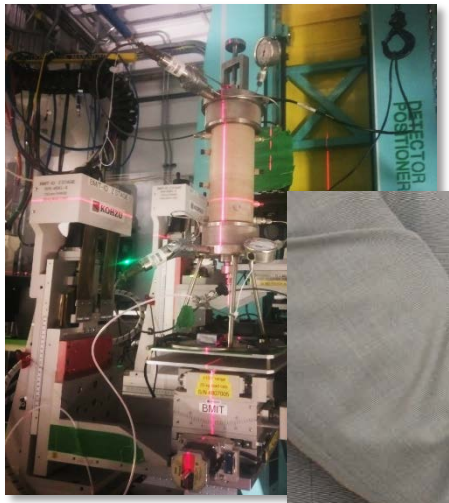
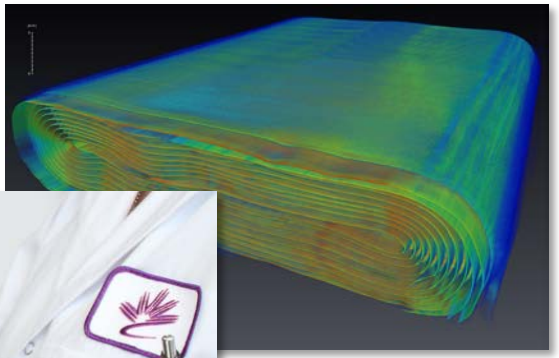
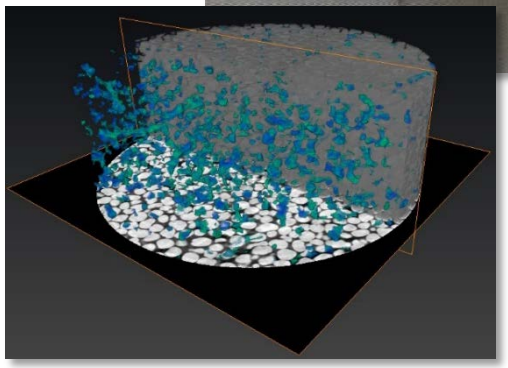
Imaging Microstructure Dynamics using Synchrotron-Based Computed Tomography







Toby Bond
Industrial Scientist: X-ray Imaging
Canadian Light Source

Outline

Outline

- X-Ray Imaging and CT

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- Synchrotron CT

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- Examples:

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  - Geological Samples
  - Fluid Dynamics

Radiography (X-Ray Projection Imaging)

- Projection imaging is the oldest x-ray technique
- Heavier elements and denser materials attenuate x-rays
- Resulting absorption image is essentially a map of electron density

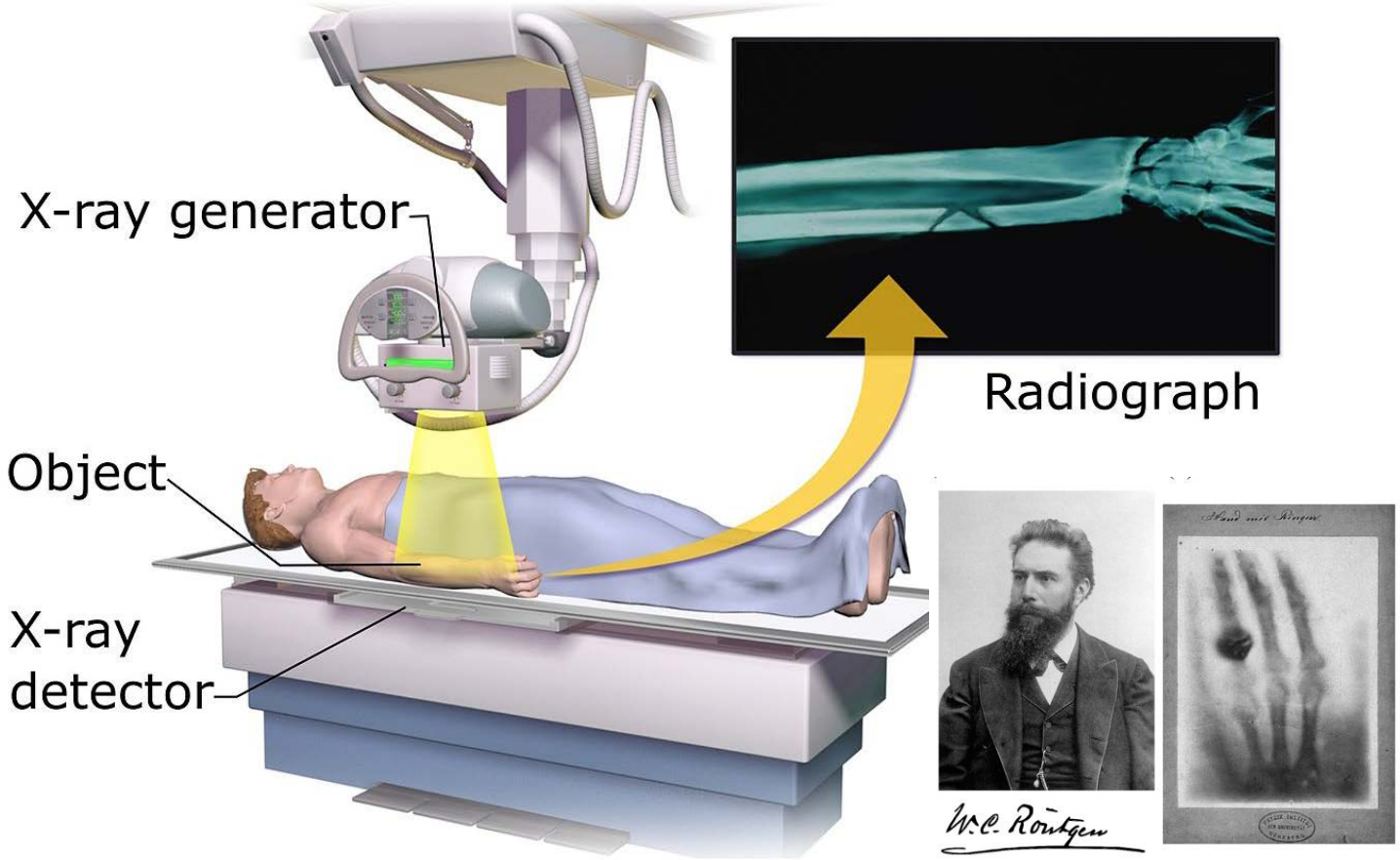


Image Source: https://en.wikipedia.org/wiki/X-ray_machine

Computed Tomography(CT)

- CT scans (aka CAT scans) are the 3D extension of x-ray projections
- Procedure:
  - Take many projections while rotating the camera/detector around the patient
  - Reconstruct the projections into a digital 3D model

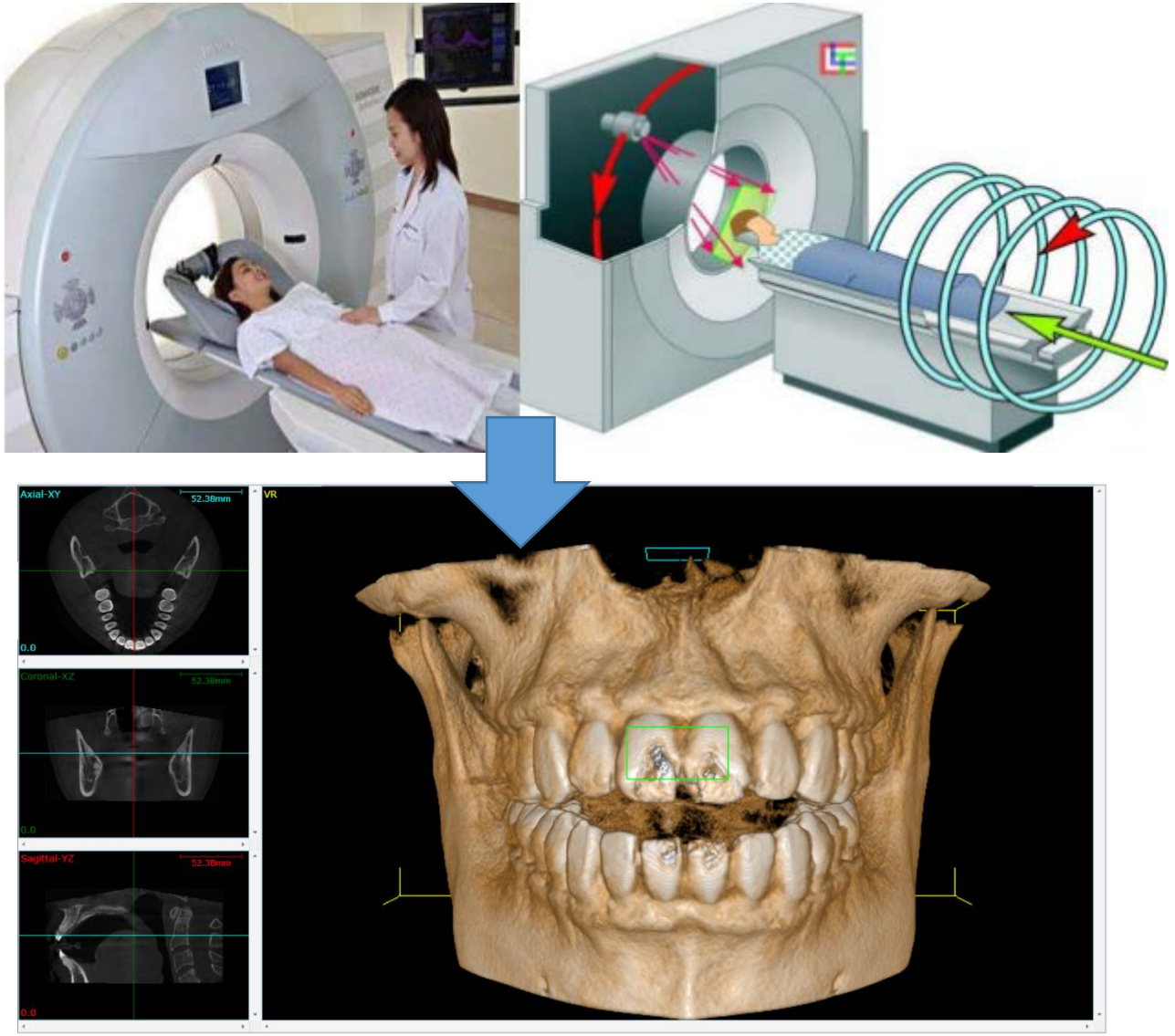
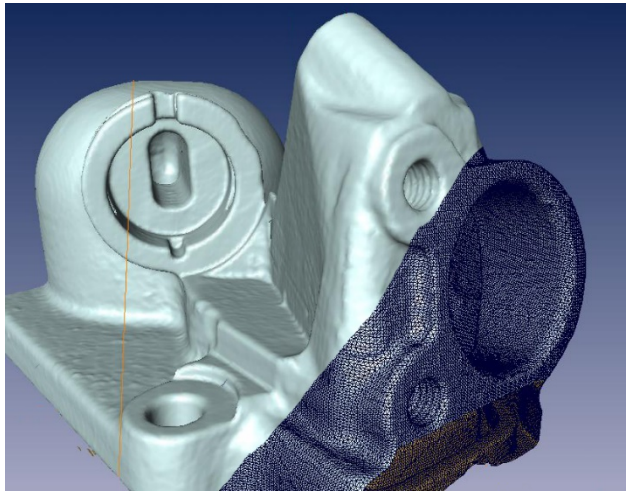


Image source: https://www.slideshare.net/shekharstar/ct-scan-final-2-63863260, https://commons.wikimedia.org/wiki/Category:Cone_beam_computed_tomography

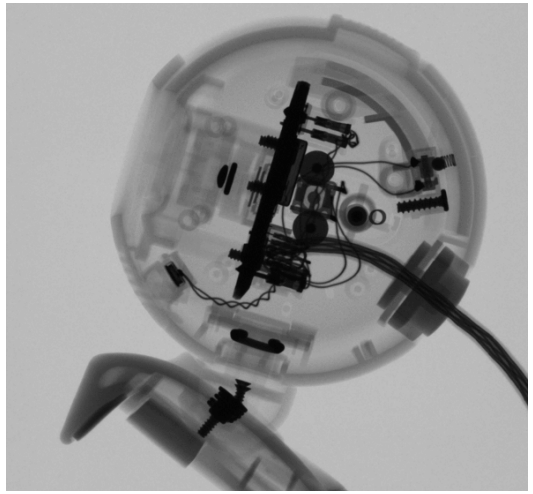
X-ray Imaging in Industry

R&D

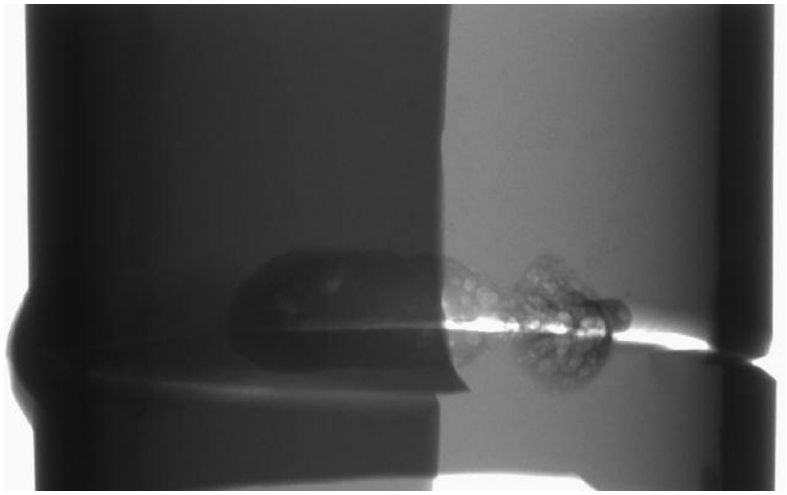
Manufacturing



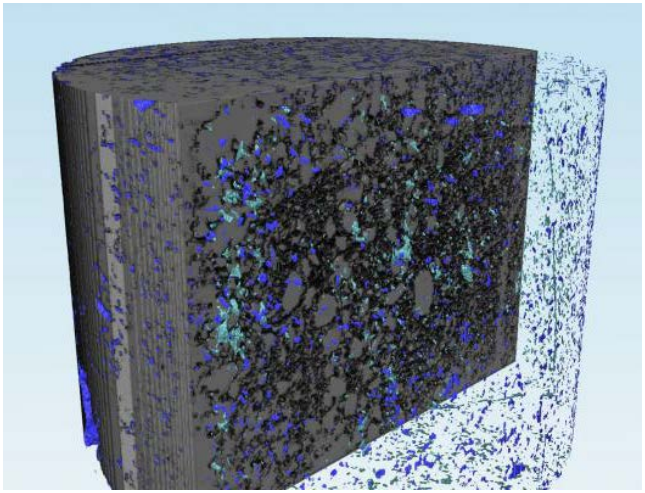
QA/QC



Devices



Defect/Failure Analysis



Geological Core Analysis

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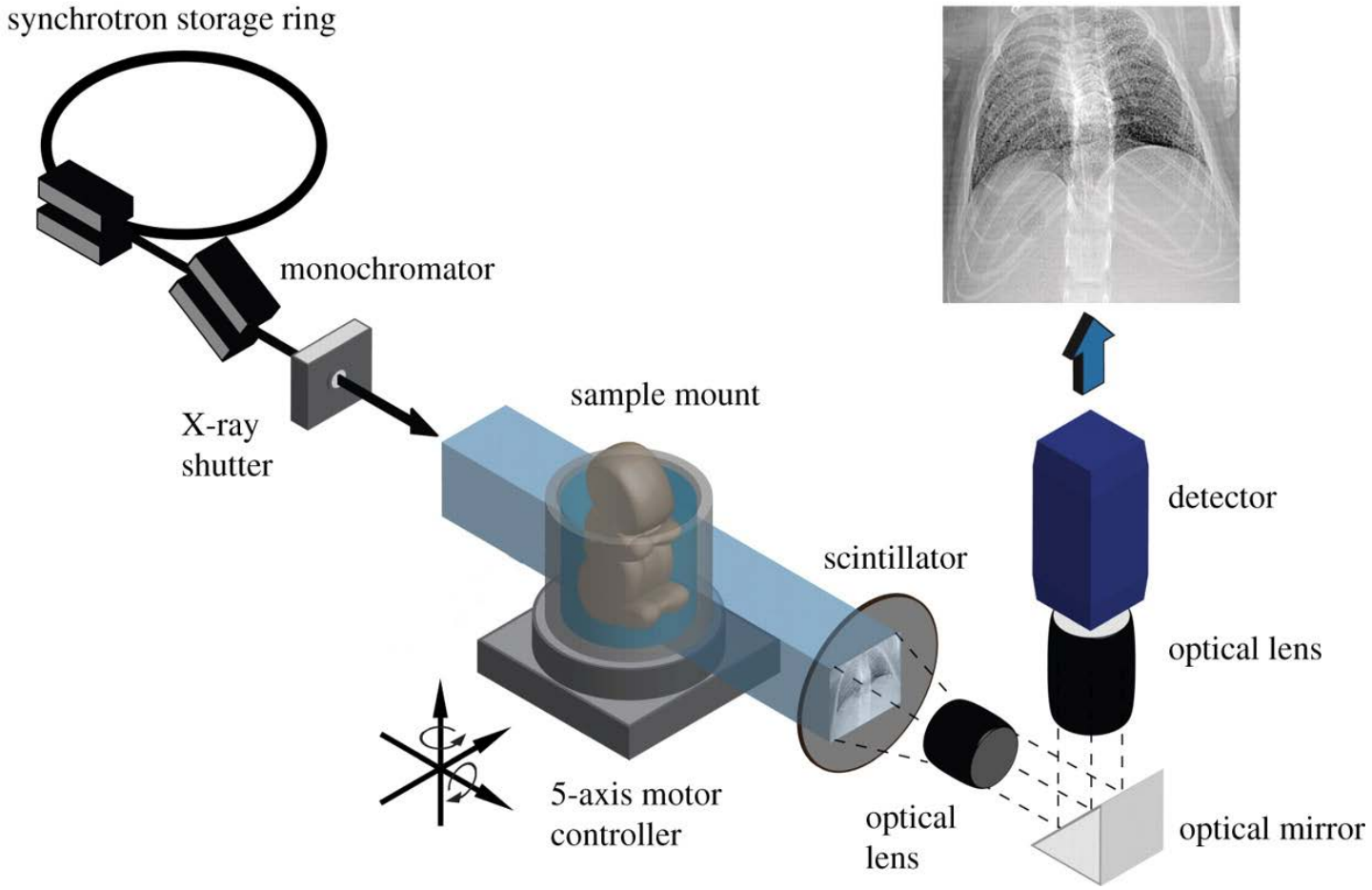
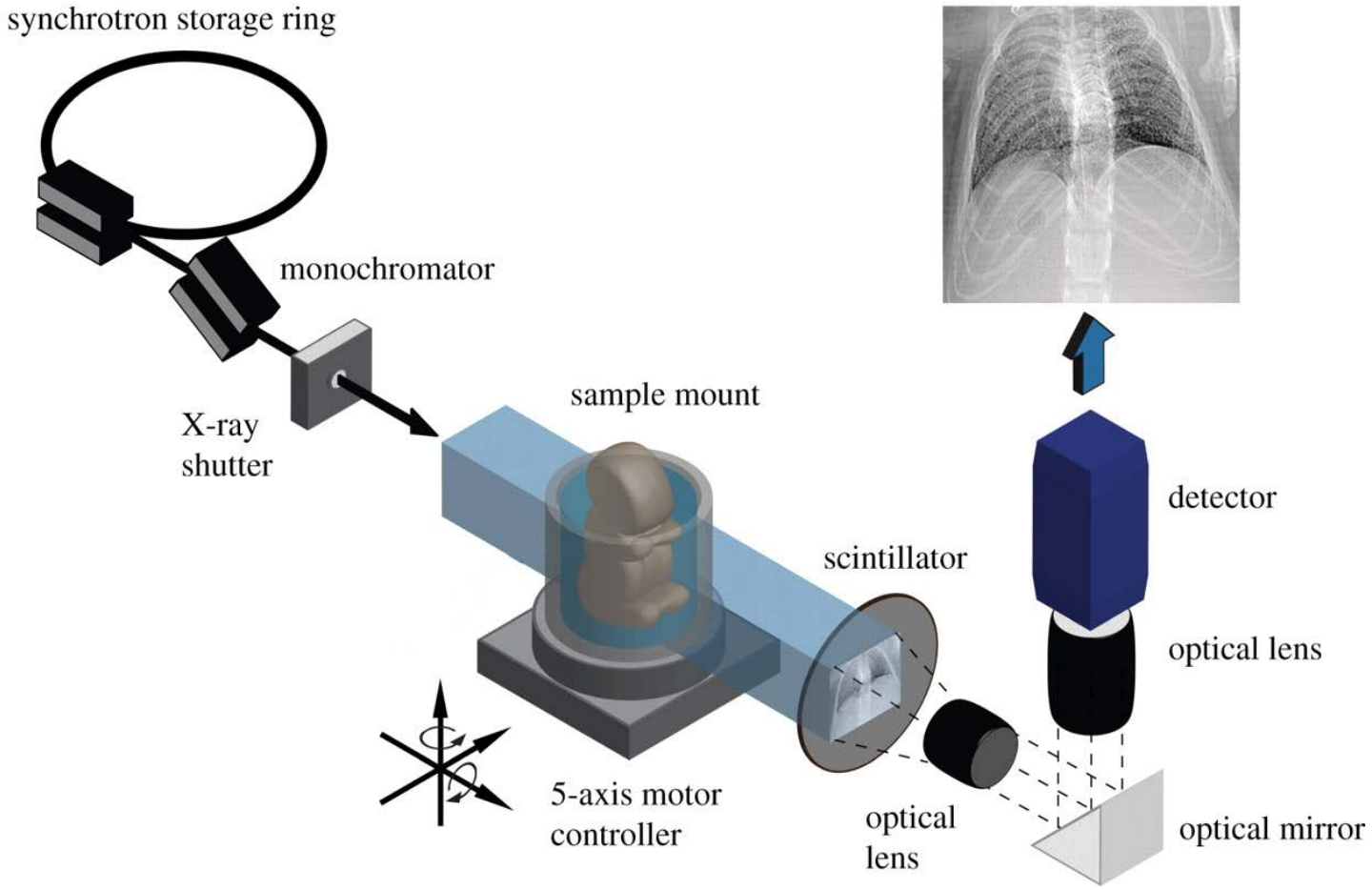
Image sources: Wikimedia commons, Saskatchewan Research Council

Synchrotron-Based CT (SR-CT)



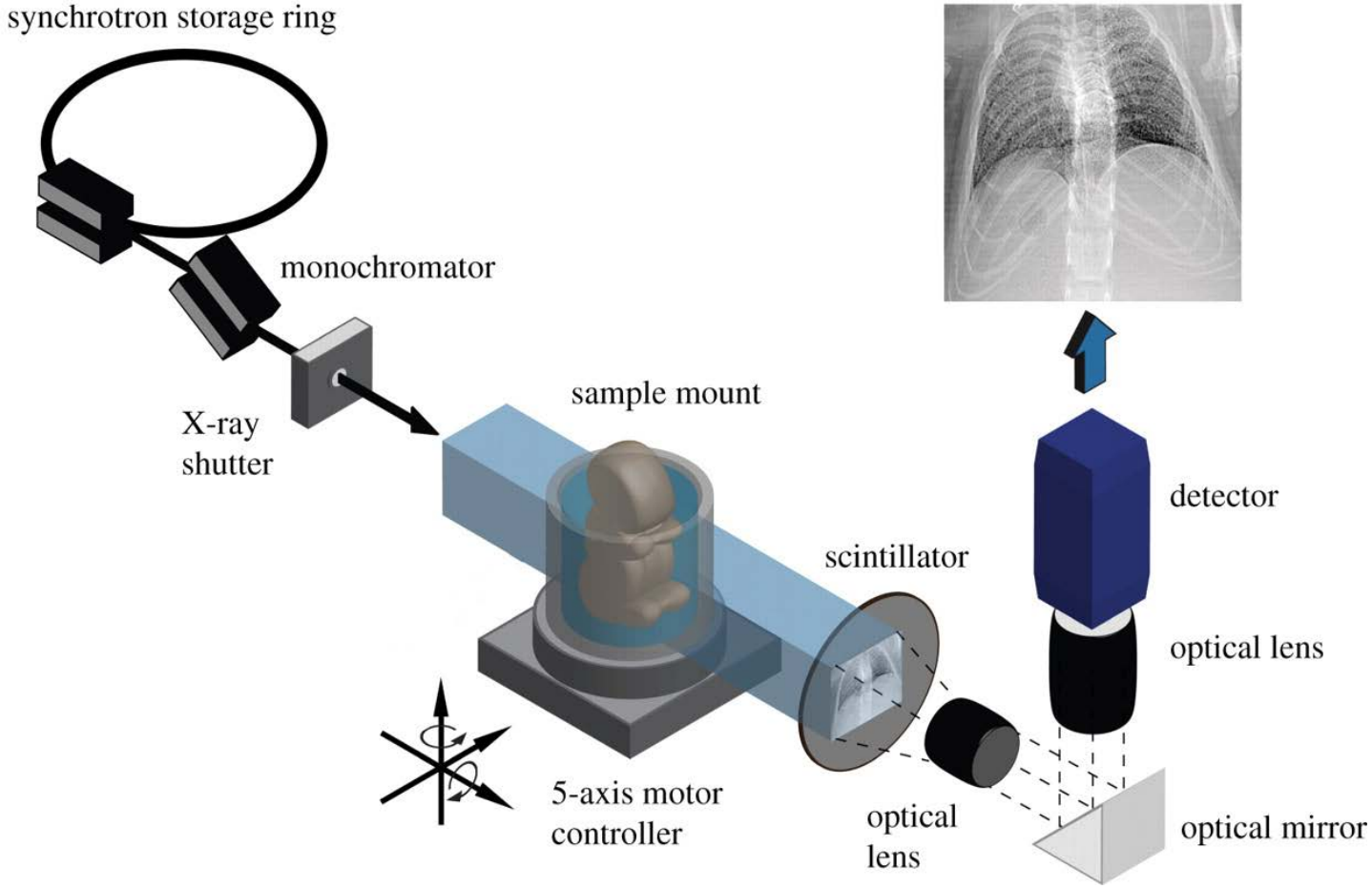
Synchrotron-Based CT (SR-CT)

- Advantages of SR-CT:



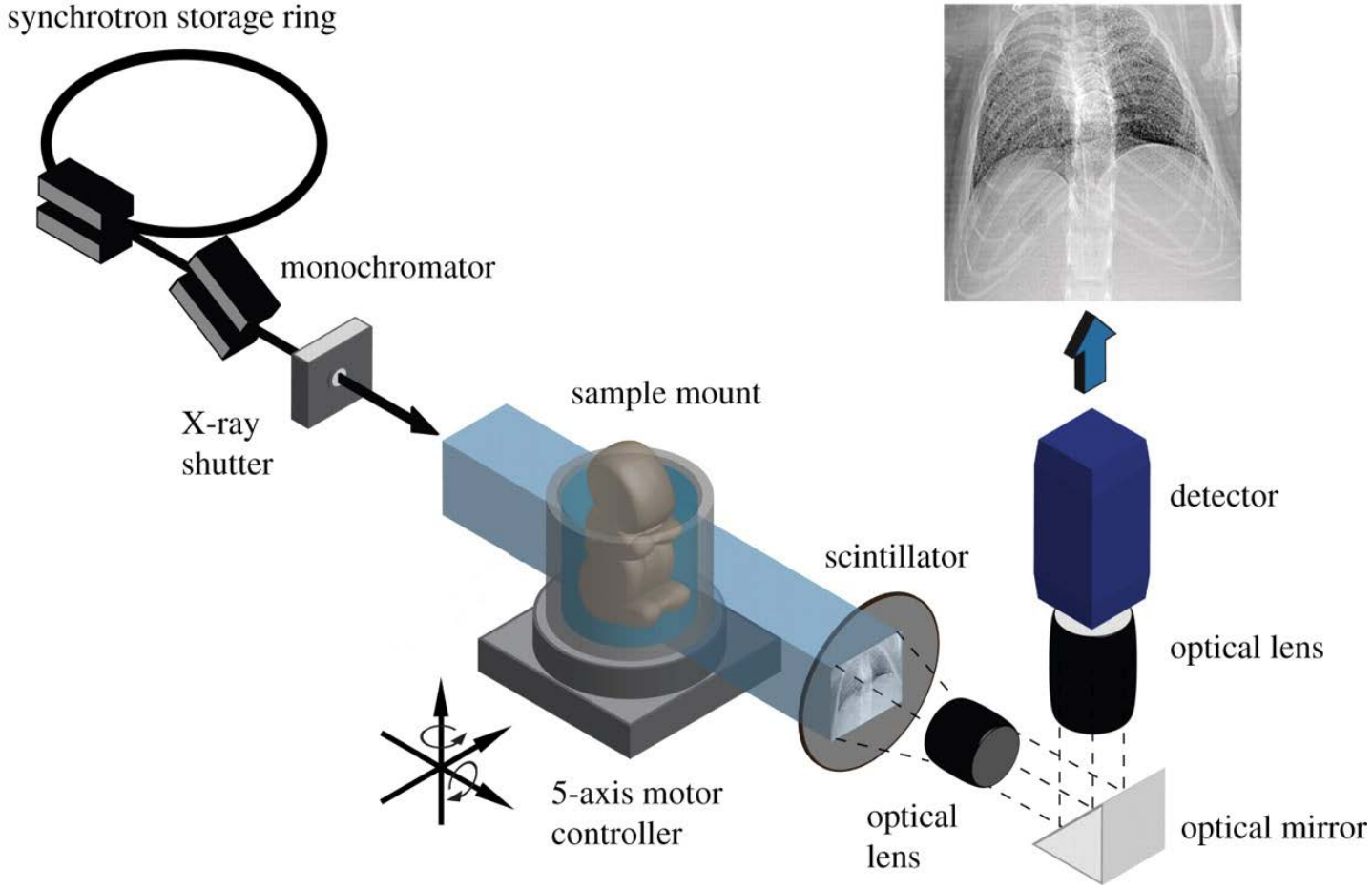
Synchrotron-Based CT (SR-CT)

- Advantages of SR-CT:
  - Measurement speed



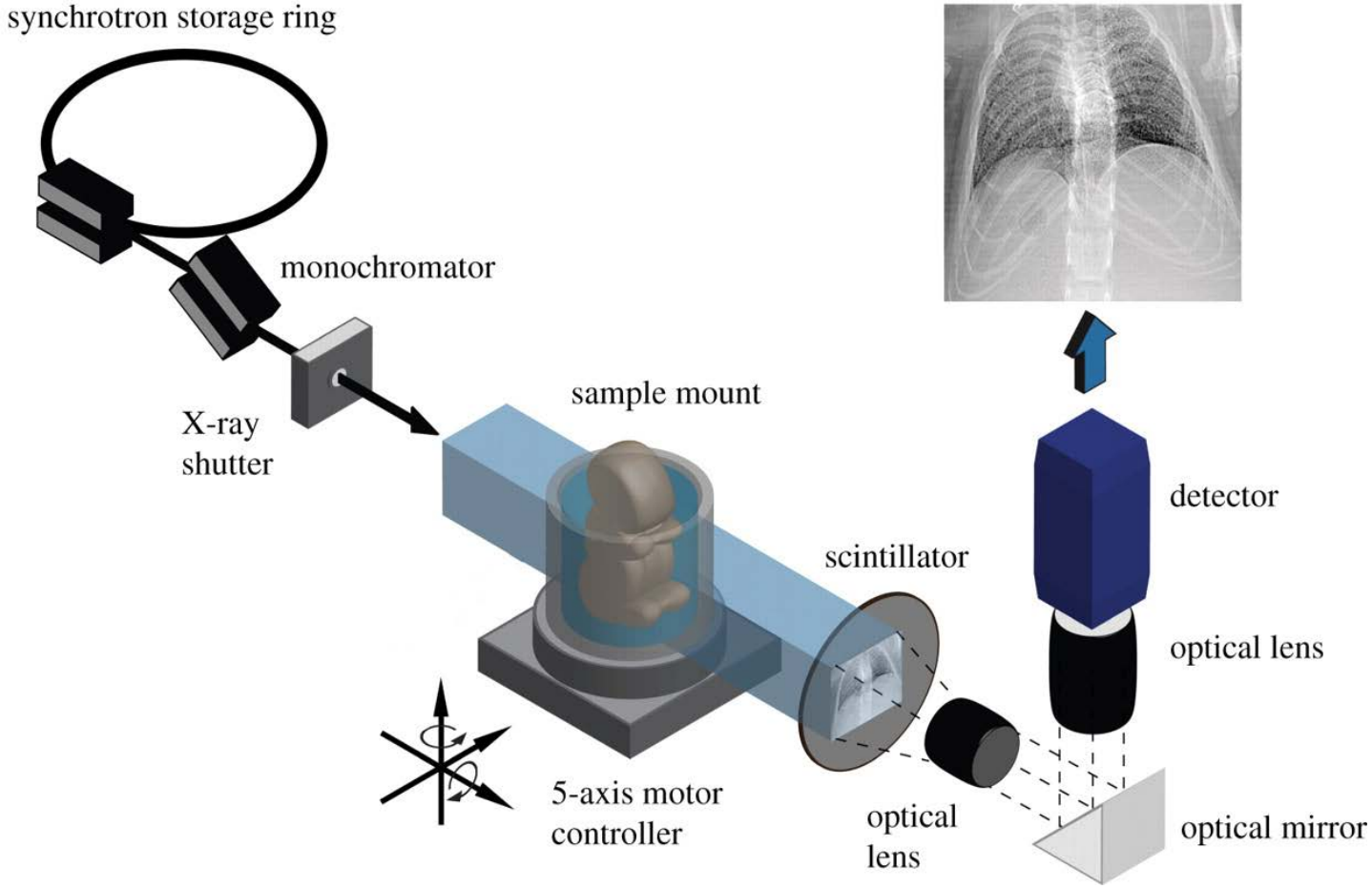
Synchrotron-Based CT (SR-CT)

- Advantages of SR-CT:
  - Measurement speed
  - Better absorption contrast



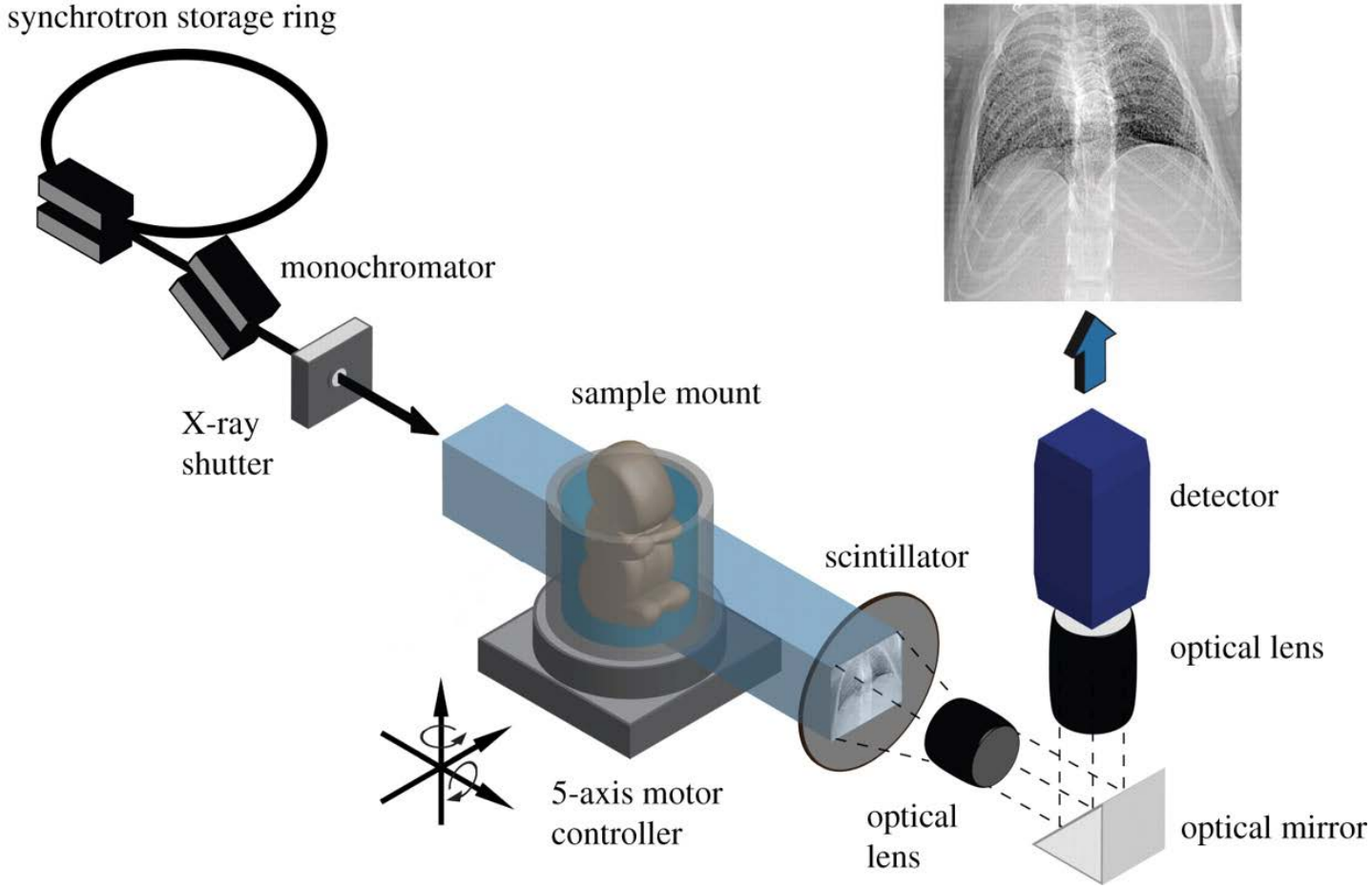
Synchrotron-Based CT (SR-CT)

- Advantages of SR-CT:
  - Measurement speed
  - Better absorption contrast
  - Large samples at high resolution



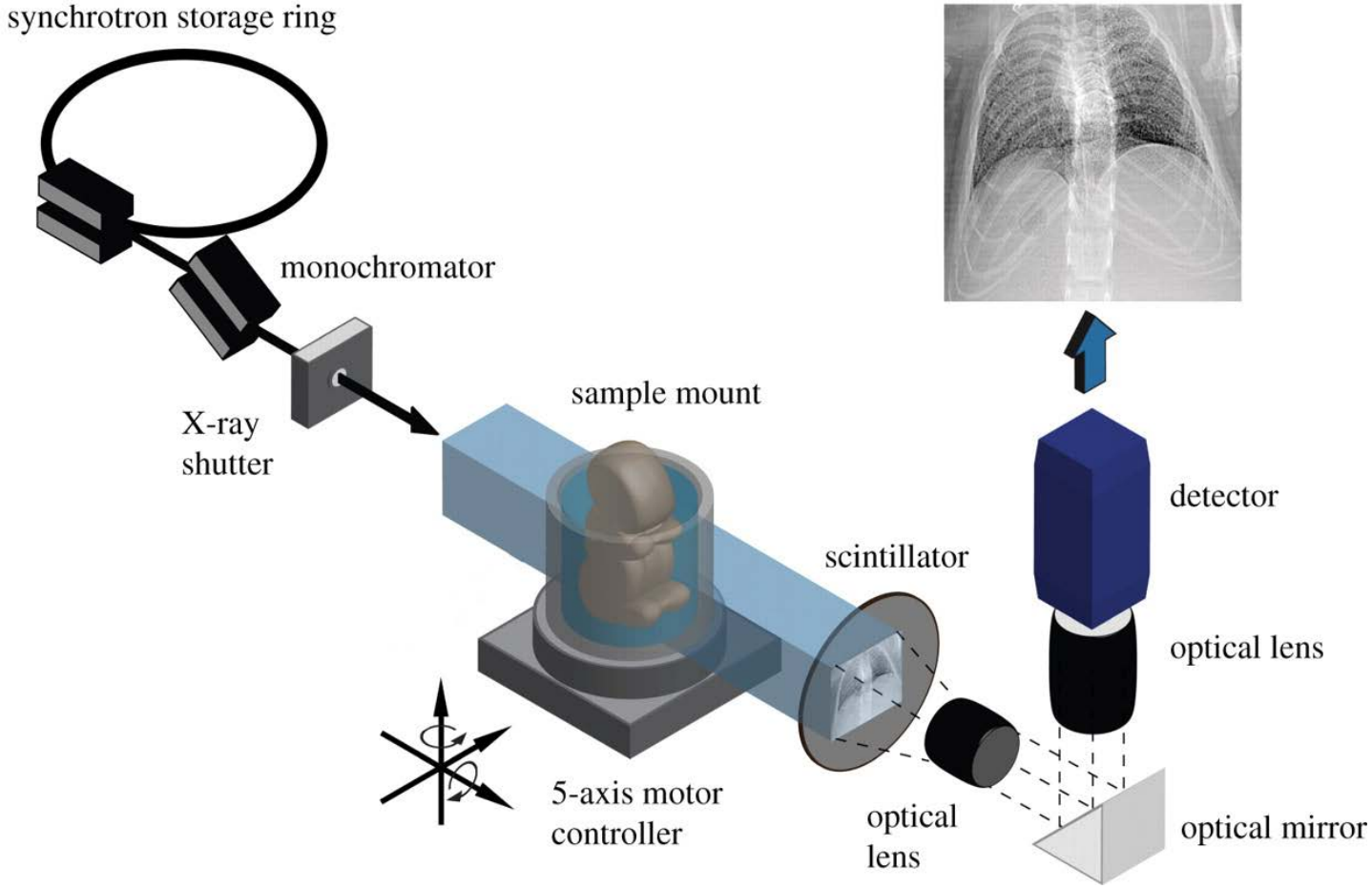
Synchrotron-Based CT (SR-CT)

- Advantages of SR-CT:
  - Measurement speed
  - Better absorption contrast
  - Large samples at high resolution
  - Elemental Mapping

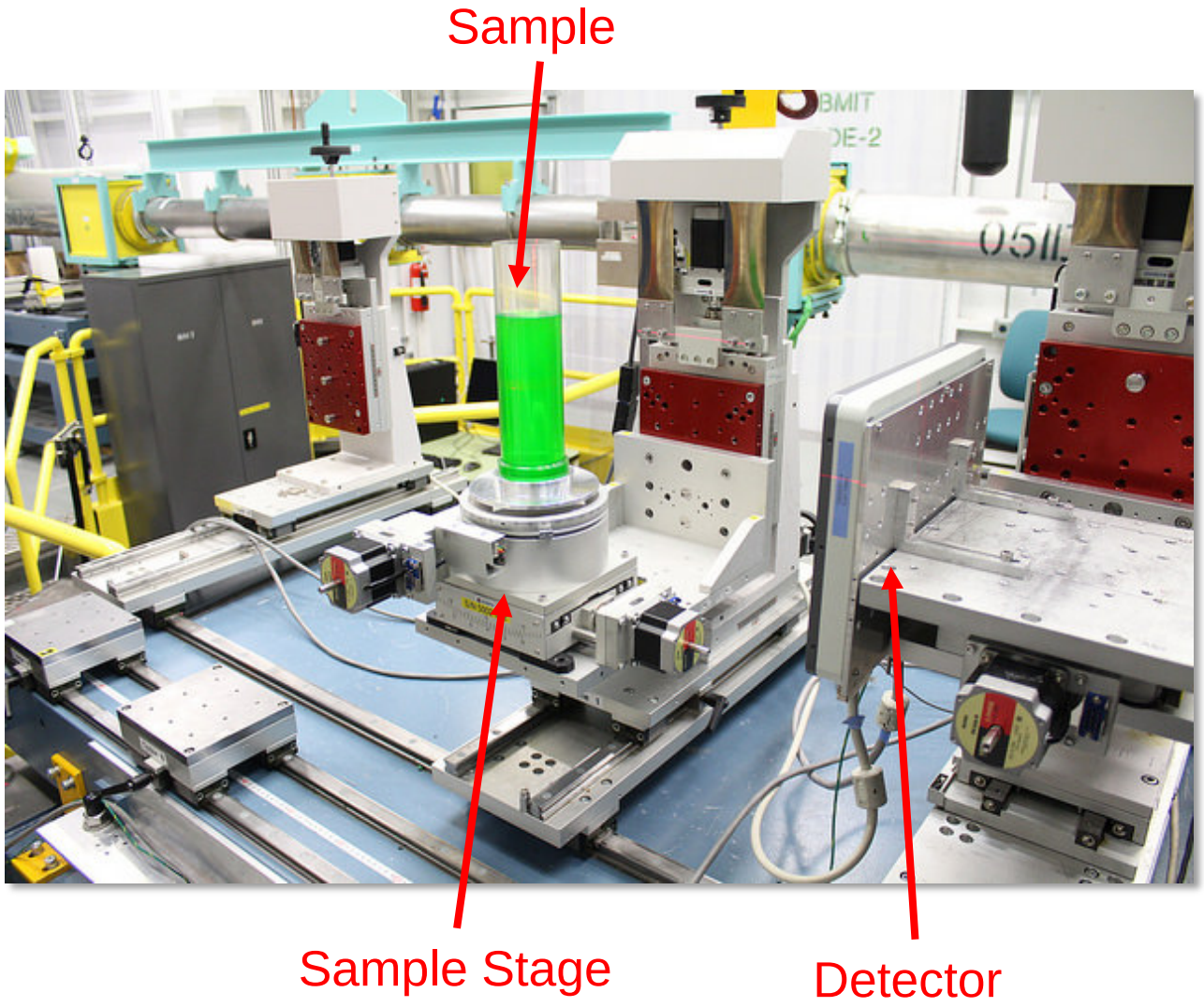


Synchrotron-Based CT (SR-CT)

- Advantages of SR-CT:
  - Measurement speed
  - Better absorption contrast
  - Large samples at high resolution
  - Elemental Mapping
  - Large enclosures

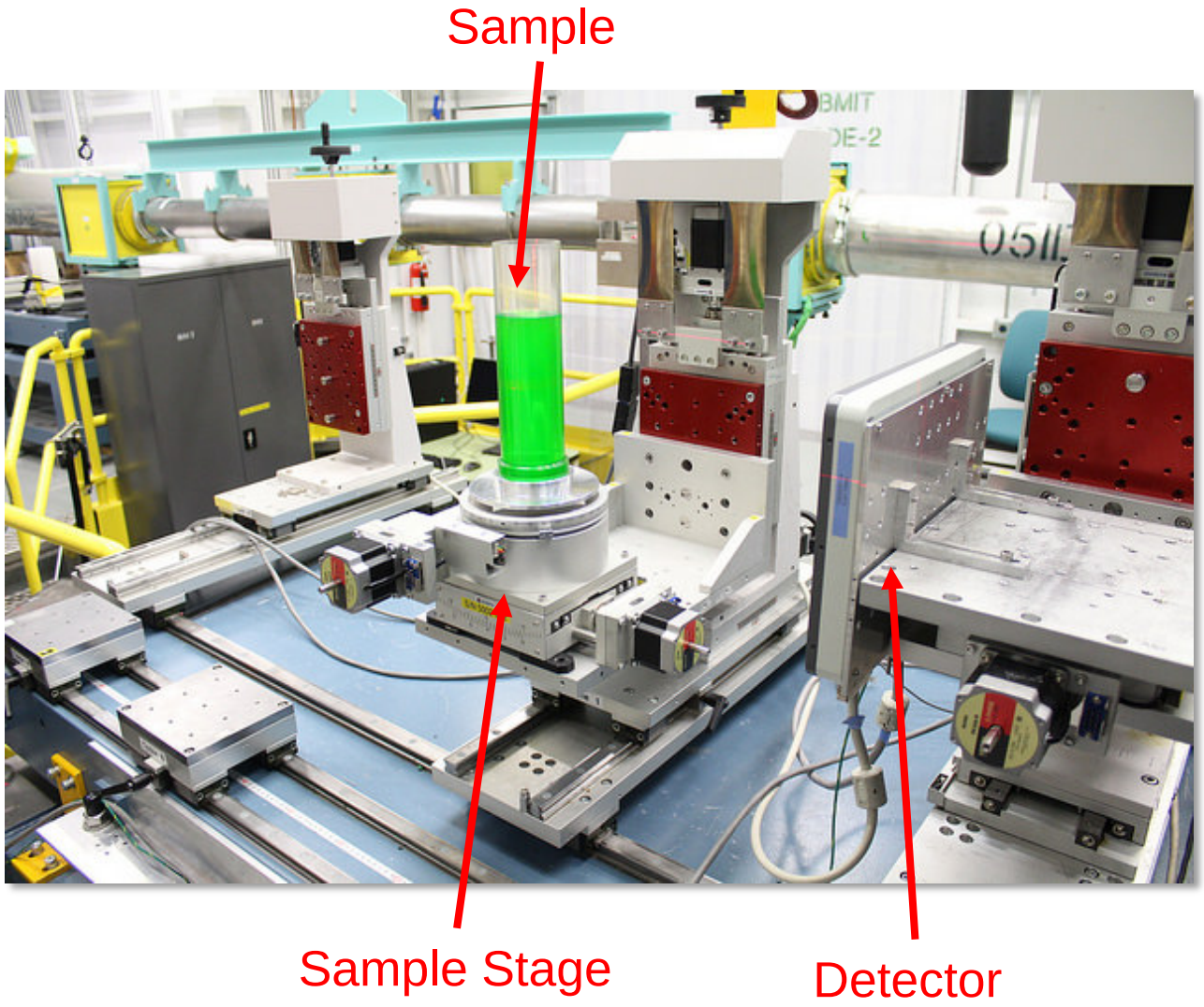


Synchrotron-Based CT (SR-CT)



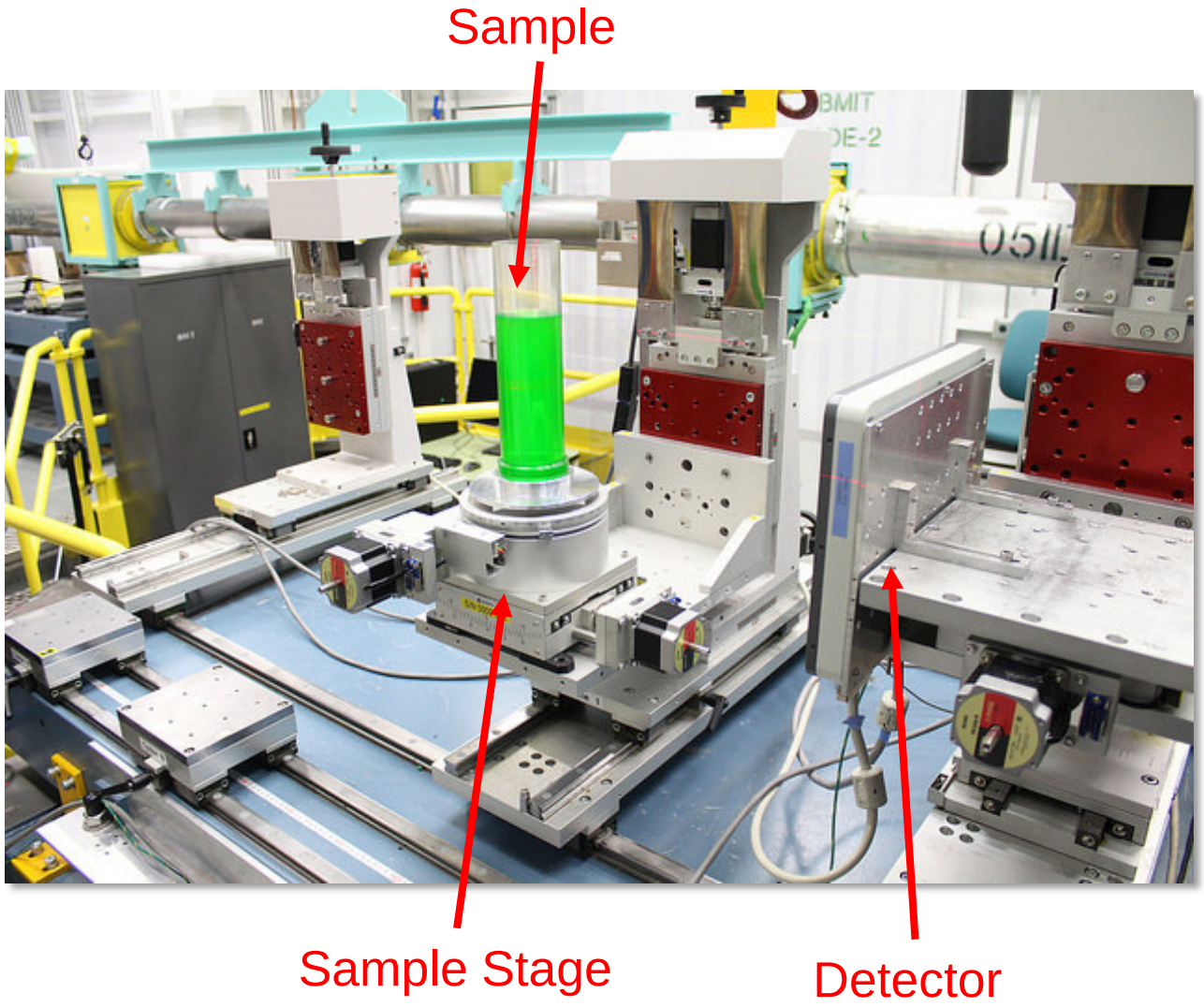
Synchrotron-Based CT (SR-CT)

- Well-suited to:



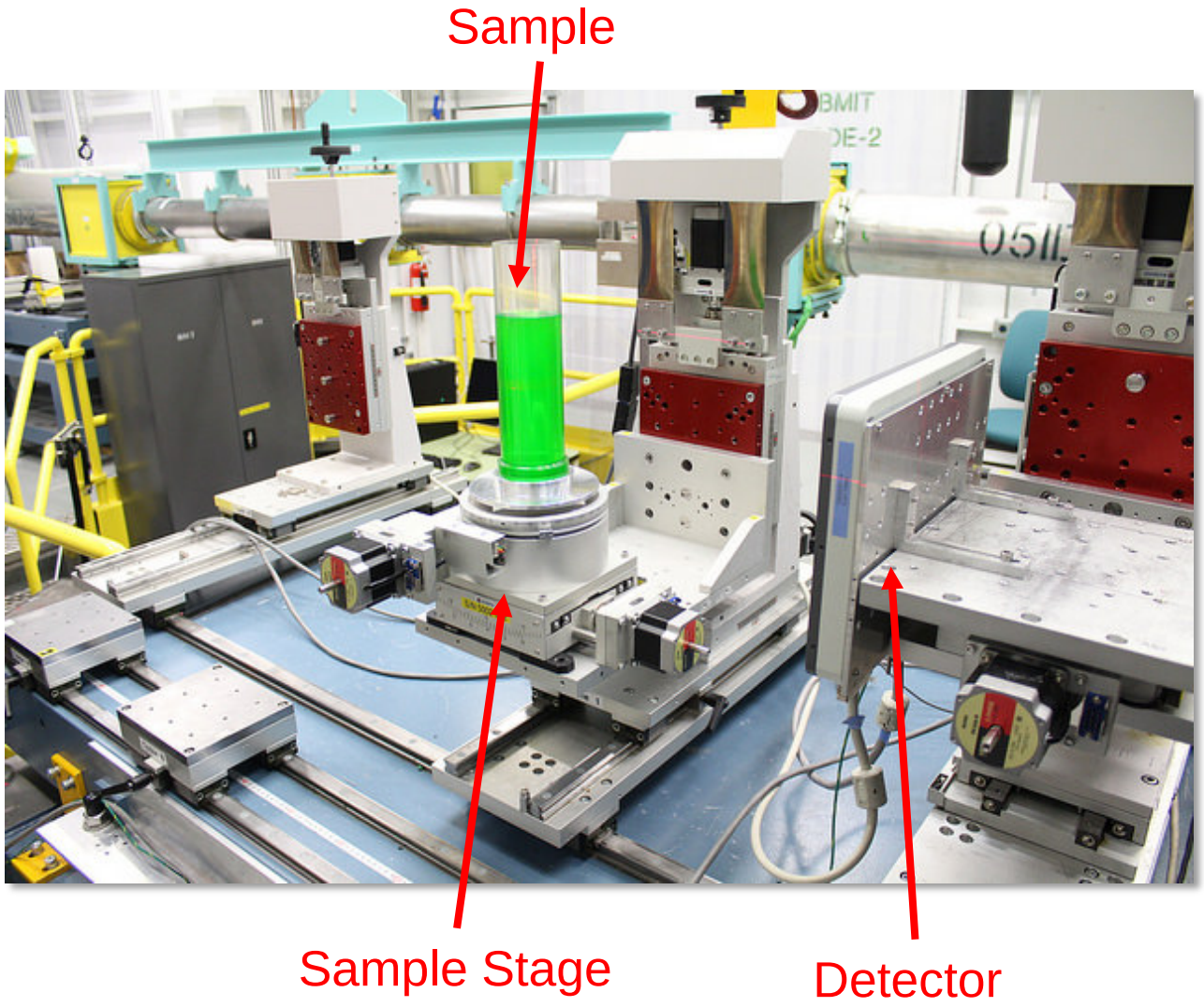
Synchrotron-Based CT (SR-CT)

- Well-suited to:
  - Low Contrast Samples



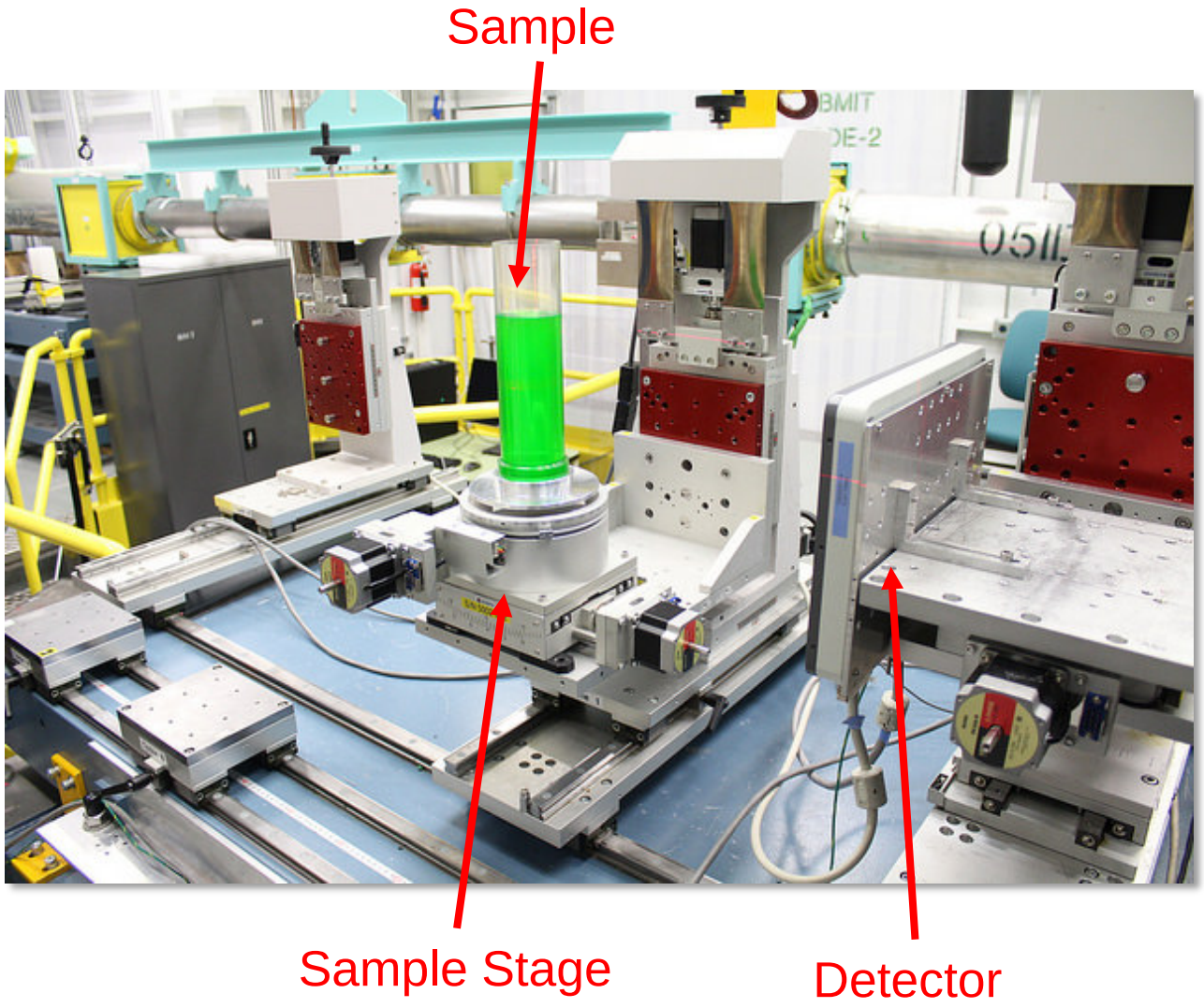
Synchrotron-Based CT (SR-CT)

- Well-suited to:
  - Low Contrast Samples
  - In-Situ imaging



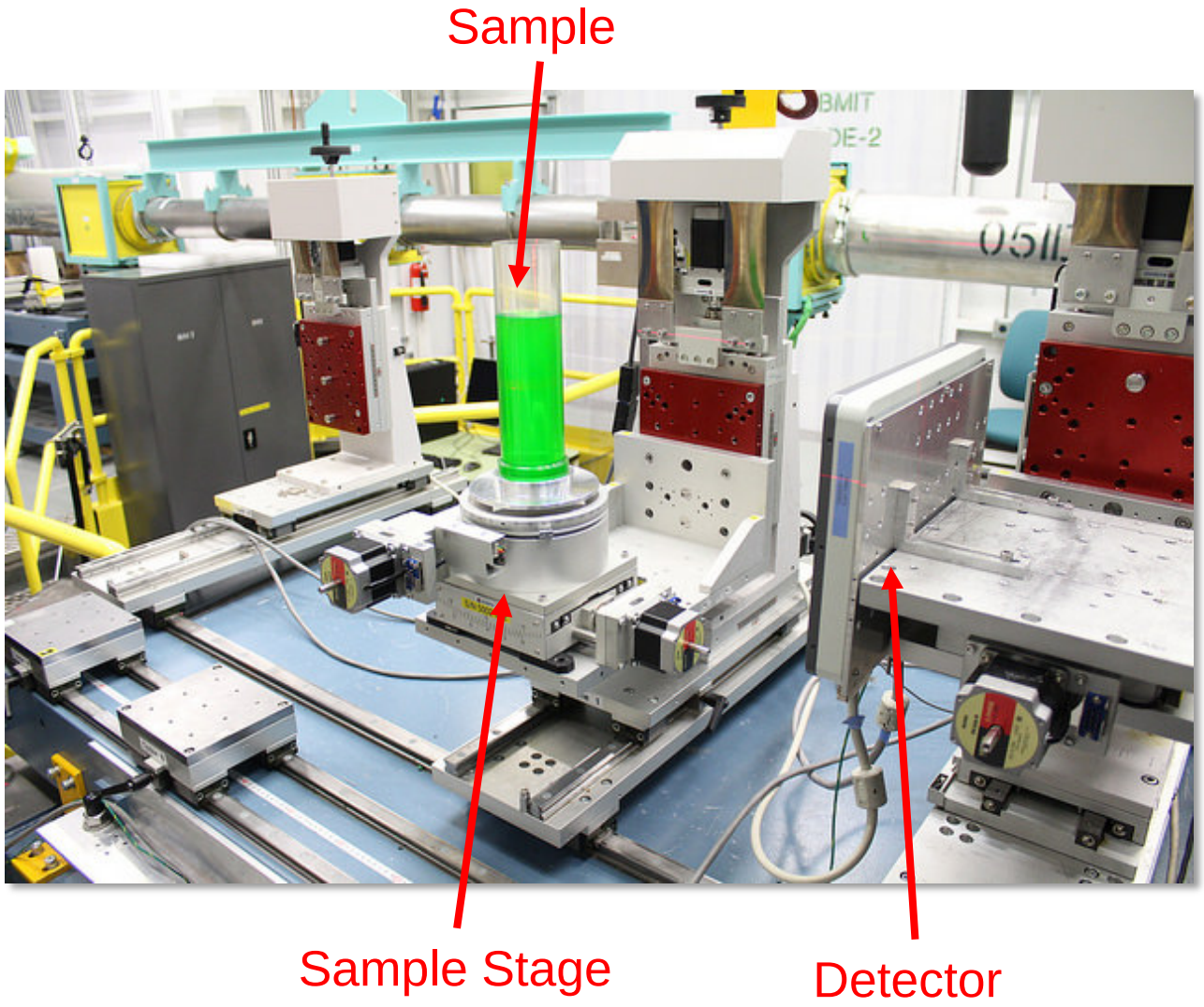
Synchrotron-Based CT (SR-CT)

- Well-suited to:
  - Low Contrast Samples
  - In-Situ imaging
  - Large samples with small features



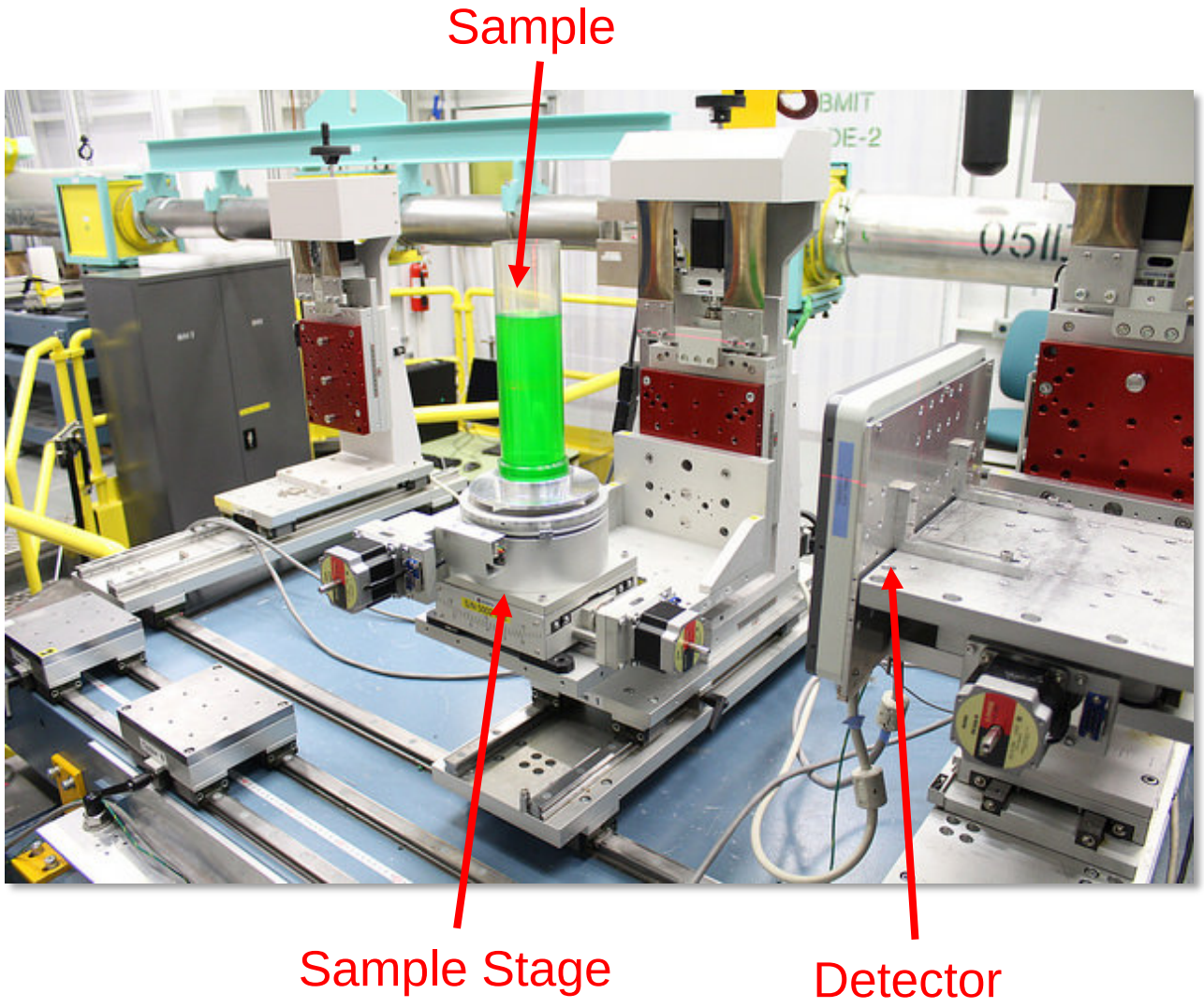
Synchrotron-Based CT (SR-CT)

- Well-suited to:
  - Low Contrast Samples
  - In-Situ imaging
  - Large samples with small features
  - Time-resolved experiments



Synchrotron-Based CT (SR-CT)

- Well-suited to:
  - Low Contrast Samples
  - In-Situ imaging
  - Large samples with small features
  - Time-resolved experiments
  - Experiments that require large or complex equipment



CT at the Canadian Light Source

BMIT-BM beamline (low-energy)

BMIT-ID beamline (high-energy)

- The CLS has two beamlines that are dedicated for SR-CT experiments, which are known as the Biomedical and Imaging Therapy beamlines (BMIT)
- The beamlines cover different energy ranges:
  - BMIT-BM: low energy for small, low-density samples (15-40 keV)
  - BMIT-ID: high energy range for large, high-density samples (30-140 keV)

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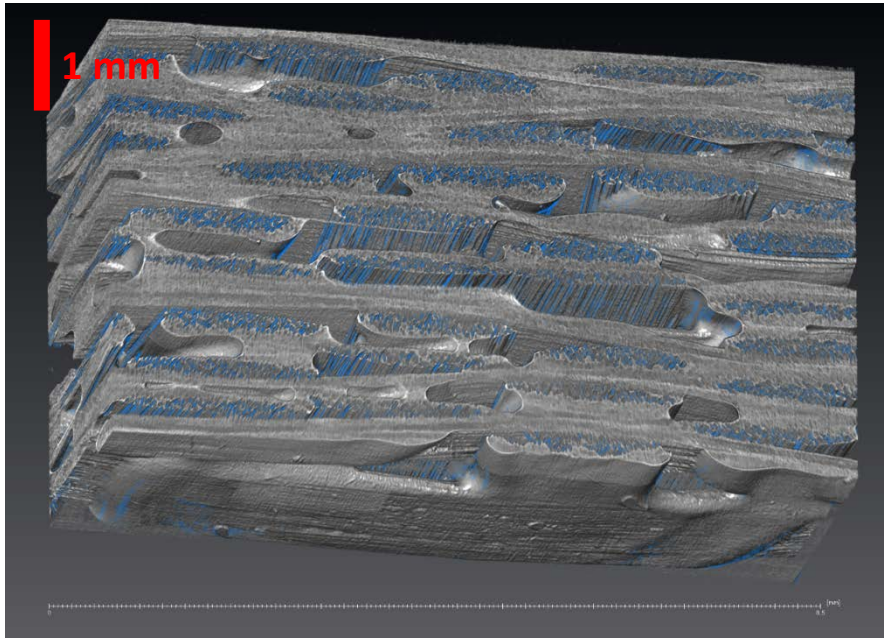
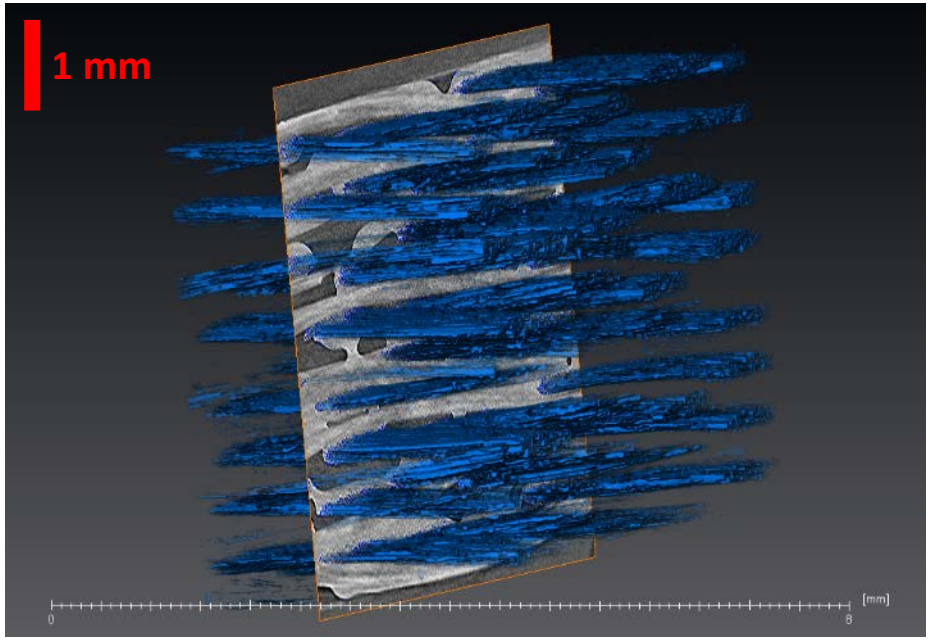
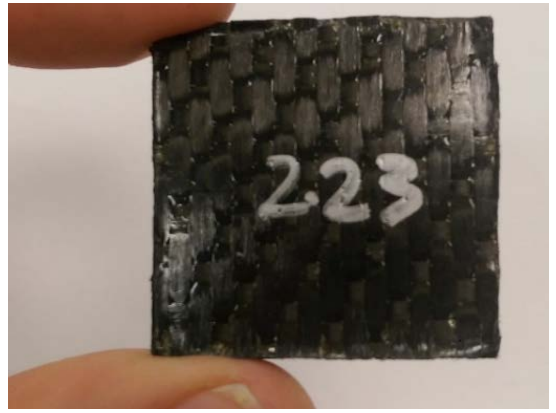
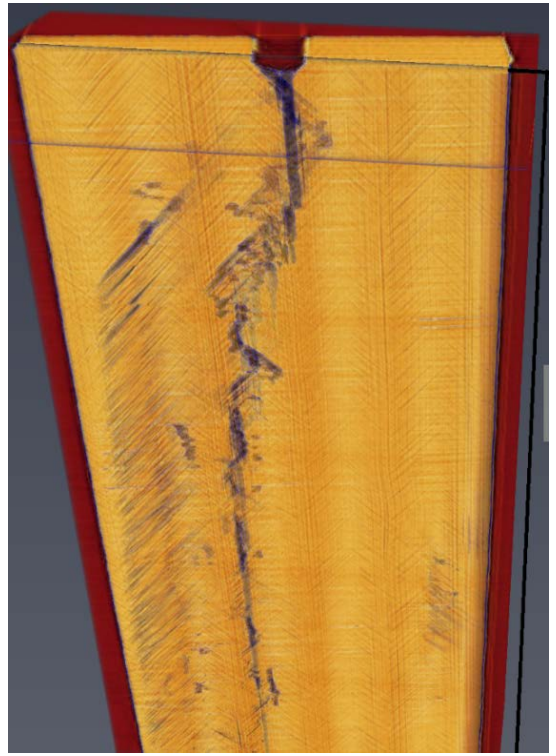
- X-Ray Imaging and CT
- Synchrotron CT
- Examples:
  - Composites
  - Devices and Batteries
  - Geological Samples
  - Fluid Dynamics

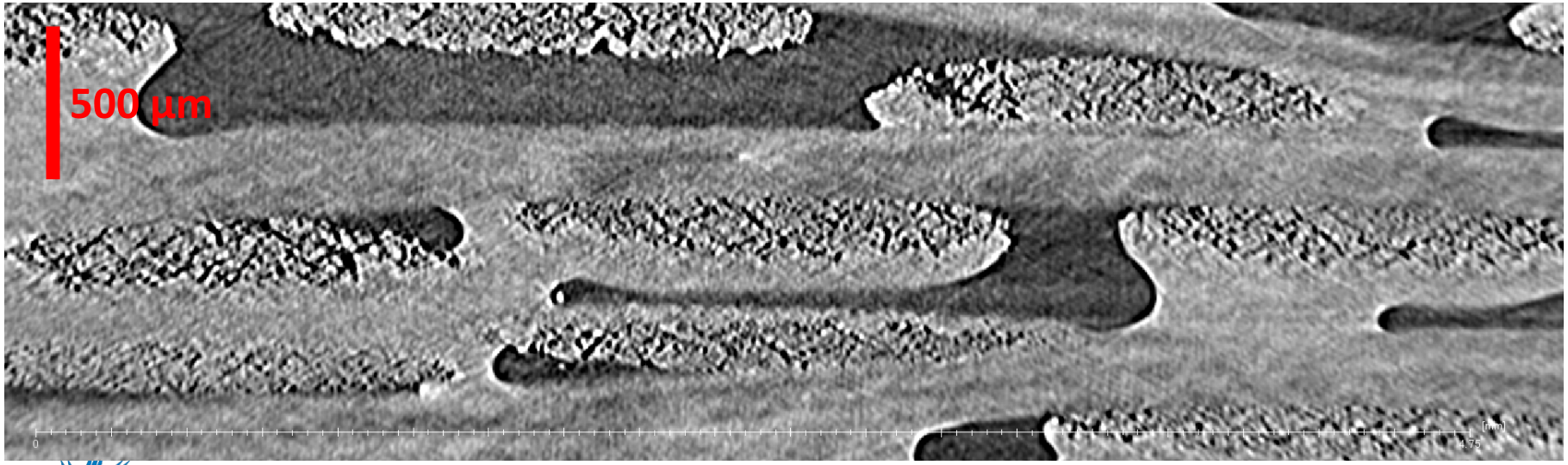
Carbon Fiber Composites



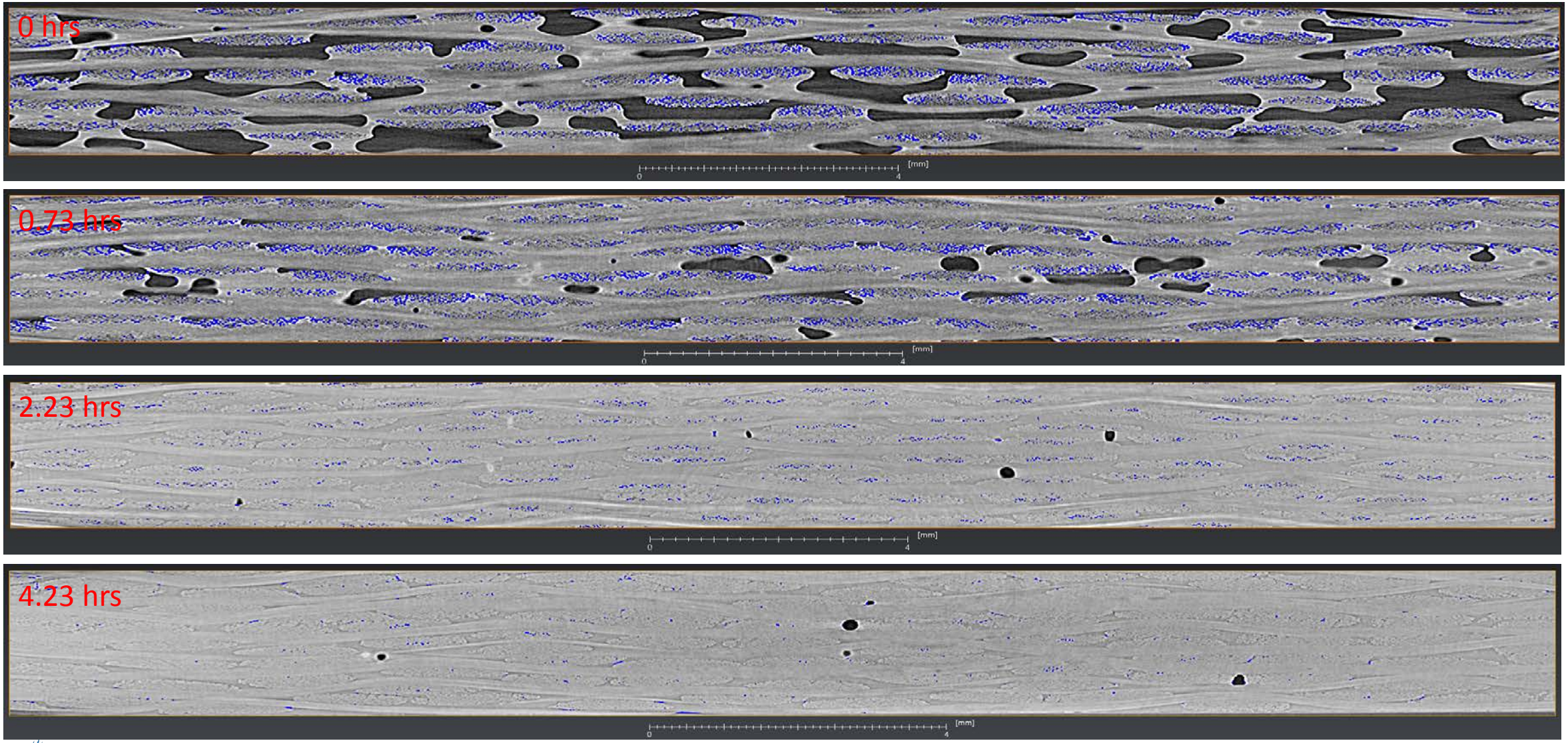




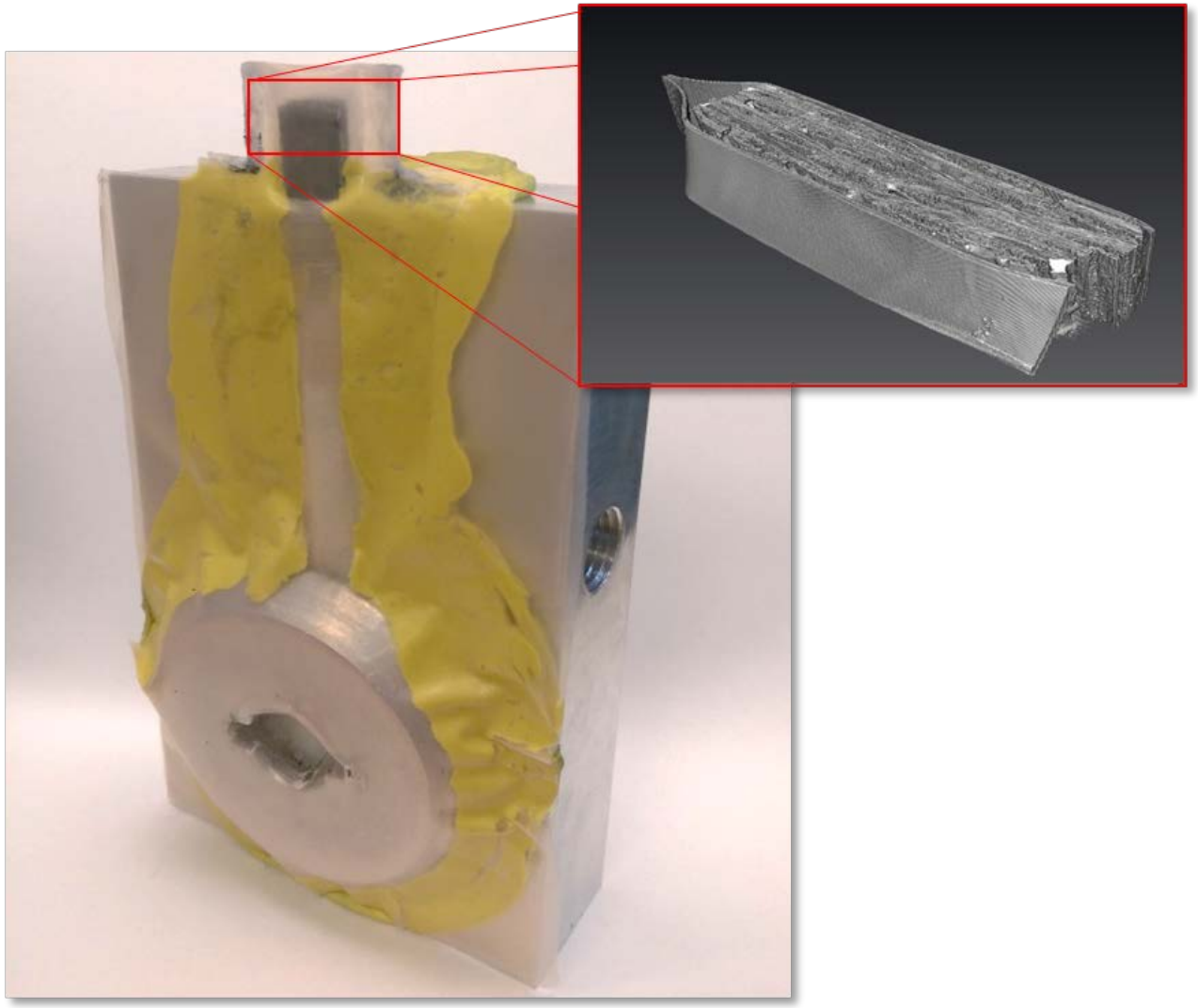




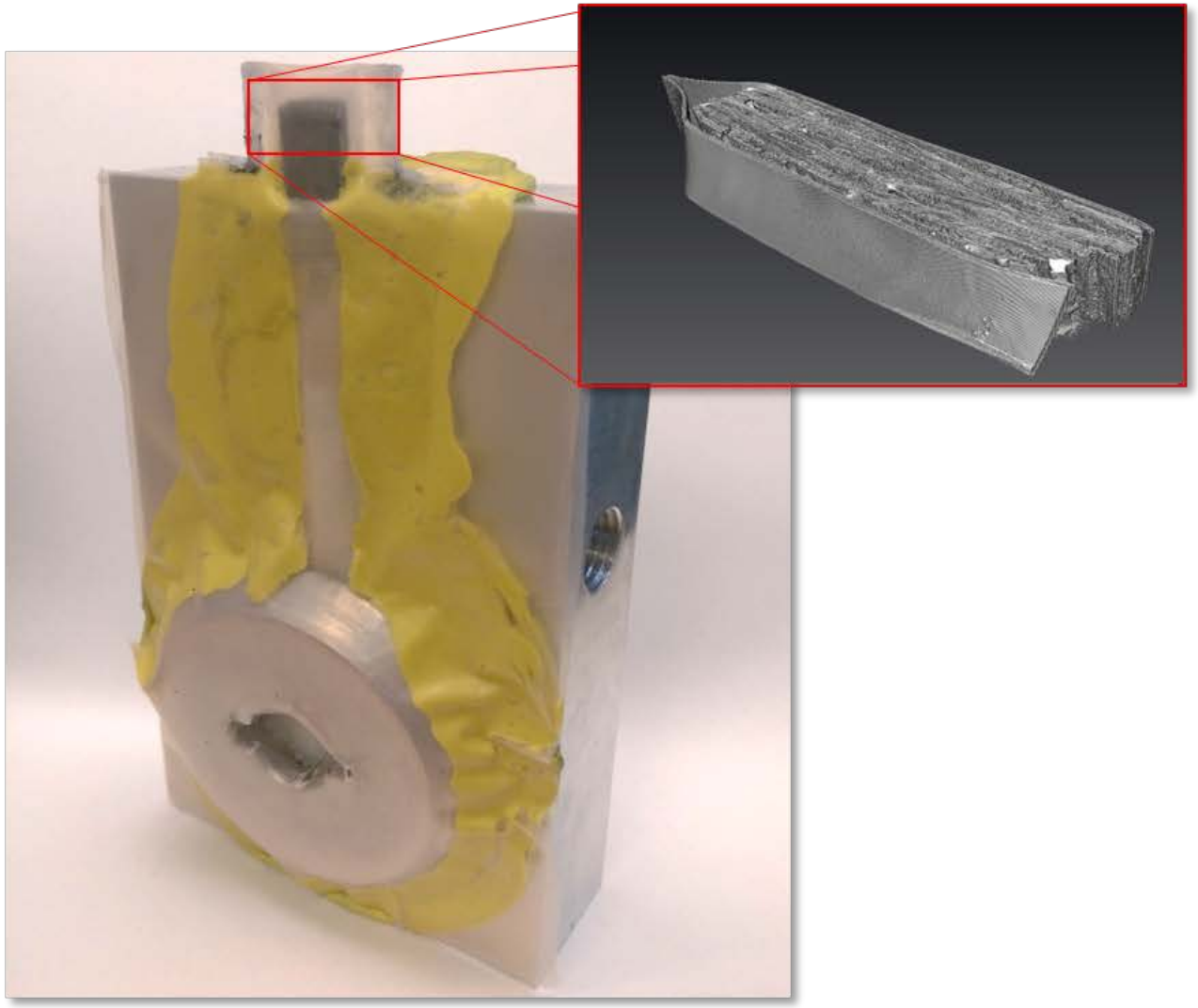
Carbon Fiber Composites

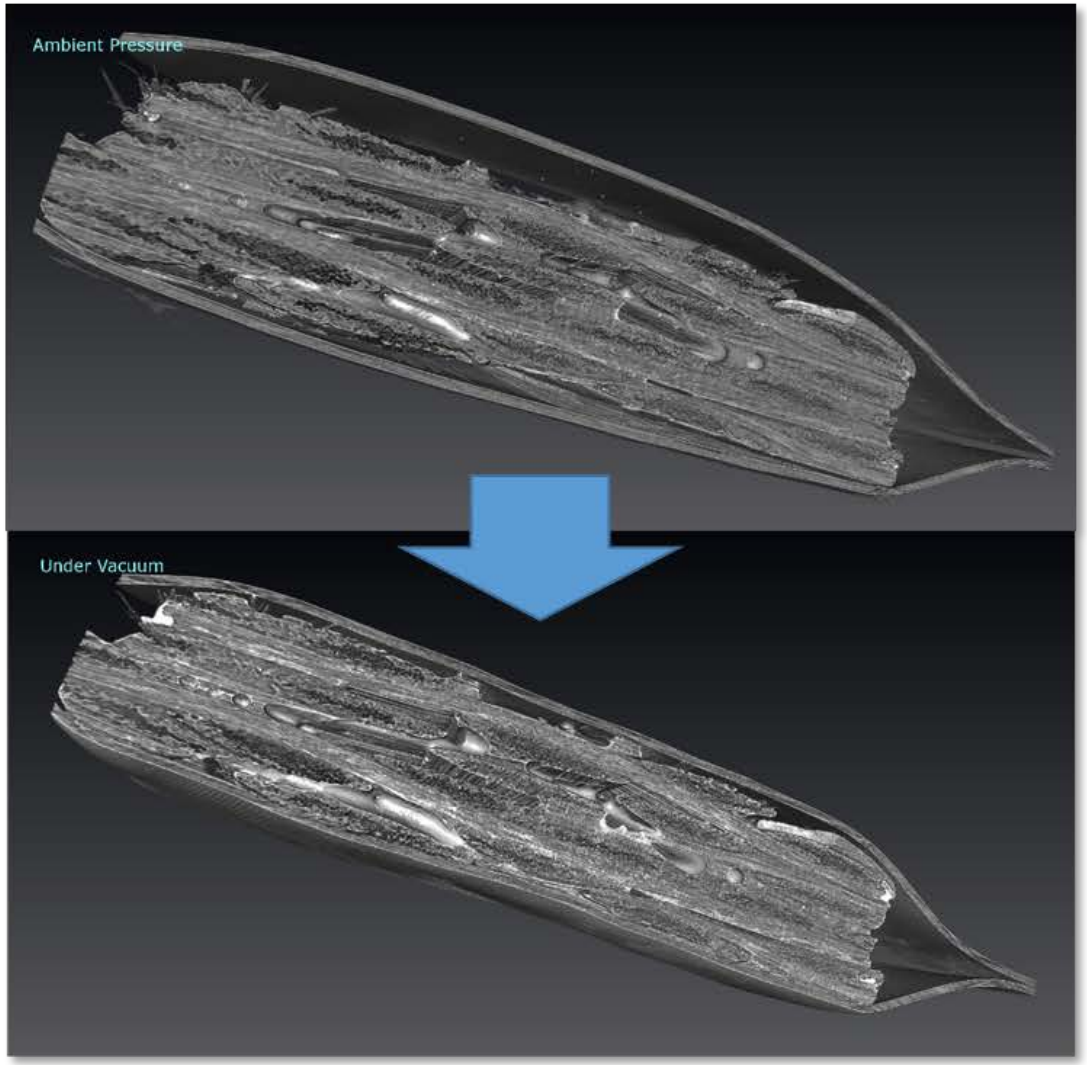


Carbon Fiber Composites



Carbon Fiber Composites

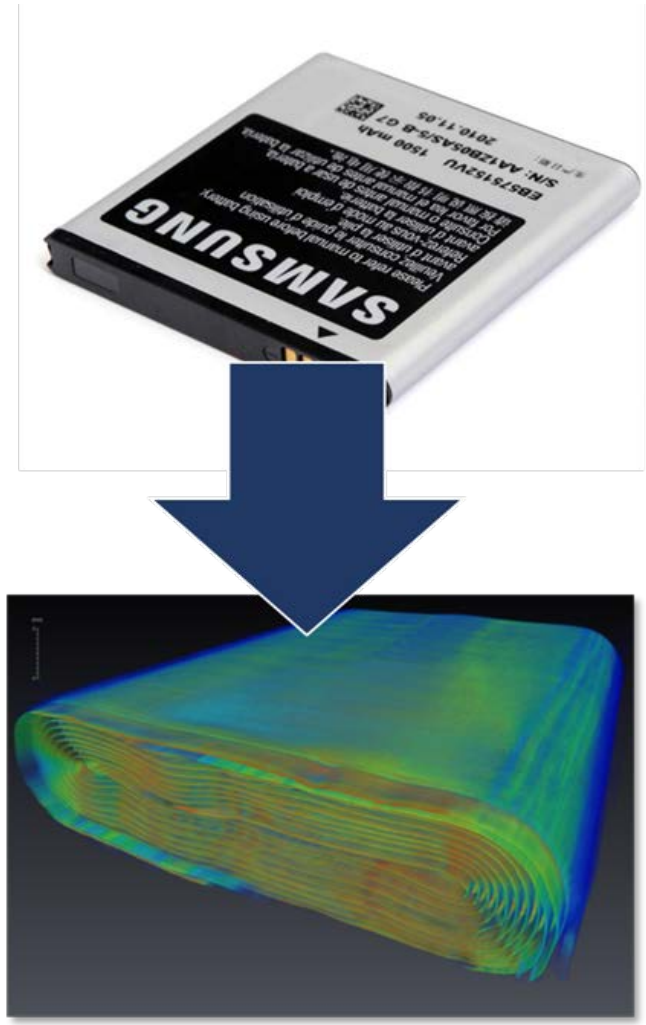




Exploding Batteries

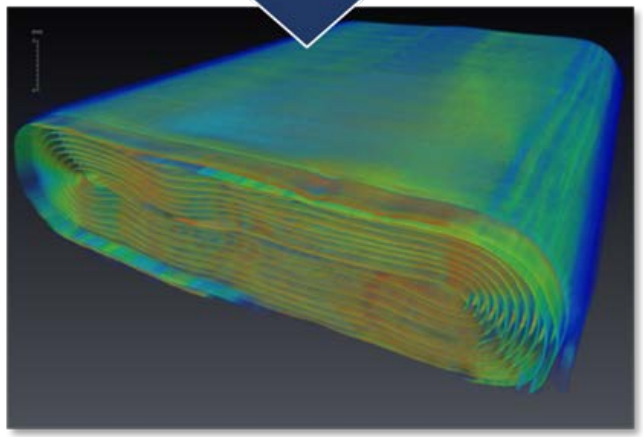
Exploding Batteries

Batteries and Devices



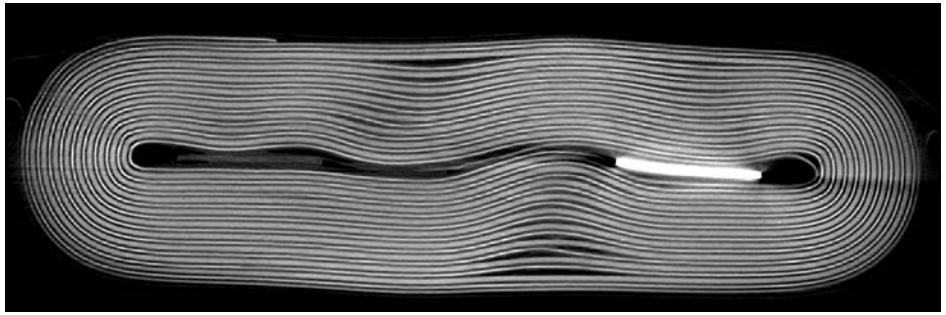
Interior of a “pouch cell” battery

Batteries and Devices

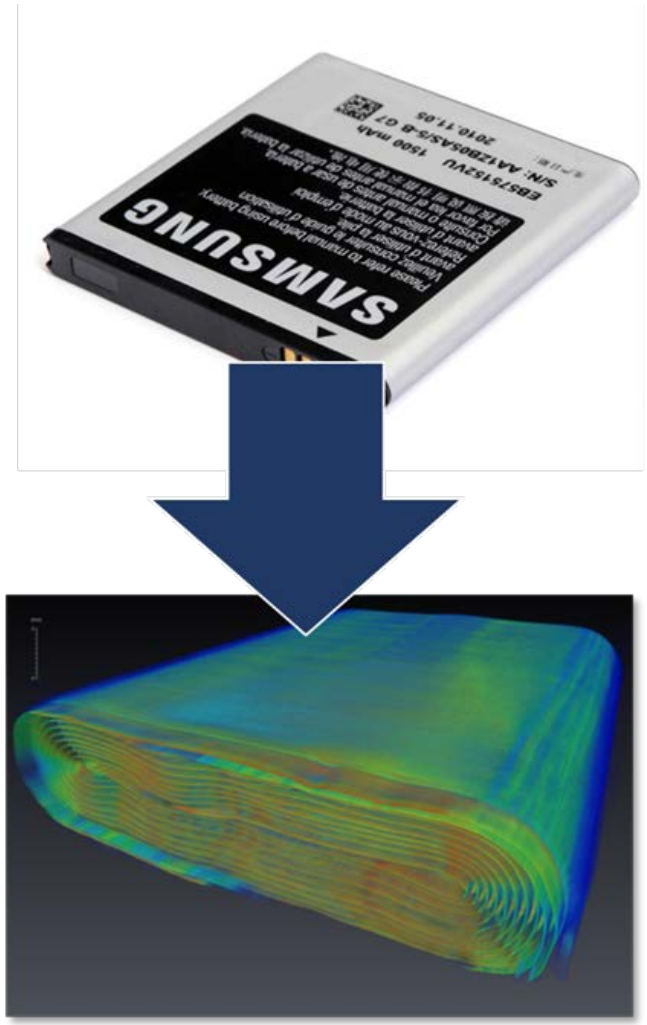


Interior of a “pouch cell” battery

Normal:



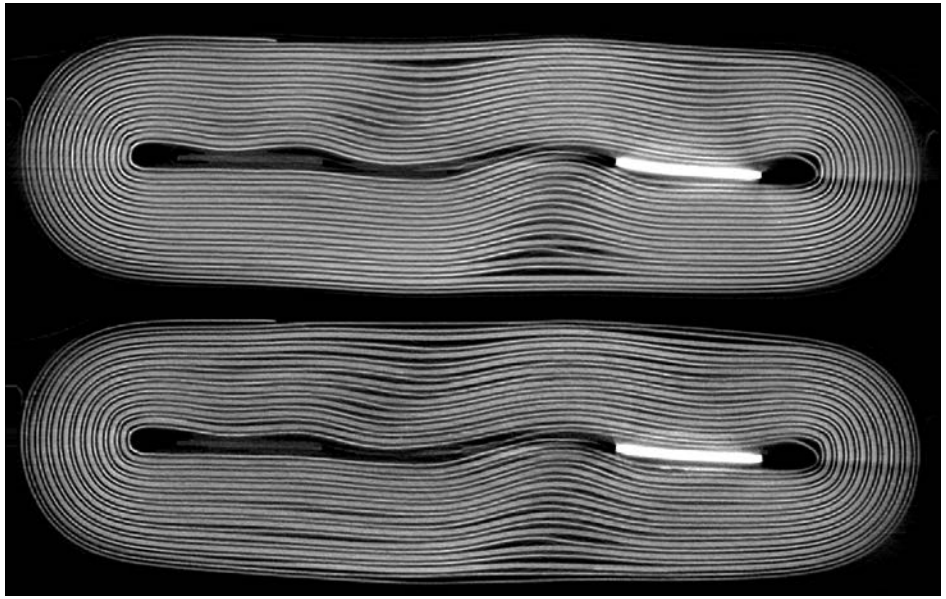
Batteries and Devices



Interior of a “pouch cell” battery

Normal:

“Pillowed”:



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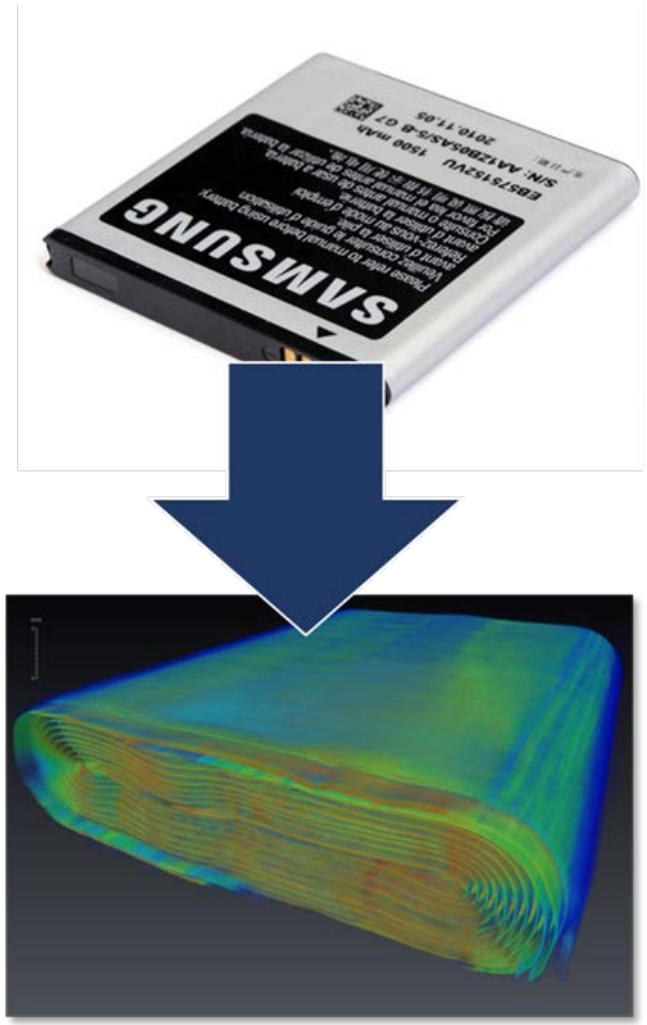
Batteries and Devices

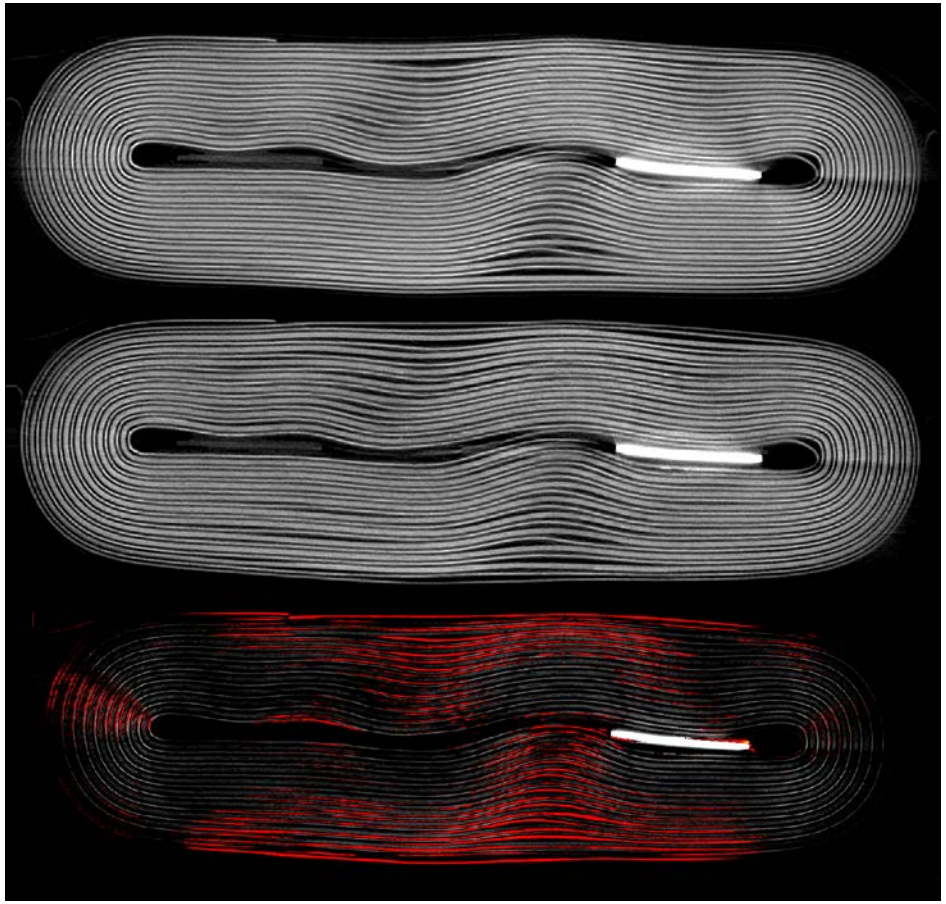


Interior of a “pouch cell” battery

Normal:

“Pillowed”:

Difference:



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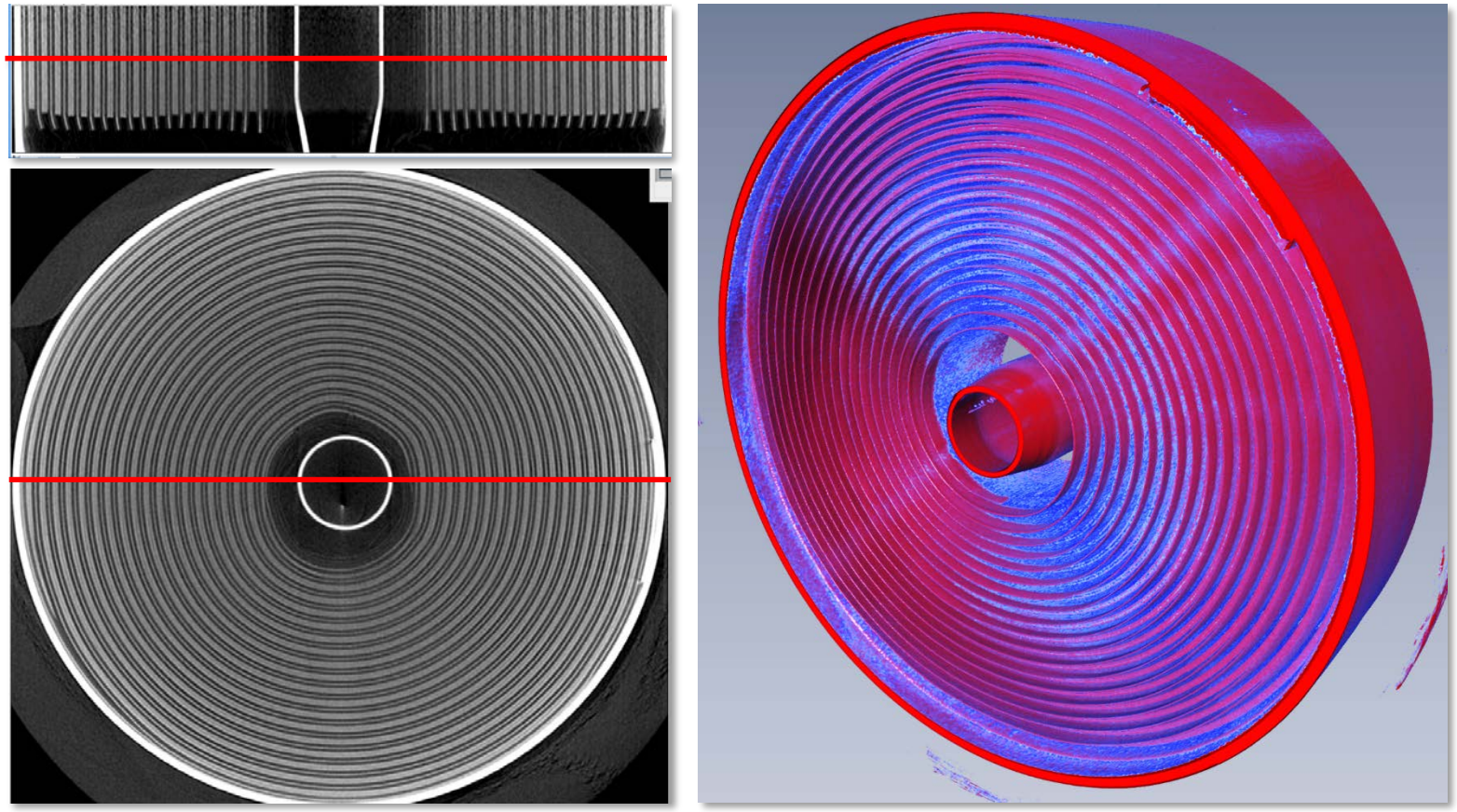
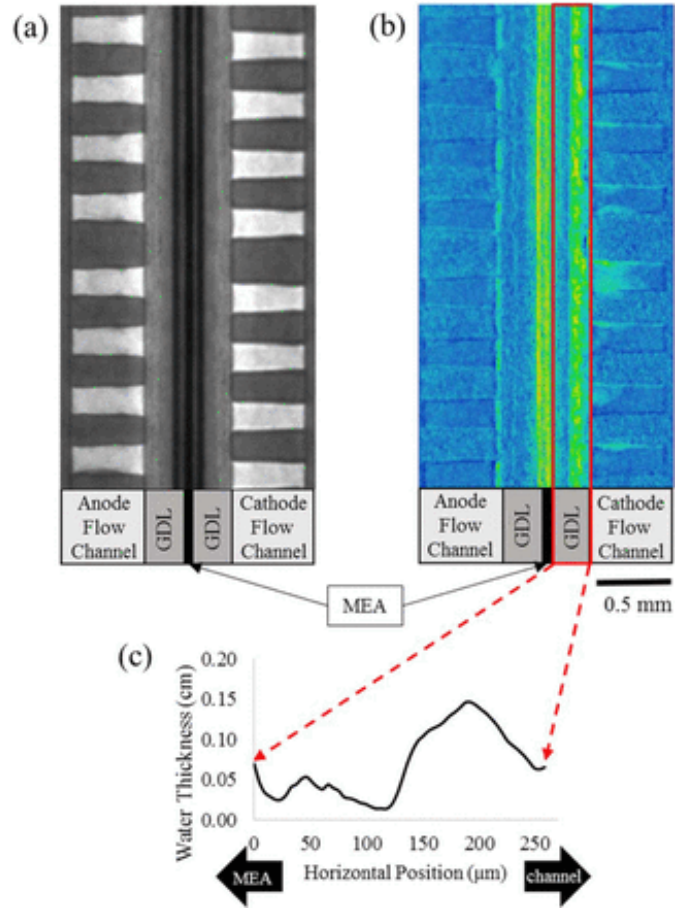
Batteries and Devices



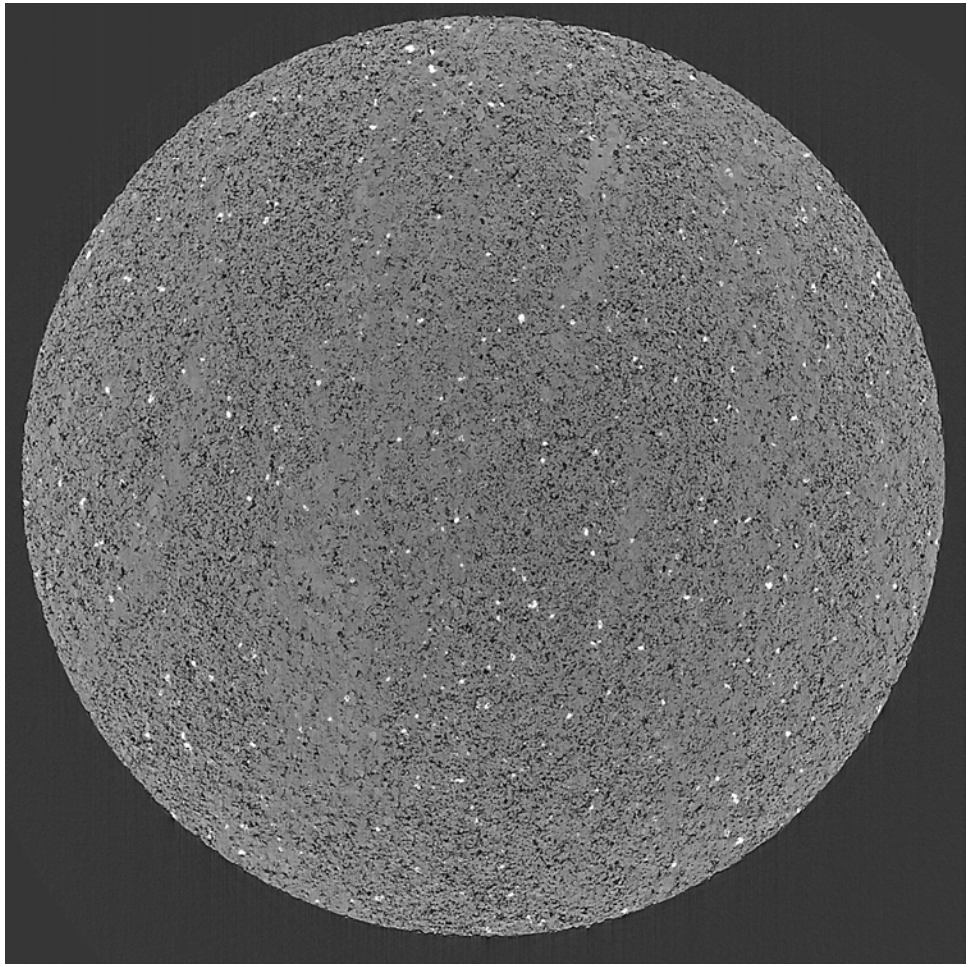
Interior of an cylindrical commercial lithium ion battery



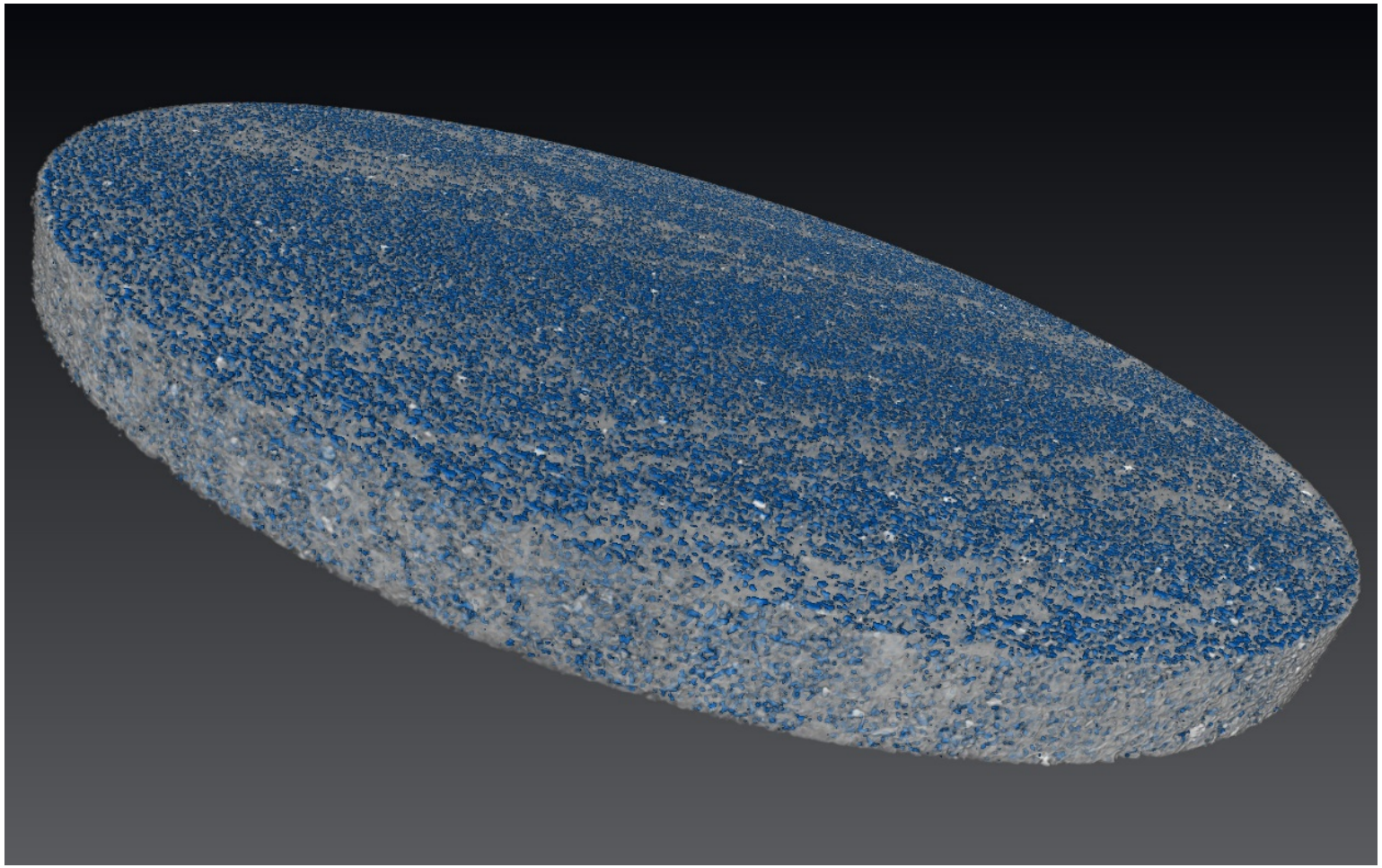
Water mapping of an in-situ hydrogen fuel cell (Bazylak et al.)

Lee, Yip, Antonacci, Ge, Kotaka, Tabuchi, and Bazylak, JECS, 162 (7) F669-F676 (2015)

Geological Cores

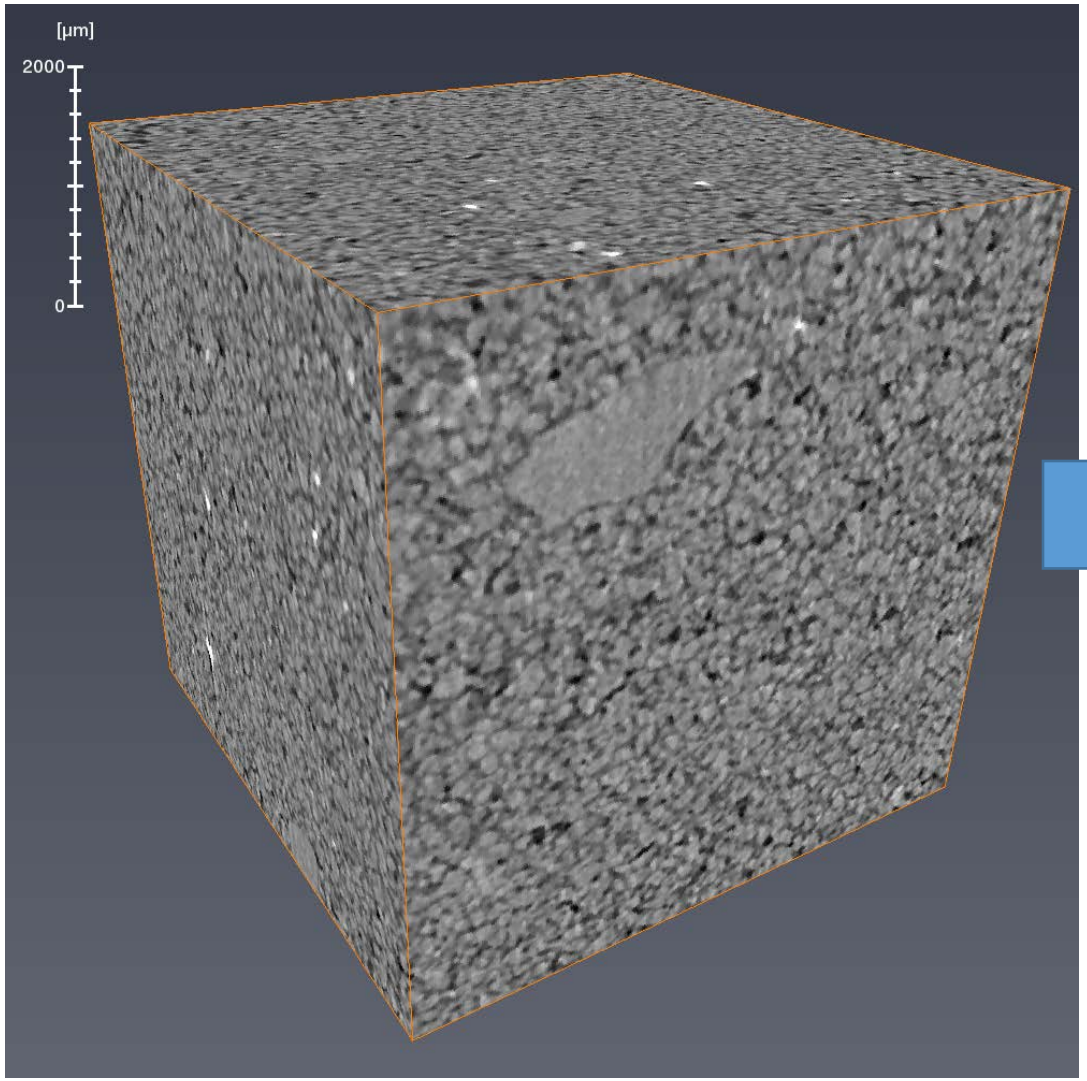


Internal 2D cross section of a 1-inch core sample

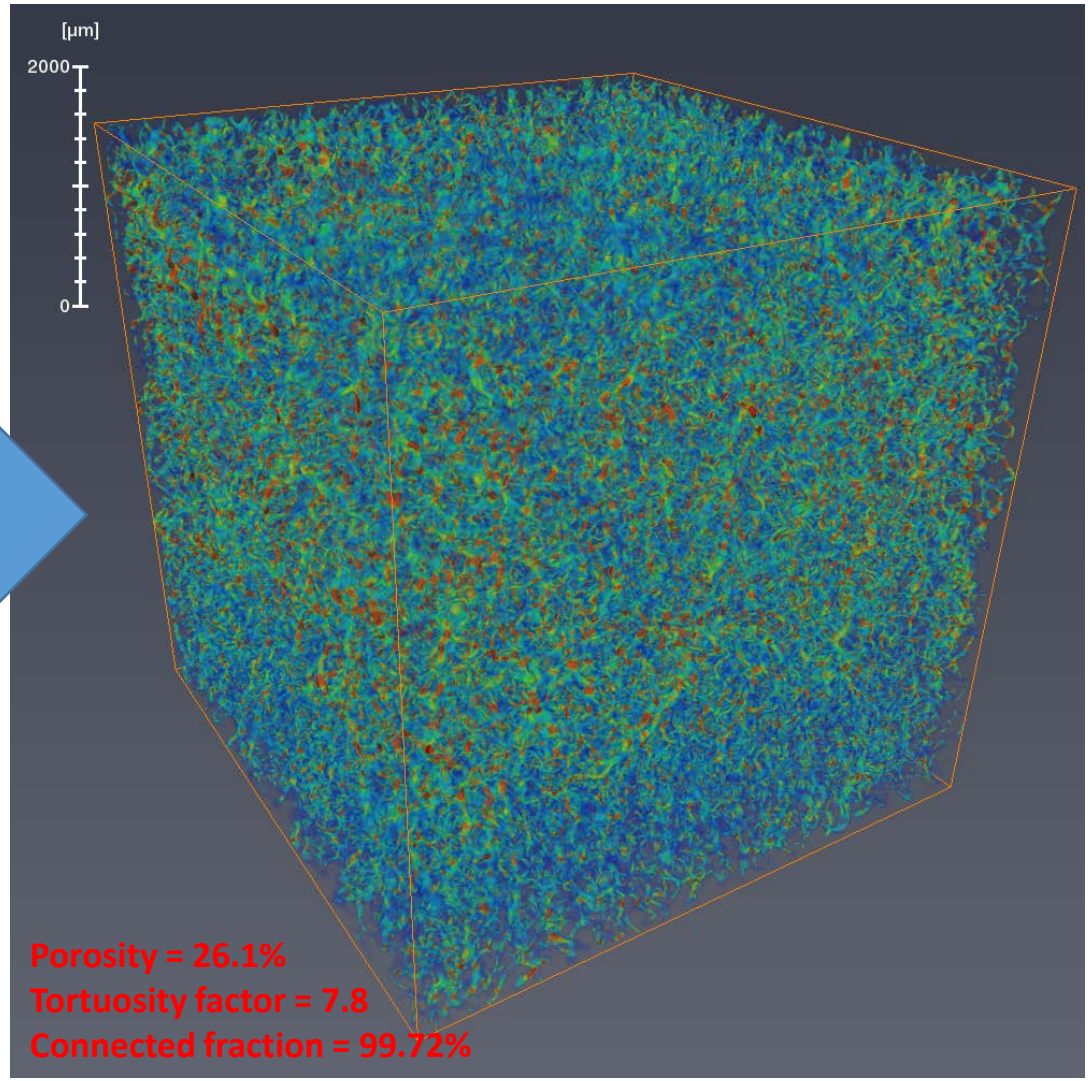


Internal 3D pore network (highlighted in blue) of a core sample

Pore Network Analysis



CT scan of porous core sample



Results of pore analysis and fluid simulation (map of total flux along vertical axis)

Time-Resolved CT of Viscous Fluid

Bitumen core sample

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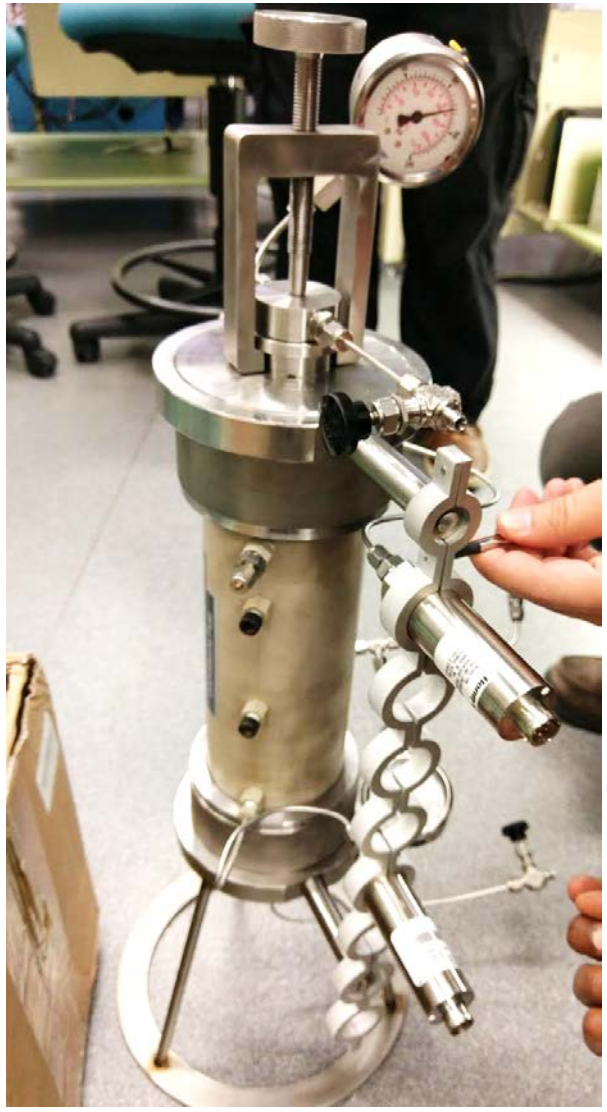
Time-Resolved CT of Viscous Fluid

Bitumen core sample



X-ray-transparent pressure vessel

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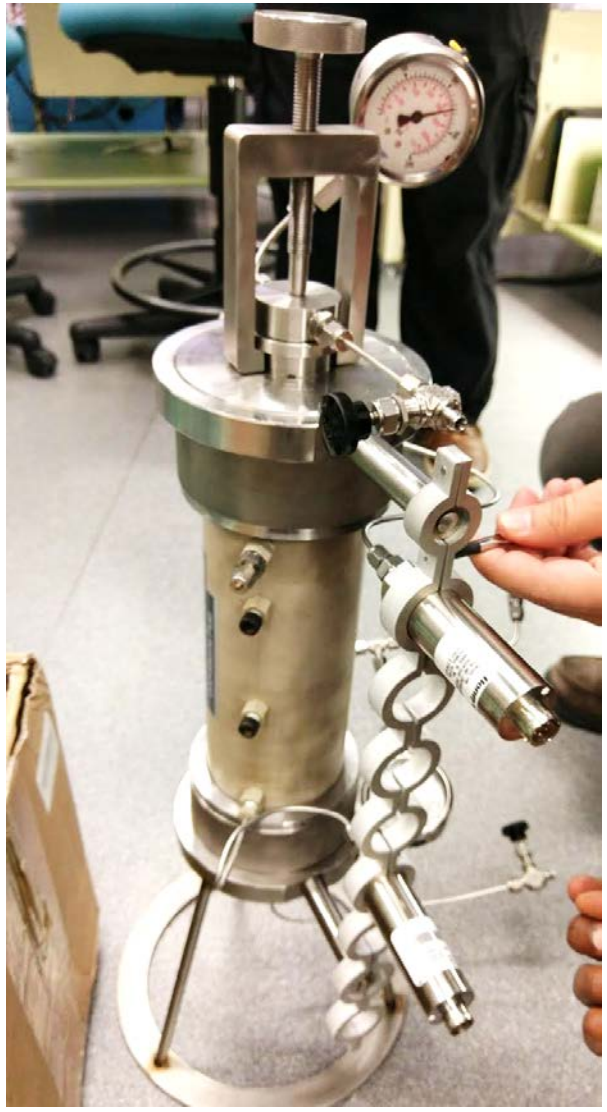
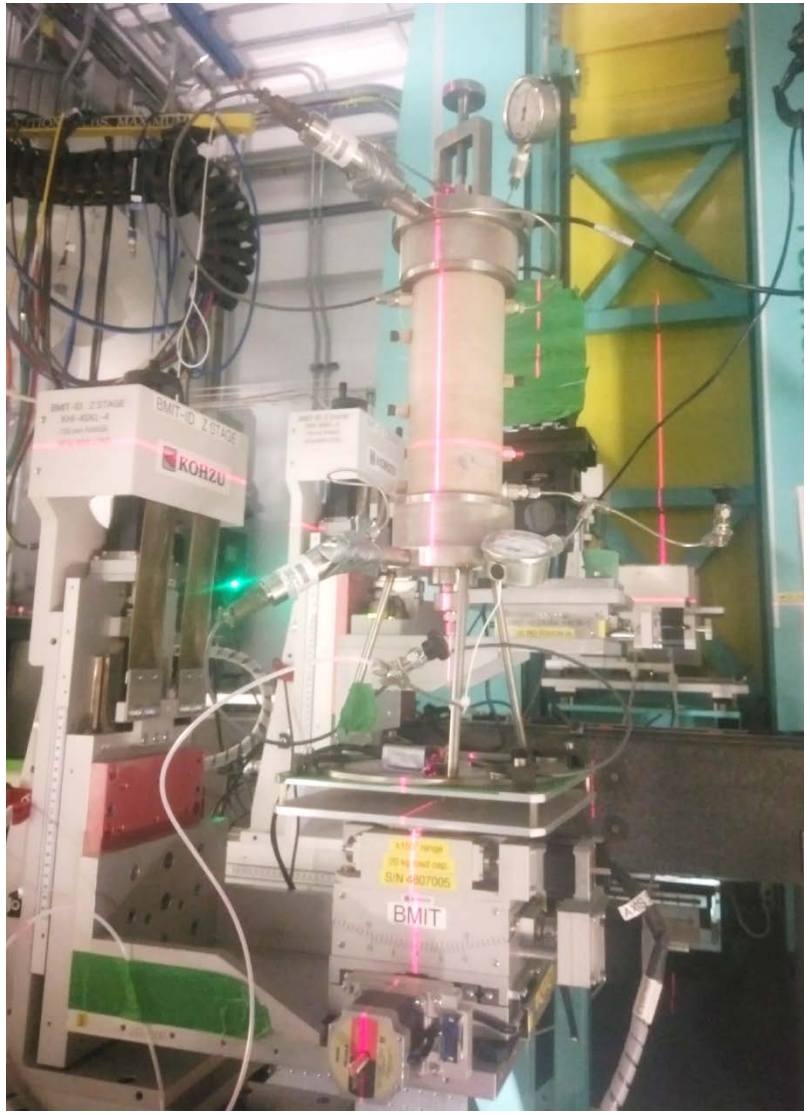
Time-Resolved CT of Viscous Fluid

Bitumen core sample

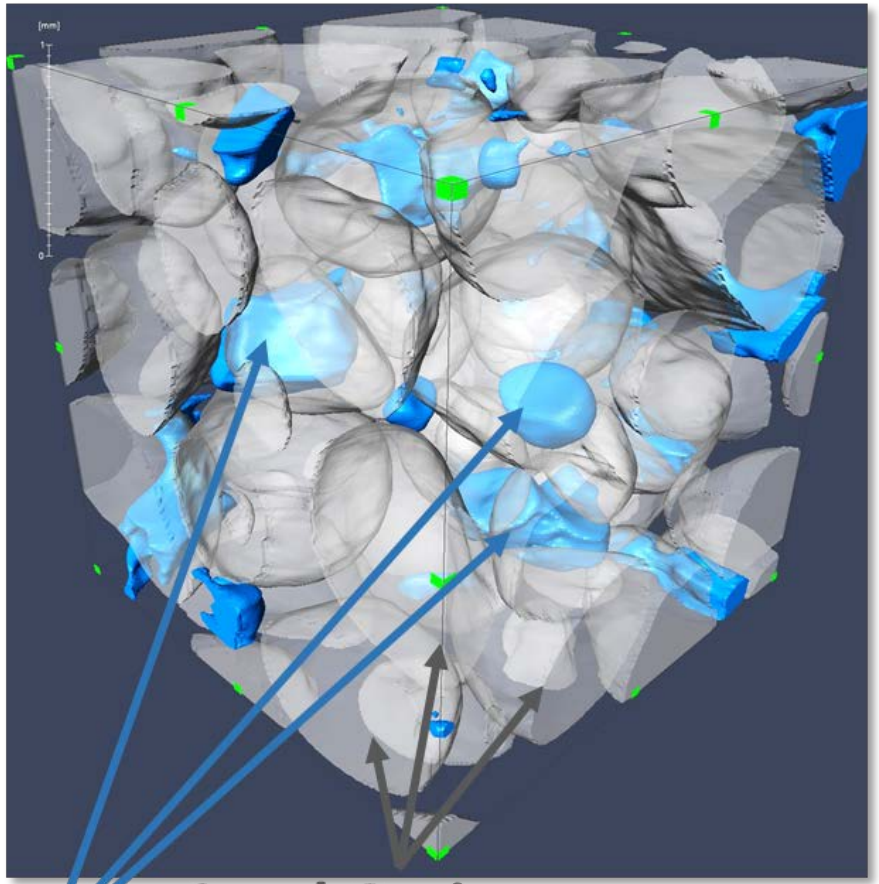


X-ray-transparent pressure vessel



Time-resolved experiment in progress

Time-Resolved CT of Viscous Fluid



Summary

Summary

- SR-CT is:

Summary

- SR-CT is:
  - Fast

Summary

- SR-CT is:
  - Fast
  - High Contrast

Summary

- SR-CT is:
  - Fast
  - High Contrast
  - High-resolution for large samples

Summary

- SR-CT is:
  - Fast
  - High Contrast
  - High-resolution for large samples
- SR-CT is ideal for:

Summary

- SR-CT is:
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  - High Contrast
  - High-resolution for large samples
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  - Imaging materials with very similar composition/density

Industrial Science Program at the CLS

- Industry access is a core mandate of the CLS
- Independent legal status allows for flexible IP policies
- The Industrial Science Division exists to facilitate industry access
- The CLS has the highest rate of industrial utilization of any synchrotron in the world

Thank You


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