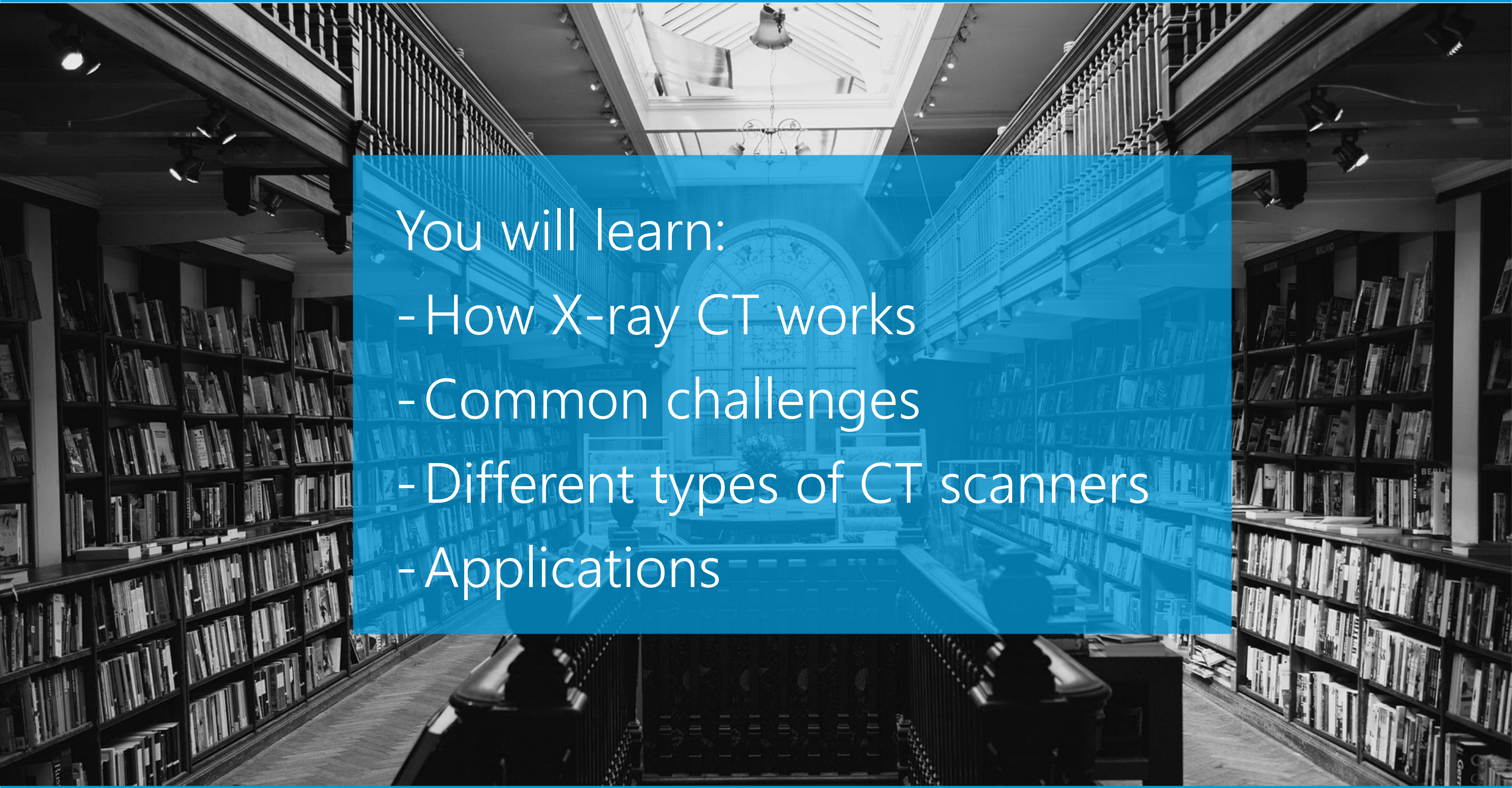
INTRODUCTION TO X-RAY CT

Aya Takase @ Rigaku



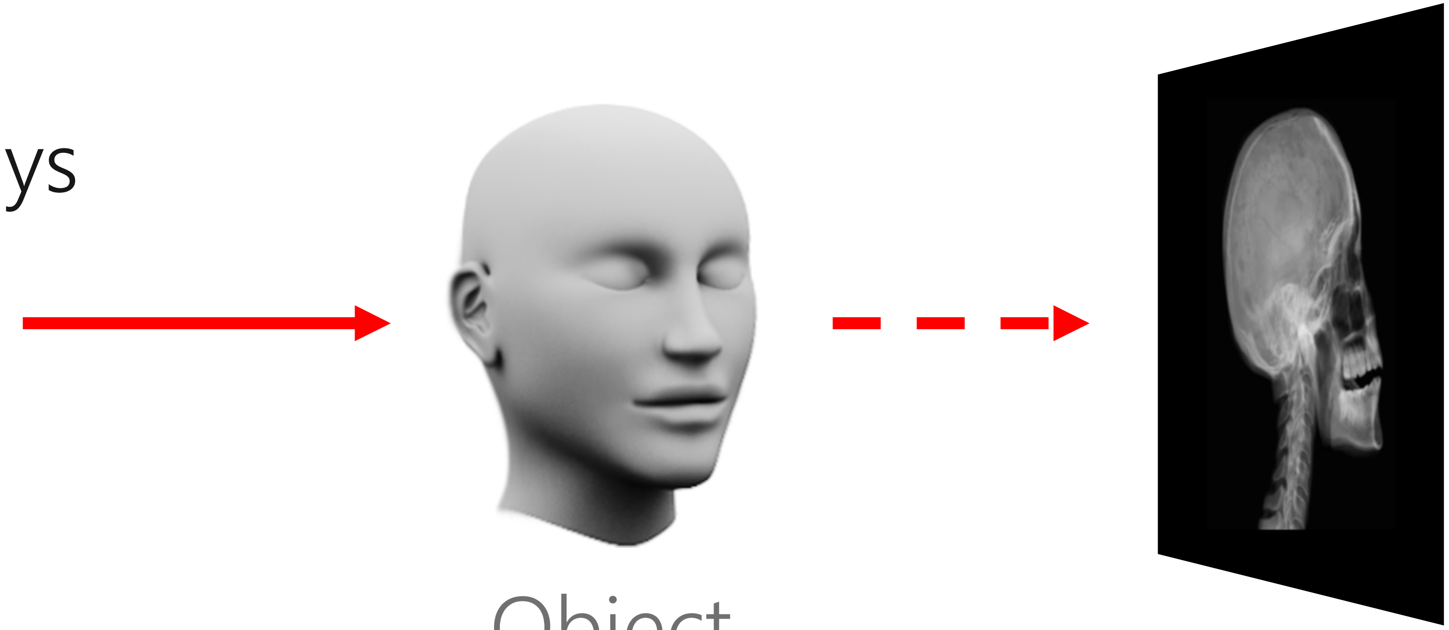
You will learn:

- How X-ray CT works
- Common challenges
- Different types of CT scanners
- Applications

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

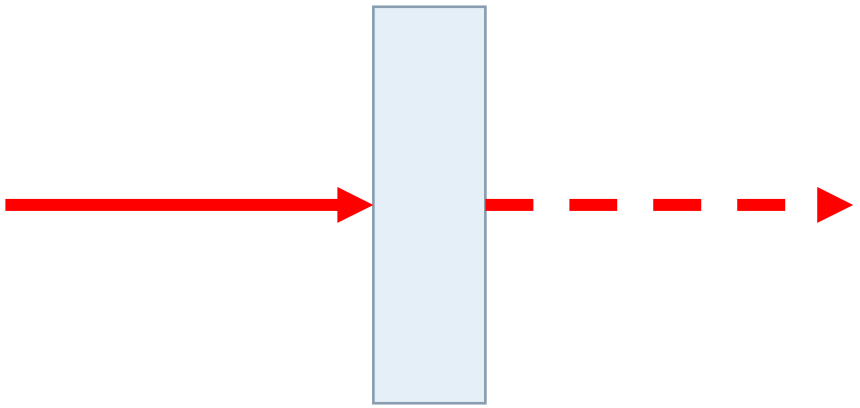
2D projection

X-rays

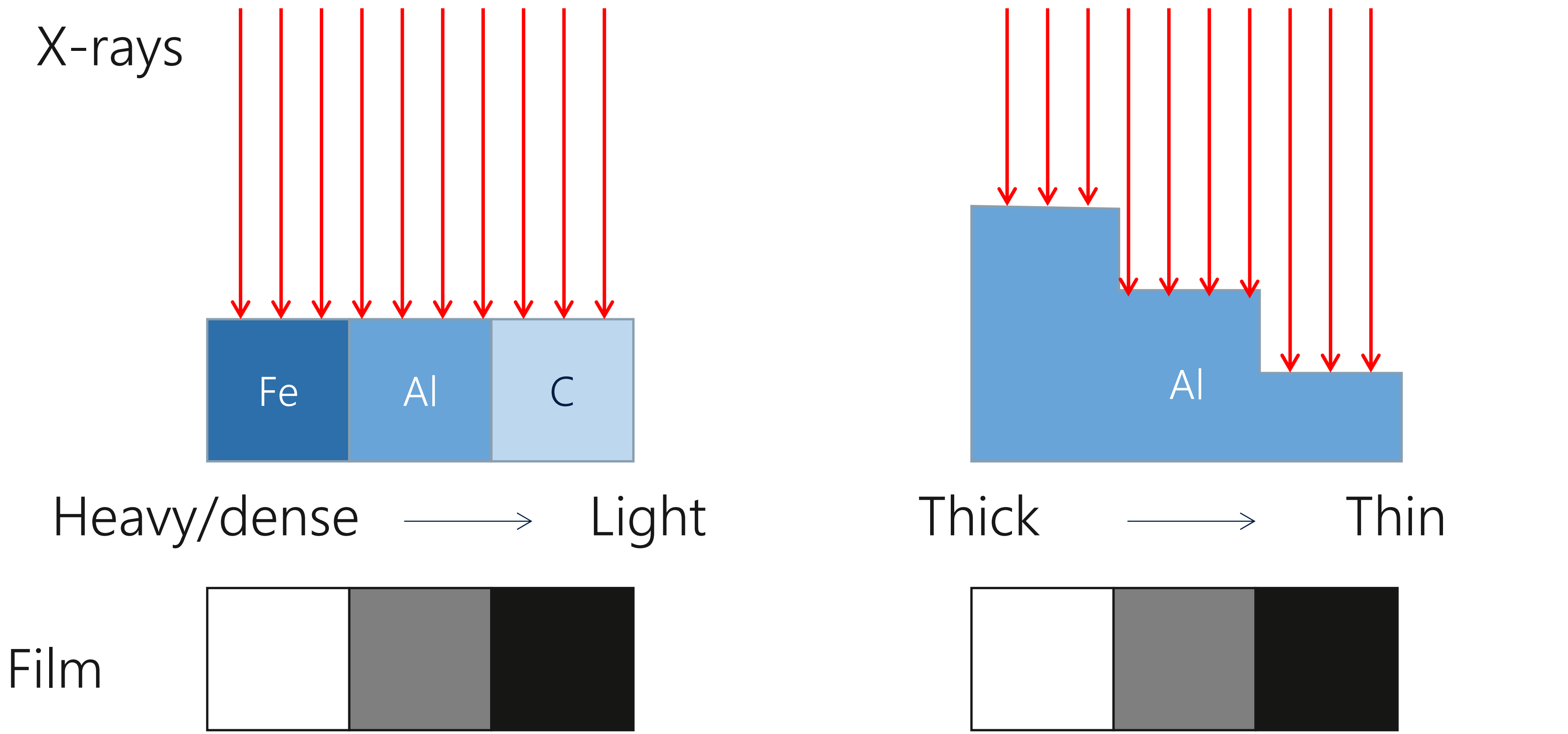


Object

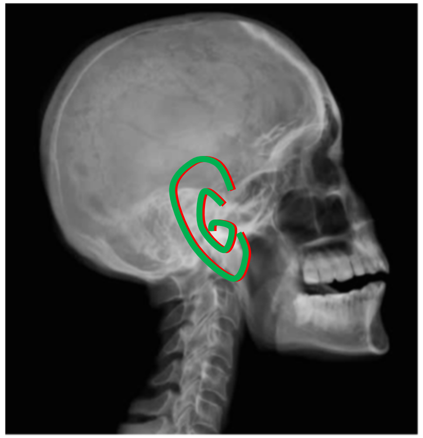
Detector



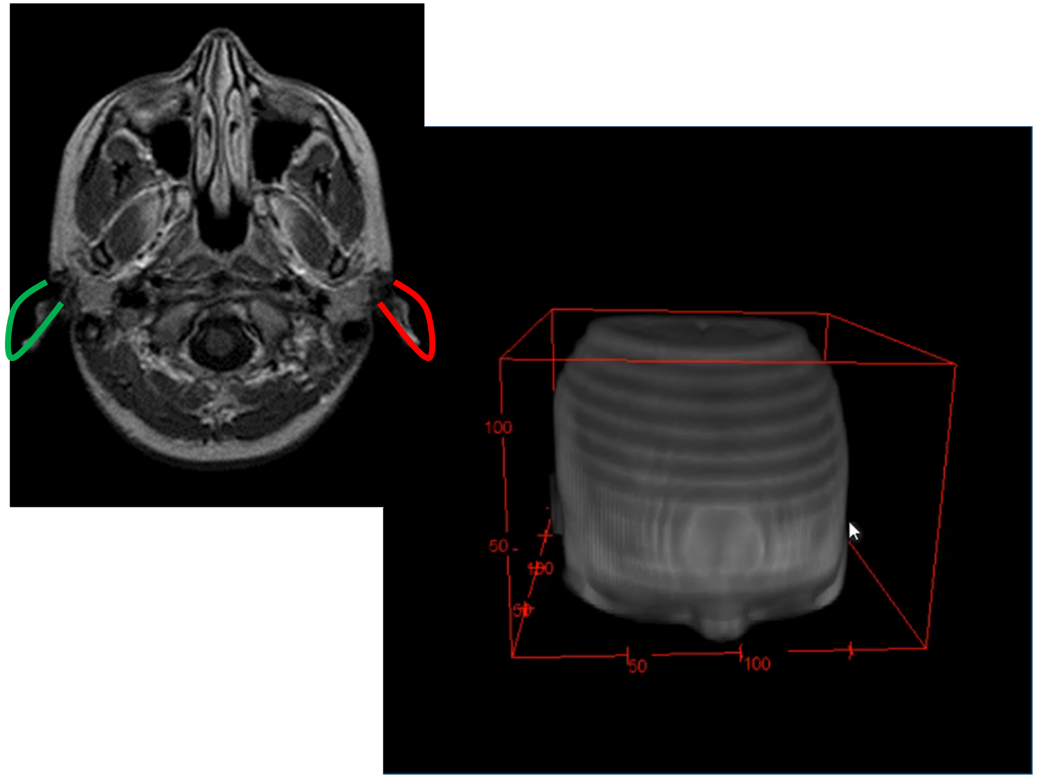
Things absorb X-rays.


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

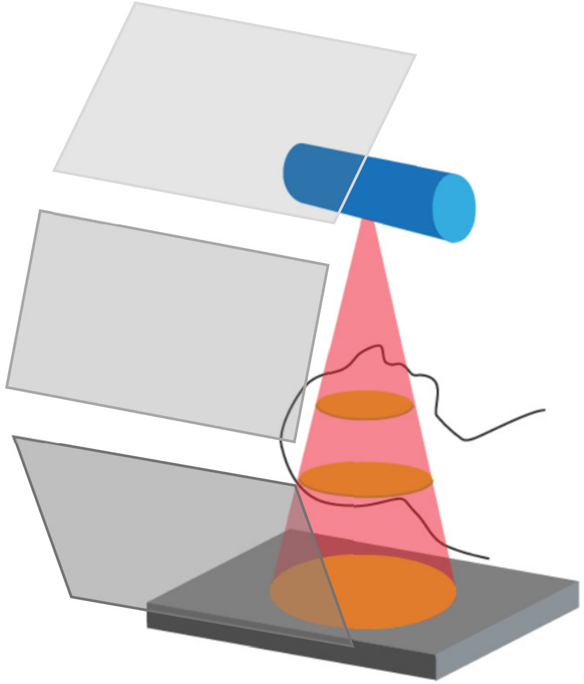
HOW DO YOU GET 3D VIEW?



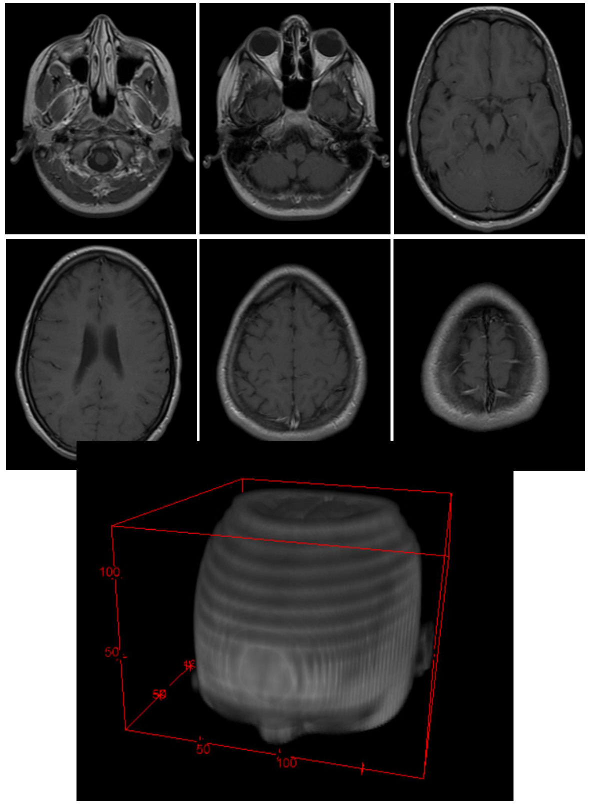
2D projection



3D computed tomography



Reconstruction

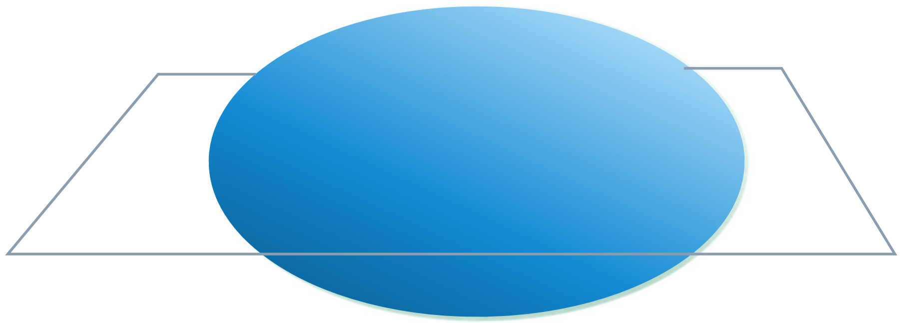


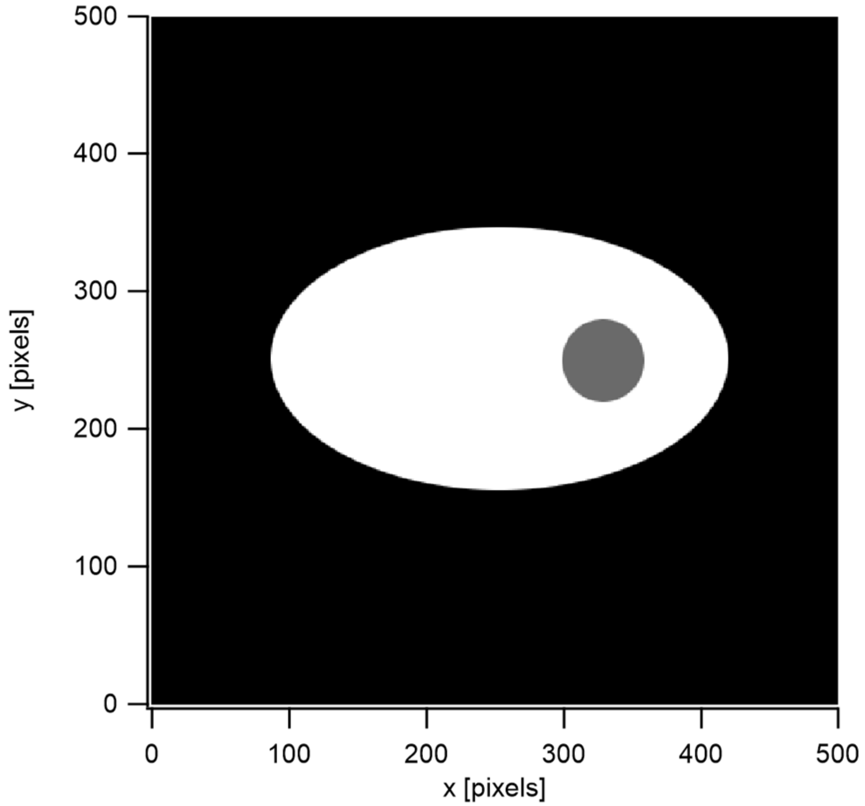
Scan

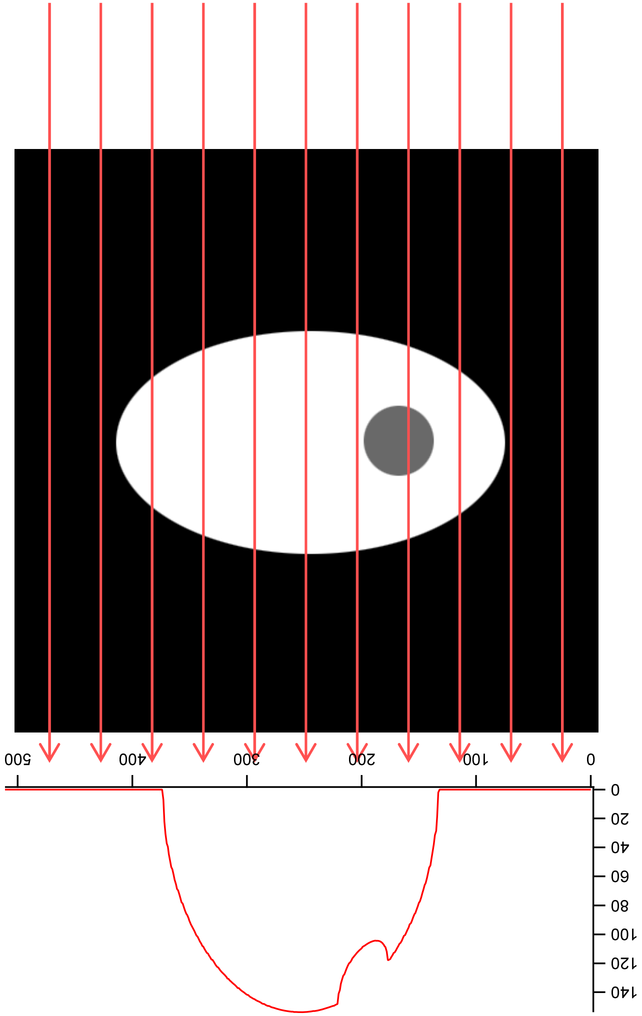
Tomographic cross sections
3D rendering

HOW DOES RECONSTRUCTION WORK?

Tomographic cross section

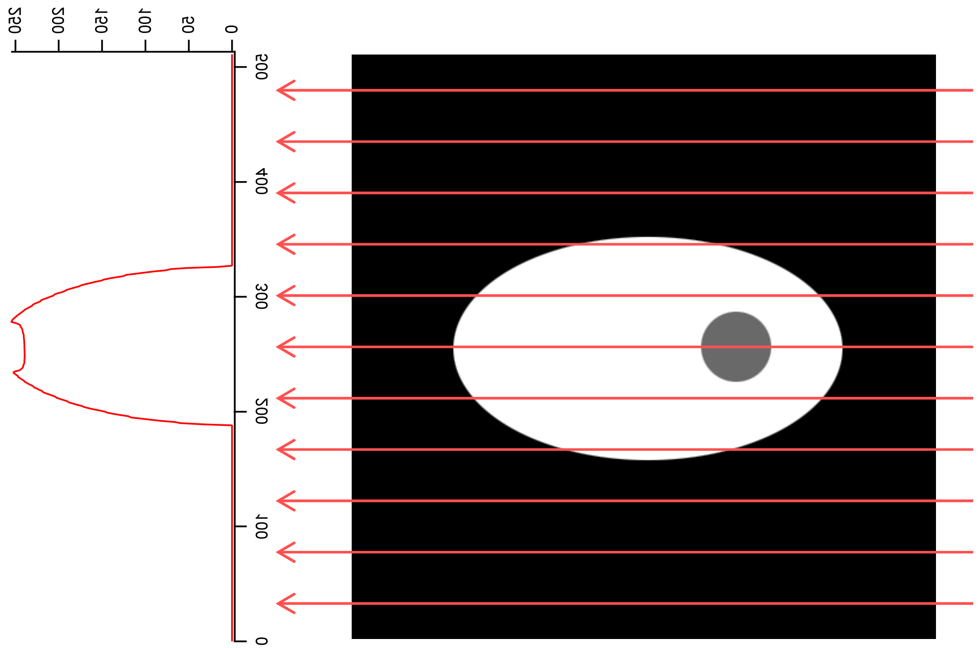


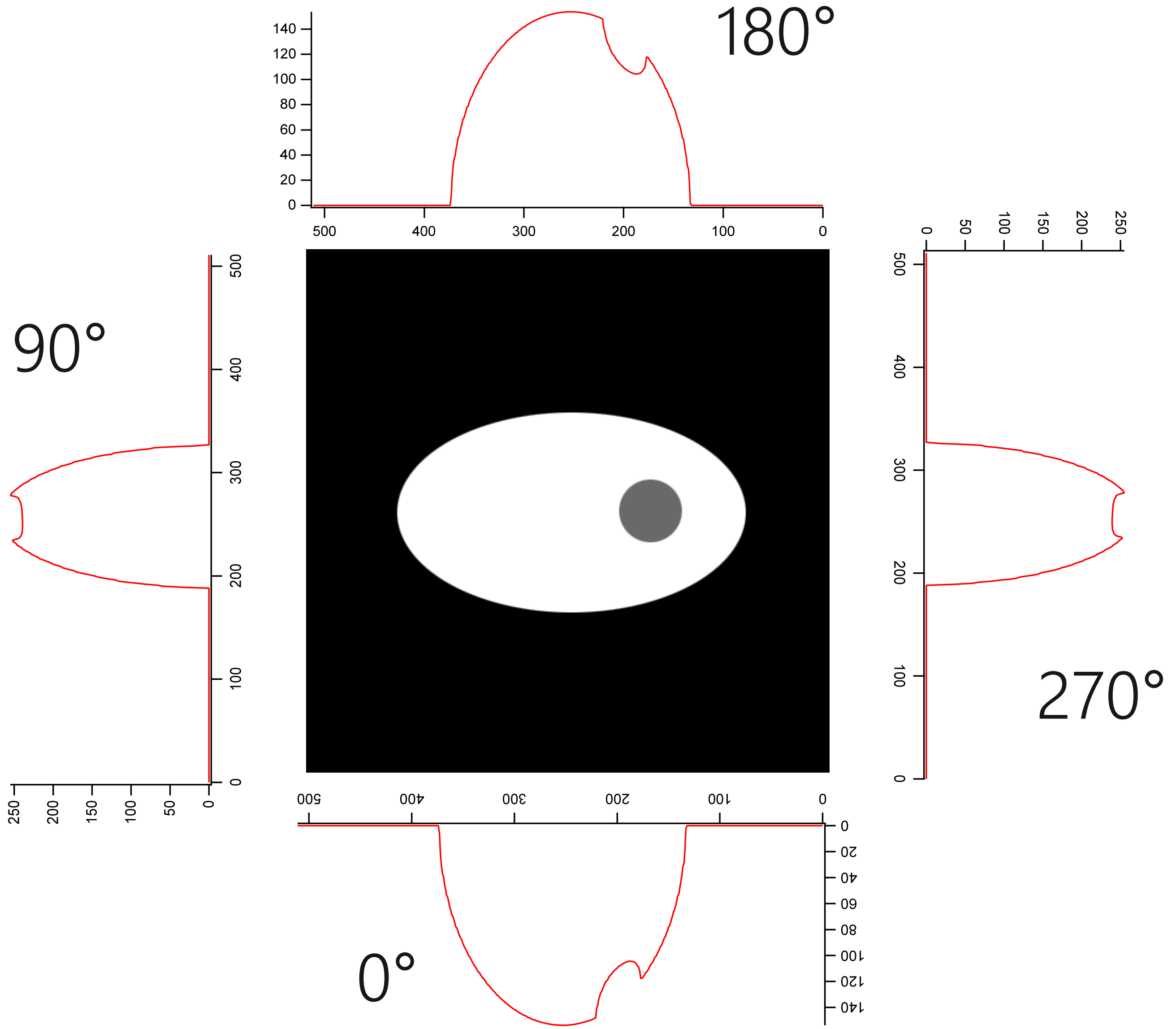




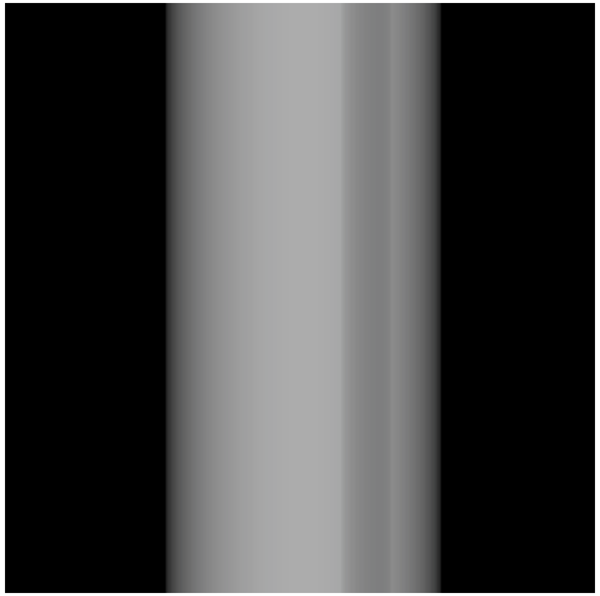
Integrated density projection angle 0°

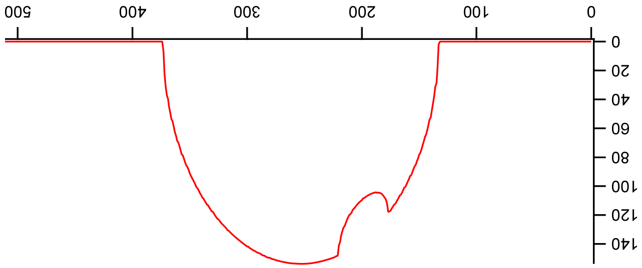
90°

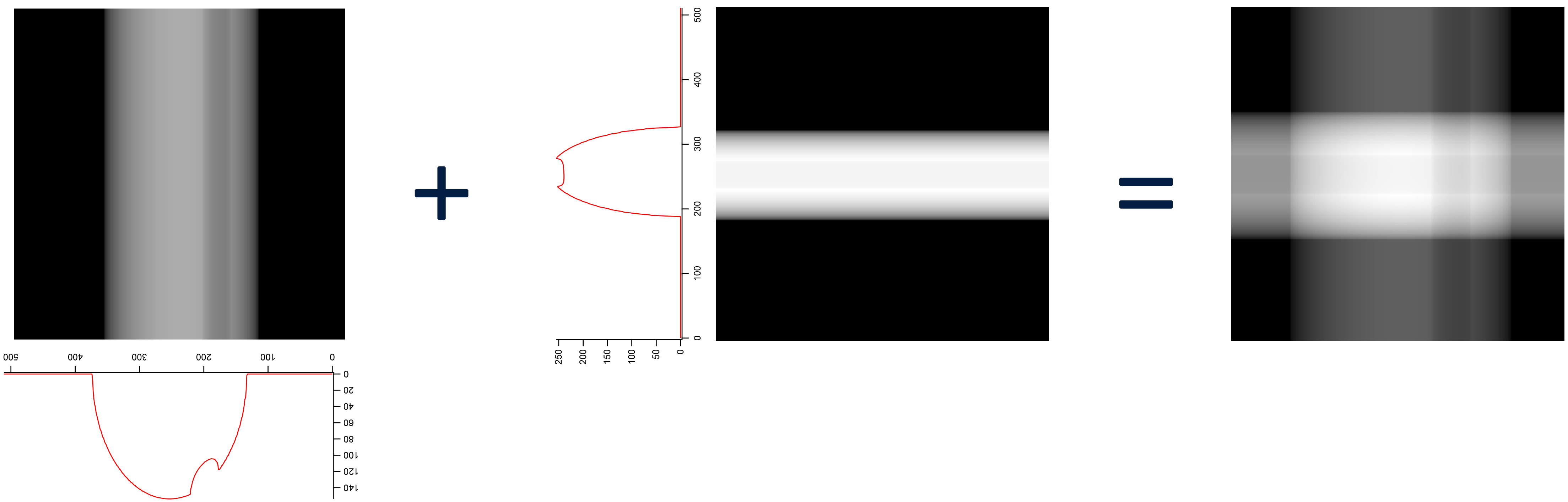


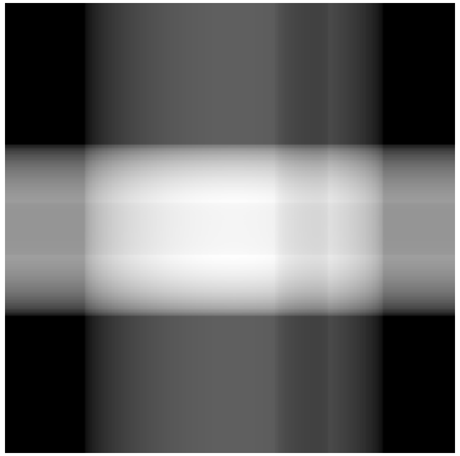


180°
90°
270°
0°

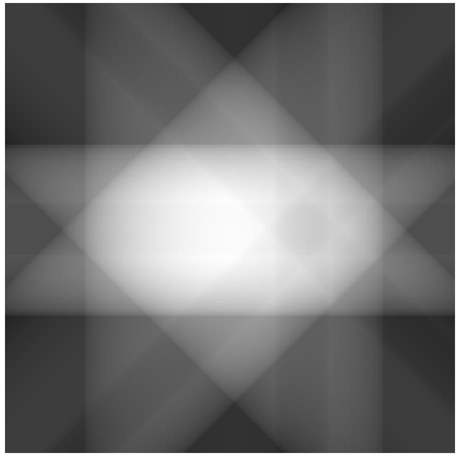



0
100
200
300
400
500
0
20
40
60
80
100
120
140

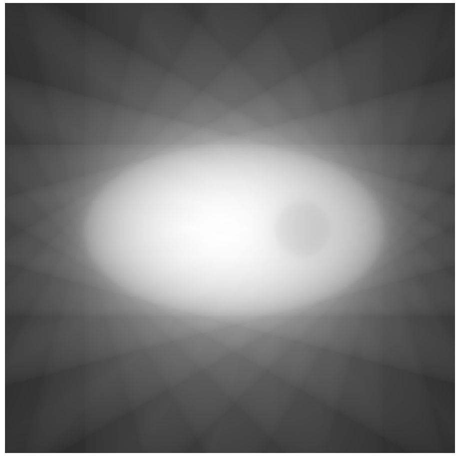




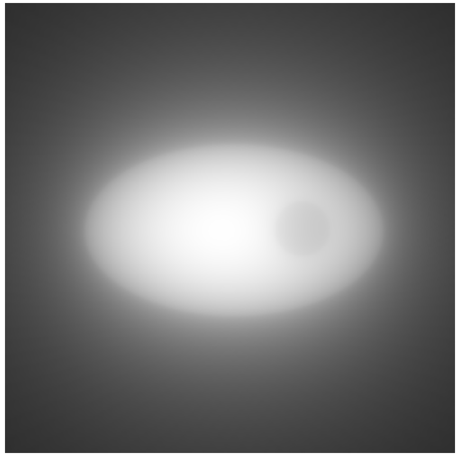
4 projections



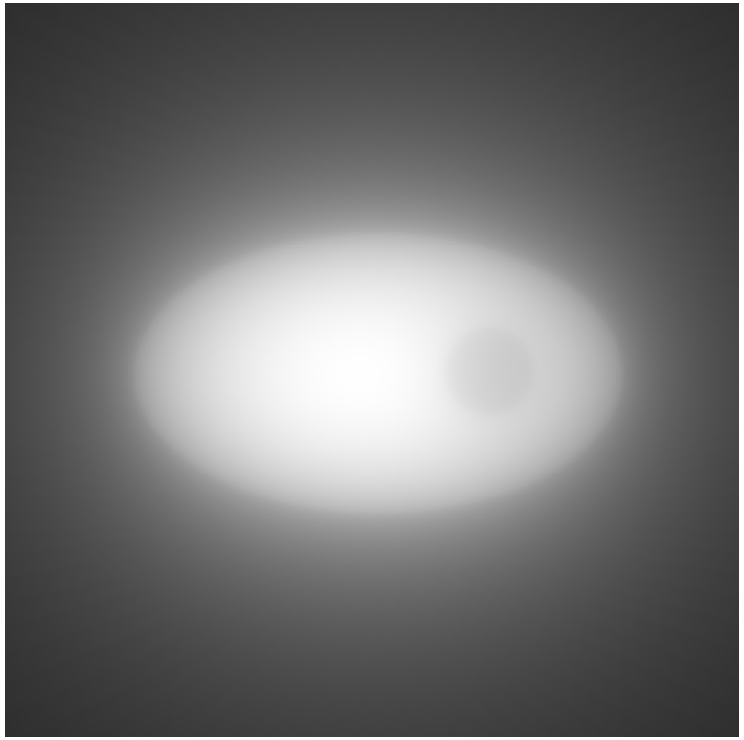
8 projections



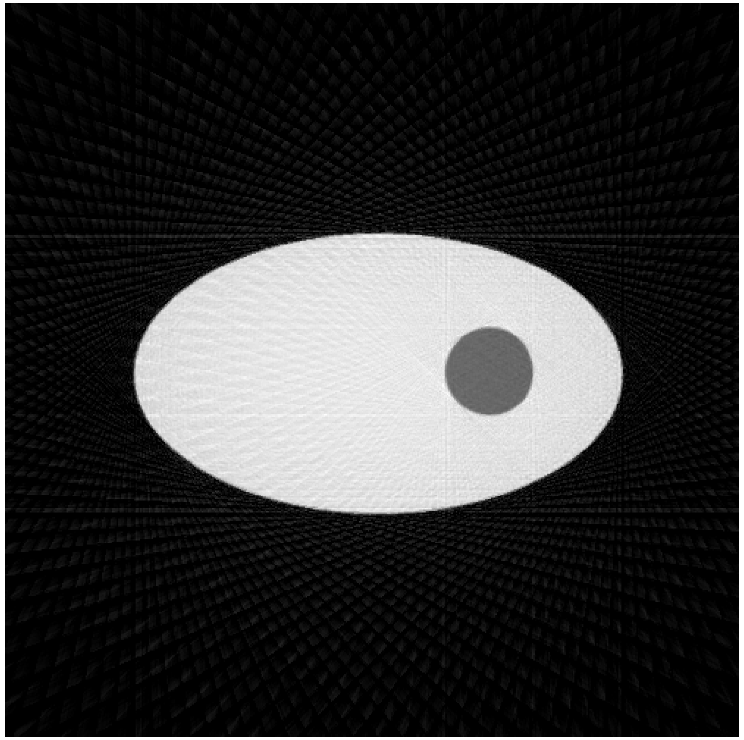
24 projections



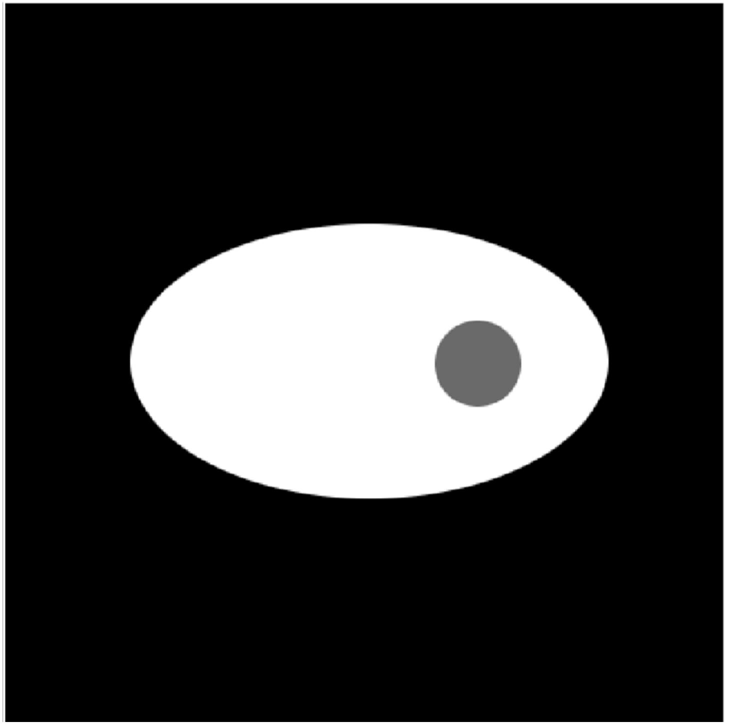
120 projections



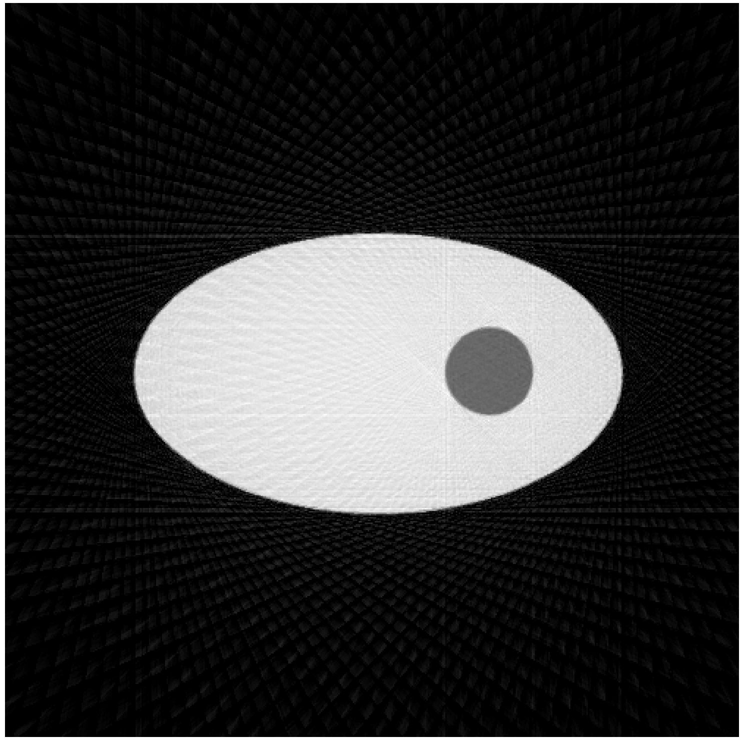
120 projections



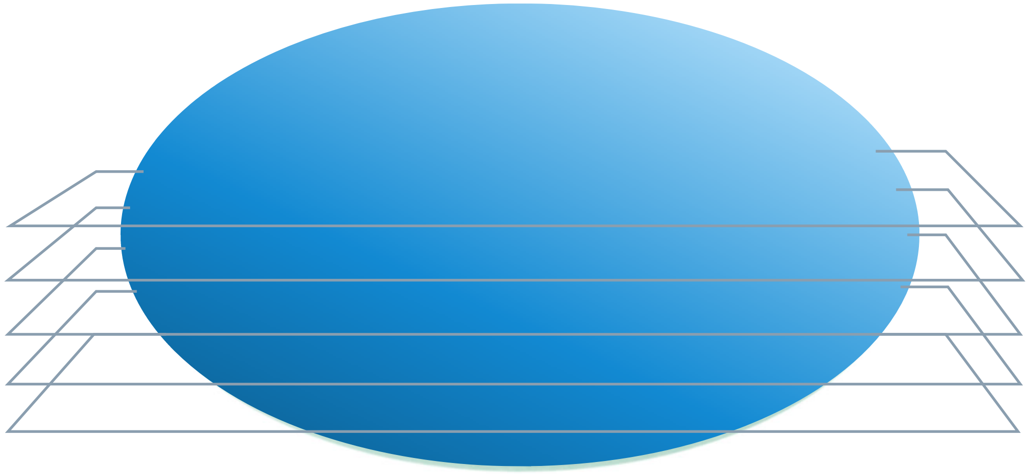
120 projections
With ramping filter

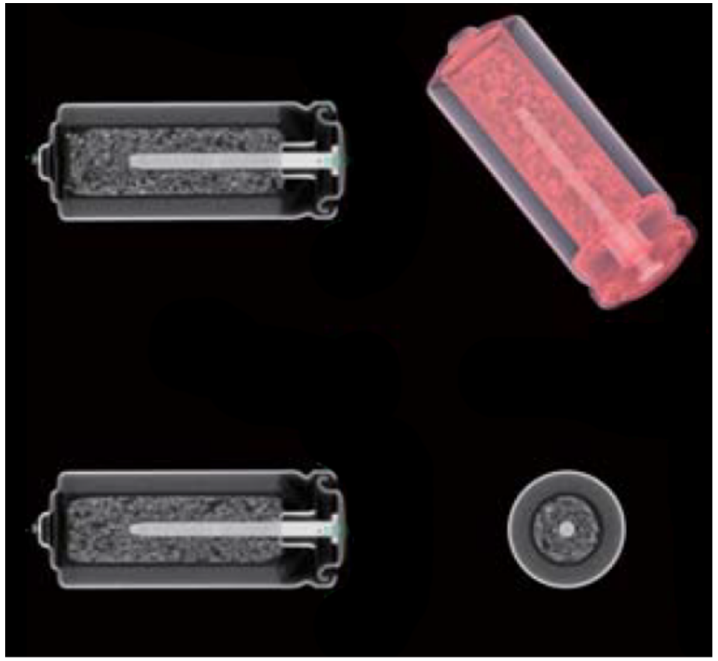


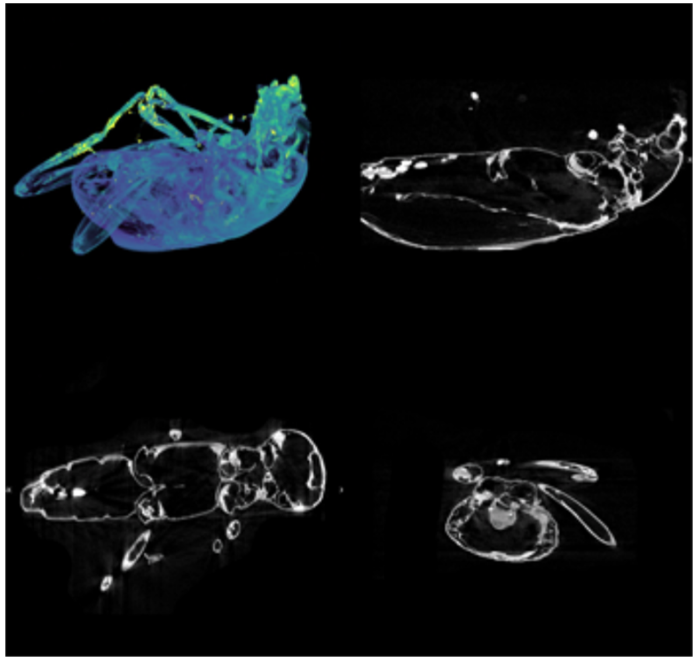
Original

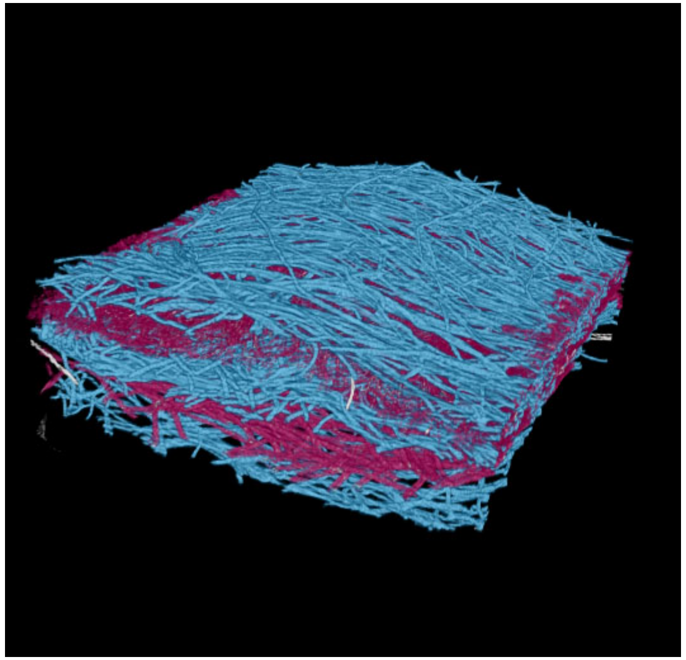


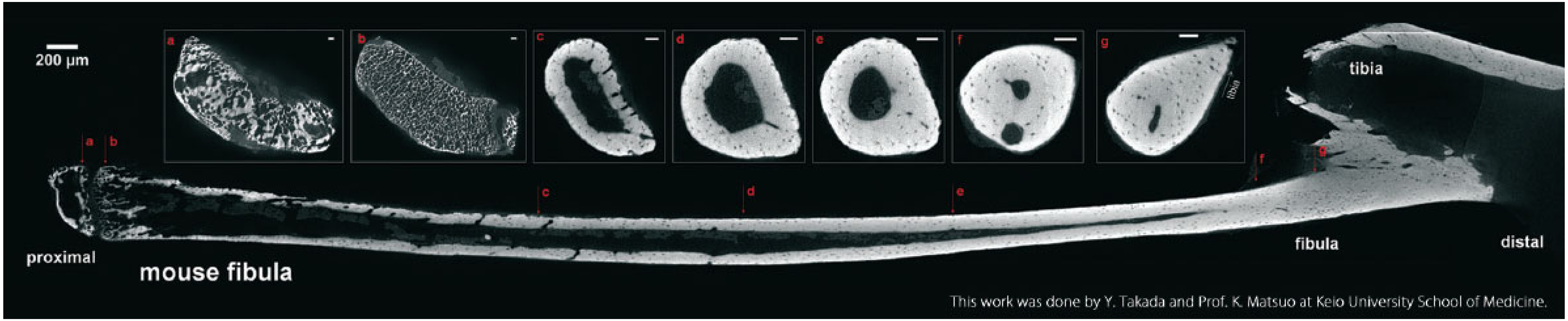
Reconstructed










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

WHAT ARE THE COMMON CHALLENGES?

COMMON CHALLENGES

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

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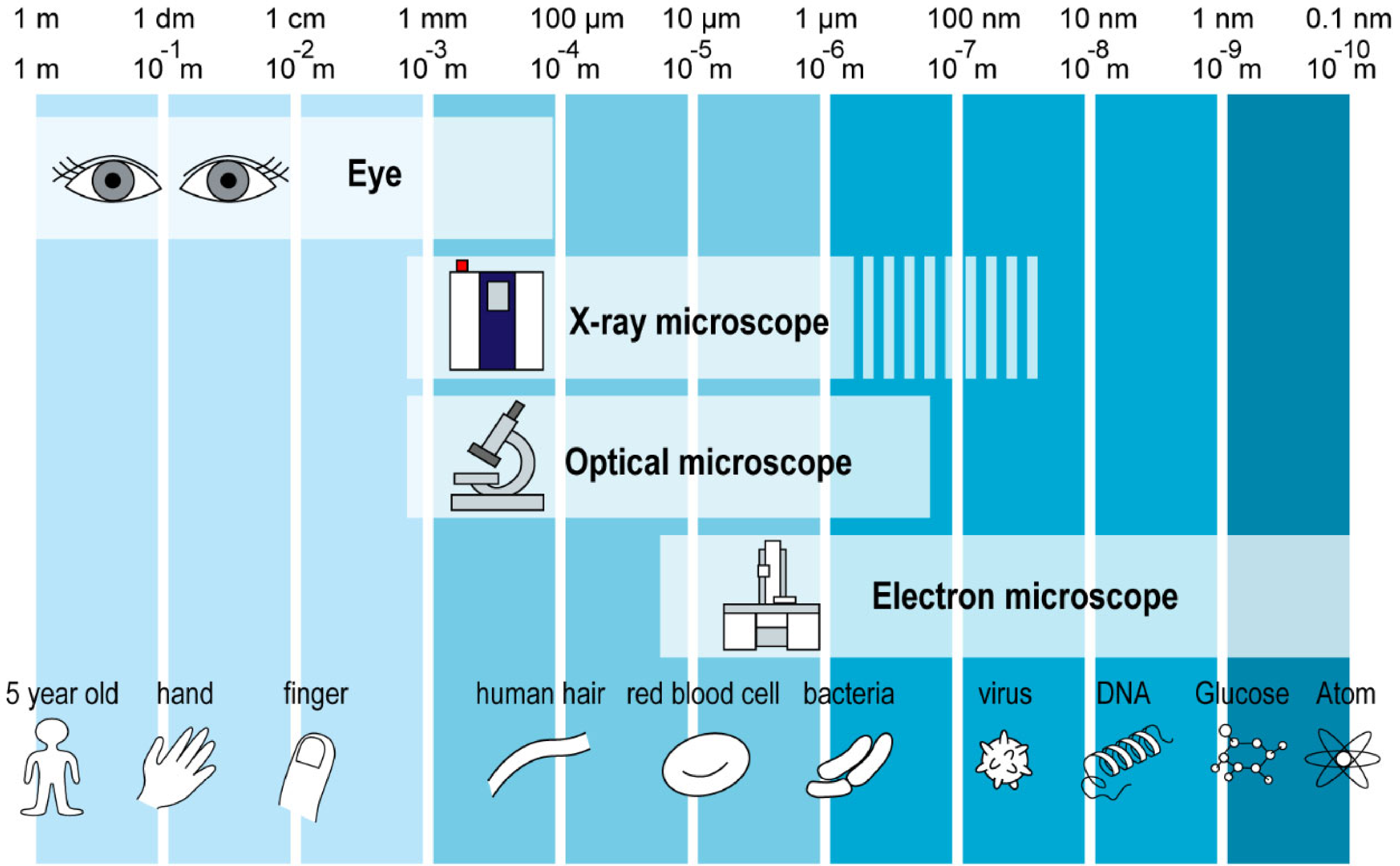
- Artifacts

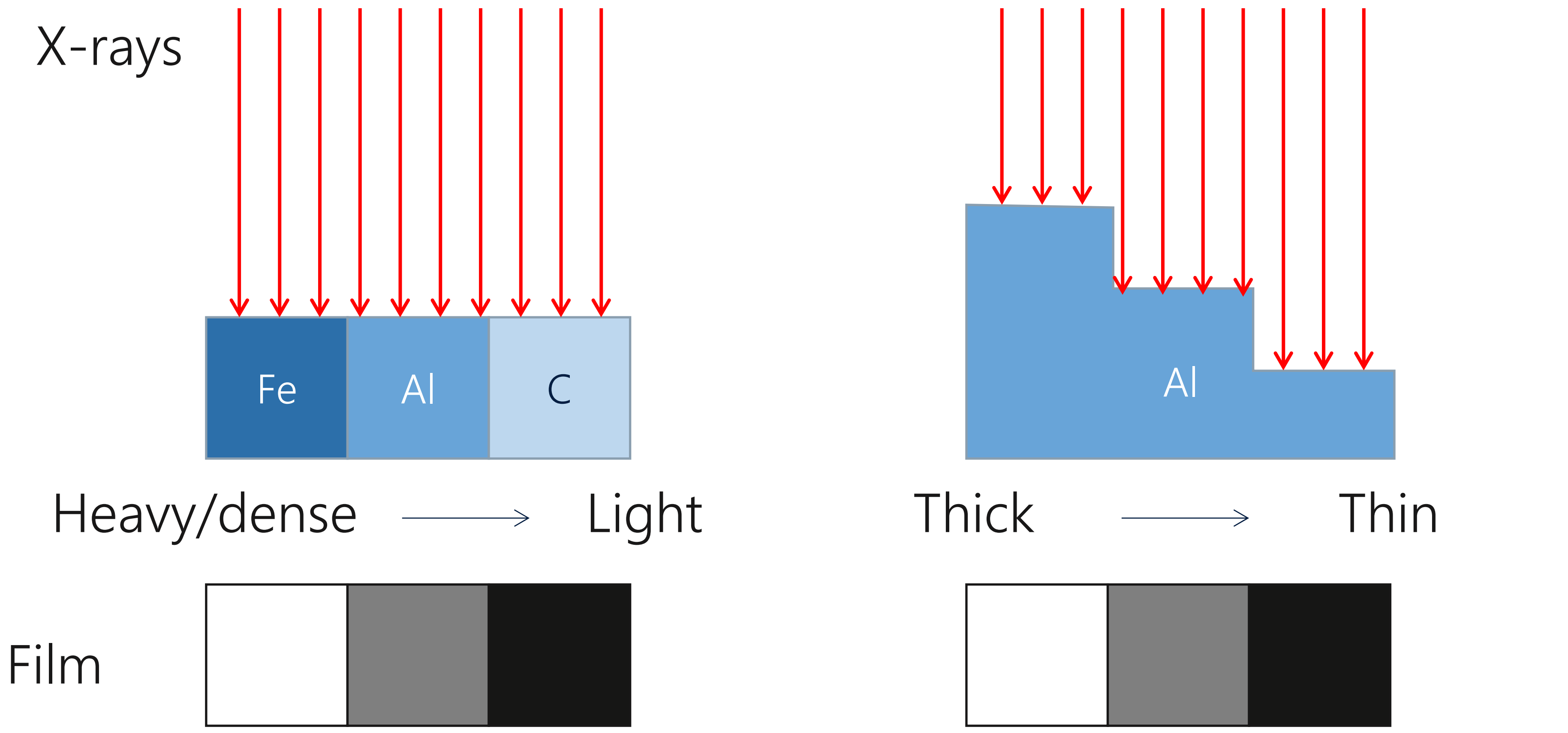
WHAT’S THE RESOLUTION?


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

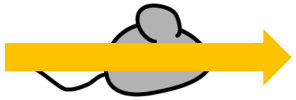
COMMON CHALLENGES

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

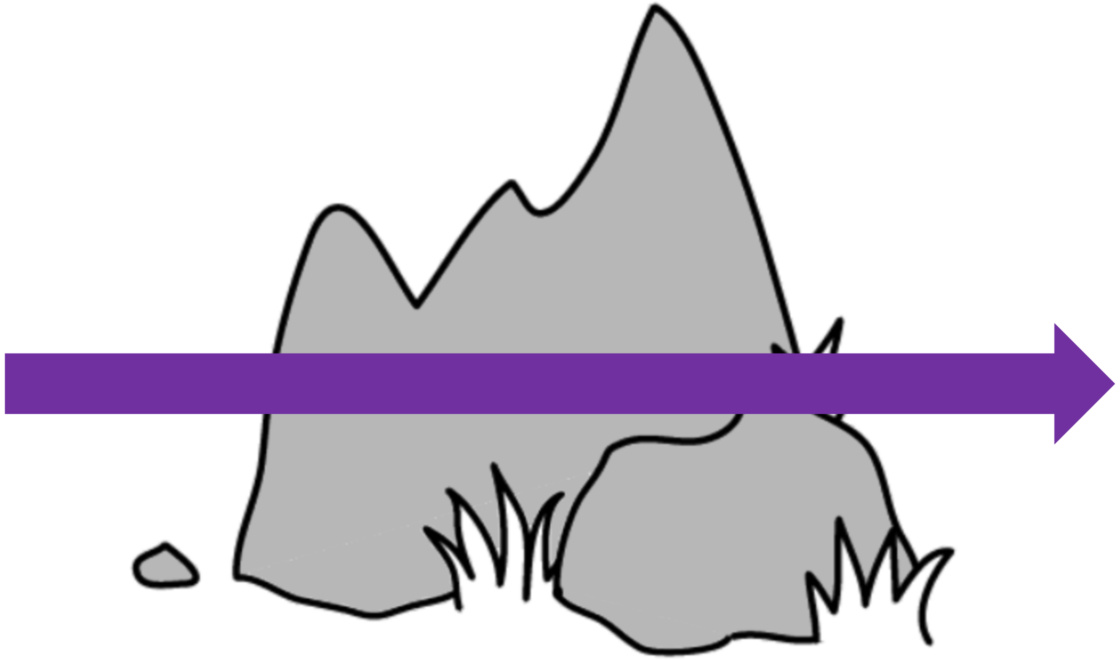
WHAT’S TOO LIGHT OR TOO HEAVY?


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

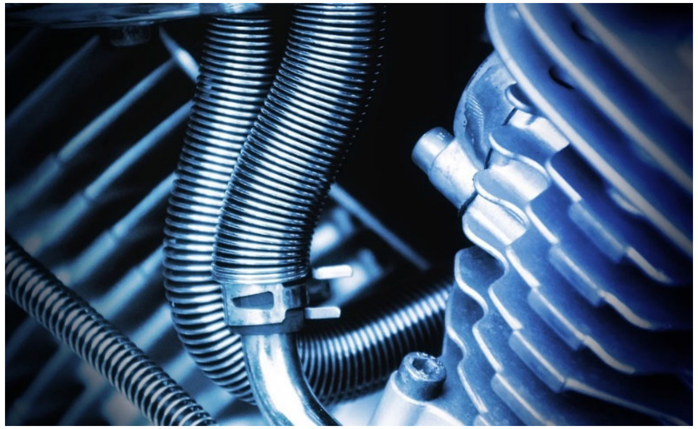


X-ray energy

5 keV

450 keV

Styrofoam
~ 5 keV



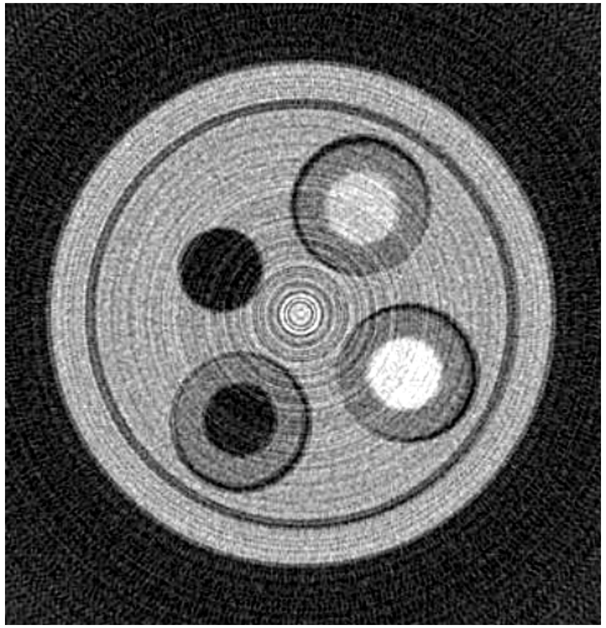
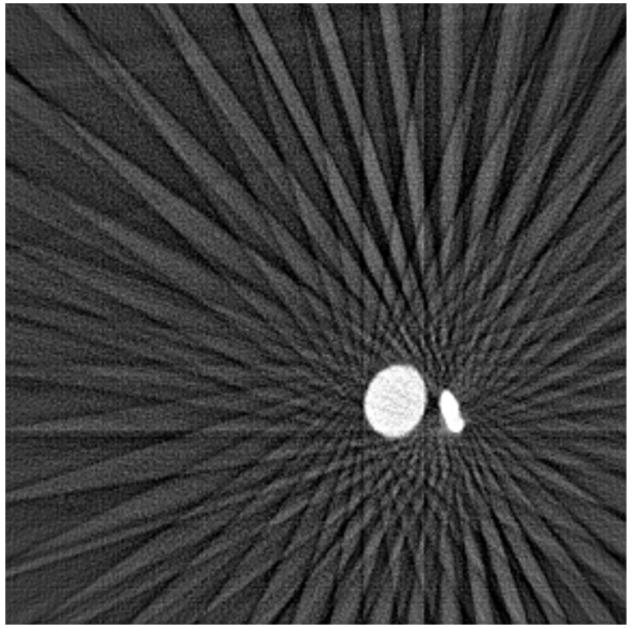
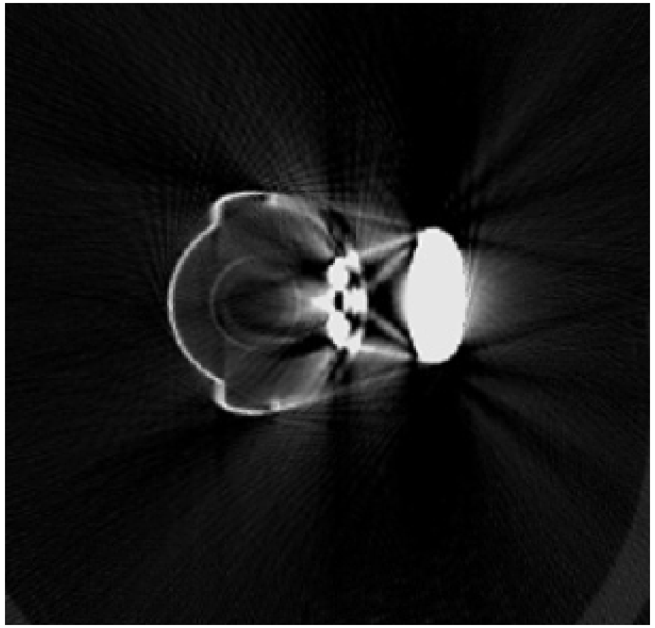
Engine parts
~ 450 keV

COMMON CHALLENGES

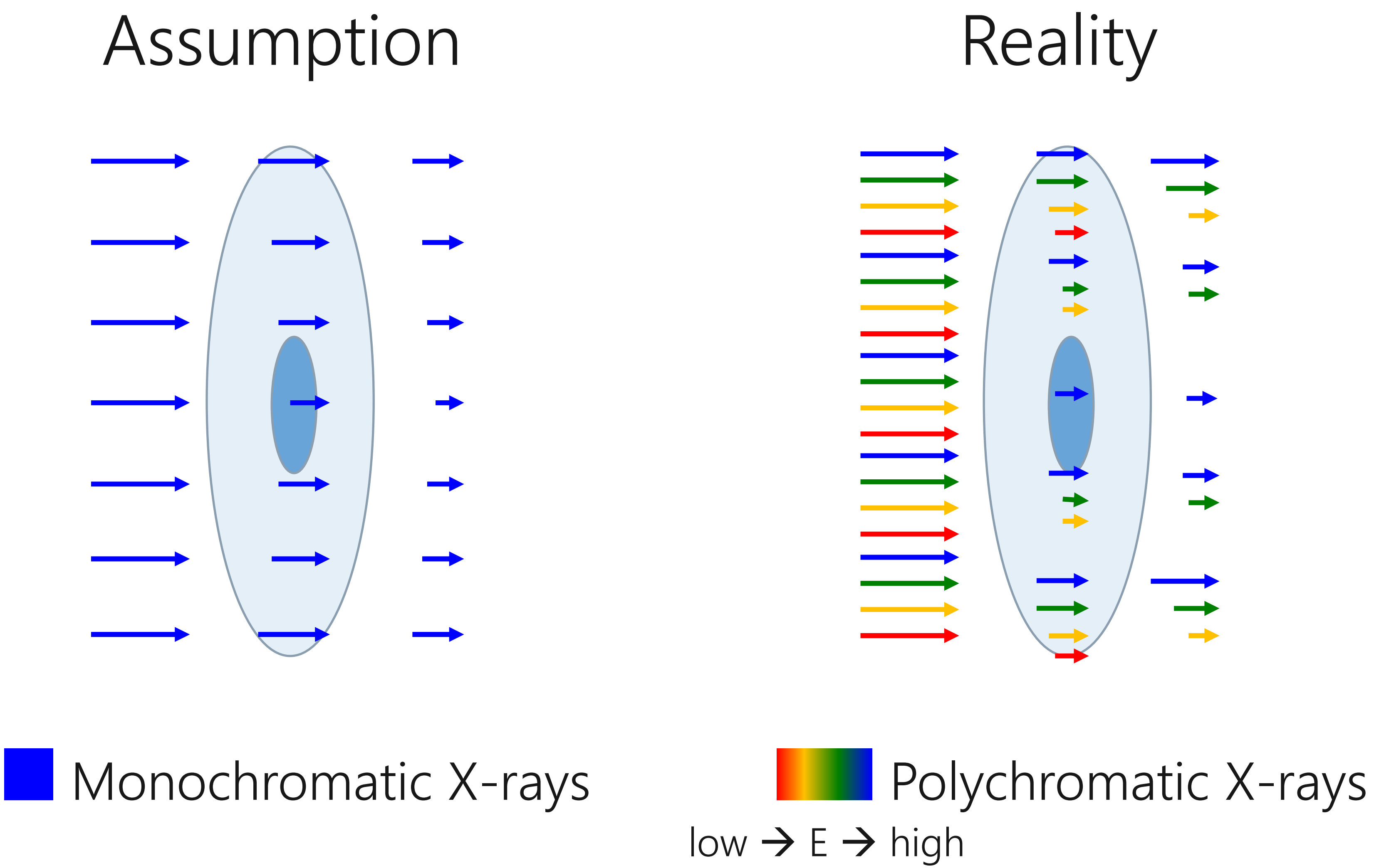
- Limited resolution compared to EM
- Too light / heavy absorbing materials
- Artifacts

WHAT ARE ARTIFACTS?

COMMON ARTIFACTS

Rings	Aliasing	Streaks & shading
		
Bad pixels	Under sampling	Beam hardening

WHAT IS BEAM HARDENING?


Assumption
Reality
Monochromatic X-rays
Polychromatic X-rays
low → E → high

BEAM HARDENING ARTIFACTS SIMULATION

Model

Simulation

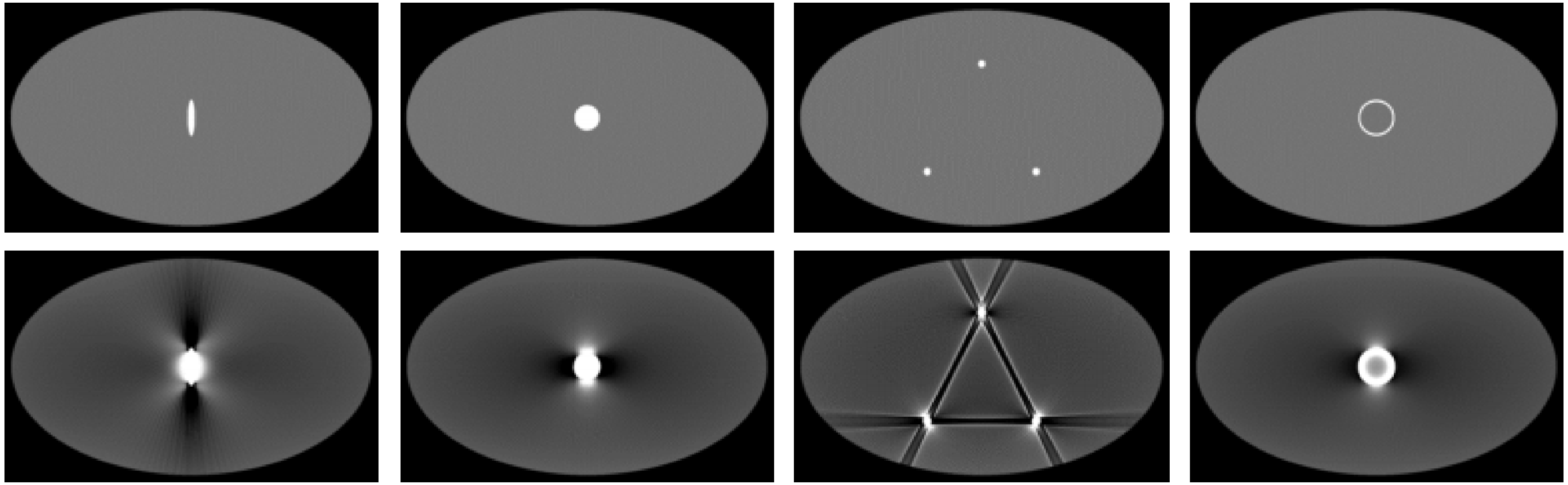


Figure 4. Simulated scans without (top row) and with (bottom row) beam hardening, showing that dark streaks occur along the lines of greatest attenuation, and bright streaks occur in other directions. Scatter produces artifacts that look similar to this. Also note the subtle decrease in Hounsfield units 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

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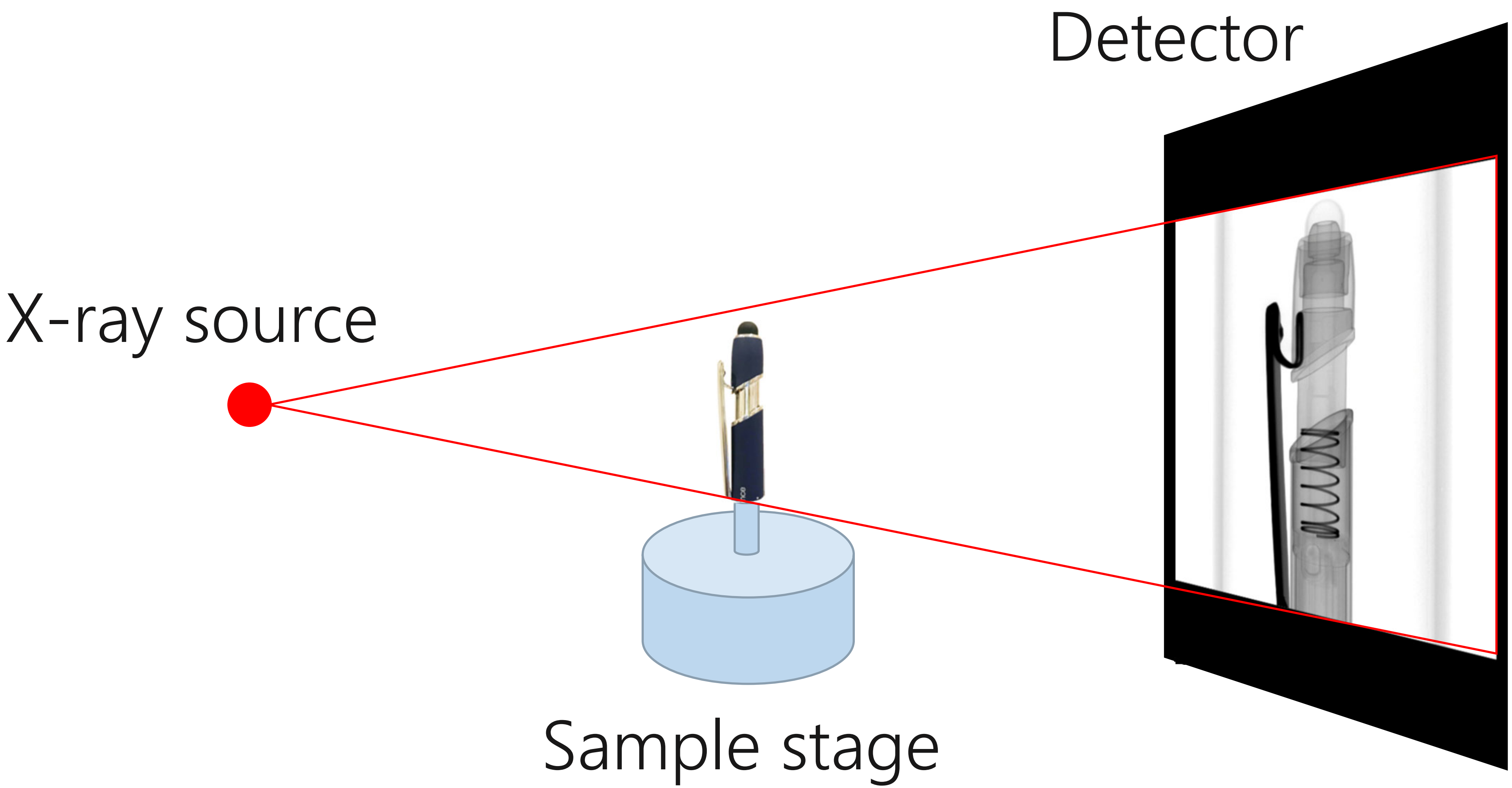
WHAT HARDWARE IS INVOLVED IN AN X-RAY CT SYSTEM?

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 kV
~ 100 W

Nikon

High energy
190 ~ 750 kV
~ 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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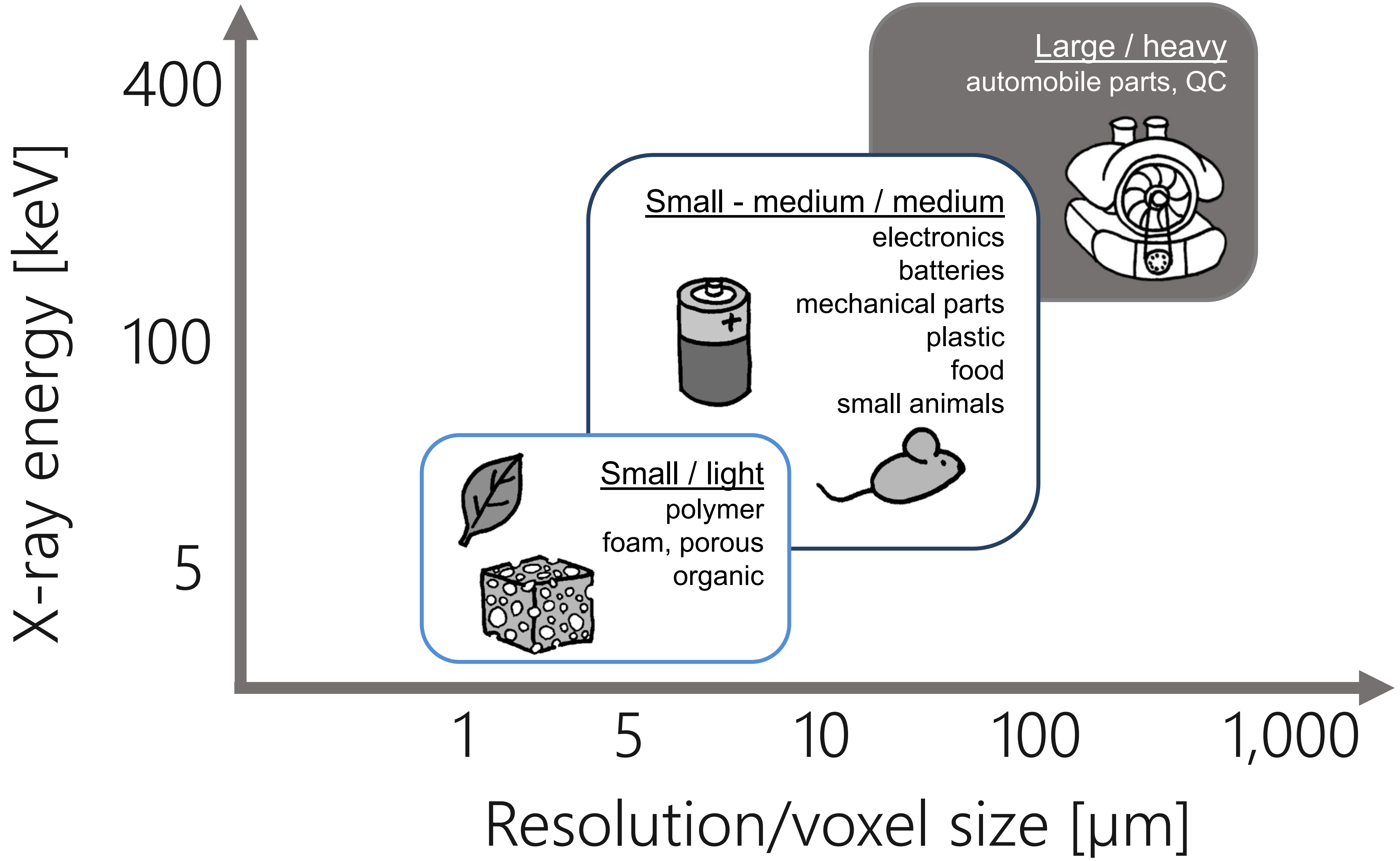
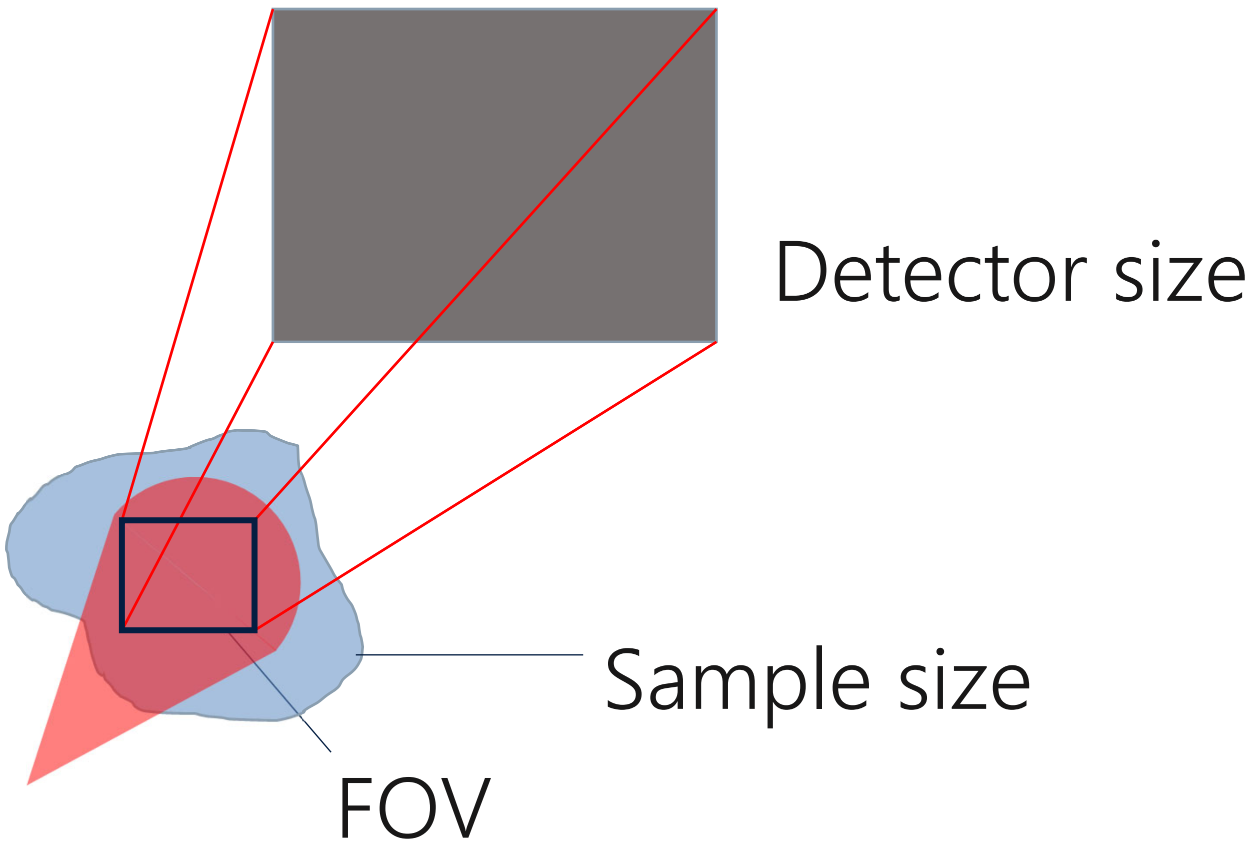
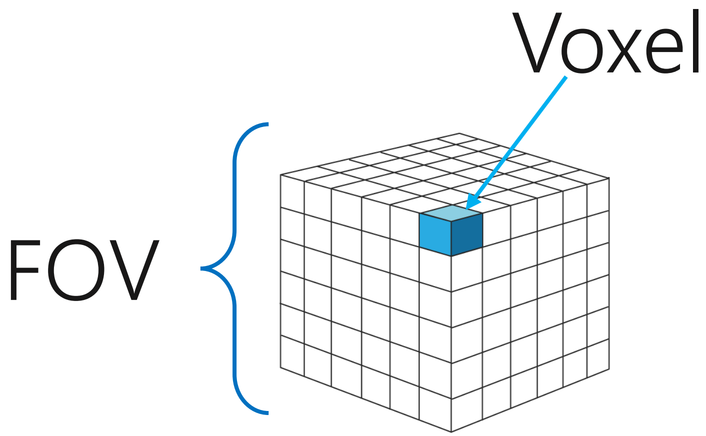

X-ray energy [keV]
400
100
5
Large / heavy
automobile parts, QC
Small - medium / medium
electronics
batteries
mechanical parts
plastic
food
small animals
Small / light
polymer
foam, porous
organic
1
5
10
100
1,000
Resolution/voxel size [μm]

IMPORTANT SPECIFICATIONS

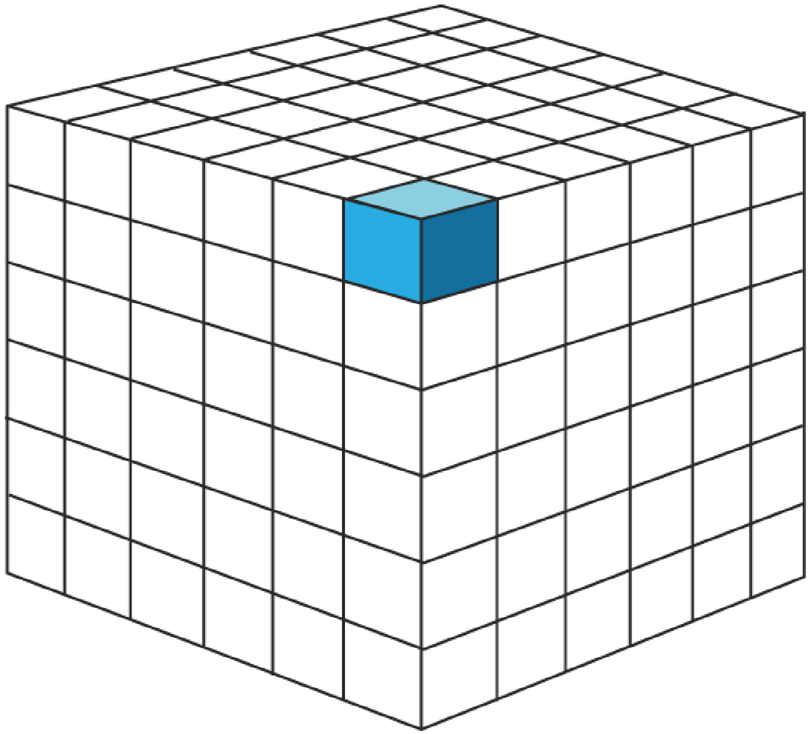
- X-ray energy
- Field of view (FOV)
- Resolution (voxel size)

- X-ray power
- Detector speed and efficiency

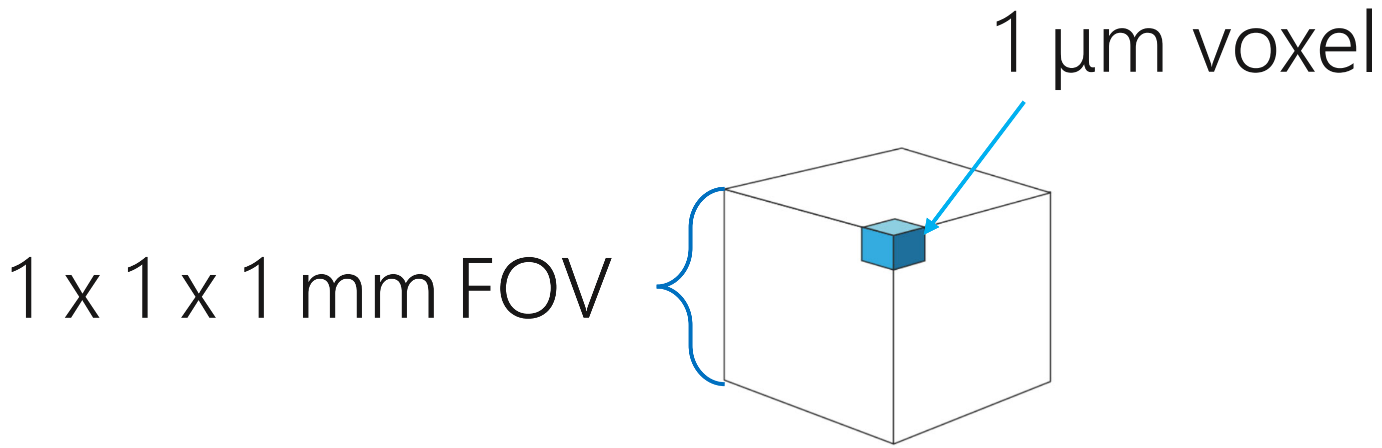

Detector size
Sample size
FOV



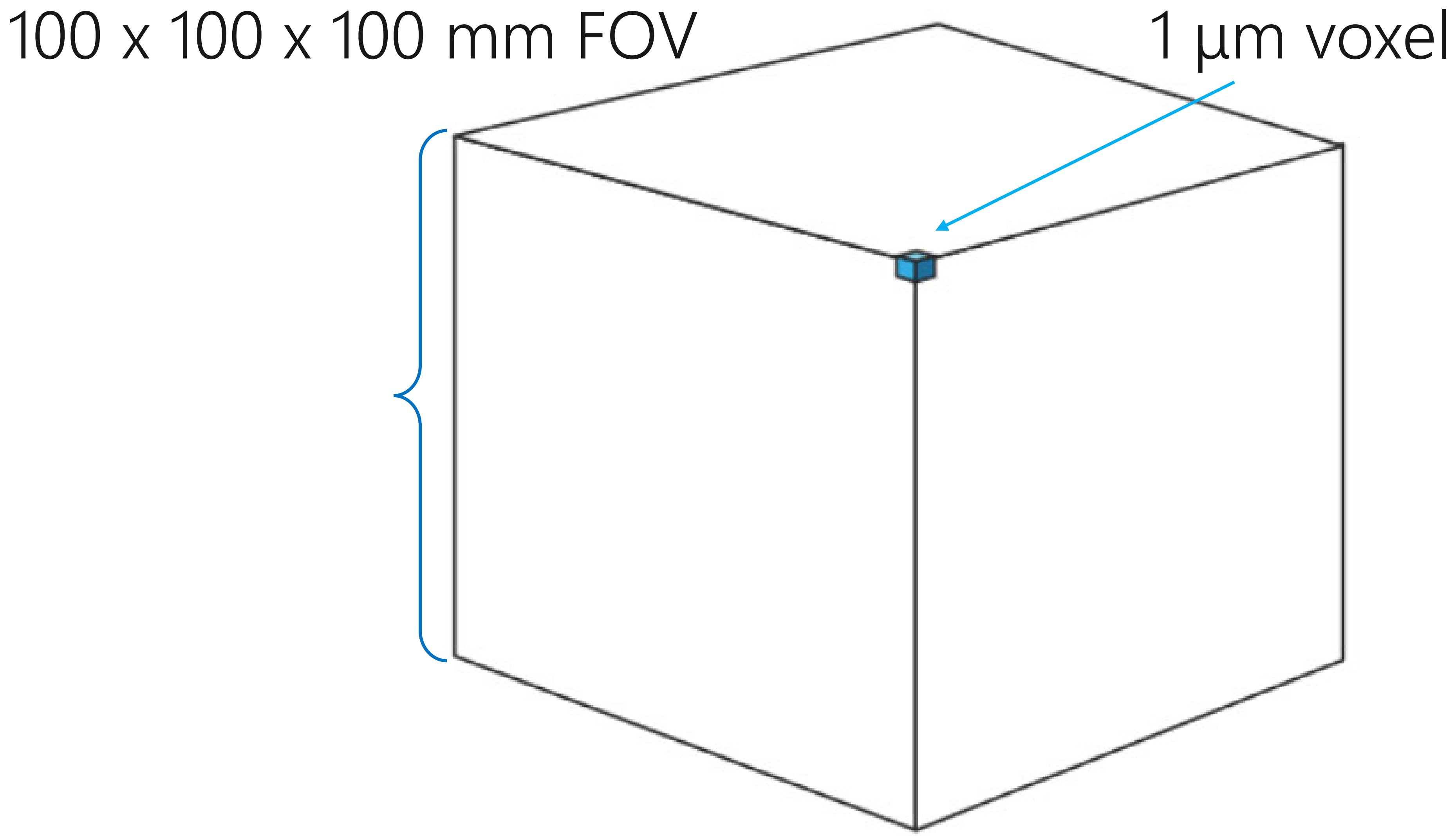
Small FOV, small voxel



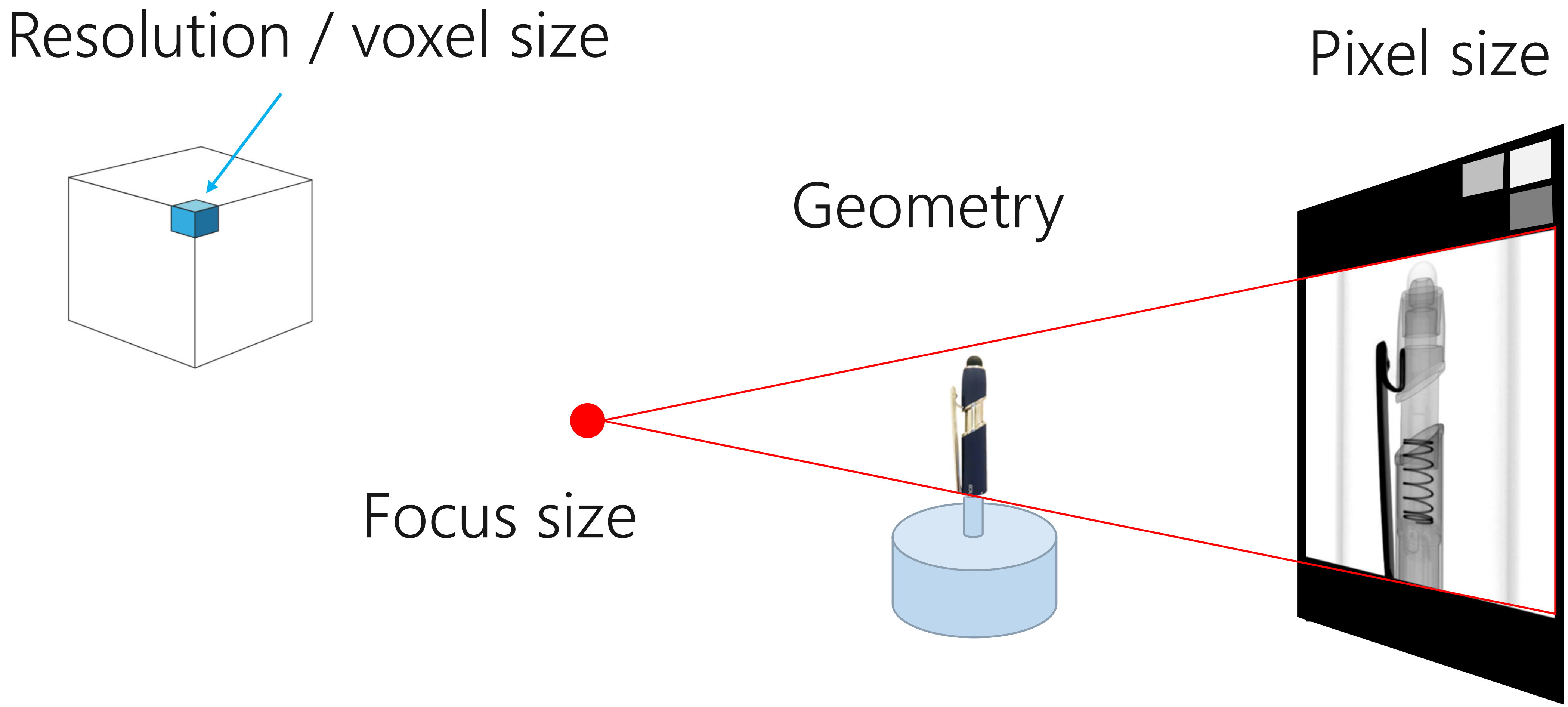
Large FOV, large voxel


1 µm voxel
1 x 1 x 1 mm FOV

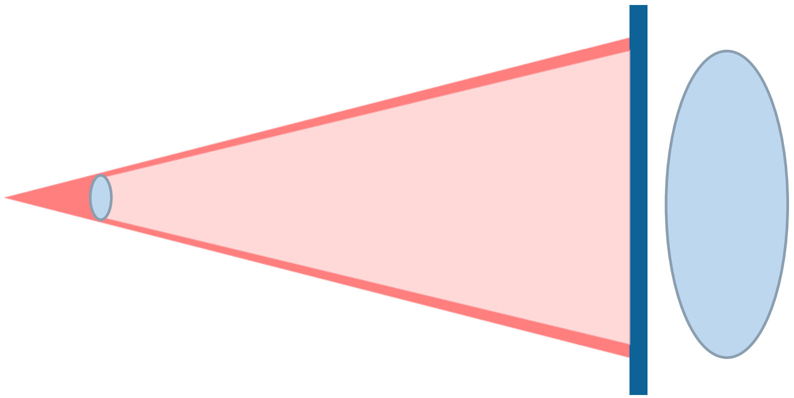
FOV [mm]	Voxel [µm]	Bit	File size
1 x 1 x 1	1	16	2 GB


100 x 100 x 100 mm FOV
1 µm voxel

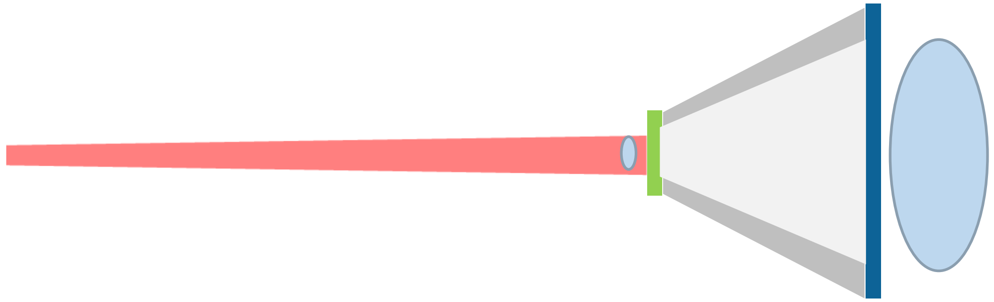
FOV [mm]	Voxel [µm]	Bit	File size
1 x 1 x 1	1	16	2 GB


Resolution / voxel size
Pixel size
Geometry
Focus size

HOW DOES MAGNIFICATION WORK?

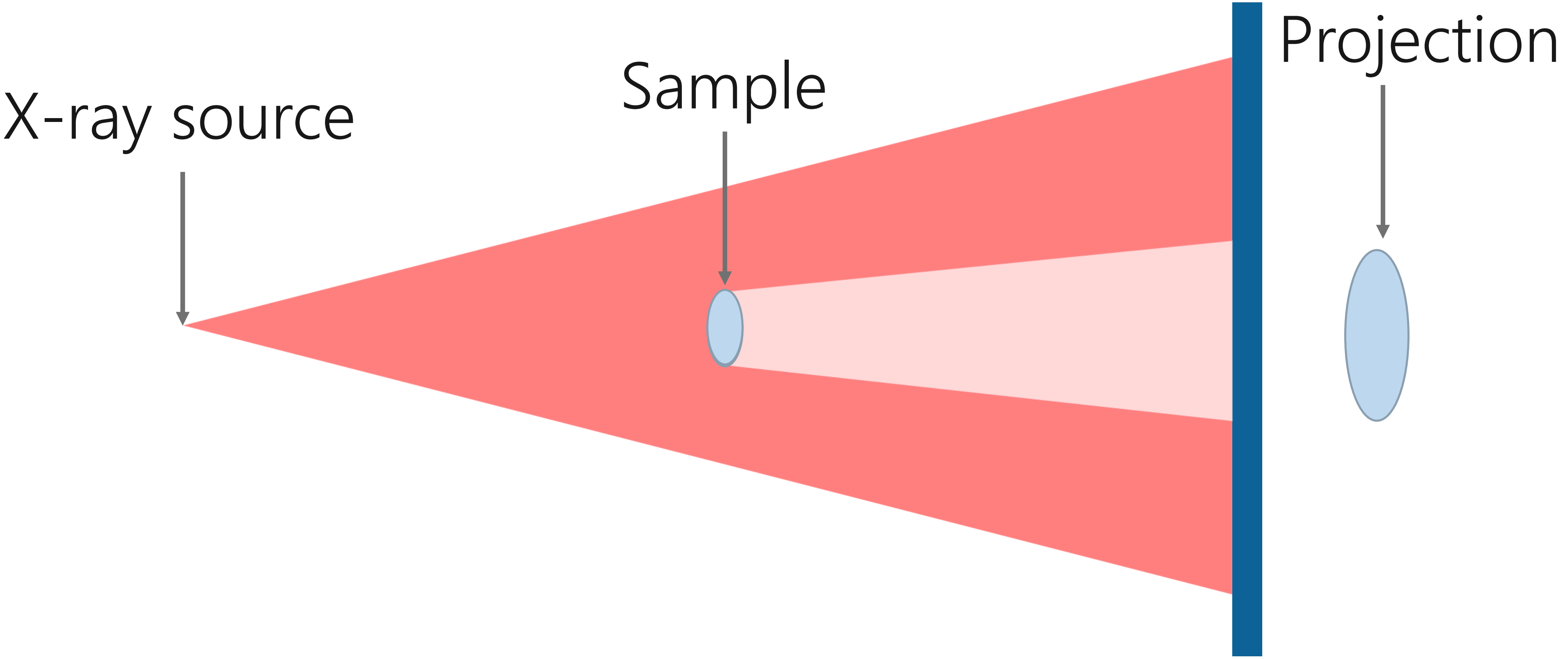


Cone beam



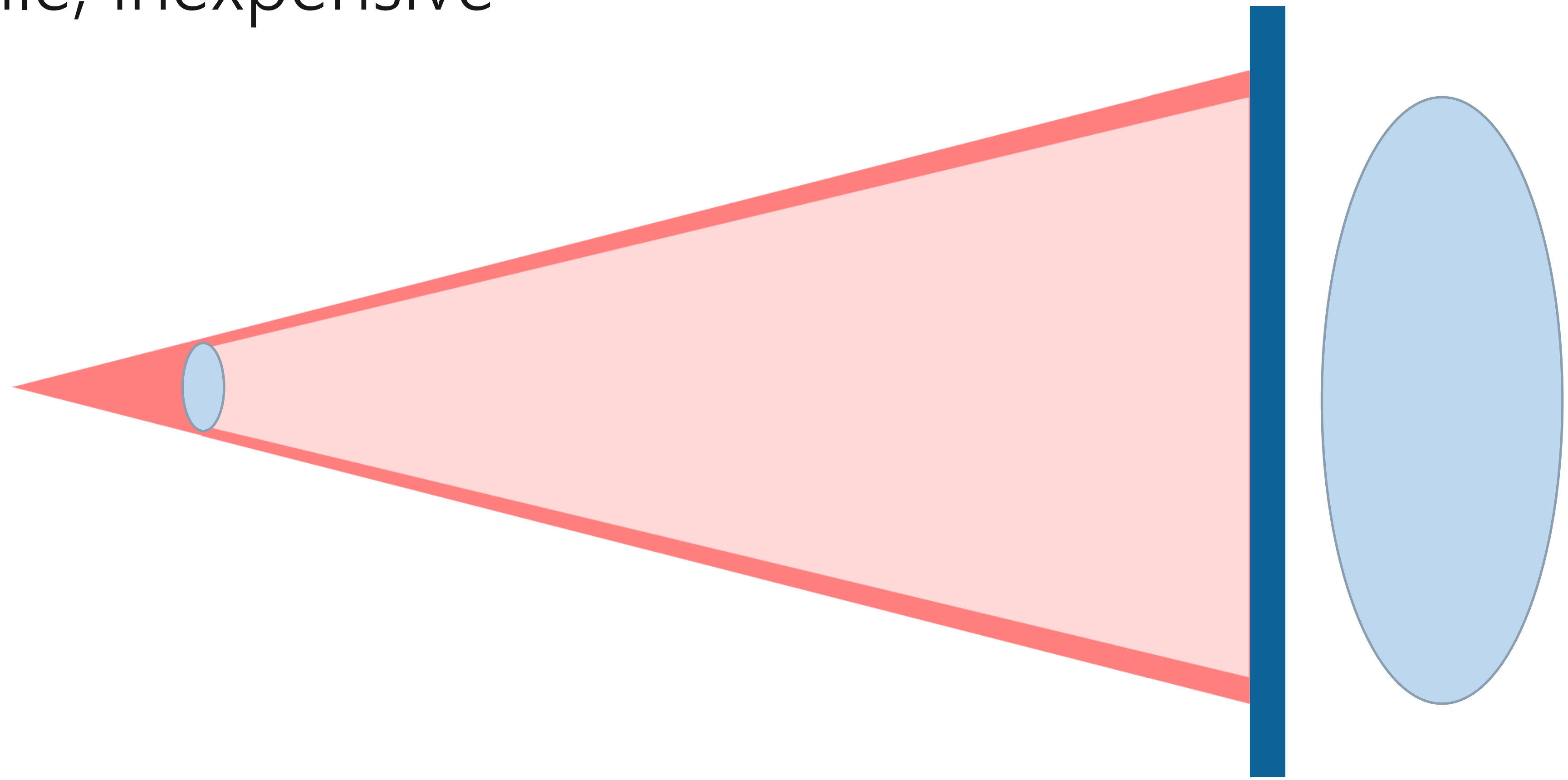
Parallel beam

CONE BEAM - MECHANICAL MAGNIFICATION



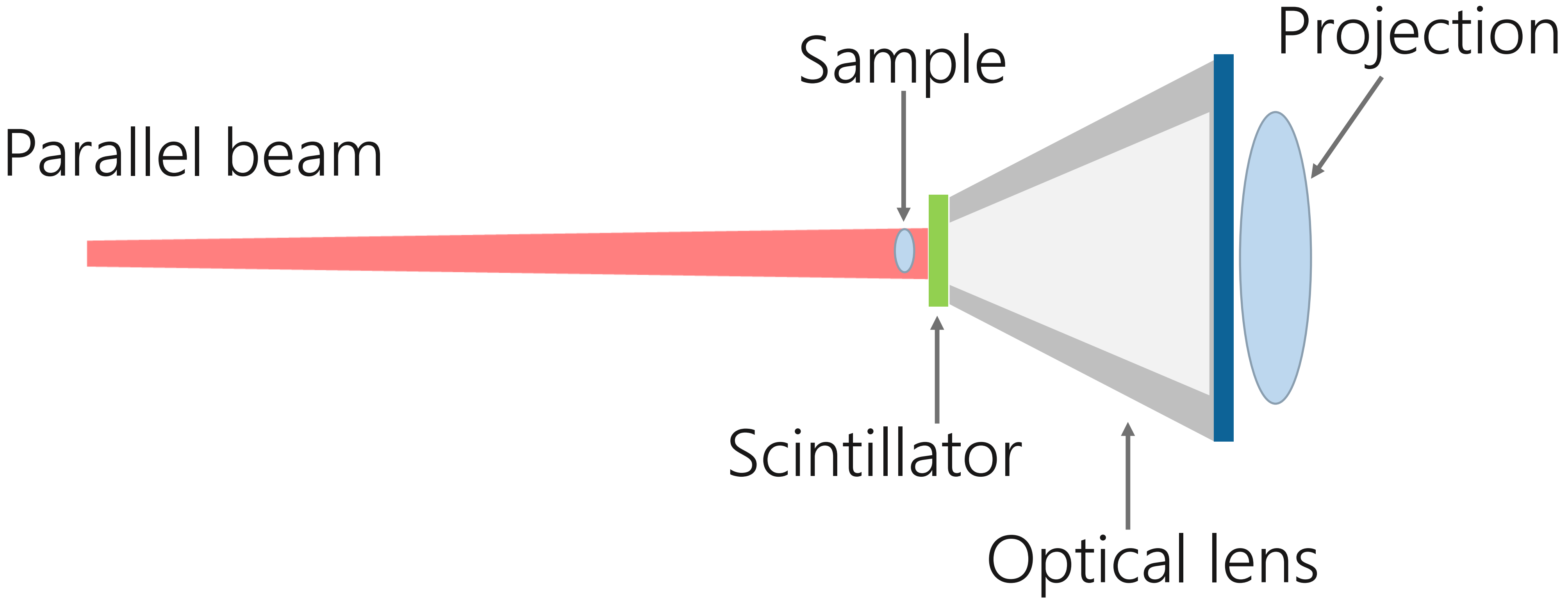
CONE BEAM - MECHANICAL MAGNIFICATION

Versatile, inexpensive

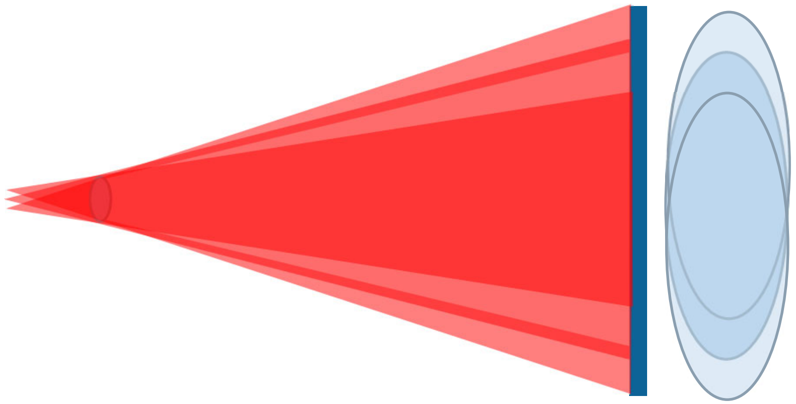


PARALLEL BEAM - OPTICAL MAGNIFICATION

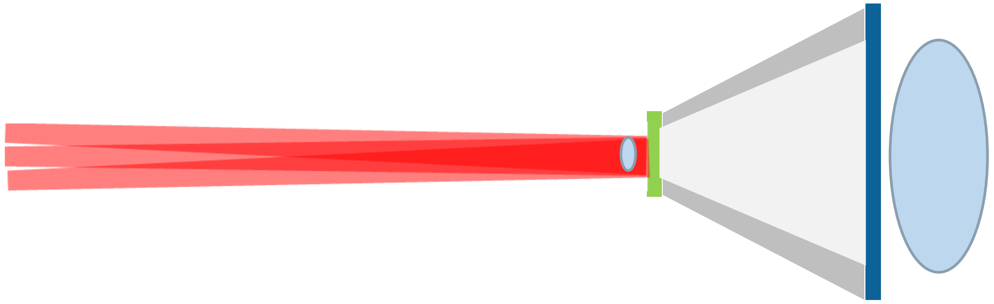
High resolution, requires high power source



CONE BEAM VS. PARALLEL BEAM



Cone beam



Parallel beam

Immune to drift → high resolution

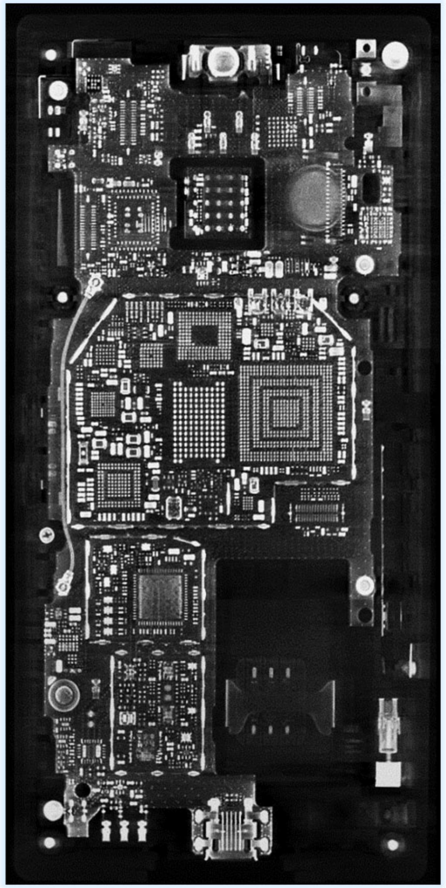
IMPORTANT SPECIFICATIONS

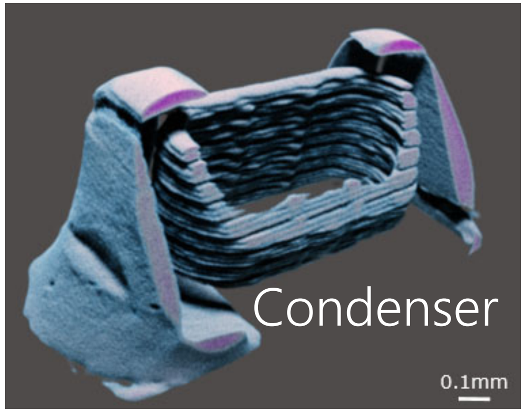
- X-ray energy
- Field of view (FOV)
- Resolution (voxel size)

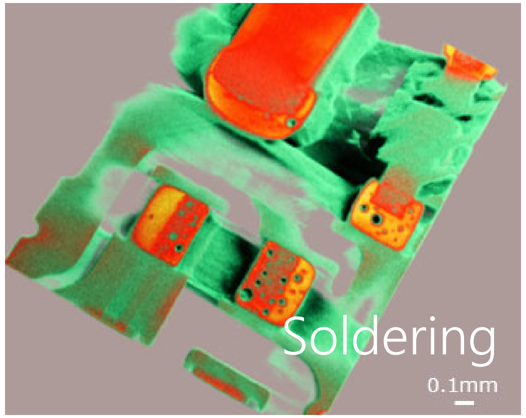
- X-ray power
- Detector speed and efficiency

ANY EXAMPLES?

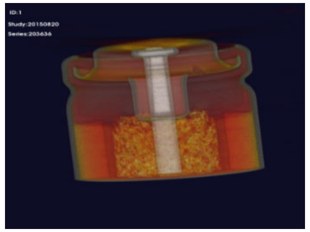
ELECTRONICS

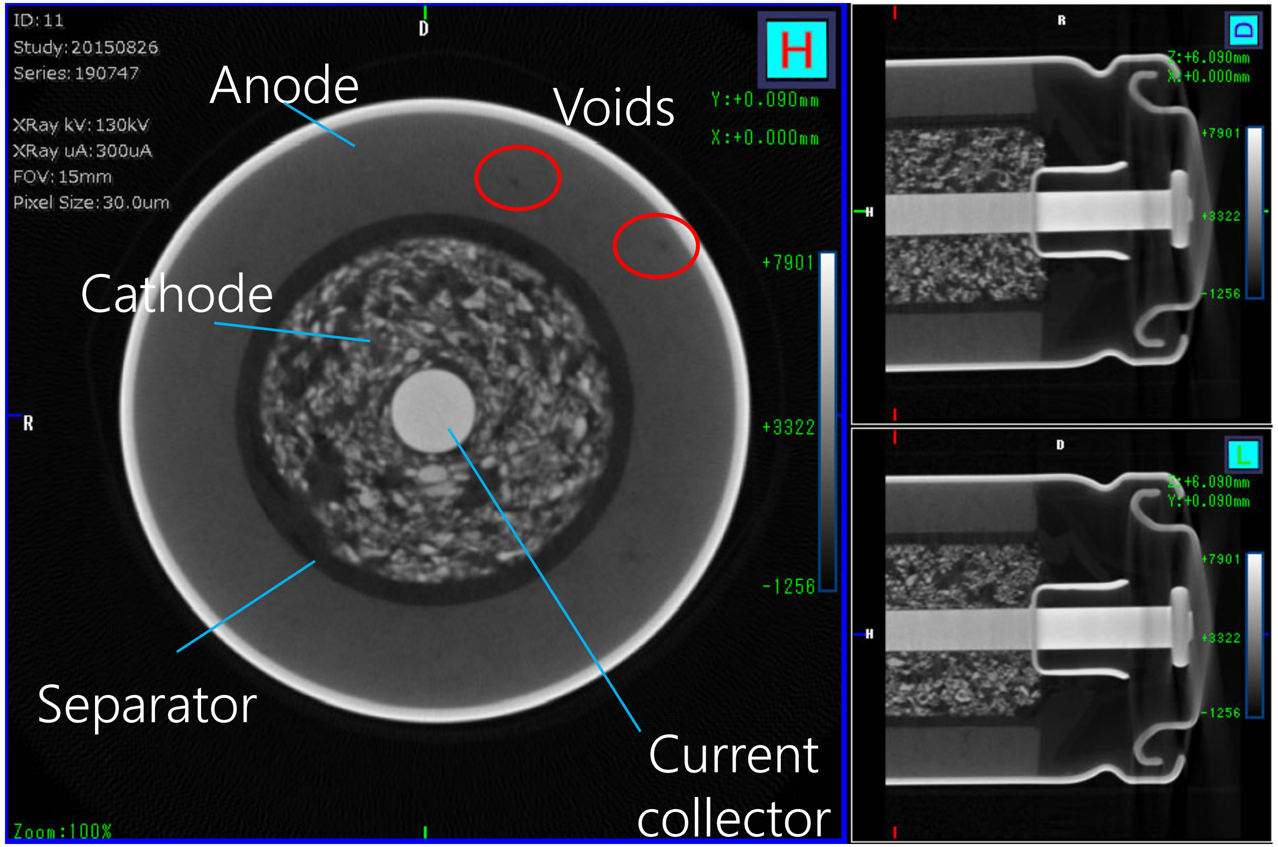






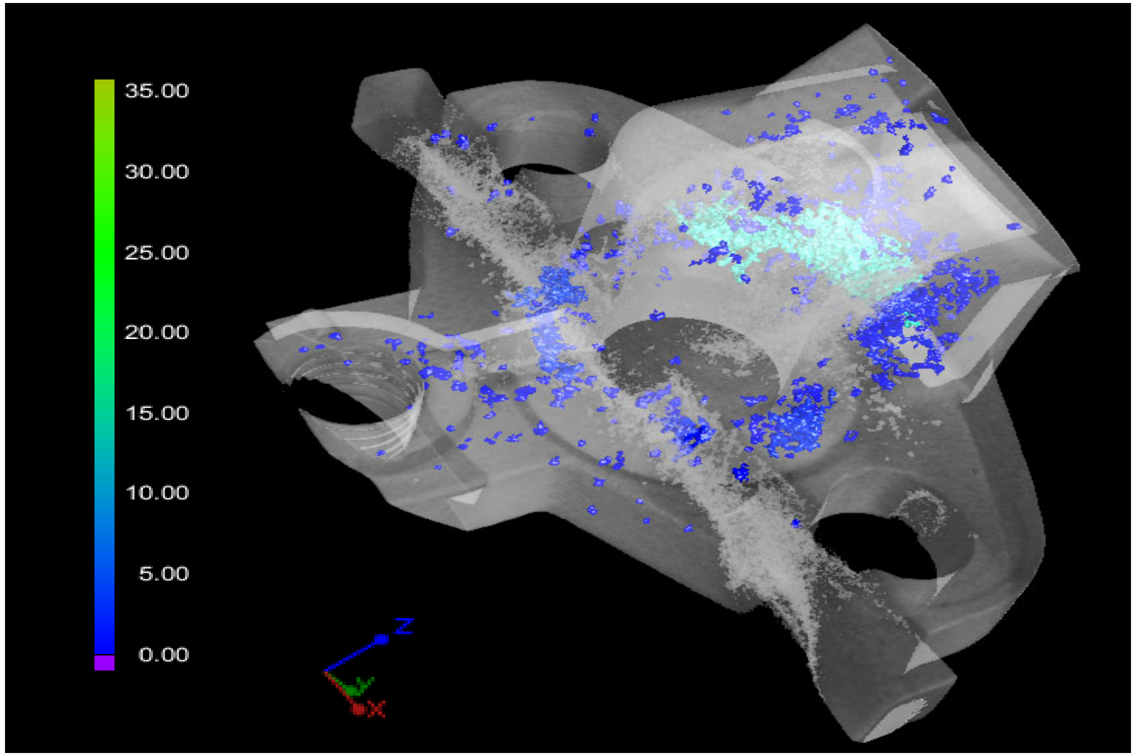
BATTERIES



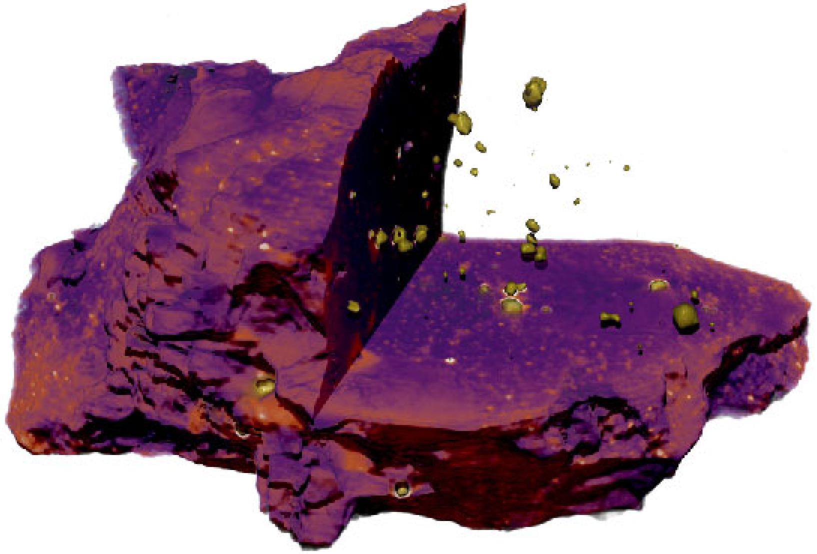

ID: 11
Study: 20150826
Series: 190747
XRay kV: 130kV
XRay uA: 300uA
FOV: 15mm
Pixel Size: 30.0um
Anode
Voids
Cathode
Separator
Current collector
Y:+0.090mm
X:+0.000mm
+7901
+3322
-1256
Zoom:100%
Z:+6.090mm
X:+0.000mm
Z:+6.090mm
Y:+0.090mm

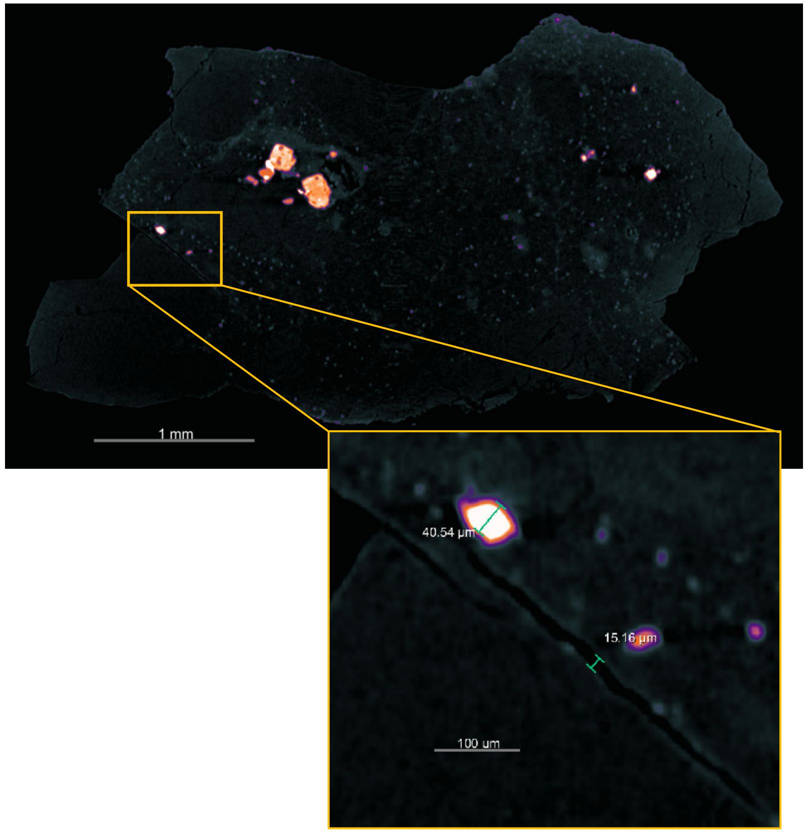
ALUMINUM DIE CASTINGS

Volume analysis
Total: 2762.56 mm^3
Void: 32.81 mm^3
→ 1.17%



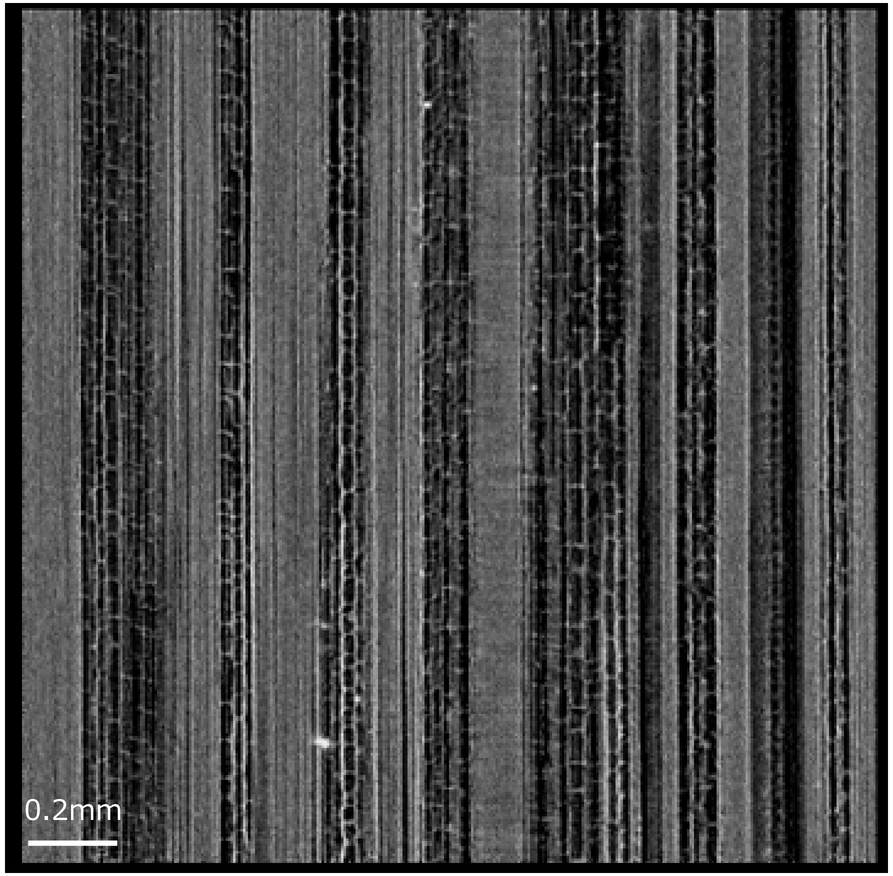
ROCKS

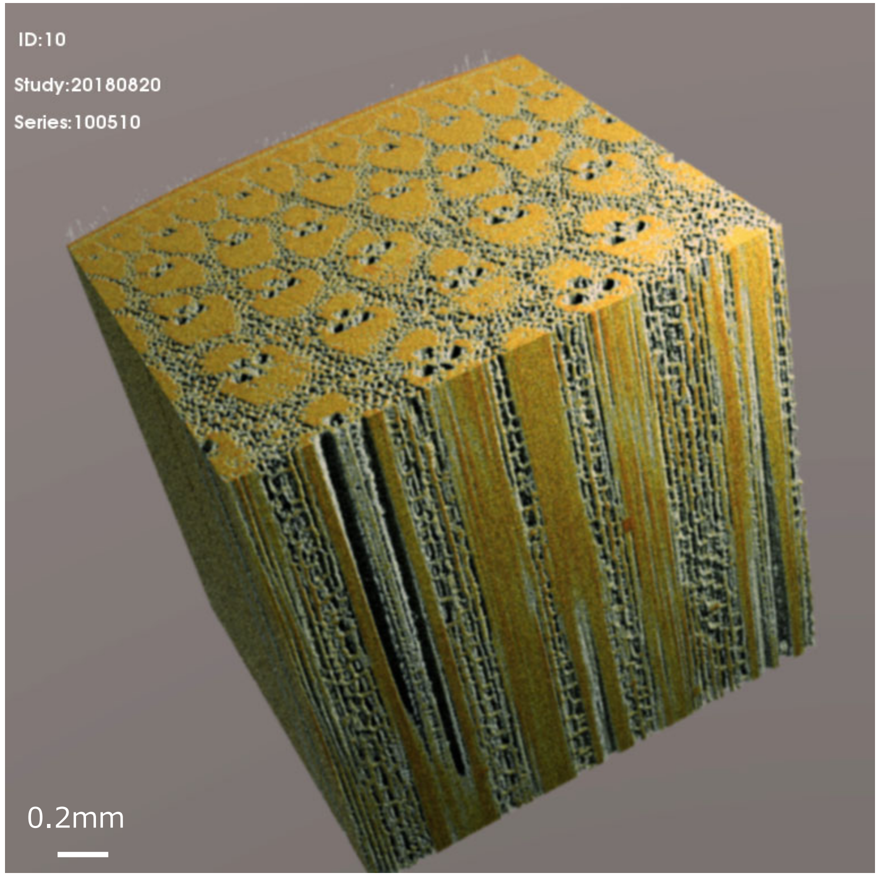




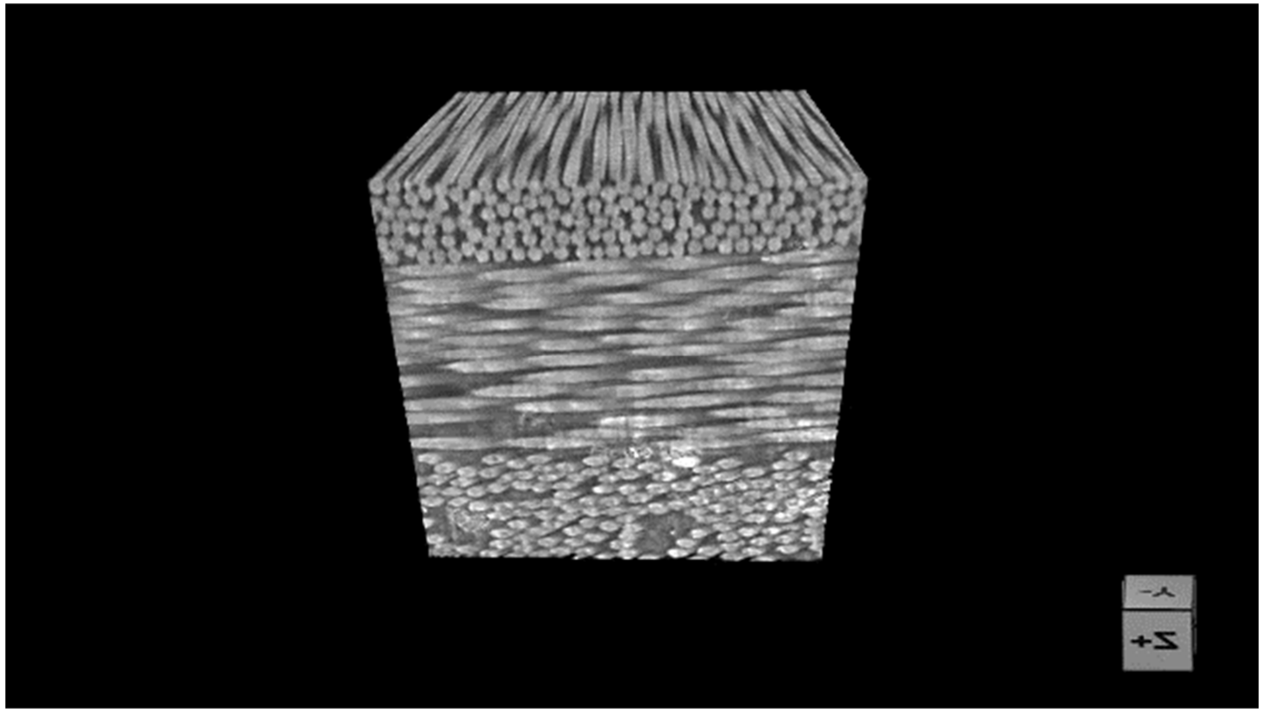
Cracks and inclusions

PLANTS

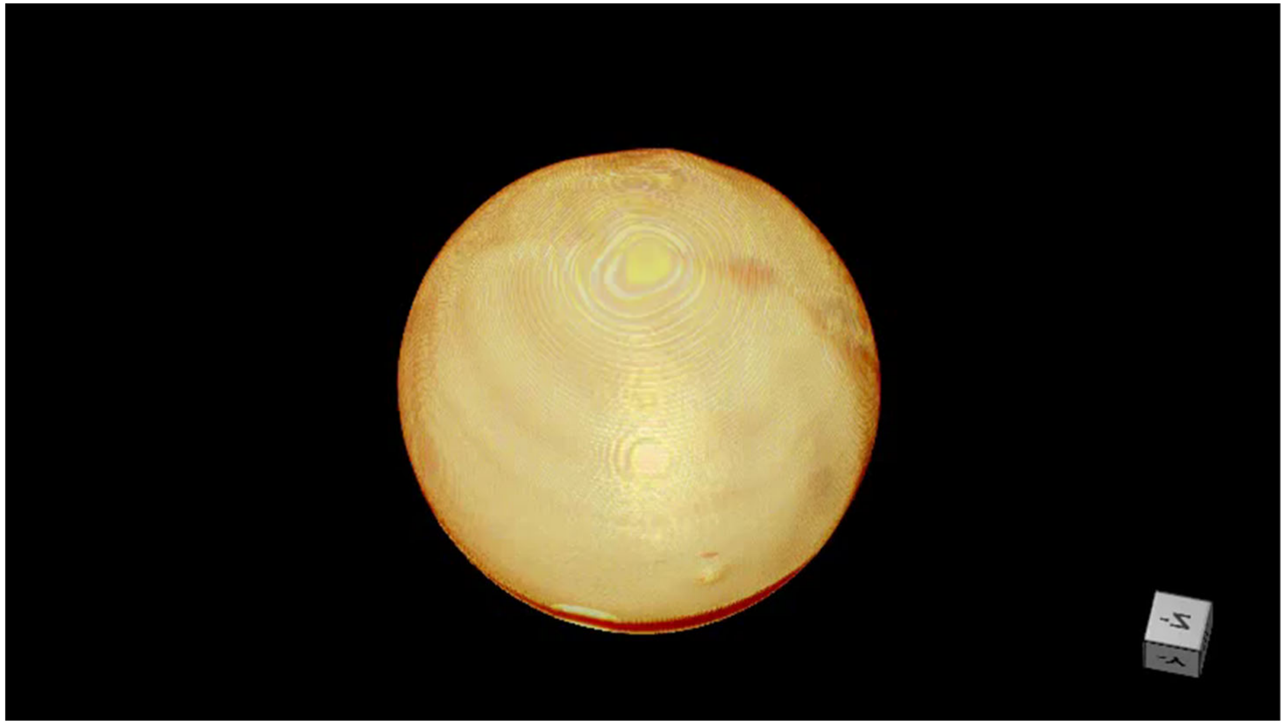




COMPOSITES



TABLETS



Electronics

Ceramics & rocks

Light metals

Composites

Plants & insects

Food & pharmaceuticals

You just learned:

- How X-ray CT works
- Common challenges
- Different types of CT scanners
- Applications

Q & A

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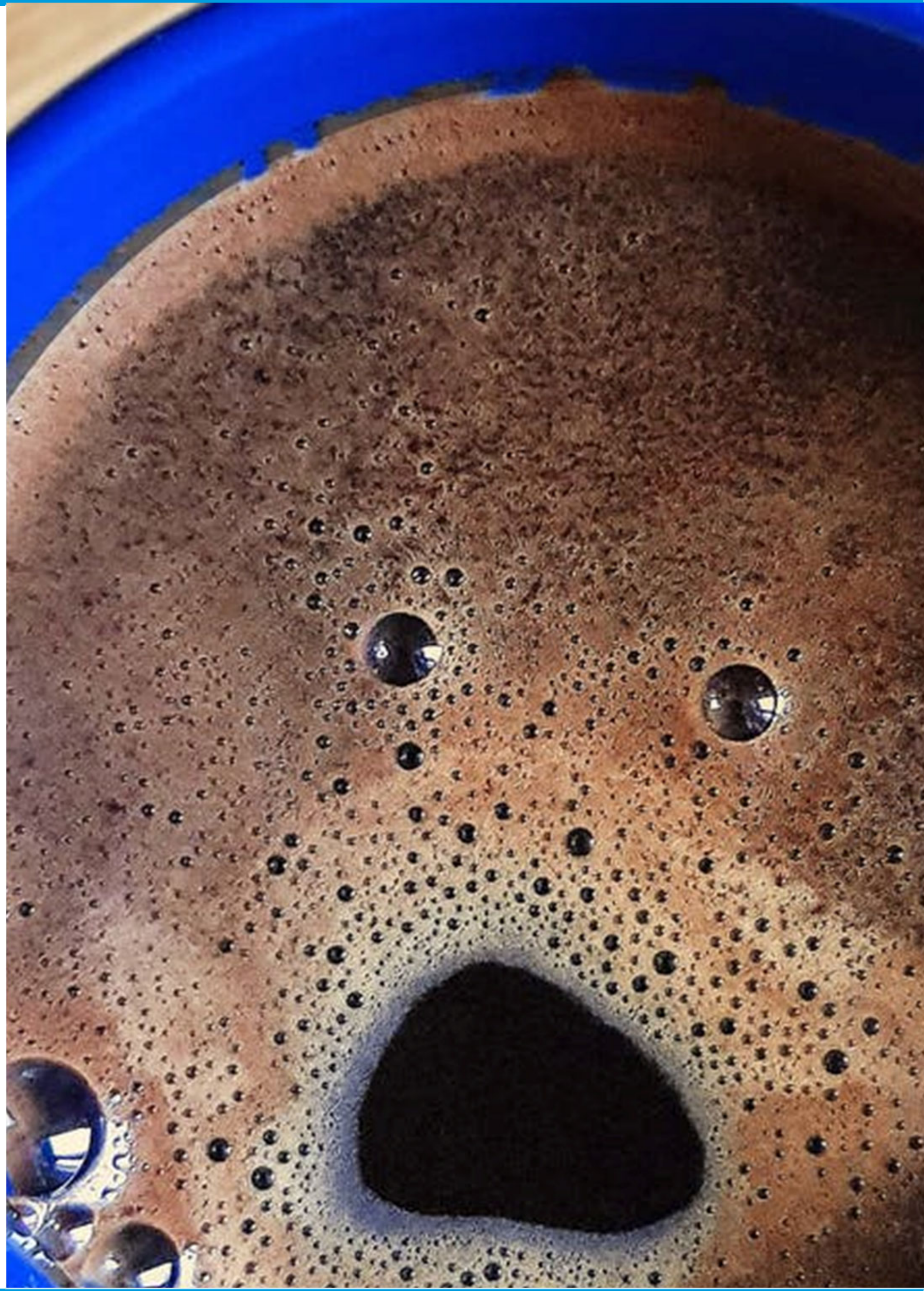

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