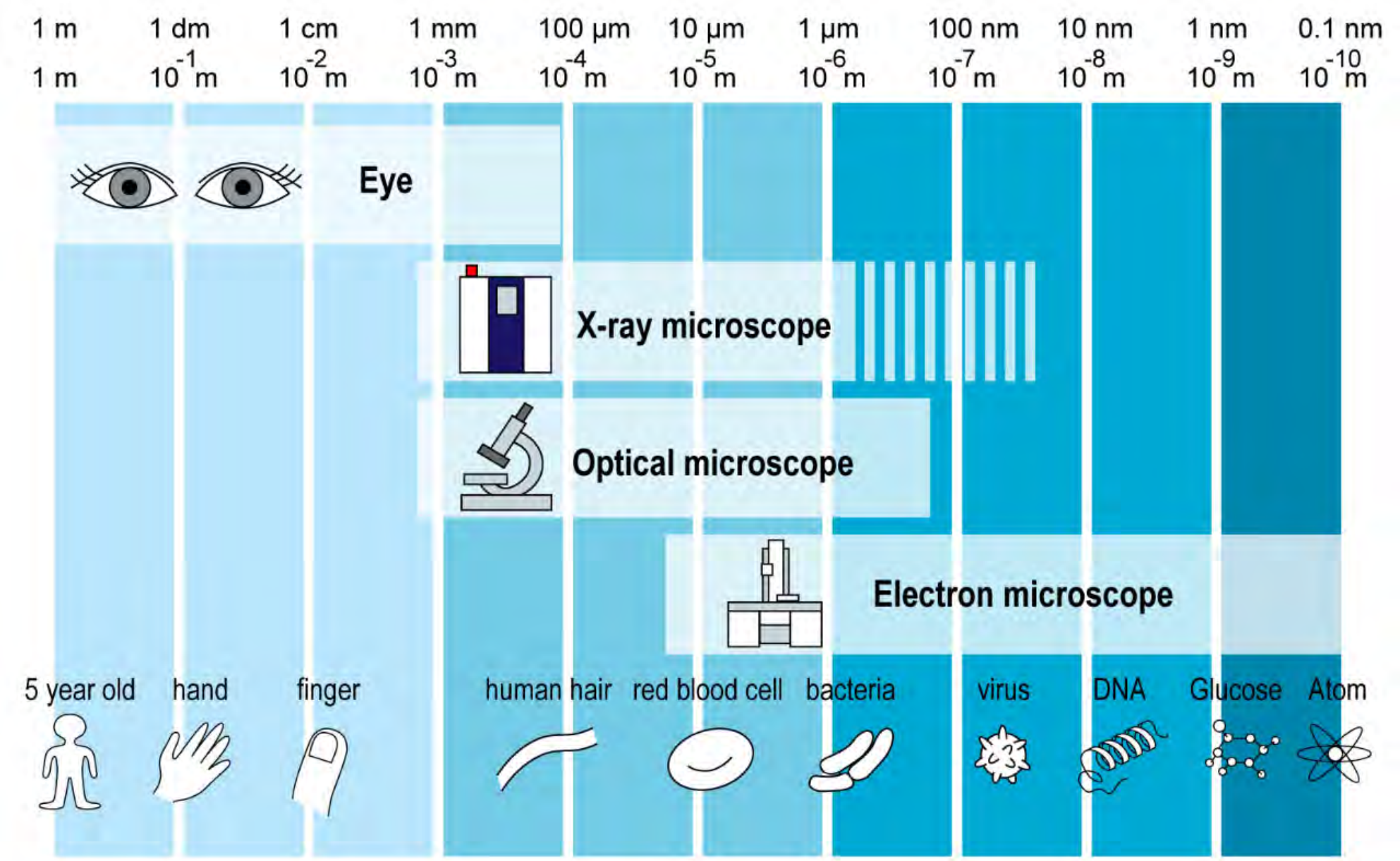

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- Limited resolution compared to EM
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- Artifacts



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WHAT'S TOO LIGHT OR TOO HEAVY?

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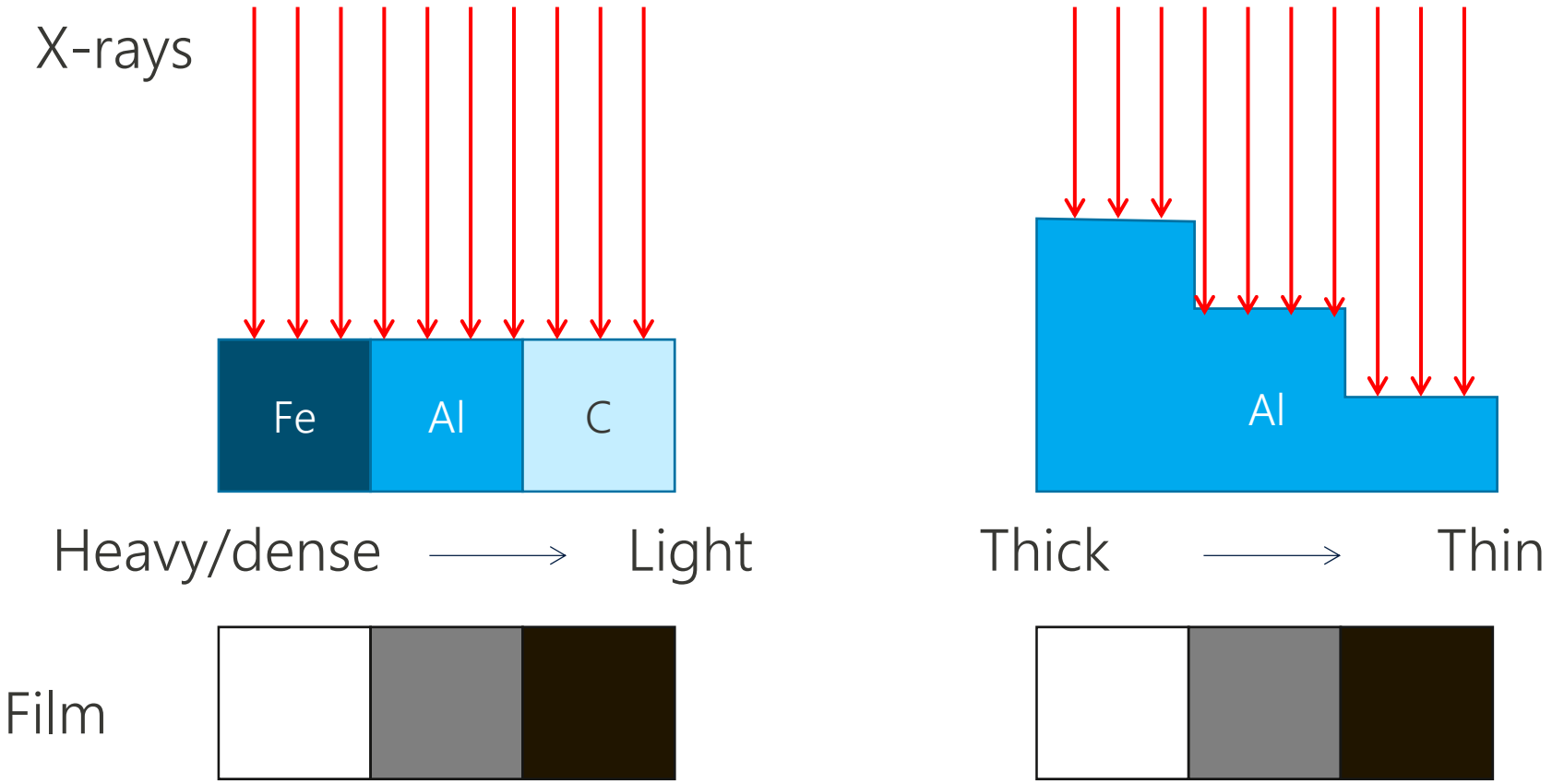

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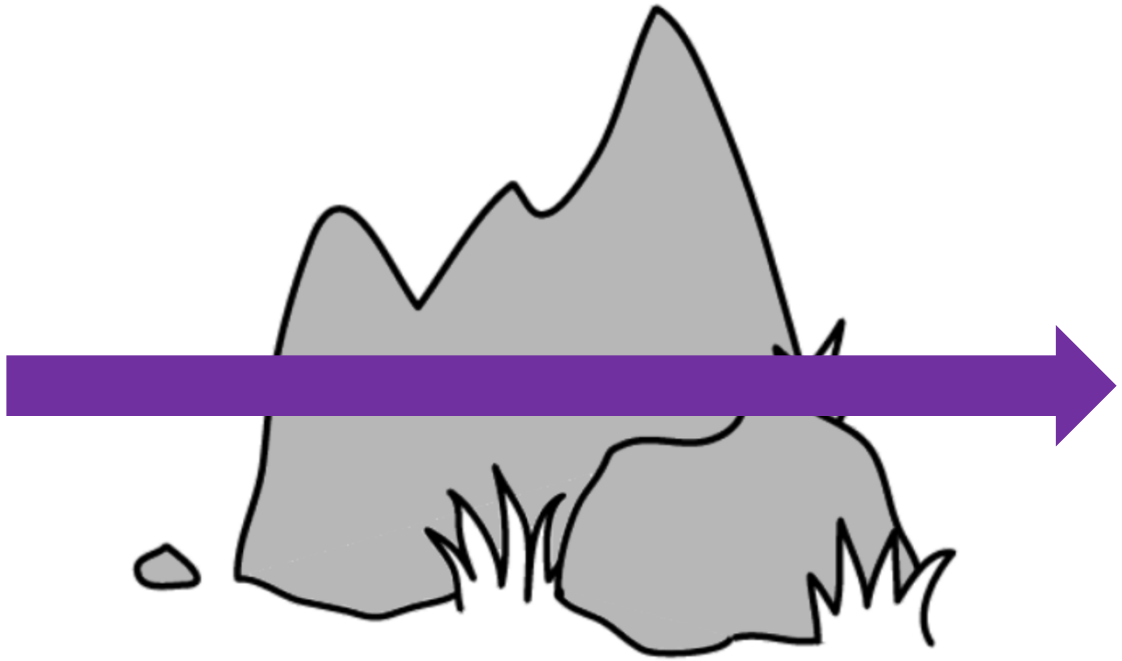
Large, high density
High energy X-rays



Small, low density
Low energy X-rays



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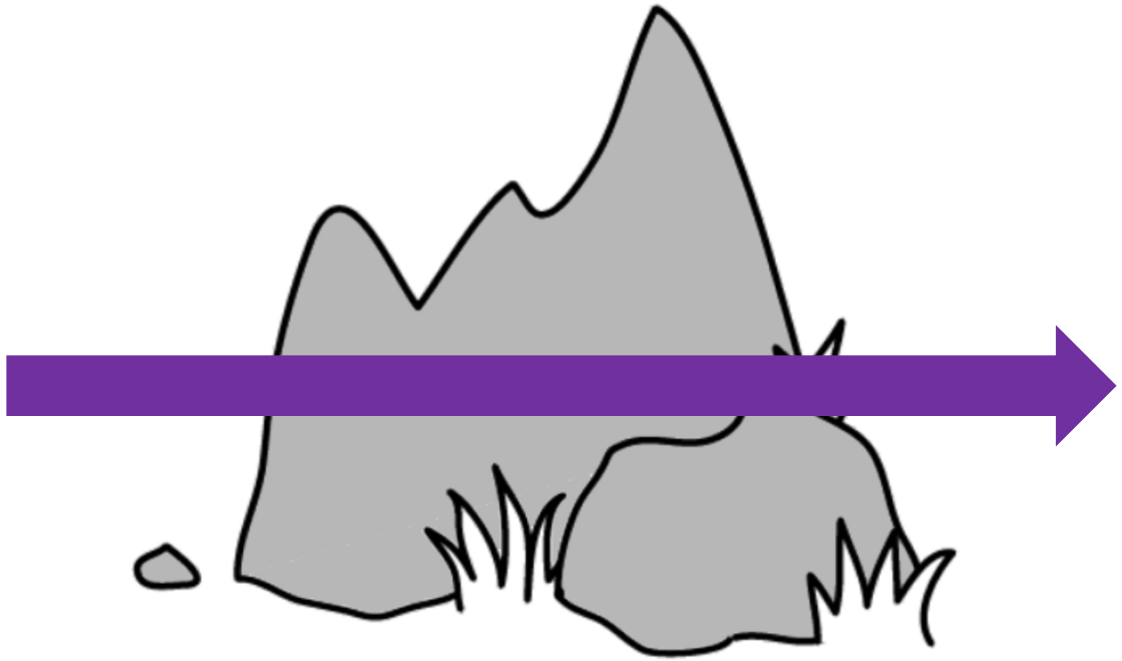
Small, low density
Low energy X-rays



Styrofoam ~ 5 keV

Large, high density
High energy X-rays



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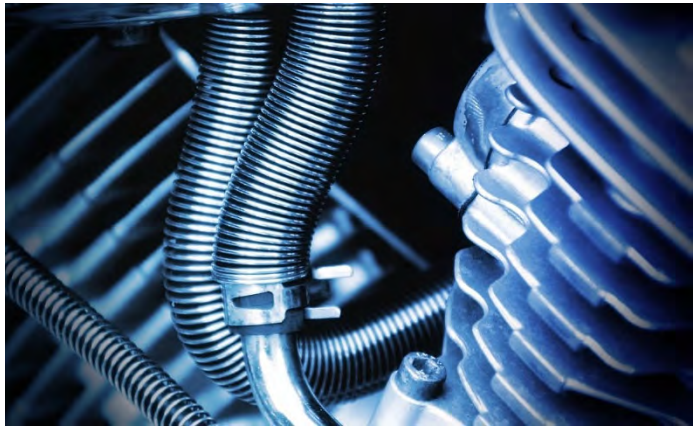
Small, low density
Low energy X-rays



Styrofoam ~ 5 keV

Large, high density
High energy X-rays



Engine parts ~ 450 keV

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- Limited resolution compared to EM
- Too light/heavy absorbing materials
- Artifacts



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WHAT ARE ARTIFACTS?

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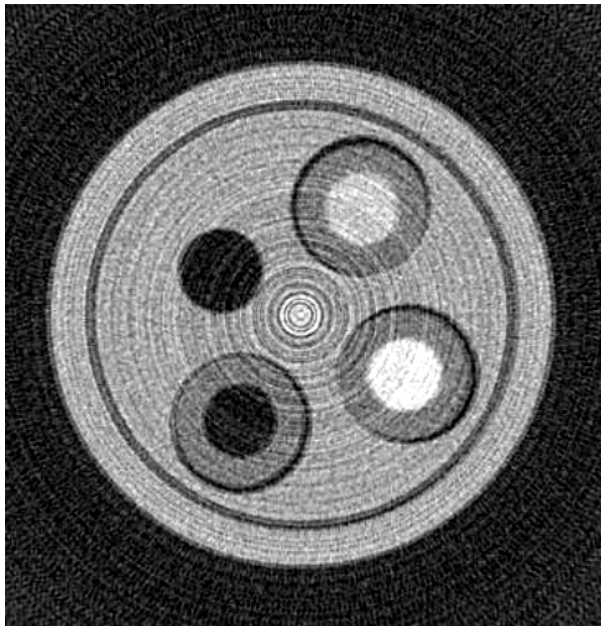
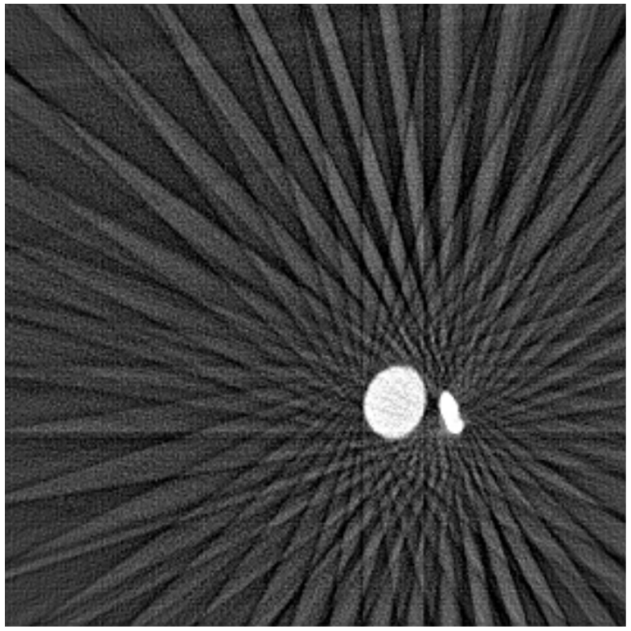
Rings



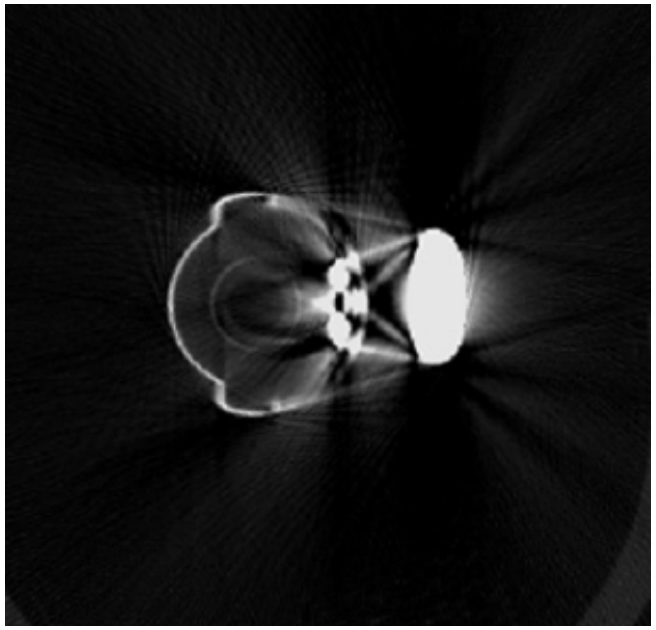
Bad pixels

Aliasing



Under sampling

Streaks & shading



Beam hardening

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- Limited resolution compared to EM
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- Artifacts



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WHAT HARDWARE IS INVOLVED IN AN X-RAY CT SYSTEM?

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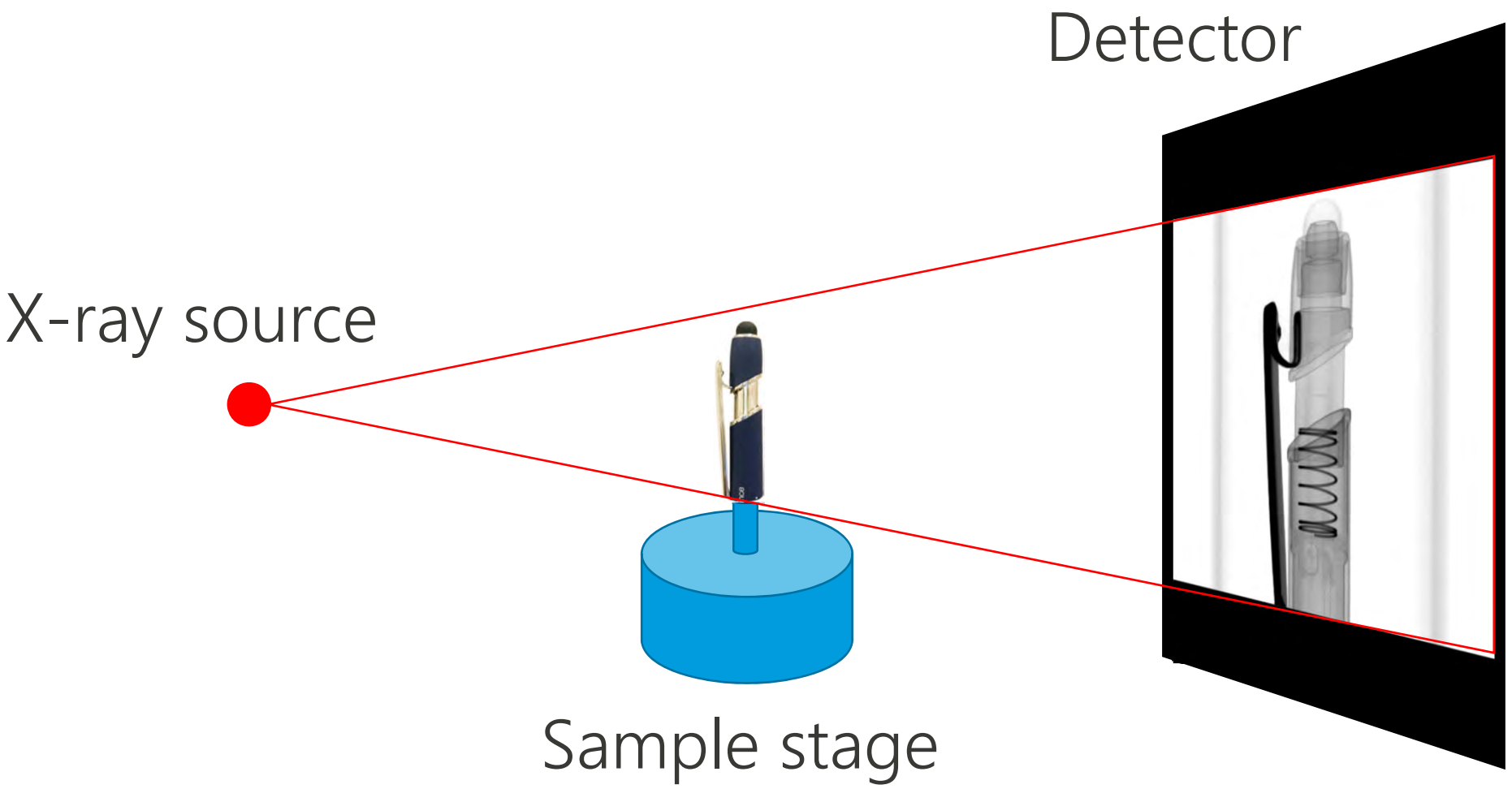

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HOW DOES MAGNIFICATION WORK?

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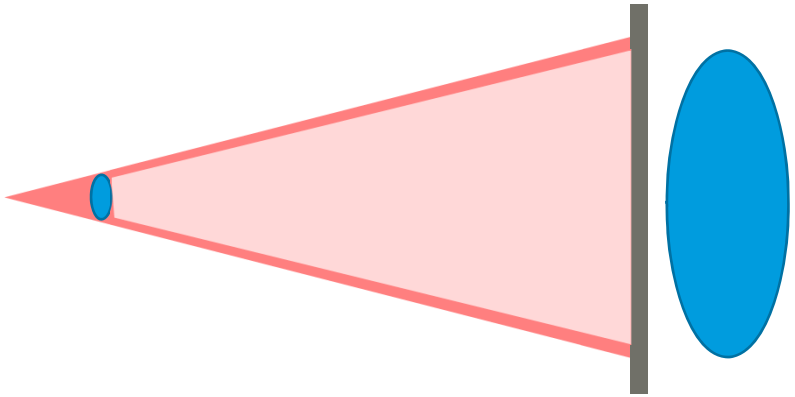
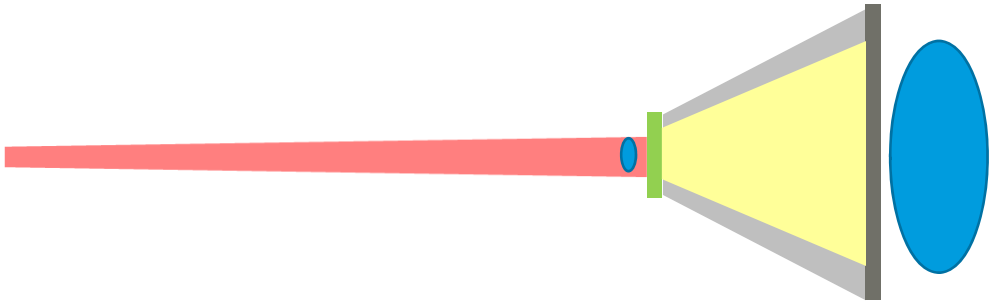


Geometrical magnification

Cone beam geometry



Optical magnification

Parallel beam geometry

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CAN YOU SCAN A LARGE FOV WITH HIGH RESOLUTION?

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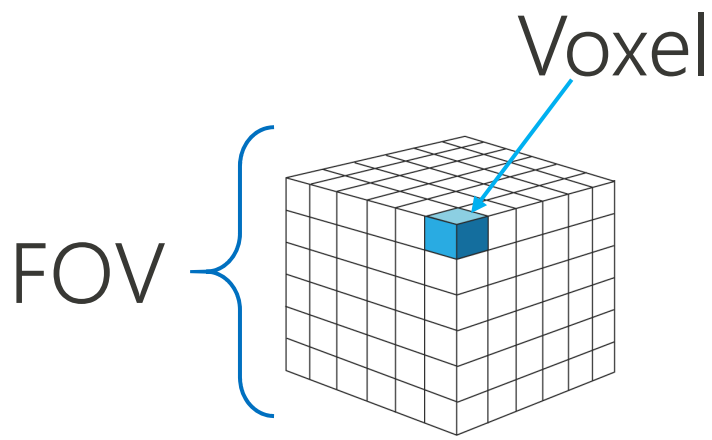
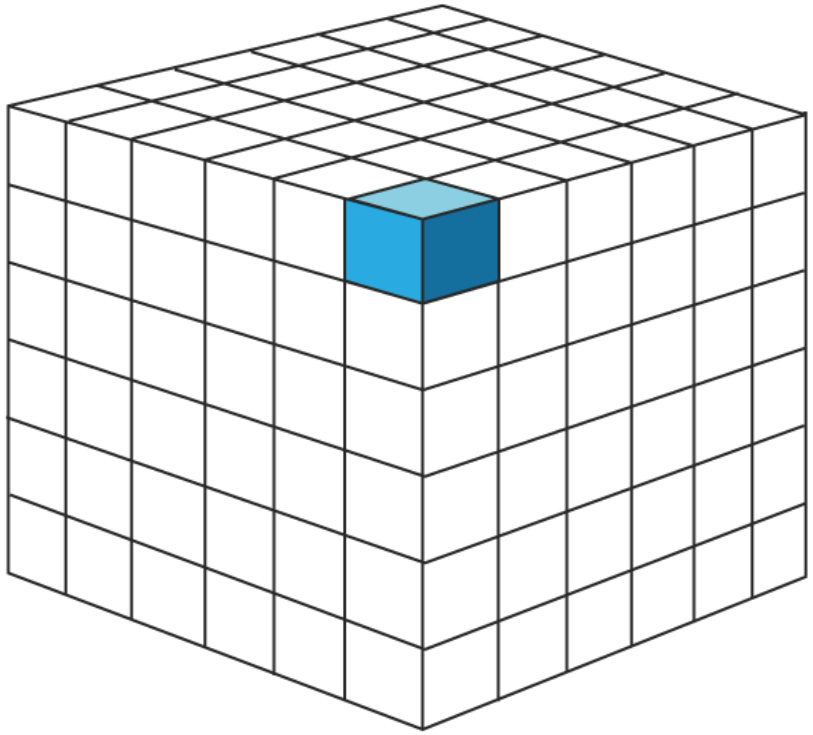


Small FOV, small voxel



Large FOV, large voxel

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$$\text{Voxel size} = \frac{\text{FOV}}{3000} \sim \frac{\text{FOV}}{1000}$$

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AA battery 14.2 x 50 mm



Whole battery @ 1 µm → 20 TB

10 mm^3 @ 10 µm → 2 GB

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WHAT DETERMINES RESOLUTION?

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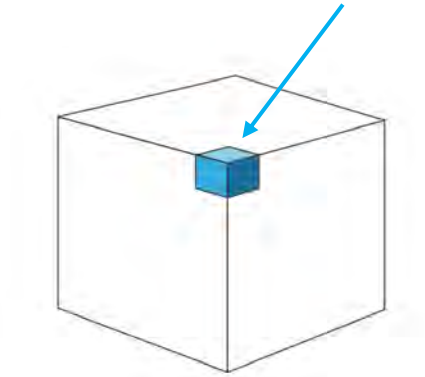
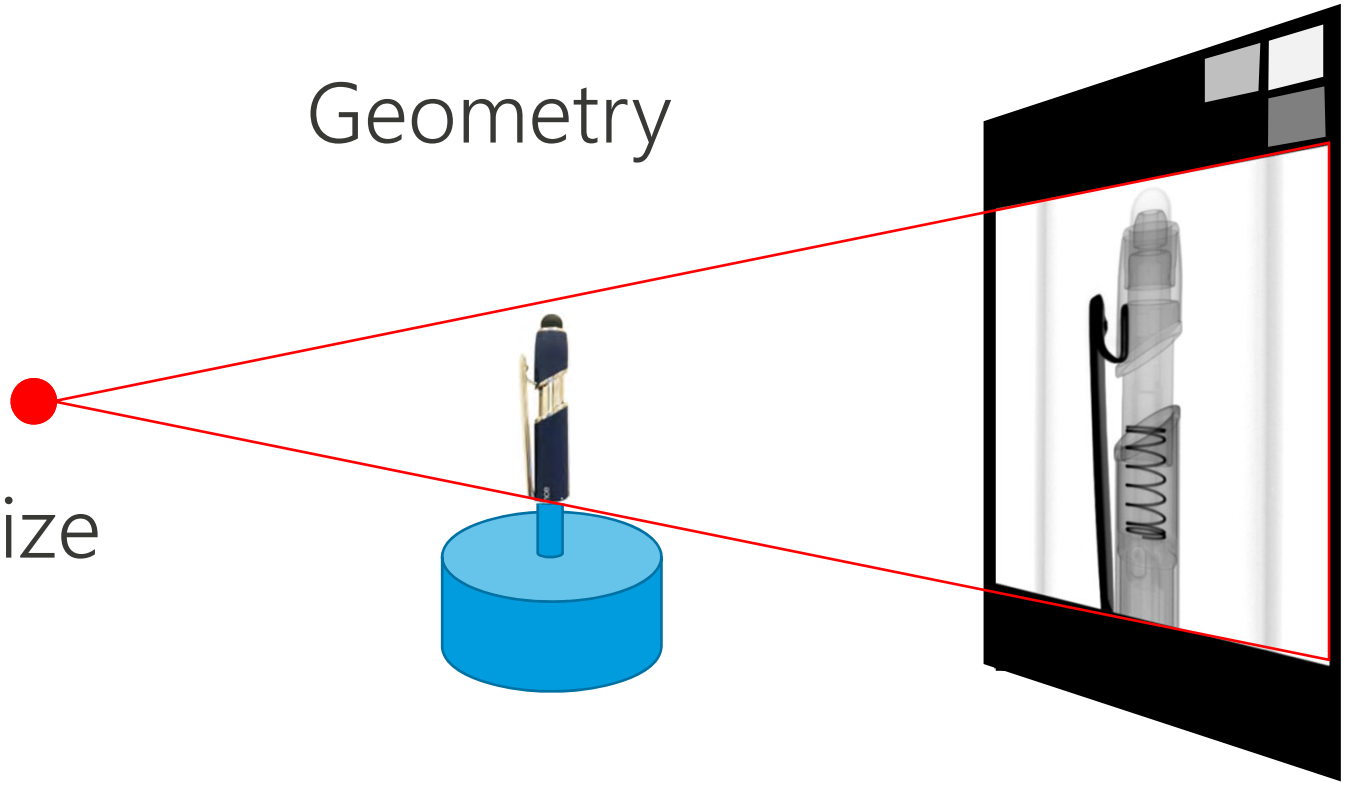
Resolution / voxel size



Pixel size

Geometry

Focus size



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CAN ONE SYSTEM DO EVERYTHING?

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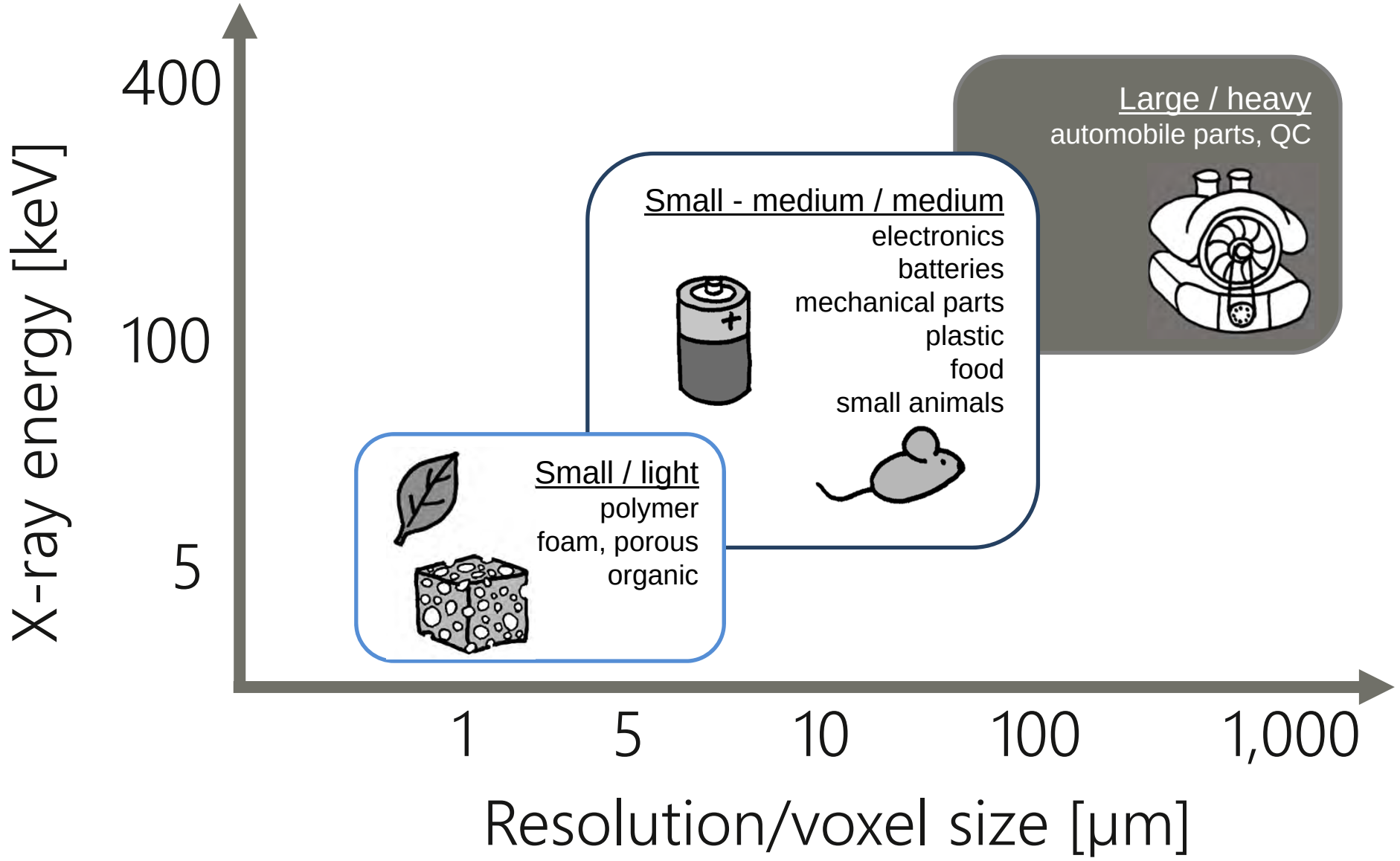

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WHAT DOES RIGAKU MAKE?

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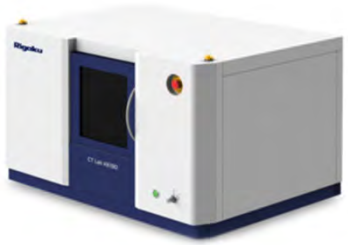
nano3DX



CT Lab HX



CT Lab GX



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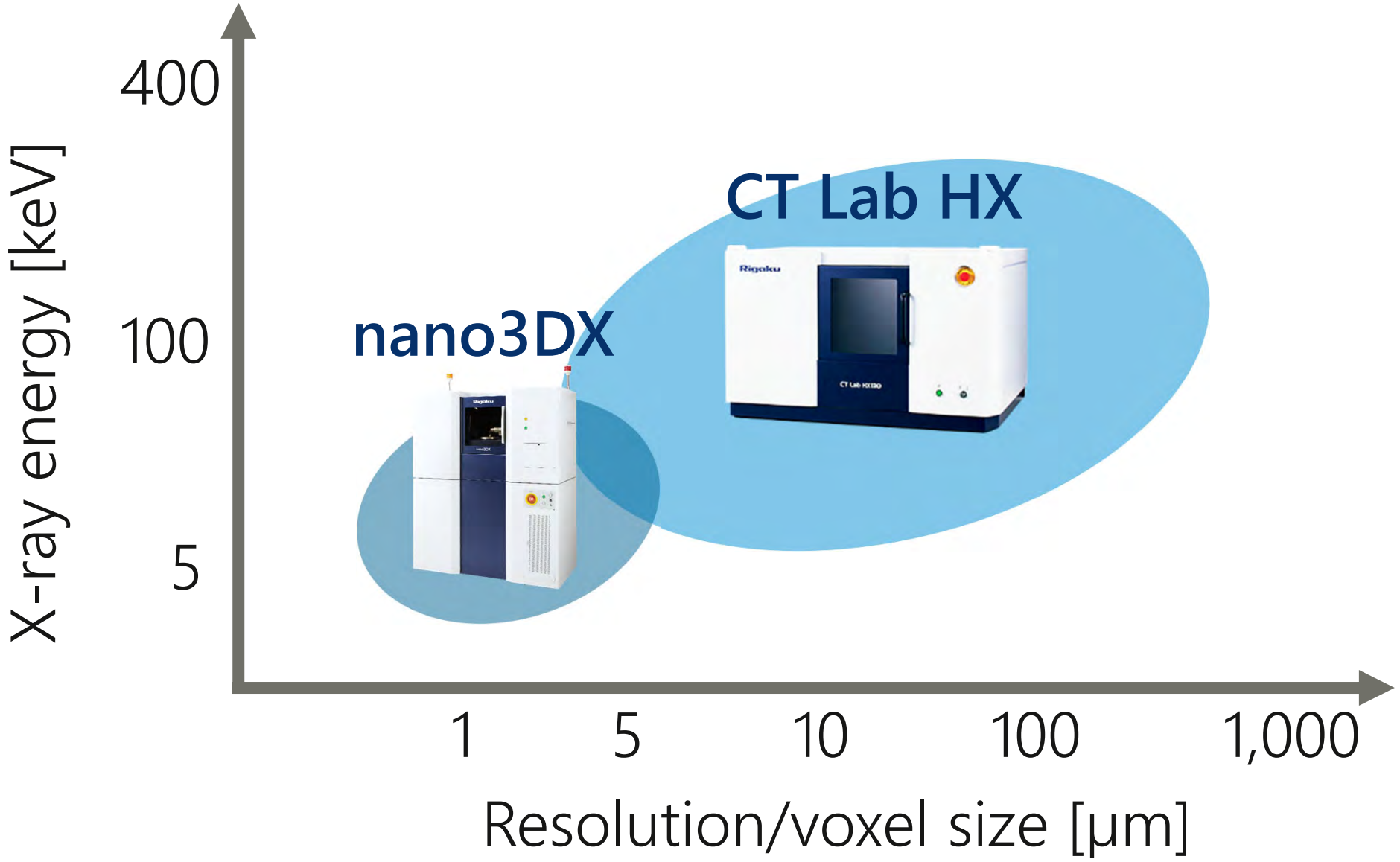

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COVALENT METROLOGY

Dr. Colleen Frazer
Dr. Ben Foley
Kenny Nguyen



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Versatile benchtop microCT

- 2.2 µm voxel resolution
- Max. 200 mmφ FOV
- 130 kV (39 W) source



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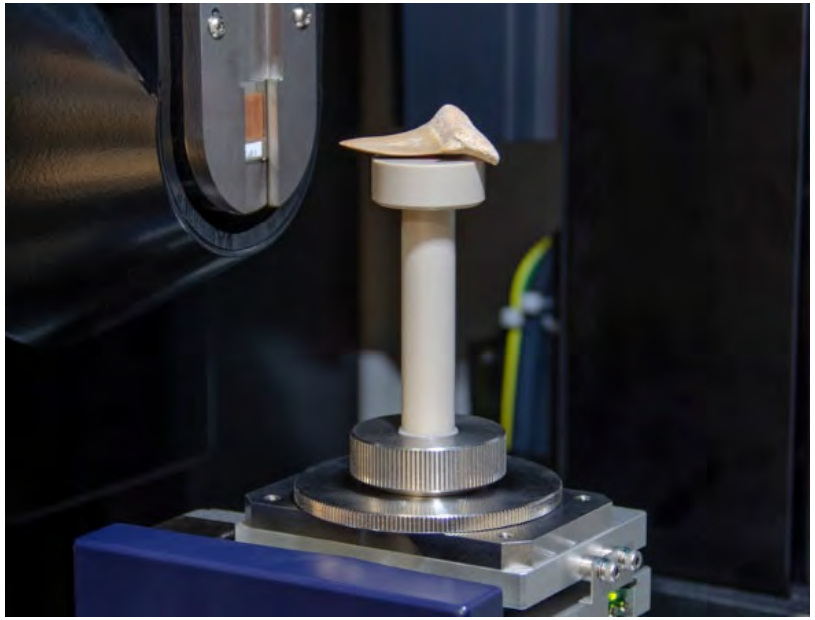

20 mm FOV



200 mm FOV

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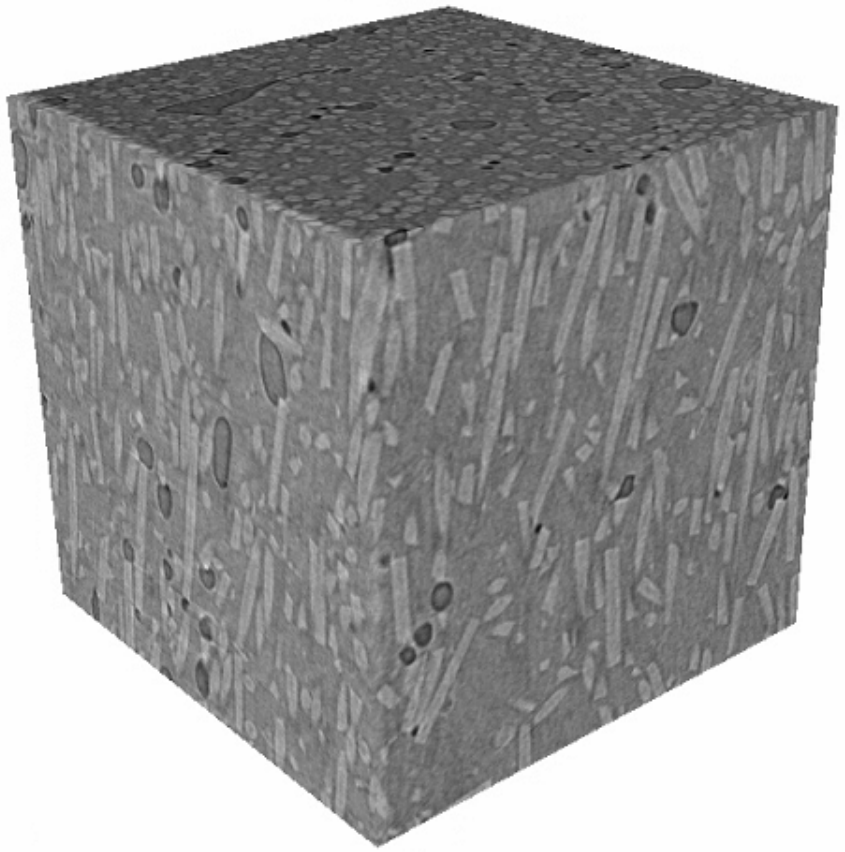

3D volume data

CFRP – nano3DX

Collect projections

Reconstruct 3D volume

Segment image

Separate objects

Analyze properties

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HOW DO YOU ANALYZE CT DATA?

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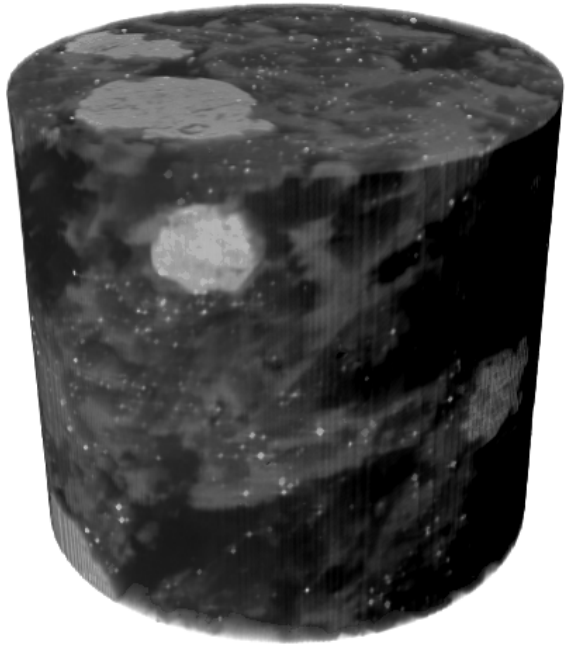
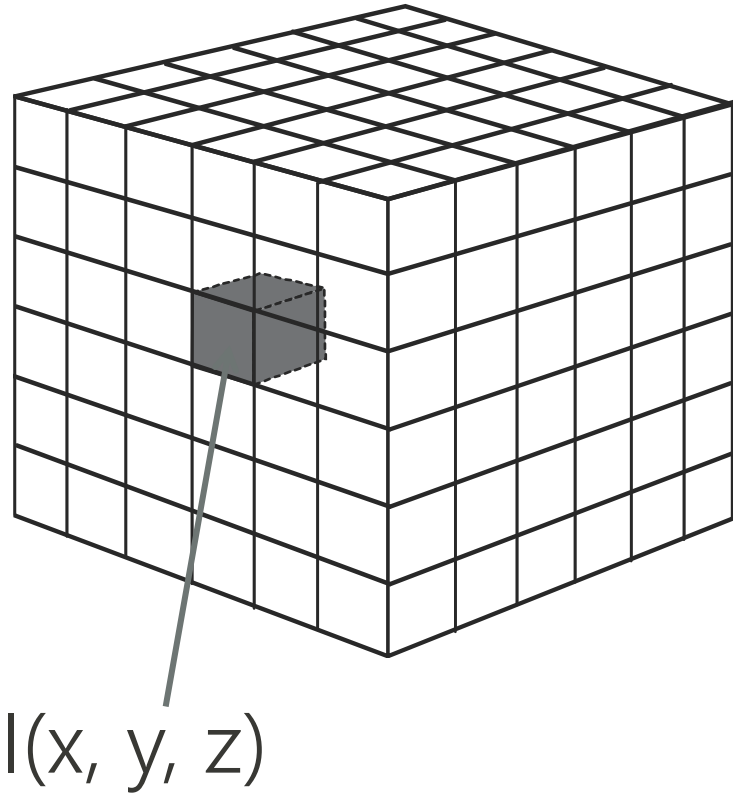
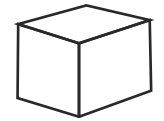
3D rendering



Rock – CT Lab HX





Voxel

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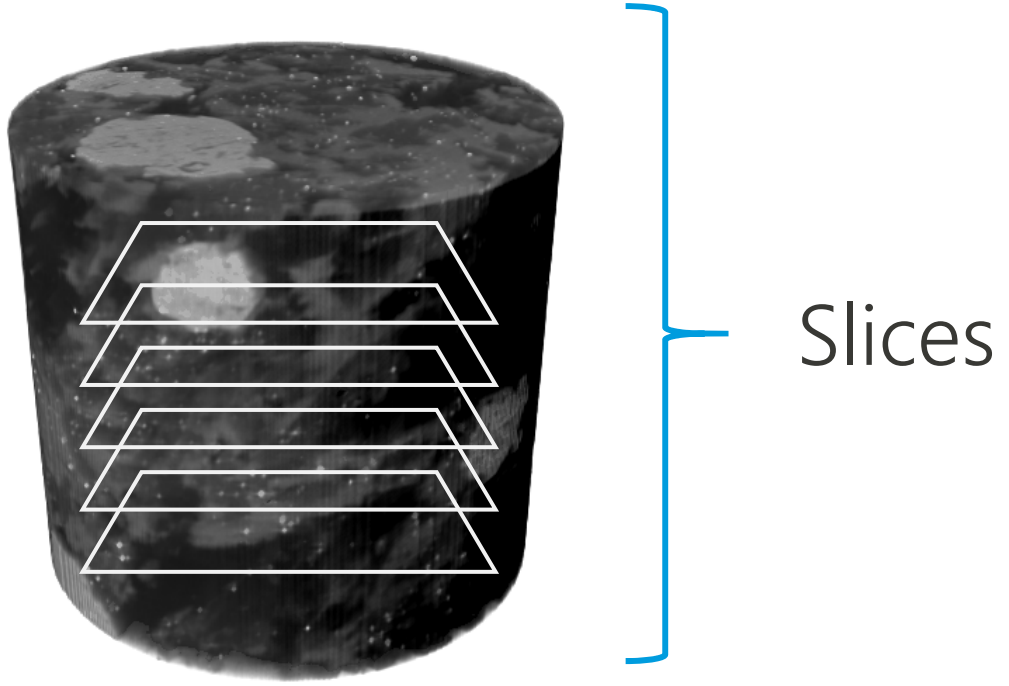

TIFF stack

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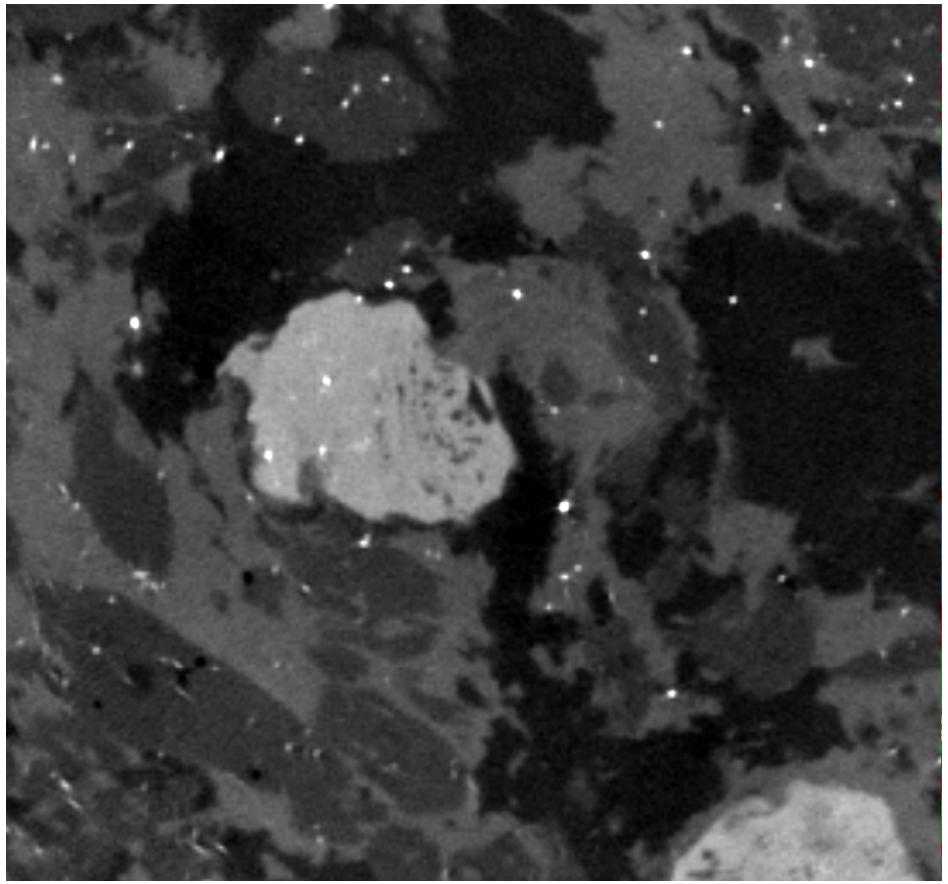

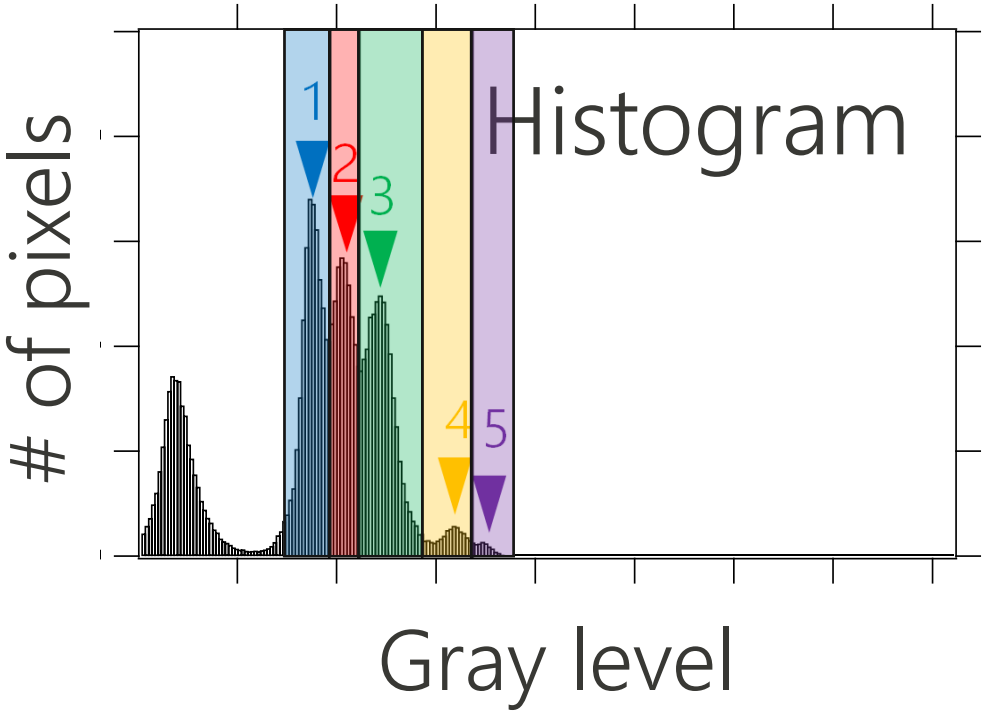

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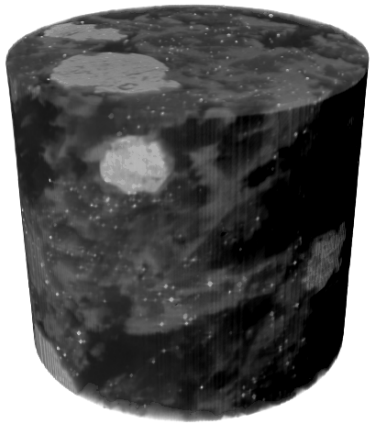

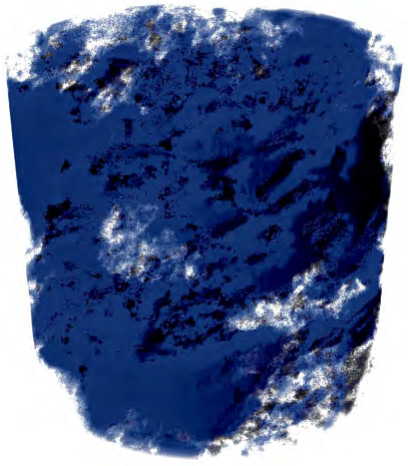



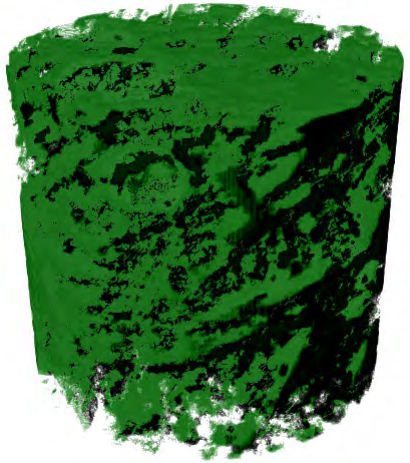



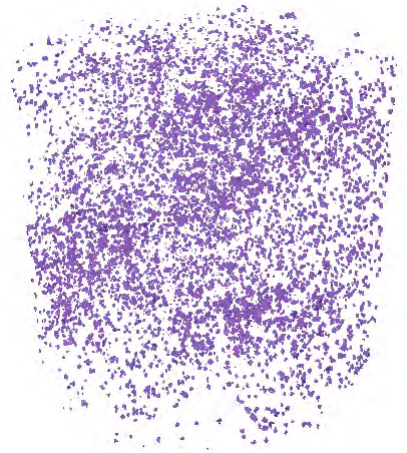

22.2 %

42.4 %

26.2 %

8.9 %

0.3 %

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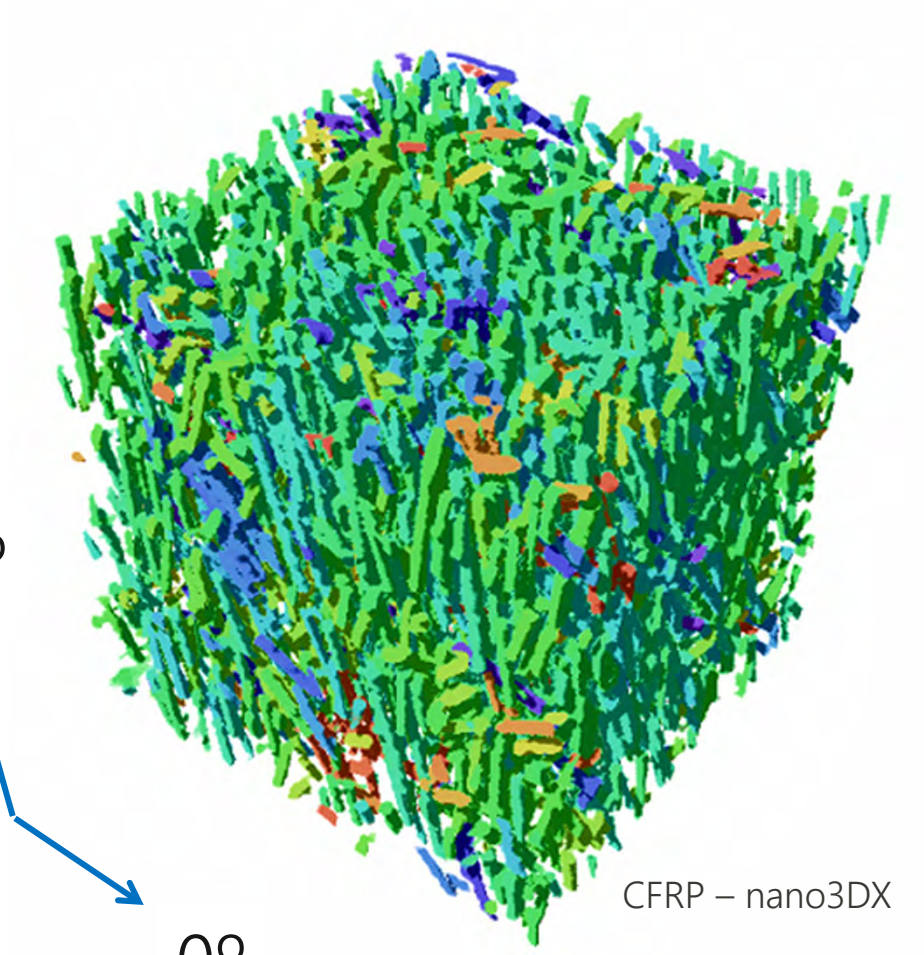
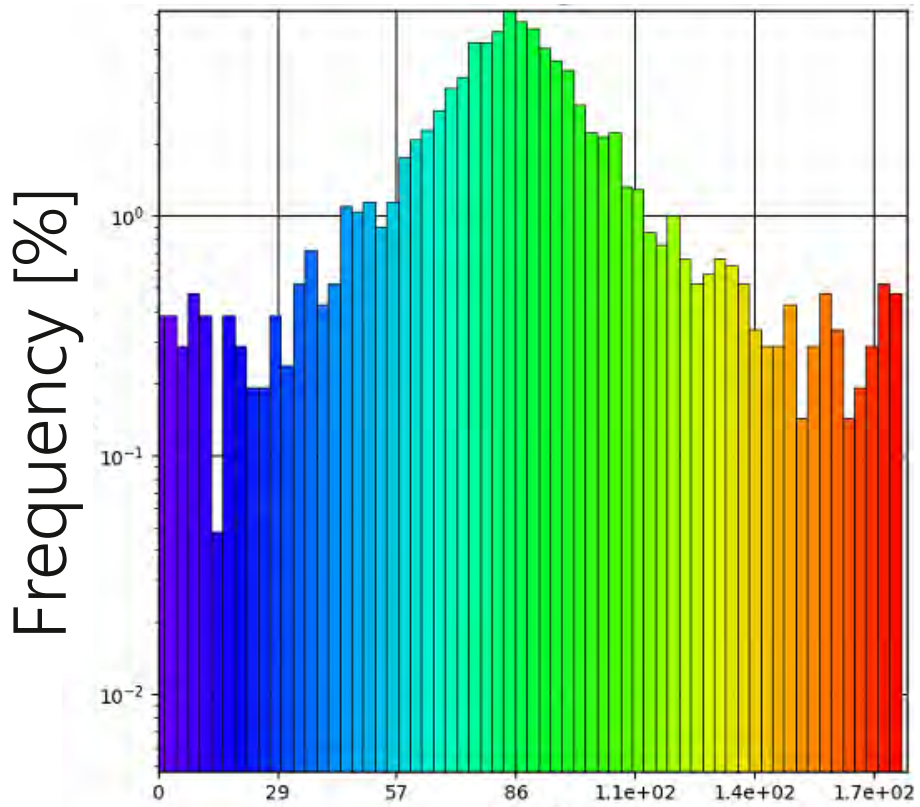


CFRP – nano3DX



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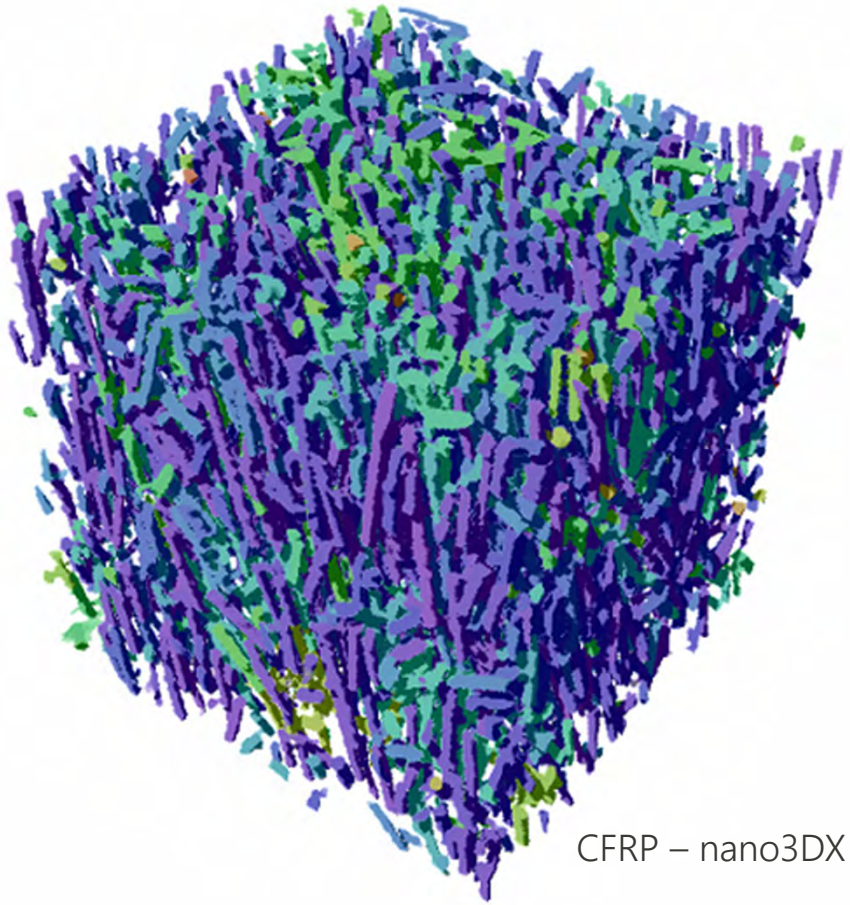
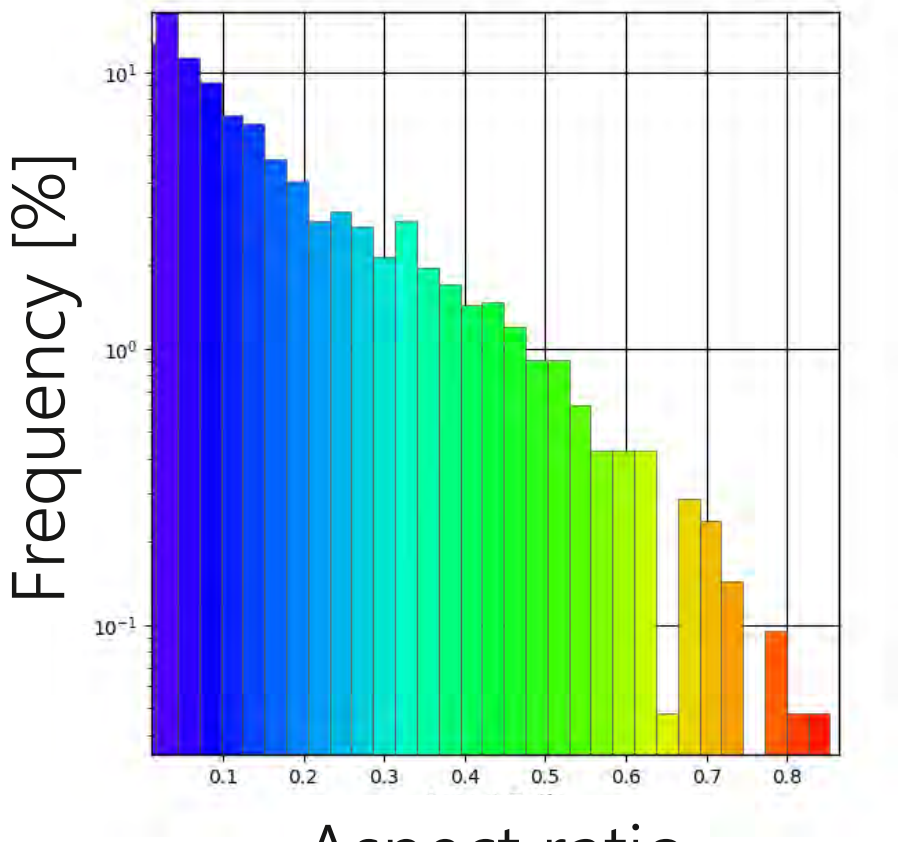


CFRP – nano3DX

Long  Short



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WHAT'S NEW?

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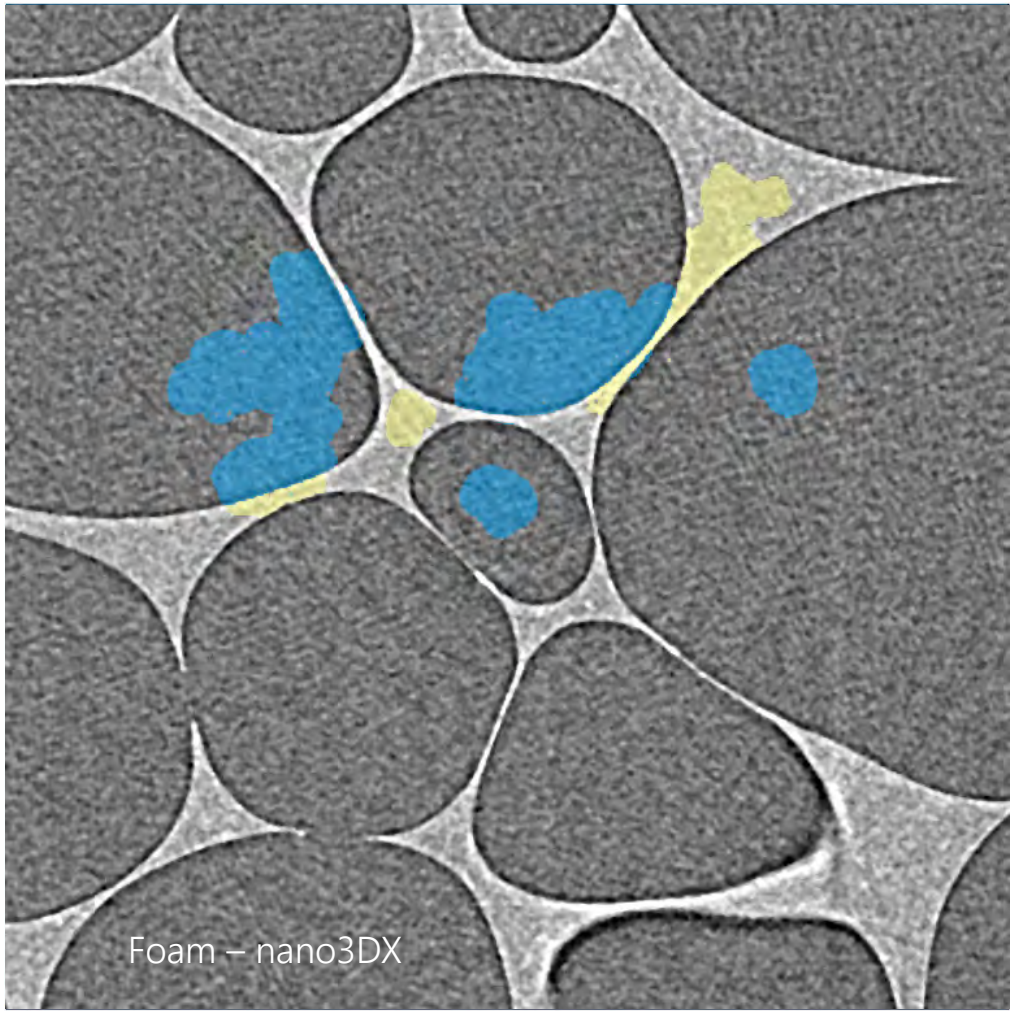
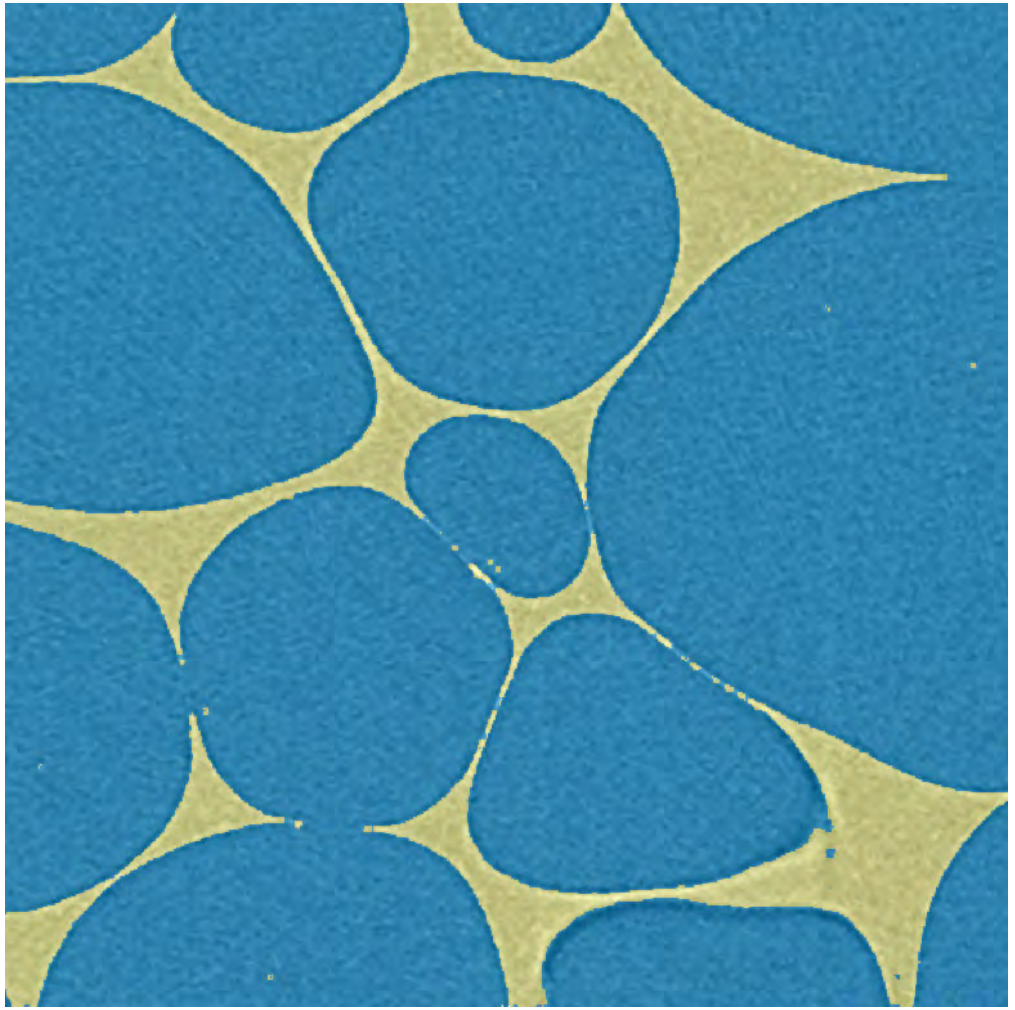
- Machine learning
- Deep learning
- CT vs. CAD
- CT → Finite element analysis
- CT → pore network
- CT → permeability



Machine learning





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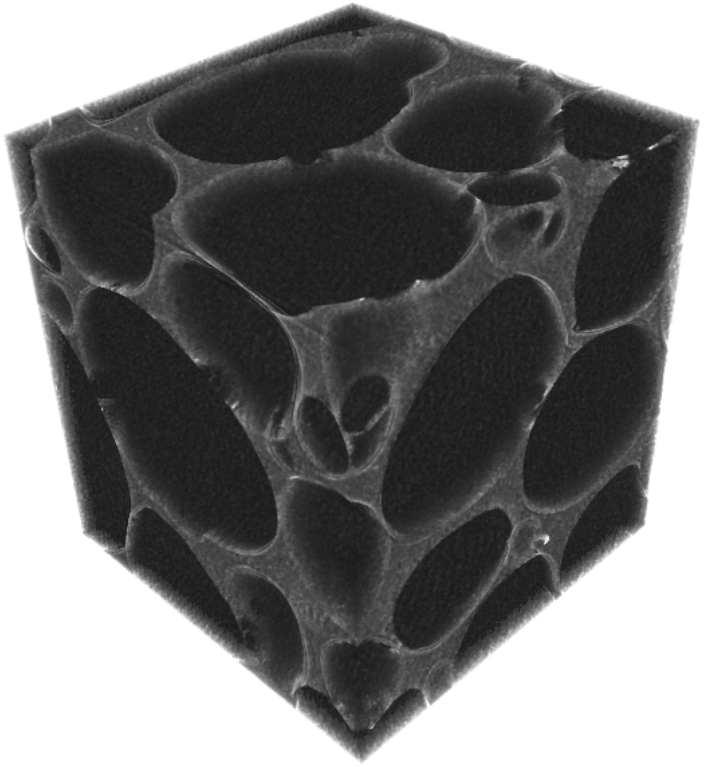
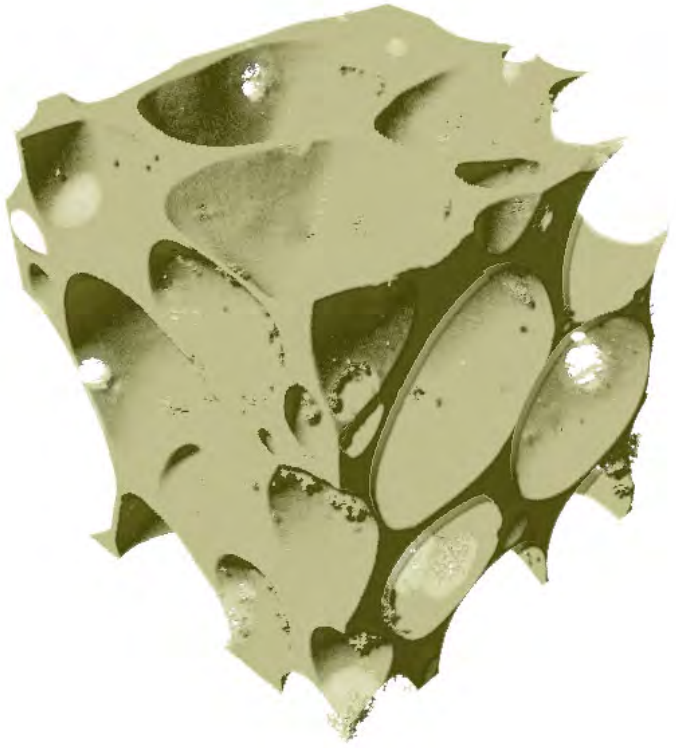
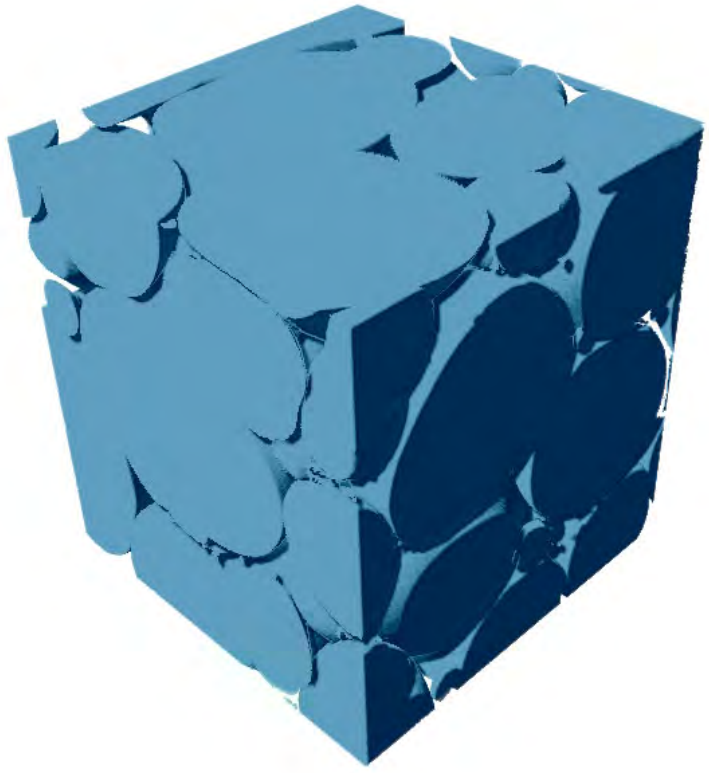
Machine learning



Raw image



Polymer



Air

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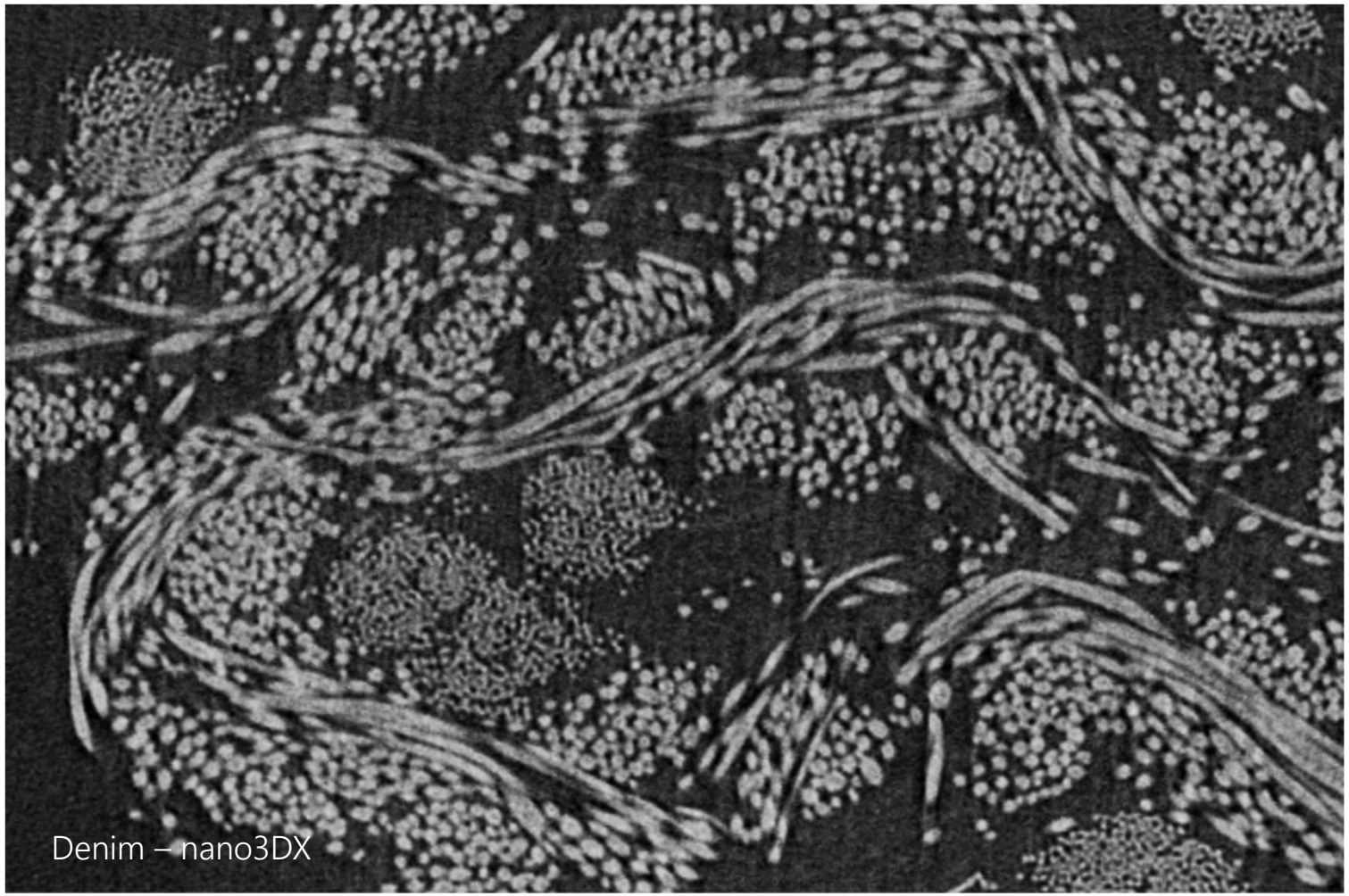
Deep learning



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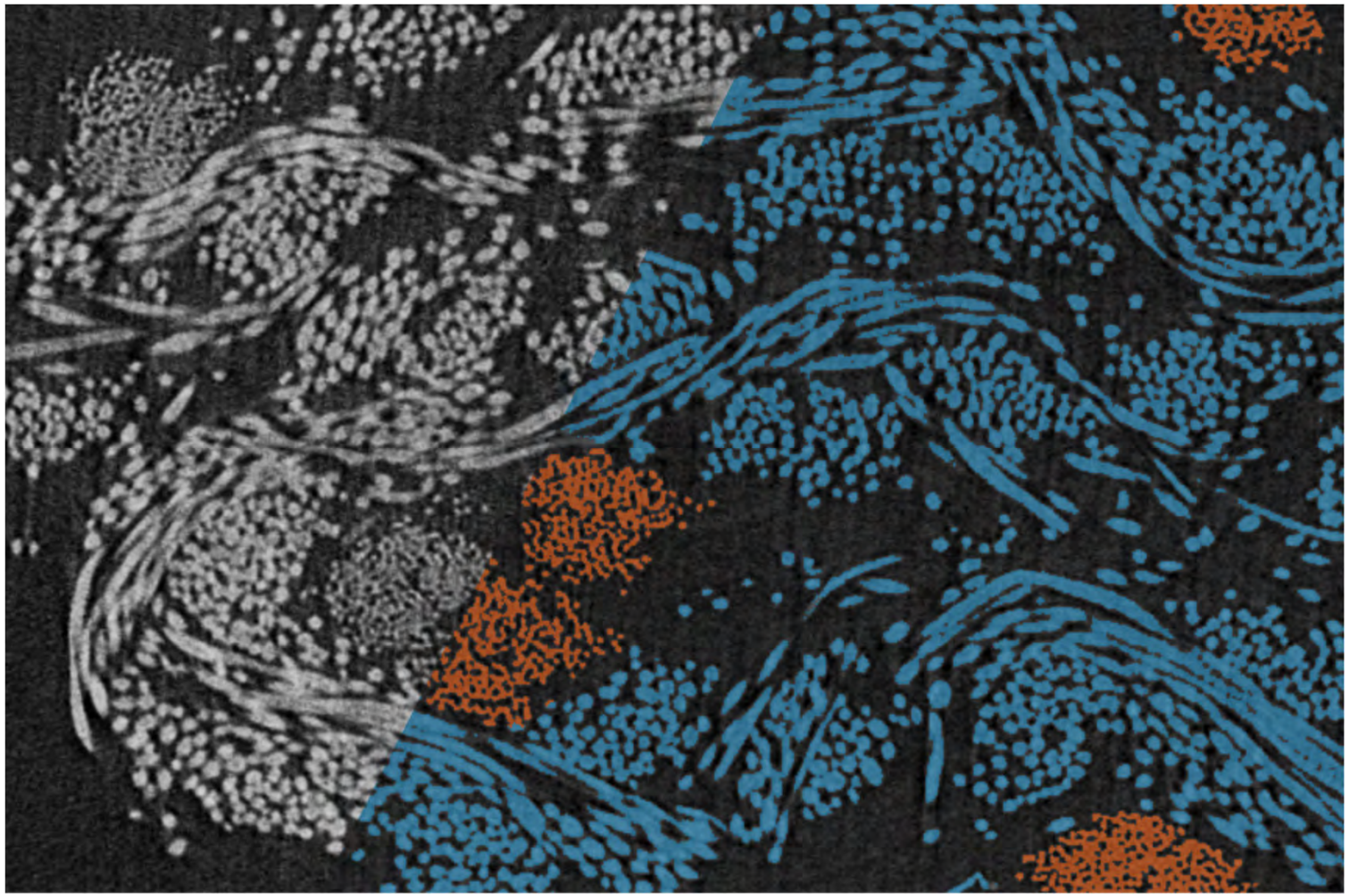
Deep learning



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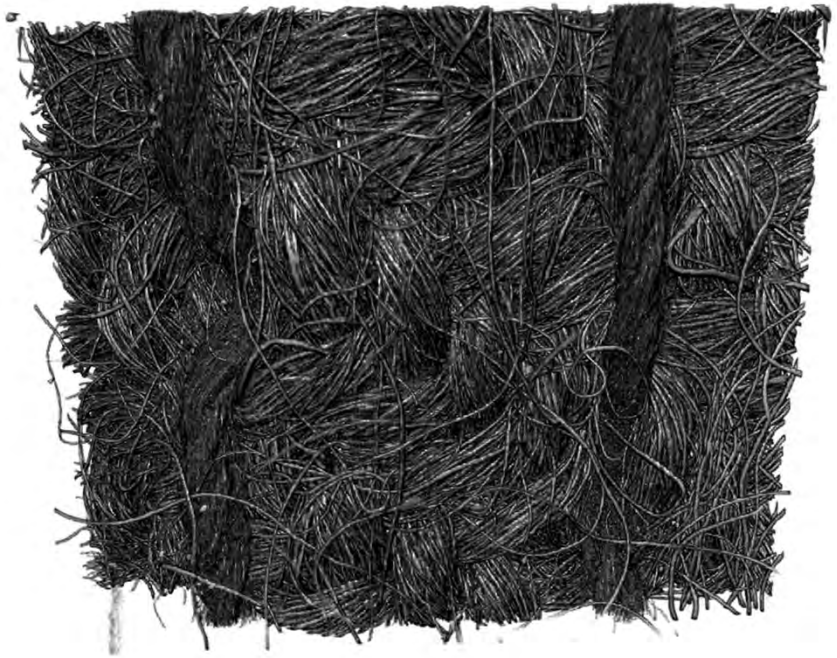
Deep learning





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Geometric dimensioning & tolerancing



Aluminum part – CT Lab HX

▱	0.25

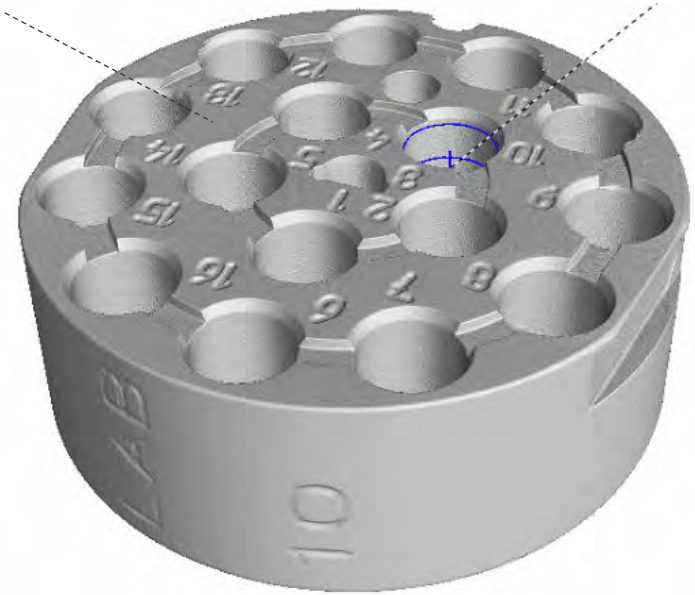
Actual 0.27 mm

● Out of tolerance

⌭	0.01

Actual 0.06 mm

● Status OK



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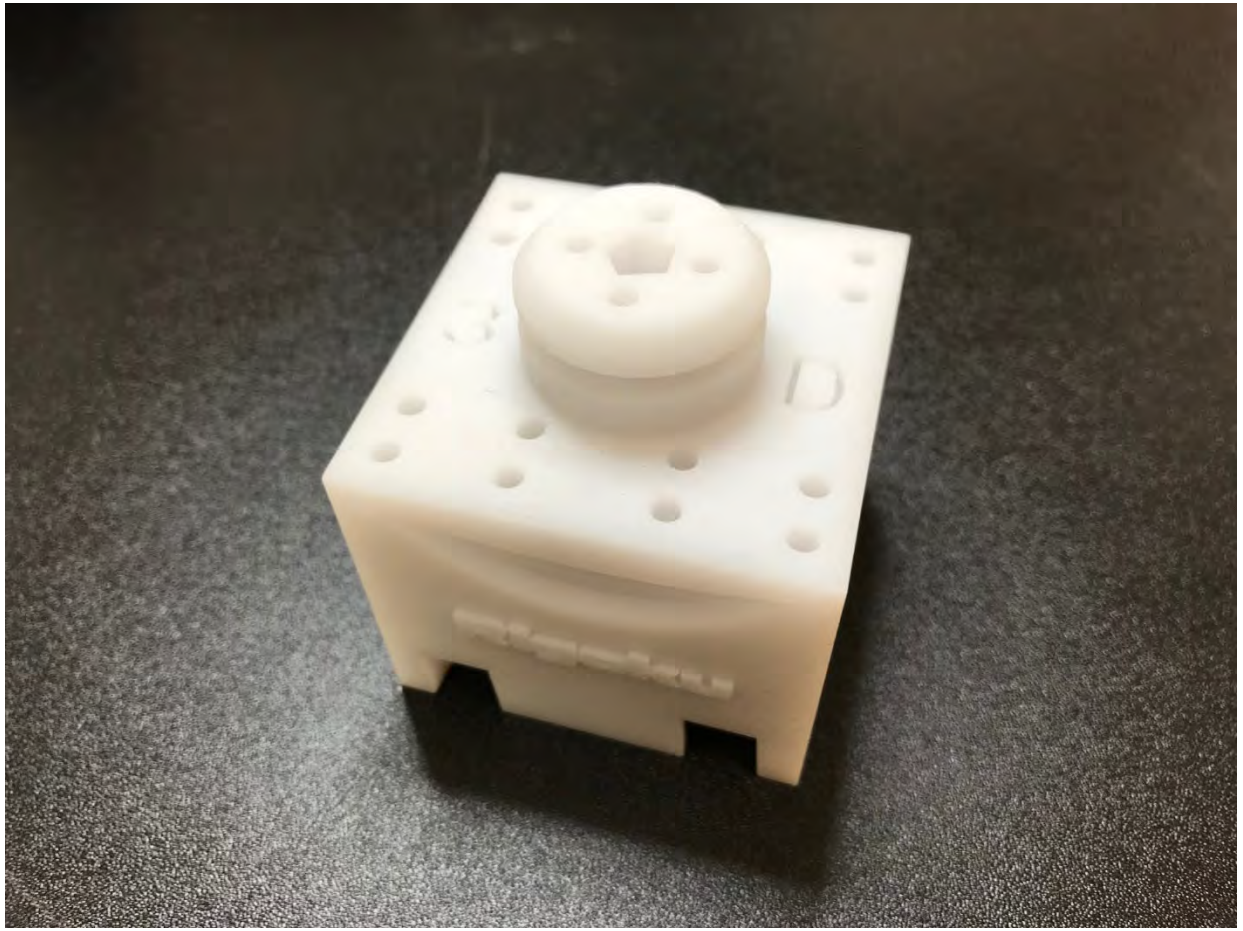
Nominal vs. actual comparison



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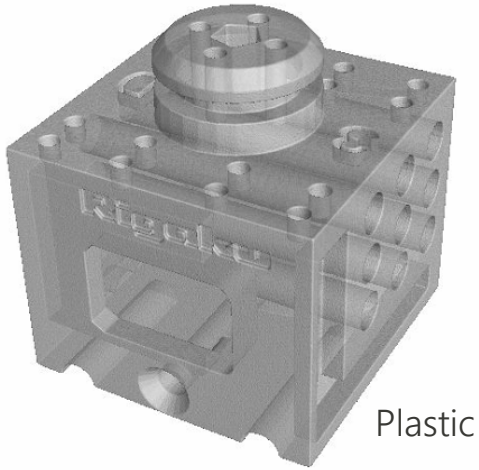
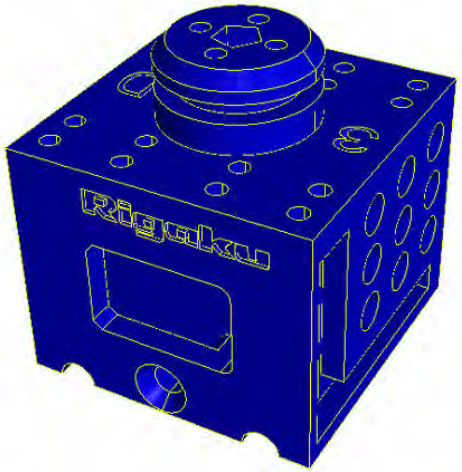
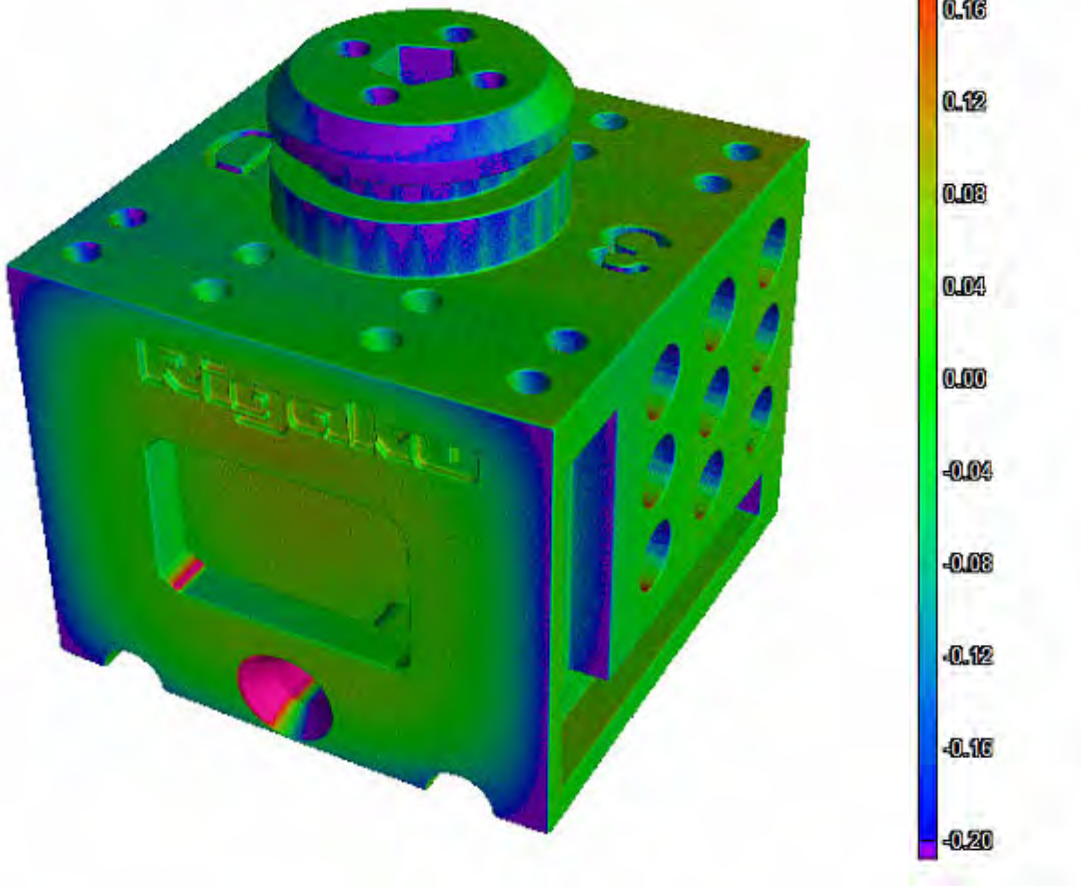
Nominal vs. actual comparison



Plastic part – CT Lab HX





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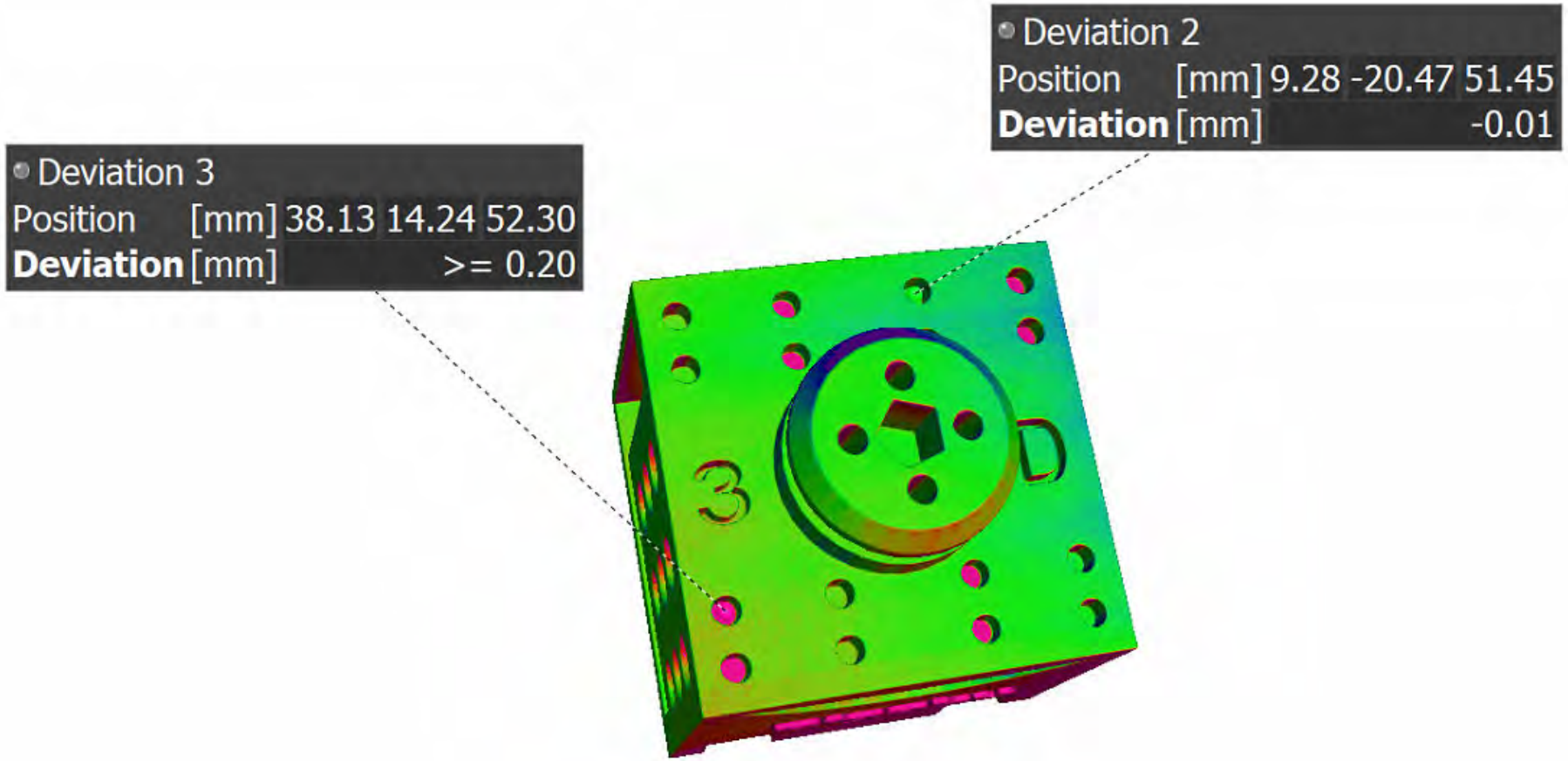

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- Machine learning
- Deep learning
- CT vs. CAD
- CT → Finite element analysis
- CT → pore network
- CT → permeability



MORE EXAMPLES

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Smartphone

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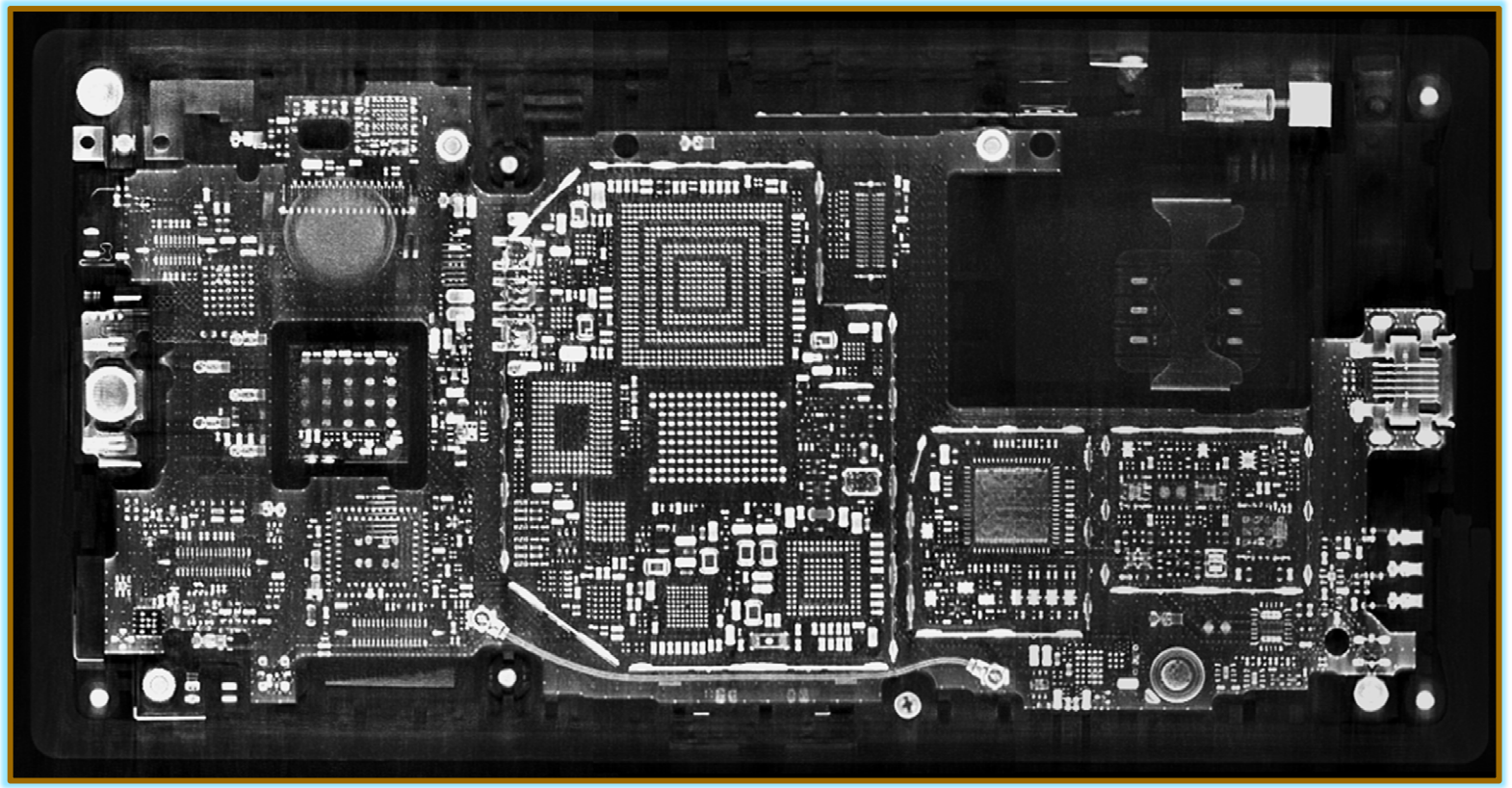

CT Lab HX

Smartphone

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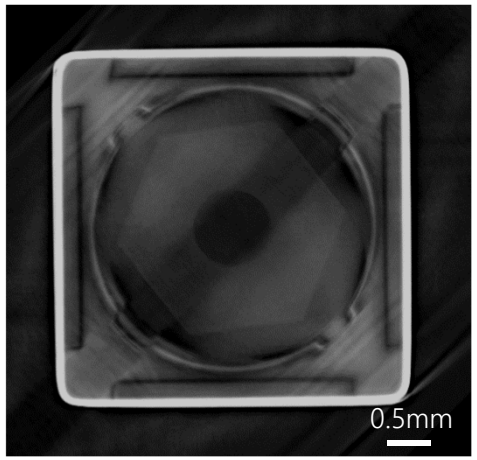
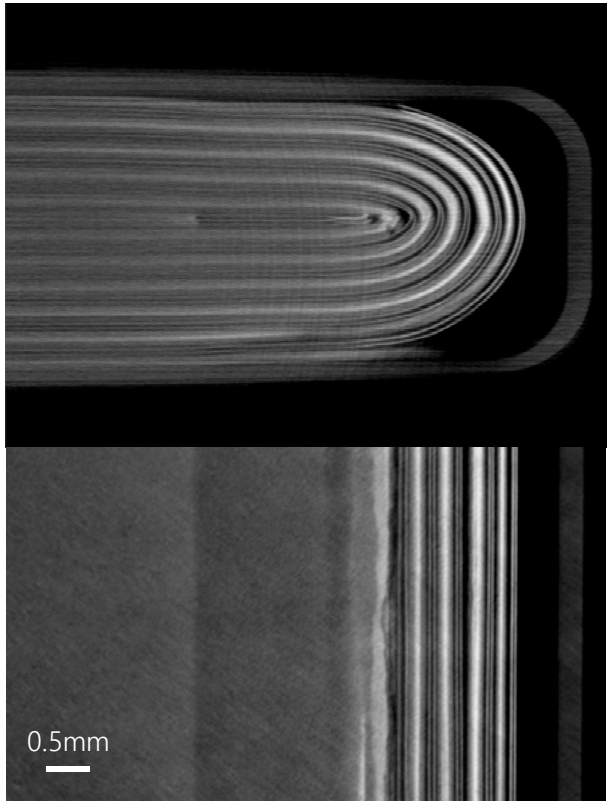
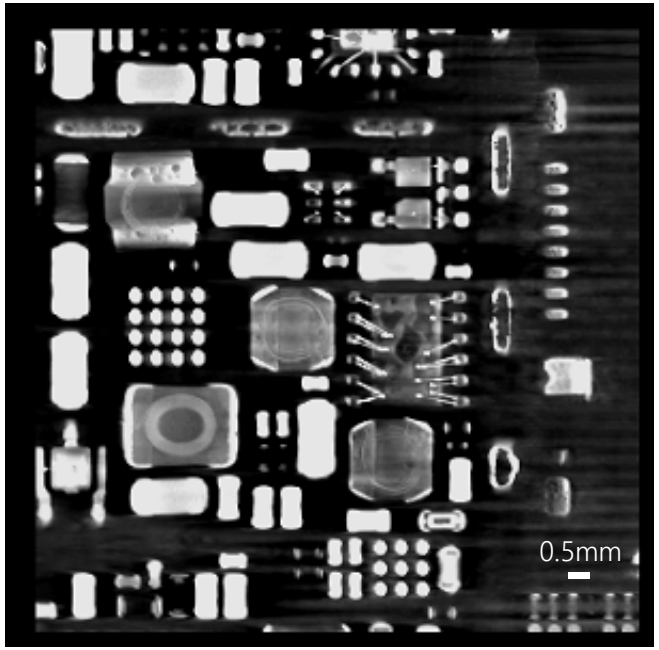


Camera lens



Li ion battery



Circuit board

CT Lab HX

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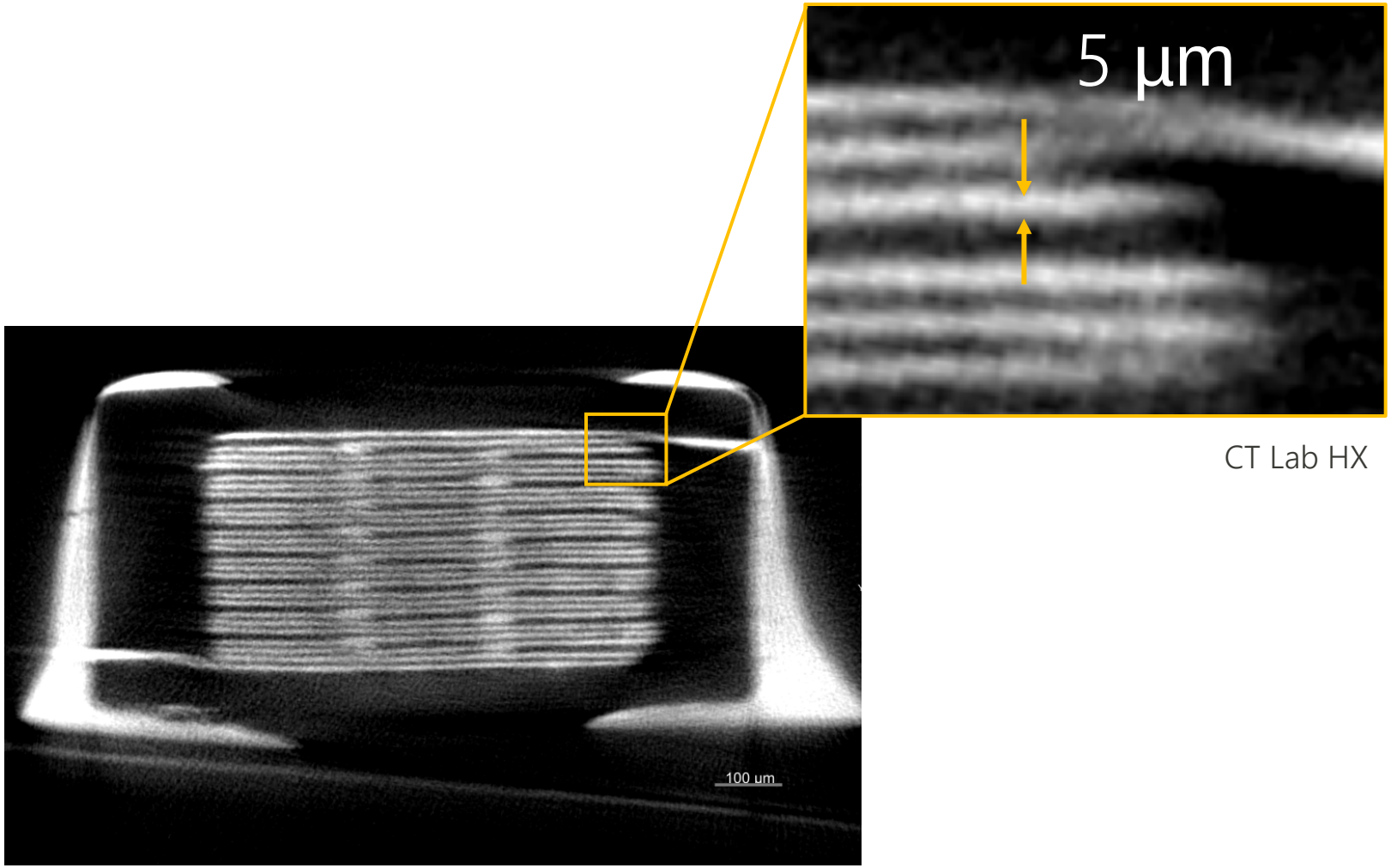

CT Lab HX

Condenser

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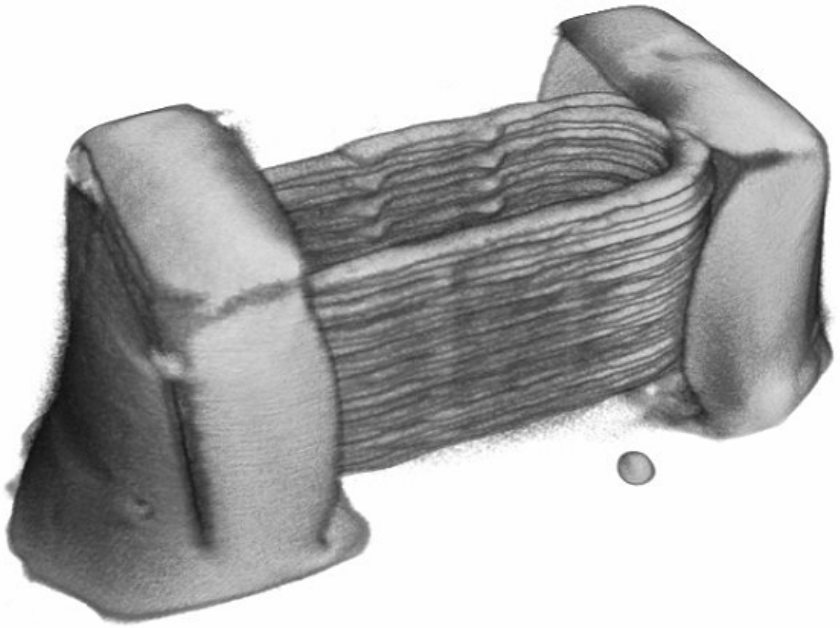

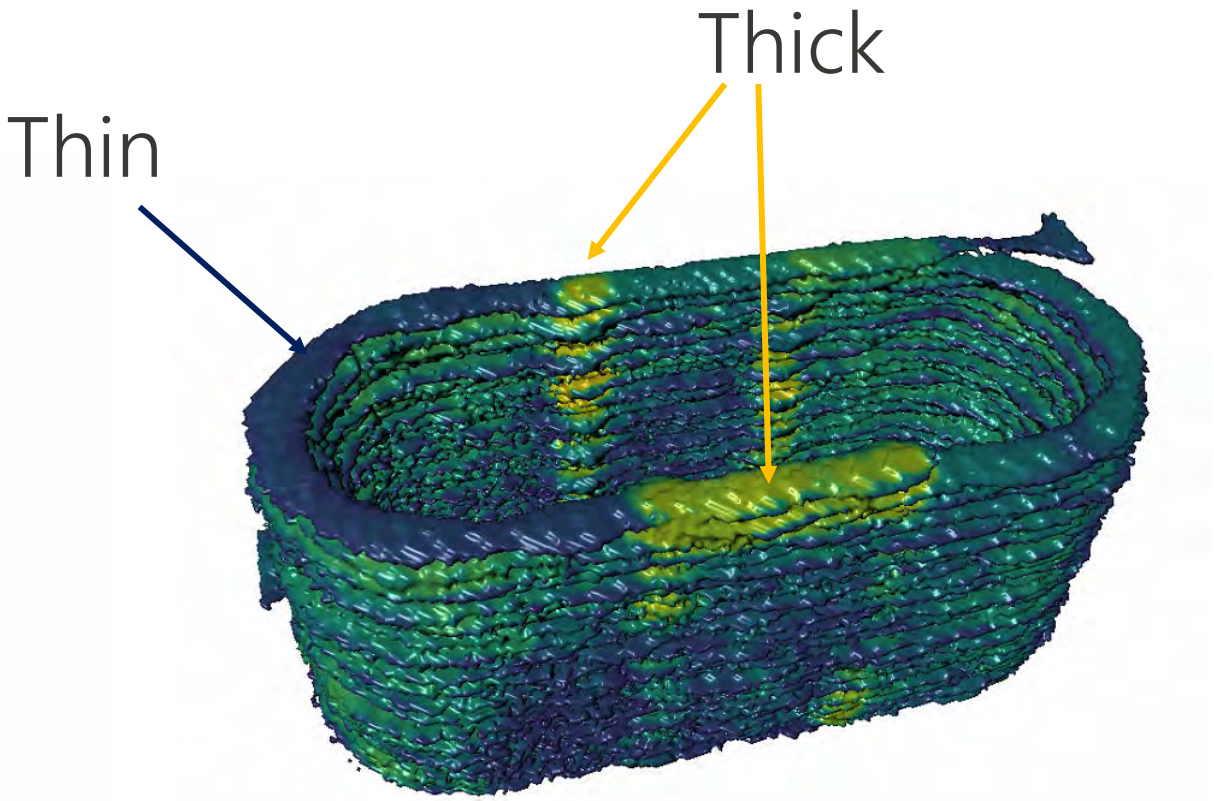

Thickness distribution

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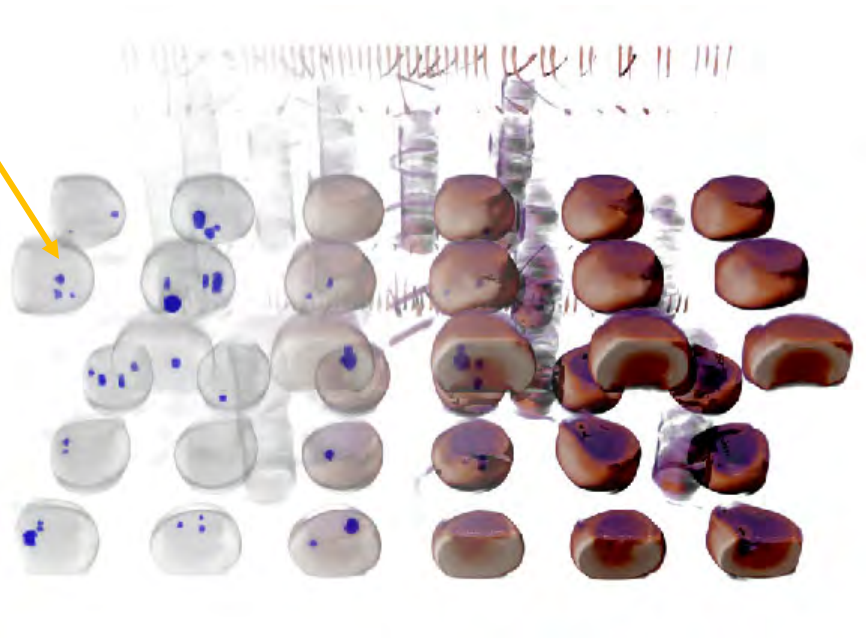
Voids in soldering



CT Lab HX

Memory card

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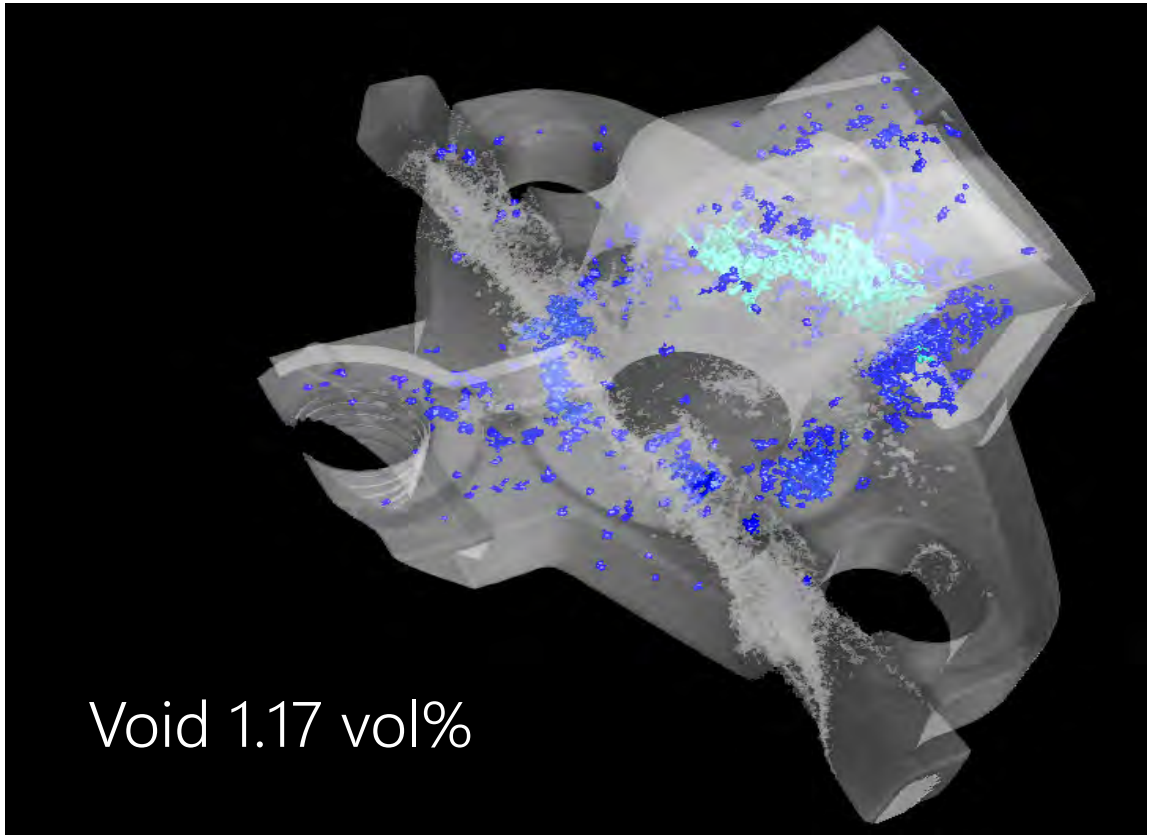

CT Lab HX

Al die-casting

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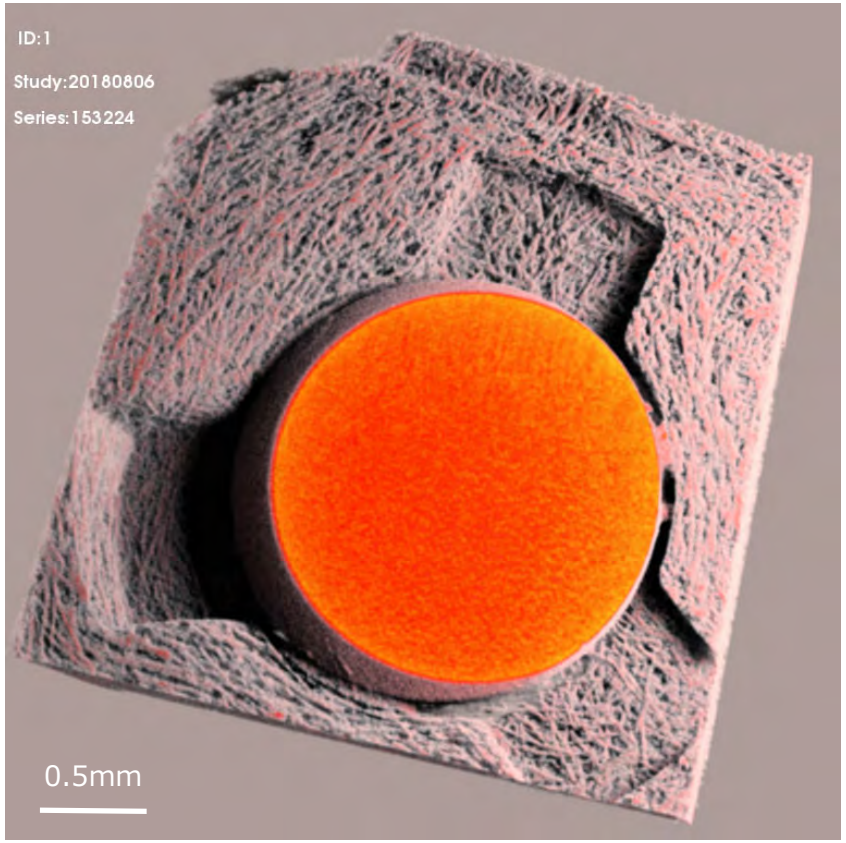

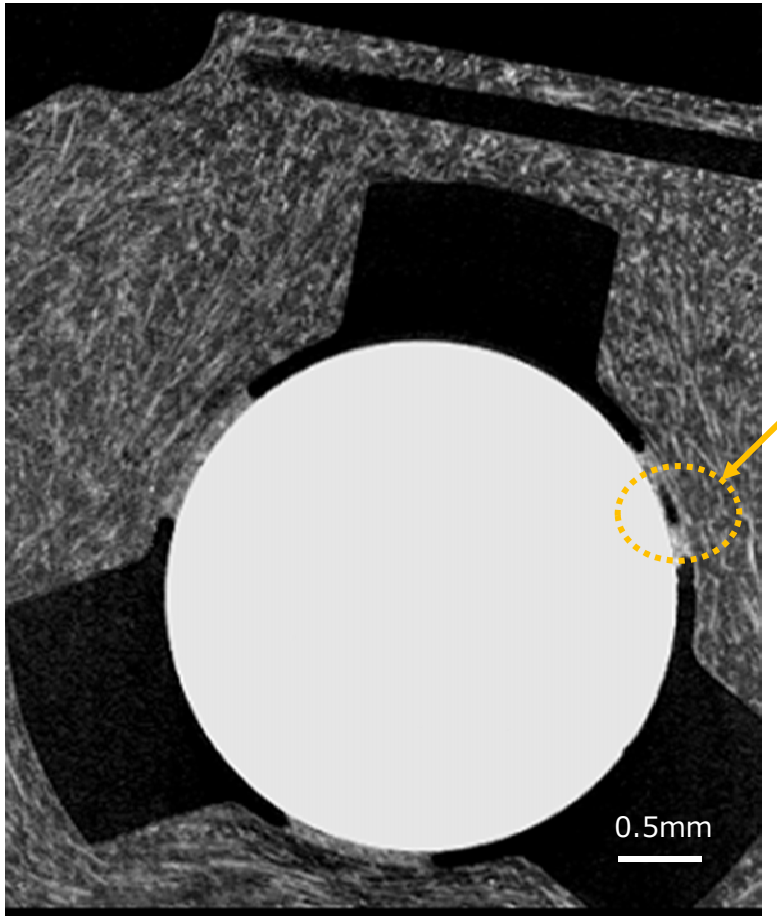

CT Lab HX

Smartphone camera assembly

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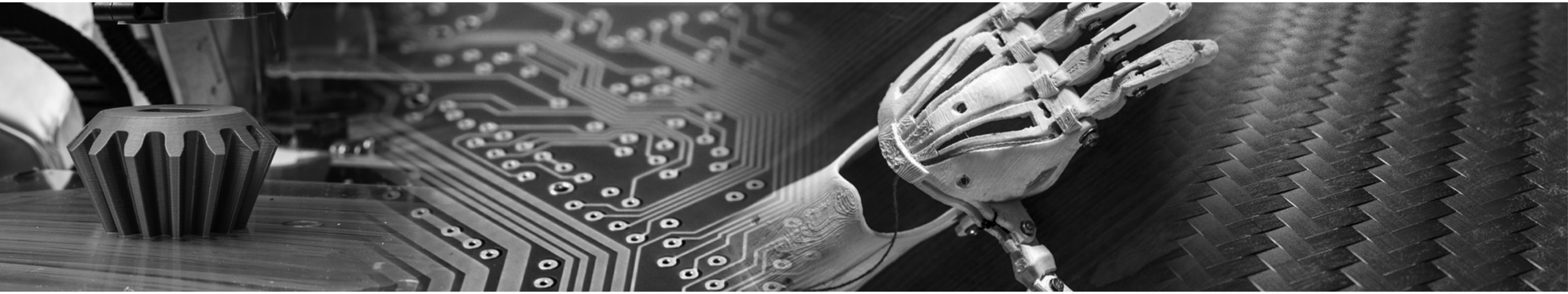

- Electronics
- Batteries
- Metal parts
- Plastic molds
- 3D printed parts
- Composites

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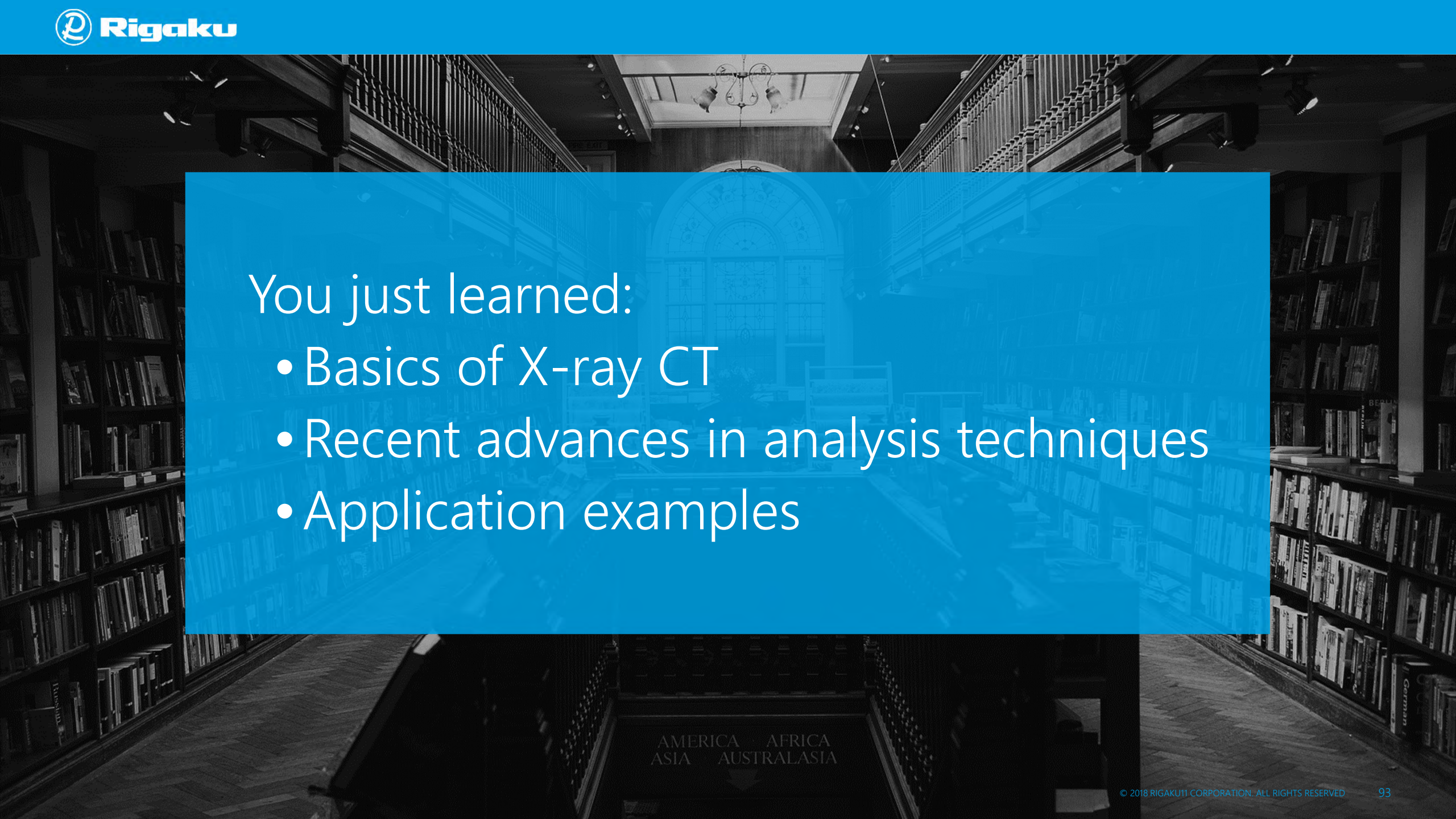

You just learned:

- Basics of X-ray CT
- Recent advances in analysis techniques
- Application examples

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