3D/4D X-ray Microtomography:

Insight into materials critical for the green transition

Combined studies at LTU and Max IV

Fredrik Forsberg (PhD)
The X-ray Microtomography Lab
Div. Fluid and Experimental Mechanics, LTU

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LUMIA – LULEÅ MATERIAL IMAGING AND ANALYSIS



Scanning Electron Microscopy, SEM
X-ray Computed Tomography, XCT

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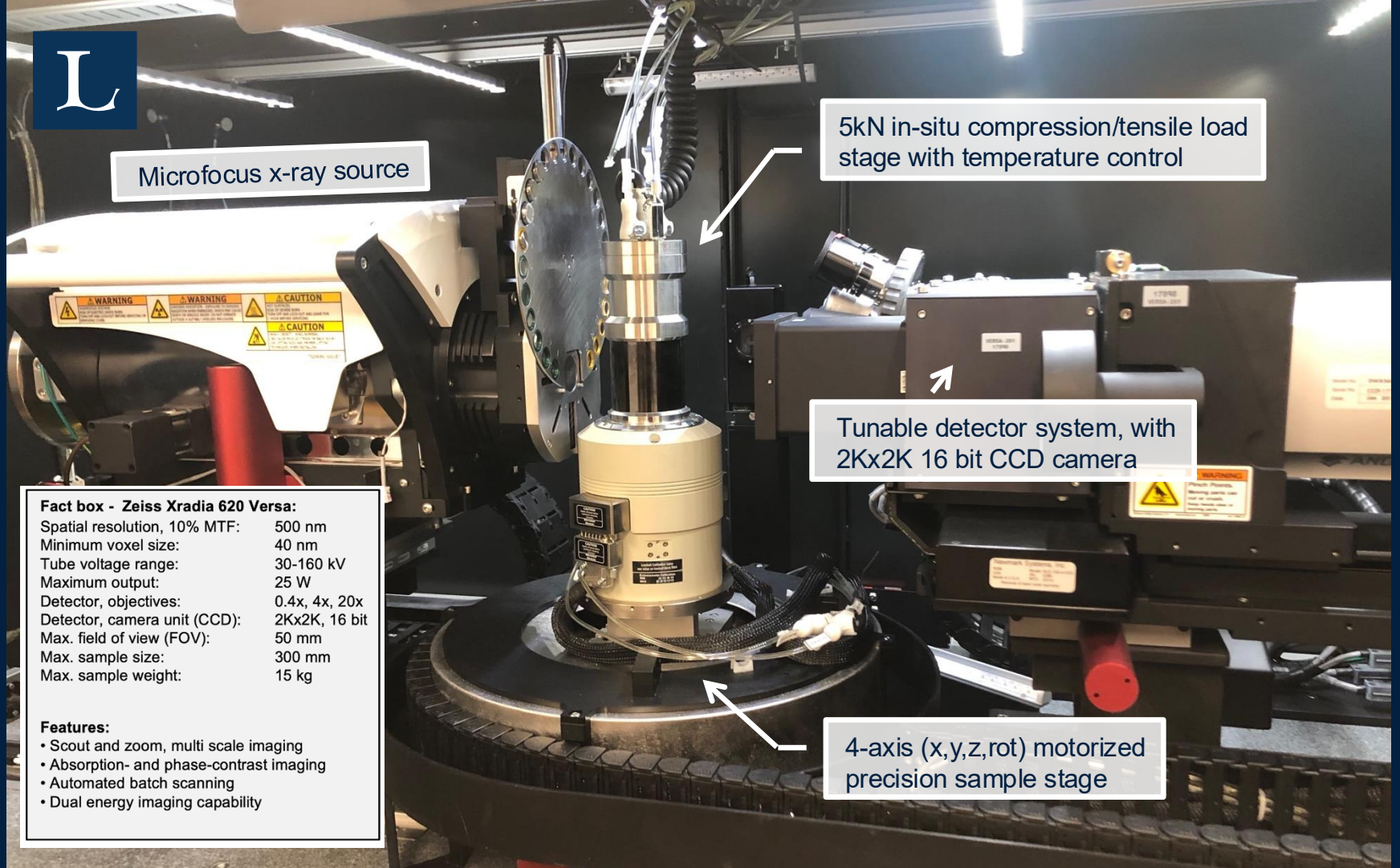
High-resolution x-ray microtomography

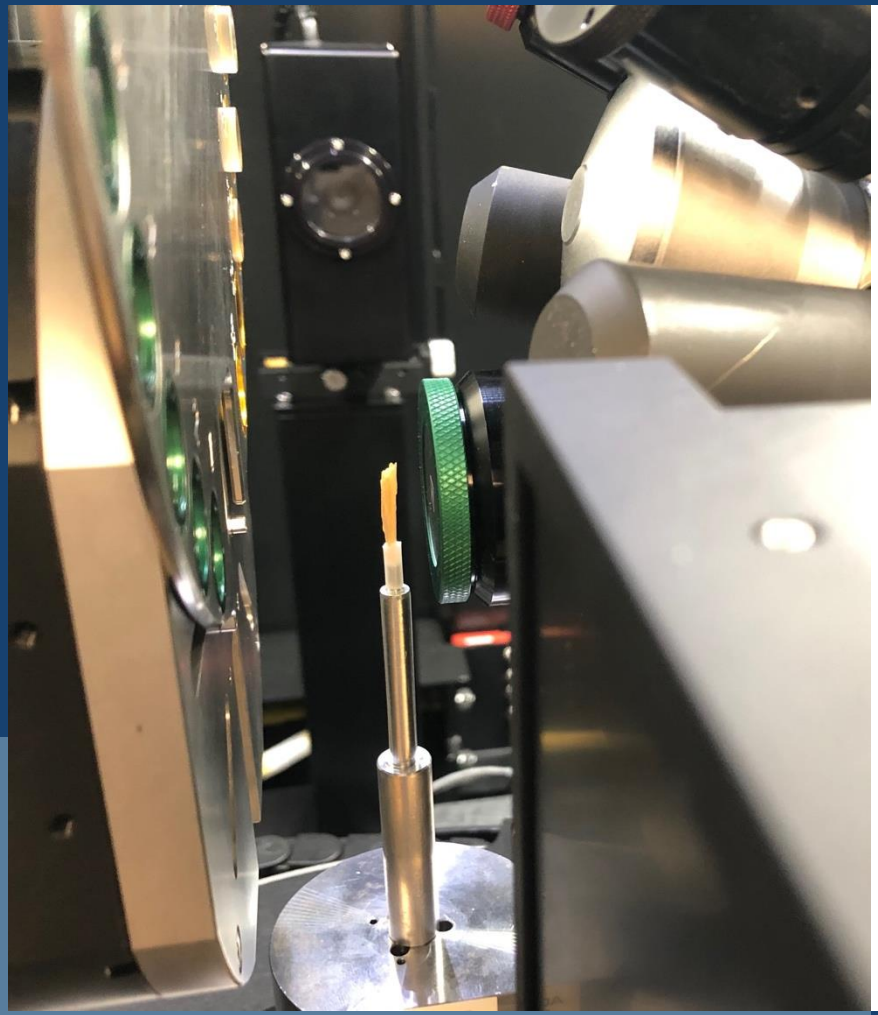
Initially installed 2016 (Zeiss Xradia 510 Versa)
Major upgrade 2022 to latest model: **Zeiss Xradia 620 Versa**




Microfocus x-ray source
5kN in-situ compression/tensile load stage with temperature control
Tunable detector system, with 2Kx2K 16 bit CCD camera
4-axis (x,y,z,rot) motorized precision sample stage
Fact box - Zeiss Xradia 620 Versa:
Spatial resolution, 10% MTF: 500 nm
Minimum voxel size: 40 nm
Tube voltage range: 30-160 kV
Maximum output: 25 W
Detector, objectives: 0.4x, 4x, 20x
Detector, camera unit (CCD): 2Kx2K, 16 bit
Max. field of view (FOV): 50 mm
Max. sample size: 300 mm
Max. sample weight: 15 kg
Features:
• Scout and zoom, multi scale imaging
• Absorption- and phase-contrast imaging
• Automated batch scanning
• Dual energy imaging capability

3D/4D X-ray Microtomography: Insight into materials critical for the green transition





Studies of cell structure in wood (Spruce)

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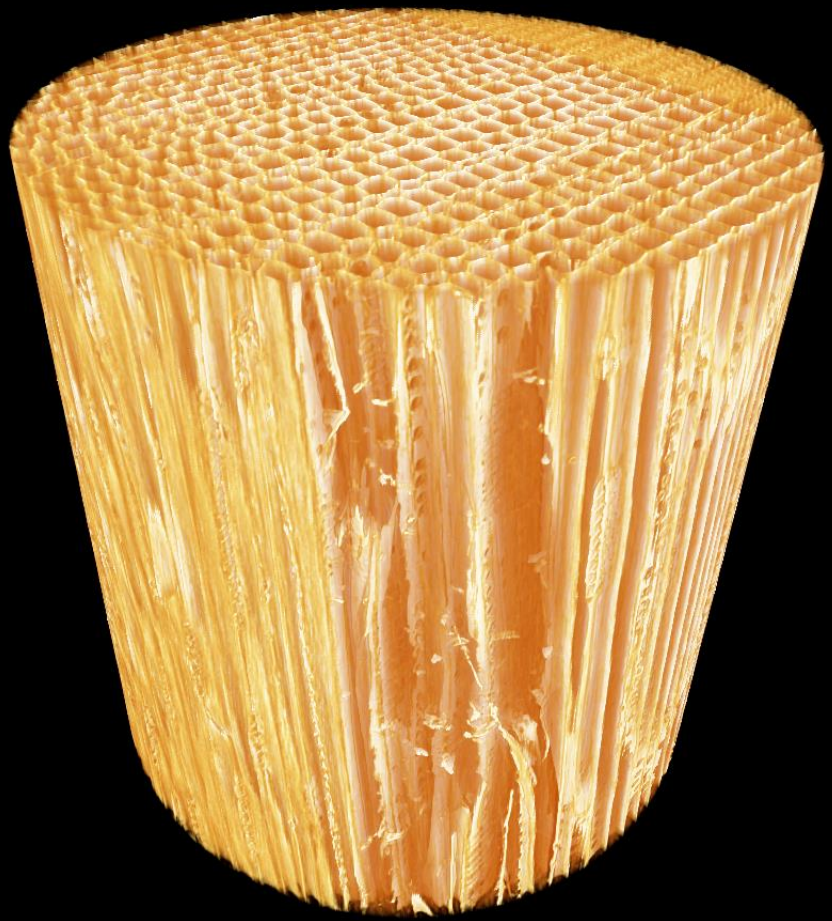
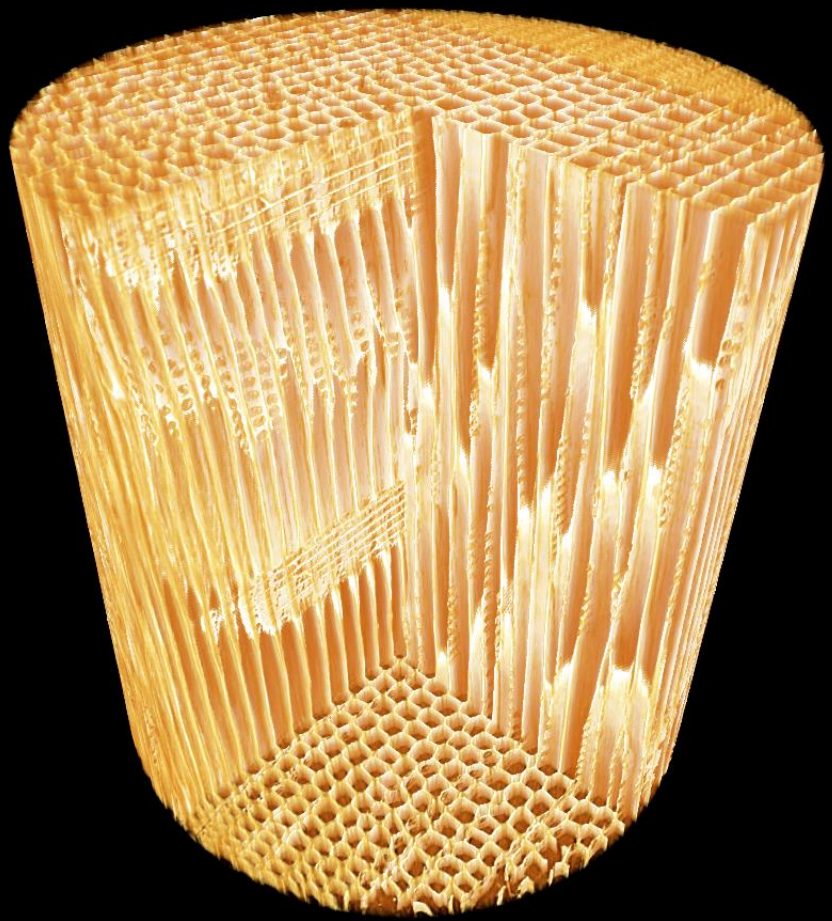
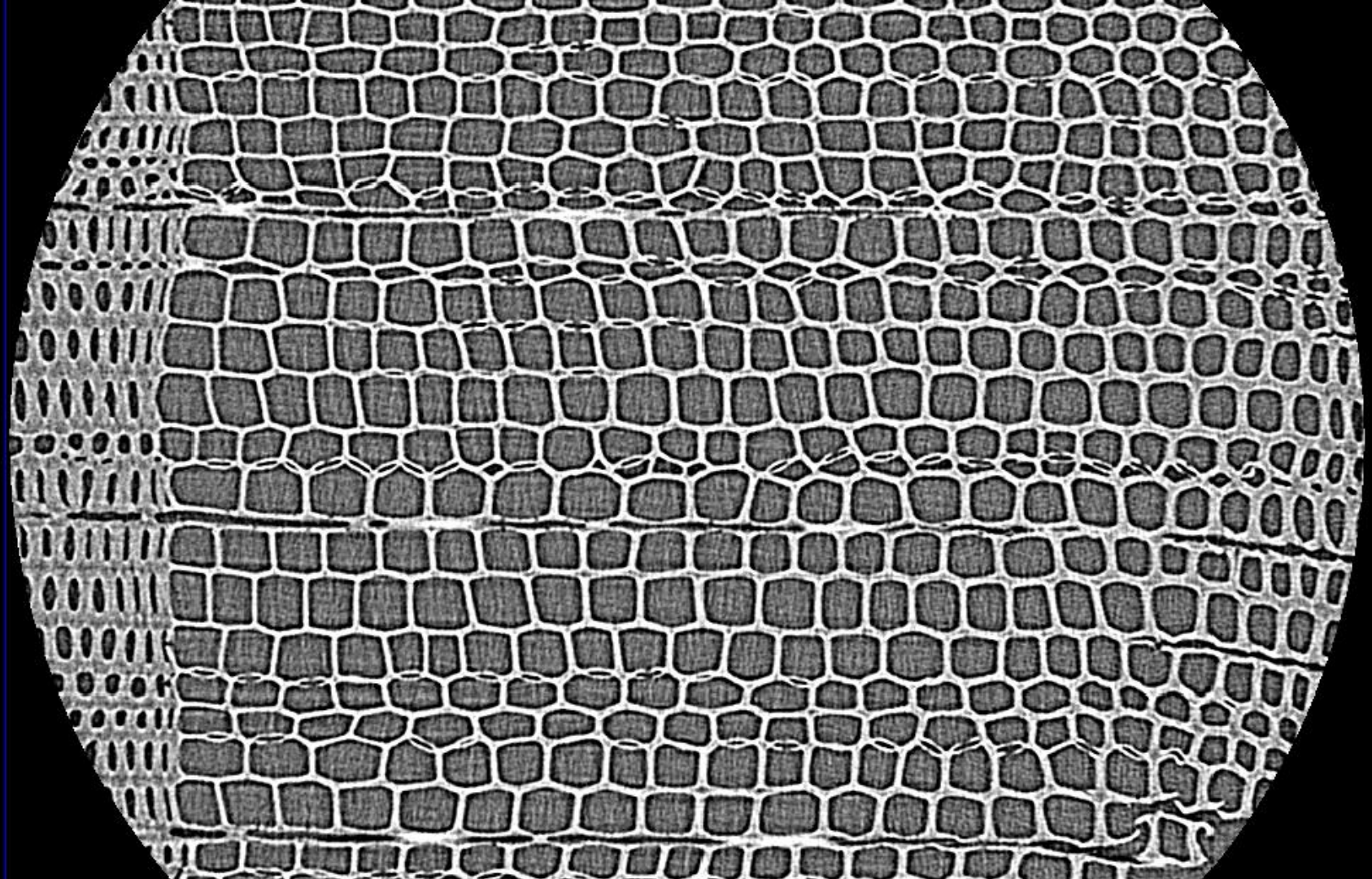
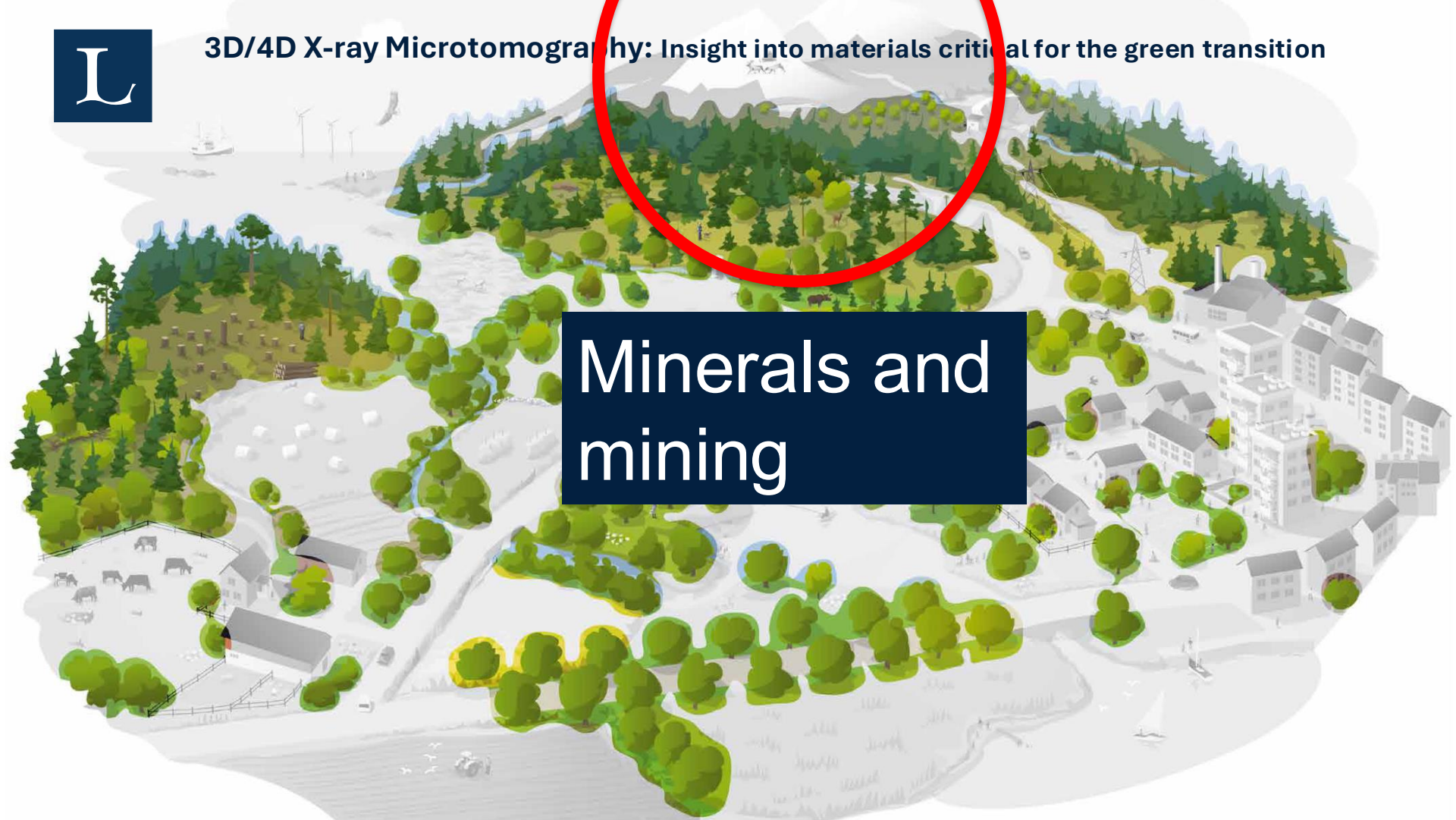


Spruce scanned with x-ray microtomography.
FOV: 1.0 mm
Voxel size: 1.0 µm

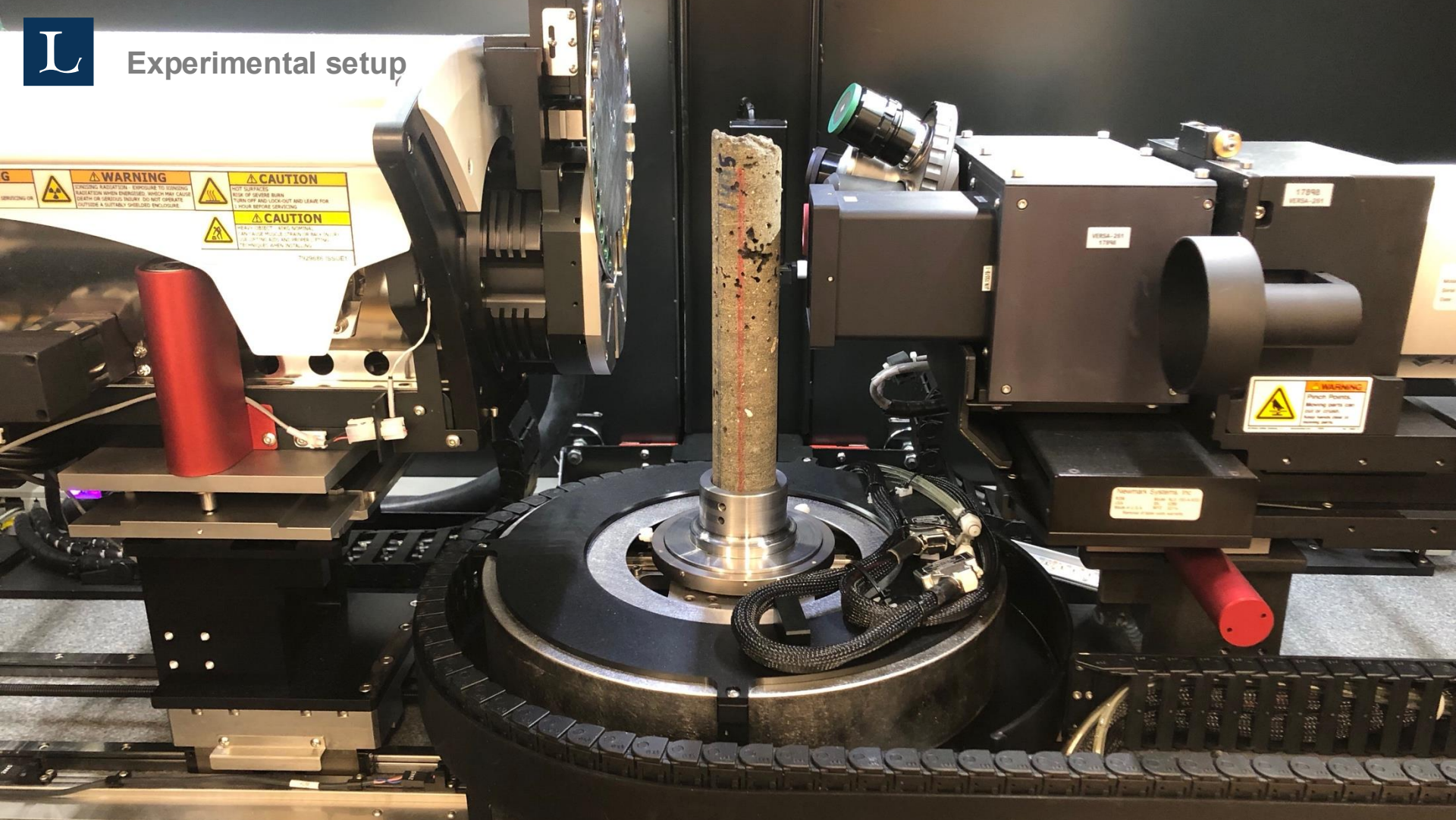


Spruce scanned with x-ray microtomography.
FOV: 1.0 mm
Voxel size: 1.0 µm

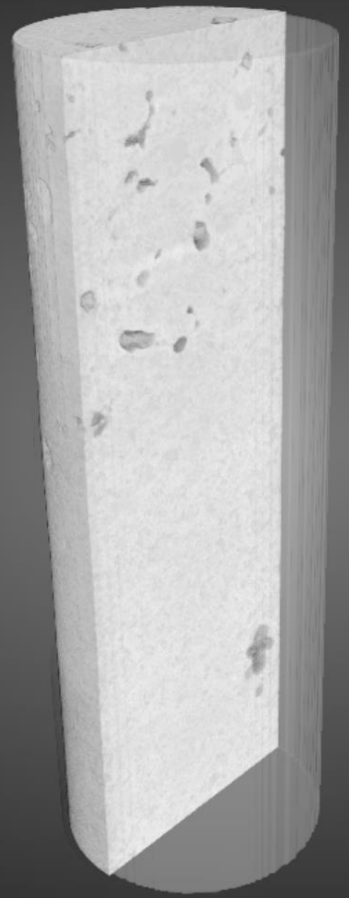



Minerals and mining

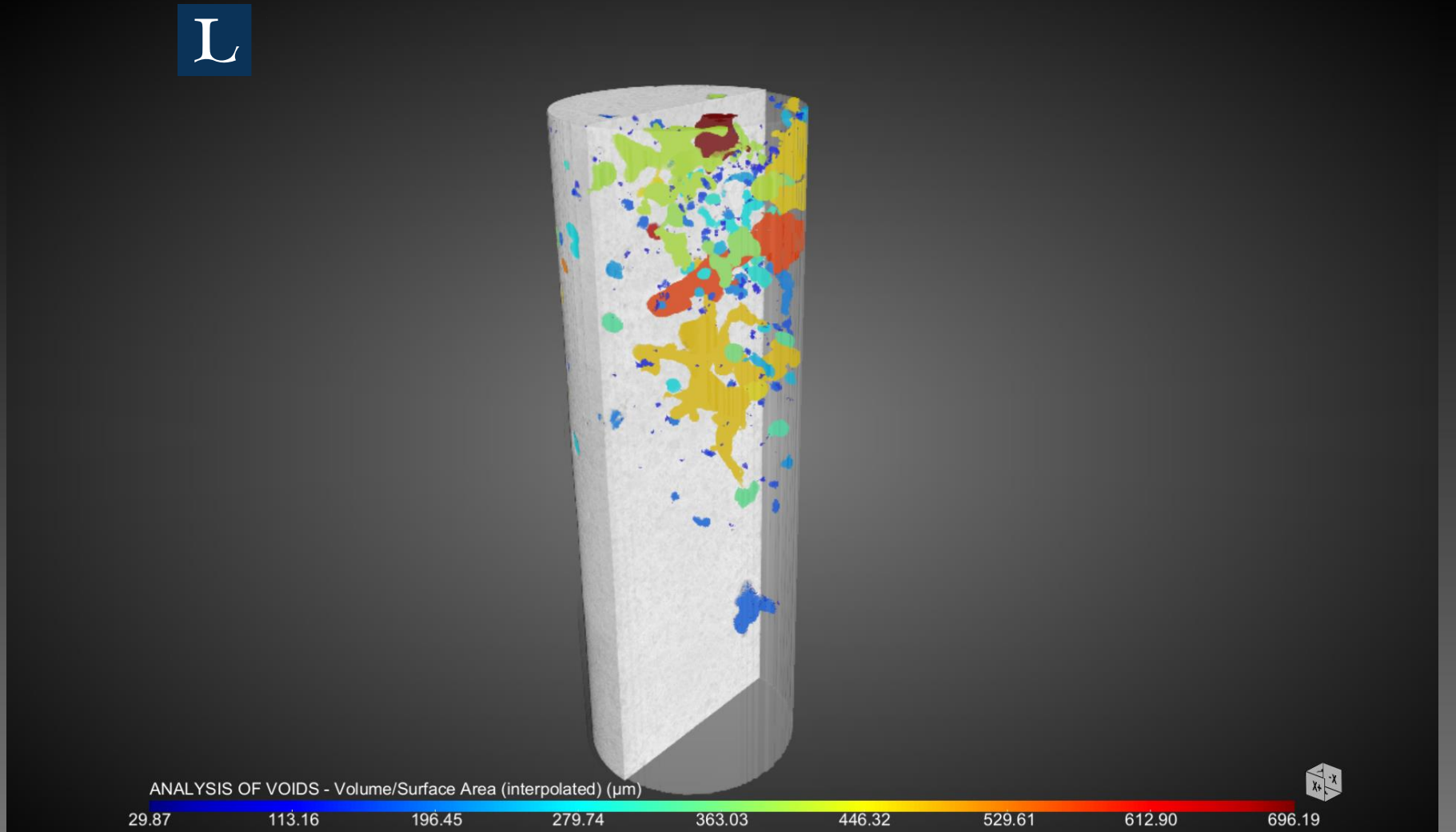
Experimental setup










ANALYSIS OF VOIDS - Volume/Surface Area (interpolated) (µm)
29.87
113.16
196.45
279.74
363.03
446.32
529.61
612.90
696.19

New equipment…

Dynamic/High-energy/spectral XCT (New investment, WISE RTP)
Installed Q2 2026

- **Dynamic XCT** will allow tomography with high temporal resolution, optimized for in-situ studies of dynamic processes, such as internal flow and rapid deformation.
- **Spectral XCT** will allow 3D elemental analysis
- **High-energy XCT** will allow larger samples and FOVs to be studied.
- **Great complement to high-res XCT at LTU** (Zeiss Xradia XRM) and synchrotron tomography (MAX IV).
- **Completely unique in Sweden**



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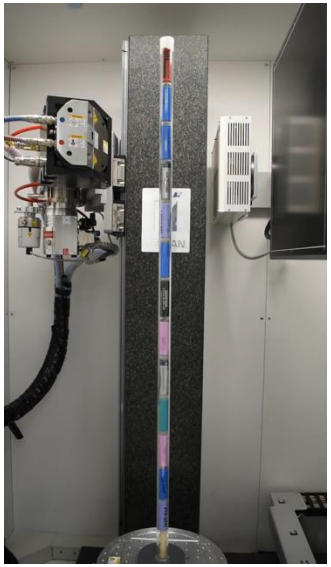
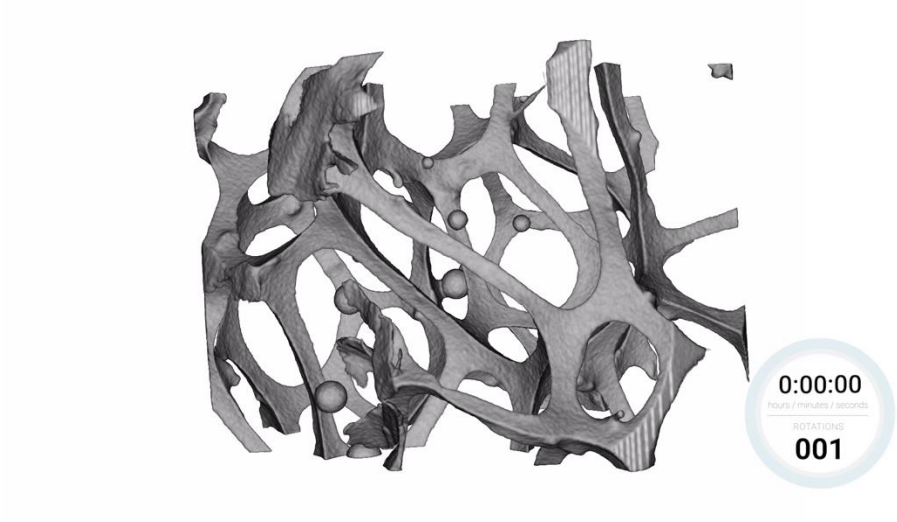
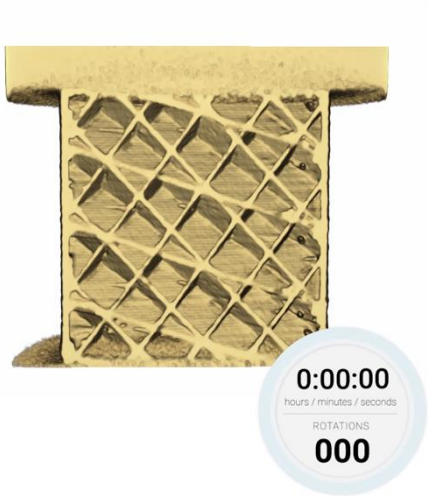
TESCAN micro-CT

Fast scanning at temporal resolutions down to seconds for high throughput and dynamic scanning







HUMIDA in-situ stage

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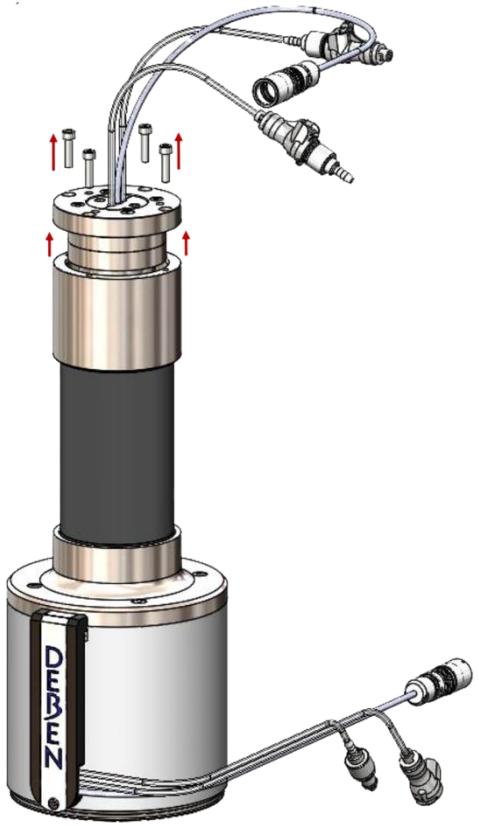
HUMIDA in-situ stage (Q1 2026)

New custom built climate chamber

Hygro-Thermal-Mechanical In-situ load device
Collaboration with Deben and ForMAX/Max IV.

Fully compatible with:

- High-resolution XCT at LTU (Zeiss)
- Dynamic XCT at LTU (Tescan)
- ForMAX beamline at Max IV



Funded by:
Kempestiftelserna, LTU Labfund, WISE RTP

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HUMIDA in-situ stage (Q1 2026)

Mechanical load

Maximum load capacity: 5kN (Loadcells: 500N, 5kN)
Compression/tensile/three-/four-point-bending

Humidity

RH: 10-90%
From external Cellkraft humidifier (Cellkraft P10).

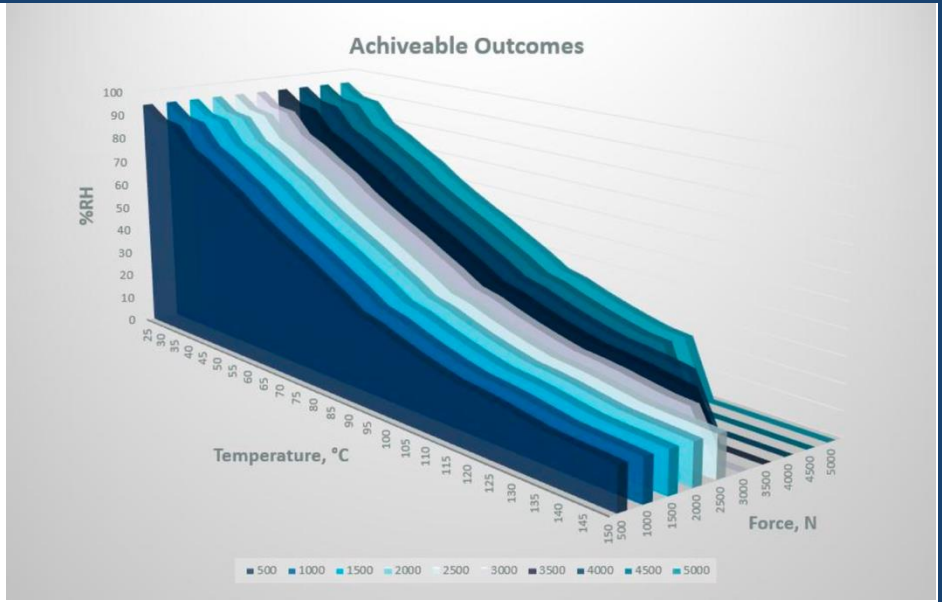
Temperature

Range: RT – 250 °C (150 °C with humidity control)

Design

Tube material: -Glossy carbon (Standard)
-Polycarbonate (SAXS/WAXS)

Compatible with: -Zeiss Xradia 620 Versa (LTU)
-Tescan UniTom XL Spectral (LTU)
-ForMAX stage (Max IV)



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HUMIDA in-situ stage (Q1 2026)



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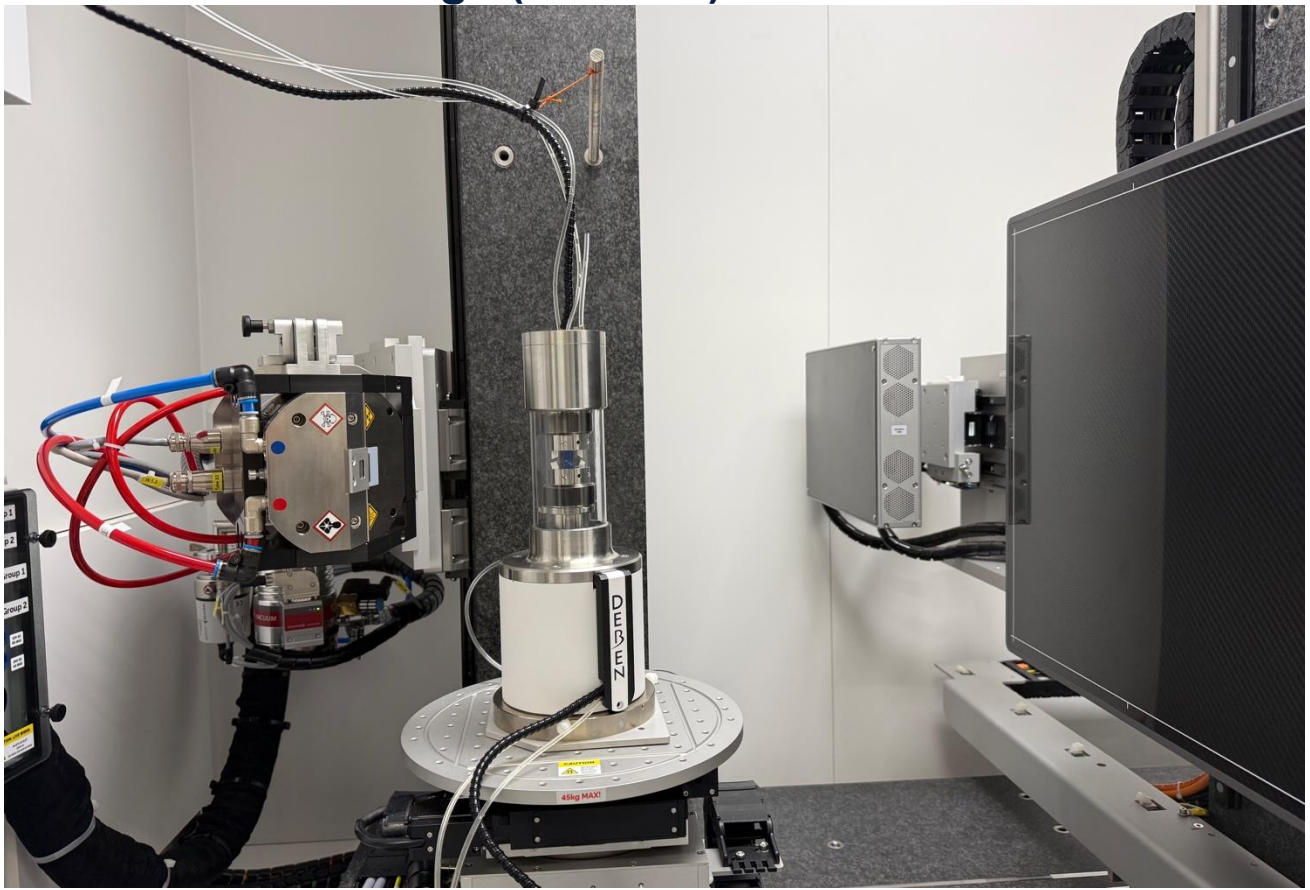
HUMIDA in-situ stage (Q1 2026)



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Studies at Max IV…

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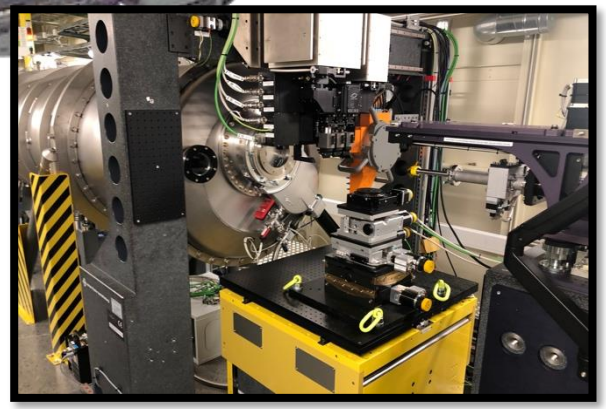
Synchrotron x-ray microtomography (SRμCT)

- Parallell x-ray beam
- High brilliance, small bandwidth and high coherence
- High spatial resolution, < 1 μm (depending on optics)
- High temporal resolution, short scan time (~ sec to min)
- Limited field-of-view (FOV) and sample size.
- Limited access (peer-review application process, limited time slots)



ForMAX beamline, MAX IV



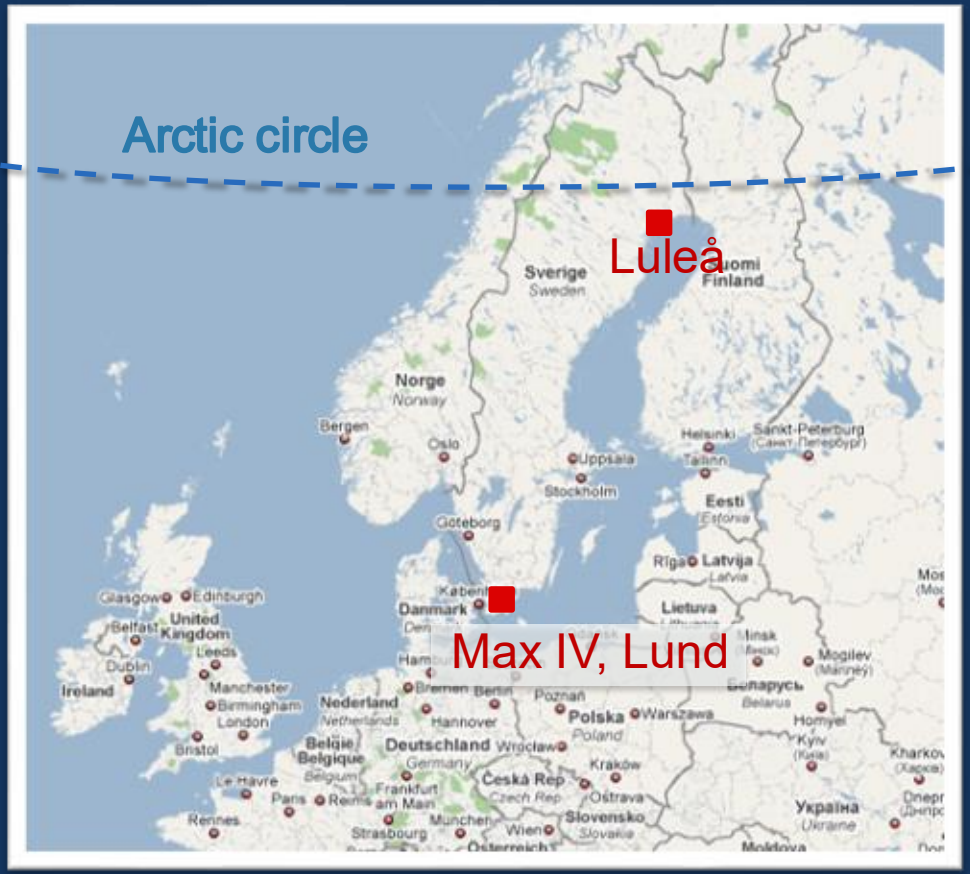
Lab-based x-ray microtomography (Lab-μCT)

- Cone-shaped x-ray beam
- High spatial resolution, < 1 μm (depending on optics)
- Low time resolution, Long scan time (~ hours)
- Polychromatic beam, lower coherence
- Large feild-of-view (FOV). Possibilty to scan larger samples.
- Easy access (can be accessed at LTU, and several other universities and research institutes)



Zeiss Xradia 620 Versa, LTU





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MAX IV



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ESS
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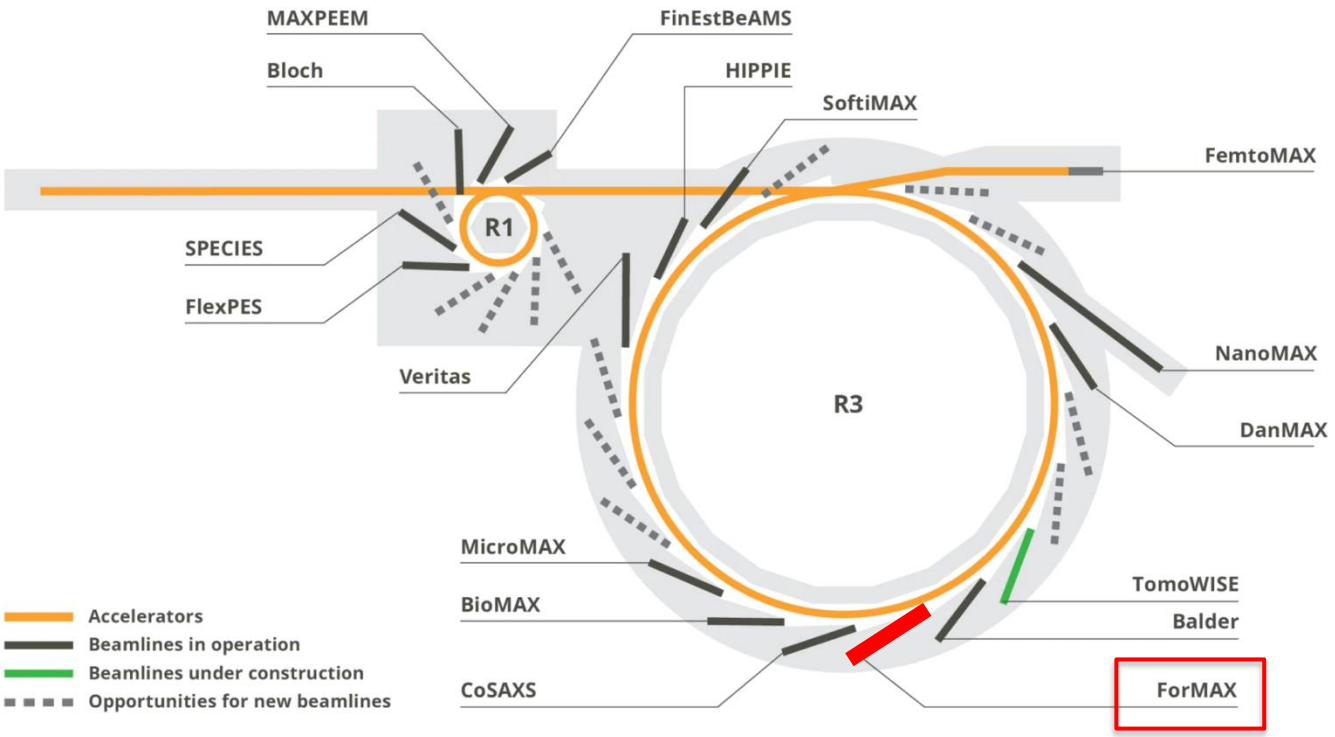
Max IV

Beamlines



R1: 1.5 GeV
R3: 3 GeV

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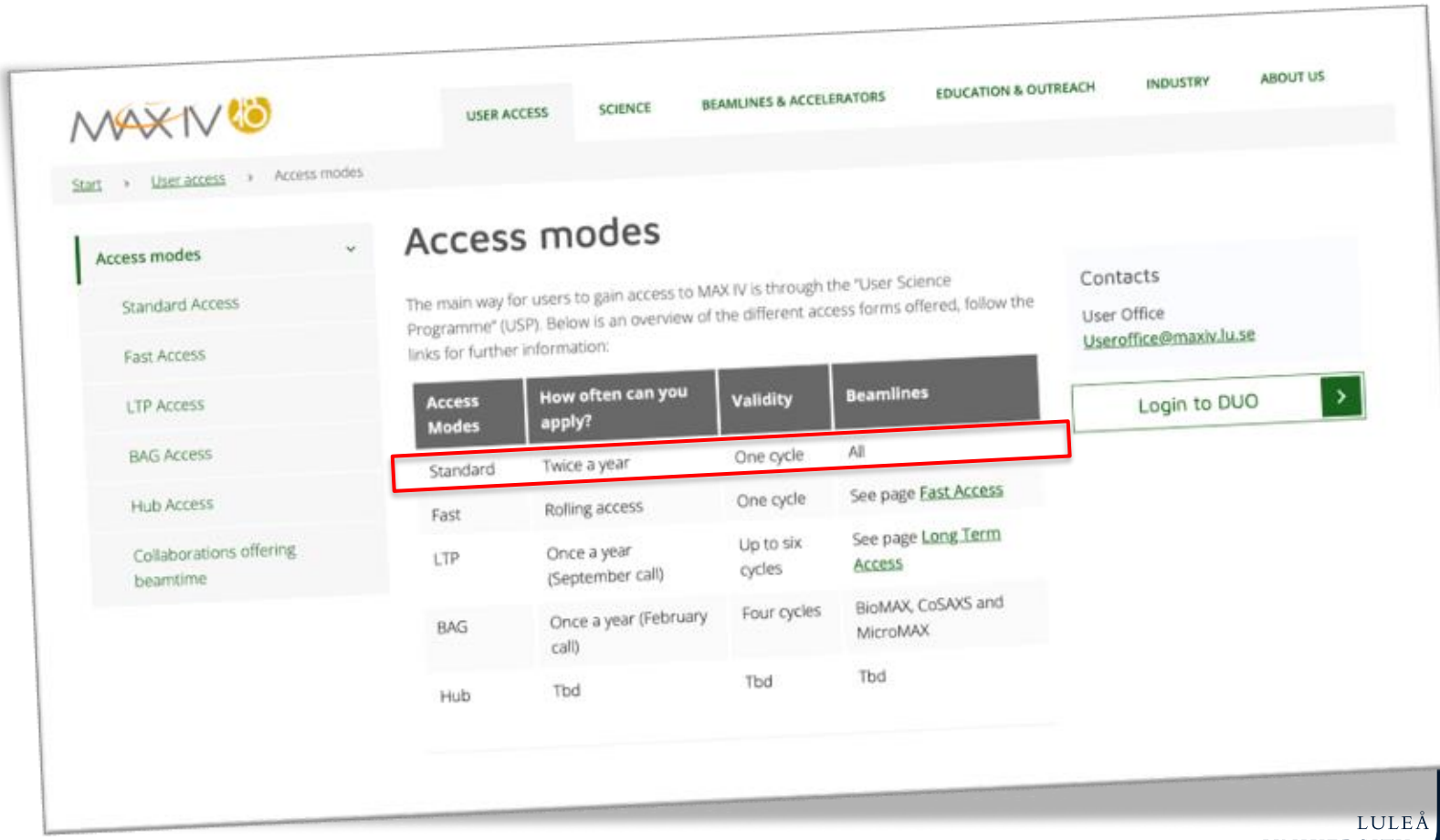

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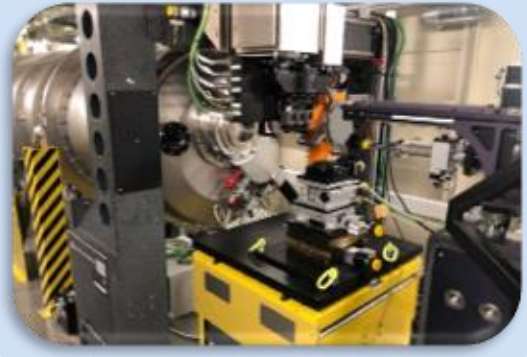
TREESEARCH

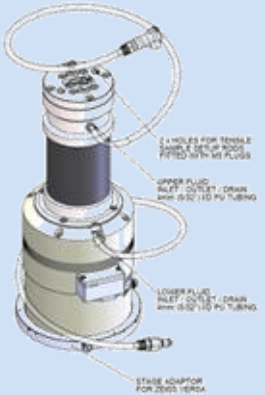
Beamtime at ForMAX, Research projects:

- Autumn 2023
- Spring 2025
- Autumn 2025
- Spring 2026
- Autumn 2026

September 2023
Commisioning at ForMAX beamline
Test/validation/calibration of instruments for in-situ-loading (own equipment)



November 2026
Commisioning of new HUMIDA module
(in-situ load-device with climate control)



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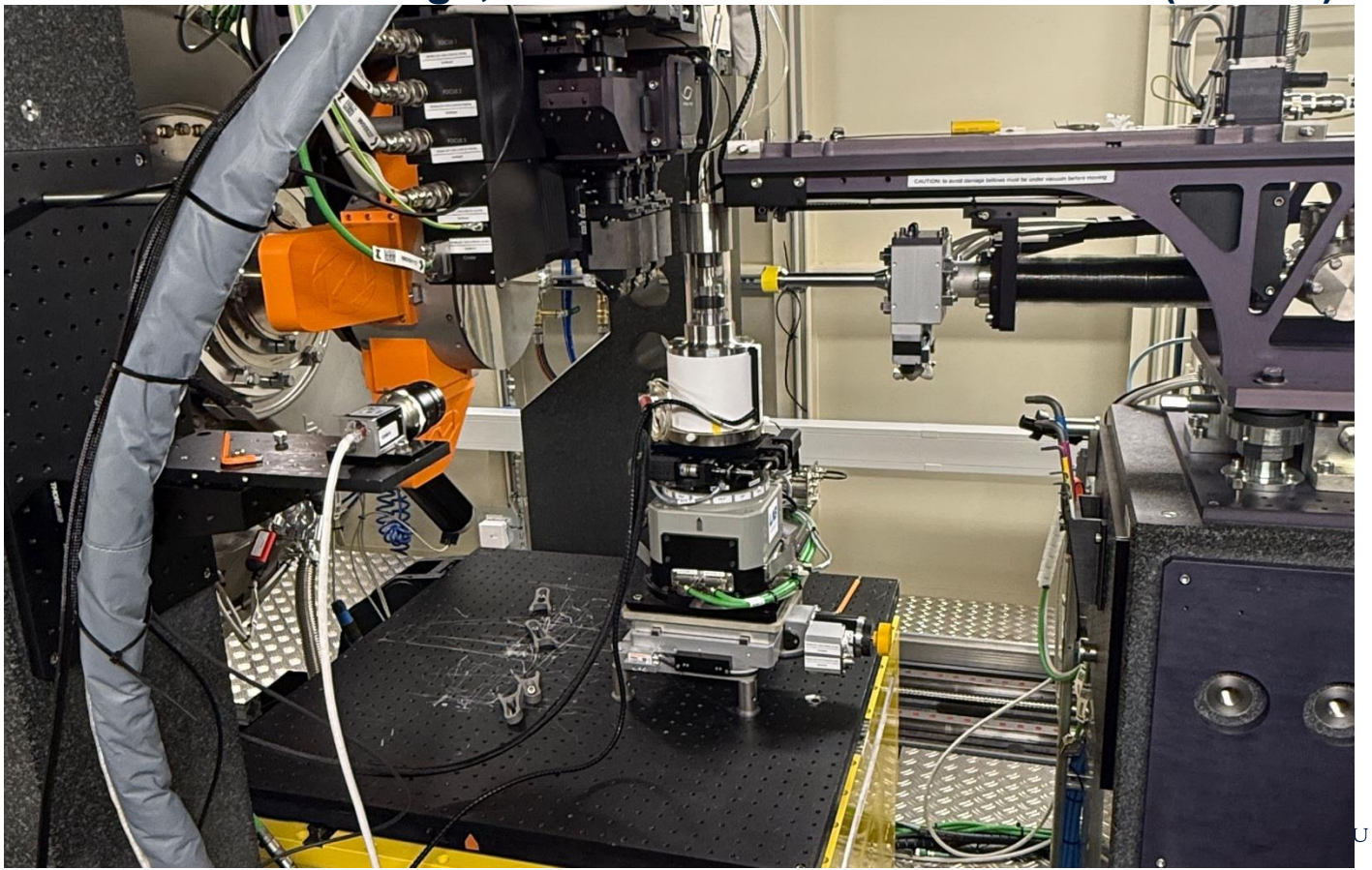
HUMIDA in-situ stage, first test at ForMAX beamline (Oct-26)



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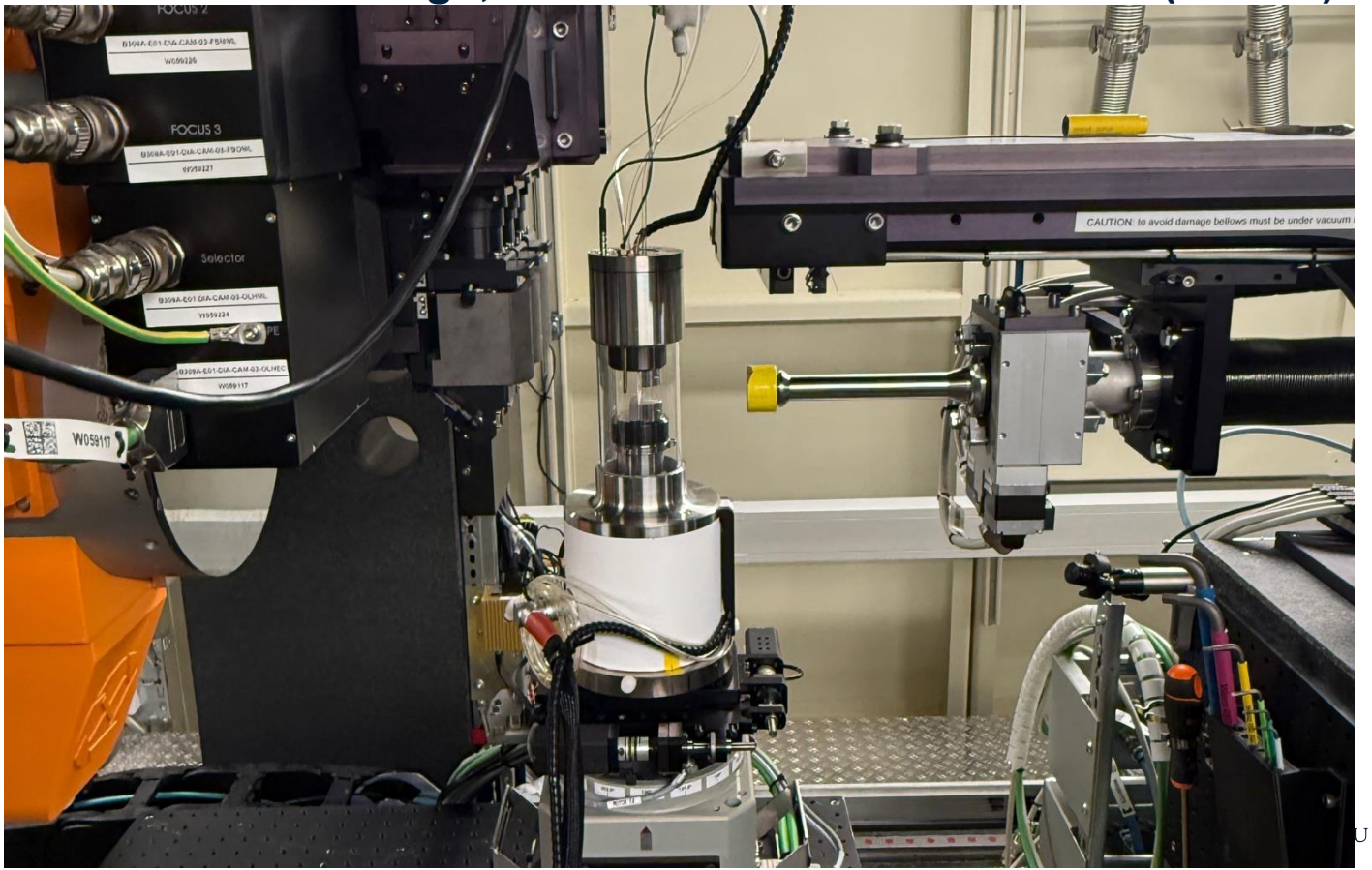

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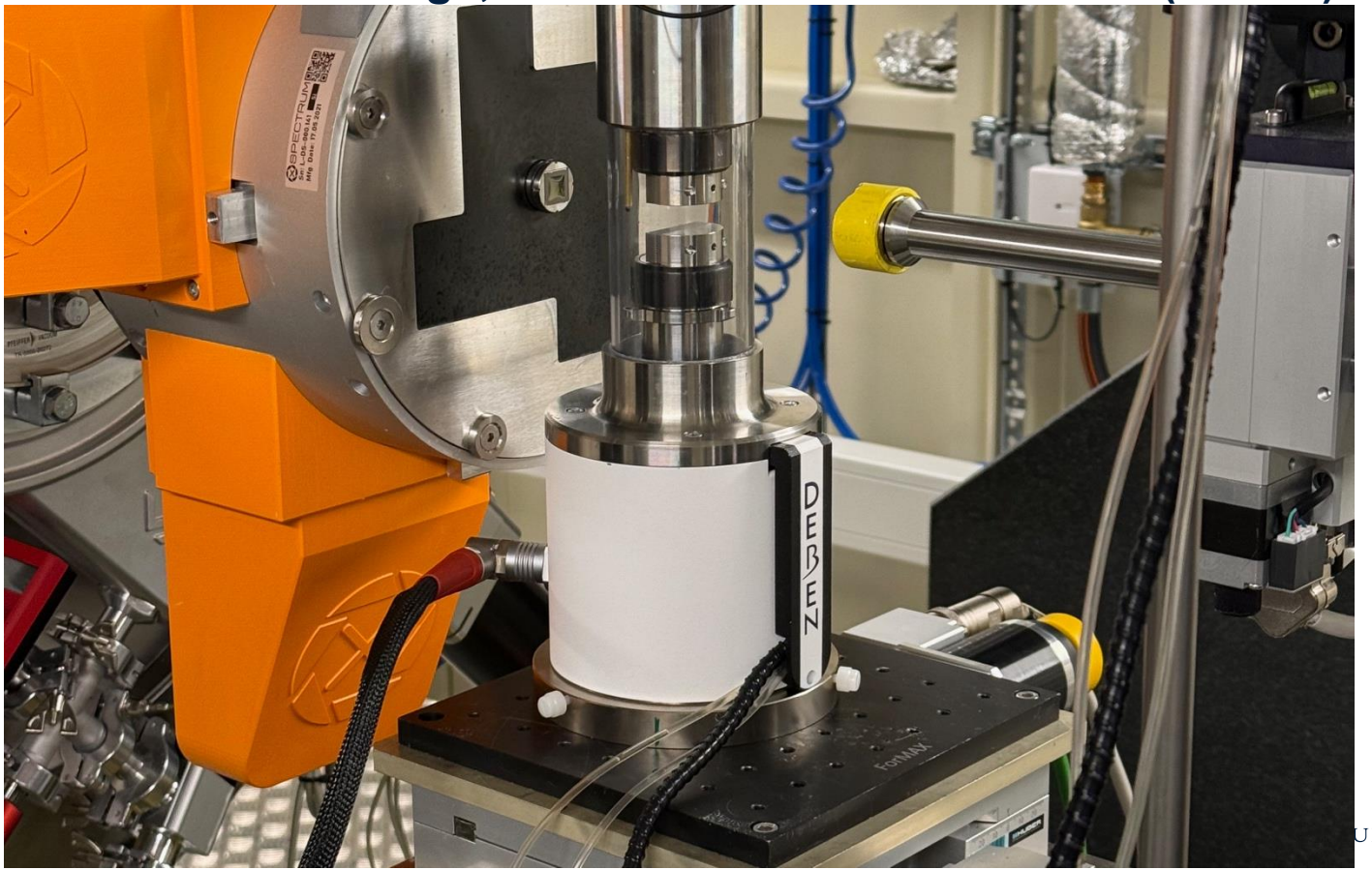

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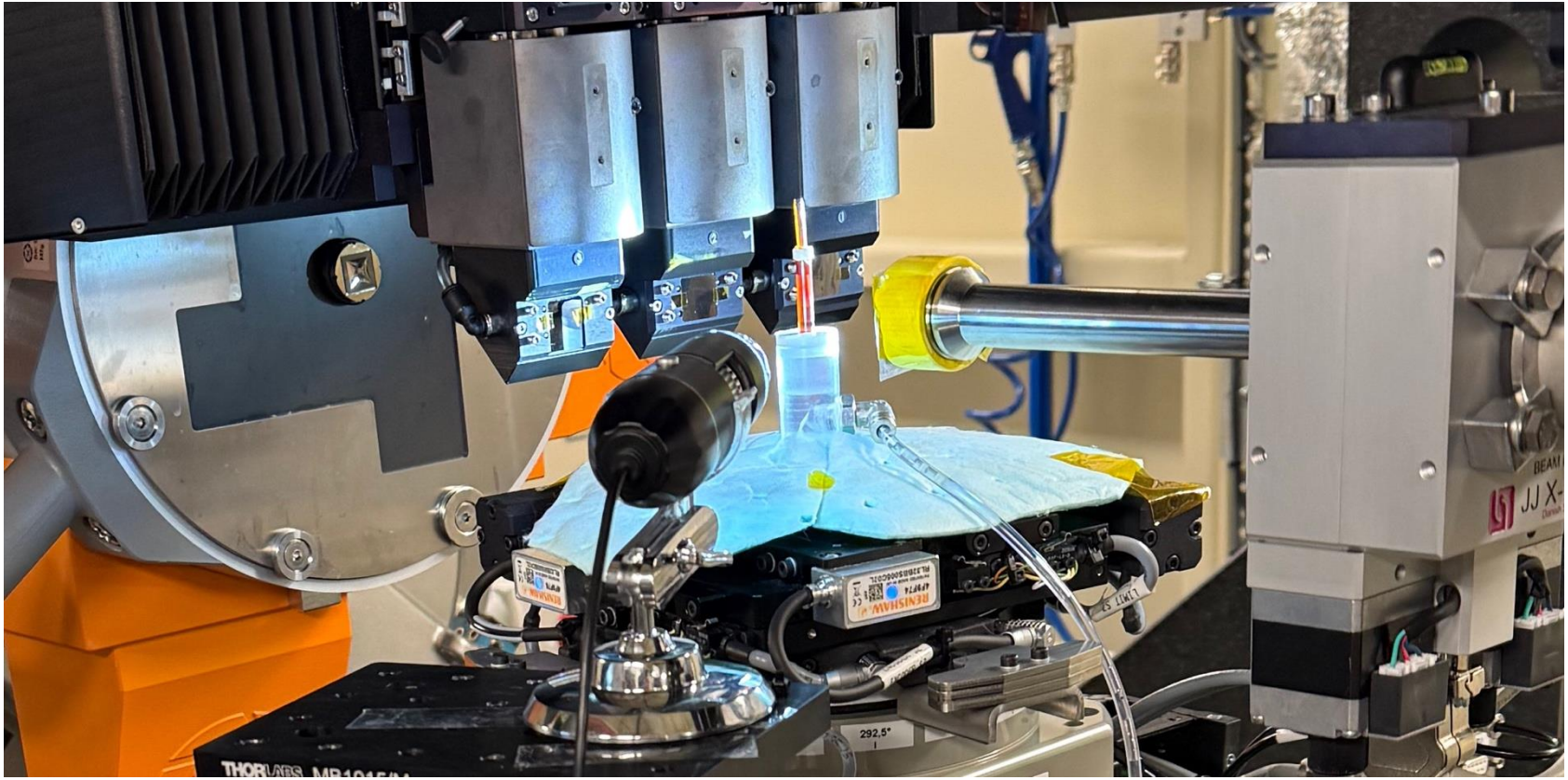
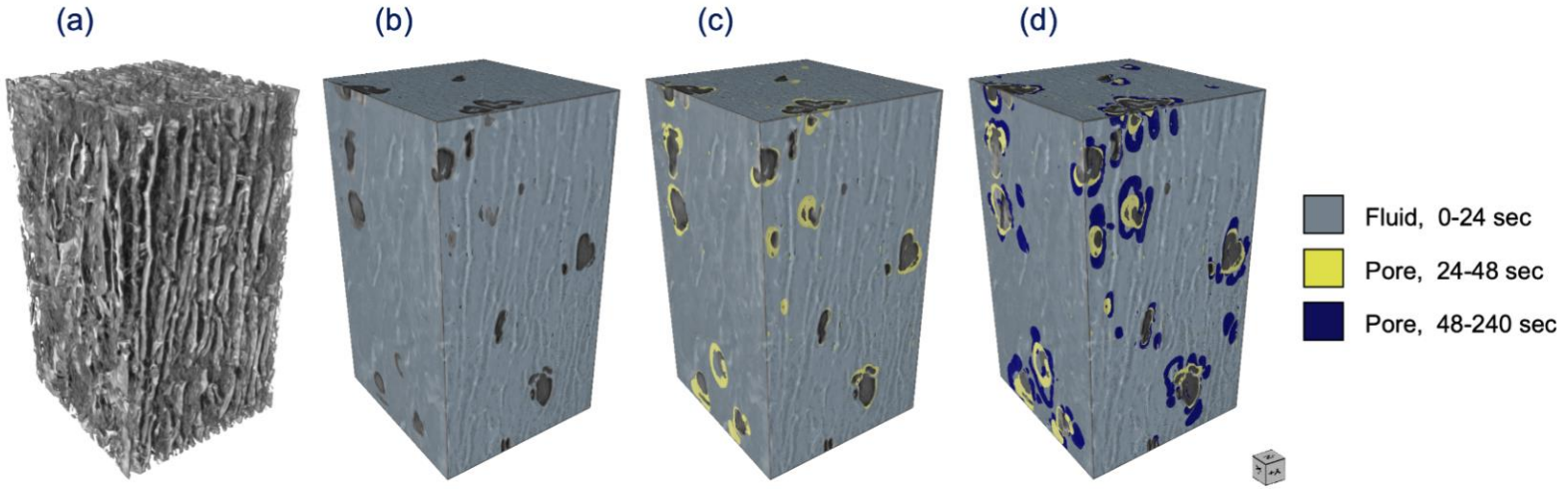
Synchrotron imaging of gel polymer electrolyte transport in carbon aerogels for next-generation energy storage



Synchrotron imaging of gel polymer electrolyte transport in carbon aerogels for next-generation energy storage



Mashkour etal. (2026), ACS APPLIED ENERGY MATERIALS 9 (15),doi: 10.1021/acsaem.6c01240.

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Transport in Porous Media (2025) 152:101
https://doi.org/10.1007/s11242-025-02238-5

Capillary-Driven Flow Through Biological Porous Media: X-ray Microtomography and Computational Fluid Dynamics

T. Staffan Lundström[1] · J. Gunnar I. Hellström[1] · Anna-Lena Ljung[1] · Fredrik Forsberg[1] · Henrik Lycksam[1] · Mehrdad Mashkour[2,3] · Mandeep Singh[2] · Kristiina Oksman[2,3] · Johannes A. J. Huber[4]

Received: 6 May 2025 / Accepted: 22 September 2025
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Abstract
This study investigates the use of X-ray microtomography (XMT) to reveal the structure o
complex porous biological tissues and the fluid flow through them during wetting. It also
evaluates fluid dynamical simulations based on XMT data to reproduce and analyse these
flows, with a final aim of revealing fluid transport and void formation in such tissues. To
fulfil the objectives, the wetting flow of a polymer liquid through an initially dry condi
tioned Norway spruce wood sample is visualised using XMT at the MAX IV synchrotron.
The liquid flow front progression captured after 24 s and 48 s reveals uneven filling o
longitudinal tracheids and flow between them via the tiny pits which connect tracheids.
Most tracheids fill between 24 and 48 s, possibly due to removal of air inclusions. Large
density gradients near cell walls suggest that the fluid followed and deposited along wal
structures. Computational fluid dynamics simulations (CFD) of saturated flow through the
tomography-based geometry indicate velocity profiles that resemble pipe flow in longitudi
nal tracheids and flow rate differences among them. The latter indicates that the geometry
itself may cause the experimentally observed uneven flow. Streamlines show intra-tracheic
flow development and clear flow direction change at the pits. Additionally, wetting simula

ACS APPLIED ENERGY MATERIALS

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Article

Synchrotron Imaging and Modeling of Gel Polymer Electrolyte Transport in Hierarchical Carbon Aerogels for Supercapacitors

Mehrdad Mashkour, Mandeep Singh, Gunnar Hellström, Anna-Lena Ljung, Fredrik Forsberg, Henrik Lycksam, Johannes A. J. Huber, T. Staffan Lundström, Alexander Bismarck, and Kristiina Oksman*

Cite This: https://doi.org/10.1021/acsaem.6c01240

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ABSTRACT: Hierarchically porous carbon aerogels offer significant potential for next-generation energy storage, yet controlling their structure and electrolyte infiltration remains a key challenge. Here, we develop fully biobased carbon aerogels (CAs) derived from a lignin-cellulose nanocrystal blend via ice-templating and carbonization. The resulting anisotropic hierarchical porous structures are infused with poly(vinyl alcohol)-potassium hydroxide gel polymer electrolyte to form semi-solid composite electrodes. Time-resolved synchrotron X-ray microtomography enables direct visualization of structural evolution during carbonization and three-dimensional electrolyte infiltration. Image-based pore-scale modeling performed directly on reconstructed synchrotron X-ray tomographic volumes reveals how the real hierarchical pore network governs gel electrolyte distribution, accessible porosity, and ion transport pathways. The results show that aligned and interconnected pore networks enable deep, uniform electrolyte penetration, reduce transport tortuosity, and increase electrochemically active volume. The structure-transport-performance relationship is validated by electrochemical testing of symmetric supercapacitors, demonstrating stable capacitance and reduced internal resistance. This work establishes a concept for renewable porous carbon electrodes and introduces a scalable CA-gel electrolyte system for high-performance solid-state energy storage.

KEYWORDS: *sustainable carbon composite, gel polymer electrolyte, porosity, anisotropic structure, energy storage, synchrotron, flow model*

1. INTRODUCTION

Composite electrodes combining porous carbon structures with solid or quasi-solid electrolytes have gained increasing interest in next-generation energy storage devices. In such systems, a continuous electrolyte phase occupies the pore space to enable ion transport, while the carbon structure provides percolating electrically conducting pathways and large interfacial area (up

templated lignin-nanocellulose aerogels show promising performance as self-supporting electrodes and as alternatives for fossil-derived carbons.[1,2] Despite these advantages, electrolyte infiltration and ion transport within such hierarchical pore structure remain poorly understood. Although recent studies on cellulose-based materials have demonstrated that internal pore structure, interconnected networks, and percolated architectures play a critical role in governing ion transport pathways

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MAX 4U
Science Case
FAQ – MAX 4U
Accelerator Design

MAX 4U



Why an Upgrade?

Tomorrow's challenges are outgrowing the capabilities we have today. MAX IV needs an upgrade to remain scientifically and strategically competitive beyond 2030 and to enable the next generation of research in areas such as semiconductors, AI hardware, quantum technologies, life sciences, and the green transition. The rest of the world has now caught up with our 4th generation light, and an upgrade preserves and extends Sweden's competitive advantage in research and innovation.

The question is not whether Sweden needs an upgraded MAX IV, the question is whether that capability will be located in Sweden. Without the upgrade, we risk falling

Contacts

MAX 4U
MAX4U@maxiv.lu.se

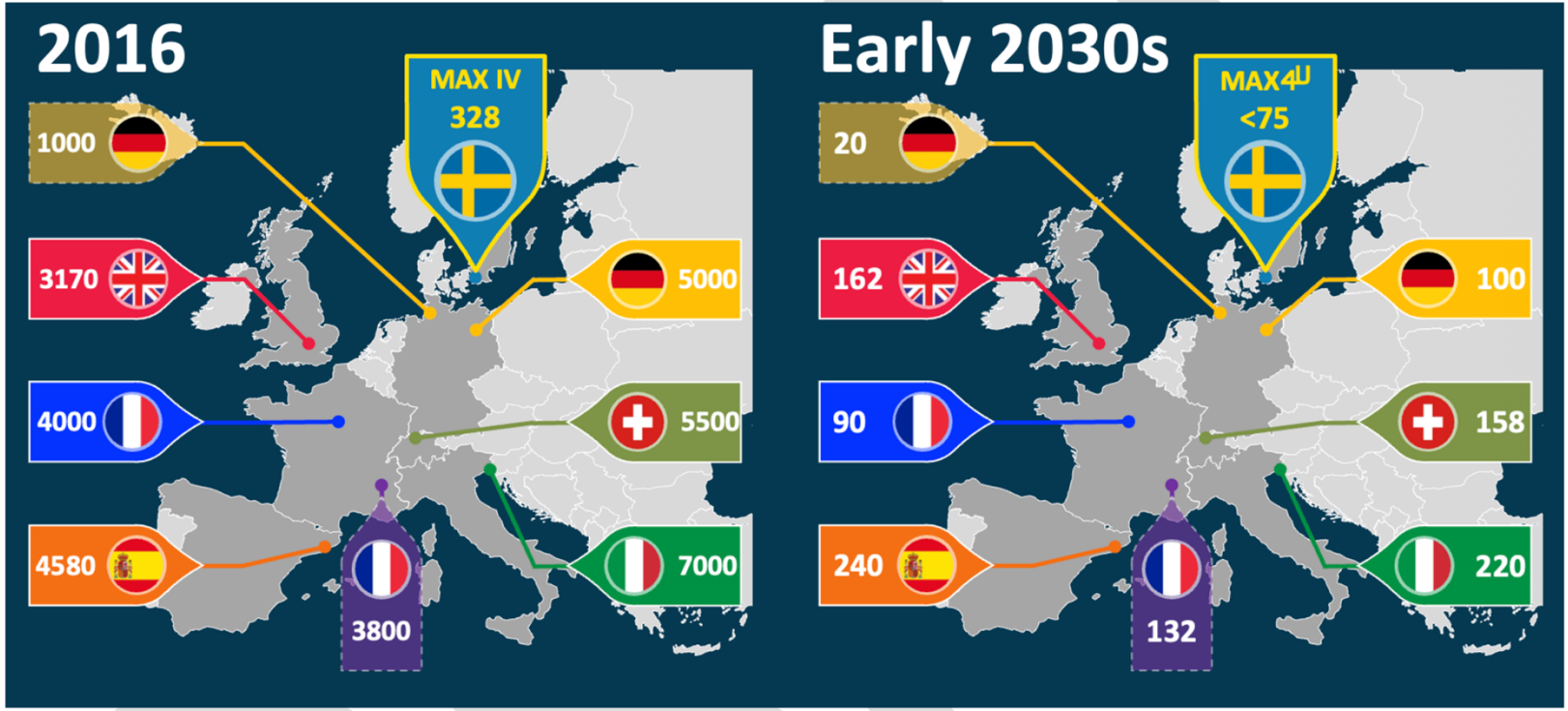

Figure Left: *Bare lattice emittance (in units of picometer radian [pm·rad]) of the European lightsources in 2016. MAX IV achieves 328 pm·rad, an emittance 3 to 20 times better than any other lightsource.* ***Right****: Emittance of those same lightsources by2030s. Facilities with dashed contours are high-energy storage rings with electron beam energies larger than 4 GeV. MAX 4^{U} aims at reaching an emittance <75 pm·rad. [Numbers quoted for 2030s are based on funded projects at the time of designing the figure.]*

LUMIA – Entry environment (instegsmiljö) for Max IV and DESY



Beamtime access cycle

LUMIA can help with:	BT proposal	Prep BT	BT	After BT
Network, with staff at Max IV	x	x		
Initial studies, with similar techniques	x	x		
Experienced users, know-how	x	x	x	x
Software for analysis of results			x	x

LUMIA – LULEÅ MATERIAL IMAGING AND ANALYSIS



Scanning Electron Microscopy, SEM
X-ray Computed Tomography, XCT

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Acknowledgement:

The purchase of this state-of-the-art instrumentation was made possible through financial support from:

Kempestiftelserna

Wallenberg Initiative Materials Science for Sustainability

The LTU Lab Fund

Knut and Alice Wallenberg Foundation

LKAB

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Snow crystal scanned at the x-ray microtomography Lab at LTU



Thank you!

Questions?

E-mail: **fredrik.forsberg@ltu.se**