WELCOME

RIGAKU WEBINAR SERIES

X-RAY COMPUTED TOMOGRAPHY FOR MATERIALS SCIENCE – *INTRODUCTION*

IS STARTING NOW.

Presenter: Aya Takase

Senior Scientist
Rigaku Americas Corporation

Host: Tom McNulty

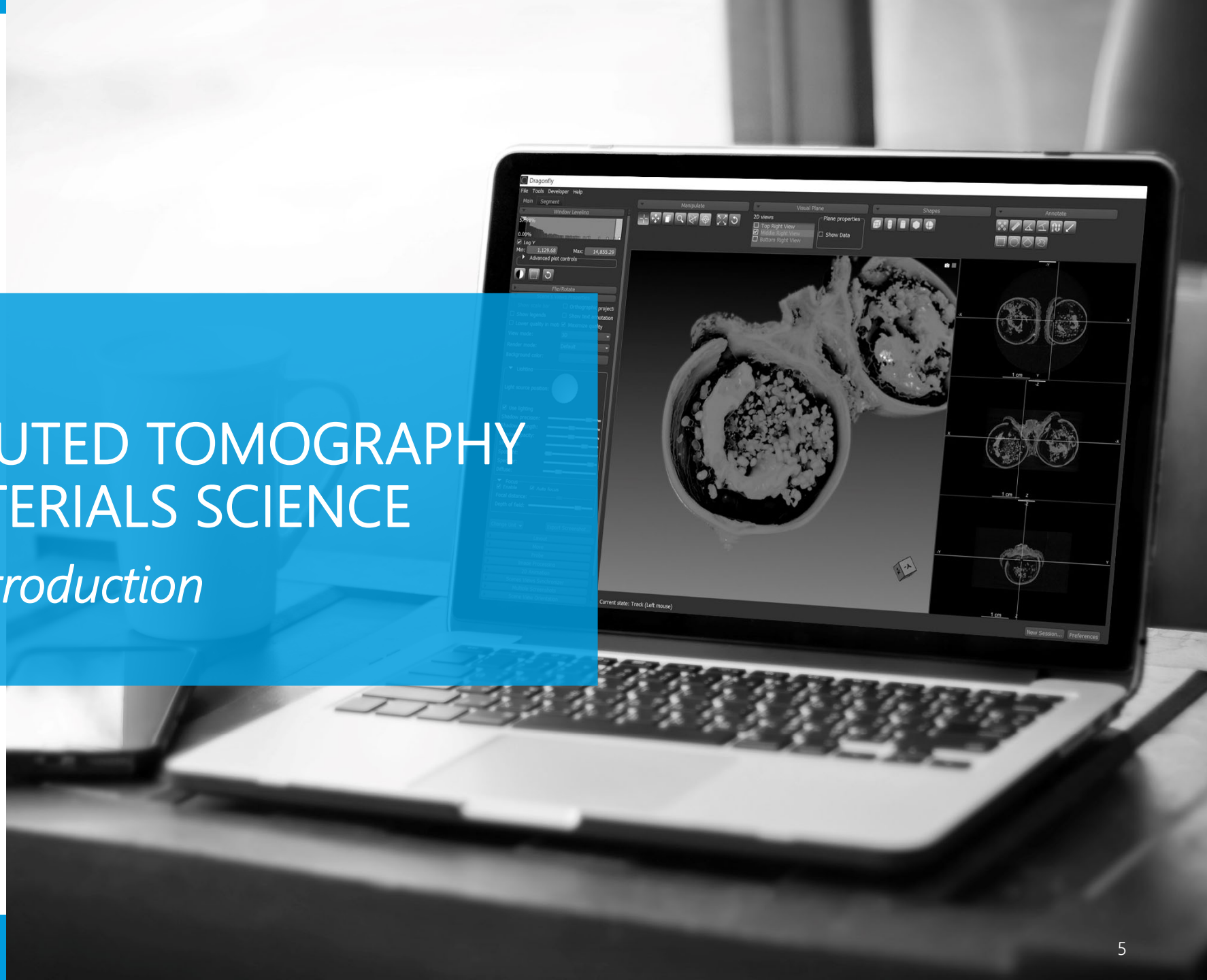
Senior Vice President
Rigaku Americas Corporation

You can send us questions during the presentation.
They will be addressed at the end of the presentation.

A recording of this webinar will be available.
You will receive an email with a link to it tomorrow.

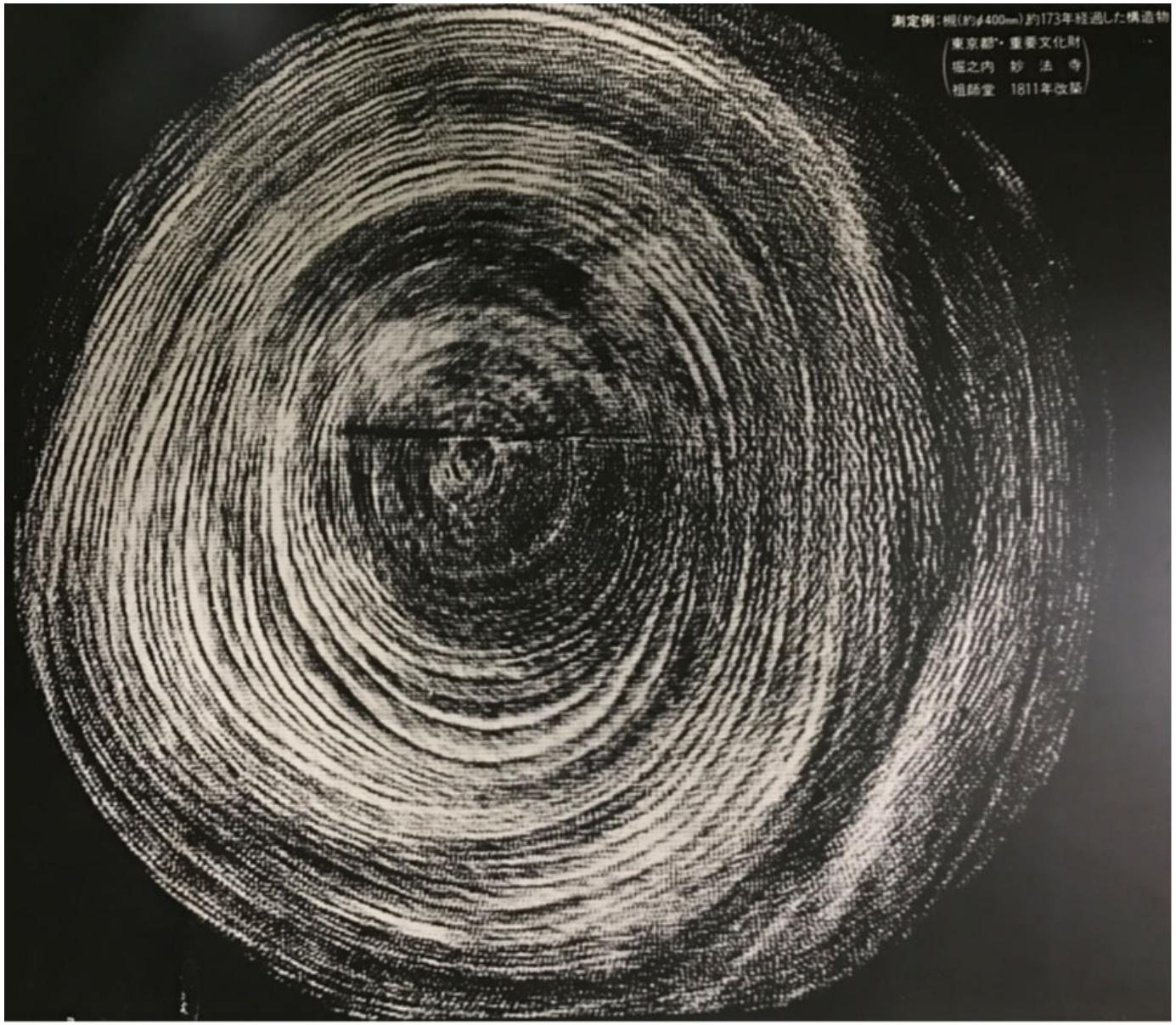
X-RAY COMPUTED TOMOGRAPHY FOR MATERIALS SCIENCE

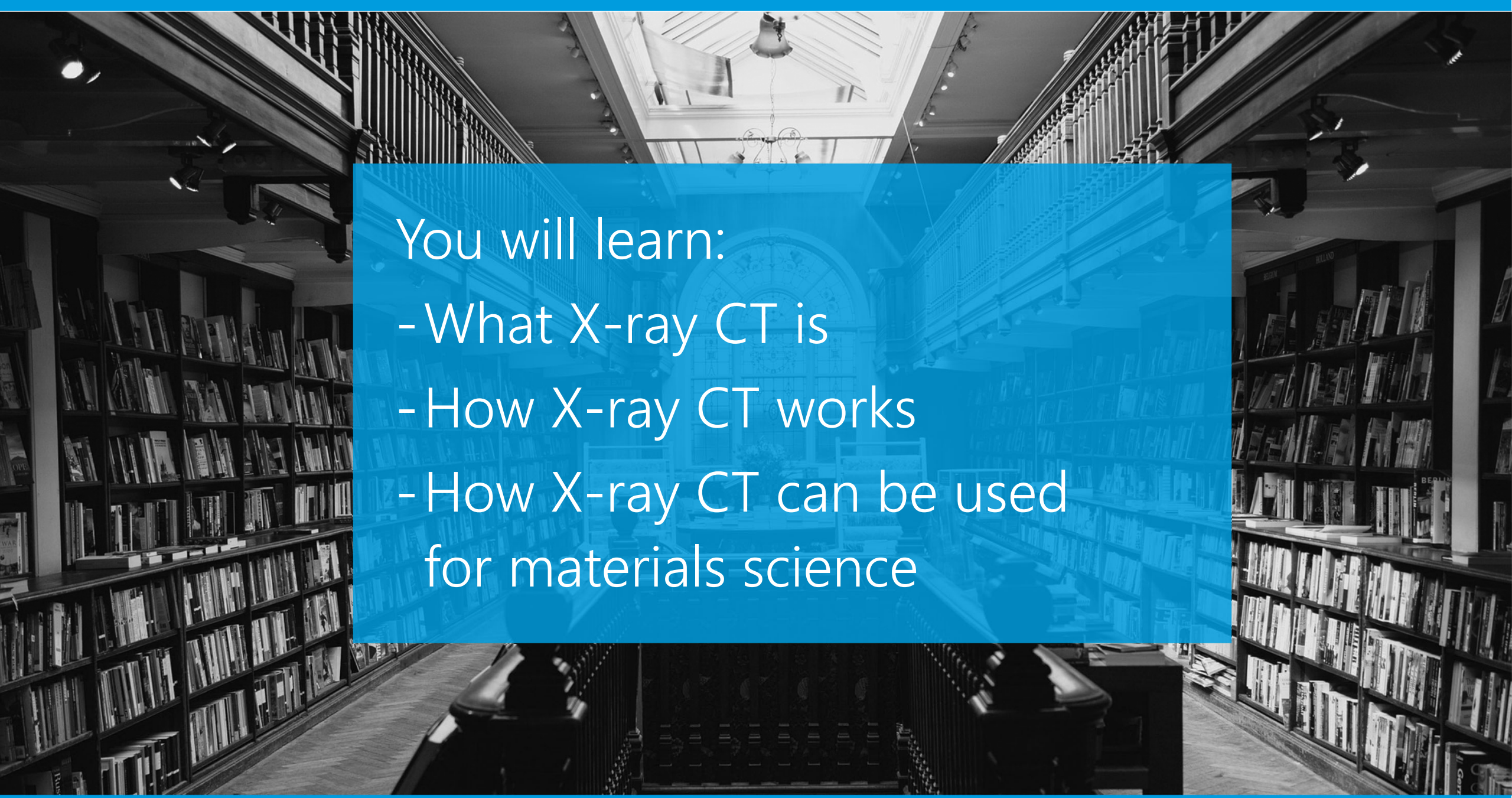
Introduction



1982

Institute of Industrial Science – The University of Tokyo X Rigaku Corporation


測定例：桧(約φ400mm)約173年経過した構造物
東京都・重要文化財
堀之内　妙　法　寺
祖師堂　1811年改築

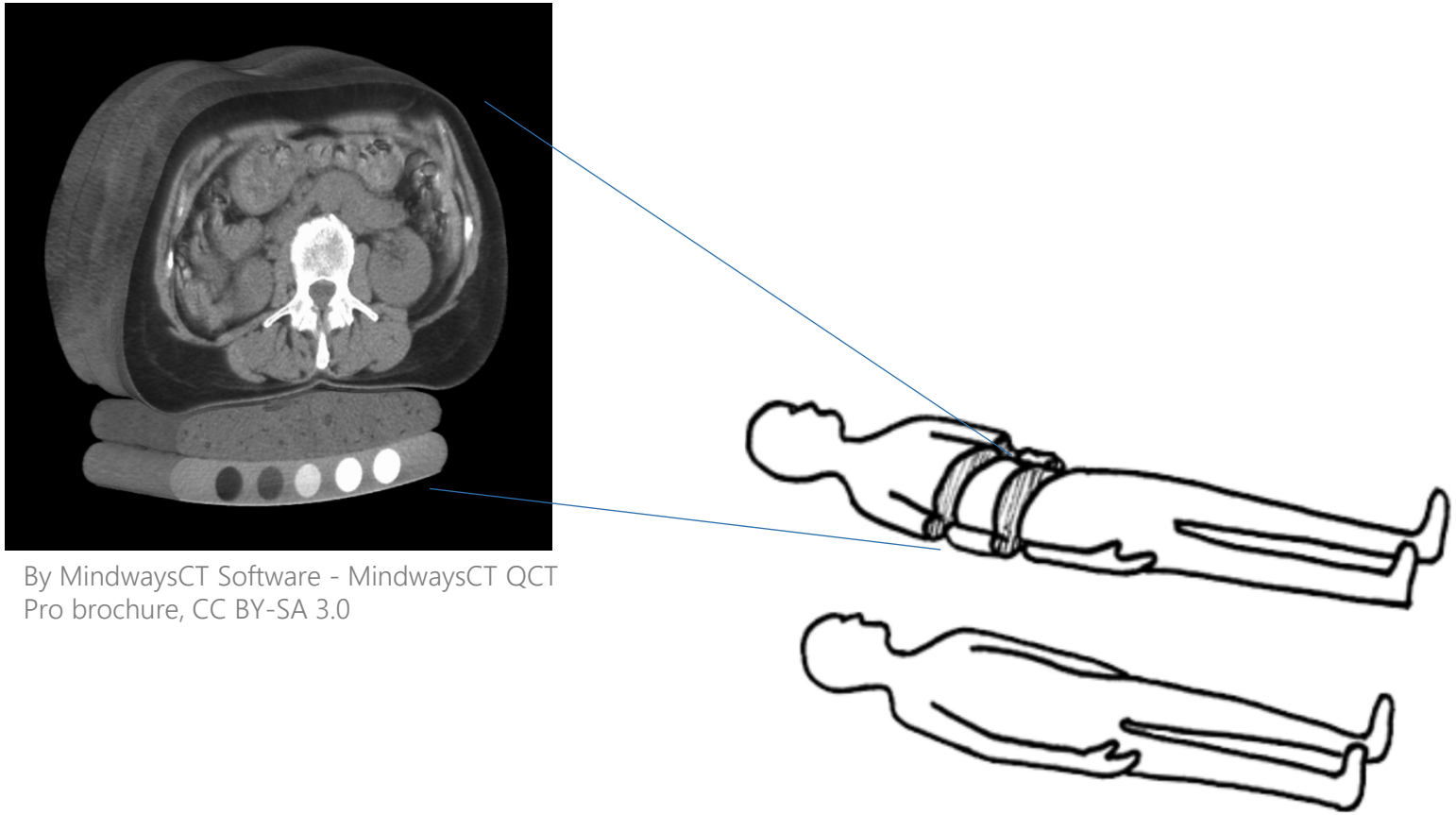


You will learn:

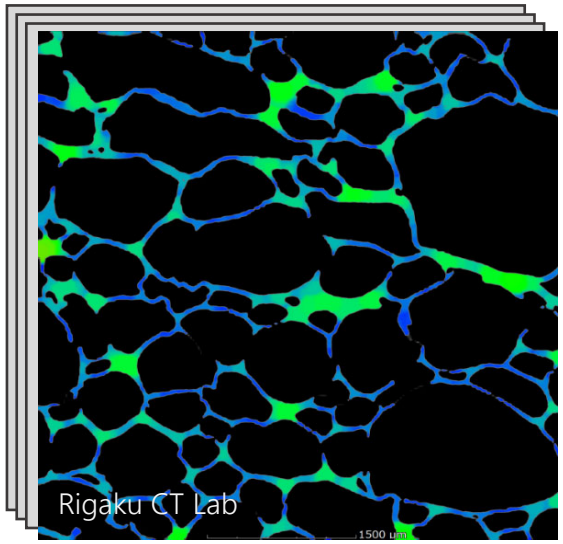
- What X-ray CT is
- How X-ray CT works
- How X-ray CT can be used for materials science

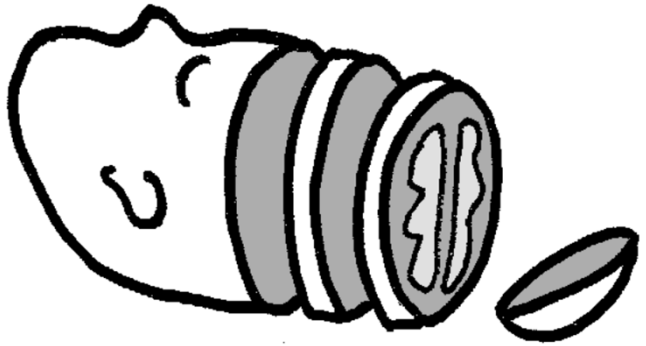
WHAT IS X-RAY CT?

By daveynin from United States - New UPMC East Uploaded by crazypaco, CC BY 2.0

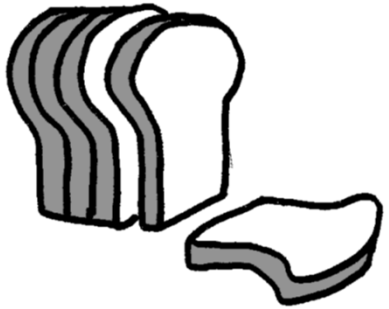


By MindwaysCT Software - MindwaysCT QCT Pro brochure, CC BY-SA 3.0



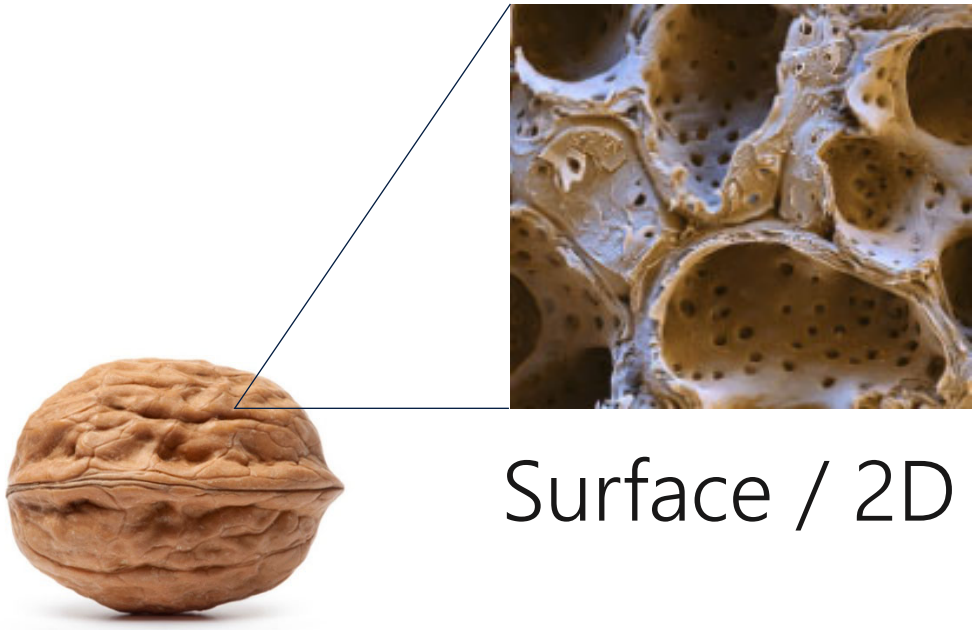


CAT Scan



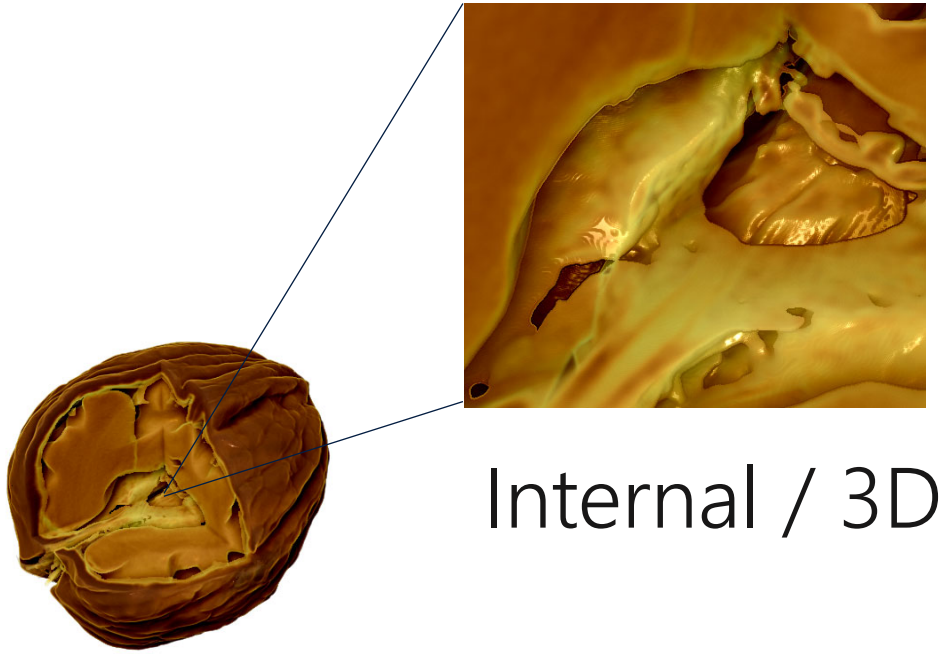
X-ray Microtomography

Optical microscopes
SEM, AFM etc.



Surface / 2D

X-ray microscopes



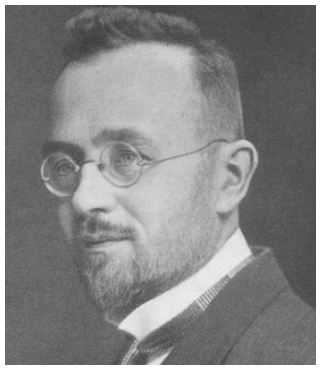
Internal / 3D

HOW LONG HAS IT BEEN AROUND?

Discovery of X-rays
Wilhelm Röntgen
(1901 Nobel prize)

First commercial CT
Godfrey N. Hounsfield
Allan M. Cormack
(1979 Nobel prize)

1895 1917 1971 2019



Introduction of
Radon transform
Johann Radon

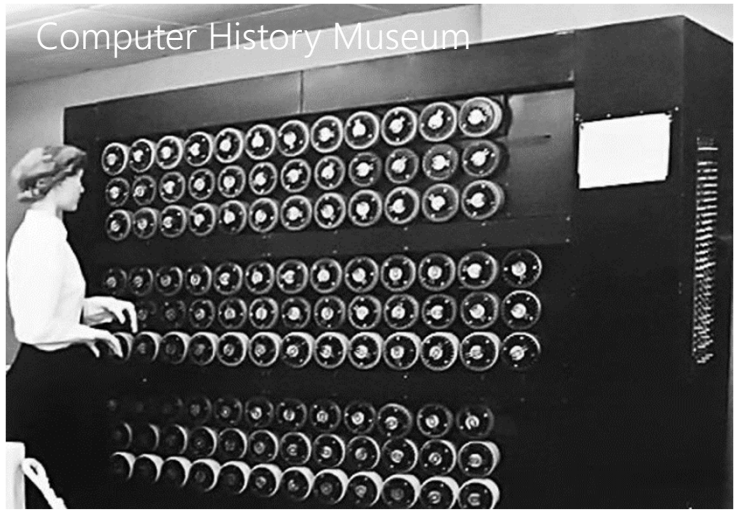
CT FOR MATERIALS SCIENCE

- Large file size (~ 30 GB)
- Image segmentation
- Quantitative analysis

Fast computer

+

AI based image analysis

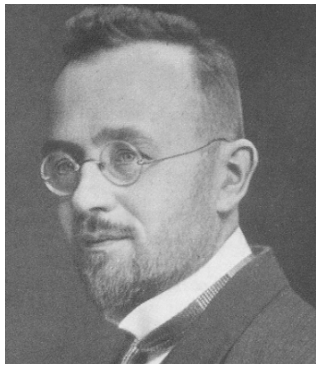


1940s
Neural network

2000s
Machine learning
Deep learning

1917

2019

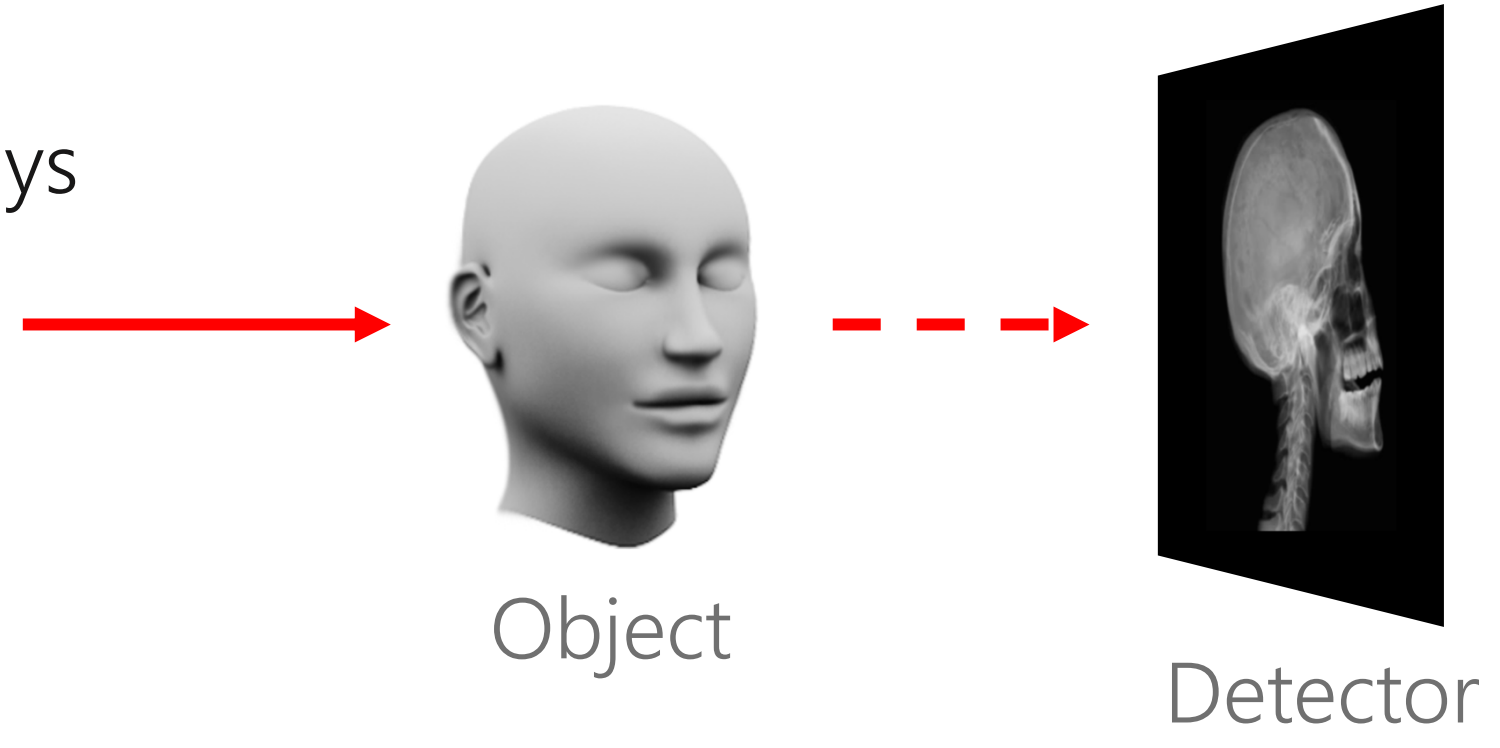


Introduction of
Radon transform
Johann Radon

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

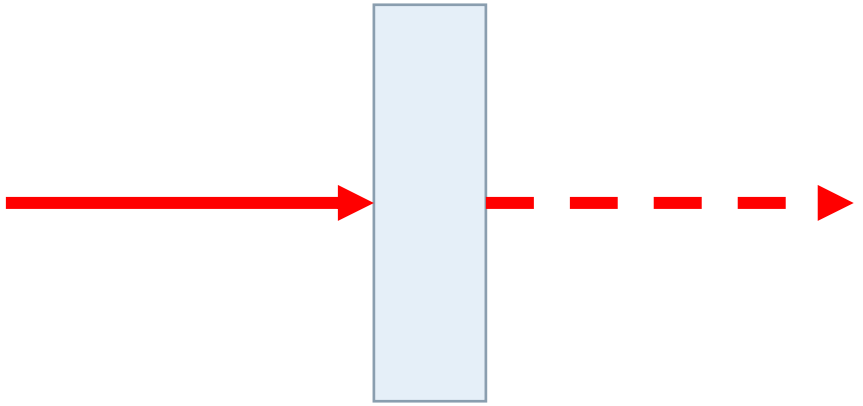
2D projection

X-rays

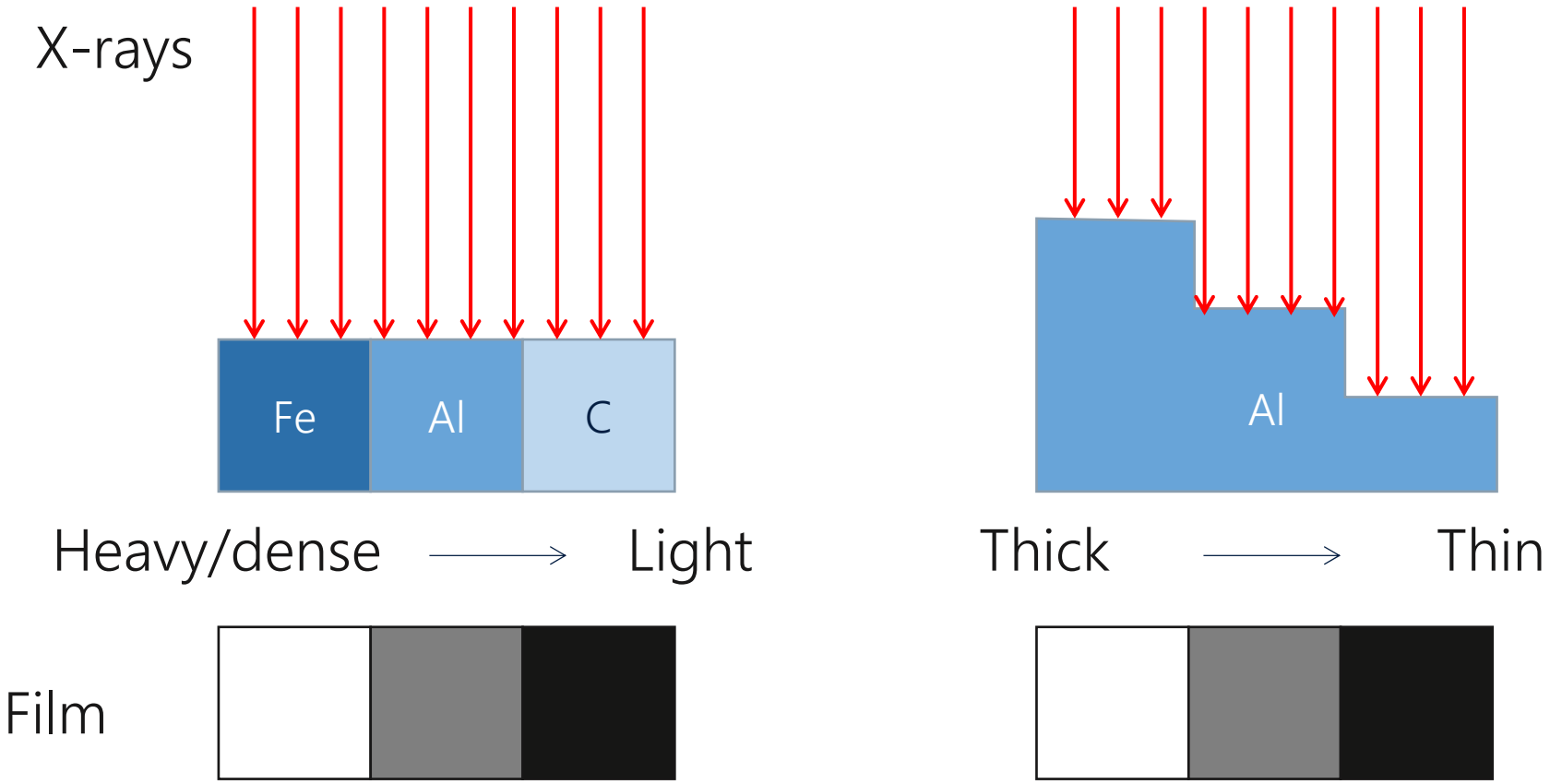


Object

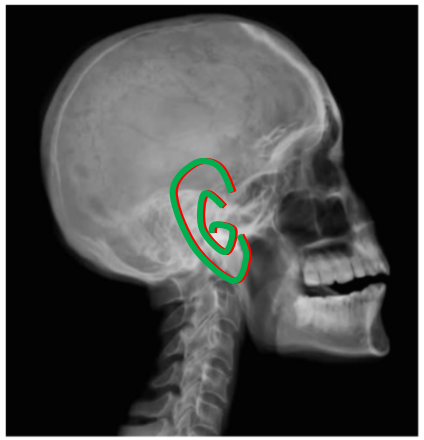
Detector



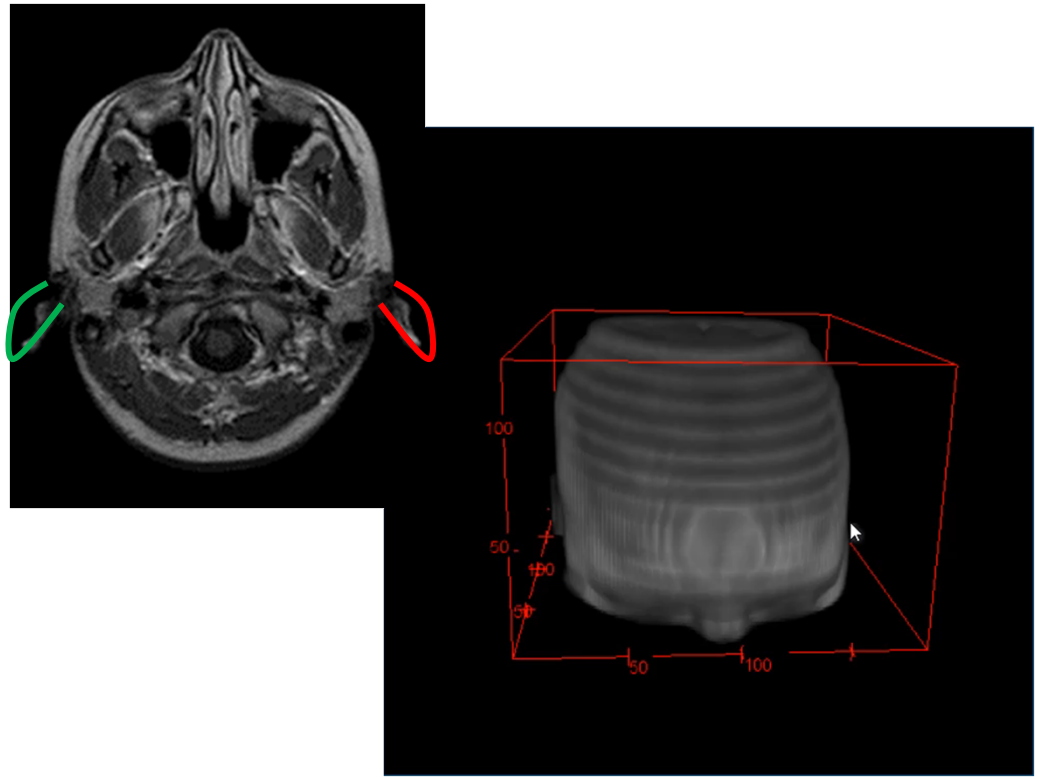
Things absorb X-rays.


X-rays
Fe
Al
C
Heavy/dense
Light
Film
Al
Thick
Thin

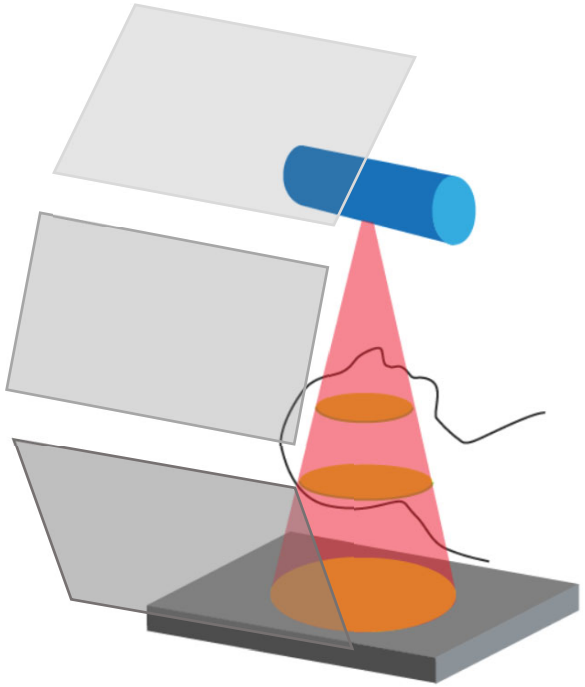
HOW DO YOU GET 3D VIEW?



2D projection

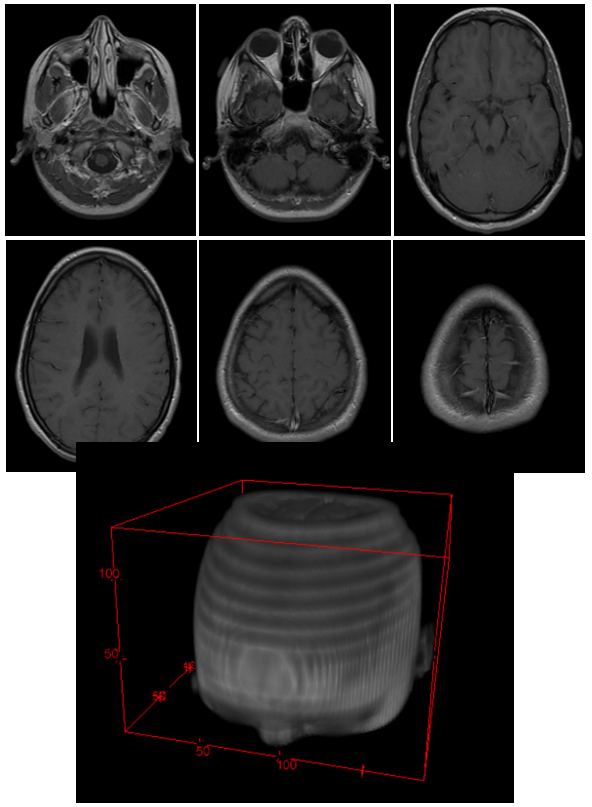


3D computed tomography



Scan

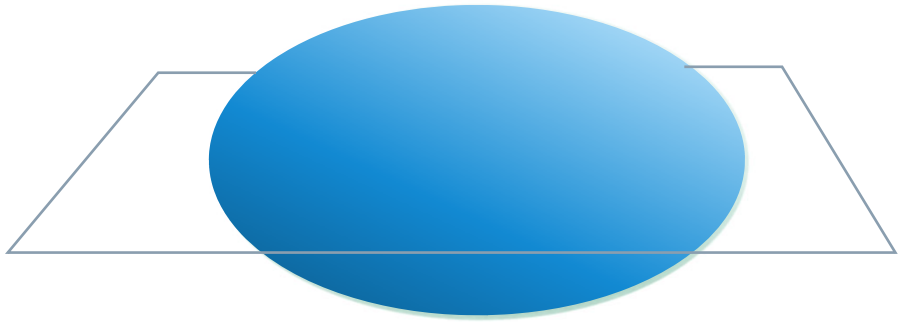
Reconstruction

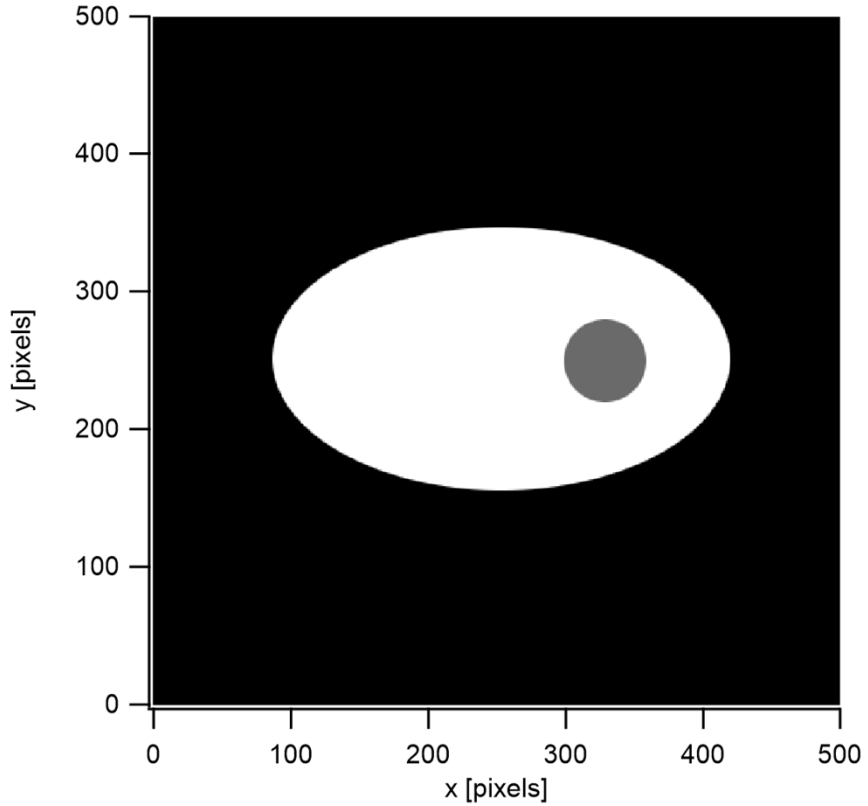


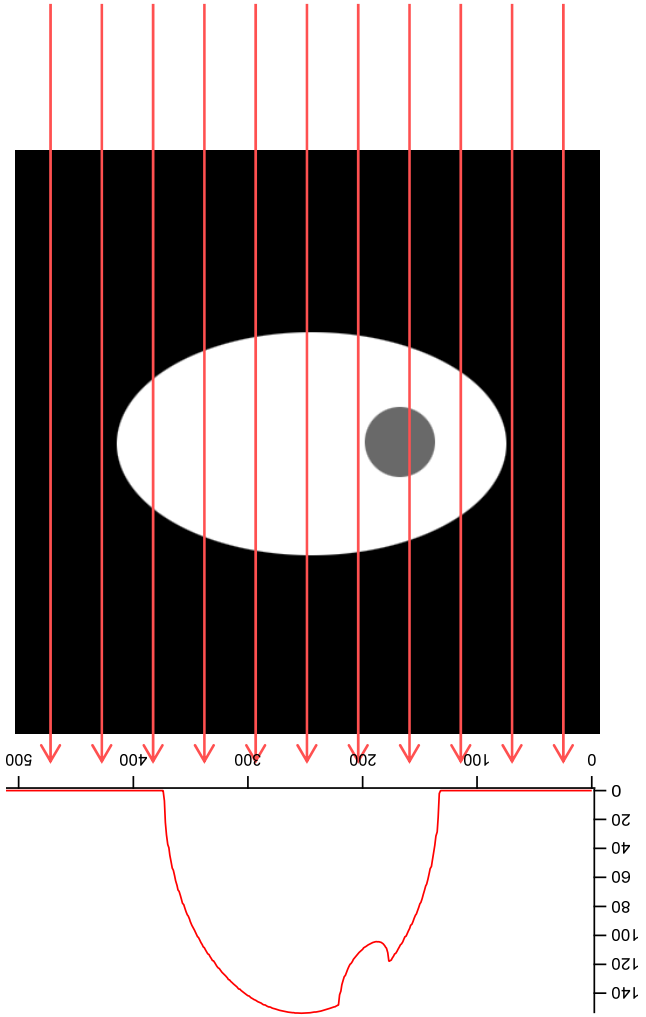
Tomographic cross sections
3D rendering

HOW DOES RECONSTRUCTION WORK?

Tomographic cross section

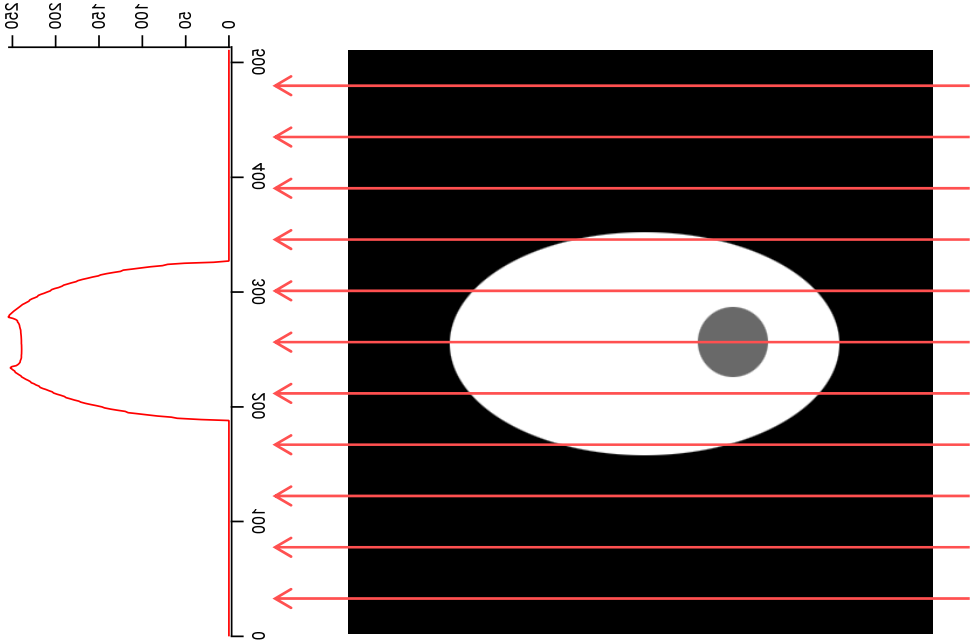


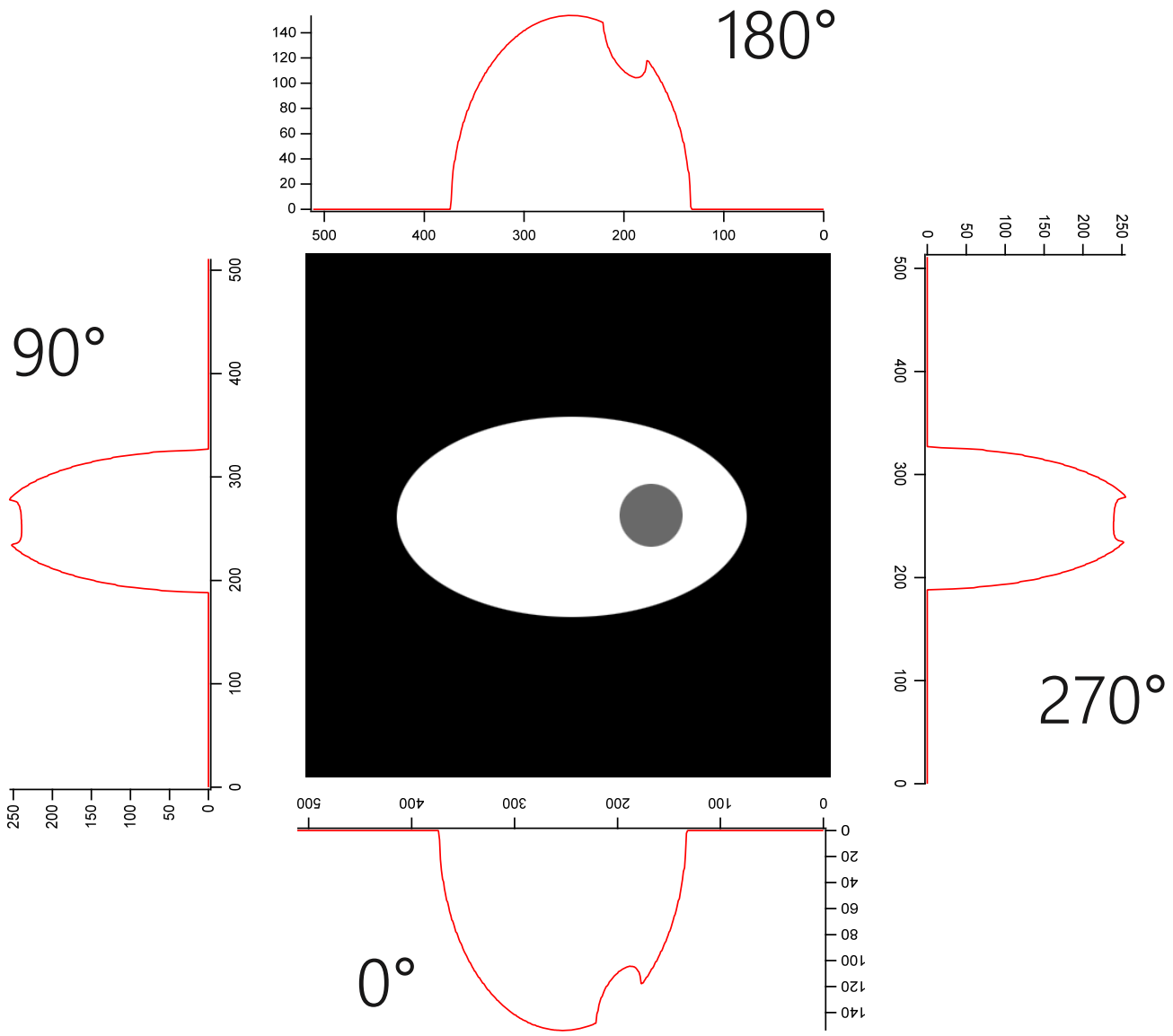


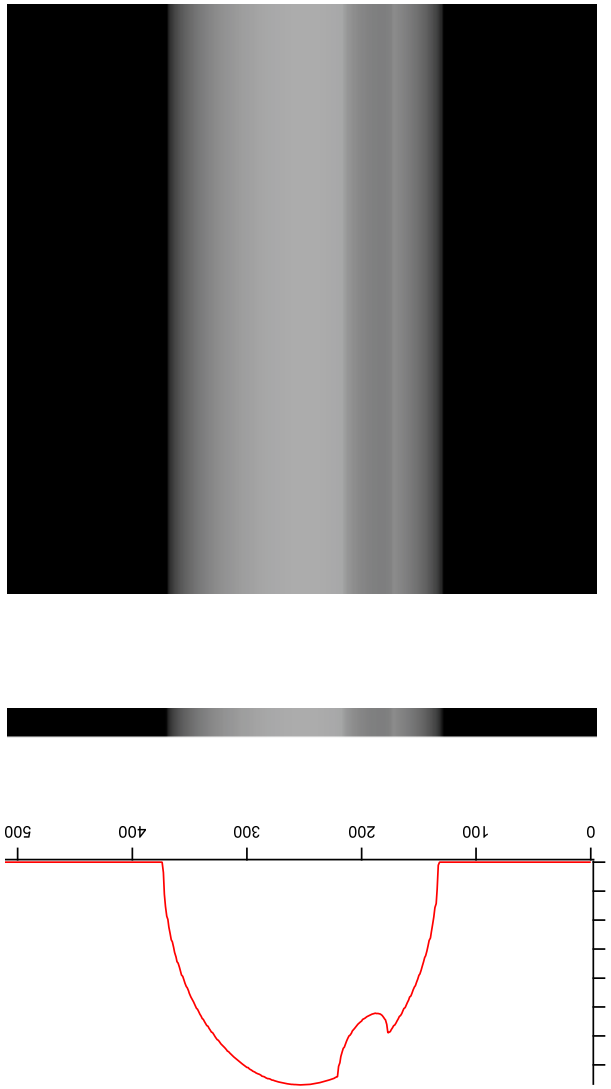


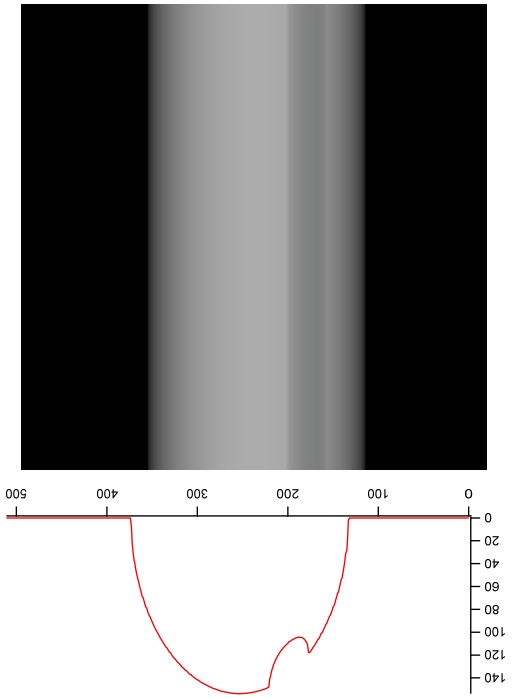
Integrated density projection angle 0°

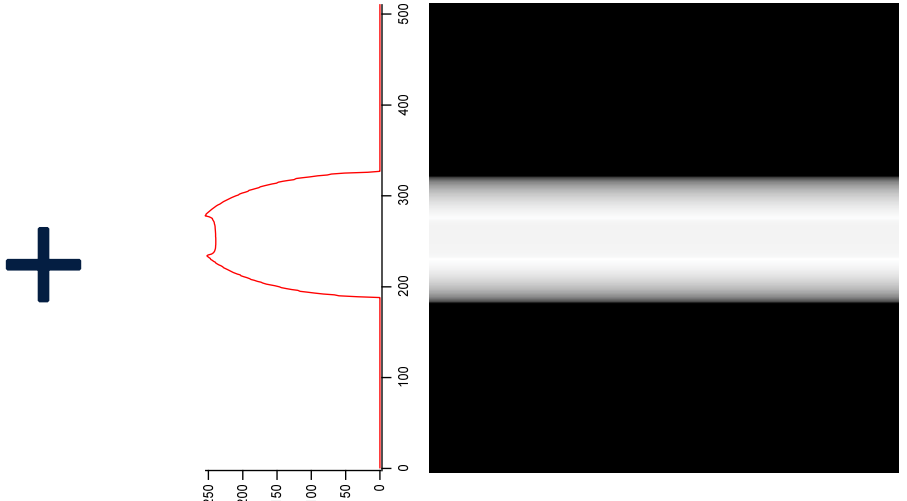
90°

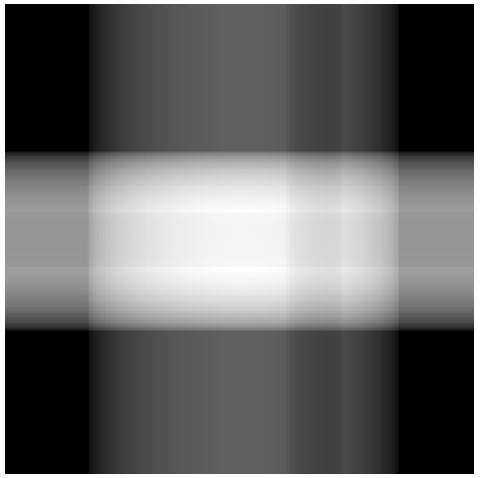


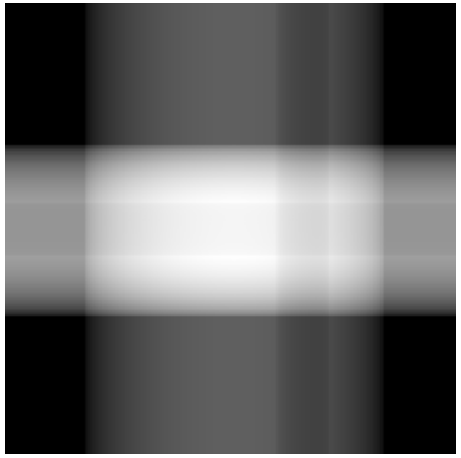

180°
90°
270°
0°


0
100
200
300
400
500
0
20
40
60
80
100
120
140

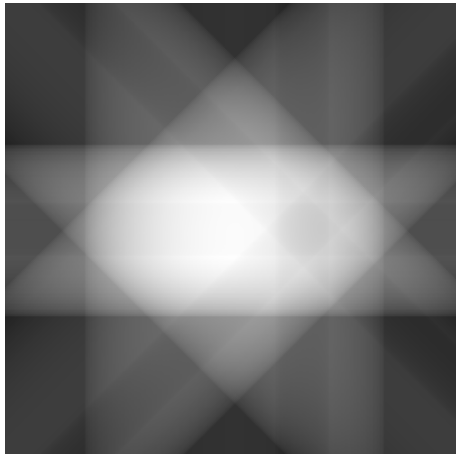

0
100
200
300
400
500
0
20
40
60
80
100
120
140


0
50
100
150
200
250
0
100
200
300
400
500

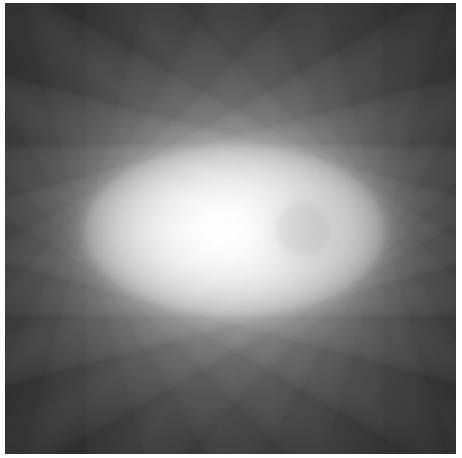




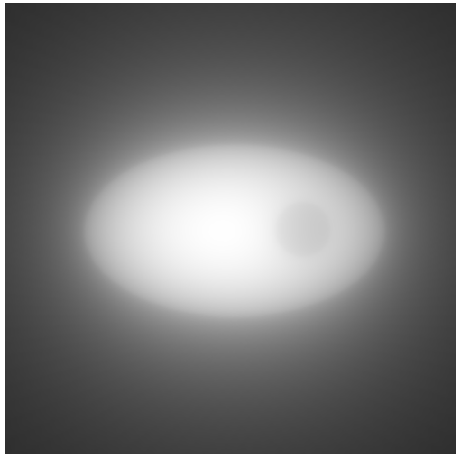
4 projections



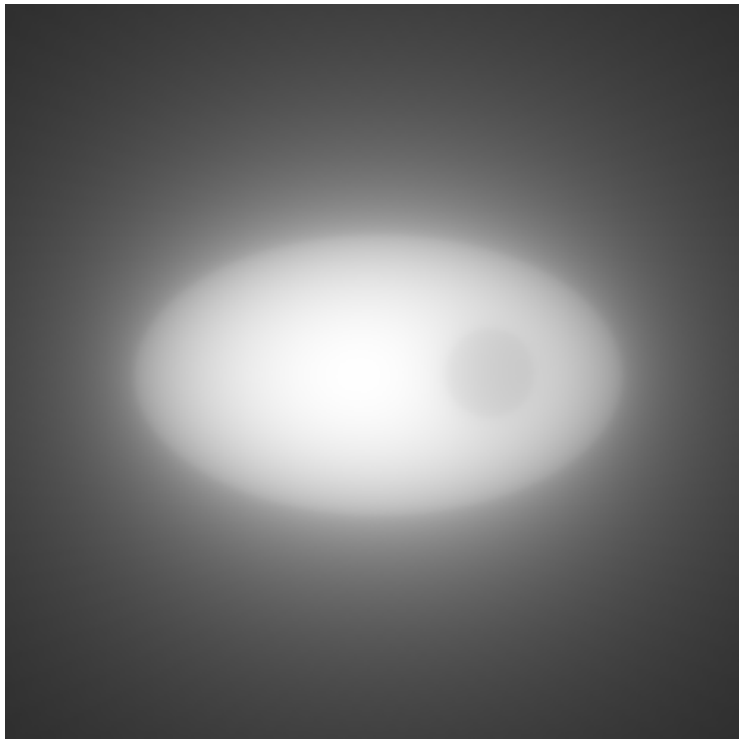
8 projections



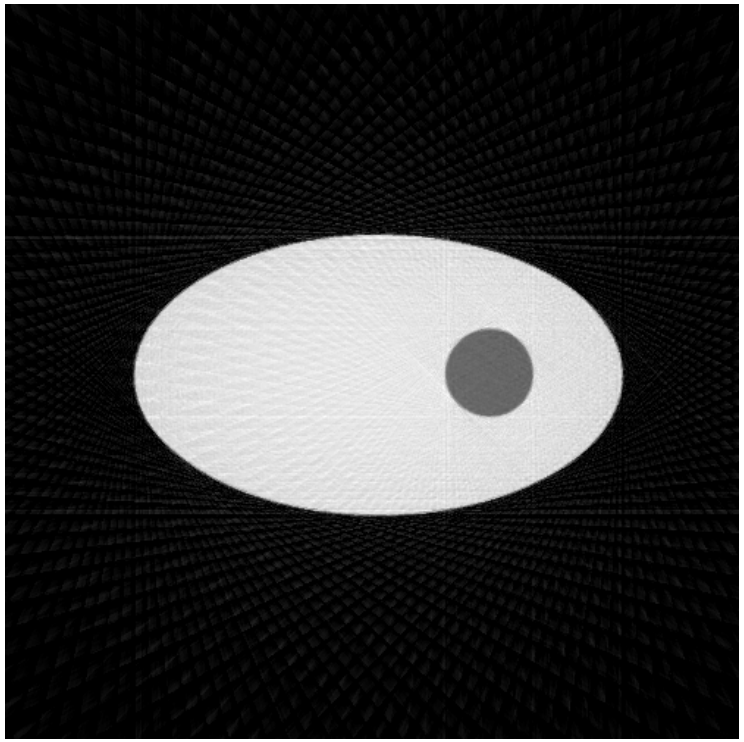
24 projections



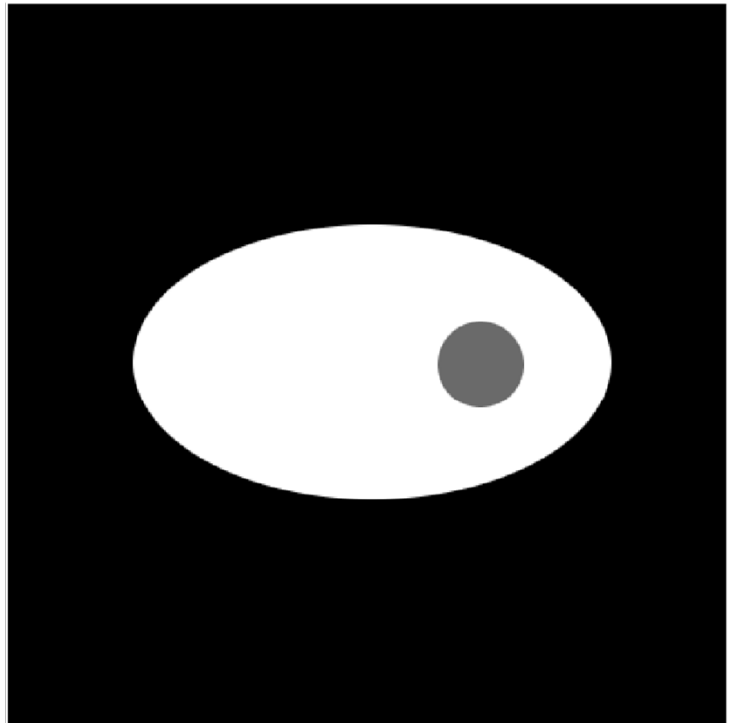
120 projections



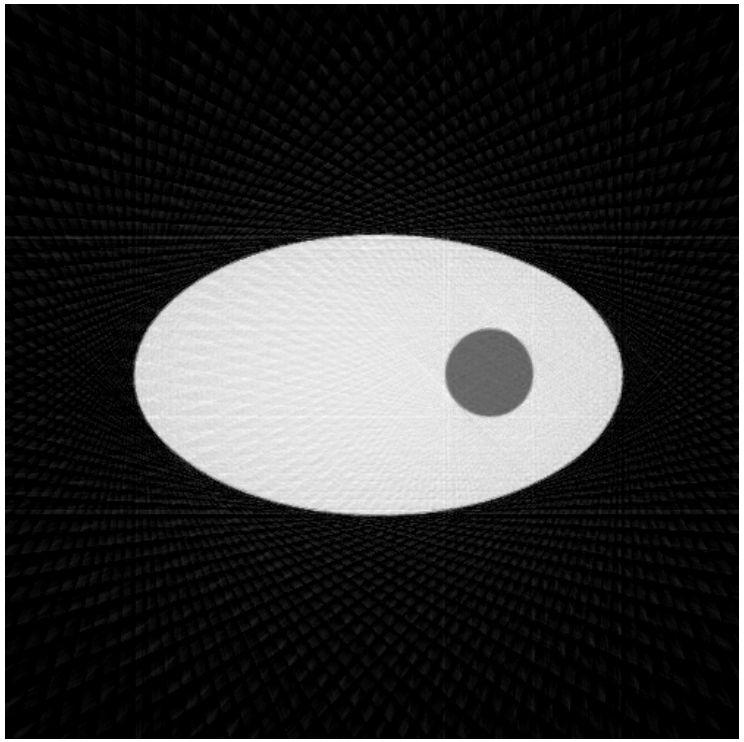
120 projections



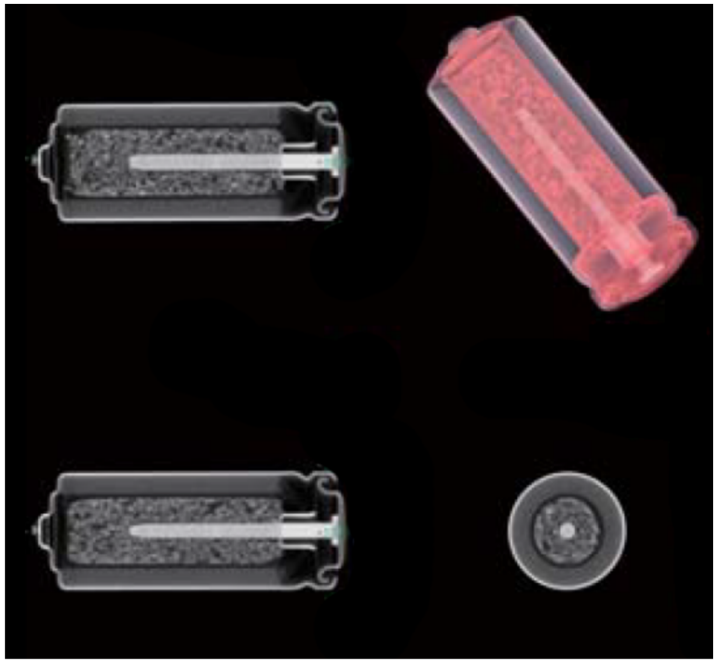
120 projections
With ramping filter

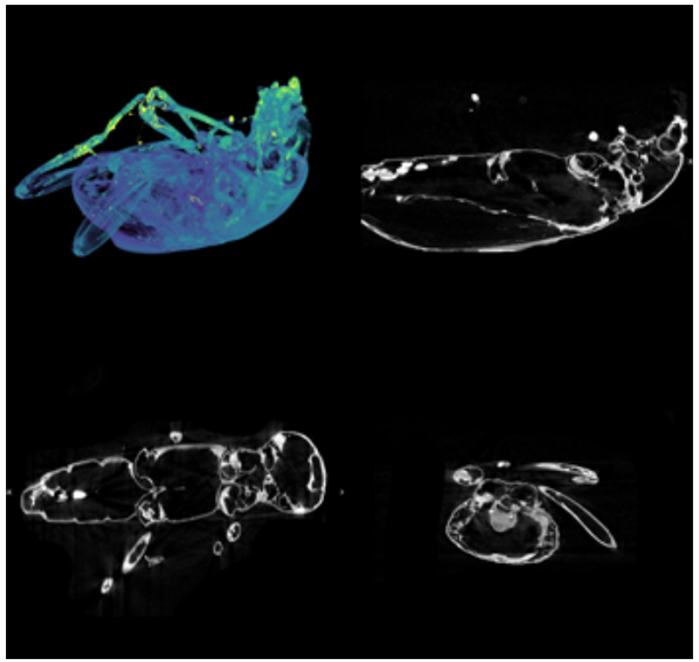


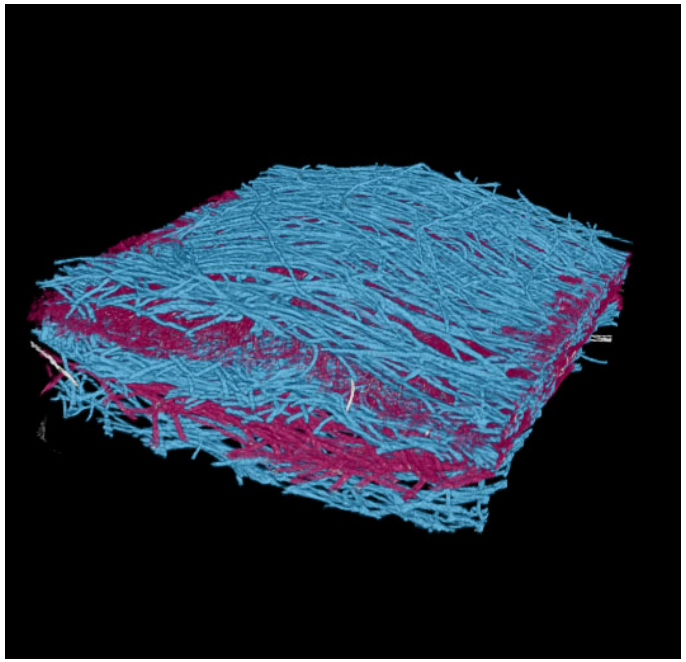
Original

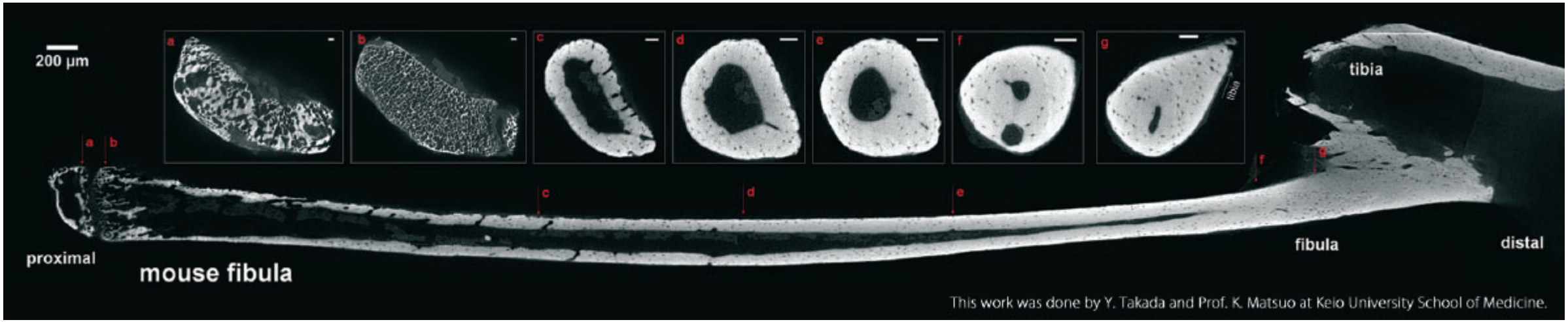


Reconstructed








200 µm
a
b
c
d
e
f
g
tibia
fibula
proximal
distal
mouse fibula
This work was done by Y. Takada and Prof. K. Matsuo at Keio University School of Medicine.

ANY LIMITATIONS OR CHALLENGES?

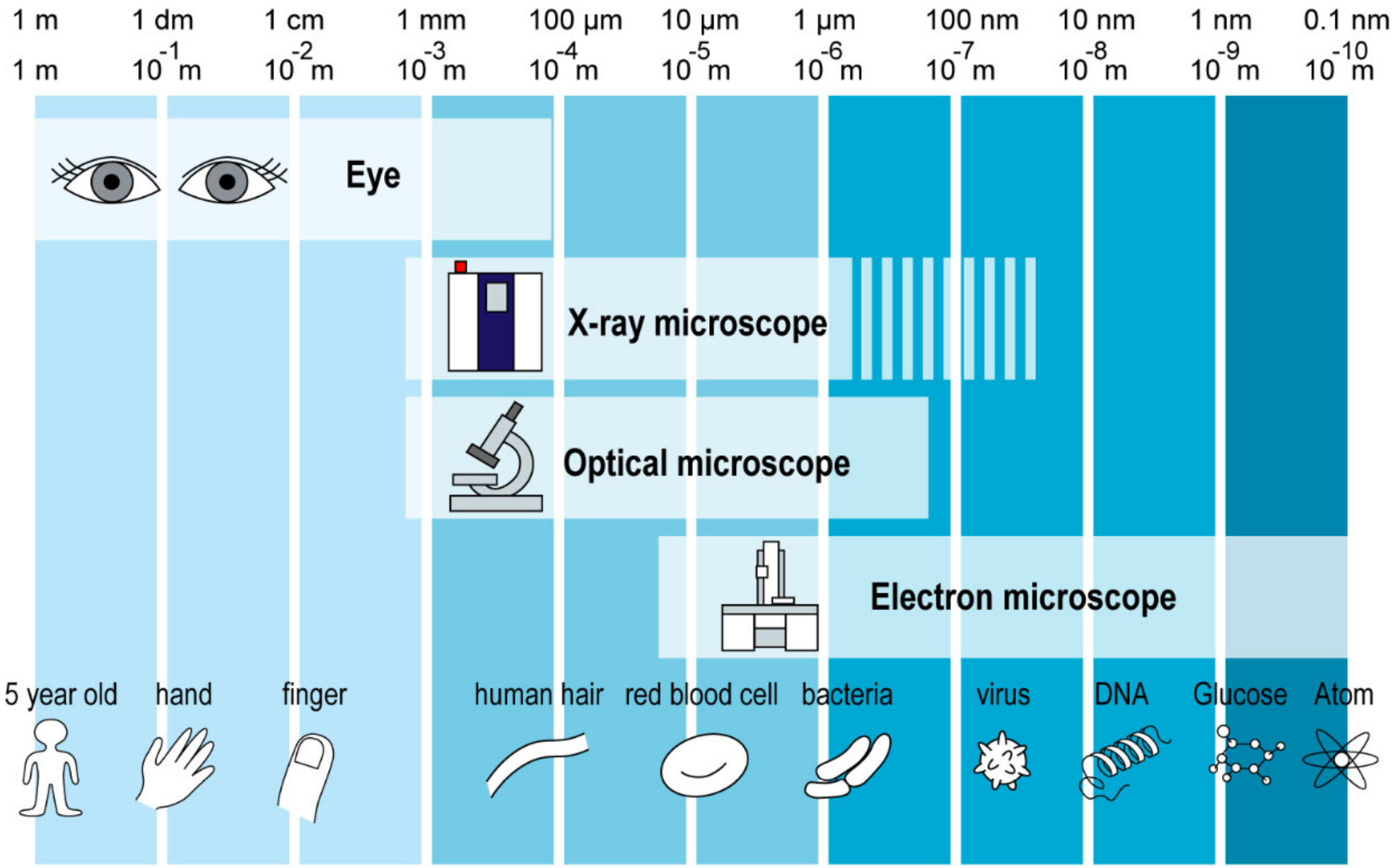
COMMON CHALLENGES

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

COMMON CHALLENGES

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

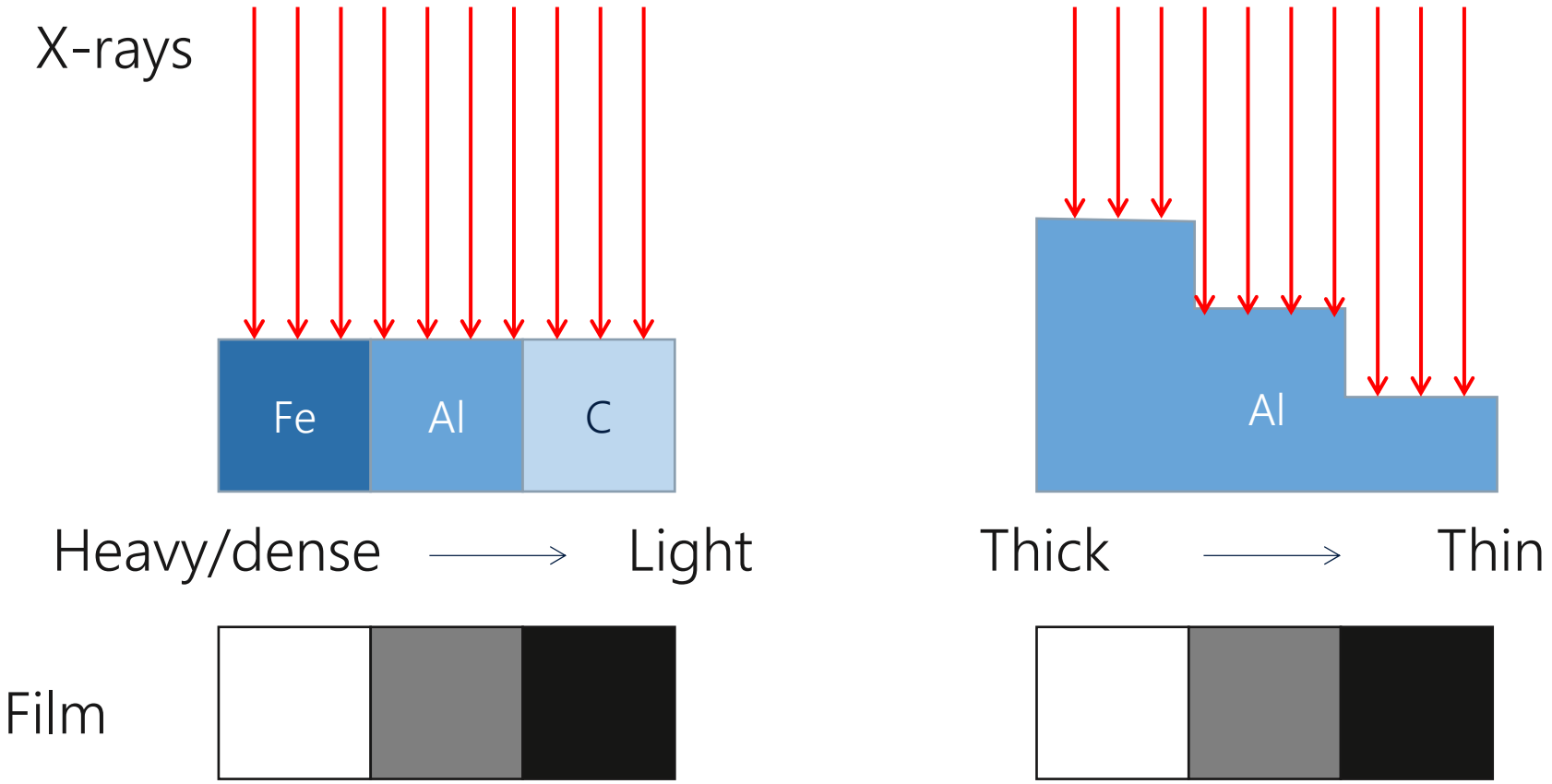
WHAT'S THE RESOLUTION?


1 m
1 m
1 dm
10^-1 m
1 cm
10^-2 m
1 mm
10^-3 m
100 µm
10^-4 m
10 µm
10^-5 m
1 µm
10^-6 m
100 nm
10^-7 m
10 nm
10^-8 m
1 nm
10^-9 m
0.1 nm
10^-10 m
Eye
X-ray microscope
Optical microscope
Electron microscope
5 year old
hand
finger
human hair
red blood cell
bacteria
virus
DNA
Glucose
Atom

COMMON CHALLENGES

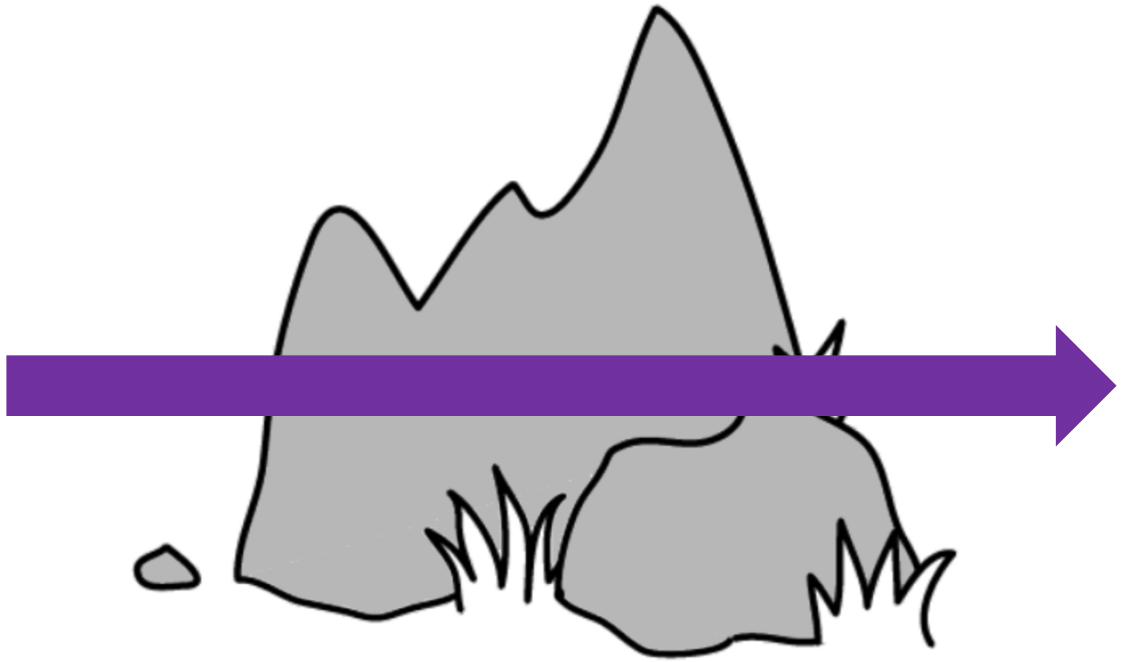
- Limited resolution compared to EM
- Too light / heavy absorbing materials
- Artifacts

WHAT'S TOO LIGHT OR TOO HEAVY?


X-rays
Fe
Al
C
Heavy/dense
Light
Film
Al
Thick
Thin

Small, low density
Low energy X-rays

Large, high density
High energy X-rays

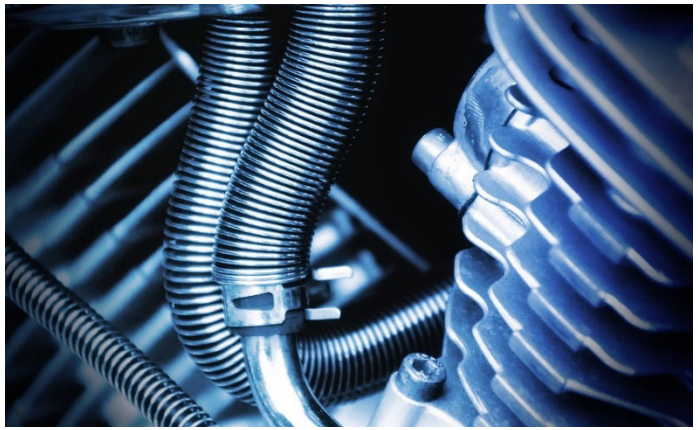


X-ray energy

5 keV

450 keV

Styrofoam
~ 5 keV



Engine parts
~ 450 keV

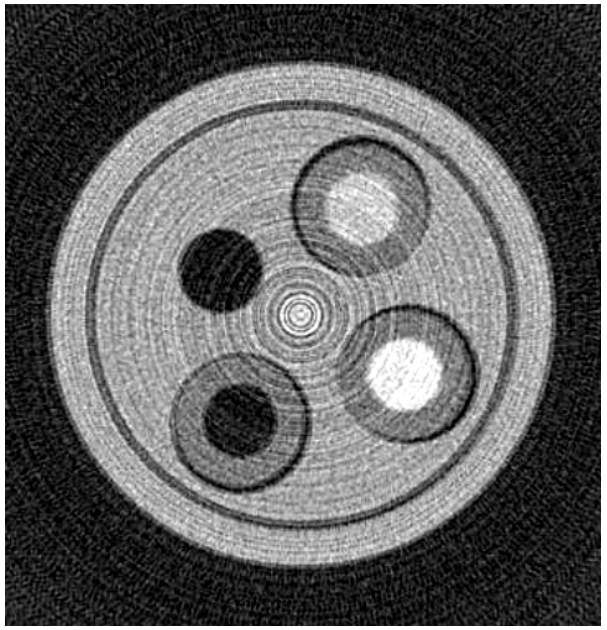
COMMON CHALLENGES

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

WHAT ARE ARTIFACTS?

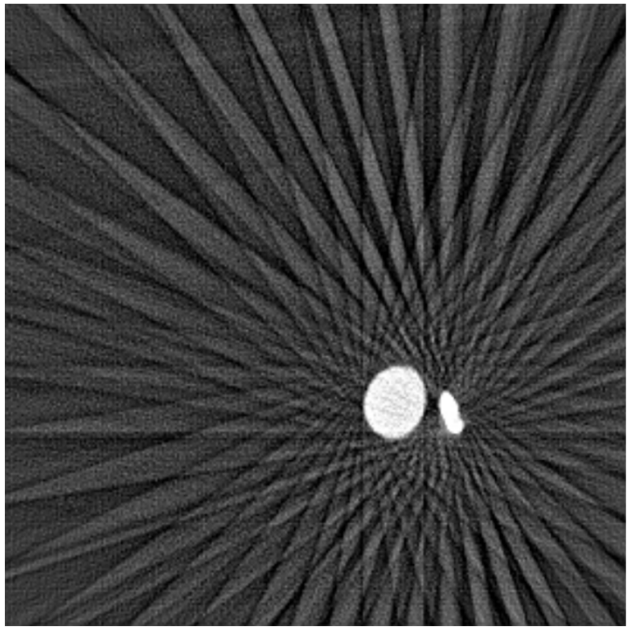
COMMON ARTIFACTS

Rings



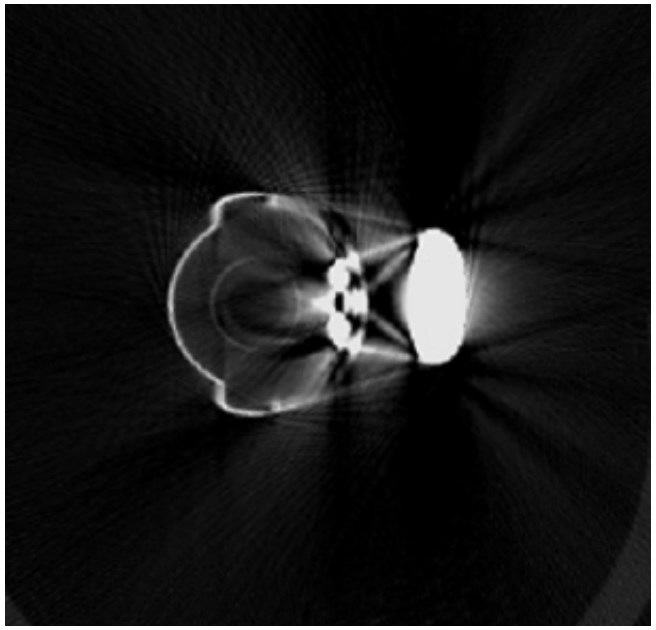
Bad pixels

Aliasing



Under sampling

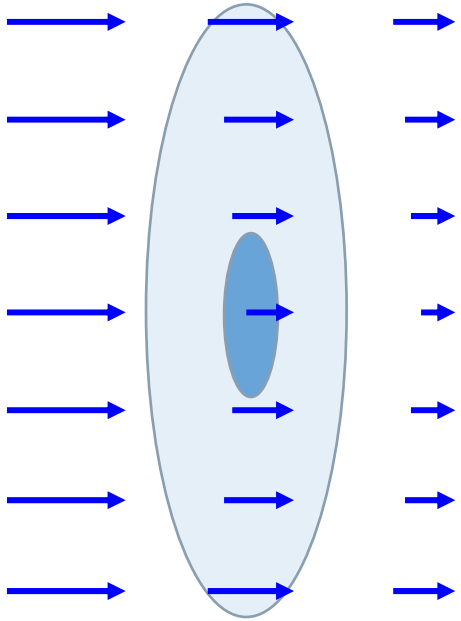
Streaks & shading



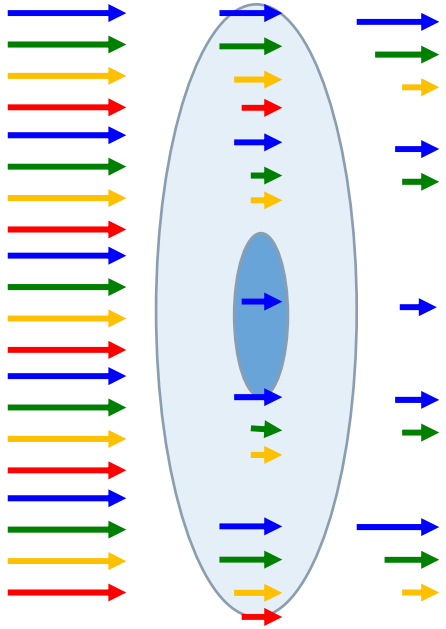
Beam hardening

WHAT IS BEAM HARDENING?

Assumption



Reality



Monochromatic X-rays

Polychromatic X-rays

low → E → high

BEAM HARDENING ARTIFACTS SIMULATION

Model

Simulation

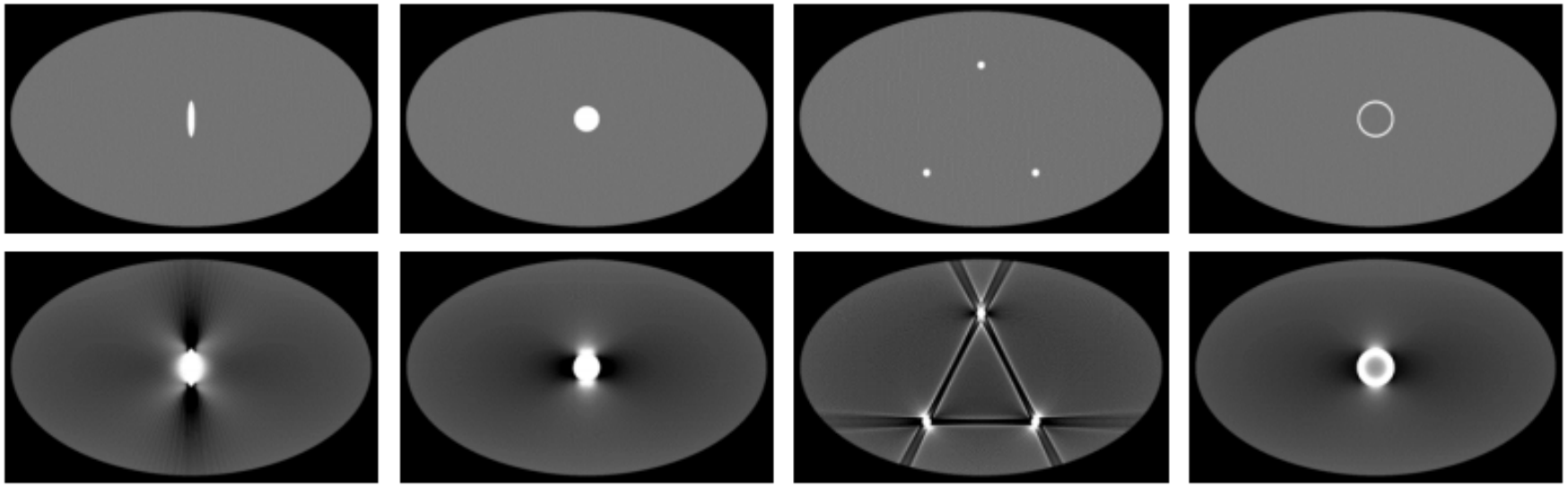


Figure 4. Simulated scans without (top row) and with (bottom row) beam hardening, showing that dark streaks occur along the lines of greatest attenuation, and bright streaks occur in other directions. Scatter produces artifacts that look similar to this. Also note the subtle decrease in Hounsfield units just beneath the surface of the "abdomen," which is caused by beam hardening. This is called cupping artifact, and it is corrected by the simple beam hardening correction built into modern scanners.

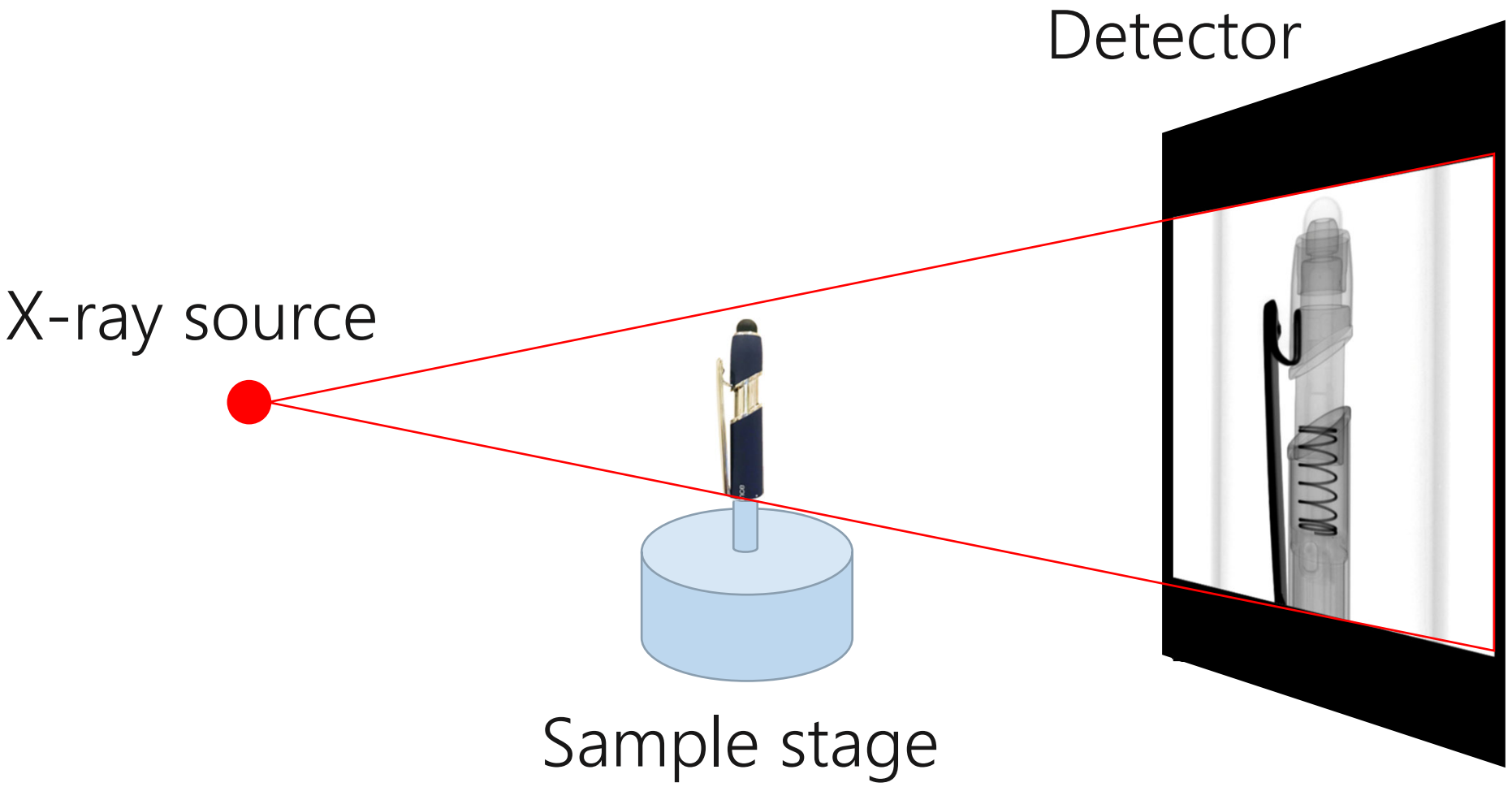
Imaging Med. (2012) 4(2), 229-240

COMMON CHALLENGES

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

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

X-RAY CT SYSTEM



MICROFOCUS X-RAY SOURCES

Rigaku

Low energy, high power
5.4, 8, 17 keV
1200 W

Hamamatsu Photonics

Medium energy
60 ~ 190 keV
~ 100 W

Nikon

High energy
190 ~ 750 keV
~ 450 W

DETECTORS

Rayence

Flat panel detector
Fast, sensitive, inexpensive
50 ~ 200 μm

Rigaku

CCD
High resolution
2.4 ~ 15 μm

Andor

sCMOS
Fast, sensitive
6.5 μm ~

IMPORTANT SPECIFICATIONS

- X-ray energy
- Field of view (FOV)
- Resolution (voxel size)

- X-ray power
- Detector speed and efficiency

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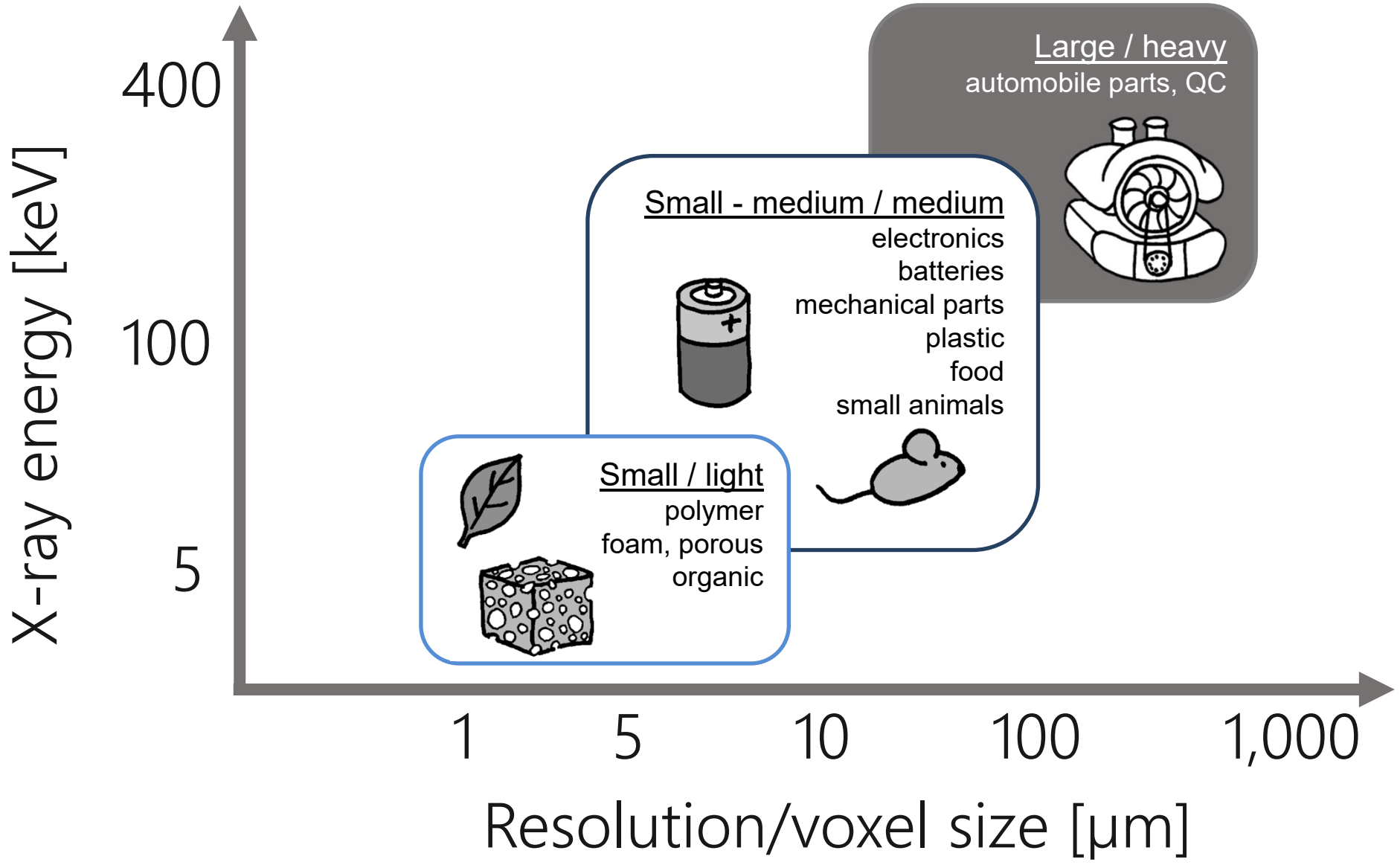
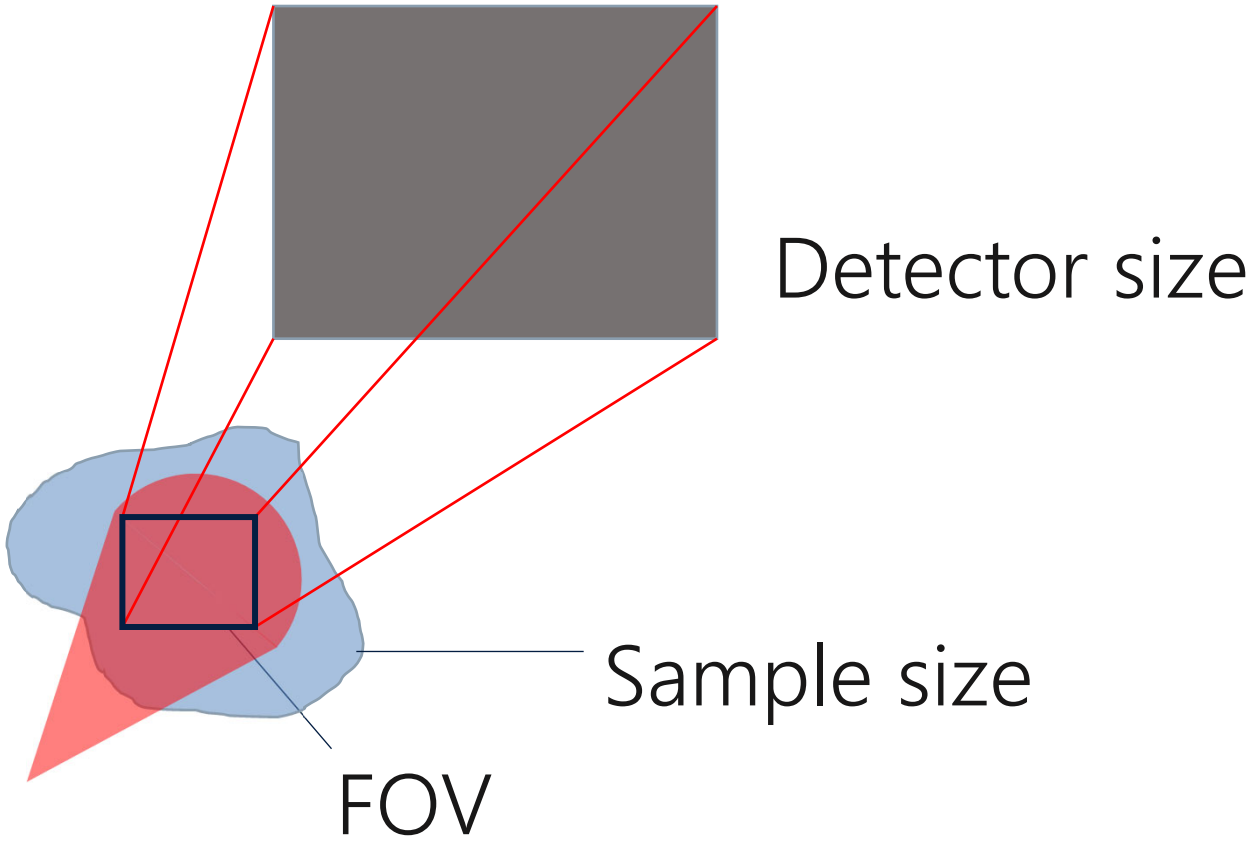
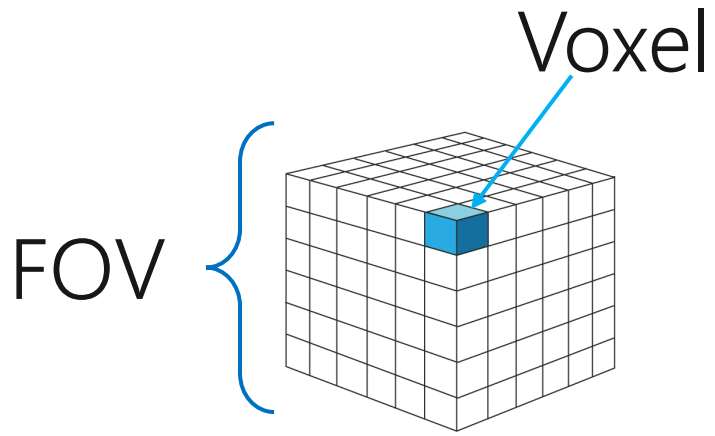

Large / heavy
automobile parts, QC
Small - medium / medium
electronics
batteries
mechanical parts
plastic
food
small animals
Small / light
polymer
foam, porous
organic
400
100
5
X-ray energy [keV]
1
5
10
100
1,000
Resolution/voxel size [μm]

IMPORTANT SPECIFICATIONS

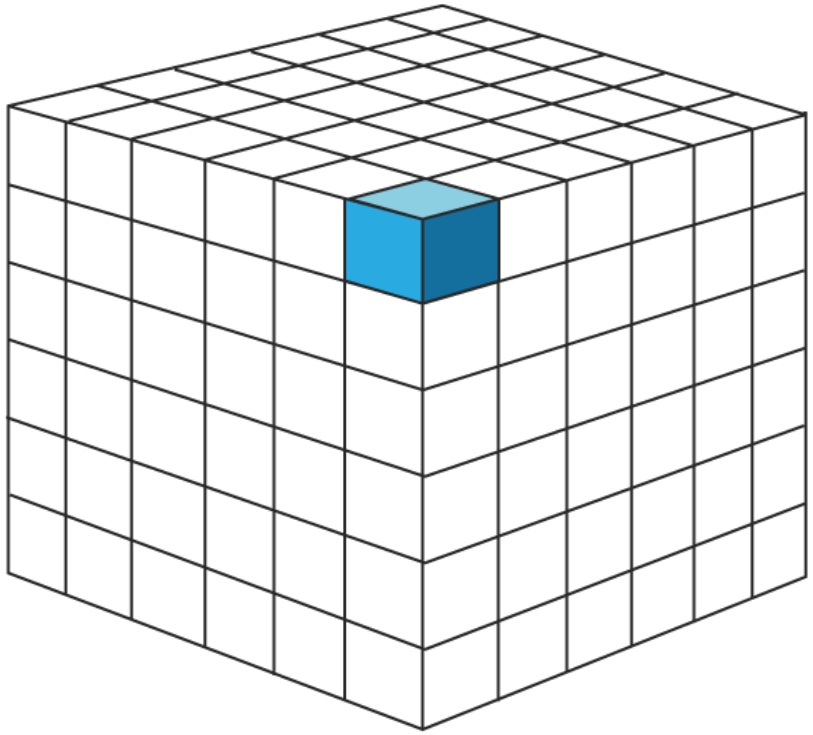
- X-ray energy
- Field of view (FOV)
- Resolution (voxel size)

- X-ray power
- Detector speed and efficiency


Detector size
Sample size
FOV



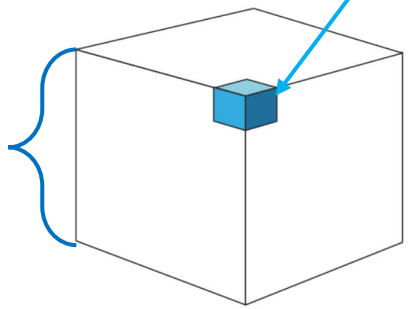
Small FOV, small voxel



Large FOV, large voxel

1 µm voxel

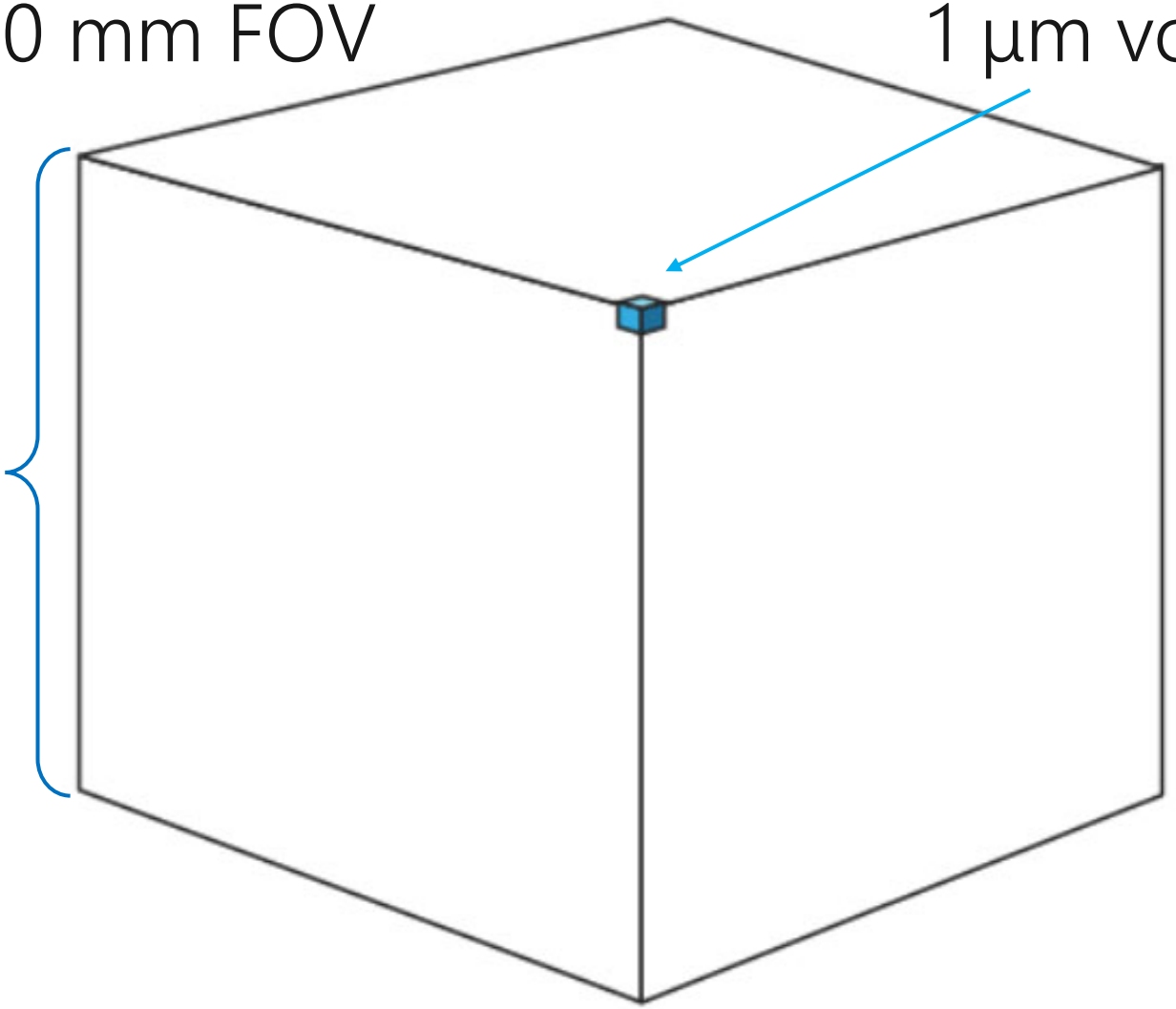
1 x 1 x 1 mm FOV



FOV [mm]	Voxel [μm]	Bit	File size
1 x 1 x 1	1	16	2 GB

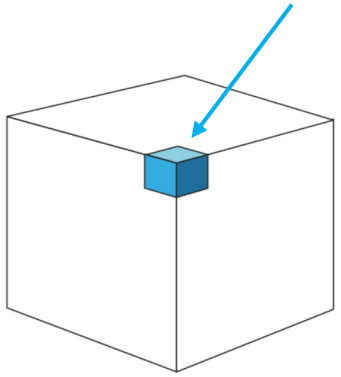
100 x 100 x 100 mm FOV

1 µm voxel



FOV [mm]	Voxel [μm]	Bit	File size
1 x 1 x 1	1	16	2 GB
100 x 100 x 100	1	16	2 PB
100 x 100 x 100	5	16	16 TB
100 x 100 x 100	25	8	64 GB
100 x 100 x 100	50	8	8 GB

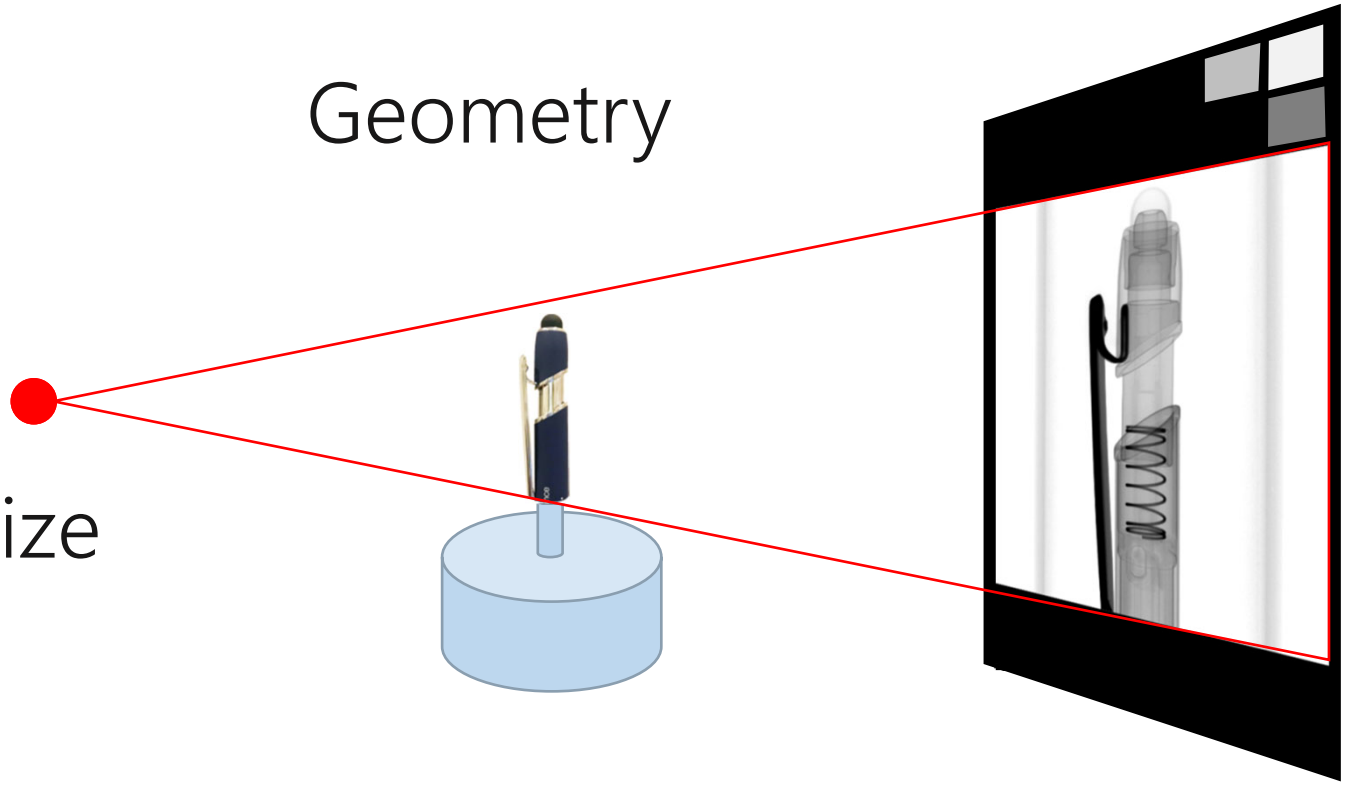
Resolution / voxel size



Pixel size

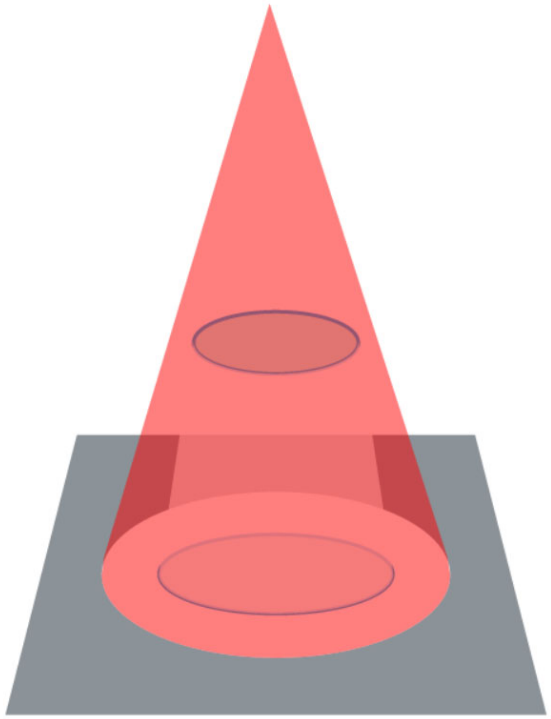
Geometry

Focus size

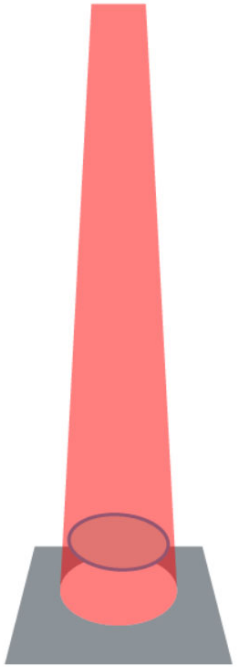


HOW DOES MAGNIFICATION WORK?

GEOMETRIES

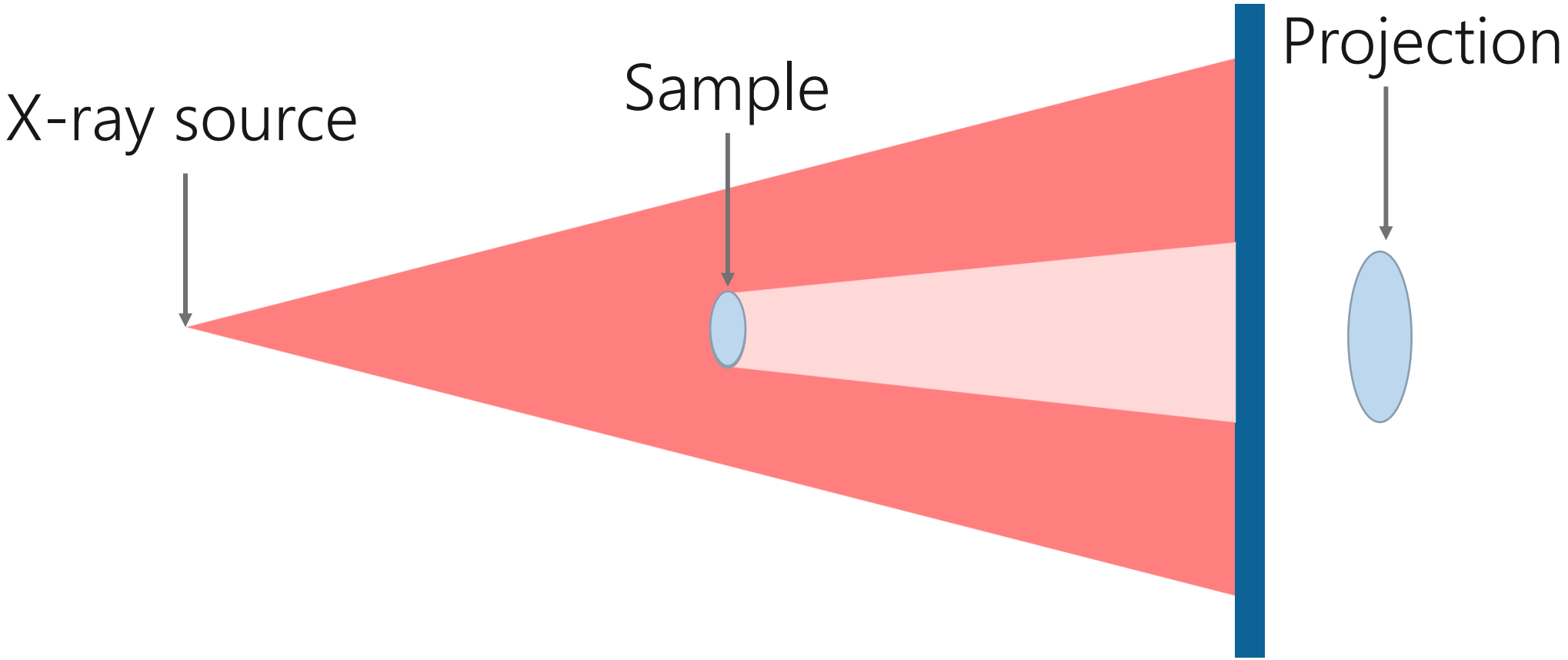


Cone beam



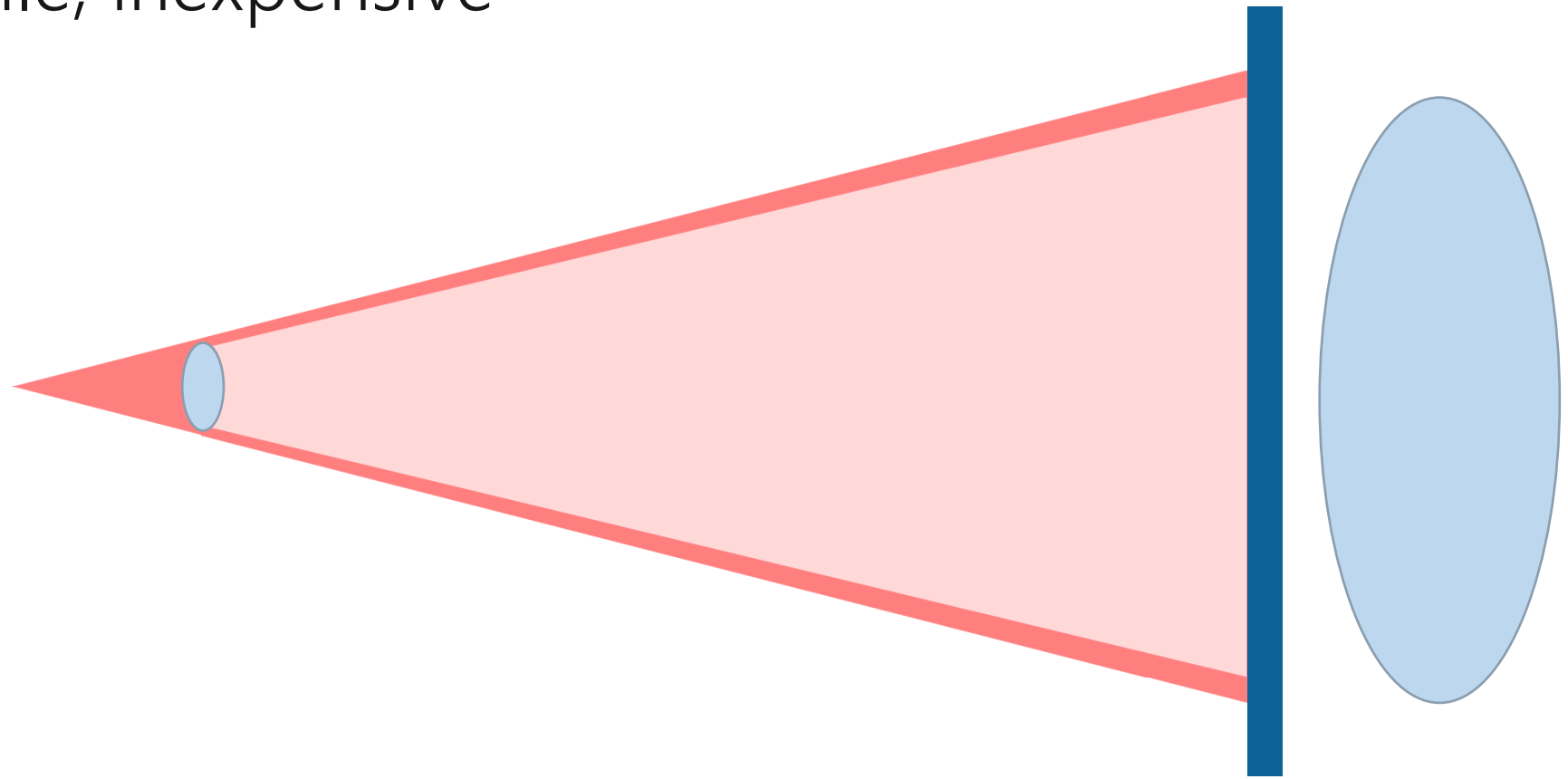
Parallel beam

CONE BEAM - MECHANICAL MAGNIFICATION



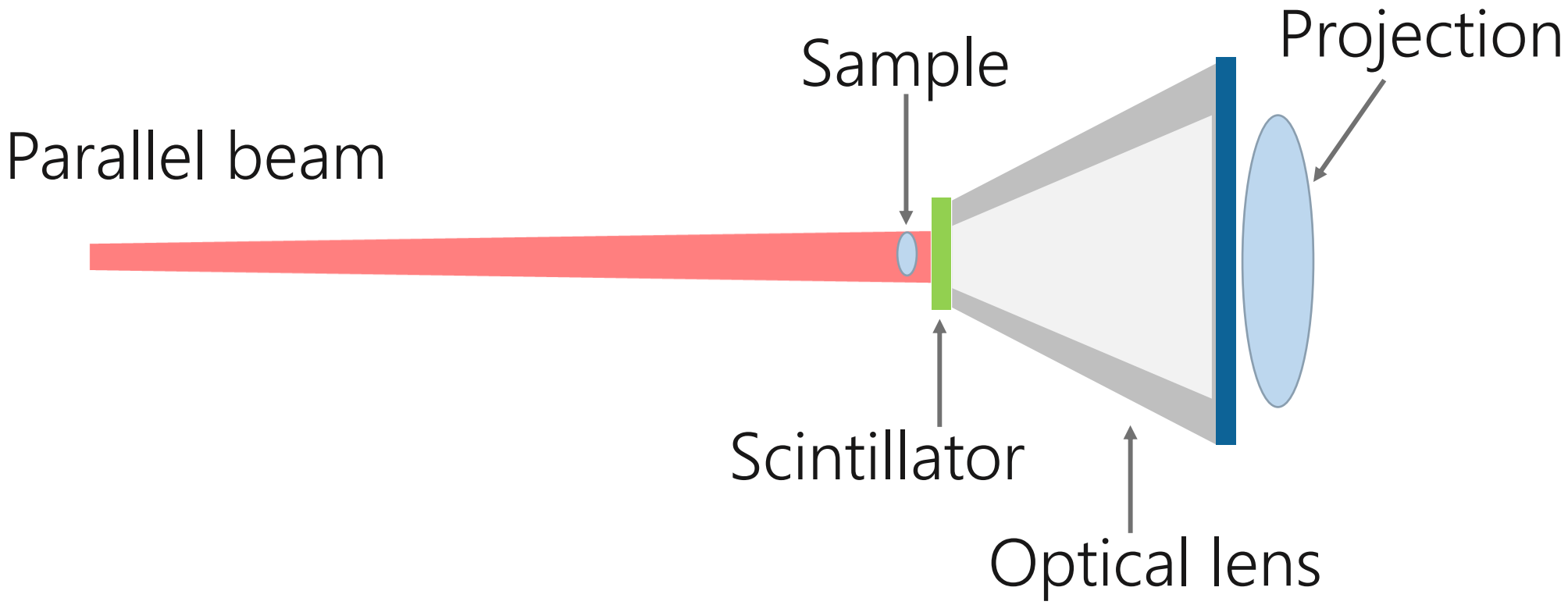
CONE BEAM - MECHANICAL MAGNIFICATION

Versatile, inexpensive

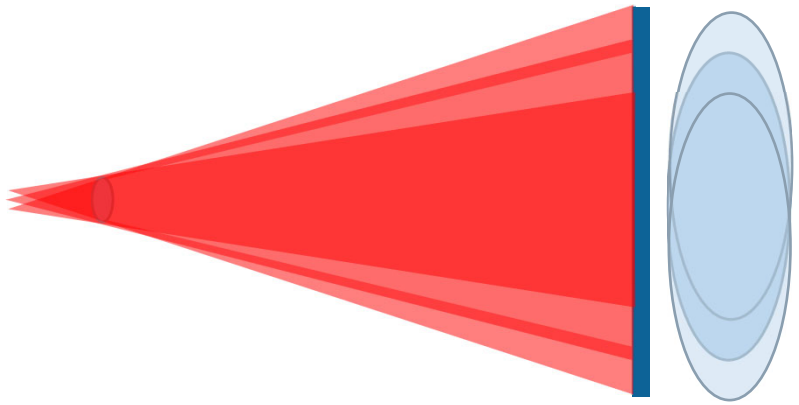


PARALLEL BEAM - OPTICAL MAGNIFICATION

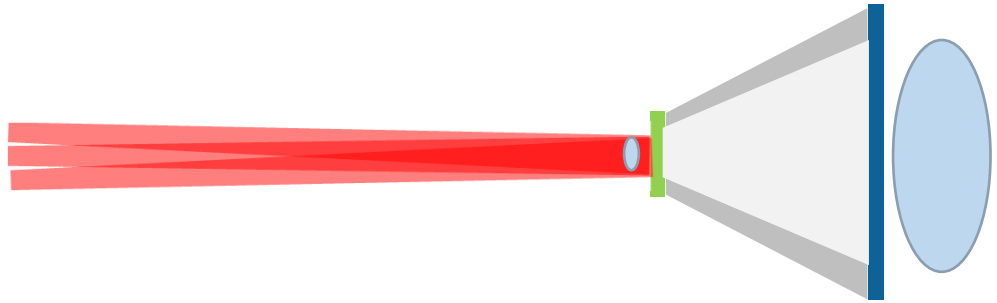
High resolution, requires high power source



CONE BEAM VS. PARALLEL BEAM



Cone beam



Parallel beam
Immune to drift → high resolution

IMPORTANT SPECIFICATIONS

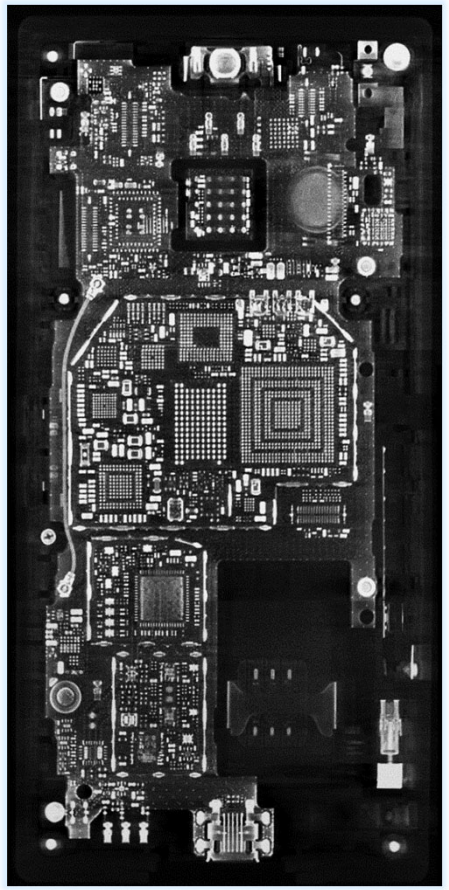
- X-ray energy
- Field of view (FOV)
- Resolution (voxel size)

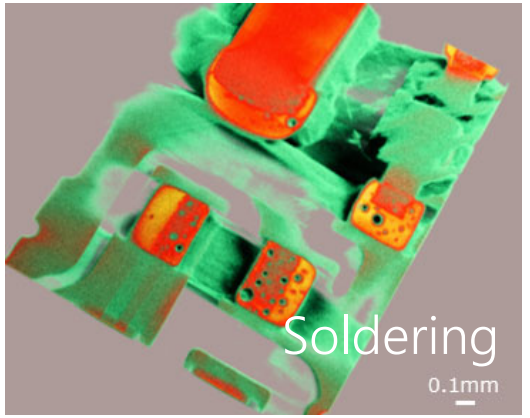
} Geometry

- X-ray power
- Detector speed and efficiency

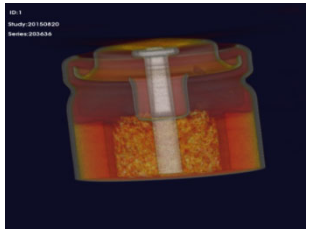
ANY EXAMPLES?

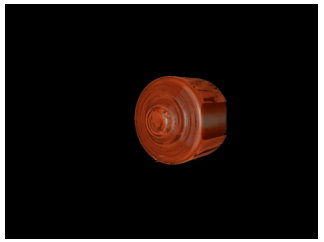
ELECTRONICS

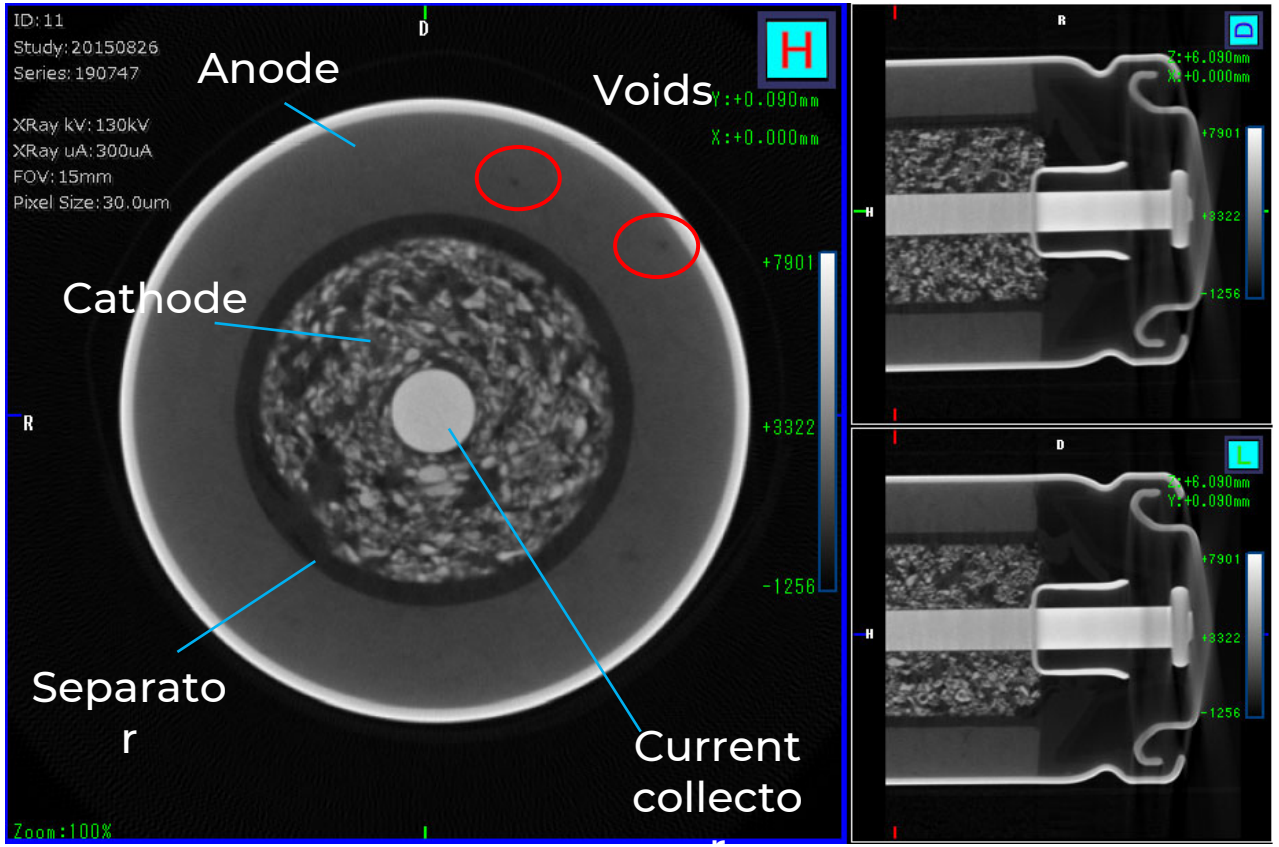




BATTERIES

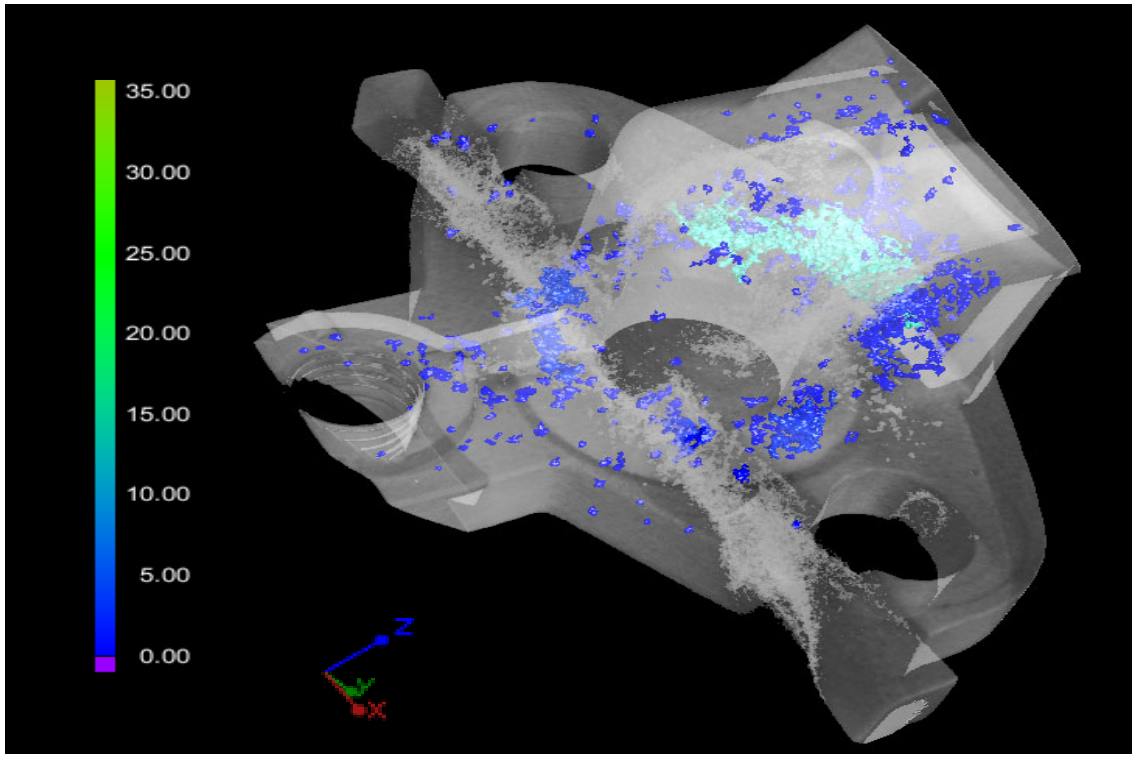




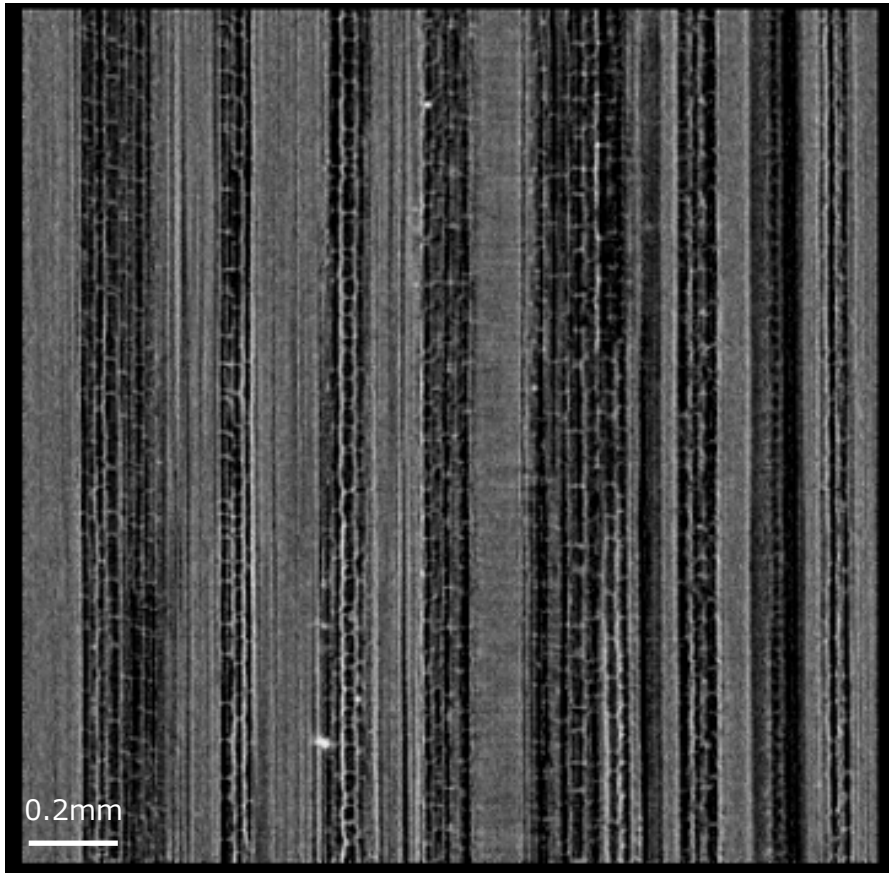

ID: 11
Study: 20150826
Series: 190747
XRay kV: 130kV
XRay uA: 300uA
FOV: 15mm
Pixel Size: 30.0um
Anode
Voids
Cathode
Separato
r
Current
collecto
Zoom: 100%
+7901
+3322
-1256

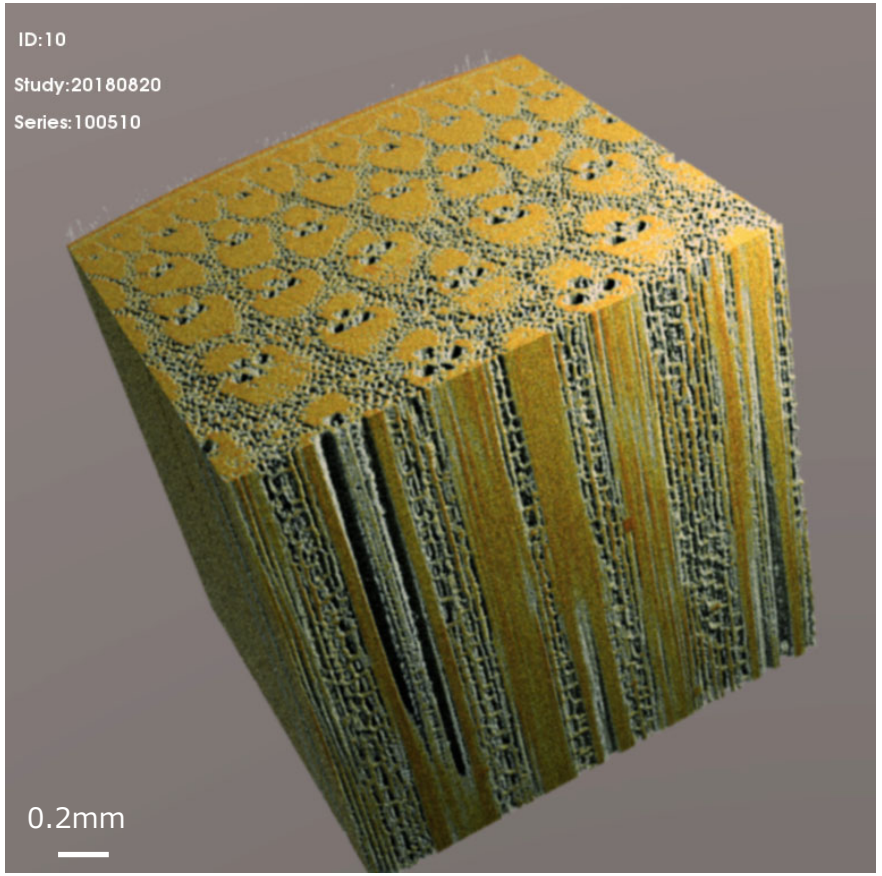
ALUMINUM DIE CASTINGS

Volume analysis
Total: 2762.56 mm³
Void: 32.81 mm³
→ 1.17%

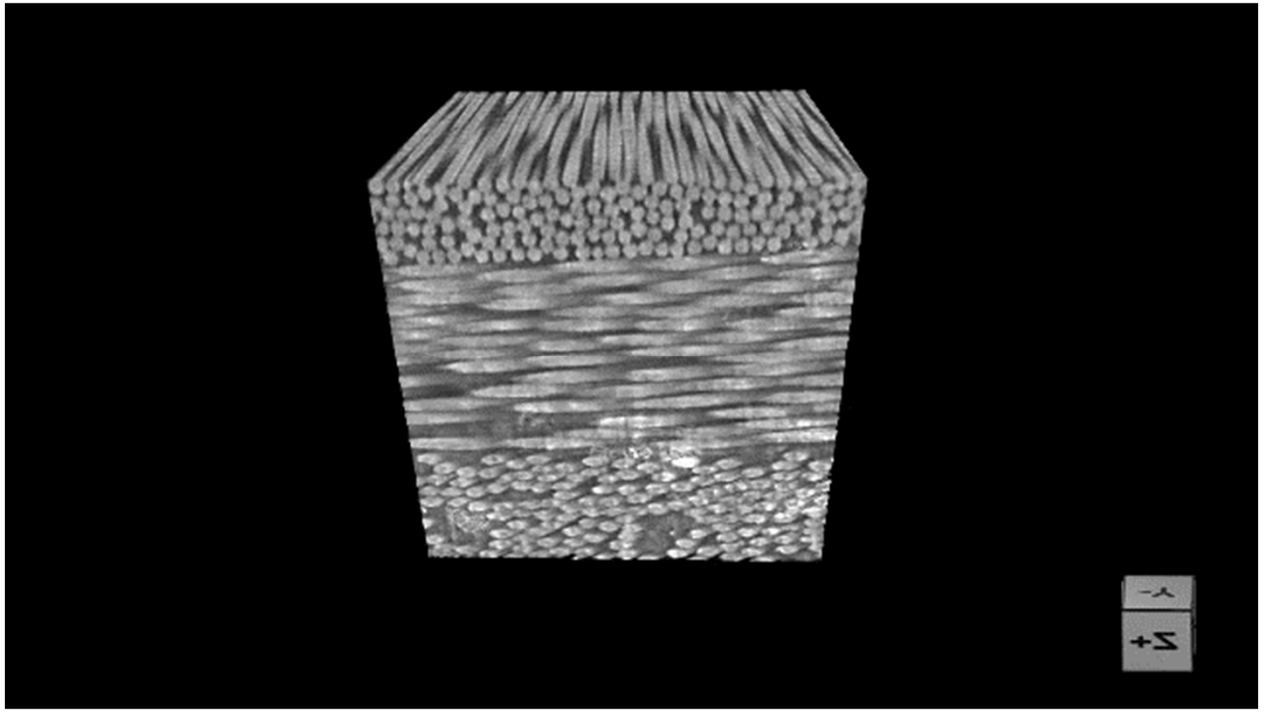


PLANTS

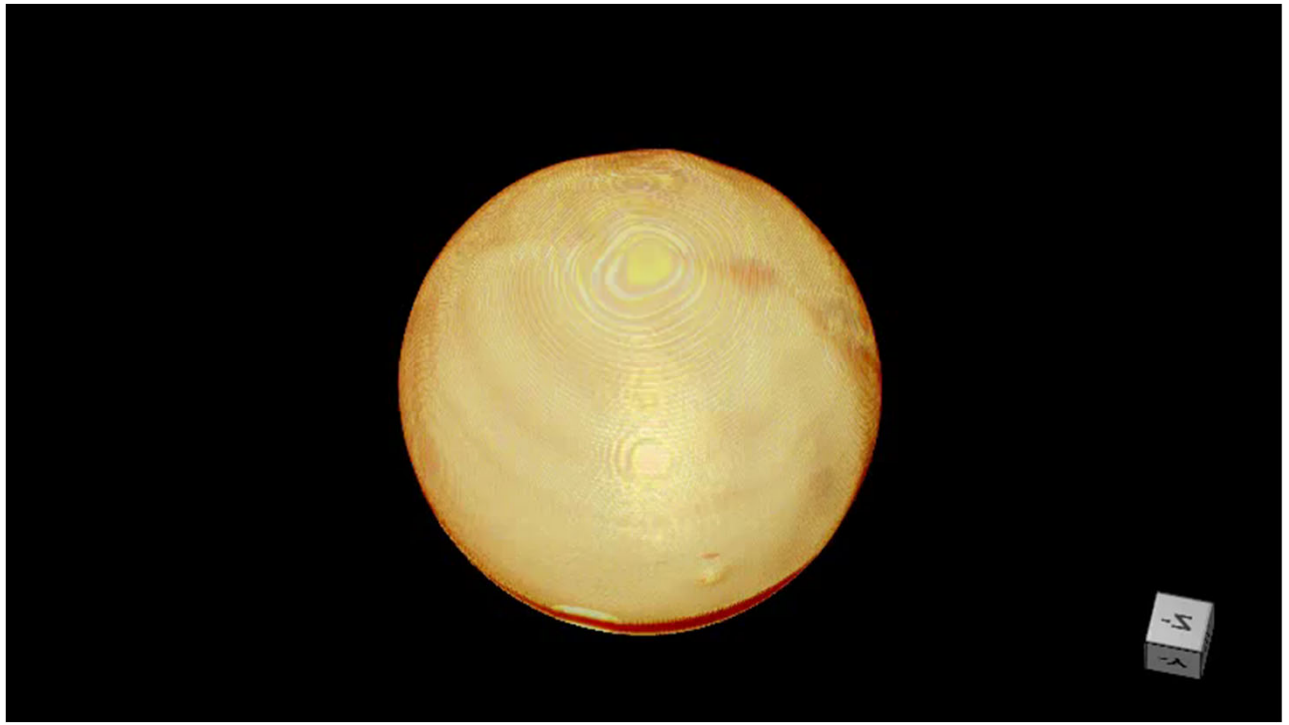




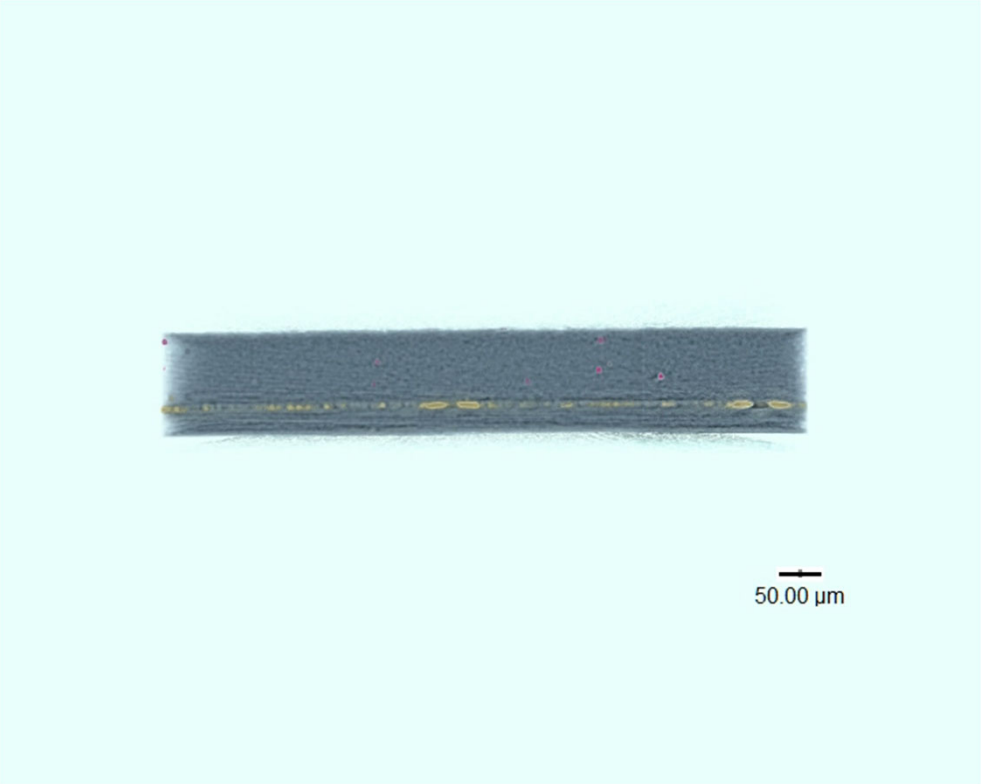
COMPOSITES



TABLETS



ORGANICS



INSECTS

Electronics

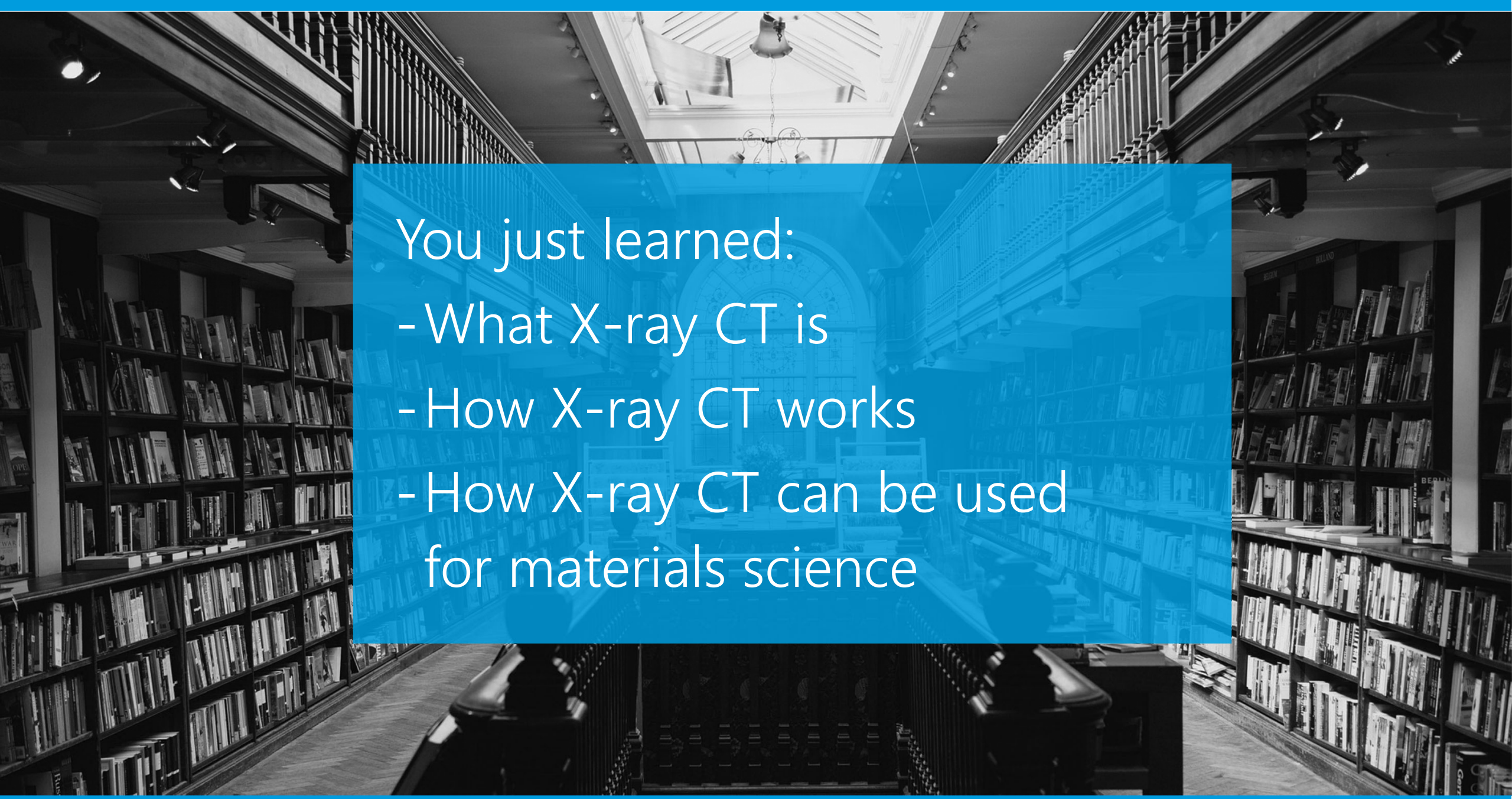
Ceramics & rocks

Light metals

Composites

Plants & insects

Food & pharmaceuticals

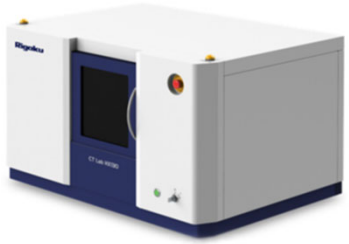


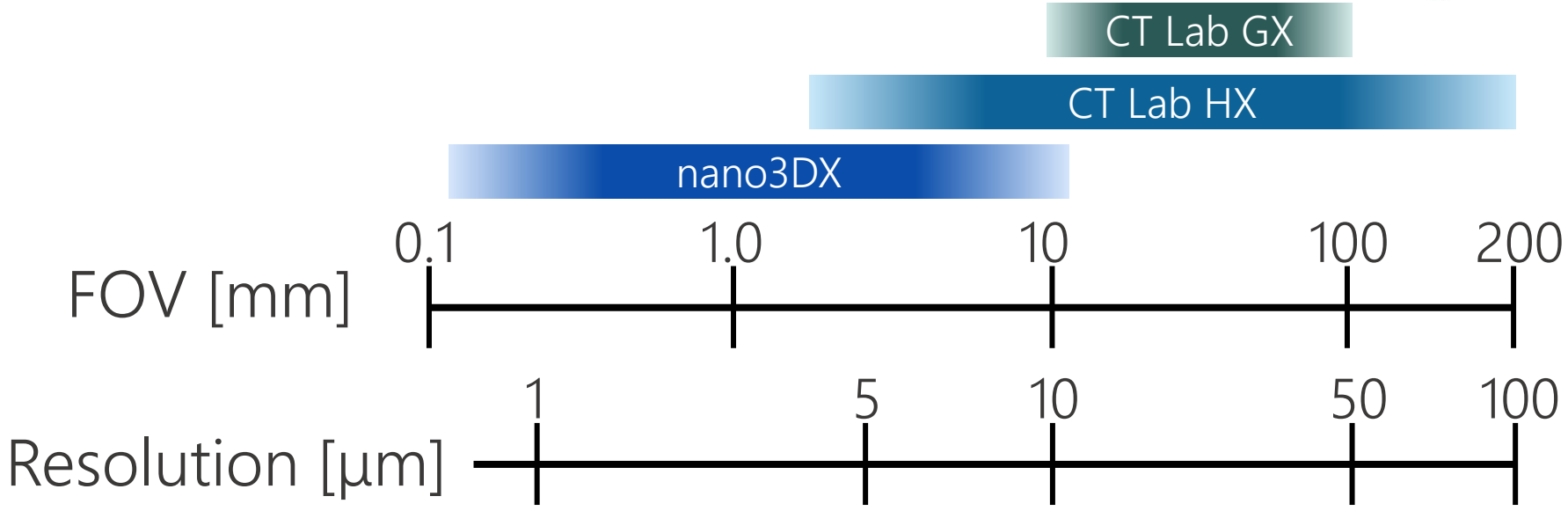
You just learned:

- What X-ray CT is
- How X-ray CT works
- How X-ray CT can be used for materials science

WHAT DOES RIGAKU MAKE?

nano3DX CT Lab HX CT Lab GX





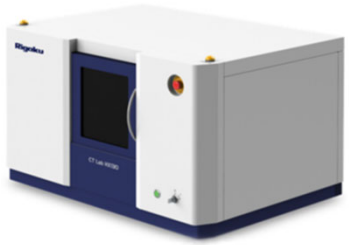
nano3DX

CT Lab HX

CT Lab GX

- High contrast
- High resolution
- High speed for soft materials

nano3DX **CT Lab HX** CT Lab GX



- Versatile benchtop X-ray CT
- Max. 200 mm FOV
- Nominal 2.2 µm resolution

nano3DX

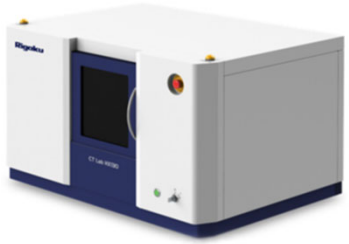
CT Lab HX

CT Lab GX

- Sample stationary geometry
- High speed 8 sec scans
- In-vivo & ex-vivo compatible

nano3DX

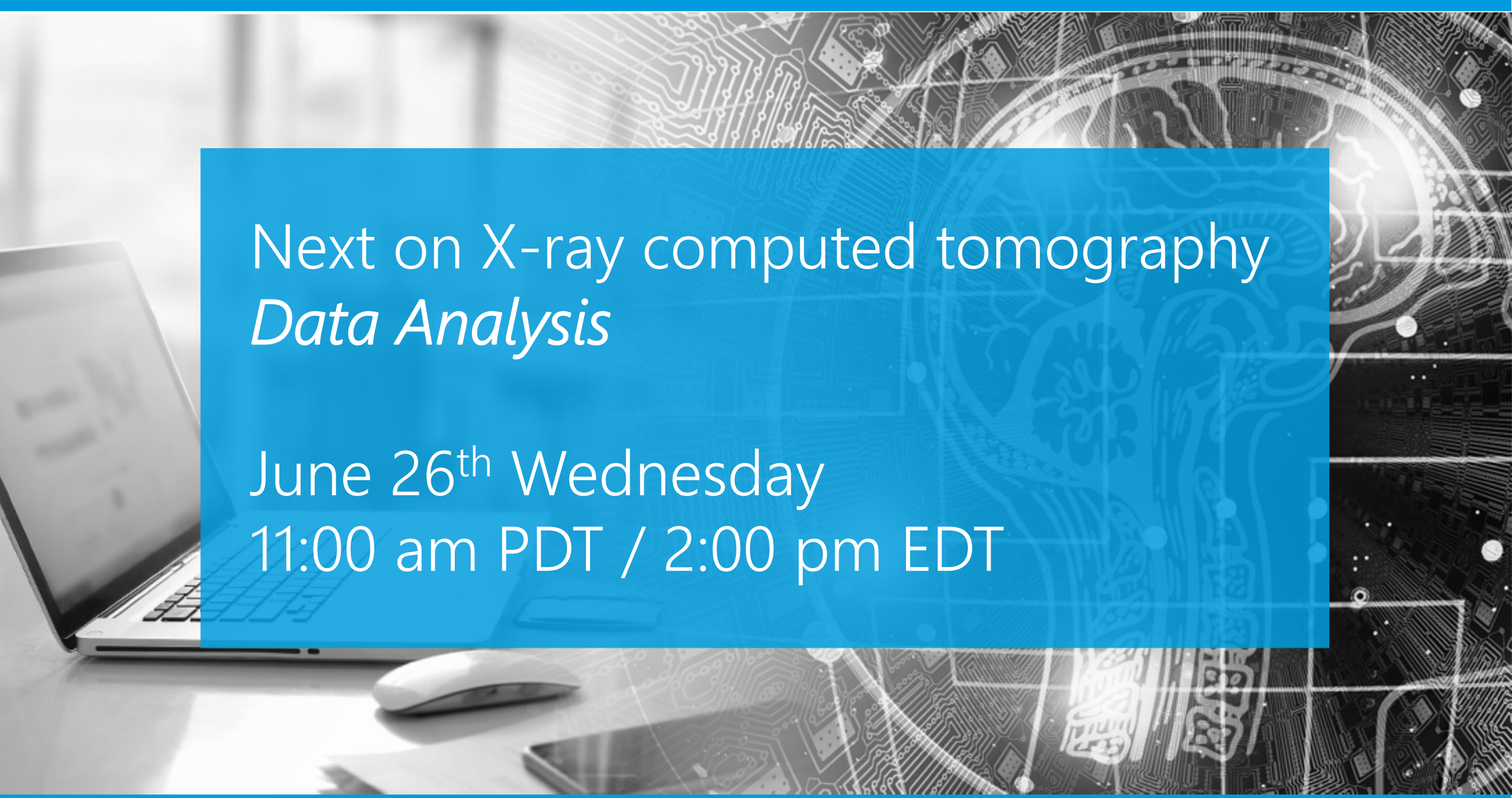
CT Lab HX



CT Lab GX

To learn more …


Rigaku.com → Contact



Next on X-ray computed tomography
Data Analysis

June 26th Wednesday
11:00 am PDT / 2:00 pm EDT

Q & A SESSION

Aya Takase

Tom McNulty

We'll follow up with your questions.

Recording will be available tomorrow.

Register for the 3nd webinar.


THANK YOU FOR JOINING US
SEE YOU NEXT TIME!