5th International Society for Sample Environment (ISSE) Training School 2026

IMAGING – TOMOGRAPHY

SAMPLE ENVIRONMENTS FOR 4D TOMOGRAPHY

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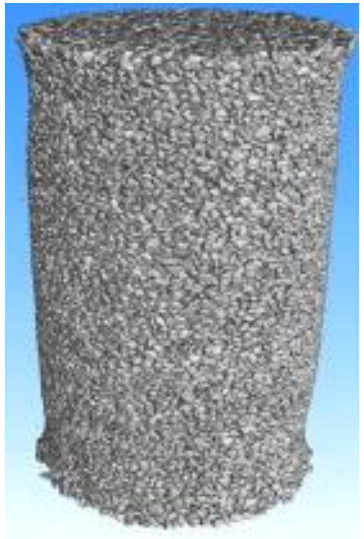
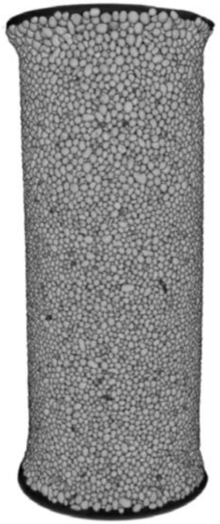
Division of Solid Mechanics

Objectives today:

- Introduce tomography (3D imaging)
- Beyond 3D images
- Examples of sample environments for 4D Imaging



3D Imaging



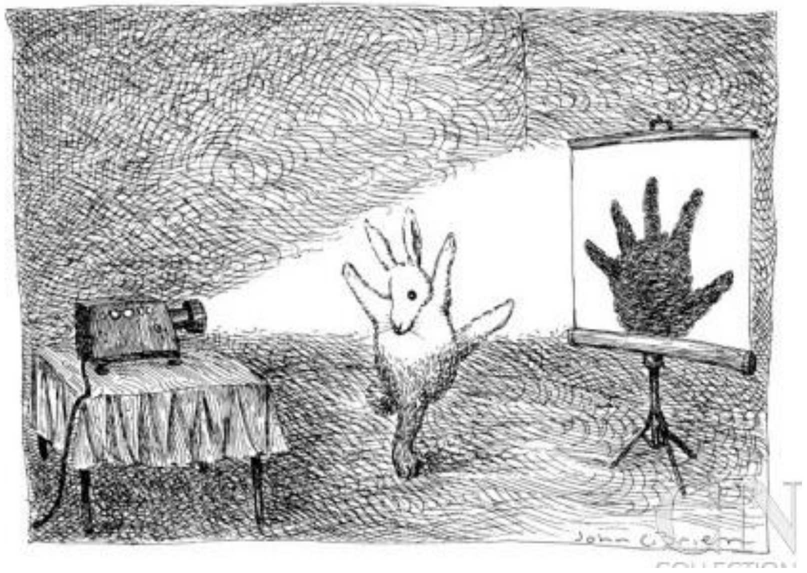
3D+t (4D) Imaging

2D → 3D imaging

radiography → tomography

When the detail to be observed (here, a fracture) is in the plane of the radiography, this can be sufficient (for medical diagnosis in this case)

But this can be misleading…



<u>Tomography</u> = slice imaging

- "extension" of radiography
- Original mathematical framework by Radon (1917)
- First X-ray CT scanner in 1972 by Hounsfield in collaboration with Cormack
- Nobel prize in Medicine in 1979

Godfrey N. Hounsfield with a medical scanner
(www.betterproductdesign.net)

Tomography “machines”

SOURCE + DETECTOR + SYSTEM FOR THE MULTI-ANGLE MEASUREMENT

3 different types of “machine” for X-ray tomography

Medical scanner

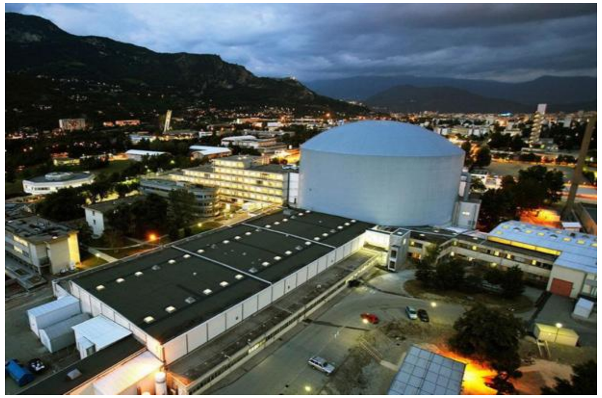
Laboratory microtomograph/3DXRM

Synchrotron

X-RAY TUBE

ACCELERATED ELECTRONS

2 types of sources for neutron tomography



Reactor source

Spallation source

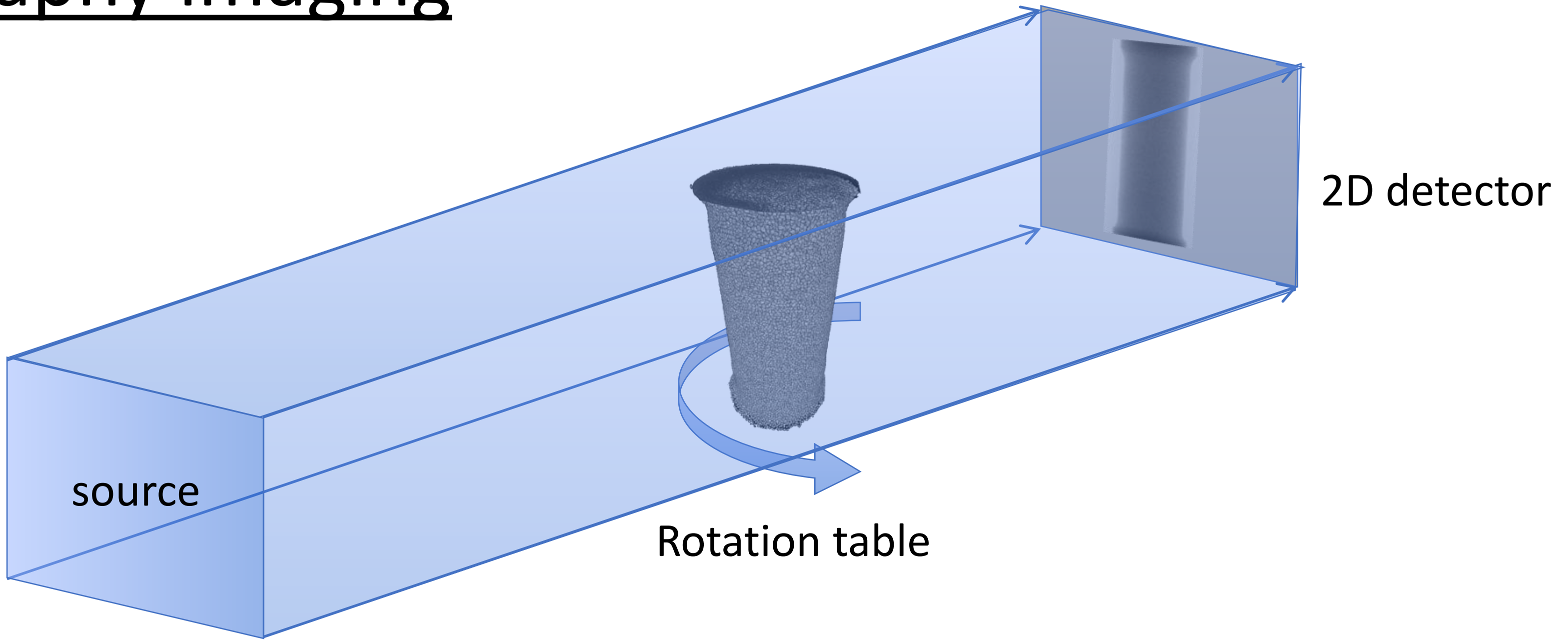
Tomography "machines": comparison

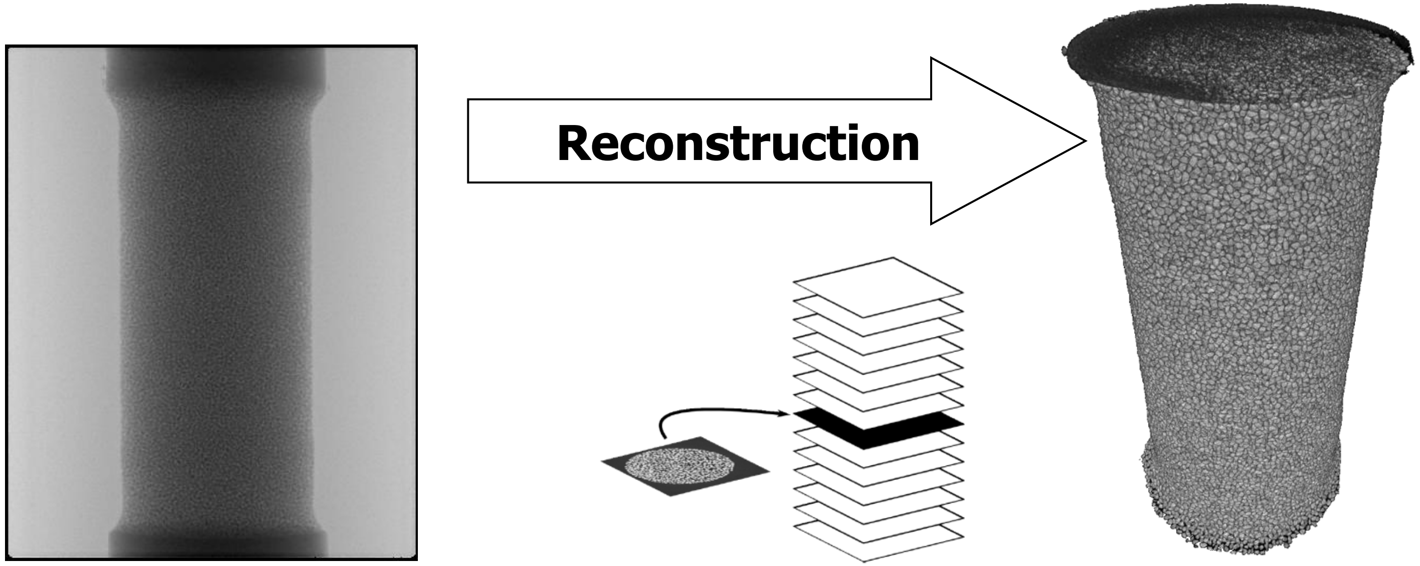
Type of scanner	Medical	Lab tomograph	Synchrotron	Neutron
Source	X-ray tube		Accelerated electrons	Reactor/spallation
Geometry beam	Fan or cone beam		Parallel beam	Semi-parallel beam
Resolution	100-500 µm	.5-100 µm	0.1-10 µm	1-100 µm
Object size	dm	cm	mm	cm
Scanning time	Seconds to min	Min to hour	Second to min	Min to hour

- Best resolution with lab tomographs and synchrotron.
- Best scanning time with medical tomographs and synchrotron.
- Synchrotron - Best conditions for slice reconstruction (i.e. parallel and monochromatic beam).
- Rapid advances are being made (30-50 nm some lab tompgraphs and <10 nm synchrotrons, but for VERY small samples)

Full field Tomography imaging

(Same principles for neutron tomography)

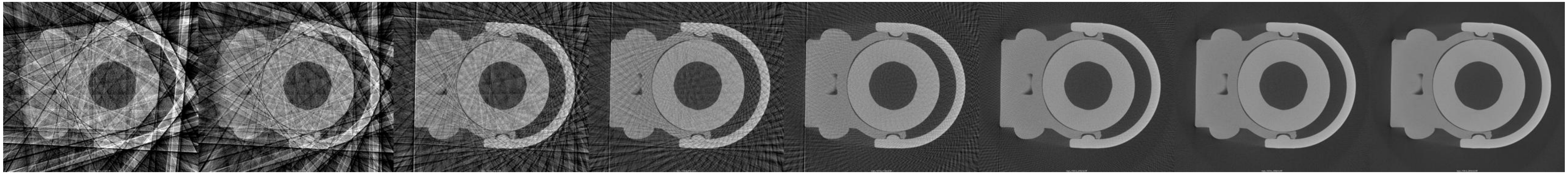




Principle of reconstruction

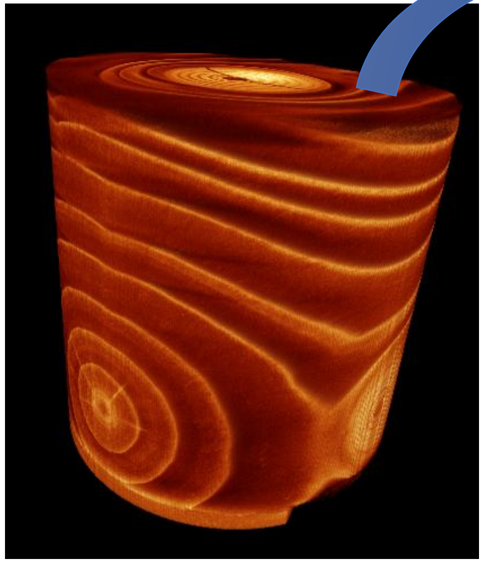
- Reconstruction of slices from different angle measurements with appropriate algorithm (analytic or algebraic methods), basic approach is back-projection:

11 15 30 60 120 240 480 960

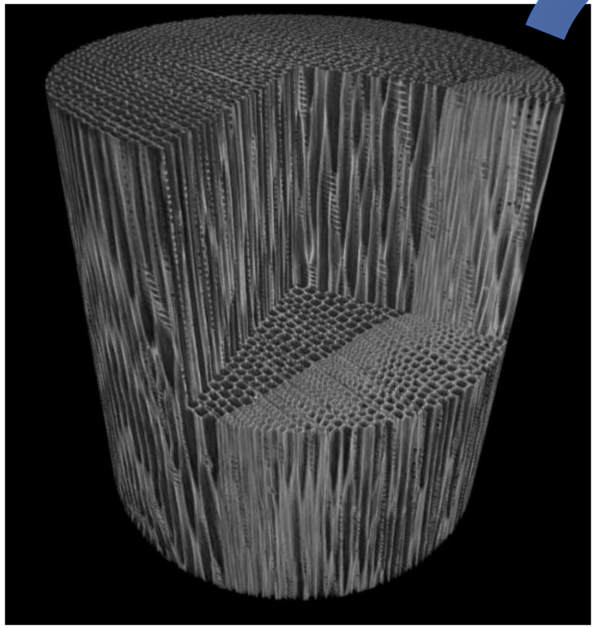


Multiscale

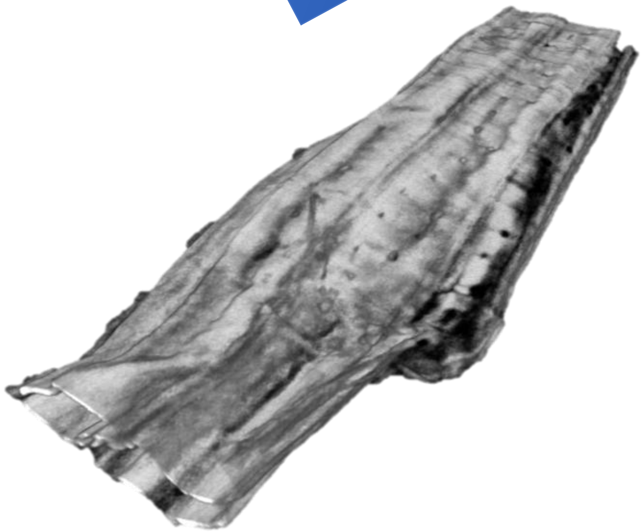
4D IMAGING LAB
A Lund university Infrastructure



Tomographic image of
Spruce wood
FoV diameter = 49 mm

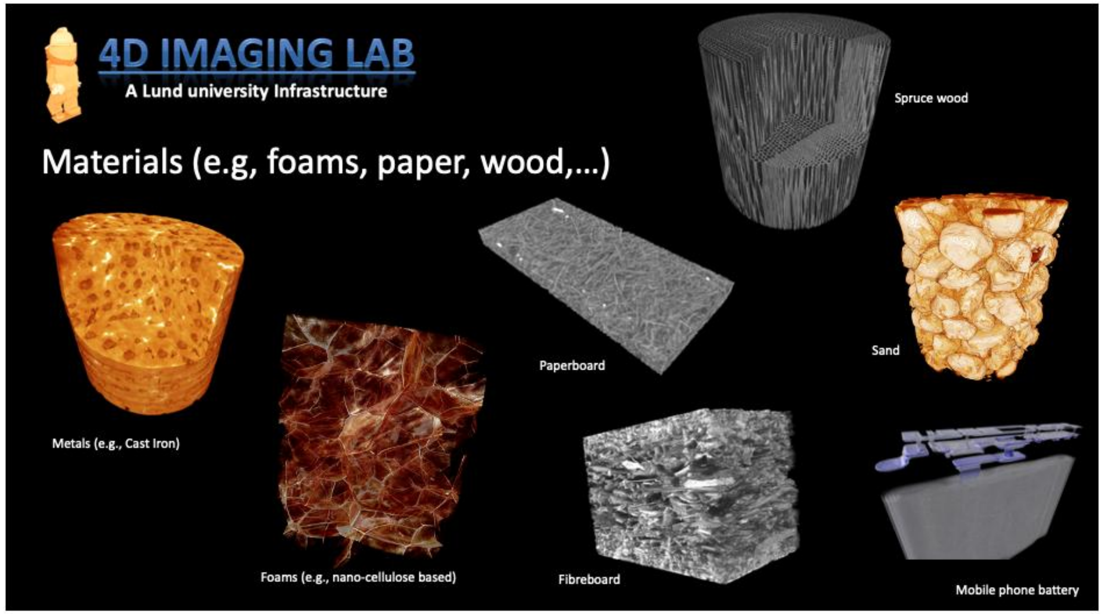


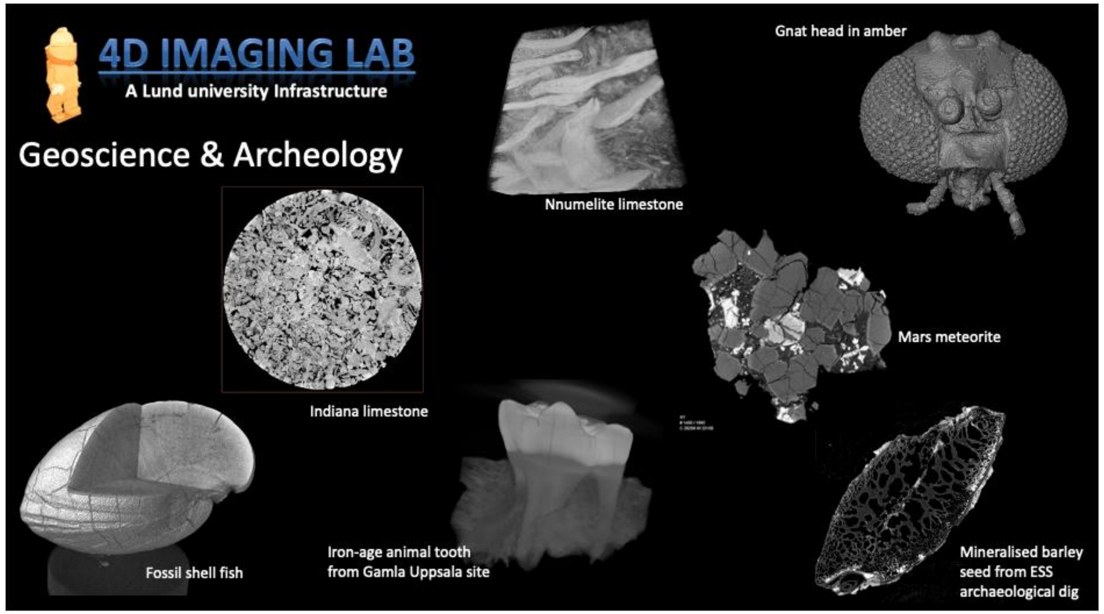
Tomographic image of a
sample of Spruce wood
FoV diameter = 1.5 mm

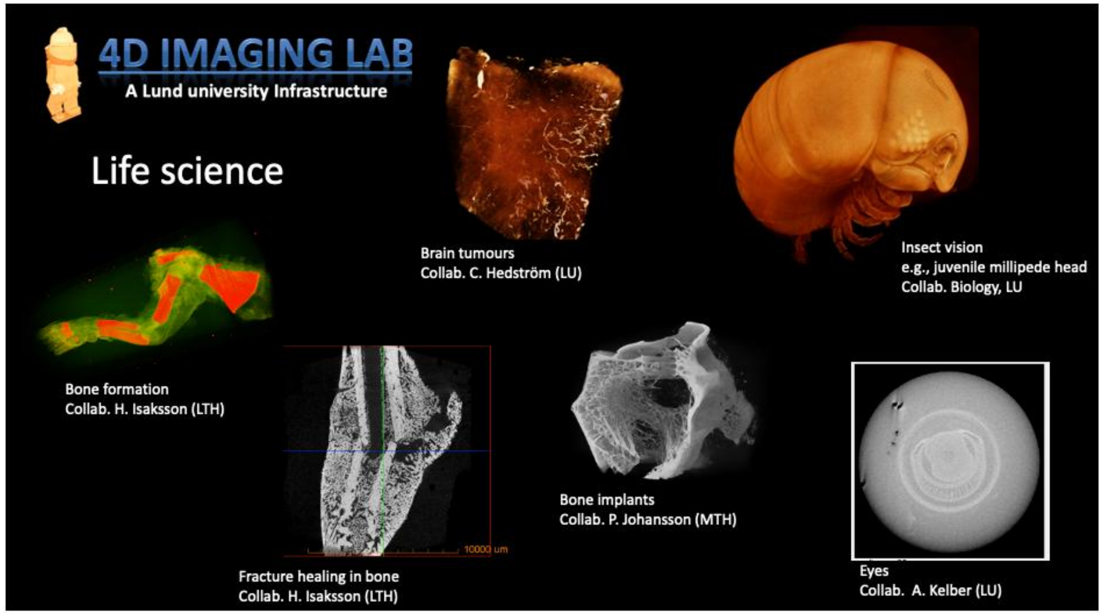


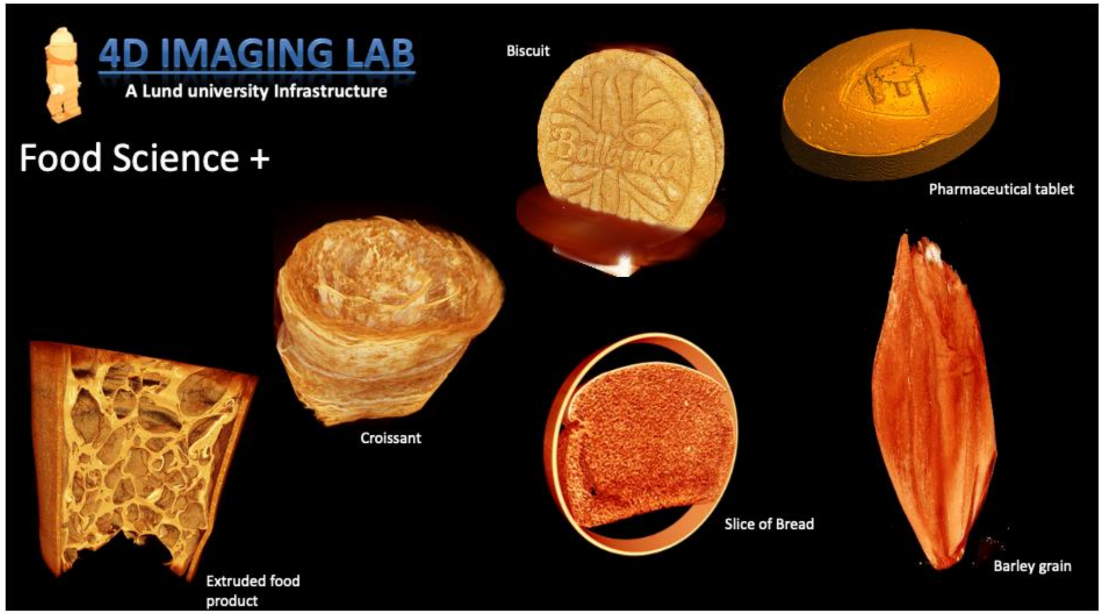
Tomographic image
of wood fibres
Voxel size = 300 nm
FoV = 300 microns

Multiple applications…



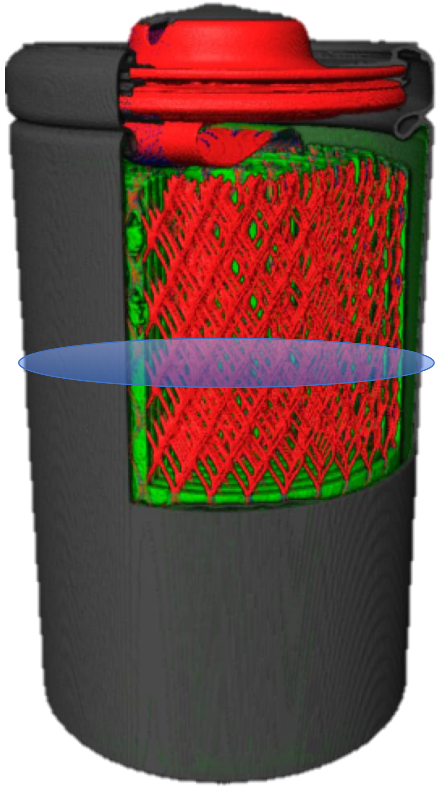


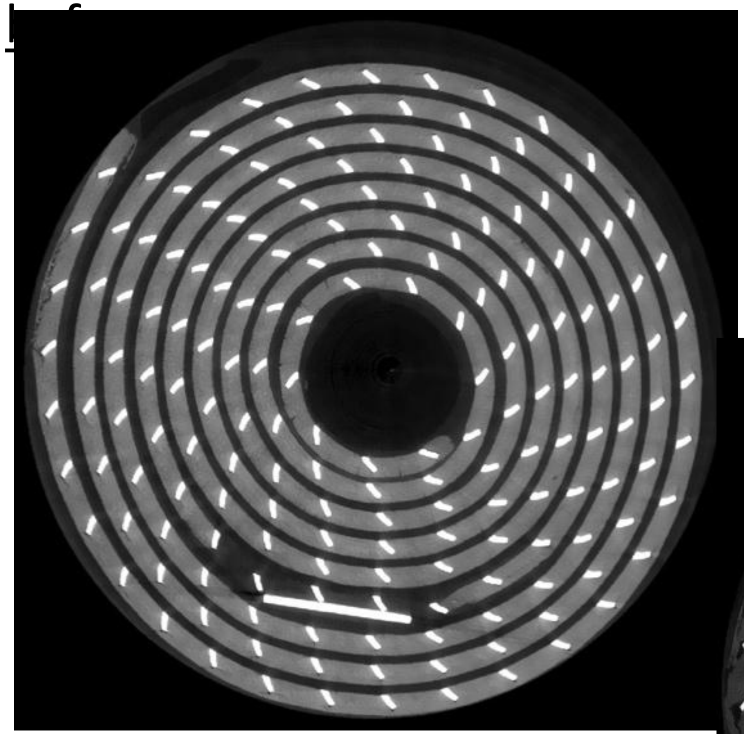


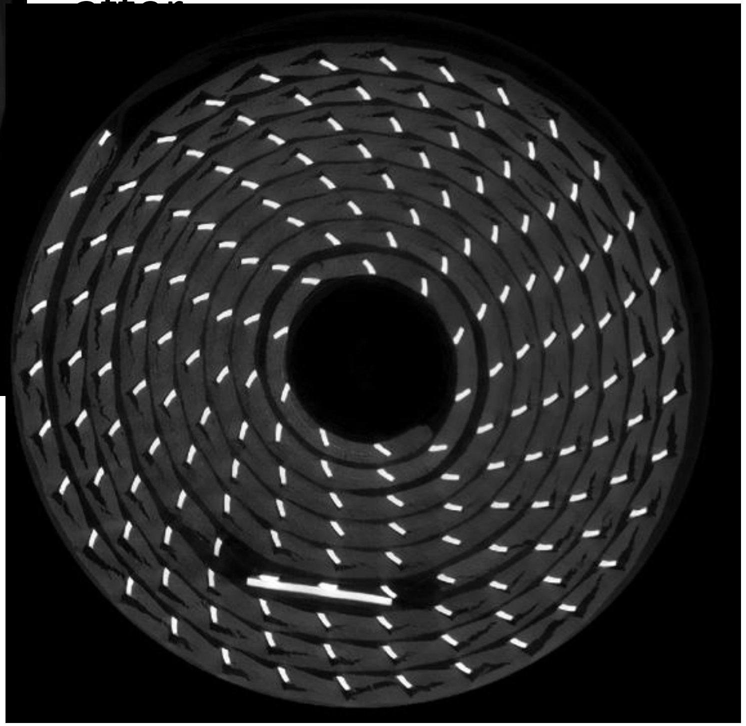


Imaging internal structures: batteries

Deformation due to charge /discharge of a CR2 Li-ion battery



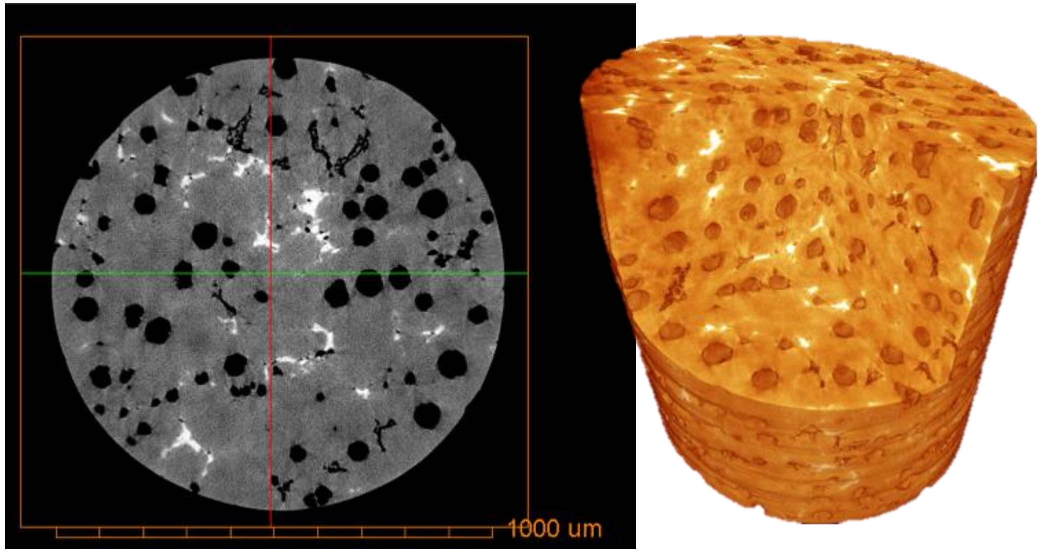




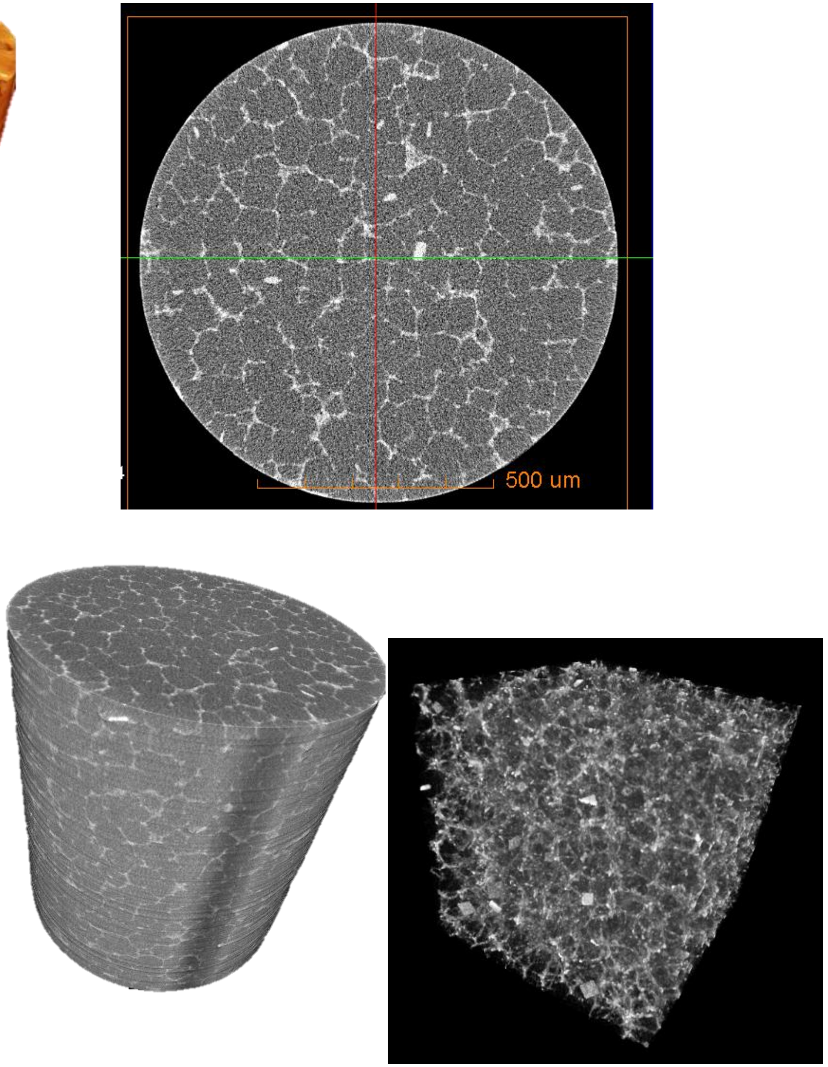
Finegan et al., 2016, Advanced Science

Imaging internal structures: metals

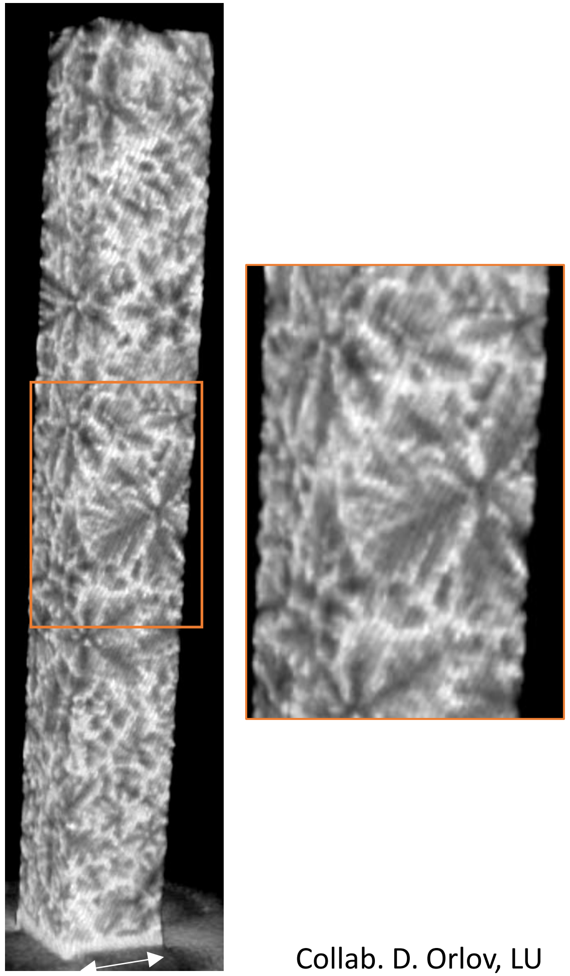
Cast iron



A205 Alumiunium alloy



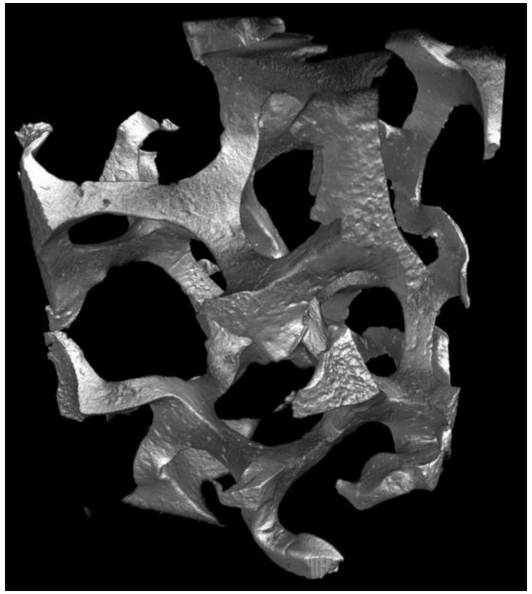
Magnesium alloy



1 mm

Collab. D. Orlov, LU

Aluminium foam

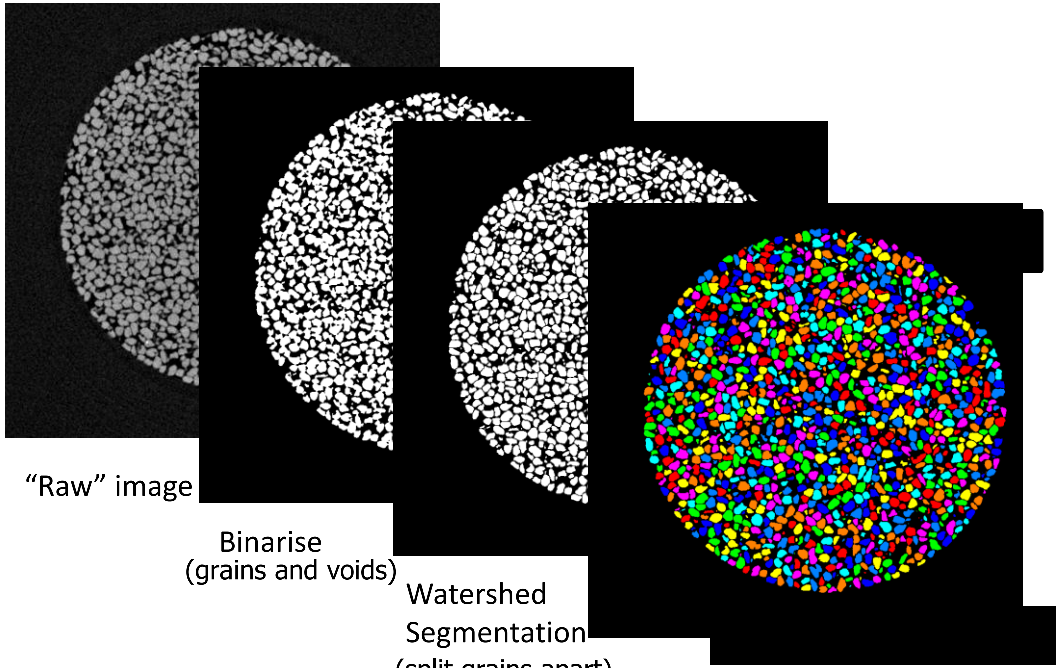


Collab. T. Sjögren, RISE

Beyond 3D images

Image Quantification

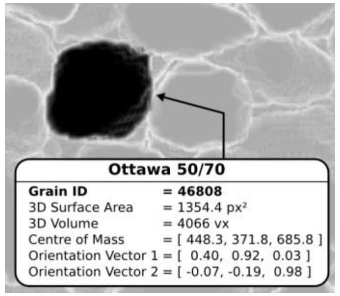
sand



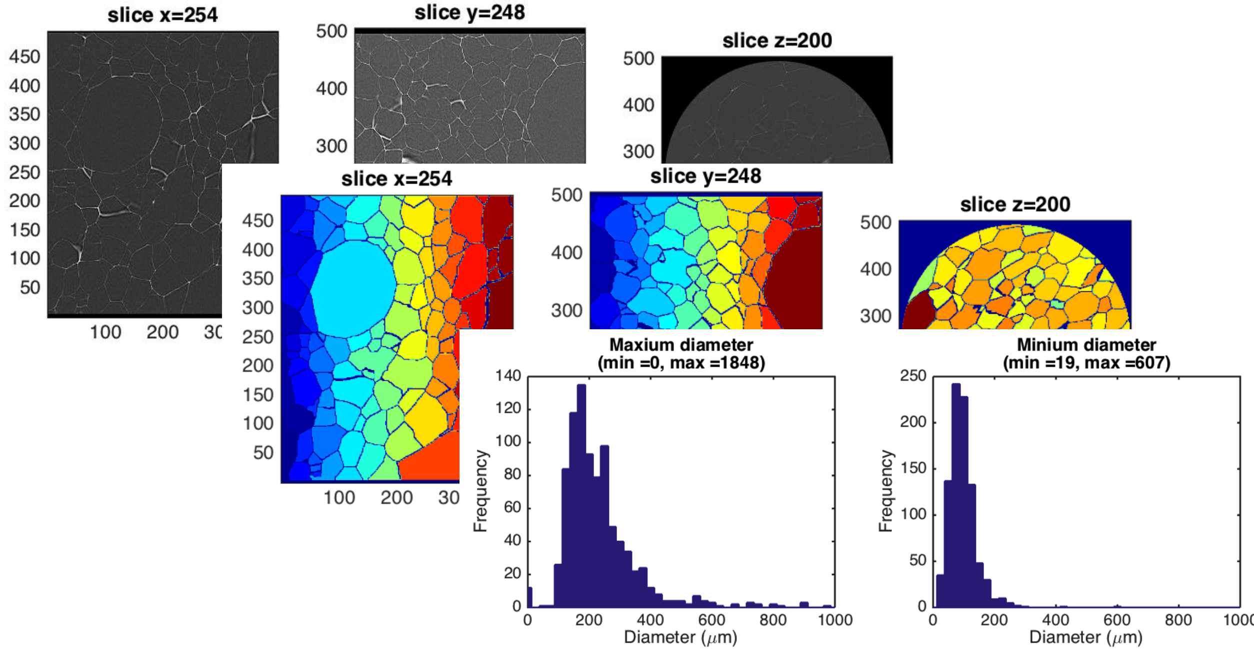
“Raw” image

Binarise
(grains and voids)

Watershed
Segmentation
(split grains apart)

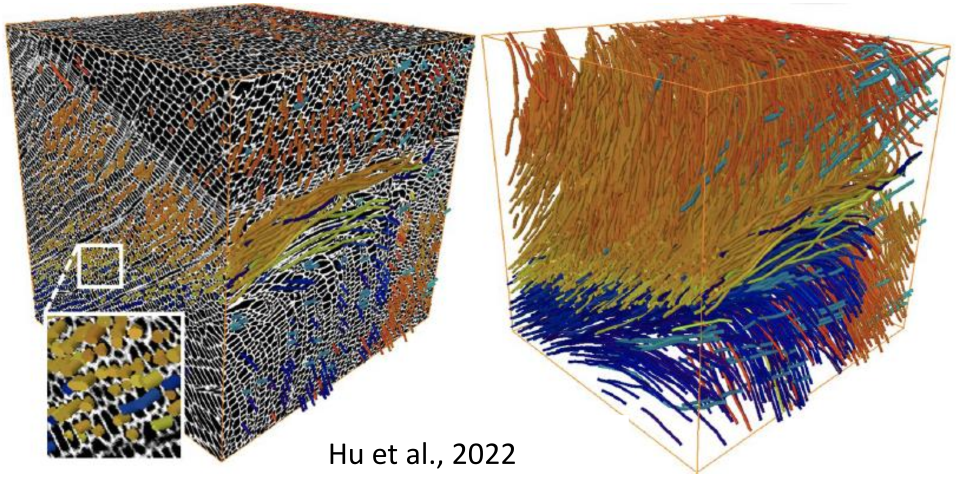


Cellulose foam



Gordeyeva_etal_2016

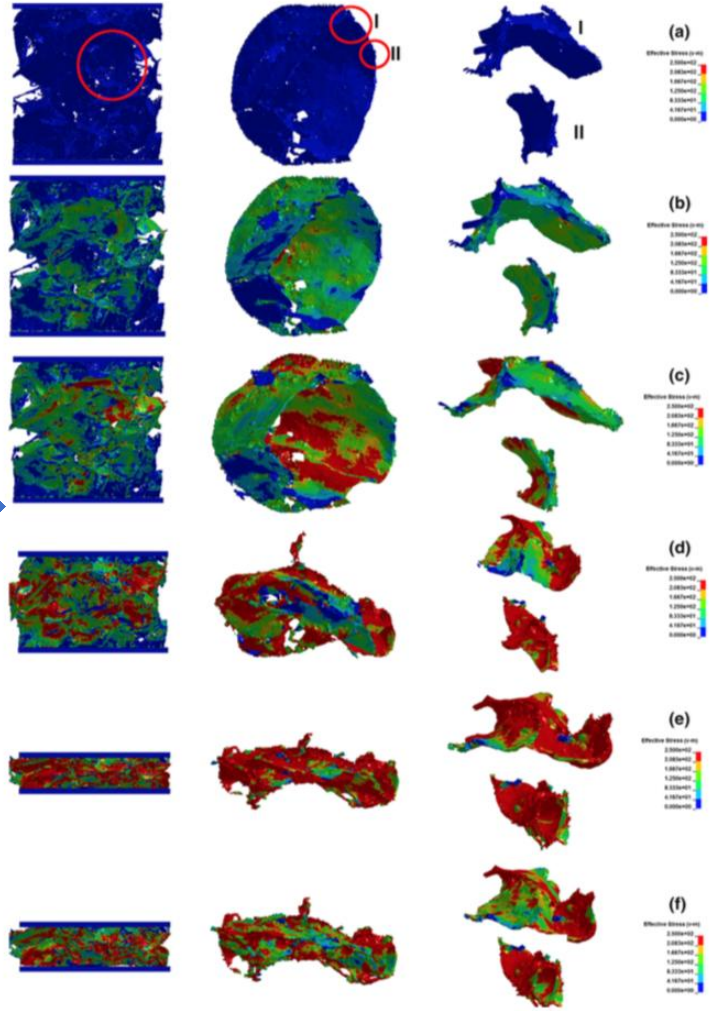
Wood fibre directions



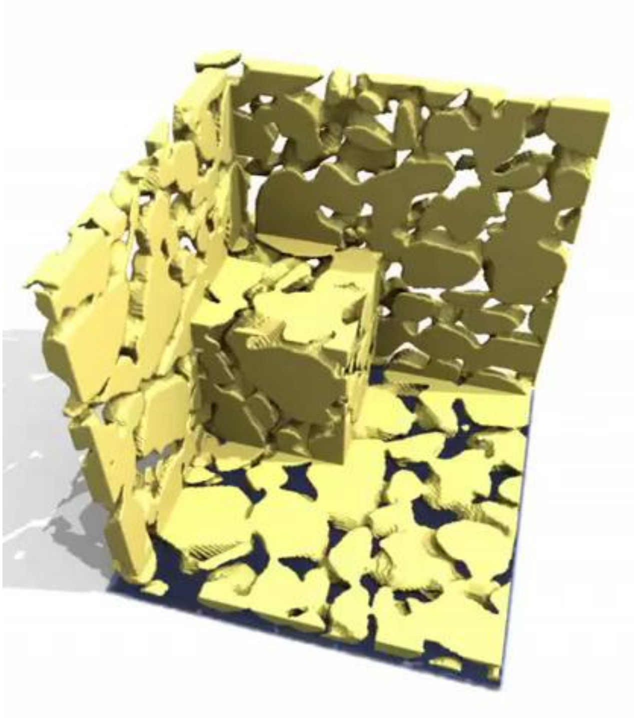
Hu et al., 2022

3D Images → models

Nanofibrillar cellulose foam
(Images from 4D Imaging Lab)

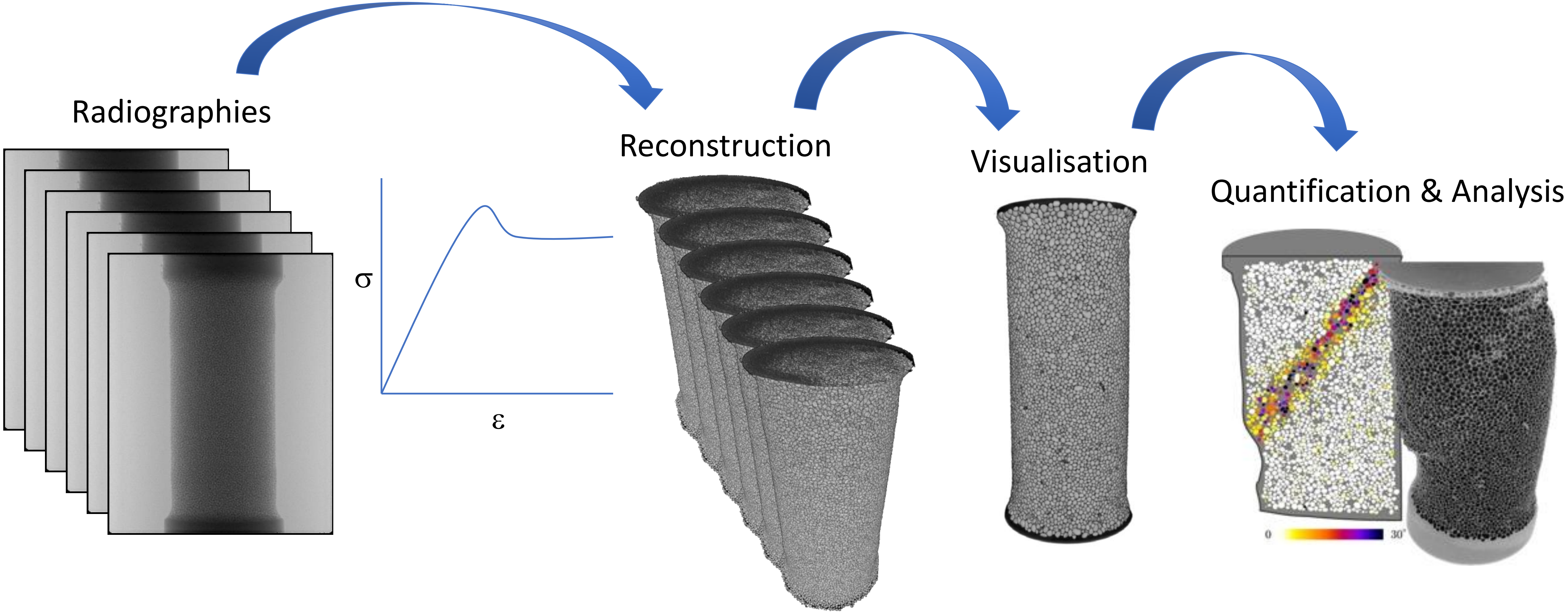


Srinivasa, Kulachenko , Karlberg, 2017, Cellulose



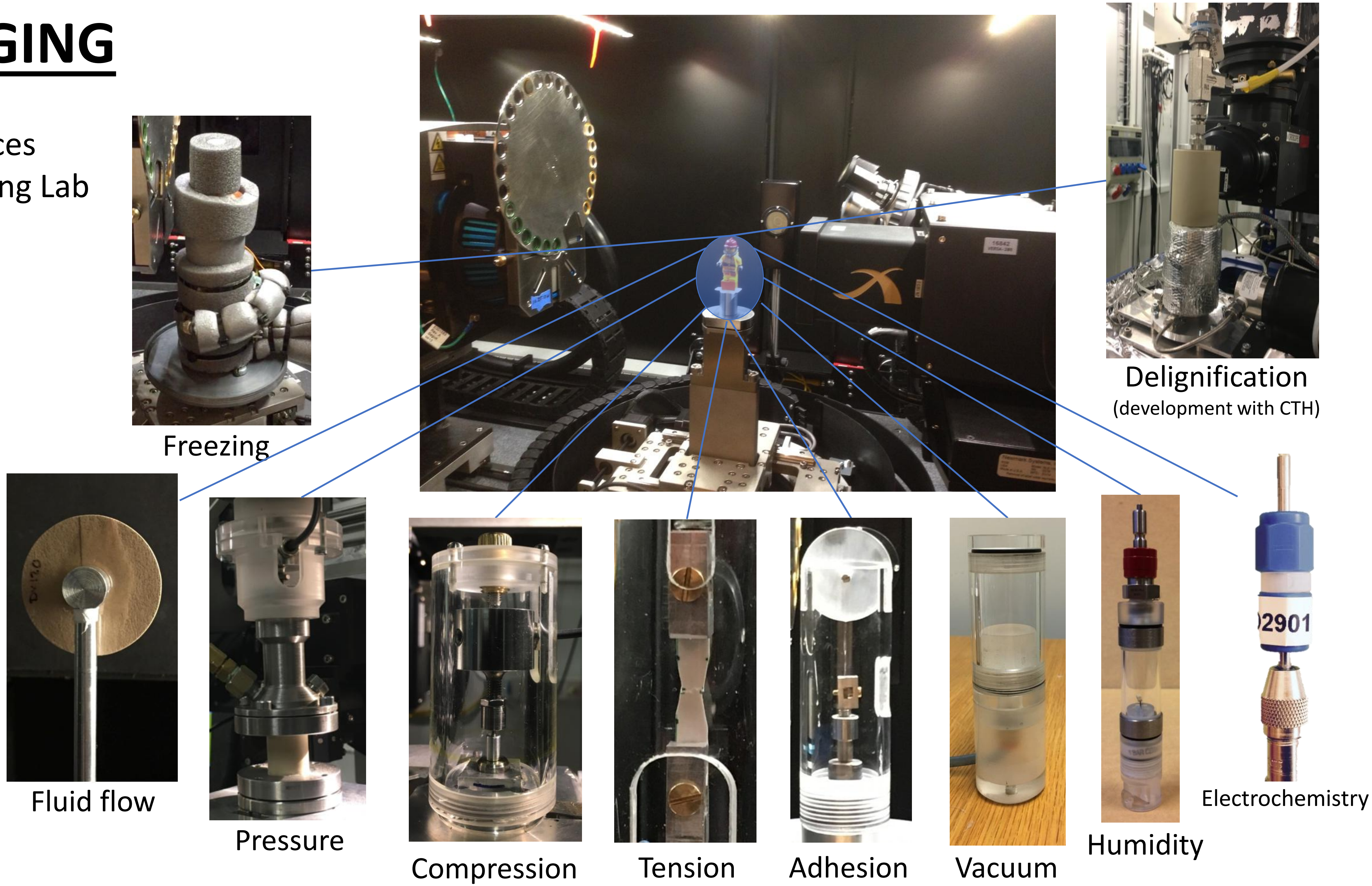
B. Ahrenholz, Youtube

4D IMAGING


Radiographies
σ
ε
Reconstruction
Visualisation
Quantification & Analysis
0
30°

4D IMAGING

In-situ devices
@ 4D Imaging Lab



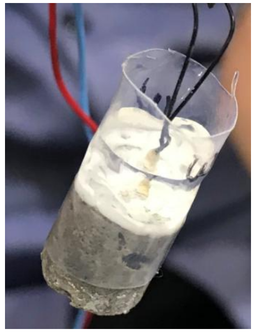
Examples of sample environments for 4D Imaging

Some design constraints

- Capture the physics
- Size
- Materials
  - Transparency
  - Activation (neutrons)

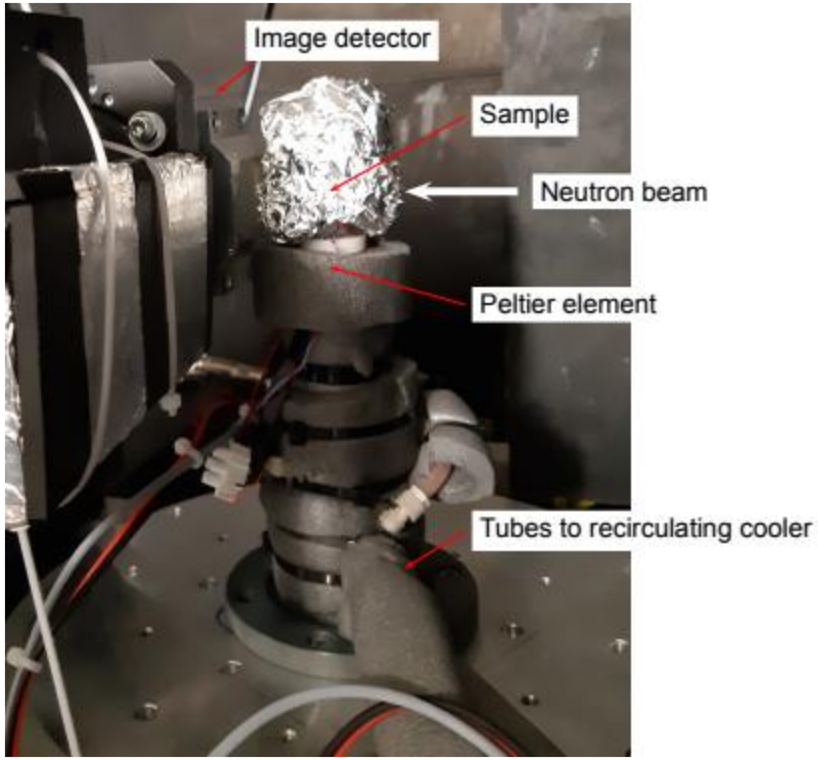
Deterioration of concrete

In-situ freeze-thaw cycling of a cement paste sample



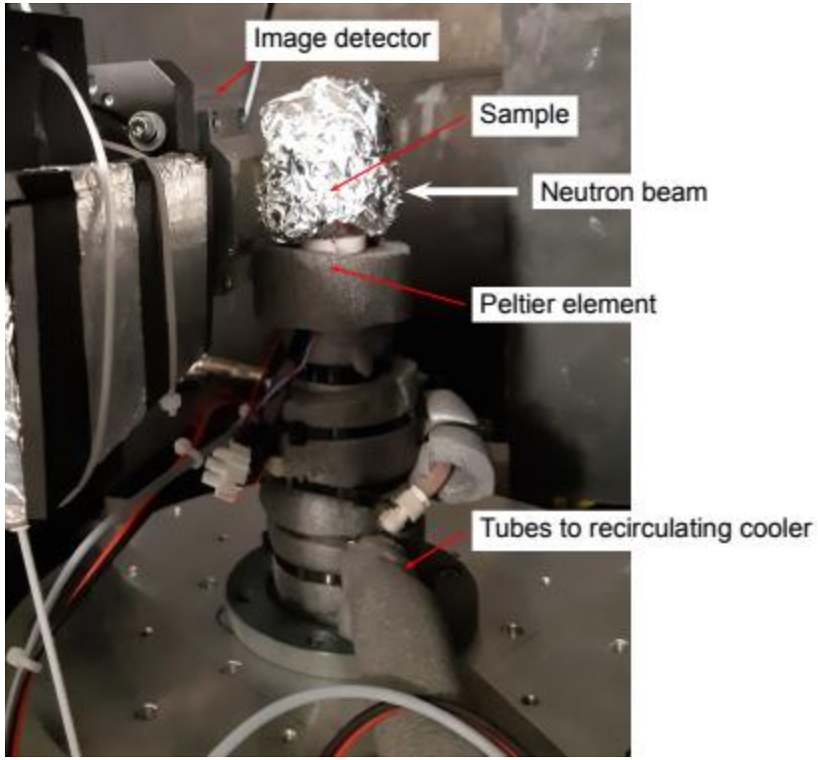
Material:

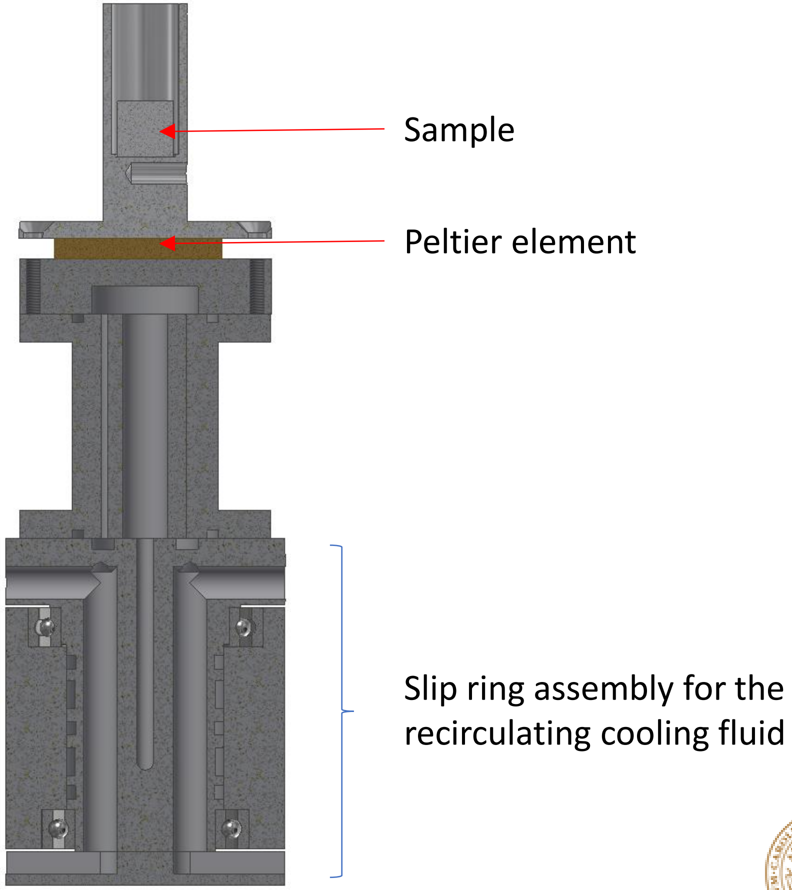
- D= 10 mm diameter, h= 10 mm
- w/c-ratio 0.40, 9% air
- Swedish commercial cement, standard sand
- Correlates to the quality of a bridge



- Dual-mode imaging of one vacuum saturated sample
- Voxel size: 7µm for neutrons 14µm for X-rays (image two samples simultaneously with X-rays)
- Duration, approximately 3 hours for neutrons and 30 minutes for x-rays
- 3 temperature cycles (+20 to -13°C)

Deterioration of concrete - measurements at ILL

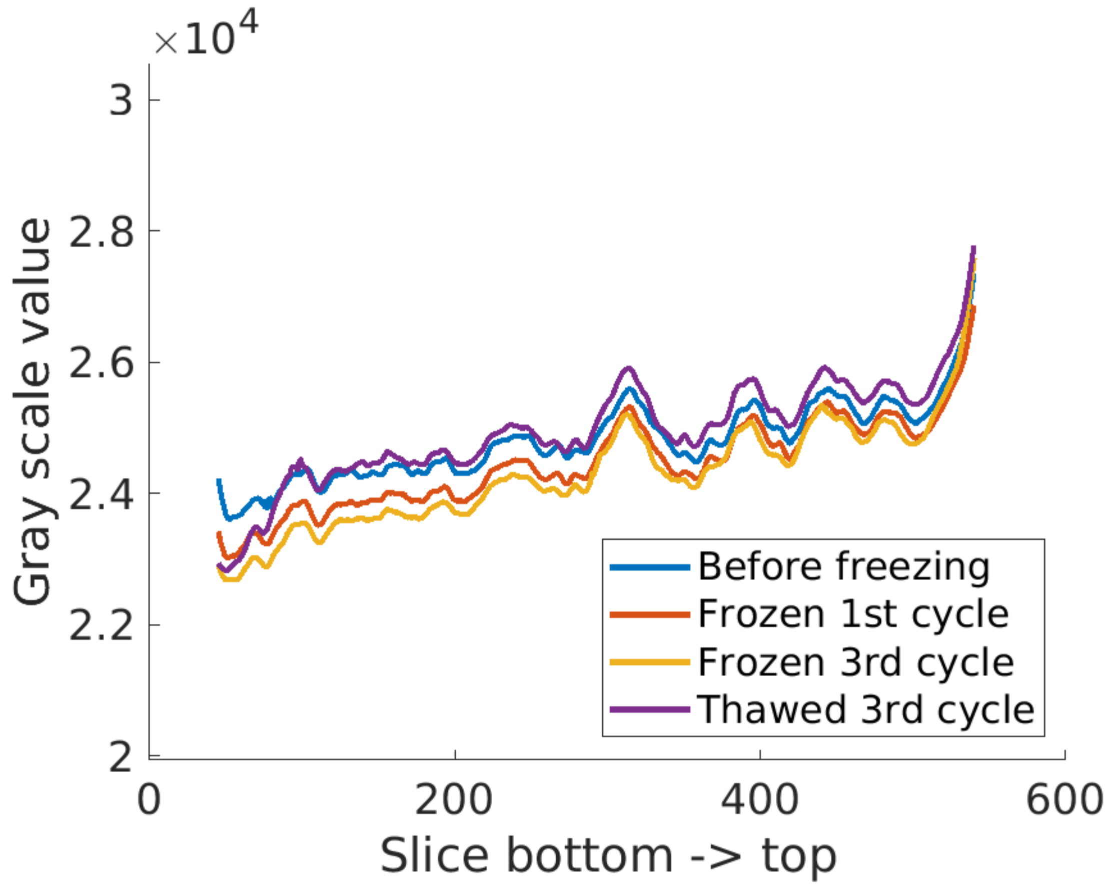




LUND UNIVERSITY

MALMÖ UNIVERSITY

Results – Freeze-thaw



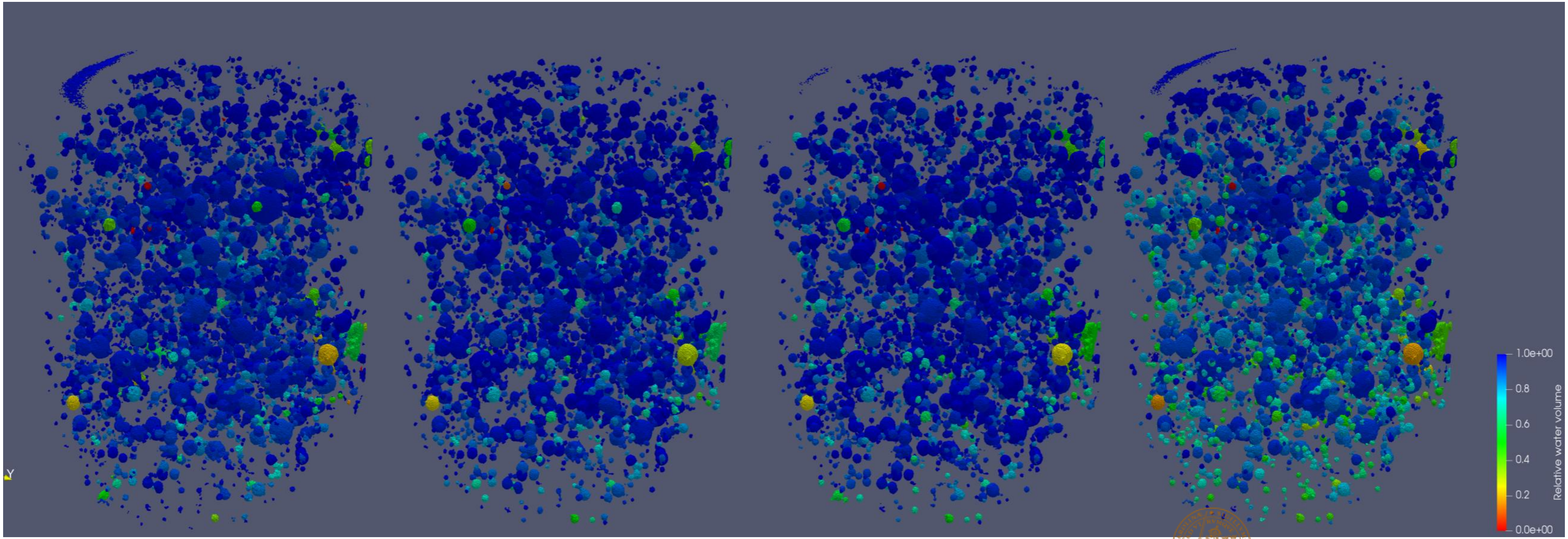
Gray scale value change:

- Increasing water content ↑
- Frozen H_20 ↓*

*Ref: Biesdorf et al. *Physical review letters* 112.24 (2014)

Relative water volume in the pores – in frozen and thawed state

Before freezing | Frozen 1st cycle | Frozen 3rd cycle | Thawed 3rd cycle



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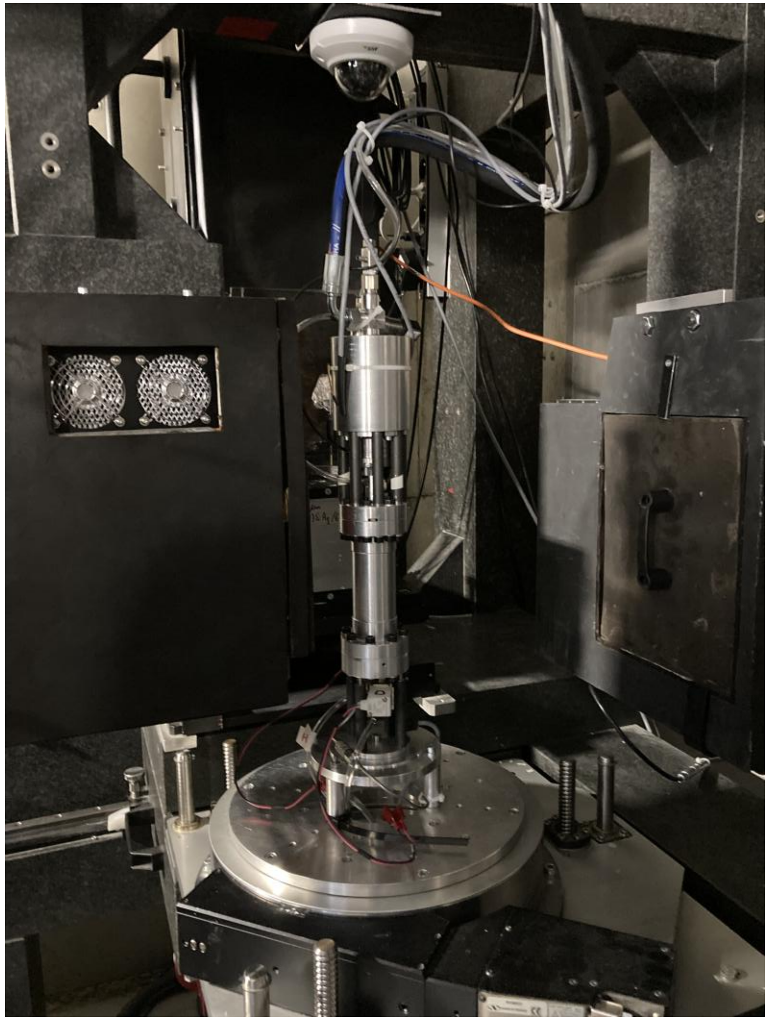
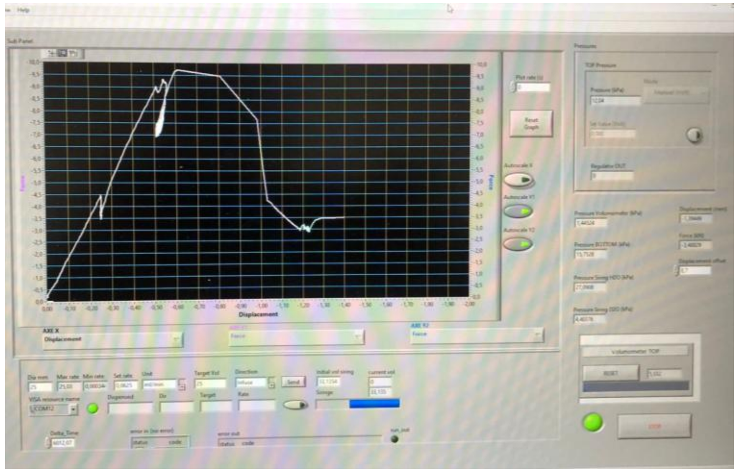
In-situ coupled hydro-mechanical experiments on rocks with x-ray and neutron tomography

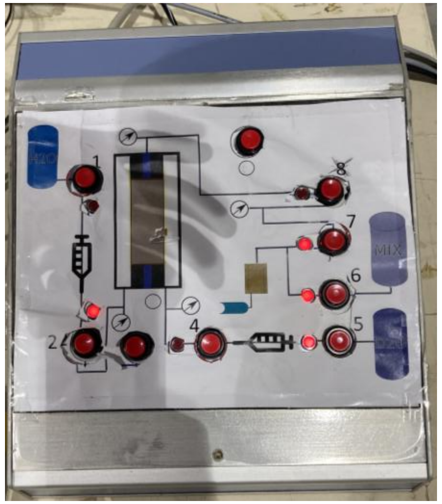
In-situ cell (capable of P_C < 35 Mpa)



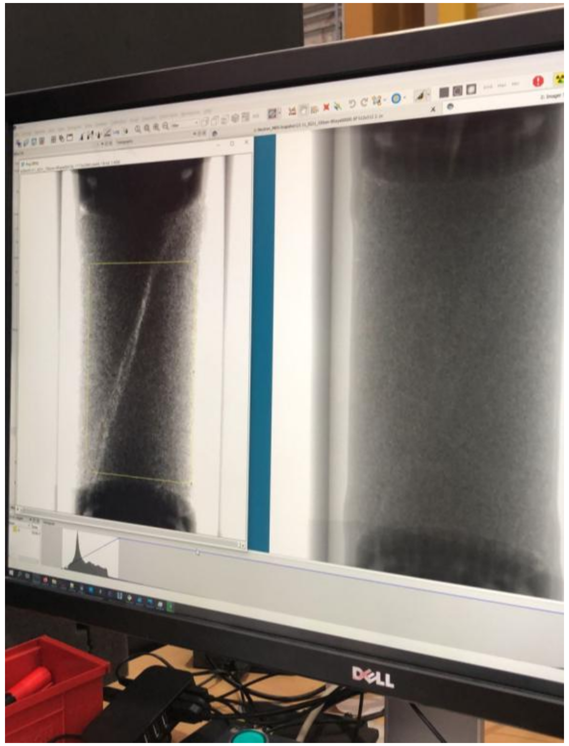
Triaxial loading: 2 tests (P_C = 1MP & 10MPa)



Hydraulic testing



Neutron & X-ray tomography



Neutron voxel size 170µm
X-ray voxel size 43µm

PhD F. Vieira Lima, Lund U.

In-situ coupled hydro-mechanical experiments on rocks with x-ray and neutron tomography

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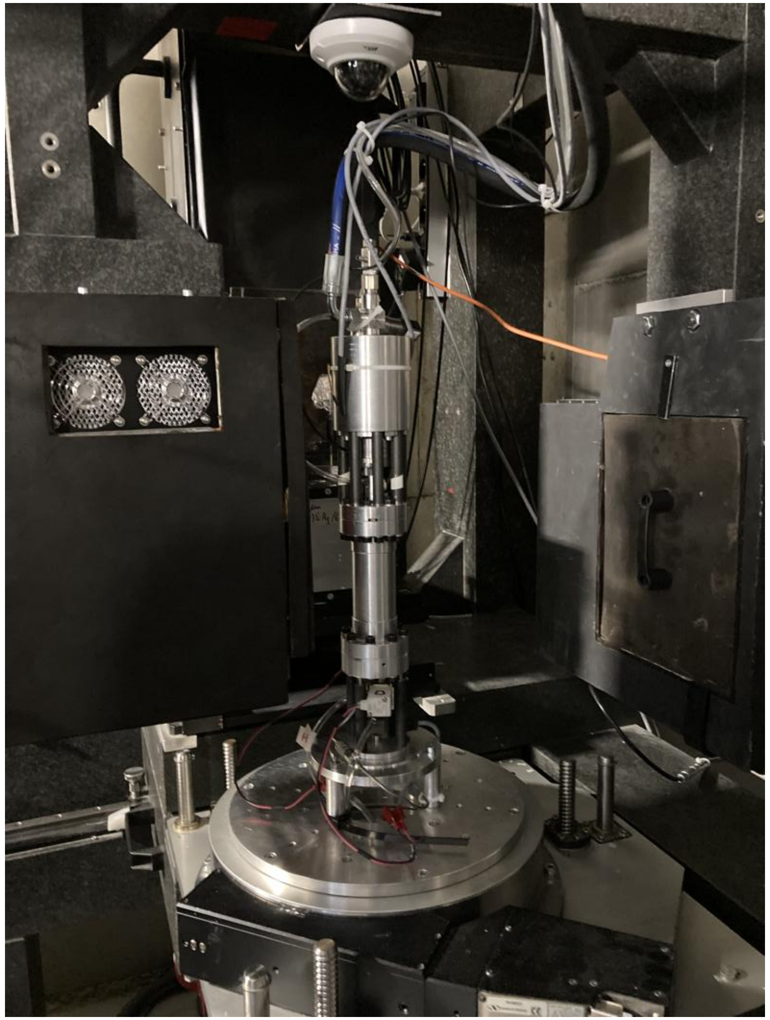
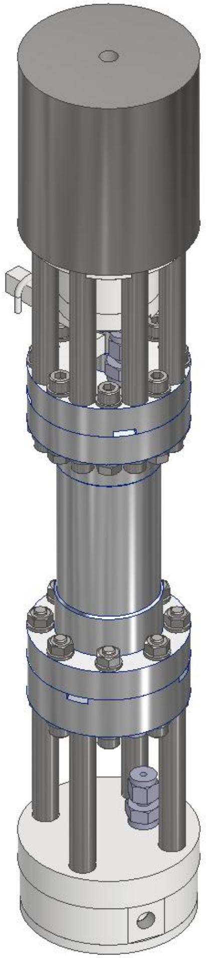
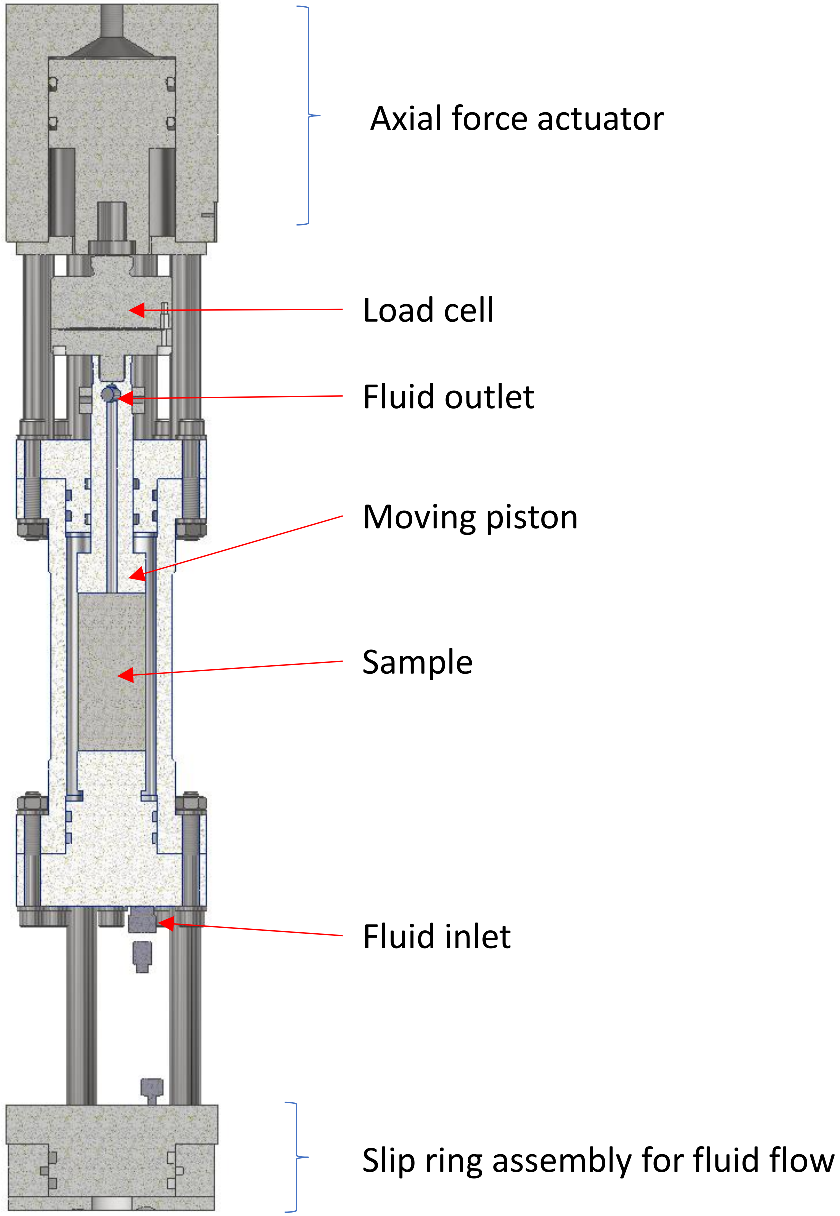
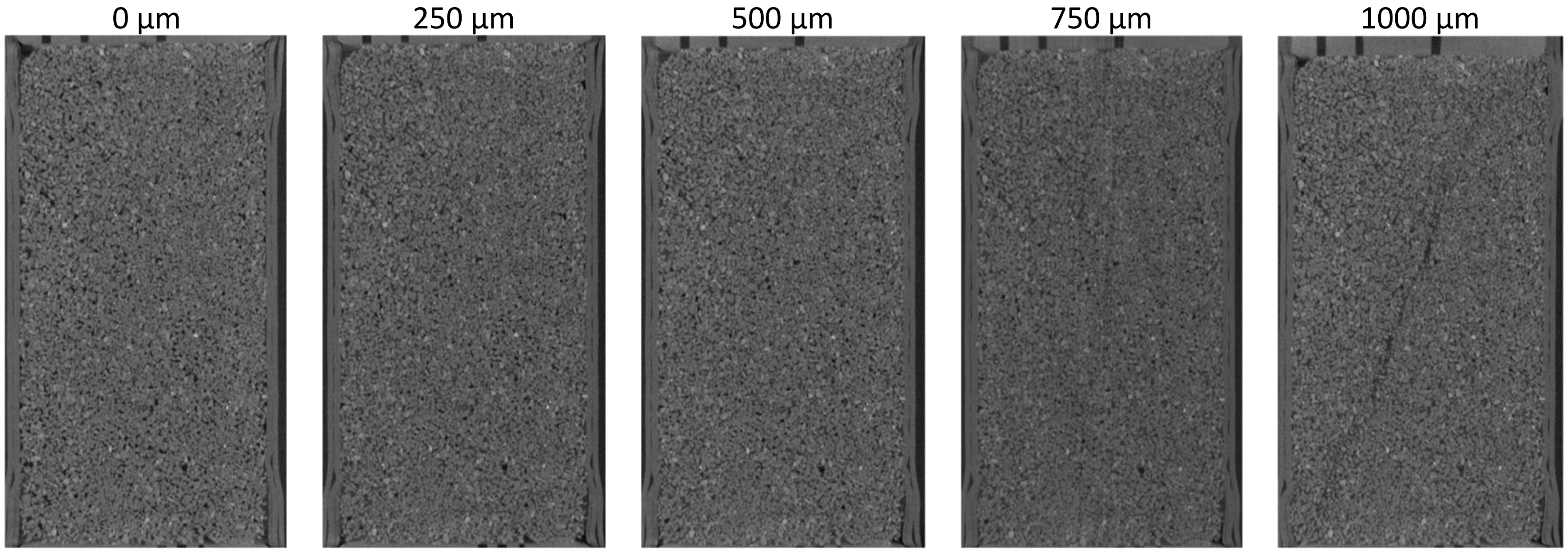






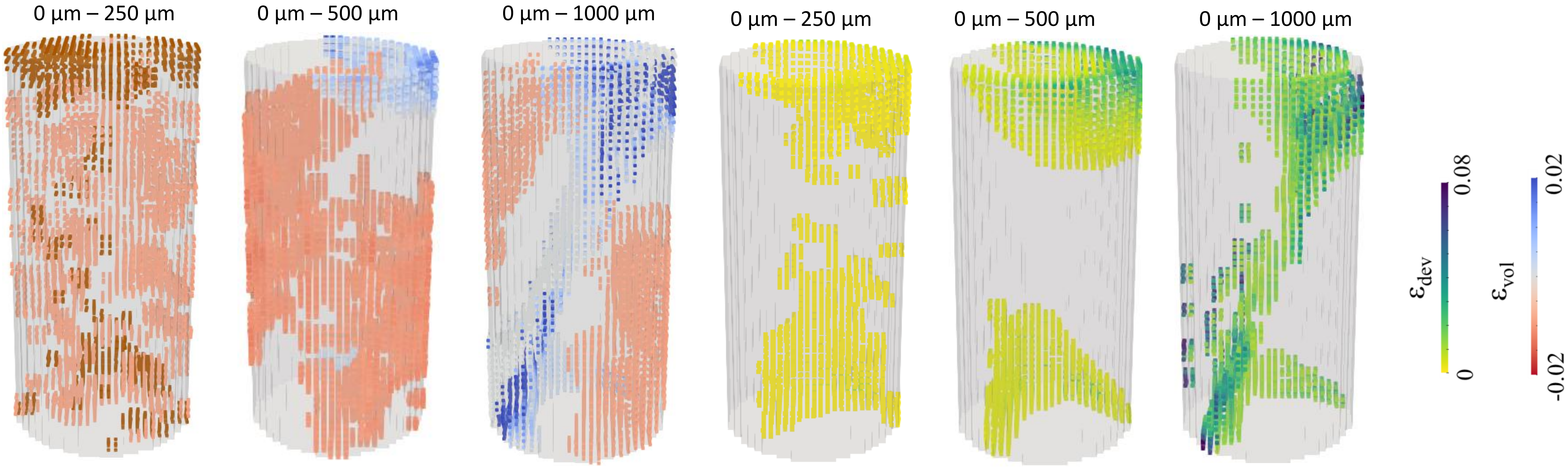
Full in-situ triaxial testing with rapid neutron tomography and grain-resolving x-ray tomography



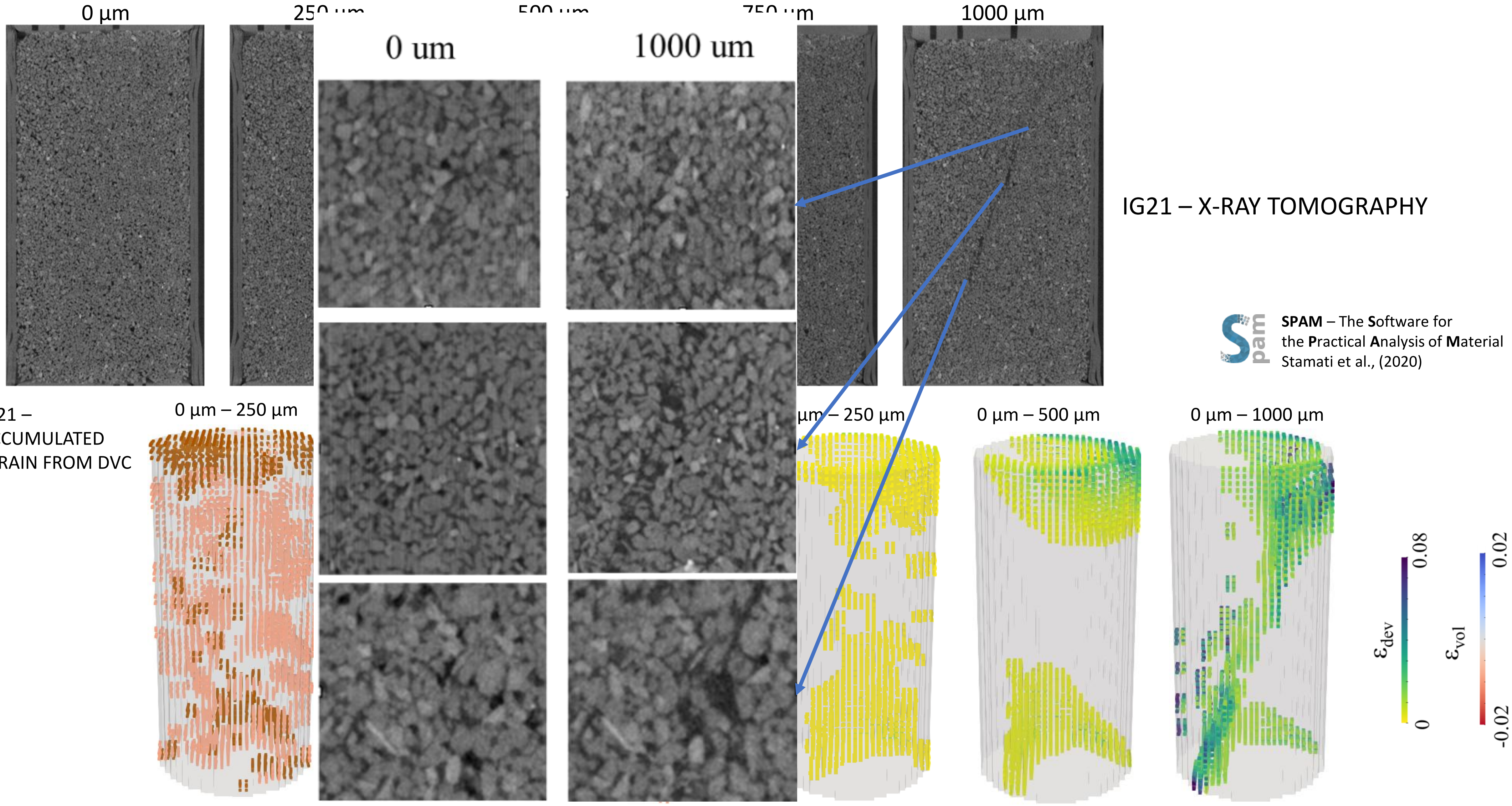
IG21 – X-RAY TOMOGRAPHY

SPAM – The **S**oftware for the **P**ractical **A**nalysis of **M**aterial
Stamati et al., (2020)

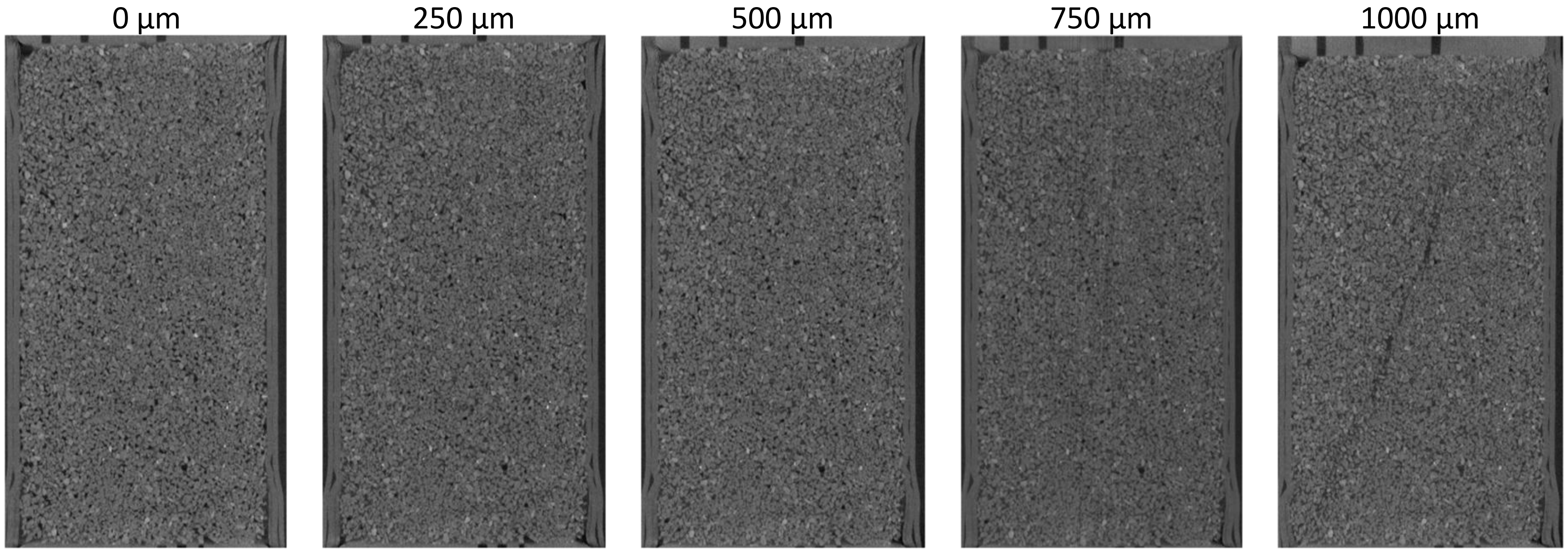
IG21 – ACCUMULATED STRAIN FROM DVC

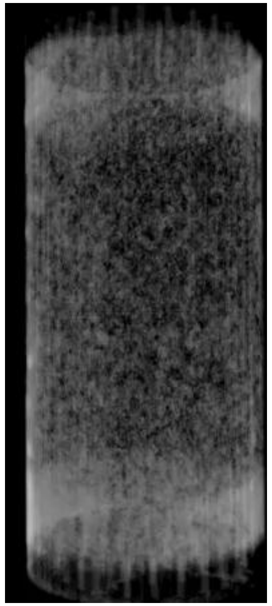


Full in-situ triaxial testing with rapid neutron tomography and grain-resolving x-ray tomography

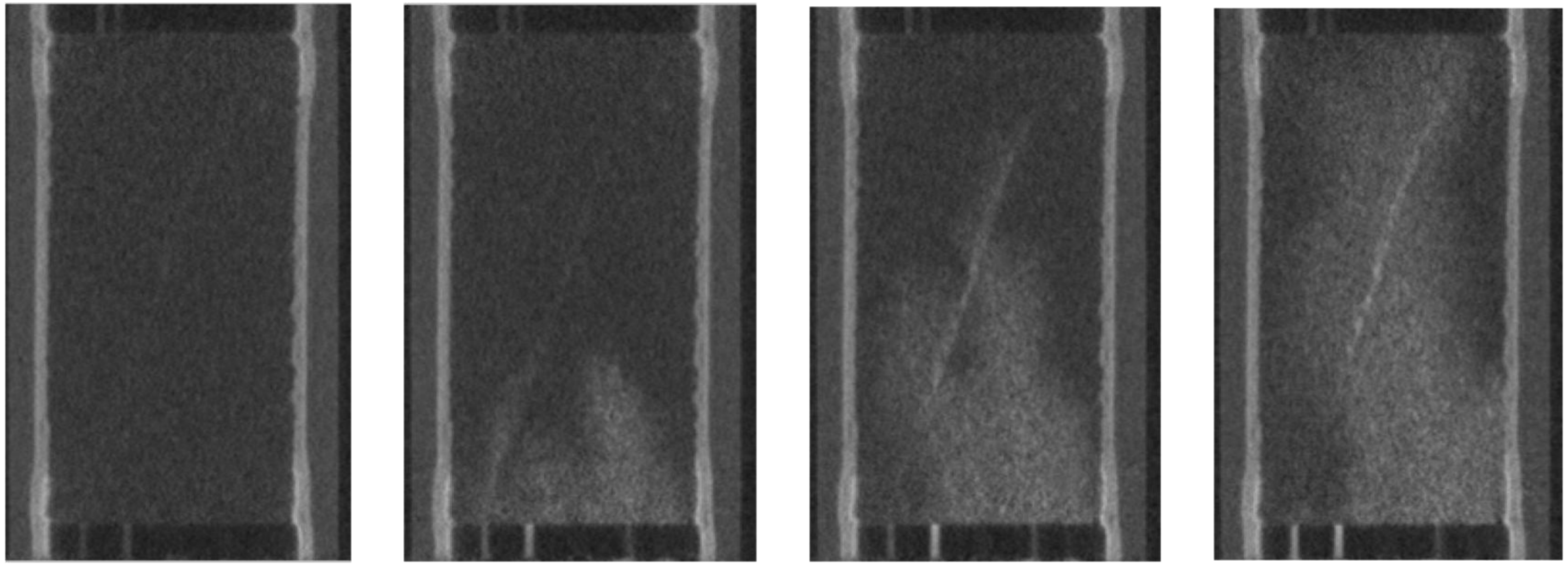


Full in-situ triaxial testing with rapid neutron tomography and grain-resolving x-ray tomography

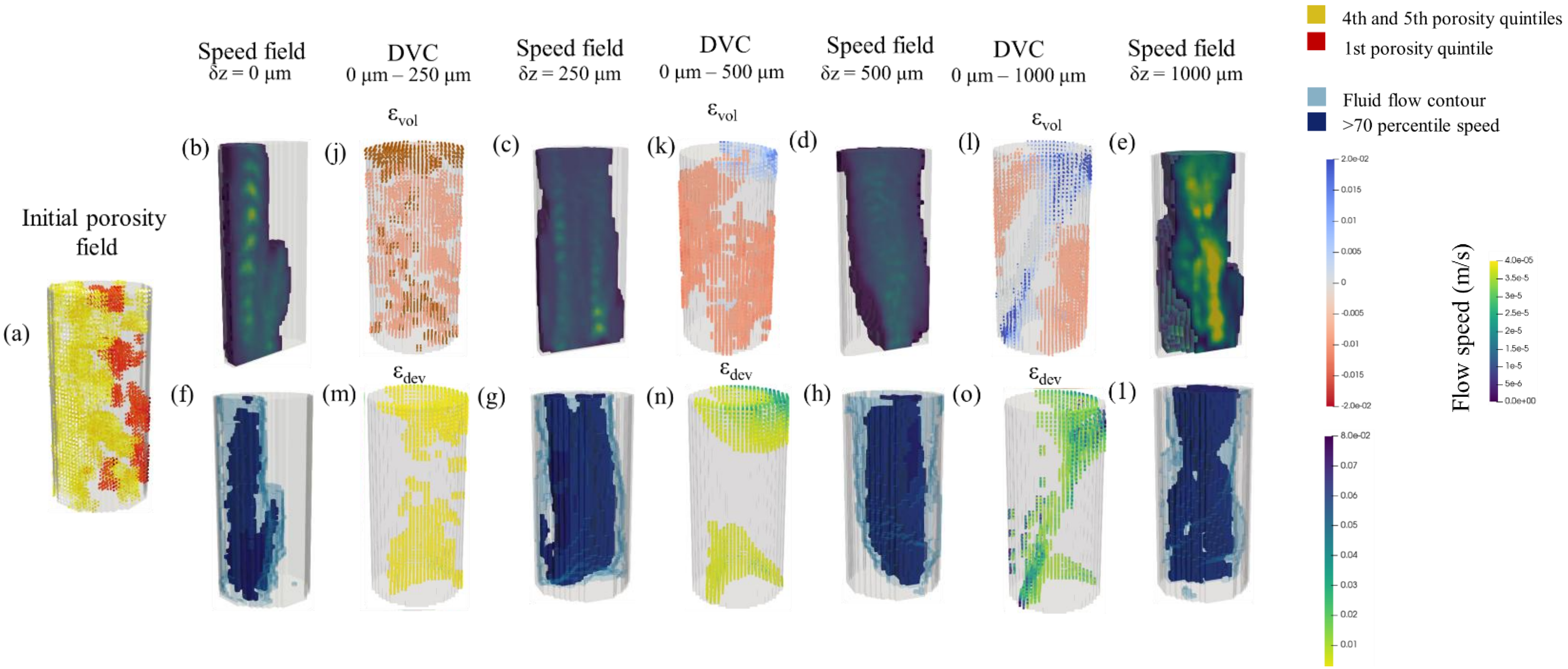




IG21 – FLOW H_2O INTO D_2O
Rapid neutron tomographies at final load step
(45 s per tomography, 170 µm voxel size)
(selected images shown)



Fluid flow evolution vs deformation – P_C = 1 MPa

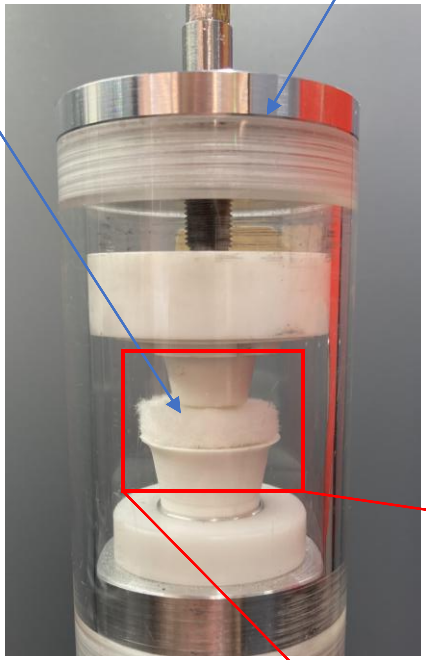


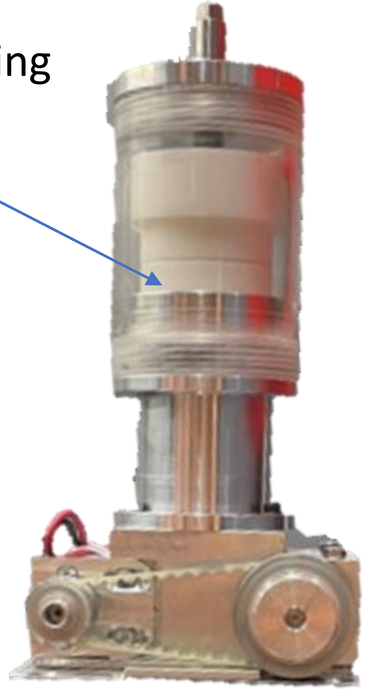
Towards next generation packaging materials with dry fibre forming

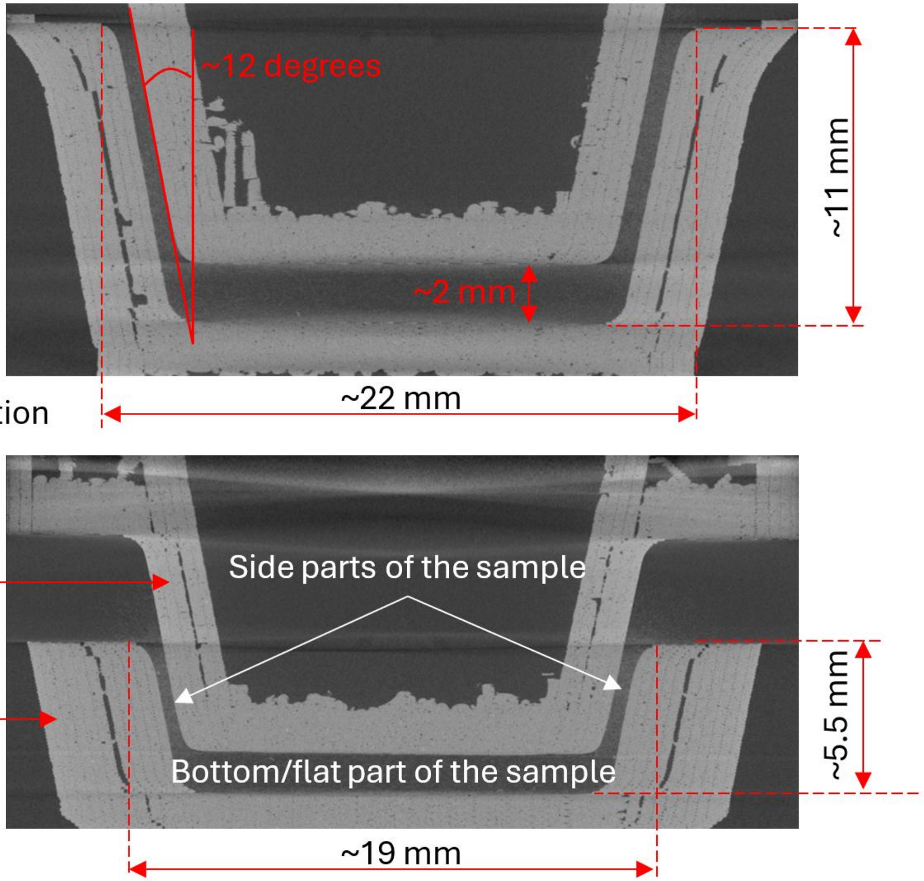
Cylindrical ~ Φ 30 × 7 mm

In-situ loading device

Pure cellulose fibers





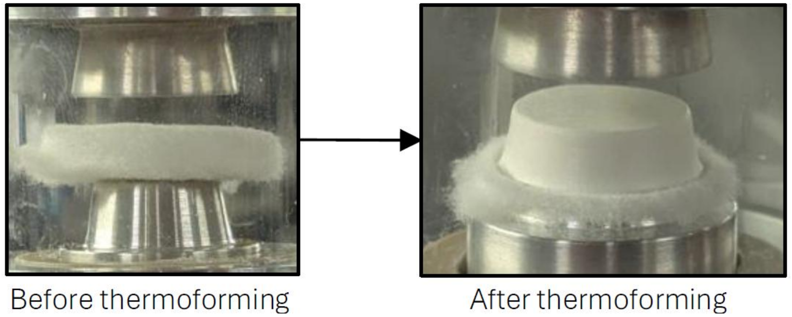


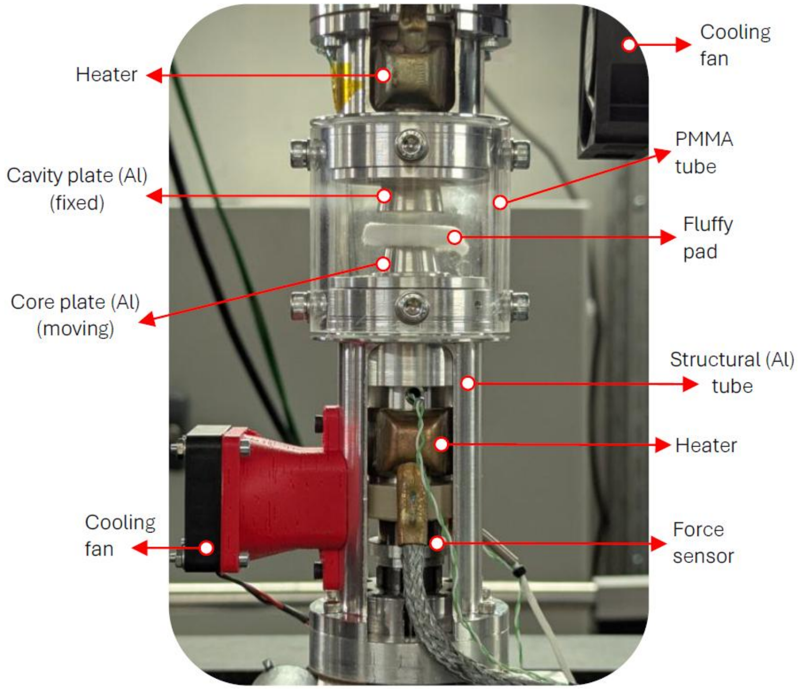
Deep mold			
200N	500N	1000N	2000N

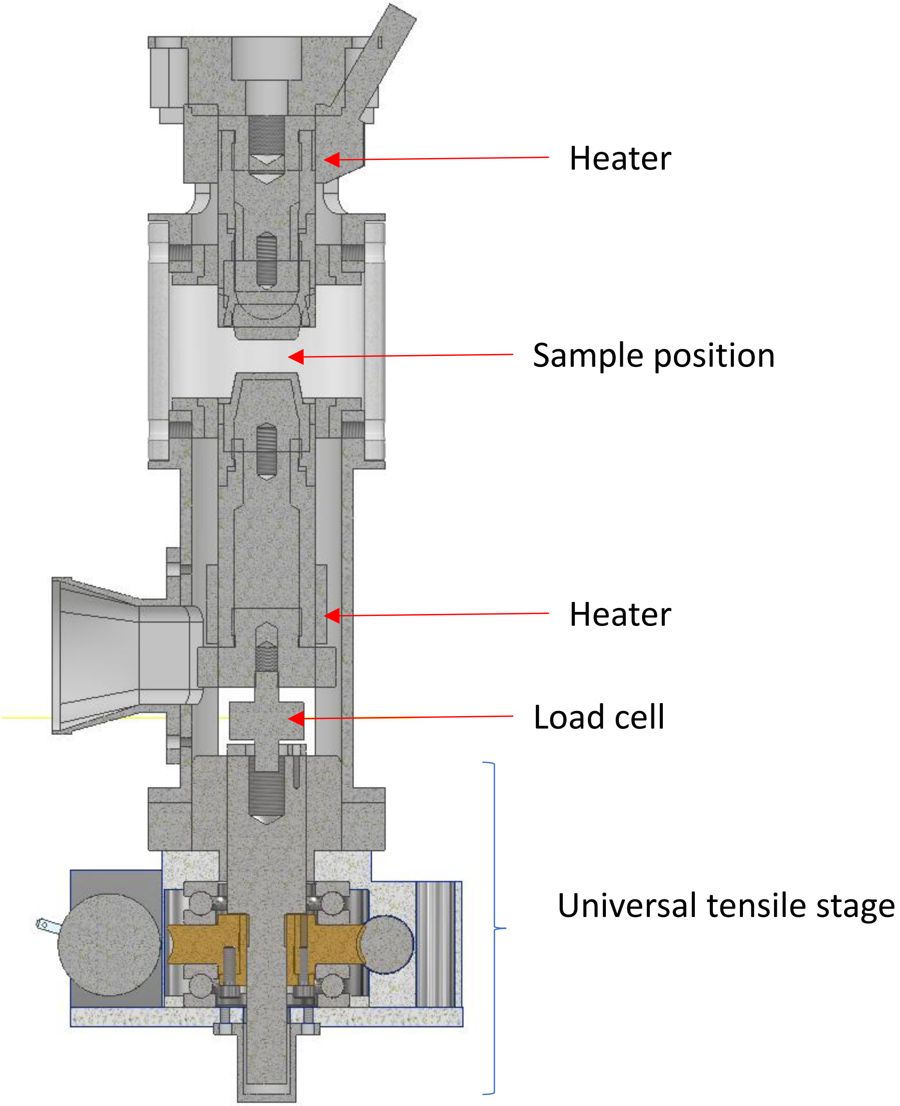
Shallow mold			
200N	600N	1200N	1800N

Towards next generation packaging materials with dry fibre forming

- *fluffy pads → 3D cups*



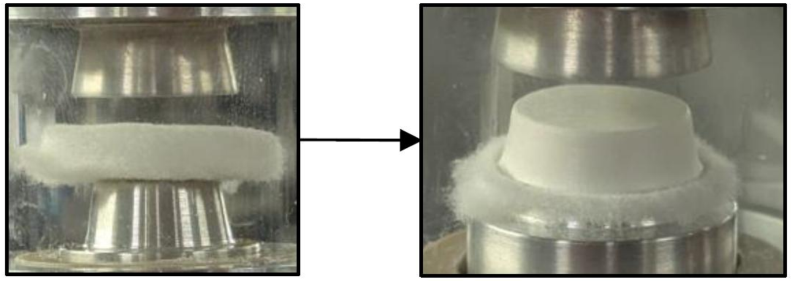




Towards next generation packaging materials with dry fibre forming

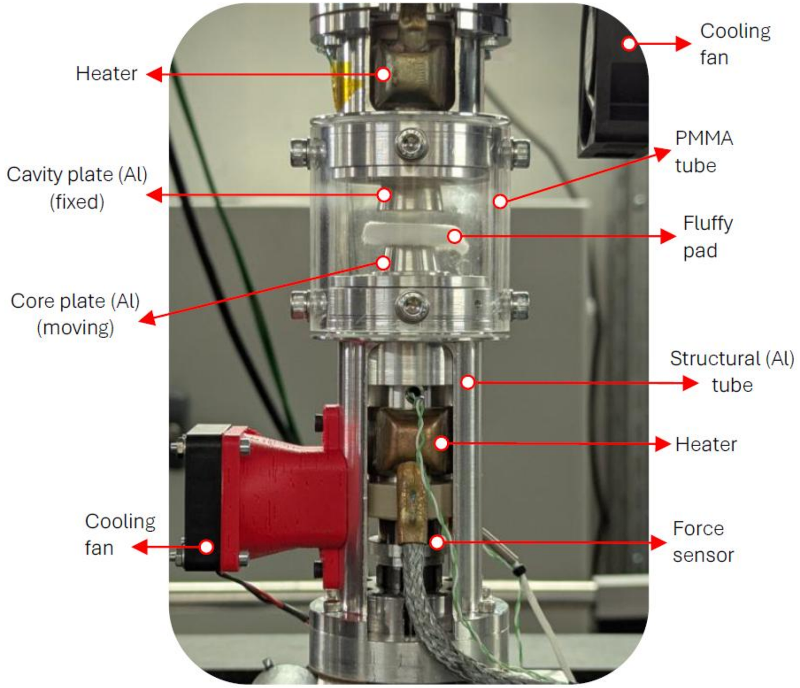
ID19

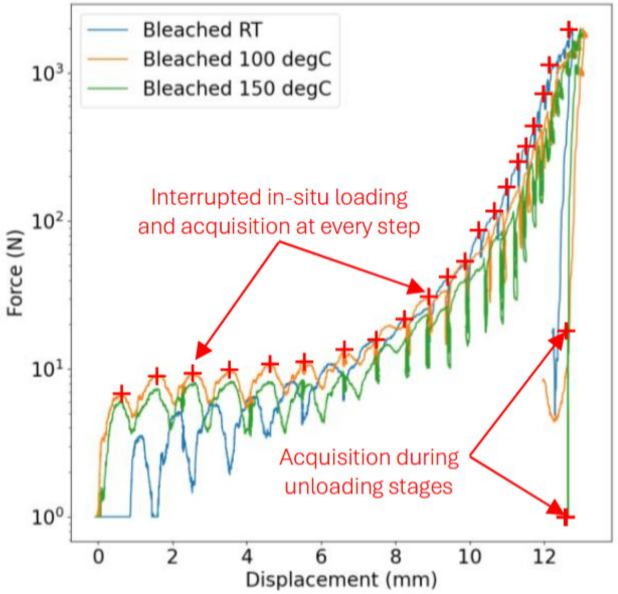
- *fluffy pads → 3D cups*

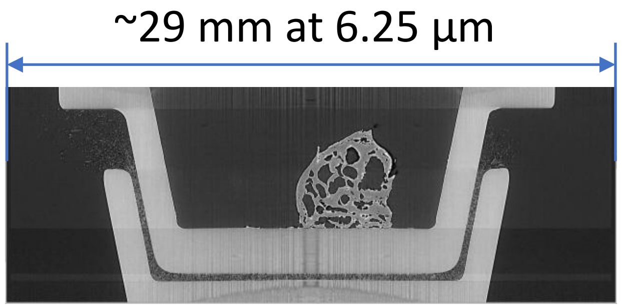


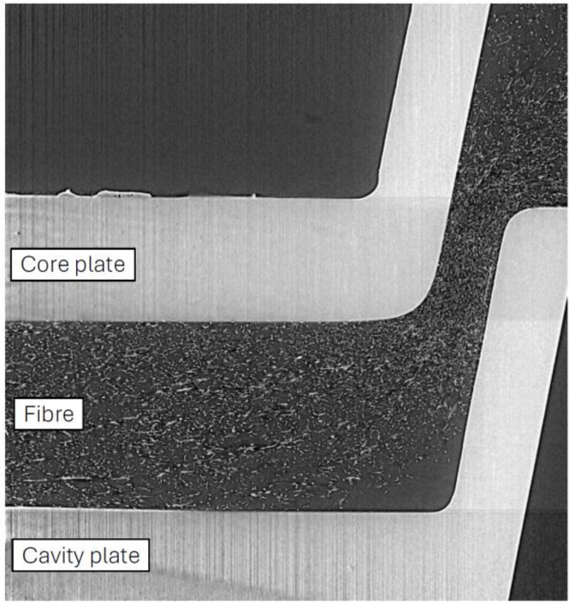
Before thermoforming

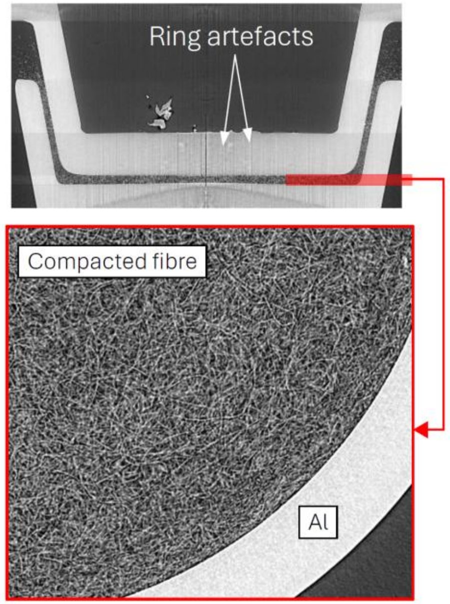
After thermoforming





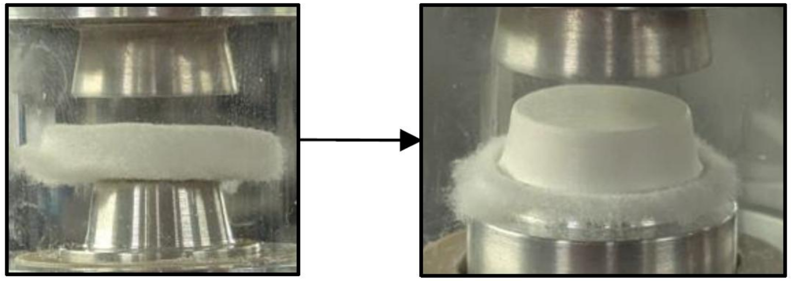




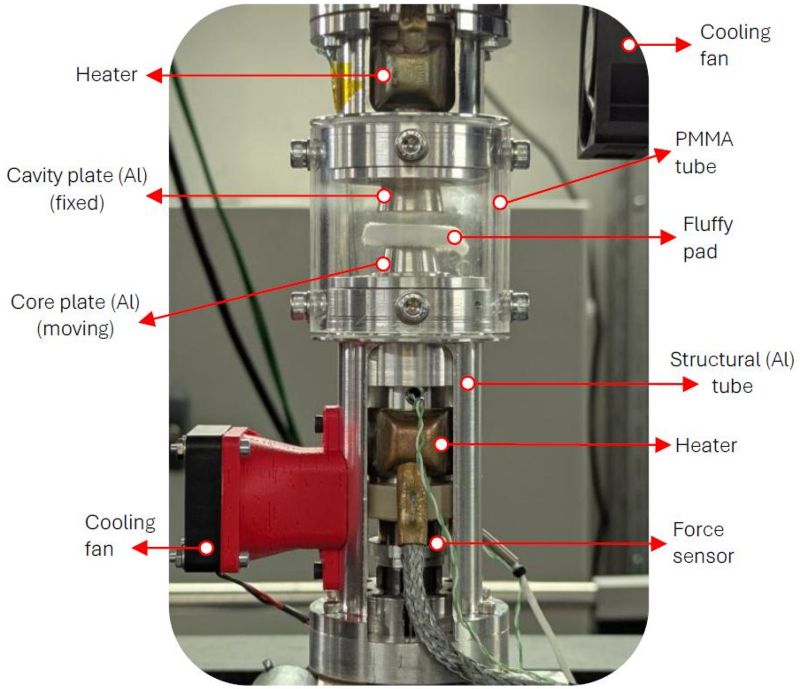


Towards next generation packaging materials with dry fibre forming

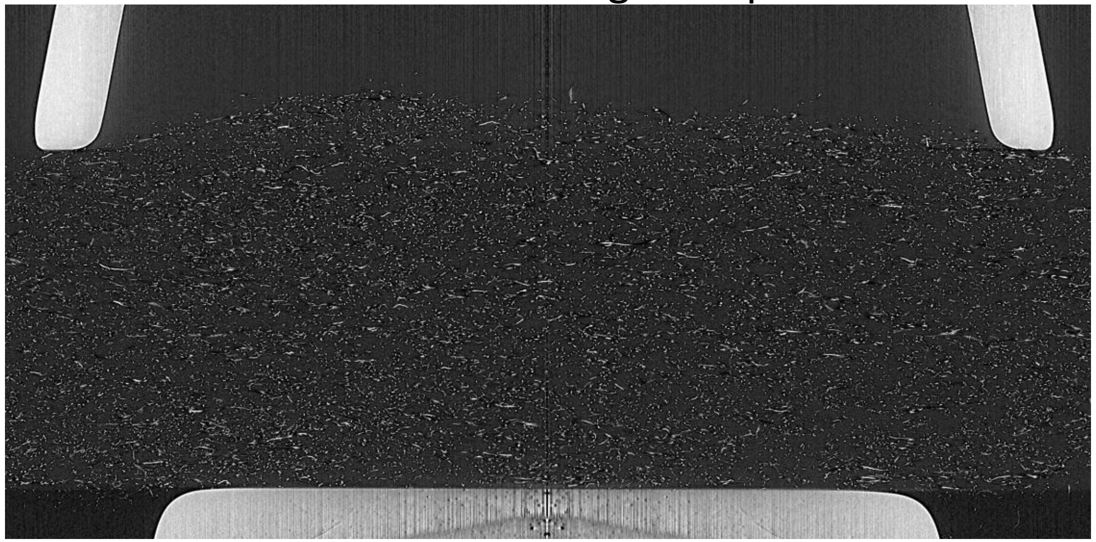
- *fluffy pads → 3D cups*



Before thermoforming   After thermoforming

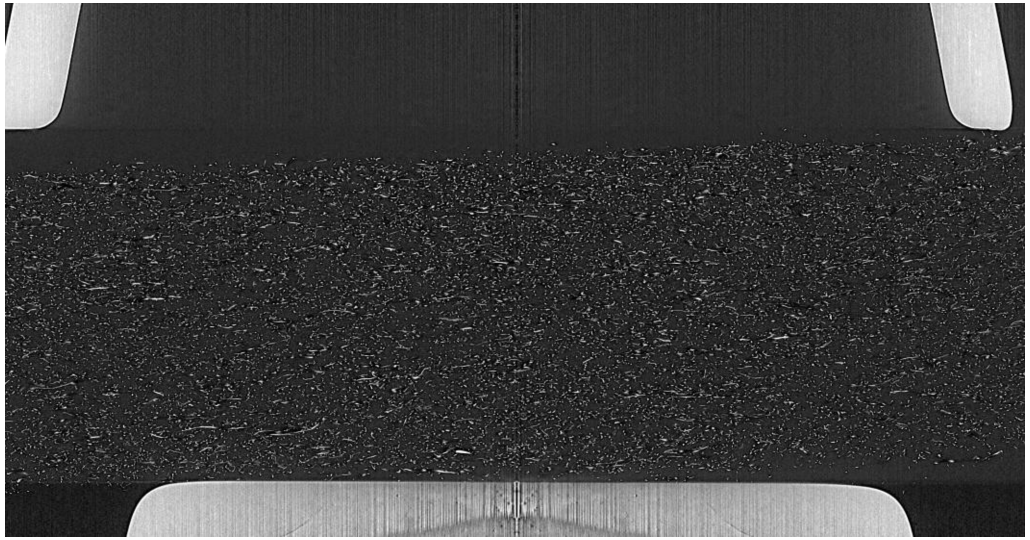


Bad forming example



Less material

Good forming example



More homogeneous

Tomography: More than just images…

- Tomography provides 3D structural information at the sub-micron to cm scale
- The technique is “non-destructive” (but samples might need to be cut to size)
- Extension to 4D with **<u>in-situ experiments</u>** allows information on processes as well as structures
- **<u>Image analysis</u>** is a key component of the process – to extract pertinent information and to link to models and model development
- Most common modality is transmission (attenuation) imaging, but phase contrast, diffraction contrast, etc. can provide further information
- Much can be done with lab facilities, but synchrotrons and neutron sources provide access to faster, higher resolution imaging and with different contrast mechanisms (phase, diffraction) → Complementary!

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