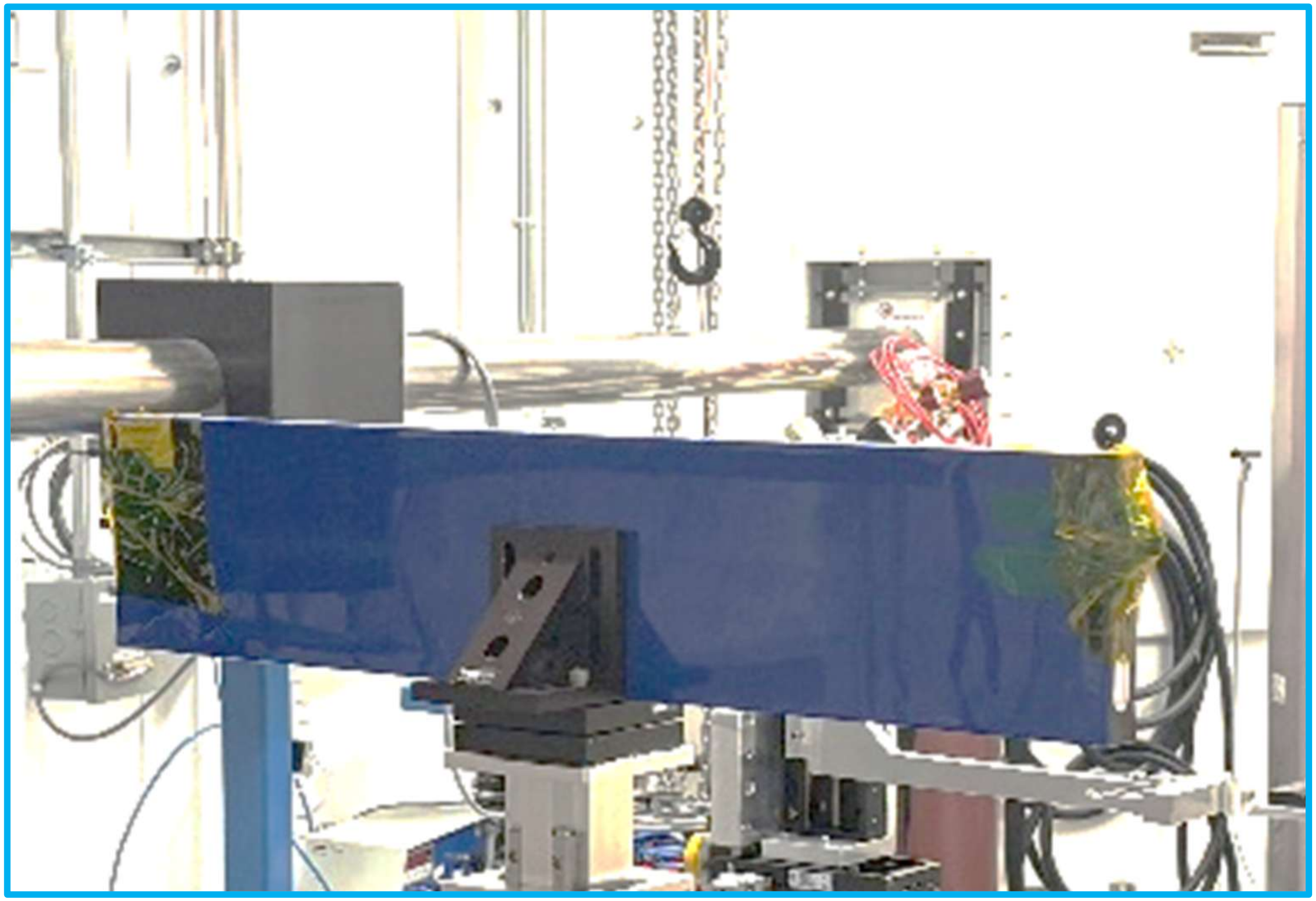
The Canadian Light Source (CLS):



Synchrotron Diffraction and Scattering Techniques for Battery Applications

Joel Reid,
Industry Services Group

Thursday,
July 16th, 2026

Canadian Light Source Centre canadien de rayonnement synchrotron

Outline

1. A brief introduction to the Canadian Light Source (CLS).

2. Examination of some of the diffraction and scattering capabilities we have at the CLS, and their application to battery materials and systems.

The Canadian Light Source (CLS)

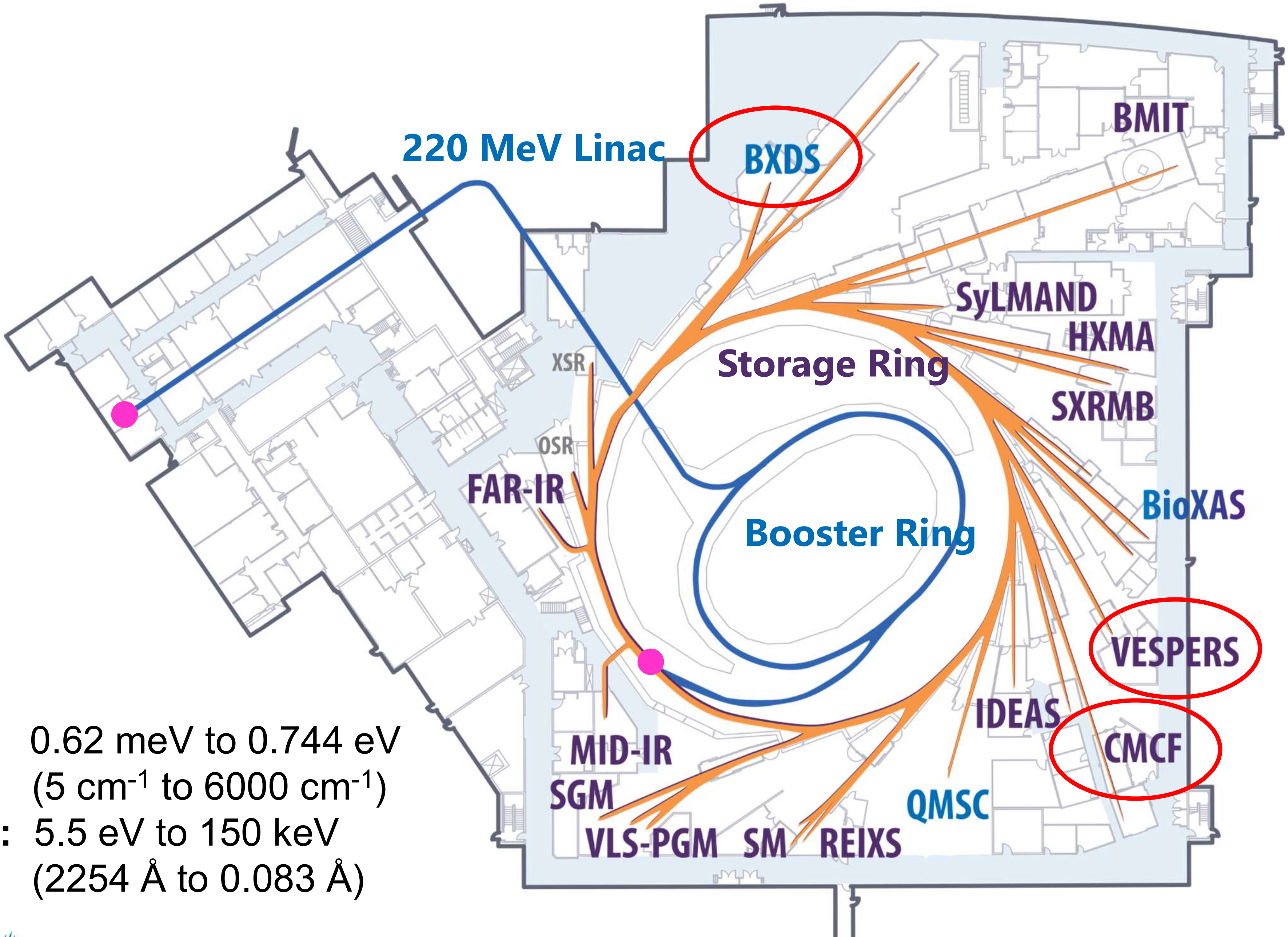
- The CLS is a 3rd generation synchrotron located in Saskatoon, Saskatchewan.

- Canada's only synchrotron facility, construction began in 1999 and the CLS was commissioned for operation in 2005.

- The CLS is a federally-funded, independent, non-profit organization with approximately 250 to 300 employees

- Industry access is a core mandate of the CLS.

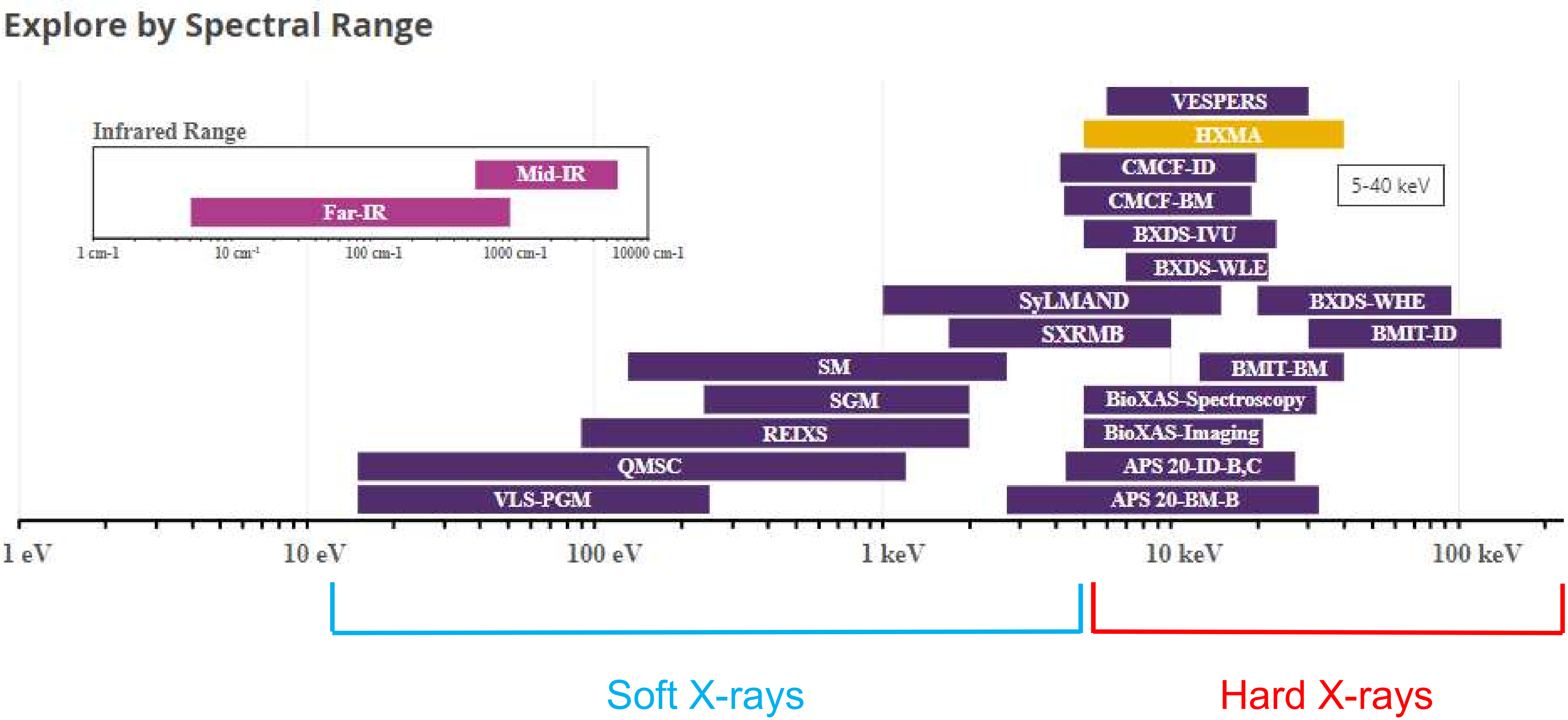
CLS Floor Plan



IR: 0.62 meV to 0.744 eV
($5\ cm^{-1}$ to $6000\ cm^{-1}$)

X-ray: 5.5 eV to 150 keV
(2254 Å to 0.083 Å)

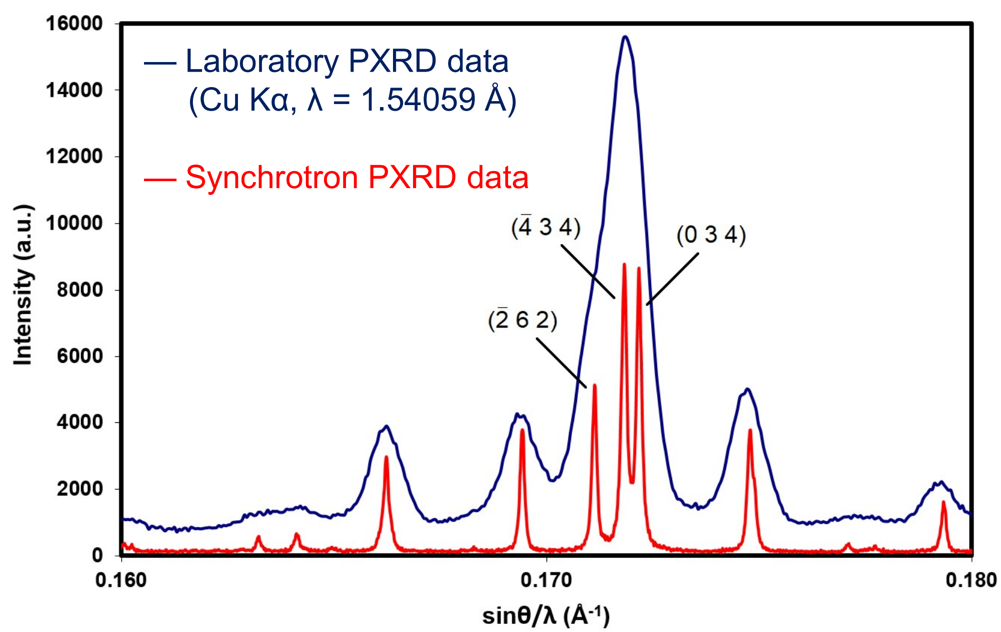
CLS Beamlines – Getting Started



https://www.lightsource.ca/facilities/beamlines/where-to-start.php

Why Synchrotron PXRD?

- Synchrotron sources provide a number of distinct advantages for powder diffraction:
  - **High resolution** (thinner peaks than a laboratory diffractometer).
  - High intensity (short data collection times, improves application of diffraction to time-resolved studies and small sample volumes).
  - Excellent signal-to-noise and intensity estimates from large 2D detectors.
  - Tunable energy over a wide range, facilitating anomalous dispersion & pair distribution function (PDF) techniques:
    - Brockhouse: E = 7 to 90 keV (λ = 1.8 to 0.14 Å).
    - CMCF: E = 4 to 18 keV (λ = 3.1 to 0.69 Å).



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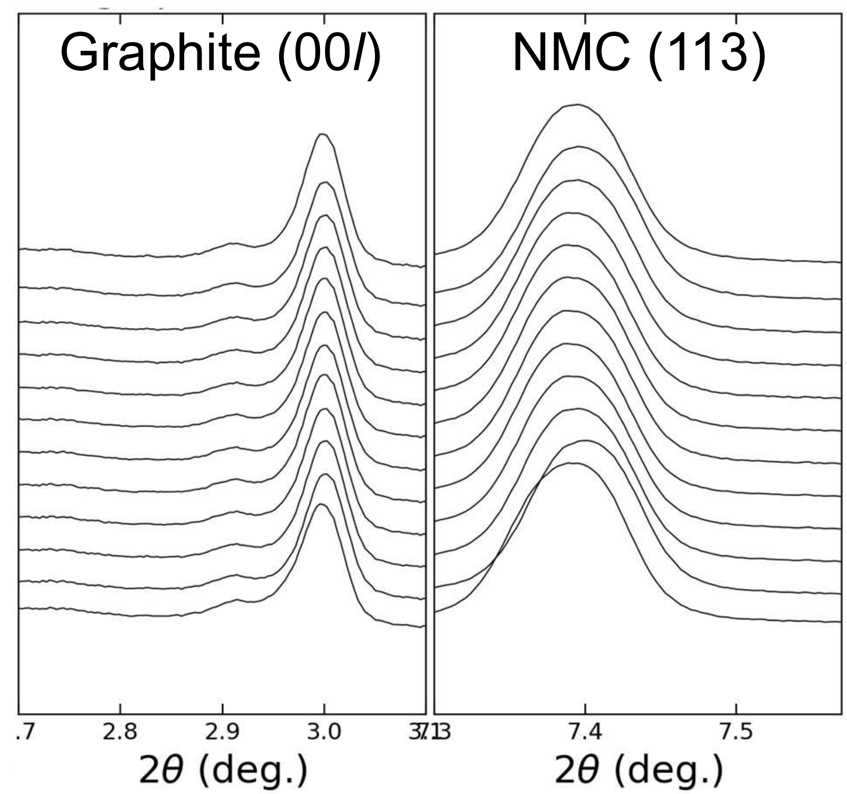

Bond, T., *et. al.* Unpublished work.

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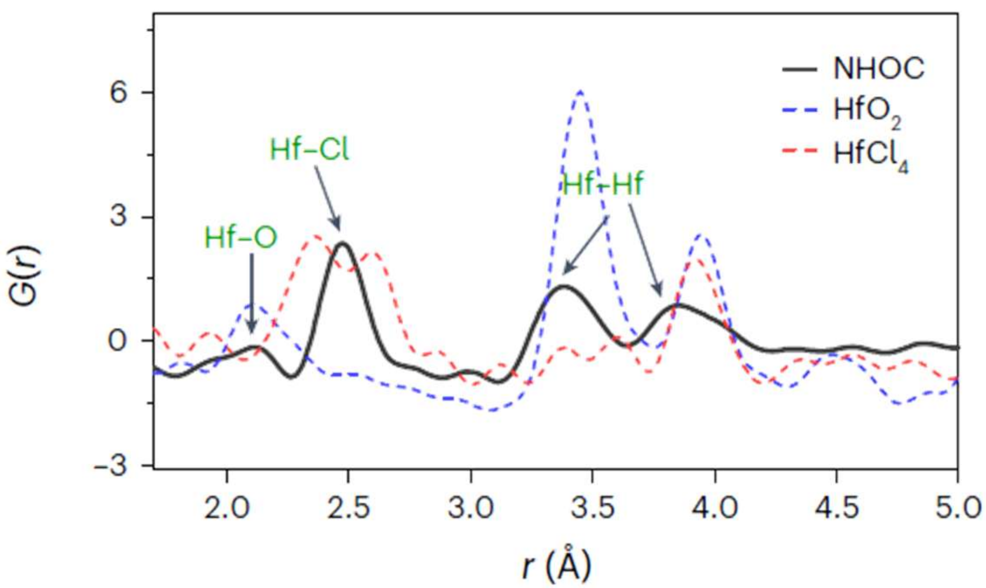

Lin, X. *et al.*
Nature Mat. **24**(1) (2025) 83-91.

PDF data

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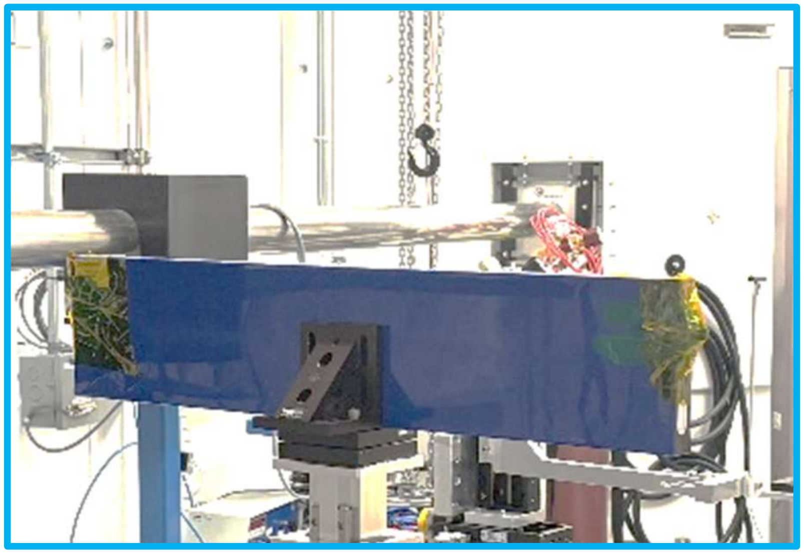
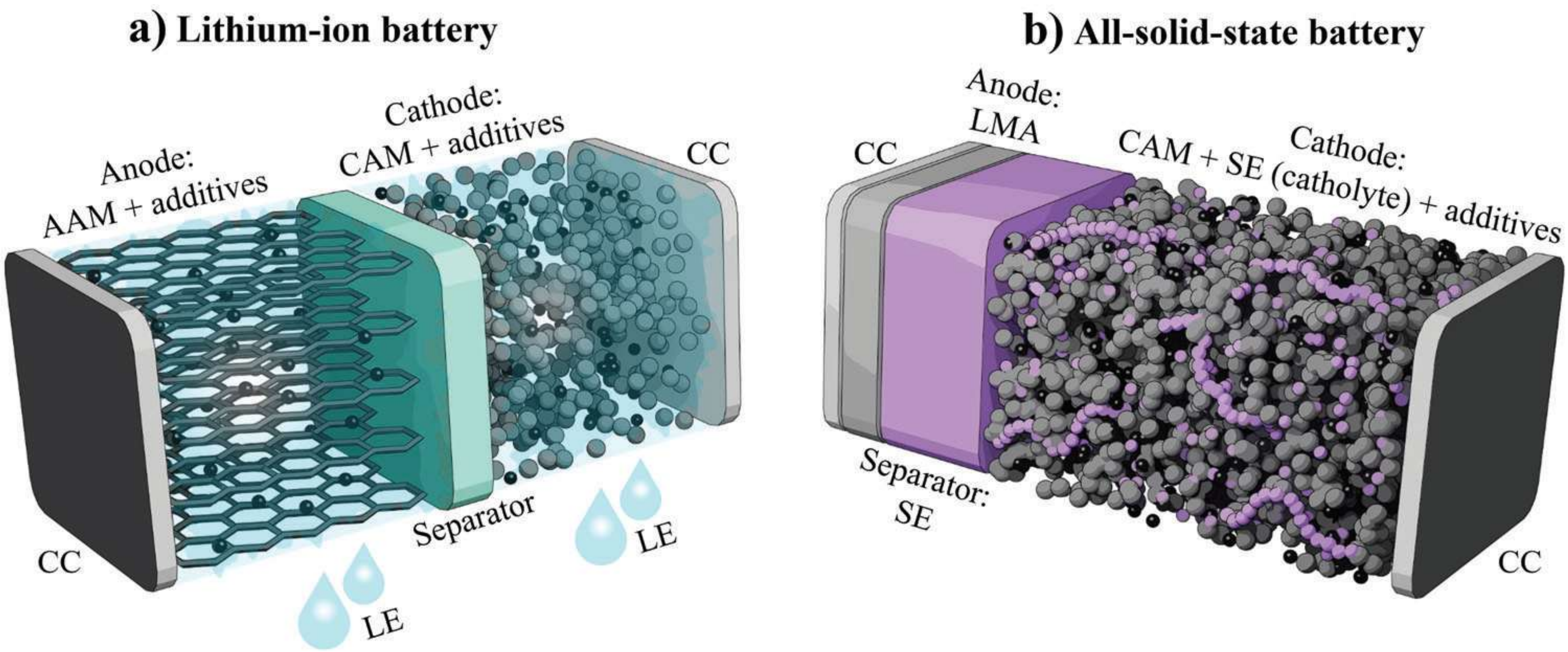
SVOLT Blade cell (LFP)



Bond, T., *et. al.* Unpublished work.

Canadian Light Source Centre canadien de rayonnement synchrotron

PXRD Example: Structures of New Battery Materials



LE = Liquid Electrolyte

SE = Solid Electrolyte \ Catholyte

CC = Current Collector

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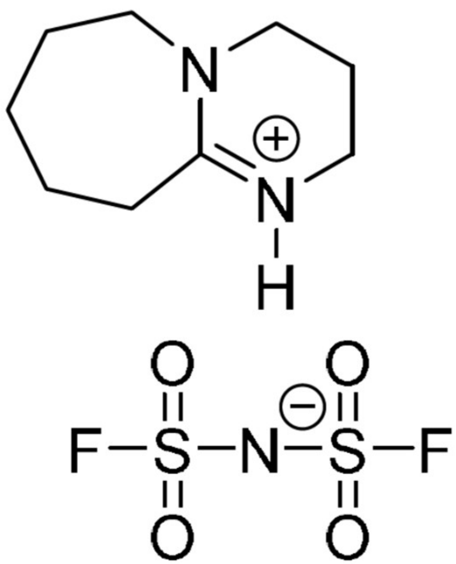
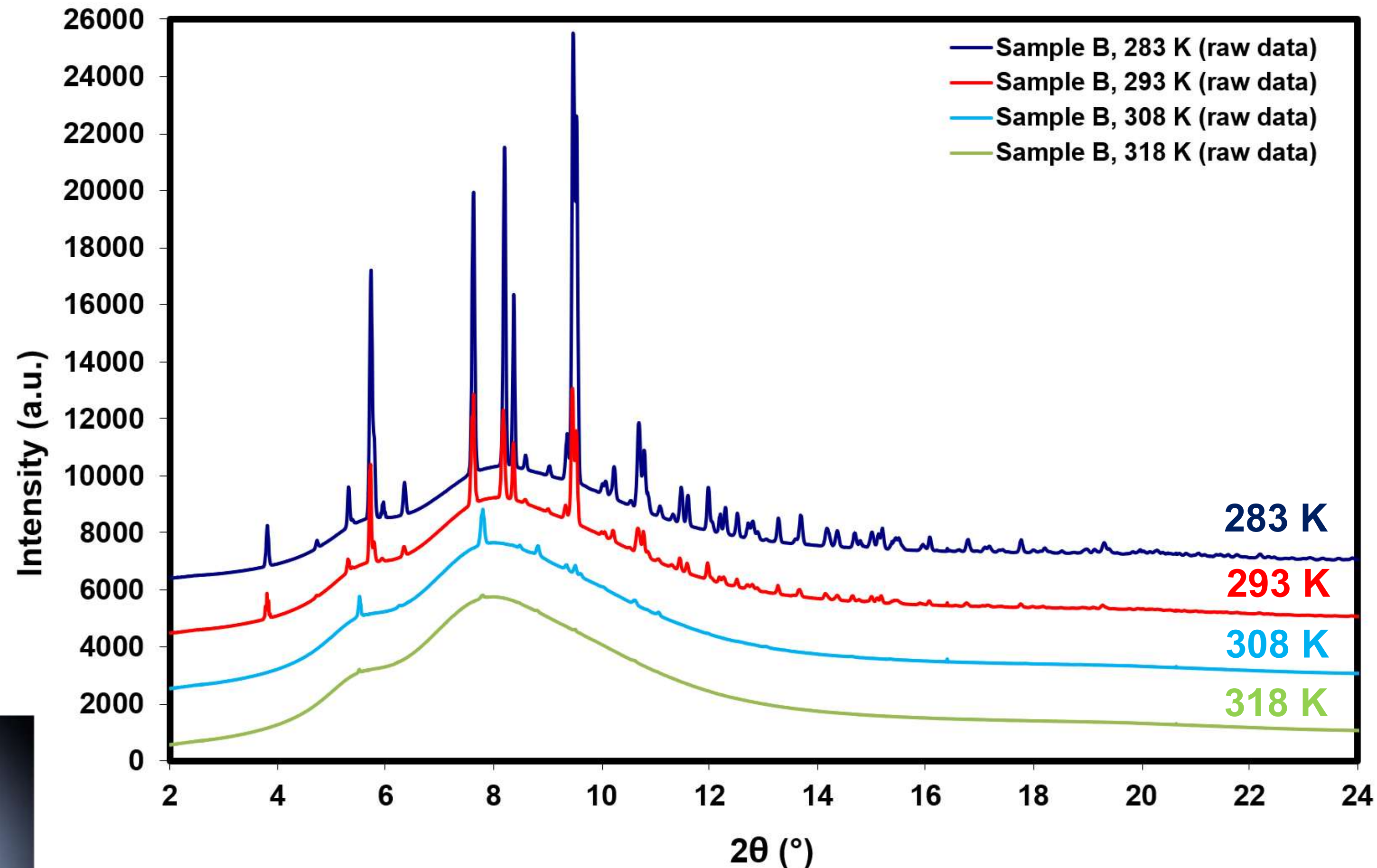
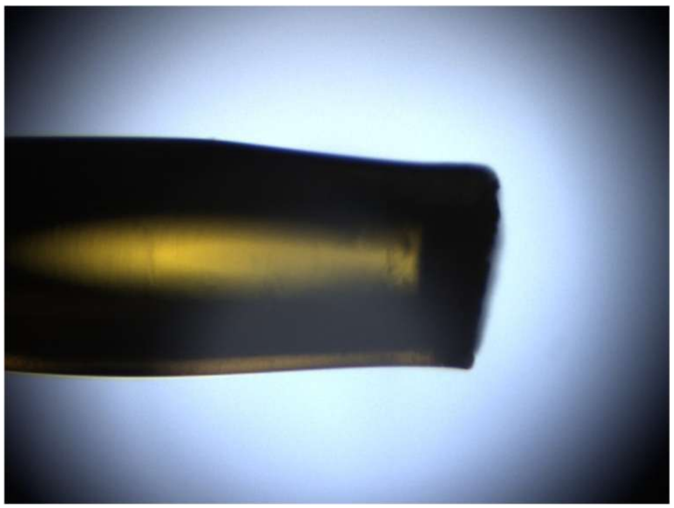
Figure taken from:
Schmaltz, T., *et al*. Adv. Energy Mater. **13** (2023) 2301886.

PXRD Example: Structures of New Battery Materials





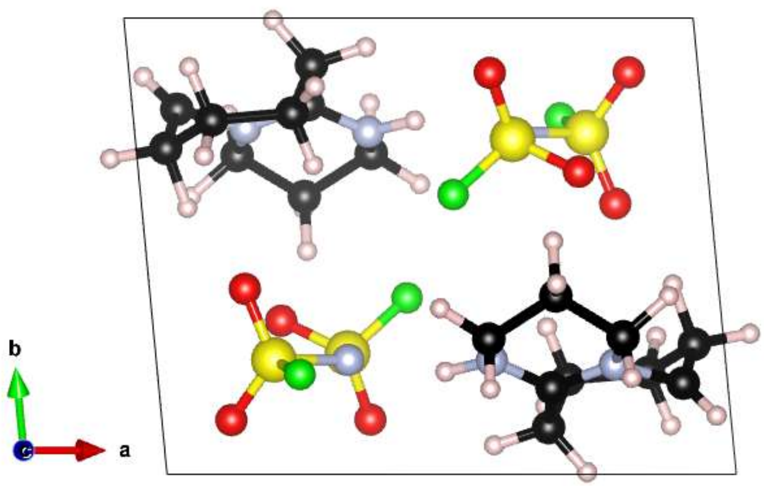
0.5 mm diameter capillary

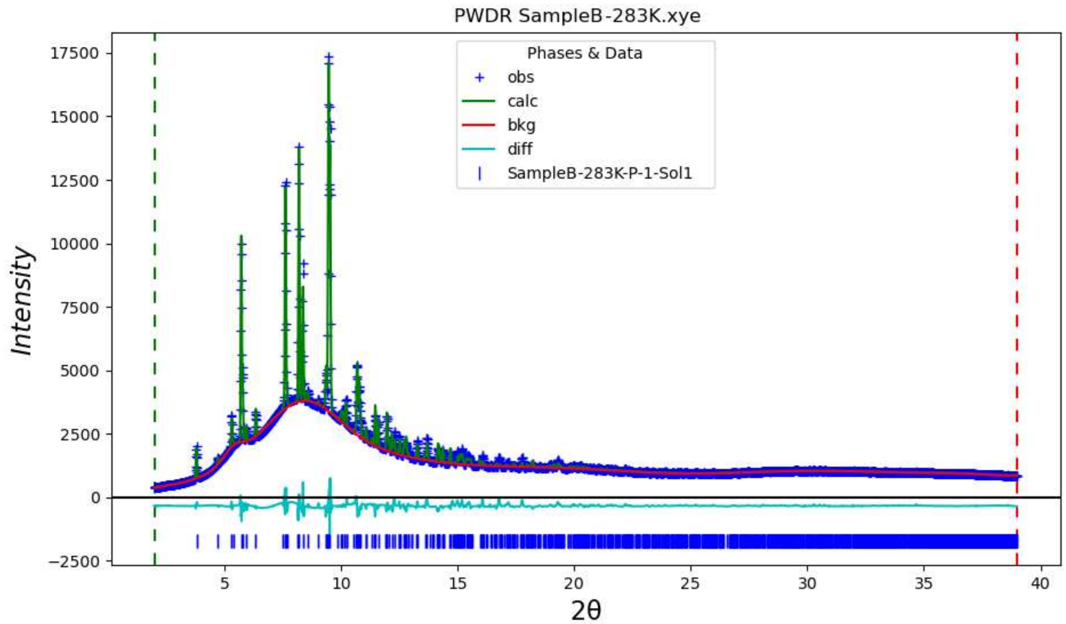


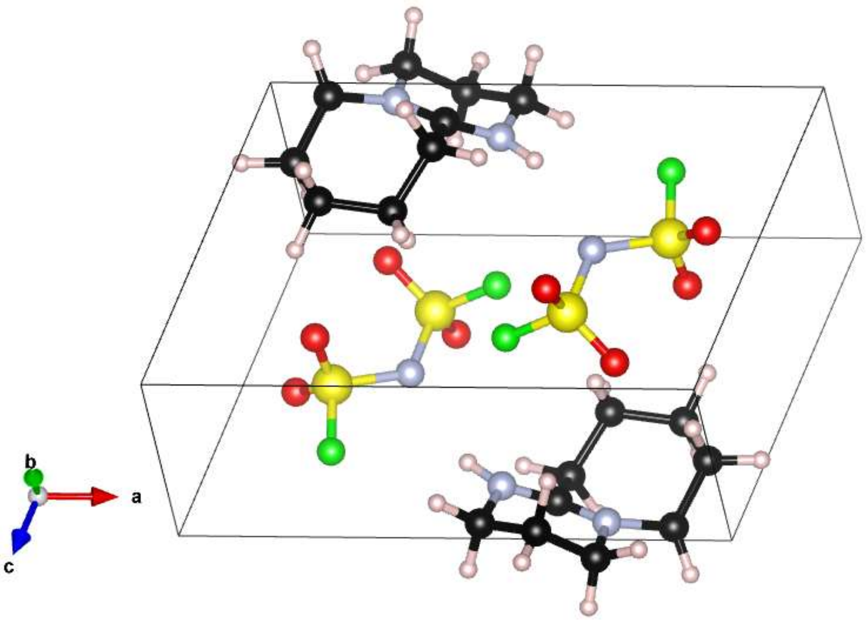
Data courtesy of Jean-Christophe Daigle and Chisu Kim (Hydro-Québec).

CMCF-BM beamline

PXRD Example: Structures of New Battery Materials







Triclinic, P-1 (#2)

a = 11.291(2) Å, b = 8.965(1) Å, c = 8.447(2) Å,
α = 69.094(2)°, β = 112.851(4)°, γ = 102.697(4)°
V = 732.8(1) $Å^3$

Data courtesy of Jean-Christophe Daigle and Chisu Kim (Hydro-Québec).

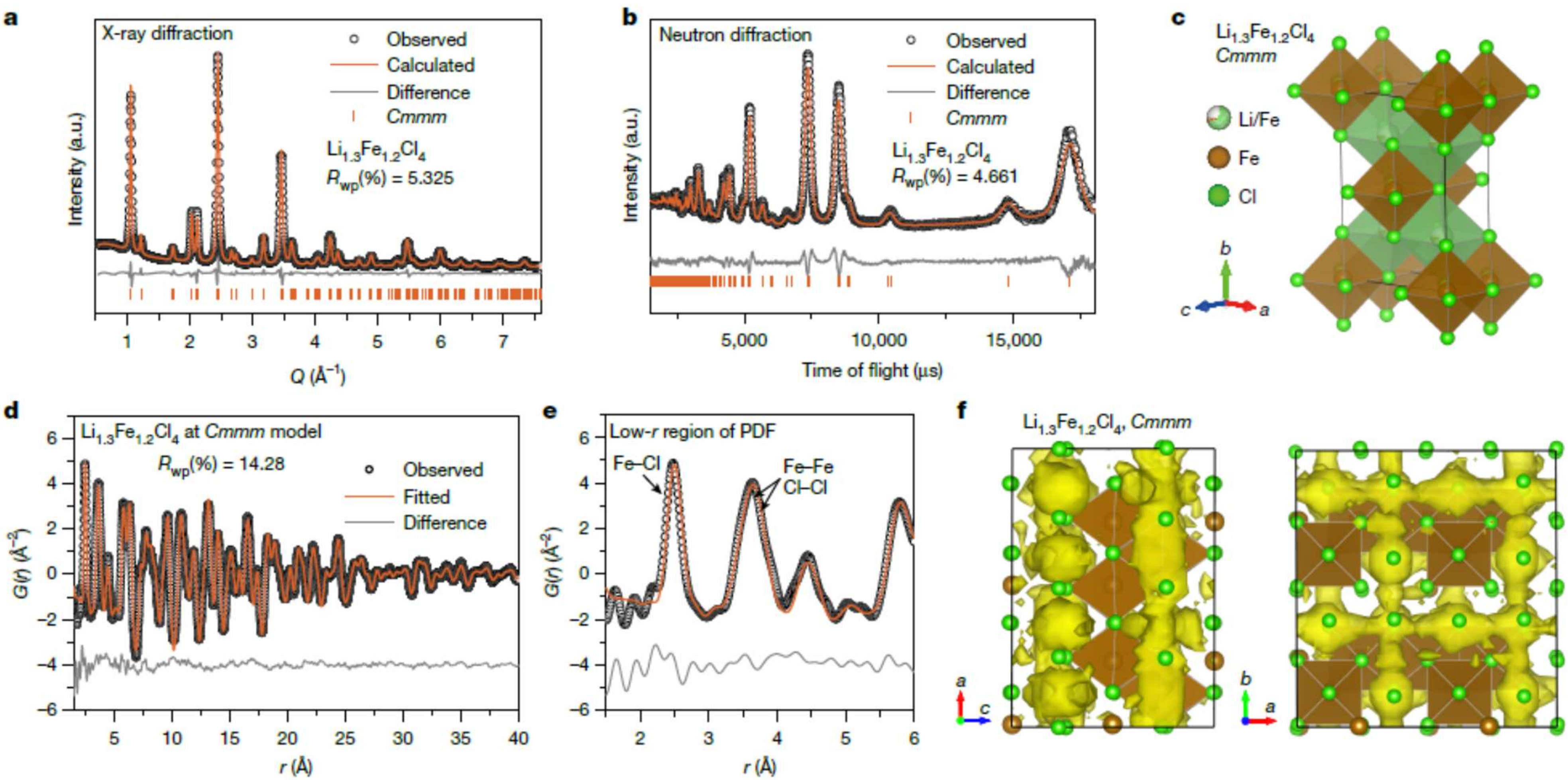
CMCF-BM beamline

PXRD Example: Structures of New Battery Materials

Synchrotron PXRD

Neutron Diffraction (ND)

$Li_{1.3}Fe_{1.2}Cl_4$



Pair Distribution Function (PDF) analysis

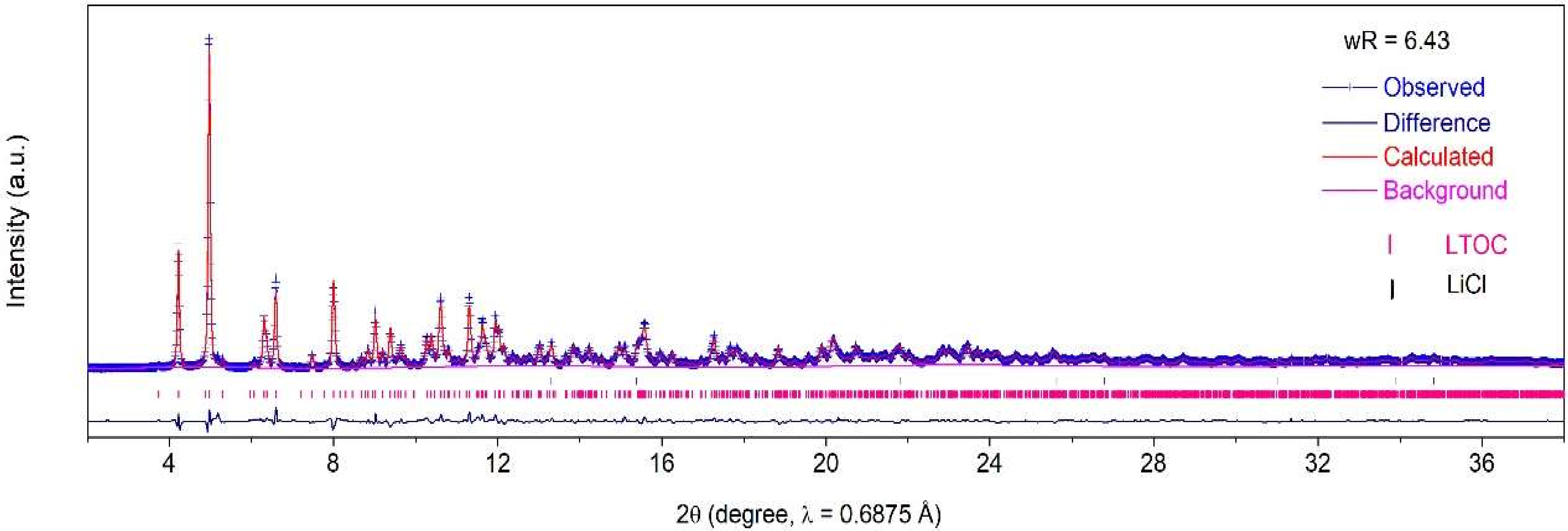
Ab Initio Molecular Dynamics (AIMD) calculations

Fu, J. *et. al*. Nature **643** (2025) 111-118

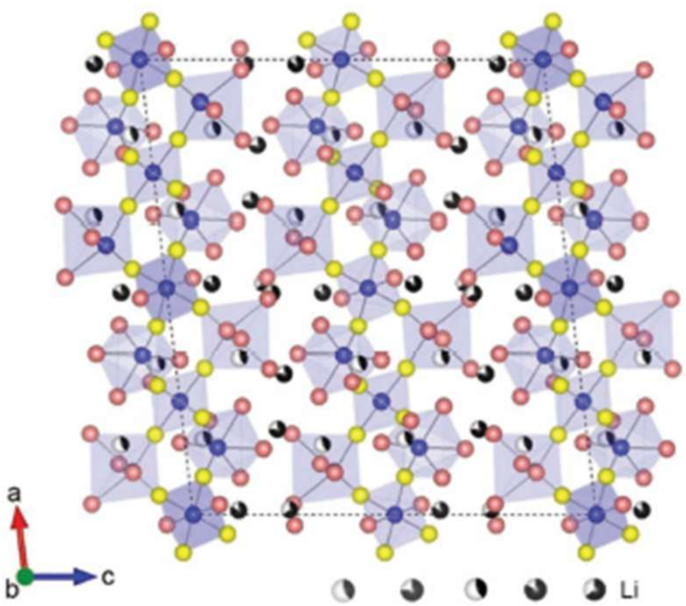
Canadian Light Source
Centre canadien de rayonnement synchrotron

BXDS-WHE beamline

PXRD Example: Structures of New Battery Materials



LTOC superionic conductor
$Li_3Ta_3O_4Cl_{10}$



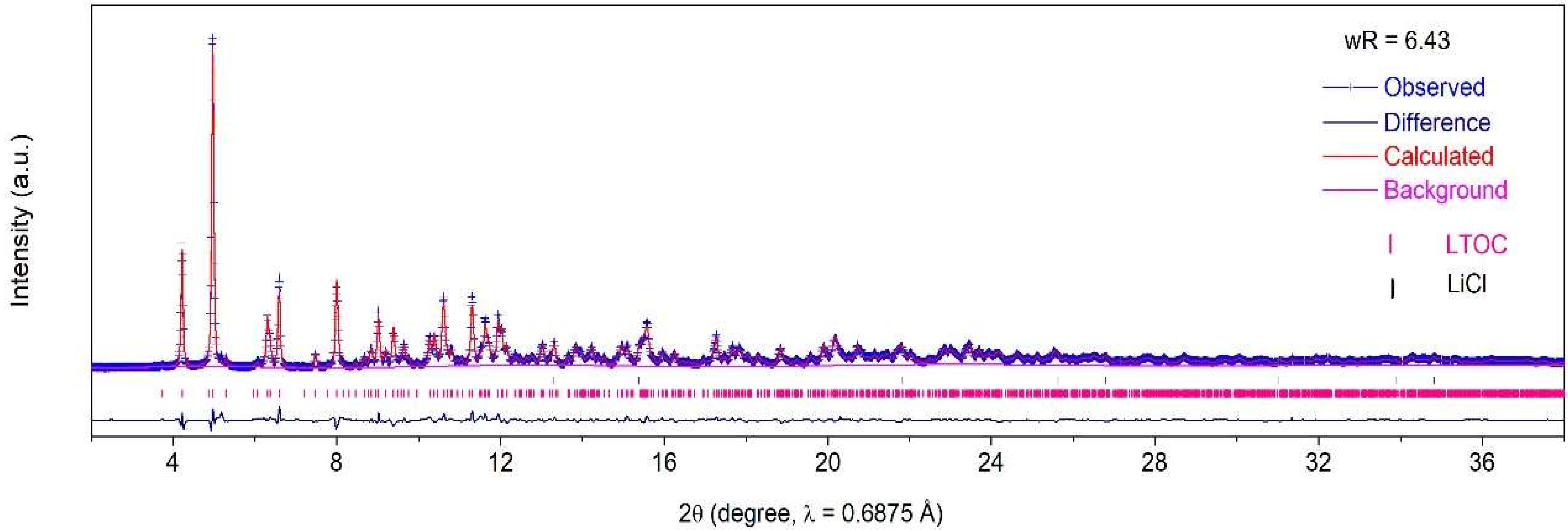
Monoclinic
I2/a (#15)

a = 21.2180(9) Å
b = 8.7562(3) Å
c = 18.7727(9) Å
β = 96.747(3)°
V = 3463.6(2) $Å^3$

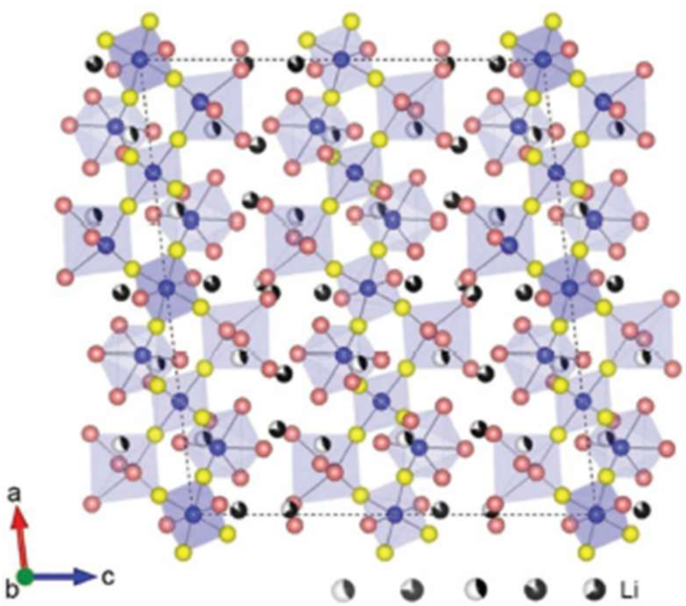
CMCF-BM beamline

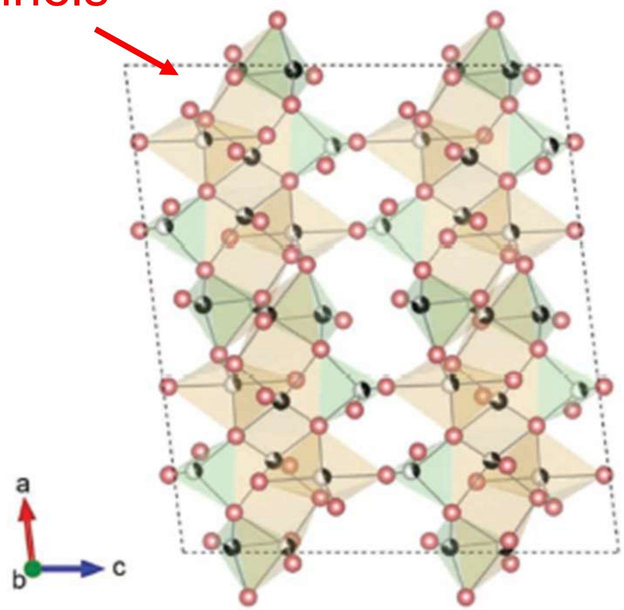
Zhao, F. *et al.* Science **390** (6769) (2025) 199-204

PXRD Example: Structures of New Battery Materials

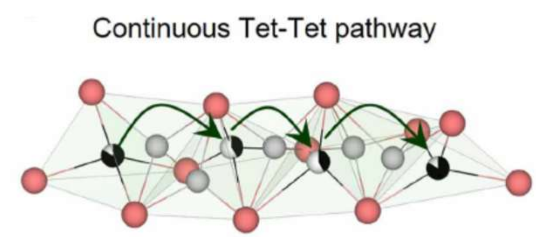


Li channels



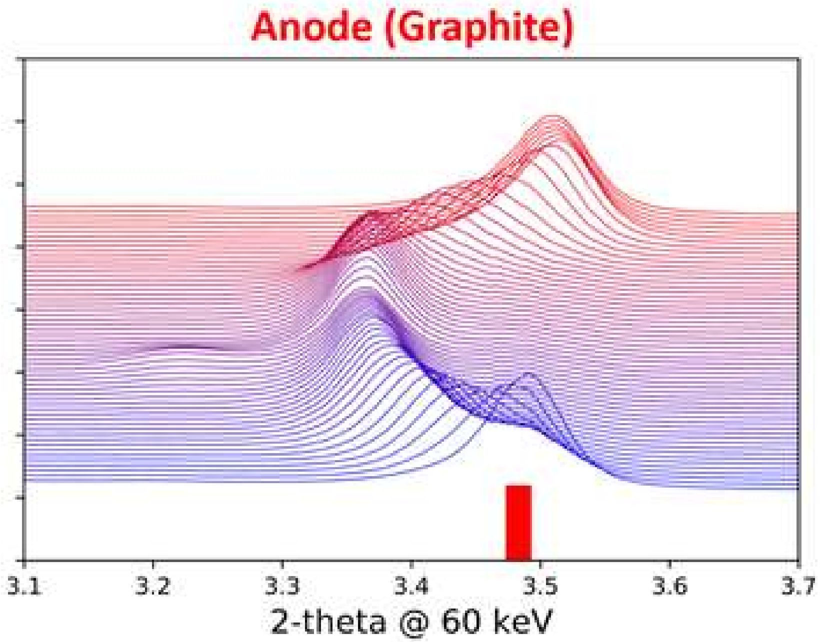


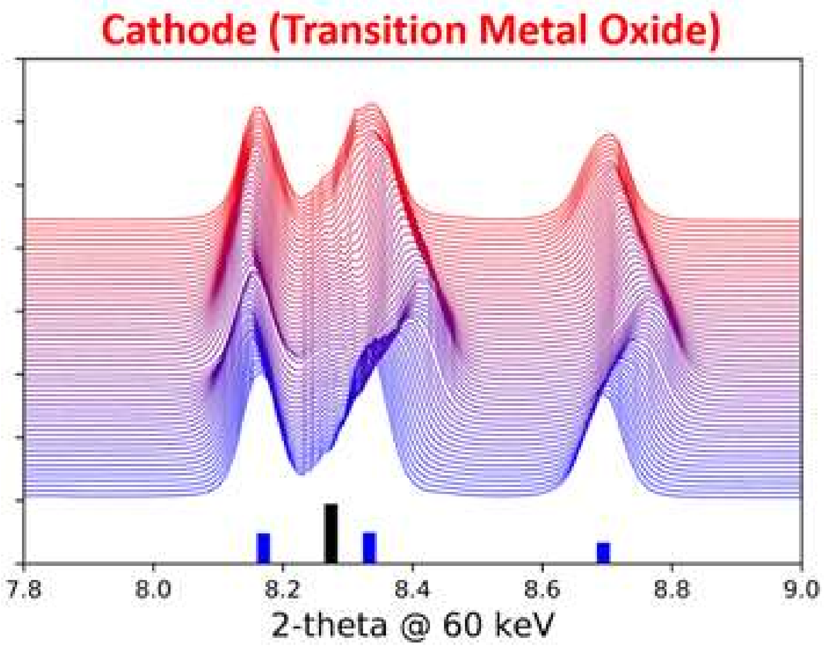
LTOC superionic conductor
$Li_3Ta_3O_4Cl_{10}$

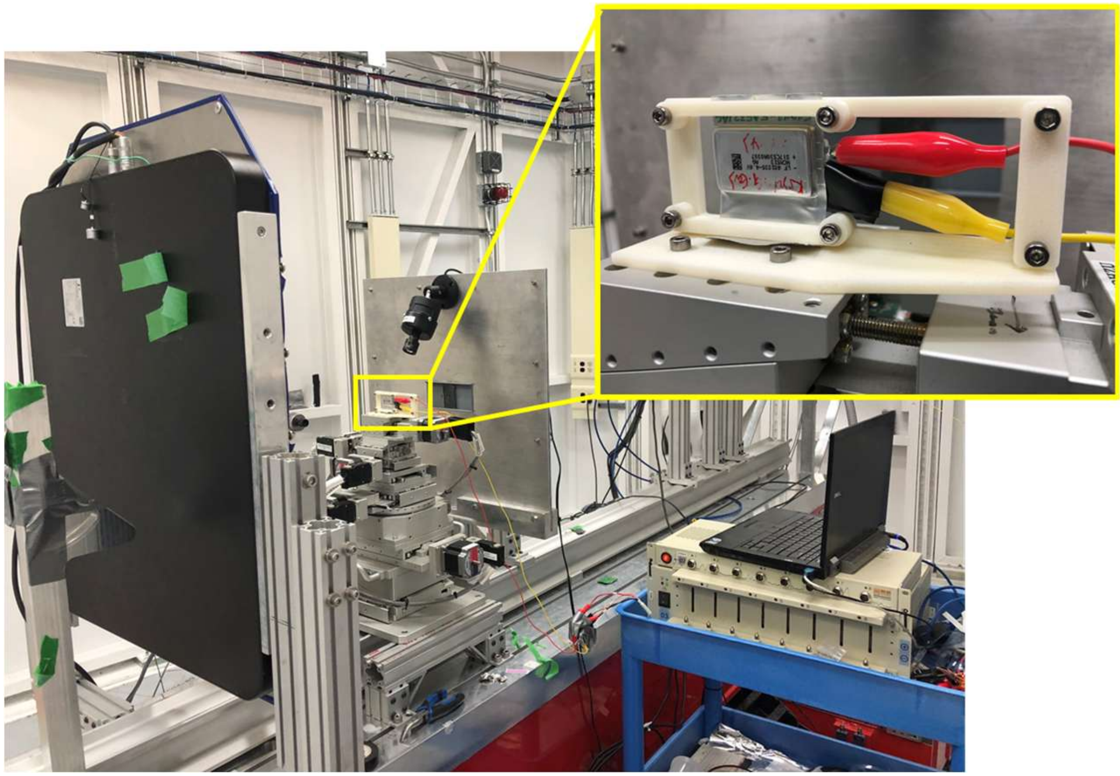


Zhao, F. *et al.* Science **390** (6769) (2025) 199-204

XRD Example: *Operando* Studies of Batteries



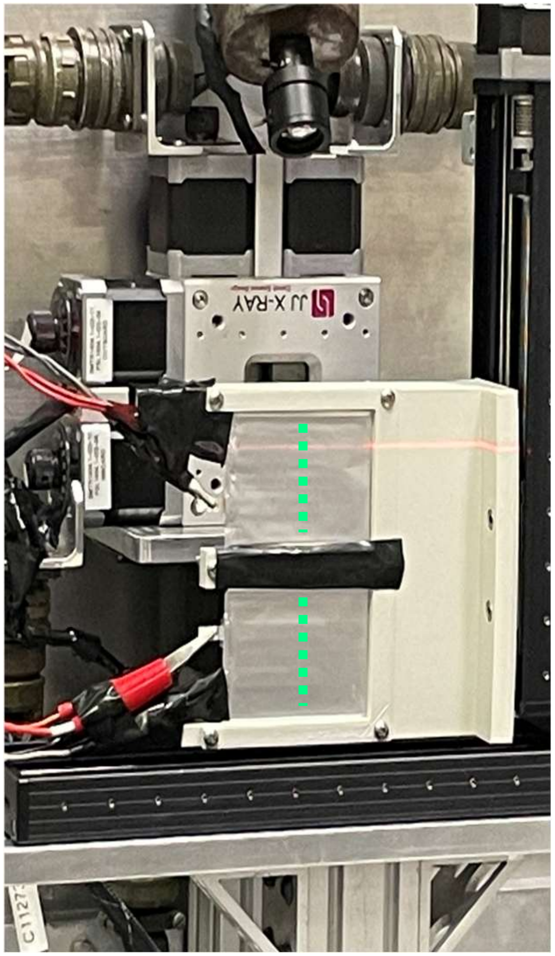


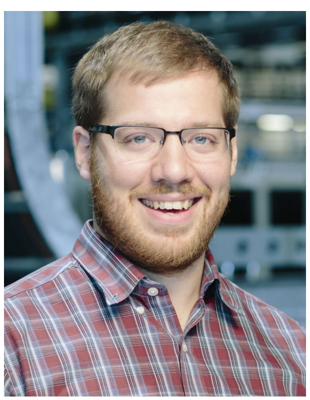


- At high energy (30 to 70 keV), X-rays can be used for transmission experiments through real systems, like commercial battery pouch cells.

BXDS-WHE beamline

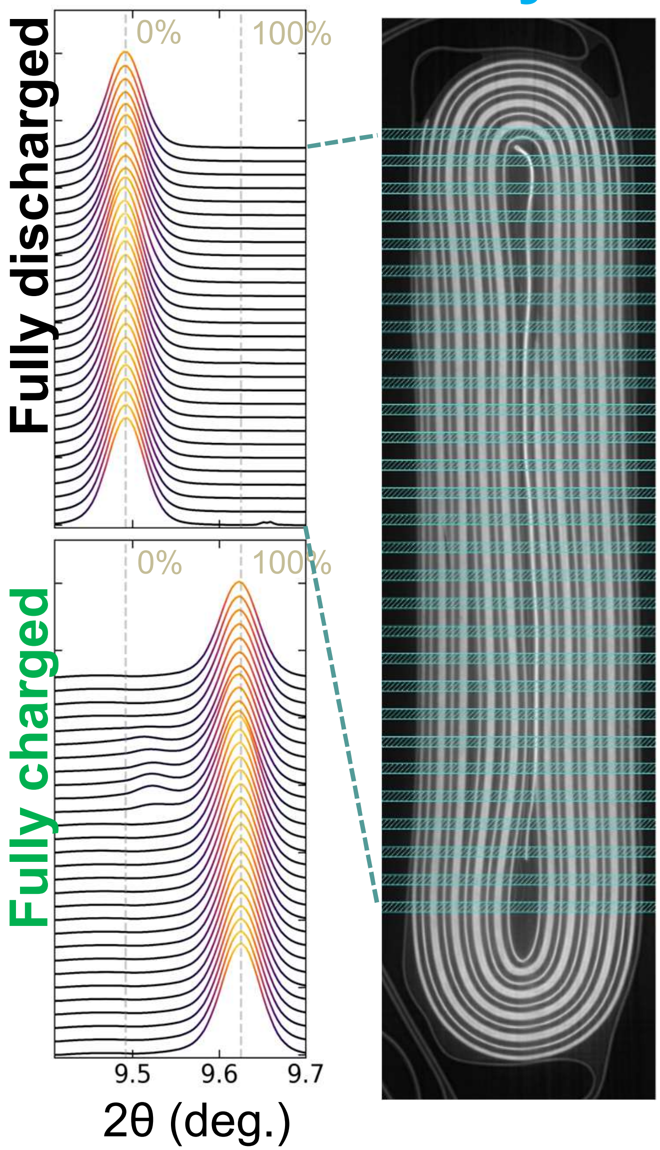
XRD Example: *Operando* Studies of Batteries



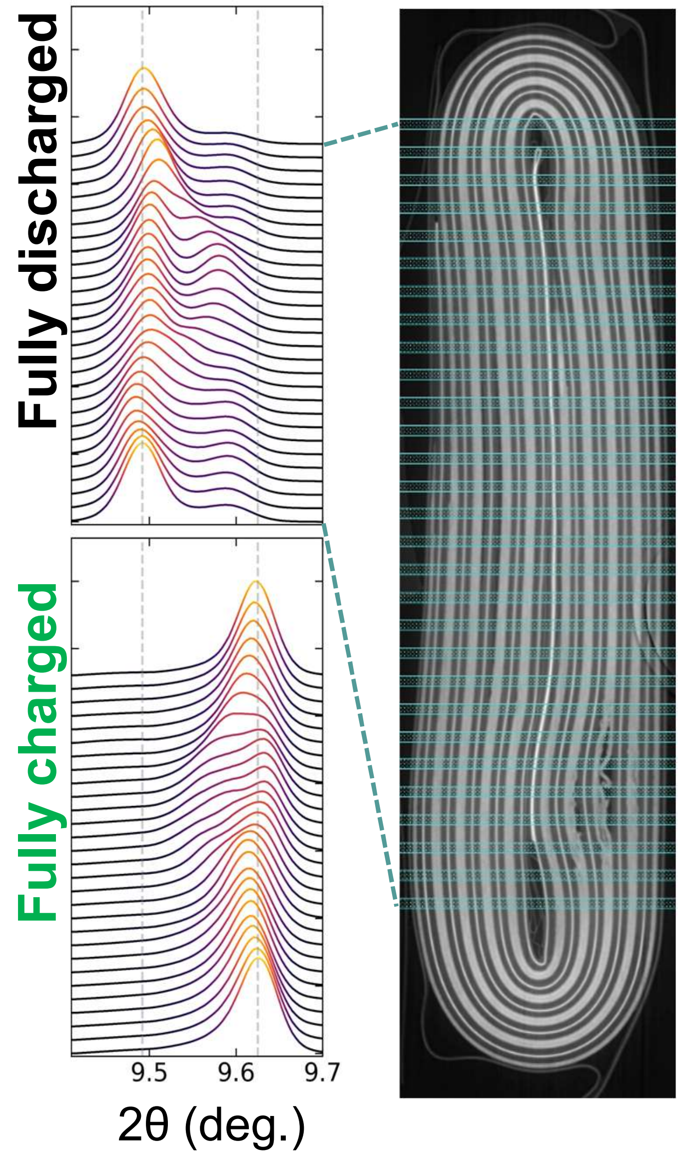


Toby Bond

New Battery



Aged Battery

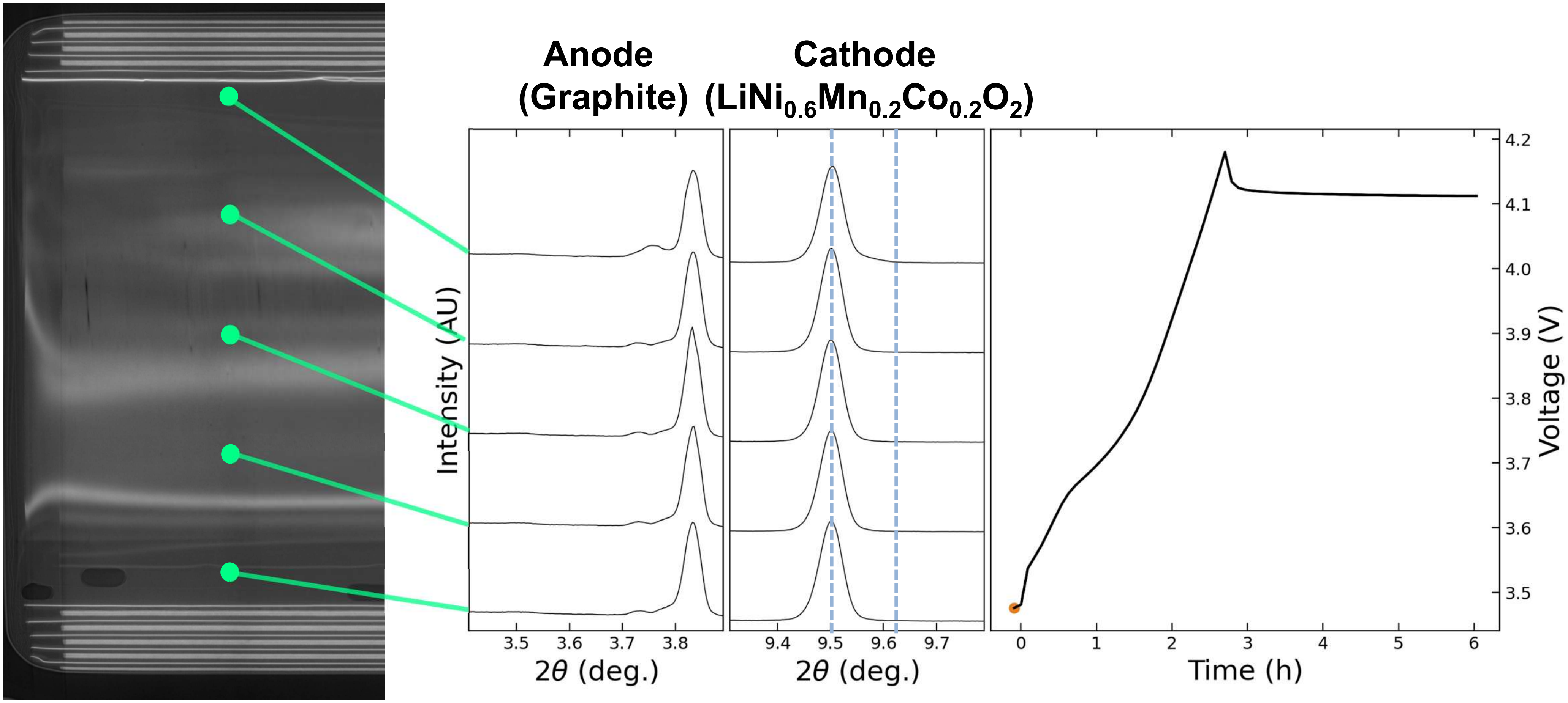


Bond, T., *et. al.,* J. Electrochem. Soc. **171** (2024) 110514.

BXDS-WHE beamline

XRD Example: *Operando* Studies of Batteries

New Battery

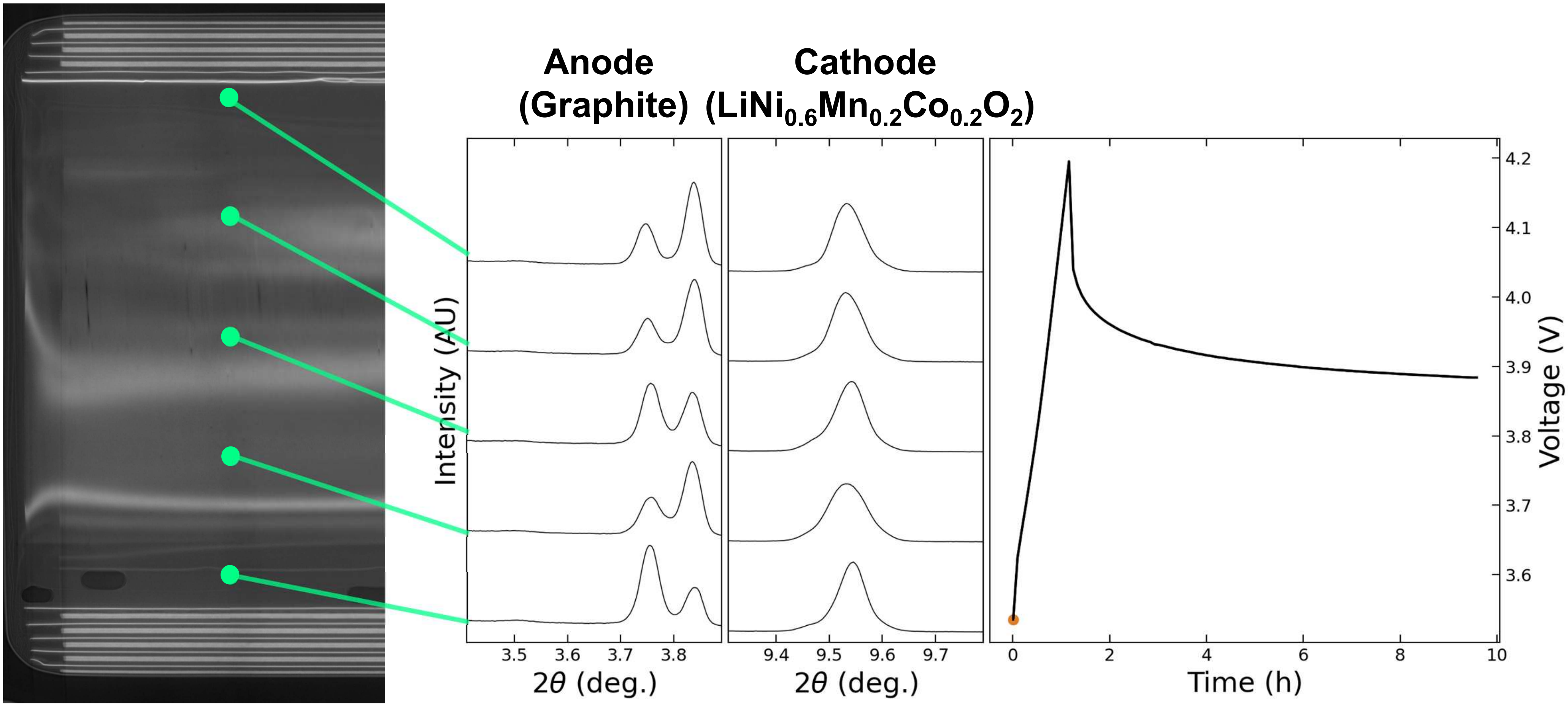


BXDS-WHE beamline

Bond, T., *et. al.,* J. Electrochem. Soc. **171** (2024) 110514

XRD Example: *Operando* Studies of Batteries

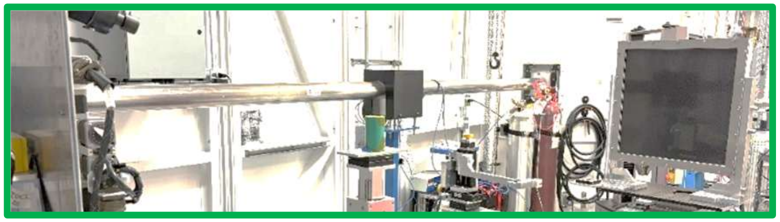
Aged Battery

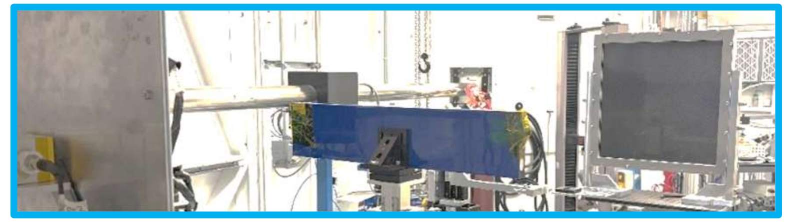


BXDS-WHE beamline

Bond, T., *et. al.* J. Electrochem. Soc. **171** (2024) 110514

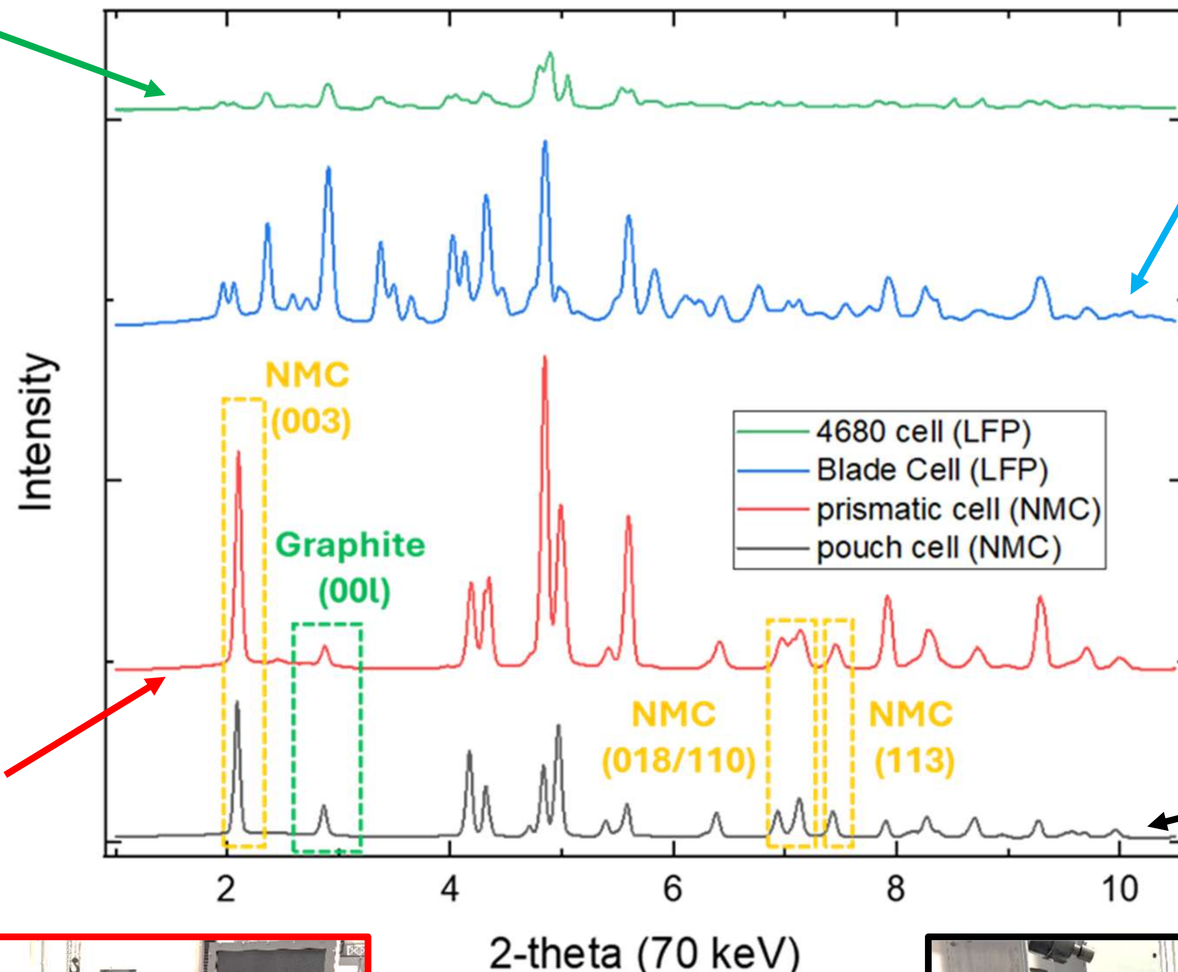
XRD Example: *Operando* Studies with Large Cells





BYD 4680 cell
LFP, 15 Ah

SVOLT Blade cell
LFP, 184 Ah
574 x 118 x 21.5 mm

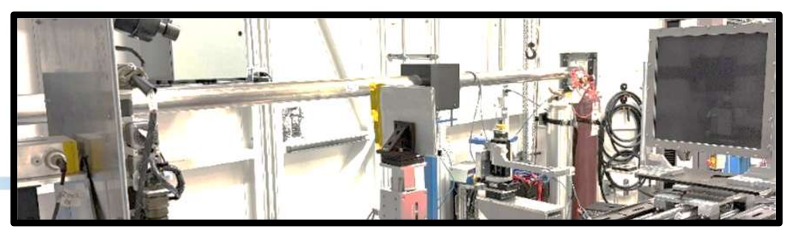


BXDS-WHE beamline

Bond, T., *et. al.*
Unpublished work.

EVE Prismatic cell
NMC, 25 Ah
148 x 99 x 18 mm

Farasis pouch cell
NMC, 53 Ah
231 x 161 x 10 mm



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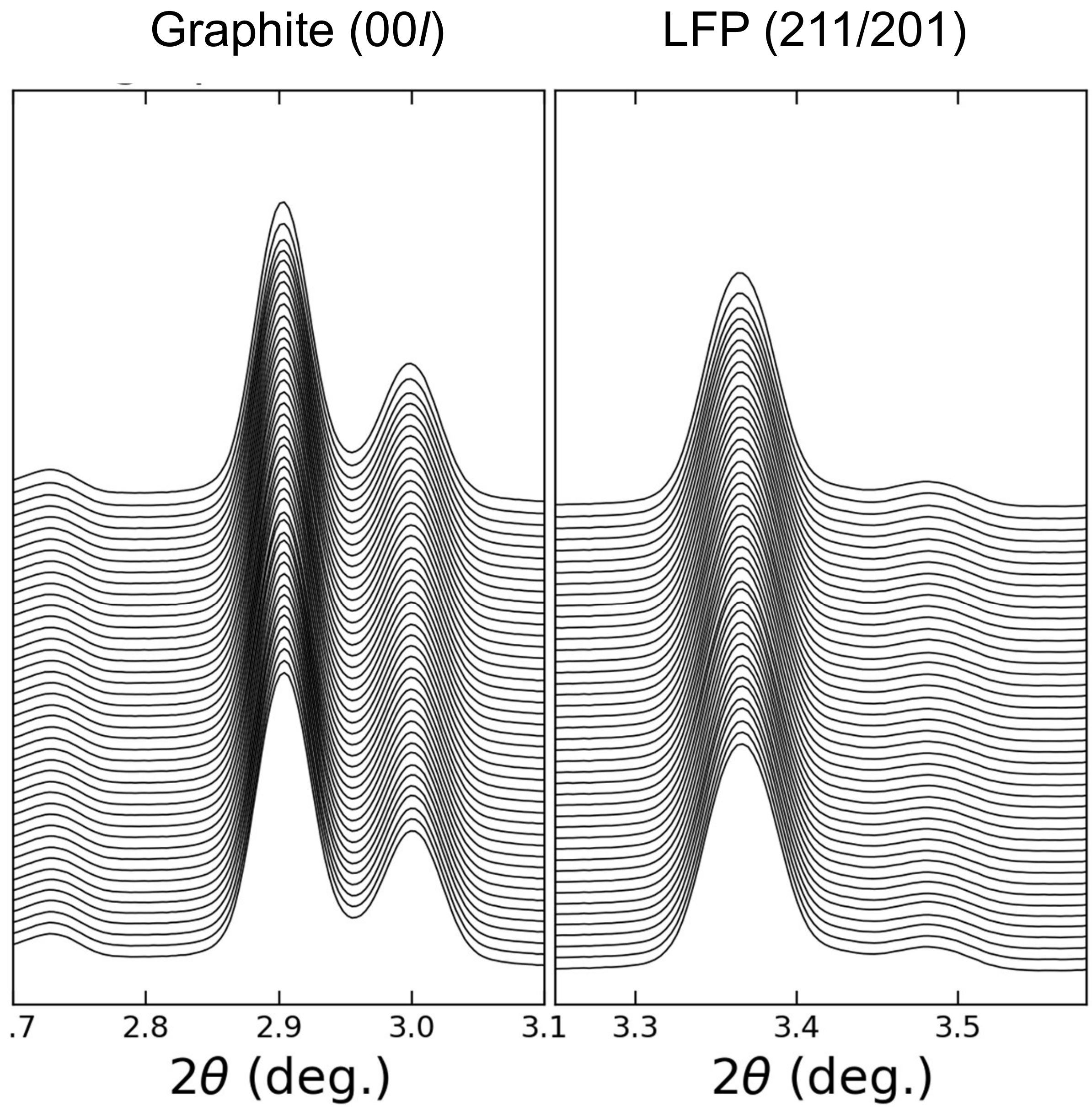
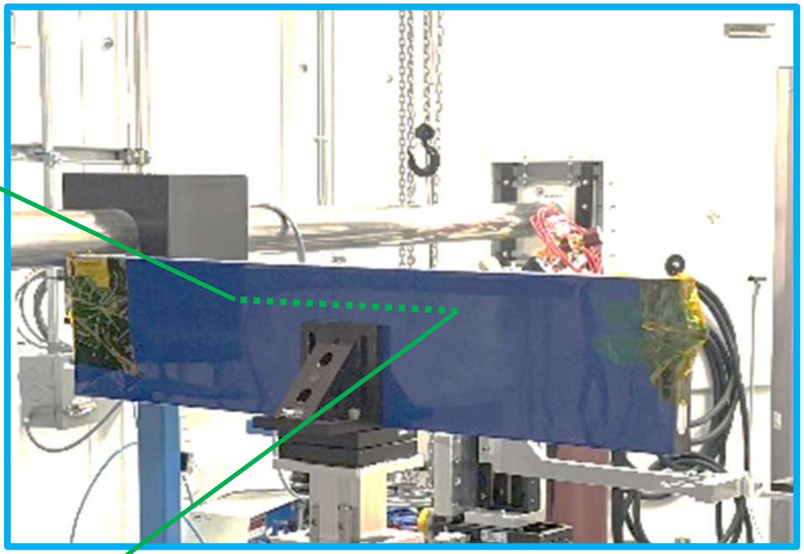


SVOLT Blade cell (LFP)
574 x 118 x 21.5 mm



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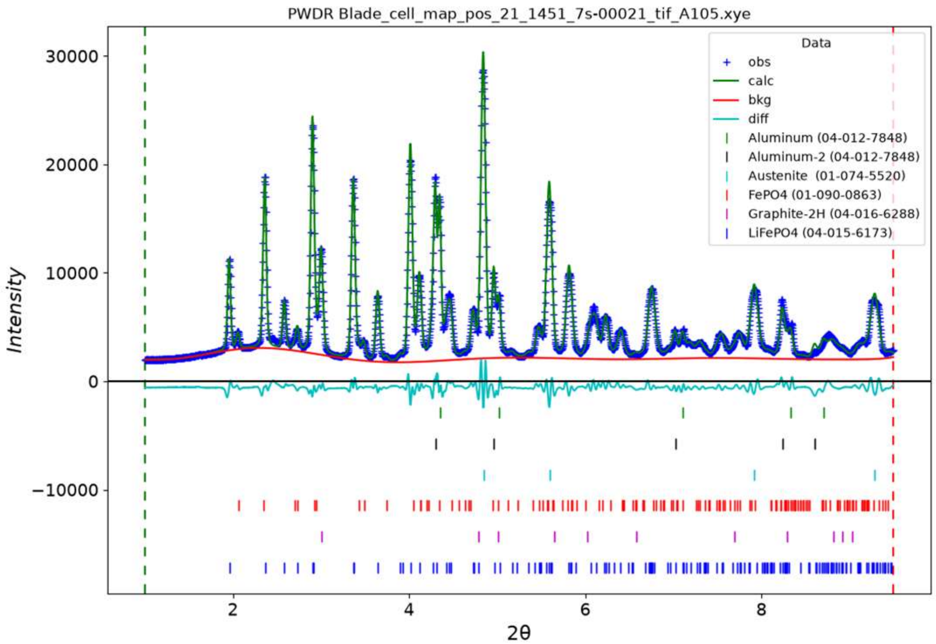

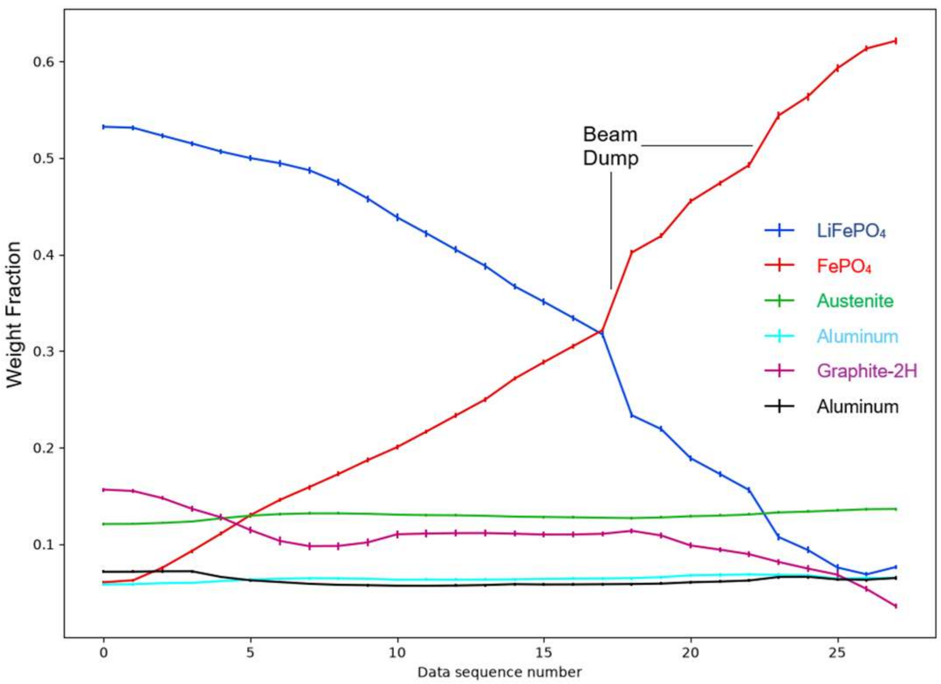

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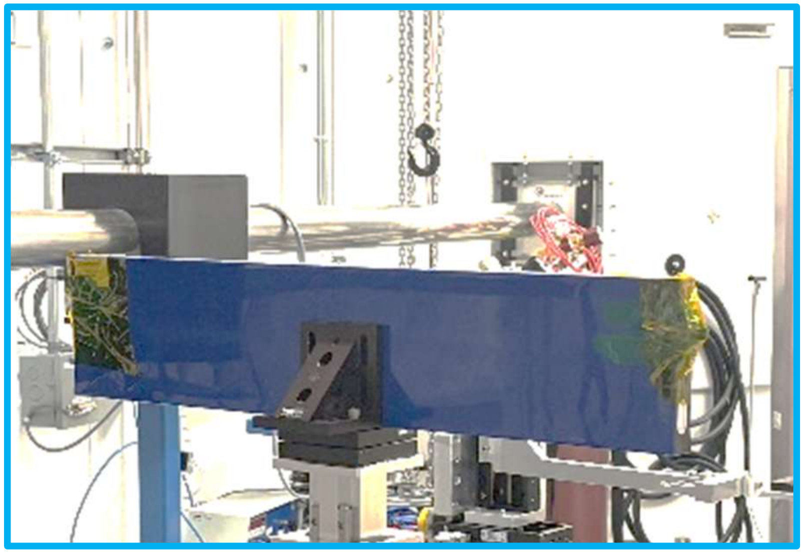
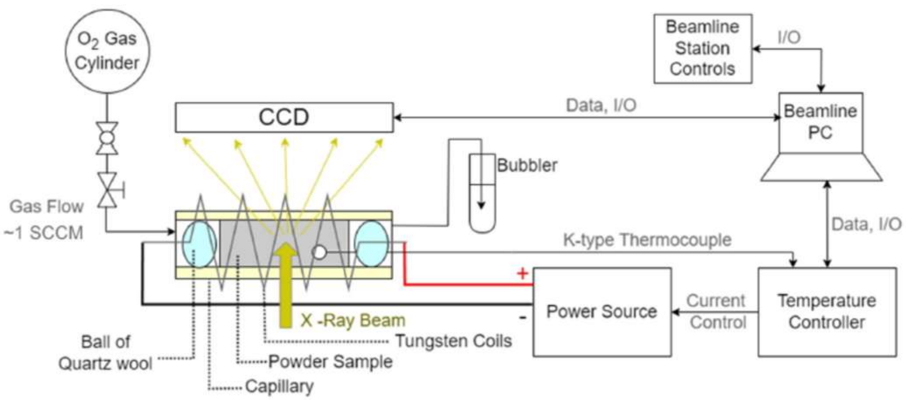
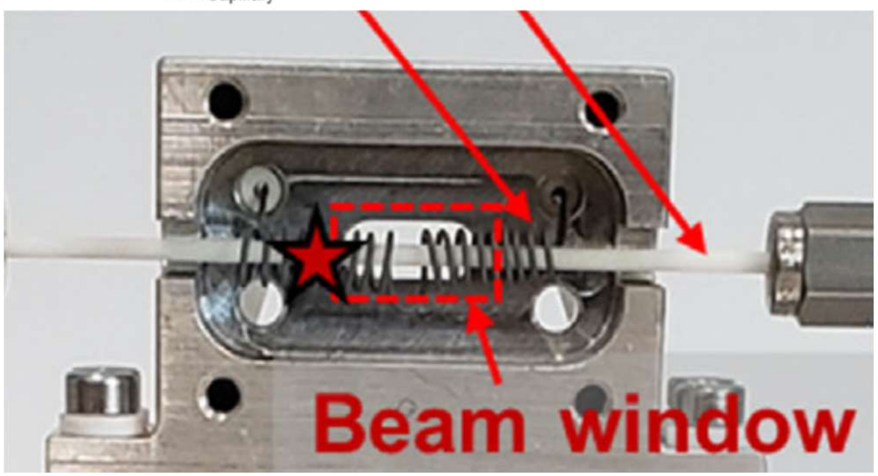
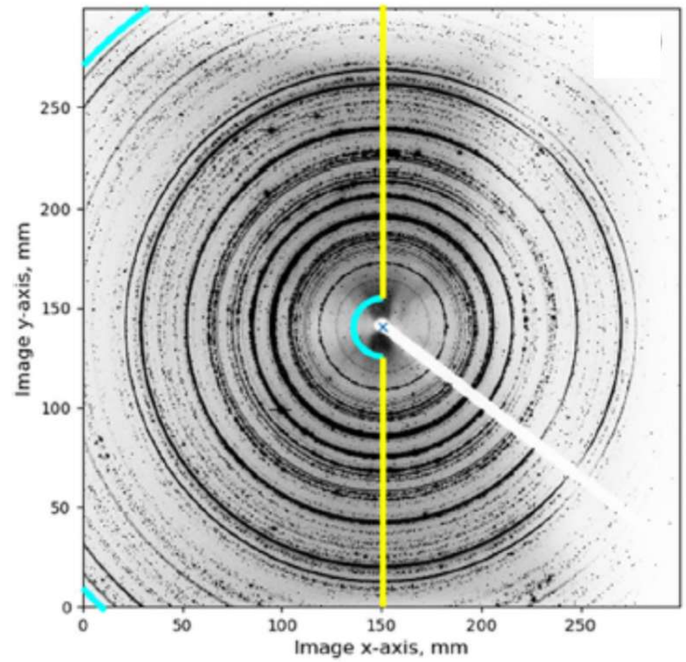


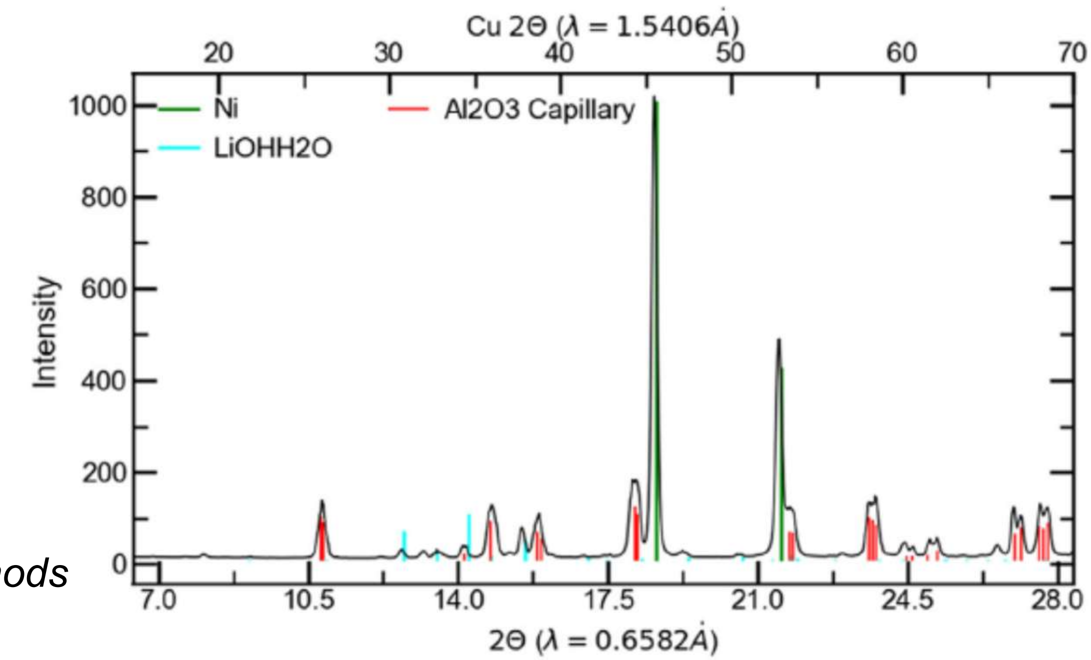
Bond, T., *et. al.*
Unpublished work.

PXRD Example: *In-Situ* High T Cathode Synthesis







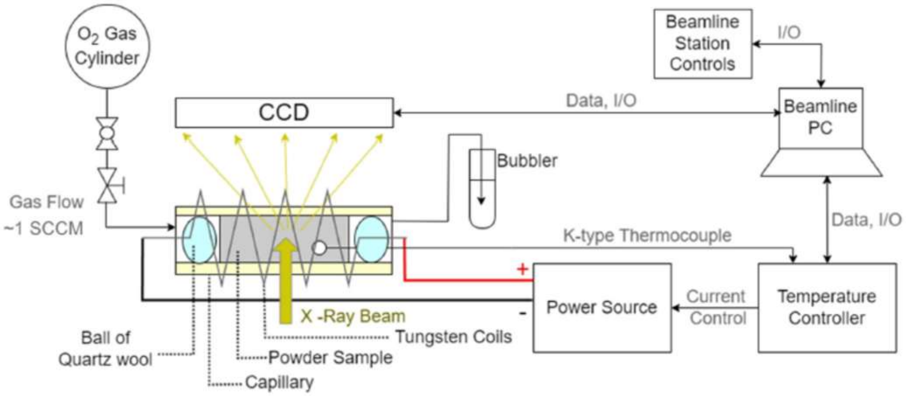


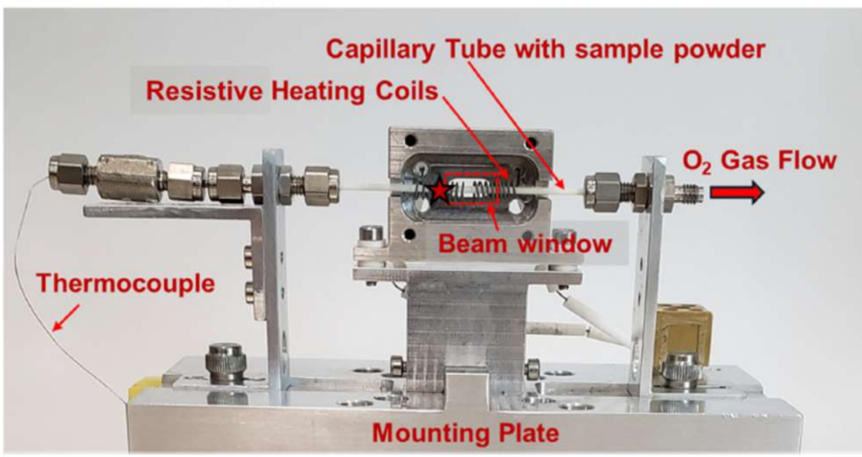
BXDS-WLE beamline

Yu, S. *et al. Small Methods* (2025) 2500632.

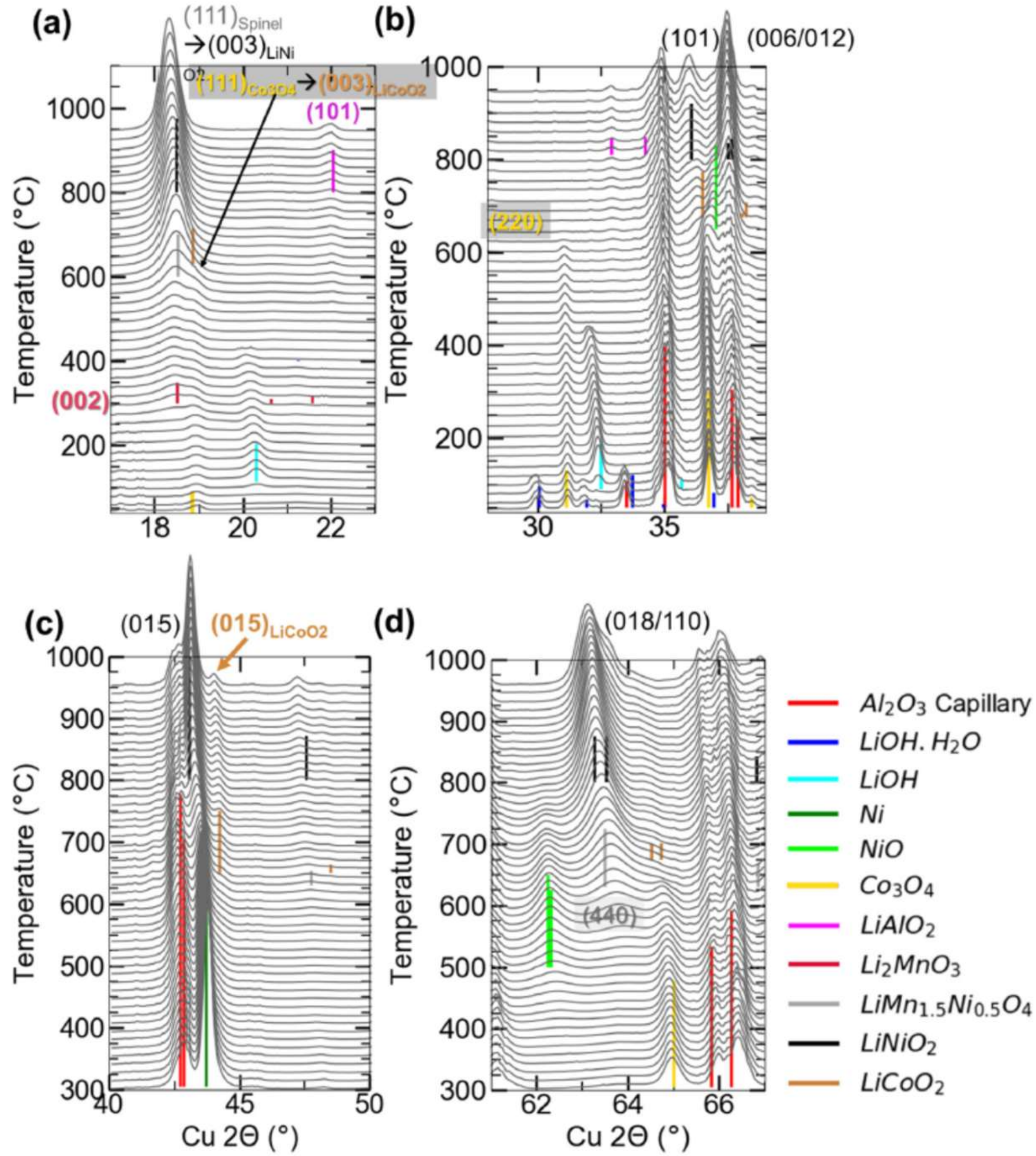
Canadian Light Source
Centre canadien de rayonnement synchrotron

PXRD Example: *In-Situ* High T Cathode Synthesis





BXDS-WLE beamline

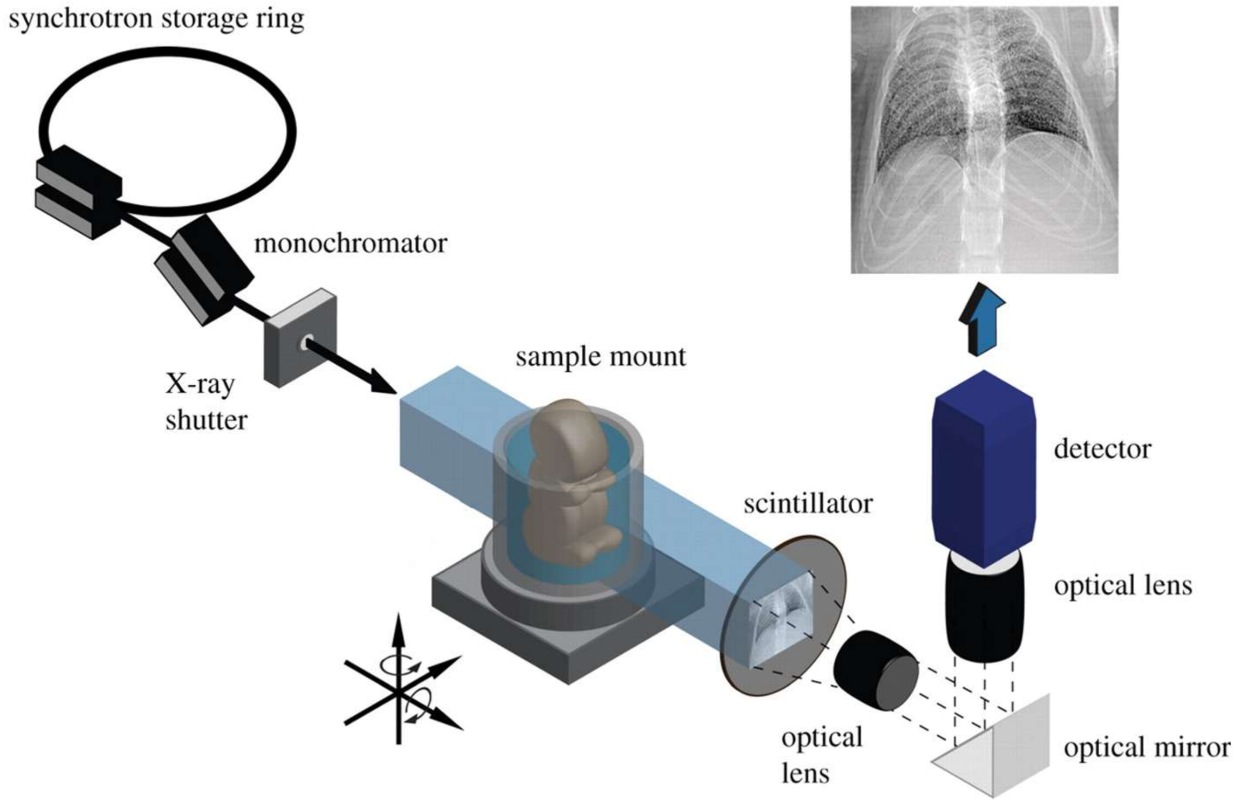


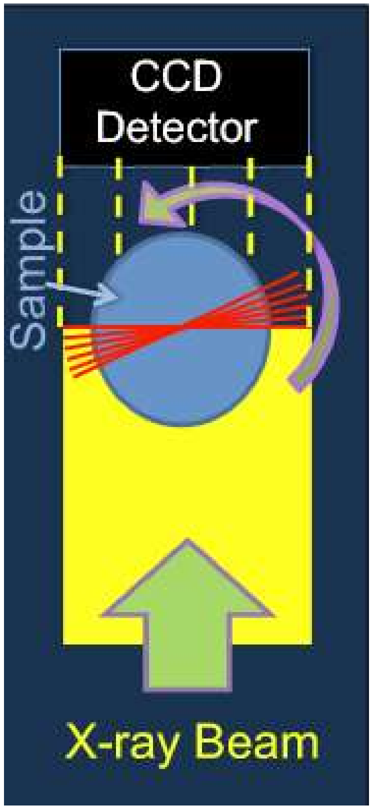
Yu, S. *et al. Small Methods* (2025) 2500632.

NMC631 = $LiNi_{0.6}Mn_{0.3}Co_{0.1}O_2$

Canadian Light Source Centre canadien de rayonnement synchrotron

Synchrotron Computed Tomography (SR-CT)

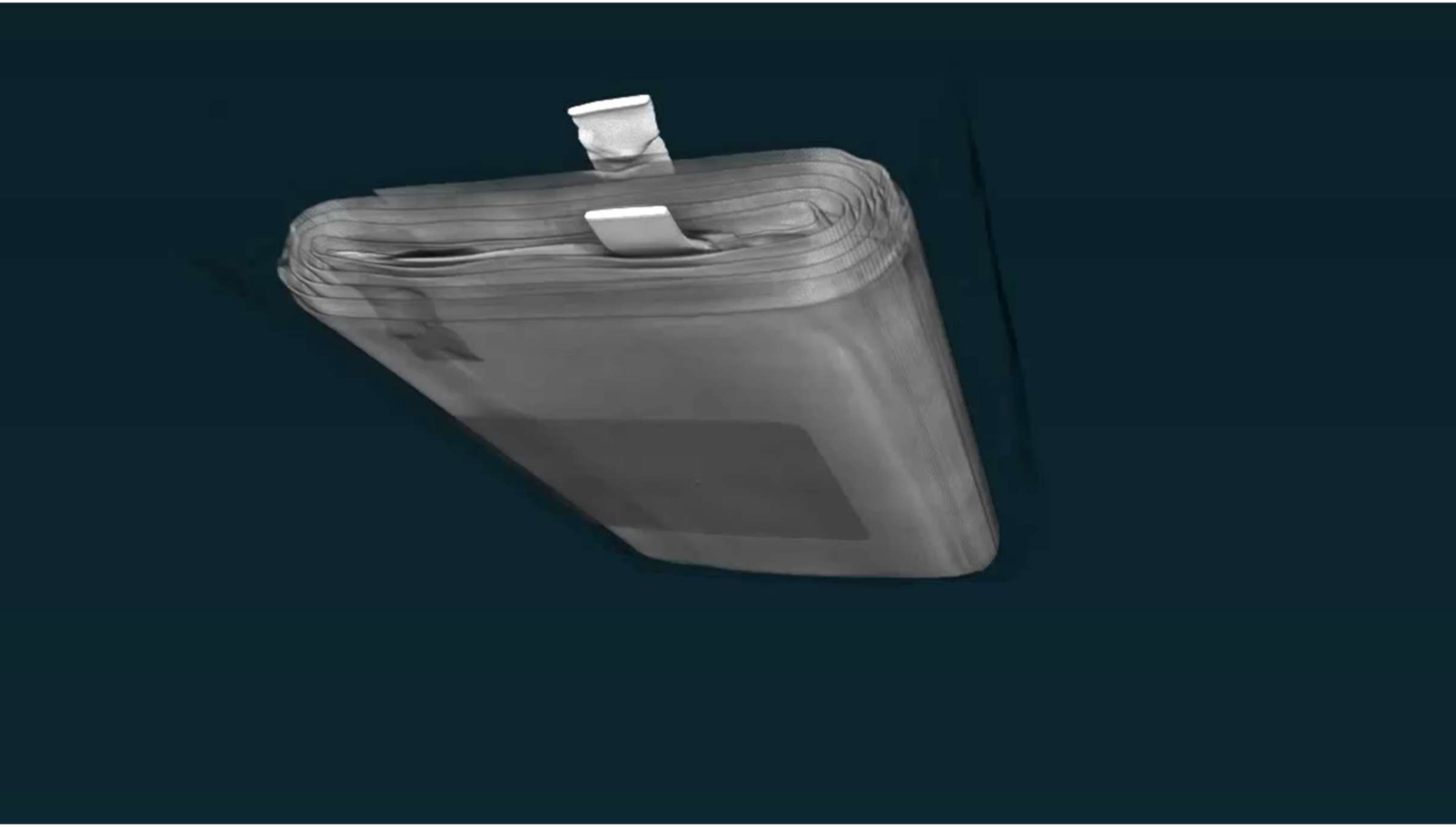




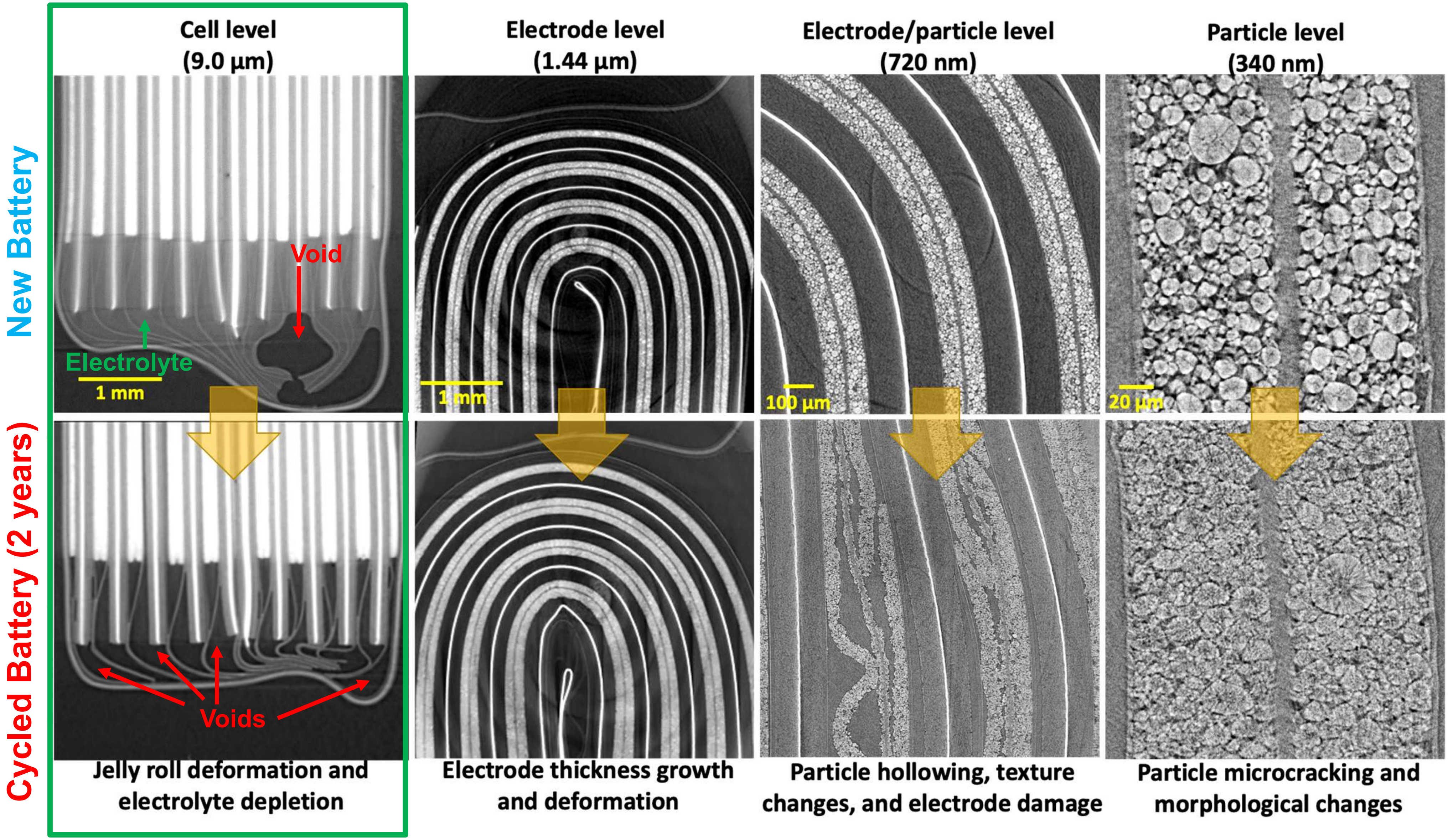
- Computed tomography (CT) provides a full 3D digital model of internal sample structure.
- Synchrotron CT (SR-CT) has several advantages:
  - Many times faster than laboratory sources (excellent for *in situ* experiments).
  - Better contrast.
  - Can image a large area at high resolution.

Toby Bond

CT Example: Structural Changes in Batteries



CT Example: Structural Changes in Batteries

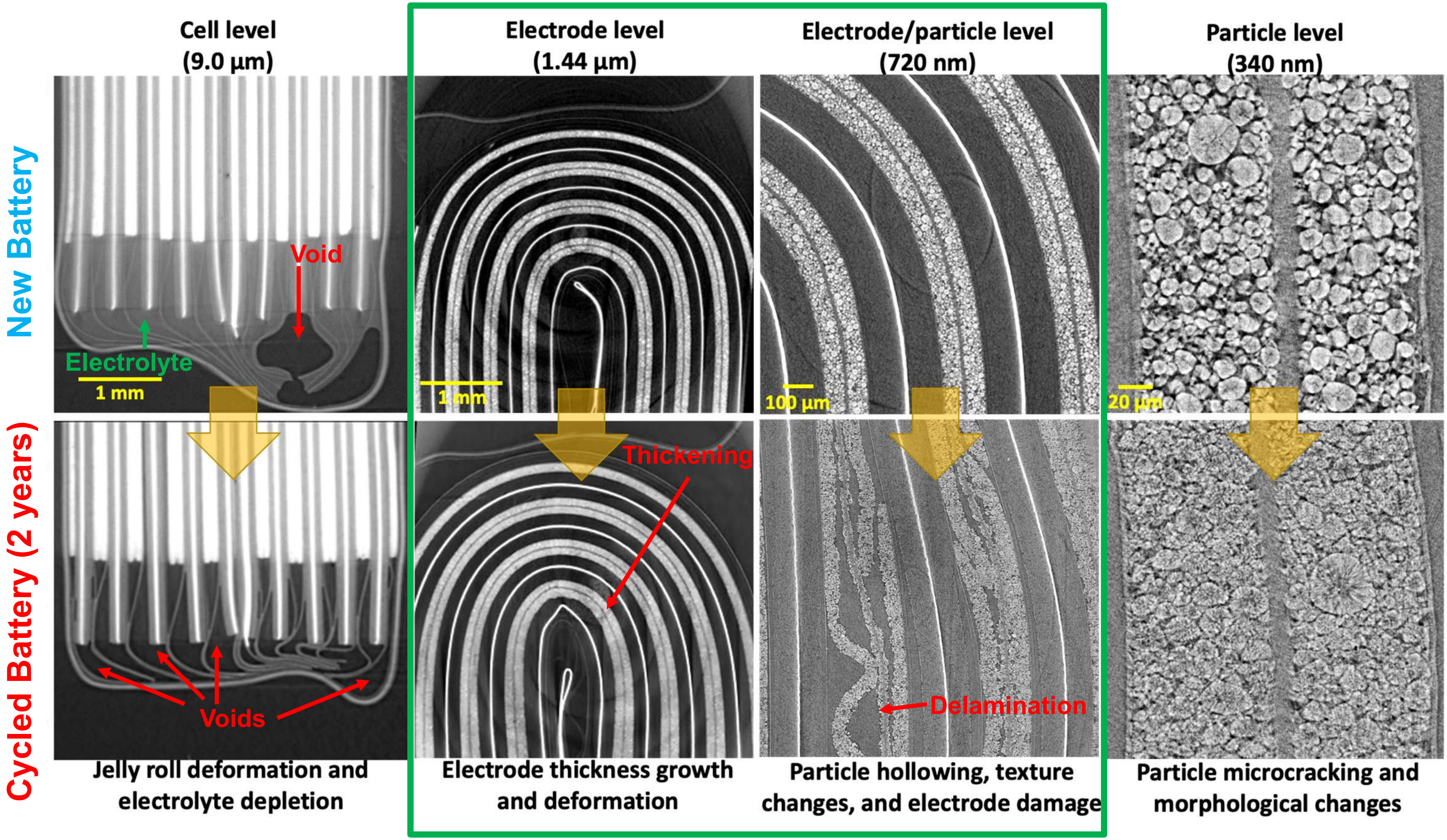


Bond, T., Gauthier, R., Gasilov, S., and Dahn, J.R.
J. Electrochem. Soc. **169** (2022) 080531

Canadian Light Source Centre canadien de rayonnement synchrotron

BMIT-BM & BMIT-ID beamlines

CT Example: Structural Changes in Batteries



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BMIT-BM & BMIT-ID beamlines

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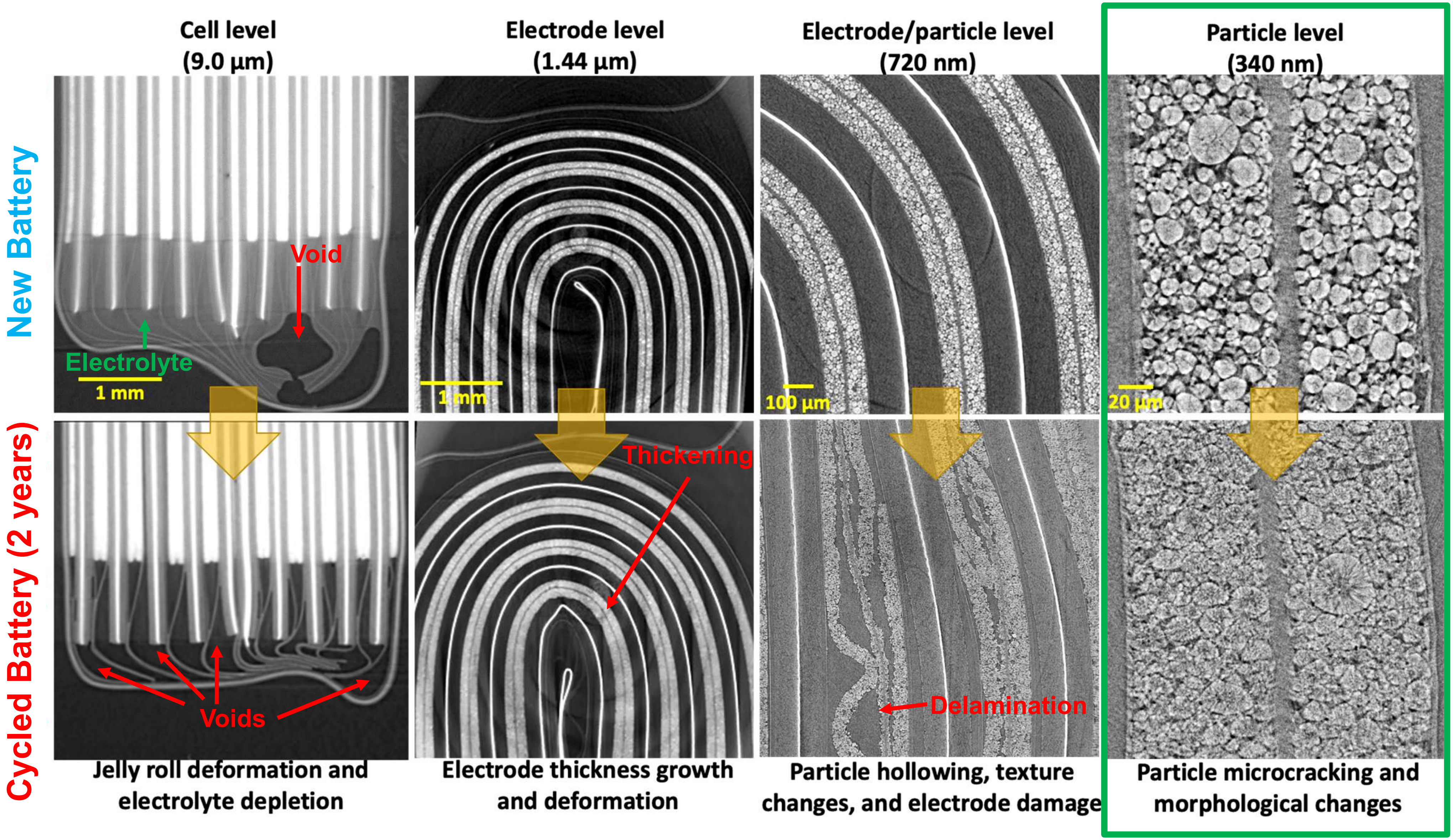

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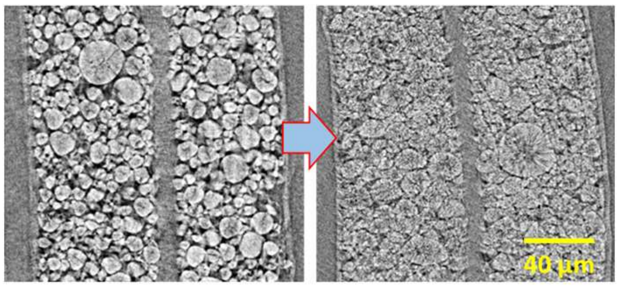
BMIT-BM & BMIT-ID beamlines

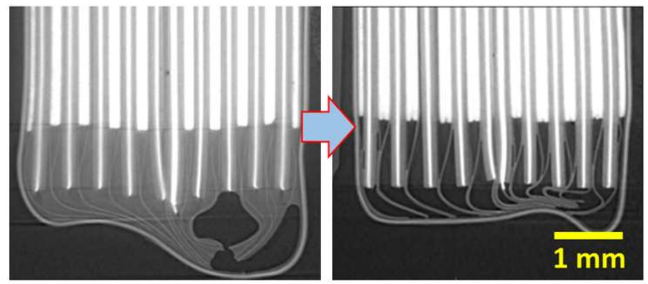
CT & PXRD: Conventional vs. Single-Crystal Cathodes

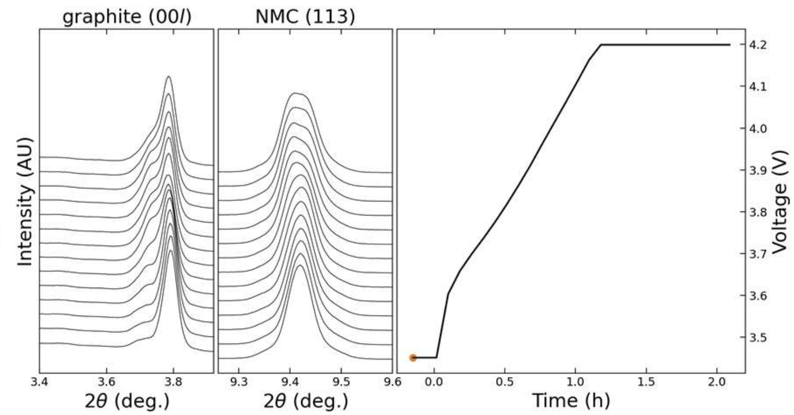
Conventional EV battery (600,000 miles)

Extensive swelling



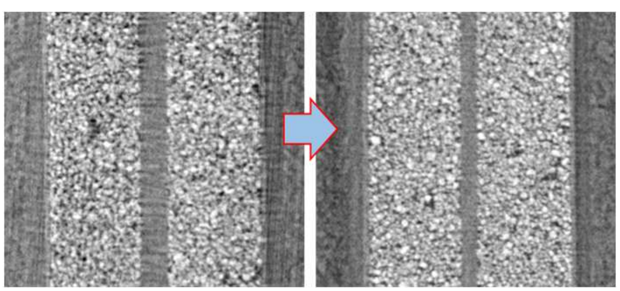
No liquid electrolyte remaining



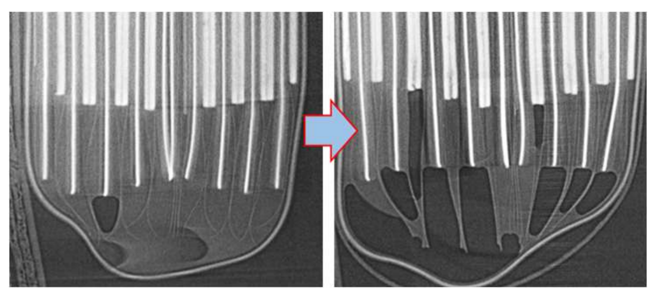


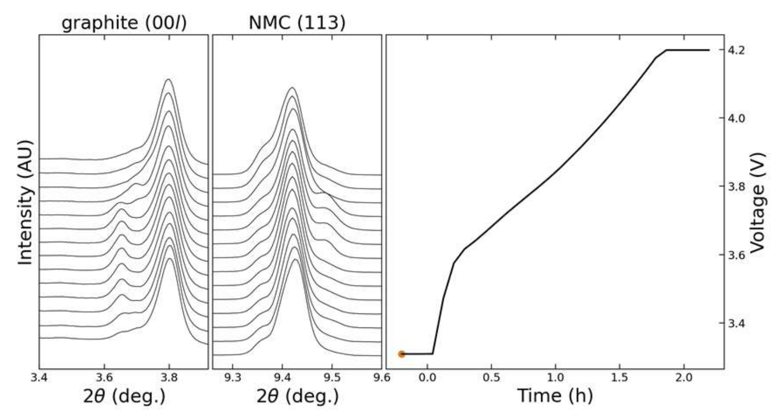
Single-crystal cathode battery (5,000,000 miles)

No measurable swelling



Plenty liquid electrolyte remaining





BMIT-BM, BMIT-ID & BXDS-WHE beamlines

Canadian Light Source | Centre canadien de rayonnement synchrotron

Bond, T., *et. al.,* J. Electrochem. Soc. **171** (2024) 110514

Summary

- The CLS is a powerful, multi-purpose tool for examining battery structure across different length scales.

- Synchrotron diffraction and scattering techniques offer major advantages for batteries:
  - High resolution for structure solution.
  - High intensity for *in-situ* and *operando* (time-resolved) studies.
  - High energy for transmission diffraction on real battery systems.
  - PDF analysis for materials that are poorly crystalline, amorphous or with properties strongly linked to short range, local order.

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Thank you for your time!

Any questions?

"All things serve the Beam."

The Dark Tower (Stephen King)