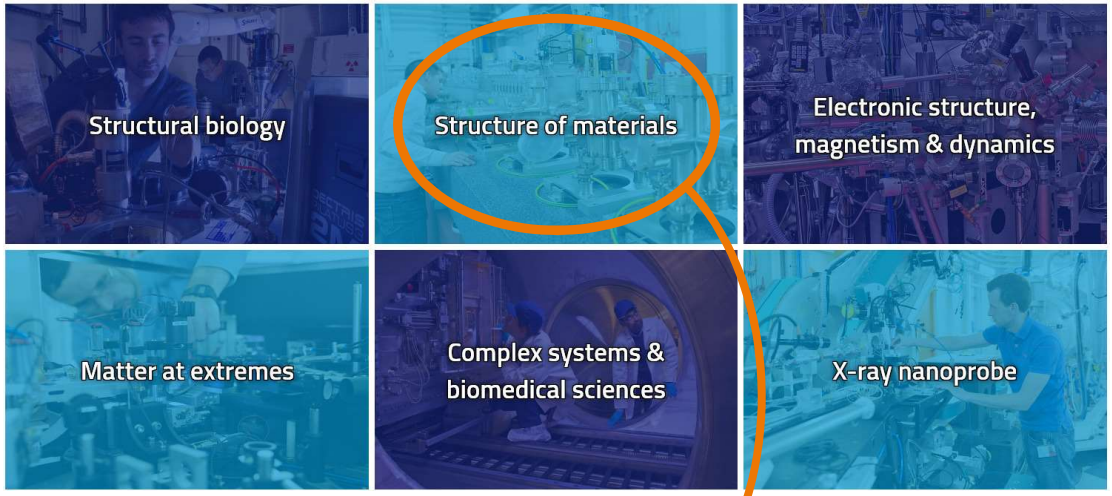

ESRF
The European Synchrotron

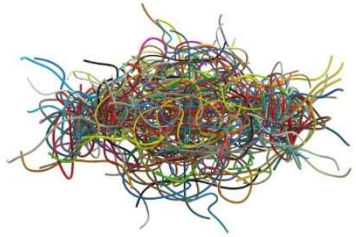
STRUCTURE OF MATERIALS GROUP



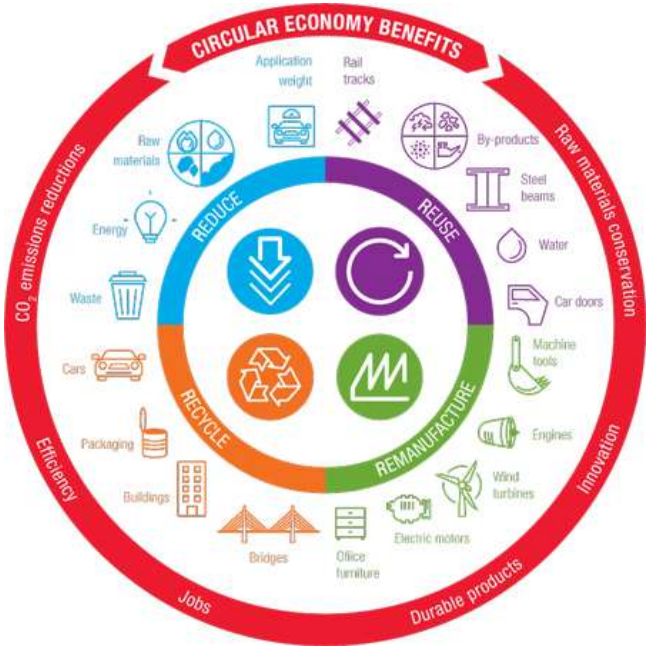
- ID03 Hard X-ray Microscope
- ID11 Materials science
- ID15A High-energy beamline for materials chemistry and engineering
- BM18 High throughput large field phase-contrast
- ID19 Microtomography beamline
- ID22 Powder diffraction
- ID31 High-energy beamline for buried interface structures and materials processing
- BM05 Instrumentation facility and proprietary tomo- and topography research

GREEN TRANSITION

- Clean energy, clean industry, security and sustainability of raw materials, etc.
- Research and innovation driven



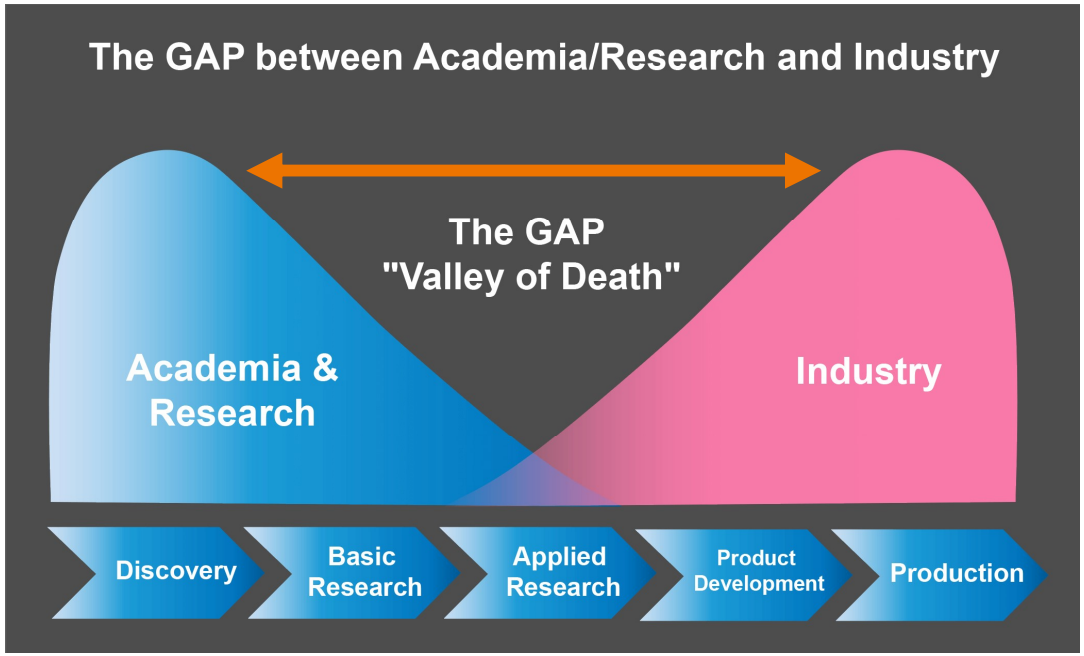
- increasing complexity
- tackling multifaceted problems

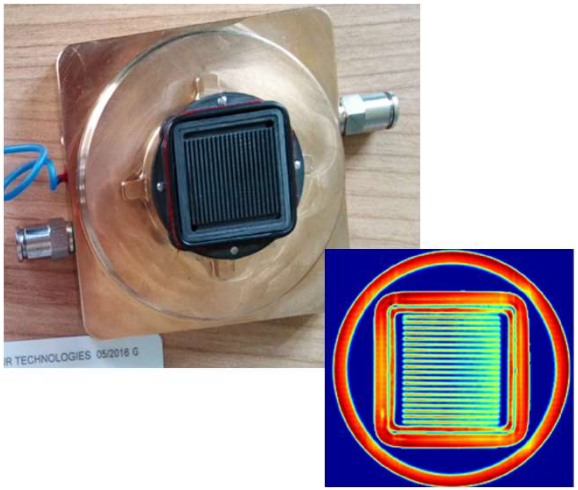


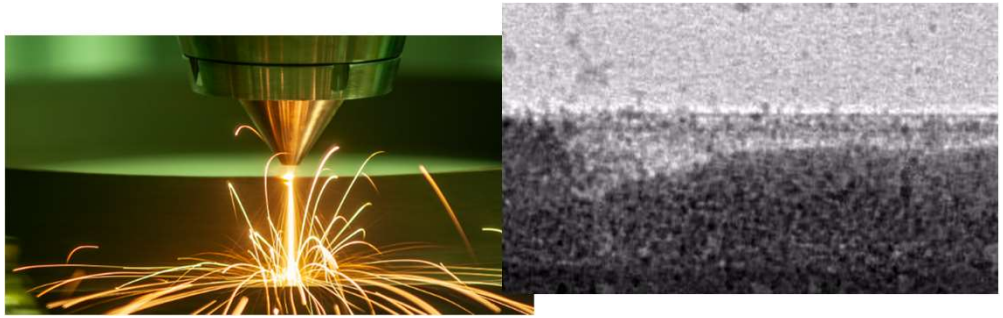
- requires the use of several techniques
- proceed from science to technology

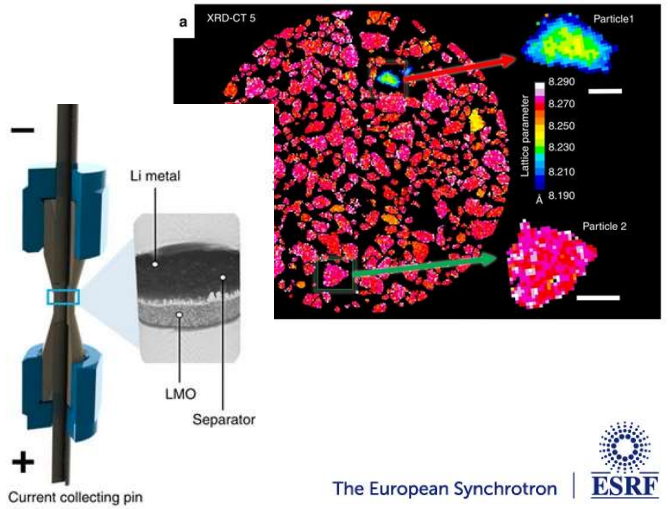
- interdisciplinary groups
- centralized facilities

Filling the Gap









Additive Manufacturing

AM is

- versatile, flexible
- highly customizable
- enables rapid low-volume production highly complex components

Widely varying materials

- metals, ceramics, glasses
- polymeric materials, tissues
- along with combinations in the form of composites, hybrid, or functionally graded materials

More art than science, the challenges remain

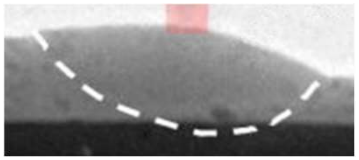
- great uncertainty in terms of the processes and controls
- obtaining objects that are functional
- 'materials' and 'metrology' to achieve this functionality in a predictive and reproductive ways
- control of material properties, geometry, and residual stresses

Tremendous discrepancy in materials and processes, with each having their own strengths and weaknesses

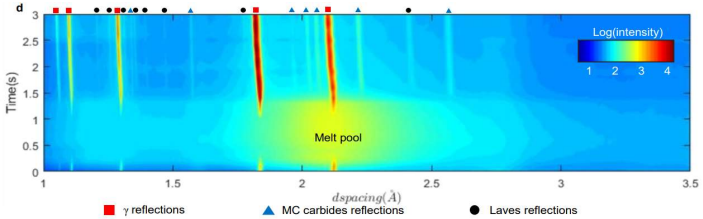
The European Synchrotron | ESRF

LASER ADDITIVE MANUFACTURING (LAM)

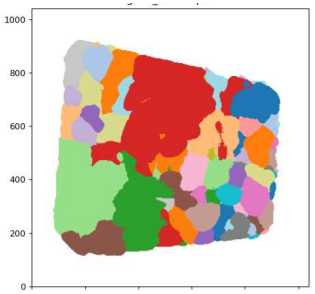
Correlative Synchrotron X-ray techniques



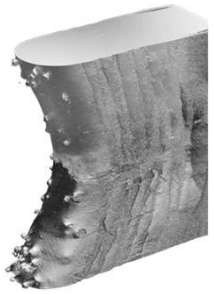
ID19: *In-situ* X-ray imaging of the laser-matter interaction



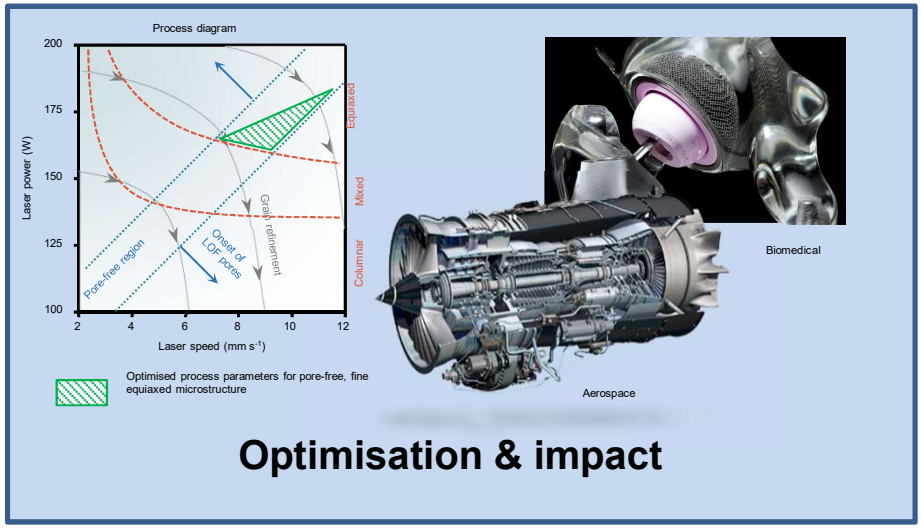
ID31: *In-situ* X-ray diffraction of the phase evolution

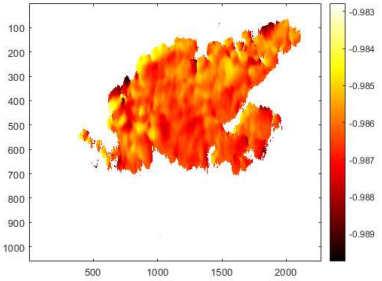


ID11: DCT and 3D-XRD LAM grain mapping



BM05, BM18 & ID19: Tomography of a LAM structure





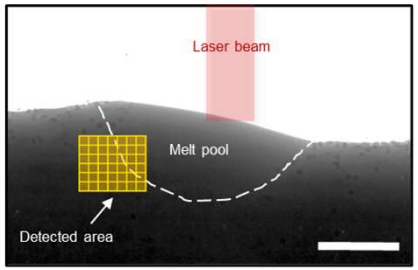
ID03: Dark Field microscopy reveal high angular resolution information of the LAM grain

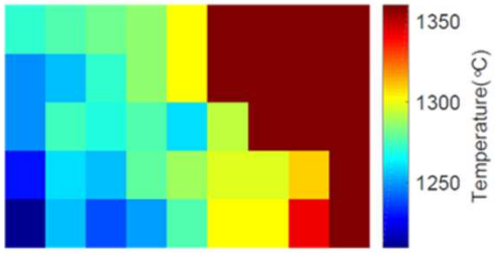
More modalities to come…

Courtesy Y. Chen (RMIT)

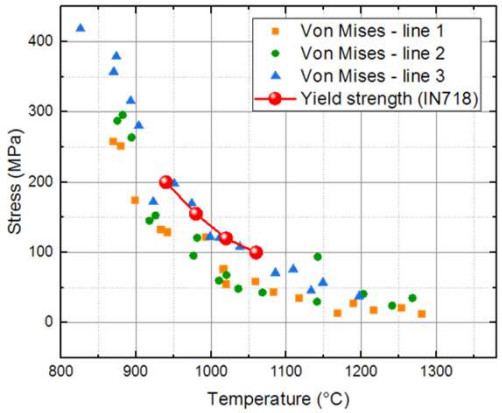
LASER ADDITIVE MANUFACTURING (LAM)

In situ X-ray diffraction of direct energy deposition LAM of IN718

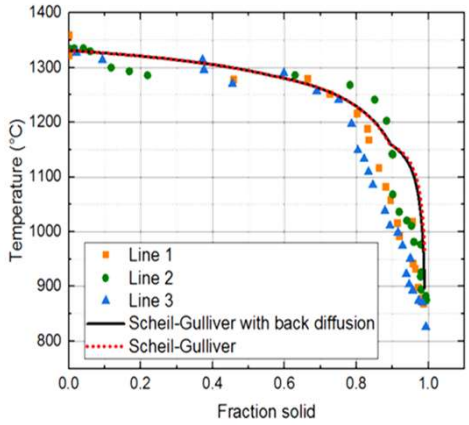




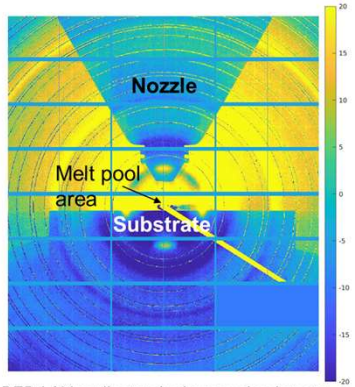
DED-LAM replicator at ID31



Solidification range of IN718



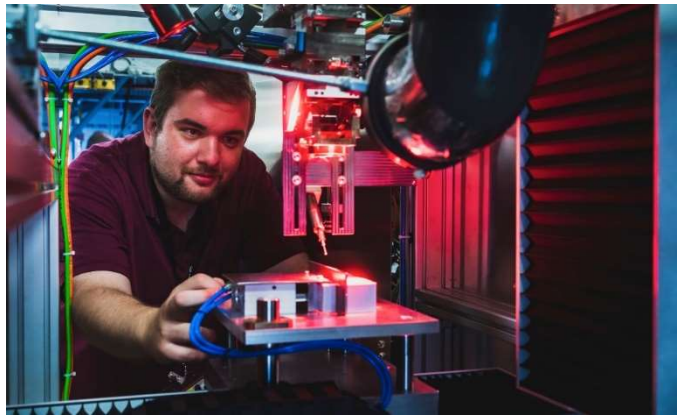
High temperature micromechanical behaviour of IN718



DED-LAM replicator shadows on the detector

Courtesy Y. Chen (RMIT)

LASER ADDITIVE MANUFACTURING (LAM)



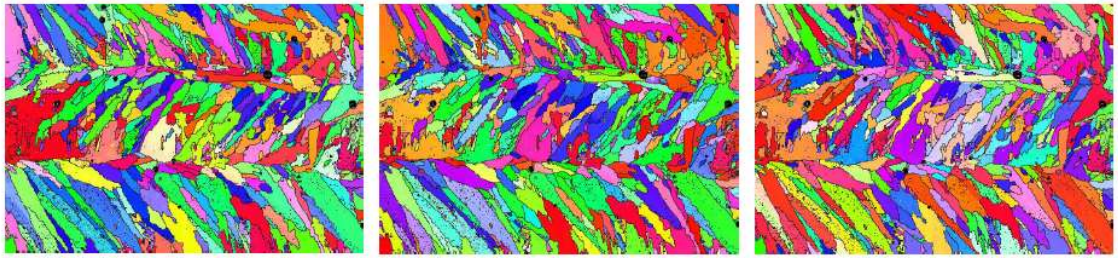
Courtesy Y. Chen (RMIT)

studying the melt pool dynamics and the keyhole formation during laser speeds ≥ 8 m/min

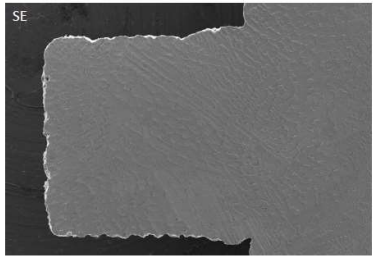
Beamline ID19 (SoM)
Technical University of Ilmenau (Germany)

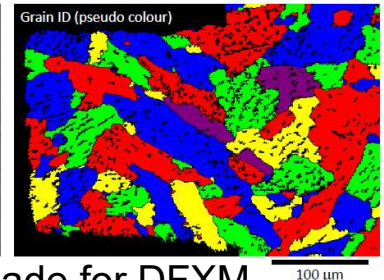
LASER ADDITIVE MANUFACTURING (LAM)

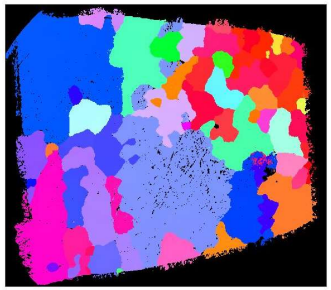
Grain mapping of LAM microstructure



EBSD of DED-LAM microstructure

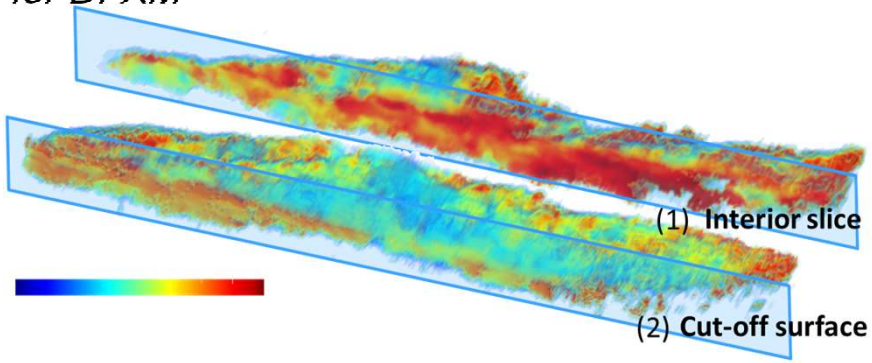






Cantilever made for DFXM

3D rendering of the DFXM scan showing grain mosaicity



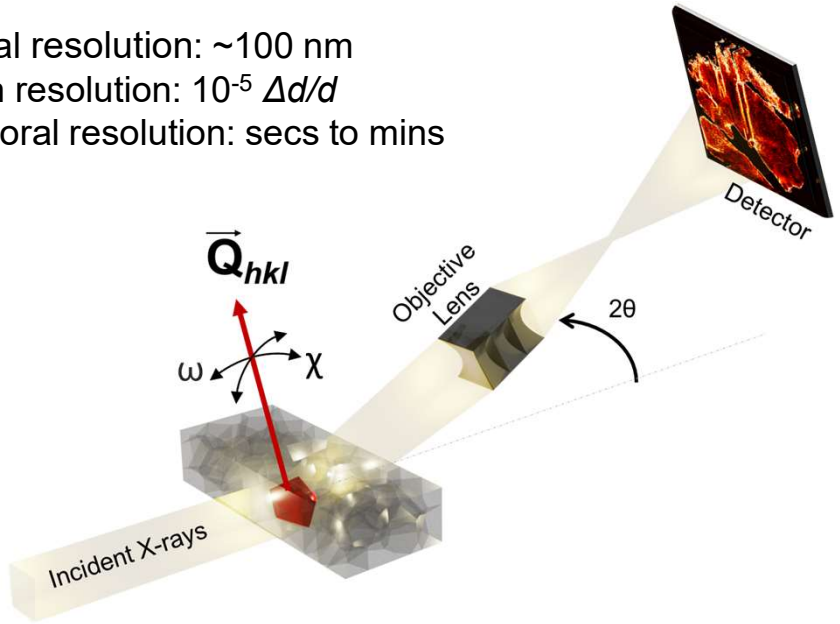
Courtesy Y. Chen (RMIT)

DARK FIELD X-RAY MICROSCOPY (DFXM)

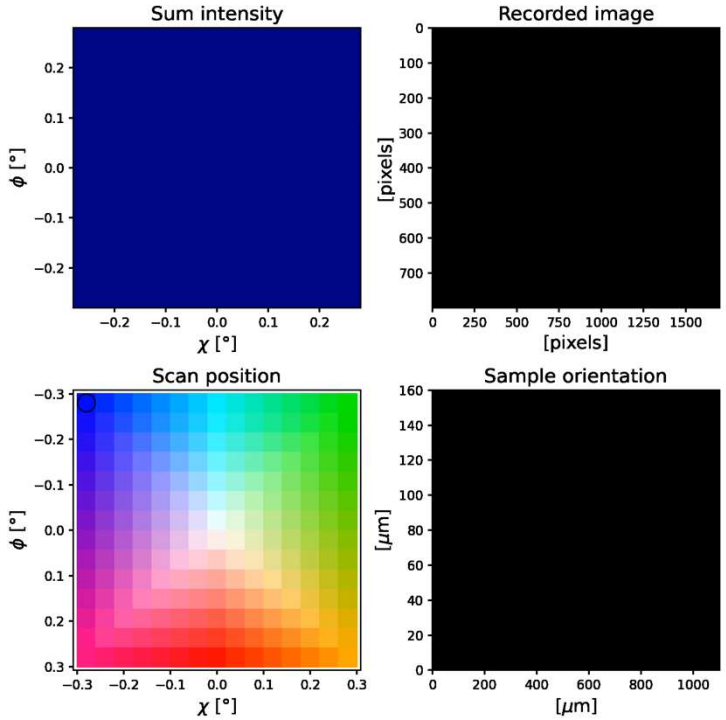
New flagship beamline EBSL02-ID03

A unique microscope to image embedded structures

Spatial resolution: ~100 nm
Strain resolution: 10^{-5} $\Delta d/d$
Temporal resolution: secs to mins



H. Simons *et al, Nat. Comm.* 2015



Courtesy C. Yildirim (ESRF)

DARK FIELD X-RAY MICROSCOPY (DFXM)

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Spatial resolution: ~100 nm
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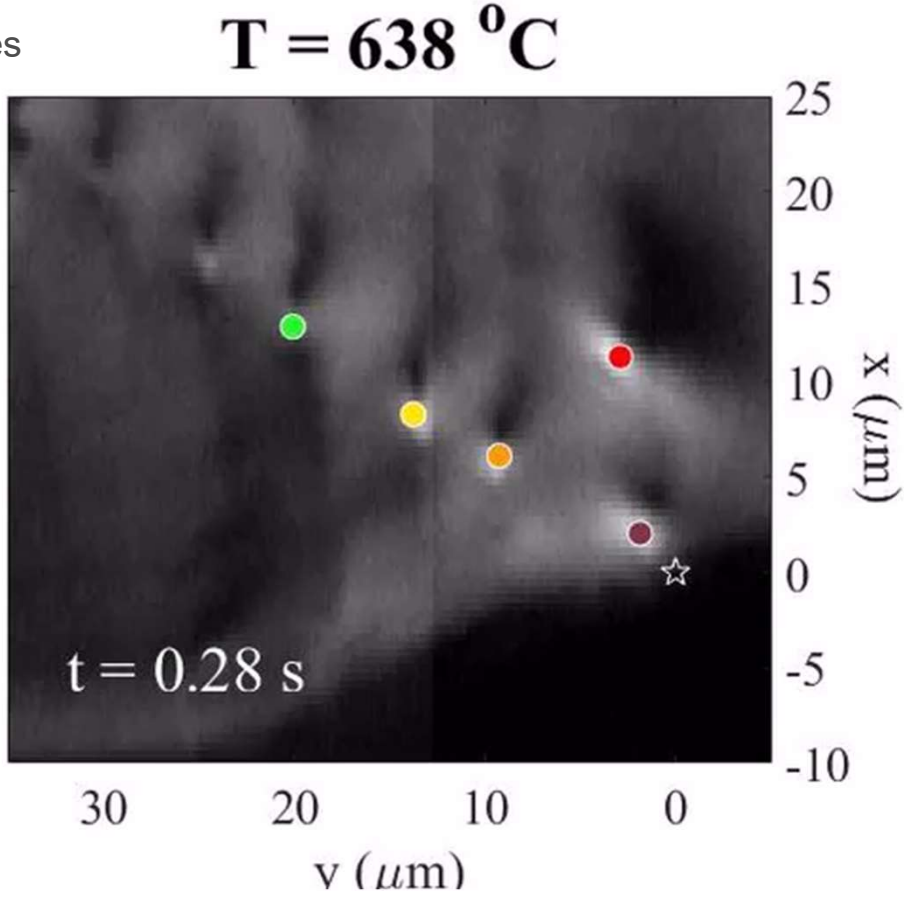
motion of dislocation boundaries in Al

Dresselhaus Marais *et al, Sci Rep*. 2023



Courtesy C. Yildirim (ESRF)

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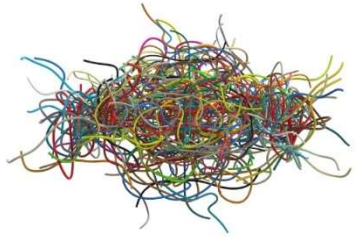

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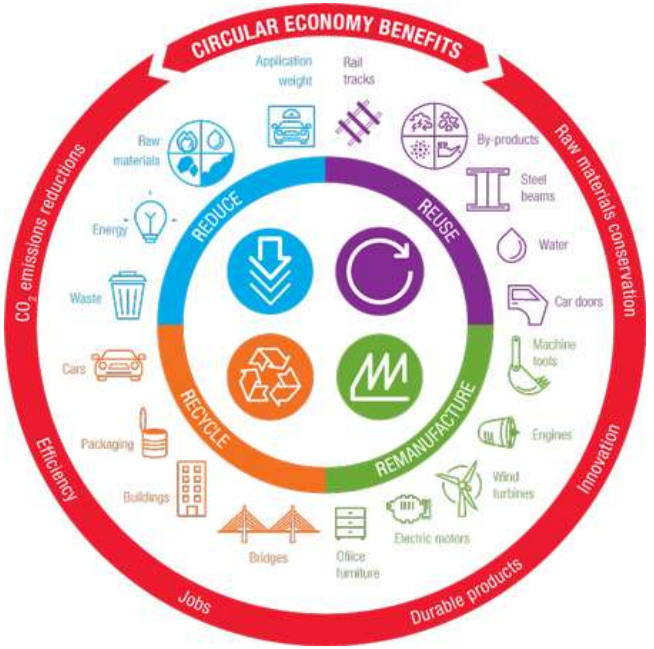

- requires the use of several techniques
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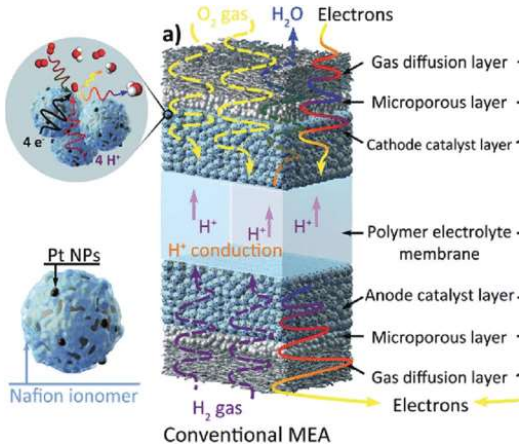
HYDROGEN AND CO_2 CONVERSION

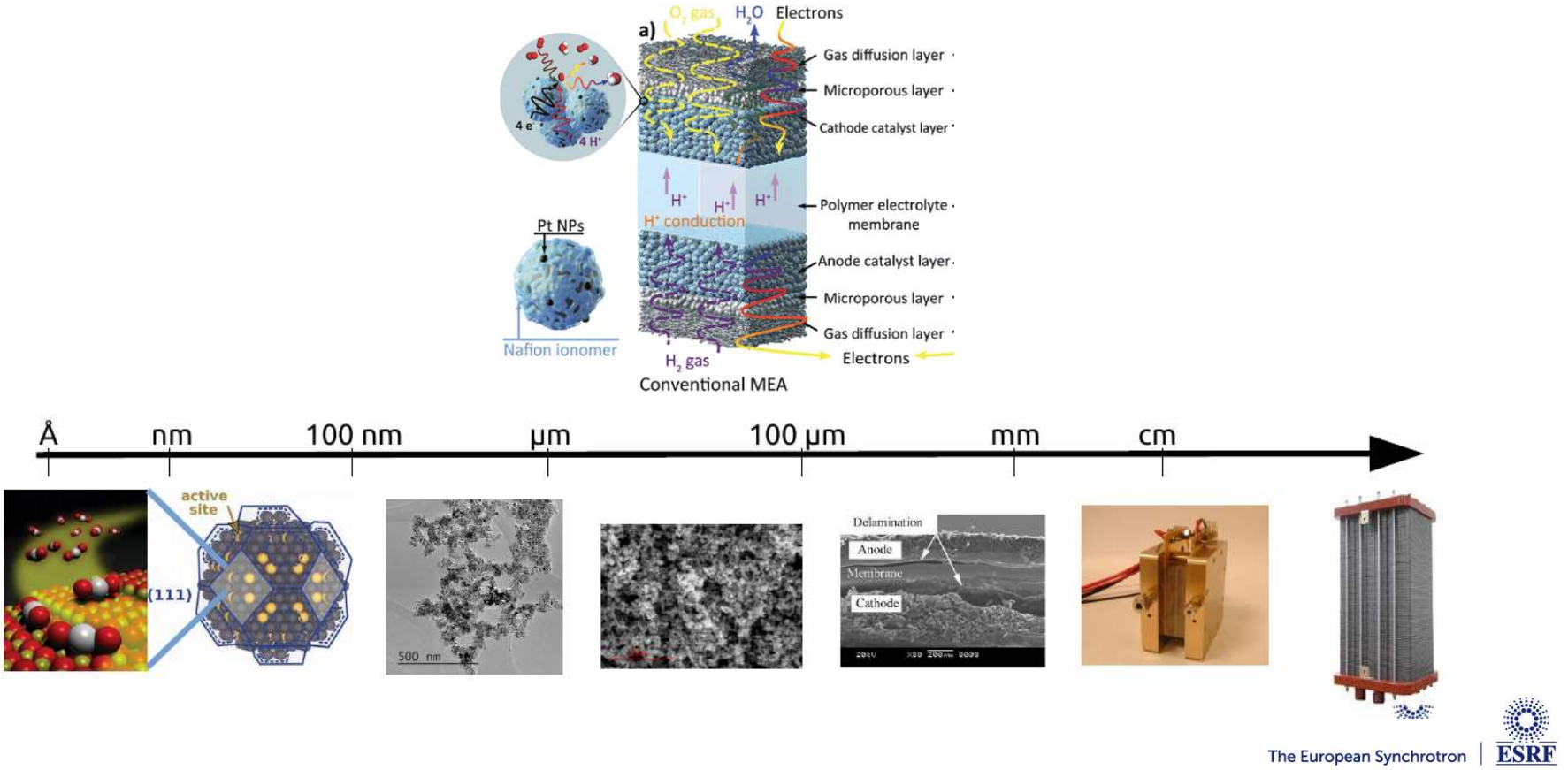
- Electrolyzers and fuel cells are **complicated heterogeneous** electrochemical systems with critical phenomena happening at many different scales



- **Materials and engineering issues** are at the origin of performance limitations
- Materials perform characteristically within their **ideal sample environment**
- The correlative characterization (***in-situ*** and ***operando***) during development of the cell has the highest importance as it is the only route to solve the material problems

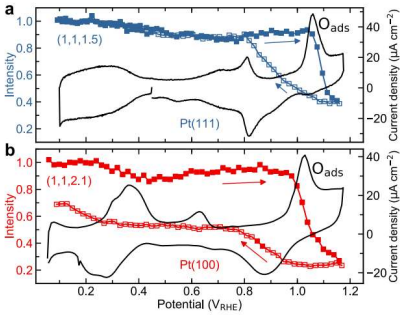
HYDROGEN AND CO_2 CONVERSION

- **Electrolyzers and fuel cells are complicated heterogeneous electrochemical systems with critical phenomena happening at many different scales**



HYDROGEN AND CO_2 CONVERSION

Model systems

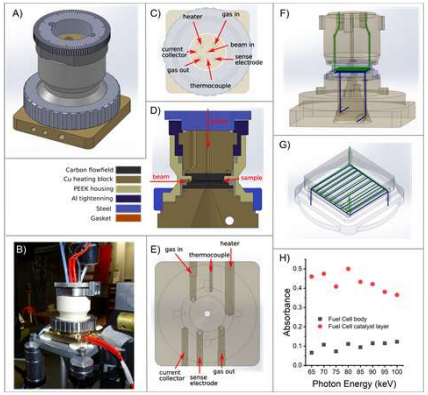


Wiegmann *et al.*, *ACS Catal*, 2022
Fuchs *et al.*, *Nat. Catal.*, 2020
Drnec *et al.*, *Echim. Acta*, 2017
Ruge *et al.*, *JACS*, 2017
…

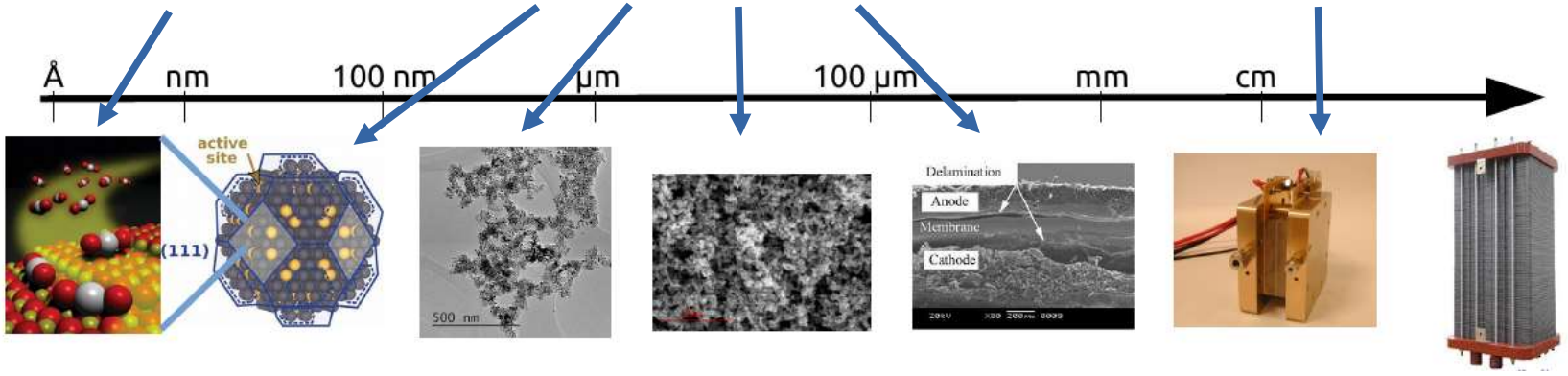
Applied systems

Chattot *et al.*, *JACS*, 2021
Chattot *et al.*, *ACS Energy Lett.*, 2020
Chattot *et al.*, *ACS Catal.*, 2020
Martens *et al.*, *ACS Appl. Energy Matter*. 2019
Chattot *et al.*, *Nat. Matter.*, 2018
…

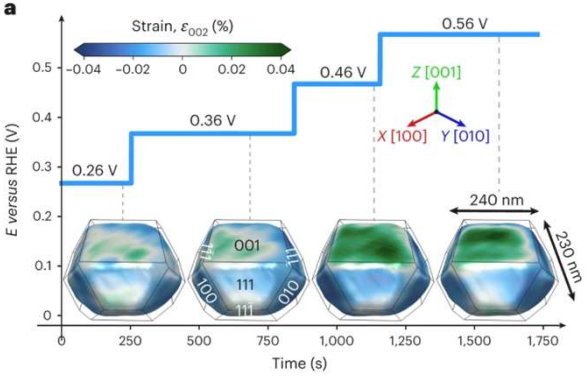
Devices



Martens *et al.*, *J. Power Sources*, 2022
Martens *et al.*, *ACS Energy Lett.*, 2021
Martens *et al.*, *J. Power Sources*, 2020



POWER TO X (CONVERSION OF HYDROGEN AND CO_2)



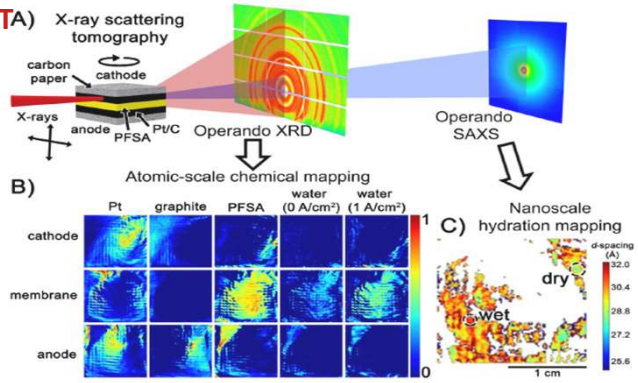
Atlan, J. *et al*, Nature Materials (2023) - ID01

Brag Coherent Diffraction Imaging

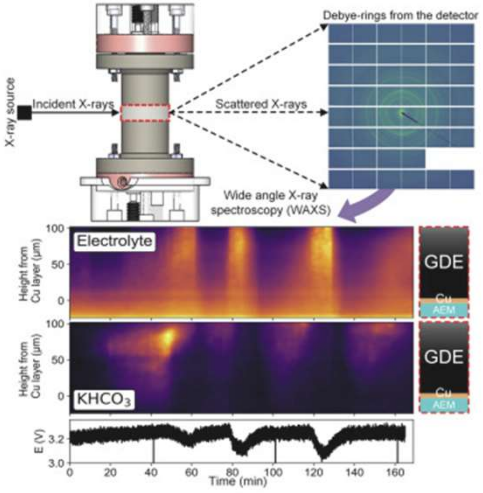
Strain evolution of Pt catalyst under applied potential

Operando XRD/SAXS-CT

Correlative imaging of high performance hydrogen fuel cell showing water distribution in the cell and its relation to the ageing phenomena



Martens *et al*, ACS Energy Letters (2021) - ID31



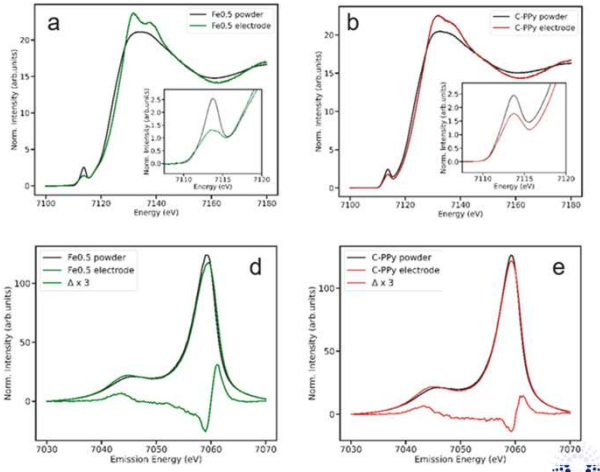
Moss *et al.*, Joule (2023) - ID31

Operando XRD

Emergence of complex oscillatory behavior in CO_2 electrolyzer

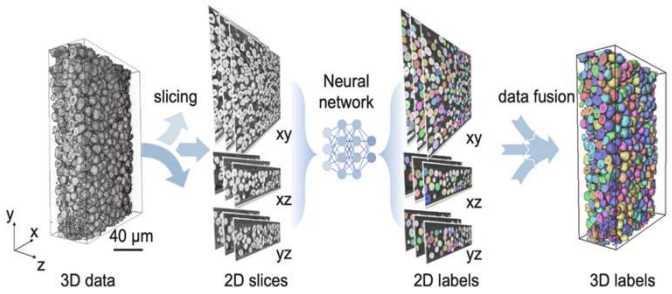
XAS on non-PGM catalysts

Evolution of electronic state of the active catalyst during ink catalyst layer preparation



Savaleva *et al.*, ACS Appl. Energy Matter (2023) - ID26

BATTERIES



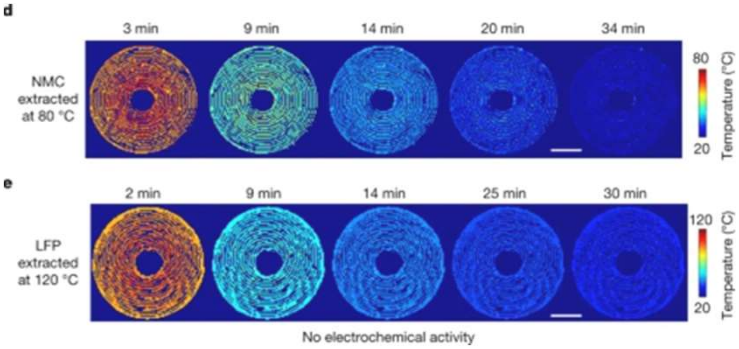
J. Li *et al.*, Science (2022) - ID16A

X-ray tomography

Lithium ion Battery Cathode: Particle Damaging Driving Force vs Cycling Number

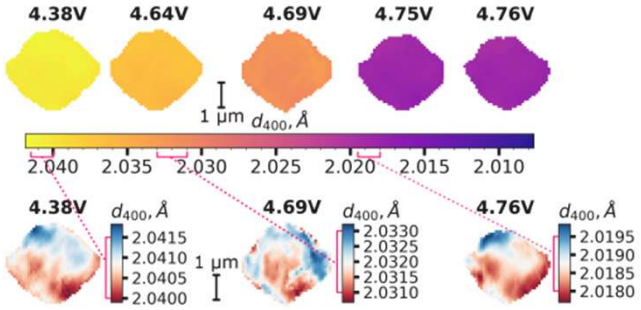
XRD-CT

Battery temperature evolution during fast charge/discharge



Heenan *et al*, Nature (2023) - ID15A

- ESRF capabilities span from fundamental research of battery materials to characterization of commercial cells
- Multiscale and multimodal
- Atomic scale structure → nanoscale and mesoscale morphology → coin cells → cylindrical commercial cells



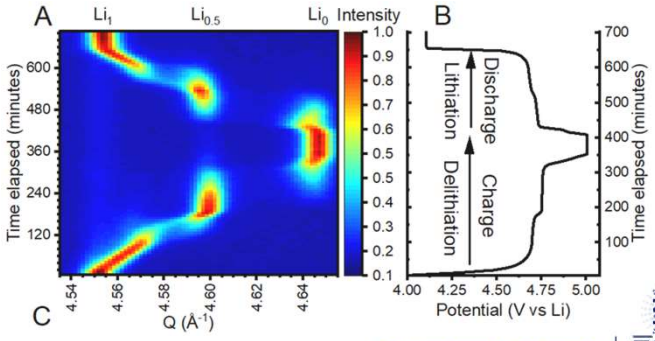
Martens *et al.*, 10.26434/chemrxiv-2022-lkzbj(2023) - ID01

Scanning Nanodiffraction

Strain evolution in cathode LMNO during battery charge

Operando XRD

Phase transitions in cathode LMNO cathode material during charge and discharge



Martens *et al*, ACS Materials Letter (2022) - ID31

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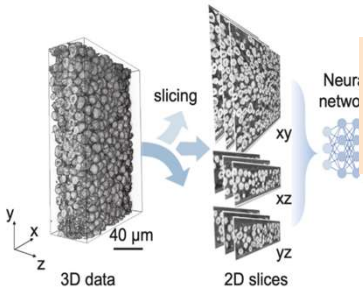
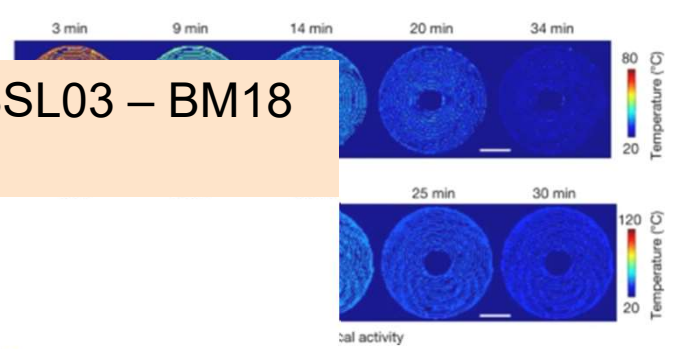
BATTERIES

Hierarchical imaging at BM05 and EBSL03 – BM18

Courtesy P. Tafforeau

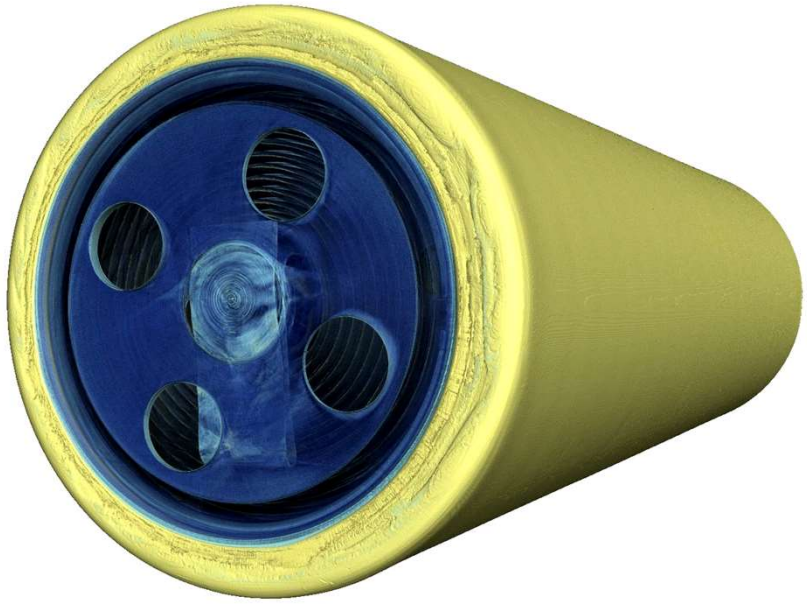


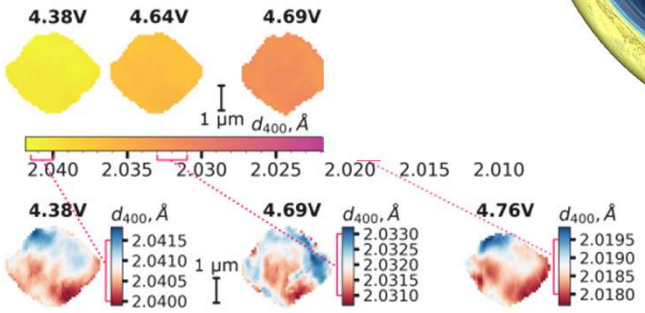
J. Li *et al.*, Science (2022) -



(2023) - ID15A

- ESRF capabilitie … ion of commercial cells
- Multiscale and m …
- Atomic scale stru … ·ical commercial cells

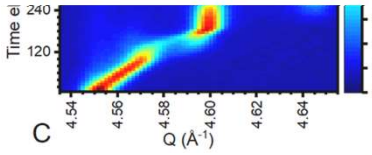


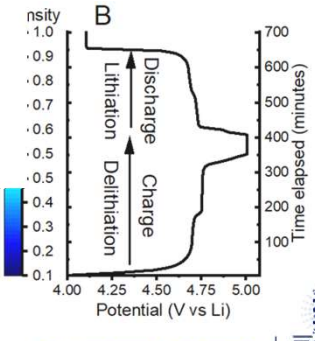


Martens *et al.*, 10.26434/chemrxiv-2022-lkzbj(2023) - ID01

in cathode LMNO during battery charge

cathode material during charge and discharge





Martens *et al*, ACS Materials Letter (2022) - ID31

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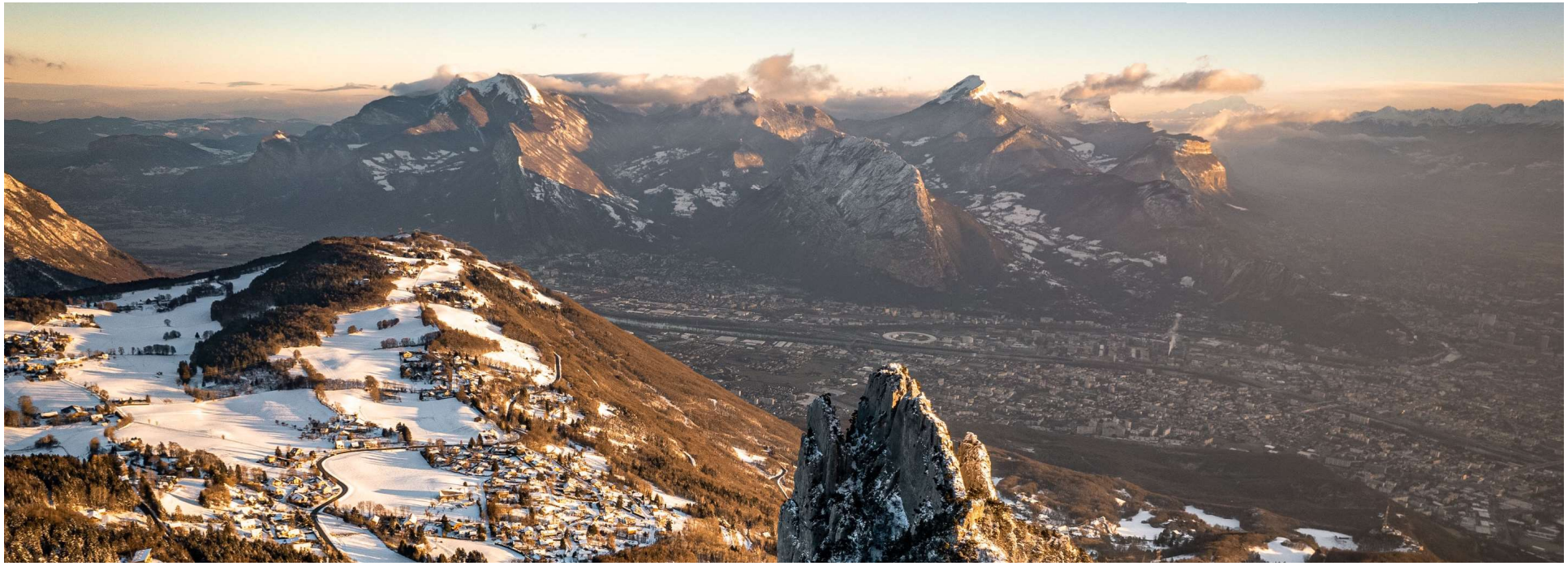

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STREAMLINE

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